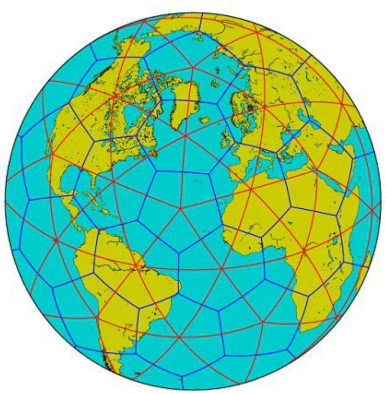
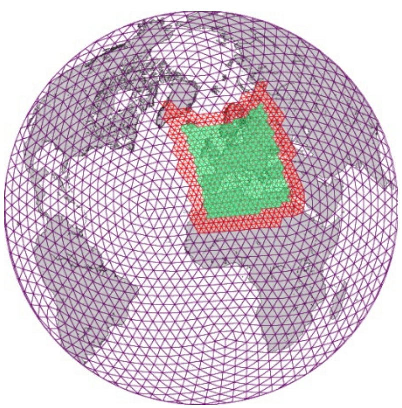
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Implementation of an improved land-surface parameterization scheme with FLake in the ICON model

J. Helmert, E. Machulskaya, D. Mironov,
M. Köhler, G. Zängl
and
the ICON development team





ICON = ICOsahedral Nonhydrostatic model

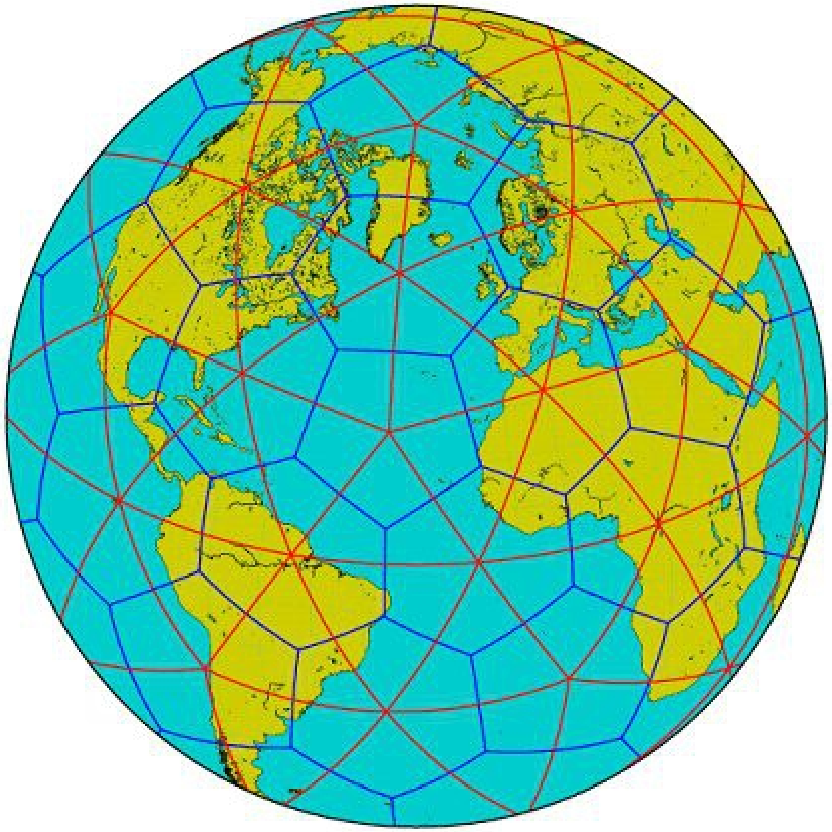
- Joint development project of DWD and Max-Planck-Institute for Meteorology for the next-generation global NWP and climate modeling system
- Nonhydrostatic dynamical core on an icosahedral-triangular C-grid
- Two-way nesting with capability for multiple nests per nesting level; vertical nesting, one-way nesting mode and limited-area mode are also available

Primary development goals

- Better conservation properties (air mass, mass of trace gases and moisture, consistent transport of tracers; hexagonal core also conserves energy)
- Applicability on a wide range of scales in space and time ("seamless prediction"); therefore, the dynamical core was requested to be nonhydrostatic
- Scalability and efficiency on massively parallel computer architectures with $O(10^4+)$ cores
- Grid nesting in order to replace both GME (global forecast model, mesh size 20 km) and COSMO-EU (regional model, mesh size 7 km) in the operational suite of DWD
- At MPI-M: Develop an ocean model based on ICON grid structures and operators; Use limited-area version of ICON to replace regional climate model REMO.
- Contribute to operational seasonal prediction in the framework of the Multi-Model Seasonal Prediction System EURO-SIP at ECMWF).

The horizontal grid

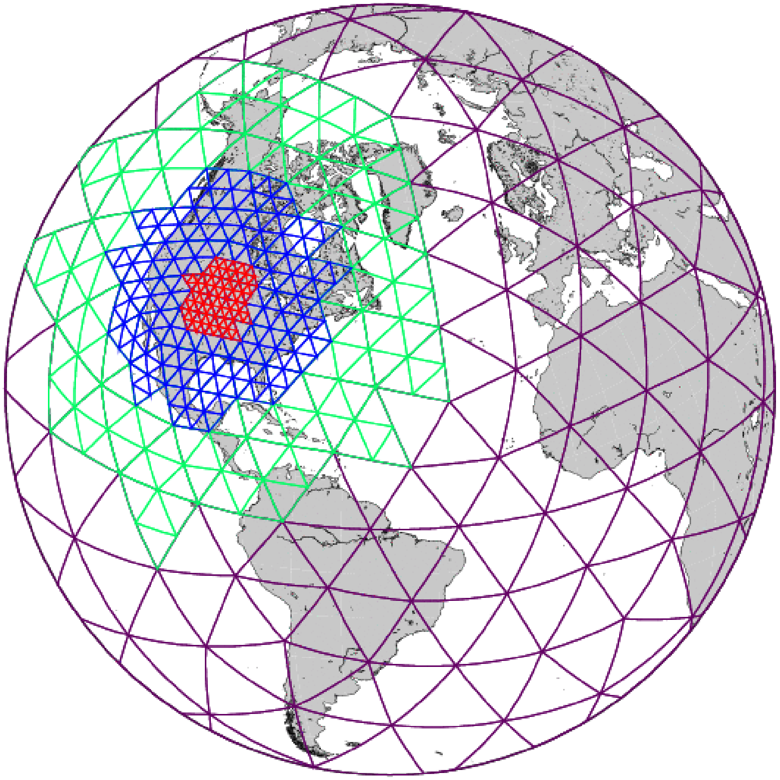
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



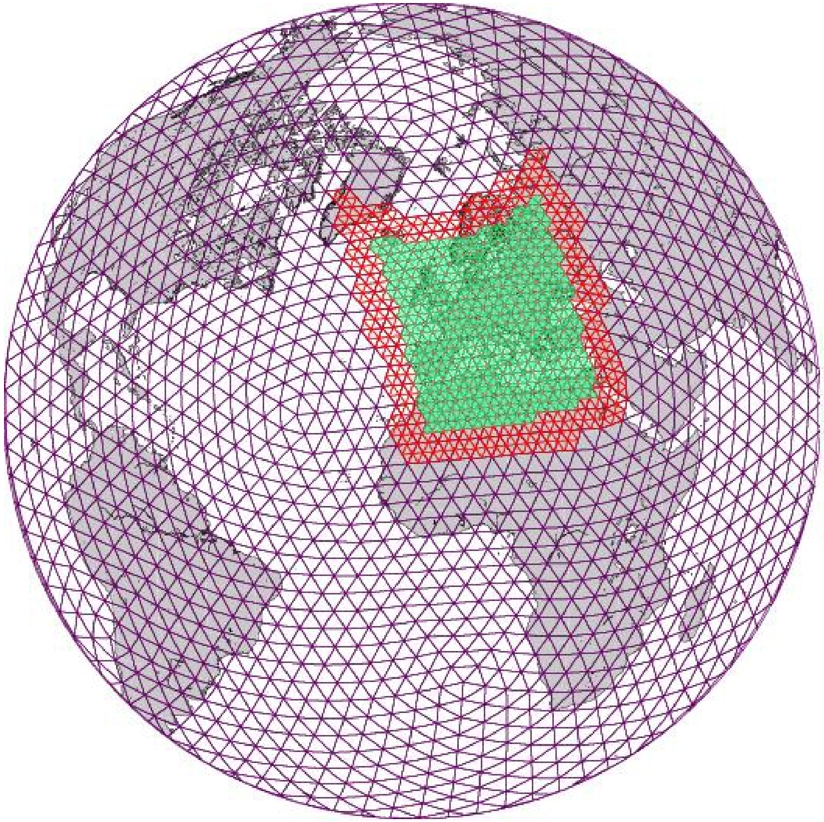
Primary (**Delaunay,** triangles) and dual grid (**Voronoi,** hexagons/pentagons)

Grid structure with nested domains

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

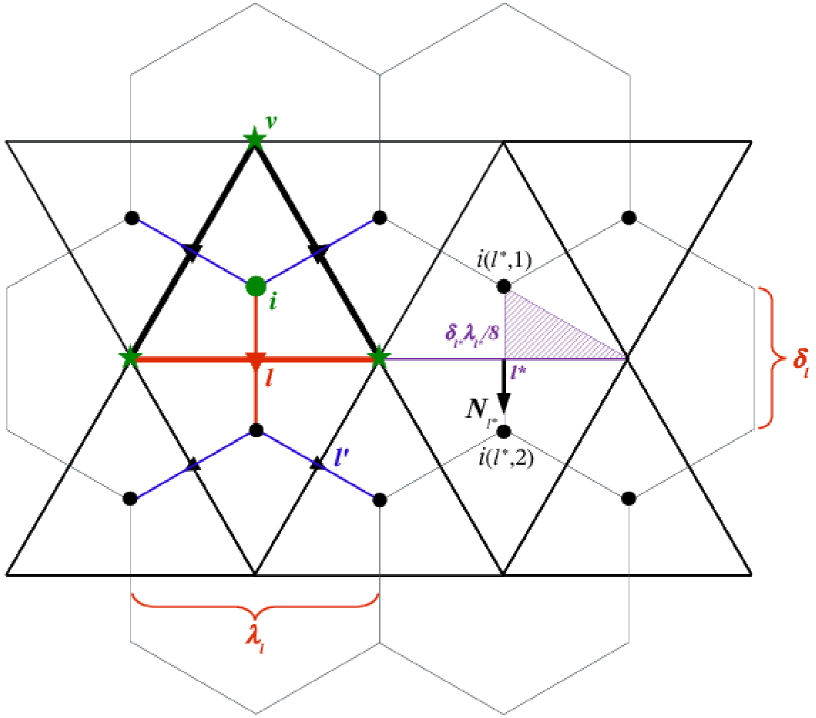


circular nests



latitude-longitude nests

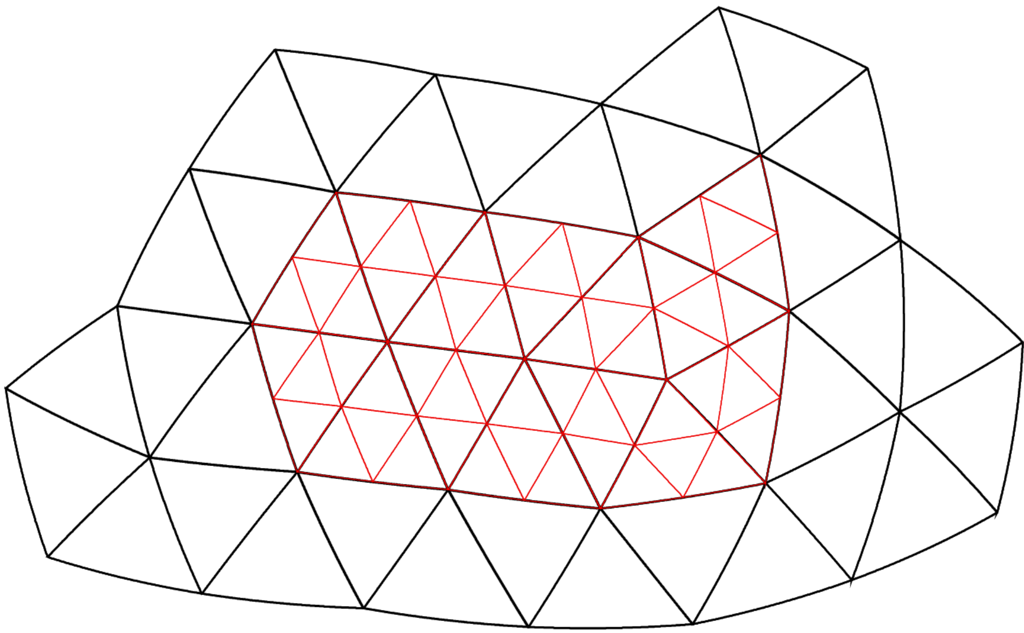
Grid structure … … in the presence of nesting



Triangles are used as primal cells

Mass points are in the circumcenter

Velocity is defined at the edge midpoints



Red cells refer to refined domain

Boundary interpolation is needed from parent to child mass points and velocity points

Comparison of GME and ICON

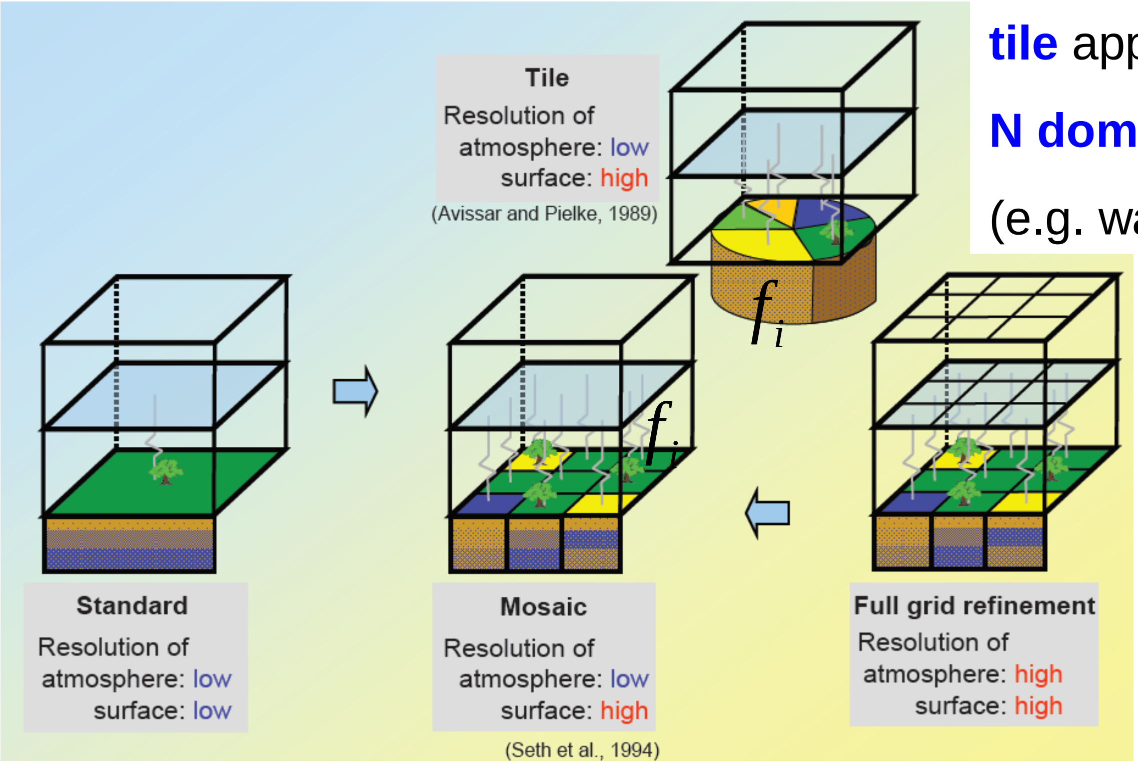
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

	GME	***ICON***
equation system	hydrostatic	non-hydrostatic
prognostical variables	p_s, T, u, v,	ρ, Θ_v, v_n, w,
	q_v, q_c, q_i, q_r,q_s	q_v, q_c, q_i, q_r,q_s
conservation variables	none	mass; tracer
horizontal grid	hexagons/pentagons Arakawa A	triangles Arakawa C
vertical grid	hybrid pressure-based	hybrid z-based
horizontal resolution	20 km	20 km / 5 km (for Europe)
vertical levels	60	90
upper boundary level	36 km	75 km
model physics	next slide	next slide
output format	GRIB1 (and GRIB2)	GRIB2 (and NetCDF)
lat-lon output	0.25° x 0.25°	0.25° x 0.25°

Process	Authors	Scheme	Origin
Radiation	Mlawer et al. (1997) Barker et al. (2002)	RRTM (later with McICA & McSI)	ECHAM6/IFS
	Ritter and Geleyn (1992)	δ two-stream	GME/COSMO
Non-orographic gravity wave drag	Scinocca (2003) Orr, Bechtold et al. (2010)	wave dissipation at critical level	IFS
Sub-grid scale orographic drag	Lott and Miller (1997)	blocking, GWD	IFS
Cloud cover	Doms and Schättler (2004)	sub-grid diagnostic	GME/COSMO
	Köhler et al. (new development)	diagnostic (later prognostic) PDF	ICON
Microphysics	Doms and Schättler (2004) Seiffert (2010)	prognostic: water vapor, cloud water,cloud ice, rain and snow	GME/COSMO
Convection	Tiedtke (1989) Bechthold et al. (2008)	mass-flux shallow and deep	IFS
Turbulent transfer	Raschendorfer (2001)	prognostic TKE	COSMO
	Brinkop and Roeckner (1995)	prognostic TKE	ECHAM6/IFS
	Neggers, Köhler, Beljaars (2010)	EDMF-DUALM	IFS
Land	Heise and Schrodin (2002), Helmert, Machulskaya, Mironov (2008, lake)	tiled TERRA + FLAKE + multi-layer snow	GME/COSMO
	Raddatz, Knorr	JSBACH	ECHAM6

Sub-grid surface

Account for non-linear effects of sub-grid inhomegeneities at surface on the exchange of energy and moisture between atmosphere and surface (cf. Ament&Simmer, 2006)



tile approach

N dominant classes

(e.g. water, snow, grass)

$$\sum_{i=1}^{N} f_i = 1$$

mosaic approach

surface divided in **N subgrid cells**

$$f_i = \frac{1}{N}$$

(Figure taken from Ament&Simmer, 2006)

Example Lindenberg area

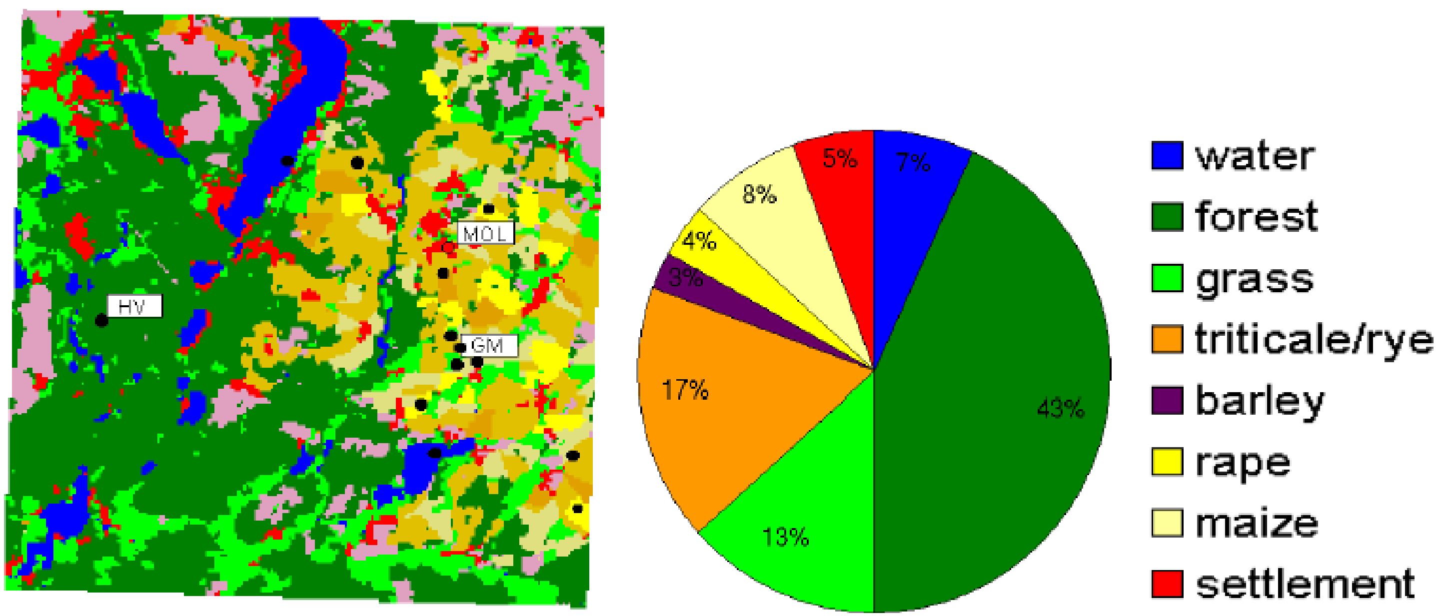


Figure 2.1: Map of the land-use within the LITFASS domain. Indicated are the measuring sites at the observatory Lindenberg (MOL), the boundary layer measuring site GM Falkenberg (GM) and the forest site (HV). (Plots by the courtesy of C. Heret, DWD Lindenberg.)

(Figure taken from

Ament, 2006)

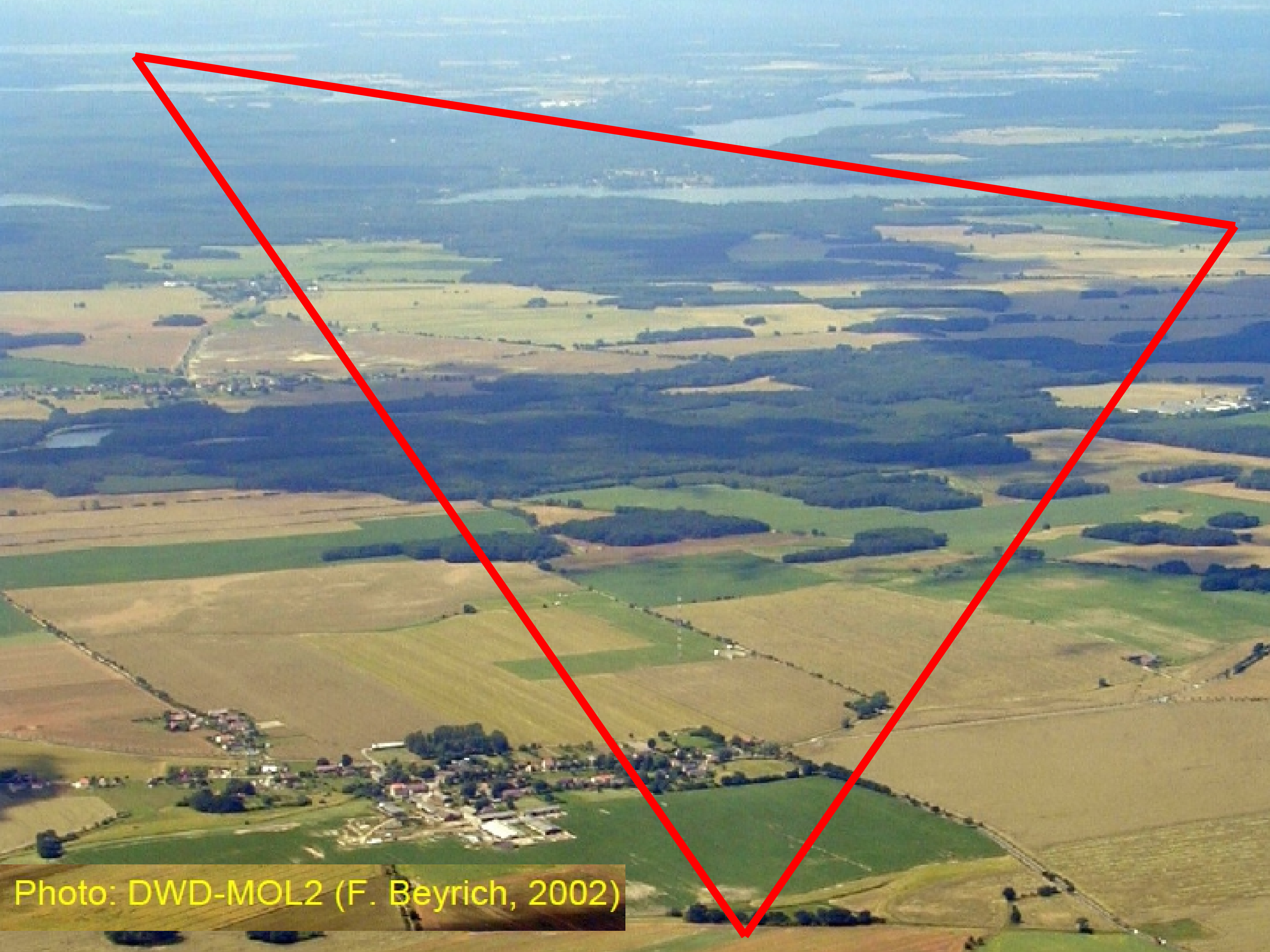
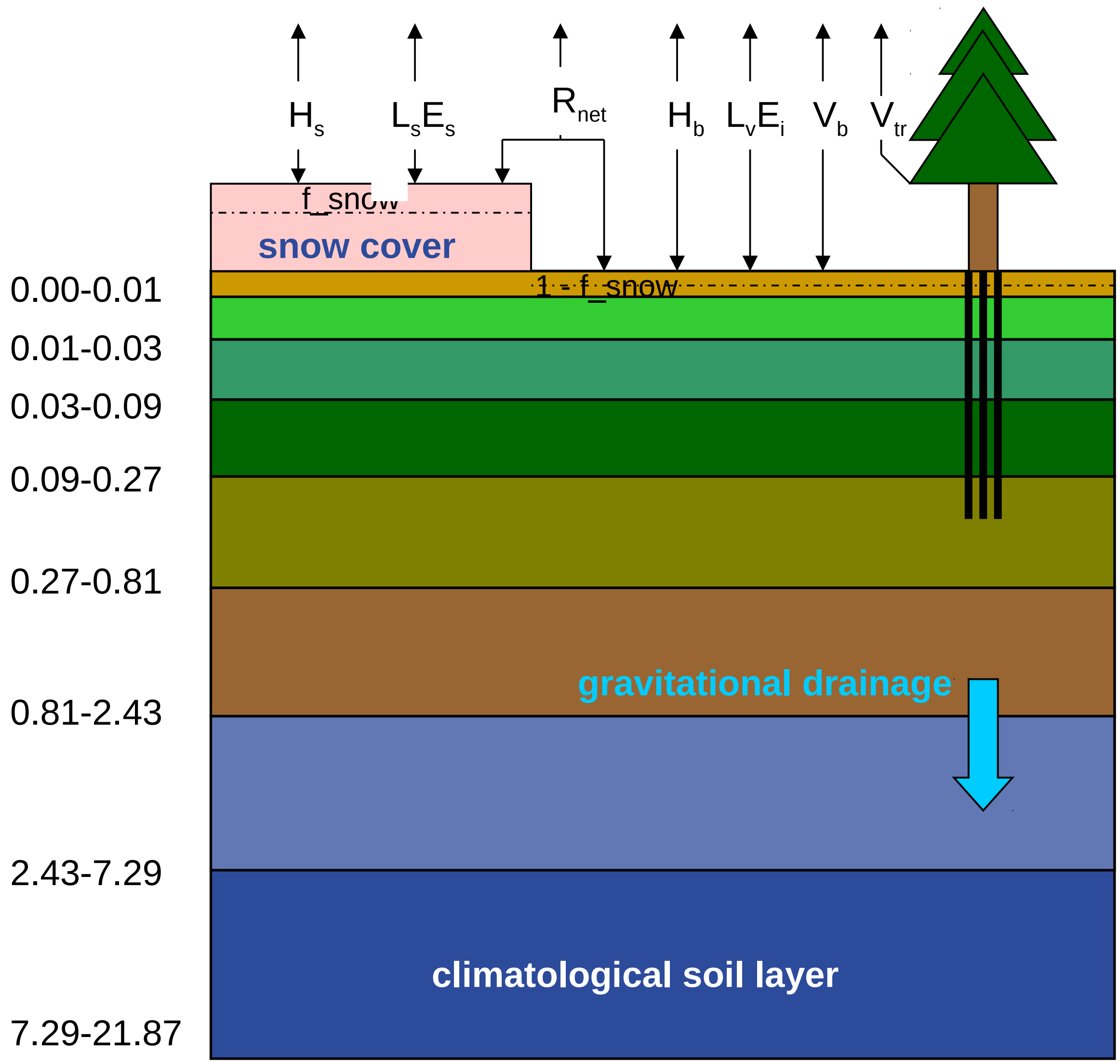
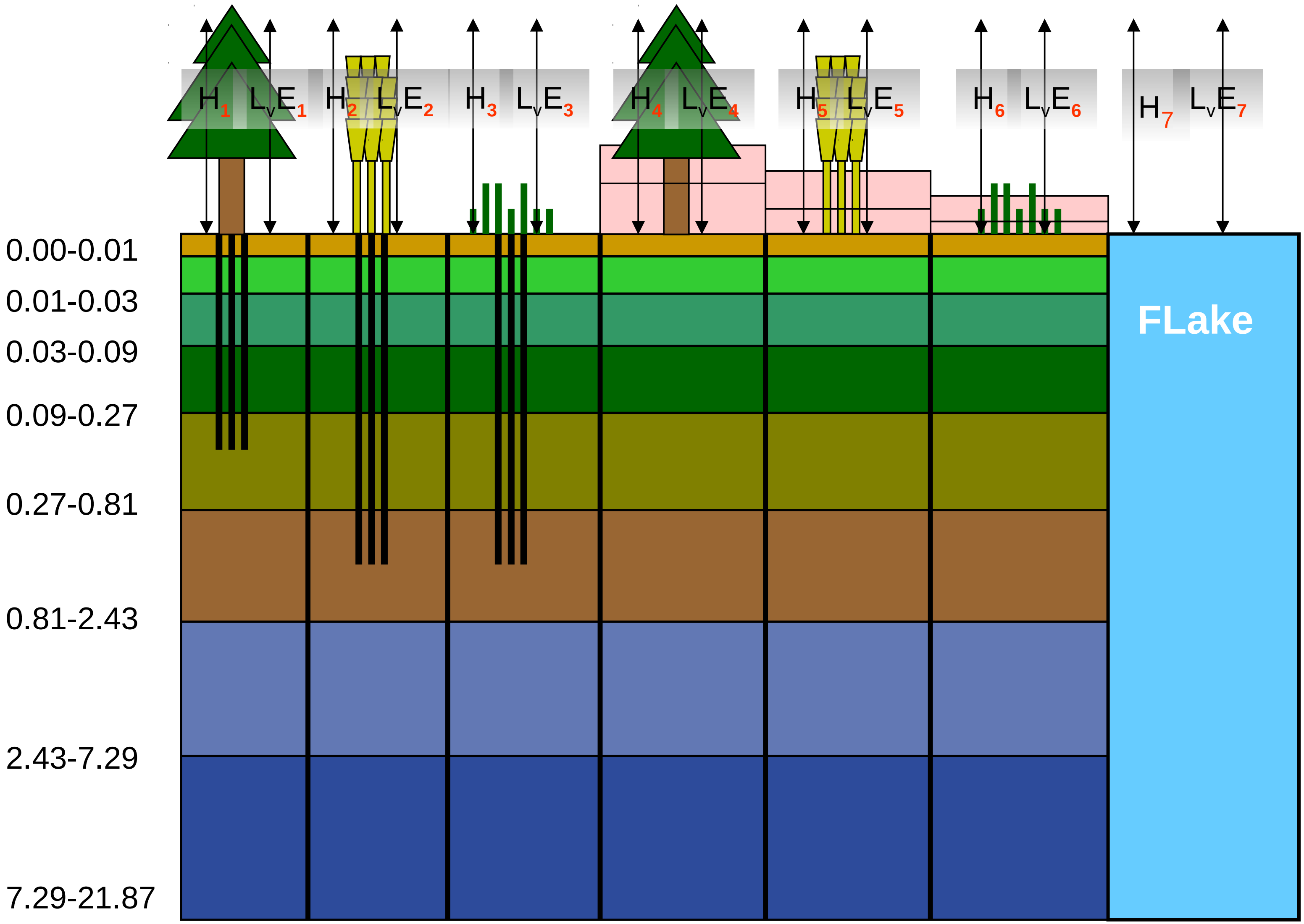


Photo: DWD-MOL2 (F. Beyrich, 2002)

TERRA no-Tiles



TERRA Tiles


H1 LvE1
H2 LvE2
H3 LvE3
H4 LvE4
H5 LvE5
H6 LvE6
H7 LvE7
0.00-0.01
0.01-0.03
0.03-0.09
0.09-0.27
0.27-0.81
0.81-2.43
2.43-7.29
7.29-21.87
FLake

Land-use data for tile fractions

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

GLC2000

```
#          z0      pcmx    laimx   rd   rsmin     snowalb snowtile

1     /    1.00,   0.8,   5.0, 1.0, 250.0,   0.38,-1., & ! evergreen broadleaf forest
2     &    1.00,   0.9,   6.0, 1.0, 150.0,   0.31,-1., & ! deciduous broadleaf closed forest
3     &    0.15,   0.8,   4.0, 2.0, 150.0,   0.31,-1., & ! deciduous broadleaf open   forest
4     &    1.00,   0.8,   5.0, 0.6, 150.0,   0.27,-1., & ! evergreen needleleaf forest
5     &    1.00,   0.9,   5.0, 0.6, 150.0,   0.33,-1., & ! deciduous needleleaf forest
6     &    1.00,   0.9,   5.0, 0.8, 150.0,   0.29,-1., & ! mixed leaf trees
7     &    1.00,   0.8,   5.0, 1.0, 150.0,   -1.0,-1., & ! fresh water flooded trees
8     &    1.00,   0.8,   5.0, 1.0, 150.0,   -1.0,-1., & ! saline water flooded trees
9     &    0.20,   0.8,   2.5, 1.0, 150.0,   -1.0, 1., & ! mosaic tree / natural vegetation
10    &    0.05,   0.5,   0.6, 0.3, 150.0,   -1.0, 1., & ! burnt tree cover
11    &    0.20,   0.8,   3.0, 1.0, 120.0,   -1.0, 1., & ! evergreen shrubs closed-open
12    &    0.15,   0.8,   1.5, 2.0, 120.0,   -1.0, 1., & ! decidous shrubs closed-open
13    &    0.03,   0.9,   3.1, 0.6,  40.0,   -1.0, 1., & ! herbaceous vegetation closed-open
14    &    0.05,   0.5,   0.6, 0.3,  40.0,   -1.0, 1., & ! sparse herbaceous or grass
15    &    0.05,   0.8,   2.0, 0.4,  40.0,   -1.0,-1., & ! flooded shrubs or herbaceous
16    &    0.07,   0.9,   3.3, 1.0, 120.0,   -1.0, 1., & ! cultivated & managed areas
17    &    0.25,   0.8,   3.0, 1.0, 120.0,   -1.0, 1., & ! mosaic crop / tree / natural vegetation
18    &    0.07,   0.9,   3.5, 1.0, 100.0,   -1.0, 1., & ! mosaic crop / shrub / grass
19    &    0.05,   0.05,  0.6, 0.3, 120.0,   -1.0, 1., & ! bare areas
20    &    0.0002,0.0,    0.0, 0.0, 120.0,   -1.0,-1., & ! water
21    &    0.01,   0.0,   0.0, 0.0, 120.0,   -1.0,-1., & ! snow & ice
22    &    1.00,   0.2,   1.0, 0.6, 120.0,   -1.0,-1., & ! artificial surface
23    &    0.00,   0.0,   0.0, 0.0,  40.0,   -1.0,-1. / ! undefined
```

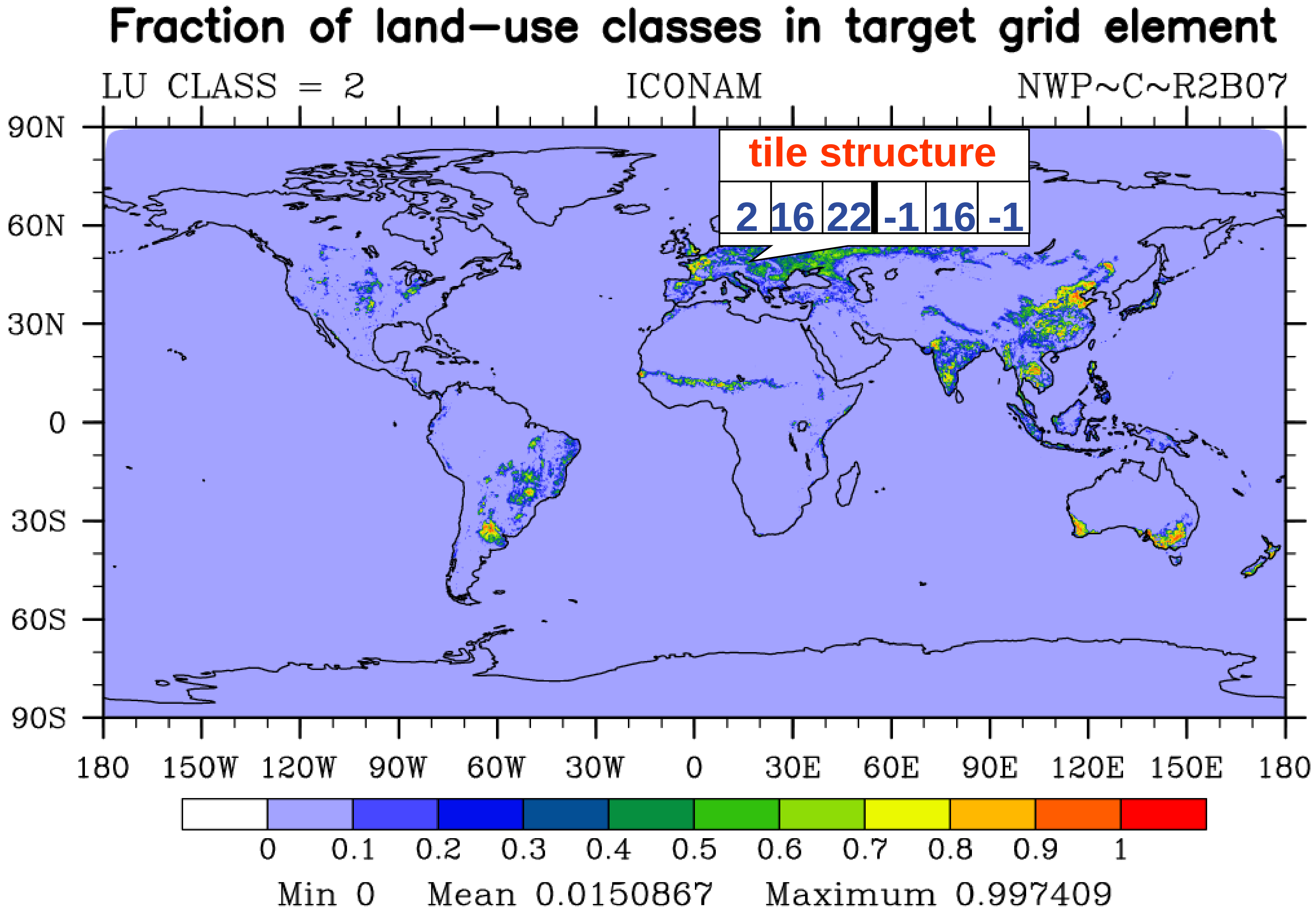
Land-use data for tile fractions

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

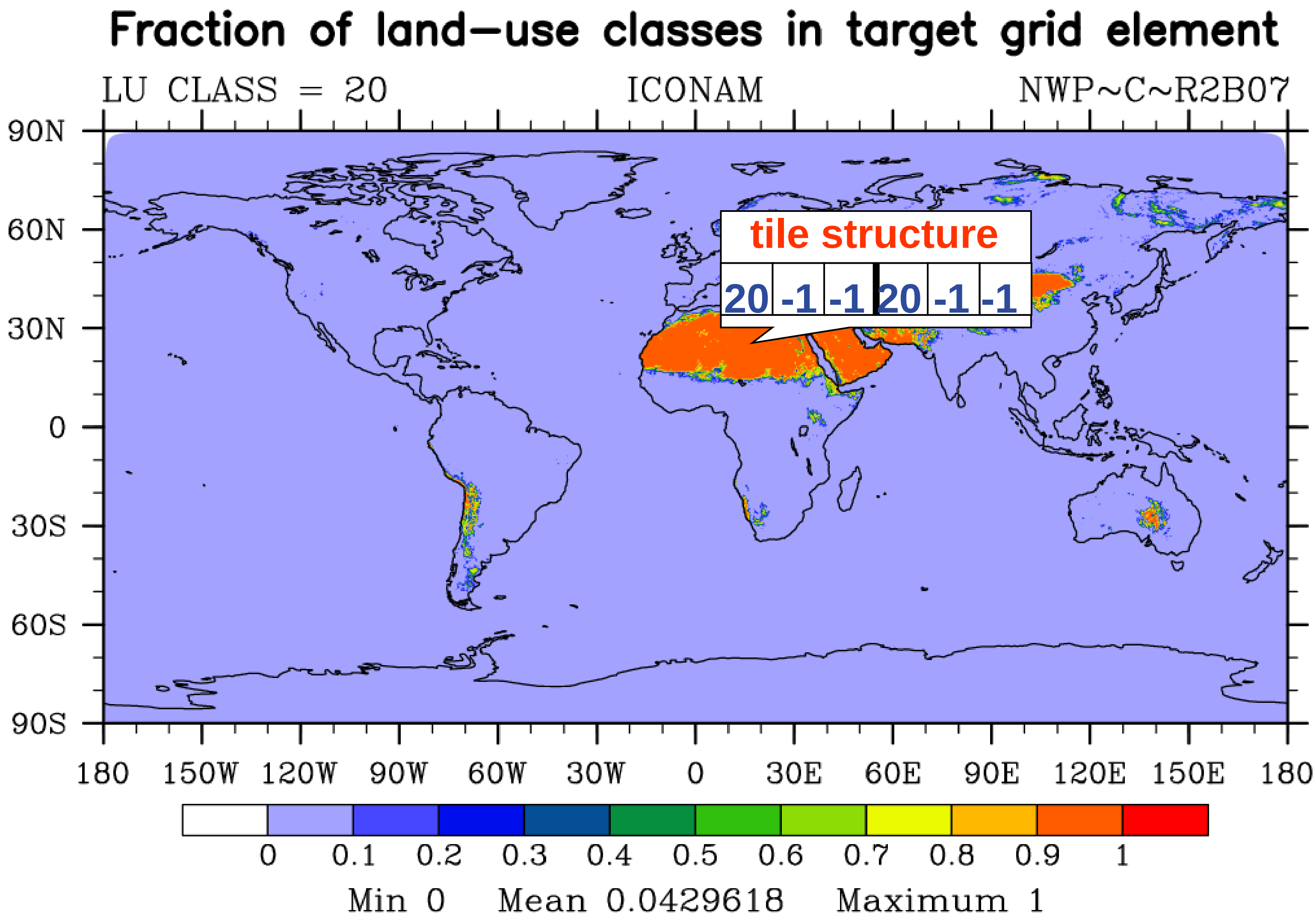
GlobCover 2009

```
#          z0       pcmx   laimx   rd     rsmin     snowalb snowtile

1   /   0.07,   0.9,   3.3, 1.0, 120.0,  -1.0, 1., & ! irrigated croplands
2   &   0.07,   0.9,   3.3, 1.0, 120.0,  -1.0, 1., & ! rainfed croplands
3   &   0.25,   0.8,   3.0, 1.0, 120.0,  -1.0, 1., & ! mosaic cropland (50-70%) - vegetation (20-50%)
4   &   0.07,   0.9,   3.5, 1.0, 100.0,  -1.0, 1., & ! mosaic vegetation (50-70%) - cropland (20-50%)
5   &   1.00,   0.8,   5.0, 1.0, 250.0,  0.38,-1., & ! closed broadleaved evergreen forest
6   &   1.00,   0.9,   6.0, 1.0, 150.0,  0.31,-1., & ! closed broadleaved deciduous forest
7   &   0.15,   0.8,   4.0, 2.0, 150.0,  0.31,-1., & ! open broadleaved deciduous forest
8   &   1.00,   0.8,   5.0, 0.6, 150.0,  0.27,-1., & ! closed needleleaved evergreen forest
9   &   1.00,   0.9,   5.0, 0.6, 150.0,  0.33,-1., & ! open needleleaved deciduous forest
10  &   1.00,   0.9,   5.0, 0.8, 150.0,  0.29,-1., & ! mixed broadleaved and needleleaved forest
11  &   0.20,   0.8,   2.5, 1.0, 150.0,  -1.0, 1., & ! mosaic shrubland (50-70%) - grassland (20-50%)
12  &   0.20,   0.8,   2.5, 1.0, 150.0,  -1.0, 1., & ! mosaic grassland (50-70%) - shrubland (20-50%)
13  &   0.15,   0.8,   2.5, 1.5, 120.0,  -1.0, 1., & ! closed to open shrubland
14  &   0.03,   0.9,   3.1, 0.6,  40.0,  -1.0, 1., & ! closed to open herbaceous vegetation
15  &   0.05,   0.5,   0.6, 0.3,  40.0,  -1.0, 1., & ! sparse vegetation
16  &   1.00,   0.8,   5.0, 1.0, 150.0,  -1.0,-1., & ! closed to open forest regulary flooded
17  &   1.00,   0.8,   5.0, 1.0, 150.0,  -1.0,-1., & ! closed forest or shrubland permanently flooded
18  &   0.05,   0.8,   2.0, 1.0,  40.0,  -1.0,-1., & ! closed to open grassland regularly flooded
19  &   1.00,   0.2,   1.6, 0.6, 120.0,  -1.0,-1., & ! artificial surfaces
20  &   0.05,   0.05,  0.6, 0.3, 120.0,  -1.0, 1., & ! bare areas
21  &   0.0002,0.0,    0.0, 0.0, 120.0,  -1.0,-1., & ! water bodies
22  &   0.01,   0.0,   0.0, 0.0, 120.0,  -1.0,-1., & ! permanent snow and ice
23  &   0.00,   0.0,   0.0, 0.0, 250.0,  -1.0,-1.  / !undefined
```

rainfed croplands



bare areas


Fraction of land-use classes in target grid element
LU CLASS = 20
ICONAM
NWP~C~R2B07
90N
60N
30N
0
30S
60S
90S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
tile structure
20 -1 -1 20 -1 -1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Min 0 Mean 0.0429618 Maximum 1

Statistics – Example R2B6N7

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

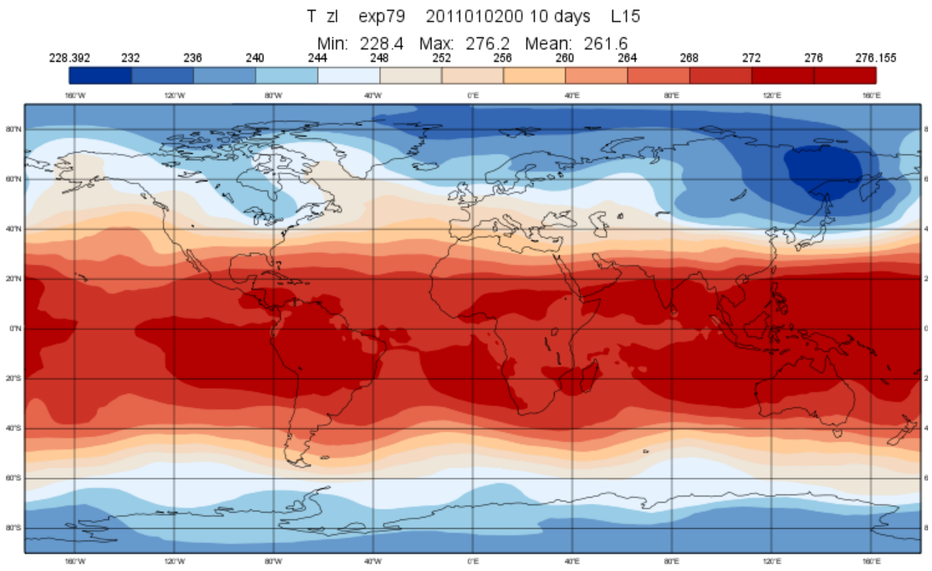
```
Index list generation - number of tiles:    3
Number of land points in domain  1:     95219
Number of sea points in domain  1:    231996
Number of lake points in domain  1:       465
Number of points in tile 1:     95219
Number of points in tile 2:     65854
Number of points in tile 3:     51090

Number of land points in domain  2:     46060
Number of sea points in domain  2:     32929
Number of lake points in domain  2:       183
Number of points in tile 1:     46060
Number of points in tile 2:     31125
Number of points in tile 3:     26519
```

First results

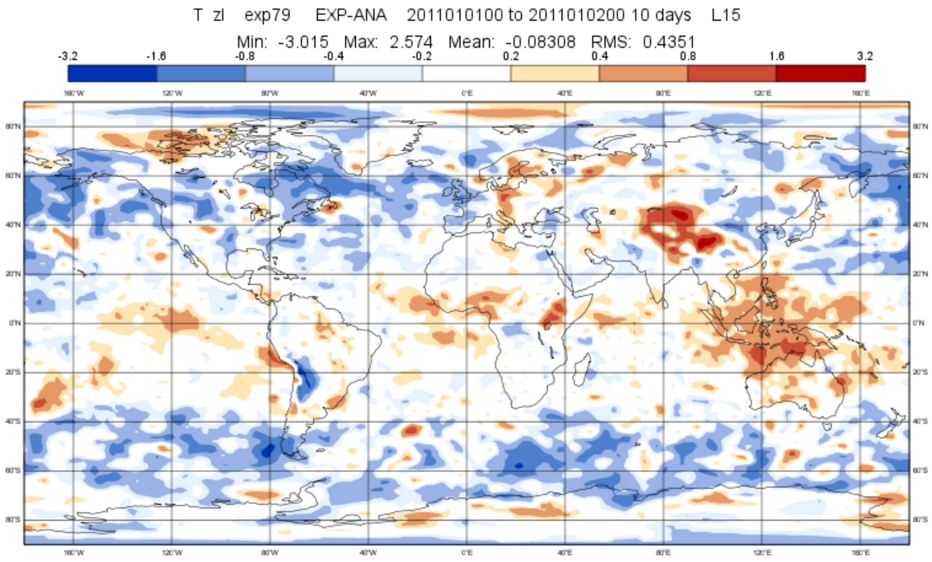
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Comparison of 24-h ICON forecasts with IFS analyses: average over 10 runs started on 10 consecutive days

Temperature at z = 5 km



ICON

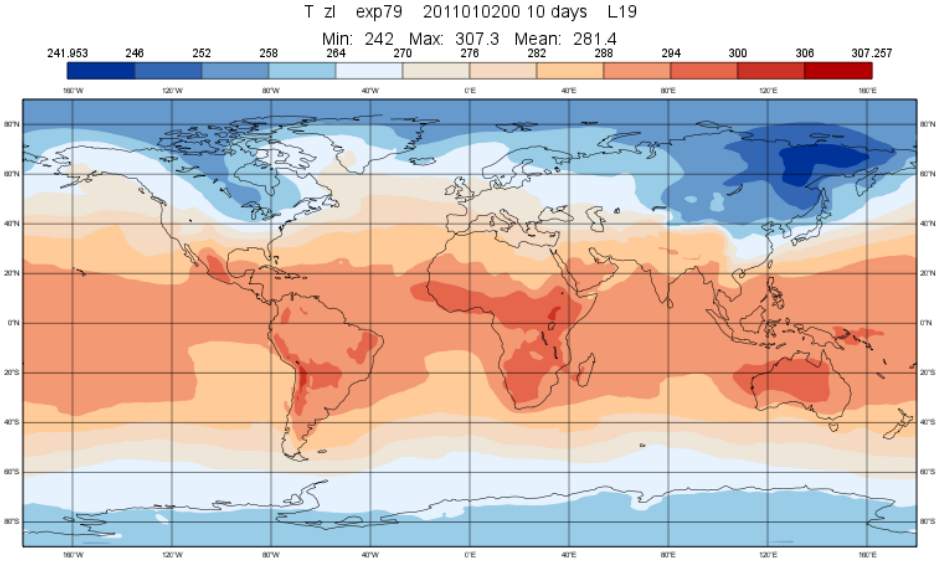


ICON - IFS ANA

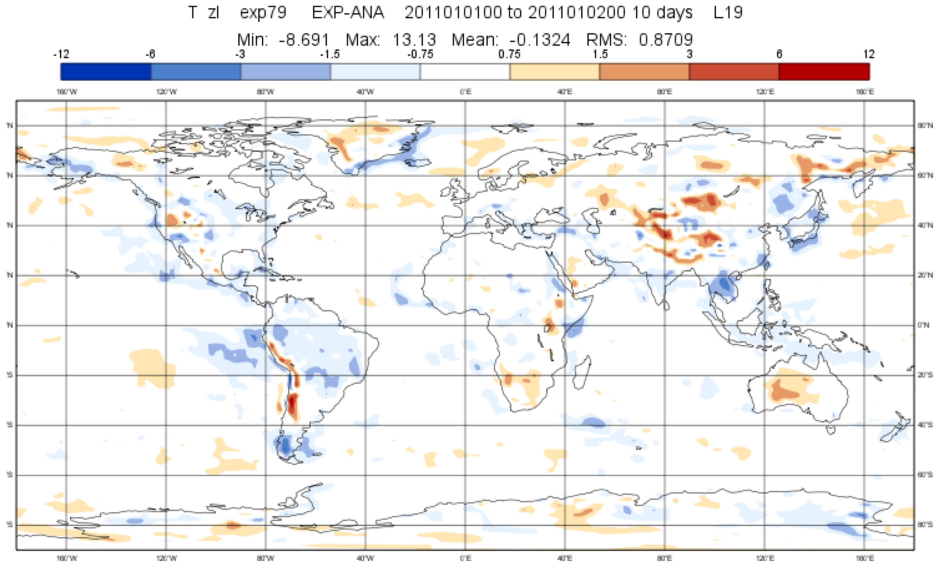
First results

Comparison of 24-h ICON forecasts with IFS analyses: average over 10 runs started on 10 consecutive days

Temperature at z = 1 km



ICON

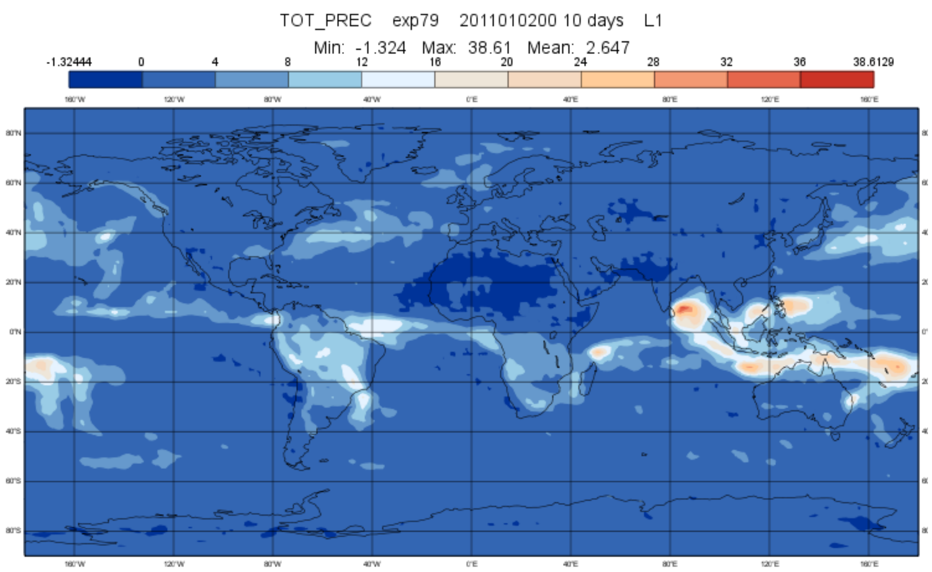


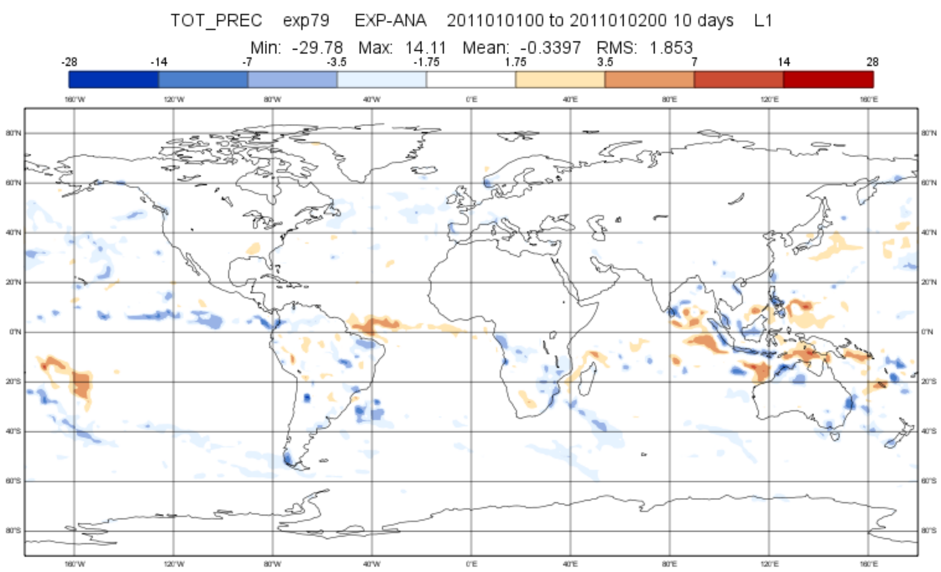
ICON - IFS ANA

First results

Comparison of 24-h ICON forecasts with IFS analyses: average over 10 runs started on 10 consecutive days

Precipitation





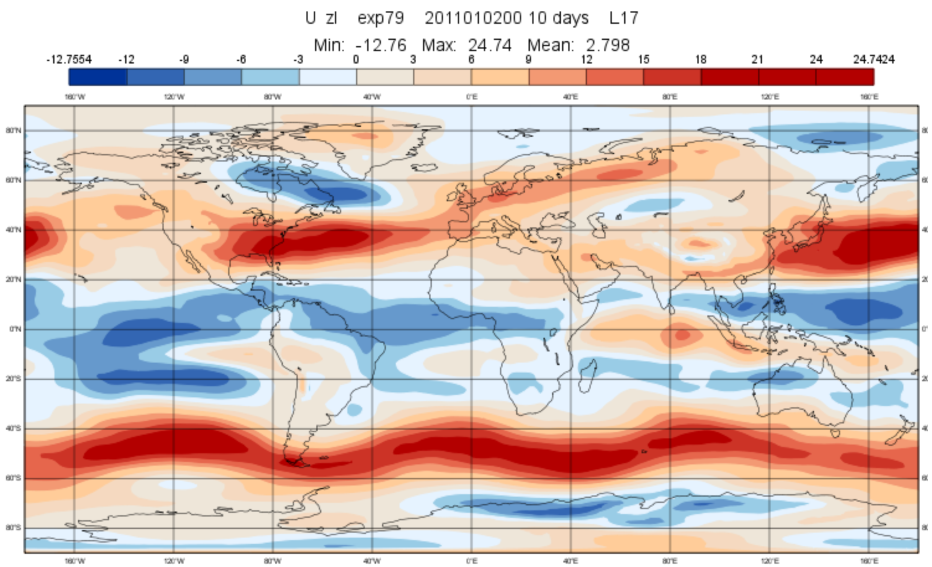
ICON

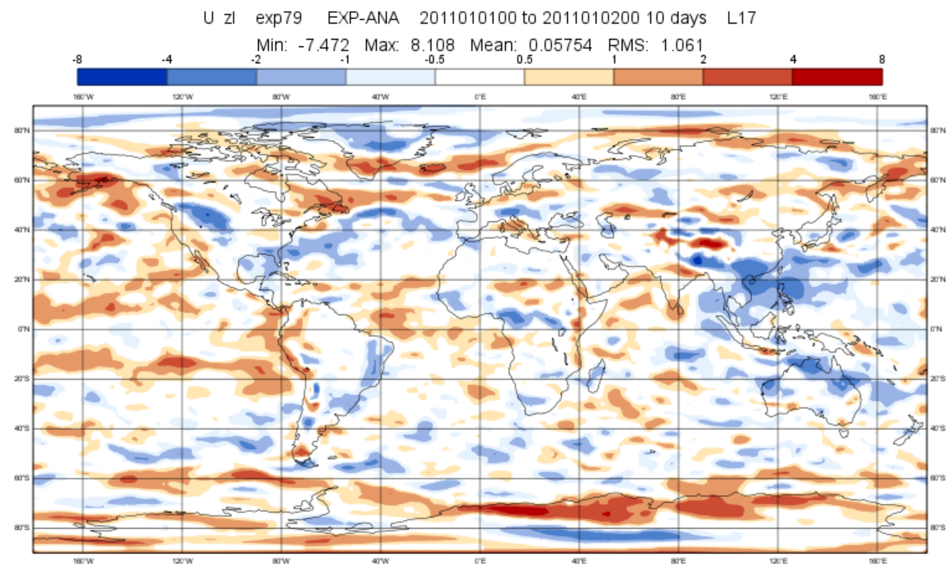
ICON - IFS ANA

First results

Comparison of 24-h ICON forecasts with IFS analyses: average over 10 runs started on 10 consecutive days

zonal wind speed at z = 3 km





ICON

ICON - IFS ANA

Conclusions and Outlook

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- New global non-hydrostatic model with better conservation properties
- Two-way nesting with capability for multiple nests per nesting level
- Improved scalability and efficiency on massively parallel computer architectures with $O(10^4+)$ cores: significantly better than for GME; roughly comparable to the COSMO model
- Improved tiled surface scheme with FLake that better account for sub-grid heterogeneities
- Test suites for ICON and GME with interpolated IFS analysis data; systematic tuning of physics parameterizations and their mutual interaction
- ToDo: Data assimilation

Thank you