ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

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

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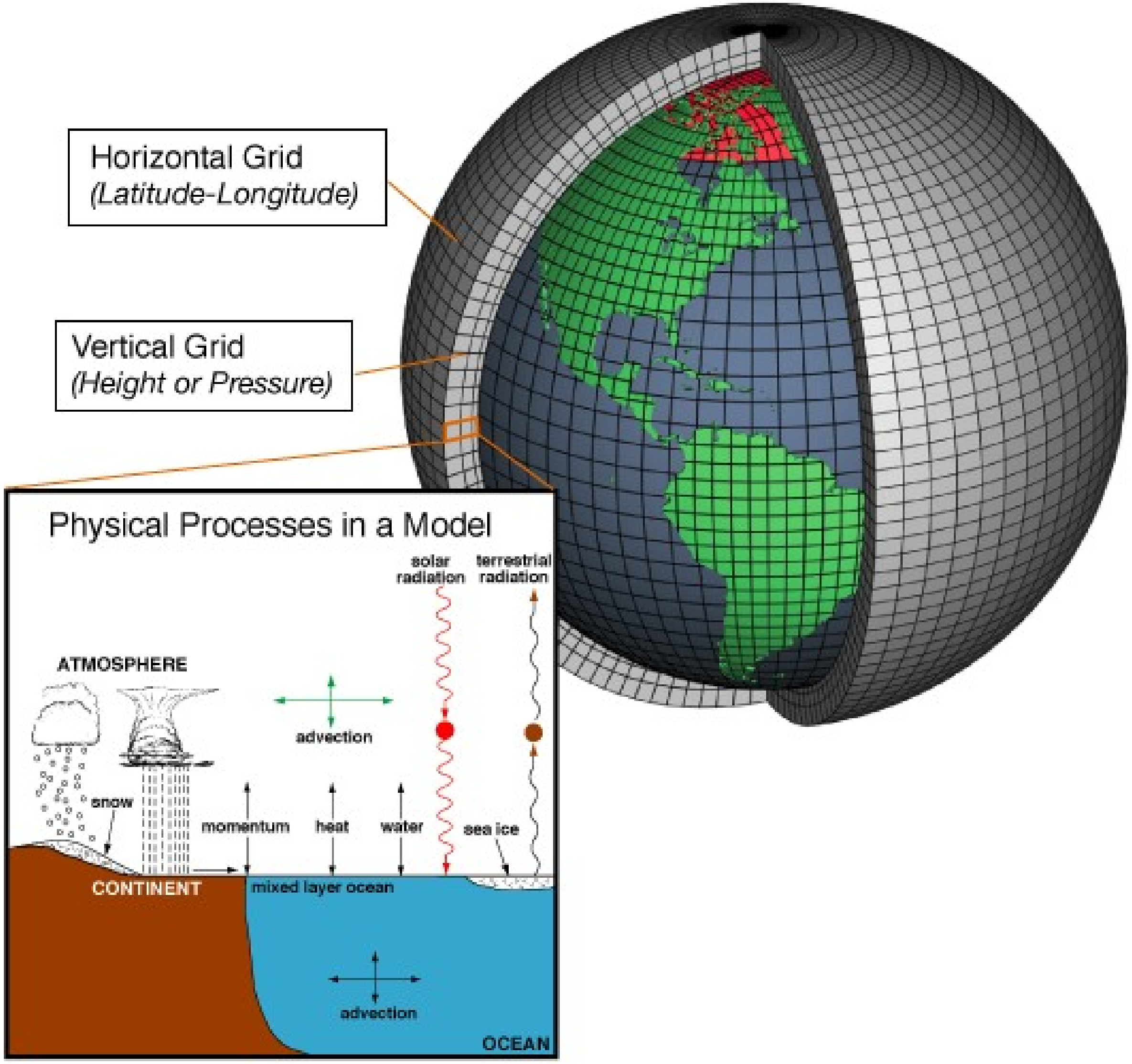
Monday, 24th of April, 2023

HELMHOLTZ
ASSOCIATION

Overview

- 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

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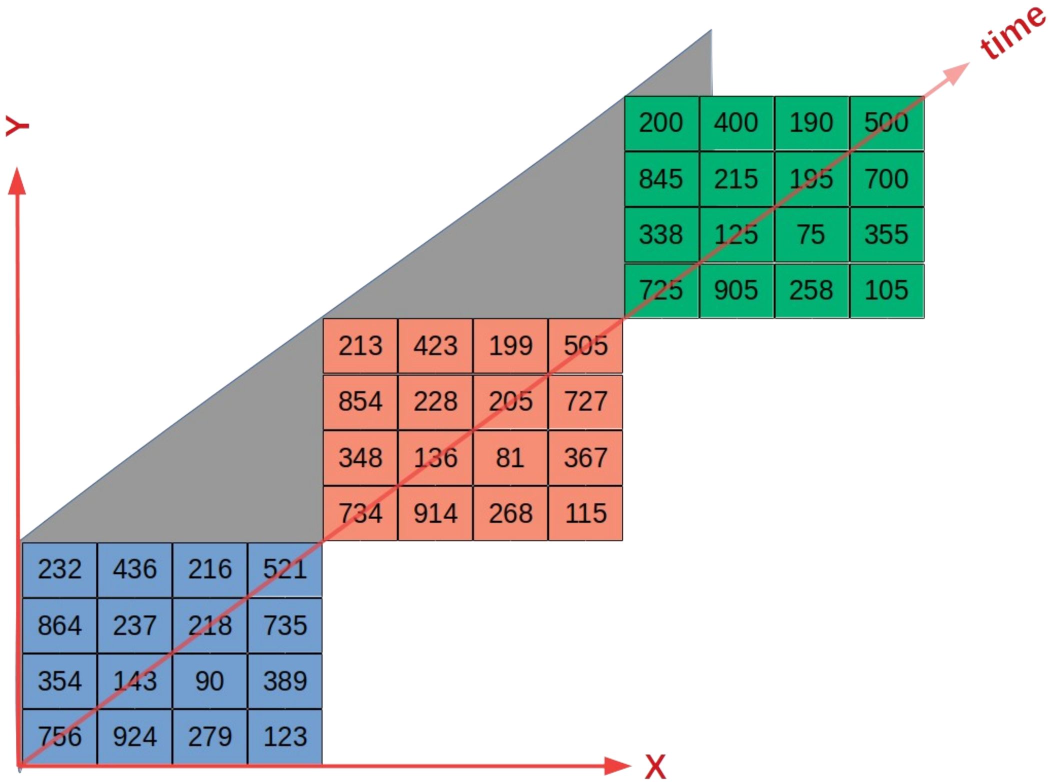

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Background: Climate Modelling

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

Latitude / deg N	Longitude / deg E	Temp. / deg C
74.995	13.97	10.3
66.967	7.633	12.4
58.762	-25.958	23.5
57.838	8.704	12.3
48.912	-126.89	9.6
41.682	-124.93	11.3
40.842	27.763	13.4
37.036	13.19	24.5
36.143	-2.622	13.3
38.412	13.577	10.6
38.262	14.03	12.3
36.746	17.718	14.4
34.953	128.881	25.5
34.535	-121.107	14.3
32.668	138.455	11.6
27.714	34.682	13.3
23.583	64.217	15.4
20.75	-18.583	26.5
20.117	117.383	15.3
43.882	-62.8	12.6
43.483	-54.867	14.3
44.527	145.042	16.4
20.217	-18.45	27.5
37.799	-10.166	16.3
37.881	-10.176	13.6
66.999	-17.961	15.3
36.032	-1.955	17.4
30.85	-10.268	28.5
21.358	-158.19	17.3
50.395	148.323	14.6
46.317	152.533	16.3
38.634	-9.454	18.4
56.33	170.699	29.5
53.993	162.376	18.3
49.376	152.878	15.6
54.55	-168.67	17.3
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44.53	147	30.5
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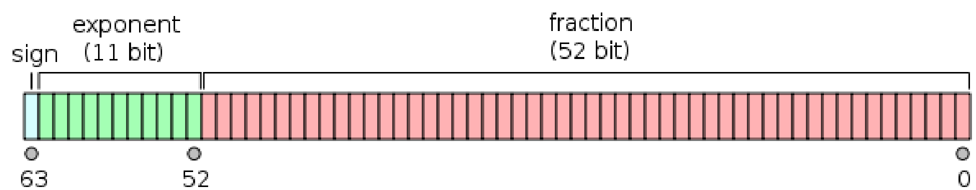

binary format:
2^{52}=4,503,599,627,370,496 ≅ 8 Byte

character format:
4,503,599,627,370,496 ≅ 16 Byte (+5)

https://en.wikipedia.org/wiki/Double-precision_floating-point_format

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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

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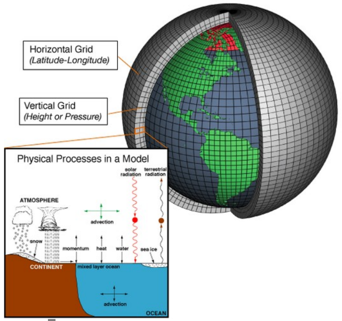
Network Common Data Form (NetCDF)

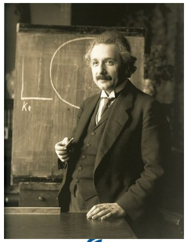
NetCDF is

- 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#whatisit



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

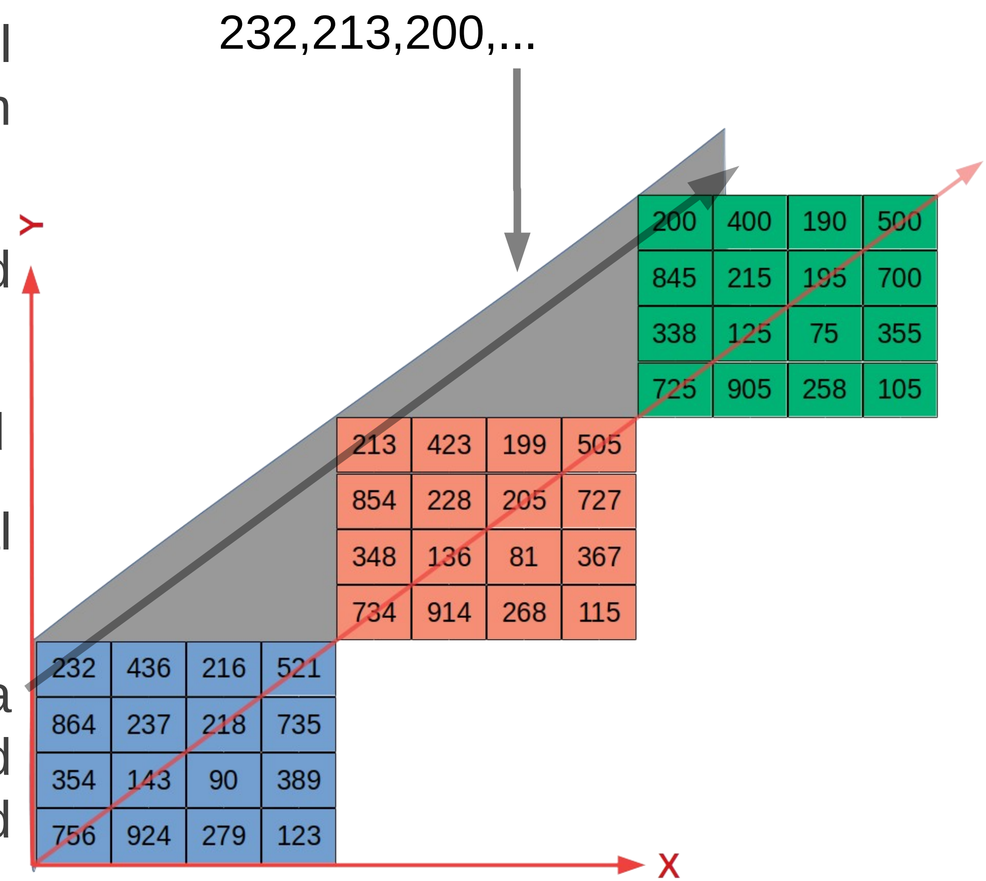


https://commons.wikimedia.org/wiki/
File:Einstein_1921_by_F_Schmutzer_-_restoration.jpg
(public domain)

Network Common Data Form (NetCDF)

It is a well organized container:

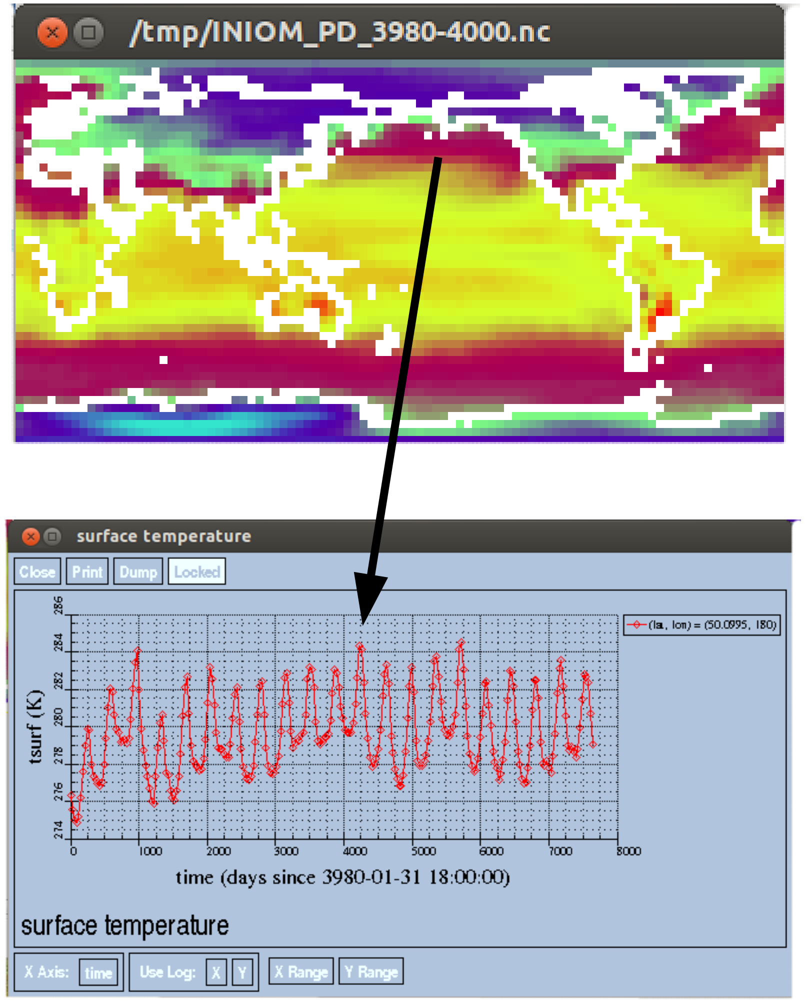
- contains data set, and a full description of the data set in one file
- data set is gridded in time and space (can be directly plotted)
- time and location data included
- further meta-data, e.g. physical units, included
- easy to create derived data sets (e.g. subsets, merged sets) using designated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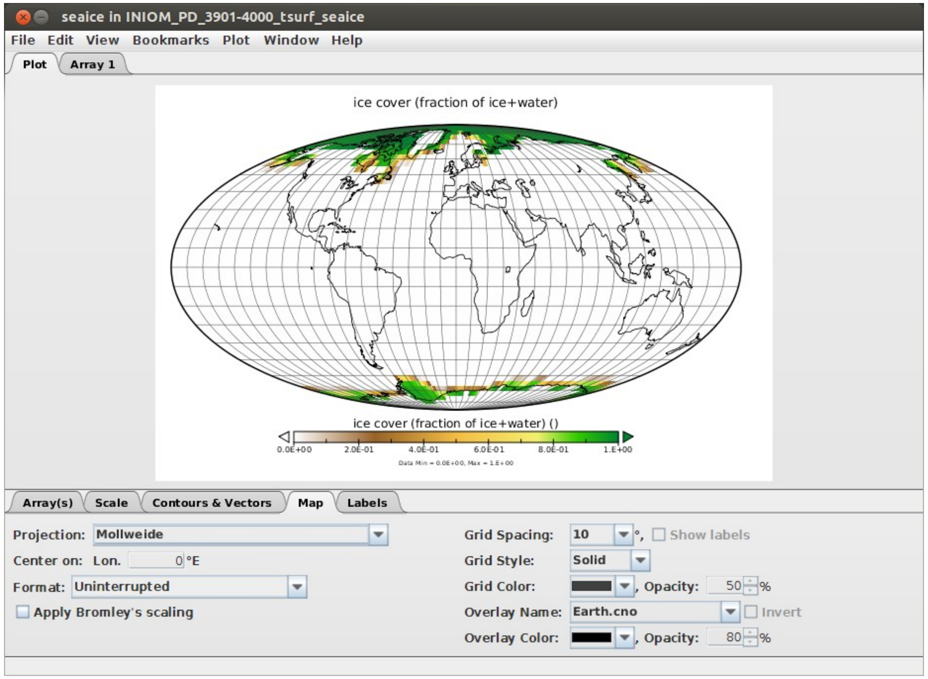

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```
netcdf INIOM_PD_3901-4000_tsurf_seaice {
dimensions:
lon = 96 ;
lat = 48 ;
time = UNLIMITED ; // (1200 currently)
variables:
double lon(lon) ;
lon:standard_name = "longitude" ;
lon:long_name = "longitude" ;
lon:units = "degrees_east" ;
lon:axis = "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 ;
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...
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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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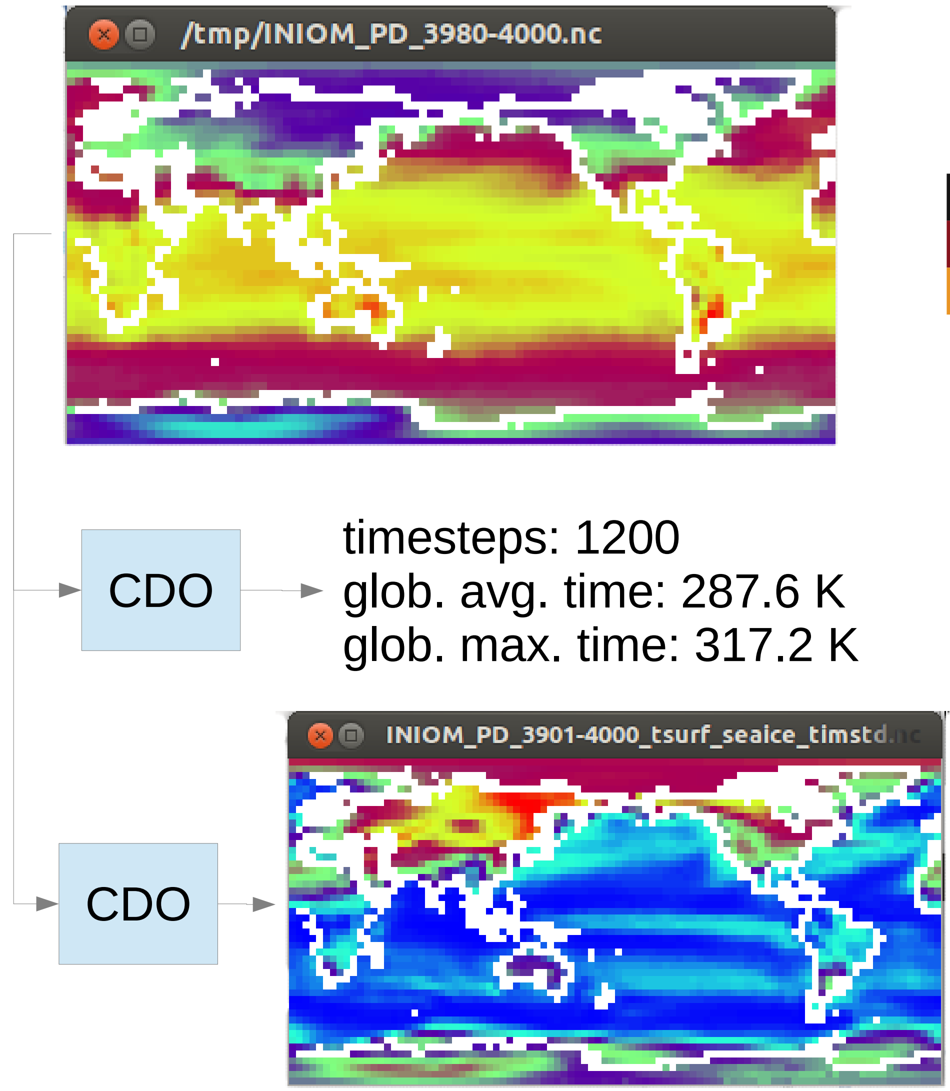

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Practical Exercises

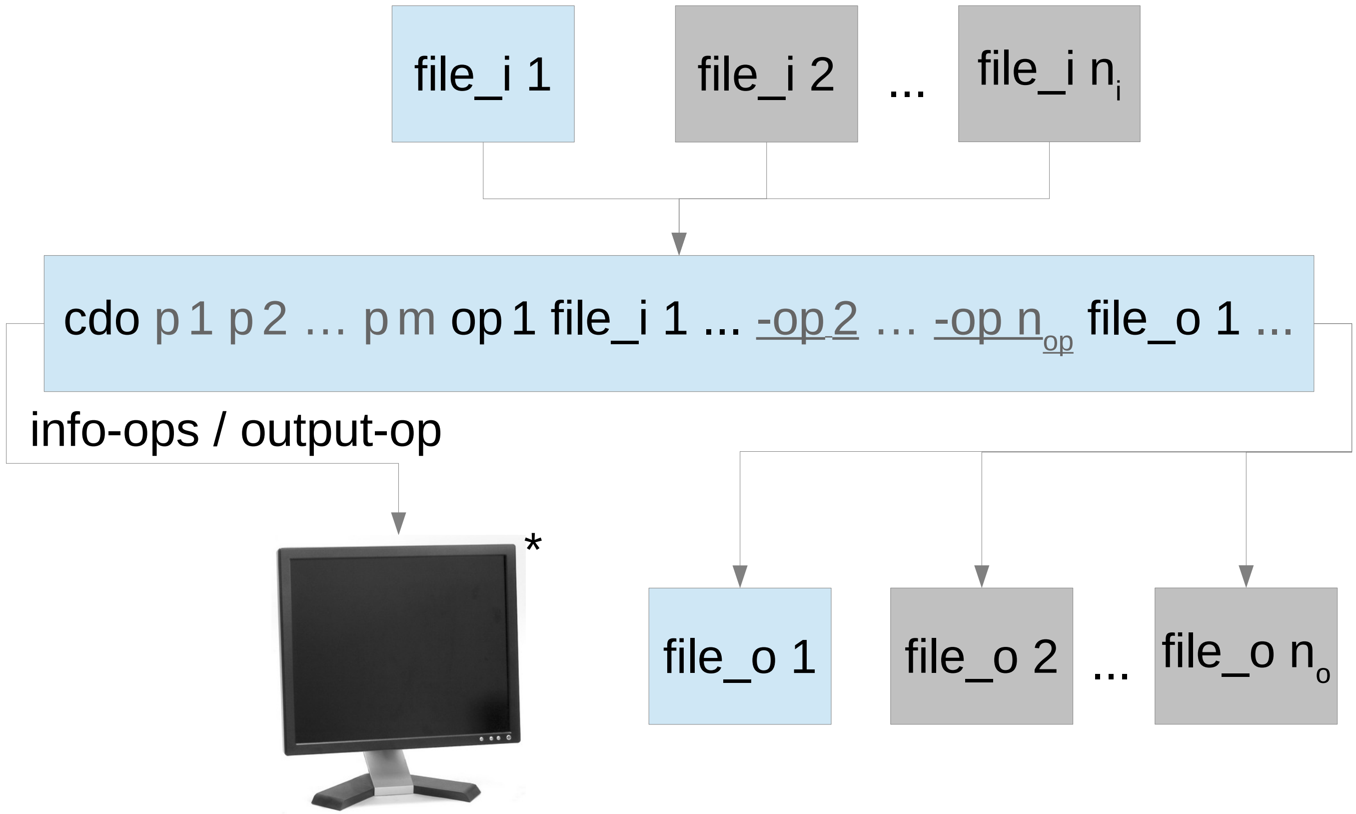
homework assignment (you may start this during the tutorial)

- 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 8th of May, 12:00 o' clock noon – the results will be distributed and discussed at the tutorial on 15th 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: piping – for complex tasks!

CDO

- 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
...
```

CDO – information operators

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  geopoth        geopotential height [m]
157  rhumidity      relative humidity
 85  tradl          net LW radiation 200mb [W/m^2]
 86  sradl          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,100000 INIOM_PD_echam5_main_mm_3901-4000_climatological_mean.nc
1000hPa.nc
```

CDO – selection operators

combine selection operations - piping:

```
$ 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)

CDO – arithmetic operators

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
```

CDO – statistical operators: averaging

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
```

CDO – statistical operators: extreme values

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
```

CDO – statistical operators: temporal

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
```

CDO – statistical operators: interpolation

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

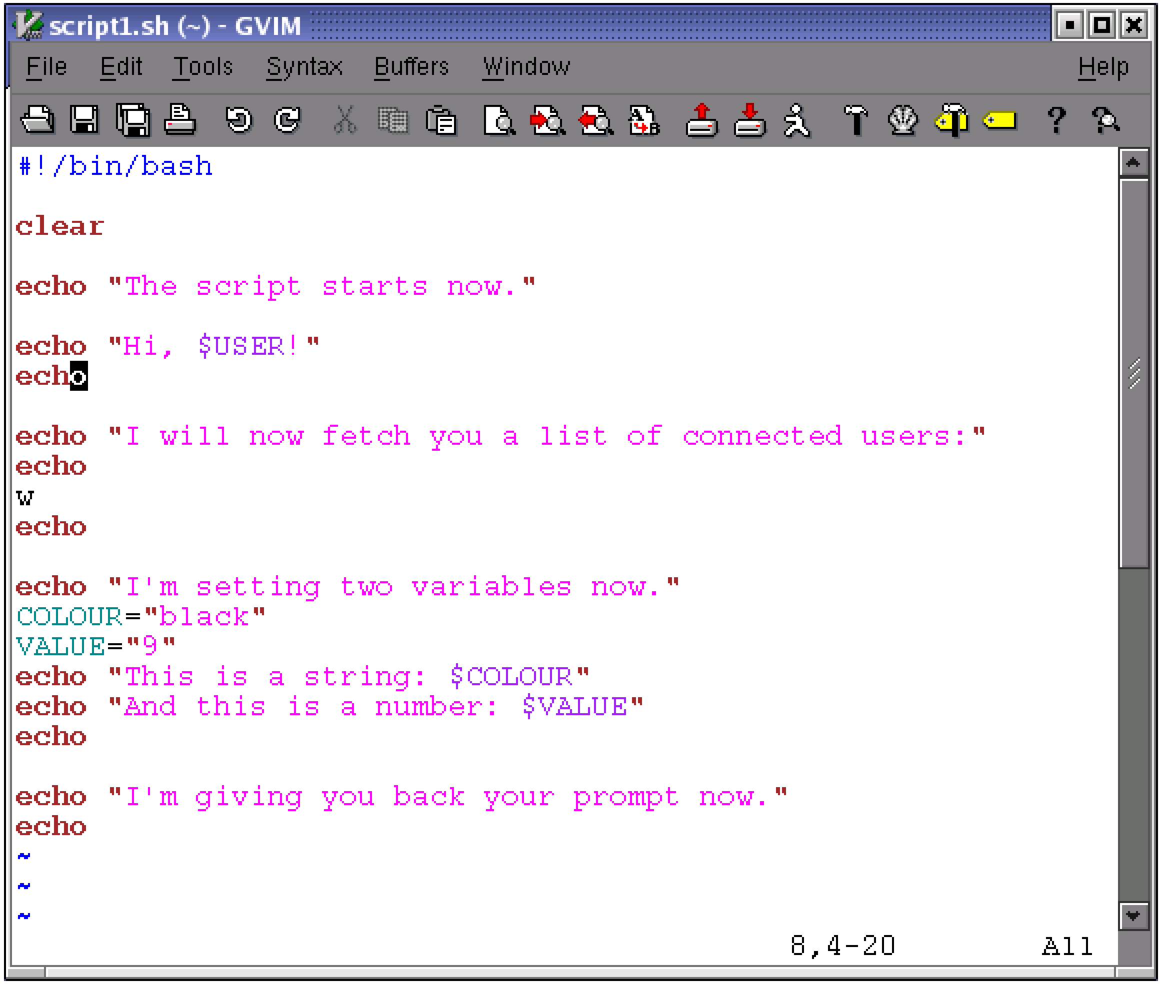
- start any available program
  - in the terminal
  - with a GUI (with “window”)
- transfer output from one program as input to another program (piping)
- redirect program output
- allows variable declarations, including arrays
- provide access to other computers via SSH
- control lengthy tasks

your interactive control center

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

Shell

The UNIX shell is programmable



http://tldp.org/LDP/Bash-Beginners-Guide/html/images/script1.sh.png

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 8th 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 15th of May.
- Much success!