IPSL Boot Camp Part 5: CDO and NCO [*]

Sabine Radanovics, Jérôme Servonnat

March 24, 2016

Contents

1 Climate Data Operators

1.1 Features

- Collection of operators for processing of climate and forecast model output
- simple statistical and arithmetic functions
- data selection and subsampling tools
- spatial interpolation
- Works for GRIB and netCDF datasets (and some other less common formats)

1.2 Limitations

- GRIB: all time steps need to have the same variables and within a time step each variable may occur only once
- NetCDF: only 2-dimensional, 3-dimensional and 4-dimensional variables are supported
- Attribute conventions: GDT, COARDS or CF

1.3 How to use CDO?

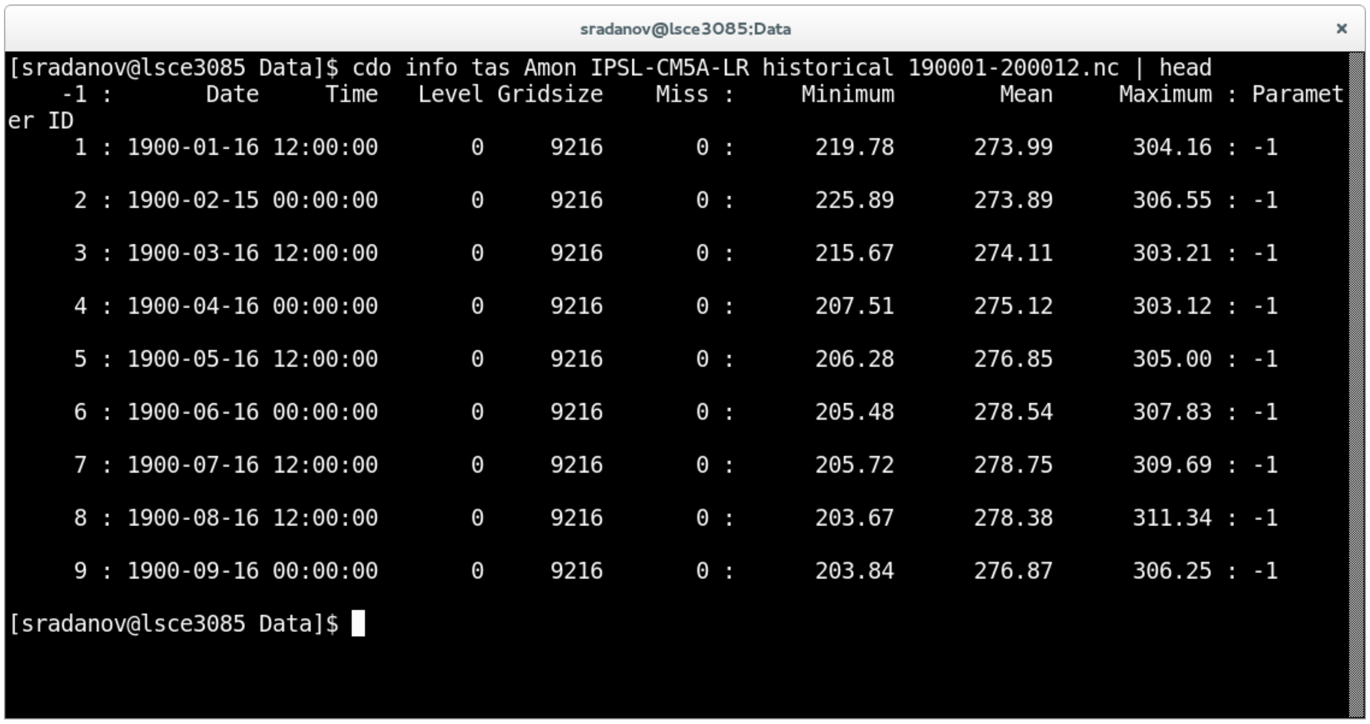
- From the command line, in a shell script or in a system call inside a program in your favorite programming language
- select the operator(s) needed from the reference card http://www.nco.ncep.noaa.gov/pmb/codes/nwprod/sorc/rtofs_cdo-1.4.0.1.fd/cdo-1.5.0/doc/cdo_refcard.pdf

1.4 Some examples

cdo info get some information about a dataset.

```
cdo info inputfile
```

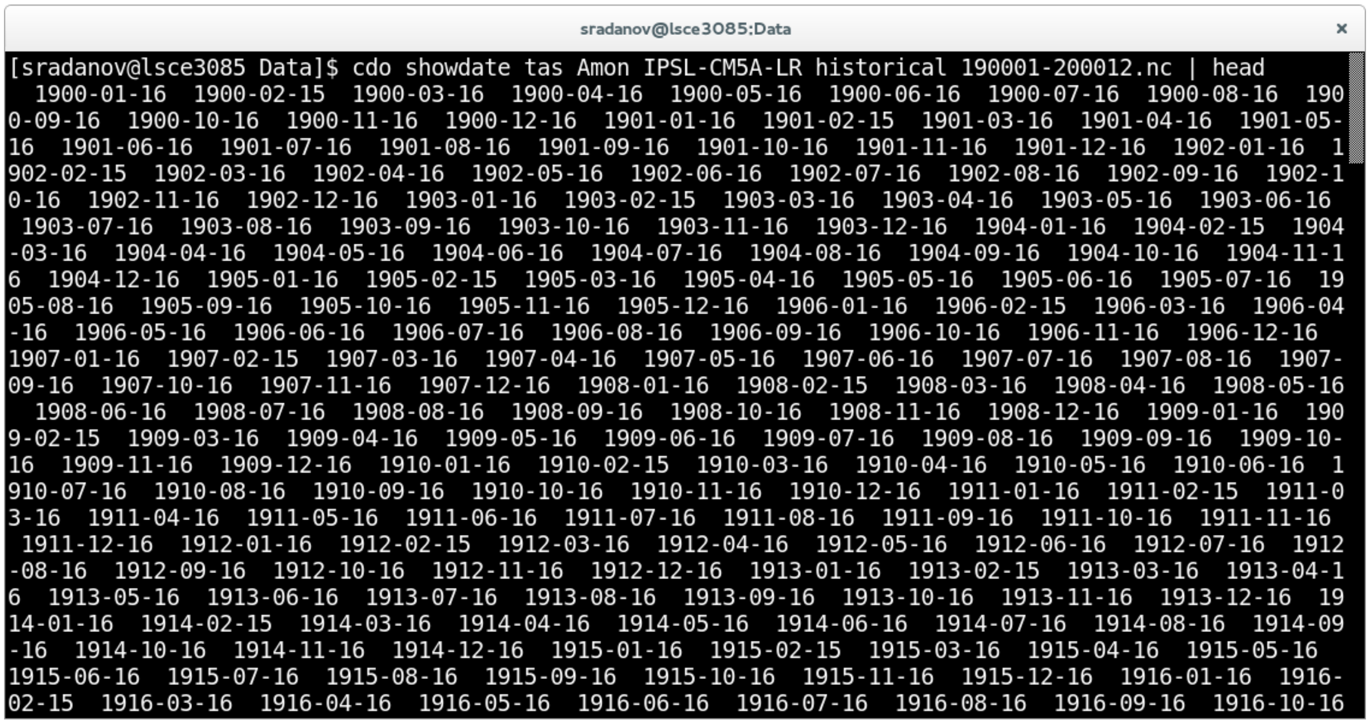
[*]Main author of this chapter: S. Radanovics, Laboratoire des Sciences du Climat et de l'Environnement (LSCE). This work is licensed under Creative Commons Attribution-ShareAlike 4.0 International License



```
[sradanov@lsce3085 Data]$ cdo info tas Amon IPSL-CM5A-LR historical 190001-200012.nc | head
    -1 :       Date     Time   Level Gridsize    Miss :     Minimum        Mean     Maximum : Paramet
er ID
     1 : 1900-01-16 12:00:00       0     9216       0 :      219.78      273.99      304.16 : -1

     2 : 1900-02-15 00:00:00       0     9216       0 :      225.89      273.89      306.55 : -1

     3 : 1900-03-16 12:00:00       0     9216       0 :      215.67      274.11      303.21 : -1

     4 : 1900-04-16 00:00:00       0     9216       0 :      207.51      275.12      303.12 : -1

     5 : 1900-05-16 12:00:00       0     9216       0 :      206.28      276.85      305.00 : -1

     6 : 1900-06-16 00:00:00       0     9216       0 :      205.48      278.54      307.83 : -1

     7 : 1900-07-16 12:00:00       0     9216       0 :      205.72      278.75      309.69 : -1

     8 : 1900-08-16 12:00:00       0     9216       0 :      203.67      278.38      311.34 : -1

     9 : 1900-09-16 00:00:00       0     9216       0 :      203.84      276.87      306.25 : -1

[sradanov@lsce3085 Data]$ 
```

cdo showdate How to display actual dates even with relative time axis.

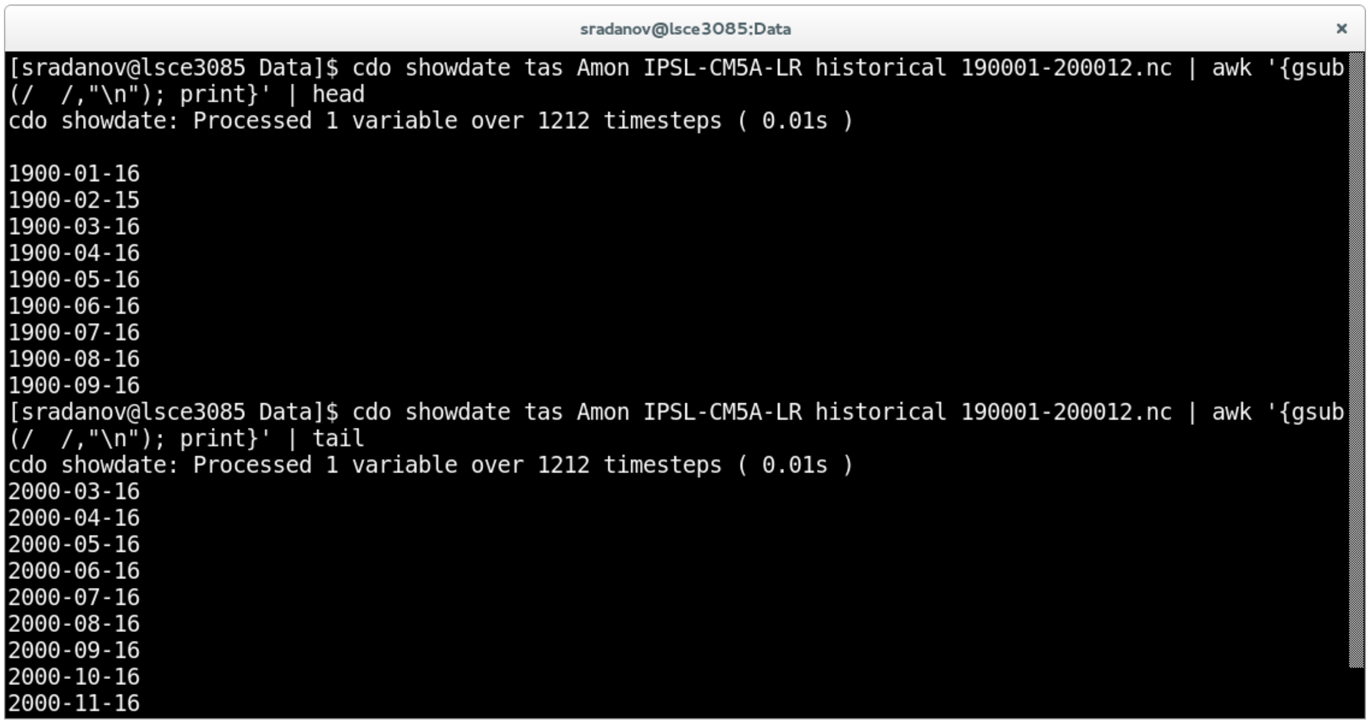
```
cdo showdate inputfile
```



```
[sradanov@lsce3085 Data]$ cdo showdate tas Amon IPSL-CM5A-LR historical 190001-200012.nc | head
  1900-01-16  1900-02-15  1900-03-16  1900-04-16  1900-05-16  1900-06-16  1900-07-16  1900-08-16  190
0-09-16  1900-10-16  1900-11-16  1900-12-16  1901-01-16  1901-02-15  1901-03-16  1901-04-16  1901-05-
16  1901-06-16  1901-07-16  1901-08-16  1901-09-16  1901-10-16  1901-11-16  1901-12-16  1902-01-16  1
902-02-15  1902-03-16  1902-04-16  1902-05-16  1902-06-16  1902-07-16  1902-08-16  1902-09-16  1902-1
0-16  1902-11-16  1902-12-16  1903-01-16  1903-02-15  1903-03-16  1903-04-16  1903-05-16  1903-06-16
 1903-07-16  1903-08-16  1903-09-16  1903-10-16  1903-11-16  1903-12-16  1904-01-16  1904-02-15  1904
-03-16  1904-04-16  1904-05-16  1904-06-16  1904-07-16  1904-08-16  1904-09-16  1904-10-16  1904-11-1
6  1904-12-16  1905-01-16  1905-02-15  1905-03-16  1905-04-16  1905-05-16  1905-06-16  1905-07-16  19
05-08-16  1905-09-16  1905-10-16  1905-11-16  1905-12-16  1906-01-16  1906-02-15  1906-03-16  1906-04
-16  1906-05-16  1906-06-16  1906-07-16  1906-08-16  1906-09-16  1906-10-16  1906-11-16  1906-12-16
1907-01-16  1907-02-15  1907-03-16  1907-04-16  1907-05-16  1907-06-16  1907-07-16  1907-08-16  1907-
09-16  1907-10-16  1907-11-16  1907-12-16  1908-01-16  1908-02-15  1908-03-16  1908-04-16  1908-05-16
  1908-06-16  1908-07-16  1908-08-16  1908-09-16  1908-10-16  1908-11-16  1908-12-16  1909-01-16  190
9-02-15  1909-03-16  1909-04-16  1909-05-16  1909-06-16  1909-07-16  1909-08-16  1909-09-16  1909-10-
16  1909-11-16  1909-12-16  1910-01-16  1910-02-15  1910-03-16  1910-04-16  1910-05-16  1910-06-16  1
910-07-16  1910-08-16  1910-09-16  1910-10-16  1910-11-16  1910-12-16  1911-01-16  1911-02-15  1911-0
3-16  1911-04-16  1911-05-16  1911-06-16  1911-07-16  1911-08-16  1911-09-16  1911-10-16  1911-11-16
 1911-12-16  1912-01-16  1912-02-15  1912-03-16  1912-04-16  1912-05-16  1912-06-16  1912-07-16  1912
-08-16  1912-09-16  1912-10-16  1912-11-16  1912-12-16  1913-01-16  1913-02-15  1913-03-16  1913-04-1
6  1913-05-16  1913-06-16  1913-07-16  1913-08-16  1913-09-16  1913-10-16  1913-11-16  1913-12-16  19
14-01-16  1914-02-15  1914-03-16  1914-04-16  1914-05-16  1914-06-16  1914-07-16  1914-08-16  1914-09
-16  1914-10-16  1914-11-16  1914-12-16  1915-01-16  1915-02-15  1915-03-16  1915-04-16  1915-05-16
1915-06-16  1915-07-16  1915-08-16  1915-09-16  1915-10-16  1915-11-16  1915-12-16  1916-01-16  1916-
02-15  1916-03-16  1916-04-16  1916-05-16  1916-06-16  1916-07-16  1916-08-16  1916-09-16  1916-10-16
```

Reformat the output with some awk.

```
cdo showdate inputfile | awk ’{gsub(/  /,"\n"); print}’
```

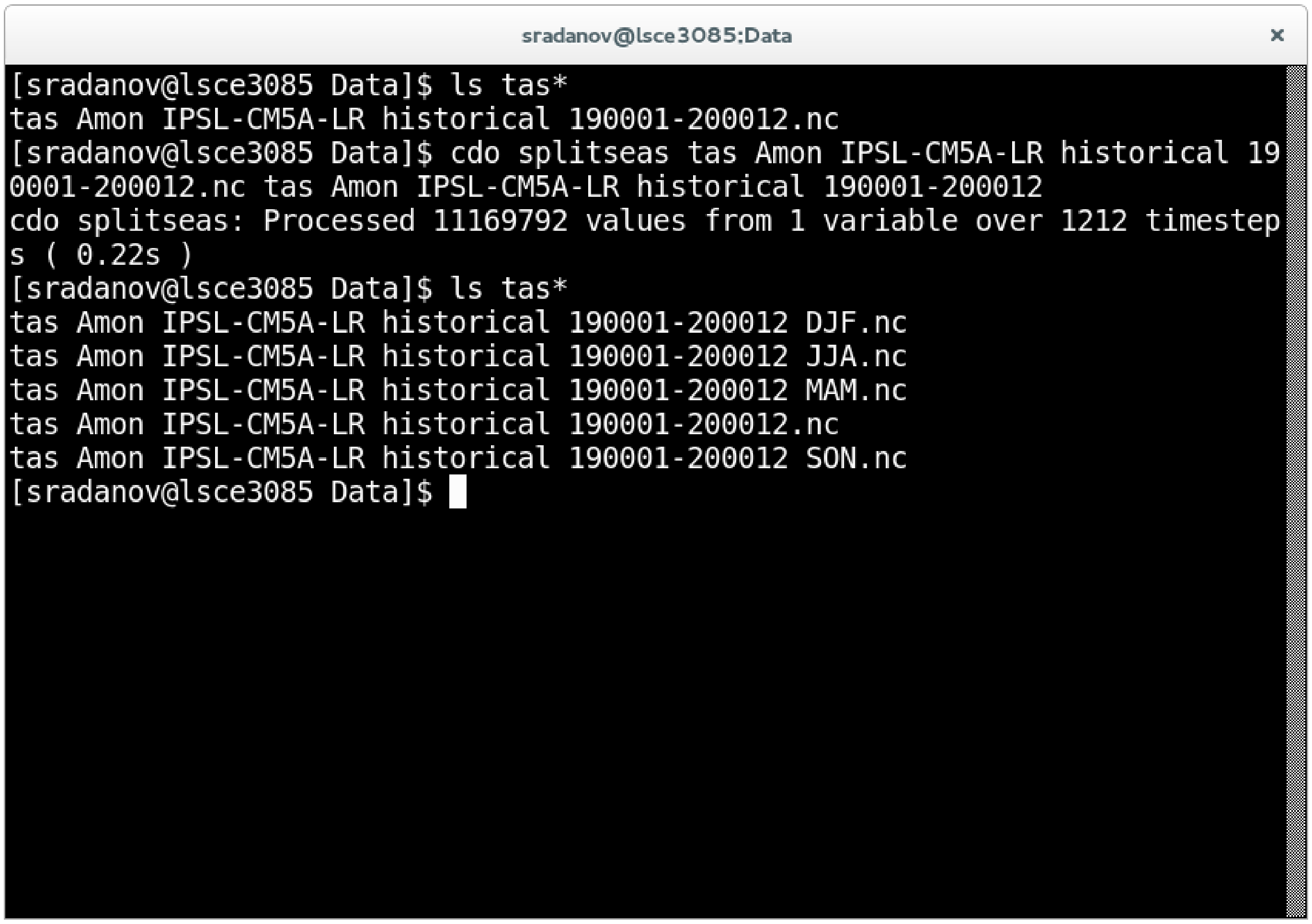


```
[sradanov@lsce3085 Data]$ cdo showdate tas Amon IPSL-CM5A-LR historical 190001-200012.nc | awk '{gsub
(/  /,"\n"); print}' | head
cdo showdate: Processed 1 variable over 1212 timesteps ( 0.01s )

1900-01-16
1900-02-15
1900-03-16
1900-04-16
1900-05-16
1900-06-16
1900-07-16
1900-08-16
1900-09-16
[sradanov@lsce3085 Data]$ cdo showdate tas Amon IPSL-CM5A-LR historical 190001-200012.nc | awk '{gsub
(/  /,"\n"); print}' | tail
cdo showdate: Processed 1 variable over 1212 timesteps ( 0.01s )
2000-03-16
2000-04-16
2000-05-16
2000-06-16
2000-07-16
2000-08-16
2000-09-16
2000-10-16
2000-11-16
```

cdo splitseas How to split a file into four files (one for each season).

```
cdo splitseas inputfile outputfileprefix
```

Here in addition to the operator and the inputfile, we have to specify an outputfile prefix. The final outputfilename will be constructed using the prefix and appending the shortname of the season (DJF, MAM...) and the suffix of the file type (.nc)


sradanov@lsce3085:Data

```
[sradanov@lsce3085 Data]$ ls tas*
tas Amon IPSL-CM5A-LR historical 190001-200012.nc
[sradanov@lsce3085 Data]$ cdo splitseas tas Amon IPSL-CM5A-LR historical 19
0001-200012.nc tas Amon IPSL-CM5A-LR historical 190001-200012
cdo splitseas: Processed 11169792 values from 1 variable over 1212 timestep
s ( 0.22s )
[sradanov@lsce3085 Data]$ ls tas*
tas Amon IPSL-CM5A-LR historical 190001-200012 DJF.nc
tas Amon IPSL-CM5A-LR historical 190001-200012 JJA.nc
tas Amon IPSL-CM5A-LR historical 190001-200012 MAM.nc
tas Amon IPSL-CM5A-LR historical 190001-200012.nc
tas Amon IPSL-CM5A-LR historical 190001-200012 SON.nc
[sradanov@lsce3085 Data]$
```

cdo sellonlatbox How to select a region? Frequently we have to do selections, for example a specific region.

```
cdo sellonlatbox,lon1,lon2,lat1,lat2 inputfile outputfile
```

This time the operator needs arguments. Operator arguments are separated by commas without spaces.

cdo setmissval When analysing data from different sources and performing arithmetic operations on them, sometimes they need to have the same missing value attribute. For example

```
cdo setmissval,-999. infile outfile
```

Sets the missing_value attribute to ”-999.”

1.5 Options

cdo has a number of options such as

- a silent mode -s
- writing output with relative (-r) or absolute (-a) time axis
- writing output in a specific format (-fnc4, -fgrb, ...)

The options are placed before the operator, here the one for a multiyear monthly mean.

```
cdo -s ymonmean inputfile outputfile
```

1.6 Interpolation and Regridding

For example using a bilinear interpolation:

```
cdo remapbil,grid inputfile outputfile
```

There are several possibilities to define *grid*:

1. Take the grid from another file.

   ```
   cdo remapbil,obs.nc model.nc model_obsgrid.nc
   ```

2. Use a predefined grid

   ```
   cdo remapbil,r360x180 model.nc model_1x1deggrid.nc
   ```

3. cdo grid description
4. SCRIP grid
5. PINGO grid

1.7 Combine operators

Combining operators produces less temporary output files and is potentially a lot faster because things can be done in parallel and with less I/O.

```
cdo operator1 -operator2 inputfile(s) outputfile
```

The operators are executed from right to left such that the result of cdo operator2 inputfile(s) becomes the input for cdo operator1.

Example combining a variable selection, the *selvar* operator with the variable name as an argument, and a file concatanation, the *cat* operator.

```
cdo cat -selvar,hgt hgt_NA_* hgt_NA_X.nc
```

A more complex example:

```
cdo ydaymean -sub -sellonlatbox,-15,25,35,65 -sellevel,500 hgt_NA_X.nc -sellonlatbox,-15,25,35,65
 -sellevel,850 hgt_NA_X.nc hgt_NA_XX.nc
```

A region (sellonlatbox,-15,25,35,65) and a level (sellevel,850) are selected from a file hgt_NA_X.nc and subtracted (sub) from an other level (sellevel,500) over the same region from the same file. Finally the multiyear daily mean of the difference (ydaymean) is written to the output file (hgt_NA_XX.nc).

Of course these operations can be applied one by one, but this gives lots of temporary outputfiles and read/write access to the disc which can make it quite slow.

Then you might change the variable name and the attributes to correspond to the new variable...

2 nco - netCDF Operators

- NCO is a suite of programs known as operators
- Each operator is a standalone, command line program executed at the shell-level.
- The operators take netCDF files as input, perform an operation and produce a netCDF file as output.
- Operators are primarily designed to aid manipulation and analysis of data
- Operators are as general as netCDF itself.
- NCO was written to consume the absolute minimum amount of system memory required to perform a given job.

NCO user guide: http://nco.sourceforge.net/nco.pdf

Examples for processing CMIP5 data with nco: http://nco.sourceforge.net/xmp_cesm.html

2.1 Concatenators

nco has two operators to join files:

ncrcat joins record variables along the record dimension (similar to cdo cat)

ncecat joins variables along a new dimension, that will be the record dimension. If there is already a record dimension it will be turned into a fixed length dimension. The corresponding variables (or hyperslabs) from each file need to have the same dimensions and size.

With the -u option you can give a name to the new record dimension, that will be called "record" otherwise.

```
ncecat -u ensemble ifiles_* outfile.nc
```

2.2 How to concatenate along any dimension?

1. turn the desired dimension into the record dimension using ncpdq
2. concatanate with ncrcat
3. maybe reorder dimesions again with ncpdq

2.3 ncpdq

- can pack or unpack data
- can re-order dimension or
- can reverse dimensions (cdo invertlat and cdo invertlev are special cases)

```
ncpdq -a lon,-lat,time infile outfile
```

-a option is for arranging dimensions in the order listed in the argument. -dim reverses the dimension dim. If there is any record dimension in the file, the first dimesion in the dimension list will become the new record dimension.

2.4 Specifying input files

Most nco operators accept several ways to specify the input files:

1. Type them explicitly in the command line
2. Specify multiple files using unix wild cards

   ```
   ncrcat infileprefix*
   ncrcat infile????.nc
   ncrcat *.nc
   ```

3. Specify a (remote) directory using the -p option. All the input files are assumed to be in the specified directory. This has no influence on where the output file is written.

   ```
   ncrcat -p /Myhugedisc/Model/Favoritmodel/  infile1.nc infile2.nc
   ```

4. Specify multiple files using the -n option.

The -n option can be used if the inputfiles are of the form
constant alphanumeric prefix fixed length numeric suffix .nc
for example: model_x_version_4_year_1850.nc
The -n option takes 3 arguments:

1. The number of files
2. The number of digits of the numeric suffix
3. The increment

Then one has to give the first file name and the others are created using the information from the arguments. Example:

```
ncrcat -n 6,4,10 model_x_version_4_year_1850.nc
```

will take the files model_x_version_4_year_1850.nc, model_x_version_4_year_1860.nc, model_x_version_4_year_1870.nc, model_x_version_4_year_1880.nc, model_x_version_4_year_1890.nc and model_x_version_4_year_1900.nc as input.

2.5 Output options

If the outputfile already exists normally there is a prompt asking weather to overwrite or to append or to abort the operation. Since this safety feature is not very practical if you process a lot of stuff in a script, there are switches to turn it off.

```
ncrcat -O ...
```

will overwrite existing files without asking

```
ncrcat -A ...
```

will try to append the output to an existing output file.

Example: Union of two files (similar to cdo merge)

```
ncks -A file1 file2
```

Limitations:

- The record dimension (unlimited dimension) has to have the same name in both files
- Non-record dimensions with the same name in both files must have the same size

2.6 ncks - netCDF Kitchen Sink

ncks is an operator for extracting and merging data from files. nco comes with many options for selection, subsetting and hyperslabs. We will introduce them with ncks, but most of them work with other operators as well.

Select variables -v option (-C, -c) Record variables to operate on can be selected using -v followed by a list of variables. The coordinate variables corresponding to the dimensions of the chosen variables are written to the output as well. This feature can be turned off using the -C option. With -c on the other hand ALL coordinate variables are written to the output. Hint: If you write your own NetCDF files make sure that the coordinate variables and the dimensions have the same name.

Example:

```
ncks -v T,Rhum,U,V infile outfile
```

Whatever the veriables in the infile were, the operator will process T, Rhum, U, V. The processed variables and the coordinate variables corresponding to the dimensions of these variables will be written to the outfile.

-x option With the -x option all the variables are selected except those listed as arguments of -v.

```
ncks -x -v T,Rhum,U,V infile outfile
```

The operator will now process whatever variable was in the infile except T, Rhum, U and V.

-d option: subsetting variables along dimensions - hyperslabs Syntax:

```
ncks -d dim,min[,max[,stride]] infile outfile
```

The -d option takes 2, 3 or 4 arguments:

1. The dimension name
2. The minimum index or value
3. The maximum index or value
4. A stride

- If min and max are integers, they are interpreted as dimension indices.
- As a default nco uses c-style index conventions, that is starts counting with 0. This can be changed to fortran-style conventions (start counting with 1) adding the -F option.
- Leaving min (max) empty, is interpreted as the first (last) index or value. (The comma is not omitted.)

  Example: Specify the first 5 indices of dimension time

  ```
  ncks -d time,0,4 infile outfile
  ncks -F -d time,1,5 infile outfile
  ncks -F -d time,,5 infile outfile
  ```

- Negative indices are counted from the last index (as in python), that is -1 corresponds to the last but first index.
- If min and max are floats (numbers with a decimal point), they are interpreted as dimension values.
- min $\leq$ max, even if the values are stored in inversed order, unless you have wrapped coordinates (such as longitude) and your operator is ncks and you want to specify for example a hyperslab from 320. to 40. degree.

  ```
  ncks -d lon,40.,320. infile outfile    # will work
   (selects everything inside the interval 40., 320.)
  ncks -d lon,320.,40. infile outfile    # will work
   (selects everything outside the interval 40., 320.)
  ncrcat -d lon,320.,40. infile outfile  # won't work
   (wrapped coordinates are only supported with ncks)
  ```

Cross sections A cross section can be selected by specifying only a dimension name and a minimum index or value without the trailing comma.

Example selecting the 6th ensemble member:

```
ncks -F -d ensemble,6 infile outfile
```

Stride Stride must be an integer following the third comma in the -d argument list. If stride is not specified the third comma has to be omitted as well.

Example: Select every 12th time step starting from the 3rd one.

```
ncks -F -d time,3,,12 infile outfile
```

Multislabs It is possible to specify multiple hyperslabs in one call for the same dimension and for different dimensions.

```
ncra -F -d time,3,,12 -d lat,-60.,-40. -d lat,40.,60. -v Tas infile outfile
```

2.7 Averagers

ncra - record averager Averages record variables along the record dimension.

```
ncra -d lat,40.,60. -d lon,-15.,35. infile(s) outfile
```

Options can be used to select variables (-v, -x) and to define hyperslabs (-d).

ncea - ensemble averager Averages (pointwise) variables with the same name from different files. Coordinate variables are not averaged.

```
ncea -n 50,2,1 -v T,Rhum ifile01.nc outfile.nc
```

ncwa - weighted averager Average variables in a single file over arbitrary dimensions, specified with the -a option. Without the -a option, variables are averaged over all their dimesions resulting in a scalar value for each of them. Coordinate variables are averaged as well.

- Weights can be specified with the -w option
- A mask can be specified with the -B option
- ncwa can computed (weighted) sums as well if the -N option is used.

ncwa - examples:

Zonal mean

```
ncwa -a lon infile outfile
```

Weighted meridional mean

```
ncwa -a lat -w weightvar infile outfile
```

weightvar is a variable in the file containing the weights. area average where the variable $ORO > 0.5$

```
ncwa -B 'ORO < 0.5' -a lat,lon infile outfile
```

2.8 ncap2 - Arithmetics

- Specify command line operations with -s
- Specify the operations in a seperate file with -S

```
ncap2 -s 'latw=cos(lat)' infile outfile
```

The cosine of the variable *lat* in the infile is calculated and stored in a new variable named *latw*. All variables in ifile plus the new variable latw are written to outfile.

- Several -s strings are accepted
- Several operations in a single string are possible if seperated by semicolons.

```
ncap2 -v -s 'const=7.;latw=cos(lat);npq=latw*const' infile outfile
```

- -v means that only the new variables are written to the output file.

2.9 ncatted

When performing arithmentic operations, the attributes for the resulting new variable are usually taken from the first input variab in the first input file. Sometimes attributes like standard_name or units will not correspond to the new variable any more. Sometimes you need to edit attributes, or you might just want to add some.

```
ncatted -a att_name,var_name,mode,att_type,att_value
```

- att_name: name of the attribute
- var_name: the name of the variable the attribute belongs to or "global" for a global attribute
- mode: one of a (append), c (create), d (delete), m (modify), o (overwrite)
- att_type: one of f (float), d (double), l (long), s (short), c (character), b (byte)
- att_value: the value of the attribute

```
cdo subc,273.15 tas_obs.nc tas_obs_degC.nc
ncatted -a units,tas,o,c,degC tos_obs_degC.nc
```

2.10 ncrename

rename attributes

```
ncrename -a oldname,newname infile outfile
```

rename variables

```
ncrename -v oldname,newname infile outfile
```

rename dimensions

```
ncrename -d oldname,newname infile outfile
```

The -a, -v and -d options can be specified more than once.

2.11 Packing vs. compression

Packing is the NetCDF3 way of reducing the file size. Record variables are stored as short integers along with the scale_factor and add_offset attributes. You can see that if you run *ncdump -h* and you see variables of type *short* in your file. It is a lossy algorithm.

To get rid of such 'short' variables you can use ncpdq with the -P option specifying unpack as an argument

```
ncpdq -P unpack infile outfile
```

Compression NetCDF4 allows compression using a loss-less algorithm. With any nco operator you can specify the output format, for example -4 for NetCDF4 and a compression level with the -L option followed by a number between 0 (no compression) and 9 (maximum compression) - the compression level. The higher the number the smaller the file and the longer the computation time.

```
ncks -4 -L 5 infile.nc outfile.nc
```