

# NCO User's Guide

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A suite of netCDF operators  
Edition 4.0.9, for NCO Version 4.0.9  
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This is the first edition of the *NCO User's Guide*,  
and is consistent with version 2 of `'texinfo.tex'`.

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The original author of this software, Charlie Zender, wants to improve it with the help of your suggestions, improvements, bug-reports, and patches.

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## Foreword

NCO is the result of software needs that arose while I worked on projects funded by NCAR, NASA, and ARM. Thinking they might prove useful as tools or templates to others, it is my pleasure to provide them freely to the scientific community. Many users (most of whom I have never met) have encouraged the development of NCO. Thanks especially to Jan Polcher, Keith Lindsay, Arlindo da Silva, John Sheldon, and William Weibel for stimulating suggestions and correspondence. Your encouragement motivated me to complete the *NCO User's Guide*. So if you like NCO, send me a note! I should mention that NCO is not connected to or officially endorsed by Unidata, ACD, ASP, CGD, or Nike.

Charlie Zender  
May 1997  
Boulder, Colorado

Major feature improvements entitle me to write another Foreword. In the last five years a lot of work has been done to refine NCO. NCO is now an open source project and appears to be much healthier for it. The list of illustrious institutions that do not endorse NCO continues to grow, and now includes UCL.

Charlie Zender  
October 2000  
Irvine, California

The most remarkable advances in NCO capabilities in the last few years are due to contributions from the Open Source community. Especially noteworthy are the contributions of Henry Butowsky and Rorik Peterson.

Charlie Zender  
January 2003  
Irvine, California

NCO was generously supported from 2004–2008 by US National Science Foundation (NSF) grant [IIS-0431203](#). This support allowed me to maintain and extend core NCO code, and others to advance NCO in new directions: Gayathri Venkitachalam helped implement

MPI; Harry Mangalam improved regression testing and benchmarking; Daniel Wang developed the server-side capability, SWAMP; and Henry Butowsky, a long-time contributor, developed `ncap2`. This support also led NCO to debut in professional journals and meetings. The personal and professional contacts made during this evolution have been immensely rewarding.

Charlie Zender  
March 2008  
Grenoble, France

## Summary

This manual describes NCO, which stands for netCDF Operators. NCO is a suite of programs known as *operators*. Each operator is a standalone, command line program executed at the shell-level like, e.g., `ls` or `mkdir`. The operators take netCDF files (including HDF5 files constructed using the netCDF API) as input, perform an operation (e.g., averaging or hyperslabbing), and produce a netCDF file as output. The operators are primarily designed to aid manipulation and analysis of data. The examples in this documentation are typical applications of the operators for processing climate model output. This stems from their origin, though the operators are as general as netCDF itself.



# 1 Introduction

## 1.1 Availability

The complete NCO source distribution is currently distributed as a *compressed tarfile* from <http://sf.net/projects/nco> and from <http://dust.ess.uci.edu/nco/nco.tar.gz>. The compressed tarfile must be uncompressed and untarred before building NCO. Uncompress the file with ‘`gunzip nco.tar.gz`’. Extract the source files from the resulting tarfile with ‘`tar -xvf nco.tar`’. GNU `tar` lets you perform both operations in one step with ‘`tar -xvzf nco.tar.gz`’.

The documentation for NCO is called the *NCO User’s Guide*. The *User’s Guide* is available in Postscript, HTML, DVI, TeXinfo, and Info formats. These formats are included in the source distribution in the files ‘`nco.ps`’, ‘`nco.html`’, ‘`nco.dvi`’, ‘`nco.texi`’, and ‘`nco.info*`’, respectively. All the documentation descends from a single source file, ‘`nco.texi`’<sup>1</sup>. Hence the documentation in every format is very similar. However, some of the complex mathematical expressions needed to describe `ncwa` can only be displayed in DVI, Postscript, and PDF formats.

A complete list of papers and publications on/about NCO is available on the NCO homepage. Most of these are freely available. The primary refereed publications are fxm ZeM06 and fxm Zen07. These contain copyright restrictions which limit their redistribution, but they are freely available in preprint form from the NCO.

If you want to quickly see what the latest improvements in NCO are (without downloading the entire source distribution), visit the NCO homepage at <http://nco.sf.net>. The HTML version of the *User’s Guide* is also available online through the World Wide Web at URL <http://nco.sf.net/nco.html>. To build and use NCO, you must have netCDF installed. The netCDF homepage is <http://www.unidata.ucar.edu/packages/netcdf>.

New NCO releases are announced on the netCDF list and on the `nco-announce` mailing list <http://lists.sf.net/mailman/listinfo/nco-announce>.

## 1.2 Operating systems compatible with NCO

NCO has been successfully ported and tested and is known to work on the following 32- and 64-bit platforms: IBM AIX 4.x, 5.x, FreeBSD 4.x, GNU/Linux 2.x, LinuxPPC, LinuxAlpha, LinuxARM, LinuxSparc64, SGI IRIX 5.x and 6.x, MacOS X 10.x, NEC Super-UX 10.x, DEC OSF, Sun SunOS 4.1.x, Solaris 2.x, Cray UNICOS 8.x–10.x, and MS Windows95 and all later versions. If you port the code to a new operating system, please send me a note and any patches you required.

The major prerequisite for installing NCO on a particular platform is the successful, prior installation of the netCDF library (and, as of 2003, the UDUnits library). Unidata has shown a commitment to maintaining netCDF and UDUnits on all popular UNIX platforms, and is moving towards full support for the Microsoft Windows operating system

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<sup>1</sup> To produce these formats, ‘`nco.texi`’ was simply run through the freely available programs `texi2dvi`, `dvips`, `texi2html`, and `makeinfo`. Due to a bug in TeX, the resulting Postscript file, ‘`nco.ps`’, contains the Table of Contents as the final pages. Thus if you print ‘`nco.ps`’, remember to insert the Table of Contents after the cover sheet before you staple the manual.

(OS). Given this, the only difficulty in implementing NCO on a particular platform is standardization of various C-language API system calls. NCO code is tested for ANSI compliance by compiling with C compilers including those from GNU (`'gcc -std=c99 -pedantic -D_BSD_SOURCE -D_POSIX_SOURCE' -Wall`)<sup>2</sup>, Comeau Computing (`'como --c99'`), Cray (`'cc'`), HP/Compaq/DEC (`'cc'`), IBM (`'xlc -c -qlanglvl=extc99'`), Intel (`'icc -std=c99'`), NEC (`'cc'`), PathScale (QLogic) (`'pathcc -std=c99'`), PGI (`'pgcc -c9x'`), SGI (`'cc -c99'`), and Sun (`'cc'`). NCO (all commands and the `libnco` library) and the C++ interface to netCDF (called `libnco_c++`) comply with the ISO C++ standards as implemented by Comeau Computing (`'como'`), Cray (`'CC'`), GNU (`'g++ -Wall'`), HP/Compaq/DEC (`'cxx'`), IBM (`'xlc'`), Intel (`'icc'`), NEC (`'c++'`), PathScale (Qlogic) (`'pathCC'`), PGI (`'pgCC'`), SGI (`'CC -LANG:std'`), and Sun (`'CC -LANG:std'`). See `'nco/bld/Makefile'` and `'nco/src/nco_c++/Makefile.old'` for more details and exact settings.

Until recently (and not even yet), ANSI-compliant has meant compliance with the 1989 ISO C-standard, usually called C89 (with minor revisions made in 1994 and 1995). C89 lacks variable-size arrays, restricted pointers, some useful `printf` formats, and many mathematical special functions. These are valuable features of C99, the 1999 ISO C-standard. NCO is C99-compliant where possible and C89-compliant where necessary. Certain branches in the code are required to satisfy the native SGI and SunOS C compilers, which are strictly ANSI C89 compliant, and cannot benefit from C99 features. However, C99 features are fully supported by modern AIX, GNU, Intel, NEC, Solaris, and UNICOS compilers. NCO requires a C99-compliant compiler as of NCO version 2.9.8, released in August, 2004.

The most time-intensive portion of NCO execution is spent in arithmetic operations, e.g., multiplication, averaging, subtraction. These operations were performed in Fortran by default until August, 1999. This was a design decision based on the relative speed of Fortran-based object code vs. C-based object code in late 1994. C compiler vectorization capabilities have dramatically improved since 1994. We have accordingly replaced all Fortran subroutines with C functions. This greatly simplifies the task of building NCO on nominally unsupported platforms. As of August 1999, NCO built entirely in C by default. This allowed NCO to compile on any machine with an ANSI C compiler. In August 2004, the first C99 feature, the `restrict` type qualifier, entered NCO in version 2.9.8. C compilers can obtain better performance with C99 restricted pointers since they inform the compiler when it may make Fortran-like assumptions regarding pointer contents alteration. Subsequently, NCO requires a C99 compiler to build correctly<sup>3</sup>.

In January 2009, NCO version 3.9.6 was the first to link to the GNU Scientific Library (GSL). GSL must be version 1.4 or later. NCO, in particular `ncap2`, uses the GSL special function library to evaluate geoscience-relevant mathematics such as Bessel functions, Legendre polynomials, and incomplete gamma functions (see [Section 4.1.19 \[GSL special functions\]](#), page 96).

In June 2005, NCO version 3.0.1 began to take advantage of C99 mathematical special functions. These include the standardized gamma function (called `tgamma()` for “true

<sup>2</sup> The `'_BSD_SOURCE'` token is required on some Linux platforms where `gcc` dislikes the network header files like `'netinet/in.h'`).

<sup>3</sup> NCO may still build with an ANSI or ISO C89 or C94/95-compliant compiler if the C pre-processor undefines the `restrict` type qualifier, e.g., by invoking the compiler with `'-Drestrict='`.



gamma”). NCO automagically takes advantage of some GNU Compiler Collection (GCC) extensions to ANSI C.

As of July 2000 and NCO version 1.2, NCO no longer performs arithmetic operations in Fortran. We decided to sacrifice executable speed for code maintainability. Since no objective statistics were ever performed to quantify the difference in speed between the Fortran and C code, the performance penalty incurred by this decision is unknown. Supporting Fortran involves maintaining two sets of routines for every arithmetic operation. The `USE_FORTRAN_ARITHMETIC` flag is still retained in the `Makefile`. The file containing the Fortran code, `nco_fortran.F`, has been deprecated but a volunteer (Dr. Frankenstein?) could resurrect it. If you would like to volunteer to maintain `nco_fortran.F` please contact me.

### 1.2.1 Compiling NCO for Microsoft Windows OS

NCO has been successfully ported and tested on most Microsoft Windows operating systems including: 95/98/NT/2000/XP/Vista. The switches necessary to accomplish this are included in the standard distribution of NCO. Using the freely available Cygwin (formerly gnu-win32) development environment<sup>4</sup>, the compilation process is very similar to installing NCO on a UNIX system. Set the `PVM_ARCH` preprocessor token to `WIN32`. Note that defining `WIN32` has the side effect of disabling Internet features of NCO (see below). NCO should now build like it does on UNIX.

The least portable section of the code is the use of standard UNIX and Internet protocols (e.g., `ftp`, `rcp`, `scp`, `sftp`, `getuid`, `gethostname`, and header files `<arpa/nameser.h>` and `<resolv.h>`). Fortunately, these UNIX-y calls are only invoked by the single NCO subroutine which is responsible for retrieving files stored on remote systems (see [Section 3.7 \[Remote storage\]](#), page 28). In order to support NCO on the Microsoft Windows platforms, this single feature was disabled (on Windows OS only). This was required by Cygwin 18.x—newer versions of Cygwin may support these protocols (let me know if this is the case). The NCO operators should behave identically on Windows and UNIX platforms in all other respects.

## 1.3 Symbolic Links

NCO relies on a common set of underlying algorithms. To minimize duplication of source code, multiple operators sometimes share the same underlying source. This is accomplished by symbolic links from a single underlying executable program to one or more invoked executable names. For example, `ncea` and `ncrcat` are symbolically linked to the `ncra` executable. The `ncra` executable behaves slightly differently based on its invocation name (i.e., `argv[0]`), which can be `ncea`, `ncra`, or `ncrcat`. Logically, these are three different operators that happen to share the same executable.

For historical reasons, and to be more user friendly, multiple synonyms (or pseudonyms) may refer to the same operator invoked with different switches. For example, `ncdiff` is the same as `ncbo` and `ncpack` is the same as `ncpdq`. We implement the symbolic links and

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<sup>4</sup> The Cygwin package is available from <http://sourceware.redhat.com/cygwin>. Currently, Cygwin 20.x comes with the GNU C/C++ compilers (`gcc`, `g++`). These GNU compilers may be used to build the netCDF distribution itself.

synonyms by the executing the following UNIX commands in the directory where the NCO executables are installed.

```
ln -s -f ncbo ncdiff      # ncbo --op_typ='+'
ln -s -f ncra ncecat      # ncra --pseudonym='ncecat'
ln -s -f ncra ncrctat     # ncra --pseudonym='ncrctat'
ln -s -f ncbo ncadd       # ncbo --op_typ='+'
ln -s -f ncbo ncsubtract  # ncbo --op_typ='-'
ln -s -f ncbo ncmultiply  # ncbo --op_typ='*'
ln -s -f ncbo ncdivide    # ncbo --op_typ='/'
ln -s -f ncpdq ncpack     # ncpdq
ln -s -f ncpdq ncunpack   # ncpdq --unpack
# NB: Cygwin executable (and link) names have an '.exe' suffix, e.g.,
ln -s -f ncbo.exe ncdiff.exe
...
```

The imputed command called by the link is given after the comment. As can be seen, some these links impute the passing of a command line argument to further modify the behavior of the underlying executable. For example, `ncdivide` is a pseudonym for `ncbo --op_typ='/'`.

## 1.4 Libraries

Like all executables, the NCO operators can be built using dynamic linking. This reduces the size of the executable and can result in significant performance enhancements on multiuser systems. Unfortunately, if your library search path (usually the `LD_LIBRARY_PATH` environment variable) is not set correctly, or if the system libraries have been moved, renamed, or deleted since NCO was installed, it is possible NCO operators will fail with a message that they cannot find a dynamically loaded (aka *shared object* or `‘.so’`) library. This will produce a distinctive error message, such as `‘ld.so.1: /usr/local/bin/ncea: fatal: libsunmath.so.1: can't open file: errno=2’`. If you received an error message like this, ask your system administrator to diagnose whether the library is truly missing<sup>5</sup>, or whether you simply need to alter your library search path. As a final remedy, you may re-compile and install NCO with all operators statically linked.

## 1.5 netCDF2/3/4 and HDF4/5 Support

netCDF version 2 was released in 1993. NCO (specifically `ncks`) began soon after this in 1994. netCDF 3.0 was released in 1996, and we were eager to reap the performance advantages of the newer netCDF implementation. One netCDF3 interface call (`nc_inq_libvers`) was added to NCO in January, 1998, to aid in maintainance and debugging. In March, 2001, the final conversion of NCO to netCDF3 was completed (coincidentally on the same day netCDF 3.5 was released). NCO versions 2.0 and higher are built with the `-DNO_NETCDF_2` flag to ensure no netCDF2 interface calls are used.

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<sup>5</sup> The `ldd` command, if it is available on your system, will tell you where the executable is looking for each dynamically loaded library. Use, e.g., `ldd ‘which ncea’`.

However, the ability to compile NCO with only netCDF2 calls is worth maintaining because HDF version 4<sup>6</sup> (available from [HDF](http://hdf.ncsa.uiuc.edu/UG41r3_html/SDS_SD_fm12.html#47784)) supports only the netCDF2 library calls (see [http://hdf.ncsa.uiuc.edu/UG41r3\\_html/SDS\\_SD\\_fm12.html#47784](http://hdf.ncsa.uiuc.edu/UG41r3_html/SDS_SD_fm12.html#47784)). Note that there are multiple versions of HDF. Currently HDF version 4.x supports netCDF2 and thus NCO version 1.2.x. If NCO version 1.2.x (or earlier) is built with only netCDF2 calls then all NCO operators should work with HDF4 files as well as netCDF files<sup>7</sup>. The preprocessor token `NETCDF2_ONLY` exists in NCO version 1.2.x to eliminate all netCDF3 calls. Only versions of NCO numbered 1.2.x and earlier have this capability. The NCO 1.2.x branch will be maintained with bugfixes only (no new features) until HDF begins to fully support the netCDF3 interface (which is employed by NCO 2.x). If, at compilation time, `NETCDF2_ONLY` is defined, then NCO version 1.2.x will not use any netCDF3 calls and, if linked properly, the resulting NCO operators will work with HDF4 files. The ‘Makefile’ supplied with NCO 1.2.x is written to simplify building in this HDF capability. When NCO is built with `make HDF4=Y`, the ‘Makefile’ sets all required preprocessor flags and library links to build with the HDF4 libraries (which are assumed to reside under `/usr/local/hdf4`, edit the ‘Makefile’ to suit your installation).

HDF version 5 became available in 1999, but did not support netCDF (or, for that matter, Fortran) as of December 1999. By early 2001, HDF5 did support Fortran90. In 2004, Unidata and NCSA began a project to implement the HDF5 features necessary to support the netCDF API. NCO version 3.0.3 added support for reading/writing netCDF4-formatted HDF5 files in October, 2005. See [Section 3.9 \[Selecting Output File Format\]](#), [page 33](#) for more details.

HDF support for netCDF was completed with HDF5 version 1.8 in 2007. The netCDF front-end that uses this HDF5 back-end was completed and released soon after as netCDF version 4. Download it from the [netCDF4](#) website.

NCO version 3.9.0, released in May, 2007, added support for all netCDF4 atomic data types except `NC_STRING`. Support for `NC_STRING`, including ragged arrays of strings, was finally added in version 3.9.9, released in June, 2009. Support for additional netCDF4 features has been incremental. We add one netCDF4 feature at a time. You must build NCO with netCDF4 to obtain this support.

The main netCDF4 features that NCO currently supports are the new atomic data types, Lempel-Ziv compression (deflation), and chunking. The new atomic data types are `NC_UBYTE`, `NC_USHORT`, `NC_UINT`, `NC_INT64`, and `NC_UINT64`. Eight-byte integer support is an especially useful improvement from netCDF3. All NCO operators support these types, e.g., `ncks` copies and prints them, `ncra` averages them, and `ncap2` processes algebraic scripts with them. `ncks` prints compression information, if any, to screen.

NCO version 3.9.1 (June, 2007) added support for netCDF4 Lempel-Ziv deflation. Lempel-Ziv deflation is a lossless compression technique. See [Section 3.23 \[Deflation\]](#), [page 53](#) for more details.

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<sup>6</sup> The Hierarchical Data Format, or HDF, is another self-describing data format similar to, but more elaborate than, netCDF.

<sup>7</sup> One must link the NCO code to the HDF4 MFHDF library instead of the usual netCDF library. Does ‘MF’ stand for Mike Folk? Perhaps. In any case, the MFHDF library only supports netCDF2 calls. Thus I will try to keep this capability in NCO as long as it is not too much trouble.

NCO version 3.9.9 (June, 2009) added support for netCDF4 chunking in `ncks` and `nccat`. NCO version 4.0.4 (September, 2010) completed support for netCDF4 chunking in the remaining operators. See [Section 3.22 \[Chunking\]](#), page 50 for more details.

netCDF4-enabled NCO handles netCDF3 files without change. In addition, it automatically handles netCDF4 (HDF5) files: If you feed NCO netCDF3 files, it produces netCDF3 output. If you feed NCO netCDF4 files, it produces netCDF4 output. Use the handy-dandy ‘-4’ switch to request netCDF4 output from netCDF3 input, i.e., to convert netCDF3 to netCDF4. See [Section 3.9 \[Selecting Output File Format\]](#), page 33 for more details.

As of 2010, netCDF4 is still relatively new software. Problems with netCDF4 and HDF libraries are still being fixed. Binary NCO distributions shipped as RPMs use the netCDF4 library, while debs use the netCDF3 library, because of upstream requirements.

One must often build NCO from source to obtain netCDF4 support. Typically, one specifies the root of the netCDF4 installation directory. Do this with the `NETCDF4_ROOT` variable. Then use your preferred NCO build mechanism, e.g.,

```
export NETCDF4_ROOT=/usr/local/netcdf4 # Set netCDF4 location
cd ~/nco;./configure --enable-netcdf4 # Configure mechanism -or-
cd ~/nco/bld;./make NETCDF4=Y allinone # Old Makefile mechanism
```

We carefully track the netCDF4 releases, and keep the netCDF4 atomic type support and other features working. Our long term goal is to utilize more of the extensive new netCDF4 feature set. The next major netCDF4 feature we are likely to utilize is parallel I/O. We will enable this in the MPI netCDF operators.

## 1.6 Help Requests and Bug Reports

We generally receive three categories of mail from users: help requests, bug reports, and feature requests. Notes saying the equivalent of "Hey, NCO continues to work great and it saves me more time everyday than it took to write this note" are a distant fourth.

There is a different protocol for each type of request. The preferred etiquette for all communications is via NCO Project Forums. Do not contact project members via personal e-mail unless your request comes with money or you have damaging information about our personal lives. *Please use the Forums*—they preserve a record of the questions and answers so that others can learn from our exchange. Also, since NCO is government-funded, this record helps us provide program officers with information they need to evaluate our project.

Before posting to the NCO forums described below, you might first [register](#) your name and email address with SourceForge.net or else all of your postings will be attributed to "nobody". Once registered you may choose to "monitor" any forum and to receive (or not) email when there are any postings including responses to your questions. We usually reply to the forum message, not to the original poster.

If you want us to include a new feature in NCO, check first to see if that feature is already on the [TODO](#) list. If it is, why not implement that feature yourself and send us the patch? If the feature is not yet on the list, then send a note to the [NCO Discussion forum](#).

Read the manual before reporting a bug or posting a help request. Sending questions whose answers are not in the manual is the best way to motivate us to write more docu-

mentation. We would also like to accentuate the contrapositive of this statement. If you think you have found a real bug *the most helpful thing you can do is simplify the problem to a manageable size and then report it*. The first thing to do is to make sure you are running the latest publicly released version of NCO.

Once you have read the manual, if you are still unable to get NCO to perform a documented function, submit a help request. Follow the same procedure as described below for reporting bugs (after all, it might be a bug). That is, describe what you are trying to do, and include the complete commands (run with ‘-D 5’), error messages, and version of NCO (with ‘-r’). Post your help request to the [NCO Help forum](#).

If you think you used the right command when NCO misbehaves, then you might have found a bug. Incorrect numerical answers are the highest priority. We usually fix those within one or two days. Core dumps and segmentation violations receive lower priority. They are always fixed, eventually.

How do you simplify a problem that reveal a bug? Cut out extraneous variables, dimensions, and metadata from the offending files and re-run the command until it no longer breaks. Then back up one step and report the problem. Usually the file(s) will be very small, i.e., one variable with one or two small dimensions ought to suffice. Run the operator with ‘-r’ and then run the command with ‘-D 5’ to increase the verbosity of the debugging output. It is very important that your report contain the exact error messages and compile-time environment. Include a copy of your sample input file, or place one on a publically accessible location, of the file(s). Post the full bug report to the [NCO Project buglist](#).

Build failures count as bugs. Our limited machine access means we cannot fix all build failures. The information we need to diagnose, and often fix, build failures are the three files output by GNU build tools, ‘nco.config.log.\${GNU\_TRP}.foo’, ‘nco.configure.\${GNU\_TRP}.foo’, and ‘nco.make.\${GNU\_TRP}.foo’. The file ‘configure.eg’ shows how to produce these files. Here \${GNU\_TRP} is the "GNU architecture triplet", the *chip-vendor-OS* string returned by ‘config.guess’. Please send us your improvements to the examples supplied in ‘configure.eg’. The regressions archive at <http://dust.ess.uci.edu/nco/rgr> contains the build output from our standard test systems. You may find you can solve the build problem yourself by examining the differences between these files and your own.



## 2 Operator Strategies

### 2.1 Philosophy

The main design goal is command line operators which perform useful, scriptable operations on netCDF files. Many scientists work with models and observations which produce too much data to analyze in tabular format. Thus, it is often natural to reduce and massage this raw or primary level data into summary, or second level data, e.g., temporal or spatial averages. These second level data may become the inputs to graphical and statistical packages, and are often more suitable for archival and dissemination to the scientific community. NCO performs a suite of operations useful in manipulating data from the primary to the second level state. Higher level interpretive languages (e.g., IDL, Yorick, Matlab, NCL, Perl, Python), and lower level compiled languages (e.g., C, Fortran) can always perform any task performed by NCO, but often with more overhead. NCO, on the other hand, is limited to a much smaller set of arithmetic and metadata operations than these full blown languages.

Another goal has been to implement enough command line switches so that frequently used sequences of these operators can be executed from a shell script or batch file. Finally, NCO was written to consume the absolute minimum amount of system memory required to perform a given job. The arithmetic operators are extremely efficient; their exact memory usage is detailed in [Section 2.9 \[Memory Requirements\]](#), [page 19](#).

### 2.2 Climate Model Paradigm

NCO was developed at NCAR to aid analysis and manipulation of datasets produced by General Circulation Models (GCMs). Datasets produced by GCMs share many features with all gridded scientific datasets and so provide a useful paradigm for the explication of the NCO operator set. Examples in this manual use a GCM paradigm because latitude, longitude, time, temperature and other fields related to our natural environment are as easy to visualize for the layman as the expert.

### 2.3 Temporary Output Files

NCO operators are designed to be reasonably fault tolerant, so that if there is a system failure or the user aborts the operation (e.g., with `C-c`), then no data are lost. The user-specified *output-file* is only created upon successful completion of the operation<sup>1</sup>. This is accomplished by performing all operations in a temporary copy of *output-file*. The name of the temporary output file is constructed by appending `.pid<process ID>.<operator name>.tmp` to the user-specified *output-file* name. When the operator completes its task with no fatal errors, the temporary output file is moved to the user-specified *output-file*. Note the construction of a temporary output file uses more disk space than just overwriting existing files “in place” (because there may be two copies of the same file on disk until the NCO operation successfully concludes and the temporary output file overwrites the existing *output-file*). Also, note this feature increases the execution time of the operator by approximately the time it takes to copy the *output-file*. Finally, note this feature allows the *output-file* to be the same as the *input-file* without any danger of “overlap”.

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<sup>1</sup> The `ncrename` operator is an exception to this rule. See [Section 4.11 \[ncrename netCDF Renamer\]](#), [page 153](#).



Other safeguards exist to protect the user from inadvertently overwriting data. If the *output-file* specified for a command is a pre-existing file, then the operator will prompt the user whether to overwrite (erase) the existing *output-file*, attempt to append to it, or abort the operation. However, in processing large amounts of data, too many interactive questions slows productivity. Therefore NCO also implements two ways to override its own safety features, the `'-O'` and `'-A'` switches. Specifying `'-O'` tells the operator to overwrite any existing *output-file* without prompting the user interactively. Specifying `'-A'` tells the operator to attempt to append to any existing *output-file* without prompting the user interactively. These switches are useful in batch environments because they suppress interactive keyboard input.

## 2.4 Appending Variables

Adding variables from one file to another is often desirable. This is referred to as *appending*, although some prefer the terminology *merging*<sup>2</sup> or *pasting*. Appending is often confused with what NCO calls *concatenation*. In NCO, concatenation refers to splicing a variable along the record dimension. The length along the record dimension of the output is the sum of the lengths of the input files. Appending, on the other hand, refers to copying a variable from one file to another file which may or may not already contain the variable<sup>3</sup>. NCO can append or concatenate just one variable, or all the variables in a file at the same time.

In this sense, `ncks` can append variables from one file to another file. This capability is invoked by naming two files on the command line, *input-file* and *output-file*. When *output-file* already exists, the user is prompted whether to *overwrite*, *append/replace*, or *exit* from the command. Selecting *overwrite* tells the operator to erase the existing *output-file* and replace it with the results of the operation. Selecting *exit* causes the operator to exit—the *output-file* will not be touched in this case. Selecting *append/replace* causes the operator to attempt to place the results of the operation in the existing *output-file*, See [Section 4.7 \[ncks netCDF Kitchen Sink\]](#), page 135.

The simplest way to create the union of two files is

```
ncks -A f1_1.nc f1_2.nc
```

This puts the contents of `'f1_1.nc'` into `'f1_2.nc'`. The `'-A'` is optional. On output, `'f1_2.nc'` is the union of the input files, regardless of whether they share dimensions and variables, or are completely disjoint. The append fails if the input files have differently named record dimensions (since netCDF supports only one), or have dimensions of the same name but different sizes.

## 2.5 Simple Arithmetic and Interpolation

Users comfortable with NCO semantics may find it easier to perform some simple mathematical operations in NCO rather than higher level languages. `ncbo` (see [Section 4.3 \[ncbo netCDF Binary Operator\]](#), page 123) does file addition, subtraction, multiplication, division,

<sup>2</sup> The terminology *merging* is reserved for an (unwritten) operator which replaces hyperslabs of a variable in one file with hyperslabs of the same variable from another file

<sup>3</sup> Yes, the terminology is confusing. By all means mail me if you think of a better nomenclature. Should NCO use *paste* instead of *append*?



and broadcasting. `ncflint` (see [Section 4.6 \[ncflint netCDF File Interpolator\]](#), page 132) does file addition, subtraction, multiplication and interpolation. Sequences of these commands can accomplish simple but powerful operations from the command line.

## 2.6 Averagers vs. Concatenators

The most frequently used operators of NCO are probably the averagers and concatenators. Because there are so many permutations of averaging (e.g., across files, within a file, over the record dimension, over other dimensions, with or without weights and masks) and of concatenating (across files, along the record dimension, along other dimensions), there are currently no fewer than five operators which tackle these two purposes: `ncra`, `ncea`, `ncwa`, `ncrcat`, and `ncecat`. These operators do share many capabilities<sup>4</sup>, but each has its unique specialty. Two of these operators, `ncrcat` and `ncecat`, are for concatenating hyperslabs across files. The other two operators, `ncra` and `ncea`, are for averaging hyperslabs across files<sup>5</sup>. First, let's describe the concatenators, then the averagers.

### 2.6.1 Concatenators `ncrcat` and `ncecat`

Joining independent files together along a record dimension is called *concatenation*. `ncrcat` is designed for concatenating record variables, while `ncecat` is designed for concatenating fixed length variables. Consider five files, '85.nc', '86.nc', ... '89.nc' each containing a year's worth of data. Say you wish to create from them a single file, '8589.nc' containing all the data, i.e., spanning all five years. If the annual files make use of the same record variable, then `ncrcat` will do the job nicely with, e.g., `ncrcat 8?.nc 8589.nc`. The number of records in the input files is arbitrary and can vary from file to file. See [Section 4.10 \[ncrcat netCDF Record Concatenator\]](#), page 151, for a complete description of `ncrcat`.

However, suppose the annual files have no record variable, and thus their data are all fixed length. For example, the files may not be conceptually sequential, but rather members of the same group, or *ensemble*. Members of an ensemble may have no reason to contain a record dimension. `ncecat` will create a new record dimension (named *record* by default) with which to glue together the individual files into the single ensemble file. If `ncecat` is used on files which contain an existing record dimension, that record dimension is converted to a fixed-length dimension of the same name and a new record dimension (named *record*) is created. Consider five realizations, '85a.nc', '85b.nc', ... '85e.nc' of 1985 predictions from the same climate model. Then `ncecat 85?.nc 85_ens.nc` glues the individual realizations together into the single file, '85\_ens.nc'. If an input variable was dimensioned [lat,lon], it will have dimensions [record,lat,lon] in the output file. A restriction of `ncecat` is that the hyperslabs of the processed variables must be the same from file to file. Normally this means all the input files are the same size, and contain data on different realizations of the same variables. See [Section 4.5 \[ncecat netCDF Ensemble Concatenator\]](#), page 130, for a complete description of `ncecat`.

<sup>4</sup> Currently `ncea` and `ncrcat` are symbolically linked to the `ncra` executable, which behaves slightly differently based on its invocation name (i.e., 'argv[0]'). These three operators share the same source code, but merely have different inner loops.

<sup>5</sup> The third averaging operator, `ncwa`, is the most sophisticated averager in NCO. However, `ncwa` is in a different class than `ncra` and `ncea` because it can only operate on a single file per invocation (as opposed to multiple files). On that single file, however, `ncwa` provides a richer set of averaging options—including weighting, masking, and broadcasting.

`ncpdq` makes it possible to concatenate files along any dimension, not just the record dimension. First, use `ncpdq` to convert the dimension to be concatenated (i.e., extended with data from other files) into the record dimension. Second, use `ncrcat` to concatenate these files. Finally, if desirable, use `ncpdq` to revert to the original dimensionality. As a concrete example, say that files `'x_01.nc'`, `'x_02.nc'`, ... `'x_10.nc'` contain time-evolving datasets from spatially adjacent regions. The time and spatial coordinates are `time` and `x`, respectively. Initially the record dimension is `time`. Our goal is to create a single file that contains joins all the spatially adjacent regions into one single time-evolving dataset.

```
for idx in 01 02 03 04 05 06 07 08 09 10; do # Bourne Shell
    ncpdq -a x,time x_${idx}.nc foo_${idx}.nc # Make x record dimension
done
ncrcat foo_???.nc out.nc          # Concatenate along x
ncpdq -a time,x out.nc out.nc    # Revert to time as record dimension
```

Note that `ncrcat` will not concatenate fixed-length variables, whereas `ncecat` concatenates both fixed-length and record variables along a new record variable. To conserve system memory, use `ncrcat` where possible.

### 2.6.2 Averagers `ncea`, `ncra`, and `ncwa`

The differences between the averagers `ncra` and `ncea` are analogous to the differences between the concatenators. `ncra` is designed for averaging record variables from at least one file, while `ncea` is designed for averaging fixed length variables from multiple files. `ncra` performs a simple arithmetic average over the record dimension of all the input files, with each record having an equal weight in the average. `ncea` performs a simple arithmetic average of all the input files, with each file having an equal weight in the average. Note that `ncra` cannot average fixed-length variables, but `ncea` can average both fixed-length and record variables. To conserve system memory, use `ncra` rather than `ncea` where possible (e.g., if each *input-file* is one record long). The file output from `ncea` will have the same dimensions (meaning dimension names as well as sizes) as the input hyperslabs (see [Section 4.4 \[ncea netCDF Ensemble Averager\]](#), [page 128](#), for a complete description of `ncea`). The file output from `ncra` will have the same dimensions as the input hyperslabs except for the record dimension, which will have a size of 1 (see [Section 4.9 \[ncra netCDF Record Averager\]](#), [page 149](#), for a complete description of `ncra`).

### 2.6.3 Interpolator `ncflint`

`ncflint` can interpolate data between or two files. Since no other operators have this ability, the description of interpolation is given fully on the `ncflint` reference page (see [Section 4.6 \[ncflint netCDF File Interpolator\]](#), [page 132](#)). Note that this capability also allows `ncflint` to linearly rescale any data in a netCDF file, e.g., to convert between differing units.

## 2.7 Large Numbers of Files

Occasionally one desires to digest (i.e., concatenate or average) hundreds or thousands of input files. Unfortunately, data archives (e.g., NASA EOSDIS) may not name netCDF files in a format understood by the `'-n loop'` switch (see [Section 3.5 \[Specifying Input Files\]](#), [page 26](#)) that automatically generates arbitrary numbers of input filenames. The `'-n loop'` switch has the virtue of being concise, and of minimizing the command line. This helps keeps

output file small since the command line is stored as metadata in the `history` attribute (see [Section 3.28 \[History Attribute\], page 62](#)). However, the `-n loop` switch is useless when there is no simple, arithmetic pattern to the input filenames (e.g., `'h00001.nc'`, `'h00002.nc'`, ... `'h90210.nc'`). Moreover, filename globbing does not work when the input files are too numerous or their names are too lengthy (when strung together as a single argument) to be passed by the calling shell to the NCO operator<sup>6</sup>. When this occurs, the ANSI C-standard `argc-argv` method of passing arguments from the calling shell to a C-program (i.e., an NCO operator) breaks down. There are (at least) three alternative methods of specifying the input filenames to NCO in environment-limited situations.

The recommended method for sending very large numbers (hundreds or more, typically) of input filenames to the multi-file operators is to pass the filenames with the UNIX *standard input* feature, aka `stdin`:

```
# Pipe large numbers of filenames to stdin
/bin/ls | grep ${CASEID}_'.....'.nc | nccat -o foo.nc
```

This method avoids all constraints on command line size imposed by the operating system. A drawback to this method is that the `history` attribute (see [Section 3.28 \[History Attribute\], page 62](#)) does not record the name of any input files since the names were not passed on the command line. This makes determining the data provenance at a later date difficult. To remedy this situation, multi-file operators store the number of input files in the `nco_input_file_number` global attribute and the input file list itself in the `nco_input_file_list` global attribute (see [Section 3.29 \[File List Attributes\], page 63](#)). Although this does not preserve the exact command used to generate the file, it does retain all the information required to reconstruct the command and determine the data provenance.

A second option is to use the UNIX `xargs` command. This simple example selects as input to `xargs` all the filenames in the current directory that match a given pattern. For illustration, consider a user trying to average millions of files which each have a six character filename. If the shell buffer can not hold the results of the corresponding globbing operator, `'??????.nc'`, then the filename globbing technique will fail. Instead we express the filename pattern as an extended regular expression, `'.....\nc'` (see [Section 3.11 \[Subsetting Variables\], page 36](#)). We use `grep` to filter the directory listing for this pattern and to pipe the results to `xargs` which, in turn, passes the matching filenames to an NCO multi-file operator, e.g., `nccat`.

```
# Use xargs to transfer filenames on the command line
/bin/ls | grep ${CASEID}_'.....'.nc | xargs -x nccat -o foo.nc
```

The single quotes protect the only sensitive parts of the extended regular expression (the `grep` argument), and allow shell interpolation (the `${CASEID}` variable substitution) to proceed unhindered on the rest of the command. `xargs` uses the UNIX pipe feature to append the suitably filtered input file list to the end of the `nccat` command options. The `-o foo.nc` switch ensures that the input files supplied by `xargs` are not confused with the output file name. `xargs` does, unfortunately, have its own limit (usually about 20,000

<sup>6</sup> The exact length which exceeds the operating system internal limit for command line lengths varies from OS to OS and from shell to shell. GNU `bash` may not have any arbitrary fixed limits to the size of command line arguments. Many OSs cannot handle command line arguments (including results of file globbing) exceeding 4096 characters.

characters) on the size of command lines it can pass. Give **xargs** the **'-x'** switch to ensure it dies if it reaches this internal limit. When this occurs, use either the **stdin** method above, or the symbolic link presented next.

Even when its internal limits have not been reached, the **xargs** technique may not be sophisticated enough to handle all situations. A full scripting language like Perl can handle any level of complexity of filtering input filenames, and any number of filenames. The technique of last resort is to write a script that creates symbolic links between the irregular input filenames and a set of regular, arithmetic filenames that the **'-n loop'** switch understands. For example, the following Perl script a monotonically enumerated symbolic link to up to one million **'.nc'** files in a directory. If there are 999,999 netCDF files present, the links are named **'000001.nc'** to **'999999.nc'**:

```
# Create enumerated symbolic links
/bin/ls | grep \.nc | perl -e \
'$idx=1;while(<STDIN>){chop;symlink $_,sprintf("%06d.nc",$idx++);}'
ncecat -n 999999,6,1 000001.nc foo.nc
# Remove symbolic links when finished
/bin/rm ??????.nc
```

The **'-n loop'** option tells the NCO operator to automatically generate the filenames of the symbolic links. This circumvents any OS and shell limits on command line size. The symbolic links are easily removed once NCO is finished. One drawback to this method is that the **history** attribute (see [Section 3.28 \[History Attribute\], page 62](#)) retains the filename list of the symbolic links, rather than the data files themselves. This makes it difficult to determine the data provenance at a later date.

## 2.8 Large Datasets

*Large datasets* are those files that are comparable in size to the amount of random access memory (RAM) in your computer. Many users of NCO work with files larger than 100 MB. Files this large not only push the current edge of storage technology, they present special problems for programs which attempt to access the entire file at once, such as **ncea** and **nccat**. If you work with a 300 MB files on a machine with only 32 MB of memory then you will need large amounts of swap space (virtual memory on disk) and NCO will work slowly, or even fail. There is no easy solution for this. The best strategy is to work on a machine with sufficient amounts of memory and swap space. Since about 2004, many users have begun to produce or analyze files exceeding 2 GB in size. These users should familiarize themselves with NCO's Large File Support (LFS) capabilities (see [Section 3.10 \[Large File Support\], page 35](#)). The next section will increase your familiarity with NCO's memory requirements. With this knowledge you may re-design your data reduction approach to divide the problem into pieces solvable in memory-limited situations.

If your local machine has problems working with large files, try running NCO from a more powerful machine, such as a network server. Certain machine architectures, e.g., Cray UNICOS, have special commands which allow one to increase the amount of interactive memory. On Cray systems, try to increase the available memory with the **ilimit** command. If you get a memory-related core dump (e.g., **'Error exit (core dumped)'**) on a GNU/Linux system, try increasing the process-available memory with **ulimit**.

The speed of the NCO operators also depends on file size. When processing large files the operators may appear to hang, or do nothing, for large periods of time. In order to see what the operator is actually doing, it is useful to activate a more verbose output mode. This is accomplished by supplying a number greater than 0 to the ‘`-D debug-level`’ (or ‘`--debug-level`’, or ‘`--dbg_lvl`’) switch. When the *debug-level* is nonzero, the operators report their current status to the terminal through the *stderr* facility. Using ‘`-D`’ does not slow the operators down. Choose a *debug-level* between 1 and 3 for most situations, e.g., `ncea -D 2 85.nc 86.nc 8586.nc`. A full description of how to estimate the actual amount of memory the multi-file NCO operators consume is given in [Section 2.9 \[Memory Requirements\]](#), page 19.

## 2.9 Memory Requirements

Many people use NCO on gargantuan files which dwarf the memory available (free RAM plus swap space) even on today’s powerful machines. These users want NCO to consume the least memory possible so that their scripts do not have to tediously cut files into smaller pieces that fit into memory. We commend these greedy users for pushing NCO to its limits!

This section describes the memory NCO requires during operation. The required memory is based on the underlying algorithms. The description below is the memory usage per thread. Users with shared memory machines may use the threaded NCO operators (see [Section 3.3 \[OpenMP Threading\]](#), page 23). The peak and sustained memory usage will scale accordingly, i.e., by the number of threads. Memory consumption patterns of all operators are similar, with the exception of `ncap2`.

### 2.9.1 Single and Multi-file Operators

The multi-file operators currently comprise the record operators, `ncra` and `ncrcat`, and the ensemble operators, `ncea` and `ncecat`. The record operators require *much less* memory than the ensemble operators. This is because the record operators operate on one single record (i.e., time-slice) at a time, whereas the ensemble operators retrieve the entire variable into memory. Let  $MS$  be the peak sustained memory demand of an operator,  $FT$  be the memory required to store the entire contents of all the variables to be processed in an input file,  $FR$  be the memory required to store the entire contents of a single record of each of the variables to be processed in an input file,  $VR$  be the memory required to store a single record of the largest record variable to be processed in an input file,  $VT$  be the memory required to store the largest variable to be processed in an input file,  $VI$  be the memory required to store the largest variable which is not processed, but is copied from the initial file to the output file. All operators require  $MI = VI$  during the initial copying of variables from the first input file to the output file. This is the *initial* (and transient) memory demand. The *sustained* memory demand is that memory required by the operators during the processing (i.e., averaging, concatenation) phase which lasts until all the input files have been processed. The operators have the following memory requirements: `ncrcat` requires  $MS \leq VR$ . `ncecat` requires  $MS \leq VT$ . `ncra` requires  $MS = 2FR + VR$ . `ncea` requires  $MS = 2FT + VT$ . `ncbo` requires  $MS \leq 3VT$  (both input variables and the output variable). `ncflint` requires  $MS \leq 3VT$  (both input variables and the output variable). `ncpdq` requires  $MS \leq 2VT$  (one input variable and the output variable). `ncwa` requires  $MS \leq 8VT$  (see below). Note that only variables that are processed, e.g., averaged, concatenated, or differenced, contribute to  $MS$ . Variables which do not appear in the



output file (see [Section 3.11 \[Subsetting Variables\]](#), page 36) are never read and contribute nothing to the memory requirements.

`ncwa` consumes between two and seven times the memory of a variable in order to process it. Peak consumption occurs when storing simultaneously in memory one input variable, one tally array, one input weight, one conformed/working weight, one weight tally, one input mask, one conformed/working mask, and one output variable. When invoked, the weighting and masking features contribute up to three-sevenths and two-sevenths of these requirements apiece. If weights and masks are *not* specified (i.e., no `-w` or `-a` options) then `ncwa` requirements drop to  $MS \leq 3VT$  (one input variable, one tally array, and the output variable).

The above memory requirements must be multiplied by the number of threads `thr_nbr` (see [Section 3.3 \[OpenMP Threading\]](#), page 23). If this causes problems then reduce (with `-t thr_nbr`) the number of threads.

## 2.9.2 Memory for `ncap2`

`ncap2` has unique memory requirements due its ability to process arbitrarily long scripts of any complexity. All scripts acceptable to `ncap2` are ultimately processed as a sequence of binary or unary operations. `ncap2` requires  $MS \leq 2VT$  under most conditions. An exception to this is when left hand casting (see [Section 4.1.4 \[Left hand casting\]](#), page 74) is used to stretch the size of derived variables beyond the size of any input variables. Let  $VC$  be the memory required to store the largest variable defined by left hand casting. In this case,  $MS \leq 2VC$ .

`ncap2` scripts are complete dynamic and may be of arbitrary length. A script that contains many thousands of operations, may uncover a slow memory leak even though each single operation consumes little additional memory. Memory leaks are usually identifiable by their memory usage signature. Leaks cause peak memory usage to increase monotonically with time regardless of script complexity. Slow leaks are very difficult to find. Sometimes a `malloc()` (or `new[]`) failure is the only noticeable clue to their existence. If you have good reasons to believe that a memory allocation failure is ultimately due to an NCO memory leak (rather than inadequate RAM on your system), then we would be very interested in receiving a detailed bug report.

## 2.10 Performance

An overview of NCO capabilities as of about 2006 is in Zender, C. S. (2008), "Analysis of Self-describing Gridded Geoscience Data with netCDF Operators (NCO)", *Environ. Modell. Softw.*, doi:10.1016/j.envsoft.2008.03.004. This paper is also available at [http://dust.ess.uci.edu/ppr/ppr\\_Zen08\\_ems.pdf](http://dust.ess.uci.edu/ppr/ppr_Zen08_ems.pdf).

NCO performance and scaling for arithmetic operations is described in Zender, C. S., and H. J. Mangalam (2007), "Scaling Properties of Common Statistical Operators for Gridded Datasets", *Int. J. High Perform. Comput. Appl.*, 21(4), 485-498, doi:10.1177/1094342007083802. This paper is also available at [http://dust.ess.uci.edu/ppr/ppr\\_ZeM07\\_ijhpca.pdf](http://dust.ess.uci.edu/ppr/ppr_ZeM07_ijhpca.pdf).

It is helpful to be aware of the aspects of NCO design that can limit its performance:

1. No data buffering is performed during `nc_get_var` and `nc_put_var` operations. Hyperslabs too large to hold in core memory will suffer substantial performance penalties because of this.
2. Since coordinate variables are assumed to be monotonic, the search for bracketing the user-specified limits should employ a quicker algorithm, like bisection, than the two-sided incremental search currently implemented.
3. *C\_format*, *FORTTRAN\_format*, *signedness*, *scale\_format* and *add\_offset* attributes are ignored by `ncks` when printing variables to screen.
4. In the late 1990s it was discovered that some random access operations on large files on certain architectures (e.g., UNICOS) were much slower with NCO than with similar operations performed using languages that bypass the netCDF interface (e.g., Yorick). This may have been a penalty of unnecessary byte-swapping in the netCDF interface. It is unclear whether such problems exist in present day (2007) netCDF/NCO environments, where unnecessary byte-swapping has been reduced or eliminated.





## 3 NCO Features

Many features have been implemented in more than one operator and are described here for brevity. The description of each feature is preceded by a box listing the operators for which the feature is implemented. Command line switches for a given feature are consistent across all operators wherever possible. If no “key switches” are listed for a feature, then that particular feature is automatic and cannot be controlled by the user.

### 3.1 Internationalization

Availability: All operators

NCO support for *internationalization* of textual input and output (e.g., Warning messages) is nascent. We hope to produce foreign language string catalogues in 2004.

### 3.2 Metadata Optimization

Availability: `ncatted`, `ncks`, `ncrename`  
Short options: None  
Long options: ‘`--hdr_pad`’, ‘`--header_pad`’

NCO supports padding headers to improve the speed of future metadata operations. Use the ‘`--hdr_pad`’ and ‘`--header_pad`’ switches to request that *hdr\_pad* bytes be inserted into the metadata section of the output file. Future metadata expansions will not incur the performance penalty of copying the entire output file unless the expansion exceeds the amount of header padding exceeded. This can be beneficial when it is known that some metadata will be added at a future date.

This optimization exploits the netCDF library `nc__enddef()` function, which behaves differently with different versions of netCDF. It will improve speed of future metadata expansion with **CLASSIC** and **64bit** netCDF files, but not necessarily with **NETCDF4** files, i.e., those created by the netCDF interface to the HDF5 library (see [Section 3.9 \[Selecting Output File Format\]](#), page 33).

### 3.3 OpenMP Threading

Availability: `ncap2`, `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncpdq`, `ncra`, `ncrcat`, `ncwa`  
Short options: ‘`-t`’  
Long options: ‘`--thr_nbr`’, ‘`--threads`’, ‘`--omp_num_threads`’

NCO supports shared memory parallelism (SMP) when compiled with an OpenMP-enabled compiler. Threads requests and allocations occur in two stages. First, users may request a specific number of threads *thr\_nbr* with the ‘`-t`’ switch (or its long option equivalent).

lents, ‘`--thr_nbr`’, ‘`--threads`’, and ‘`--omp_num_threads`’). If not user-specified, OpenMP obtains *thr\_nbr* from the `OMP_NUM_THREADS` environment variable, if present, or from the OS, if not.

NCO may modify *thr\_nbr* according to its own internal settings before it requests any threads from the system. Certain operators contain hard-code limits to the number of threads they request. We base these limits on our experience and common sense, and to reduce potentially wasteful system usage by inexperienced users. For example, `ncrcat` is extremely I/O-intensive so we restrict *thr\_nbr*  $\leq 2$  for `ncrcat`. This is based on the notion that the best performance that can be expected from an operator which does no arithmetic is to have one thread reading and one thread writing simultaneously. In the future (perhaps with `netCDF4`), we hope to demonstrate significant threading improvements with operators like `ncrcat` by performing multiple simultaneous writes.

Compute-intensive operators (`ncap`, `ncwa` and `ncpdq`) benefit most from threading. The greatest increases in throughput due to threading occur on large datasets where each thread performs millions, at least, of floating point operations. Otherwise, the system overhead of setting up threads probably outweighs the speed enhancements due to SMP parallelism. However, we have not yet demonstrated that the SMP parallelism scales well beyond four threads for these operators. Hence we restrict *thr\_nbr*  $\leq 4$  for all operators. We encourage users to play with these limits (edit file ‘`nco_omp.c`’) and send us their feedback.

Once the initial *thr\_nbr* has been modified for any operator-specific limits, NCO requests the system to allocate a team of *thr\_nbr* threads for the body of the code. The operating system then decides how many threads to allocate based on this request. Users may keep track of this information by running the operator with *dbg\_lvl*  $> 0$ .

By default, threaded operators attach one global attribute, `nco_openmp_thread_number`, to any file they create or modify. This attribute contains the number of threads the operator used to process the input files. This information helps to verify that the answers with threaded and non-threaded operators are equal to within machine precision. This information is also useful for benchmarking.

### 3.4 Command Line Options

Availability: All operators

NCO achieves flexibility by using *command line options*. These options are implemented in all traditional UNIX commands as single letter *switches*, e.g., ‘`ls -l`’. For many years NCO used only single letter option names. In late 2002, we implemented GNU/POSIX extended or long option names for all options. This was done in a backward compatible way such that the full functionality of NCO is still available through the familiar single letter options. In the future, however, some features of NCO may require the use of long options, simply because we have nearly run out of single letter options. More importantly, mnemonics for single letter options are often non-intuitive so that long options provide a more natural way of expressing intent.

Extended options, also called long options, are implemented using the system-supplied ‘`getopt.h`’ header file, if possible. This provides the `getopt_long` function to NCO<sup>1</sup>.

The syntax of *short options* (single letter options) is `-key value` (dash-key-space-value). Here, *key* is the single letter option name, e.g., ‘`-D 2`’.

The syntax of *long options* (multi-letter options) is `--long_name value` (dash-dash-key-space-value), e.g., ‘`--dbg_lvl 2`’ or `--long_name=value` (dash-dash-key-equal-value), e.g., ‘`--dbg_lvl=2`’. Thus the following are all valid for the ‘`-D`’ (short version) or ‘`--dbg_lvl`’ (long version) command line option.

```
ncks -D 3 in.nc          # Short option
ncks --dbg_lvl=3 in.nc  # Long option, preferred form
ncks --dbg_lvl 3 in.nc  # Long option, alternate form
```

The last example is preferred for two reasons. First, ‘`--dbg_lvl`’ is more specific and less ambiguous than ‘`-D`’. The long option form makes scripts more self documenting and less error prone. Often long options are named after the source code variable whose value they carry. Second, the equals sign = joins the key (i.e., *long\_name*) to the value in an uninterruptible text block. Experience shows that users are less likely to mis-parse commands when restricted to this form.

GNU implements a superset of the POSIX standard which allows any unambiguous truncation of a valid option to be used.

```
ncks -D 3 in.nc          # Short option
ncks --dbg_lvl=3 in.nc  # Long option, full form
ncks --dbg=3 in.nc      # Long option, unambiguous truncation
ncks --db=3 in.nc       # Long option, unambiguous truncation
ncks --d=3 in.nc        # Long option, ambiguous truncation
```

The first four examples are equivalent and will work as expected. The final example will exit with an error since `ncks` cannot disambiguate whether ‘`--d`’ is intended as a truncation of ‘`--dbg_lvl`’, of ‘`--dimension`’, or of some other long option.

NCO provides many long options for common switches. For example, the debugging level may be set in all operators with any of the switches ‘`-D`’, ‘`--debug-level`’, or ‘`--dbg_lvl`’. This flexibility allows users to choose their favorite mnemonic. For some, it will be ‘`--debug`’ (an unambiguous truncation of ‘`--debug-level`’, and other will prefer ‘`--dbg`’. Interactive users usually prefer the minimal amount of typing, i.e., ‘`-D`’. We recommend that scripts which are re-usable employ some form of the long options for future maintainability.

This manual generally uses the short option syntax. This is for historical reasons and to conserve space. The remainder of this manual specifies the full *long\_name* of each option. Users are expected to pick the unambiguous truncation of each option name that most suits their taste.

---

<sup>1</sup> If a `getopt_long` function cannot be found on the system, NCO will use the `getopt_long` from the `my_getopt` package by Benjamin Sittler [bsittler@iname.com](mailto:bsittler@iname.com). This is BSD-licensed software available from [http://www.geocities.com/ResearchTriangle/Node/9405/#my\\_getopt](http://www.geocities.com/ResearchTriangle/Node/9405/#my_getopt).

### 3.5 Specifying Input Files

Availability (-n): `ncea`, `necat`, `ncra`, `ncrcat`  
 Availability (-p): All operators  
 Short options: '-n', '-p'  
 Long options: '--nintap', '--pth', '--path'

It is important that users be able to specify multiple input files without typing every filename in full, often a tedious task even by graduate student standards. There are four different ways of specifying input files to NCO: explicitly typing each, using UNIX shell wildcards, and using the NCO '-n' and '-p' switches (or their long option equivalents, '--nintap' or '--pth' and '--path', respectively). Techniques to augment these methods to specify arbitrary numbers (e.g., thousands) and patterns of filenames are discussed separately (see [Section 2.7 \[Large Numbers of Files\]](#), page 16).

To illustrate these methods, consider the simple problem of using `ncra` to average five input files, '85.nc', '86.nc', ... '89.nc', and store the results in '8589.nc'. Here are the four methods in order. They produce identical answers.

```
ncra 85.nc 86.nc 87.nc 88.nc 89.nc 8589.nc
ncra 8[56789].nc 8589.nc
ncra -p input-path 85.nc 86.nc 87.nc 88.nc 89.nc 8589.nc
ncra -n 5,2,1 85.nc 8589.nc
```

The first method (explicitly specifying all filenames) works by brute force. The second method relies on the operating system shell to *glob* (expand) the *regular expression* `8[56789].nc`. The shell passes valid filenames which match the expansion to `ncra`. The third method uses the '-p *input-path*' argument to specify the directory where all the input files reside. NCO prepends *input-path* (e.g., '/data/username/model') to all *input-files* (but not to *output-file*). Thus, using '-p', the path to any number of input files need only be specified once. Note *input-path* need not end with '/'; the '/' is automatically generated if necessary.

The last method passes (with '-n') syntax concisely describing the entire set of filenames<sup>2</sup>. This option is only available with the *multi-file operators*: `ncra`, `ncrcat`, `ncea`, and `necat`. By definition, multi-file operators are able to process an arbitrary number of *input-files*. This option is very useful for abbreviating lists of filenames representable as *alphanumeric\_prefix+numeric\_suffix+'.'+filetype* where *alphanumeric\_prefix* is a string of arbitrary length and composition, *numeric\_suffix* is a fixed width field of digits, and *filetype* is a standard filetype indicator. For example, in the file 'ccm3\_h0001.nc', we have *alphanumeric\_prefix* = 'ccm3\_h', *numeric\_suffix* = '0001', and *filetype* = 'nc'.

NCO is able to decode lists of such filenames encoded using the '-n' option. The simpler (3-argument) '-n' usage takes the form `-n file_number,digit_number,numeric_increment` where *file\_number* is the number of files, *digit\_number* is the fixed number of numeric digits comprising the *numeric\_suffix*, and *numeric\_increment* is the constant,

<sup>2</sup> The '-n' option is a backward compatible superset of the NINTAP option from the NCAR CCM Processor.

integer-valued difference between the *numeric\_suffix* of any two consecutive files. The value of *alphanumeric\_prefix* is taken from the input file, which serves as a template for decoding the filenames. In the example above, the encoding `-n 5,2,1` along with the input file name `'85.nc'` tells NCO to construct five (5) filenames identical to the template `'85.nc'` except that the final two (2) digits are a numeric suffix to be incremented by one (1) for each successive file. Currently *filetype* may be either be empty, `'nc'`, `'cdf'`, `'hdf'`, or `'hd5'`. If present, these *filetype* suffixes (and the preceding `'.'`) are ignored by NCO as it uses the `'-n'` arguments to locate, evaluate, and compute the *numeric\_suffix* component of filenames.

Recently the `'-n'` option has been extended to allow convenient specification of filenames with “circular” characteristics. This means it is now possible for NCO to automatically generate filenames which increment regularly until a specified maximum value, and then wrap back to begin again at a specified minimum value. The corresponding `'-n'` usage becomes more complex, taking one or two additional arguments for a total of four or five, respectively: `-n file_number,digit_number,numeric_increment[,numeric_max[,numeric_min]]` where *numeric\_max*, if present, is the maximum integer-value of *numeric\_suffix* and *numeric\_min*, if present, is the minimum integer-value of *numeric\_suffix*. Consider, for example, the problem of specifying non-consecutive input files where the filename suffixes end with the month index. In climate modeling it is common to create summertime and wintertime averages which contain the averages of the months June–July–August, and December–January–February, respectively:

```
ncra -n 3,2,1 85_06.nc 85_0608.nc
ncra -n 3,2,1,12 85_12.nc 85_1202.nc
ncra -n 3,2,1,12,1 85_12.nc 85_1202.nc
```

The first example shows that three arguments to the `'-n'` option suffice to specify consecutive months (06, 07, 08) which do not “wrap” back to a minimum value. The second example shows how to use the optional fourth and fifth elements of the `'-n'` option to specify a wrap value to NCO. The fourth argument to `'-n'`, if present, specifies the maximum integer value of *numeric\_suffix*. In this case the maximum value is 12, and will be formatted as `'12'` in the filename string. The fifth argument to `'-n'`, if present, specifies the minimum integer value of *numeric\_suffix*. The default minimum filename suffix is 1, which is formatted as `'01'` in this case. Thus the second and third examples have the same effect, that is, they automatically generate, in order, the filenames `'85_12.nc'`, `'85_01.nc'`, and `'85_02.nc'` as input to NCO.

### 3.6 Specifying Output Files

Availability: All operators  
 Short options: `'-o'`  
 Long options: `'--fl_out'`, `'--output'`

NCO commands produce no more than one output file, *fl\_out*. Traditionally, users specify *fl\_out* as the final argument to the operator, following all input file names. This is the *positional argument* method of specifying input and output file names. The positional ar-

gument method works well in most applications. NCO also supports specifying *fl\_out* using the command line switch argument method, `-o fl_out`.

Specifying *fl\_out* with a switch, rather than as a positional argument, allows *fl\_out* to precede input files in the argument list. This is particularly useful with multi-file operators for three reasons. Multi-file operators may be invoked with hundreds (or more) filenames. Visual or automatic location of *fl\_out* in such a list is difficult when the only syntactic distinction between input and output files is their position. Second, specification of a long list of input files may be difficult (see [Section 2.7 \[Large Numbers of Files\]](#), page 16). Making the input file list the final argument to an operator facilitates using `xargs` for this purpose. Some alternatives to `xargs` are very ugly and undesirable. Finally, many users are more comfortable specifying output files with `-o fl_out` near the beginning of an argument list. Compilers and linkers are usually invoked this way.

Users should specify *fl\_out* using either but not both methods. If *fl\_out* is specified twice (once with the switch and once as the last positional argument), then the positional argument takes precedence.

### 3.7 Accessing Remote Files

Availability: All operators  
 Short options: `-p`, `-l`  
 Long options: `--pth`, `--path`, `--lcl`, `--local`

All NCO operators can retrieve files from remote sites as well as from the local file system. A remote site can be an anonymous FTP server, a machine on which the user has `rcp`, `scp`, or `sftp` privileges, or NCAR's Mass Storage System (MSS), or an OPeNDAP server. Examples of each are given below, following a brief description of the particular access protocol.

To access a file via an anonymous FTP server, supply the remote file's URL. FTP is an intrinsically insecure protocol because it transfers passwords in plain text format. Users should access sites using anonymous FTP when possible. Some FTP servers require a login/password combination for a valid user account. NCO allows these transactions so long as the required information is stored in the `.netrc` file. Usually this information is the remote machine name, login, and password, in plain text, separated by those very keywords, e.g.,

```
machine dust.ess.uci.edu login zender password bushlied
```

Eschew using valuable passwords for FTP transactions, since `.netrc` passwords are potentially exposed to eavesdropping software<sup>3</sup>.

---

<sup>3</sup> NCO does not implement command line options to specify FTP logins and passwords because copying those data into the `history` global attribute in the output file (done by default) poses an unacceptable security risk.

SFTP, i.e., secure FTP, uses SSH-based security protocols that solve the security issues associated with plain FTP. NCO supports SFTP protocol access to files specified with a homebrew syntax of the form

```
sftp://machine.domain.tld:/path/to/filename
```

Note the second colon following the top-level-domain (tld). This syntax is a hybrid between an FTP URL and a standard remote file syntax.

To access a file using `rcp` or `scp`, specify the Internet address of the remote file. Of course in this case you must have `rcp` or `scp` privileges which allow transparent (no password entry required) access to the remote machine. This means that `~/.rhosts` or `~/.ssh/authorized_keys` must be set accordingly on both local and remote machines.

To access a file on a High Performance Storage System (HPSS) (such as that at NCAR, ECMWF, LANL, DKRZ, LLNL) specify the full HPSS pathname of the remote file. NCO will attempt to detect whether the local machine has direct (synchronous) HPSS access. In this case, NCO attempts to use the Hierarchical Storage Interface (HSI) command `hsi get`<sup>4</sup>.

The following examples show how one might analyze files stored on remote systems.

```
ncks -l . ftp://dust.ess.uci.edu/pub/zender/nco/in.nc
ncks -l . sftp://dust.ess.uci.edu:/home/ftp/pub/zender/nco/in.nc
ncks -l . dust.ess.uci.edu:/home/zender/nco/data/in.nc
ncks -l . /ZENDER/nco/in.nc
ncks -l . /home/zender/nco/in.nc
ncks -l . http://motherlode.ucar.edu:8080/thredds/dodsC/testdods/in.nc
```

The first example works verbatim if your system is connected to the Internet and is not behind a firewall. The second example works if you have `sftp` access to the machine `dust.ess.uci.edu`. The third example works if you have `rcp` or `scp` access to the machine `dust.ess.uci.edu`. The fourth and fifth examples work on NCAR computers with local access to the HPSS `hsi get` command<sup>5</sup>. The sixth command works if your local version of NCO is OPeNDAP-enabled (this is fully described in [Section 3.7.1 \[OPeNDAP\]](#), page 30), or if the remote file is accessible via `wget`. The above commands can be rewritten using the `-p input-path` option as follows:

```
ncks -p ftp://dust.ess.uci.edu/pub/zender/nco -l . in.nc
ncks -p sftp://dust.ess.uci.edu:/home/ftp/pub/zender/nco -l . in.nc
ncks -p dust.ess.uci.edu:/home/zender/nco -l . in.nc
ncks -p /ZENDER/nco -l . in.nc
ncks -p /home/zender/nco -l . in.nc # HPSS
ncks -p http://motherlode.ucar.edu:8080/thredds/dodsC/testdods \
-l . in.nc
```

<sup>4</sup> The `hsi` command must be in the user's path in one of the following directories: `/usr/local/bin` or `/opt/hpss/bin`. Tell us if the HPSS installation at your site places the `hsi` command in a different location, and we will add that location to the list of acceptable paths to search for `hsi`.

<sup>5</sup> NCO supported the old NCAR Mass Storage System (MSS) until version 4.0.7 in April, 2011. NCO supported MSS-retrievals via a variety of mechanisms including the `msread`, `msrcp`, and `nrnet` commands invoked either automatically or with sentinels like `ncks -p mss:/ZENDER/nco -l . in.nc`. Once the MSS was decommissioned in March, 2011, support for these retrieval mechanisms was removed from NCO.



Using `'-p'` is recommended because it clearly separates the *input-path* from the filename itself, sometimes called the *stub*. When *input-path* is not explicitly specified using `'-p'`, NCO internally generates an *input-path* from the first input filename. The automatically generated *input-path* is constructed by stripping the input filename of everything following the final `'/'` character (i.e., removing the *stub*). The `'-l output-path'` option tells NCO where to store the remotely retrieved file and the output file. Often the path to a remotely retrieved file is quite different than the path on the local machine where you would like to store the file. If `'-l'` is not specified then NCO internally generates an *output-path* by simply setting *output-path* equal to *input-path* stripped of any machine names. If `'-l'` is not specified and the remote file resides on the NCAR HPSS system, then the leading character of *input-path*, `'/'`, is also stripped from *output-path*. Specifying *output-path* as `'-l ./'` tells NCO to store the remotely retrieved file and the output file in the current directory. Note that `'-l .'` is equivalent to `'-l ./'` though the latter is recommended as it is syntactically more clear.

### 3.7.1 OPeNDAP

The Distributed Oceanographic Data System (DODS) provides useful replacements for common data interface libraries like netCDF. The DODS versions of these libraries implement network transparent access to data via a client-server data access protocol that uses the HTTP protocol for communication. Although DODS-technology originated with oceanography data, it applies to virtually all scientific data. In recognition of this, the data access protocol underlying DODS (which is what NCO cares about) has been renamed the Open-source Project for a Network Data Access Protocol, OPeNDAP. We use the terms DODS and OPeNDAP interchangeably, and often write OPeNDAP/DODS for now. In the future we will deprecate DODS in favor of DAP or OPeNDAP, as appropriate<sup>6</sup>.

NCO may be DAP-enabled by linking NCO to the OPeNDAP libraries. This is described in the OPeNDAP documentation and automatically implemented in NCO build mechanisms<sup>7</sup>. The `'./configure'` mechanism automatically enables NCO as OPeNDAP clients if it can find the required OPeNDAP libraries<sup>8</sup>. in the usual locations. The `$DODS_ROOT` environment variable may be used to override the default OPeNDAP library location at NCO compile-time. Building NCO with `'bld/Makefile'` and the command `make DODS=Y` adds the (non-intuitive) commands to link to the OPeNDAP libraries installed in the `$DODS_ROOT` directory. The file `'doc/opendap.sh'` contains a generic script intended to help users install OPeNDAP before

---

<sup>6</sup> DODS is being deprecated because it is ambiguous, referring both to a protocol and to a collection of (oceanography) data. It is superseded by two terms. DAP is the discipline-neutral Data Access Protocol at the heart of DODS. The National Virtual Ocean Data System (NVODS) refers to the collection of oceanography data and oceanographic extensions to DAP. In other words, NVODS is implemented with OPeNDAP. OPeNDAP is *also* the open source project which maintains, develops, and promulgates the DAP standard. OPeNDAP and DAP really are interchangeable. Got it yet?

<sup>7</sup> Automagic support for DODS version 3.2.x was deprecated in December, 2003 after NCO version 2.8.4. NCO support for OPeNDAP versions 3.4.x commenced in December, 2003, with NCO version 2.8.5. NCO support for OPeNDAP versions 3.5.x commenced in June, 2005, with NCO version 3.0.1. NCO support for OPeNDAP versions 3.6.x commenced in June, 2006, with NCO version 3.1.3. NCO support for OPeNDAP versions 3.7.x commenced in January, 2007, with NCO version 3.1.9.

<sup>8</sup> The minimal set of libraries required to build NCO as OPeNDAP clients are, in link order, `'libnc-dap.a'`, `'libdap.a'`, and `'libxml2'` and `'libcurl.a'`.



building NCO. The documentation at the [OPeNDAP Homepage](#) is voluminous. Check there and on the [DODS mail lists](#). to learn more about the extensive capabilities of OPeNDAP<sup>9</sup>.

Once NCO is DAP-enabled the operators are OPeNDAP clients. All OPeNDAP clients have network transparent access to any files controlled by a OPeNDAP server. Simply specify the input file path(s) in URL notation and all NCO operations may be performed on remote files made accessible by a OPeNDAP server. This command tests the basic functionality of OPeNDAP-enabled NCO clients:

```
% ncks -O -o ~/foo.nc -C -H -v one -l /tmp \
  -p http://motherlode.ucar.edu:8080/thredds/dodsC/testdods in.nc
% ncks -H -v one ~/foo.nc
one = 1
```

The `one = 1` outputs confirm (first) that `ncks` correctly retrieved data via the OPeNDAP protocol and (second) that `ncks` created a valid local copy of the subsetted remote file. With minor changes to the above command, `netCDF4` can be used as both the input and output file format:

```
% ncks -4 -O -o ~/foo.nc -C -H -v one -l /tmp \
  -p http://motherlode.ucar.edu:8080/thredds/dodsC/testdods in_4.nc
% ncks -H -v one ~/foo.nc
one = 1
```

And, of course, OPeNDAP-enabled NCO clients continue to support other, orthogonal features such as UDUnits (see [Section 3.19 \[UDUnits Support\]](#), [page 45](#)):

```
% ncks -u -C -H -v wvl -d wvl,'0.4 micron','0.7 micron' \
  -p http://motherlode.ucar.edu:8080/thredds/dodsC/testdods in_4.nc
% wvl[0]=5e-07 meter
```

The next command is a more advanced example which demonstrates the real power of OPeNDAP-enabled NCO clients. The `ncwa` client requests an equatorial hyperslab from remotely stored NCEP reanalyses data of the year 1969. The NOAA OPeNDAP server (hopefully!) serves these data. The local `ncwa` client then computes and stores (locally) the regional mean surface pressure (in Pa).

```
ncwa -C -a lat,lon,time -d lon,-10.,10. -d lat,-10.,10. -l /tmp -p \
  http://www.esrl.noaa.gov/psd/thredds/dodsC/Datasets/ncep.reanalysis.dailyavgs/surface
  pres.sfc.1969.nc ~/foo.nc
```

All with one command! The data in this particular input file also happen to be packed (see [Section 4.1.11 \[Methods and functions\]](#), [page 82](#)), although this is completely transparent to the user since NCO automatically unpacks data before attempting arithmetic.

NCO obtains remote files from the OPeNDAP server (e.g., `'www.cdc.noaa.gov'`) rather than the local machine. Input files are first copied to the local machine, then processed. The OPeNDAP server performs data access, hyperslabbing, and transfer to the local machine.

---

<sup>9</sup> We are most familiar with the OPeNDAP ability to enable network-transparent data access. OPeNDAP has many other features, including sophisticated hyperslabbing and server-side processing via *constraint expressions*. If you know more about this, please consider writing a section on "OPeNDAP Capabilities of Interest to NCO Users" for incorporation in the *NCO User's Guide*.

This allows the I/O to appear to NCO as if the input files were local. The local machine performs all arithmetic operations. Only the hyperslabbed output data are transferred over the network (to the local machine) for the number-crunching to begin. The advantages of this are obvious if you are examining small parts of large files stored at remote locations.

### 3.8 Retaining Retrieved Files

Availability: All operators  
 Short options: `-R`  
 Long options: `--rtn`, `--retain`

In order to conserve local file system space, files retrieved from remote locations are automatically deleted from the local file system once they have been processed. Many NCO operators were constructed to work with numerous large (e.g., 200 MB) files. Retrieval of multiple files from remote locations is done serially. Each file is retrieved, processed, then deleted before the cycle repeats. In cases where it is useful to keep the remotely-retrieved files on the local file system after processing, the automatic removal feature may be disabled by specifying `-R` on the command line.

Invoking `-R` disables the default printing behavior of `ncks`. This allows `ncks` to retrieve remote files without automatically trying to print them. See [Section 4.7 \[ncks netCDF Kitchen Sink\]](#), [page 135](#), for more details.

Note that the remote retrieval features of NCO can always be used to retrieve *any* file, including non-netCDF files, via SSH, anonymous FTP, or `msrcp`. Often this method is quicker than using a browser, or running an FTP session from a shell window yourself. For example, say you want to obtain a JPEG file from a weather server.

```
ncks -R -p ftp://weather.edu/pub/pix/jpeg -l . storm.jpg
```

In this example, `ncks` automatically performs an anonymous FTP login to the remote machine and retrieves the specified file. When `ncks` attempts to read the local copy of `'storm.jpg'` as a netCDF file, it fails and exits, leaving `'storm.jpg'` in the current directory.

If your NCO is DAP-enabled (see [Section 3.7.1 \[OPeNDAP\]](#), [page 30](#)), then you may use NCO to retrieve any files (including netCDF, HDF, etc.) served by an OPeNDAP server to your local machine. For example,

```
ncks -R -l . -p \
http://www.esrl.noaa.gov/psd/thredds/dodsC/Datasets/ncp.reanalysis.dailyavgs/surface
pres.sfc.1969.nc
```

Note that NCO is never the preferred way to transport files from remote machines. For large jobs, that is best handled by FTP, SSH, or `wget`. It may occasionally be useful to use NCO to transfer files when your other preferred methods are not available locally.

### 3.9 Selecting Output File Format

Availability: `ncap2`, `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncks`, `ncpdq`, `ncra`, `ncrcat`, `ncwa`  
 Short options: `'-3'`, `'-4'`  
 Long options: `'--3'`, `'--4'`, `'--64bit'`, `'--fl_fmt'`, `'--netcdf4'`

All NCO operators support (read and write) all three (or four, depending on how one counts) file formats supported by netCDF4. The default output file format for all operators is the input file format. The operators listed under “Availability” above allow the user to specify the output file format independent of the input file format. These operators allow the user to convert between the various file formats. (The operators `ncatted` and `ncrename` do not support these switches so they always write the output netCDF file in the same format as the input netCDF file.)

netCDF supports four types of files: `CLASSIC`, `64BIT`, `NETCDF4`, and `NETCDF4_CLASSIC`. The `CLASSIC` format is the traditional 32-bit offset written by netCDF2 and netCDF3. As of 2005, most netCDF datasets are in `CLASSIC` format. The `64BIT` format was added in Fall, 2004.

The `NETCDF4` format uses HDF5 as the file storage layer. The files are (usually) created, accessed, and manipulated using the traditional netCDF3 API (with numerous extensions). The `NETCDF4_CLASSIC` format refers to netCDF4 files created with the `NC_CLASSIC_MODEL` mask. Such files use HDF5 as the back-end storage format (unlike netCDF3), though they incorporate only netCDF3 features. Hence `NETCDF4_CLASSIC` files are perfectly readable by applications which use only the netCDF3 API and library. NCO must be built with netCDF4 to write files in the new `NETCDF4` and `NETCDF4_CLASSIC` formats, and to read files in the new `NETCDF4` format. Users are advised to use the default `CLASSIC` format or the `NETCDF4_CLASSIC` format until netCDF4 is more widespread. Widespread support for `NETCDF4` format files is not expected for a few more years, 2013–2014, say. If performance or coolness are issues, then use `NETCDF4_CLASSIC` instead of `CLASSIC` format files.

As mentioned above, all operators write use the input file format for output files unless told otherwise. Toggling the long option `'--64bit'` switch (or its *key-value* equivalent `'--fl_fmt=64bit'`) produces the netCDF3 64-bit offset format named `64BIT`. NCO must be built with netCDF 3.6 or higher to produce a `64BIT` file. Using the `'-4'` switch (or its long option equivalents `'--4'` or `'--netcdf4'`), or setting its *key-value* equivalent `'--fl_fmt=netcdf4'` produces a `NETCDF4` file (i.e., HDF). Casual users are advised to use the default (netCDF3) `CLASSIC` format until netCDF 3.6 and netCDF 4.0 are more widespread. Conversely, operators given the `'-3'` (or `'--3'`) switch without arguments will (attempt to) produce netCDF3 `CLASSIC` output, even from netCDF4 input files.

These examples demonstrate converting a file from any netCDF format into any other netCDF format (subject to limits of the format):

```
ncks --fl_fmt=classic in.nc foo_3c.nc # netCDF3 classic
ncks --fl_fmt=64bit in.nc foo_364.nc # netCDF3 64bit
ncks --fl_fmt=netcdf4_classic in.nc foo_4c.nc # netCDF4 classic
ncks --fl_fmt=netcdf4 in.nc foo_4.nc # netCDF4
```

```
ncks -3 in.nc foo_3c.nc # netCDF3 classic
ncks --3 in.nc foo_3c.nc # netCDF3 classic
ncks -4 in.nc foo_4.nc # netCDF4
ncks --4 in.nc foo_4.nc # netCDF4
ncks --64 in.nc foo364.nc # netCDF3 64bit
```

Of course since most operators support these switches, the “conversions” can be done at the output stage of arithmetic or metadata processing rather than requiring a separate step. Producing (netCDF3) CLASSIC or 64BIT files from NETCDF4\_CLASSIC files will always work. However, producing netCDF3 files from NETCDF4 files will only work if the output files are not required to contain netCDF4-specific features.

Note that NETCDF4 and NETCDF4\_CLASSIC are the same binary format. The latter simply causes a writing application to fail if it attempts to write a NETCDF4 file that cannot be completely read by the netCDF3 library. Conversely, NETCDF4\_CLASSIC indicates to a reading application that all of the file contents are readable with the netCDF3 library. As of October, 2005, NCO writes no netCDF4-specific data structures and so always succeeds at writing NETCDF4\_CLASSIC files.

There are at least three ways to discover the format of a netCDF file, i.e., whether it is a classic (32-bit offset) or newer 64-bit offset netCDF3 format, or is netCDF4 format. Each method returns the information using slightly different terminology that becomes easier to understand with practice.

First, examine the end of the first line of global metadata output by ‘ncks -M’:

```
% ncks -M foo_3c.nc
Opened file foo_3c.nc: dimensions = 19, variables = 261, global atts. = 4,
  id = 65536, type = NC_FORMAT_CLASSIC
% ncks -M foo_364.nc
Opened file foo_364.nc: dimensions = 19, variables = 261, global atts. = 4,
  id = 65536, type = NC_FORMAT_64BIT
% ncks -M foo_4c.nc
Opened file foo_4c.nc: dimensions = 19, variables = 261, global atts. = 4,
  id = 65536, type = NC_FORMAT_NETCDF4_CLASSIC
% ncks -M foo_4.nc
Opened file foo_4.nc: dimensions = 19, variables = 261, global atts. = 4,
  id = 65536, type = NC_FORMAT_NETCDF4
```

This method requires a netCDF4-enabled NCO version 3.9.0+ (i.e., from 2007 or later).

Second, query the file with ‘ncdump -k’:

```
% ncdump -k foo_3.nc
classic
% ncdump -k foo_364.nc
64-bit-offset
% ncdump -k foo_4c.nc
netCDF-4 classic model
% ncdump -k foo_4.nc
netCDF-4
```

This method requires a netCDF4-enabled netCDF 3.6.2+ (i.e., from 2007 or later).

The third option uses the POSIX-standard `od` (octal dump) command:

```
% od -An -c -N4 foo_3c.nc
  C   D   F 001
% od -An -c -N4 foo_364.nc
  C   D   F 002
% od -An -c -N4 foo_4c.nc
211   H   D   F
% od -An -c -N4 foo_4.nc
211   H   D   F
```

This option works without NCO and `ncdump`. Values of ‘C D F 001’ and ‘C D F 002’ indicate 32-bit (classic) and 64-bit netCDF3 formats, respectively, while values of ‘211 H D F’ indicate the newer netCDF4 file format.

### 3.10 Large File Support

Availability: All operators  
Short options: none  
Long options: none

NCO has Large File Support (LFS), meaning that NCO can write files larger than 2 GB on some 32-bit operating systems with netCDF libraries earlier than version 3.6. If desired, LFS support must be configured when both netCDF and NCO are installed. netCDF versions 3.6 and higher support 64-bit file addresses as part of the netCDF standard. We recommend that users ignore LFS support which is difficult to configure and is implemented in NCO only to support netCDF versions prior to 3.6. This obviates the need for configuring explicit LFS support in applications (such as NCO) which now support 64-bit files directly through the netCDF interface. See [Section 3.9 \[Selecting Output File Format\]](#), [page 33](#) for instructions on accessing the different file formats, including 64-bit files, supported by the modern netCDF interface.

If you are still interesting in explicit LFS support for netCDF versions prior to 3.6, know that LFS support depends on a complex, interlocking set of operating system<sup>10</sup> and netCDF support issues. The netCDF LFS FAQ at <http://my.unidata.ucar.edu/content/software/netcdf/faq-lfs.html> describes the various file size limitations imposed by different versions of the netCDF standard. NCO and netCDF automatically attempt to configure LFS at build time.

---

<sup>10</sup> Linux and AIX are known to support LFS.

### 3.11 Subsetting Variables

Availability: (ncap2), ncbo, ncea, ncecat, ncflint, ncks, ncpdq, ncra, ncrcat, ncwa  
 Short options: '-v', '-x'  
 Long options: '--variable', '--exclude' or '--xcl'

Subsetting variables refers to explicitly specifying variables to be included or excluded from operator actions. Subsetting is implemented with the '-v var[,...]' and '-x' options. A list of variables to extract is specified following the '-v' option, e.g., '-v time,lat,lon'. Not using the '-v' option is equivalent to specifying all variables. The '-x' option causes the list of variables specified with '-v' to be *excluded* rather than *extracted*. Thus '-x' saves typing when you only want to extract fewer than half of the variables in a file.

Variables explicitly specified for extraction with '-v var[,...]' *must* be present in the input file or an error will result. Variables explicitly specified for *exclusion* with '-x -v var[,...]' need not be present in the input file. Remember, if averaging or concatenating large files stresses your systems memory or disk resources, then the easiest solution is often to use the '-v' option to retain only the most important variables (see [Section 2.9 \[Memory Requirements\]](#), page 19).

Due to its special capabilities, ncap2 interprets the '-v' switch differently (see [Section 4.1 \[ncap2 netCDF Arithmetic Processor\]](#), page 68). For ncap2, the '-v' switch takes no arguments and indicates that *only* user-defined variables should be output. ncap2 neither accepts nor understands the -x switch.

As of NCO 2.8.1 (August, 2003), variable name arguments of the '-v' switch may contain *extended regular expressions*. As of NCO 3.9.6 (January, 2009), variable names arguments to ncatted may contain *extended regular expressions*. For example, '-v ^DST' selects all variables beginning with the string 'DST'. Extended regular expressions are defined by the GNU `egrep` command. The meta-characters used to express pattern matching operations are '^\$+?.\*[]{}|\''. If the regular expression pattern matches *any* part of a variable name then that variable is selected. This capability is called *wildcarding*, and is very useful for sub-setting large data files.

Because of its wide availability, NCO uses the POSIX regular expression library `regex`. Regular expressions of arbitrary complexity may be used. Since netCDF variable names are relatively simple constructs, only a few varieties of variable wildcards are likely to be useful. For convenience, we define the most useful pattern matching operators here:

'^'	Matches the beginning of a string
'\$'	Matches the end of a string
'.'	Matches any single character

The most useful repetition and combination operators are

'?'	The preceding regular expression is optional and matched at most once
'*'	The preceding regular expression will be matched zero or more times

- ‘+’        The preceding regular expression will be matched one or more times
- ‘|’        The preceding regular expression will be joined to the following regular expression. The resulting regular expression matches any string matching either subexpression.

To illustrate the use of these operators in extracting variables, consider a file with variables Q, Q01–Q99, Q100, QAA–QZZ, Q\_H20, X\_H20, Q\_C02, X\_C02.

```
ncks -v 'Q.?' in.nc          # Variables that contain Q
ncks -v '^Q.?' in.nc         # Variables that start with Q
ncks -v '^Q+?.?' in.nc       # Q, Q0--Q9, Q01--Q99, QAA--QZZ, etc.
ncks -v '^Q..' in.nc         # Q01--Q99, QAA--QZZ, etc.
ncks -v '^Q[0-9][0-9]' in.nc  # Q01--Q99, Q100
ncks -v '^Q[[:digit:]]{2}' in.nc # Q01--Q99
ncks -v 'H20$' in.nc         # Q_H20, X_H20
ncks -v 'H20$|C02$' in.nc    # Q_H20, X_H20, Q_C02, X_C02
ncks -v '^Q[0-9][0-9]$' in.nc # Q01--Q99
ncks -v '^Q[0-6][0-9]|7[0-3]' in.nc # Q01--Q73, Q100
ncks -v '(Q[0-6][0-9]|7[0-3])$' in.nc # Q01--Q73
ncks -v '^[_a-z][_a-z]{3}$' in.nc # Q_H20, X_H20, Q_C02, X_C02
```

Beware—two of the most frequently used repetition pattern matching operators, ‘\*’ and ‘?’, are also valid pattern matching operators for filename expansion (globbing) at the shell-level. Confusingly, their meanings in extended regular expressions and in shell-level filename expansion are significantly different. In an extended regular expression, ‘\*’ matches zero or more occurrences of the preceding regular expression. Thus ‘Q\*’ selects all variables, and ‘Q+.’ selects all variables containing ‘Q’ (the ‘+’ ensures the preceding item matches at least once). To match zero or one occurrence of the preceding regular expression, use ‘?’. Documentation for the UNIX **egrep** command details the extended regular expressions which NCO supports.

One must be careful to protect any special characters in the regular expression specification from being interpreted (globbed) by the shell. This is accomplished by enclosing special characters within single or double quotes

```
ncra -v Q?? in.nc out.nc    # Error: Shell attempts to glob wildcards
ncra -v '^Q+..' in.nc out.nc # Correct: NCO interprets wildcards
ncra -v '^Q+..' in*.nc out.nc # Correct: NCO interprets, Shell globs
```

The final example shows that commands may use a combination of variable wildcarding and shell filename expansion (globbing). For globbing, ‘\*’ and ‘?’ *have nothing to do* with the preceding regular expression! In shell-level filename expansion, ‘\*’ matches any string, including the null string and ‘?’ matches any single character. Documentation for **bash** and **csh** describe the rules of filename expansion (globbing).



### 3.12 Subsetting Coordinate Variables

Availability: `ncap2`, `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncks`, `ncpdq`, `ncra`, `ncrcat`, `ncwa`  
 Short options: `'-C'`, `'-c'`  
 Long options: `'--no-coords'`, `'--no-crd'`, `'--crd'`, `'--coords'`

By default, coordinates variables associated with any variable appearing in the *input-file* will be placed in the *output-file*, even if they are not explicitly specified, e.g., with the `'-v'` switch. Thus variables with a latitude coordinate `lat` always carry the values of `lat` with them into the *output-file*. This feature can be disabled with `'-C'`, which causes NCO to not automatically add coordinates to the variables appearing in the *output-file*. However, using `'-C'` does not preclude the user from including some coordinates in the output files simply by explicitly selecting the coordinates with the `-v` option. The `'-c'` option, on the other hand, is a shorthand way of automatically specifying that *all* coordinate variables in the *input-files* should appear in the *output-file*. Thus `'-c'` allows the user to select all the coordinate variables without having to know their names. As of NCO version 3.9.6 (January, 2009) both `'-c'` and `'-C'` honor the CF `coordinates` convention described in [Section 3.30 \[CF Conventions\]](#), page 64. As of NCO version 4.0.8 (April, 2011) both `'-c'` and `'-C'` honor the CF `bounds` convention described in [Section 3.30 \[CF Conventions\]](#), page 64.

### 3.13 C and Fortran Index conventions

Availability: `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncks`, `ncpdq`, `ncra`, `ncrcat`, `ncwa`  
 Short options: `'-F'`  
 Long options: `'--fortran'`

The `'-F'` switch changes NCO to read and write with the Fortran index convention. By default, NCO uses C-style (0-based) indices for all I/O. In C, indices count from 0 (rather than 1), and dimensions are ordered from slowest (inner-most) to fastest (outer-most) varying. In Fortran, indices count from 1 (rather than 0), and dimensions are ordered from fastest (inner-most) to slowest (outer-most) varying. Hence C and Fortran data storage conventions represent mathematical transposes of each other. Note that record variables contain the record dimension as the most slowly varying dimension. See [Section 4.8 \[ncpdq netCDF Permute Dimensions Quickly\]](#), page 142 for techniques to re-order (including transpose) dimensions and to reverse data storage order.

Consider a file `'85.nc'` containing 12 months of data in the record dimension `time`. The following hyperslab operations produce identical results, a June-July-August average of the data:

```
ncra -d time,5,7 85.nc 85_JJA.nc
ncra -F -d time,6,8 85.nc 85_JJA.nc
```

Printing variable `three_dmn_var` in file `'in.nc'` first with the C indexing convention, then with Fortran indexing convention results in the following output formats:



```
% ncks -v three_dmn_var in.nc
lat[0]=-90 lev[0]=1000 lon[0]=-180 three_dmn_var[0]=0
...
% ncks -F -v three_dmn_var in.nc
lon(1)=0 lev(1)=100 lat(1)=-90 three_dmn_var(1)=0
...
```

### 3.14 Hyperslabs

Availability: `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncks`, `ncpdq`, `ncra`, `ncrcat`, `ncwa`  
 Short options: `'-d dim,[min][,[max][,[stride]]]'`  
 Long options: `'--dimension dim,[min][,[max][,[stride]]]'`,  
`'--dmn dim,[min][,[max][,[stride]]]'`

A *hyperslab* is a subset of a variable's data. The coordinates of a hyperslab are specified with the `-d dim,[min][,[max][,[stride]]]` short option (or with the same arguments to the `'--dimension'` or `'--dmn'` long options). At least one hyperslab argument (*min*, *max*, or *stride*) must be present. The bounds of the hyperslab to be extracted are specified by the associated *min* and *max* values. A half-open range is specified by omitting either the *min* or *max* parameter. The separating comma must be present to indicate the omission of one of these arguments. The unspecified limit is interpreted as the maximum or minimum value in the unspecified direction. A cross-section at a specific coordinate is extracted by specifying only the *min* limit and omitting a trailing comma. Dimensions not mentioned are passed with no reduction in range. The dimensionality of variables is not reduced (in the case of a cross-section, the size of the constant dimension will be one). If values of a coordinate-variable are used to specify a range or cross-section, then the coordinate variable must be monotonic (values either increasing or decreasing). In this case, command-line values need not exactly match coordinate values for the specified dimension. Ranges are determined by seeking the first coordinate value to occur in the closed range `[min,max]` and including all subsequent values until one falls outside the range. The coordinate value for a cross-section is the coordinate-variable value closest to the specified value and must lie within the range or coordinate-variable values.

Coordinate values should be specified using real notation with a decimal point required in the value, whereas dimension indices are specified using integer notation without a decimal point. This convention serves only to differentiate coordinate values from dimension indices. It is independent of the type of any netCDF coordinate variables. For a given dimension, the specified limits must both be coordinate values (with decimal points) or dimension indices (no decimal points). The *stride* option, if any, must be a dimension index, not a coordinate value. See [Section 3.15 \[Stride\]](#), [page 40](#), for more information on the *stride* option.

User-specified coordinate limits are promoted to double precision values while searching for the indices which bracket the range. Thus, hyperslabs on coordinates of type `NC_BYTE` and `NC_CHAR` are computed numerically rather than lexically, so the results are unpredictable.

The relative magnitude of *min* and *max* indicate to the operator whether to expect a *wrapped coordinate* (see [Section 3.17 \[Wrapped Coordinates\]](#), page 42), such as longitude. If *min* > *max*, the NCO expects the coordinate to be wrapped, and a warning message will be printed. When this occurs, NCO selects all values outside the domain [*max* < *min*], i.e., all the values exclusive of the values which would have been selected if *min* and *max* were swapped. If this seems confusing, test your command on just the coordinate variables with **ncks**, and then examine the output to ensure NCO selected the hyperslab you expected (coordinate wrapping is currently only supported by **ncks**).

Because of the way wrapped coordinates are interpreted, it is very important to make sure you always specify hyperslabs in the monotonically increasing sense, i.e., *min* < *max* (even if the underlying coordinate variable is monotonically decreasing). The only exception to this is when you are indeed specifying a wrapped coordinate. The distinction is crucial to understand because the points selected by, e.g., `-d longitude,50.,340.`, are exactly the complement of the points selected by `-d longitude,340.,50..`

Not specifying any hyperslab option is equivalent to specifying full ranges of all dimensions. This option may be specified more than once in a single command (each hyperslabbed dimension requires its own `-d` option).

### 3.15 Stride

Availability: **ncbo**, **ncea**, **ncecat**, **ncflint**, **ncks**, **ncpdq**, **ncra**, **ncrcat**, **ncwa**  
 Short options: `'-d dim,[min][,[max][,[stride]]]'`  
 Long options: `'--dimension dim,[min][,[max][,[stride]]]'`,  
`'--dmn dim,[min][,[max][,[stride]]]'`

All data operators support specifying a *stride* for any and all dimensions at the same time. The *stride* is the spacing between consecutive points in a hyperslab. A *stride* of 1 picks all the elements of the hyperslab, and a *stride* of 2 skips every other element, etc.. **ncks** multislabs support strides, and are more powerful than the regular hyperslabs supported by the other operators (see [Section 3.16 \[Multislabs\]](#), page 41). Using the *stride* option for the record dimension with **ncra** and **ncrcat** makes it possible, for instance, to average or concatenate regular intervals across multi-file input data sets.

The *stride* is specified as the optional fourth argument to the `'-d'` hyperslab specification: `-d dim,[min][,[max][,[stride]]]`. Specify *stride* as an integer (i.e., no decimal point) following the third comma in the `'-d'` argument. There is no default value for *stride*. Thus using `'-d time,,,2'` is valid but `'-d time,,,2.0'` and `'-d time,,,'` are not. When *stride* is specified but *min* is not, there is an ambiguity as to whether the extracted hyperslab should begin with (using C-style, 0-based indexes) element 0 or element `'stride-1'`. NCO must resolve this ambiguity and it chooses element 0 as the first element of the hyperslab when *min* is not specified. Thus `'-d time,,,stride'` is syntactically equivalent to `'-d time,0,,,stride'`. This means, for example, that specifying the operation `'-d time,,,2'` on the array `'1,2,3,4,5'` selects the hyperslab `'1,3,5'`. To obtain the hyperslab `'2,4'` instead, simply explicitly specify the starting index as 1, i.e., `'-d time,1,,,2'`.

For example, consider a file ‘8501\_8912.nc’ which contains 60 consecutive months of data. Say you wish to obtain just the March data from this file. Using 0-based subscripts (see [Section 3.13 \[C and Fortran Index Conventions\]](#), page 38) these data are stored in records 2, 14, ... 50 so the desired *stride* is 12. Without the *stride* option, the procedure is very awkward. One could use `ncks` five times and then use `ncrcat` to concatenate the resulting files together:

```
for idx in 02 14 26 38 50; do # Bourne Shell
  ncks -d time,${idx} 8501_8912.nc foo.${idx}
done
foreach idx (02 14 26 38 50) # C Shell
  ncks -d time,${idx} 8501_8912.nc foo.${idx}
end
ncrcat foo.?? 8589_03.nc
rm foo.??
```

With the *stride* option, `ncks` performs this hyperslab extraction in one operation:

```
ncks -d time,2,,12 8501_8912.nc 8589_03.nc
```

See [Section 4.7 \[ncks netCDF Kitchen Sink\]](#), page 135, for more information on `ncks`.

Applying the *stride* option to the record dimension in `ncra` and `ncrcat` makes it possible, for instance, to average or concatenate regular intervals across multi-file input data sets.

```
ncra -F -d time,3,,12 85.nc 86.nc 87.nc 88.nc 89.nc 8589_03.nc
ncrcat -F -d time,3,,12 85.nc 86.nc 87.nc 88.nc 89.nc 8503_8903.nc
```

### 3.16 Multislabs

Availability: `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncks`, `ncpdq`, `ncra`, `ncrcat`  
 Short options: ‘-d *dim*, [*min*][, [*max*][, [*stride*]]]’  
 Long options: ‘--dimension *dim*, [*min*][, [*max*][, [*stride*]]]’,  
 ‘--dmn *dim*, [*min*][, [*max*][, [*stride*]]]’

A multislabs is a union of one or more hyperslabs. One defines multislabs by chaining together hyperslab commands, i.e., `-d` options (see [Section 3.14 \[Hyperslabs\]](#), page 39). Support for specifying a *multi-hyperslab* or *multislabs* for any variable was first added to `ncks` in late 2002. The other operators received MSA capabilities in April 2008. Sometimes multislabbing is referred to by the acronym MSA, which stands for “Multi-Slabbing Algorithm”.

Multislabs overcome some restraints that limit hyperslabs. A single `-d` option can only specify a contiguous and/or a regularly spaced multi-dimensional data array. Multislabs are constructed from multiple `-d` options and may therefore have non-regularly spaced arrays. For example, suppose it is desired to operate on all longitudes from 10.0 to 20.0 and from 80.0 to 90.0 degrees. The combined range of longitudes is not selectable in a single hyperslab specification of the form ‘-d *dimension*,*min*,*max*’ or ‘-d *dimension*,*min*,*max*,*stride*’ because its elements are irregularly spaced in coordinate space (and presumably in index

space too). The multislab specification for obtaining these values is simply the union of the hyperslabs specifications that comprise the multislab, i.e.,

```
ncks -d lon,10.,20. -d lon,80.,90. in.nc out.nc
ncks -d lon,10.,15. -d lon,15.,20. -d lon,80.,90. in.nc out.nc
```

Any number of hyperslabs specifications may be chained together to specify the multislab.

Users may specify redundant ranges of indices in a multislab, e.g.,

```
ncks -d lon,0,4 -d lon,2,9,2 in.nc out.nc
```

This command retrieves the first five longitudes, and then every other longitude value up to the tenth. Elements 0, 2, and 4 are specified by both hyperslab arguments (hence this is redundant) but will count only once if an arithmetic operation is being performed. This example uses index-based (not coordinate-based) multislabs because the *stride* option only supports index-based hyper-slabbing. See [Section 3.15 \[Stride\]](#), page 40, for more information on the *stride* option.

Multislabs are more efficient than the alternative of sequentially performing hyperslab operations and concatenating the results. This is because NCO employs a novel multislab algorithm to minimize the number of I/O operations when retrieving irregularly spaced data from disk. The NCO multislab algorithm retrieves each element from disk once and only once. Thus users may take some shortcuts in specifying multislabs and the algorithm will obtain the intended values. Specifying redundant ranges is not encouraged, but may be useful on occasion and will not result in unintended consequences.

A final example shows the real power of multislabs. Suppose the *Q* variable contains three dimensional arrays of distinct chemical constituents in no particular order. We are interested in the NO<sub>y</sub> species in a certain geographic range. Say that NO, NO<sub>2</sub>, and N<sub>2</sub>O<sub>5</sub> are elements 0, 1, and 5 of the *species* dimension of *Q*. The multislab specification might look something like

```
ncks -d species,0,1 -d species,5 -d lon,0,4 -d lon,2,9,2 in.nc out.nc
```

Multislabs are powerful because they may be specified for every dimension at the same time. Thus multislabs obsolete the need to execute multiple **ncks** commands to gather the desired range of data.

### 3.17 Wrapped Coordinates

Availability: **ncks**

Short options: `'-d dim,[min][,[max][,[stride]]]'`

Long options: `'--dimension dim,[min][,[max][,[stride]]]'`,

`'--dmn dim,[min][,[max][,[stride]]]'`

A *wrapped coordinate* is a coordinate whose values increase or decrease monotonically (nothing unusual so far), but which represents a dimension that ends where it begins (i.e., wraps around on itself). Longitude (i.e., degrees on a circle) is a familiar example of a wrapped coordinate. Longitude increases to the East of Greenwich, England, where it is

defined to be zero. Halfway around the globe, the longitude is 180 degrees East (or West). Continuing eastward, longitude increases to 360 degrees East at Greenwich. The longitude values of most geophysical data are either in the range  $[0,360)$ , or  $[-180,180)$ . In either case, the Westernmost and Easternmost longitudes are numerically separated by 360 degrees, but represent contiguous regions on the globe. For example, the Saharan desert stretches from roughly 340 to 50 degrees East. Extracting the hyperslab of data representing the Sahara from a global dataset presents special problems when the global dataset is stored consecutively in longitude from 0 to 360 degrees. This is because the data for the Sahara will not be contiguous in the *input-file* but is expected by the user to be contiguous in the *output-file*. In this case, `ncks` must invoke special software routines to assemble the desired output hyperslab from multiple reads of the *input-file*.

Assume the domain of the monotonically increasing longitude coordinate `lon` is  $0 < lon < 360$ . `ncks` will extract a hyperslab which crosses the Greenwich meridian simply by specifying the westernmost longitude as *min* and the easternmost longitude as *max*. The following commands extract a hyperslab containing the Saharan desert:

```
ncks -d lon,340.,50. in.nc out.nc
ncks -d lon,340.,50. -d lat,10.,35. in.nc out.nc
```

The first example selects data in the same longitude range as the Sahara. The second example further constrains the data to having the same latitude as the Sahara. The coordinate `lon` in the *output-file*, '`out.nc`', will no longer be monotonic! The values of `lon` will be, e.g., '340, 350, 0, 10, 20, 30, 40, 50'. This can have serious implications should you run '`out.nc`' through another operation which expects the `lon` coordinate to be monotonically increasing. Fortunately, the chances of this happening are slim, since `lon` has already been hyperslabbled, there should be no reason to hyperslab `lon` again. Should you need to hyperslab `lon` again, be sure to give dimensional indices as the hyperslab arguments, rather than coordinate values (see [Section 3.14 \[Hyperslabs\]](#), page 39).

### 3.18 Auxiliary Coordinates

Availability: `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncks`, `ncpdq`, `ncra`, `ncrcat`  
 Short options: '`-X lon_min,lon_max,lat_min,lat_max`'  
 Long options: '`--auxiliary lon_min,lon_max,lat_min,lat_max`'

Utilize auxiliary coordinates specified in values of the coordinate variable's `standard_name` attributes, if any, when interpreting hyperslab and multi-slab options. Also '`--auxiliary`'. This switch supports hyperslabbing cell-based grids over coordinate ranges. This works on datasets that associate coordinate variables to grid-mappings using the CF-convention (see [Section 3.30 \[CF Conventions\]](#), page 64) coordinates and `standard_name` attributes described [here](#). Currently, NCO understands auxiliary coordinate variables pointed to by the `standard_name` attributes for *latitude* and *longitude*. Cells that contain a value within the user-specified range `[lon_min,lon_max,lat_min,lat_max]` are included in the output hyperslab.

A cell-based grid collapses the horizontal spatial information (latitude and longitude) and stores it along a one-dimensional coordinate that has a one-to-one mapping to both latitude and longitude coordinates. Rectangular (in longitude and latitude) horizontal hyperslabs cannot be selected using the typical procedure (see [Section 3.14 \[Hyperslabs\]](#), [page 39](#)) of separately specifying ‘-d’ arguments for longitude and latitude. Instead, when the ‘-X’ is used, NCO learns the names of the latitude and longitude coordinates by searching the `standard_name` attribute of all variables until it finds the two variables whose `standard_name`’s are “latitude” and “longitude”, respectively. This `standard_name` attribute for latitude and longitude coordinates follows the CF-convention (see [Section 3.30 \[CF Conventions\]](#), [page 64](#)).

Putting it all together, consider a variable `gds_3dvar` output from simulations on a cell-based geodesic grid. Although the variable contains three dimensions of data (time, latitude, and longitude), it is stored in the netCDF file with only two dimensions, `time` and `gds_crd`.

```
% ncks -m -C -v gds_3dvar ~/nco/data/in.nc
gds_3dvar: type NC_FLOAT, 2 dimensions, 4 attributes, chunked? no, compressed? no, pack
gds_3dvar RAM size is 10*8*sizeof(NC_FLOAT) = 80*4 = 320 bytes
gds_3dvar dimension 0: time, size = 10 NC_DOUBLE, dim. ID = 20 (CRD)(REC)
gds_3dvar dimension 1: gds_crd, size = 8 NC_FLOAT, dim. ID = 17 (CRD)
gds_3dvar attribute 0: long_name, size = 17 NC_CHAR, value = Geodesic variable
gds_3dvar attribute 1: units, size = 5 NC_CHAR, value = meter
gds_3dvar attribute 2: coordinates, size = 15 NC_CHAR, value = lat_gds lon_gds
gds_3dvar attribute 3: purpose, size = 64 NC_CHAR, value = Test auxiliary coordinates
```

The `coordinates` attribute lists the names of the latitude and longitude coordinates, `lat_gds` and `lon_gds`, respectively. The `coordinates` attribute is recommended though optional. With it, the user can immediately identify which variables contain the latitude and longitude coordinates. Without a `coordinates` attribute it would be unclear at first glance whether a variable resides on a cell-based grid. In this example, `time` is a normal record dimension and `gds_crd` is the cell-based dimension.

The cell-based grid file must contain two variables whose `standard_name` attributes are “latitude”, and “longitude”:

```
% ncks -m -C -v lat_gds,lon_gds ~/nco/data/in.nc
lat_gds: type NC_DOUBLE, 1 dimensions, 4 attributes, chunked? no, compressed? no, pack
lat_gds RAM size is 8*sizeof(NC_DOUBLE) = 8*8 = 64 bytes
lat_gds dimension 0: gds_crd, size = 8 NC_FLOAT, dim. ID = 17 (CRD)
lat_gds attribute 0: long_name, size = 8 NC_CHAR, value = Latitude
lat_gds attribute 1: standard_name, size = 8 NC_CHAR, value = latitude
lat_gds attribute 2: units, size = 6 NC_CHAR, value = degree
lat_gds attribute 3: purpose, size = 62 NC_CHAR, value = 1-D latitude coordinate refer

lon_gds: type NC_DOUBLE, 1 dimensions, 4 attributes, chunked? no, compressed? no, pack
lon_gds RAM size is 8*sizeof(NC_DOUBLE) = 8*8 = 64 bytes
lon_gds dimension 0: gds_crd, size = 8 NC_FLOAT, dim. ID = 17 (CRD)
lon_gds attribute 0: long_name, size = 9 NC_CHAR, value = Longitude
lon_gds attribute 1: standard_name, size = 9 NC_CHAR, value = longitude
```



```
lon_gds attribute 2: units, size = 6 NC_CHAR, value = degree
lon_gds attribute 3: purpose, size = 63 NC_CHAR, value = 1-D longitude coordinate reference
```

In this example `lat_gds` and `lon_gds` represent the latitude or longitude, respectively, of cell-based variables. These coordinates (must) have the same single dimension (`gds_crd`, in this case) as the cell-based variables. And the coordinates must be one-dimensional—multidimensional coordinates will not work.

This infrastructure allows NCO to identify, interpret, and process (e.g., hyperslab) the variables on cell-based grids as easily as it works with regular grids. To time-average all the values between zero and 180 degrees longitude and between plus and minus 30 degrees latitude, we use

```
ncra -O -X 0.,180.,-30.,30. -v gds_3dvar in.nc out.nc
```

NCO accepts multiple ‘-X’ arguments for cell-based grid multi-slabs, just as it accepts multiple ‘-d’ arguments for multi-slabs of regular coordinates.

```
ncra -O -X 0.,180.,-30.,30. -X 270.,315.,45.,90. in.nc out.nc
```

The arguments to ‘-X’ are always interpreted as floating point numbers, i.e., as coordinate values rather than dimension indices so that these two commands produce identical results

```
ncra -X 0.,180.,-30.,30. in.nc out.nc
ncra -X 0,180,-30,30 in.nc out.nc
```

In contrast, arguments to ‘-d’ require decimal places to be recognized as coordinates not indices (see [Section 3.14 \[Hyperslabs\]](#), page 39). We recommend always using decimal points with ‘-X’ arguments to avoid confusion.

### 3.19 UDUnits Support

Availability: `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncks`, `ncpdq`, `ncra`, `ncrcat`, `ncwa`  
 Short options: ‘-d *dim*, [*min*][, [*max*][, [*stride*]]]’  
 Long options: ‘--dimension *dim*, [*min*][, [*max*][, [*stride*]]]’,  
 ‘--dmn *dim*, [*min*][, [*max*][, [*stride*]]]’

There is more than one way to hyperskin a cat. The **UDUnits** package provides a library which, if present, NCO uses to translate user-specified physical dimensions into the physical dimensions of data stored in netCDF files. Unidata provides UDUnits under the same terms as netCDF, so sites should install both. Compiling NCO with UDUnits support is currently optional but may become required in a future version of NCO.

Two examples suffice to demonstrate the power and convenience of UDUnits support. First, consider extraction of a variable containing non-record coordinates with physical dimensions stored in MKS units. In the following example, the user extracts all wavelengths in the visible portion of the spectrum in terms of the units very frequently used in visible spectroscopy, microns:

```
% ncks -C -H -v wvl -d wvl,"0.4 micron","0.7 micron" in.nc
wvl[0]=5e-07 meter
```

The hyperslab returns the correct values because the `wvl` variable is stored on disk with a length dimension that UDUnits recognizes in the `units` attribute. The automagical algorithm that implements this functionality is worth describing since understanding it helps one avoid some potential pitfalls. First, the user includes the physical units of the hyperslab dimensions she supplies, separated by a simple space from the numerical values of the hyperslab limits. She encloses each coordinate specifications in quotes so that the shell does not break the *value-space-unit* string into separate arguments before passing them to NCO. Double quotes (`"foo"`) or single quotes (`'foo'`) are equally valid for this purpose. Second, NCO recognizes that units translation is requested because each hyperslab argument contains text characters and non-initial spaces. Third, NCO determines whether the `wvl` is dimensioned with a coordinate variable that has a `units` attribute. In this case, `wvl` itself is a coordinate variable. The value of its `units` attribute is `meter`. Thus `wvl` passes this test so UDUnits conversion is attempted. If the coordinate associated with the variable does not contain a `units` attribute, then NCO aborts. Fourth, NCO passes the specified and desired dimension strings (microns are specified by the user, meters are required by NCO) to the UDUnits library. Fifth, the UDUnits library that these dimension are commensurate and it returns the appropriate linear scaling factors to convert from microns to meters to NCO. If the units are incommensurate (i.e., not expressible in the same fundamental MKS units), or are not listed in the UDUnits database, then NCO aborts since it cannot determine the user's intent. Finally, NCO uses the scaling information to convert the user-specified hyperslab limits into the same physical dimensions as those of the corresponding coordinate variable on disk. At this point, NCO can perform a coordinate hyperslab using the same algorithm as if the user had specified the hyperslab without requesting units conversion.

The translation and dimensional interpretation of time coordinates shows a more powerful, and probably more common, UDUnits application. In this example, the user prints all data between 4 PM and 7 PM on December 8, 1999, from a variable whose time dimension is hours since the year 1900:

```
% ncks -u -H -C -v time_udunits -d time_udunits,"1999-12-08 \
16:00:0.0","1999-12-08 19:00:0.0" in.nc
time_udunits[1]=876018 hours since 1900-01-01 00:00:0.0
```

Here, the user invokes the stride (see [Section 3.15 \[Stride\], page 40](#)) capability to obtain every other timeslice. This is possible because the UDUnits feature is additive, not exclusive—it works in conjunction with all other hyperslabbing (see [Section 3.14 \[Hyperslabs\], page 39](#)) options and in all operators which support hyperslabbing. The following example shows how one might average data in a time period spread across multiple input files

```
ncra -d time,"1939-09-09 12:00:0.0","1945-05-08 00:00:0.0" \
in1.nc in2.nc in3.nc out.nc
```

Note that there is no excess whitespace before or after the individual elements of the `-d` argument. This is important since, as far as the shell knows, `-d` takes only *one* command-line argument. Parsing this argument into its component `dim,[min][,[max][,[stride]]` elements (see [Section 3.14 \[Hyperslabs\], page 39](#)) is the job of NCO. When unquoted whitespace is present between these elements, the shell passes NCO argument fragments which will not parse as intended.



NCO implemented support for the UDUnits2 library with version 3.9.2 (August, 2007). The **UDUnits2** package supports non-ASCII characters and logarithmic units. We are interested in user-feedback on these features.

One aspect that deserves mention is that UDUnits, and thus NCO, supports run-time definition of the location of the relevant UDUnits databases. With UDUnits version 1, users may specify the directory which contains the UDUnits database, ‘udunits.dat’, via the UDUNITS\_PATH environment variable. With UDUnits version 2, users may specify the UDUnits database file itself, ‘udunits2.xml’, via the UDUNITS2\_XML\_PATH environment variable.

```
export UDUNITS_PATH='/nonstandard/location/share/udunits' # UDUnits1
export UDUNITS2_XML_PATH='/nonstandard/location/share/udunits/udunits2.xml' # UDUnits2
```

This run-time flexibility can enable the full functionality of pre-built binaries on machines with libraries in different locations.

The **UDUnits** package documentation describes the supported formats of time dimensions. Among the metadata conventions which adhere to these formats are the **Climate and Forecast (CF) Conventions** and the **Cooperative Ocean/Atmosphere Research Data Service (COARDS) Conventions**. The following ‘-d arguments’ extract the same data using commonly encountered time dimension formats:

```
-d time,"1918-11-11 11:00:0.0","1939-09-09 00:00:0.0"
```

All of these formats include at least one dash - in a non-leading character position (a dash in a leading character position is a negative sign). NCO assumes that a non-leading dash in a limit string indicates that a UDUnits date conversion is requested.

As of version 4.0.0 (January, 2010), NCO supports some calendar attributes specified by the CF conventions.

#### Supported types:

```
"365_day"/"noleap", "360_day", "gregorian", "standard"
```

#### Unsupported types:

```
"366_day"/"all_leap","proleptic_gregorian","julian","none"
```

Unsupported types default to mixed Gregorian/Julian as defined by UDUnits.

An Example: Consider the following netCDF variable

```
variables:
  double lon_cal(lon_cal) ;
    lon_cal:long_name = "lon_cal" ;
    lon_cal:units = "days since 1964-2-28 0:0:0" ;
    lon_cal:calendar = "365_day" ;
data:
  lon_cal = 1,2,3,4,5,6,7,8,9,10;
```

So the command

```
"ncks -v lon_cal -d lon_cal,'1964-3-1 0:00:0.0','1964-3-4 00:00:0.0' in.nc out.nc"
```

Results in the hyperslab lon\_cal=1,2,3,4

netCDF variables should always be stored with MKS (i.e., God's) units, so that application programs may assume MKS dimensions apply to all input variables. The UDUnits feature is intended to alleviate some of the NCO user's pain when handling MKS units. It connects users who think in human-friendly units (e.g., miles, millibars, days) to extract data which are always stored in God's units, MKS (e.g., meters, Pascals, seconds). The feature is not intended to encourage writers to store data in esoteric units (e.g., furlongs, pounds per square inch, fortnights).

### 3.20 Rebasing Time Coordinate

Availability: `ncra`, `ncrcat` Short options: None

Time re-basing is performed automatically when UDUnits is installed. Time rebasing is invoked when numerous files share a common time-based record coordinate, and the record coordinate is in the same time units in each file, but the date offset differs among files. For example suppose the time coordinate is in hours and each day in January is stored in its own daily file. Each daily file records the temperature variable `tpt(time)` with an (unadjusted) time coordinate value between 0–23 hours, and uses the `units` attribute to advance the base time:

```
file01.nc time:units="hours since 1990-1-1"
file02.nc time:units="hours since 1990-1-2"
...
file31.nc time:units="hours since 1990-1-31"

// Find mean noontime temperature in January
ncra -v tpt -d time,"1990-1-1 12:00:00","1990-1-31 23:59:59",24 \
    file??.nc noon.nc

// Concatenate day2 noon through day3 noon records
ncrcat -v tpt -d time,"1990-1-2 12:00:00","1990-1-3 11:59:59" \
    file01.nc file02.nc file03.nc noon.nc

// Results: time is "re-based" to the time units in "file01.nc"
time=36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52,
    53, 54, 55, 56, 57, 58, 59 ;

// If we repeat the above command but with only two input files...
ncrcat -v tpt -d time,"1990-1-2 12:00:00","1990-1-3 11:59:59" \
    file02.nc file03 noon.nc

// ...then the output time coordinate is based on the time units in "file02.nc"
time = 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28,
    29, 30, 31, 32, 33, 34, 35 ;
```

### 3.21 Missing values

Availability: `ncap2`, `ncbo`, `ncea`, `ncflint`, `ncpdq`, `ncra`, `ncwa`  
 Short options: None

The phrase *missing data* refers to data points that are missing, invalid, or for any reason not intended to be arithmetically processed in the same fashion as valid data. The NCO arithmetic operators attempt to handle missing data in an intelligent fashion. There are four steps in the NCO treatment of missing data:

1. Identifying variables that may contain missing data.

NCO follows the convention that missing data should be stored with the `_FillValue` specified in the variable's `_FillValue` attributes. The *only* way NCO recognizes that a variable *may* contain missing data is if the variable has a `_FillValue` attribute. In this case, any elements of the variable which are numerically equal to the `_FillValue` are treated as missing data.

NCO adopted the behavior that the default attribute name, if any, assumed to specify the value of data to ignore is `_FillValue` with version 3.9.2 (August, 2007). Prior to that, the `missing_value` attribute, if any, was assumed to specify the value of data to ignore. Supporting both of these attributes simultaneously is not practical. Hence the behavior NCO once applied to *missing\_value* it now applies to any `_FillValue`. NCO now treats any *missing\_value* as normal data<sup>11</sup>.

It has been and remains most advisable to create both `_FillValue` and `missing_value` attributes with identical values in datasets. Many legacy datasets contain only `missing_value` attributes. NCO can help migrating datasets between these conventions. One may use `ncrename` (see [Section 4.11 \[ncrename netCDF Renamer\]](#), [page 153](#)) to rename all `missing_value` attributes to `_FillValue`:

```
ncrename -a .missing_value,_FillValue inout.nc
```

Alternatively, one may use `ncatted` (see [Section 4.2 \[ncatted netCDF Attribute Editor\]](#), [page 118](#)) to add a `_FillValue` attribute to all variables

```
ncatted -O -a _FillValue,,o,f,1.0e36 inout.nc
```

2. Converting the `_FillValue` to the type of the variable, if necessary.

Consider a variable `var` of type `var_type` with a `_FillValue` attribute of type `att_type` containing the value `_FillValue`. As a guideline, the type of the `_FillValue` attribute should be the same as the type of the variable it is attached to. If `var_type` equals `att_type` then NCO straightforwardly compares each value of `var` to `_FillValue` to determine which elements of `var` are to be treated as missing data. If not, then NCO converts `_FillValue` from `att_type` to `var_type` by using the implicit conversion rules of C, or, if `att_type` is `NC_CHAR`<sup>12</sup>, by typecasting the results of the C function `strtod(_FillValue)`. You may use the NCO operator `ncatted` to change the `_FillValue` at-

<sup>11</sup> The old functionality, i.e., where the ignored values are indicated by `missing_value` not `_FillValue`, may still be selected *at NCO build time* by compiling NCO with the token definition `CPPFLAGS='-DNC0_MSS_VAL_SNG=missing_value'`.

<sup>12</sup> For example, the DOE ARM program often uses `att_type = NC_CHAR` and `_FillValue = '-99999.'`.

tribute and all data whose data is *\_FillValue* to a new value (see [Section 4.2 \[ncatted netCDF Attribute Editor\]](#), page 118).

3. Identifying missing data during arithmetic operations.

When an NCO arithmetic operator processes a variable *var* with a *\_FillValue* attribute, it compares each value of *var* to *\_FillValue* before performing an operation. Note the *\_FillValue* comparison imposes a performance penalty on the operator. Arithmetic processing of variables which contain the *\_FillValue* attribute always incurs this penalty, even when none of the data are missing. Conversely, arithmetic processing of variables which do not contain the *\_FillValue* attribute never incurs this penalty. In other words, do not attach a *\_FillValue* attribute to a variable which does not contain missing data. This exhortation can usually be obeyed for model generated data, but it may be harder to know in advance whether all observational data will be valid or not.

4. Treatment of any data identified as missing in arithmetic operators.

NCO averagers (*ncra*, *ncea*, *ncwa*) do not count any element with the value *\_FillValue* towards the average. *ncbo* and *ncflint* define a *\_FillValue* result when either of the input values is a *\_FillValue*. Sometimes the *\_FillValue* may change from file to file in a multi-file operator, e.g., *ncra*. NCO is written to account for this (it always compares a variable to the *\_FillValue* assigned to that variable in the current file). Suffice it to say that, in all known cases, NCO does “the right thing”.

It is impossible to determine and store the correct result of a binary operation in a single variable. One such corner case occurs when both operands have differing *\_FillValue* attributes, i.e., attributes with different numerical values. Since the output (result) of the operation can only have one *\_FillValue*, some information may be lost. In this case, NCO always defines the output variable to have the same *\_FillValue* as the first input variable. Prior to performing the arithmetic operation, all values of the second operand equal to the second *\_FillValue* are replaced with the first *\_FillValue*. Then the arithmetic operation proceeds as normal, comparing each element of each operand to a single *\_FillValue*. Comparing each element to two distinct *\_FillValue*'s would be much slower and would be no likelier to yield a more satisfactory answer. In practice, judicious choice of *\_FillValue* values prevents any important information from being lost.

## 3.22 Chunking

Availability: *ncap2*, *ncbo*, *ncea*, *ncecat*, *ncflint*, *ncks*, *ncpdq*, *ncra*, *ncrcat*, *ncwa*  
 Short options: none  
 Long options: ‘--cnk\_dmn *dmn\_nm*,*cnk\_sz*’, ‘--chunk\_dimension *dmn\_nm*,*cnk\_sz*’,  
 ‘--cnk\_map *cnk\_map*’, ‘--chunk\_map *cnk\_map*’,  
 ‘--cnk\_plc *cnk\_plc*’, ‘--chunk\_policy *cnk\_plc*’,  
 ‘--cnk\_scl *cnk\_sz*’, ‘--chunk\_scalar *cnk\_sz*’

All netCDF4-enabled NCO operators that define variables support a plethora of chunk-size options. Chunking can significantly accelerate or degrade read/write access to large datasets. Dataset chunking issues are described in detail [here](#).

The NCO chunking implementation is designed to be flexible. Users control three aspects of the chunking implementation. These are known as the *chunking policy*, *chunking map*, and *chunksize*. The first two are high-level mechanisms that apply to an entire file, while the third allows per-dimension specification of parameters. The implementation is a hybrid of the `ncpdq` packing policies (see [Section 4.8 \[ncpdq netCDF Permute Dimensions Quickly\]](#), [page 142](#)), and the hyperslab specifications (see [Section 3.14 \[Hyperslabs\]](#), [page 39](#)). Each aspect is intended to have a sensible default, so that most users will only need to set one switch to obtain sensible chunking. Power users can tune the three switches in tandem to obtain optimal performance.

The user specifies the desired chunking policy with the ‘-P’ switch (or its long option equivalents, ‘--cnk\_plc’ and ‘--chunk\_policy’) and its *cnk\_plc* argument. Five chunking policies are currently implemented:

#### *Chunk All Variables [default]*

Definition: Chunk all variables possible  
 Alternate invocation: `ncchunk`  
*cnk\_plc* key values: ‘all’, ‘cnk\_all’, ‘plc\_all’  
 Mnemonic: All

#### *Chunk Variables with at least Two Dimensions*

Definition: Chunk all variables possible with at least two dimensions  
 Alternate invocation: none  
*cnk\_plc* key values: ‘g2d’, ‘cnk\_g2d’, ‘plc\_g2d’  
 Mnemonic: Greater than or equal to 2 Dimensions

#### *Chunk Variables with at least Three Dimensions*

Definition: Chunk all variables possible with at least three dimensions  
 Alternate invocation: none  
*cnk\_plc* key values: ‘g3d’, ‘cnk\_g3d’, ‘plc\_g3d’  
 Mnemonic: Greater than or equal to 3 Dimensions

#### *Chunk Variables Containing Explicitly Chunked Dimensions*

Definition: Chunk all variables possible that contain at least one dimension whose chunksize was explicitly set with the ‘--cnk\_dmn’ option. Alternate invocation: none  
*cnk\_plc* key values: ‘xpl’, ‘cnk\_xpl’, ‘plc\_xpl’  
 Mnemonic: EXPLicitly specified dimensions

#### *Unchunking*

Definition: Unchunk all variables  
 Alternate invocation: `ncunchunk`  
*cnk\_plc* key values: ‘uck’, ‘cnk\_uck’, ‘plc\_uck’, ‘unchunk’  
 Mnemonic: UnChunK

Equivalent key values are fully interchangeable. Multiple equivalent options are provided to satisfy disparate needs and tastes of NCO users working with scripts and from the command line.

The chunking algorithms must know the chunksizes of each dimension of each variable to be chunked. The correspondence between the input variable shape and the chunksizes is called the *chunking map*. The user specifies the desired chunking map with the ‘-M’ switch (or its long option equivalents, ‘--cnk\_map’ and ‘--chunk\_map’) and its *cnk\_map* argument. Four chunking maps are currently implemented:

*Chunksize Equals Dimension Size [default]*

Definition: Chunksize defaults to dimension size. Explicitly specify chunksizes for particular dimensions with ‘--cnk\_dmn’ option.

*cnk\_map* key values: ‘dmn’, ‘cnk\_dmn’, ‘map\_dmn’

Mnemonic: *DiMeNsion*

*Chunksize Equals Dimension Size except Record Dimension*

Definition: Chunksize equals dimension size except record dimension has size one. Explicitly specify chunksizes for particular dimensions with ‘--cnk\_dmn’ option.

*cnk\_map* key values: ‘rd1’, ‘cnk\_rd1’, ‘map\_rd1’

Mnemonic: *Record Dimension size 1*

*Chunksize Equals Scalar Size Specified*

Definition: Chunksize for all dimensions is set with the ‘--cnk\_scl’ option.

*cnk\_map* key values: ‘xpl’, ‘cnk\_xpl’, ‘map\_xpl’

Mnemonic: *EXPLicitly specified dimensions*

*Chunksize Product Equals Scalar Size Specified*

Definition: The product of the chunksizes for each variable (approximately) equals the size specified with the ‘--cnk\_scl’ option. For a variable of rank  $R$  (i.e., with  $R$  non-degenerate dimensions), the chunksize in each non-degenerate dimension is the  $R$ th root of *cnk\_scl*.

*cnk\_map* key values: ‘prd’, ‘cnk\_prd’, ‘map\_prd’

Mnemonic: *PRoDuct*

It is possible to combine the above chunking map algorithms with user-specified per-dimension (but not per-variable) chunksizes that override specific chunksizes determined by the maps above. The user specifies the per-dimension chunksizes with the (equivalent) long options ‘--cnk\_dmn’ or ‘--chunk\_dimension’). The option takes two comma-separated arguments, *dmn\_nm,cnk\_sz*, which are the dimension name and its chunksize, respectively. The ‘--cnk\_dmn’ option may be used as many times as necessary.

```
# Simple chunking and unchunking
ncks -O -4 --cnk_plc=all      in.nc out.nc # Chunk in.nc
```

```

ncks -O -4 --cnk_plc=unchunk in.nc out.nc # Unchunk in.nc

# Chunk data then unchunk it, printing informative metadata
ncks -O -4 -D 4 --cnk_plc=all ~/nco/data/in.nc ~/foo.nc
ncks -O -4 -D 4 --cnk_plc=uck ~/foo.nc ~/foo.nc

# More complex chunking procedures, with informative metadata
ncks -O -4 -D 4 --cnk_scl=8 ~/nco/data/in.nc ~/foo.nc
ncks -O -4 -D 4 --cnk_scl=8 /data/zender/dstmch90/dstmch90_clm.nc ~/foo.nc
ncks -O -4 -D 4 --cnk_dmn lat,64 --cnk_dmn lon,128 /data/zender/dstmch90/dstmch90_clm.nc ~/foo.nc
ncks -O -4 -D 4 --cnk_plc=uck ~/foo.nc ~/foo.nc
ncks -O -4 -D 4 --cnk_plc=g2d --cnk_map=rd1 --cnk_dmn lat,32 --cnk_dmn lon,128 /data/zender/dstmch90/dstmch90_clm.nc ~/foo.nc

# Chunking works with all operators...
ncap2 -O -4 -D 4 --cnk_scl=8 -S ~/nco/data/ncap2_tst.nc ~/nco/data/in.nc ~/foo.nc
ncbo -O -4 -D 4 --cnk_scl=8 -p ~/nco/data/in.nc in.nc ~/foo.nc
ncecat -O -4 -D 4 -n 12,2,1 --cnk_dmn lat,32 -p /data/zender/dstmch90 dstmch90_clm01.nc ~/foo.nc
ncflint -O -4 -D 4 --cnk_scl=8 ~/nco/data/in.nc ~/foo.nc
ncpdq -O -4 -D 4 -P all_new --cnk_scl=8 -L 5 ~/nco/data/in.nc ~/foo.nc
ncrcat -O -4 -D 4 -n 12,2,1 --cnk_dmn lat,32 -p /data/zender/dstmch90 dstmch90_clm01.nc ~/foo.nc
ncwa -O -4 -D 4 -a time --cnk_plc=g2d --cnk_map=rd1 --cnk_dmn lat,32 --cnk_dmn lon,128 /data/zender/dstmch90/dstmch90_clm.nc ~/foo.nc

```

It is appropriate to conclude by informing users about an aspect of chunking that may not be expected: Record dimensions are always chunked with a chunksize of one. Hence all variables that contain the record dimension are also stored as chunked (since data must be stored with chunking either in all dimensions, or in no dimensions). Unless otherwise specified by the user, the other (fixed, non-record) dimensions of such variables are assigned default chunk sizes. The HDF5 layer does all this automatically to optimize the on-disk variable/file storage geometry of record variables. Do not be surprised to learn that files created without any explicit instructions to activate chunking nevertheless contain chunked variables.

### 3.23 Deflation

Availability: `ncap2`, `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncks`, `ncpdq`, `ncra`, `ncrcat`, `ncwa`  
 Short options: ‘-L’  
 Long options: ‘--dfl\_lv1’, ‘--deflate’

All NCO operators that define variables support the netCDF4 feature of storing variables compressed with Lempel-Ziv deflation. The Lempel-Ziv algorithm is a lossless data compression technique. Activate this deflation with the `-L dfl_lv1` short option (or with the same argument to the ‘--dfl\_lv1’ or ‘--deflate’ long options). Specify the deflation level `dfl_lv1` on a scale from no deflation (`dfl_lv1 = 0`) to maximum deflation (`dfl_lv1 = 9`). Minimal deflation (`dfl_lv1 = 1`) achieves considerable storage compression with little time penalty. Higher deflation levels require more time for compression. File sizes resulting from



minimal ( $dfl\_lvl = 1$ ) and maximal ( $dfl\_lvl = 9$ ) deflation levels typically differ by a few percent in size.

To compress an entire file using deflation, use

```
ncks -4 -L 0 in.nc out.nc # No deflation (fast, no time penalty)
ncks -4 -L 1 in.nc out.nc # Minimal deflation (little time penalty)
ncks -4 -L 9 in.nc out.nc # Maximal deflation (much slower)
```

Unscientific testing shows that deflation compresses typical climate datasets by 30-60%. Packing, a lossy compression technique available for all netCDF files (see [Section 3.24 \[Packed data\]](#), [page 54](#)), can easily compress files by 50%. Packed data may be deflated to squeeze datasets by about 80%:

```
ncks -4 -L 1 in.nc out.nc # Minimal deflation (~30-60% compression)
ncks -4 -L 9 in.nc out.nc # Maximal deflation (~31-63% compression)
ncpdq in.nc out.nc # Standard packing (~50% compression)
ncpdq -4 -L 9 in.nc out.nc # Deflated packing (~80% compression)
```

`ncks` prints deflation parameters, if any, to screen (see [Section 4.7 \[ncks netCDF Kitchen Sink\]](#), [page 135](#)).

### 3.24 Packed data

Availability: `ncap2`, `ncbo`, `ncea`, `ncflint`, `ncpdq`, `ncra`, `ncwa`  
 Short options: None

The phrase *packed data* refers to data which are stored in the standard netCDF3 packing format which employs a lossy algorithm. See [Section 4.7 \[ncks netCDF Kitchen Sink\]](#), [page 135](#) for a description of deflation, a lossless compression technique available with netCDF4 only. Packed data may be deflated to save additional space.

#### Packing Algorithm

*Packing* The standard netCDF packing algorithm is lossy, and produces data with the same dynamic range as the original but which requires no more than half the space to store. The packed variable is stored (usually) as type `NC_SHORT` with the two attributes required to unpack the variable, `scale_factor` and `add_offset`, stored at the original (unpacked) precision of the variable<sup>13</sup>. Let *min* and *max* be the minimum and maximum values of *x*.

$$\begin{aligned} \text{scale\_factor} &= (\text{max} - \text{min}) / \text{ndrv} \\ \text{add\_offset} &= (\text{min} + \text{max}) / 2 \\ \text{pck} &= (\text{upk} - \text{add\_offset}) / \text{scale\_factor} \\ &= \frac{\text{ndrv} \times [\text{upk} - (\text{min} + \text{max}) / 2]}{\text{max} - \text{min}} \end{aligned}$$

where *ndrv* is the number of discrete representable values for given type of packed variable. The theoretical maximum value for *ndrv* is two raised to the number of bits used to store

<sup>13</sup> Although not a part of the standard, NCO enforces the policy that the `_FillValue` attribute, if any, of a packed variable is also stored at the original precision.



the packed variable. Thus if the variable is packed into type `NC_SHORT`, a two-byte datatype, then there are at most  $2^{16} = 65536$  distinct values representable. In practice, the number of discretely representable values is taken to be two less than the theoretical maximum. This leaves space for a missing value and solves potential problems with rounding that may occur during the unpacking of the variable. Thus for `NC_SHORT`,  $ndrv = 65536 - 2 = 65534$ . Less often, the variable may be packed into type `NC_CHAR`, where  $ndrv = 256 - 2 = 254$ , or type `NC_INT` where  $ndrv = 4294967295 - 2 = 4294967293$ . One useful feature of (lossy) netCDF packing algorithm is that additional, loss-less packing algorithms perform well on top of it.

## Unpacking Algorithm

*Unpacking* The unpacking algorithm depends on the presence of two attributes, `scale_factor` and `add_offset`. If `scale_factor` is present for a variable, the data are multiplied by the value `scale_factor` after the data are read. If `add_offset` is present for a variable, then the `add_offset` value is added to the data after the data are read. If both `scale_factor` and `add_offset` attributes are present, the data are first scaled by `scale_factor` before the offset `add_offset` is added.

$$\begin{aligned} \text{upk} &= \text{scale\_factor} \times \text{pck} + \text{add\_offset} \\ &= \frac{\text{pck} \times (\text{max} - \text{min})}{\text{ndrv}} + \frac{\text{min} + \text{max}}{2} \end{aligned}$$

When `scale_factor` and `add_offset` are used for packing, the associated variable (containing the packed data) is typically of type `byte` or `short`, whereas the unpacked values are intended to be of type `int`, `float`, or `double`. An attribute's `scale_factor` and `add_offset` and `_FillValue`, if any, should all be of the type intended for the unpacked data, i.e., `int`, `float` or `double`.

## Default Handling of Packed Data

All NCO arithmetic operators understand packed data. The operators automatically unpack any packed variable in the input file which will be arithmetically processed. For example, `ncra` unpacks all record variables, and `ncwa` unpacks all variable which contain a dimension to be averaged. These variables are stored unpacked in the output file.

On the other hand, arithmetic operators do not unpack non-processed variables. For example, `ncra` leaves all non-record variables packed, and `ncwa` leaves packed all variables lacking an averaged dimension. These variables (called fixed variables) are passed unaltered from the input to the output file. Hence fixed variables which are packed in input files remain packed in output files. Completely packing and unpacking files is easily accomplished with `ncpdq` (see [Section 4.8 \[ncpdq netCDF Permute Dimensions Quickly\]](#), page 142). Packing and unpacking individual variables may be done with `ncpdq` and the `ncap2 pack()` and `unpack()` functions (see [Section 4.1.11 \[Methods and functions\]](#), page 82).

### 3.25 Operation Types

Availability: `ncap2`, `ncra`, `ncea`, `ncwa`  
 Short options: `'-y'`  
 Long options: `'--operation'`, `'--op_typ'`

The `'-y op_typ'` switch allows specification of many different types of operations. Set `op_typ` to the abbreviated key for the corresponding operation:

<code>avg</code>	Mean value
<code>sqravg</code>	Square of the mean
<code>avgsqr</code>	Mean of sum of squares
<code>max</code>	Maximum value
<code>min</code>	Minimum value
<code>rms</code>	Root-mean-square (normalized by $N$ )
<code>rmssdn</code>	Root-mean square (normalized by $N-1$ )
<code>sqrt</code>	Square root of the mean
<code>ttd</code>	Sum of values

NCO assumes coordinate variables represent grid axes, e.g., longitude. The only rank-reduction which makes sense for coordinate variables is averaging. Hence NCO implements the operation type requested with `'-y'` on all non-coordinate variables, but not on coordinate variables. When an operation requires a coordinate variable to be reduced in rank, i.e., from one dimension to a scalar or from one dimension to a degenerate (single value) array, then NCO *always averages* the coordinate variable regardless of the arithmetic operation type performed on the non-coordinate variables.

The mathematical definition of each arithmetic operation is given below. See [Section 4.12 \[ncwa netCDF Weighted Averager\]](#), page 155, for additional information on masks and normalization. If an operation type is not specified with `'-y'` then the operator performs an arithmetic average by default. Averaging is described first so the terminology for the other operations is familiar.

The masked, weighted average of a variable  $x$  can be generally represented as

$$\bar{x}_j = \frac{\sum_{i=1}^{i=N} \mu_i m_i w_i x_i}{\sum_{i=1}^{i=N} \mu_i m_i w_i}$$

where  $\bar{x}_j$  is the  $j$ 'th element of the output hyperslab,  $x_i$  is the  $i$ 'th element of the input hyperslab,  $\mu_i$  is 1 unless  $x_i$  equals the missing value,  $m_i$  is 1 unless  $x_i$  is masked, and  $w_i$  is the weight. This formidable looking formula represents a simple weighted average whose bells and whistles are all explained below. It is not too early to note, however, that when  $\mu_i = m_i = w_i = 1$ , the generic averaging expression above reduces to a simple arithmetic average. Furthermore,  $m_i = w_i = 1$  for all operators except `ncwa`. These variables are

included in the discussion below for completeness, and for possible future use in other operators.

The size  $J$  of the output hyperslab for a given variable is the product of all the dimensions of the input variable which are not averaged over. The size  $N$  of the input hyperslab contributing to each  $\bar{x}_j$  is simply the product of the sizes of all dimensions which are averaged over (i.e., dimensions specified with ‘-a’). Thus  $N$  is the number of input elements which *potentially* contribute to each output element. An input element  $x_i$  contributes to the output element  $x_j$  except in two conditions:

1.  $x_i$  equals the *missing value* (see [Section 3.21 \[Missing Values\]](#), page 49) for the variable.
2.  $x_i$  is located at a point where the mask condition (see [Section 4.12.1 \[Mask condition\]](#), page 156) is false.

Points  $x_i$  in either of these two categories do not contribute to  $x_j$ —they are ignored. We now define these criteria more rigorously.

Each  $x_i$  has an associated Boolean weight  $\mu_i$  whose value is 0 or 1 (false or true). The value of  $\mu_i$  is 1 (true) unless  $x_i$  equals the *missing value* (see [Section 3.21 \[Missing Values\]](#), page 49) for the variable. Thus, for a variable with no `_FillValue` attribute,  $\mu_i$  is always 1. All NCO arithmetic operators (`ncbo`, `ncra`, `ncea`, `ncflint`, `ncwa`) treat missing values analogously.

Besides (weighted) averaging, `ncwa`, `ncra`, and `ncea` also compute some common non-linear operations which may be specified with the ‘-y’ switch (see [Section 3.25 \[Operation Types\]](#), page 56). The other rank-reducing operations are simple variations of the generic weighted mean described above. The total value of  $x$  (`-y ttl`) is

$$\bar{x}_j = \sum_{i=1}^{i=N} \mu_i m_i w_i x_i$$

Note that the total is the same as the numerator of the mean of  $x$ , and may also be obtained in `ncwa` by using the ‘-N’ switch (see [Section 4.12 \[ncwa netCDF Weighted Averager\]](#), page 155).

The minimum value of  $x$  (`-y min`) is

$$\bar{x}_j = \min[\mu_1 m_1 w_1 x_1, \mu_2 m_2 w_2 x_2, \dots, \mu_N m_N w_N x_N]$$

Analogously, the maximum value of  $x$  (`-y max`) is

$$\bar{x}_j = \max[\mu_1 m_1 w_1 x_1, \mu_2 m_2 w_2 x_2, \dots, \mu_N m_N w_N x_N]$$

Thus the minima and maxima are determined after any weights are applied.

The square of the mean value of  $x$  (`-y sqavg`) is

$$\bar{x}_j = \left( \frac{\sum_{i=1}^{i=N} \mu_i m_i w_i x_i}{\sum_{i=1}^{i=N} \mu_i m_i w_i} \right)^2$$

The mean of the sum of squares of  $x$  (`-y avgsqr`) is

$$\bar{x}_j = \frac{\sum_{i=1}^{i=N} \mu_i m_i w_i x_i^2}{\sum_{i=1}^{i=N} \mu_i m_i w_i}$$

If  $x$  represents a deviation from the mean of another variable,  $x_i = y_i - \bar{y}$  (possibly created by `ncbo` in a previous step), then applying `avgsqr` to  $x$  computes the approximate variance of  $y$ . Computing the true variance of  $y$  requires subtracting 1 from the denominator, discussed below. For a large sample size however, the two results will be nearly indistinguishable.

The root mean square of  $x$  (`-y rms`) is

$$\bar{x}_j = \sqrt{\frac{\sum_{i=1}^{i=N} \mu_i m_i w_i x_i^2}{\sum_{i=1}^{i=N} \mu_i m_i w_i}}$$

Thus `rms` simply computes the squareroot of the quantity computed by `avgsqr`.

The root mean square of  $x$  with standard-deviation-like normalization (`-y rmssdn`) is implemented as follows. When weights are not specified, this function is the same as the root mean square of  $x$  except one is subtracted from the sum in the denominator

$$\bar{x}_j = \sqrt{\frac{\sum_{i=1}^{i=N} \mu_i m_i x_i^2}{-1 + \sum_{i=1}^{i=N} \mu_i m_i}}$$

If  $x$  represents the deviation from the mean of another variable,  $x_i = y_i - \bar{y}$ , then applying `rmssdn` to  $x$  computes the standard deviation of  $y$ . In this case the  $-1$  in the denominator compensates for the degree of freedom already used in computing  $\bar{y}$  in the numerator. Consult a statistics book for more details.

When weights are specified it is unclear how to compensate for this extra degree of freedom. Weighting the numerator and denominator of the above by  $w_i$  and subtracting one from the denominator is only appropriate when all the weights are 1.0. When the weights are arbitrary (e.g., Gaussian weights), subtracting one from the sum in the denominator does not necessarily remove one degree of freedom. Therefore when `-y rmssdn` is requested and weights are specified, `ncwa` actually implements the `rms` procedure. `ncea` and `ncra`, which do not allow weights to be specified, always implement the `rmssdn` procedure when asked.

The square root of the mean of  $x$  (`-y sqrt`) is

$$\bar{x}_j = \sqrt{\frac{\sum_{i=1}^{i=N} \mu_i m_i w_i x_i}{\sum_{i=1}^{i=N} \mu_i m_i w_i}}$$

The definitions of some of these operations are not universally useful. Mostly they were chosen to facilitate standard statistical computations within the NCO framework. We are open to redefining and or adding to the above. If you are interested in having other statistical quantities defined in NCO please contact the NCO project (see [Section 1.6 \[Help Requests and Bug Reports\]](#), page 10).

## EXAMPLES

Suppose you wish to examine the variable `prs_sfc(time,lat,lon)` which contains a time series of the surface pressure as a function of latitude and longitude. Find the minimum value of `prs_sfc` over all dimensions:

```
ncwa -y min -v prs_sfc in.nc foo.nc
```

Find the maximum value of `prs_sfc` at each time interval for each latitude:

```
ncwa -y max -v prs_sfc -a lon in.nc foo.nc
```

Find the root-mean-square value of the time-series of `prs_sfc` at every gridpoint:

```
ncra -y rms -v prs_sfc in.nc foo.nc
ncwa -y rms -v prs_sfc -a time in.nc foo.nc
```

The previous two commands give the same answer but `ncra` is preferred because it has a smaller memory footprint. Also, by default, `ncra` leaves the (degenerate) `time` dimension in the output file (which is usually useful) whereas `ncwa` removes the `time` dimension (unless `-b` is given).

These operations work as expected in multi-file operators. Suppose that `prs_sfc` is stored in multiple timesteps per file across multiple files, say `'jan.nc'`, `'feb.nc'`, `'march.nc'`. We can now find the three month maximum surface pressure at every point.

```
ncea -y max -v prs_sfc jan.nc feb.nc march.nc out.nc
```

It is possible to use a combination of these operations to compute the variance and standard deviation of a field stored in a single file or across multiple files. The procedure to compute the temporal standard deviation of the surface pressure at all points in a single file `'in.nc'` involves three steps.

```
ncwa -O -v prs_sfc -a time in.nc out.nc
ncbo -O -v prs_sfc in.nc out.nc out.nc
ncra -O -y rmssdn out.nc out.nc
```

First construct the temporal mean of `prs_sfc` in the file `'out.nc'`. Next overwrite `'out.nc'` with the anomaly (deviation from the mean). Finally overwrite `'out.nc'` with the root-mean-square of itself. Note the use of `'-y rmssdn'` (rather than `'-y rms'`) in the final step. This ensures the standard deviation is correctly normalized by one fewer than the number of time samples. The procedure to compute the variance is identical except for the use of `'-y var'` instead of `'-y rmssdn'` in the final step.

`ncap2` can also compute statistics like standard deviations. Brute-force implementation of formulae is one option, e.g.,

```
ncap2 -s 'prs_sfc_sdn=sqrt((prs_sfc-prs_sfc.avg($time)^2).total($time))/($time.size-1)' \
in.nc out.nc
```

The operation may, of course, be broken into multiple steps in order to archive intermediate quantities, such as the time-anomalies

```
ncap2 -s 'prs_sfc_anm=prs_sfc-prs_sfc.avg($time)' \
-s 'prs_sfc_sdn=sqrt((prs_sfc_anm^2).total($time))/($time.size-1)' \
```

```
in.nc out.nc
```

`ncap2` supports intrinsic standard deviation functions (see [Section 3.25 \[Operation Types\]](#), page 56) which simplify the above expression to

```
ncap2 -s 'prs_sfc_sdn=(prs_sfc-prs_sfc.avg($time)).rmssdn($time)' in.nc out.nc
```

These intrinsic functions compute the answer quickly and concisely.

The procedure to compute the spatial standard deviation of a field in a single file `in.nc` involves three steps.

```
ncwa -O -v prs_sfc,gw -a lat,lon -w gw in.nc out.nc
ncbo -O -v prs_sfc,gw in.nc out.nc out.nc
ncwa -O -y rmssdn -v prs_sfc -a lat,lon -w gw out.nc out.nc
```

First the appropriately weighted (with `'-w gw'`) spatial mean values are written to the output file. This example includes the use of a weighted variable specified with `'-w gw'`. When using weights to compute standard deviations one must remember to include the weights in the initial output files so that they may be used again in the final step. The initial output file is then overwritten with the gridpoint deviations from the spatial mean. Finally the root-mean-square of the appropriately weighted spatial deviations is taken.

The `ncap2` solution to the spatially-weighted standard deviation problem is

```
ncap2 -s 'prs_sfc_sdn=(prs_sfc*gw-prs_sfc*gw.avg($lat,$lon)).rmssdn($lat,$lon)' \
in.nc out.nc
```

Be sure to multiply the variable by the weight prior to computing the anomalies and the standard deviation.

The procedure to compute the standard deviation of a time-series across multiple files involves one extra step since all the input must first be collected into one file.

```
ncrcat -O -v tpt in.nc in.nc foo1.nc
ncwa -O -a time foo1.nc foo2.nc
ncbo -O -v tpt foo1.nc foo2.nc foo3.nc
ncra -O -y rmssdn foo3.nc out.nc
```

The first step assembles all the data into a single file. Though this may consume a lot of temporary disk space, it is more or less required by the `ncbo` operation in the third step.

## 3.26 Type Conversion

Availability: `ncap2`, `ncbo`, `ncea`, `ncra`, `ncwa`  
 Short options: None

Type conversion (often called *promotion* or *demotion*) refers to the casting of one fundamental data type to another, e.g., converting `NC_SHORT` (two bytes) to `NC_DOUBLE` (eight bytes). Type conversion is automatic when the language carries out this promotion according to an internal set of rules without explicit user intervention. In contrast, manual type conversion refers to explicit user commands to change the type of a variable or attribute.

Most type conversion happens automatically, yet there are situations in which manual type conversion is advantageous.

### 3.26.1 Automatic type conversion

As a general rule, automatic type conversions should be avoided for at least two reasons. First, type conversions are expensive since they require creating (temporary) buffers and casting each element of a variable from the type it was stored at to some other type. Second, the dataset's creator probably had a good reason for storing data as, say, `NC_FLOAT` rather than `NC_DOUBLE`. In a scientific framework there is no reason to store data with more precision than the observations were made. Thus NCO tries to avoid performing automatic type conversions when performing arithmetic.

Automatic type conversion during arithmetic in the languages C and Fortran is performed only when necessary. All operands in an operation are converted to the most precise type before the operation takes place. However, following this parsimonious conversion rule dogmatically results in numerous headaches. For example, the average of the two `NC_SHORT`s `17000s` and `17000s` results in garbage since the intermediate value which holds their sum is also of type `NC_SHORT` and thus cannot represent values greater than  $32,767^{14}$ . There are valid reasons for expecting this operation to succeed and the NCO philosophy is to make operators do what you want, not what is most pure. Thus, unlike C and Fortran, but like many other higher level interpreted languages, NCO arithmetic operators will perform automatic type conversion when all the following conditions are met<sup>15</sup>:

1. The operator is `ncea`, `ncra`, or `ncwa`. `ncbo` is not yet included in this list because subtraction did not benefit from type conversion. This will change in the future
2. The arithmetic operation could benefit from type conversion. Operations that could benefit (e.g., from larger representable sums) include averaging, summation, or any "hard" arithmetic. Type conversion does not benefit searching for minima and maxima ('-y min', or '-y max').
3. The variable on disk is of type `NC_BYTE`, `NC_CHAR`, `NC_SHORT`, or `NC_INT`. Type `NC_DOUBLE` is not type converted because there is no type of higher precision to convert to. Type `NC_FLOAT` is not type converted because, in our judgement, the performance penalty of always doing so would outweigh the (extremely rare) potential benefits.

When these criteria are all met, the operator promotes the variable in question to type `NC_DOUBLE`, performs all the arithmetic operations, casts the `NC_DOUBLE` type back to the original type, and finally writes the result to disk. The result written to disk may not be what you expect, because of incommensurate ranges represented by different types, and because of (lack of) rounding. First, continuing the above example, the average (e.g., '-y avg') of `17000s` and `17000s` is written to disk as `17000s`. The type conversion feature of NCO makes this possible since the arithmetic and intermediate values are stored as `NC_DOUBLES`, i.e., `34000.0d` and only the final result must be represented as an `NC_SHORT`. Without the type conversion feature of NCO, the average would have been garbage (albeit predictable garbage near `-15768s`). Similarly, the total (e.g., '-y ttl') of `17000s` and `17000s` written to

<sup>14</sup>  $32767 = 2^{15} - 1$

<sup>15</sup> Operators began performing type conversions before arithmetic in NCO version 1.2, August, 2000. Previous versions never performed unnecessary type conversion for arithmetic.



disk is garbage (actually `-31536s`) since the final result (the true total) of 34000 is outside the range of type `NC_SHORT`.

Type conversions use the `floor` function to convert floating point number to integers. Type conversions do not attempt to round floating point numbers to the nearest integer. Thus the average of `1s` and `2s` is computed in double precision arithmetic as  $(1.0d + 1.5d)/2 = 1.5d$ . This result is converted to `NC_SHORT` and stored on disk as `floor(1.5d) = 1s`<sup>16</sup>. Thus no "rounding up" is performed. The type conversion rules of C can be stated as follows: If  $n$  is an integer then any floating point value  $x$  satisfying  $n \leq x < n + 1$  will have the value  $n$  when converted to an integer.

### 3.26.2 Manual type conversion

`ncap2` provides intrinsic functions for performing manual type conversions. This, for example, converts variable `tpt` to external type `NC_SHORT` (a C-type `short`), and variable `prs` to external type `NC_DOUBLE` (a C-type `double`).

```
ncap2 -s 'tpt=short(tpt);prs=double(prs)' in.nc out.nc
```

See [Section 4.1 \[ncap2 netCDF Arithmetic Processor\]](#), page 68, for more details.

## 3.27 Batch Mode

Availability: All operators

Short options: `'-O'`, `'-A'`

Long options: `'--ovr'`, `'--overwrite'`, `'--apn'`, `'--append'`

If the *output-file* specified for a command is a pre-existing file, then the operator will prompt the user whether to overwrite (erase) the existing *output-file*, attempt to append to it, or abort the operation. However, interactive questions reduce productivity when processing large amounts of data. Therefore NCO also implements two ways to override its own safety features, the `'-O'` and `'-A'` switches. Specifying `'-O'` tells the operator to overwrite any existing *output-file* without prompting the user interactively. Specifying `'-A'` tells the operator to attempt to append to any existing *output-file* without prompting the user interactively. These switches are useful in batch environments because they suppress interactive keyboard input.

## 3.28 History Attribute

Availability: All operators

Short options: `'-h'`

Long options: `'--hst'`, `'--history'`

All operators automatically append a `history` global attribute to any file they create or modify. The `history` attribute consists of a timestamp and the full string of the invocation

<sup>16</sup> The actual type conversions are handled by intrinsic C-language type conversion, so the `floor()` function is not explicitly called, though the results would be the same if it were.



command to the operator, e.g., ‘Mon May 26 20:10:24 1997: ncks in.nc foo.nc’. The full contents of an existing `history` attribute are copied from the first *input-file* to the *output-file*. The timestamps appear in reverse chronological order, with the most recent timestamp appearing first in the `history` attribute. Since NCO and many other netCDF operators adhere to the `history` convention, the entire data processing path of a given netCDF file may often be deduced from examination of its `history` attribute. As of May, 2002, NCO is case-insensitive to the spelling of the `history` attribute name. Thus attributes named `History` or `HISTORY` (which are non-standard and not recommended) will be treated as valid history attributes. When more than one global attribute fits the case-insensitive search for “history”, the first one found will be used. `history` attribute To avoid information overkill, all operators have an optional switch (‘-h’, ‘--hst’, or ‘--history’) to override automatically appending the `history` attribute (see [Section 4.2 \[ncatted netCDF Attribute Editor\]](#), page 118). Note that the ‘-h’ switch also turns off writing the `nco_input_file_list` attribute for multi-file operators (see [Section 3.29 \[File List Attributes\]](#), page 63).

### 3.29 File List Attributes

Availability: `ncea`, `nccat`, `ncra`, `ncrcat`

Short options: ‘-H’

Long options: ‘--fl\_lst\_in’, ‘--file\_list’

Many methods of specifying large numbers of input file names pass these names via pipes, encodings, or argument transfer programs (see [Section 2.7 \[Large Numbers of Files\]](#), page 16). When these methods are used, the input file list is not explicitly passed on the command line. This results in a loss of information since the `history` attribute no longer contains the exact command by which the file was created.

NCO solves this dilemma by archiving input file list attributes. When the input file list to a multi-file operator is specified via `stdin`, the operator, by default, attaches two global attributes to any file they create or modify. The `nco_input_file_number` global attribute contains the number of input files, and `nco_input_file_list` contains the file names, specified as standard input to the multi-file operator. This information helps to verify that all input files the user thinks were piped through `stdin` actually arrived. Without the `nco_input_file_list` attribute, the information is lost forever and the “chain of evidence” would be broken.

The ‘-H’ switch overrides (turns off) the default behavior of writing the input file list global attributes when input is from `stdin`. The ‘-h’ switch does this too, and turns off the `history` attribute as well (see [Section 3.28 \[History Attribute\]](#), page 62). Hence both switches allows space-conscious users to avoid storing what may amount to many thousands of filenames in a metadata attribute.

### 3.30 CF Conventions

Availability: `ncbo`, `ncea`, `ncecat`, `ncflint`, `ncpdq`, `ncra`, `ncwa`  
 Short options: None

NCO recognizes the Climate and Forecast (CF) metadata conventions, and applies special rules to such data. NCO also handles older NCAR model datasets, such as CCM and early CCSM datasets, with its CF rules even though the earlier data may not contain an explicit `Conventions` attribute (e.g., ‘CF-1.0’). We refer to all such data collectively as CF data. Skip this section if you never work with CF data.

The CF netCDF conventions are described [here](#). Most CF netCDF conventions are transparent to NCO<sup>17</sup>. There are no known pitfalls associated with using any NCO operator on files adhering to these conventions<sup>18</sup>. However, to facilitate maximum user friendliness, NCO applies special rules to certain variables in CF files. The special functions are not required by the CF netCDF conventions, yet experience shows that they simplify data analysis.

Currently, NCO determines whether a datafile is a CF output datafile simply by checking (case-insensitively) whether the value of the global attribute `Conventions` (if any) equals ‘CF-1.0’ or ‘NCAR-CSM’. Should `Conventions` equal either of these in the (first) *input-file*, NCO will apply special rules to certain variables because of their usual meaning in CF files. NCO will not average the following variables often found in CF files: `ntrm`, `ntrn`, `ntrk`, `ndbase`, `nsbase`, `nbdate`, `nbsec`, `mdt`, `mhisf`. These variables contain scalar metadata such as the resolution of the host geophysical model and it makes no sense to change their values.

Furthermore, the *size and rank-preserving arithmetic operators* try not to operate on certain grid properties. These operators are `ncap`, `ncbo`, `ncea`, `ncflint`, and `ncpdq` (when used for packing, not for permutation). These operators do not operate, by default, on (i.e., add, subtract, pack, etc.) the following variables: `ORO`, `area`, `datesec`, `date`, `gw`, `hyai`, `hyam`, `hybi`, `hybm`, `lat_bnds`, `lon_bnds`, `msk_*`. These variables represent the Gaussian weights, the orography field, time fields, hybrid pressure coefficients, and latitude/longitude boundaries. We call these fields non-coordinate *grid properties*. Coordinate grid properties are easy to identify because they are coordinate variables such as `latitude` and `longitude`.

Users usually want *all* grid properties to remain unaltered in the output file. To be treated as a grid property, the variable name must *exactly* match a name in the above list, or be a coordinate variable. The handling of `msk_*` is exceptional in that *any* variable name beginning with the string `msk_` is considered to be a “mask” and is thus preserved (not operated on arithmetically).

<sup>17</sup> The exception is appending/altering the attributes `x_op`, `y_op`, `z_op`, and `t_op` for variables which have been averaged across space and time dimensions. This feature is scheduled for future inclusion in NCO.

<sup>18</sup> The CF conventions recommend `time` be stored in the format *time* since *base\_time*, e.g., the `units` attribute of `time` might be ‘days since 1992-10-8 15:15:42.5 -6:00’. A problem with this format occurs when using `ncrcat` to concatenate multiple files together, each with a different *base\_time*. That is, any `time` values from files following the first file to be concatenated should be corrected to the *base\_time* offset specified in the `units` attribute of `time` from the first file. The analogous problem has been fixed in ARM files (see [Section 3.31 \[ARM Conventions\]](#), [page 65](#)) and could be fixed for CF files if there is sufficient lobbying.

You must spoof NCO if you would like any grid properties or other special CF fields processed normally. For example rename the variables first with `ncrename`, or alter the `Conventions` attribute.

As of NCO version 4.0.8 (April, 2011), NCO supports the CF `bounds` convention for cell boundaries described [here](#). This convention allows coordinate variables (including multidimensional coordinates) to describe the boundaries of their cells. This is done by naming the variable which contains the bounds in the `bounds` attribute. Note that coordinates of rank  $N$  have bounds of rank  $N + 1$ . NCO-generated subsets of CF-compliant files with `bounds` attributes will include the coordinates specified by the `bounds` attribute, if any. Hence the subsets will themselves be CF-compliant.

As of NCO version 3.9.6 (January, 2009), NCO supports the CF `coordinates` convention described [here](#). This convention allows variables to specify additional coordinates (including multidimensional coordinates) in a space-separated string attribute named `coordinates`. NCO attaches any such coordinates to the extraction list along with variable and its usual (one-dimensional) coordinates, if any. These auxiliary coordinates are subject to the user-specified overrides described in [Section 3.12 \[Subsetting Coordinate Variables\]](#), page 38.

### 3.31 ARM Conventions

Availability: `ncrcat`

Short options: None

`ncrcat` has been programmed to correctly handle data files which utilize the Atmospheric Radiation Measurement (ARM) Program [convention](#) for time and time offsets. If you do not work with ARM data then you may skip this section. ARM data files store time information in two variables, a scalar, `base_time`, and a record variable, `time_offset`. Subtle but serious problems can arise when these type of files are just blindly concatenated. Therefore `ncrcat` has been specially programmed to be able to chain together consecutive ARM *input-files* and produce an *output-file* which contains the correct time information. Currently, `ncrcat` determines whether a datafile is an ARM datafile simply by testing for the existence of the variables `base_time`, `time_offset`, and the dimension `time`. If these are found in the *input-file* then `ncrcat` will automatically perform two non-standard, but hopefully useful, procedures. First, `ncrcat` will ensure that values of `time_offset` appearing in the *output-file* are relative to the `base_time` appearing in the first *input-file* (and presumably, though not necessarily, also appearing in the *output-file*). Second, if a coordinate variable named `time` is not found in the *input-files*, then `ncrcat` automatically creates the `time` coordinate in the *output-file*. The values of `time` are defined by the ARM conventions  $time = base\_time + time\_offset$ . Thus, if *output-file* contains the `time_offset` variable, it will also contain the `time` coordinate. A short message is added to the `history` global attribute whenever these ARM-specific procedures are executed.

### 3.32 Operator Version

Availability: All operators

Short options: `-r`

Long options: `--revision`, `--version`, or `--vrs`

All operators can be told to print their version information, library version, copyright notice, and compile-time configuration with the `-r` switch, or its long-option equivalent `--revision`. The `--version` or `--vrs` switches print the operator version information only. The internal version number varies between operators, and indicates the most recent change to a particular operator's source code. This is useful in making sure you are working with the most recent operators. The version of NCO you are using might be, e.g., 3.9.5. Using `-r` on, say, `ncks`, produces something like `'NCO netCDF Operators version "3.9.5" last modified 2008/05/11 built May 12 2008 on neige by zender Copyright (C) 1995--2008 Charlie Zender ncks version 20090918'`. This tells you that `ncks` contains all patches up to version 3.9.5, which dates from May 11, 2008.

## 4 Operator Reference Manual

This chapter presents reference pages for each of the operators individually. The operators are presented in alphabetical order. All valid command line switches are included in the syntax statement. Recall that descriptions of many of these command line switches are provided only in [Chapter 3 \[Common features\]](#), [page 23](#), to avoid redundancy. Only options specific to, or most useful with, a particular operator are described in any detail in the sections below.

## 4.1 ncap2 netCDF Arithmetic Processor

**ncap2** understands a relatively full-featured language of operations, including loops, conditionals, arrays, and math functions. **ncap2** is the most rapidly changing NCO operator and its documentation is incomplete. The distribution file `'data/ncap2_tst.nc'` contains an up-to-date overview of its syntax and capabilities. The `'data/*.nc'` distribution files (especially `'bin_cnt.nc'`, `'psd_wrf.nc'`, and `'rgr.nc'`) contain in-depth examples of **ncap2** solutions to complex problems.

### SYNTAX

```
ncap2 [-3] [-4] [-6] [-A] [-C] [-c] [-D dbg] [-F] [-f] [-L dfl_lvl]
      [-l path] [-O] [-o output-file] [-p path] [-R] [-r]
      [-s algebra] [-S fl.nc] [-t thr_nbr] [-v]
      input-file [output-file]
```

### DESCRIPTION

**ncap2** arithmetically processes netCDF files<sup>1</sup>. The processing instructions are contained either in the NCO script file `'fl.nc'` or in a sequence of command line arguments. The options `'-s'` (or long options `'--spt'` or `'--script'`) are used for in-line scripts and `'-S'` (or long options `'--fl_spt'` or `'--script-file'`) are used to provide the filename where (usually multiple) scripting commands are pre-stored. **ncap2** was written to perform arbitrary algebraic transformations of data and archive the results as easily as possible. See [Section 3.21 \[Missing Values\], page 49](#), for treatment of missing values. The results of the algebraic manipulations are called *derived fields*.

Unlike the other operators, **ncap2** does not accept a list of variables to be operated on as an argument to `'-v'` (see [Section 3.11 \[Subsetting Variables\], page 36](#)). Rather, the `'-v'` switch takes no arguments and indicates that **ncap2** should output *only* user-defined variables. **ncap2** neither accepts nor understands the `-x` switch.

Defining new variables in terms of existing variables is a powerful feature of **ncap2**. Derived fields inherit the metadata (i.e., attributes) of their ancestors, if any, in the script or input file. When the derived field is completely new (no identically-named ancestors exist), then it inherits the metadata (if any) of the left-most variable on the right hand side of the defining expression. This metadata inheritance is called *attribute propagation*. Attribute propagation is intended to facilitate well-documented data analysis, and we welcome suggestions to improve this feature.

The only exception to this rule of attribute propagation is in cases of left hand casting (see [Section 4.1.4 \[Left hand casting\], page 74](#)). The user must manually define the proper metadata for variables defined using left hand casting.

---

<sup>1</sup> **ncap2** is the successor to **ncap** which was put into maintenance mode in November, 2006. This documentation refers to **ncap2**, which has a superset of the **ncap** functionality. Eventually **ncap** will be deprecated in favor **ncap2**. **ncap2** may be renamed **ncap** in 2011.

### 4.1.1 Syntax of ncap2 statements

Mastering `ncap2` is relatively simple. Each valid statement *statement* consists of standard forward algebraic expression. The ‘`fl.nc`’, if present, is simply a list of such statements, whitespace, and comments. The syntax of statements is most like the computer language C. The following characteristics of C are preserved:

Array syntax

Arrays elements are placed within `[]` characters;

Array indexing

Arrays are 0-based;

Array storage

Last dimension is most rapidly varying;

Assignment statements

A semi-colon ‘`;`’ indicates the end of an assignment statement.

Comments

Multi-line comments are enclosed within `/* */` characters. Single line comments are preceded by `//` characters.

Nesting

Files may be nested in scripts using `#include script`. Note that the `#include` command is not followed by a semi-colon because it is a pre-processor directive, not an assignment statement. The filename ‘`script`’ is interpreted relative to the run directory.

Attribute syntax

The at-sign `@` is used to delineate an attribute name from a variable name.

### 4.1.2 Expressions

Expressions are the fundamental building block of `ncap2`. Expressions are composed of variables, numbers, literals, and attributes. The following C operators are “overloaded” and work with scalars and multi-dimensional arrays:

```
Arithmetic Operators: * / % + - ^
Binary Operators:    > >= < <= == != == || && >> <<
Unary Operators:     + - ++ -- !
Conditional Operator: exp1 ? exp2 : exp3
Assign Operators:    = += -= /= *=
```

In the following section a *variable* also refers to a number literal which is read in as a scalar variable:

#### Arithmetic and Binary Operators

Consider `var1 'op' var2`

#### Precision

- When both operands are variables, the result has the precision of the higher precision operand.
- When one operand is a variable and the other an attribute, the result has the precision of the variable.

- When both operands are attributes, the result has the precision of the more precise attribute.
- The exponentiation operator “^” is an exception to the above rules. When both operands have type less than NC\_FLOAT, the result is NC\_FLOAT. When either type is NC\_DOUBLE, the result is also NC\_DOUBLE.

### Rank

- The Rank of the result is generally equal to Rank of the operand that has the greatest number of dimensions.
- If the dimensions in var2 are a subset of the dimensions in var1 then its possible to make var2 conform to var1 through broadcasting and or dimension reordering.
- Broadcasting a variable means creating data in non-existing dimensions from the data in existing dimensions.
- More specifically: If the numbers of dimensions in var1 is greater than or equal to the number of dimensions in var2 then an attempt is made to make var2 conform to var1 ,else var1 is made to conform to var2. If conformance is not possible then an error message will be emitted and script execution will cease.

Even though the logical operators return True(1) or False(0) they are treated in the same way as the arithmetic operators with regard to precision and rank.

Examples:

```
dimensions: time=10, lat=2, lon=4
```

Suppose we have the two variables:

```
double P(time,lat,lon);
float PZ0(lon,lat); // PZ0=1,2,3,4,5,6,7,8;
```

Consider now the expression:

```
PZ=P-PZ0
```

PZ0 is made to conform to P and the result is

PZ0 =

```
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
1,3,5,7,2,4,6,8,
```

Once the expression is evaluated then PZ will be of type double;



Consider now

```
start=four-att_var@double_att; // start =-69 and is of type intger;
four_pow=four^3.0f // four_pow=64 and is of type float
three_nw=three_dmn_var_sht*1.0f; // type is now float
start@n1=att_var@short_att*att_var@int_att;
// start@n1=5329 and is type int
```

### Binary Operators

Unlike C the binary operators return an array of values. There is no such thing as short circuiting with the AND/OR operators. Missing values are carried into the result in the same way they are with the arithmetic operators. When an expression is evaluated in an `if()` the missing values are treated as true.

The binary operators are, in order of precedence:

```
!   Logical Not
-----
<< Less Than Selection
>> Greater Than Selection
-----
>   Greater than
>=  Greater than or equal to
<   Less than
<=  Less than or equal to
-----
==  Equal to
!=  Not equal to
-----
&& Logical AND
-----
|| Logical OR
-----
```

To see all operators: see [Section 4.1.26 \[Operators precedence and associativity\]](#), page 116  
Examples:

```
tm1= time>2 && time <7; // tm1 = 0, 0, 1, 1, 1, 1, 0, 0, 0, 0 ; type double;
tm2= time==3 || time>=6; // tm2 = 0, 0, 1, 0, 0, 1, 1, 1, 1, 1 ; type double
tm3= int(!tm1); // tm3= 1, 1, 0, 0, 0, 0, 1, 1, 1, 1 ; type int
tm4= tm1 && tm2; // tm4= 0, 0, 1, 0, 0, 1, 0, 0, 0, 0 ; type double;
tm5= !tm4; // tm5= 1, 1, 0, 1, 1, 0, 1, 1, 1, 1 ; type double;
```

### Regular Assign Operator

*var1* '=' *exp1*

If *var1* doesn't already exist in Output then *var1* is written to Output with the values and dimensions from *exp1*. If *var1* already exists in Output, then the only requirement on *exp1* is that the number of elements must match the number already on disk. The type of *exp1* is converted if necessary to the disk type.

**Other Assign Operators +=,-=,\*=,/=**

*var1 'ass\_op' exp1*

if *exp1* is a variable and it doesn't conform to *var1* then an attempt is made to make it conform to *var1*. If *exp1* is an attribute it must have unity size or else have the same number of elements as *var1*. If *exp1* has a different type to *var1* the it is converted to the *var1* type.

example:

```
z1=four+=one*=10 // z1=14 four=14 one=10;
time-=2          // time= -1,0,1,2,3,4,5,6,7,8
```

**Increment/ Decrement Operators**

These work in a similar fashion to their regular C counterparts. If say the variable "four" is input only then the statement "++four" effectively means -read four from input increment each element by one , then write the new values to Output;

Example:

```
n2=++four;    n2=5, four=5
n3=one--++20; n3=21 one=0;
n4=--time;    n4=time=0.,1.,2.,3.,4.,5.,6.,7.,8.,9.;
```

**Conditional Operator ?:**

*exp1 ? exp2 : exp3*

The conditional operator (or ternary Operator) is a succinct way of writing an if/then/else. If *exp1* evaluates to true then *exp2* is returned else *exp3* is returned.

Example:

```
weight_avg= weight.avg();
weight_avg@units= (weight_avg ==1 ? "kilo" : "kilos");
PS_nw= PS - (PS.min() >100000 ? 100000 : 0 );
```

**Clipping Operators****<< Less-than Clipping**

For arrays, the less-than selection operator selects all values in the left operand that are less than the corresponding value in the right operand. If the value of the left side is greater than or equal to the corresponding value of the right side, then the right side value is placed in the result

**>> Greater-than Clipping**

For arrays, the greater-than selection operator selects all values in the left operand that are greater than the corresponding value in the right operand. If the value of the left side is less than or equal to the corresponding value of the right side, then the right side value is placed in the result.

Example:

```
RDM2= RDM >>100.0; RDM2=100,100,100,100,126,126,100,100,100, 100; // type double
```

```
RDM2= RDM << 90s ; RDM3= 1, 9, 36, 84, 90, 90, 84, 36, 9, 1; // type int
```

### 4.1.3 Dimensions

Dimensions are defined in Output using the `defdim()` function.

```
defdim("cnt",10);
```

This dimension name must then be prefixed with a dollar-sign '\$' when referred to in method arguments or left-hand-casting, e.g.,

```
new_var[$cnt]=time;
temperature[$time,$lat,$lon]=35.5;
temp_avg=temperature.avg($time);
```

The `size` method allows the dimension size to be used in an arithmetic expression:

```
time_avg=time.total() / $time.size;
```

Increase the size of a new variable by one and set new member to zero:

```
defdim("cnt_new",$cnt.size+1);
new_var[$cnt_new]=0.0;
new_var(0:($cnt_new.size-2))=old_var;
```

#### Dimension Abbreviations

It is possible to use dimension abbreviations as method arguments:

\$0 is the first dimension of a variable

\$1 is the second dimension of a variable

\$n is the n+1 dimension of a variable

```
float four_dmn_rec_var(time,lat,lev,lon);
double three_dmn_var_dbl(time,lat,lon);

four_nw=four_dmn_rev_var.reverse($time,$lon)
four_nw=four_dmn_rec_var.reverse($0,$3);

four_avg=four_dmn_rec_var.avg($lat,$lev);
four_avg=four_dmn_rec_var.avg($1,$2);

three_mw=three_dmn_var_dbl.permute($time,$lon,$lat);
three_mw=three_dmn_var_dbl.permute($0,$2,$1);
```

#### ID Quoting

If the dimension name contains non-regular characters use ID quoting. See [Section 4.1.27 \[ID Quoting\], page 116](#)

```
defdim("a--list.A",10);
A1['$a--list.A']=30.0;
```

#### GOTCHA

It is not possible to manually define in Output any dimensions that exist in Input. When

a variable from Input appears in an expression or statement its dimensions in Input are automagically copied to Output (if they are not already present)

#### 4.1.4 Left hand casting

The following examples demonstrate the utility of the *left hand casting* ability of `ncap2`. Consider first this simple, artificial, example. If *lat* and *lon* are one dimensional coordinates of dimensions *lat* and *lon*, respectively, then addition of these two one-dimensional arrays is intrinsically ill-defined because whether *lat\_lon* should be dimensioned *lat* by *lon* or *lon* by *lat* is ambiguous (assuming that addition is to remain a *commutative* procedure, i.e., one that does not depend on the order of its arguments). Differing dimensions are said to be *orthogonal* to one another, and sets of dimensions which are mutually exclusive are orthogonal as a set and any arithmetic operation between variables in orthogonal dimensional spaces is ambiguous without further information.

The ambiguity may be resolved by enumerating the desired dimension ordering of the output expression inside square brackets on the left hand side (LHS) of the equals sign. This is called *left hand casting* because the user resolves the dimensional ordering of the RHS of the expression by specifying the desired ordering on the LHS.

```
ncap2 -s 'lat_lon[lat,lon]=lat+lon' in.nc out.nc
ncap2 -s 'lon_lat[lon,lat]=lat+lon' in.nc out.nc
```

The explicit list of dimensions on the LHS, `[lat,lon]` resolves the otherwise ambiguous ordering of dimensions in *lat\_lon*. In effect, the LHS *casts* its rank properties onto the RHS. Without LHS casting, the dimensional ordering of *lat\_lon* would be undefined and, hopefully, `ncap2` would print an error message.

Consider now a slightly more complex example. In geophysical models, a coordinate system based on a blend of terrain-following and density-following surfaces is called a *hybrid coordinate system*. In this coordinate system, four variables must be manipulated to obtain the pressure of the vertical coordinate: *PO* is the domain-mean surface pressure offset (a scalar), *PS* is the local (time-varying) surface pressure (usually two horizontal spatial dimensions, i.e. latitude by longitude), *hyam* is the weight given to surfaces of constant density (one spatial dimension, pressure, which is orthogonal to the horizontal dimensions), and *hybm* is the weight given to surfaces of constant elevation (also one spatial dimension). This command constructs a four-dimensional pressure `prs_mdp` from the four input variables of mixed rank and orthogonality:

```
ncap2 -s 'prs_mdp[time,lat,lon,lev]=P0*hyam+PS*hybm' in.nc out.nc
```

Manipulating the four fields which define the pressure in a hybrid coordinate system is easy with left hand casting.

#### 4.1.5 Arrays and hyperslabs

Generating a regularly spaced one-dimensional array with `ncap2` is simple with the `array()` function. The syntax is

```
output=array(val_srt,val_ncr,$dmn_nm); // One-dimensional output
output=array(val_srt,val_ncr,var_tpl); // Multi-dimensional output
h
```

where the arguments are the starting value *val\_srt*, incremental value *val\_ncr*, and, for one-dimensional output, the single dimension *\$dmn\_nm*, or, for multi-dimensional output, a template variable *var\_tpl*, i.e., a variable with the same shape as the desired output.

Once the associated dimensions have been defined, the start and increment arguments may be supplied as values, mathematical expressions, or variables:

```
var_out=array(1,1,$time); // 1,2,3,4,5,6,7,8,9,10
var_out=array(1+2-2,one,$time); // 1,2,3,4,5,6,7,8,9,10
var_out=array(1,2,three_dmn_rec_var); // 1,3,5,...155,157,159
```

Hyperslabs in *ncap2* are more limited than hyperslabs with the other NCO operators. *ncap2* does not understand the shell command-line syntax used to specify multi-slabs, wrapped co-ordinates, negative stride or coordinate value limits. However with a bit of syntactic magic they are all are possible. *ncap2* accepts (in fact, it requires) *N*-hyperslab arguments for a variable of rank *N*:

```
var1(arg1,arg2 ... argN);
```

where each hyperslab argument is of the form

```
start:end:stride
```

and the arguments for different dimensions are separated by commas. If "start" is omitted, it defaults to 0. If "end" is omitted, it defaults to dimension size minus one. If "stride" is omitted, it defaults to 1.

If a single value is present then it is assumed that that dimension collapses to a single value (i.e., a cross-section). The number of hyperslab arguments **MUST** equal the variable's rank.

### Hyperslabs on the Right Hand Side of an assign

A simple 1D example:

```
($time.size=10)
od[$time]={20,22,24,26,28,30,32,34,36,38};

od(7);      // 34
od(7:);     // 34,36,38
od(:7);     // 20,22,24,26,28,30,32,34
od(::4);    // 20,28,36
od(1:6:2)   // 22,26,30
od(:)       // 20,22,24,26,28,30,32,34,36,38
```

A more complex three dimensional example:

```
($lat.size=2,$lon.size=4)
th[$time,$lat,$lon]=
    {1, 2, 3, 4, 5, 6, 7, 8,
     9,10,11,12,13,14,15,16,
     17,18,19,20,21,22,23,24,
```

```

-99,-99,-99,-99,-99,-99,-99,-99,
33,34,35,36,37,38,39,40,
41,42,43,44,45,46,47,48,
49,50,51,52,53,54,55,56,
-99,58,59,60,61,62,63,64,
65,66,67,68,69,70,71,72,
-99,74,75,76,77,78,79,-99 };

th(1,1,3);          // 16
th(2,0,:);          // 17, 18, 19, 20
th(:,1,3);          // 8, 16, 24, -99, 40, 48, 56, 64, 72, -99
th(:,:,5, :,0:3:2); // 1, 3, 5, 7, 41, 43, 45, 47

```

If hyperslab arguments collapse to a single value (a cross-section has been specified), then that dimension is removed from the returned variable. If all the values collapse then a scalar variable is returned. So, for example, the following is valid:

```

th_nw=th(0,:::)+th(9,:::);
// th_nw has dimensions $lon,$lat
// NB: the time dimension has become degenerate

```

The following is invalid:

```

th_nw=th(0,::,0:1)+th(9,::,0:1);

```

because the `$lon` dimension now only has two elements. The above can be calculated by using a LHS cast with `$lon_nw` as replacement dim for `$lon`:

```

defdim("lon_nw",2);
th_nw[$lat,$lon_nw]=th(0,::,0:1) +th(9,::,0:1);

```

### Hyperslabs on the Left Hand Side of an assign

When hyperslabbing on the LHS, the expression on the RHS must evaluate to a scalar or a variable/attribute with the same number of elements as the LHS hyperslab. Set all elements of the last record to zero:

```

th(9,::,:)=0.0;

```

Set first element of each lon element to 1.0:

```

th(:,::,0)=1.0;

```

One may hyperslab on both sides of an assign. For example, this sets the last record to the first record:

```

th(9,::,:)=th(0,::,:);

```

Say `th0` represents pressure at height=0 and `th1` represents pressure at height=1. Then it is possible to insert these hyperslabs into the records

```

prs[$time,$height,$lat,$lon]=0.0;
prs(:,0,::,:)=th0;
prs(:,1,::,:)=th1

```

**Reverse method**

Use the `reverse()` method to reverse a dimension's elements in a variable with at least one dimension. This is equivalent to a negative stride, e.g.,

```
th_rv=th(1 ,:,:).reverse($lon); // {12,11,10,9 }, {16,15,14,13}
od_rv=od.reverse($time);        // {38,36,34,32,30,28,26,24,22,20}
```

**Permute method**

Use the `permute()` method to swap the dimensions of a variable. The number and names of dimension arguments must match the dimensions in the variable. If the first dimension in the variable is of record type then this must remain the first dimension. If you want to change the record dimension then consider using `ncpdq`.

Consider the variable:

```
float three_dmn_var(lat,lev,lon);
three_dmn_var_prm=three_dmn_var.permute($lon,$lat,$lev);
// The permuted values are
three_dmn_var_prm=
  0,4,8,
 12,16,20,
  1,5,9,
 13,17,21,
  2,6,10,
 14,18,22,
  3,7,11,
 15,19,23;
```

**4.1.6 Attributes**

Attributes are referred to by *var\_nm@att\_nm*

All the following are valid statements:

```
global@text="Test Attributes"; /* Assign a global variable attribute */
a1[$time]=time*20;
a1@long_name="Kelvin";
a1@min=a1.min();
a1@max=a1.max();
a1@min++;
--a1@max; q
a1(0)=a1@min;
a1($time.size-1)=a1@max;
```

A *value list* can be used on the RHS of an assign...

```
a1@trip1={1,2,3} ;
a1@triplet={a1@min,(a1@min+a1@max)/2,a1@max};
```

The netCDF specification allows all attribute types to have a size greater than one. The maximum is defined by `NC_MAX_ATTRS`. The following is an `ncdump` of the metadata for variable *a1*



```
double a1(time) ;
  a1:long_name = "Kelvin" ;
  a1:max = 199. ;
  a1:min = 21. ;
  a1:trip1 = 1, 2, 3 ;
  a1:triplet = 21., 110., 199. ;
```

The `size()` method can be used with attributes. For example, to save an attribute text string in a variable,

```
defdim("sng_len", a1@long_name.size());
sng_arr[$sng_len]=a1@long_name; // sng_arr now contains "Kelvin"
```

Attributes defined in a script are stored in memory and are written to Output after script completion. To stop the attribute being written use the `ram_delete()` method or use a bogus variable name.

### Attribute Propagation & Inheritance

- Attribute propagation occurs in a regular assign statement. The variable being defined on the LHS gets copies of the attributes from the leftmost variable on the RHS
- Attribute Inheritance: The LHS variable "inherits" attributes from an Input variable with the same name
- It is possible to have a regular assign statement for which both propagation and inheritance occur.

```
prs_mdp[time,lat,lon,lev]=P0*hyam+hybm*PS; // prs_mdp gets attributes from P0
th_min=1.0 + 2*three_dmn_var_dbl.min($time); // th_min gets attributes from three_dmn
```

If the attribute name contains non-regular characters use ID quoting. See [Section 4.1.27 \[ID Quoting\]](#), page 116

```
'b..m1@c--lost'=23;
```

### 4.1.7 Number literals

The table below lists the postfix character(s) to add to a number literal for type cohesion. To use the new netCDF4 types NCO must be compiled/linked to the netCDF4 library and the output file must be HDF5.

```
n1[$time]=1UL; // n1 will now be of type NC_UINT
n2[$lon]=4b; // n2 will be of type NC_BYTE
n3[$lat]=5ull; // n3 will be of type NC_UINT64
n3@a1=6.0d; // attribute will be type NC_DOUBLE
n3@a2=-666L; // attribute will be type NC_INT
```

A floating point number without a postfix will default to `NC_DOUBLE`. An integer without a postfix will default to type `NC_INT`. There is no postfix for characters, use a quoted string instead.

```
n4[$rlev]=0.1 // n4 will be of type NC_DOUBLE
n5[$lon_grd]=2.0 // n5 will be of type NC_DOUBLE
n6[$gds_crd]=2e3; // n6 will be of type NC_DOUBLE
```

```
n7[$gds_crd]=2e3f; // n7 will be of type NC_FLOAT
n6@a1=41;          // attribute will be type NC_INT
n6@a2=-21;          // attribute will be type NC_INT
n6@units="kelvin" // attribute will be type NC_CHAR
```

#### **netCDF3/4 Types**

b B	NC_BYTE, a signed 1-byte integer
none	NC_CHAR, an ISO/ASCII character
s S	NC_SHORT, a signed 2-byte integer
l L	NC_INT, a signed 4-byte integer
f F	NC_FLOAT, a single-precision (4-byte) floating point number
d D	NC_DOUBLE, a double-precision (8-byte) floating point number

#### **netCDF4 Types**

ub UB	NC_UBYTE, an unsigned 1-byte integer
us US	NC_USHORT, an unsigned 2-byte integer
u U ul UL	NC_UINT, an unsigned 4-byte integer
ll LL	NC_INT64, a signed 8-byte integer
ull ULL	NC_UINT64, an unsigned 8-byte integer

### **4.1.8 if statement**

The syntax of the if statement is similar to its C counterpart. The *Conditional Operator* (*ternary operator*) has also been implemented.

```
if(exp1)
    stmt1;
else if(exp2)
    stmt2;
else
    stmt3;
```

# Can use code blocks as well:

```
if(exp1){
    stmt1;
    stmt1a;
    stmt1b;
} else if(exp2)
    stmt2;
else {
    stmt3;
    stmt3a;
```

```
    stmt3b;
}
```

For a variable or attribute expression to be logically true all its non-missing value elements must be logically true, i.e., non-zero. The expression can be of any type. Unlike C there is no short-circuiting of an expression with the OR (||) AND (&&) operators. The whole expression is evaluated regardless if one of the AND/OR operands are true/false.

```
# Simple example
if(time>0)
    print("All values of time are greater than zero\n");
else if( time<0)
    print("All values of time are less than zero\n");
else {
    time_max=time.max();
    time_min=time.min();
    print("min value of time=");print(time_min,"%f");
    print("max value of time=");print(time_max,"%f");
}

# Example from ddra.nco
if(fl_typ==fl_typ_gcm){
    var_nbr_apx=32;
    lmn_nbr=1.0*var_nbr_apx*varsz_gcm_4D; /* [nbr] Variable size */
    if(nco_op_typ==nco_op_typ_avg){
        lmn_nbr_avg=1.0*var_nbr_apx*varsz_gcm_4D; /* [nbr] Averaging block size */
        lmn_nbr_wgt=dmnsz_gcm_lat; /* [nbr] Weight size */
    } // !nco_op_typ_avg
}else if(fl_typ==fl_typ_stl){
    var_nbr_apx=8;
    lmn_nbr=1.0*var_nbr_apx*varsz_stl_2D; /* [nbr] Variable size */
    if(nco_op_typ==nco_op_typ_avg){
        lmn_nbr_avg=1.0*var_nbr_apx*varsz_stl_2D; /* [nbr] Averaging block size */
        lmn_nbr_wgt=dmnsz_stl_lat; /* [nbr] Weight size */
    } // !nco_op_typ_avg
} // !fl_typ
```

### Conditional Operator

```
// netCDF4 needed for this example
th_nw=(three_dmn_var_sht >= 0 ? three_dmn_var_sht.uint() : three_dmn_var_sht.int() );
```

#### 4.1.9 print statement

```
print(variable_name/attribute name/string, format string);
```

The print function takes a variable name or attribute name or a quoted string and prints the contents in a similar fashion to `ncks -H`. There is also an optional C style format string argument. Currently the print function cannot print RAM variables or expressions

such as `'print(var_msk*3+4)'`. To print an expression, first evaluate it as a non-RAM variable (so it will be saved and can be printed), and then print the variable.

examples

```
print(lon);
lon[0]=0
lon[1]=90
lon[2]=180
lon[3]=270

print(lon_2D_rrg,"%3.2f,");
0.00,0.00,180.00,0.00,180.00,0.00,180.00,0.00,

print(mss_val_fst@_FillValue);
mss_val_fst@_FillValue, size = 1 NC_FLOAT, value = -999

print("This function \t is monotonic\n");
This function is      monotonic
```

#### 4.1.10 Missing values ncap2

Missing values operate slightly differently in `ncap2` Consider the expression where `op` is any of the following operators (excluding `'='`)

```
Arithmetic operators ( * / % + - ^ )
Binary Operators    ( >, >= <, <= ==, !=,==,||,&&, >>,<< )
Assign Operators    ( +=,-=,/=, *= )
```

```
var1 'op' var2
```

If `var1` has a missing value then this is the value used in the operation, otherwise the missing value for `var2` is used. If during the element-by-element operation an element from either operand is equal to the missing value then the missing value is carried through. In this way missing values 'percolate' or propagate through an expression.

Missing values associated with Output variables are stored in memory and are written to disk after the script finishes. During script execution its possible (and legal) for the missing value of a variable to take on several different values.

```
# Consider the variable:
int rec_var_int_mss_val_int(time); =-999,2,3,4,5,6,7,8,-999,-999;
rec_var_int_mss_val_int:_FillValue = -999;

n2=rec_var_int_mss_val_int + rec_var_int_mss_val_int.reverse($time);

n2=-999,-999,11,11,11,11,11,11,999,-999;
```

The following methods are used to edit the missing value associated with a variable. They only work on variables in Output.

`set_miss(expr)`

Takes one argument the missing value. Sets or overwrites the existing missing value. The argument given is converted if necessary to the variable type

`change_miss(expr)`

Changes the missing value elements of the variable to the new missing value (nb an expensive function).

`get_miss()`

Returns the missing value of a variable. If the variable exists in Input and Output then the missing value of the variable in Output is returned. If the variable has no missing value then an error is returned.

`delete_miss()`

Deletes the missing value associated with a variable.

```
th=three_dmn_var_dbl;
th.change_miss(-1e10d);
/* Set values less than 0 or greater than 50 to missing value */
where(th < 0.0 || th > 50.0) th=th.get_miss();

# Another example:
new[$time,$lat,$lon]=1.0;
new.set_miss(-997.0);

// Extract only elements divisible by 3
where (three_dmn_var_dbl%3 == 0)
    new=three_dmn_var_dbl;
elsewhere
    new=new.get_miss();
```

#### 4.1.11 Methods and functions

The convention within this document is that methods can be used as functions. However, functions are not and cannot be used as methods. Methods can be daisy chained together and their syntax is cleaner than functions. Method names are reserved words and CANNOT be used as variable names. The command `ncap2 -f` shows the complete list of methods available on your build.

```
n2=sin(theta)
n2=theta.sin()
n2=sin(theta)^2 + cos(theta)^2
n2=theta.sin().pow(2) + theta.cos()^2
```

This statement chains methods together to convert `three_dmn_var_sht` to type double, average it, then convert this back to type short:

```
three_avg=three_dmn_var_sht.double().avg().short();
```

#### Aggregate Methods

These methods mirror the averaging types available in `ncwa`. The arguments to the methods

are the dimensions to average over. Specifying no dimensions is equivalent to specifying all dimensions i.e., averaging over all dimensions. A masking variable and a weighting variable can be manually created and applied as needed.

```

avg()      Mean value
sqravg()   Square of the mean
avgsqr()   Mean of sum of squares
max()      Maximum value
min()      Minimum value
rms()      Root-mean-square (normalize by  $N$ )
rmssdn()   Root-mean square (normalize by  $N-1$ )
ttl() or total()
            Sum of values

// Average a variable over time
four_time_avg=four_dmn_rec_var($time);

```

### Packing Methods

For more information see [Section 3.24 \[Packed data\]](#), page 54 and see [Section 4.8 \[ncpdq netCDF Permute Dimensions Quickly\]](#), page 142

```

pack() & pack_short()
            The default packing algorithm is applied and variable is packed to NC_SHORT
pack_byte()
            Variable is packed to NC_BYTE
pack_short()
            Variable is packed to NC_SHORT
pack_int()
            Variable is packed to NC_INT
unpack()    The standard unpacking algorithm is applied.

```

### Basic Methods

These methods work with variables and attributes. They have no arguments

```

size()      Total number of elements
ndims()     Number of dimensions in variable
type()      Returns the netcdf type (see previous section)

```

### Utility Methods

These functions are used to manipulate missing values and RAM variables. see [Section 4.1.10 \[Missing values ncap2\]](#), page 81

**set\_miss(expr)**  
 Takes one argument the missing value. Sets or overwrites the existing missing value. The argument given is converted if necessary to the variable type

**change\_miss(expr)**  
 Changes the missing value elements of the variable to the new missing value (n.b. an expensive function).

**get\_miss()**  
 Returns the missing value of a variable in Input or Output

**delete\_miss()**  
 Deletes the missing value associated with a variable.

**ram\_write()**  
 Writes a RAM variable to disk i.e., converts it to a regular disk type variable

**ram\_delete()**  
 Deletes a RAM variable or an attribute

### PDQ Methods

See see [Section 4.8 \[ncpdq netCDF Permute Dimensions Quickly\]](#), page 142

**reverse(dim args)**  
 Reverses the dimension ordering of elements in a variable.

**permute(dim args)**  
 Re-shapes variables by re-ordering the dimensions. All the dims of the variable must be specified in the arguments. A limitation of this permute (unlike ncpdq) is that the record dimension cannot be re-assigned.

// Swap dimensions about and reorder along lon

```
lat_2D_rrg_new=lat_2D_rrg.permute($lon,$lat).reverse($lon);
lat_2D_rrg_new=0,90,-30,30,-30,30,-90,0
```

### Type Conversion Methods

These methods allow **ncap2** to convert variables and attributes to the different netcdf types. For more details on automatic and manual type conversion see (see [Section 3.26 \[Type Conversion\]](#), page 60). You can only use the new netCDF4 types if you have compiled/links NCO with the netCDF4 library and the Output file is HDF5.

#### netCDF3/4 Types

<b>byte()</b>	convert to NC_BYTE, a signed 1-byte integer
<b>char()</b>	convert to NC_CHAR, an ISO/ASCII character
<b>short()</b>	convert to NC_SHORT, a signed 2-byte integer
<b>int()</b>	convert to NC_INT, a signed 4-byte integer
<b>float()</b>	convert to NC_FLOAT, a single-precision (4-byte) floating point number



`double()` convert to `NC_DOUBLE`, a double-precision (8-byte) floating point number

#### **netCDF4 Types**

`ubyte()` convert to `NC_UBYTE`, an unsigned 1-byte integer

`ushort()` convert to `NC_USHORT`, an unsigned 2-byte integer

`uint()` convert to `NC_UINT`, an unsigned 4-byte integer

`int64()` convert to `NC_INT64`, a signed 8-byte integer

`uint64()` convert to `NC_UINT64`, an unsigned 8-byte integer

#### **Intrinsic Mathematical Methods**

The list of mathematical methods is system dependant. For the full list see [Section 4.1.25 \[Intrinsic mathematical methods\]](#), page 113

All the mathematical methods take a single operand ,with the exception of `atan2` and `pow` which take two. If the operand type is less than *float* then the result will be of type *float*. If the operand is type *double* then the result will be type *double*. Like the other methods, you are free to use the mathematical methods as functions.

```
n1=pow(2,3.0f)    // n1 type float
n2=atan2(2,3.0)   // n2 type double
n3=1/(three_dmn_var_dbl.cos()).pow(2))-tan(three_dmn_var_dbl)^2; // n3 type double
```

#### **4.1.12 RAM variables**

Unlike regular variables, RAM variables are never written to disk. Hence using RAM variables in place of regular variables (especially within loops) significantly increases execution speed. Variables that are frequently accessed within `for` or `where` clauses provide the greatest opportunities for optimization. To declare and define a RAM variable simply prefix the variable name with an asterisk (\*) when the variable is declared/initialized. To delete a RAM variables (and recover their memory) use the `ram_delete()` method. To write a RAM variable to disk (like a regular variable) use `ram_write()`.

```
*temp[$time,$lat,lon]=10.0;    // Cast
*temp_avg=temp.avg($time);     // Regular assign
temp.ram_delete();             // Delete RAM variable
temp_avg.ram_write();          // Write Variable to output

// Create and increment a RAM variable from "one" in Input
*one++;
// Create RAM variables from the variables three and four in Input.
// Multiply three by 10 and add it to four.
*four+=*three*=10; // three=30, four=34
```

#### **4.1.13 Where statement**

A `where()` combines the definition and application of a mask all in one go and can lead to succinct code. The full syntax of a `where()` statement is as follows:

```
// Single assign (the 'elsewhere' block is optional)
where(mask)
    var1=expr1;
elsewhere
    var1=expr2;

// Multiple assigns
where(mask){
    var1=expr1;
    var2=expr2;
    ...
}elsewhere{
    var1=expr3
    var2=expr4
    var3=expr5;
    ...
}
```

- The only expression allowed in the predicate of a where is assign, i.e., 'var=expr'. This assign differs from a regular `ncap2` assign. The LHS var must already exist in Input or Output. The RHS expression must evaluate to a scalar or a variable/attribute of the same size as the LHS variable.
- Consider when both the LHS and RHS are variables: For every element where mask condition is True, the corresponding LHS variable element is re-assigned to its partner element on the RHS. In the elsewhere part the mask is logically inverted and the assign process proceeds as before.
- If the mask dimensions are a subset of the LHS variable's dimensions, then it is made to conform; if it cannot be made to conform then script execution halts.
- Missing values in the mask evaluate to False in the where code/block statement and to True in the elsewhere block/statement. LHS variable elements set to missing value are not re-assigned. For these reasons, do not explicitly reference missing values in the masking condition, e.g., `where(foo=foo.get_missing()) foo=1;` will not work as expected.

Example: Consider the variables `float lon_2D_rct(lat,lon);` and `float var_msk(lat,lon);`. Suppose we wish to multiply by two the elements for which `var_msk` equals 1:

```
where(var_msk==1) lon_2D_rct=2*lon_2D_rct;
```

Suppose that we have the variable `int RDM(time)` and that we want to set its values less than 8 or greater than 80 to 0:

```
where(RDM < 8 || RDM > 80) RDM=0;
```

Consider irregularly gridded  
data, described using rank 2 coordinates: `double lat(south_north,east_west), double lon(south_north,east_west), double temperature(south_north,east_west)`. To find the average temperature in a region bounded by `[lat_min,lat_max]` and `[lon_min,lon_max]`:

```

temperature_msk[$south_north,$east_west]=0.0;
where(lat >= lat_min && lat <= lat_max) && (lon >= lon_min && lon <= lon_max)
    temperature_msk=temperature;
elsewhere
    temperature_msk=temperature@_FillValue;

temp_avg=temperature_msk.avg();
temp_max=temperature.max();

```

#### 4.1.14 Loops

ncap supplies `for()` loops and `while()` loops. They are completely unoptimized so use them only with RAM variables unless you want thrash your disk to death. To break out of a loop use the `break` command. To iterate to the next cycle use the `continue` command.

```

// Following sets elements in variable double temp(time,lat)
// If element < 0 set to 0, if element > 100 set to 100
*sz_idx=$time.size;
*sz_jdx=$lat.size;

for(*idx=0;idx<sz_idx;idx++)
    for(*jdx=0;jdx<sz_jdx;jdx++)
        if(temp(idx,jdx) > 100) temp(idx,jdx)=100.0;
        else if(temp(idx,jdx) < 0) temp(idx,jdx)=0.0;

// Are values of co-ordinate variable double lat(lat) monotonic?
*sz=$lat.size;

for(*idx=1;idx<sz;idx++)
    if(lat(idx)-lat(idx-1) < 0.0)
        break;

if(idx == sz)
    print("lat co-ordinate is monotonic\n");
else
    print("lat co-ordinate is NOT monotonic\n");

// Sum odd elements
*idx=0;
*sz=$lat_nw.size;
*sum=0.0;
while(idx<sz){
    if(lat(idx)%2) sum+=lat(idx);
    idx++;
}

ram_write(sum);
print("Total of odd elements ");print(sum);print("\n");

```

#### 4.1.15 Include files

The syntax of an *include-file* is:

```
#include "script.nco"
```

The script filename is searched relative to the run directory. It is possible to nest include files to an arbitrary depth. A handy use of include files is to store often used constants. Use RAM variables if you do not want these constants written to *output-file*.

```
// script.nco
// Sample file to #include in ncap2 script
*pi=3.1415926535; // RAM variable, not written to output
*h=6.62607095e-34; // RAM variable, not written to output
e=2.71828; // Regular (disk) variable, written to output
```

#### 4.1.16 sort methods

In ncap there are two ways to sort data. The first is a regular **sort**. This sorts ALL the elements of a variable or attribute without regard to any dimensions. The second method applies a sort map to a variable. To apply this sort map the size of the variable must be exactly divisible by the size of the sort map. The method **sort(var\_in,&var\_map)** is overloaded. The second optional argument is to supply a call-by-reference variable to hold the returned sort map.

```
a1[$time]={10,2,3,4,6,5,7,3,4,1};
a1_sort=sort(a1);
print(a1_sort);
// 1, 2, 3, 3, 4, 4, 5, 6, 7, 10;

a2[$lon]={2,1,4,3};
a2_sort=sort(a2,&a2_map);
print(a2);
// 1, 2, 3, 4
print(a2_map);
// 1, 0, 3, 2;
```

If the map variable does not exist prior to the **sort()** call, then it will be created with the same shape as the input variable and be of type **NC\_INT**. If the map variable already exists, then the only restriction is that it be of at least the same size as the input variable. To apply a map use **dsort(var\_in,var\_map)**.

```
defdim("nlat",5);

a3[$lon]={2,5,3,7};
a4[$nlat,$lon]={
  1, 2, 3, 4,
  5, 6, 7, 8,
  9,10,11,12,
  13,14,15,16,
  17,18,19,20};
```

```

a3_sort=sort(a3,&a3_map);
print(a3_map);
// 0, 2, 1, 3;

a4_sort=dsort(a4,a3_map);
print(a4_sort);
// 1, 3, 2, 4,
// 5, 7, 6, 8,
// 9,11,10,12,
// 13,15,14,16,
// 17,19,18,20;

a3_map2[$nlat]={4,3,0,2,1};

a4_sort2=dsort(a4,a3_map2);
print(a4_sort2);
// 3, 5, 4, 2, 1
// 8, 10, 9,7, 6,
// 13,15,14,12,11,
// 18,20,19,17,16

```

As in the above example you may create your own sort map. To sort in descending order, apply the `reverse()` method after the `sort()`.

Here is an extended example of how to use `ncap2` features to hyperslab an irregular region based on the values of a variable not a coordinate. The distinction is crucial: hyperslabbing based on dimensional indices or coordinate values is straightforward. Using the values of single or multi-dimensional variable to define a hyperslab is quite different.

```

cat > ~/ncap2_foo.nco << 'EOF'
// Purpose: Save irregular 1-D regions based on variable values

// Included in NCO User's Guide at http://nco.sf.net/nco.html#sort

/* NB: Single quotes around EOF above turn off shell parameter
   expansion in "here documents". This in turn prevents the
   need for protecting dollarsign characters in NCO scripts with
   backslashes when the script is cut-and-pasted (aka "moused")
   from an editor or e-mail into a shell console window */

/* Copy coordinates and variable(s) of interest into RAM variable(s)
   Benefits:
   1. ncap2 defines writes all variables on LHS of expression to disk
      Only exception is RAM variables, which are stored in RAM only
      Repeated operations on regular variables takes more time,
      because changes are written to disk copy after every change.
      RAM variables are only changed in RAM so script works faster

```

```

        RAM variables can be written to disk at end with ram_write()
2. Script permutes variables of interest during processing
   Safer to work with copies that have different names
   This discourages accidental, mistaken use of permuted versions
3. Makes this script a more generic template:
   var_in instead of specific variable names everywhere */
*var_in=one_dmn_rec_var;
*crd_in=time;
*dmn_in_sz=$time.size; // [nbr] Size of input arrays

/* Create all other "intermediate" variables as RAM variables
   to prevent them from cluttering the output file.
   Mask flag and sort map are same size as variable of interest */
*msk_flg=var_in;
*srt_map=var_in;

/* In this example we mask for all values evenly divisible by 3
   This is the key, problem-specific portion of the template
   Replace this where() condition by that for your problem
   Mask variable is Boolean: 1=Meets condition, 0=Fails condition */
where(var_in % 3 == 0) msk_flg=1; elsewhere msk_flg=0;

// print("msk_flg = ");print(msk_flg); // For debugging...

/* The sort() routine is overloaded, and takes one or two arguments
   The second argument (optional) is the "sort map" (srt_map below)
   Pass the sort map by reference, i.e., prefix with an ampersand
   If the sort map does not yet exist, then it will be created and
   returned as an integer type the same shape as the input variable.
   The output of sort(), on the LHS, is a sorted version of the input
   msk_flg is not needed in its original order after sort()
   Hence we use msk_flg as both input to and output from sort()
   Doing this prevents the need to define a new, unneeded variable */
msk_flg=sort(msk_flg,&srt_map);

// Count number of valid points in mask by summing the one's
*msk_nbr=msk_flg.total();

// Define output dimension equal in size to number of valid points
defdim("crd_out",msk_nbr);

/* Now sort the variable of interest using the sort map and dsort()
   The output, on the LHS, is the input re-arranged so that all points
   meeting the mask condition are contiguous at the end of the array
   Use same srt_map to hyperslab multiple variables of the same shape
   Remember to apply srt_map to the coordinate variables */
crd_in=dsort(crd_in,srt_map);

```

```

var_in=dsort(var_in,srt_map);

/* Hyperslab last msk_nbr values of variable(s) of interest */
crd_out[crd_out]=crd_in((dmn_in_sz-msk_nbr):(dmn_in_sz-1));
var_out[crd_out]=var_in((dmn_in_sz-msk_nbr):(dmn_in_sz-1));

/* NB: Even though we created all variables possible as RAM variables,
the original coordinate of interest, time, is written to the ouput.
I'm not exactly sure why. For now, delete it from the output with:
ncks -O -x -v time ~/foo.nc ~/foo.nc
*/
EOF
ncap2 -O -v -S ~/ncap2_foo.nco ~/nco/data/in.nc ~/foo.nc
ncks -O -x -v time ~/foo.nc ~/foo.nc
ncks ~/foo.nc

```

Here is an extended example of how to use `ncap2` features to sort multi-dimensional arrays based on the coordinate values along a single dimension.

```

cat > ~/ncap2_foo.nco << 'EOF'
/* Purpose: Sort multi-dimensional array based on coordinate values
This example sorts the variable three_dmn_rec_var(time,lat,lon)
based on the values of the time coordinate. */

// Included in NCO User's Guide at http://nco.sf.net/nco.html#sort

// Randomize the time coordinate
time=10.0*gsl_rng_uniform(time);
//print("original randomized time =\n");print(time);

/* The sort() routine is overloaded, and takes one or two arguments
The first argument is a one dimensional array
The second argument (optional) is the "sort map" (srt_map below)
Pass the sort map by reference, i.e., prefix with an ampersand
If the sort map does not yet exist, then it will be created and
returned as an integer type the same shape as the input variable.
The output of sort(), on the LHS, is a sorted version of the input */

time=sort(time,&srt_map);
//print("sorted time (ascending order) and associated sort map =\n");print(time);print

/* sort() always sorts in ascending order
The associated sort map therefore re-arranges the original,
randomized time array into ascending order.
There are two methods to obtain the descending order the user wants
1) We could solve the problem in ascending order (the default)
and then apply the reverse() method to re-arrange the results.
2) We could change the sort map to return things in descending

```



```

    order of time and solve the problem directly in descending order. */

// Following shows how to do method one:

/* Expand the sort map to srt_map_3d, the size of the data array
1. Use data array to provide right shape for the expanded sort map
2. Coerce data array into an integer so srt_map_3d is an integer
3. Multiply data array by zero so 3-d map elements are all zero
4. Add the 1-d sort map to the 3-d sort map (NCO automatically resizes)
5. Add the spatial (lat,lon) offsets to each time index
6. de-sort using the srt_map_3d
7. Use reverse to obtain descending in time order
Loops could accomplish the same thing (exercise left for reader)
However, loops are slow for large datasets */

/* Following index manipulation requires understanding correspondence
between 1-d (unrolled, memory order of storage) and access into that
memory as a multidimensional (3-d, in this case) rectangular array.
Key idea to understand is how dimensionality affects offsets */
// Copy 1-d sort map into 3-d sort map
srt_map_3d=(0*int(three_dmn_rec_var))+srt_map;
// Multiply base offset by factorial of lesser dimensions
srt_map_3d*=$lat.size*$lon.size;
lon_idx=array(0,1,$lon);
lat_idx=array(0,1,$lat)*$lon.size;
lat_lon_idx[$lat,$lon]=lat_idx+lon_idx;
srt_map_3d+=lat_lon_idx;

print("sort map 3d =\n");print(srt_map_3d);

// Use dsort() to "de-sort" the data using the sort map
three_dmn_rec_var=dsort(three_dmn_rec_var,srt_map_3d);

// Finally, reverse data so time coordinate is descending
time=time.reverse($time);
//print("sorted time (descending order) =\n");print(time);
three_dmn_rec_var=three_dmn_rec_var.reverse($time);

// Method two: Key difference is srt_map=$time.size-srt_map-1;
EOF
ncap2 -O -v -S ~/ncap2_foo.nco ~/nco/data/in.nc ~/foo.nc

```

#### 4.1.17 Irregular Grids

NCO is capable of analyzing datasets for many different underlying coordinate grid types. netCDF was developed for and initially used with grids comprised of orthogonal dimensions forming a rectangular coordinate system. We call such grids *standard* grids. It is increas-

ingly common for datasets to use metadata to describe much more complex grids. Let us first define three important coordinate grid properties: rectangularity, regularity, and fxm.

Grids are *regular* if the spacing between adjacent is constant. For example, a 4-by-5 degree latitude-longitude grid is regular because the spacings between adjacent latitudes (4 degrees) are constant as are the (5 degrees) spacings between adjacent longitudes. Spacing in *irregular* grids depends on the location along the coordinate. Grids such as Gaussian grids have uneven spacing in latitude (points cluster near the equator) and so are irregular.

Grids are *rectangular* if the number of elements in any dimension is not a function of any other dimension. For example, a T42 Gaussian latitude-longitude grid is rectangular because there are the same number of longitudes (128) for each of the (64) latitudes. Grids are *non-rectangular* if the elements in any dimension depend on another dimension. Non-rectangular grids present many special challenges to analysis software like NCO.

Wrapped coordinates (see [Section 3.17 \[Wrapped Coordinates\]](#), [page 42](#)), such as longitude, are independent of these grid properties (regularity, rectangularity).

The preferred NCO technique to analyze data on non-standard coordinate grids is to create a region mask with `ncap2`, and then to use the mask within `ncap2` for variable-specific processing, and/or with other operators (e.g., `ncwa`, `ncdiff`) for entire file processing.

Before describing the construction of masks, let us review how irregularly gridded geoscience data are described. Say that latitude and longitude are stored as  $R$ -dimensional arrays and the product of the dimension sizes is the total number of elements  $N$  in the other variables. Geoscience applications tend to use  $R = 1$ ,  $R = 2$ , and  $R = 3$ .

If the grid is has no simple representation (e.g., discontinuous) then it makes sense to store all coordinates as 1D arrays with the same size as the number of grid points. These gridpoints can be completely independent of all the other (own weight, area, etc.).

$R=1$ : lat(number\_of\_gridpoints) and lon(number\_of\_gridpoints)

If the horizontal grid is time-invariant then  $R=2$  is common:

$R=2$ : lat(south\_north,east\_west) and lon(south\_north,east\_west)

The Weather and Research Forecast (WRF) model uses  $R=3$ :

$R=3$ : lat(time,south\_north,east\_west), lon(time,south\_north,east\_west)

and so supports grids that change with time.

Grids with  $R > 1$  often use missing values to indicated empty points. For example, so-called "staggered grids" will use fewer east\_west points near the poles and more near the equator. netCDF only accepts rectangular arrays so space must be allocated for the maximum number of east\_west points at all latitudes. Then the application writes missing values into the unused points near the poles.

We demonstrate the `ncap2` analysis technique for irregular regions by constructing a mask for an  $R=2$  grid. We wish to find, say, the mean temperature within  $[lat\_min,lat\_max]$  and  $[lon\_min,lon\_max]$ :

```
ncap2 -s 'mask_var= (lat >= lat_min && lat <= lat_max) && \
          (lon >= lon_min && lon <= lon_max);' in.nc out.nc
```

Arbitrarily shaped regions can be defined by more complex conditional statements. Once defined, masks can be applied to specific variables, and to entire files:

```
ncap2 -s 'temperature_avg=(temperature*mask_var).avg()' in.nc out.nc
ncwa -a lat,lon -m mask_var -w area in.nc out.nc
```

Crafting such commands on the command line is possible though unwieldy. In such cases, a script is often cleaner and allows you to document the procedure:

```
cat > ncap2.in << 'EOF'
mask_var = (lat >= lat_min && lat <= lat_max) && (lon >= lon_min && lon <= lon_max);
if(mask_var.total() > 0){ // Check that mask contains some valid values
    temperature_avg=(temperature*mask_var).avg(); // Average temperature
    temperature_max=(temperature*mask_var).max(); // Maximum temperature
}
EOF
ncap2 -S ncap2.in in.nc out.nc
```

For WRF files creating regional masks looks like

```
mask_var = (XLAT >= lat_min && XLAT <= lat_max) && (XLONG >= lon_min && XLONG <= lon_max);
```

In practice with WRF it's a bit more complicated because you must use the global metadata to determine the grid staggering and offsets to translate XLAT and XLONG into real latitudes and longitudes and missing points. The WRF grid documentation should describe this.

A few notes: Irregular regions are the union of arrays lat/lon\_min/max's. The mask procedure is identical for all *R*.

#### 4.1.18 Bilinear interpolation

As of version 4.0.0 NCO has internal routines to perform bilinear interpolation on gridded data sets. In mathematics, bilinear interpolation is an extension of linear interpolation for interpolating functions of two variables on a regular grid. The idea is to perform linear interpolation first in one direction, and then again in the other direction.

Suppose we have an irregular grid of data `temperature[lat,lon]`, with co-ordinate vars `lat[lat]`, `lon[lon]`. We wish to find the temperature at an arbitrary point `[X,Y]` within the grid. If we can locate `lat_min,lat_max` and `lon_min,lon_max` such that `lat_min <= X <= lat_max` and `lon_min <= Y <= lon_max` then we can interpolate in two dimensions to find the temperature at `[X,Y]`.

The general form of the `ncap2` interpolation function is

```
var_out=bilinear_interp(grid_in,grid_out,grid_out_x,grid_out_y,grid_in_x,grid_in_y)
```

where

**grid\_in**    Input function data. Usually a two dimensional variable. It must be of size `grid_in_x.size()*grid_in_y.size()`

**grid\_out**    This variable is the shape of `var_out`. Usually a two dimensional variable. It must be of size `grid_out_x.size()*grid_out_y.size()`

`grid_out_x`  
     X output values

`grid_out_y`  
     Y output values

`grid_in_x`  
     X input values values. Must be montonic (increasing or decreasing).

`grid_in_y`  
     Y input values values. Must be montonic (increasing or decreasing).

Prior to calculations all arguments are converted to type `NC_DOUBLE`. After calculations `var_out` is converted to the input type of `grid_in`.

Suppose the first part of an `ncap2` script is

```
defdim("X",4);
defdim("Y",5);

// Temperature
T_in[$X,$Y]=
  {100, 200, 300, 400, 500,
   101, 202, 303, 404, 505,
   102, 204, 306, 408, 510,
   103, 206, 309, 412, 515.0 };

// Coordinate variables
x_in[$X]={0.0,1.0,2.0,3.01};
y_in[$Y]={1.0,2.0,3.0,4.0,5};
```

Now we interpolate with the following variables:

```
defdim("Xn",3);
defdim("Yn",4);
T_out[$Xn,$Yn]=0.0;
x_out[$Xn]={0.0,0.02,3.01};
y_out[$Yn]={1.1,2.0,3,4};

var_out=bilinear_interp(T_in,T_out,x_out,y_out,x_in,y_in);
print(var_out);
// 110, 200, 300, 400,
// 110.022, 200.04, 300.06, 400.08,
// 113.3, 206, 309, 412 ;
```

It is possible to interpolate a single point:

```
var_out=bilinear_interp(T_in,0.0,3.0,4.99,x_in,y_in);
print(var_out);
// 513.920594059406
```

### Wrapping and Extrapolation

The function `bilinear_interp_wrap()` takes the same arguments as `bilinear_interp()`

but performs wrapping (*Y*) and extrapolation (*X*) for points off the edge of the grid. If the given range of longitude is say (25-335) and we have a point at 20 degrees, then the endpoints of the range are used for the interpolation. This is what wrapping means. For wrapping to occur *Y* must be longitude and must be in the range (0,360) or (-180,180). There are no restrictions on the longitude (*X*) values, though typically these are in the range (-90,90). This `ncap2` script illustrates both wrapping and extrapolation of end points:

```
defdim("lat_in",6);
defdim("lon_in",5);

// Coordinate input vars
lat_in[$lat_in]={-80,-40,0,30,60.0,85.0};
lon_in[$lon_in]={30, 110, 190, 270, 350.0};

T_in[$lat_in,$lon_in]=
  {10,40,50,30,15,
   12,43,52,31,16,
   14,46,54,32,17,
   16,49,56,33,18,
   18,52,58,34,19,
   20,55,60,35,20.0 };

defdim("lat_out",4);
defdim("lon_out",3);

// Coordinate variables
lat_out[$lat_out]={-90,0,70,88.0};
lon_out[$lon_out]={0,190,355.0};

T_out[$lat_out,$lon_out]=0.0;

T_out=bilinear_interp_wrap(T_in,T_out,lat_out,lon_out,lat_in,lon_in);
print(T_out);
// 13.4375, 49.5, 14.09375,
// 16.25, 54, 16.625,
// 19.25, 58.8, 19.325,
// 20.15, 60.24, 20.135 ;
```

#### 4.1.19 GSL special functions

As of version 3.9.6 (released January, 2009), NCO can link to the GNU Scientific Library (GSL). `ncap2` can access most GSL special functions including Airy, Bessel, error, gamma, beta, hypergeometric, and Legendre functions and elliptical integrals. GSL must be version 1.4 or later. To list the GSL functions available with your NCO build, use `ncap2 -f | grep ^gsl`.

The function names used by `ncap2` mirror their GSL names. The NCO wrappers for GSL functions automatically call the error-handling version of the GSL function when available<sup>2</sup>. This allows NCO to return a missing value when the GSL library encounters a domain error or a floating point exception. The slow-down due to calling the error-handling version of the GSL numerical functions was found to be negligible (please let us know if you find otherwise).

Consider the gamma function.

The GSL function prototype is

```
int gsl_sf_gamma_e(const double x, gsl_sf_result * result)
```

The `ncap` script would be:

```
lon_in[lon]={-1,0.1,0,2,0.3};
lon_out=gsl_sf_gamma(lon_in);
lon_out= _, 9.5135, 4.5908, 2.9915
```

The first value is set to `_FillValue` since the gamma function is undefined for negative integers. If the input variable has a missing value then this value is used. Otherwise, the default double fill value is used (defined in the `netCDF` header '`netcdf.h`' as `NC_FILL_DOUBLE = 9.969e+36`).

Consider a call to a Bessel function with GSL prototype

```
int gsl_sf_bessel_Jn_e(int n, double x, gsl_sf_result * result)
```

An `ncap` script would be

```
lon_out=gsl_sf_bessel_Jn(2,lon_in);
lon_out=0.11490, 0.0012, 0.00498, 0.011165
```

This computes the Bessel function of order  $n=2$  for every value in `lon_in`. The Bessel order argument, an integer, can also be a non-scalar variable, i.e., an array.

```
n_in[lon]={0,1,2,3};
lon_out=gsl_sf_bessel_Jn(n_in,0.5);
lon_out= 0.93846, 0.24226, 0.03060, 0.00256
```

Arguments to GSL wrapper functions in `ncap` must conform to one another, i.e., they must share the same sub-set of dimensions. For example: `three_out=gsl_sf_bessel_Jn(n_in,three_dmn_var_dbl)` is valid because the variable `three_dmn_var_dbl` has a `lon` dimension, so `n_in` in can be broadcast to conform to `three_dmn_var_dbl`. However `time_out=gsl_sf_bessel_Jn(n_in,time)` is invalid.

Consider the elliptical integral with prototype `int gsl_sf_ellint_RD_e(double x, double y, double z, gsl_mode_t mode, gsl_sf_result * result)`

```
three_out=gsl_sf_ellint_RD(0.5,time,three_dmn_var_dbl);
```

The three arguments are all conformable so the above `ncap` call is valid. The mode argument in the function prototype controls the convergence of the algorithm. It also appears in the Airy Function prototypes. It can be set by defining the environment variable `GSL_PREC_`

---

<sup>2</sup> These are the GSL standard function names postfixed with `_e`. NCO calls these functions automatically, without the NCO command having to specifically indicate the `_e` function suffix.

MODE. If unset it defaults to the value `GSL_PREC_DOUBLE`. See the GSL manual for more details.

```
export GSL_PREC_MODE=0 // GSL_PREC_DOUBLE
export GSL_PREC_MODE=1 // GSL_PREC_SINGLE
export GSL_PREC_MODE=2 // GSL_PREC_APPROX
```

The `ncap` wrappers to the array functions are slightly different. Consider the following GSL prototype

```
int gsl_sf_bessel_Jn_array(int nmin, int nmax, double x, double *result_array)

    b1=lon.double();
    x=0.5;
    status=gsl_sf_bessel_Jn_array(1,4,x,&b1);
    print(status);
    b1=0.24226,0.0306,0.00256,0.00016;
```

This calculates the Bessel function of  $x=0.5$  for  $n=1$  to 4. The first three arguments are scalar values. If a non-scalar variable is supplied as an argument then only the first value is used. The final argument is the variable where the results are stored (NB: the `&` indicates this is a call by reference). This final argument must be of type `double` and must be of least size  $nmax-nmin+1$ . If either of these conditions is not met then the function returns an error message. The function/wrapper returns a status flag. Zero indicates success.

Consider another array function

```
int gsl_sf_legendre_Pl_array( int lmax, double x, double *result_array);

    a1=time.double();
    x=0.3;
    status=gsl_sf_legendre_Pl_array(a1.size()-1, x,&a1);
    print(status);
```

This call calculates  $P_l(0.3)$  for  $l=0..9$ . Note that  $|x| \leq 1$ , otherwise there will be a domain error. See the GSL documentation for more details.

The GSL functions implemented in NCO are listed in the table below. This table is correct for GSL version 1.10. To see what functions are available on your build run the command `ncap2 -f |grep ^gsl`. To see this table along with the GSL C-function prototypes look at the spreadsheet [doc/nco-gsl.ods](#).

GSL NAME	I	NCAP FUNCTION CALL
<code>gsl_sf_airy_Ai_e</code>	Y	<code>gsl_sf_airy_Ai(dbl_expr)</code>
<code>gsl_sf_airy_Bi_e</code>	Y	<code>gsl_sf_airy_Bi(dbl_expr)</code>
<code>gsl_sf_airy_Ai_scaled_e</code>	Y	<code>gsl_sf_airy_Ai_scaled(dbl_expr)</code>
<code>gsl_sf_airy_Bi_scaled_e</code>	Y	<code>gsl_sf_airy_Bi_scaled(dbl_expr)</code>
<code>gsl_sf_airy_Ai_deriv_e</code>	Y	<code>gsl_sf_airy_Ai_deriv(dbl_expr)</code>
<code>gsl_sf_airy_Bi_deriv_e</code>	Y	<code>gsl_sf_airy_Bi_deriv(dbl_expr)</code>
<code>gsl_sf_airy_Ai_deriv_scaled_e</code>	Y	<code>gsl_sf_airy_Ai_deriv_scaled(dbl_expr)</code>
<code>gsl_sf_airy_Bi_deriv_scaled_e</code>	Y	<code>gsl_sf_airy_Bi_deriv_scaled(dbl_expr)</code>



<code>gsl_sf_airy_zero_Ai_e</code>	Y	<code>gsl_sf_airy_zero_Ai(uint_expr)</code>
<code>gsl_sf_airy_zero_Bi_e</code>	Y	<code>gsl_sf_airy_zero_Bi(uint_expr)</code>
<code>gsl_sf_airy_zero_Ai_deriv_e</code>	Y	<code>gsl_sf_airy_zero_Ai_deriv(uint_expr)</code>
<code>gsl_sf_airy_zero_Bi_deriv_e</code>	Y	<code>gsl_sf_airy_zero_Bi_deriv(uint_expr)</code>
<code>gsl_sf_bessel_J0_e</code>	Y	<code>gsl_sf_bessel_J0(dbl_expr)</code>
<code>gsl_sf_bessel_J1_e</code>	Y	<code>gsl_sf_bessel_J1(dbl_expr)</code>
<code>gsl_sf_bessel_Jn_e</code>	Y	<code>gsl_sf_bessel_Jn(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_Jn_array</code>	Y	<code>status=gsl_sf_bessel_Jn_array(int,int,double,&amp;var_out)</code>
<code>gsl_sf_bessel_Y0_e</code>	Y	<code>gsl_sf_bessel_Y0(dbl_expr)</code>
<code>gsl_sf_bessel_Y1_e</code>	Y	<code>gsl_sf_bessel_Y1(dbl_expr)</code>
<code>gsl_sf_bessel_Yn_e</code>	Y	<code>gsl_sf_bessel_Yn(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_Yn_array</code>	Y	<code>gsl_sf_bessel_Yn_array</code>
<code>gsl_sf_bessel_I0_e</code>	Y	<code>gsl_sf_bessel_I0(dbl_expr)</code>
<code>gsl_sf_bessel_I1_e</code>	Y	<code>gsl_sf_bessel_I1(dbl_expr)</code>
<code>gsl_sf_bessel_In_e</code>	Y	<code>gsl_sf_bessel_In(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_In_array</code>	Y	<code>status=gsl_sf_bessel_In_array(int,int,double,&amp;var_out)</code>
<code>gsl_sf_bessel_I0_scaled_e</code>	Y	<code>gsl_sf_bessel_I0_scaled(dbl_expr)</code>
<code>gsl_sf_bessel_I1_scaled_e</code>	Y	<code>gsl_sf_bessel_I1_scaled(dbl_expr)</code>
<code>gsl_sf_bessel_In_scaled_e</code>	Y	<code>gsl_sf_bessel_In_scaled(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_In_scaled_array</code>	Y	<code>status=gsl_sf_bessel_In_scaled_array(int,int,double,&amp;var_out)</code>
<code>gsl_sf_bessel_K0_e</code>	Y	<code>gsl_sf_bessel_K0(dbl_expr)</code>
<code>gsl_sf_bessel_K1_e</code>	Y	<code>gsl_sf_bessel_K1(dbl_expr)</code>
<code>gsl_sf_bessel_Kn_e</code>	Y	<code>gsl_sf_bessel_Kn(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_Kn_array</code>	Y	<code>status=gsl_sf_bessel_Kn_array(int,int,double,&amp;var_out)</code>
<code>gsl_sf_bessel_K0_scaled_e</code>	Y	<code>gsl_sf_bessel_K0_scaled(dbl_expr)</code>
<code>gsl_sf_bessel_K1_scaled_e</code>	Y	<code>gsl_sf_bessel_K1_scaled(dbl_expr)</code>
<code>gsl_sf_bessel_Kn_scaled_e</code>	Y	<code>gsl_sf_bessel_Kn_scaled(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_Kn_scaled_array</code>	Y	<code>status=gsl_sf_bessel_Kn_scaled_array(int,int,double,&amp;var_out)</code>
<code>gsl_sf_bessel_j0_e</code>	Y	<code>gsl_sf_bessel_J0(dbl_expr)</code>
<code>gsl_sf_bessel_j1_e</code>	Y	<code>gsl_sf_bessel_J1(dbl_expr)</code>
<code>gsl_sf_bessel_j2_e</code>	Y	<code>gsl_sf_bessel_J2(dbl_expr)</code>
<code>gsl_sf_bessel_jl_e</code>	Y	<code>gsl_sf_bessel_Jl(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_jl_array</code>	Y	<code>status=gsl_sf_bessel_Jl_array(int,double,&amp;var_out)</code>
<code>gsl_sf_bessel_jl_stepped_array</code>	Y	<code>gsl_sf_bessel_Jl_stepped_array</code>
<code>gsl_sf_bessel_y0_e</code>	Y	<code>gsl_sf_bessel_Y0(dbl_expr)</code>
<code>gsl_sf_bessel_y1_e</code>	Y	<code>gsl_sf_bessel_Y1(dbl_expr)</code>
<code>gsl_sf_bessel_y2_e</code>	Y	<code>gsl_sf_bessel_Y2(dbl_expr)</code>
<code>gsl_sf_bessel_yl_e</code>	Y	<code>gsl_sf_bessel_Yl(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_yl_array</code>	Y	<code>status=gsl_sf_bessel_Yl_array(int,double,&amp;var_out)</code>
<code>gsl_sf_bessel_i0_scaled_e</code>	Y	<code>gsl_sf_bessel_I0_scaled(dbl_expr)</code>
<code>gsl_sf_bessel_i1_scaled_e</code>	Y	<code>gsl_sf_bessel_I1_scaled(dbl_expr)</code>
<code>gsl_sf_bessel_i2_scaled_e</code>	Y	<code>gsl_sf_bessel_I2_scaled(dbl_expr)</code>
<code>gsl_sf_bessel_il_scaled_e</code>	Y	<code>gsl_sf_bessel_Il_scaled(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_il_scaled_array</code>	Y	<code>status=gsl_sf_bessel_Il_scaled_array(int,double,&amp;var_out)</code>
<code>gsl_sf_bessel_k0_scaled_e</code>	Y	<code>gsl_sf_bessel_K0_scaled(dbl_expr)</code>
<code>gsl_sf_bessel_k1_scaled_e</code>	Y	<code>gsl_sf_bessel_K1_scaled(dbl_expr)</code>
<code>gsl_sf_bessel_k2_scaled_e</code>	Y	<code>gsl_sf_bessel_K2_scaled(dbl_expr)</code>

<code>gsl_sf_bessel_kl_scaled_e</code>	Y	<code>gsl_sf_bessel_kl_scaled(int_expr,dbl_expr)</code>
<code>gsl_sf_bessel_kl_scaled_array</code>	Y	<code>status=gsl_sf_bessel_kl_scaled_array(int,double,&amp;var_out)</code>
<code>gsl_sf_bessel_Jnu_e</code>	Y	<code>gsl_sf_bessel_Jnu(dbl_expr,dbl_expr)</code>
<code>gsl_sf_bessel_Ynu_e</code>	Y	<code>gsl_sf_bessel_Ynu(dbl_expr,dbl_expr)</code>
<code>gsl_sf_bessel_sequence_Jnu_e</code>	N	<code>gsl_sf_bessel_sequence_Jnu</code>
<code>gsl_sf_bessel_Inu_scaled_e</code>	Y	<code>gsl_sf_bessel_Inu_scaled(dbl_expr,dbl_expr)</code>
<code>gsl_sf_bessel_Inu_e</code>	Y	<code>gsl_sf_bessel_Inu(dbl_expr,dbl_expr)</code>
<code>gsl_sf_bessel_Knu_scaled_e</code>	Y	<code>gsl_sf_bessel_Knu_scaled(dbl_expr,dbl_expr)</code>
<code>gsl_sf_bessel_Knu_e</code>	Y	<code>gsl_sf_bessel_Knu(dbl_expr,dbl_expr)</code>
<code>gsl_sf_bessel_lnKnu_e</code>	Y	<code>gsl_sf_bessel_lnKnu(dbl_expr,dbl_expr)</code>
<code>gsl_sf_bessel_zero_J0_e</code>	Y	<code>gsl_sf_bessel_zero_J0(uint_expr)</code>
<code>gsl_sf_bessel_zero_J1_e</code>	Y	<code>gsl_sf_bessel_zero_J1(uint_expr)</code>
<code>gsl_sf_bessel_zero_Jnu_e</code>	N	<code>gsl_sf_bessel_zero_Jnu</code>
<code>gsl_sf_clausen_e</code>	Y	<code>gsl_sf_clausen(dbl_expr)</code>
<code>gsl_sf_hydrogenicR_1_e</code>	N	<code>gsl_sf_hydrogenicR_1</code>
<code>gsl_sf_hydrogenicR_e</code>	N	<code>gsl_sf_hydrogenicR</code>
<code>gsl_sf_coulomb_wave_FG_e</code>	N	<code>gsl_sf_coulomb_wave_FG</code>
<code>gsl_sf_coulomb_wave_F_array</code>	N	<code>gsl_sf_coulomb_wave_F_array</code>
<code>gsl_sf_coulomb_wave_FG_array</code>	N	<code>gsl_sf_coulomb_wave_FG_array</code>
<code>gsl_sf_coulomb_wave_FGp_array</code>	N	<code>gsl_sf_coulomb_wave_FGp_array</code>
<code>gsl_sf_coulomb_wave_sphF_array</code>	N	<code>gsl_sf_coulomb_wave_sphF_array</code>
<code>gsl_sf_coulomb_CL_e</code>	N	<code>gsl_sf_coulomb_CL</code>
<code>gsl_sf_coulomb_CL_array</code>	N	<code>gsl_sf_coulomb_CL_array</code>
<code>gsl_sf_coupling_3j_e</code>	N	<code>gsl_sf_coupling_3j</code>
<code>gsl_sf_coupling_6j_e</code>	N	<code>gsl_sf_coupling_6j</code>
<code>gsl_sf_coupling_RacahW_e</code>	N	<code>gsl_sf_coupling_RacahW</code>
<code>gsl_sf_coupling_9j_e</code>	N	<code>gsl_sf_coupling_9j</code>
<code>gsl_sf_coupling_6j_INCORRECT_e</code>	N	<code>gsl_sf_coupling_6j_INCORRECT</code>
<code>gsl_sf_dawson_e</code>	Y	<code>gsl_sf_dawson(dbl_expr)</code>
<code>gsl_sf_debye_1_e</code>	Y	<code>gsl_sf_debye_1(dbl_expr)</code>
<code>gsl_sf_debye_2_e</code>	Y	<code>gsl_sf_debye_2(dbl_expr)</code>
<code>gsl_sf_debye_3_e</code>	Y	<code>gsl_sf_debye_3(dbl_expr)</code>
<code>gsl_sf_debye_4_e</code>	Y	<code>gsl_sf_debye_4(dbl_expr)</code>
<code>gsl_sf_debye_5_e</code>	Y	<code>gsl_sf_debye_5(dbl_expr)</code>
<code>gsl_sf_debye_6_e</code>	Y	<code>gsl_sf_debye_6(dbl_expr)</code>
<code>gsl_sf_dilog_e</code>	N	<code>gsl_sf_dilog</code>
<code>gsl_sf_complex_dilog_xy_e</code>	N	<code>gsl_sf_complex_dilog_xy_e</code>
<code>gsl_sf_complex_dilog_e</code>	N	<code>gsl_sf_complex_dilog</code>
<code>gsl_sf_complex_spence_xy_e</code>	N	<code>gsl_sf_complex_spence_xy_e</code>
<code>gsl_sf_multiply_e</code>	N	<code>gsl_sf_multiply</code>
<code>gsl_sf_multiply_err_e</code>	N	<code>gsl_sf_multiply_err</code>
<code>gsl_sf_ellint_Kcomp_e</code>	Y	<code>gsl_sf_ellint_Kcomp(dbl_expr)</code>
<code>gsl_sf_ellint_Ecomp_e</code>	Y	<code>gsl_sf_ellint_Ecomp(dbl_expr)</code>
<code>gsl_sf_ellint_Pcomp_e</code>	Y	<code>gsl_sf_ellint_Pcomp(dbl_expr,dbl_expr)</code>
<code>gsl_sf_ellint_Dcomp_e</code>	Y	<code>gsl_sf_ellint_Dcomp(dbl_expr)</code>
<code>gsl_sf_ellint_F_e</code>	Y	<code>gsl_sf_ellint_F(dbl_expr,dbl_expr)</code>
<code>gsl_sf_ellint_E_e</code>	Y	<code>gsl_sf_ellint_E(dbl_expr,dbl_expr)</code>

<code>gsl_sf_ellint_P_e</code>	Y	<code>gsl_sf_ellint_P(dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_ellint_D_e</code>	Y	<code>gsl_sf_ellint_D(dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_ellint_RC_e</code>	Y	<code>gsl_sf_ellint_RC(dbl_expr,dbl_expr)</code>
<code>gsl_sf_ellint_RD_e</code>	Y	<code>gsl_sf_ellint_RD(dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_ellint_RF_e</code>	Y	<code>gsl_sf_ellint_RF(dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_ellint_RJ_e</code>	Y	<code>gsl_sf_ellint_RJ(dbl_expr,dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_elljac_e</code>	N	<code>gsl_sf_elljac</code>
<code>gsl_sf_erfc_e</code>	Y	<code>gsl_sf_erfc(dbl_expr)</code>
<code>gsl_sf_log_erfc_e</code>	Y	<code>gsl_sf_log_erfc(dbl_expr)</code>
<code>gsl_sf_erf_e</code>	Y	<code>gsl_sf_erf(dbl_expr)</code>
<code>gsl_sf_erf_Z_e</code>	Y	<code>gsl_sf_erf_Z(dbl_expr)</code>
<code>gsl_sf_erf_Q_e</code>	Y	<code>gsl_sf_erf_Q(dbl_expr)</code>
<code>gsl_sf_hazard_e</code>	Y	<code>gsl_sf_hazard(dbl_expr)</code>
<code>gsl_sf_exp_e</code>	Y	<code>gsl_sf_exp(dbl_expr)</code>
<code>gsl_sf_exp_e10_e</code>	N	<code>gsl_sf_exp_e10</code>
<code>gsl_sf_exp_mult_e</code>	Y	<code>gsl_sf_exp_mult(dbl_expr,dbl_expr)</code>
<code>gsl_sf_exp_mult_e10_e</code>	N	<code>gsl_sf_exp_mult_e10</code>
<code>gsl_sf_expm1_e</code>	Y	<code>gsl_sf_expm1(dbl_expr)</code>
<code>gsl_sf_exprel_e</code>	Y	<code>gsl_sf_exprel(dbl_expr)</code>
<code>gsl_sf_exprel_2_e</code>	Y	<code>gsl_sf_exprel_2(dbl_expr)</code>
<code>gsl_sf_exprel_n_e</code>	Y	<code>gsl_sf_exprel_n(int_expr,dbl_expr)</code>
<code>gsl_sf_exp_err_e</code>	Y	<code>gsl_sf_exp_err(dbl_expr,dbl_expr)</code>
<code>gsl_sf_exp_err_e10_e</code>	N	<code>gsl_sf_exp_err_e10</code>
<code>gsl_sf_exp_mult_err_e</code>	N	<code>gsl_sf_exp_mult_err</code>
<code>gsl_sf_exp_mult_err_e10_e</code>	N	<code>gsl_sf_exp_mult_err_e10</code>
<code>gsl_sf_expint_E1_e</code>	Y	<code>gsl_sf_expint_E1(dbl_expr)</code>
<code>gsl_sf_expint_E2_e</code>	Y	<code>gsl_sf_expint_E2(dbl_expr)</code>
<code>gsl_sf_expint_En_e</code>	Y	<code>gsl_sf_expint_En(int_expr,dbl_expr)</code>
<code>gsl_sf_expint_E1_scaled_e</code>	Y	<code>gsl_sf_expint_E1_scaled(dbl_expr)</code>
<code>gsl_sf_expint_E2_scaled_e</code>	Y	<code>gsl_sf_expint_E2_scaled(dbl_expr)</code>
<code>gsl_sf_expint_En_scaled_e</code>	Y	<code>gsl_sf_expint_En_scaled(int_expr,dbl_expr)</code>
<code>gsl_sf_expint_Ei_e</code>	Y	<code>gsl_sf_expint_Ei(dbl_expr)</code>
<code>gsl_sf_expint_Ei_scaled_e</code>	Y	<code>gsl_sf_expint_Ei_scaled(dbl_expr)</code>
<code>gsl_sf_Shi_e</code>	Y	<code>gsl_sf_Shi(dbl_expr)</code>
<code>gsl_sf_Chi_e</code>	Y	<code>gsl_sf_Chi(dbl_expr)</code>
<code>gsl_sf_expint_3_e</code>	Y	<code>gsl_sf_expint_3(dbl_expr)</code>
<code>gsl_sf_Si_e</code>	Y	<code>gsl_sf_Si(dbl_expr)</code>
<code>gsl_sf_Ci_e</code>	Y	<code>gsl_sf_Ci(dbl_expr)</code>
<code>gsl_sf_atanint_e</code>	Y	<code>gsl_sf_atanint(dbl_expr)</code>
<code>gsl_sf_fermi_dirac_m1_e</code>	Y	<code>gsl_sf_fermi_dirac_m1(dbl_expr)</code>
<code>gsl_sf_fermi_dirac_0_e</code>	Y	<code>gsl_sf_fermi_dirac_0(dbl_expr)</code>
<code>gsl_sf_fermi_dirac_1_e</code>	Y	<code>gsl_sf_fermi_dirac_1(dbl_expr)</code>
<code>gsl_sf_fermi_dirac_2_e</code>	Y	<code>gsl_sf_fermi_dirac_2(dbl_expr)</code>
<code>gsl_sf_fermi_dirac_int_e</code>	Y	<code>gsl_sf_fermi_dirac_int(int_expr,dbl_expr)</code>
<code>gsl_sf_fermi_dirac_mhalf_e</code>	Y	<code>gsl_sf_fermi_dirac_mhalf(dbl_expr)</code>
<code>gsl_sf_fermi_dirac_half_e</code>	Y	<code>gsl_sf_fermi_dirac_half(dbl_expr)</code>
<code>gsl_sf_fermi_dirac_3half_e</code>	Y	<code>gsl_sf_fermi_dirac_3half(dbl_expr)</code>

<code>gsl_sf_fermi_dirac_inc_0_e</code>	Y	<code>gsl_sf_fermi_dirac_inc_0(dbl_expr,dbl_expr)</code>
<code>gsl_sf_lngamma_e</code>	Y	<code>gsl_sf_lngamma(dbl_expr)</code>
<code>gsl_sf_lngamma_sgn_e</code>	N	<code>gsl_sf_lngamma_sgn</code>
<code>gsl_sf_gamma_e</code>	Y	<code>gsl_sf_gamma(dbl_expr)</code>
<code>gsl_sf_gammastar_e</code>	Y	<code>gsl_sf_gammastar(dbl_expr)</code>
<code>gsl_sf_gammainv_e</code>	Y	<code>gsl_sf_gammainv(dbl_expr)</code>
<code>gsl_sf_lngamma_complex_e</code>	N	<code>gsl_sf_lngamma_complex</code>
<code>gsl_sf_taylorcoeff_e</code>	Y	<code>gsl_sf_taylorcoeff(int_expr,dbl_expr)</code>
<code>gsl_sf_fact_e</code>	Y	<code>gsl_sf_fact(uint_expr)</code>
<code>gsl_sf_doublefact_e</code>	Y	<code>gsl_sf_doublefact(uint_expr)</code>
<code>gsl_sf_lnfact_e</code>	Y	<code>gsl_sf_lnfact(uint_expr)</code>
<code>gsl_sf_lndoublefact_e</code>	Y	<code>gsl_sf_lndoublefact(uint_expr)</code>
<code>gsl_sf_lnchoose_e</code>	N	<code>gsl_sf_lnchoose</code>
<code>gsl_sf_choose_e</code>	N	<code>gsl_sf_choose</code>
<code>gsl_sf_lnpoch_e</code>	Y	<code>gsl_sf_lnpoch(dbl_expr,dbl_expr)</code>
<code>gsl_sf_lnpoch_sgn_e</code>	N	<code>gsl_sf_lnpoch_sgn</code>
<code>gsl_sf_poch_e</code>	Y	<code>gsl_sf_poch(dbl_expr,dbl_expr)</code>
<code>gsl_sf_pochrel_e</code>	Y	<code>gsl_sf_pochrel(dbl_expr,dbl_expr)</code>
<code>gsl_sf_gamma_inc_Q_e</code>	Y	<code>gsl_sf_gamma_inc_Q(dbl_expr,dbl_expr)</code>
<code>gsl_sf_gamma_inc_P_e</code>	Y	<code>gsl_sf_gamma_inc_P(dbl_expr,dbl_expr)</code>
<code>gsl_sf_gamma_inc_e</code>	Y	<code>gsl_sf_gamma_inc(dbl_expr,dbl_expr)</code>
<code>gsl_sf_lnbeta_e</code>	Y	<code>gsl_sf_lnbeta(dbl_expr,dbl_expr)</code>
<code>gsl_sf_lnbeta_sgn_e</code>	N	<code>gsl_sf_lnbeta_sgn</code>
<code>gsl_sf_beta_e</code>	Y	<code>gsl_sf_beta(dbl_expr,dbl_expr)</code>
<code>gsl_sf_beta_inc_e</code>	N	<code>gsl_sf_beta_inc</code>
<code>gsl_sf_gegenpoly_1_e</code>	Y	<code>gsl_sf_gegenpoly_1(dbl_expr,dbl_expr)</code>
<code>gsl_sf_gegenpoly_2_e</code>	Y	<code>gsl_sf_gegenpoly_2(dbl_expr,dbl_expr)</code>
<code>gsl_sf_gegenpoly_3_e</code>	Y	<code>gsl_sf_gegenpoly_3(dbl_expr,dbl_expr)</code>
<code>gsl_sf_gegenpoly_n_e</code>	N	<code>gsl_sf_gegenpoly_n</code>
<code>gsl_sf_gegenpoly_array</code>	Y	<code>gsl_sf_gegenpoly_array</code>
<code>gsl_sf_hyperg_0F1_e</code>	Y	<code>gsl_sf_hyperg_0F1(dbl_expr,dbl_expr)</code>
<code>gsl_sf_hyperg_1F1_int_e</code>	Y	<code>gsl_sf_hyperg_1F1_int(int_expr,int_expr,dbl_expr)</code>
<code>gsl_sf_hyperg_1F1_e</code>	Y	<code>gsl_sf_hyperg_1F1(dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_hyperg_U_int_e</code>	Y	<code>gsl_sf_hyperg_U_int(int_expr,int_expr,dbl_expr)</code>
<code>gsl_sf_hyperg_U_int_e10_e</code>	N	<code>gsl_sf_hyperg_U_int_e10</code>
<code>gsl_sf_hyperg_U_e</code>	Y	<code>gsl_sf_hyperg_U(dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_hyperg_U_e10_e</code>	N	<code>gsl_sf_hyperg_U_e10</code>
<code>gsl_sf_hyperg_2F1_e</code>	Y	<code>gsl_sf_hyperg_2F1(dbl_expr,dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_hyperg_2F1_conj_e</code>	Y	<code>gsl_sf_hyperg_2F1_conj(dbl_expr,dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_hyperg_2F1_renorm_e</code>	Y	<code>gsl_sf_hyperg_2F1_renorm(dbl_expr,dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_hyperg_2F1_conj_renorm_e</code>	Y	<code>gsl_sf_hyperg_2F1_conj_renorm(dbl_expr,dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_hyperg_2F0_e</code>	Y	<code>gsl_sf_hyperg_2F0(dbl_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_laguerre_1_e</code>	Y	<code>gsl_sf_laguerre_1(dbl_expr,dbl_expr)</code>
<code>gsl_sf_laguerre_2_e</code>	Y	<code>gsl_sf_laguerre_2(dbl_expr,dbl_expr)</code>
<code>gsl_sf_laguerre_3_e</code>	Y	<code>gsl_sf_laguerre_3(dbl_expr,dbl_expr)</code>
<code>gsl_sf_laguerre_n_e</code>	Y	<code>gsl_sf_laguerre_n(int_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_lambert_W0_e</code>	Y	<code>gsl_sf_lambert_W0(dbl_expr)</code>

<code>gsl_sf_lambert_Wm1_e</code>	Y	<code>gsl_sf_lambert_Wm1(dbl_expr)</code>
<code>gsl_sf_legendre_Pl_e</code>	Y	<code>gsl_sf_legendre_Pl(int_expr,dbl_expr)</code>
<code>gsl_sf_legendre_Pl_array</code>	Y	<code>status=gsl_sf_legendre_Pl_array(int,double,&amp;var_out)</code>
<code>gsl_sf_legendre_Pl_deriv_array</code>	N	<code>gsl_sf_legendre_Pl_deriv_array</code>
<code>gsl_sf_legendre_P1_e</code>	Y	<code>gsl_sf_legendre_P1(dbl_expr)</code>
<code>gsl_sf_legendre_P2_e</code>	Y	<code>gsl_sf_legendre_P2(dbl_expr)</code>
<code>gsl_sf_legendre_P3_e</code>	Y	<code>gsl_sf_legendre_P3(dbl_expr)</code>
<code>gsl_sf_legendre_Q0_e</code>	Y	<code>gsl_sf_legendre_Q0(dbl_expr)</code>
<code>gsl_sf_legendre_Q1_e</code>	Y	<code>gsl_sf_legendre_Q1(dbl_expr)</code>
<code>gsl_sf_legendre_Ql_e</code>	Y	<code>gsl_sf_legendre_Ql(int_expr,dbl_expr)</code>
<code>gsl_sf_legendre_Plm_e</code>	Y	<code>gsl_sf_legendre_Plm(int_expr,int_expr,dbl_expr)</code>
<code>gsl_sf_legendre_Plm_array</code>	Y	<code>status=gsl_sf_legendre_Plm_array(int,int,double,&amp;var_out)</code>
<code>gsl_sf_legendre_Plm_deriv_array</code>	N	<code>gsl_sf_legendre_Plm_deriv_array</code>
<code>gsl_sf_legendre_sphPlm_e</code>	Y	<code>gsl_sf_legendre_sphPlm(int_expr,int_expr,dbl_expr)</code>
<code>gsl_sf_legendre_sphPlm_array</code>	Y	<code>status=gsl_sf_legendre_sphPlm_array(int,int,double,&amp;var_out)</code>
<code>gsl_sf_legendre_sphPlm_deriv_array</code>	N	<code>gsl_sf_legendre_sphPlm_deriv_array</code>
<code>gsl_sf_legendre_array_size</code>	N	<code>gsl_sf_legendre_array_size</code>
<code>gsl_sf_conicalP_half_e</code>	Y	<code>gsl_sf_conicalP_half(dbl_expr,dbl_expr)</code>
<code>gsl_sf_conicalP_mhalf_e</code>	Y	<code>gsl_sf_conicalP_mhalf(dbl_expr,dbl_expr)</code>
<code>gsl_sf_conicalP_0_e</code>	Y	<code>gsl_sf_conicalP_0(dbl_expr,dbl_expr)</code>
<code>gsl_sf_conicalP_1_e</code>	Y	<code>gsl_sf_conicalP_1(dbl_expr,dbl_expr)</code>
<code>gsl_sf_conicalP_sph_reg_e</code>	Y	<code>gsl_sf_conicalP_sph_reg(int_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_conicalP_cyl_reg_e</code>	Y	<code>gsl_sf_conicalP_cyl_reg(int_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_legendre_H3d_0_e</code>	Y	<code>gsl_sf_legendre_H3d_0(dbl_expr,dbl_expr)</code>
<code>gsl_sf_legendre_H3d_1_e</code>	Y	<code>gsl_sf_legendre_H3d_1(dbl_expr,dbl_expr)</code>
<code>gsl_sf_legendre_H3d_e</code>	Y	<code>gsl_sf_legendre_H3d(int_expr,dbl_expr,dbl_expr)</code>
<code>gsl_sf_legendre_H3d_array</code>	N	<code>gsl_sf_legendre_H3d_array</code>
<code>gsl_sf_legendre_array_size</code>	N	<code>gsl_sf_legendre_array_size</code>
<code>gsl_sf_log_e</code>	Y	<code>gsl_sf_log(dbl_expr)</code>
<code>gsl_sf_log_abs_e</code>	Y	<code>gsl_sf_log_abs(dbl_expr)</code>
<code>gsl_sf_complex_log_e</code>	N	<code>gsl_sf_complex_log</code>
<code>gsl_sf_log_1plusx_e</code>	Y	<code>gsl_sf_log_1plusx(dbl_expr)</code>
<code>gsl_sf_log_1plusx_mx_e</code>	Y	<code>gsl_sf_log_1plusx_mx(dbl_expr)</code>
<code>gsl_sf_mathieu_a_array</code>	N	<code>gsl_sf_mathieu_a_array</code>
<code>gsl_sf_mathieu_b_array</code>	N	<code>gsl_sf_mathieu_b_array</code>
<code>gsl_sf_mathieu_a</code>	N	<code>gsl_sf_mathieu_a</code>
<code>gsl_sf_mathieu_b</code>	N	<code>gsl_sf_mathieu_b</code>
<code>gsl_sf_mathieu_a_coeff</code>	N	<code>gsl_sf_mathieu_a_coeff</code>
<code>gsl_sf_mathieu_b_coeff</code>	N	<code>gsl_sf_mathieu_b_coeff</code>
<code>gsl_sf_mathieu_ce</code>	N	<code>gsl_sf_mathieu_ce</code>
<code>gsl_sf_mathieu_se</code>	N	<code>gsl_sf_mathieu_se</code>
<code>gsl_sf_mathieu_ce_array</code>	N	<code>gsl_sf_mathieu_ce_array</code>
<code>gsl_sf_mathieu_se_array</code>	N	<code>gsl_sf_mathieu_se_array</code>
<code>gsl_sf_mathieu_Mc</code>	N	<code>gsl_sf_mathieu_Mc</code>
<code>gsl_sf_mathieu_Ms</code>	N	<code>gsl_sf_mathieu_Ms</code>
<code>gsl_sf_mathieu_Mc_array</code>	N	<code>gsl_sf_mathieu_Mc_array</code>
<code>gsl_sf_mathieu_Ms_array</code>	N	<code>gsl_sf_mathieu_Ms_array</code>

<code>gsl_sf_pow_int_e</code>	N	<code>gsl_sf_pow_int</code>
<code>gsl_sf_psi_int_e</code>	Y	<code>gsl_sf_psi_int(int_expr)</code>
<code>gsl_sf_psi_e</code>	Y	<code>gsl_sf_psi(dbl_expr)</code>
<code>gsl_sf_psi_1piy_e</code>	Y	<code>gsl_sf_psi_1piy(dbl_expr)</code>
<code>gsl_sf_complex_psi_e</code>	N	<code>gsl_sf_complex_psi</code>
<code>gsl_sf_psi_1_int_e</code>	Y	<code>gsl_sf_psi_1_int(int_expr)</code>
<code>gsl_sf_psi_1_e</code>	Y	<code>gsl_sf_psi_1(dbl_expr)</code>
<code>gsl_sf_psi_n_e</code>	Y	<code>gsl_sf_psi_n(int_expr,dbl_expr)</code>
<code>gsl_sf_synchrotron_1_e</code>	Y	<code>gsl_sf_synchrotron_1(dbl_expr)</code>
<code>gsl_sf_synchrotron_2_e</code>	Y	<code>gsl_sf_synchrotron_2(dbl_expr)</code>
<code>gsl_sf_transport_2_e</code>	Y	<code>gsl_sf_transport_2(dbl_expr)</code>
<code>gsl_sf_transport_3_e</code>	Y	<code>gsl_sf_transport_3(dbl_expr)</code>
<code>gsl_sf_transport_4_e</code>	Y	<code>gsl_sf_transport_4(dbl_expr)</code>
<code>gsl_sf_transport_5_e</code>	Y	<code>gsl_sf_transport_5(dbl_expr)</code>
<code>gsl_sf_sin_e</code>	N	<code>gsl_sf_sin</code>
<code>gsl_sf_cos_e</code>	N	<code>gsl_sf_cos</code>
<code>gsl_sf_hypot_e</code>	N	<code>gsl_sf_hypot</code>
<code>gsl_sf_complex_sin_e</code>	N	<code>gsl_sf_complex_sin</code>
<code>gsl_sf_complex_cos_e</code>	N	<code>gsl_sf_complex_cos</code>
<code>gsl_sf_complex_logsin_e</code>	N	<code>gsl_sf_complex_logsin</code>
<code>gsl_sf_sinc_e</code>	N	<code>gsl_sf_sinc</code>
<code>gsl_sf_lnsinh_e</code>	N	<code>gsl_sf_lnsinh</code>
<code>gsl_sf_lncosh_e</code>	N	<code>gsl_sf_lncosh</code>
<code>gsl_sf_polar_to_rect</code>	N	<code>gsl_sf_polar_to_rect</code>
<code>gsl_sf_rect_to_polar</code>	N	<code>gsl_sf_rect_to_polar</code>
<code>gsl_sf_sin_err_e</code>	N	<code>gsl_sf_sin_err</code>
<code>gsl_sf_cos_err_e</code>	N	<code>gsl_sf_cos_err</code>
<code>gsl_sf_angle_restrict_symm_e</code>	N	<code>gsl_sf_angle_restrict_symm</code>
<code>gsl_sf_angle_restrict_pos_e</code>	N	<code>gsl_sf_angle_restrict_pos</code>
<code>gsl_sf_angle_restrict_symm_err_e</code>	N	<code>gsl_sf_angle_restrict_symm_err</code>
<code>gsl_sf_angle_restrict_pos_err_e</code>	N	<code>gsl_sf_angle_restrict_pos_err</code>
<code>gsl_sf_zeta_int_e</code>	Y	<code>gsl_sf_zeta_int(int_expr)</code>
<code>gsl_sf_zeta_e</code>	Y	<code>gsl_sf_zeta(dbl_expr)</code>
<code>gsl_sf_zetam1_e</code>	Y	<code>gsl_sf_zetam1(dbl_expr)</code>
<code>gsl_sf_zetam1_int_e</code>	Y	<code>gsl_sf_zetam1_int(int_expr)</code>
<code>gsl_sf_hzeta_e</code>	Y	<code>gsl_sf_hzeta(dbl_expr,dbl_expr)</code>
<code>gsl_sf_eta_int_e</code>	Y	<code>gsl_sf_eta_int(int_expr)</code>
<code>gsl_sf_eta_e</code>	Y	<code>gsl_sf_eta(dbl_expr)</code>

#### 4.1.20 GSL interpolation

As of version 3.9.9 (released July, 2009), NCO has wrappers to the GSL interpolation functions.

Given a set of data points  $(x_1, y_1) \dots (x_n, y_n)$  the GSL functions computes a continuous interpolating function  $Y(x)$  such that  $Y(x_i) = y_i$ . The interpolation is piecewise smooth, and its behavior at the end-points is determined by the type of interpolation used. For more information consult the GSL manual.

Interpolation with `ncap2` is a two stage process. In the first stage, a ram variable is created from the chosen interpolating function and the data set. This ram variable holds in memory a GSL interpolation object. In the second stage, points along the interpolating function are calculated. If you have a very large data set or are interpolating many sets then consider deleting the ram variable when it is redundant. Use the command `ram_delete(var_nm)`.

A simple example

```
x_in[$lon]={1.0,2.0,3.0,4.0};
y_in[$lon]={1.1,1.2,1.5,1.8};

// Ram variable is declared and defined here
gsl_interp_cspline(&ram_sp,x_in,y_in);

x_out[$lon_grd]={1.1,2.0,3.0,3.1,3.99};

y_out=gsl_spline_eval(ram_sp,x_out);
y2=gsl_spline_eval(ram_sp,1.3);
y3=gsl_spline_eval(ram_sp,0.0);
ram_delete(ram_sp);

print(y_out);    // 1.10472, 1.2, 1.4, 1.42658, 1.69680002
print(y2);       // 1.12454
print(y3);       // '_'
```

Note in the above example `y3` is set to 'missing value' because 0.0 isn't within the input X range.

### **GSL Interpolation Types**

All the interpolation functions have been implemented. These are:

```
gsl_interp_linear()
gsl_interp_polynomial()
gsl_interp_cspline()
gsl_interp_cspline_periodic()
gsl_interp_akima()
gsl_interp_akima_periodic()
```

### **Evaluation of Interpolating Types**

#### **Implemented**

```
gsl_spline_eval()
```

#### **Unimplemented**

```
gsl_spline_deriv()
```

```
gsl_spline_deriv2()
```

```
gsl_spline_integ()
```



#### 4.1.21 GSL least-squares fitting

Least Squares fitting is a method of calculating a straight line through a set of experimental data points in the XY plane. The data maybe weighted or unweighted. For more information please refer to the GSL manual.

These GSL functions fall into three categories:

- A) Fitting data to  $Y=c_0+c_1*X$
- B) Fitting data (through the origin)  $Y=c_1*X$
- C) Multi-parameter fitting (not yet implemented)

##### Section A

**status=gsl\_fit\_linear**

(data\_x, stride\_x, data\_y, stride\_y, n, &c0, &c1, &cov00, &cov01, &cov11, &sumsq)

**Input variables:** data\_x, stride\_x, data\_y, stride\_y, n

From the above variables an X and Y vector both of length 'n' are derived. If data\_x or data\_y is less than type double then it is converted to type double. It is up to you to do bounds checking on the input data. For example if stride\_x=3 and n=8 then the size of data\_x must be at least 24

**Output variables:** c0, c1, cov00, cov01, cov11, sumsq

The '&' prefix indicates that these are call-by-reference variables. If any of the output variables don't exist prior to the call then they are created on the fly as scalar variables of type double. If they already exist then their existing value is overwritten. If the function call is successful then **status=0**.

**status=gsl\_fit\_wlinear**(data\_x, stride\_x, data\_w, stride\_w, data\_y, stride\_y, n, &c0, &c1, &cov00, &cov01, &cov11, &chisq)

Similar to the above call except it creates an additional weighting vector from the variables data\_w, stride\_w, n

**data\_y\_out=gsl\_fit\_linear\_est**(data\_x, c0, c1, cov00, cov01, cov11)

This function calculates y values along the line  $Y=c_0+c_1*X$

##### Section B

**status=gsl\_fit\_mul**(data\_x, stride\_x, data\_y, stride\_y, n, &c1, &cov11, &sumsq)

**Input variables:** data\_x, stride\_x, data\_y, stride\_y, n

From the above variables an X and Y vector both of length 'n' are derived. If data\_x or data\_y is less than type double then it is converted to type double.

**Output variables:** c1, cov11, sumsq



```
status= gsl_fit_wmul(data_x, stride_x, data_w, stride_w, data_y, stride_
y, n, &c1, &cov11, &sumsq)
```

Similar to the above call except it creates an additional weighting vector from the variables data\_w, stride\_w, n

```
data_y_out=gsl_fit_mul_est(data_x, c0, c1, cov11)
```

This function calculates y values along the line  $Y=c1*X$

The below example shows **gsl\_fit\_linear()** in action

```
defdim("d1",10);
xin[d1]={1,2,3,4,5,6,7,8,9,10.0};
yin[d1]={3.1,6.2,9.1,12.2,15.1,18.2,21.3,24.0,27.0,30.0};
gsl_fit_linear(xin,1,yin,1,$d1.size,&c0,&c1,&cov00,&cov01,&cov11,&sumsq);
print(c0); // 0.2
print(c1); // 2.98545454545

defdim("e1",4);
xout[e1]={1.0,3.0,4.0,11};
yout[e1]=0.0;

yout=gsl_fit_linear_est(xout, c0,c1, cov00,cov01, cov11, sumsq);

print(yout); // 3.18545454545 ,9.15636363636, ,12.1418181818 ,33.04
```

### 4.1.22 GSL statistics

Wrappers for most of the GSL Statistical functions have been implemented. The GSL function names include a type specifier (except for type double functions). To obtain the equivalent NCO name simply remove the type specifier; then depending on the data type the appropriate GSL function is called. The weighed statistical functions e.g **gsl\_stats\_wvariance()** are only defined in GSL for floating point types; so your data must of type float or double otherwise ncap2 will emit an error message. To view the implemented functions use the shell command **ncap2 -f|grep \_stats**

GSL Functions

```
short gsl_stats_max (short data[], size_t stride, size_t n);
double gsl_stats_int_mean (int data[], size_t stride, size_t n);
double gsl_stats_short_sd_with_fixed_mean (short data[], size_t stride, size_t n, double
double gsl_stats_wmean (double w[], size_t wstride, double data[], size_t stride, size
double gsl_stats_quantile_from_sorted_data (double sorted_data[], size_t stride, size_
```

Equivalent `ncap2` wrapper functions

```
short gsl_stats_max (var_data, data_stride, n);
double gsl_stats_mean (var_data, data_stride, n);
double gsl_stats_sd_with_fixed_mean (var_data, data_stride, n, var_mean);
double gsl_stats_wmean (var_weight, weight_stride, var_data, data_stride, n, var_mean);
double gsl_stats_quantile_from_sorted_data (var_sorted_data, data_stride, n, var_f) ;
```

GSL has no notion of missing values or dimensionality beyond one. If your data has missing values which you want ignored in the calculations then use the `ncap2` built in aggregate functions( [Section 4.1.11 \[Methods and functions\], page 82](#) ). The GSL functions operate on a vector of values created from the `var_data/stride/n` arguments. The `ncap` wrappers check that there is no bounding error with regard to the size of the data and the final value in the vector.

Some examples

```
a1[time]={1,2,3,4,5,6,7,8,9,10 };

a1_avg=gsl_stats_mean(a1,1,10);
print(a1_avg); // 5.5

a1_var=gsl_stats_variance(a1,4,3);
print(a1_var); // 16.0

// bounding error, vector attempts to access element a1(10)
a1_sd=gsl_stats_sd(a1,5,3);
```

For functions with the signature **func\_nm(var\_data,data\_stride,n)**, one may omit the second or third arguments. The default value for *stride* is 1. The default value for *n* is `1+(data.size()-1)/stride`.

```
// Following statements are equivalent
n2=gsl_stats_max(a1,1,10)
n2=gsl_stats_max(a1,1);
n2=gsl_stats_max(a1);

// Following statements are equivalent
n3=gsl_stats_median_from_sorted_data(a1,2,5);
n3=gsl_stats_median_from_sorted_data(a1,2);

// Following statements are NOT equivalent
n4=gsl_stats_kurtosis(a1,3,2);
n4=gsl_stats_kurtosis(a1,3); //default n=4
```

The following example illustrates some of the weighted functions. The data are randomly generated. In this case the value of the weight for each datum is either 0.0 or 1.0

```
defdim("r1",2000);
data[r1]=1.0;
```

```

// Fill with random numbers [0.0,10.0)
data=10.0*gsl_rng_uniform(data);

// Create a weighting variable
weight=(data>4.0);

wmean=gsl_stats_wmean(weight,1,data,1,$r1.size);
print(wmean);

wsd=gsl_stats_wsd(weight,1,data,1,$r1.size);
print(wsd);

// number of values in data that are greater than 4
weight_size=weight.total();
print(weight_size);

// print min/max of data
dmin=data.gsl_stats_min();
dmax=data.gsl_stats_max();
print(dmin);print(dmax);

```

### 4.1.23 GSL random number generation

The GSL library has a large number of random number generators. In addition there are a large set of functions for turning uniform random numbers into discrete or continuous probability distributions. The random number generator algorithms vary in terms of quality numbers output, speed of execution and maximum number output. For more information see the GSL documentation. The algorithm and seed are set via environment variables, these are picked up by the `ncap2` code.

#### Setup

The number algorithm is set by the environment variable `GSL_RNG_TYPE`. If this variable isn't set then the default rng algorithm is `gsl_rng_19937`. The seed is set with the environment variable `GSL_RNG_SEED`. The following wrapper functions in `ncap2` provide information about the chosen algorithm.

```

gsl_rng_min()
    the minimum value returned by the rng algorithm.

gsl_rng_max()
    the maximum value returned by the rng algorithm.

```

#### Uniformly Distributed Random Numbers

```

gsl_rng_get(var_in)
    This function returns var_in with integers from the chosen rng algorithm. The
    min and max values depend upon the chosen rng algorithm.

```

`gsl_rng_uniform_int(var_in)`  
 This function returns `var_in` with random integers from 0 to `n-1`. The value `n` must be less than or equal to the maximum value of the chosen rng algorithm.

`gsl_rng_uniform(var_in)`  
 This function returns `var_in` with double precision numbers in the range `[0.0,1)`. The range includes 0.0 and excludes 1.0.

`gsl_rng_uniform_pos(var_in)`  
 This function returns `var_in` with double precision numbers in the range `(0.0,1)`, excluding both 0.0 and 1.0.

Below are examples of `gsl_rng_get()` and `gsl_rng_uniform_int()` in action.

```
export GSL_RNG_TYPE=ranlux
export GSL_RNG_SEED=10
ncap2 -v -O -s 'a1[time]=0;a2=gsl_rng_get(a1);' in.nc foo.nc
// 10 random numbers from the range 0 - 16777215
// a2=9056646, 12776696, 1011656, 13354708, 5139066, 1388751, 11163902, 7730127, 15531

ncap2 -v -O -s 'a1[time]=21;a2=gsl_rng_uniform_int(a1).sort();' in.nc foo.nc
// 10 random numbers from the range 0 - 20
a2 = 1, 1, 6, 9, 11, 13, 13, 15, 16, 19 ;
```

The following example produces an `ncap2` runtime error. This is because the chose rng algorithm has a maximum value greater than `NC_MAX_INT=2147483647` ; the wrapper functions to `gsl_rng_get()` and `gsl_rng_uniform_int()` return variable of type `NC_INT`. Please be aware of this when using random number distribution functions from the GSL library which return `unsigned int`. Examples of these are `gsl_ran_geometric()` and `gsl_ran_pascal()`.

```
export GSL_RNG_TYPE=mt19937
ncap2 -v -O -s 'a1[time]=0;a2=gsl_rng_get(a1);' in.nc foo.nc
```

To find the maximum value of the chosen rng algorithm use the following code snippet.

```
ncap2 -v -O -s 'rng_max=gsl_rng_max();print(rng_max)' in.nc foo.nc
```

### Random Number Distributions

The GSL library has a rich set of random number distribution functions. The library also provides cumulative distribution functions and inverse cumulative distribution functions sometimes referred to a quantile functions. To see whats available on your build use the shell command `ncap2 -f|grep -e _ran -e _cdf`.

The following examples all return variables of type `NC_INT`

```
defdim("out",15);
a1[$out]=0.5;
a2=gsl_ran_binomial(a1,30).sort();
//a2 = 10, 11, 12, 12, 13, 14, 14, 15, 15, 16, 16, 16, 16, 17, 22 ;
a3=gsl_ran_geometric(a2).sort();
```

```
//a2 = 1, 1, 1, 1, 1, 1, 1, 1, 2, 2, 2, 2, 3, 4, 5 ;
a4=gsl_ran_pascal(a2,50);
//a5 = 37, 40, 40, 42, 43, 45, 46, 49, 52, 58, 60, 62, 62, 65, 67 ;
```

The following all return variables of type NC\_DOUBLE;

```
defdim("b1",1000);
b1[$b1]=0.8;
b2=gsl_ran_exponential(b1);
b2_avg=b2.avg();
print(b2_avg);
// b2_avg = 0.756047976787

b3=gsl_ran_gaussian(b1);
b3_avg=b3.avg();
b3_rms=b3.rms();
print(b3_avg);
// b3_avg = -0.00903446534258;
print(b3_rms);
// b3_rms = 0.81162979889;

b4[$b1]=10.0;
b5[$b1]=20.0;
b6=gsl_ran_flat(b4,b5);
b6_avg=b6.avg();
print(b6_avg);
// b6_avg=15.0588129413
```

#### 4.1.24 Examples ncap2

See the ‘ncap.in’ and ‘ncap2.in’ scripts released with NCO for more complete demonstrations of ncap2 functionality (script available on-line at <http://nco.sf.net/ncap2.in>).

Define new attribute *new* for existing variable *one* as twice the existing attribute *double\_att* of variable *att\_var*:

```
ncap2 -s 'one@new=2*att_var@double_att' in.nc out.nc
```

Average variables of mixed types (result is of type double):

```
ncap2 -s 'average=(var_float+var_double+var_int)/3' in.nc out.nc
```

Multiple commands may be given to ncap2 in three ways. First, the commands may be placed in a script which is executed, e.g., ‘tst.nco’. Second, the commands may be individually specified with multiple ‘-s’ arguments to the same ncap2 invocation. Third, the commands may be chained together into a single ‘-s’ argument to ncap2. Assuming the file ‘tst.nco’ contains the commands `a=3;b=4;c=sqrt(a^2+b^2);`, then the following ncap2 invocations produce identical results:

```
ncap2 -v -S tst.nco in.nc out.nc
ncap2 -v -s 'a=3' -s 'b=4' -s 'c=sqrt(a^2+b^2)' in.nc out.nc
ncap2 -v -s 'a=3;b=4;c=sqrt(a^2+b^2)' in.nc out.nc
```

The second and third examples show that `ncap2` does not require that a trailing semi-colon ';' be placed at the end of a '-s' argument, although a trailing semi-colon ';' is always allowed. However, semi-colons are required to separate individual assignment statements chained together as a single '-s' argument.

`ncap2` may be used to "grow" dimensions, i.e., to increase dimension sizes without altering existing data. Say 'in.nc' has `ORO(lat,lon)` and the user wishes a new file with `new_ORO(new_lat,new_lon)` that contains zeros in the undefined portions of the new grid.

```
defdim("new_lat",$lat.size+1); // Define new dimension sizes
defdim("new_lon",$lon.size+1);
new_ORO[$new_lat,$new_lon]=0.0f; // Initialize to zero
new_ORO(0:$lat.size-1,0:$lon.size-1)=ORO; // Fill valid data
```

The commands to define new coordinate variables `new_lat` and `new_lon` in the output file follow a similar pattern. One might store these commands in a script 'grow.nco' and then execute the script with

```
ncap2 -v -S grow.nco in.nc out.nc
```

Imagine you wish to create a binary flag based on the value of an array. The flag should have value 1.0 where the array exceeds 1.0, and value 0.0 elsewhere. This example creates the binary flag `ORO_flg` in 'out.nc' from the continuous array named `ORO` in 'in.nc'.

```
ncap2 -s 'ORO_flg=(ORO > 1.0)' in.nc out.nc
```

Suppose your task is to change all values of `ORO` which equal 2.0 to the new value 3.0:

```
ncap2 -s 'ORO_msk=(ORO==2.0);ORO=ORO_msk*3.0+!ORO_msk*ORO' in.nc out.nc
```

This creates and uses `ORO_msk` to mask the subsequent arithmetic operation. Values of `ORO` are only changed where `ORO_msk` is true, i.e., where `ORO` equals 2.0

Using the `where` statement the above code simplifies to :

```
ncap2 -s 'where(ORO==2.0) ORO=3.0;' in.nc foo.nc
```

This example uses `ncap2` to compute the covariance of two variables. Let the variables  $u$  and  $v$  be the horizontal wind components. The *covariance* of  $u$  and  $v$  is defined as the time mean product of the deviations of  $u$  and  $v$  from their respective time means. Symbolically, the covariance  $[u'v'] = [uv] - [u][v]$  where  $[x]$  denotes the time-average of  $x$ ,  $[x] \equiv \frac{1}{\tau} \int_{t=0}^{t=\tau} x(t) dt$  and  $x'$  denotes the deviation from the time-mean. The covariance tells us how much of the correlation of two signals arises from the signal fluctuations versus the mean signals. Sometimes this is called the *eddy covariance*. We will store the covariance in the variable `uprmvprm`.

```
ncwa -O -a time -v u,v in.nc foo.nc # Compute time mean of u,v
ncrename -O -v u,uavg -v v,vavg foo.nc # Rename to avoid conflict
ncks -A -v uavg,vavg foo.nc in.nc # Place time means with originals
ncap2 -O -s 'uprmvprm=u*v-uavg*vavg' in.nc in.nc # Covariance
ncra -O -v uprmvprm in.nc foo.nc # Time-mean covariance
```

The mathematically inclined will note that the same covariance would be obtained by replacing the step involving `ncap2` with

```
ncap2 -O -s 'uprmvprm=(u-uavg)*(v-vavg)' foo.nc foo.nc # Covariance
```

As of NCO version 3.1.8 (December, 2006), `ncap2` can compute averages, and thus covariances, by itself:

```
ncap2 -s 'uavg=u.avg($time);vavg=v.avg($time);uprmvprm=u*v-uavg*vavg' \
-s 'uprmvrpmavg=uprmvprm.avg($time)' in.nc foo.nc
```

We have not seen a simpler method to script and execute powerful arithmetic than `ncap2`.

`ncap2` utilizes many meta-characters (e.g., '\$', '?', ';', '()', '[]') that can confuse the command-line shell if not quoted properly. The issues are the same as those which arise in utilizing extended regular expressions to subset variables (see [Section 3.11 \[Subsetting Variables\]](#), page 36). The example above will fail with no quotes and with double quotes. This is because shell globbing tries to *interpolate* the value of `$time` from the shell environment unless it is quoted:

```
ncap2 -s 'uavg=u.avg($time)' in.nc foo.nc # Correct (recommended)
ncap2 -s uavg=u.avg('$time') in.nc foo.nc # Correct (and dangerous)
ncap2 -s uavg=u.avg($time) in.nc foo.nc # Fails ($time = '')
ncap2 -s "uavg=u.avg($time)" in.nc foo.nc # Fails ($time = '')
```

Without the single quotes, the shell replaces `$time` with an empty string. The command `ncap2` receives from the shell is `uavg=u.avg()`. This causes `ncap2` to average over all dimensions rather than just the *time* dimension, and unintended consequence.

We recommend using single quotes to protect `ncap2` command-line scripts from the shell, even when such protection is not strictly necessary. Expert users may violate this rule to exploit the ability to use shell variables in `ncap2` command-line scripts (see [Chapter 6 \[CCSM Example\]](#), page 165). In such cases it may be necessary to use the shell backslash character '`\`' to protect the `ncap2` meta-character.

Whether a degenerate record dimension is desirable or undesirable depends on the application. Often a degenerate *time* dimension is useful, e.g., for concatenating, but it may cause problems with arithmetic. Such is the case in the above example, where the first step employs `ncwa` rather than `ncra` for the time-averaging. Of course the numerical results are the same with both operators. The difference is that, unless '`-b`' is specified, `ncwa` writes no *time* dimension to the output file, while `ncra` defaults to keeping *time* as a degenerate (size 1) dimension. Appending `u` and `v` to the output file would cause `ncks` to try to expand the degenerate time axis of `uavg` and `vavg` to the size of the non-degenerate *time* dimension in the input file. Thus the append (`ncks -A`) command would be undefined (and should fail) in this case. Equally important is the '`-C`' argument (see [Section 3.12 \[Subsetting Coordinate Variables\]](#), page 38) to `ncwa` to prevent any scalar *time* variable from being written to the output file. Knowing when to use `ncwa -a time` rather than the default `ncra` for time-averaging takes, well, time.

#### 4.1.25 Intrinsic mathematical methods

`ncap2` supports the standard mathematical functions supplied with most operating systems. Standard calculator notation is used for addition `+`, subtraction `-`, multiplication `*`, division

/, exponentiation ^, and modulus %. The available elementary mathematical functions are:

<code>abs(x)</code>	<i>Absolute value</i> Absolute value of $x$ , $ x $ . Example: <code>abs(-1) = 1</code>
<code>acos(x)</code>	<i>Arc-cosine</i> Arc-cosine of $x$ where $x$ is specified in radians. Example: <code>acos(1.0) = 0.0</code>
<code>acosh(x)</code>	<i>Hyperbolic arc-cosine</i> Hyperbolic arc-cosine of $x$ where $x$ is specified in radians. Example: <code>acosh(1.0) = 0.0</code>
<code>asin(x)</code>	<i>Arc-sine</i> Arc-sine of $x$ where $x$ is specified in radians. Example: <code>asin(1.0) = 1.57079632679489661922</code>
<code>asinh(x)</code>	<i>Hyperbolic arc-sine</i> Hyperbolic arc-sine of $x$ where $x$ is specified in radians. Example: <code>asinh(1.0) = 0.88137358702</code>
<code>atan(x)</code>	<i>Arc-tangent</i> Arc-tangent of $x$ where $x$ is specified in radians between $-\pi/2$ and $\pi/2$ . Example: <code>atan(1.0) = 0.78539816339744830961</code>
<code>atan2(y,x)</code>	<i>Arc-tangent2</i> Arc-tangent of $y/x$
<code>atanh(x)</code>	<i>Hyperbolic arc-tangent</i> Hyperbolic arc-tangent of $x$ where $x$ is specified in radians between $-\pi/2$ and $\pi/2$ . Example: <code>atanh(3.14159265358979323844) = 1.0</code>
<code>ceil(x)</code>	<i>Ceil</i> Ceiling of $x$ . Smallest integral value not less than argument. Example: <code>ceil(0.1) = 1.0</code>
<code>cos(x)</code>	<i>Cosine</i> Cosine of $x$ where $x$ is specified in radians. Example: <code>cos(0.0) = 1.0</code>
<code>cosh(x)</code>	<i>Hyperbolic cosine</i> Hyperbolic cosine of $x$ where $x$ is specified in radians. Example: <code>cosh(0.0) = 1.0</code>
<code>erf(x)</code>	<i>Error function</i> Error function of $x$ where $x$ is specified between $-1$ and $1$ . Example: <code>erf(1.0) = 0.842701</code>
<code>erfc(x)</code>	<i>Complementary error function</i> Complementary error function of $x$ where $x$ is specified between $-1$ and $1$ . Example: <code>erfc(1.0) = 0.15729920705</code>
<code>exp(x)</code>	<i>Exponential</i> Exponential of $x$ , $e^x$ . Example: <code>exp(1.0) = 2.71828182845904523536</code>
<code>floor(x)</code>	<i>Floor</i> Floor of $x$ . Largest integral value not greater than argument. Example: <code>floor(1.9) = 1</code>
<code>gamma(x)</code>	<i>Gamma function</i> Gamma function of $x$ , $\Gamma(x)$ . The well-known and loved continuous factorial function. Example: <code>gamma(0.5) = <math>\sqrt{\pi}</math></code>
<code>gamma_inc_P(x)</code>	<i>Incomplete Gamma function</i> Incomplete Gamma function of parameter $a$ and variable $x$ , $P(a, x)$ . One of the four incomplete gamma functions. Example: <code>gamma_inc_P(1, 1) = <math>1 - e^{-1}</math></code>
<code>ln(x)</code>	<i>Natural Logarithm</i> Natural logarithm of $x$ , $\ln(x)$ . Example: <code>ln(2.71828182845904523536) = 1.0</code>



<code>log(x)</code>	<i>Natural Logarithm</i> Exact synonym for <code>ln(x)</code> .
<code>log10(x)</code>	<i>Base 10 Logarithm</i> Base 10 logarithm of <code>x</code> , $\log_{10}(x)$ . Example: <code>log(10.0) = 1.0</code>
<code>nearbyint(x)</code>	<i>Round inexactly</i> Nearest integer to <code>x</code> is returned in floating point format. No exceptions are raised for <i>inexact conversions</i> . Example: <code>nearbyint(0.1) = 0.0</code>
<code>pow(x,y)</code>	<i>Power</i> Value of <code>x</code> is raised to the power of <code>y</code> . Exceptions are raised for <i>domain errors</i> . Due to type-limitations in the C language <code>pow</code> function, integer arguments are promoted (see <a href="#">Section 3.26 [Type Conversion]</a> , page 60) to type <code>NC_FLOAT</code> before evaluation. Example: <code>pow(2,3) = 8</code>
<code>rint(x)</code>	<i>Round exactly</i> Nearest integer to <code>x</code> is returned in floating point format. Exceptions are raised for <i>inexact conversions</i> . Example: <code>rint(0.1) = 0</code>
<code>round(x)</code>	<i>Round</i> Nearest integer to <code>x</code> is returned in floating point format. Round halfway cases away from zero, regardless of current IEEE rounding direction. Example: <code>round(0.5) = 1.0</code>
<code>sin(x)</code>	<i>Sine</i> Sine of <code>x</code> where <code>x</code> is specified in radians. Example: <code>sin(1.57079632679489661922) = 1.0</code>
<code>sinh(x)</code>	<i>Hyperbolic sine</i> Hyperbolic sine of <code>x</code> where <code>x</code> is specified in radians. Example: <code>sinh(1.0) = 1.1752</code>
<code>sqrt(x)</code>	<i>Square Root</i> Square Root of <code>x</code> , $\sqrt{x}$ . Example: <code>sqrt(4.0) = 2.0</code>
<code>tan(x)</code>	<i>Tangent</i> Tangent of <code>x</code> where <code>x</code> is specified in radians. Example: <code>tan(0.78539816339744830961) = 1.0</code>
<code>tanh(x)</code>	<i>Hyperbolic tangent</i> Hyperbolic tangent of <code>x</code> where <code>x</code> is specified in radians. Example: <code>tanh(1.0) = 0.761594155956</code>
<code>trunc(x)</code>	<i>Truncate</i> Nearest integer to <code>x</code> is returned in floating point format. Round half-way cases toward zero, regardless of current IEEE rounding direction. Example: <code>trunc(0.5) = 0.0</code>

The complete list of mathematical functions supported is platform-specific. Functions mandated by ANSI C are *guaranteed* to be present and are indicated with an asterisk <sup>3</sup>. and are indicated with an asterisk. Use the ‘-f’ (or ‘fnc\_tbl’ or ‘prn\_fnc\_tbl’) switch to print a complete list of functions supported on your platform. <sup>4</sup>

---

<sup>3</sup> ANSI C compilers are guaranteed to support double precision versions of these functions. These functions normally operate on netCDF variables of type `NC_DOUBLE` without having to perform intrinsic conversions. For example, ANSI compilers provide `sin` for the sine of C-type `double` variables. The ANSI standard does not require, but many compilers provide, an extended set of mathematical functions that apply to single (`float`) and quadruple (`long double`) precision variables. Using these functions (e.g., `sinf` for `float`, `sinl` for `long double`), when available, is (presumably) more efficient than casting variables to type `double`, performing the operation, and then re-casting. NCO uses the faster intrinsic functions when they are available, and uses the casting method when they are not.

<sup>4</sup> Linux supports more of these intrinsic functions than other OSs.

### 4.1.26 Operators precedence and associativity

This page lists the `ncap` operators in order of precedence (highest to lowest). Their associativity indicates in what order operators of equal precedence in an expression are applied.

Operator	Description	Associativity
<code>++ --</code>	Postfix Increment/Decrement	Right to Left
<code>()</code>	Parentheses (function call)	
<code>.</code>	Method call	
<code>++ --</code>	Prefix Increment/Decrement	Right to Left
<code>+ -</code>	Unary Plus/Minus	
<code>!</code>	Logical Not	
<code>^</code>	Power of Operator	Right to Left
<code>* / %</code>	Multiply/Divide/Modulus	Left To Right
<code>+ -</code>	Addition/Subtraction	Left To Right
<code>&gt;&gt; &lt;&lt;</code>	Fortran style array clipping	Left to Right
<code>&lt; &lt;=</code>	Less than/Less than or equal to	Left to Right
<code>&gt; &gt;=</code>	Greater than/Greater than or equal to	
<code>== !=</code>	Equal to/Not equal to	Left to Right
<code>&amp;&amp;</code>	Logical AND	Left to Right
<code>  </code>	Logical OR	Left to Right
<code>?:</code>	Ternary Operator	Right to Left
<code>=</code>	Assignment	Right to Left
<code>+= -=</code>	Addition/subtraction assignment	
<code>*= /=</code>	Multiplication/division assignment	

### 4.1.27 ID Quoting

In this section when I refer to a name I mean a variable name, attribute name or a dimension name. The allowed characters in a valid netCDF name vary from release to release. (See end section). If you want to use metacharacters in a name or use a method name as a variable name then the name has to be quoted wherever it occurs.

The default NCO name is specified by the regular expressions:

```
DGT:      ('0'..'9');
LPH:      ('a'..'z' | 'A'..'Z' | '_' );
name:     (LPH)(LPH|DGT)+
```

The first character of a valid name must be alphabetic or the underscore. Any subsequent characters must be alphanumeric or underscore. ( e.g `a1_-23`, `hell_is_666` )

The valid characters in a quoted name are specified by the regular expressions:

```
LPHDGT:   ('a'..'z' | 'A'..'Z' | '_' | '0'..'9');
name:     (LPHDGT|'-'|'+'|'.'|'('|')'|':' )+ ;
```

Quote a variable:

```
'avg' , '10_+10','set_miss' '+-90field' , '-test'=10.0d
```

Quote a attribute:

```
'three@10', 'set_mss@+10', '666@hell', 't1@+units'="kelvin"
```

Quote a dimension:

```
'$10', '$t1-', '$-odd', c1['$10', '$t1-']=23.0d
```

The following comments are from the netCDF library definitions and detail the naming conventions for each release. netcdf-3.5.1

netcdf-3.6.0-p1

netcdf-3.6.1

netcdf-3.6.2

```
/*
 * ( [a-zA-Z][0-9]|'_'|'-'|'+'|'.'|'|':'|'@'|'('|')' )+
 * Verify that a name string is valid
 * CDL syntax, eg, all the characters are
 * alphanumeric, '-', '_', '+', or '.'.
 * Also permit ':', '@', '(', or ')' in names for chemists currently making
 * use of these characters, but don't document until ncgen and ncdump can
 * also handle these characters in names.
 */
```

netcdf-3.6.3

netcdf-4.0 Final 2008/08/28

```
/*
 * Verify that a name string is valid syntax. The allowed name
 * syntax (in RE form) is:
 *
 * ([a-zA-Z_]|{UTF8})([^\x00-\x1F\x7F/]|{UTF8})*
 *
 * where UTF8 represents a multibyte UTF-8 encoding. Also, no
 * trailing spaces are permitted in names. This definition
 * must be consistent with the one in ncgen.1. We do not allow '/'
 * because HDF5 does not permit slashes in names as slash is used as a
 * group separator. If UTF-8 is supported, then a multi-byte UTF-8
 * character can occur anywhere within an identifier. We later
 * normalize UTF-8 strings to NFC to facilitate matching and queries.
 */
```

## 4.2 ncatted netCDF Attribute Editor

### SYNTAX

```
ncatted [-a att_dsc] [-a ...] [-D dbg] [-h] [--hdr_pad nbr]
        [-l path] [-O] [-o output-file] [-p path] [-R] [-r]
        input-file [[output-file]]
```

### DESCRIPTION

**ncatted** edits attributes in a netCDF file. If you are editing attributes then you are spending too much time in the world of metadata, and **ncatted** was written to get you back out as quickly and painlessly as possible. **ncatted** can *append*, *create*, *delete*, *modify*, and *overwrite* attributes (all explained below). Furthermore, **ncatted** allows each editing operation to be applied to every variable in a file. This saves time when changing attribute conventions throughout a file. Note that **ncatted** interprets character attributes (i.e., attributes of type `NC_CHAR`) as strings.

Because repeated use of **ncatted** can considerably increase the size of the `history` global attribute (see [Section 3.28 \[History Attribute\]](#), page 62), the ‘-h’ switch is provided to override automatically appending the command to the `history` global attribute in the *output-file*.

When **ncatted** is used to change the `_FillValue` attribute, it changes the associated missing data self-consistently. If the internal floating point representation of a missing value, e.g., 1.0e36, differs between two machines then netCDF files produced on those machines will have incompatible missing values. This allows **ncatted** to change the missing values in files from different machines to a single value so that the files may then be concatenated together, e.g., by **ncrcat**, without losing any information. See [Section 3.21 \[Missing Values\]](#), page 49, for more information.

The key to mastering **ncatted** is understanding the meaning of the structure that describes the attribute modification, *att\_dsc* specified by the required option ‘-a’ or ‘--attribute’. Each *att\_dsc* contains five elements, which makes using **ncatted** somewhat complicated, but powerful. The *att\_dsc* argument structure contains five arguments in the following order:

*att\_dsc* = *att\_nm*, *var\_nm*, *mode*, *att\_type*, *att\_val*

<i>att_nm</i>	Attribute name. Example: <code>units</code>
<i>var_nm</i>	Variable name. Regular expressions (see <a href="#">Section 3.11 [Subsetting Variables]</a> , page 36) are accepted and will select any matching variable names. Example: <code>pressure</code> , ‘ <code>^H2O</code> ’.
<i>mode</i>	Edit mode abbreviation. Example: <code>a</code> . See below for complete listing of valid values of <i>mode</i> .
<i>att_type</i>	Attribute type abbreviation. Example: <code>c</code> . See below for complete listing of valid values of <i>att_type</i> .
<i>att_val</i>	Attribute value. Example: <code>pascal</code> .

There should be no empty space between these five consecutive arguments. The description of these arguments follows in their order of appearance.

The value of *att\_nm* is the name of the attribute you want to edit. This meaning of this should be clear to all users of the **ncatted** operator. If *att\_nm* is omitted (i.e., left blank) and *Delete* mode is selected, then all attributes associated with the specified variable will be deleted.

The value of *var\_nm* is the name of the variable containing the attribute (named *att\_nm*) that you want to edit. There are three very important and useful exceptions to this rule. The value of *var\_nm* can also be used to direct **ncatted** to edit global attributes, or to repeat the editing operation for every variable in a file. A value of *var\_nm* of “global” indicates that *att\_nm* refers to a global attribute, rather than a particular variable’s attribute. This is the method **ncatted** supports for editing global attributes. If *var\_nm* is left blank, on the other hand, then **ncatted** attempts to perform the editing operation on every variable in the file. This option may be convenient to use if you decide to change the conventions you use for describing the data. Finally, as mentioned above, *var\_nm* may be specified as a regular expression.

The value of *mode* is a single character abbreviation (**a**, **c**, **d**, **m**, or **o**) standing for one of five editing modes:

- a**      *Append.* Append value *att\_val* to current *var\_nm* attribute *att\_nm* value *att\_val*, if any. If *var\_nm* does not have an attribute *att\_nm*, there is no effect.
- c**      *Create.* Create variable *var\_nm* attribute *att\_nm* with *att\_val* if *att\_nm* does not yet exist. If *var\_nm* already has an attribute *att\_nm*, there is no effect.
- d**      *Delete.* Delete current *var\_nm* attribute *att\_nm*. If *var\_nm* does not have an attribute *att\_nm*, there is no effect. If *att\_nm* is omitted (left blank), then all attributes associated with the specified variable are automatically deleted. When *Delete* mode is selected, the *att\_type* and *att\_val* arguments are superfluous and may be left blank.
- m**      *Modify.* Change value of current *var\_nm* attribute *att\_nm* to value *att\_val*. If *var\_nm* does not have an attribute *att\_nm*, there is no effect.
- o**      *Overwrite.* Write attribute *att\_nm* with value *att\_val* to variable *var\_nm*, overwriting existing attribute *att\_nm*, if any. This is the default mode.

The value of *att\_type* is a single character abbreviation (**f**, **d**, **l**, **i**, **s**, **c**, **b**, **u**) or a short string standing for one of the twelve primitive netCDF data types:

- f**      *Float.* Value(s) specified in *att\_val* will be stored as netCDF intrinsic type NC\_FLOAT.
- d**      *Double.* Value(s) specified in *att\_val* will be stored as netCDF intrinsic type NC\_DOUBLE.

<code>i, l</code>	<i>Integer or Long.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_INT</code> .
<code>s</code>	<i>Short.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_SHORT</code> .
<code>c</code>	<i>Char.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_CHAR</code> .
<code>b</code>	<i>Byte.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_BYTE</code> .
<code>ub</code>	<i>Unsigned Byte.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_UBYTE</code> .
<code>us</code>	<i>Unsigned Short.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_USHORT</code> .
<code>u, ui, ul</code>	<i>Unsigned Int.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_UINT</code> .
<code>ll, int64</code>	<i>Int64.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_INT64</code> .
<code>ull, uint64</code>	<i>Uint64.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_UINT64</code> .
<code>sng</code>	<i>String.</i> Value(s) specified in <i>att_val</i> will be stored as netCDF intrinsic type <code>NC_STRING</code> .

The specification of *att\_type* is optional (and is ignored) in *Delete* mode.

The value of *att\_val* is what you want to change attribute *att\_nm* to contain. The specification of *att\_val* is optional in *Delete* (and is ignored) mode. Attribute values for all types besides `NC_CHAR` must have an attribute length of at least one. Thus *att\_val* may be a single value or one-dimensional array of elements of type *att\_type*. If the *att\_val* is not set or is set to empty space, and the *att\_type* is `NC_CHAR`, e.g., `-a units,T,o,c,""` or `-a units,T,o,c,,`, then the corresponding attribute is set to have zero length. When specifying an array of values, it is safest to enclose *att\_val* in single or double quotes, e.g., `-a levels,T,o,s,"1,2,3,4"` or `-a levels,T,o,s,'1,2,3,4'`. The quotes are strictly unnecessary around *att\_val* except when *att\_val* contains characters which would confuse the calling shell, such as spaces, commas, and wildcard characters.

NCO processing of `NC_CHAR` attributes is a bit like Perl in that it attempts to do what you want by default (but this sometimes causes unexpected results if you want unusual data storage). If the *att\_type* is `NC_CHAR` then the argument is interpreted as a string and it may contain C-language escape sequences, e.g., `\n`, which NCO will interpret before writing anything to disk. NCO translates valid escape sequences and stores the appropriate ASCII code instead. Since two byte escape sequences, e.g., `\n`, represent one-byte ASCII codes, e.g., ASCII 10 (decimal), the stored string attribute is one byte shorter than the input string length for each embedded escape sequence. The most frequently used C-language escape sequences are `\n` (for linefeed) and `\t` (for horizontal tab). These sequences in particular

allow convenient editing of formatted text attributes. The other valid ASCII codes are `\a`, `\b`, `\f`, `\r`, `\v`, and `\\`. See [Section 4.7 \[ncks netCDF Kitchen Sink\], page 135](#), for more examples of string formatting (with the `ncks -s` option) with special characters.

Analogous to `printf`, other special characters are also allowed by `ncatted` if they are "protected" by a backslash. The characters `"`, `'`, `?`, and `\` may be input to the shell as `\"`, `\'`, `\?`, and `\\`. `NCO` simply strips away the leading backslash from these characters before editing the attribute. No other characters require protection by a backslash. Backslashes which precede any other character (e.g., `3`, `m`, `$`, `!`, `&`, `@`, `%`, `{`, and `}`) will not be filtered and will be included in the attribute.

Note that the NUL character `\0` which terminates C language strings is assumed and need not be explicitly specified. If `\0` is input, it is translated to the NUL character. However, this will make the subsequent portion of the string, if any, invisible to C standard library string functions. And that may cause unintended consequences. Because of these context-sensitive rules, one must use `ncatted` with care in order to store data, rather than text strings, in an attribute of type `NC_CHAR`.

## EXAMPLES

Append the string "Data version 2.0.\n" to the global attribute `history`:

```
ncatted -a history,global,a,c,"Data version 2.0\n" in.nc
```

Note the use of embedded C language `printf()`-style escape sequences.

Change the value of the `long_name` attribute for variable `T` from whatever it currently is to "temperature":

```
ncatted -a long_name,T,o,c,temperature in.nc
```

Delete all existing `units` attributes:

```
ncatted -a units,,d,, in.nc
```

The value of `var_nm` was left blank in order to select all variables in the file. The values of `att_type` and `att_val` were left blank because they are superfluous in *Delete* mode.

Delete all attributes associated with the `tpt` variable, and delete all global attributes

```
ncatted -a ,tpt,d,, -a ,global,d,, in.nc
```

The value of `att_nm` was left blank in order to select all attributes associated with the variable. To delete all global attributes, simply replace `tpt` with `global` in the above.

Modify all existing `units` attributes to "meter second-1":

```
ncatted -a units,,m,c,"meter second-1" in.nc
```

Add a `units` attribute of "kilogram kilogram-1" to all variables whose first three characters are 'H2O':

```
ncatted -a units,'^H2O',c,c,"kilogram kilogram-1" in.nc
```

Overwrite the `quanta` attribute of variable `energy` to an array of four integers.

```
ncatted -0 -a quanta,energy,o,s,"010,101,111,121" in.nc
```

As of NCO 3.9.6 (January, 2009), variable names arguments to `ncatted` may contain *extended regular expressions*. Create `isotope` attributes for all variables containing 'H2O' in their names.

```
ncatted -O -a isotope,'^H2O*',c,s,"18" in.nc
```

See [Section 3.11 \[Subsetting Variables\]](#), page 36 for more details.

Demonstrate input of C-language escape sequences (e.g., `\n`) and other special characters (e.g., `\"`)

```
ncatted -h -a special,global,o,c,  
'\nDouble quote: \"\nTwo consecutive double quotes: \"\"\\n  
Single quote: Beyond my shell abilities!\nBackslash: \\n  
Two consecutive backslashes: \\nQuestion mark: \?\n' in.nc
```

Note that the entire attribute is protected from the shell by single quotes. These outer single quotes are necessary for interactive use, but may be omitted in batch scripts.



## 4.3 ncbo netCDF Binary Operator

### SYNTAX

```
ncbo [-3] [-4] [-6] [-A] [-C] [-c]
      [--cnk_dmn nm,sz] [--cnk_map map] [--cnk_plc plc] [--cnk_scl sz]
      [-D dbg] [-d dim,[min][,[max][,[stride]]] [-F] [-h]
      [-L dfl_lvl] [-l path] [-O] [-o file_3] [-p path] [-R] [-r]
      [-t thr_nbr] [-v var[,...]] [-X ...] [-x] [-y op_typ]
      file_1 file_2 [file_3]
```

### DESCRIPTION

**ncbo** performs binary operations on variables in *file\_1* and the corresponding variables (those with the same name) in *file\_2* and stores the results in *file\_3*. The binary operation operates on the entire files (modulo any excluded variables). See [Section 3.21 \[Missing Values\]](#), page 49, for treatment of missing values. One of the four standard arithmetic binary operations currently supported must be selected with the ‘*-y op\_typ*’ switch (or long options ‘*--op\_typ*’ or ‘*--operation*’). The valid binary operations for **ncbo**, their definitions, corresponding values of the *op\_typ* key, and alternate invocations are:

*Addition*    Definition:  $file\_3 = file\_1 + file\_2$   
                  Alternate invocation: **ncadd**  
                  *op\_typ* key values: ‘add’, ‘+’, ‘addition’  
                  Examples: ‘ncbo --op\_typ=add 1.nc 2.nc 3.nc’, ‘ncadd 1.nc 2.nc 3.nc’

*Subtraction*    Definition:  $file\_3 = file\_1 - file\_2$   
                  Alternate invocations: **ncdiff**, **ncsub**, **ncsubtract**  
                  *op\_typ* key values: ‘sbt’, ‘-’, ‘dff’, ‘diff’, ‘sub’, ‘subtract’, ‘subtraction’  
                  Examples: ‘ncbo --op\_typ=- 1.nc 2.nc 3.nc’, ‘ncdiff 1.nc 2.nc 3.nc’

*Multiplication*    Definition:  $file\_3 = file\_1 * file\_2$   
                  Alternate invocations: **ncmult**, **ncmultiply**  
                  *op\_typ* key values: ‘mlt’, ‘\*’, ‘mult’, ‘multiply’, ‘multiplication’  
                  Examples: ‘ncbo --op\_typ=mlt 1.nc 2.nc 3.nc’, ‘ncmult 1.nc 2.nc 3.nc’

*Division*    Definition:  $file\_3 = file\_1 / file\_2$   
                  Alternate invocation: **ncdivide**  
                  *op\_typ* key values: ‘dvd’, ‘/’, ‘divide’, ‘division’  
                  Examples: ‘ncbo --op\_typ=/ 1.nc 2.nc 3.nc’, ‘ncdivide 1.nc 2.nc 3.nc’

Care should be taken when using the shortest form of key values, i.e., ‘+’, ‘-’, ‘\*’, and ‘/’. Some of these single characters may have special meanings to the shell <sup>1</sup>. Place these

<sup>1</sup> A naked (i.e., unprotected or unquoted) ‘\*’ is a wildcard character. A naked ‘-’ may confuse the command line parser. A naked ‘+’ and ‘/’ are relatively harmless.

characters inside quotes to keep them from being interpreted (globbed) by the shell<sup>2</sup>. For example, the following commands are equivalent

```
ncbo --op_type=* 1.nc 2.nc 3.nc # Dangerous (shell may try to glob)
ncbo --op_type='*' 1.nc 2.nc 3.nc # Safe ('*' protected from shell)
ncbo --op_type="*" 1.nc 2.nc 3.nc # Safe ('*' protected from shell)
ncbo --op_type=mlt 1.nc 2.nc 3.nc
ncbo --op_type=mult 1.nc 2.nc 3.nc
ncbo --op_type=multiply 1.nc 2.nc 3.nc
ncbo --op_type=multiplication 1.nc 2.nc 3.nc
ncmult 1.nc 2.nc 3.nc # First do 'ln -s ncbo ncmult'
ncmultiply 1.nc 2.nc 3.nc # First do 'ln -s ncbo ncmultiply'
```

No particular argument or invocation form is preferred. Users are encouraged to use the forms which are most intuitive to them.

Normally, `ncbo` will fail unless an operation type is specified with `'-y'` (equivalent to `'--op_type'`). You may create exceptions to this rule to suit your particular tastes, in conformance with your site's policy on *symbolic links* to executables (files of a different name point to the actual executable). For many years, `ncdiff` was the main binary file operator. As a result, many users prefer to continue invoking `ncdiff` rather than memorizing a new command (`'ncbo -y sbt'`) which behaves identically to the original `ncdiff` command. However, from a software maintenance standpoint, maintaining a distinct executable for each binary operation (e.g., `ncadd`) is untenable, and a single executable, `ncbo`, is desirable. To maintain backward compatibility, therefore, NCO automatically creates a symbolic link from `ncbo` to `ncdiff`. Thus `ncdiff` is called an *alternate invocation* of `ncbo`. `ncbo` supports many additional alternate invocations which must be manually activated. Should users or system administrators decide to activate them, the procedure is simple. For example, to use `'ncadd'` instead of `'ncbo --op_type=add'`, simply create a symbolic link from `ncbo` to `ncadd`<sup>3</sup>. The alternate invocations supported for each operation type are listed above. Alternatively, users may always define `'ncadd'` as an *alias* to `'ncbo --op_type=add'`<sup>4</sup>.

It is important to maintain portability in NCO scripts. Therefore we recommend that site-specific invocations (e.g., `'ncadd'`) be used only in interactive sessions from the command-line. For scripts, we recommend using the full invocation (e.g., `'ncbo --op_type=add'`). This ensures portability of scripts between users and sites.

`ncbo` operates (e.g., adds) variables in *file\_2* with the corresponding variables (those with the same name) in *file\_1* and stores the results in *file\_3*. Variables in *file\_2* are *broadcast* to conform to the corresponding variable in *file\_1* if necessary, but the reverse is not true. Broadcasting a variable means creating data in non-existing dimensions from the data in existing dimensions. For example, a two dimensional variable in *file\_2* can be subtracted from a four, three, or two (but not one or zero) dimensional variable (of the same name) in

<sup>2</sup> The widely used shell Bash correctly interprets all these special characters even when they are not quoted. That is, Bash does not prevent NCO from correctly interpreting the intended arithmetic operation when the following arguments are given (without quotes) to `ncbo`: `'--op_type=+'`, `'--op_type=-'`, `'--op_type=*'`, and `'--op_type=/'`

<sup>3</sup> The command to do this is `'ln -s -f ncbo ncadd'`

<sup>4</sup> The command to do this is `'alias ncadd='ncbo --op_type=add''`

**file\_1**. This functionality allows the user to compute anomalies from the mean. Note that variables in *file\_1* are *not* broadcast to conform to the dimensions in *file\_2*. In the future, we will broadcast variables in *file\_1*, if necessary to conform to their counterparts in *file\_2*. Thus, presently, the number of dimensions, or *rank*, of any processed variable in *file\_1* must be greater than or equal to the rank of the same variable in *file\_2*. Furthermore, the size of all dimensions common to both *file\_1* and *file\_2* must be equal.

When computing anomalies from the mean it is often the case that *file\_2* was created by applying an averaging operator to a file with initially the same dimensions as *file\_1* (often *file\_1* itself). In these cases, creating *file\_2* with **ncra** rather than **ncwa** will cause the **ncbo** operation to fail. For concreteness say the record dimension in *file\_1* is **time**. If *file\_2* were created by averaging *file\_1* over the **time** dimension with the **ncra** operator rather than with the **ncwa** operator, then *file\_2* will have a **time** dimension of size 1 rather than having no **time** dimension at all <sup>5</sup>. In this case the input files to **ncbo**, *file\_1* and *file\_2*, will have unequally sized **time** dimensions which causes **ncbo** to fail. To prevent this from occurring, use **ncwa** to remove the **time** dimension from *file\_2*. See the example below.

**ncbo** never operates on coordinate variables or variables of type **NC\_CHAR** or **NC\_BYTE**. This ensures that coordinates like (e.g., latitude and longitude) are physically meaningful in the output file, *file\_3*. This behavior is hardcoded. **ncbo** applies special rules to some CF-defined (and/or NCAR CCSM or NCAR CCM fields) such as **OR0**. See [Section 3.30 \[CF Conventions\]](#), page 64 for a complete description. Finally, we note that **ncflint** (see [Section 4.6 \[ncflint netCDF File Interpolator\]](#), page 132) is designed for file interpolation. As such, it also performs file subtraction, addition, multiplication, albeit in a more convoluted way than **ncbo**.

## EXAMPLES

Say files ‘85\_0112.nc’ and ‘86\_0112.nc’ each contain 12 months of data. Compute the change in the monthly averages from 1985 to 1986:

```
ncbo -op_ttyp=sub 86_0112.nc 85_0112.nc 86m85_0112.nc
ncdiff 86_0112.nc 85_0112.nc 86m85_0112.nc
```

The following examples demonstrate the broadcasting feature of **ncbo**. Say we wish to compute the monthly anomalies of **T** from the yearly average of **T** for the year 1985. First we create the 1985 average from the monthly data, which is stored with the record dimension **time**.

```
ncra 85_0112.nc 85.nc
ncwa -0 -a time 85.nc 85.nc
```

The second command, **ncwa**, gets rid of the **time** dimension of size 1 that **ncra** left in ‘85.nc’. Now none of the variables in ‘85.nc’ has a **time** dimension. A quicker way to accomplish this is to use **ncwa** from the beginning:

```
ncwa -a time 85_0112.nc 85.nc
```

We are now ready to use **ncbo** to compute the anomalies for 1985:

---

<sup>5</sup> This is because **ncra** collapses the record dimension to a size of 1 (making it a *degenerate* dimension), but does not remove it, while, unless ‘-b’ is given, **ncwa** removes all averaged dimensions. In other words, by default **ncra** changes variable size but not rank, while, **ncwa** changes both variable size and rank.

```
ncdiff -v T 85_0112.nc 85.nc t_anm_85_0112.nc
```

Each of the 12 records in 't\_anm\_85\_0112.nc' now contains the monthly deviation of T from the annual mean of T for each gridpoint.

Say we wish to compute the monthly gridpoint anomalies from the zonal annual mean. A *zonal mean* is a quantity that has been averaged over the longitudinal (or x) direction. First we use `ncwa` to average over longitudinal direction `lon`, creating '85\_x.nc', the zonal mean of '85.nc'. Then we use `ncbo` to subtract the zonal annual means from the monthly gridpoint data:

```
ncwa -a lon 85.nc 85_x.nc
ncdiff 85_0112.nc 85_x.nc tx_anm_85_0112.nc
```

This examples works assuming '85\_0112.nc' has dimensions `time` and `lon`, and that '85\_x.nc' has no `time` or `lon` dimension.

As a final example, say we have five years of monthly data (i.e., 60 months) stored in '8501\_8912.nc' and we wish to create a file which contains the twelve month seasonal cycle of the average monthly anomaly from the five-year mean of this data. The following method is just one permutation of many which will accomplish the same result. First use `ncwa` to create the five-year mean:

```
ncwa -a time 8501_8912.nc 8589.nc
```

Next use `ncbo` to create a file containing the difference of each month's data from the five-year mean:

```
ncbo 8501_8912.nc 8589.nc t_anm_8501_8912.nc
```

Now use `ncks` to group the five January anomalies together in one file, and use `ncra` to create the average anomaly for all five Januarys. These commands are embedded in a shell loop so they are repeated for all twelve months:

```
for idx in {1..12}; do # Bash Shell (version 3.0+)
  idx=$(printf "%02d" ${idx}) # Zero-pad to preserve order
  ncks -F -d time,${idx},,12 t_anm_8501_8912.nc foo.${idx}
  ncra foo.${idx} t_anm_8589_${idx}.nc
done
for idx in 01 02 03 04 05 06 07 08 09 10 11 12; do # Bourne Shell
  ncks -F -d time,${idx},,12 t_anm_8501_8912.nc foo.${idx}
  ncra foo.${idx} t_anm_8589_${idx}.nc
done
foreach idx (01 02 03 04 05 06 07 08 09 10 11 12) # C Shell
  ncks -F -d time,${idx},,12 t_anm_8501_8912.nc foo.${idx}
  ncra foo.${idx} t_anm_8589_${idx}.nc
end
```

Note that `ncra` understands the `stride` argument so the two commands inside the loop may be combined into the single command

```
ncra -F -d time,${idx},,12 t_anm_8501_8912.nc foo.${idx}
```

Finally, use `ncrcat` to concatenate the 12 average monthly anomaly files into one twelve-record file which contains the entire seasonal cycle of the monthly anomalies:

```
ncrcat t_anm_8589_?.nc t_anm_8589_0112.nc
```

## 4.4 ncea netCDF Ensemble Averager

### SYNTAX

```
ncea [-3] [-4] [-6] [-A] [-C] [-c]
    [--cnk_dmn nm,sz] [--cnk_map map] [--cnk_plc plc] [--cnk_scl sz]
    [-D dbg] [-d dim,[min][, [max][, [stride]]] [-F] [-h] [-L dfl_lv1] [-l path]
    [-n loop] [-O] [-o output-file] [-p path] [-R] [-r]
    [-t thr_nbr] [-v var[,...]] [-X ...] [-x] [-y op_typ]
    [input-files] [output-file]
```

### DESCRIPTION

**ncea** performs gridpoint averages of variables across an arbitrary number (an *ensemble*) of *input-files*, with each file receiving an equal weight in the average. **ncea** averages entire files, and weights each file evenly. This is distinct from **ncra**, which only averages over the record dimension (e.g., *time*), and weights each record in the record dimension evenly,

Variables in the *output-file* are the same size as the variable in each of the *input-files*, and all *input-files* must be the same size. The only exception is that **ncea** allows files to differ in the record dimension size if the requested record hyperslab (see [Section 3.14 \[Hyperslabs\]](#), page 39) resolves to the same size for all files. **ncea** recomputes the record dimension hyperslab limits for each input file so that coordinate limits may be used to select equal length timeseries from unequal length files. This simplifies analysis of unequal length timeseries from simulation ensembles (e.g., the CMIP IPCC AR4 archive).

**ncea** *always averages* coordinate variables regardless of the arithmetic operation type performed on the non-coordinate variables. (see [Section 3.25 \[Operation Types\]](#), page 56). All dimensions, including the record dimension, are treated identically and preserved in the *output-file*.

See [Section 2.6 \[Averaging vs. Concatenating\]](#), page 15, for a description of the distinctions between the various averagers and concatenators. As a multi-file operator, **ncea** will read the list of *input-files* from **stdin** if they are not specified as positional arguments on the command line (see [Section 2.7 \[Large Numbers of Files\]](#), page 16).

The file is the logical unit of organization for the results of many scientific studies. Often one wishes to generate a file which is the gridpoint average of many separate files. This may be to reduce statistical noise by combining the results of a large number of experiments, or it may simply be a step in a procedure whose goal is to compute anomalies from a mean state. In any case, when one desires to generate a file whose properties are the mean of all the input files, then **ncea** is the operator to use.

**ncea** only allows coordinate variables to be processed by the linear average, minimum, and maximum operations. **ncea** will return the linear average of coordinates unless extrema are explicitly requested. Other requested operations (e.g., square-root, RMS) are applied only to non-coordinate variables. In these cases the linear average of the coordinate variable will be returned.

### EXAMPLES

Consider a model experiment which generated five realizations of one year of data, say 1985. You can imagine that the experimenter slightly perturbs the initial conditions of the

problem before generating each new solution. Assume each file contains all twelve months (a seasonal cycle) of data and we want to produce a single file containing the ensemble average (mean) seasonal cycle. Here the numeric filename suffix denotes the experiment number (*not* the month):

```
ncea 85_01.nc 85_02.nc 85_03.nc 85_04.nc 85_05.nc 85.nc
ncea 85_0[1-5].nc 85.nc
ncea -n 5,2,1 85_01.nc 85.nc
```

These three commands produce identical answers. See [Section 3.5 \[Specifying Input Files\], page 26](#), for an explanation of the distinctions between these methods. The output file, ‘85.nc’, is the same size as the inputs files. It contains 12 months of data (which might or might not be stored in the record dimension, depending on the input files), but each value in the output file is the average of the five values in the input files.

In the previous example, the user could have obtained the ensemble average values in a particular spatio-temporal region by adding a hyperslab argument to the command, e.g.,

```
ncea -d time,0,2 -d lat,-23.5,23.5 85_??.nc 85.nc
```

In this case the output file would contain only three slices of data in the *time* dimension. These three slices are the average of the first three slices from the input files. Additionally, only data inside the tropics is included.

## 4.5 ncecat netCDF Ensemble Concatenator

### SYNTAX

```
ncecat [-3] [-4] [-6] [-A] [-C] [-c]
      [--cnk_dmn nm,sz] [--cnk_map map] [--cnk_plc plc] [--cnk_scl sz]
      [-D dbg] [-d dim,[min][,[max][,[stride]]] [-F] [-h] [-L dfl_lvl] [-l path]
      [-M] [-n loop] [-O] [-o output-file] [-p path] [-R] [-r]
      [-t thr_nbr] [-u ulm_nm] [-v var[,...]] [-X ...] [-x]
      [input-files] [output-file]
```

### DESCRIPTION

**ncecat** concatenates an arbitrary number of input files into a single output file. The *input-files* are stored consecutively as records in *output-file*. Each variable (except coordinate variables) in each input file becomes one record in the same variable in the output file. Coordinate variables are not concatenated, they are instead simply copied from the first input file to the *output-file*. All *input-files* must contain all extracted variables (or else there would be "gaps" in the output file).

A new record dimension is the glue which binds the input file data together. The new record dimension name is, by default, "record". Its name can be specified with the '-u *ulm\_nm*' short option (or the '--u*lm\_nm*' or 'rcd\_*nm*' long options).

Each extracted variable must be constant in size and rank across all *input-files*. The only exception is that **ncecat** allows files to differ in the record dimension size if the requested record hyperslab (see [Section 3.14 \[Hyperslabs\]](#), page 39) resolves to the same size for all files. This allows easier gluing/averaging of unequal length timeseries from simulation ensembles (e.g., the IPCC AR4 archive).

Thus, the *output-file* size is the sum of the sizes of the extracted variables in the input files. See [Section 2.6 \[Averaging vs. Concatenating\]](#), page 15, for a description of the distinctions between the various averagers and concatenators. As a multi-file operator, **ncecat** will read the list of *input-files* from *stdin* if they are not specified as positional arguments on the command line (see [Section 2.7 \[Large Numbers of Files\]](#), page 16).

Turn off global metadata copying. By default all NCO operators copy the global metadata of the first input file into *output-file*. This helps preserve the provenance of the output data. However, the use of metadata is burgeoning and is not uncommon to encounter files with excessive amounts of extraneous metadata. Extracting small bits of data from such files leads to output files which are much larger than necessary due to the automatically copied metadata. **ncecat** supports turning off the default copying of global metadata via the '-M' switch (or its long option equivalents, '--glb\_mtd\_spr' and '--global\_metadata\_suppress').

Consider five realizations, '85a.nc', '85b.nc', ... '85e.nc' of 1985 predictions from the same climate model. Then **ncecat** 85?.nc 85\_ens.nc glues the individual realizations together into the single file, '85\_ens.nc'. If an input variable was dimensioned [lat,lon], it will by default have dimensions [record,lat,lon] in the output file. A restriction of **ncecat** is that the hyperslabs of the processed variables must be the same from file to file. Normally this means all the input files are the same size, and contain data on different realizations of the same variables.



Concatenating a variable packed with different scales across multiple datasets is beyond the capabilities of `nccat` (and `ncrcat`, the other concatenator (Section 2.6.1 [Concatenation], page 15). `nccat` does not unpack data, it simply *copies* the data from the *input-files*, and the metadata from the *first input-file*, to the *output-file*. This means that data compressed with a packing convention must use the identical packing parameters (e.g., `scale_factor` and `add_offset`) for a given variable across *all* input files. Otherwise the concatenated dataset will not unpack correctly. The workaround for cases where the packing parameters differ across *input-files* requires three steps: First, unpack the data using `ncpdq`. Second, concatenate the unpacked data using `nccat`, Third, re-pack the result with `ncpdq`.

#### EXAMPLES

Consider a model experiment which generated five realizations of one year of data, say 1985. You can imagine that the experimenter slightly perturbs the initial conditions of the problem before generating each new solution. Assume each file contains all twelve months (a seasonal cycle) of data and we want to produce a single file containing all the seasonal cycles. Here the numeric filename suffix denotes the experiment number (*not* the month):

```
nccat 85_01.nc 85_02.nc 85_03.nc 85_04.nc 85_05.nc 85.nc
nccat 85_0[1-5].nc 85.nc
nccat -n 5,2,1 85_01.nc 85.nc
```

These three commands produce identical answers. See Section 3.5 [Specifying Input Files], page 26, for an explanation of the distinctions between these methods. The output file, ‘85.nc’, is five times the size as a single *input-file*. It contains 60 months of data.

One often prefers that the (new) record dimension have a more descriptive, context-based name than simply “record”. This is easily accomplished with the ‘`-u ulm_nm`’ switch:

```
nccat -u realization 85_0[1-5].nc 85.nc
```

Users are more likely to understand the data processing history when such descriptive coordinates are used.

Consider a file with an existing record dimension named `time`. and suppose the user wishes to convert `time` from a record dimension to a non-record dimension. This may be useful, for example, when the user has another use for the record variable. The procedure is to use `nccat` followed by `ncwa`:

```
nccat in.nc out.nc # Convert time to non-record dimension
ncwa -a record in.nc out.nc # Remove new degenerate record dimension
```

The second step removes the degenerate record dimension. See Section 4.8 [ncpdq netCDF Permute Dimensions Quickly], page 142 and Section 4.7 [ncks netCDF Kitchen Sink], page 135 for other methods of changing variable dimensionality, including the record dimension.

## 4.6 ncflint netCDF File Interpolator

### SYNTAX

```
ncflint [-3] [-4] [-6] [-A] [-C] [-c]
        [--cnk_dmn nm,sz] [--cnk_map map] [--cnk_plc plc] [--cnk_scl sz]
        [-D dbg] [-d dim,[min][,[max][,[stride]]] [-F] [-h] [-i var,val3]
        [-L dfl_lv1] [-l path] [-O] [-o file_3] [-p path] [-R] [-r]
        [-t thr_nbr] [-v var[,...]] [-w wgt1[,wgt2]] [-X ...] [-x]
        file_1 file_2 [file_3]
```

### DESCRIPTION

**ncflint** creates an output file that is a linear combination of the input files. This linear combination is a weighted average, a normalized weighted average, or an interpolation of the input files. Coordinate variables are not acted upon in any case, they are simply copied from *file\_1*.

There are two conceptually distinct methods of using **ncflint**. The first method is to specify the weight each input file contributes to the output file. In this method, the value *val3* of a variable in the output file *file\_3* is determined from its values *val1* and *val2* in the two input files according to  $val3 = wgt1 \times val1 + wgt2 \times val2$ . Here at least *wgt1*, and, optionally, *wgt2*, are specified on the command line with the ‘-w’ (or ‘--weight’ or ‘--wgt\_var’) switch. If only *wgt1* is specified then *wgt2* is automatically computed as  $wgt2 = 1 - wgt1$ . Note that weights larger than 1 are allowed. Thus it is possible to specify *wgt1* = 2 and *wgt2* = -3. One can use this functionality to multiply all the values in a given file by a constant.

The second method of using **ncflint** is to specify the interpolation option with ‘-i’ (or with the ‘--ntp’ or ‘--interpolate’ long options). This is really the inverse of the first method in the following sense. When the user specifies the weights directly, **ncflint** has no work to do besides multiplying the input values by their respective weights and adding the results together to produce the output values. It makes sense to use this when the weights are known *a priori*.

Another class of problems has the *arrival value* (i.e., *val3*) of a particular variable *var* known *a priori*. In this case, the implied weights can always be inferred by examining the values of *var* in the input files. This results in one equation in two unknowns, *wgt1* and *wgt2*:  $val3 = wgt1 \times val1 + wgt2 \times val2$ . Unique determination of the weights requires imposing the additional constraint of normalization on the weights:  $wgt1 + wgt2 = 1$ . Thus, to use the interpolation option, the user specifies *var* and *val3* with the ‘-i’ option. **ncflint** then computes *wgt1* and *wgt2*, and uses these weights on all variables to generate the output file. Although *var* may have any number of dimensions in the input files, it must represent a single, scalar value. Thus any dimensions associated with *var* must be *degenerate*, i.e., of size one.

If neither ‘-i’ nor ‘-w’ is specified on the command line, **ncflint** defaults to weighting each input file equally in the output file. This is equivalent to specifying ‘-w 0.5’ or ‘-w 0.5,0.5’. Attempting to specify both ‘-i’ and ‘-w’ methods in the same command is an error.

`ncflint` does not interpolate variables of type `NC_CHAR` and `NC_BYTE`. This behavior is hardcoded.

Depending on your intuition, `ncflint` may treat missing values unexpectedly. Consider a point where the value in one input file, say *val1*, equals the missing value *mss\_val\_1* and, at the same point, the corresponding value in the other input file *val2* is not missing (i.e., does not equal *mss\_val\_2*). There are three plausible answers, and this creates ambiguity.

Option one is to set *val3* = *mss\_val\_1*. The rationale is that `ncflint` is, at heart, an interpolator and interpolation involving a missing value is intrinsically undefined. `ncflint` currently implements this behavior since it is the most conservative and least likely to lead to misinterpretation.

Option two is to output the weighted valid data point, i.e.,  $val3 = wgt2 \times val2$ . The rationale for this behavior is that interpolation is really a weighted average of known points, so `ncflint` should weight the valid point.

Option three is to return the *unweighted* valid point, i.e., *val3* = *val2*. This behavior would appeal to those who use `ncflint` to estimate data using the closest available data. When a point is not bracketed by valid data on both sides, it is better to return the known datum than no datum at all.

The current implementation uses the first approach, Option one. If you have strong opinions on this matter, let us know, since we are willing to implement the other approaches as options if there is enough interest.

## EXAMPLES

Although it has other uses, the interpolation feature was designed to interpolate *file\_3* to a time between existing files. Consider input files '85.nc' and '87.nc' containing variables describing the state of a physical system at times `time` = 85 and `time` = 87. Assume each file contains its timestamp in the scalar variable `time`. Then, to linearly interpolate to a file '86.nc' which describes the state of the system at time at `time` = 86, we would use

```
ncflint -i time,86 85.nc 87.nc 86.nc
```

Say you have observational data covering January and April 1985 in two files named '85\_01.nc' and '85\_04.nc', respectively. Then you can estimate the values for February and March by interpolating the existing data as follows. Combine '85\_01.nc' and '85\_04.nc' in a 2:1 ratio to make '85\_02.nc':

```
ncflint -w 0.667 85_01.nc 85_04.nc 85_02.nc
ncflint -w 0.667,0.333 85_01.nc 85_04.nc 85_02.nc
```

Multiply '85.nc' by 3 and by -2 and add them together to make 'tst.nc':

```
ncflint -w 3,-2 85.nc 85.nc tst.nc
```

This is an example of a null operation, so 'tst.nc' should be identical (within machine precision) to '85.nc'.

Add '85.nc' to '86.nc' to obtain '85p86.nc', then subtract '86.nc' from '85.nc' to obtain '85m86.nc'

```
ncflint -w 1,1 85.nc 86.nc 85p86.nc
```

```
ncflint -w 1,-1 85.nc 86.nc 85m86.nc
ncdiff 85.nc 86.nc 85m86.nc
```

Thus `ncflint` can be used to mimic some `ncbo` operations. However this is not a good idea in practice because `ncflint` does not broadcast (see [Section 4.3 \[ncbo netCDF Binary Operator\]](#), page 123) conforming variables during arithmetic. Thus the final two commands would produce identical results except that `ncflint` would fail if any variables needed to be broadcast.

Rescale the dimensional units of the surface pressure `prs_sfc` from Pascals to hectopascals (millibars)

```
ncflint -C -v prs_sfc -w 0.01,0.0 in.nc in.nc out.nc
ncatted -a units,prs_sfc,o,c,millibar out.nc
```

## 4.7 ncks netCDF Kitchen Sink

### SYNTAX

```
ncks [-3] [-4] [-6] [-A] [-a] [-B] [-b binary-file] [-C] [-c]
      [--cnk_dmn nm,sz] [--cnk_map map] [--cnk_plc plc] [--cnk_scl sz]
      [-D dbg] [-d dim,[min][,max][,stride]] [--fix_rec_dmn]
      [-F] [-H] [-h] [--hdr_pad nbr] [-L dfl_lvl] [-l path] [-M] [-m] [--mk_rec_dmn dim]
      [-O] [-o output-file] [-P] [-p path] [-Q] [-q] [-R] [-r]
      [-s format] [-u] [-v var[,...]] [-X ...] [-x]
      input-file [[output-file]]
```

### DESCRIPTION

**ncks** combines selected features of **ncdump**, **ncxtr**, and the **nccut** and **ncpaste** specifications into one versatile utility. **ncks** extracts a subset of the data from *input-file* and prints it as ASCII text to **stdout**, writes it in flat binary format to **binary-file**, and writes (or pastes) it in netCDF format to *output-file*.

**ncks** will print netCDF data in ASCII format to **stdout**, like **ncdump**, but with these differences: **ncks** prints data in a tabular format intended to be easy to search for the data you want, one datum per screen line, with all dimension subscripts and coordinate values (if any) preceding the datum. Option **-s** (or long options **--sng\_fmt** and **--string**) lets the user format the data using C-style format strings.

Options **-a**, **-F**, **-H**, **-M**, **-m**, **-P**, **-Q**, **-q**, **-s**, and **-u** (and their long option counterparts) control the formatted appearance of the data.

**ncks** extracts (and optionally creates a new netCDF file comprised of) only selected variables from the input file (similar to the old **ncxtr** specification). Only variables and coordinates may be specifically included or excluded—all global attributes and any attribute associated with an extracted variable are copied to the screen and/or output netCDF file. Options **-c**, **-C**, **-v**, and **-x** (and their long option synonyms) control which variables are extracted.

**ncks** extracts hyperslabs from the specified variables (**ncks** implements the original **nccut** specification). Option **-d** controls the hyperslab specification. Input dimensions that are not associated with any output variable do not appear in the output netCDF. This feature removes superfluous dimensions from netCDF files.

**ncks** will append variables and attributes from the *input-file* to *output-file* if *output-file* is a pre-existing netCDF file whose relevant dimensions conform to dimension sizes of *input-file*. The append features of **ncks** are intended to provide a rudimentary means of adding data from one netCDF file to another, conforming, netCDF file. If naming conflicts exist between the two files, data in *output-file* is usually overwritten by the corresponding data from *input-file*. Thus, when appending, the user should backup *output-file* in case valuable data are inadvertently overwritten.

If *output-file* exists, the user will be queried whether to *overwrite*, *append*, or *exit* the **ncks** call completely. Choosing *overwrite* destroys the existing *output-file* and create an entirely new one from the output of the **ncks** call. Append has differing effects depending on the uniqueness of the variables and attributes output by **ncks**: If a variable or attribute

extracted from *input-file* does not have a name conflict with the members of *output-file* then it will be added to *output-file* without overwriting any of the existing contents of *output-file*. In this case the relevant dimensions must agree (conform) between the two files; new dimensions are created in *output-file* as required. When a name conflict occurs, a global attribute from *input-file* will overwrite the corresponding global attribute from *output-file*. If the name conflict occurs for a non-record variable, then the dimensions and type of the variable (and of its coordinate dimensions, if any) must agree (conform) in both files. Then the variable values (and any coordinate dimension values) from *input-file* will overwrite the corresponding variable values (and coordinate dimension values, if any) in *output-file*<sup>1</sup>.

Since there can only be one record dimension in a file, the record dimension must have the same name (but not necessarily the same size) in both files if a record dimension variable is to be appended. If the record dimensions are of differing sizes, the record dimension of *output-file* will become the greater of the two record dimension sizes, the record variable from *input-file* will overwrite any counterpart in *output-file* and fill values will be written to any gaps left in the rest of the record variables (I think). In all cases variable attributes in *output-file* are superseded by attributes of the same name from *input-file*, and left alone if there is no name conflict.

Some users may wish to avoid interactive **ncks** queries about whether to overwrite existing data. For example, batch scripts will fail if **ncks** does not receive responses to its queries. Options `-O` and `-A` are available to force overwriting existing files and variables, respectively.

## Options specific to **ncks**

The following list provides a short summary of the features unique to **ncks**. Features common to many operators are described in [Chapter 3 \[Common features\]](#), page 23.

`-a` Do not alphabetize extracted fields. By default, the specified output variables are extracted, printed, and written to disk in alphabetical order. This tends to make long output lists easier to search for particular variables. Specifying `-a` results in the variables being extracted, printed, and written to disk in the order in which they were saved in the input file. Thus `-a` retains the original ordering of the variables. Also `--abc` and `--alphabetize`.

`-B 'file'` Activate native machine binary output writing to the default binary file, `'ncks.bnr'`. The `-B` switch is redundant when the `-b 'file'` option is specified, and native binary output will be directed to the binary file `'file'`. Also `--bnr` and `--binary`. Writing packed variables in binary format is not supported.

`-b 'file'` Activate native machine binary output writing to binary file `'file'`. Also `--fl_bnr` and `--binary-file`. Writing packed variables in binary format is not supported.

---

<sup>1</sup> Those familiar with netCDF mechanics might wish to know what is happening here: **ncks** does not attempt to redefine the variable in *output-file* to match its definition in *input-file*, **ncks** merely copies the values of the variable and its coordinate dimensions, if any, from *input-file* to *output-file*.

`'-d dim,[min][,[max][,[stride]]]'`

Add *stride* argument to hyperslabber. For a complete description of the *stride* argument, See [Section 3.15 \[Stride\]](#), page 40.

`'--fix_rec_dmn'`

Change all record dimensions in the input file into fixed dimensions in the output file. Also `'--no_rec_dmn'`.

`'--mk_rec_dmn dim'`

Change existing dimension *dim* to a record dimension in the output file. See [Section 4.5 \[ncecat netCDF Ensemble Concatenator\]](#), page 130 and [Section 4.8 \[ncpdq netCDF Permute Dimensions Quickly\]](#), page 142 for other methods of changing variable dimensionality, including the record dimension.

`'-H'`

Print data to screen. Also activated using `'--print'` or `'--prn'`. By default `ncks` prints all metadata and data to screen if no netCDF output file is specified. Use `'-H'` to print data to screen if a netCDF output is specified, or to restrict printing to data (no metadata) when no netCDF output is specified. Unless otherwise specified (with `-s`), each element of the data hyperslab prints on a separate line containing the names, indices, and, values, if any, of all of the variables dimensions. The dimension and variable indices refer to the location of the corresponding data element with respect to the variable as stored on disk (i.e., not the hyperslab).

```
% ncks -C -v three_dmn_var in.nc
lat[0]=-90 lev[0]=100 lon[0]=0 three_dmn_var[0]=0
lat[0]=-90 lev[0]=100 lon[1]=90 three_dmn_var[1]=1
lat[0]=-90 lev[0]=100 lon[2]=180 three_dmn_var[2]=2
...
lat[1]=90 lev[2]=1000 lon[1]=90 three_dmn_var[21]=21
lat[1]=90 lev[2]=1000 lon[2]=180 three_dmn_var[22]=22
lat[1]=90 lev[2]=1000 lon[3]=270 three_dmn_var[23]=23
```

Printing the same variable with the `'-F'` option shows the same variable indexed with Fortran conventions

```
% ncks -F -C -v three_dmn_var in.nc
lon(1)=0 lev(1)=100 lat(1)=-90 three_dmn_var(1)=0
lon(2)=90 lev(1)=100 lat(1)=-90 three_dmn_var(2)=1
lon(3)=180 lev(1)=100 lat(1)=-90 three_dmn_var(3)=2
...
```

Printing a hyperslab does not affect the variable or dimension indices since these indices are relative to the full variable (as stored in the input file), and the input file has not changed. However, if the hyperslab is saved to an output file and those values are printed, the indices will change:

```
% ncks -H -d lat,90.0 -d lev,1000.0 -v three_dmn_var in.nc out.nc
...
lat[1]=90 lev[2]=1000 lon[0]=0 three_dmn_var[20]=20
lat[1]=90 lev[2]=1000 lon[1]=90 three_dmn_var[21]=21
lat[1]=90 lev[2]=1000 lon[2]=180 three_dmn_var[22]=22
lat[1]=90 lev[2]=1000 lon[3]=270 three_dmn_var[23]=23
```



```
% ncks -C -v three_dmn_var out.nc
lat[0]=90 lev[0]=1000 lon[0]=0 three_dmn_var[0]=20
lat[0]=90 lev[0]=1000 lon[1]=90 three_dmn_var[1]=21
lat[0]=90 lev[0]=1000 lon[2]=180 three_dmn_var[2]=22
lat[0]=90 lev[0]=1000 lon[3]=270 three_dmn_var[3]=23
```

**‘-M’** Print to screen the global metadata describing the file. This includes file summary information and global attributes. Also **‘--Mtd’** and **‘--Metadata’**. By default **ncks** prints global metadata to screen if no netCDF output file and no variable extraction list is specified (with **‘-v’**). Use **‘-M’** to print global metadata to screen if a netCDF output is specified, or if a variable extraction list is specified (with **‘-v’**).

The various combinations of printing switches can be confusing. In an attempt to anticipate what most users want to do, **ncks** uses context-sensitive defaults for printing. Our goal is to minimize the use of switches required to accomplish the common operations. We assume that users creating a new file or overwriting (e.g., with **‘-O’**) an existing file usually wish to copy all global and variable-specific attributes to the new file. In contrast, we assume that users appending (e.g., with **‘-A’**) an explicit variable list from one file to another usually wish to copy only the variable-specific attributes to the output file. The switches **‘-H’**, **‘-M’**, and **‘-m’** switches are implemented as toggles which reverse the default behavior. The most confusing aspect of this is that **‘-M’** inhibits copying global metadata in overwrite mode and causes copying of global metadata in append mode.

```
ncks -O in.nc out.nc # Copy VAs and GAs
ncks -O -v one in.nc out.nc # Copy VAs and GAs
ncks -O -M -v one in.nc out.nc # Copy VAs not GAs
ncks -O -m -v one in.nc out.nc # Copy GAs not VAs
ncks -O -M -m -v one in.nc out.nc # Copy only data (no atts)
ncks -A in.nc out.nc # Append VAs and GAs
ncks -A -v one in.nc out.nc # Append VAs not GAs
ncks -A -M -v one in.nc out.nc # Append VAs and GAs
ncks -A -m -v one in.nc out.nc # Append only data (no atts)
ncks -A -M -m -v one in.nc out.nc # Append GAs not VAs
```

where **VAs** and **GAs** denote variable and global attributes, respectively.

**‘-m’** Print variable metadata to screen (similar to ***ncdump -h***). This displays all metadata pertaining to each variable, one variable at a time. This includes information on the storage properties of the variable, such as whether it employs chunking, compression, or packing. Also activated using **‘--mtd’** and **‘--metadata’**. The **ncks** default behavior is to print variable metadata to screen if no netCDF output file is specified. Use **‘-m’** to print variable metadata to screen if a netCDF output is specified.

**‘-P’** Print data, metadata, and units to screen. The **‘-P’** switch is a convenience abbreviation for **‘-C -H -M -m -u’**. Also activated using **‘--print’** or **‘--prn’**. This set of switches is useful for exploring file contents.



- ‘-Q’      Toggle printing of dimension indices and coordinate values when printing arrays. Each variable’s name appears flush left in the output. This helps locate specific variables in lists with many variables and different dimensions.
- ‘-q’      Turn off all printing to screen. This overrides the setting of all print-related switches, equivalent to `-H -M -m` when in single-file printing mode. When invoked with `-R` (see [Section 3.8 \[Retaining Retrieved Files\]](#), page 32), `ncks` automatically sets `-q`. This allows `ncks` to retrieve remote files without automatically trying to print them. Also ‘`--quiet`’.
- ‘-s format’      String format for text output. Accepts C language escape sequences and `printf()` formats. Also ‘`--string`’ and ‘`--sng_fmt`’.
- ‘-u’      Toggle the printing of a variable’s `units` attribute, if any, with its values. Also ‘`--units`’.

## EXAMPLES

View all data in netCDF ‘`in.nc`’, printed with Fortran indexing conventions:

```
ncks -F in.nc
```

Copy the netCDF file ‘`in.nc`’ to file ‘`out.nc`’.

```
ncks in.nc out.nc
```

Now the file ‘`out.nc`’ contains all the data from ‘`in.nc`’. There are, however, two differences between ‘`in.nc`’ and ‘`out.nc`’. First, the `history` global attribute (see [Section 3.28 \[History Attribute\]](#), page 62) will contain the command used to create ‘`out.nc`’. Second, the variables in ‘`out.nc`’ will be defined in alphabetical order. Of course the internal storage of variable in a netCDF file should be transparent to the user, but there are cases when alphabetizing a file is useful (see description of `-a` switch).

Copy all global attributes (and no variables) from ‘`in.nc`’ to ‘`out.nc`’:

```
ncks -A -x ~/nco/data/in.nc ~/out.nc
```

The ‘`-x`’ switch tells NCO to use the complement of the extraction list (see [Section 3.11 \[Subsetting Variables\]](#), page 36). Since no extraction list is explicitly specified (with ‘`-v`’), the default is to extract all variables. The complement of all variables is no variables. Without any variables to extract, the append (‘`-A`’) command (see [Section 2.4 \[Appending Variables\]](#), page 14) has only to extract and copy (i.e., append) global attributes to the output file.

Print variable `three_dmn_var` from file ‘`in.nc`’ with default notations. Next print `three_dmn_var` as an un-annotated text column. Then print `three_dmn_var` signed with very high precision. Finally, print `three_dmn_var` as a comma-separated list.

```
% ncks -C -v three_dmn_var in.nc
lat[0]=-90 lev[0]=100 lon[0]=0 three_dmn_var[0]=0
lat[0]=-90 lev[0]=100 lon[1]=90 three_dmn_var[1]=1
...
lat[1]=90 lev[2]=1000 lon[3]=270 three_dmn_var[23]=23
```

```
% ncks -s '%f\n' -C -v three_dmn_var in.nc
0.000000
1.000000
...
23.000000
% ncks -s '%+16.10f\n' -C -v three_dmn_var in.nc
+0.0000000000
+1.0000000000
...
+23.0000000000
% ncks -s '%f, ' -C -v three_dmn_var in.nc
0.000000, 1.000000, ..., 23.000000,
```

The second and third options are useful when pasting data into text files like reports or papers. See [Section 4.2 \[ncatted netCDF Attribute Editor\]](#), page 118, for more details on string formatting and special characters.

One dimensional arrays of characters stored as netCDF variables are automatically printed as strings, whether or not they are NUL-terminated, e.g.,

```
ncks -v fl_nm in.nc
```

The `%c` formatting code is useful for printing multidimensional arrays of characters representing fixed length strings

```
ncks -s '%c' -v fl_nm_arr in.nc
```

Using the `%s` format code on strings which are not NUL-terminated (and thus not technically strings) is likely to result in a core dump.

Create netCDF `'out.nc'` containing all variables, and any associated coordinates, except variable `time`, from netCDF `'in.nc'`:

```
ncks -x -v time in.nc out.nc
```

Extract variables `time` and `pressure` from netCDF `'in.nc'`. If `'out.nc'` does not exist it will be created. Otherwise the you will be prompted whether to append to or to overwrite `'out.nc'`:

```
ncks -v time,pressure in.nc out.nc
ncks -C -v time,pressure in.nc out.nc
```

The first version of the command creates an `'out.nc'` which contains `time`, `pressure`, and any coordinate variables associated with `pressure`. The `'out.nc'` from the second version is guaranteed to contain only two variables `time` and `pressure`.

Create netCDF `'out.nc'` containing all variables from file `'in.nc'`. Restrict the dimensions of these variables to a hyperslab. Print (with `-H`) the hyperslabs to the screen for good measure. The specified hyperslab is: the fifth value in dimension `time`; the half-open range `lat > 0`. in coordinate `lat`; the half-open range `lon < 330`. in coordinate `lon`; the closed interval `0.3 < band < 0.5` in coordinate `band`; and cross-section closest to 1000. in coordinate `lev`. Note that limits applied to coordinate values are specified with a decimal

point, and limits applied to dimension indices do not have a decimal point See [Section 3.14 \[Hyperslabs\]](#), page 39.

```
ncks -H -d time,5 -d lat,,0.0 -d lon,330.0, -d band,0.3,0.5  
-d lev,1000.0 in.nc out.nc
```

Assume the domain of the monotonically increasing longitude coordinate `lon` is  $0 < lon < 360$ . Here, `lon` is an example of a wrapped coordinate. `ncks` will extract a hyperslab which crosses the Greenwich meridian simply by specifying the westernmost longitude as *min* and the easternmost longitude as *max*, as follows:

```
ncks -d lon,260.0,45.0 in.nc out.nc
```

For more details See [Section 3.17 \[Wrapped Coordinates\]](#), page 42.

## 4.8 ncpdq netCDF Permute Dimensions Quickly

### SYNTAX

```
ncpdq [-3] [-4] [-6] [-A] [-a [-]dim[,...]] [-C] [-c]
      [--cnk_dmn nm,sz] [--cnk_map map] [--cnk_plc plc] [--cnk_scl sz]
      [-D dbg] [-d dim,[min][,[max][,[stride]]] [-F] [-h] [-L dfl_lvl] [-l path]
      [-M pck_map] [-O] [-o output-file] [-P pck_plc] [-p path]
      [-R] [-r] [-t thr_nbr] [-U] [-v var[,...]] [-X ...] [-x]
      input-file [output-file]
```

### DESCRIPTION

**ncpdq** performs one of two distinct functions, packing or dimension permutation, but not both, when invoked. **ncpdq** is optimized to perform these actions in a parallel fashion with a minimum of time and memory. The *pdq* may stand for “Permute Dimensions Quickly”, “Pack Data Quietly”, “Pillory Dan Quayle”, or other silly uses.

### Packing and Unpacking Functions

The **ncpdq** packing (and unpacking) algorithms are described in [Section 4.1.11 \[Methods and functions\]](#), [page 82](#), and are also implemented in **ncap2**. **ncpdq** extends the functionality of these algorithms by providing high level control of the *packing policy* so that users can consistently pack (and unpack) entire files with one command. The user specifies the desired packing policy with the ‘-P’ switch (or its long option equivalents, ‘--pck\_plc’ and ‘--pack\_policy’) and its *pck\_plc* argument. Four packing policies are currently implemented:

#### *Packing (and Re-Packing) Variables [default]*

Definition: Pack unpacked variables, re-pack packed variables

Alternate invocation: **ncpack**

*pck\_plc* key values: ‘all\_new’, ‘pck\_all\_new\_att’

#### *Packing (and not Re-Packing) Variables*

Definition: Pack unpacked variables, copy packed variables

Alternate invocation: none

*pck\_plc* key values: ‘all\_xst’, ‘pck\_all\_xst\_att’

#### *Re-Packing Variables*

Definition: Re-pack packed variables, copy unpacked variables

Alternate invocation: none

*pck\_plc* key values: ‘xst\_new’, ‘pck\_xst\_new\_att’

#### *Unpacking*

Definition: Unpack packed variables, copy unpacked variables

Alternate invocation: **ncunpack**

*pck\_plc* key values: ‘upk’, ‘unpack’, ‘pck\_upk’

Equivalent key values are fully interchangeable. Multiple equivalent options are provided to satisfy disparate needs and tastes of NCO users working with scripts and from the command line.

Regardless of the packing policy selected, `ncpdq` no longer (as of NCO version 4.0.4 in October, 2010) packs coordinate variables, or the special variables, weights, and other grid properties described in [Section 3.30 \[CF Conventions\]](#), page 64. Prior `ncpdq` versions treated coordinate variables and grid properties no differently from other variables. However, coordinate variables are one-dimensional, so packing saves little space on large files, and the resulting files are difficult for humans to read. Concurrently, Gaussian and area weights and other grid properties are often used to derive fields in re-inflated (unpacked) files, so packing such grid properties causes a considerable loss of precision in downstream data processing. If users express strong wishes to pack grid properties, we will implement new packing policies. An immediate workaround for those needing to pack grid properties now, is to use the `ncap2` packing functions or to rename the grid properties prior to calling `ncpdq`. We welcome your feedback.

To reduce required memorization of these complex policy switches, `ncpdq` may also be invoked via a synonym or with switches that imply a particular policy. `ncpack` is a synonym for `ncpdq` and behaves the same in all respects. Both `ncpdq` and `ncpack` assume a default packing policy request of `'all_new'`. Hence `ncpack` may be invoked without any `'-P'` switch, unlike `ncpdq`. Similarly, `ncunpack` is a synonym for `ncpdq` except that `ncpack` implicitly assumes a request to unpack, i.e., `'-P pck_upk'`. Finally, the `ncpdq` `'-U'` switch (or its long option equivalents, `'--upk'` and `'--unpack'`) requires no argument. It simply requests unpacking.

Given the menagerie of synonyms, equivalent options, and implied options, a short list of some equivalent commands is appropriate. The following commands are equivalent for packing: `ncpdq -P all_new`, `ncpdq --pck_plc=all_new`, and `ncpack`. The following commands are equivalent for unpacking: `ncpdq -P upk`, `ncpdq -U`, `ncpdq --pck_plc=unpack`, and `ncunpack`. Equivalent commands for other packing policies, e.g., `'all_xst'`, follow by analogy. Note that `ncpdq` synonyms are subject to the same constraints and recommendations discussed in the section on `ncbo` synonyms (see [Section 4.3 \[ncbo netCDF Binary Operator\]](#), page 123). That is, symbolic links must exist from the synonym to `ncpdq`, or else the user must define an `alias`.

The `ncpdq` packing algorithms must know to which type particular types of input variables are to be packed. The correspondence between the input variable type and the output, packed type, is called the *packing map*. The user specifies the desired packing map with the `'-M'` switch (or its long option equivalents, `'--pck_map'` and `'--map'`) and its `pck_map` argument. Five packing maps are currently implemented:

#### *Pack Floating Precisions to NC\_SHORT [default]*

Definition: Pack floating precision types to NC\_SHORT

Map: Pack [NC\_DOUBLE,NC\_FLOAT] to NC\_SHORT

Types copied instead of packed: [NC\_INT,NC\_SHORT,NC\_CHAR,NC\_BYTE]

`pck_map` key values: `'flt_sht'`, `'pck_map_flt_sht'`

*Pack Floating Precisions to NC\_BYTE*

Definition: Pack floating precision types to NC\_BYTE

Map: Pack [NC\_DOUBLE,NC\_FLOAT] to NC\_BYTE

Types copied instead of packed: [NC\_INT,NC\_SHORT,NC\_CHAR,NC\_BYTE]

*pck\_map* key values: 'flt\_byt', 'pck\_map\_flt\_byt'

*Pack Higher Precisions to NC\_SHORT*

Definition: Pack higher precision types to NC\_SHORT

Map: Pack [NC\_DOUBLE,NC\_FLOAT,NC\_INT] to NC\_SHORT

Types copied instead of packed: [NC\_SHORT,NC\_CHAR,NC\_BYTE]

*pck\_map* key values: 'hgh\_sht', 'pck\_map\_hgh\_sht'

*Pack Higher Precisions to NC\_BYTE*

Definition: Pack higher precision types to NC\_BYTE

Map: Pack [NC\_DOUBLE,NC\_FLOAT,NC\_INT,NC\_SHORT] to NC\_BYTE

Types copied instead of packed: [NC\_CHAR,NC\_BYTE]

*pck\_map* key values: 'hgh\_byt', 'pck\_map\_hgh\_byt'

*Pack to Next Lesser Precision*

Definition: Pack each type to type of next lesser size

Map: Pack NC\_DOUBLE to NC\_INT. Pack [NC\_FLOAT,NC\_INT] to NC\_SHORT. Pack NC\_SHORT to NC\_BYTE.

Types copied instead of packed: [NC\_CHAR,NC\_BYTE]

*pck\_map* key values: 'nxt\_lsr', 'pck\_map\_nxt\_lsr'

The default 'all\_new' packing policy with the default 'flt\_sht' packing map reduces the typical NC\_FLOAT-dominated file size by about 50%. 'flt\_byt' packing reduces an NC\_DOUBLE-dominated file by about 87%.

The netCDF packing algorithm (see [Section 4.1.11 \[Methods and functions\], page 82](#)) is lossy—once packed, the exact original data cannot be recovered without a full backup. Hence users should be aware of some packing caveats: First, the interaction of packing and data equal to the *\_FillValue* is complex. Test the *\_FillValue* behavior by performing a pack/unpack cycle to ensure data that are missing *stay* missing and data that are not missing do not join the Air National Guard and go missing. This may lead you to elect a new *\_FillValue*. Second, *ncpdq* actually allows packing into NC\_CHAR (with, e.g., 'flt\_chr'). However, the intrinsic conversion of *signed char* to higher precision types is tricky for values equal to zero, i.e., for NUL. Hence packing to NC\_CHAR is not documented or advertised. Pack into NC\_BYTE (with, e.g., 'flt\_byt') instead.

**Dimension Permutation**

*ncpdq* re-shapes variables in *input-file* by re-ordering and/or reversing dimensions specified in the dimension list. The dimension list is a whitespace-free, comma separated list of dimension names, optionally prefixed by negative signs, that follows the '-a' (or long options '--arrange', '--permute', '--re-order', or '--rdr') switch. To re-order variables by a

subset of their dimensions, specify these dimensions in a comma-separated list following ‘-a’, e.g., ‘-a lon,lat’. To reverse a dimension, prefix its name with a negative sign in the dimension list, e.g., ‘-a -lat’. Re-ordering and reversal may be performed simultaneously, e.g., ‘-a lon,-lat,time,-lev’.

Users may specify any permutation of dimensions, including permutations which change the record dimension identity. The record dimension is re-ordered like any other dimension. This unique `ncpdq` capability makes it possible to concatenate files along any dimension. See [Section 2.6.1 \[Concatenation\]](#), page 15 for a detailed example. The record dimension is always the most slowly varying dimension in a record variable (see [Section 3.13 \[C and Fortran Index Conventions\]](#), page 38). The specified re-ordering fails if it requires creating more than one record dimension amongst all the output variables<sup>1</sup>.

Two special cases of dimension re-ordering and reversal deserve special mention. First, it may be desirable to completely reverse the storage order of a variable. To do this, include all the variable’s dimensions in the dimension re-order list in their original order, and prefix each dimension name with the negative sign. Second, it may be useful to transpose a variable’s storage order, e.g., from C to Fortran data storage order (see [Section 3.13 \[C and Fortran Index Conventions\]](#), page 38). To do this, include all the variable’s dimensions in the dimension re-order list in reversed order. Explicit examples of these two techniques appear below.

NB: fxm `ncpdq` documentation will evolve through Fall 2004. I will upload updates to documentation linked to by the NCO homepage. `ncpdq` is a powerful operator, and I am unfamiliar with the terminology needed to describe what `ncpdq` does. Sequences, sets, sheesh! I just know that it does “The right thing” according to my gut feelings. Now do you feel more comfortable using it?

Let  $\mathbf{D}(x)$  represent the dimensionality of the variable  $x$ . Dimensionality describes the order and sizes of dimensions. If  $x$  has rank  $N$ , then we may write  $\mathbf{D}(x)$  as the  $N$ -element vector

$$\mathbf{D}(x) = [D_1, D_2, D_3, \dots, D_{n-1}, D_n, D_{n+1}, \dots, D_{N-2}, D_{N-1}, D_N]$$

where  $D_n$  is the size of the  $n$ ’th dimension.

The dimension re-order list specified with ‘-a’ is the  $R$ -element vector

$$\mathbf{R} = [R_1, R_2, R_3, \dots, R_{r-1}, R_r, R_{r+1}, \dots, R_{R-2}, R_{R-1}, R_R]$$

There need be no relation between  $N$  and  $R$ . Let the  $S$ -element vector  $\mathbf{S}$  be the intersection (i.e., the ordered set of unique shared dimensions) of  $\mathbf{D}$  and  $\mathbf{R}$ . Then

$$\begin{aligned} \mathbf{S} &= \mathbf{R} \cap \mathbf{D} \\ &= [S_1, S_2, S_3, \dots, S_{s-1}, S_s, S_{s+1}, \dots, S_{S-2}, S_{S-1}, S_S] \end{aligned}$$

$\mathbf{S}$  is empty if  $\mathbf{R} \not\subseteq \mathbf{D}$ .

Re-ordering (or re-shaping) a variable means mapping the input state with dimensionality  $\mathbf{D}(x)$  to the output state with dimensionality  $\mathbf{D}'(x')$ . In practice, mapping occurs in

---

<sup>1</sup> This limitation, imposed by the netCDF storage layer, may be relaxed in the future with netCDF4.

three logically distinct steps. First, we translate the user input to a one-to-one mapping  $\mathcal{M}$  between input and output dimensions,  $\mathbf{D} \mapsto \mathbf{D}'$ . This tentative map is final unless external constraints (typically netCDF restrictions) impose themselves. Second, we check and, if necessary, refine the tentative mapping so that the re-shaped variables will co-exist in the same file without violating netCDF-imposed storage restrictions. This refined map specifies the final (output) dimensionality. Third, we translate the output dimensionality into one-dimensional memory offsets for each datum according to the C language convention for multi-dimensional array storage. Dimension reversal changes the ordering of data, but not the dimensionality, and so is part of the third step.

Dimensions  $R$  disjoint from  $\mathbf{D}$  play no role in re-ordering. The first step taken to re-order a variable is to determine  $\mathbf{S}$ .  $\mathbf{R}$  is constant for all variables, whereas  $\mathbf{D}$ , and hence  $\mathbf{S}$ , is variable-specific.  $\mathbf{S}$  is empty if  $\mathbf{R} \not\subseteq \mathbf{D}$ . This may be the case for some extracted variables. The user may explicitly specify the one-to-one mapping of input to output dimension order by supplying (with ‘-a’) a re-order list  $\mathbf{R}$  such that  $S = N$ . In this case  $D'_n = S_n$ . The degenerate case occurs when  $\mathbf{D} = \mathbf{S}$ . This produces the identity mapping  $D'_n = D_n$ .

The mapping of input to output dimension order is more complex when  $S \neq N$ . In this case  $D'_n = D_n$  for the  $N - S$  dimensions  $D'_n \notin \mathbf{S}$ . For the  $S$  dimensions  $D'_n \in \mathbf{S}$ ,  $D'_n = S_s$ .

## EXAMPLES

Pack and unpack all variables in file ‘in.nc’ and store the results in ‘out.nc’:

```
ncpdq in.nc out.nc # Same as ncpack in.nc out.nc
ncpdq -P all_new -M flt_sht in.nc out.nc # Defaults
ncpdq -P all_xst in.nc out.nc
ncpdq -P upk in.nc out.nc # Same as ncunpack in.nc out.nc
ncpdq -U in.nc out.nc # Same as ncunpack in.nc out.nc
```

The first two commands pack any unpacked variable in the input file. They also unpack and then re-pack every packed variable. The third command only packs unpacked variables in the input file. If a variable is already packed, the third command copies it unchanged to the output file. The fourth and fifth commands unpack any packed variables. If a variable is not packed, the third command copies it unchanged.

The previous examples all utilized the default packing map. Suppose you wish to archive all data that are currently unpacked into a form which only preserves 256 distinct values. Then you could specify the packing map *pck\_map* as ‘hgh\_byt’ and the packing policy *pck\_plc* as ‘all\_xst’:

```
ncpdq -P all_xst -M hgh_byt in.nc out.nc
```

Many different packing maps may be used to construct a given file by performing the packing on subsets of variables (e.g., with ‘-v’) and using the append feature with ‘-A’ (see [Section 2.4 \[Appending Variables\]](#), page 14).

Re-order file ‘in.nc’ so that the dimension *lon* always precedes the dimension *lat* and store the results in ‘out.nc’:

```
ncpdq -a lon,lat in.nc out.nc
ncpdq -v three_dmn_var -a lon,lat in.nc out.nc
```



The first command re-orders every variable in the input file. The second command extracts and re-orders only the variable `three_dmn_var`.

Suppose the dimension `lat` represents latitude and monotonically increases from south to north. Reversing the `lat` dimension means re-ordering the data so that latitude values decrease monotonically from north to south. Accomplish this with

```
% ncpdq -a -lat in.nc out.nc
% ncks -C -v lat in.nc
lat[0]=-90
lat[1]=90
% ncks -C -v lat out.nc
lat[0]=90
lat[1]=-90
```

This operation reversed the latitude dimension of all variables. Whitespace immediately preceding the negative sign that specifies dimension reversal may be dangerous. Quotes and long options can help protect negative signs that should indicate dimension reversal from being interpreted by the shell as dashes that indicate new command line switches.

```
ncpdq -a -lat in.nc out.nc # Dangerous? Whitespace before "-lat"
ncpdq -a '-lat' in.nc out.nc # OK. Quotes protect "-" in "-lat"
ncpdq -a lon,-lat in.nc out.nc # OK. No whitespace before "-"
ncpdq --rdr=-lat in.nc out.nc # Preferred. Uses "=" not whitespace
```

To create the mathematical transpose of a variable, place all its dimensions in the dimension re-order list in reversed order. This example creates the transpose of `three_dmn_var`:

```
% ncpdq -a lon,lev,lat -v three_dmn_var in.nc out.nc
% ncks -C -v three_dmn_var in.nc
lat[0]=-90 lev[0]=100 lon[0]=0 three_dmn_var[0]=0
lat[0]=-90 lev[0]=100 lon[1]=90 three_dmn_var[1]=1
lat[0]=-90 lev[0]=100 lon[2]=180 three_dmn_var[2]=2
...
lat[1]=90 lev[2]=1000 lon[1]=90 three_dmn_var[21]=21
lat[1]=90 lev[2]=1000 lon[2]=180 three_dmn_var[22]=22
lat[1]=90 lev[2]=1000 lon[3]=270 three_dmn_var[23]=23
% ncks -C -v three_dmn_var out.nc
lon[0]=0 lev[0]=100 lat[0]=-90 three_dmn_var[0]=0
lon[0]=0 lev[0]=100 lat[1]=90 three_dmn_var[1]=12
lon[0]=0 lev[1]=500 lat[0]=-90 three_dmn_var[2]=4
...
lon[3]=270 lev[1]=500 lat[1]=90 three_dmn_var[21]=19
lon[3]=270 lev[2]=1000 lat[0]=-90 three_dmn_var[22]=11
lon[3]=270 lev[2]=1000 lat[1]=90 three_dmn_var[23]=23
```

To completely reverse the storage order of a variable, include all its dimensions in the re-order list, each prefixed by a negative sign. This example reverses the storage order of `three_dmn_var`:

```
% ncpdq -a -lat,-lev,-lon -v three_dmn_var in.nc out.nc
```

```
% ncks -C -v three_dmn_var in.nc
lat[0]=-90 lev[0]=100 lon[0]=0 three_dmn_var[0]=0
lat[0]=-90 lev[0]=100 lon[1]=90 three_dmn_var[1]=1
lat[0]=-90 lev[0]=100 lon[2]=180 three_dmn_var[2]=2
...
lat[1]=90 lev[2]=1000 lon[1]=90 three_dmn_var[21]=21
lat[1]=90 lev[2]=1000 lon[2]=180 three_dmn_var[22]=22
lat[1]=90 lev[2]=1000 lon[3]=270 three_dmn_var[23]=23
% ncks -C -v three_dmn_var out.nc
lat[0]=90 lev[0]=1000 lon[0]=270 three_dmn_var[0]=23
lat[0]=90 lev[0]=1000 lon[1]=180 three_dmn_var[1]=22
lat[0]=90 lev[0]=1000 lon[2]=90 three_dmn_var[2]=21
...
lat[1]=-90 lev[2]=100 lon[1]=180 three_dmn_var[21]=2
lat[1]=-90 lev[2]=100 lon[2]=90 three_dmn_var[22]=1
lat[1]=-90 lev[2]=100 lon[3]=0 three_dmn_var[23]=0
```

Creating a record dimension named, e.g., `time`, in a file which has no existing record dimension is simple with `ncecat`:

```
ncecat -O -u time in.nc out.nc # Create degenerate record dimension named "time"
```

Now consider a file with all dimensions, including `time`, fixed (non-record). Suppose the user wishes to convert `time` from a fixed dimension to a record dimension. This may be useful, for example, when the user wishes to append additional time slices to the data. As of NCO version 4.0.1 (April, 2010) the preferred method for doing this is with `ncks`:

```
ncks -O --mk_rec_dmn time in.nc out.nc # Change "time" to record dimension
```

Prior to 4.0.1, the procedure to change an existing fixed dimension into a record dimension required three separate commands, `ncecat` followed by `ncpdq`, and then `ncwa`. It is still instructive to present the original procedure, as it shows how multiple operators can achieve the same ends by different means:

```
ncecat -O in.nc out.nc # Add degenerate record dimension named "record"
ncpdq -O -a time,record out.nc out.nc # Switch "record" and "time"
ncwa -O -a record out.nc out.nc # Remove (degenerate) "record"
```

The first step creates a degenerate (size equals one) record dimension named (by default) `record`. The second step swaps the ordering of the dimensions named `time` and `record`. Since `time` now occupies the position of the first (least rapidly varying) dimension, it becomes the record dimension. The dimension named `record` is no longer a record dimension. The third step averages over this degenerate `record` dimension. Averaging over a degenerate dimension does not alter the data. The ordering of other dimensions in the file (`lat`, `lon`, etc.) is immaterial to this procedure. See [Section 4.5 \[ncecat netCDF Ensemble Concatenator\]](#), page 130 and [Section 4.7 \[ncks netCDF Kitchen Sink\]](#), page 135 for other methods of changing variable dimensionality, including the record dimension.

## 4.9 ncra netCDF Record Averager

### SYNTAX

```
ncra [-3] [-4] [-6] [-A] [-C] [-c]
      [--cnk_dmn nm,sz] [--cnk_map map] [--cnk_plc plc] [--cnk_scl sz]
      [-D dbg] [-d dim,[min][,[max][,[stride]]] [-F] [-h] [-L dfl_lvl] [-l path]
      [-n loop] [-O] [-o output-file] [-p path] [-R] [-r]
      [-t thr_nbr] [-v var[,...]] [-X ...] [-x] [-y op_typ]
      [input-files] [output-file]
```

### DESCRIPTION

**ncra** averages record variables across an arbitrary number of *input-files*. The record dimension is, by default, retained as a degenerate (size 1) dimension in the output variables. See [Section 2.6 \[Averaging vs. Concatenating\]](#), page 15, for a description of the distinctions between the various averagers and concatenators. As a multi-file operator, **ncra** will read the list of *input-files* from **stdin** if they are not specified as positional arguments on the command line (see [Section 2.7 \[Large Numbers of Files\]](#), page 16).

Input files may vary in size, but each must have a record dimension. The record coordinate, if any, should be monotonic (or else non-fatal warnings may be generated). Hyperslabs of the record dimension which include more than one file work correctly. **ncra** supports the *stride* argument to the ‘-d’ hyperslab option (see [Section 3.14 \[Hyperslabs\]](#), page 39) for the record dimension only, *stride* is not supported for non-record dimensions.

**ncra** weights each record (e.g., time slice) in the *input-files* equally. **ncra** does not attempt to see if, say, the **time** coordinate is irregularly spaced and thus would require a weighted average in order to be a true time average. **ncra** *always averages* coordinate variables regardless of the arithmetic operation type performed on the non-coordinate variables. (see [Section 3.25 \[Operation Types\]](#), page 56).

### EXAMPLES

Average files ‘85.nc’, ‘86.nc’, ... ‘89.nc’ along the record dimension, and store the results in ‘8589.nc’:

```
ncra 85.nc 86.nc 87.nc 88.nc 89.nc 8589.nc
ncra 8[56789].nc 8589.nc
ncra -n 5,2,1 85.nc 8589.nc
```

These three methods produce identical answers. See [Section 3.5 \[Specifying Input Files\]](#), page 26, for an explanation of the distinctions between these methods.

Assume the files ‘85.nc’, ‘86.nc’, ... ‘89.nc’ each contain a record coordinate *time* of length 12 defined such that the third record in ‘86.nc’ contains data from March 1986, etc. NCO knows how to hyperslab the record dimension across files. Thus, to average data from December, 1985 through February, 1986:

```
ncra -d time,11,13 85.nc 86.nc 87.nc 8512_8602.nc
ncra -F -d time,12,14 85.nc 86.nc 87.nc 8512_8602.nc
```

The file '87.nc' is superfluous, but does not cause an error. The '-F' turns on the Fortran (1-based) indexing convention. The following uses the *stride* option to average all the March temperature data from multiple input files into a single output file

```
ncra -F -d time,3,,12 -v temperature 85.nc 86.nc 87.nc 858687_03.nc
```

See [Section 3.15 \[Stride\]](#), [page 40](#), for a description of the *stride* argument.

Assume the *time* coordinate is incrementally numbered such that January, 1985 = 1 and December, 1989 = 60. Assuming '??' only expands to the five desired files, the following averages June, 1985–June, 1989:

```
ncra -d time,6.,54. ??nc 8506_8906.nc
```

## 4.10 nccat netCDF Record Concatenator

### SYNTAX

```
nccat [-3] [-4] [-6] [-A] [-C] [-c]
      [--cnk_dmn nm,sz] [--cnk_map map] [--cnk_plc plc] [--cnk_scl sz]
      [-D dbg] [-d dim,[min][,[max][,[stride]]] [-F] [-h] [-L dfl_lv1] [-l path]
      [-n loop] [-O] [-o output-file] [-p path] [-R] [-r]
      [-t thr_nbr] [-v var[,...]] [-X ...] [-x]
      [input-files] [output-file]
```

### DESCRIPTION

**nccat** concatenates record variables across an arbitrary number of *input-files*. The final record dimension is by default the sum of the lengths of the record dimensions in the input files. See [Section 2.6 \[Averaging vs. Concatenating\]](#), [page 15](#), for a description of the distinctions between the various averagers and concatenators. As a multi-file operator, **nccat** will read the list of *input-files* from *stdin* if they are not specified as positional arguments on the command line (see [Section 2.7 \[Large Numbers of Files\]](#), [page 16](#)).

Input files may vary in size, but each must have a record dimension. The record coordinate, if any, should be monotonic (or else non-fatal warnings may be generated). Hyperslabs along the record dimension that span more than one file are handled correctly. **nccat** supports the *stride* argument to the ‘-d’ hyperslab option for the record dimension only, *stride* is not supported for non-record dimensions.

Concatenating a variable packed with different scales multiple datasets is beyond the capabilities of **nccat** (and **ncecat**, the other concatenator ([Section 2.6.1 \[Concatenation\]](#), [page 15](#))). **nccat** does not unpack data, it simply *copies* the data from the *input-files*, and the metadata from the *first input-file*, to the *output-file*. This means that data compressed with a packing convention must use the identical packing parameters (e.g., *scale\_factor* and *add\_offset*) for a given variable across *all* input files. Otherwise the concatenated dataset will not unpack correctly. The workaround for cases where the packing parameters differ across *input-files* requires three steps: First, unpack the data using **ncpdq**. Second, concatenate the unpacked data using **nccat**, Third, re-pack the result with **ncpdq**.

**nccat** applies special rules to ARM convention time fields (e.g., *time\_offset*). See [Section 3.31 \[ARM Conventions\]](#), [page 65](#) for a complete description.

### EXAMPLES

Concatenate files ‘85.nc’, ‘86.nc’, ... ‘89.nc’ along the record dimension, and store the results in ‘8589.nc’:

```
nccat 85.nc 86.nc 87.nc 88.nc 89.nc 8589.nc
nccat 8[56789].nc 8589.nc
nccat -n 5,2,1 85.nc 8589.nc
```

These three methods produce identical answers. See [Section 3.5 \[Specifying Input Files\]](#), [page 26](#), for an explanation of the distinctions between these methods.

Assume the files ‘85.nc’, ‘86.nc’, ... ‘89.nc’ each contain a record coordinate *time* of length 12 defined such that the third record in ‘86.nc’ contains data from March 1986, etc.

NCO knows how to hyperslab the record dimension across files. Thus, to concatenate data from December, 1985–February, 1986:

```
ncrcat -d time,11,13 85.nc 86.nc 87.nc 8512_8602.nc
ncrcat -F -d time,12,14 85.nc 86.nc 87.nc 8512_8602.nc
```

The file ‘87.nc’ is superfluous, but does not cause an error. When `ncra` and `ncrcat` encounter a file which does contain any records that meet the specified hyperslab criteria, they disregard the file and proceed to the next file without failing. The ‘-F’ turns on the Fortran (1-based) indexing convention.

The following uses the *stride* option to concatenate all the March temperature data from multiple input files into a single output file

```
ncrcat -F -d time,3,,12 -v temperature 85.nc 86.nc 87.nc 858687_03.nc
```

See [Section 3.15 \[Stride\]](#), [page 40](#), for a description of the *stride* argument.

Assume the *time* coordinate is incrementally numbered such that January, 1985 = 1 and December, 1989 = 60. Assuming ?? only expands to the five desired files, the following concatenates June, 1985–June, 1989:

```
ncrcat -d time,6.,54. ?? .nc 8506_8906.nc
```

## 4.11 ncrename netCDF Renamer

### SYNTAX

```
ncrename [-a old_name,new_name] [-a ...] [-D dbg]
         [-d old_name,new_name] [-d ...] [-h] [--hdr_pad nbr] [-l path]
         [-O] [-o output-file] [-p path] [-R] [-r]
         [-v old_name,new_name] [-v ...]
         input-file [[output-file]]
```

### DESCRIPTION

**ncrename** renames dimensions, variables, and attributes in a netCDF file. Each object that has a name in the list of old names is renamed using the corresponding name in the list of new names. All the new names must be unique. Every old name must exist in the input file, unless the old name is preceded by the period (or “dot”) character ‘.’. The validity of *old\_name* is not checked prior to the renaming. Thus, if *old\_name* is specified without the ‘.’ prefix and is not present in *input-file*, **ncrename** will abort. The *new\_name* should never be prefixed by a ‘.’ (or else the period will be included as part of the new name). The OPTIONS and EXAMPLES show how to select specific variables whose attributes are to be renamed.

**ncrename** is the exception to the normal rules that the user will be interactively prompted before an existing file is changed, and that a temporary copy of an output file is constructed during the operation. If only *input-file* is specified, then **ncrename** will change the names of the *input-file* in place without prompting and without creating a temporary copy of *input-file*. This is because the renaming operation is considered reversible if the user makes a mistake. The *new\_name* can easily be changed back to *old\_name* by using **ncrename** one more time.

Note that renaming a dimension to the name of a dependent variable can be used to invert the relationship between an independent coordinate variable and a dependent variable. In this case, the named dependent variable must be one-dimensional and should have no missing values. Such a variable will become a coordinate variable.

According to the *netCDF User’s Guide*, renaming properties in netCDF files does not incur the penalty of recopying the entire file when the *new\_name* is shorter than the *old\_name*.

### OPTIONS

‘-a *old\_name,new\_name*’

Attribute renaming. The old and new names of the attribute are specified with ‘-a’ (or ‘--attribute’) by the associated *old\_name* and *new\_name* values. Global attributes are treated no differently than variable attributes. This option may be specified more than once. As mentioned above, all occurrences of the attribute of a given name will be renamed unless the ‘.’ form is used, with one exception. To change the attribute name for a particular variable, specify the *old\_name* in the format *old.var.name@old.att.name*. The ‘@’ symbol delimits the variable and attribute names. If the attribute is uniquely named (no other variables contain the attribute) then the *old.var.name@old.att.name* syntax is

redundant. The `var_name@att_name` syntax is accepted, but not required, for the `new_name`.

`'-d old_name,new_name'`

Dimension renaming. The old and new names of the dimension are specified with `'-d'` (or `'--dmn'`, `'--dimension'`) by the associated `old_name` and `new_name` values. This option may be specified more than once.

`'-v old_name,new_name'`

Variable renaming. The old and new names of the variable are specified with `'-v'` (or `'--variable'`) by the associated `old_name` and `new_name` values. This option may be specified more than once.

## EXAMPLES

Rename the variable `p` to `pressure` and `t` to `temperature` in netCDF `'in.nc'`. In this case `p` must exist in the input file (or `ncrename` will abort), but the presence of `t` is optional:

```
ncrename -v p,pressure -v .t,temperature in.nc
```

Rename the attribute `long_name` to `largo_nombre` in the variable `u`, and no other variables in netCDF `'in.nc'`.

```
ncrename -a u:long_name,largo_nombre in.nc
```

`ncrename` does not automatically attach dimensions to variables of the same name. If you want to rename a coordinate variable so that it remains a coordinate variable, you must separately rename both the dimension and the variable:

```
ncrename -d lon,longitude -v lon,longitude in.nc
```

Create netCDF `'out.nc'` identical to `'in.nc'` except the attribute `_FillValue` is changed to `missing_value`, the attribute `units` is changed to `CGS_units` (but only in those variables which possess it), the attribute `hieght` is changed to `height` in the variable `tpt`, and in the variable `prs_sfc`, if it exists.

```
ncrename -a _FillValue,missing_value -a .units,CGS_units \
-a tpt@hieght,height -a prs_sfc@.hieght,height in.nc out.nc
```

The presence and absence of the `'.'` and `'@'` features cause this command to execute successfully only if a number of conditions are met. All variables *must* have a `_FillValue` attribute *and* `_FillValue` must also be a global attribute. The `units` attribute, on the other hand, will be renamed to `CGS_units` wherever it is found but need not be present in the file at all (either as a global or a variable attribute). The variable `tpt` must contain the `hieght` attribute. The variable `prs_sfc` need not exist, and need not contain the `hieght` attribute.



## 4.12 ncwa netCDF Weighted Averager

### SYNTAX

```
ncwa [-3] [-4] [-6] [-A] [-a dim[,...]] [-B mask_cond] [-b] [-C] [-c]
  [--cnk_dmn nm,sz] [--cnk_map map] [--cnk_plc plc] [--cnk_scl sz]
  [-D dbg] [-d dim,[min][,[max][,[stride]]] [-F] [-h] [-I] [-L dfl_lvl] [-l path]
  [-M mask_val] [-m mask_var] [-N] [-O]
  [-o output-file] [-p path] [-R] [-r] [-T mask_comp]
  [-t thr_nbr] [-v var[,...]] [-w weight] [-X ...] [-x] [-y op_typ]
  input-file [output-file]
```

### DESCRIPTION

**ncwa** averages variables in a single file over arbitrary dimensions, with options to specify weights, masks, and normalization. See [Section 2.6 \[Averaging vs. Concatenating\], page 15](#), for a description of the distinctions between the various averagers and concatenators. The default behavior of **ncwa** is to arithmetically average every numerical variable over all dimensions and to produce a scalar result for each.

Averaged dimensions are, by default, eliminated as dimensions. Their corresponding coordinates, if any, are output as scalars. The ‘-b’ switch (and its long option equivalents ‘--rdd’ and ‘--retain-degenerate-dimensions’) causes **ncwa** to retain averaged dimensions as degenerate (size 1) dimensions. This maintains the association between a dimension (or coordinate) and variables after averaging and simplifies, for instance, later concatenation along the degenerate dimension.

To average variables over only a subset of their dimensions, specify these dimensions in a comma-separated list following ‘-a’, e.g., ‘-a time,lat,lon’. As with all arithmetic operators, the operation may be restricted to an arbitrary hyperslab by employing the ‘-d’ option (see [Section 3.14 \[Hyperslabs\], page 39](#)). **ncwa** also handles values matching the variable’s `_FillValue` attribute correctly. Moreover, **ncwa** understands how to manipulate user-specified weights, masks, and normalization options. With these options, **ncwa** can compute sophisticated averages (and integrals) from the command line.

*mask\_var* and *weight*, if specified, are broadcast to conform to the variables being averaged. The rank of variables is reduced by the number of dimensions which they are averaged over. Thus arrays which are one dimensional in the *input-file* and are averaged by **ncwa** appear in the *output-file* as scalars. This allows the user to infer which dimensions may have been averaged. Note that that it is impossible for **ncwa** to make a *weight* or *mask\_var* of rank *W* conform to a *var* of rank *V* if  $W > V$ . This situation often arises when coordinate variables (which, by definition, are one dimensional) are weighted and averaged. **ncwa** assumes you know this is impossible and so **ncwa** does not attempt to broadcast *weight* or *mask\_var* to conform to *var* in this case, nor does **ncwa** print a warning message telling you this, because it is so common. Specifying *dbg* > 2 does cause **ncwa** to emit warnings in these situations, however.

Non-coordinate variables are always masked and weighted if specified. Coordinate variables, however, may be treated specially. By default, an averaged coordinate variable, e.g., *latitude*, appears in *output-file* averaged the same way as any other variable containing an averaged dimension. In other words, by default **ncwa** weights and masks coordinate

variables like all other variables. This design decision was intended to be helpful but for some applications it may be preferable not to weight or mask coordinate variables just like all other variables. Consider the following arguments to `ncwa`: `-a latitude -w lat_wgt -d latitude,0.,90.` where `lat_wgt` is a weight in the `latitude` dimension. Since, by default `ncwa` weights coordinate variables, the value of `latitude` in the *output-file* depends on the weights in `lat_wgt` and is not likely to be 45.0, the midpoint latitude of the hyperslab. Option `'-I'` overrides this default behavior and causes `ncwa` not to weight or mask coordinate variables<sup>1</sup>. In the above case, this causes the value of `latitude` in the *output-file* to be 45.0, an appealing result. Thus, `'-I'` specifies simple arithmetic averages for the coordinate variables. In the case of `latitude`, `'-I'` specifies that you prefer to archive the arithmetic mean latitude of the averaged hyperslabs rather than the area-weighted mean latitude.<sup>2</sup>

As explained in See [Section 3.25 \[Operation Types\]](#), page 56, `ncwa` *always averages* coordinate variables regardless of the arithmetic operation type performed on the non-coordinate variables. This is independent of the setting of the `'-I'` option. The mathematical definition of operations involving rank reduction is given above (see [Section 3.25 \[Operation Types\]](#), page 56).

#### 4.12.1 Mask condition

Each  $x_i$  also has an associated masking weight  $m_i$  whose value is 0 or 1 (false or true). The value of  $m_i$  is always 1 unless a *mask\_var* is specified (with `'-m'`). As noted above, *mask\_var* is broadcast, if possible, to conform to the variable being averaged. In this case, the value of  $m_i$  depends on the *mask condition* also known as the *truth condition*. As expected,  $m_i = 1$  when the mask condition is *true* and  $m_i = 0$  otherwise.

The mask condition has the syntax *mask\_var mask\_comp mask\_val*. The preferred method to specify the mask condition is in one string with the `'-B'` or `'--mask_condition'` switches. The older method is to use the three switches `'-m'`, `'-T'`, and `'-M'` to specify the *mask\_var*, *mask\_comp*, and *mask\_val*, respectively.<sup>3</sup> The *mask\_condition* string is automatically parsed into its three constituents *mask\_var*, *mask\_comp*, and *mask\_val*.

Here *mask\_var* is the name of the masking variable (specified with `'-m'`, `'--mask-variable'`, `'--mask_variable'`, `'--msk_nm'`, or `'--msk_var'`). The truth *mask\_comp* argument (specified with `'-T'`, `'--mask_comparator'`, `'--msk_cmp_typ'`, or `'--op_rlt'`) may be any one of the six arithmetic comparators: *eq*, *ne*, *gt*, *lt*, *ge*, *le*. These are the Fortran-style character abbreviations for the logical comparisons `=`, `≠`, `>`, `<`, `≥`, `≤`. The mask comparator defaults to *eq* (equality). The *mask\_val* argument to `'-M'` (or `'--mask-value'`, or `'--msk_val'`) is the right hand side of the *mask condition*. Thus for the  $i$ 'th element of the hyperslab to be averaged, the mask condition is  $mask_i$  *mask\_comp* *mask\_val*.

Each  $x_i$  is also associated with an additional weight  $w_i$  whose value may be user-specified. The value of  $w_i$  is identically 1 unless the user specifies a weighting variable *weight* (with

<sup>1</sup> The default behavior of `'-I'` changed on 1998/12/01—before this date the default was not to weight or mask coordinate variables.

<sup>2</sup> If `lat_wgt` contains Gaussian weights then the value of `latitude` in the *output-file* will be the area-weighted centroid of the hyperslab. For the example given, this is about 30 degrees.

<sup>3</sup> The three switches `'-m'`, `'-T'`, and `'-M'` are maintained for backward compatibility and may be deprecated in the future. It is safest to write scripts using `'--mask_condition'`.

‘-w’, ‘--weight’, or ‘--wgt\_var’). In this case, the value of  $w_i$  is determined by the *weight* variable in the *input-file*. As noted above, *weight* is broadcast, if possible, to conform to the variable being averaged.

$M$  is the number of input elements  $x_i$  which actually contribute to output element  $x_j$ .  $M$  is also known as the *tally* and is defined as

$$M = \sum_{i=1}^{i=N} \mu_i m_i$$

$M$  is identical to the denominator of the generic averaging expression except for the omission of the weight  $w_i$ . Thus  $M = N$  whenever no input points are missing values or are masked. Whether an element contributes to the output, and thus increments  $M$  by one, has more to do with the above two criteria (missing value and masking) than with the numeric value of the element per se. For example,  $x_i = 0.0$  does contribute to  $x_j$  (assuming the `_FillValue` attribute is not 0.0 and location  $i$  is not masked). The value  $x_i = 0.0$  will not change the numerator of the generic averaging expression, but it will change the denominator (unless its weight  $w_i = 0.0$  as well).

### 4.12.2 Normalization and Integration

`ncwa` has one switch which controls the normalization of the averages appearing in the *output-file*. Short option ‘-N’ (or long options ‘--nmr’ or ‘--numerator’) prevents `ncwa` from dividing the weighted sum of the variable (the numerator in the averaging expression) by the weighted sum of the weights (the denominator in the averaging expression). Thus ‘-N’ tells `ncwa` to return just the numerator of the arithmetic expression defining the operation (see [Section 3.25 \[Operation Types\]](#), page 56).

With this normalization option, `ncwa` can integrate variables. Averages are first computed as sums, and then normalized to obtain the average. The original sum (i.e., the numerator of the expression in [Section 3.25 \[Operation Types\]](#), page 56) is output if default normalization is turned off (with ‘-N’). This sum is the integral (not the average) over the specified (with ‘-a’, or all, if none are specified) dimensions. The weighting variable, if specified (with ‘-w’), plays the role of the differential increment and thus permits more sophisticated integrals (i.e., weighted sums) to be output. For example, consider the variable `lev` where `lev = [100, 500, 1000]` weighted by the weight `lev_wgt` where `lev_wgt = [10, 2, 1]`. The vertical integral of `lev`, weighted by `lev_wgt`, is the dot product of `lev` and `lev_wgt`. That this is 3000.0 can be seen by inspection and verified with the integration command

```
ncwa -N -a lev -v lev -w lev_wgt in.nc foo.nc;ncks foo.nc
```

#### EXAMPLES

Given file ‘85\_0112.nc’:

```
netcdf 85_0112 {
  dimensions:
    lat = 64 ;
    lev = 18 ;
    lon = 128 ;
    time = UNLIMITED ; // (12 currently)
```

```

variables:
    float lat(lat) ;
    float lev(lev) ;
    float lon(lon) ;
    float time(time) ;
    float scalar_var ;
    float three_dmn_var(lat, lev, lon) ;
    float two_dmn_var(lat, lev) ;
    float mask(lat, lon) ;
    float gw(lat) ;
}

```

Average all variables in 'in.nc' over all dimensions and store results in 'out.nc':

```
ncwa in.nc out.nc
```

All variables in 'in.nc' are reduced to scalars in 'out.nc' since **ncwa** averages over all dimensions unless otherwise specified (with '-a').

Store the zonal (longitudinal) mean of 'in.nc' in 'out.nc':

```
ncwa -a lon in.nc out1.nc
ncwa -a lon -b in.nc out2.nc
```

The first command turns **lon** into a scalar and the second retains **lon** as a degenerate dimension in all variables.

```
% ncks -C -H -v lon out1.nc
lon = 135
% ncks -C -H -v lon out2.nc
lon[0] = 135
```

In either case the tally is simply the size of **lon**, i.e., 180 for the '85\_0112.nc' file described by the sample header above.

Compute the meridional (latitudinal) mean, with values weighted by the corresponding element of **gw**<sup>4</sup>:

```
ncwa -w gw -a lat in.nc out.nc
```

Here the tally is simply the size of **lat**, or 64. The sum of the Gaussian weights is 2.0.

Compute the area mean over the tropical Pacific:

```
ncwa -w gw -a lat,lon -d lat,-20.,20. -d lon,120.,270. in.nc out.nc
```

Here the tally is  $64 \times 128 = 8192$ .

Compute the area-mean over the globe using only points for which  $ORO < 0.5$ <sup>5</sup>:

```
ncwa -B 'ORO < 0.5' -w gw -a lat,lon in.nc out.nc
ncwa -m ORO -M 0.5 -T lt -w gw -a lat,lon in.nc out.nc
```

<sup>4</sup> **gw** stands for *Gaussian weight* in many climate models.

<sup>5</sup> **ORO** stands for *Orography* in some climate models and in those models  $ORO < 0.5$  selects ocean gridpoints.

It is considerably simpler to specify the complete *mask\_cond* with the single string argument to ‘-B’ than with the three separate switches ‘-m’, ‘-T’, and ‘-M’. If in doubt, enclose the *mask\_cond* within quotes since some of the comparators have special meanings to the shell.

Assuming 70% of the gridpoints are maritime, then here the tally is  $0.70 \times 8192 \approx 5734$ .

Compute the global annual mean over the maritime tropical Pacific:

```
ncwa -B 'ORO < 0.5' -w gw -a lat,lon,time \
-d lat,-20.0,20.0 -d lon,120.0,270.0 in.nc out.nc
ncwa -m ORO -M 0.5 -T lt -w gw -a lat,lon,time \
-d lat,-20.0,20.0 -d lon,120.0,270.0 in.nc out.nc
```

Further examples will use the one-switch specification of *mask\_cond*.

Determine the total area of the maritime tropical Pacific, assuming the variable *area* contains the area of each gridcell

```
ncwa -N -v area -B 'ORO < 0.5' -a lat,lon \
-d lat,-20.0,20.0 -d lon,120.0,270.0 in.nc out.nc
```

Weighting *area* (e.g., by *gw*) is not appropriate because *area* is *already* area-weighted by definition. Thus the ‘-N’ switch, or, equivalently, the ‘-y ttl’ switch, correctly integrate the cell areas into a total regional area.

Mask a file to contain *\_FillValue* everywhere except where  $thr\_min \leq msk\_var \leq thr\_max$ :

```
# Set masking variable and its scalar thresholds
export msk_var='three_dmn_var_dbl' # Masking variable
export thr_max='20' # Maximum allowed value
export thr_min='10' # Minimum allowed value
ncecat -O in.nc out.nc # Wrap out.nc in degenerate "record" dimension
ncwa -O -a record -B "${msk_var} <= ${thr_max}" out.nc out.nc
ncecat -O out.nc out.nc # Wrap out.nc in degenerate "record" dimension
ncwa -O -a record -B "${msk_var} >= ${thr_min}" out.nc out.nc
```

After the first use of *ncwa*, ‘out.nc’ contains *\_FillValue* where  $\{msk\_var\} \geq \{thr\_max\}$ . The process is then repeated on the remaining data to filter out points where  $\{msk\_var\} \leq \{thr\_min\}$ . The resulting ‘out.nc’ contains valid data only where  $thr\_min \leq msk\_var \leq thr\_max$ .



## 5 Contributing

We welcome contributions from anyone. The project homepage at <https://sf.net/projects/nco> contains more information on how to contribute.

Financial contributions to NCO development may be made through PayPal. NCO has been shared for over 10 years yet only two users have contributed any money to the developers<sup>1</sup>. So you could be the third!

### 5.1 Contributors

The primary contributors to NCO development have been:

Charlie Zender

Concept, design and implementation of operators from 1995-2000. Since then autotools, bug-squashing, chunking, documentation, packing, NCO library redesign, `ncap2` features, `ncbo`, `ncpdq`, SMP threading and MPI parallelization, netCDF4 integration, external funding, project management, science research, releases.

Henry Butowsky

Non-linear operations and `min()`, `max()`, `total()` support in `ncra` and `ncwa`. Type conversion for arithmetic. Migration to netCDF3 API. `ncap` parser, lexer, and I/O. Multislabbing algorithm. Variable wildcarding. Various hacks. `ncap2` language.

Rorik Peterson

Original autotool build support. Long command-line options. Original UDUnits support. Debianization. Numerous bug-fixes.

Daniel Wang

Script Workflow Analysis for MultiProcessing (SWAMP). RPM support.

Harry Mangalam

Benchmarking. OPeNDAP configuration.

Brian Mays

Original packaging for Debian GNU/Linux, `nroff` man pages.

George Shapovalov

Packaging for Gentoo GNU/Linux.

Bill Kocik Memory management.

Len Makin

NEC SX architecture support.

---

<sup>1</sup> Happy users have sent me a few gifts, though. This includes a box of imported chocolate. Mmm. Appreciation and gifts are definitely better than money. Naturally, I'm too lazy to split and send gifts to the other developers. However, unlike some NCO developers, I have a steady "real job". My intent is to split monetary donations among the active developers and to send them their shares via PayPal.

Jim Edwards

AIX architecture support.

Juliana Rew

Compatibility with large PIDs.

Karen Schuchardt

Auxiliary coordinate support.

Gayathri Venkitachalam

MPI implementation.

Scott Capps

Large work-load testing

Martin Dix, Mark Flanner, Keith Lindsay, Mike Page, Martin Schmidt, Michael Schulz,  
Remik Ziemplinski

Excellent bug reports and feature requests.

Markus Liebig

Proof-read the ncap documentation

Daniel Baumann, Barry deFreese, Francesco Lovergine, Matej Vela, Luk Claes

Debian packaging

Patrice Dumas, Ed Hill, Orion Poplawski

RedHat packaging

George Shapavalov, Patrick Kursawe

Gentoo packaging

Filipe Fernandes

OpenSuse packaging

Takeshi Enomoto, Alexander Hansen

Mac OS packaging

Eric Blake Autoconf/M4 help

Gavin Burris, Kyle Wilcox

RHEL and CentOS build scripts and bug reports.

Please let me know if your name was omitted!

## 5.2 Proposals for Institutional Funding

NSF has funded a **project** to improve Distributed Data Reduction & Analysis (DDRA) by evolving NCO into a suite of Scientific Data Operators called SDO. The two main components of this project are NCO parallelism (OpenMP, MPI) and Server-Side DDRA (SSDDRA) implemented through extensions to OPeNDAP and netCDF4. This project will dramatically reduce bandwidth usage for NCO DDRA.

With this first NCO proposal funded, the content of the next NCO proposal is clear. We are interested in obtaining NASA support for HDF-specific enhancements to NCO. We plan to submit a proposal to the next suitable NASA NRA or NSF opportunity.



We are considering a lot of interesting ideas for still more proposals. Please contact us if you wish to be involved with any future NCO-related proposals. Comments on the proposals and letters of support are also very welcome.



## 6 CCSM Example

This chapter illustrates how to use NCO to process and analyze the results of a CCSM climate simulation.

```
*****
Task 0: Finding input files
*****
The CCSM model outputs files to a local directory like:
```

```
/ptmp/zender/archive/T42x1_40
```

Each component model has its own subdirectory, e.g.,

```
/ptmp/zender/archive/T42x1_40/atm
/ptmp/zender/archive/T42x1_40/cpl
/ptmp/zender/archive/T42x1_40/ice
/ptmp/zender/archive/T42x1_40/lnd
/ptmp/zender/archive/T42x1_40/ocn
```

within which model output is tagged with the particular model name

```
/ptmp/zender/archive/T42x1_40/atm/T42x1_40.cam2.h0.0001-01.nc
/ptmp/zender/archive/T42x1_40/atm/T42x1_40.cam2.h0.0001-02.nc
/ptmp/zender/archive/T42x1_40/atm/T42x1_40.cam2.h0.0001-03.nc
...
/ptmp/zender/archive/T42x1_40/atm/T42x1_40.cam2.h0.0001-12.nc
/ptmp/zender/archive/T42x1_40/atm/T42x1_40.cam2.h0.0002-01.nc
/ptmp/zender/archive/T42x1_40/atm/T42x1_40.cam2.h0.0002-02.nc
...
```

or

```
/ptmp/zender/archive/T42x1_40/lnd/T42x1_40.clm2.h0.0001-01.nc
/ptmp/zender/archive/T42x1_40/lnd/T42x1_40.clm2.h0.0001-02.nc
/ptmp/zender/archive/T42x1_40/lnd/T42x1_40.clm2.h0.0001-03.nc
...
```

```
*****
Task 1: Regional processing
*****
The first task in data processing is often creating seasonal cycles.
Imagine a 100-year simulation with its 1200 monthly mean files.
Our goal is to create a single file containing 12 months of data.
Each month in the output file is the mean of 100 input files.
```

Normally, we store the "reduced" data in a smaller, local directory.

```

caseid='T42x1_40'
#drc_in="${DATA}/archive/${caseid}/atm"
drc_in="${DATA}/${caseid}"
drc_out="${DATA}/${caseid}"
mkdir -p ${drc_out}
cd ${drc_out}

```

Method 1: Assume all data in directory applies

```

for mth in {1..12}; do
    mm='printf "%02d" $mth'
    ncra -O -D 1 -o ${drc_out}/${caseid}_clm${mm}.nc \
        ${drc_in}/${caseid}.cam2.h0.*-${mm}.nc
done # end loop over mth

```

Method 2: Use shell 'globbing' to construct input filenames

```

for mth in {1..12}; do
    mm='printf "%02d" $mth'
    ncra -O -D 1 -o ${drc_out}/${caseid}_clm${mm}.nc \
        ${drc_in}/${caseid}.cam2.h0.00??-${mm}.nc \
        ${drc_in}/${caseid}.cam2.h0.0100-${mm}.nc
done # end loop over mth

```

Method 3: Construct input filename list explicitly

```

for mth in {1..12}; do
    mm='printf "%02d" $mth'
    fl_lst_in=''
    for yr in {1..100}; do
        yyyy='printf "%04d" $yr'
        fl_in=${caseid}.cam2.h0.${yyyy}-${mm}.nc
        fl_lst_in="${fl_lst_in} ${caseid}.cam2.h0.${yyyy}-${mm}.nc"
    done # end loop over yr
    ncra -O -D 1 -o ${drc_out}/${caseid}_clm${mm}.nc -p ${drc_in} \
        ${fl_lst_in}
done # end loop over mth

```

Make sure the output file averages correct input files!  
ncks -M prints global metadata:

```
ncks -M ${drc_out}/${caseid}_clm01.nc
```

The input files ncra used to create the climatological monthly mean will appear in the global attribute named 'history'.

Use ncr\_cat to aggregate the climatological monthly means

```
ncr_cat -O -D 1 \
```

```
{drc_out}/{caseid}_clm??nc {drc_out}/{caseid}_clm_0112.nc
```

Finally, create climatological means for reference.

The climatological time-mean:

```
ncra -O -D 1 \
    {drc_out}/{caseid}_clm_0112.nc {drc_out}/{caseid}_clm.nc
```

The climatological zonal-mean:

```
ncwa -O -D 1 -a lon \
    {drc_out}/{caseid}_clm.nc {drc_out}/{caseid}_clm_x.nc
```

The climatological time- and spatial-mean:

```
ncwa -O -D 1 -a lon,lat,time -w gw \
    {drc_out}/{caseid}_clm.nc {drc_out}/{caseid}_clm_xyt.nc
```

This file contains only scalars, e.g., "global mean temperature", used for summarizing global results of a climate experiment.

Climatological monthly anomalies = Annual Cycle:

Subtract climatological mean from climatological monthly means.

Result is annual cycle, i.e., climate-mean has been removed.

```
ncbo -O -D 1 -o {drc_out}/{caseid}_clm_0112_anm.nc \
    {drc_out}/{caseid}_clm_0112.nc {drc_out}/{caseid}_clm_xyt.nc
```

```
*****
```

Task 2: Correcting monthly averages

```
*****
```

The previous step approximates all months as being equal, so, e.g.,

February weighs slightly too much in the climatological mean.

This approximation can be removed by weighting months appropriately.

We must add the number of days per month to the monthly mean files.

First, create a shell variable dpm:

```
unset dpm # Days per month
declare -a dpm
dpm=(0 31 28.25 31 30 31 30 31 31 30 31 30 31) # Allows 1-based indexing
```

Method 1: Create dpm directly in climatological monthly means

```
for mth in {1..12}; do
```

```
    mm='printf "%02d" ${mth}';
```

```
    ncap2 -O -s "dpm=0.0*date+${dpm[${mth}]}" \
```

```
        {drc_out}/{caseid}_clm${mm}.nc {drc_out}/{caseid}_clm${mm}.nc
```

```
done # end loop over mth
```

```

Method 2: Create dpm by aggregating small files
for mth in {1..12}; do
    mm=$(printf "%02d" ${mth})
    ncaps2 -O -v -s "dpm=${dpm[${mth}]}" ~/nco/data/in.nc \
        ${drc_out}/foo_${mm}.nc
done # end loop over mth
ncecat -O -D 1 -p ${drc_out} -n 12,2,2 foo_${mm}.nc foo.nc
ncrename -O -D 1 -d record,time ${drc_out}/foo.nc
ncatted -O -h \
    -a long_name,dpm,o,c,"Days per month" \
    -a units,dpm,o,c,"days" \
    ${drc_out}/${caseid}_clm_0112.nc
ncks -A -v dpm ${drc_out}/foo.nc ${drc_out}/${caseid}_clm_0112.nc

```

```

Method 3: Create small netCDF file using ncgen
cat > foo.cdl << 'EOF'
netcdf foo {
dimensions:
time=unlimited;
variables:
float dpm(time);
dpm:long_name="Days per month";
dpm:units="days";
data:
dpm=31,28.25,31,30,31,30,31,31,30,31,30,31;
}
EOF
ncgen -b -o foo.nc foo.cdl
ncks -A -v dpm ${drc_out}/foo.nc ${drc_out}/${caseid}_clm_0112.nc

```

Another way to get correct monthly weighting is to average daily output files, if available.

\*\*\*\*\*

### Task 3: Regional processing

\*\*\*\*\*

Let's say you are interested in examining the California region.  
Hyperslab your dataset to isolate the appropriate latitude/longitudes.

```

ncks -O -D 1 -d lat,30.0,37.0 -d lon,240.0,270.0 \
    ${drc_out}/${caseid}_clm_0112.nc ${drc_out}/${caseid}_clm_0112-Cal.nc

```

The dataset is now much smaller!  
To examine particular metrics.

\*\*\*\*\*

## Task 4: Accessing data stored remotely

```
*****
```

OPeNDAP server examples:

UCI DAP servers:

```
ncks -M -p http://dust.ess.uci.edu/cgi-bin/dods/nph-dods/dodsdata in.nc
ncrcat -O -C -D 3 -p http://dust.ess.uci.edu/cgi-bin/dods/nph-dods/dodsdata \
-l /tmp in.nc in.nc ~/foo.nc
```

Unidata DAP servers:

```
ncks -M -p http://motherlode.ucar.edu:8080/thredds/dodsC/testdods in.nc
ncrcat -O -C -D 3 -p http://motherlode.ucar.edu:8080/thredds/dodsC/testdods \
-l /tmp in.nc in.nc ~/foo.nc
```

NOAA DAP servers:

```
ncwa -O -C -a lat,lon,time -d lon,-10.,10. -d lat,-10.,10. -l /tmp -p \
http://www.esrl.noaa.gov/psd/thredds/dodsC/Datasets/ncep.reanalysis.dailyavgs/surface
pres.sfc.1969.nc ~/foo.nc
```

LLNL PCMDI IPCC OPeNDAP Data Portal:

```
ncks -M -p http://username:password@esgcet.llnl.gov/cgi-bin/dap-cgi.py/ipcc4/sresa1b/n
```

Earth System Grid (ESG): <http://www.earthsystemgrid.org>

```
caseid='b30.025.ES01'
```

```
CCSM3.0 1% increasing CO2 run, T42_gx1v3, 200 years starting in year 400
```

```
Atmospheric post-processed data, monthly averages, e.g.,
```

```
/data/zender/tmp/b30.025.ES01.cam2.h0.TREFHT.0400-01_cat_0449-12.nc
```

```
/data/zender/tmp/b30.025.ES01.cam2.h0.TREFHT.0400-01_cat_0599-12.nc
```

ESG supports password-protected FTP access by registered users

NCO uses the .netrc file, if present, for password-protected FTP access

Syntax for accessing single file is, e.g.,

```
ncks -O -D 3 \
-p ftp://climate.llnl.gov/sresa1b/atm/mo/tas/ncar_ccsm3_0/run1 \
-l /tmp tas_A1.SRESA1B_1.CCSM.atmm.2000-01_cat_2099-12.nc ~/foo.nc
```

```
# Average surface air temperature tas for SRESA1B scenario
```

```
# This loop is illustrative and will not work until NCO correctly
```

```
# translates '*' to FTP 'mget' all remote files
```

```
for var in 'tas'; do
```

```
for scn in 'sresa1b'; do
```

```
for mdl in 'cccma_cgcm3_1 cccma_cgcm3_1_t63 cnrm_cm3 csiro_mk3_0 \
```

```
gfdl_cm2_0 gfdl_cm2_1 giss_aom giss_model_e_h giss_model_e_r \
```

```
iap_fgoals1_0_g inmcm3_0 ipsl_cm4 miroc3_2_hires miroc3_2_medres \
```

```
miub_echo_g mpi_echam5 mri_cgcm2_3_2a ncar_ccsm3_0 ncar_pcm1 \
```

```
ukmo_hadcm3 ukmo_hadgem1'; do
```

```

for run in '1'; do
    ncks -R -O -D 3 -p ftp://climate.llnl.gov/${scn}/atm/mo/${var}/${mdl}/run${run}
done # end loop over run
done # end loop over mdl
done # end loop over scn
done # end loop over var

```

```

cd sresa1b/atm/mo/tas/ukmo_hadcm3/run1/
ncks -H -m -v lat,lon,lat_bnds,lon_bnds -M tas_A1.nc | m
bds -x 096 -y 073 -m 33 -o ${DATA}/data/dst_3.75x2.5.nc # ukmo_hadcm3
ncview ${DATA}/data/dst_3.75x2.5.nc

```

```

# msk_rgn is California mask on ukmo_hadcm3 grid
# area is correct area weight on ukmo_hadcm3 grid
ncks -A -v area,msk_rgn ${DATA}/data/dst_3.75x2.5.nc \
${DATA}/sresa1b/atm/mo/tas/ukmo_hadcm3/run1/area_msk_ukmo_hadcm3.nc

```

Template for standardized data:

```

${scn}_${mdl}_${run}_${var}_${yyyymm}_${yyyymm}.nc

```

e.g., raw data

```

${DATA}/sresa1b/atm/mo/tas/ukmo_hadcm3/run1/tas_A1.nc

```

becomes standardized data

Level 0: raw from IPCC site--no changes except for name

Make symbolic link name match raw data

Template: `${scn}_${mdl}_${run}_${var}_${yyyymm}_${yyyymm}.nc`

```

ln -s -f tas_A1.nc sresa1b_ukmo_hadcm3_run1_tas_200101_209911.nc
area_msk_ukmo_hadcm3.nc

```

Level I: Add all variables (but not standardized in time)

to file containing msk\_rgn and area

Template: `${scn}_${mdl}_${run}_${yyyymm}_${yyyymm}.nc`

```

/bin/cp area_msk_ukmo_hadcm3.nc sresa1b_ukmo_hadcm3_run1_200101_209911.nc
ncks -A -v tas sresa1b_ukmo_hadcm3_run1_tas_200101_209911.nc \
sresa1b_ukmo_hadcm3_run1_200101_209911.nc
ncks -A -v pr sresa1b_ukmo_hadcm3_run1_pr_200101_209911.nc \
sresa1b_ukmo_hadcm3_run1_200101_209911.nc

```

If already have file then:

```

mv sresa1b_ukmo_hadcm3_run1_200101_209911.nc foo.nc
/bin/cp area_msk_ukmo_hadcm3.nc sresa1b_ukmo_hadcm3_run1_200101_209911.nc
ncks -A -v tas,pr foo.nc sresa1b_ukmo_hadcm3_run1_200101_209911.nc

```

Level II: Correct # years, months



Template: \${scn}\_\${mdl}\_\${run}\_\${var}\_\${yyyymm}\_\${yyyymm}.nc

```
ncks -d time,..... file1.nc file2.nc
ncrcat file2.nc file3.nc sresa1b_ukmo_hadcm3_run1_200001_209912.nc
```

Level III: Many derived products from level II, e.g.,

A. Global mean timeseries

```
ncwa -w area -a lat,lon \
      sresa1b_ukmo_hadcm3_run1_200001_209912.nc \
sresa1b_ukmo_hadcm3_run1_200001_209912_xy.nc
```

B. California average timeseries

```
ncwa -m msk_rgn -w area -a lat,lon \
      sresa1b_ukmo_hadcm3_run1_200001_209912.nc \
sresa1b_ukmo_hadcm3_run1_200001_209912_xy_Cal.nc
```



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