Deutscher Wetterdienst
Wetter und Klima aus einer Hand

DWD

Hans-Ertel-Zentrum
für Wetterforschung



ICON

ICOsahedral Nonhydrostatic Model

DKRZ
DEUTSCHES
KLIMARECHENZENTRUM

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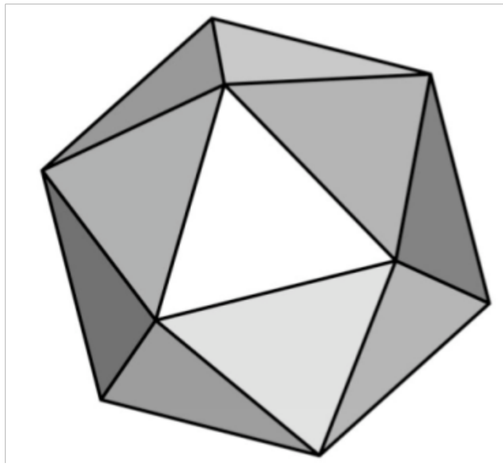
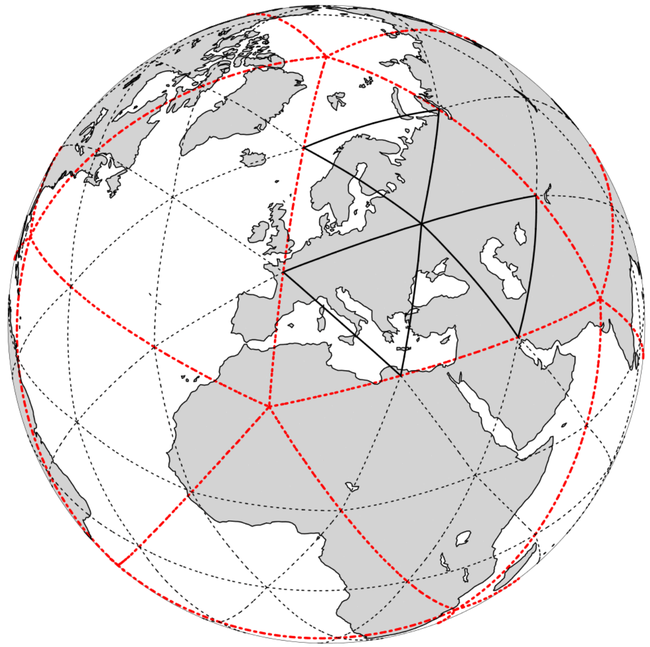
Horizontal grid topology

- grid generation is based on the Icosahedron
- RnBk denotes a grid that originates from an icosahedron whose
  - edges have been initially divided into n parts,
  - followed by k subsequent edge bisections.
- The total number of grid cells in the ICON grid is given by

$$n_{\text{cells}} = 20\, n^2 4^k$$

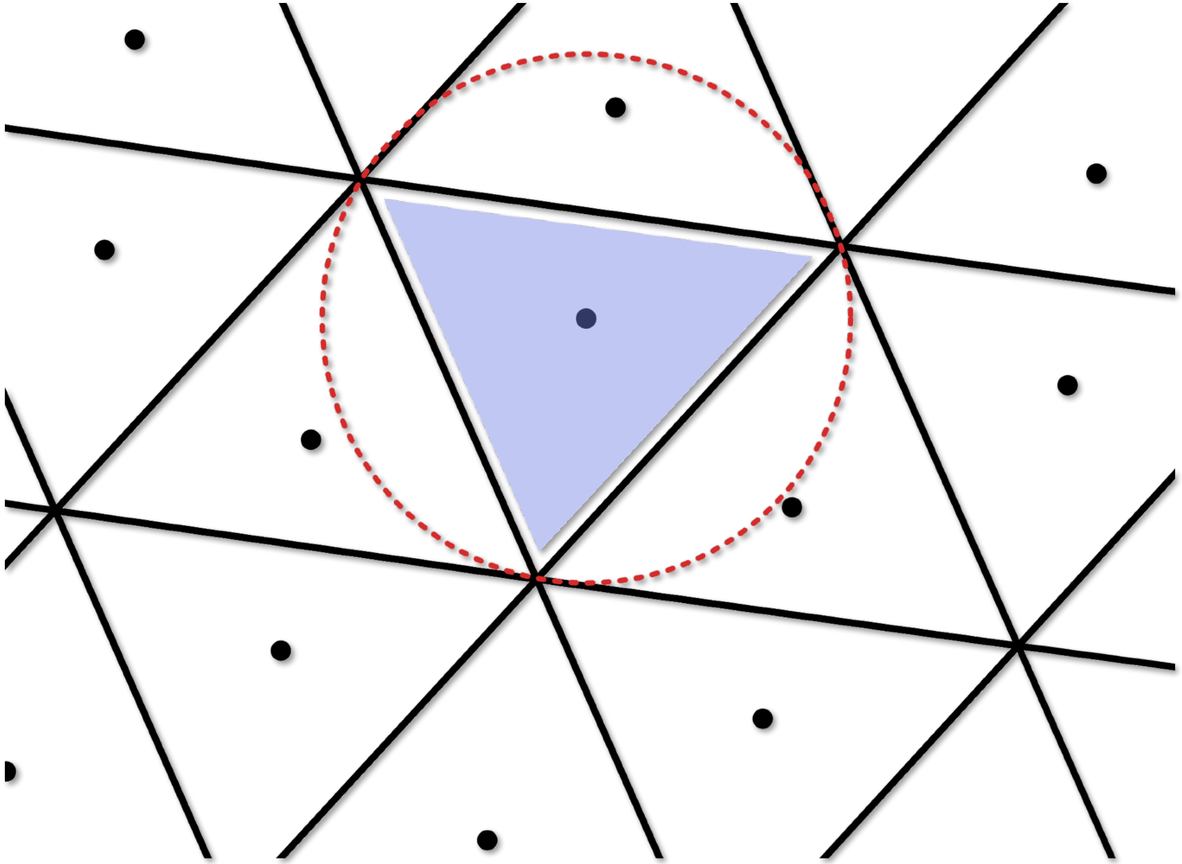
- operationally used:
  - R03B07, which corresponds to ~ 3 million cells (13km resolution)
  - with a R03B08N02 nest with ~ 700000 cells (6.5km resolution)
- DYAMOND:
  - R02B10, which corresponds to ~84 million cells (2.5km resolution)





R3B0 (black)

Horizontal grid topology



Horizontal grid topology is stored in separate files

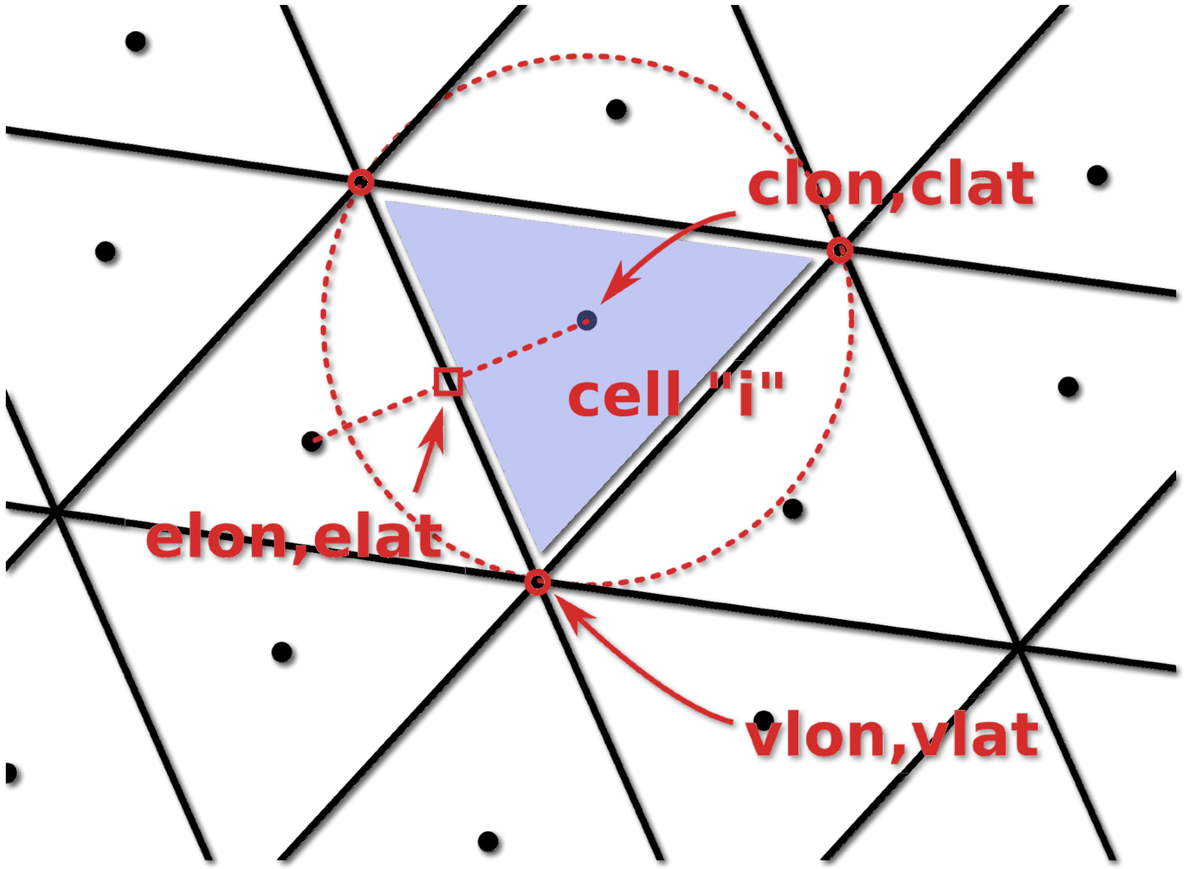
- 2.5km DYAMOND run aka R02B10:

`/work/bk1040/experiments/input/2.5km/icon_grid_0017_R02B10_G.nc`

- more generally:

`/work/bk1040/experiments/input/<resolution>/icon_grid_<a number>_<res>_G.nc`

Horizontal grid topology



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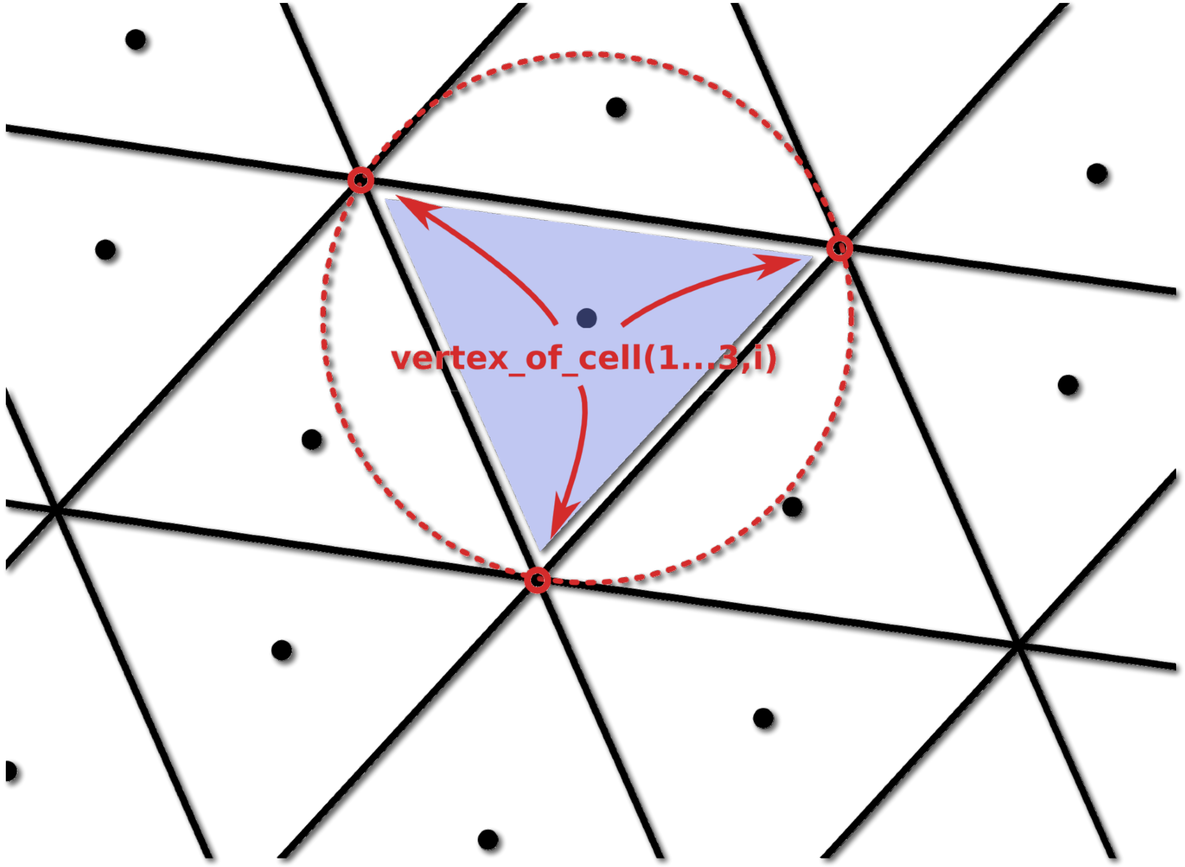
- more generally:

`/work/bk1040/experiments/input/<resolution>/icon_grid_<a number>_<res>_G.nc`

Horizontal grid topology



Horizontal grid topology is stored in separate files

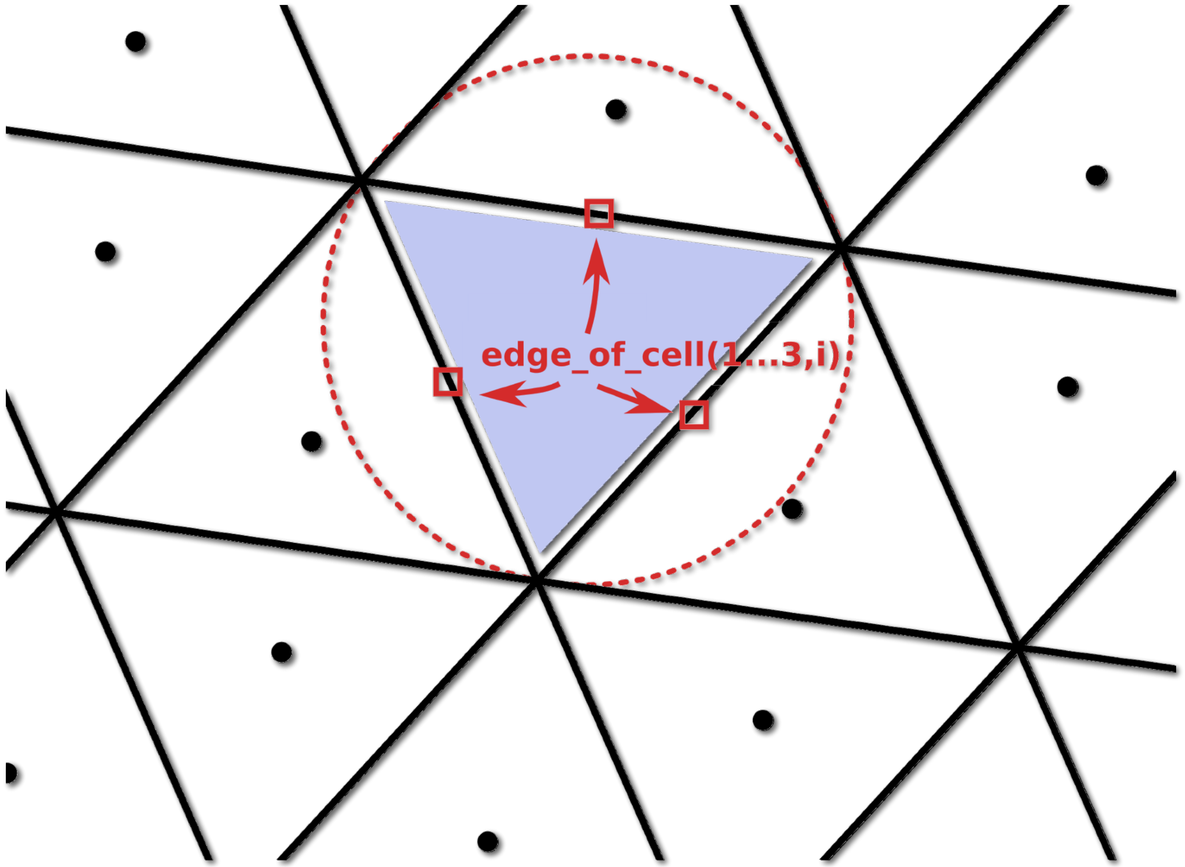
- 2.5km DYAMOND run aka R02B10:

`/work/bk1040/experiments/input/2.5km/icon_grid_0017_R02B10_G.nc`

- more generally:

`/work/bk1040/experiments/input/<resolution>/icon_grid_<a number>_<res>_G.nc`

Horizontal grid topology



Horizontal grid topology is stored in separate files

- 2.5km DYAMOND run aka R02B10:

`/work/bk1040/experiments/input/2.5km/icon_grid_0017_R02B10_G.nc`

- more generally:

`/work/bk1040/experiments/input/<resolution>/icon_grid_<a number>_<res>_G.nc`

Horizontal grid topology

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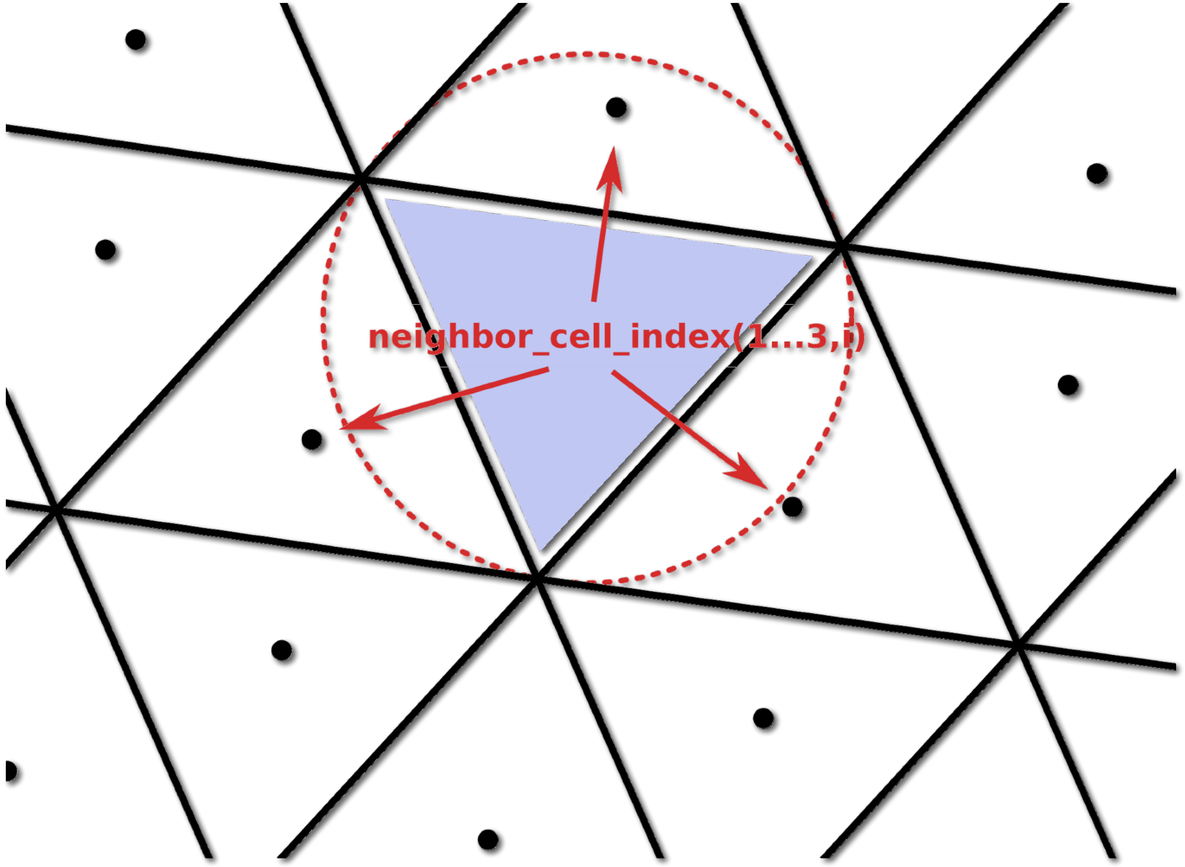
Data files contain „fingerprint“ of the horizontal grid

Attribute **uuidOfHGrid**



Horizontal grid topology is stored in separate files

- 2.5km DYAMOND run aka R02B10:

`/work/bk1040/experiments/input/2.5km/icon_grid_0017_R02B10_G.nc`

- more generally:

`/work/bk1040/experiments/input/<resolution>/icon_grid_<a number>_<res>_G.nc`

Resolution

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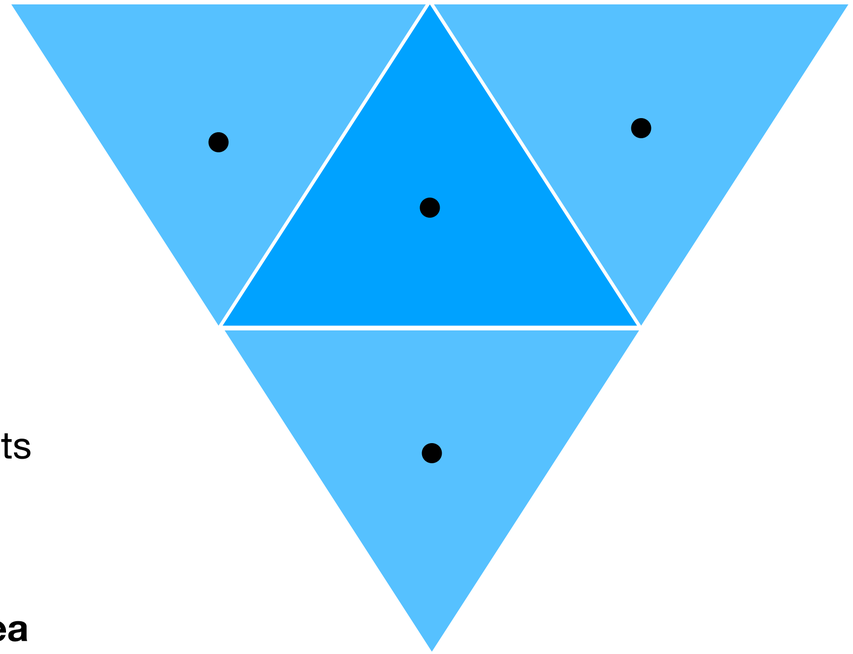
A word on resolution:

It is very differently defined in different models and usually does not mean the same thing



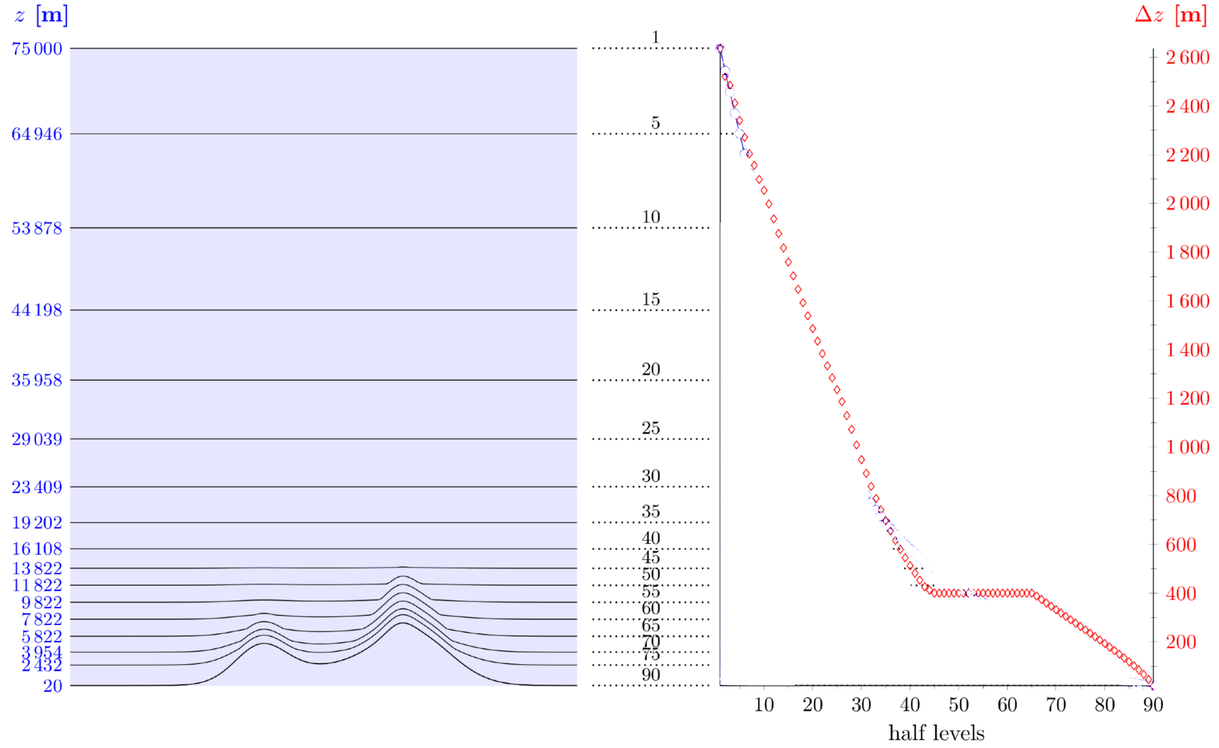
Distance between centre points

Edge length

Square root of mean cell area

Vertical grid

- Terrain following hybrid σ-z coordinates (i.e. height based !)
  - ➡ Schär et al. (2002)
- ICON generates level heights during setup
- Level ordering is top-down
- Note: topography is processed at start-up by a smoothing function
  - ➡ topography in external data is **not** the one used



Data files also contain „fingerprint“ of the vertical grid

Attribute **uuidOfVGrid** (similar to attribute **uuidOfHGrid)**

Vertical grid is stored here:

- 2.5km DYAMOND run aka R02B10:

`/work/bk1040/experiments/input/2.5km/dyamond_R2B10_lkm1007_vgrid.grib`

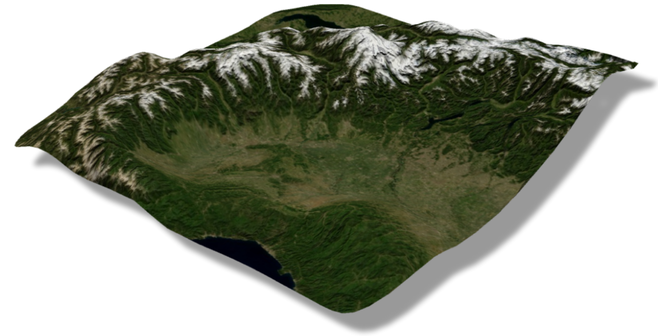
- more generally:

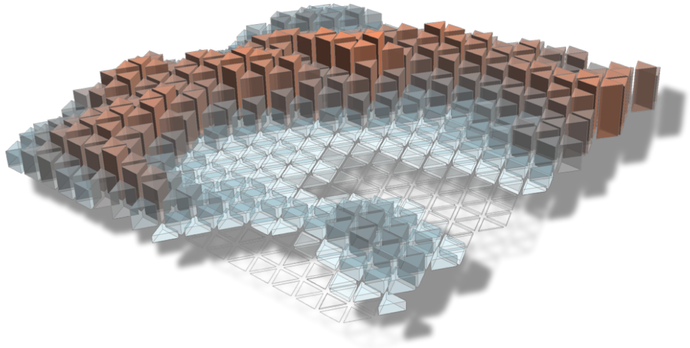
`/work/bk1040/experiments/input/<resolution>/dyamond_<res>_<exp>_vgrid.grib`

Lower boundary data - external parameter

- land-sea mask, orography, soil type, land-use and other geographical datasets
- based on observations
- Note: topography is processed at start-up by a smoothing function

  ➡ topography in external data is **not** the one used, but very minimal topography smoothing





Data files also contain „fingerprint“ of the horizontal grid

Attribute **uuidOfHGrid**

External data is stored here:

- 2.5km DYAMOND run aka R02B10:

`/work/bk1040/experiments/input/2.5km/icon_extpar_0017_R02B10_G20180810_tiles.nc`

- more generally:

`/work/bk1040/experiments/input/<resolution>/icon_extpar_<num>_<res>_*.nc`

Full set of governing equations

- describes two-component system (dry air + water)
- fully compressible nonhydrostatic, shallow atmosphere approx.
- vector invariant form $(\boldsymbol{u} \cdot \nabla \boldsymbol{u} = \nabla K + \boldsymbol{\zeta} \times \boldsymbol{u})$ for horizontal wind component

$$\frac{\partial \widehat{v_n}}{\partial t} + \frac{\partial \widehat{K}_h}{\partial n} + (\widehat{\zeta} + f)\widehat{v}_t + \widehat{w}\frac{\partial \widehat{v}_n}{\partial z} = -c_{pd}\widehat{\theta}_v \frac{\partial \overline{\pi}}{\partial n} - F(v_n) \qquad \textbf{momentum}$$

$$\frac{\partial \widehat{w}}{\partial t} + \widehat{\boldsymbol{v}}_h \cdot \nabla \widehat{w} + \widehat{w}\frac{\partial \widehat{w}}{\partial z} = -c_{pd}\widehat{\theta}_v \frac{\partial \overline{\pi}}{\partial z} - g$$

$$\frac{\partial \overline{\rho}\widehat{\theta}_v}{\partial t} + \nabla \cdot (\overline{\rho}\widehat{\boldsymbol{v}}\widehat{\theta}_v) = \overline{Q} \qquad \textbf{energy}$$

$$\frac{\partial \overline{\rho}}{\partial t} + \nabla \cdot (\overline{\rho}\widehat{\boldsymbol{v}}) = 0 \qquad \textbf{mass}$$

$$\frac{\partial \overline{\rho}\hat{q}_k}{\partial t} + \nabla \cdot (\overline{\rho}\widehat{q}_k\widehat{\boldsymbol{v}}) = -\nabla \cdot \left(\overline{\boldsymbol{J}}_k + \overline{\rho q_k'' \boldsymbol{v}''}\right) \qquad \textbf{partial mass}$$

based on Gassmann and Herzog (2008)

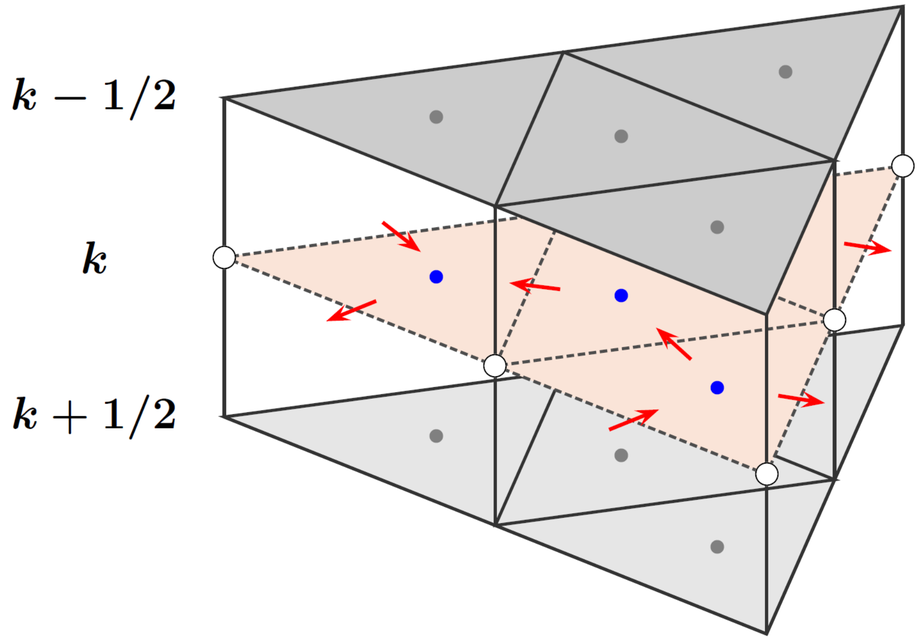
Prognostic variables and staggering

- C-staggering in the horizontal
- Lorenz-type staggering in the vertical: vertical velocity at level boundaries (half-levels) and other prognostic variables at center of full levels
- Top-down numbering of model levels

prognostic fields:

v_n	edge-normal vel. component
w	vertical velocity
ρ	density of moist air
θ_v	virtual potential temperature
q_i	mass fractions

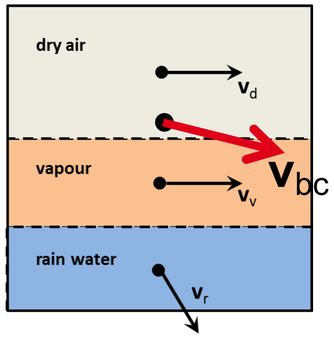
staggering:



Remarks

- Equation set describes **mixture** of dry air and water (all 3 phases)
  - ρ is the total density (including water vapour and condensate)
    - velocity is defined as the barycentric velocity (Wacker et al. 2003)

$$\boldsymbol{v}_{bc} = \frac{\sum_k \rho_k \boldsymbol{v}_k}{\sum_k \rho_k}$$



  - current implementation contains approximations w.r.t. moisture effects

$$\text{i.e.} \quad w_{bc} = 0 \quad \text{at the surface}$$

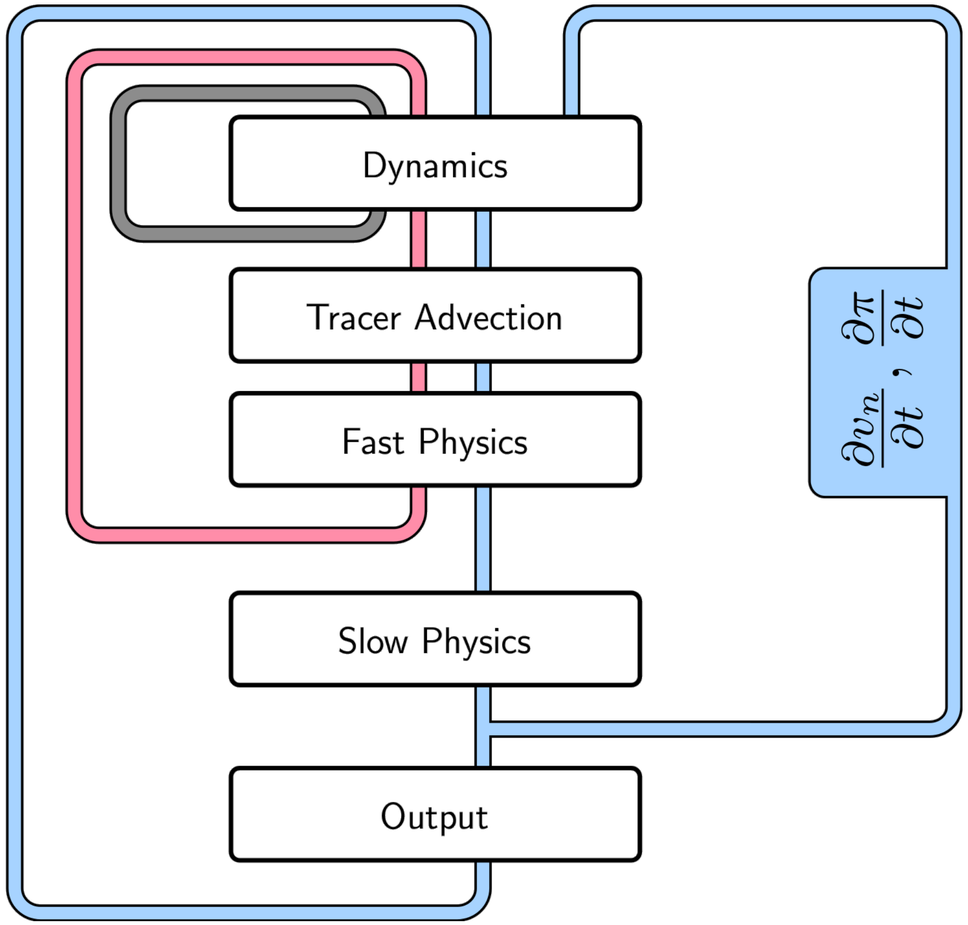
  - flux form for ρ and q_k -> inherently **mass conserving**
  - prognostic equations for θ_v actually re-formulated into equation for Exner pressure

Time stepping

- Two-time-level **predictor-corrector** time stepping **scheme** for v_n, w, ρ, π
- **Explicit scheme**. - Exception: terms describing vertical sound wave propagation. Implicit (tridiagonal system) solver in the column.
- Integrated at **acoustic time step** (not split-explicit)

For details, see Zängl et al (2015; QJRMS)

Physics - dynamics coupling



- Distinction between ‘fast physics’ and ‘slow physics’.
  - distinction based on process time scale vs. model time step
- Processes assumed to take place at constant ρ (not p!)

Slow physics:

- Called every k^{th} fast physics time step (k is process dependent)
- treated in parallel-split mode
  - all processes computed from the same state
- tendencies are passed to the dycore

DYAMOND (2.5km aka R02B10): dtime=22.5s, nsub=5, *choices*=450s (radiation=900s)

Physics package

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Process	Scheme	Calling frequency
Radiation	RRTM (Mlawer et al., 1997, Baker et al. 2003)	900s
Sub-grid scale orographic drag	Lott and Miller scheme (Lott and Miller 1997)	450s
Microphysics	COSMO Single-moment scheme (Doms et al. 2011; Seifert 2008)	dtime (22.5s)
Land	Tiled TERRA (Schrodin and Heise 2002)	dtime (22.5)
Turbulent transfer	COSMO prognostic TKE (Raschendorfer 2001)	dtime (22.5)
Lake	Flake (Mironov 2008)	dtime (22.5)
Cloud cover	Diagnostic PDF	as radiation

DYAMOND data

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Where?

`/work/ka1081/DYAMOND/ICON-<resolution>-<conv/fix-sst>`

What else do I need?

`/work/bk1040/experiments/input/<resolution>`

Grib, really?

```
export GRIB_DEFINITION_PATH=/mnt/lustre01/sw/rhel6-x64/eccodes/definitions
```

What data is there?

A lot! …. see next slides

3D model level: One file per day, hourly data

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File names:
nwp_<res>_<exp>_atm_3d_<var>_ml_<YYYYMMDD>T000000Z.grb

```
bash-4.1$ cdo sinfov nwp_R2B10_lkm1007_atm_3d_tot_qc_dia_ml_20160801T000000Z.grb
   File format : GRIB2 aec
    -1 : Institut Source   T Steptype Levels Num    Points Num Dtype : Parameter name
     1 : MPIMET   unknown  v instant      77   1  83886080   1  P16a : QC_DIA
   Grid coordinates :
     1 : unstructured             : points=83886080
                           grid : number=17  position=1
                           uuid : 36d404b8-7551-11e8-b1af-17a1ae0ab23a
   Vertical coordinates :
     1 : generalized_height       : levels=77
                         height : 14.5 to 90.5 by 1
                         bounds : 14-15 to 90-91
                          zaxis : number=4
                           uuid : 5f5fbc93-65b1-8baa-8f24-b89ab41a2ee0
   Time coordinate :  unlimited steps
     RefTime =  2016-08-01 00:00:00  Units = hours  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
  2016-08-01 00:00:00  2016-08-01 03:00:00  2016-08-01 06:00:00  2016-08-01 09:00:00
```

Temperature
Pressure
U-wind
V-wind
W-wind
QV (vapor)
QC (liquid)
QI (ice)

Why only 77 level?
top level are not saved to optimise disk space usage

3D pressure level: One file per day, 15 minute data

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Relative humidity

File names:
nwp_<res>_<exp>_atm_3d_<var>_pl_<YYYYMMDD>T000000Z.grb

5 pressure level
- **200 hPa**
- **300 hPa**
- **500 hPa**
- **700 hPa**
- **850 hPa**

```
bash-4.1$ cdo sinfov nwp_R2B10_lkm1007_atm_rh_3d_pl_20160801T000000Z.grb
   File format : GRIB2 aec
    -1 : Institut Source   T Steptype Levels Num    Points Num Dtype : Parameter name
     1 : MPIMET   unknown  v instant       5   1  83886080   1  P16a : RELHUM
   Grid coordinates :
     1 : unstructured             : points=83886080
                            grid : number=17  position=1
                            uuid : 36d404b8-7551-11e8-b1af-17a1ae0ab23a
   Vertical coordinates :
     1 : pressure                 : levels=5
                            plev : 20000 to 85000 Pa
   Time coordinate :  unlimited steps
     RefTime =  2016-08-03 00:00:00  Units = hours  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
  2016-08-03 00:00:00  2016-08-03 00:15:00  2016-08-03 00:30:00  2016-08-03 00:45:00
..
```

Omega and geopotential

```
bash-4.1$ cdo sinfov nwp_R2B10_lkm1007_atm_omega_3d_pl_20160801T000000Z.grb
   File format : GRIB2 aec
    -1 : Institut Source   T Steptype Levels Num    Points Num Dtype : Parameter name
     1 : MPIMET   unknown  v instant       5   1  83886080   1  P16a : OMEGA
     2 : MPIMET   unknown  v instant       5   1  83886080   1  P16a : FI
   Grid coordinates :
     1 : unstructured             : points=83886080
                            grid : number=17  position=1
                            uuid : 36d404b8-7551-11e8-b1af-17a1ae0ab23a
```

2D radiation: One file per day, 15 minute data

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File names:
nwp_<res>_<exp>_atm_2d_avg_ml_<YYYYMMDD>T000000Z.grb

```
bash-4.1$ cdo sinfov nwp_R2B10_lkm1007_atm_2d_avg_ml_20160801T000000Z.grb
   File format : GRIB2 aec
    -1 : Institut Source   T Steptype Levels Num    Points Num Dtype : Parameter name
     1 : MPIMET   unknown  v avg           1   1  83886080   1  P16a : ASOB_S
     2 : MPIMET   unknown  v avg           1   1  83886080   1  P16a : ATHB_S
     3 : MPIMET   unknown  v avg           1   2  83886080   1  P16a : ASOB_T
     4 : MPIMET   unknown  v avg           1   2  83886080   1  P16a : ATHB_T
     5 : MPIMET   unknown  v avg           1   2  83886080   1  P16a : ASOU_T
     6 : MPIMET   unknown  v avg           1   1  83886080   1  P16a : ASWDIFU_S
     7 : MPIMET   unknown  v avg           1   1  83886080   1  P16a : ATHD_S
     8 : MPIMET   unknown  v avg           1   1  83886080   1  P16a : ATHU_S
   Grid coordinates :
     1 : unstructured            : points=83886080
                           grid : number=17  position=1
                           uuid : 36d404b8-7551-11e8-b1af-17a1ae0ab23a
   Vertical coordinates :
     1 : surface                 : levels=1
     2 : top_of_atmosphere       : levels=1
                            toa : 0
   Time coordinate :  unlimited steps
     RefTime =  2016-08-01 00:00:00  Units = hours  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
  2016-08-01 00:00:00  2016-08-01 00:15:00  2016-08-01 00:30:00  2016-08-01 00:45:00
```

Variable names decoding

_S = surface
_T = top
TH = LW
SO = SW
SW = SW
B = net
U = up
D = down
A = averaged
DIF = diffusive

2D vertical integrals of hydrometeors: One file per day, 15 minute data

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File names:
nwp_<res>_<exp>_atm1_2d_ml_<YYYYMMDD>T000000Z.grb

```
bash-4.1$ cdo sinfov nwp_R2B10_lkm1007_atm1_2d_ml_20160801T000000Z.grb
   File format : GRIB2 aec
    -1 : Institut Source   T Steptype Levels Num    Points Num Dtype : Parameter name
     1 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : TQV_DIA
     2 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : TQC_DIA
     3 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : TQI_DIA
     4 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : TQG
     5 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : TQS
   Grid coordinates :
     1 : unstructured            : points=83886080
                           grid : number=17  position=1
                           uuid : 36d404b8-7551-11e8-b1af-17a1ae0ab23a
   Vertical coordinates :
     1 : surface                 : levels=1
   Time coordinate :  unlimited steps
     RefTime =  2016-08-01 00:00:00  Units = hours  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
  2016-08-01 00:00:00  2016-08-01 00:15:00  2016-08-01 00:30:00  2016-08-01 00:45:00
```

Variable names decoding
TQV (vapor)
TQC (liquid)
TQI (ice)
TQG (graupel)
TQS (snow)

2D mixed bag: One file per day, 15 minute data

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File names:
nwp_<res>_<exp>_atm2_2d_ml_<YYYYMMDD>T000000Z.grb

```
bash-4.1$ cdo sinfov nwp_R2B10_lkm1007_atm2_2d_ml_20160801T000000Z.grb
   File format : GRIB2 aec
    -1 : Institut Source   T Steptype Levels Num    Points Num Dtype : Parameter name
     1 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : CLCT
     2 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : LHFL_S
     3 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : SHFL_S
     4 : MPIMET   unknown  v instant       1   2  83886080   1  P16a : PMSL
     5 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : PS
     6 : MPIMET   unknown  v accum         1   1  83886080   1  P16a : TOT_PREC
     7 : MPIMET   unknown  v instant       1   3  83886080   1  P16a : CAPE_ML
   Grid coordinates :
     1 : unstructured             : points=83886080
                           grid : number=17  position=1
                           uuid : 36d404b8-7551-11e8-b1af-17a1ae0ab23a
   Vertical coordinates :
     1 : surface                  : levels=1
     2 : meansea                  : levels=1
                            lev : 0 level
     3 : generic      (ltype=192) : levels=1
                            lev : 0
   Time coordinate :  unlimited steps
     RefTime =  2016-08-01 00:00:00  Units = hours  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
  2016-08-01 00:00:00  2016-08-01 00:15:00  2016-08-01 00:30:00  2016-08-01 00:45:00
```

Variable names decoding
CLCT: total cloud cover
LHFL_S: surface latent heat flux
SHFL_S: surface sensible heat flux
PMSL: mean sea level pressure
PS: surface pressure
TOT_PREC: Total precipitation (accu)
CAPE_ML: convective available potential energy

2D mixed bag 2: One file per day, 15 minute data

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File names:
nwp_<res>_<exp>_atm3_2d_ml_<YYYYMMDD>T000000Z.grb

```
bash-4.1$ cdo sinfov nwp_R2B10_lkm1007_atm3_2d_ml_20160801T000000Z.grb
   File format : GRIB2 aec
    -1 : Institut Source   T Steptype Levels Num    Points Num Dtype : Parameter name
     1 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : U_10M
     2 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : V_10M
     3 : MPIMET   unknown  v instant       1   2  83886080   1  P16a : T_2M
     4 : MPIMET   unknown  v instant       1   2  83886080   1  P16a : QV_2M
     5 : MPIMET   unknown  v instant       1   3  83886080   1  P16a : TQR
   Grid coordinates :
     1 : unstructured             : points=83886080
                           grid : number=17  position=1
                           uuid : 36d404b8-7551-11e8-b1af-17a1ae0ab23a
   Vertical coordinates :
     1 : height                   : levels=1
                          height : 10 m
     2 : height                   : levels=1
                          height : 2 m
     3 : surface                  : levels=1
   Time coordinate :  unlimited steps
     RefTime =  2016-08-01 00:00:00  Units = hours  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
  2016-08-01 00:00:00  2016-08-01 00:15:00  2016-08-01 00:30:00  2016-08-01 00:45:00
```

Variable names decoding
U_10M
V_10M
T_2M
QV_2M
TQR (rain water)

2D mixed bag 3: One file per day, 15 minute data

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File names:
nwp_<res>_<exp>_atm4_2d_ml_<YYYYMMDD>T000000Z.grb

```
bash-4.1$ cdo sinfov nwp_R2B10_lkm1007_atm4_2d_ml_20160801T000000Z.grb
   File format : GRIB2 aec
    -1 : Institut Source   T Steptype Levels Num    Points Num Dtype : Parameter name
     1 : MPIMET   unknown  v instant       1   1  83886080   1  P16a : CIN_ML
     2 : MPIMET   unknown  v instant       1   2  83886080   1  P16a : T_G
     3 : MPIMET   unknown  v instant       1   2  83886080   1  P16a : QV_S
     4 : MPIMET   unknown  v instant       1   2  83886080   1  P16a : UMFL_S
     5 : MPIMET   unknown  v instant       1   2  83886080   1  P16a : VMFL_S
   Grid coordinates :
     1 : unstructured             : points=83886080
                            grid : number=17  position=1
                            uuid : 36d404b8-7551-11e8-b1af-17a1ae0ab23a
   Vertical coordinates :
     1 : generic      (ltype=192) : levels=1
                             lev : 0
     2 : surface                  : levels=1
   Time coordinate :  unlimited steps
     RefTime =  2016-08-01 00:00:00  Units = hours  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
  2016-08-01 00:00:00  2016-08-01 00:15:00  2016-08-01 00:30:00  2016-08-01 00:45:00
```

Variable names decoding
CIN: convective inhibition
T_G: ground temperature (weighted)
QV_S
UMFLS_S: U surface momentum flux
VMFLS_S: V surface momentum flux

Have fun…

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