Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Guideline for the transformation of GRIB2 datasets from the original triangular to the regular lat/lon grid

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Product Design and Customer Relations Division
Deutscher Wetterdienst
Frankfurter Straße 135
63067 Offenbach
Germany
http://www.dwd.de

1 Climate Data Operators – CDO

Climate Data Operators (CDO) is a command-line tool to manipulate and analyze climate and numerical weather prediction model data. Supported data formats are GRIB 1/2[1], NetCDF 3/4[2], SERVICE, EXTRA and IEG. There are more than 600 operators available including simple statistical and arithmetic functions, data selection and subsampling tools-, and spatial interpolation. The software tool is open source and covered by the GNU General Public License v2 (GPL). More information can be found at https://code.mpimet.mpg.de/projects/CDO and https://code.mpimet.mpg.de/projects/CDO/wiki. CDO can be used to transform or, to be more significant, to interpolate numerical weather prediction data sets from the triangular grid into the regular lat/lon grid like ICON (ICOsahedral Nonhydrostatic) as well for the COSMO (Consortium for Small Scale Modelling). The transformation processes will be described in detail in the following sections. To be able to perform the transformation and to take full advantage of CDO features the following additional libraries should be installed:

Unidata NetCDF library (https://www.unidata.ucar.edu/software/netcdf) version 3 or higher, needed to process NetCDF files with CDO. ECMWF ecCodes library (https://software.ecmwf.int/wiki/display/ECC/ecCodes+Home) version 2.3.0 or higher, which is needed to process GRIB2 files with CDO. More information can be found at https://code.mpimet.mpg.de/projects/CDO/wiki/CDO and http://www.studytrails.com/blog/install-climate-data-operator-CDO-with-netCDF-GRIB2-and-hdf5-support. For the different distributions please visit the following sites: for Linux distributions https://code.mpimet.mpg.de/projects/CDO/wiki/Linux_Platform, Windows distributions https://code.mpimet.mpg.de/projects/CDO/wiki/Win32, MacOS distributions https://code.mpimet.mpg.de/projects/CDO/wiki/MacOS_Platform.

1.1 CDO features NetCDF and ecCodes

CDO uses a template `$GRIB_SAMPLES_PATH/GRIB2.tmpl` in order to write GRIB2 data. Note that when reading an input GRIB2 dataset the applying GRIB2 table version will always be taken by the defined template and picket not out of the used inputdataset < `in` >. The directory of the environment variable `GRIB_SAMPLES_PATH` and the definitionpath are given by the commands `grib_info` (GRIB-API) or `codes_info` (ecCodes).

```
grib_info

GRIB_api Version 1.23.1
Default definition files path is used: /usr/local/pkg/GRIB_api/definitions/release/1.23.1/definitions.edzw:/usr/local/
     pkg/GRIB_api/definitions/release/1.23.1/definitions Definition files path can be changed setting
     GRIB_DEFINITION_PATH environment variable
SAMPLES path from environment variable GRIB_SAMPLES_PATH=/usr/local/pkg/GRIB_api/definitions/release/1.23.1/share/
     GRIB_api/samples
```

The template `GRIB2.tmpl` can be changed using `grib_set -s tablesVersion=11 GRIB2.tmpl GRIB2.tmpl`. Accordingly, the definition paths of GRIB-API and ecCodes have to be adjusted in the config file `section.1.def` line "MasterTableVersion".

[1] GRIB version 1, from the World Meteorological Organisation (WMO)

[2] NetCDF Software Package, from the UNIDATA Program Center of the University Corporation for Atmospheric Research

2 Transformation of ICON datasets from the triangular grid to the regular lat/lon grid

In order to transform GRIB2 datasets of ICON, which are available on opendata in the original triangular grid, into a regular lat/lon grid, three basic files are necessary:

- `icon_grid_0026_R03B07_G.nc`, which contains the greid information,
- the grid description of the output file `TARGET_GRID_DESCRIPTION` and
- the area weights `WEIGHTS_FILE`.

These basic files make it possible to run the lat/lon transformation for any section of the original triangular grid. The files can be downloaded from the following url: https://opendata.dwd.de/weather/lib/cdo/ICON_GLOBAL*.tar.bz2. If errors occur during transformation, it might be helpful to first split the grib file into individual files for each parameter using `grib_copy infile.grib2 outfile_[shortName].grib2`, and then perform the transform.

2.1 Transformation from the original grid to the lat/lon grid ($0.25° \times 0.25°$)

This section shows how to use CDO to transform a GRIB2 file of ICON global model from the original triangular grid into a regular lat/lon grid with a resolution of $0.25° \times 0.25°$. The area weights (`weights_icogl2world_025.nc`), which are needed for the interpolation, can be calculated using the grid-description (`target_grid_025.txt`) and the grid-information file `icon_grid_0026_R03B07_G.nc`. This has to be calculated[3] only once.

```
cdo gennn,${TARGET_GRID_DESCRIPTION} icon_grid_0026_R03B07_G.nc ${WEIGHTS_FILE}
```

Based on the resulting weights file `weights_icogl2world_025.nc`, CDO can all ICON global GRIB2 files to meet the given grid description using the following command:

```
  cdo -f nc remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
```

The option `-f nc` defines that the result is written to a netCDF file, the option `-f grb2` defines that the output file is written in the GRIB2 format.

2.2 An illustrative example

First of all, the necessary data and spatial data files have to be downloaded from https://opendata.dwd.de/weather/lib/cdo/ICON_GLOBAL*.tar.bz2 and stored in a local directory (`/user/directory/...`). Once this is complete, the interpolation can be started. The following bash script shows how a transformation from the ICON-global triangular grid into a regular lat/lon grid can be performed:

```
#!/bin/bash
export WORKDIR=/user/directory/Transform_Originalgitter_RegGitter
export ICON_GRID_FILE=${WORKDIR}/icon_grid_0026_R03B07_G.nc
export TARGET_GRID_DESCRIPTION=${WORKDIR}/target_grid_world_025.txt
```

[3] The area weights are generated via the "nearest neighbour interpolation (`CDOgennn`)" method.

```
5  export  WEIGHTS_FILE=${WORKDIR}/weights_icogl2world_025.nc
6  export  in_file=${WORKDIR}/ICON_single_level_elements_world_T_2M_2017062512_000.GRIB2
7  #export  out_file=${WORKDIR}/ICON_world_025x025_T_2M_2017062512_000.nc # if netCDF output
8  export out_file=${WORKDIR}/ICON_world_025x025_T_2M_2017062512_000.grb2 # if GRIB2 output
9  cd ${WORKDIR}
10 time cdo gennn,${TARGET_GRID_DESCRIPTION} ${ICON_GRID_FILE} ${WEIGHTS_FILE}
11 echo "end of weights generation with CDO"
12 echo "in_file: "${in_file}   echo "out_file: "${out_file}
13 #For OutputFile: netCDF
14 #time cdo -f nc remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
15 #For OutputFile: GRIB2
16 time cdo -f grb2 remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
```

Note, that the command in line 10 calculates the interpolation weights WEIGHTS_FILE and that this has to be done only once. The resulting interp[lation weights can also be used for all other cases with the same grid-description. Several lines can be commented out or deleted from the script, simplifying it as follows:

```
#!/bin/bash
export WORKDIR=/user/directory/
export TARGET_GRID_DESCRIPTION=${WORKDIR}/target_grid_world_025.txt
export WEIGHTS_FILE=weights_icogl2world_025.nc
export in_file=${WORKDIR}/ICON_single_level_elements_world_T_2M_2017062512_000.GRIB2
# if output file has to be netCDF
#export out_file=${WORKDIR}/ICON_world_025x025_T_2M_2017062512_000.nc
# if output file has to be GRIB2
export out_file=${WORKDIR}/ICON_world_025x025_T_2M_2017062512_000.grb2
cd ${WORKDIR}
echo "WORKDIR: "${WORKDIR} echo "TARGET_GRID_DESCRIPTION: "${TARGET_GRID_DESCRIPTION}
echo "WEIGHTS_FILE: "${WEIGHTS_FILE}
echo "in_file: "${in_file} echo "out_file: "${out_file}
echo "start remap CDO"
#netCDF
#time cdo -f nc remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
#GRIB2
time cdo -f grb2 remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
echo "done remap CDO"
```

2.3 Transformation from the original triangular grid to the lat/lon grid $(0.125° \times 0.125°)$

Analogously to section 2.2 the following commands have to be used for a resolution of $0.125° \times 0.125°$ (see Appendix 3.2):

```
CDO -f nc remap,target_grid_world_0125.txt,weights_icogl2world_0125.nc ${in_file} ${out_file} # for netCDF output
CDO -f grb2 remap,target_grid_world_0125.txt,weights_icogl2world_0125.nc ${in_file} ${out_file} # for GRIB2 output
```

2.4 Transformation from the original triangular grid to the lat/lon grid $(0.125° \times 0.125°)$for an determined european region

CDO also allows the transformation of self-defined area sections. Let's take the European area section fedined by the lat/lon edges $(-75\,;\,75\,;\,5\,;\,80)$ as an example.For this, the TARGET_GRID_DESCRIPTION file has to be changed accordingly and the interpolation weights WEIGHTS_FILE have to be recalculated (see Appendix 3.3):

```
#!/bin/bash
export  WORKDIR=/user/directory/Transform_Originalgitter_RegGitter/
export  ICON_GRID_FILE=/user/directory/Transform_Originalgitter_RegGitter/src/icon_grid_0026_R03B07_G.nc
export  TARGET_GRID_DESCRIPTION=${WORKDIR}/target_grid_europa_ausschnitt.txt
export  WEIGHTS_FILE=weights_icogl2world_025_EUAU.nc
export  in_file=${WORKDIR}/ICON_single_level_elements_world_T_2M_2017062512_000.GRIB2
#export  out_file=${WORKDIR}/ICON_world_025x025_T_2M_2017062512_000_EUAU.nc # if netCDF output
```

```
export out_file=${WORKDIR}/ICON_world_025x025_T_2M_2017062512_000_EUAU.grb2 # if GRIB2 output
cd ${WORKDIR}
time CDO gennn,${TARGET_GRID_DESCRIPTION} ${ICON_GRID_FILE} ${WEIGHTS_FILE}
echo "end of weights generation with CDO"
echo "in_file: "${in_file}   echo "out_file: "${out_file}
#For OutputFile: netCDF
#time cdo -f nc remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
#For OutputFile: GRIB2
time cdo -f grb2 remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
```

whereby the file `target_grid_europa_ausschnitt.txt` contains the following values:

```
# CDO grid description file for regular grid Europe source ICON_GLOBAL
gridtype  = lonlat
xsize     = 1201
ysize     = 601
xfirst    = -75.0
xinc      = 0.125
yfirst    = 5.0
yinc      = 0.125
```

Thereby, the transformation will be done for the chosen area section$(-75\,;\,75\,;\,5\,;\,80)$ only $(-180\,;\,180\,;\,-90\,;\,90)$. Note, that the script has been code can be simplified by delete the code for calculation of the weights:

```
#!/bin/bash
export WORKDIR=/user/directory/
export TARGET_GRID_DESCRIPTION=${WORKDIR}/ICON_GLOBAL2EUAU_0125/target_grid_EUAU_0125.txt
export WEIGHTS_FILE=${WORKDIR}/ICON_GLOBAL2EUAU_0125/weights_icogl2world_0125_EUAU.nc
export in_file=${WORKDIR}/ICON_single_level_elements_world_T_2M_2017062512_000.GRIB2
# if output file has to be netCDF
#export out_file=${WORKDIR}/ICON_world_T_2M_2017062512_000_EUAU_0125.nc
# if output file has to be GRIB2
export out_file=${WORKDIR}/ICON_world_T_2M_2017062512_000_EUAU_0125.grb2
echo "start remap CDO"
cd ${WORKDIR}
#For OutputFile: netCDF
#time cdo -f nc remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
#For OutputFile: GRIB2
time cdo -f grb2 remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
echo "done remap CDO"
```

2.5 Grid description

The grid description defines the boundaries or edges of the target grid as well as the resolution of the target-grid by defining the increment. A valid grid description (`TARGET_GRID_DESCRIPTION`) is necessary in order to carry out the transformation from an original triangular grid to a regular lat/lon grid. The boundaries for a valid description are given by the following equations:

$$
\begin{aligned}
y_{\texttt{size}} &= \frac{1}{y_{\text{inc}}} \times (y_{\text{end}} - y_{\text{first}}) \text{ mit } y_{\text{inc}} \in [0.25, 0.125]\,,\ y_{\text{first}}, y_{\text{end}} = [-90; 90] \\
x_{\texttt{size}} &= \frac{1}{x_{\text{inc}}} \times (x_{\text{end}} - x_{\texttt{first}}) \text{ mit } x_{\text{inc}} \in [0.25, 0.125]\,,\ x_{\texttt{end}}, x_{\text{first}} = [-180; 180]
\end{aligned}
$$

whereby x_{inc} and y_{inc} should take the values 0.25 or 0.125 and $x_{\text{first}}, x_{\text{end}}$ values between -180 and 180. The differences between $y_{\text{end}} - y_{\text{first}}$ and $x_{\text{end}} - x_{\text{first}}$ have to be positive.

2.6 Interpolation

The transformation-examples presented in this document use the nearest neighbor method. However, the ICON model relies on different interpolation methods for different model output fields and there are three different algorithms used at the DWD for the ICON model outputs in the regular lat/lon grid:

- Barycentric interpolation,
- Interpolation through radial basis function and
- Nearest neighbor interpolation.

Each method is used for different model output fields. The ICON model documentation includes a description of the different methods and an explanation of which method is used for which model output field (Section 10.2. of the ICON model documentation.) Additionally, tables 6.2-11 (page 26ff) and 7.2-8 of the documentation show the interpolation-method for each model output field (see column (**LL IntpType**)). For more information, please refer to the model documentation. Note that the barycentric interpolation and interpolation through radial basis function are not supported by default in CDO.

3 Appendix

3.1 Transformation from the original triangular grid to a regular lat/lon grid ($0.25° \times 0.25°$)

A transformation from original triangular grid to a lat/lon grid with a resolution of $0.25° \times 0.25°$ can be executed by using CDO. However, some necessary files (downloadable from `https://www.dwd.de/DE/leistungen/opendata/hilfe.html`) have to be included in CDO (see Section 2.0). In bash, this can be done as shown in the example below:

```
#!/bin/bash
export WORKDIR=/user/directory/
export TARGET_GRID_DESCRIPTION=${WORKDIR}/ICON_GLOBAL2WORLD_025/target_grid_world_025.txt
export WEIGHTS_FILE=${WORKDIR}/ICON_GLOBAL2WORLD_025/weights_icogl2world_025.nc
export in_file=${WORKDIR}/ICON_single_level_elements_world_reg_T_2M_2017062512_000.GRIB2
# if output file has to be netCDF
#export out_file=${WORKDIR}/ICON_world_[YYYYMMDD][modelrun]_[timestep]_025.nc
# if output file has to be GRIB2
export out_file=${WORKDIR}/ICON_world_[shortname]_[YYYYMMDD][modelrun]_[timestep]_025.grb2
cd ${WORKDIR}
echo "WORKDIR: "${WORKDIR} echo "TARGET_GRID_DESCRIPTION: "${TARGET_GRID_DESCRIPTION}
echo "WEIGHTS_FILE: "${WEIGHTS_FILE}
echo "start remap cdo"
#netCDF
#time cdo -f nc remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
#GRIB2
time cdo -f grb2 remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
echo "done remap cdo"
```

3.2 Transformation from the original triangular grid to a regular lat/lon grid $(0.125° \times 0.125°)$

Analogously to section 3.1, one way to transform the dataset with a resolution of $(\mathbf{0.125°} \times \mathbf{0.125°})$ is given by:

```bash
#!/bin/bash
export WORKDIR=/user/directory/
export TARGET_GRID_DESCRIPTION=${WORKDIR}/ICON_GLOBAL2WORLD_0125/target_grid_world_0125.txt
export WEIGHTS_FILE=${WORKDIR}/ICON_GLOBAL2WORLD_0125/weights_icogl2world_0125.nc
export in_file=${WORKDIR}/ICON_single_level_elements_world_reg_T_2M_2017062512_000.GRIB2
# if output file has to be netCDF
#export out_file=${WORKDIR}/ICON_iko_world_[shortname]_[YYYYMMDD][modelrun]_[timestep]_0125.nc
# if output file has to be GRIB2
export out_file=${WORKDIR}/ICON_iko_world_[shortname]_[YYYYMMDD][modelrun]_[timestep]_0125.grb2
cd ${WORKDIR}
echo "WORKDIR: "${WORKDIR} echo "TARGET_GRID_DESCRIPTION: "${TARGET_GRID_DESCRIPTION}
echo "WEIGHTS_FILE: "${WEIGHTS_FILE}
echo "start remap cdo"
#netCDF
#time cdo -f nc remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
#GRIB2
time cdo -f grb2 remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
echo "done remap cdo"
```

3.3 Transformation from the original triangular grid to the lat/lon grid $(0.25° \times 0.25°)$ for a specific European region

Analogously to section 3.3, one way to transform the dataset with a resolution of $(\mathbf{0.25°} \times \mathbf{0.25°})$ is given by:

```bash
#!/bin/bash
export WORKDIR=/user/directory/
export TARGET_GRID_DESCRIPTION=${WORKDIR}/ICON_GLOBAL2EUAU_025/target_grid_EUAU_025.txt
export WEIGHTS_FILE=${WORKDIR}/ICON_GLOBAL2EUAU_025/weights_icogl2world_025_EUAU.nc
export in_file=${WORKDIR}/ICON_iko_single_level_elements_world_[YYYYMMDD][modelrun]_[timestep].GRIB2
# if output file has to be netCDF
#export out_file=${WORKDIR}/ICON_iko_world_[shortname]_[YYYYMMDD][modelrun]_[timestep]_025.nc
# if output file has to be GRIB2
export out_file=${WORKDIR}/ICON_iko_world_[shortname]_[YYYYMMDD][modelrun]_[timestep]_025.grb2
cd ${WORKDIR}
echo "WORKDIR: "${WORKDIR} echo "TARGET_GRID_DESCRIPTION: "${TARGET_GRID_DESCRIPTION}
echo "WEIGHTS_FILE: "${WEIGHTS_FILE}
echo "start remap cdo"
#netCDF
#time cdo -f nc remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
#GRIB2
time cdo -f grb2 remap,${TARGET_GRID_DESCRIPTION},${WEIGHTS_FILE} ${in_file} ${out_file}
echo "done remap cdo"
```