NCAR Command Language
(NCL)

Mini-Language Reference Manual

NCL Version 6.4.0 February 2017

This manual includes a brief description of the NCL language, file IO, printing, data processing, command line options, and using external codes. Send direct comments about this manual to **ncl-talk@ucar.edu**.

http://www.ncl.ucar.edu/Document/Manuals/

`keyword`	courier-bold
`built-in functions`	courier-bold blue
`contributed functions`	courier-bold green
symbols	bold
`plot templates`	courier-bold green
`plot resources`	courier-bold
user variables	italics
WWW links	underline

Section 1: Introduction

The NCAR Command Language (NCL) is an interpreted programming language, specifically designed for the access, analysis, and visualization of data. NCL has many features common to modern programming languages: variables (numeric and non-numeric types), operators, expressions, conditional statements, loops, and functions and procedures. The most complete and current documentation for NCL is the Reference Manual located at:

http://www.ncl.ucar.edu/Document/Manuals/Ref_Manual/

NCL may already be installed on your local system. If not, NCL binaries and source code are free and are available for the most common Linux/Unix, MacOSX and Cygwin (Windows) operating systems. Click "Download" at:

http://www.ncl.ucar.edu/

Section 1.1 Setting the user path

In order to run NCL, you must set your NCARG_ROOT environment variable to the *root* location of where the NCL software is installed. You also need to make sure that the directory where the NCL executables reside is in your search path. It is best to do this from one of your .* files in your home directory. If you are not sure which shell you are running, you can do an "echo $SHELL".

One of the most common errors after NCL installation is that the NCARG_ROOT environment variable has not been set or has been set incorrectly. If NCL resides in (say) `/usr/local`, the following setting would be appropriate:

From C-shell (csh):

```
setenv NCARG_ROOT /usr/local
setenv PATH $NCARG_ROOT:${PATH}
```

From bash, ksh:

```
export NCARG_ROOT=/usr/local
export PATH=/usr/local/bin:$PATH
```

If an error is encountered, please see the following for more details:

http://www.ncl.ucar.edu/FAQ/#err_msgs_002

Section 1.2 Executing NCL

NCL may be executed interactively. NCL is case sensitive, and all statements require a return to terminate a statement. NCL's interactive environment is not as sophisticated as some other tools but it is adequate for simple tasks. Note that it is possible to save the statements entered using the optional **record** and **stop record** statements (Section 2.6).

Interactive mode:

```
ncl <return>
  record "savefile"              ; optional (this is not commonly used)
  statement(s)
 stop record                     ; only if record is present
quit
```

Batch mode: When a script containing a sequence of prewritten NCL statements is executed it is called batch-mode. Batch-mode scripts often have a "**.ncl**" suffix. However, this is a convention only and is not required. The batch-mode script may be invoked at the command line via:

```
ncl foo.ncl
ncl foo.ncl>&! foo.out   [C-Shell; output sent to foo.out]
ncl foo.ncl>&! foo.out & [C-Shell; run in background]
ncl < foo.ncl            [acceptable but not often used]
```

NCL allows the user to specify several options on the command line that may alter NCL's behavior. Using "ncl –h" will display currently supported options. See Section 6.

External NCL functions/procedures (Section 5) and shared objects (Section 7) can be accessed in interactive or batch mode via:

```
load "myfoo.ncl"
load "$HOME/myscripts/funct.ncl"
external DEMO "/tmp/Path/myfoo.so"
```

Section 2: Language

Section 2.1 Symbols

NCL has a suite of syntax symbols that facilitate assorted tasks. Commonly used syntax symbols include:

;	begins a comment. Text to the right of **;** is ignored.
/; … ;/	Block comment; all text/lines bracketed are ignored (available in V6.4.0)
=	assignment
:=	reassignment (available in V6.1.2)
@	create or reference attributes
!	create or reference named dimensions
&	create or reference a coordinate variable
{...}	used for coordinate subscripting
$	enclose strings when importing/exporting variables via **addfile**
[...]	subscript variables of type **list**

(/.../)	construct an array
:	used in array syntax
|	used as a separator for named dimensions
\	continue statement for spanning multiple lines
: :	used as separator when calling external codes
->	used for variable input/output with supported data formats
=>	used to access netCDF-4/HDF5 groups

Section 2.2 Data types

Numeric: double (64 bit), float (32 bit), long (32 or 64 bit), integer (32 bit), short (16 bit), byte (8 bits), complex is not supported. NCL v6.0.0 was expanded to include many additional numeric types. This was done to be consistent with the numeric types supported by netCDF4 and HDF5.

Non-numeric: string, character, graphic, file, logical, list.

Please see a complete description of NCL's data types at

http://www.ncl.ucar.edu/Document/Manuals/Ref_Manual/NclDataTypes.shtml

Section 2.3 Reserved keywords

`begin, break, byte, character, continue, create, defaultapp, do, double, else, end, enumeric, external, False, file, float, function, getvalues, graphic, if, integer, int64, list, load, local, logical, long, _Missing, Missing, new, noparent, numeric, procedure, quit, Quit, QUIT, record, return, setvalues, short, string, then, True, undef, while` and all built-in function and procedure names. A current list of all NCL keywords is at:

http://www.ncl.ucar.edu/Document/Manuals/Ref_Manual/NclKeywords.shtml

Section 2.4 Expressions

Precedence rules can be circumvented by use of parentheses "(...)" around expressions. NCL does not operate on any array element set to **`_FillValue`** (see section 2.13).

Algebraic operators:

+	addition (+ is an overloaded operator; also used for string concatenation)
-	subtraction
*****	multiplication
^	exponent
%	modulus, integers only

#	matrix multiply
>, <	greater than, less than (sometimes called “clipping” operators)

Logical:

.lt.	less than
.le.	less than or equal to
.gt.	greater than
.ne.	not equal to
.eq.	equal to
.and.	and
.or.	or
.xor.	exclusive or
.not.	not

Section 2.5 Variables

Variable names must begin with an alphabetic character but can contain any mix of numeric and alphabetic characters. The underscore "_" is also allowed. NCL variables are based upon the netCDF variable model. As such, variables may have ancillary information (called metadata) attached to the variable. Metadata may be accessed, created, changed and deleted via NCL functions and syntax (see sections 2.11-2.13).

Variables imported via NCL’s **`addfile`** or **`addfiles`** functions (Section 3) will have all available metadata automatically attached to the variable. This greatly simplifies coding and access to each variable’s metadata.

Section 2.6 Statements

Statements are the fundamental element of NCL. Everything NCL does happens only after a statement is entered. Statements are case sensitive and are not restricted to being a single line of source, and statements can be nested within statements. There are 17 different kinds of statements: assignment, procedure call, function definition, procedure definition, block, do, if-then, if-then-else, break, continue, setvalues, getvalues, return, record, new, stop, and quit.

Section 2.7 Loops

NCL provides two kinds of do loops: a **while** loop that repeats until its *scalar_logical_expression* evaluates to False, and a traditional **do** loop that loops from a start value through an end value incrementing or decrementing a loop variable either by one or by a specified stride.

```
do n=start,end,optional_stride
     [statement(s)]
end do                                ; space is required
```

```
do while (scalar_logical_expression)
       [statement(s)]
end do
```

With each kind of loop, the keywords ***break*** and ***continue*** can be used.

`break`: jump to first statement after `end do`

`continue`: proceed directly to the next iteration

Use of loops should be minimized in any interpreted language. Often, loops can be replaced by array syntax or a built-in function. If multiple **do** loops are required and execution speed is a concern, linking codes written in Fortran or C may be the best approach. (Section 7.)

Section 2.8 Blocks and if statements

Blocks provide a way to group a list of statements. Since blocks are statements, the statements within the **begin** and **end** do not get executed until the **end** statement is parsed and the source is determined to be free of syntax errors. The use of **begin** and **end** is optional for the main or driver script.

```
begin                          ; optional but recommended
     [statement(s)]
end                            ; required if begin present
```

There are two kinds of **if** statements: the **if-then** statement and the **if-then-else** statement. These function like **if** statements in other popular programming languages.

```
if (scalar_logical_expression) then
     [statement(s)]
end if

if (scalar_logical_expression) then
     [statement(s)]
else
     [statement(s)]
end if
```

Technically, there is no explicit `else if` statement in NCL. However, nested **if** statements can be used. Each **if** must have a corresponding **end if**.

```
if (scalar_logical_expression) then
     [A_statement(s)]
  else if (scalar_logical_expression) then
     [B_statement(s)]
  else if (scalar_logical_expression) then
     [C_statement(s)]
  else
      [D_statement(s)]
```

```
    end if                    ; C & D
    end if                    ; B
  end if                      ; A
```

Logical expressions are evaluated left to right, so in multiple expression statements, place the expression most likely to fail on the left:

```
  if (z.eq.3 .and. all(x.gt.0)) then
       [statement(s)]
  end if
```

Section 2.9 Dimensions and subscripting

There are two types of array subscripting in NCL: standard and coordinate. Standard subscripting features are similar to the array subscripting available in F90, Matlab, and IDL. In addition, NCL dimensions may have names associated with them (Section 2.10). NCL subscript indices start at 0 and end at *N*-1. Like the C computer language, NCL is row major. For multidimensional arrays this means that the rightmost subscript varies fastest and the leftmost subscript varies slowest. Subscripts have the form:

start_index **:** *end_index* **:** *optional_stride*

Omission of *start_index* defaults to 0; omission of *end_index* defaults to *N*-1; the default *optional_stride* is 1. Therefore, a "**:**" without a start or end index means all elements.

Section 2.9.1 Standard subscripting may be used to index any array variable. For the following examples, assume variable *T* is a 3D array of size (nt, ny, nx) with named dimensions (time, lat, lon).

```
                           Index
  T                   ; entire array [don't need T(:,:,:)]
  T(0,:,::5)          ; 1st time, all lat, every 5th lon
  T(0,::-1,4:50)      ; 1st time, reverse lat, lon index values 4-50
  T(:1,45,10:20)      ; 1st two time, 46th lat, 10-20 lon
```

Section 2.9.2 Coordinate subscripting may be used for any dimension conforming to the netCDF coordinate variable data model. By definition, coordinate variables must be one-dimensional arrays of monotonically increasing or decreasing values where the variable's name and associated dimension name are the same (e.g. time(time), lat(lat), p(p), *etc.*). Coordinate subscripting is invoked by enclosing the natural coordinates between curly braces "**{...}**".

```
  X = T(:,{-20:20},{90:290:2})
```

Select all time, -20 to 20 latitude inclusive, 90 to 290 longitude with a stride of 2.

Section 2.10 Dimension reduction

When a constant subscript is specified, dimension reduction occurs. This means the rank of the array is reduced (*ie*., fewer dimensions). Assume *T* is dimensioned (`nt`, `nz`, `ny`, `nx`), then:

```
T1 = T(5,:,12,:)  ; yields T1(nz,nx); the 5 and 12 are degenerate
T2 = T(:,:,:,0)   ; yields T2(nt,nz,ny); the 0 is degenerate
```

NCL ignores the degenerate dimension but all appropriate metadata are copied. The user may force retention of the degenerate dimension via:

```
T3 = T(5:5,:,12,:)            ; T3(1,nz,nx)
T4 = T(5:5,:,12:12,:)         ; T4(1,nz,1,nx)
```

Section 2.11 Named dimensions

All variables read from netCDF, GRIB and HDF files have named dimensions. In addition, users may name or rename a dimension. Named dimensions are only used to reshape an array (e.g. transpose). The **!** symbol is used to create a named dimension or to retrieve a dimension name. Dimension numbering proceeds from left-to-right with the leftmost dimension equal to 0. Assume *T* is 3D array with size (ntime, nlat, nlon):

Assignment of named dimensions via **!** syntax:

```
T!0   = "time"
T!1   = "lat"
T!2   = "lon"
```

Retrieval of named dimensions:

```
LAT   = T!1       ; LAT = "lat"
```

Section 2.11.1 Dimension reordering: Named dimensions should *only* be used when dimension reordering is required.

```
reordered_T = T(lon|:,lat|:,time|:)         ; (lon,lat,time)
```

Named dimensions are not subscripts. However, named dimensions can be used with coordinate and standard subscripting.

```
X = T({lat|-20:20}, lon|30:42, time|:)
```

(Reorder to (lat,lon,time) and select latitudes –20 to 20, longitude indices 30 through 42, all time values.)

Section 2.12 Coordinate variables

By netCDF definition, a coordinate variable is a one-dimensional array containing monotonically increasing or decreasing values that has the same name and size as the dimension to which they are assigned (e.g. `time(time)`, `level(level)`, `lat(lat)`, *etc.*). Coordinate variables represent the data coordinates for each index in a named dimension and can be used in coordinate subscripting. The **&** operator is used to reference and assign coordinate variables. In order to assign a coordinate variable to a dimension, the dimension must first have a name associated with it:

```
T!0     = "lat"                          ; name a dimension
T!1     = "lon"
T&lat   = (/-90.,-85.,...,85.,90./)  ; assign values to named dim
T&lon   = fspan(0.,355.,72)
```

(See section 5.3 for a description of the array constructors **(/…/)**.)

Section 2.13 Attributes

Attributes are descriptive information that may be associated with an existing variable. They are very useful for communicating information to the user about specific data. Variable attributes are referenced by entering the variable name, followed by the symbol **@** and the attribute name:

```
T@units           = "Degrees C"      ; assign attribute
T@_FillValue      =  -9999.0         ; assign scalar float
T@wgt             = (/.25,.50,.25/) ; assign 1D array
W                 = T@wgt            ; retrieve attribute
```

Attributes can be used in expressions and subscripted in the same fashion as variables:

```
T = TS * TS@scale_factor + TS@add_offset
```

Note this equation uses array syntax (see section 5.1).

Section 2.14 _Fill Value

The attribute **`_FillValue`** is a netCDF and NCL reserved attribute name that indicates missing values. Some graphics and algebraic operations treat **`_FillValue`** in a special way. Note that the attribute "missing_value" has no special status in NCL. If your data has a "missing_value" attribute but no **`_FillValue`** attribute, you can assign it:

```
x@_FillValue = x@missing_value
```

Section 2.15 Coercion

Coercion is the implicit conversion of data from one data type to another. This occurs when two or more values of different variable types are operands to the same operator. A simple example is:

```
X = 5.2 + 9
```

Here 5.2 is of type float while 9 is of type integer. In this case, the 9 is silently coerced (promoted) to float prior to the addition. NCL will automatically coerce when no information is lost. If *K* is of type integer and *X* is of type float (or double) then the following statement would result in a fatal error (no coercion because information is possibly lost):

```
K = X
```

When information may be lost, explicit conversion functions must be used.

```
K = toint(X)
```

Variables of type double may be explicity created using the "d" format:

```
x = 23431234.0d
```

Other type conversion functions and qualifiers may be found at:

http://www.ncl.ucar.edu/Document/Functions/type_convert.shtml

Section 2.16 Variables and metadata

There are two types of assignments in NCL, value-only assignments and variable-to-variable assignments. Only the latter copies metadata.

Value-only assignments occur when the right side of the assignment is not a variable. The right side can be a constant, the result of an expression, or the result of the array constructor syntax **(/…/).** No dimension names, coordinate variables or attributes other than **_FillValue** are assigned. If the right side of the expression does not contain any missing values, then **_FillValue** is not assigned. Examples:

```
a  =  (/1,2,3,4,5,6,7,8,9,10/)
b  =  ispan(1,10,1)
q  =  w * sin(z) + 5
b  =  19911231.5d    ; double
```

If the left side was defined prior to the assignment statement, then the value on the left side is assigned the value of the right side. If the left side is a subscripted reference to a variable, then the right side elements are mapped to the appropriate location in the left side variable. If the left side has any attributes, dimension names, or coordinate variables, they will be left unchanged since only values are being assigned to the left side variable. For example, assume *T* is a variable which has named dimensions, coordinate arrays, and attributes. Further, *T* contains temperature data and has a units attribute such that:

```
T@units = "degC"
```

indicating that the units are degrees Celsius. Converting to degrees Kelvin would be a value-only assignment (no metadata transferred) because the right side is an expression:

```
    T = T + 273.15
```

T would retain its original metadata including the units attribute. In this case, it is the user's responsibility to update the units attribute:

```
    T@units = "degK"
```

Variable-to-variable assignments means all attributes, coordinate variables, and dimension names, in addition to the actual values, are assigned. Assignment occurs when both the left side and the right side are variables. If *y* did not exist, then *y=x* would result in *y* being an exact copy of *x* including any metadata. If *y* was previously defined, then *x* must be of the same type (or be coercible to the type of *y*), and *x* must have the same dimensionality as *y*. Further, if *y* had metadata then the metadata associated with *x* would replace those associated with *y*. It is important to note that the array constructor characters **(/…/)** can be used to assign one variable to another so that only values are assigned while attributes, dimensions, and coordinates variables are ignored. For example:

```
    y = (/ x /)   ; y same size, shape, type as x; no meta data
```

Section 2.17 Variable Reassignment

NCL is a strongly typed language. By default, it will not allow a variable to be dynamically reassigned like (say) Matlab, Python or IDL. For example, let

```
    k = (/1,2,3,8/)     ; type integer, size 4
```

NCL **will allow** the following (rhs means 'right hand side'):

```
    k = (/4,5,6,9/)     ; rhs is same type and size
```

NCL **will not allow** the following:

```
    k = (/1,2,3,8/)*1.0 ; rhs is float  (different type)
    k = (/1,2,3,8,9/)   ; rhs is size 5 (different size)
```

Prior to v6.1.2, the user would have to **delete**(k) prior to the assignment. NCL v6.1.2 introduced a new **re**assignment operator invoked by the **:=** syntax. This allows dynamic reassignment (no need to explicitly delete the variable prior to assignment):

```
    k := (/1,2,3,8/)*1.0
    k := (/1,2,3,8,9/)
```

The **re**assignment operator is commonly used in loops where array sizes change with each iteration.

Section 2.18 Variable of Type List (Container Variable)

A variable of type list can contain multiple variables. Consider, three variables

```
     a = ...   ; may have meta data (type double)
     b = ...   ;  "   "     "    "  (type string)
     c = ...   ;  "   "     "    "  (type integer)
```

A list variable can be created via the [/…/] syntax

```
       myList = [/ a,b,c /]    ; create a variable of type list
```

A more complete description may be found (search for 'List variables') at:

http://www.ncl.ucar.edu/Document/Manuals/Ref_Manual/NclVariables.shtml

Section 3: NCL File input/output

NCL has excellent file support for a variety of common data formats.

Section 3.1 Supported formats

File formats that are known to NCL are called supported formats. These formats include netCDF3/4, HDF4 (Scientific Data Set), HDF4-EOS, HDF5, HDF5-EOS, GRIB-1, GRIB-2, shapefile, and CCM History Tape format (Cray only).   For details see:

http://www.ncl.ucar.edu/Document/Manuals/Ref_Manual/NclFormatSupport.shtml

Section 3.1.1 Creation of a file reference

The function, **addfile**, can be used to import all supported formats:

```
      f = addfile (fname.ext, status)
```

f is a reference or pointer to a file. It can be any valid variable name. *fname* is the full or relative path of the data file. Supported formats have different (case insensitive) file extensions (*ext*). NCL recognizes most commonly encountered file extensions. Some of the more common are indicated below.

status:	"r"	[read: *all* supported formats]
	"c"	[create: netCDF, HDF *only*]
	"w"	[read/write: netCDF, HDF *only*]

Examples:

```
                                               ; some other .ext
      f    = addfile("foo.nc", "r")            ; .cdf, .nc4
      grb  = addfile("/my/dir/foo.grb", "r")   ; .grib1, .grib2
      hdf  = addfile("/your/hdf/foo.hdf","c")  ; .h5, .hdf5
      heos = addfile("foo.hdfeos", "r")        ; .he2,.he5
```

Alternate ways of specifying the file path include:

```
diri  = "/some/path/"
fili  = "space.nc4"
sat   = addfile(diri+fili, "r")

diri  = "~/some/other/path/"
fili  = "gpm"
ext   = ".h5"
sat   = addfile(diri+fili+ext, "r")
```

A nice feature of **addfile** is that the file on the disk need *not* have the file extension attached to the file name. E.g., if a grib file is named "foo", **addfile**("foo.grb", "r") will initially search for a file named foo.grb. If the file does not exist under the specified name, **addfile** will search for a file named "foo" and treat it as a GRIB file.

The introduction of HDF-5 and netCDF-4 (which is a restricted subset of HDF-5) required enhancements to internal file and variable structures. The user can require that NCL use the advanced structure when invoking NCL via '**ncl –f**' (see Section 6.1) or within a script via the **setfileoption** procedure (Section 3.1.8).

Section 3.1.2 Reading Variables from Supported File Formats

Importing (reading) variables from any supported format is simple. If *X* is a variable on a file referenced (pointed-to) by *f*, then:

```
x = f->X
```

If variable metadata (attributes and/or coordinate variables) are available they will automatically be attached to the variable *x*. The user need not explicitly read any attributes or coordinate. An important NCL feature is that when a variable is imported, it is placed into a consistent variable model (data structure) regardless of the original source file format (netCDF-3/4, HDF-4/5, GRIB-1/2, shapefile). This facilitates data processing and the creation of generic functions.

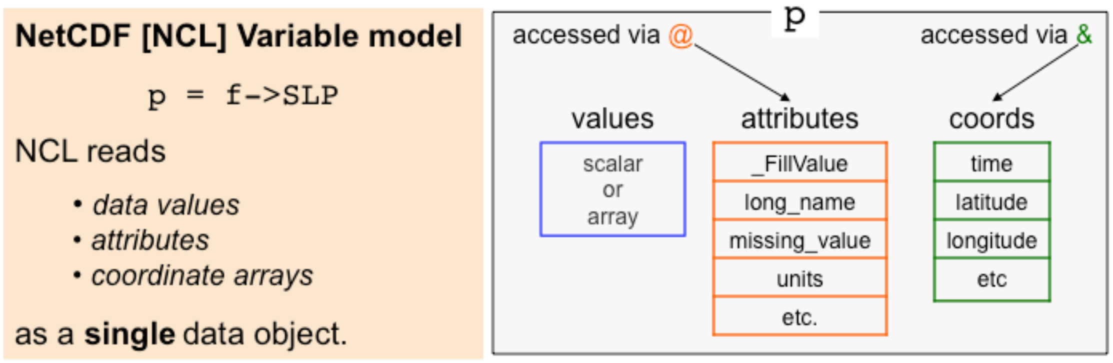
HDF-5 and netCDF-4 introduced new file data types. One is named a *"group".* For illustration, an **ncl_filedump** of a HDF-5 file from the Global Precipitation Measurement (GPM) Mission would show:

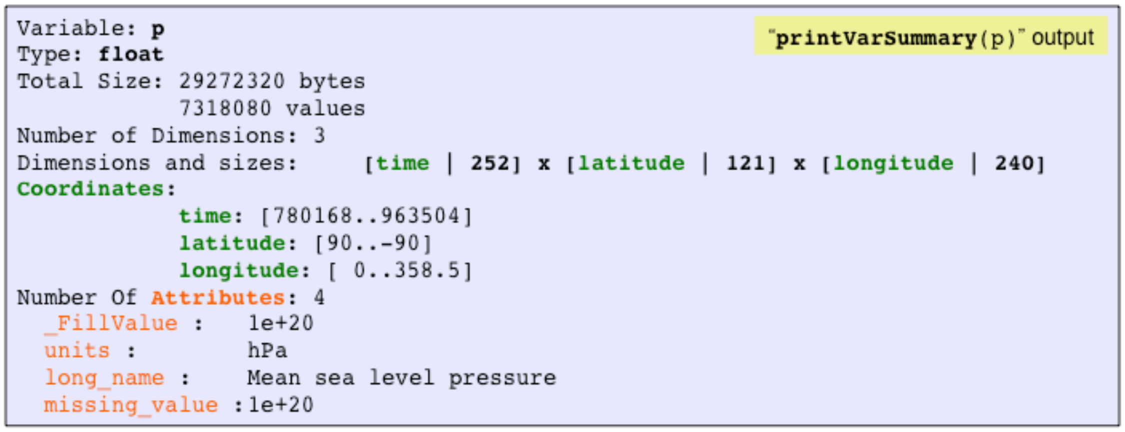
```
dimensions:
   lon = 3600
   lat = 1800
variables:
  group </Grid>       🡐 Grid is the name of the group
```

Embedded within the *group* named "/Grid" is a variable named "precipitation". Because there could be multiple *groups* on the file a new syntax (**=>**)was introduced to allow specific *group* references. An example:

```
f   = addfile ("GPM.h5" "r")        ; file reference (pointer)
grp = f=>/Grid                       ; grp will reference the group named /Grid
prc = grp->precipitation             ; import the variable "precipitation" from /Grid
```

It is important to note that the imported variable will have the same consistent data structure used for all NCL variables. The following figure illustrates NCL's netCDF-based variable model including a printed overview of a variable (here named "p").





```
Variable: p
Type: float
Total Size: 29272320 bytes
            7318080 values
Number of Dimensions: 3
Dimensions and sizes:     [time | 252] x [latitude | 121] x [longitude | 240]
Coordinates:
            time: [780168..963504]
            latitude: [90..-90]
            longitude: [ 0..358.5]
Number Of Attributes: 4
  _FillValue :    1e+20
  units :         hPa
  long_name :     Mean sea level pressure
  missing_value :1e+20
```

Section 3.1.3 When to use the $ syntax

In some instances, the variable name must be enclosed by **$** symbols. This is necessary if the variable on the file has a non-alphanumeric character (*e.g.,* space, "+", "-", *etc.*) embedded in the name:

```
x = f->$"ice cream+oreo-cookies…yummy!"$
```

More commonly, the variable on the right hand side of the pointer (**->**) is a variable of type string:

```
vars  = (/"T","U","V"/)
x     = f->$vars(n)$          ; loop indices: n=0,1,2
```

Section 3.1.4 Printing the contents of a supported file

`print` can be used to view the contents of any supported format or variable. When used on a file the printed information will be similar to that produced by "*ncdump* –h foo.nc". (Note: *ncdump* is a netCDF/Unidata application; it is not part of NCL.) For example:

```
f = addfile ("foo.grb","r")
print(f)               ; looks like ncdump -h
```

Note: The NCL command line utility **ncl_filedump** can produce an overview of any supported file's contents from the command line. See Section 3.1.9:

http://www.ncl.ucar.edu/Document/Tools/ncl_filedump.shtml

```
ncl_filedump foo.grb     ; netCDF, GRIB of HDF
```

Section 3.1.5 Reordering a variable on input

Assume *X* is a 3D variable with dimension sizes (ntime, nlat, nlon). To reverse the latitude ordering of the array:

```
X = f->X(:,::-1,:)       ; use NCL array syntax
```

Section 3.1.6 Importing byte or short data with conversion to float

Distributed with NCL is a suite of user-contributed functions. Several functions in this library will convert variables of type **`short`** and **`byte`** to type **`float`**:

```
x = short2flt(f->X)      ; also, x = short2flt_hdf(f->X)
y = byte2flt(f->Y)
```

To use these functions, the "contributed.ncl" library must be loaded prior to use:

load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/contributed.ncl"

Section 3.1.7 Spanning multiple files

The function **`addfiles`** (note the trailing 's') provides the user with the ability to access data spanning multiple files. This function can concatenate records (default; "cat") or "join" variables from different files by adding an extra dimension. In this example, we use **`systemfunc`** (see section 5.8) to get a listing of all the ann* netCDF files in the current directory.

```
fils = systemfunc("ls ann*.nc")
f    = addfiles(fils,"r")
T    = f[:]->T
```

or use coordinate subscripting if appropriate

```
    T    = f[:]->T(:,{500},{-30:30},: )
```

The resultant variable, *T*, will span all the files.

For more detail, see:

http://www.ncl.ucar.edu/Document/Functions/Built-in/addfiles.shtml

Section 3.1.8 Altering the default behavior of addfile(s)

The **setfileoption** procedure can be used to alter the default file handling settings. Some examples:

```
    setfileoption ("nc", "FileStructure", "Advanced")    ; netCDF-4, HDF-5
    setfileoption ("bin","WriteByteOrder","BigEndian") ; write big-endian
```

Details and more examples are at:

http://www.ncl.ucar.edu/Document/Functions/Built-in/setfileoption.shtml

Section 3.1.9 ncl_filedump

This command line operator will generate a text description of a specified file. The file may be in *any* supported file format: netCDF, GRIB, HDF or HDF-EOS. The default output is to the standard output [screen] but it may be redirected to a file. Regardless of the input file format, the textual form of the output is similar to that produced by 'ncdump –h'.

```
    ncl_filedump [options] fname.ext              ; to screen
    ncl_filedump [options] fname.ext | less       ; to pager
    ncl_filedump [options] fname.ext >&! dump     ; to file "dump
```

The file name on the disk is not required to have the file extension. E.g., if the specified file is "foo.grb" then, **ncl_filedump** will initially search for that file name. If the file does not exist under the specified name, **ncl_filedump** will search for a file named "foo" and treat it as a GRIB file.

The options are may be seen by entering '**ncl_filedump** –h' or, for more details, consult

http://www.ncl.ucar.edu/Document/Tools/ncl_filedump.shtml

Section 3.1.10 ncl_convert2nc

This command line operator will convert any GRIB, HDF or HDF-EOS file to netCDF format.

```
    ncl_convert2nc fname(s) [options]
```

Note that the options are specified *after* the file name(s). The options may be seen by entering '**ncl_convert2nc** –h' or, for more details and extensive examples, consult

http://www.ncl.ucar.edu/Document/Tools/ncl_convert2nc.shtml

Section 3.2 Binary data files

Binary data are not necessarily portable. Most machines write IEEE binary. Notable exceptions include the CRAY native binary. Even IEEE binaries are not necessarily portable. IEEE binaries are in two different flavors: big endian and little endian. Depending on the machine, a binary file may have to reorder the bytes (byte swap). NCL allows for dynamic byte swapping via the **setfileoption** procedure.

Reading binary files:

Several functions read binary data files. Most read IEEE binary and several read CRAY binary. There is no standard file extension for binary files. The ".bin" is arbitrary.

fbinrecread(*path*:string,*recnum*:integer,*dims*[*]:integer,*type*:string) can be used to read a Fortran unformatted sequential file. Records, which start at 0, can be of varying type and length.

```
    x = fbinrecread("a.bin",0,(/64,128/),"float")
```

fbindirread(*path*:string,*rnum*:integer,*dims*[*]:integer,*type*:string) can be used to read binary records of fixed record length (direct access). All records in the file must be the same dimensionality and type. To read the (*n*+1)th record:

```
    x = fbindirread("b.bin",n,(/73,144/),"float")
```

Other functions for reading binary data include: **cbinread**, **fbinread**, and **craybinrecread**.

Writing binary files:

Several procedures write IEEE binary data files.

fbinrecwrite(*path*:string,*recnum*:integer,*value*) can be used to write a Fortran unformatted sequential file. Records can be of varying type and length.

Assume you have the following five variables: *time*(ntime), *lat*(nlat), *lon*(nlon), *y*(ntime,nlat,nlon), *z*(nlat,nlon). Note that using a –1 as a record number means to append.

```
    fbinrecwrite("f.bin",-1,   time)
```

```
fbinrecwrite("f.bin",-1,  lat)
fbinrecwrite("f.bin",-1,  lon)
fbinrecwrite("f.bin",-1,  y)
fbinrecwrite("f.bin",-1,  z)
```

fbindirwrite(*path*:string,*value*) can be used to write a Fortran direct access file. All records must be of the same length and type.

```
do n=0,ntim-1
   fbindirwrite("/my/path/f.bin",y(nt,:,:))
end do
```

Other procedures for writing IEEE binary data include: **cbinwrite** and **fbinwrite**.

Reading/writing big endian and little endian files:

The default behavior of NCL's binary read/write functions and procedures is to assume the files are compatible with the endian type for the system. The **setfileoption** procedure can be used to dynamically perform byte swapping, if needed.

Section 3.3 ASCII

Reading ASCII files:

asciiread(*filepath*:string,*dims*[*]:integer,*datatype*:string), allows the data to be shaped upon input. Complicated ASCII files (e.g., multiple variable types or differing numbers of columns) should be read by importing the file as type string and using the string and conversion functions to parse the data. Alternatively, C or Fortran subroutines could be used.

```
z = asciiread("data.asc",(/100,13/),"float")
```

z will be a float variable with 100 rows and 13 columns, e.g. (100,13). Also see Section 5.8.

NCL is distributed with several functions in contributed.ncl that facilitate access to ascii files that are partitioned into header and tabular numbers. These functions are called **readAsciiHeader** and **readAsciiTable**, respectively.

Writing ASCII files:

asciiwrite(filepath:string, value) writes one column of values and the user has no control over format.

```
asciiwrite("foo.ascii",x)   ; one element per row
```

write_matrix(data[*][*]:numeric, fmtf:string, option) can write multiple columns and the user has format control (also see section 4.4).

```
fmtf        ="15f7.2" ; format string using fortran notation
opt         = True
opt@fout    = "foo.ascii"
write_matrix(x,fmtf,opt)
```

write_table(filepath:string, option:string, alist:list, fmtf:string), introduced in v6.1.0, is the most flexible of the procedures that write ascii files. It can write or append all elements of a list variable to a user specified file.

```
alist = [/a,b,c,d,f/]  ; list with different variables
write_table("foo.ascii", "w", alist, "%d%16.2f%s%d%ld")
```

Section 3.4 Writing netCDF/HDF

There are two approaches for creating netCDF (or HDF) files. The first method is called the "simple method" while the second method follows the "traditional approach" of explicitly predefining the file's contents before writing any values to the file.

Simple method:

This method is straightforward. One could substitute ".hdf" for the ".nc" to create an HDF file.

```
fo = addfile("foo.nc","c")
fo->X = x
fo->Y = y
```

To create an UNLIMITED dimension, which is usually time, it is necessary to add the following line of code prior to writing any values:

```
filedimdef(fo,"time",-1,True)
```

Traditional method:

Sometimes the "simple method" to netCDF file creation can be slow, particularly if there are many variables or the resulting output file is large. The "traditional method" is more efficient. This approach requires the user to explicitly define the content of the entire file, *prior* to writing.

NCL functions that predefine a netCDF file:

filevardef:	define name of one or more variables
filevarattdef:	copy attributes from a variable to one or more file variables
filedimdef:	define dimensions including unlimited dimension
fileattdef:	copy attributes from a variable to a file as global attributes
setfileoption:	some options can dramatically improve performance

For the following example, assume that the variables `time,lat,lon` and `T` reside in memory. When written to the netCDF file, the variable `T` is to be named `TMP`.

```
fout = addfile("out.nc","c")

; create global attributes
fileAtt                   = True
fileAtt@title             = "Sample"
fileAtt@Conventions       = "None"
fileAtt@creation_date     = systemfunc("date")
setfileoption(fout,"DefineMode",True)        ; optional
fileattdef(fout,fileAtt)

; predefine coordinate variables
dimNames          = (/"time","lat","lon"/)
dimSizes          = (/-1,nlat,nlon/) ; -1 means unspecified
dimUnlim          = (/True,False,False/)

; predefine names, type, dimensions
; explicit dimension naming or getvardims can be used
filedimdef(fout,dimNames,dimSizes,dimUnlim)
filevardef(fout,"time",typeof(time),getvardims(time))
filevardef(fout,"lat" ,typeof(lat) ,"lat")
filevardef(fout,"lon" ,typeof(lon) ,"lon")
filevardef(fout,"TMP" ,typeof(T)   , getvardims(T) )

; predefine each variable's attributes
filevarattdef(fout,"time",time)
filevarattdef(fout,"lat" ,lat)
filevarattdef(fout,"lon" ,lon)
filevarattdef(fout,"TMP" ,T)
setfileoption(fout,"SuppressDefineMode",False) ; optional

; output values only      [use  (/… /) to strip metadata]
fout->time        = (/time/)
fout->lat         = (/lat/)
fout->lon         = (/lon/)
fout->TMP         = (/T/)         ; T in script; TMP on file
```

Writing scalars to netCDF:

NCL uses the reserved dimension name "ncl_scalar" to identify scalar values that are to be written to netCDF.

; simple method

```
fo                = addfile("simple.nc","c")
con               = 5
con!0             = "ncl_scalar"
fo->constant      = con
```

; traditional method

```
re               = 6.37122e06
re@long_name     = "radius of earth"
re@units         = "m"

fout = addfile("traditional.nc", "c")
filevardef(fout,"re",typeof(re),"ncl_scalar")
filevarattdef(fout,"re",re)
fout->re = (/re/)
```

Writing compressed files:

Writing compressed files can result in considerable reduction in file size. The **setfileoption** procedure has an option called "CompressionLevel". This can be used to specify the compression-level for data written to a NetCDF4 classic file. Prior to opening the file , the following file options should be set:

```
setfileoption ("nc", "Format","NetCDF4Classic")
setfileoption ("nc", "CompressionLevel", 1)      ;  0 through 9 possible
```

All data written to the file will be compressed. Currently, there is no way to selectively activate compression on a per-variable basis. A “CompressionLevel” of one is best.

Contents of a well-written netCDF/HDF File:

Global file attributes that should be in any file include title, conventions (if any) and source. Other file attributes may include history, references, etc.

Command line conversion of supported formats to netCDF:

NCL has a command line utility, **ncl_convert2nc**, that will convert any supported format [GRIB-1, GRIB-2, HDF4, HDF4-EOS] to netCDF. For details see:

http://www.ncl.ucar.edu/Document/Tools/ncl_convert2nc.shtml

Section 3.5 Remote file access: OPeNDAP

Some (not all!) data servers allow remote data access via **OPeNDAP**: **Ope**n Source Project for **N**etwork **D**ata **A**ccess **P**rotocol. OPeNDAP-enabled NCL is available on some UNIX systems. File access is via a URL that is running an OPeNDAP server:

```
f      = addfile ("http://path/foo.nc","r")
```
or
```
fils   = "http://path/" + (/ "foo1.nc", "foo2.nc", "foo3.nc"/)
f      = addfiles(fils, "r")
```

Users can test for file availability using **isfilepresent**. Please note that if you are behind a firewall, you may not be able to access data in this manner. Also, some OPeNDAP servers require user registration prior to access.

Section 4: Printing

NCL provides limited printing capabilities. In some instances, it may be better to invoke Fortran or C routines to have better format control. Available functions and procedures include:

printVarSummary	provides and overview of a variable including all metadata
print	same as **printVarSummary** + each value of the variable
sprinti, **sprintf**	provides some format control
write_matrix	prints one variable in tabular form
print_table	prints multiple variables of different types

Section 4.1 printVarSummary

Usage: `printVarSummary(u)`

```
Variable: u
Type: double
Total Size: bytes
            147456   values
Number of Dimensions:  4
            Dimensions / Sizes:  [time | 1]  x  [lev | 18]  x
                                 [lat | 64]  x  [lon | 128]
Coordinates:
            time:   [4046..4046]
            lev:    [4.809 .. 992.5282]
            lat:    [-87.86379 .. 87.86379]
            lon:    [ 0. 0 .. 357.1875]
Number of Attributes:  2
            long_name: zonal wind component
            units:         m/s
```

Section 4.2 print

Usage: `print(u)`
This will print the same information as `printVarSummary` followed by each individual value and the associated subscript:

```
(0,0,0,0)   31.7
(0,0,0,1)   31.4
(0,0,0,2)   32.3   [snip]
```

The printing of the subscripts may be avoided by invoking NCL via: **ncl –n** `foo.ncl`.

```
print(u(0,{500},:,{100}))
```

would print *u* for all latitudes at time index 0, the level closest to 500 and the longitude closest to 100.

```
print("min(u)="+min(u)+" max(u)="+max(u))
```

results in the following string:

```
min(u)= -53.8125 max(u)=55.9736
```

Section 4.3 sprintf, sprinti

```
print("min(u)="+sprintf("%5.2f",min(u)))
```

results in:

```
min(u) = -53.81
```

```
ii=(/-47,3579,24680/)
print(sprinti("%+7.5i",ii))
```

results in the following (on different lines):

```
-00047, +03579, +24680
```

Section 4.4 Pretty Print: write_matrix, print_table

If *T*(*nrow,ncol*), where *nrow* = 3 and *ncol* = 5 then

```
write_matrix(T,"5f7.2",False):
```

```
4.36   4.66   3.77  -1.66   4.06
9.73  -5.84   0.89   8.46  10.39
4.91   4.59  -3.09   7.55   4.56
```

Note: although **write_matrix** is prototyped for 2D arrays, arrays of higher dimensionality can be printed using **ndtooned** and **onedtond**. Assume *X*(nt,nz,ny,nx):

```
dimx = (/nt,nz*ny*nx/) or
dimx = (/nt*nz,ny*nx/)
write_matrix(onedtond(ndtooned(X),dimx),"12f8.3",False)
```

A more flexible procedure was introduced in v6.1.0: **print_table.** This allows multiple variables of mixed data types to be printed with different formats.

```
alist = [/a,b,c,d,f/] ; variables of different types
print_table(alist, "%d,%16.2f,%s,%d,%ld")
```

Section 5: Data analysis and Arrays

NCL offers different approaches to analyzing data: (1) array syntax and operations, (2) hundreds of built-in functions, (3) many user contributed functions and, (4) invoking Fortran or C language routines. Tips on coding efficiently can be found at:

http://www.ncl.ucar.edu/Document/Manuals/Ref_Manual/NclUsage.shtml

Section 5.1 Array ordering and syntax

NCL arrays are *row major* and use *zero-based* indexing similar to that used by the Python, C and C++ languages and the ordering of arrays within netCDF files. By comparison, other common processing languages (*eg.,* fortran, MATLAB, R) are *column major* and use *one-based* indexing while the IDL language is column major but uses zero-based indexing. Row major means that for each row all the columns are grouped together. In practice, this means that in row major languages the leftmost dimension varies slowest while the rightmost varies fastest. A simple is example is in Section 7.6.

NCL's algebra, like Fortran 90, MATLAB and IDL supports operations on scalars and arrays rather than single scalar values like C, C++ and PASCAL. For array operations to work, both operands must have the same number of dimensions and same size dimensions, otherwise an error condition occurs. Furthermore, the data types of each operand must be equivalent, or one operand must be coercible to the type of the other operand. Let *A* and *B* be (10,30,64,128):

```
C = A+B    ; element-by-element addition
D = A-B    ; element-by-element subtraction
E = A*B    ; element-by-element multiplication
```

C, *D* and *E* will be created automatically if they did not previously exist. If they did exist then the result of the operation on the right hand side must be coercible to the type of left hand side.

Scalar values are special cases when considering array operations. When scalar values appear in an expression with a multi-dimensional value (i.e., an array), the scalar value is applied to each element of the array. Consider

```
F = 2*E + 5
```

Here, each element of array *E* will be multiplied by 2 and then 5 will be added to each element. The result will be assigned to *F*.

NCL's **<** and **>** array operators (sometimes called "clipping operators") are not commonly used in other languages. Assume *sst* is (100,72,144) and *sice* = -1.8 (a scalar). The statement:

```
sst = sst > sice
```

means that any values of *sst* less than *sice* will be replaced by *sice*.

All array expressions automatically ignore any operation involving values set to **_FillValue**.

Section 5.2 Array conformance

Array expressions require that all operands have the same number of dimensions and same size dimensions. In this case, the arrays are said to "conform" to each other. Scalars conform to the shape of any array. Assume *T* and *P* are dimensioned (10,30,64,128):

```
theta = T*( 1000/P )^0.286
```

This results in *theta* being dimensioned (10,30,64,128). **conform** or **conform_dims** can be used to generate arrays that conform to another array. Assume *T* is dimensioned (10,30,64,128) and *P* is dimensioned (30):

```
theta = T*(1000/conform(T,P,1))^0.286
```

conform expands *P*, which matches dimension "1" of *T*. For more details see:

http://www.ncl.ucar.edu/Document/Functions/Built-in/conform.shtml
http://www.ncl.ucar.edu/Document/Functions/Built-in/conform_dims.shtml

Section 5.3 Array memory allocation

Memory can be explicitly allocated/created for arrays in two ways:

1) Use of the array constructor **(/.../)**

```
a_integer  = (/1,2,3/)
a_float    = (/1.0, 2.0, 3.0/)
a_double   = (/4d0,5d-5,1d30/)
a_string   = (/"a","b","c"/)
a_logical  = (/True,False,True/)
a_2darray  = (/(/1,2/),(/5,6/),(/8,9/)/) ; 3 rows x 2 cols
```

2) Use the **new**(array_size,shape,type,[_FillValue]) statement: The inclusion of **_FillValue** is optional. If it is not present, a default value will be assigned. Specifying "**No_FillValue**" will result in no default **_FillValue** being assigned.

```
                                        ; _FillValue
a  = new(3,float)                       ; 9.96921e+36
b  = new(10,float,1e20)                 ; 1e20
c  = new((/5,6,7/),integer)             ; -2147483647
d  = new(dimsizes(U),double)         ; 9.969209968386869e+36
e  = new(dimsizes(ndtooned(U)),logical); Missins  =
new(100,string)                   ; "missing"
      q  = new(3,float,"No_FillValue")       ; no _FillValue
```

Memory is automatically created by functions for returned variables; thus, use of the **new** statement is not often needed or recommended.

Section 5.4 Functions and procedures

NCL has both functions and procedures:

(a) Functions are expressions because they return one or more values and can therefore be used as part of an expression. E.g., **max**, **sin** and **exp** are all standard mathematical functions:

```
      z = exp(sin(max(q))) + 12.345
```

Functions are not required to return the same type or size array every time they are called.

(b) Procedures (analogous to Fortran subroutines) cannot be part of an expression because they do not return values. NCL procedures perform a specific task and/or are used to modify one or more of the input arguments.

Arguments to NCL functions and procedures:

Arguments are passed by reference. This means that changes to their values, attributes, dimension names, and coordinate variables within a function or procedure will change their values in the main program. By convention, arguments to functions should not be changed by a function although this is not required. In the following discussion, it will be assumed that arguments to functions follow this convention.

Argument prototyping:

Function and procedure arguments can be specified to be very constrained and require a specific type, number of dimensions, and a dimension size for each dimension, or arguments can have no type or dimension constraints. This is called argument prototyping.

(a) Constrained argument specification means arguments are required to have a specific type, size and dimension shape.

```
      procedure ex (x[*][*]:float,y[2]:byte,\
                    res:logical,text:string)
```

The argument *x* must be a two-dimensional array of type **float**, *y* must be a one-dimensional array of length 2, *res* and *text* must be of type **logical** and **string** respectively, but can be of any dimensionality.

(b) Generic type prototyping: type only

```
function xy_interp(x:numeric,y:numeric)
```

Here **numeric** means any numeric data type listed in section 2.2.

(c) No type, no size, no dimension shape specification:

```
procedure foo(a,b,c)
```

(d) Combination:

```
function ex(d[*]:float,x:numeric,wks:graphic,y[2],a)
```

There is one very important feature which users should be aware of when passing arguments to procedures. This is an issue only when the procedure is expected to modify the input arguments. When an input argument must be coerced to the correct type for the procedure, NCL is not able to coerce data in the reverse direction so the argument is not affected by changes made to it within the procedure. NCL does generate a WARNING message.

Section 5.5 Built-in functions and procedures

NCL contains hundreds of built-in functions and procedures from the simple to the complex:

http://www.ncl.ucar.edu/Document/Functions/

Functions can return a scalar, an array or a variable of type list, The latter can contain multiple variables of different sizes, shapes and types. There is no need to preallocate array memory. For example, let *G* be a 4D array with dimension sizes (ntime, nlev, 73, 144) To interpolate *G* to a Gaussian grid with 128 longitudes and 64 latitudes with a triangular truncation at wave 42, the following built-in function may be used:

```
g = f2gsh(G,(/64,128/),42)
```

f2gsh will perform the interpolation at all times and levels. The return array *g* will be dynamically created and will be of size (ntime, nlev, 64, 128)

Generally, built-in functions do not return, create or change metadata. However, many of the more commonly used built-in functions have "**_Wrap**" versions located in a script of user contributed functions named “**contributed.ncl**”. These wrappers will handle the metadata appropriately.

http://ww.ncl.ucar.edu/Document/Functions/Contributed/

NCL has many functions for performing operations on multidimensional arrays. These include the **dim_*_n** suite of functions plus numerous other ***_n** functions (*eg*, **center_finite_diff_n**, **detrend_n**). When an appropriate ***_n** function is available, it should be utilized. The ***_n** functions require the user to specify the dimension number(s) upon which an operation is to be performed. As a simple example, consider the variable X(ntim,klev,nlat,mlon). NCL's dimension numbering is left-to-right and begins with zero: time => 0, lev => 1, lat => 2, and lon => 3. To compute zonal and time averages,

```
Xzon = dim_avg_n(T, 3)       ; Xzon(ntim,klev,nlat)
Xtim = dim_avg_n(T, 0)       ; Xtim(klev,nlat,mlon)
```

Some functions and procedures *may* require that the dimensions of a particular argument appear in a specific order. In these cases, the dimensions of the arguments may have to be reordered using named dimensions. Consider the **eofunc** function used to compute empirical orthogonal functions. Assume *T* is a 3D variable with size (ntime,nlat,nlon) and with named dimensions (time,lat, lon). Most commonly the **eofunc** function is used to derive orthogonal spatial patterns which vary in importance over time (principal components; **eofunc_ts**). To accomplish this partitioning the **eofunc** function requires that the rightmost dimension be time. Hence, dimension reordering must be used:

```
eof = eofunc(T(lat|:,lon|:,time|:), 3, option)   ; 3 EOFs
```

This results in a variable (*eof*) dimensioned (3, nlat, nlon).

In general, functions do not require memory to be explicitly allocated. The filling of an array as part of a loop is an example of when it may be required. Assume *T* contains 10 years of monthly means (ntim=120). To compute the monthly climatology and standard deviation for each of the twelve months, memory for returned values must be preallocated because the calculation occurs in a loop.

```
; preallocate array
nmos = 12
Tclm  = new((/nmos,klev,nlat,nlon /),typeof(T),T@_FillValue)
Tstd  = Tclm                          ; same size/shape
ntim  = dimsizes(time)                ; get size of time (120)

do n=0,nmos-1
   Tclm(n,:,:,:) = dim_avg_n    (T(n:ntim-1:nmos,:,:,:) , 0)
   Tstd(n,:,:,:) = dim_stddev_n(T(n:ntim-1:nmos,:,:,:), 0)
end do
```

Preallocation of arrays for procedures:

If a procedure is to return one or more arguments, memory for the returned variables must be preallocated. Consider **uv2sfvpg**, which takes as input the zonal (u) and meridional (v) velocity components and returns the stream function (psi) and velocity potential (chi). The returned arrays must be the same size and type as the velocity components:

```
psi   = new(dimsizes(u),typeof(u))
chi   = new(dimsizes(u),typeof(u))
uv2sfvp(u,v,psi,chi)
```

Function embedding:

Functions are themselves expressions so they can form parts of larger expressions, which can reduce the number of lines of code. The readability of embedded functions is subjective, however. Consider:

```
X = f2gsh(fo2fsh(fbinrecread(f,6,(/72,144/),"float")),(/nlat,lon/),42)
```

More lines of code may make the sequence easier to follow:

```
      G = fbinrecread(f,6,(/72,144/),"float")
      X = f2gsh(fo2fsh(G),(/nlat,mlon/),42)
```

Built-in utility functions:

Learning how to use NCL's built-in utility functions can make processing simpler and cleaner. The most commonly used are: **`all`**, **`any`**, **`conform`**, **`conform_dims`**, **`ind`**, **`ind_resolve`**, **`dimsizes`**, **`fspan`**, **`ispan`**, **`ndtooned`**, **`onedtond`**, **`mask`**, **`ismissing`**, **`system`**, **`systemfunc`**, **`print`**, **`printVarSummary`** and **`where`**.

See these URLs for more details:

http://www.ncl.ucar.edu/Document/Functions/array_manip.shtml
http://www.ncl.ucar.edu/Document/Functions/array_query.shtml

Section 5.6 contributed.ncl

The NCL distribution includes a library named "contributed.ncl" which contains functions that facilitate analyses. Prior to NCL 6.2.0, users were required to explicitly **load** this via:

load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/contributed.ncl"

More recent versions automatically load this library.

Brief descriptions of the functions and procedures contained in contributed.ncl are at:

http://www.ncl.ucar.edu/Document/Functions/Contributed/

While not required, most NCL users prefer to have a variable's metadata readily available. This information is particularly useful when using certain high-level graphical interfaces or when creating netCDF or HDF files. Since NCL's built-in functions do not create, change, or copy metadata, it becomes the user's responsibility to maintain or create metadata. Many of the functions in "contributed.ncl" can be grouped by how they handle metadata.

Section 5.6.1 Wrap functions

The "contributed.ncl" script contains many functions that contain code to create or maintain all appropriate meta data for built-in functions. The are called ‘wrap” functions. The purpose of the wrap functions is to associate metadata with the returned variable. The wrappers have the same calling sequence as the corresponding function, and the name of the wrapper is the same as the function with an appended suffix ("**`_Wrap`**").

The use of **`dim_avg_n`** would result in the loss of *T*'s metadata:

```
Tzon = dim_avg_n(T, 0)
```

The use of **`dim_avg_n_Wrap`** would retain the metadata:

```
Tzon = dim_avg_n_Wrap (T, 0)
```

For a complete list of available wrap functions see:

http://www.ncl.ucar.edu/Document/Functions/Contributed/

`copy_VarAtts`, **`copy_VarCoords`**, **`copy_VarMeta`**, and **`copyatt`** are a few of the functions that users have added to the contributed library for the purpose of explicitly copying coordinate variables, attributes or both. Each performs this function in a slightly different way.

Section 5.6.2 Type conversion

Assorted "contributed.ncl" functions that convert one type to another while retaining metadata include **`short2flt`**, **`byte2flt, short2flt_hdf, numeric2int`** and **`dble2flt`**.

Section 5.6.3 Climatology functions:

contributed.ncl has several climatology and anomaly functions that also create the appropriate metadata: **`clmMon*()`**, **`stdMon*()`**, and **`month_to_month`** are just a few of the examples.

Users are encouraged to peruse contributed.ncl to learn about various functions. The functions can be taken and modified for your own purposes.

Section 5.7 User-defined functions and procedures

Users may create their own functions and procedures to accomplish repetitive tasks. The general structure is:

```
undef("function_name")
function function_name(argument declaration)
local local_variable_list
begin
     [statement(s)]
return (return_value) ; individual variable (any type)
end
```

```
undef("procedure_name")
procedure procedure_name(argument declaration)
local local_variable_list
begin
      [statement(s)]
end
```

The **undef** procedure causes any previously defined user function or procedure to be deleted. (Note: Built-in functions can ***not*** be deleted or redefined.) The **local** statement lists variables local to the current function or procedure. The use of **undef** or **local** is not required, but is recommended.

One frequently asked question is: What is the difference between a function and procedure? A function returns a variable which may be used in subsequent code. A procedure performs a task. Two common tasks are the creation of plots and files. Users often establish personal libraries of functions and procedures. This allows for the creation of cleaner and more compact scripts.

A second frequently asked question is : Can NCL user defined functions return multiple variables? The answer is "yes". However, it is not as convenient as (say) Matlab which allows : [a,b,c] = *foo*(…)
.
Consider the following simple example:

```
undef("foo")
function foo(argument declaration)
local a,b,c [other local variables]
begin
   [statements]
   a = …          ; may have meta data (type double)
   b = …          ;  "    "    "    "   (type string)
   c = …          ;  "    "    "    "   (type graphic)
return ( [/ a,b,c /] ) ; return as a 'list' variable
end
```

Use the function via

```
q  =  foo(…)           ; q is a variable of type list
```

There is NCL syntax to access each variable within the list variable. However, it may be clearer to explicitly extract the individual variables from the list variable via the list **[..]** syntax

```
aa = q[0]         ; aa will include any meta data
bb = q[1]         ; bb   "     "     "    "   "
cc = q[2]         ; cc   "     "     "    "   "
delete(q)         ; list variable 'q' no longer needed
```

Important Note: All user created functions/procedures must be loaded prior to use. They can be in the same script or located elsewhere.

```
load  "/path/to/myLibrary.ncl"
```

Optional arguments:

Users may input optional arguments to procedures and functions. By convention, this is accomplished by attaching attributes to a variable prototyped as `logical`. The high-level graphical functions and procedures all use optional arguments in this manner. This argument can then be queried using NCL's built-in suite of `is*` functions (e.g. `isatt`).

```
opt         = True
opt@scale   = 0.01
opt@add     = 1000
opt@wgts    = (/0.25,0.50,0.25/)
opt@a3d     = array_3D

undef ("foo")
function foo(x:numeric,opt:logical)
local dimx,rankx,xx
begin
       dimx  = dimsizes(x)
       rankx = dimsizes(dimx)
       if(typeof(x).eq."short")then
             if(opt.and.isatt(opt,"scale"))then
                   xx = x*opt@scale
             else
                   xx = x
             end if
       else
             return(x)
       end if
end
```

Section 5.8 System interaction

Users may interact with the system via `systemfunc` and `system`. Basically, the user creates a string containing the Unix command to be executed. The semicolon can separate multiple Unix commands. Options to Unix commands can be included by using single quotes within the string.

`systemfunc` allows system commands to be executed and information is returned to an NCL variable.

```
files_full_path  = systemfunc("ls /my/data/*.nc")
files_names      = systemfunc("cd /my/data ; ls *.nc")
date             = systemfunc("date")
```

Use the Unix "cut" command to extract columns 14-19 of an ASCII file (sample.txt), return as a one-dimensional array of type string, and convert to type float.

```
    x = tofloat(systemfunc("cut -c14-19 sample.txt"))
```

`system` allows the user to execute an action. This is different than `systemfunc` in that no information is returned to NCL. Some examples:

```
    system("cp 10.nc /ptmp/user/")  ; copy a file
    system("sed 's/NaN/-999./g' "+asc_input+" > asc_output")
```

In the following, all of the netCDF files for 1995 are acquired from NCAR's High Performance storage System (HPSS) system and put into the directory /ptmp/user/.

```
    HPSS = "/USER/Data/Path"
    dir  = "/ptmp/user/"
    year = 1995

    system("hsi -q 'cd "+HPSS+" ; prompt ; lcd "+dir      \
                            +" ; mget "+ nyear+ "-*.nc' ")
```

By default, NCL invokes the Bourne shell when it passes commands to the system. The following uses Bourne shell syntax to create a directory if it does not already exist:

```
    DIR = "SAMPLE"
    system("if ! test -d "+DIR+" ; then mkdir "+DIR+" ; fi")
```

Users may be more familiar with other UNIX shells. The following uses C-shell syntax to accomplish the same task.:

```
system("csh -c 'if (! -d "+DIR+") then ; mkdir "+DIR+" ; endif'")
```

To prevent the Bourne shell from attempting to interpret csh syntax, the commands are enclosed by single quotes ('). If the csh command contains single quotes they would need to be escaped with a backslash (\ ).

Section 6: Command line options and assignments

NCL supports a limited number of options and the setting and execution of simple NCL statements at the command line, in either interactive or batch mode. Details with examples are described at:

http://www.ncl.ucar.edu/Document/Manuals/Ref_Manual/NclCLO.shtml

Section 6.1 Options altering behavior when NCL is invoked

The following is a selected list of the predefined options and what they do:

-*h*	display command line options usage
-f	use New File Structure, and NetCDF4 features
-*n*	do not enumerate values in print()

-o retain former behavior for certain backwards-incompatible changes
-p do not page output from the system() command
-Q do not print the NCL copyright information
-*x* echo NCL statements as encountered
-*V* print the NCL version and exit

Here's a simple example of using the –*x* option:

```
% ncl -x
 Copyright (C) 1995-2017 - All Rights Reserved
 University Corporation for Atmospheric Research
 NCAR Command Language Version 6.4.0
 The use of this software is governed by a License Agreement.
 See http://www.ncl.ucar.edu/ for more details.
ncl 0> a = 5
+ a = 5
ncl 1> exit
+ exit
```

Section 6.2 Specifying variable assignments on command line

Creating variables on the command line when NCL is invoked can facilitate data processing tasks. Some simple examples of command line arguments (***CLA***s):

```
ncl nyrStrt=1800 nyrLast=2005 foo.ncl
ncl 'f="test.nc"' p=(/850,500,200/) 'v=(/"T","Q"/)' foo.ncl
```

Spaces are not allowed. Statements containing strings must be enclosed with single quotes.

The script may contain default settings for variables that are optional:

```
ncl a=5 c=3.14d0 foo3.ncl
```

The foo3.ncl script could check the command line for a variable via the **isvar** function:

```
if(.not.isvar("a")) then
    a = 10                    ; set to 10 if a not defined
end if
if(.not.isvar("b") then
    b = 72.5                  ; set to 72.5 if not defined.
end if
```

Invoking ***CLA***s within a Unix shell script can be a nuisance. The shell script must be escaped by using special shell characters. The NCL command line

```
ncl 'filName="foo.nc"' tst.ncl
```

would be the following in C-shell syntax:

```
#!/bin/csh –f
set a=foo.nc
eval  ncl  filName=\\\″$a\\\″  tst.ncl
```

This is approach requires knowledge of Unix shell syntax. It may be cleaner and easier to use an NCL script for typical shell script tasks (See Section 7.8). A simple script:

```
dq   =  str_get_dq()                            ; double quote character
a     = “foo.nc”
NCL= "ncl 'filName="+dq+ a +dq+"' tst.ncl"       ; “ncl  ‘filName=”foo.nc”’ test.ncl”
print(“NCL=”+NCL)                               ; echo contents
system(NCL)                                     ; execute
```

Section 7: Using external codes

NCL, which is written in C, has been designed to allow users to invoke external codes (e.g., Fortran, C, or other libraries). The primary focus here is the use of Fortran (f77, f90) subroutines. To use external C-language functions see:

http://www.ncl.ucar.edu/Document/Manuals/Ref_Manual/NclExtend.shtml

Section 7.1 NCL/Fortran interface

The use of Fortran subroutines is greatly facilitated by the **WRAPIT** utility, which is distributed with NCL. Options available may be viewed by entering “**WRAPIT -h**” on the command line. **WRAPIT** compiles the external code and generates a file that, by convention, is called a "shared object". This object is identified by a ".so" extension. The only information that **WRAPIT** requires is the interface between Fortran and NCL including the subroutine declaration statement and arguments. Explicit specification of the argument types is not necessary since **WRAPIT** is aware of Fortran’s default typing. Of course, users can override the default typing by explicitly specifying the type in the Fortran declarations. NCL uses the interface delimiter pair:

```
C   NCLFORTSTART
C   NCLEND
```

to identify the interface section. Note that the delimiters are in the form of f77 comments and, thus, have no affect on the code. The **C NCLFORTSTART** precedes the subroutine statement while **C NCLEND** follows the last declaration of arguments pertaining to the interface.

```
C    NCLFORTSTART
           subroutine demo(xin,xout,mlon,nlat,text)
           integer mlon, nlat
           real    xin(mlon,nlat), xout(mlon,nlat)
```

```
                 character*(*) text
C    NCLEND
```

Section 7.2 f77 subroutines

The four-step process to create and call shared objects is best illustrated by an example. Consider an existing file called foo.f. This file may contain one or more f77 subroutines.

1) Bracket each subroutine being called with interface delimiters:

```
C    NCLFORTSTART
                 subroutine demo(xin,xout,mlon,nlat,text)
                 integer mlon, nlat
                 real    xin(mlon,nlat), xout(mlon,nlat)
                 character*(*) text
C    NCLEND
```

The rest of Fortran code may include many subroutines.

2) Create a shared object using **WRAPIT**. The default behaviour is for **WRAPIT** to name the .so file the same as the Fortran file name (e.g. foo.so):

```
WRAPIT  foo.f
```

3) Add an **external** statement to the NCL script. The **external** statement consists of an arbitrary identifier, which NCL uses to dynamically select the correct shared object (most commonly, this is the name of the Fortran file) and the location of the shared object. The default location is the current directory.

```
external FOO "./foo.so"
```

4) Invoke the specific subroutine(s) from NCL. There is a special three-part syntax that must be used which includes (a) the name by which NCL identifies the target shared object, (b) the :: separator syntax, and (c) the Fortran subroutine interface.

```
FOO::demo(xin,xout,nlon,nlat,text)
```

A schematic NCL script would be:

```
external FOO "./foo.so"
begin
      [statement(s)]
      xout = new((/nlat,nlon/),typeof(xin)
  FOO::demo(xin,xout,mlon,nlat,text)
      [statement(s)]
end
```

Section 7.3 f90 subroutines

Invoking f90 subroutines is essentially the same process used for f77 subroutines except for step (1). In f77, the NCL interface delimiters are inserted directly into the f77 subroutines. Unfortunately, the Fortran parser used by **`WRAPIT`** does not understand f90 syntax. Thus, the user must create a "stub" interface for each subroutine called by NCL. These stub files are a repeat of the f90 declaration list in f77 syntax. There is no need for the stub files to be complete subroutines. Remember, **`WRAPIT`** only cares about the subroutine call and its arguments. Consider the following f90 subroutines contained in a file called "quad.f90":

```
subroutine cquad(a,b,c,nq,x,quad)
  implicit none
  integer, intent(in) :: nq
  real, intent(in)    :: a, b, c, x(nq)
  real, intent(out)   :: quad(nq)
  integer             :: i ! local

  quad = a*x**2 + b*x + c   ! f90 array syntax
  return
end subroutine cquad

subroutine prntq(x,q,nq)
  implicit none
  integer, intent(in) :: nq
  real, intent(in)    :: x(nq),q(nq)
  integer :: i     ! local
  do i = 1,nq
     write(*,'(I5, 2F10.3)')i,x(i),q(i)
  end do
  return
end subroutine prntq
```

1) Create interface stubs using f77 syntax and store in file quad90.stub. Each stub file requires a set of **`C NCLFORTSTART`** and **`C NCLEND`** delimiters.

```
C   NCLFORTSTART
    subroutine cquad (a,b,c,nq,x,quad)
    dimension x(nq),quad(nq)  ! ftn default
C   NCLEND
C   NCLFORTSTART
    subroutine prntq(x,q,nq)
    integer nq
    real x(nq),q(nq)
C   NCLEND
```

2) Create the shared object using **`WRAPIT`**. If f90 modules were present, they should be compiled prior to the routines that use them. The user must specify the compiler to be used on the command line. Enter **`WRAPIT -h`** for a list of command line options.

```
WRAPIT quad90.stub quad.f90
```

3-4) Same as section 7.2.

A sample NCL script would be:

```
external  QUPR  "./quad90.so"
begin
      a     = 2.5
      b     = -.5
      c     = 100.
      nx    = 10
      x     = fspan(1.,10.,10)
      q     = new(nx,float)
      QUPR::cquad(a,b,c,nx,x,q)
      QUPR::prntq(x,q,nx)
end
```

Section 7.4 Accessing the LAPACK library distributed with NCL

NCL is distributed with a 'double precision' version of LAPACK. Users can access this library by creating a stub (interface) subroutine and then using `WRAPIT` to create a shared object. For example, let's say a user wants to use LAPACK's ***DGELS*** subroutine to solve an overdetermined or underdetermined real linear system. The stub/interface subroutine, here name ***DGELSI*** located in the file 'dgels_interface.f**'**, would look like

```
C NCLFORTSTART
      SUBROUTINE DGELSI( M, N, NRHS, A, B, LWORK, WORK )
      IMPLICIT   NONE
      INTEGER    M, N, NRHS, LWORK
      DOUBLE PRECISION   A( M, N ), B( M, NRHS), WORK(LWORK)
C NCLEND
C                          declare local variables
      INTEGER     INFO
      CHARACTER*1 TRANS

      TRANS = "N”
      CALL DGELS(TRANS, M,N,NRHS,A,LDA,B,LDB,WORK,LWORK,INFO)
      RETURN
      END
```

Use `WRAPIT` to compile the wrapper subroutine and to specify the location of the LAPACK library for the local system.

```
WRAPIT -L $NCARG_ROOT/lib  -l  lapack_ncl   dgels_interface.f
```

The sample script in the next section illustrates how one can invoke the shared object from within an NCL script.

Section 7.5 Using commercial libraries

The process is similar to using f90 codes because the user must create a stub file to explicitly specify the required calling sequence and argument types. Let's assume we want to use IMSL's rcurv subroutine. For convenience, f77 syntax will be used.

1) Create a wrapper program arbitrarily named rcurvwWap.f

```
C   NCLFORTSTART
    subroutine rcurvwrap(n,x,y,nd,b,s,st,n1)
    integer  n, nd, n1
    real x(n),y(n),st(10),b(n1),s(n1)
C   NCLEND
    call rcurv (n,x,y,nd,b,s,st)  ! IMSL name
    return
    end
```

2) Use **WRAPIT** to compile the wrapper subroutine and to specify the location of the IMSL library for the local system.

```
WRAPIT -l mp -L /usr/local/lib64/r4i4 -l imsl_mp rcurvWrap.f
```

3-4) Same as section 7.2 and 7.3

Sample script:

```
external IMSL "./rcurvWrap.so"
begin
     x = (/0,0,1,1,2,2,4,4,5,5,6,6,7,7/)

     y = (/508.1,498.4,568.2,577.3,651.7,657.0,\
     755.3,758.9,787.6,792.1.841.4,831.8,854.7,\
     871.4/)
     nobs  = dimsizes(y)
     nd     = 2
     n1    = nd+1
     b     = new(n1,typeof(y))  ; create return arrays
     s     = new(n1,typeof(y))
     st    = new(10,typeof(y))
                                  ; call IMSL routine
     IMSL::rcurvwrap(nobs,x,y,nd,b,s,st,n1)
     print(b)
     print(s)
     print(st)
end
```

Section 7.6 What WRAPIT does

WRAPIT is a UNIX script that performs a number of tasks including using Fortran compilation and linking that creates the shared object (.so). It provides users with many options:

```
      WRAPIT -h  <return>
```

WRAPIT performs the following tasks:

1) Uses an NCL utility **wrapit77**, a C-language program, to create a C wrapper program that invokes the f77 parser and creates the required C code to interface between NCL and Fortran.

```
      wrapit77  <  foo.f   >!  foo_W.c
```

2) Compiles and creates object modules for the C and Fortran codes:

```
      cc -c foo_W.c    ; foo_W.o
      f77 -c foo.f     ; foo.o
```

3) Creates a dynamic shared object (.so) using the local ld.

4) Cleans up temporary files so that only the shared object file (*.so) remains.

Section 7.7 NCL/Fortran array mapping

In Fortran, the leftmost array dimension varies fastest while in NCL the rightmost array dimension varies fastest. Sometimes this causes confusion. Rarely is reordering an array required when invoking a Fortran subroutine from an NCL script. Thus, even though the array dimension names appear in reverse order the individual array elements directly map. The rule "fastest varying dimesnsions in one language map to fastest varying dimension in another language" applies here.

NCL		Fortran
x(time,lev,lat,lon)	<=map=>	x(lon,lat,lev,time)

Consider the following two arrays where N=2 and M=3:

ncl: x(N,M)	<==>	x(M,N) :Fortran
x(0,0)	<==>	x(1,1)
x(0,1)	<==>	x(2,1)
x(0,2)	<==>	x(3,1)
x(1,0)	<==>	x(1,2)
x(1,1)	<==>	x(2,2)
x(1,2)	<==>	x(3,2)

Section 7.8 NCL and Fortran (or C) in Unix shell script

When working on an NCL script that is invoking one or more Fortran (or C) shared objects, it is convenient to combine all the various steps into a single Unix shell script. The following outlines the components via a C-shell script.

```
#!/usr/bin/csh
# =========== Edit NCL Code ============
cat   >!   main.ncl   <<  "END_NCL"
load ”$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_code.ncl"
load ”$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_csm.ncl“
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/contributed.ncl“
external SUB  "./sub.so"
begin
    ...NCL code…
end
"END_NCL"

# ===========Edit Fortran Code ========
cat   >!   sub.f   << "END_SUBF"
C NCLFORTSTART
    ...
C NCLEND
"END_SUBF"

# =========== Invoke WRAPIT ==========
 WRAPIT sub.f

# =========== EXECUTE ========
ncl  main.ncl  >&!  main.out
exit
```

Section 7.9 Using NCL as a scripting language

NCL can be used like a scripting language. Often, it is cleaner and easier then using a Unix shell. The following uses an NCL do loop to (a) access files from NCAR’s High Performance Storage System (*HPSS*); (b) invoke a netCDF operator (*ncrcat*) to create a new netCDF file; and, (c) remove (*rm*) the files created in step (a). The general procedure is to create a string that is passed to the system for execution via the **system** procedure. The **print** statements are included to track the state of the script. Note thesingle ‘ in the `hpsscmd`.

```
hpss   = “/Model/Sample/”      ; HPSS path
diri   = “/ptmp/user/”         ; dir containing input files
fili   = “b20.007.pop.h.0”     ; prefix of input files
diro   = “/ptmp/user/out/”     ; dir containing output files
filo   = “b20.TEMP.”           ; prefix of output files

nyrStrt = 300                  ; 1st year
nyrLast = 999                  ; last year
do nyear=nyrStrt,nyrLast
   print (“---- “+nyear+” ----”)
                               ; acquire 12 MSS files for year
   hpsscmd = "hsi -q 'cd "+ hpssi +" ; lcd "+diri+ \
              " ; prompt; mget "+fili+nyear+"-[0-1][0-9].nc'"
```

```
        print ("hpsscmd= "+ hpsscmd)

        print (“hpsscmd=“+hpsscmd)
        system (hpsscmd)
                                       ; strip off the TEMP variable
        ncocmd = “ncrcat -v TEMP “ +diri+fili+”*.nc “+ \
                  diro+filo+nyear+”.nc”
        print (“ncocmd=“+ncocmd)
        system (ncocmd)
                                       ; remove the monthly files
        rmcmd = “’rm’ “+diri+fili+nyear+ ”.nc”
        print (“rmcmd=“+rmcmd)
        system (rmcmd)
     end do
```

A 2nd scripting example where an NCL ‘driver’ script is used to call another NCL script (here, plt.ncl) which is capable of interpreting a varying number of command line assignments. One issue is that double quotes (“) must be embedded within single quotes (‘) so they will not be acted upon by the UNIX interpreter when passed via **system**.

```
    ; Schematic NCL driver calling another NCL script
    ; Double quotes (“) must be embedded within single quotes (‘)

    undef("DQF")                                ; concatenate
    function DQF(s1[1]:string, s2[1]:string) ; local utility to return a string
    local dq                                   ; with embedded " and enclosed with '
    begin
      dq = str_get_dq()                                ; double quote character
                                                       ; DQF("PATH","./FOO.nc")
      return ("'"+ s1 +"="+ dq+s2+dq +"'") ;           ; 'PATH="./FOO.nc"'
    end

    begin                                       ; driver
     pth =  "./FOO.nc"

     var = "slp"
     NCL = "ncl "+DQF("PATH",pth)+" "+DQF("vname",var)+" plt.ncl"
     print("NCL="+NCL) ; ncl ’fili=”./FOO.nc”’ ’vname=”slp”’ plt.ncl
     system(NCL)

     nt  = 3
     var = "precip"
     NCL = "ncl "+DQF("PATH",pth)+" "+DQF("vname",var)+" nt="+nt
+" plt.ncl"
     print("NCL="+NCL)
            ; ncl ’fili="./FOO.nc"’ ’vname="precip"’ nt=2  plt.ncl
     system(NCL)
    end
```