

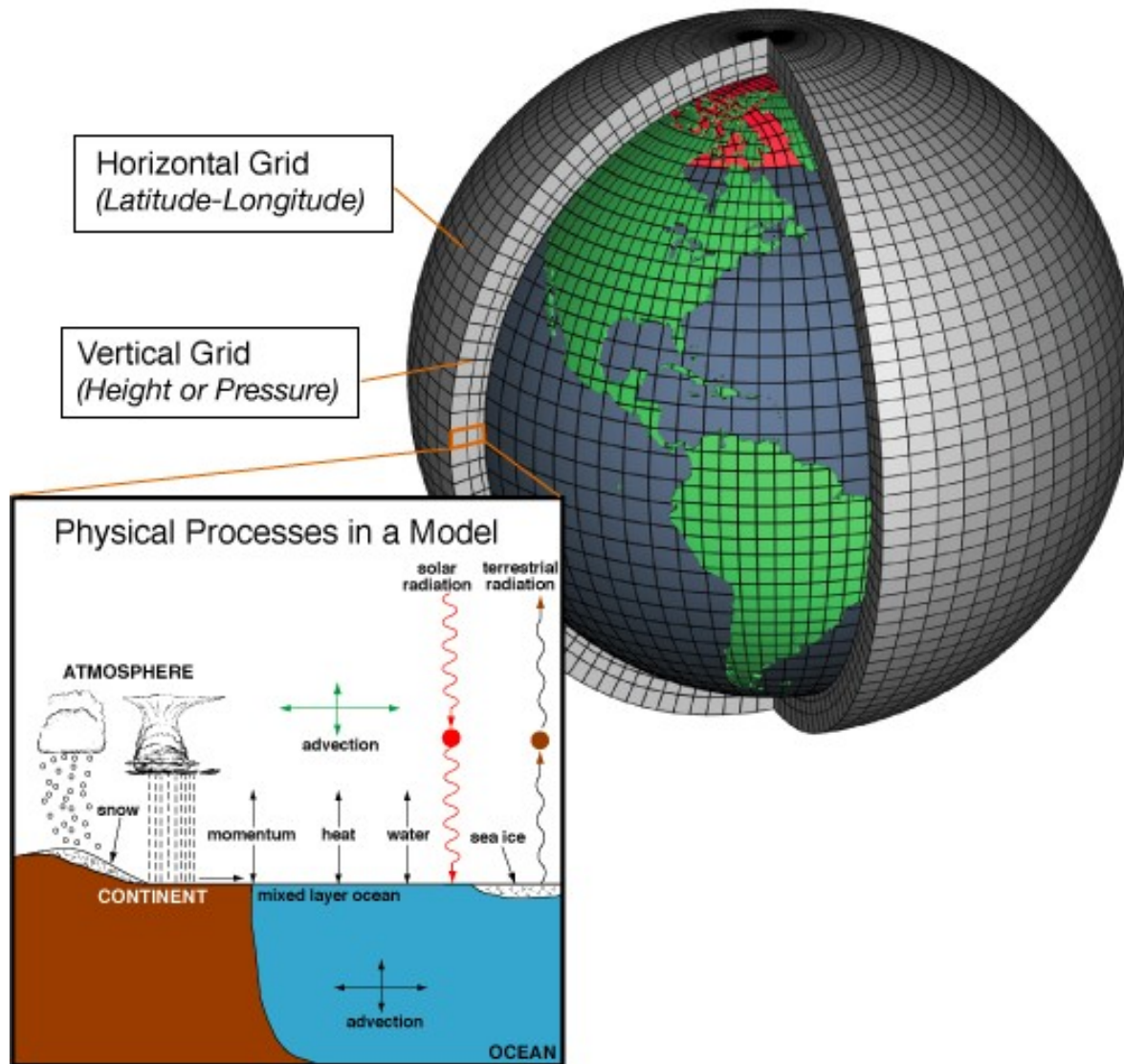
A very short Introduction to NetCDF, CDO and Shell-Programming

Dr. rer. nat. Christian Stepanek

Monday, 29th of April, 2024

- NetCDF
 - binary file format for scientific (model) data
 - analysis tools
- CDO
 - toolbox for analysis of climate data
 - basic usage examples
- Shell-Programming
 - multi-purpose program- and control environment in UNIX-like systems
 - basic usage examples
- Practical Examples

Background: Climate Modelling



<https://upload.wikimedia.org/wikipedia/commons/7/73/AtmosphericModelSchematic.png> (public domain)

Background: Climate Modelling



special demands for data storage

- large data sets (100s of MByte per simulation year)
- data sets to be merged / split into subsets
- gridded data
- many physical quantities → meta-data becomes of relevance

1	64	sh_vdiff	column heating due to vertical diffusion [W/m**2]
2	65	ev_vdiff	column moistening due to vertical diffusion [kg/m**2s]
3	66	ch_concloud	convective heating [W/m**s]
4	67	cw_concloud	convective moistening [kg/m**2s]
5	68	fage	aging factor of snow on ice
6	69	snfrac	fraction of ice covered with snow
7	70	barefrac	bare ice fraction
8	71	alsom	albedo of melt ponds
9	72	alsobs	albedo of bare ice and snow without ponds
10	73	sicepdw	melt pond depth on sea-ice [m]
11	74	sicepdi	ice thickness on melt pond [m]
12	75	tsicepdi	ice temperature on frozen melt pond [K]
13	76	sicepres	residual heat flux [W/m**2]
14	77	ameltdepth	total melt pond depth [m]
15	78	ameltfrac	fract area of melt ponds on sea-ice
16	79	albedo_vis_dir	surface albedo visible range direct
17	80	albedo_nir_dir	surface albedo NIR range direct
18	81	albedo_vis_dif	surface albedo visible range diffuse
19	82	albedo_nir_dif	surface albedo NIR range diffuse
20	83	ocu	ocean eastward velocity [m/s]
21	84	ocv	ocean northward velocity [m/s]
22	85	tradl	thermal radiation 200mb [W/m**2]
23	86	sradl	solar radiation 200mb [W/m**2]
24	87	trafl	thermal radiation 200mb (clear sky) [W/m**2]
25	88	srafl	solar radiation 200mb (clear sky) [W/m**2]
26	89	amlcorac	mixed layer flux correction [W/m**2]

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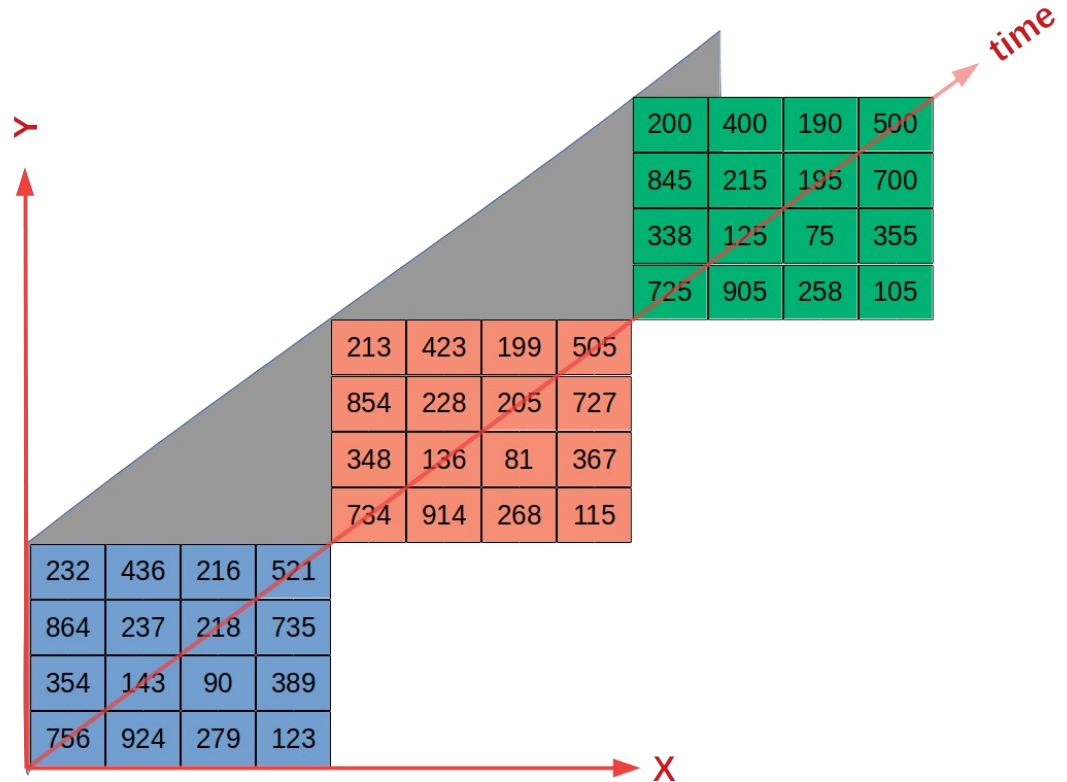
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classical ASCII data not a suitable file format

- input / output relatively slow
- storage of numerical data via characters inefficient
- data structure difficult to represent
- handling of metadata difficult

1	Latitude / deg N	Longitude / deg E	Temp. / deg C
2	74.995	13.97	10.3
3	66.967	7.633	12.4
4	58.762	-25.958	23.5
5	57.838	8.704	12.3
6	48.912	-126.89	9.6
7	41.682	-124.93	11.3
8	40.842	27.763	13.4
9	37.036	13.19	24.5
10	36.143	-2.622	13.3
11	38.412	13.577	10.6
12	38.262	14.03	12.3
13	36.746	17.718	14.4
14	34.953	128.881	25.5
15	34.535	-121.107	14.3
16	32.668	138.455	11.6
17	27.714	34.682	13.3
18	23.583	64.217	15.4
19	20.75	-18.583	26.5
20	20.117	117.383	15.3
21	43.882	-62.8	12.6
22	43.483	-54.867	14.3
23	44.527	145.042	16.4
24	20.217	-18.45	27.5
25	37.799	-10.166	16.3
26	37.881	-10.176	13.6
27	66.999	-17.961	15.3
28	36.032	-1.955	17.4
29	30.85	-10.268	28.5
30	21.358	-158.19	17.3
31	50.395	148.323	14.6
32	46.317	152.533	16.3
33	38.634	-9.454	18.4
34	56.33	170.699	29.5
35	53.993	162.376	18.3
36	49.376	152.878	15.6
37	54.55	-168.67	17.3
38	40.4	143.5	19.4
39	44.53	147	30.5
40	42.23	144.209	19.3
41	59.555	-144.154	16.6



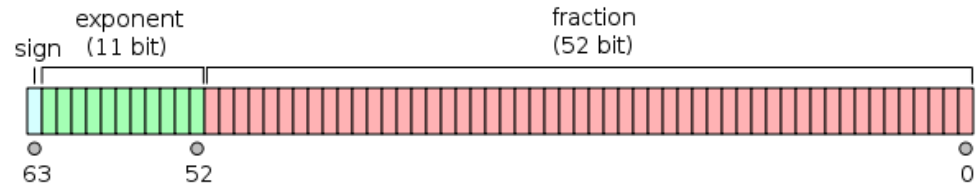
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binary format:

$$2^{52} = 4,503,599,627,370,496 \approx 8 \text{ Byte}$$

character format:

$$4,503,599,627,370,496 \approx 16 \text{ Byte (+5)}$$

37	54.55	-108.07	17.3
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https://en.wikipedia.org/wiki/Double-precision_floating-point_format

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```
stepanek@bkli06l048:~/data$ ls -l
total 89248
```

```
-rw-r--r-- 1 stepanek 55985588 10:49 INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

```
stepanek@bkli06l048:~/data$ ncdump INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc >
INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc.dump
```

```
stepanek@bkli06l048:~/data$ ls -l
total 250784
```

```
-rw-r--r-- 1 stepanek 55985588 10:49 INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
-rw-rw-r-- 1 stepanek 165410369 10:50 INIOM_PD_echam5_main_mm_3901-
4000_climatological_mean.nc.dump
```

```
stepanek@bkli06l048:~/data$ head -n10 INIOM_PD_echam5_main_mm_3901-
4000_climatological_mean.nc.dump
```

```
netcdf INIOM_PD_echam5_main_mm_3901-4000_climatological_mean {
```

```
dimensions:
```

```
lon = 96 ;
lat = 48 ;
lev = 17 ;
lev_2 = 19 ;
nhym = 19 ;
nhyi = 20 ;
time = UNLIMITED ; // (12 currently)
```

```
variables:
```

```
[...]
```

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10 36.143               -2.622                 13.3
11 30.413               12.577                 10.6
```

- 1.) compute average between 20°N and 50°N
- 2.) select all data points east of 20°E
 - lots of loops and if-statements
 - scanning of data (row) that is not relevant
 - tedious and difficult

```
37 54.55                -108.07                17.3
38 40.4                 143.5                  19.4
39 44.53                147                    30.5
40 42.23                144.209                19.3
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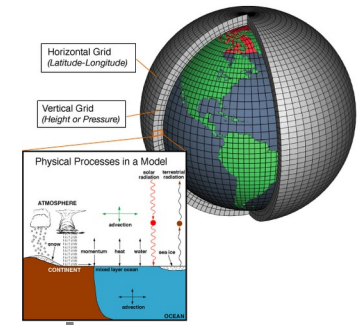


Network Common Data Form (NetCDF)

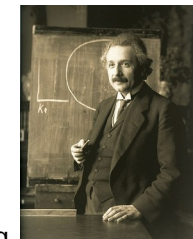
NetCDF is

- a set of interfaces for array-oriented data access
- a freely distributed collection of data access libraries for C, Fortran, C++, Java, and other languages
- the netCDF libraries support a machine-independent format for representing scientific data
- together, the interfaces, libraries, and format support the creation, access, and sharing of scientific data.

<http://www.unidata.ucar.edu/software/netcdf/docs/faq.html#whatitisit>



Mr Snrub at the English language Wikipedia / CC BY-SA
(<http://creativecommons.org/licenses/by-sa/3.0/>)
[https://commons.wikimedia.org/wiki/
File:Railroad_car_with_container_loads.jpg](https://commons.wikimedia.org/wiki/File:Railroad_car_with_container_loads.jpg)

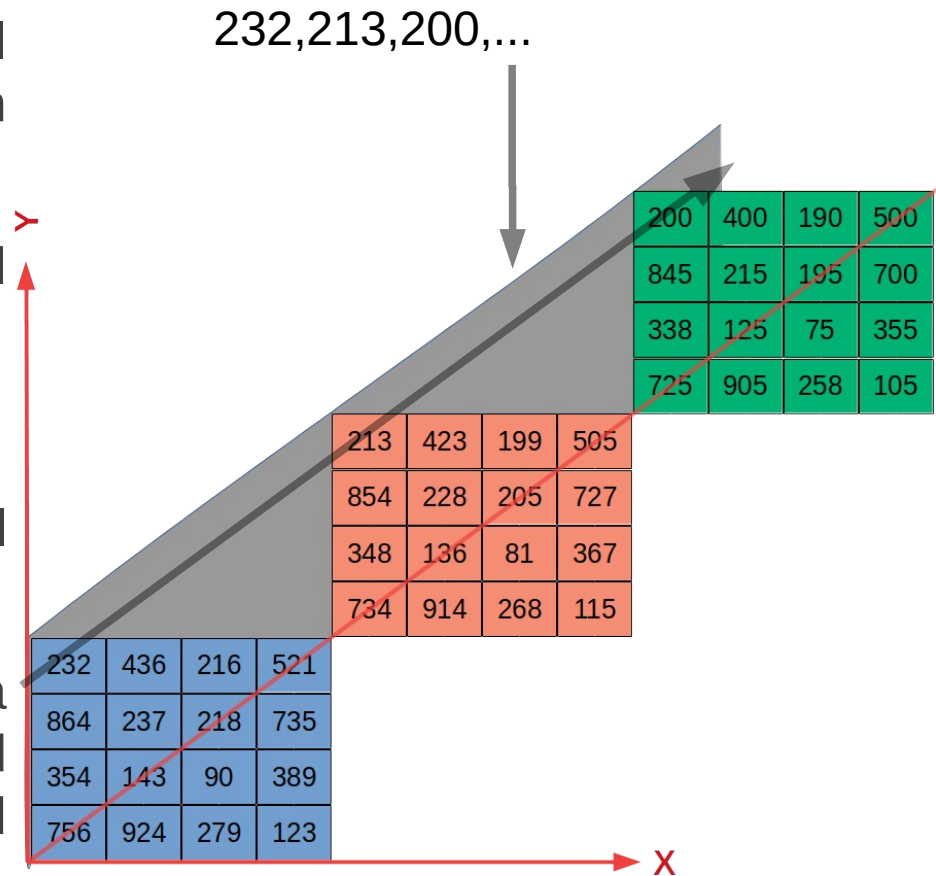


[https://commons.wikimedia.org/wiki/
File:Einstein_1921_by_F_Schmutzer_-_restoration.jpg](https://commons.wikimedia.org/wiki/File:Einstein_1921_by_F_Schmutzer_-_restoration.jpg)
(public domain)

Network Common Data Form (NetCDF)

It is a well organized container:

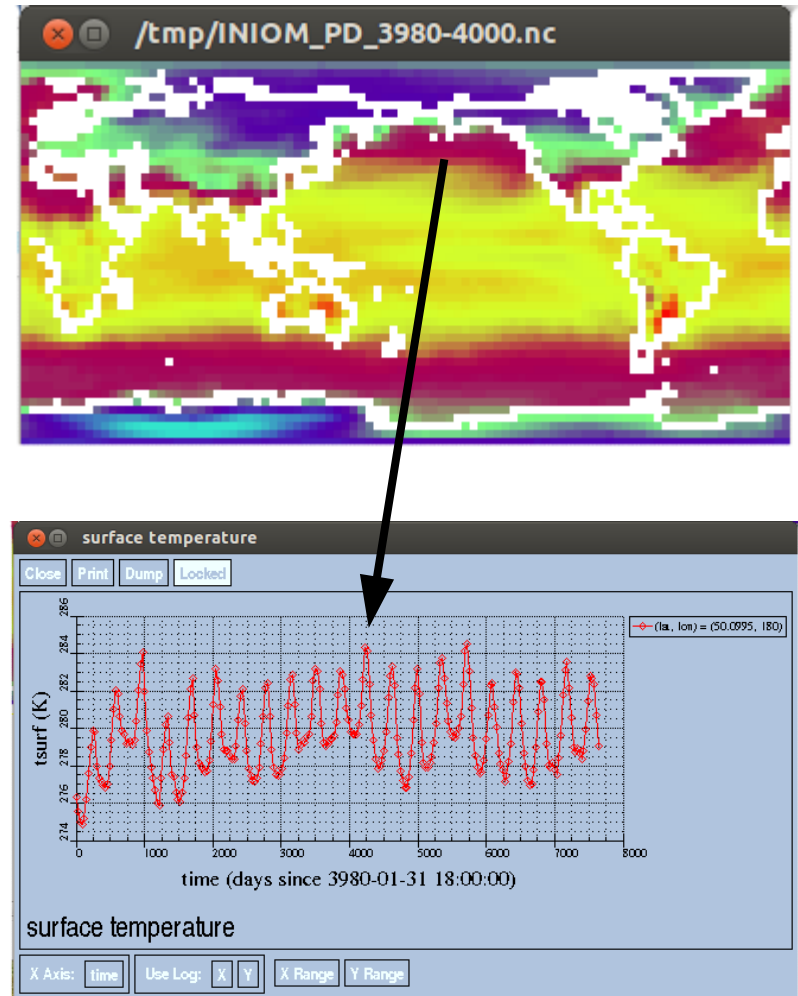
- contains data set, and a full description of the data set in one file
- data set is gridded in time and space (can be directly plotted)
- time and location data included
- further meta-data, e.g. physical units, included
- easy to create derived data sets (e.g. subsets, merged sets) using designated software tools



Network Common Data Form (NetCDF)

Special tools available for data analysis, plotting, inspection, ...

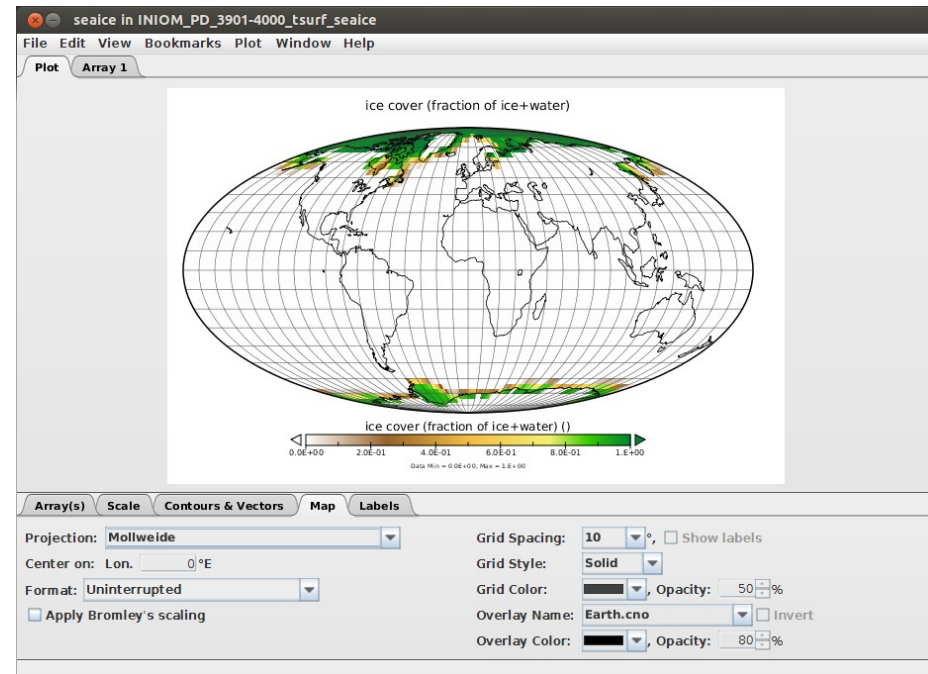
- LINUX/UNIX has many tools available
 - viewers: **ncview**/panoply
 - translators: ncdump/ncgen
 - analysis tools: CDO, ...
- Windows
 - some tools available, e.g. via cygwin
 - but: reduced functionality



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```
netcdf INIOM_PD_3901-4000_tsurf_seaice {
dimensions:
lon = 96 ;
lat = 48 ;
time = UNLIMITED ; // (1200 currently)
variables:
double lon(lon) ;
lon:standard_name = "longitude" ;
lon:long_name = "longitude" ;
lon:units = "degrees_east" ;
lon:axis = "X" ;
double lat(lat) ;
...
double time(time) ;
...
tsurf:long_name = "surface temperature" ;
tsurf:units = "K" ;
tsurf:code = 169 ;
tsurf:table = 128 ;
tsurf:grid_type = "gaussian" ;
float seaice(time, lat, lon) ;
seaice:long_name = "ice cover (fraction of ice+water)" ;
seaice:code = 210 ;
seaice:table = 128 ;
seaice:grid_type = "gaussian" ;
...
```

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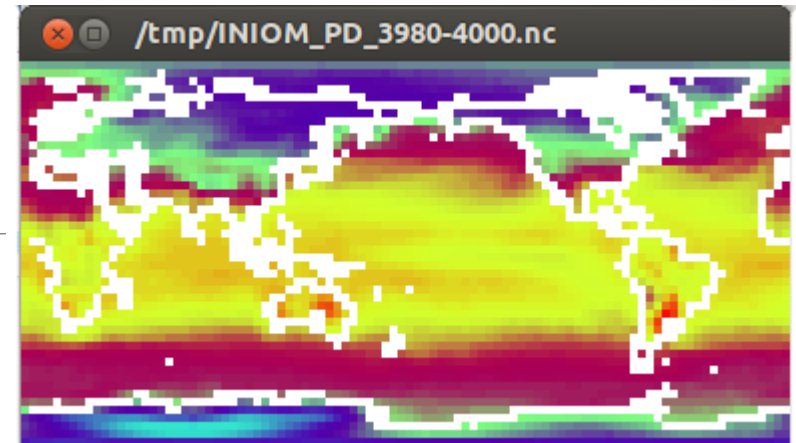
ls -lh tsurf.nc*

```
-rw-r--r-- 1 a270061 ab0246 76K 14. Apr 15:14 tsurf.nc
-rw-r--r-- 1 a270061 ab0246 196K 14. Apr 15:15 tsurf.nc.dump
```

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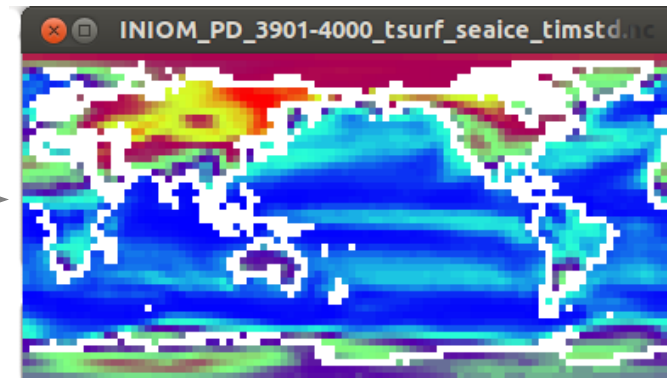
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CDO

timesteps: 1200
glob. avg. time: 287.6 K
glob. max. time: 317.2 K

CDO



Practical Exercises



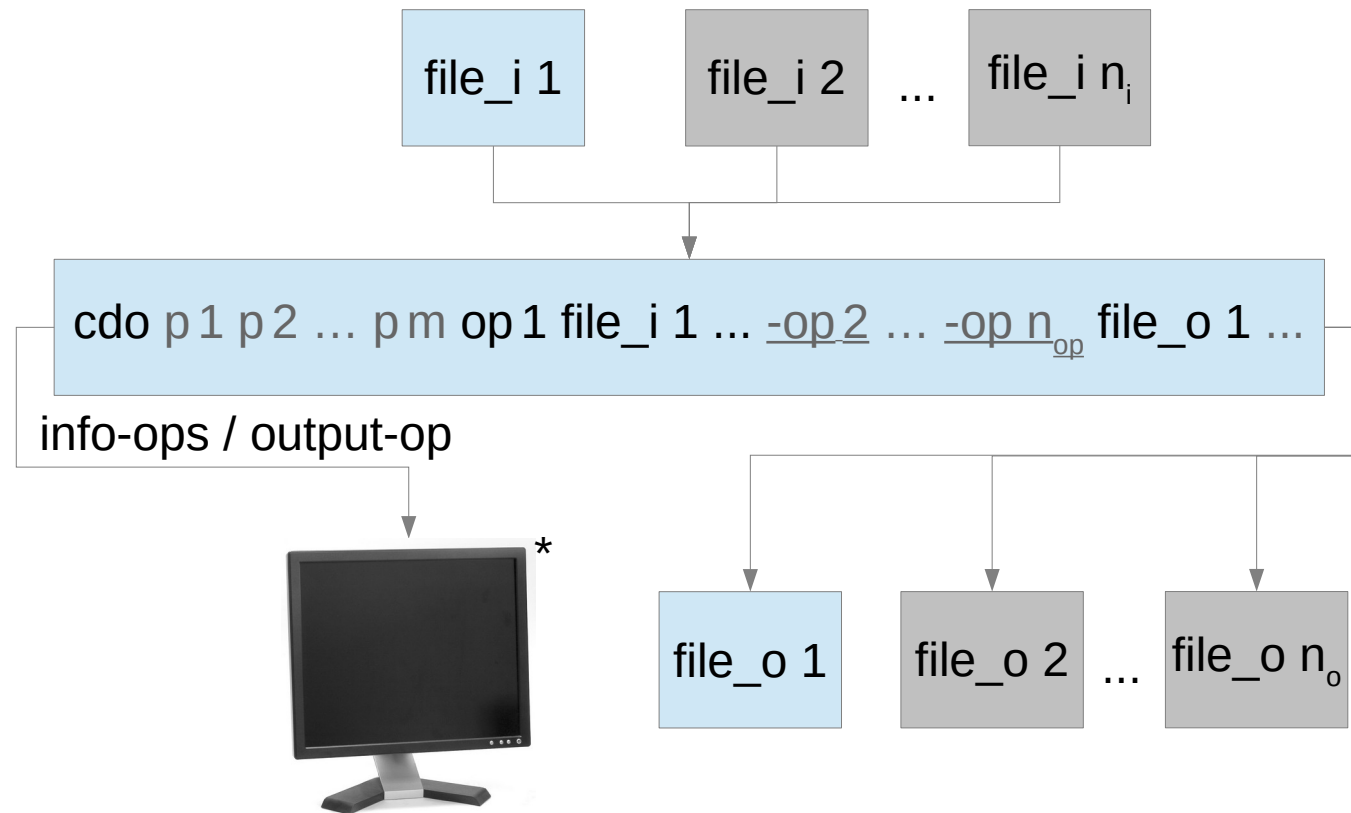
homework assignment (you may start this during the tutorial)

- answer the questions that you find on the homework sheet
- you may get up to 10 points,
+1 bonus point, if:
 - you correctly answer the bonus question
 - and lost at least one point at other questions
- if questions arise: contact me right now or per email
(Christian.Stepanek@awi.de)
- hand in your results by 10th of May, 12:00 o' clock noon – the results will be distributed and discussed at the tutorial on 13th of May
- Much success!

CDO

CDO is a toolbox for analysis and modification of (NetCDF) climate data

- information
- file operations
- selection
- modification
- arithmetic
- statistic
- regression
- interpolation
- ... (see documentation)



input files file_i, output files file_o, program options p, operators op1; grey: optional; underlined: **pipng – for complex tasks!**

*https://en.wikipedia.org/wiki/Computer_monitor#/media/File:Computer_monitor.jpg (public domain)

- installation (ubuntu): `sudo apt-get install cdo`
- windows version (limited functionality):
`https://code.zmaw.de/attachments/download/8378/cdo-1.6.4-win32.zip`
- comprehensive documentation of the CDO available at:
`https://code.zmaw.de/projects/cdo/embedded/index.html`
- looks complex, but easy to use with basic understanding of CDO's functionality

CDO – information operators



general short overview on a file:

```
$ cdo sinfo INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc

File format : netCDF

-1 : Institut Source   Ttype   Levels Num   Points Num Dtype : Parameter ID
   1 : MPIMET   ECHAM5.4 instant    17    1    4608    1  F32   : 130.128
   2 : MPIMET   ECHAM5.4 instant    17    1    4608    1  F32   : 131.128
   3 : MPIMET   ECHAM5.4 instant    17    1    4608    1  F32   : 132.128

...

Grid coordinates :

   1 : gaussian                : points=4608 (96x48) np=0
                                lon : 0 to 356.25 by 3.75 degrees_east  circular
                                lat : 87.1591 to -87.1591 degrees_north

Vertical coordinates :

   1 : pressure                : levels=17
                                lev : 100000 to 1000 Pa

   2 : surface                 : levels=1

   3 : hybrid                  : levels=19
                                lev_2 : 1 to 19 by 1 level
                                available : vct

Time coordinate : 12 steps

   RefTime = 3901-01-31 18:00:00 Units = days Calendar = proleptic_gregorian
   YYYY-MM-DD hh:mm:ss   YYYY-MM-DD hh:mm:ss   YYYY-MM-DD hh:mm:ss   YYYY-MM-DD hh:mm:ss
   4000-01-31 18:00:00   4000-02-29 18:00:00   4000-03-31 18:00:00   4000-04-30 18:00:00

...
```

quantities (variables) contained in a file:

```
$ cdo pardes INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

```
130 t          temperature [K]
131 u          u-velocity [m/s]
132 v          v-velocity [m/s]
133 q          specific humidity [kg/kg]
135 omega      vertical velocity [Pa/s]
155 sd        divergence [1/s]
156 geopot    geopotential height [m]
157 rhumidity  relative humidity
  85 tradl    net LW radiation 200mb [W/m^2]
  86 sradi    net SW radiation 200mb [W/m^2]
      .
      .
      .
```


CDO – information operators



time axis contained in a file:

```
$ cdo showdate INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc  
4000-01-31 4000-02-29 4000-03-31 4000-04-30 4000-05-31 4000-06-30 4000-  
07-31 4000-08-31 4000-09-30 4000-10-31 4000-11-30 4000-12-31
```

levels contained in a file:

```
$ cdo showlevel INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc  
100000 92500 85000 77500 70000 60000 50000 40000 30000 25000 20000 15000 10000  
7000 5000 3000 1000
```

time steps / months contained in a file:

```
$ cdo ntime INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

```
12
```

```
$ cdo nmon INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

```
12
```

CDO – description operators



grid description of a file:

```
$ cdo griddes INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

```
gridtype = gaussian
gridsize = 4608
xname    = lon
xlongname = longitude
xunits   = degrees_east
yname    = lat
ylongname = latitude
yunits   = degrees_north
np       = 0
xsize    = 96
ysize    = 48
xfirst   = 0
xinc     = 3.75
yvals    = 87.1590946 83.4789367 79.7770457 76.0702445 72.361581 68.6520168 64.9419495
          61.2315732 57.5209938 53.810274 50.0994534 46.3885581 42.6776062 38.9666105
          35.2555805 31.5445233 27.8334445 24.1223483 20.4112384 16.7001177 12.9889886
          9.27785325 5.56671363 1.85557149 -1.85557149 -5.56671363 -9.27785325
          -12.9889886 -16.7001177 -20.4112384 -24.1223483 -27.8334445 -31.5445233
          -35.2555805 -38.9666105 -42.6776062 -46.3885581 -50.0994534 -53.810274
          -57.5209938 -61.2315732 -64.9419495 -68.6520168 -72.361581 -76.0702445
          -79.7770457 -83.4789367 -87.1590946
```

CDO – selection operators



select variable tsurf (note the parameter syntax ','):

```
$ cdo selvar,tsurf INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc tsurf.nc
```

select months March, April, May (note the range selection syntax '/'):

```
$ cdo selmon,3/5 INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc march-may.nc
```

select northern hemisphere (NH) data (multiple parameters separated by ','):

```
$ cdo sellonlatbox,0,360,0,90 INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc NH.nc
```

select data at 1000 hPa:

```
$ cdo sellevel,1000 INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc 1000hPa.nc
```

CDO – selection operators



combine selection operations - **pipng**:

```
$ cdo sellevel,100000 -sellonlatbox,0,360,0,90 -selmon,3/5 -selvar,t  
INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc selected.nc
```

→ evaluated **right to left**

→ simplifies complex operations

alternative: 'select'-operator:

```
$ cdo select,name=t,month=3,4,5,level=100000 INIOM_PD_echam5_main_mm_3901-  
4000_climatological_mean.nc selected.nc
```

→ not all possible operations reflected by 'select'
(e.g. no lon-lat-box selection)

adding two fields (note the piping!):

```
$ cdo add -selvar,tsurf INIOM_PD_echam5_main_mm_3901-  
4000_climatological_mean.nc -selvar,tsurf LGM-W_echam5_6100-  
6200_climatological_mean.nc added.nc
```

dividing by a constant:

```
$ cdo divc,2 added.nc divided.nc
```

adding and dividing by constant
(here: arithmetic mean, note the piping!):

```
$ cdo divc,2 -add -selvar,tsurf INIOM_PD_echam5_main_mm_3901-  
4000_climatological_mean.nc -selvar,tsurf LGM-W_echam5_6100-  
6200_climatological_mean.nc mean.nc
```

ensemble mean T:

```
$ cdo ensmean -selvar,tsurf INIOM_PD_echam5_main_mm_3901-  
4000_climatological_mean.nc -selvar,tsurf LGM-W_echam5_6100-  
6200_climatological_mean.nc mean.nc
```

spatial average T (note the 'output'-operator):

```
$ cdo output -fldmean -selvar,tsurf INIOM_PD_echam5_main_mm_3901-  
4000_climatological_mean.nc
```

time average T:

```
$ cdo timmean -selvar,tsurf INIOM_PD_echam5_main_mm_3901-  
4000_climatological_mean.nc timmean.nc
```

monthly maximum T globally:

```
$ cdo output -fldmax -selvar,tsurf INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

coldest monthly T of the global average:

```
$ cdo output -timmin -fldmean -selvar,tsurf  
INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

global average summer T (note the range selection syntax '/'):

```
$ cdo output -fldmean -timmean -selmon,6/8 -selvar,tsurf  
INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

global average annual mean:

```
$ cdo output -fldmean -yearmean -selvar,tsurf  
INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

warmest month (per location):

```
$ cdo timmax -selvar,tsurf INIOM_PD_echam5_main_mm_3901-  
4000_climatological_mean.nc timmax.nc
```


nearest neighbour interpolation, 1x1 degree:

```
$ cdo remapnn,r360x180 INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc 1x1_nn.nc
```

find T at 20°N, 134°E, bilinear interp.:

```
$ cdo output -remapbil,lon=134/lat=20 -selvar,tsurf  
INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

dependence of result on interp. method:

```
$ cdo output -timmean -sub -fldmean -remapbil,r360x180 -selvar,tsurf  
INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc  
-fldmean -remapnn,r360x180 -selvar,tsurf  
INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
```

Shell

The shell in UNIX can

- start any available program
 - in the terminal
 - with a GUI (with “window”)
- transfer output from one program as input to another program (piping)
- redirect program output
- allows variable declarations, including arrays
- provide access to other computers via SSH
- control lengthy tasks

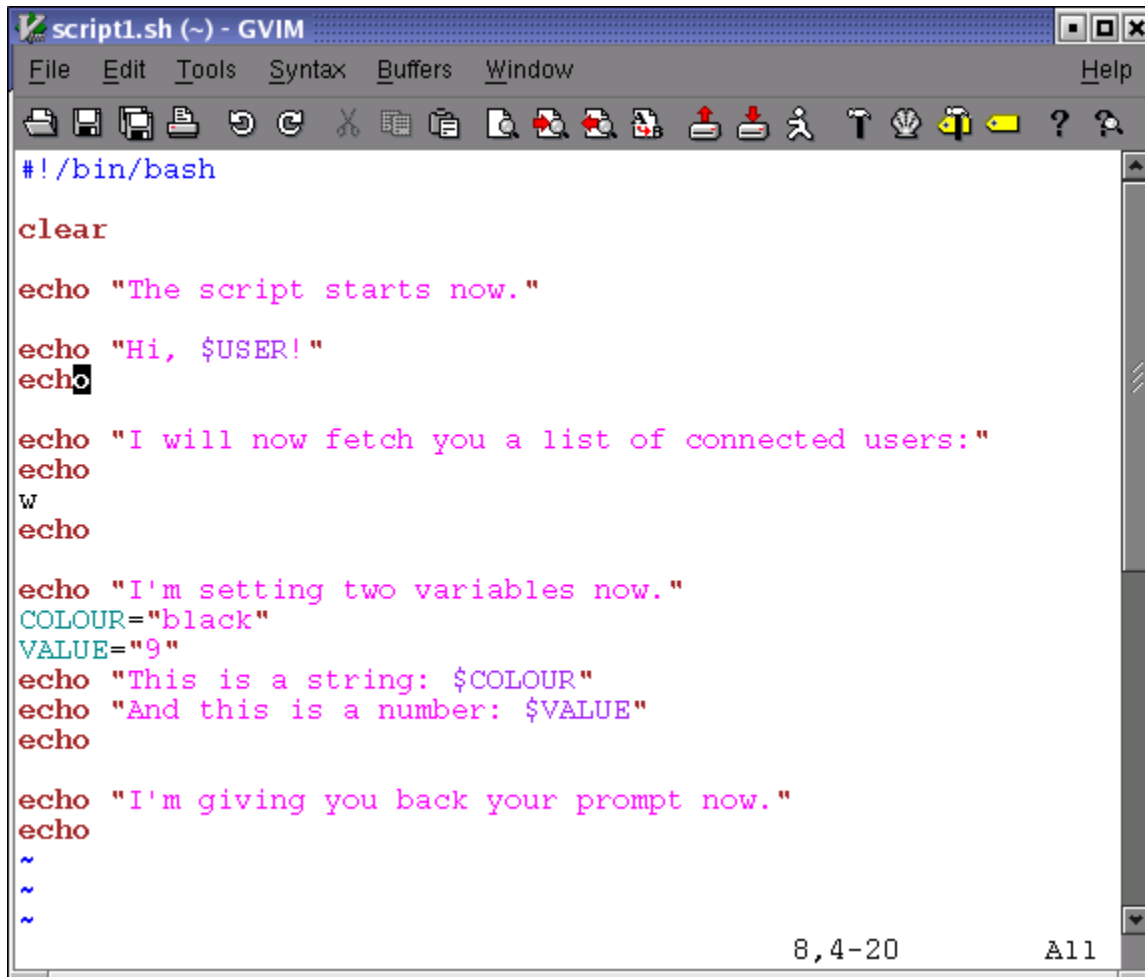
your interactive control center



http://www.nasa.gov/images/content/160446main_jsc2006e43860_high.jpg
(public domain)

Shell

The UNIX shell is programmable



```
#!/bin/bash

clear

echo "The script starts now."

echo "Hi, $USER!"
echo

echo "I will now fetch you a list of connected users:"
echo
w
echo

echo "I'm setting two variables now."
COLOUR="black"
VALUE="9"
echo "This is a string: $COLOUR"
echo "And this is a number: $VALUE"
echo

echo "I'm giving you back your prompt now."
echo
~
~
~
```

your automated control center



http://www.nasa.gov/images/content/160446main_jsc2006e43860_high.jpg
(public domain)

Practical Exercises

homework assignment (you may start this during the tutorial)

- answer the questions that you find on the homework sheet
- you may get up to 10 points
(+1 bonus point if
 - you correctly answer the bonus question
 - and lost at least one point at other questions))
- if questions arise: contact me right now or per email
(Christian.Stepanek@awi.de)
- hand in your results by 10th of May, 12:00 o'clock noon, in groups of up to three students, clearly identifying who contributed to the solutions – the results will be distributed and discussed at the tutorial on 13th of May.
- Much success!