Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Research and Development at DWD

Database Reference Manual for ICON and ICON-EPS

Version 1.2.4

D. Reinert, F. Prill, H. Frank, M. Denhard, and G. Zängl

Offenbach am Main, 2018

Version: 1.2.4

DOI: 10.5676/DWD_pub/nwv/icon_1.2.4

Publisher
Deutscher Wetterdienst
Business Area “Research and Development”
Frankfurter Straße 135
63067 Offenbach
www.dwd.de

Editors
Daniel Reinert, FE13,
Tel. +49 (69) 8062-2060, daniel.reinert@dwd.de
Helmut Frank, FE13,
Tel. +49 (69) 8062-2742, helmut.frank@dwd.de
Florian Prill, FE13,
Tel. +49 (69) 8062-2727, florian.prill@dwd.de

For **data requests** please contact: datenservice@dwd.de

Revision History

Revision	Date	Author(s)	Description
0.1.0	10.01.13	DR, FP	Generated preliminary list of available GRIB2 output fields
0.2.0	12.07.13	DR, FP	Added a short section describing the horizontal ICON grid. AUMFL_S, AVMFL_S added to the list of available output fields
0.2.1	15.07.13	DR	Provide newly available output fields in tabulated form. Change levelType of 3D atmospheric fields from 105 (Hybrid) to 150 (Generalized vertical height coordinate)
0.2.2	16.07.13	FP	Short description of ICON's vertical grid.
0.2.3	25.09.13	DR	Added description of available First Guess and analysis fields
0.2.4	17.12.13	DR	Added description of external paramater fields
0.3.0	24.01.14	DR	Added information about horizontal output grids
0.3.1	24.01.14	DR	Added information about newly available output field OMEGA
0.4.0	22.05.14	HF	Added SKY-database documentation
0.4.1	15.07.14	DR	Some documentation on statistical processing and minor updates. New output fields ASWDIR_S, ASWDIFD_S, ASWDIFU_S, DTKE_CON
0.4.2	10.09.14	DR	New output fields CLCT_MOD, CLDEPTH
0.5.0	01.10.14	DR	Description of IAU initialization method
0.5.1	15.10.14	DR	Updated description of necessary input fields
0.5.2	31.10.14	DR	Add full table with model half level heights
0.6.0	05.12.14	DR	Add short introduction and fix some minor bugs
0.6.1	10.12.14	DR	New output field APAB_S
0.7.0	16.12.14	DR	Revised documentation of time invariant fields and a couple of bug fixes
0.7.2	09.01.15	DR	General GRIB2 description
0.8.0	15.01.15	FP, DR	Couple of bug fixes regarding the available fields on triangular and regular grids
0.8.1	16.01.15	FP, DR	List of pressure-level variables available on triangular grids
0.8.2	16.01.15	FP	List of height-level variables available on regular grids
0.8.3	16.01.15	DR	List of variables exclusively available for $VV = 0$
0.8.4	06.02.15	FP, DR	Details of internal interpolation onto lon-lat grids. Details regarding output frequency.
0.8.5	18.02.15	FP	Additional pressure levels for regular grid output.
0.8.6	23.02.15	FP	Formula for computing non-zero topography level height.
1.0.0	23.02.15	FP	Additional table of model full levels.
1.0.1	24.02.15	DR	Update on available forecast runs and time span.

1.0.2	27.02.15	FP	Added tables for grid point with maximum topo height.
1.0.3	13.03.15	DR, FP	Section on statistically processed fields.
1.1.0	15.04.15	FP, DR	Section on ICON EU nest (preliminary).
1.1.1	07.07.15	HF	Added SMA list, list of half levels for EU nest, modified output lists to automatically write model level variables in the namelist templates.
1.1.1	17.07.15	HF	Preliminary add T_S because it is already written in operations. Some other minor modifications.
1.1.2	14.08.15	FP	Added note on ICON's earth radius and a table summarizing regular grids.
1.1.3	04.12.15	FP	Added WW code table 6.8.
1.1.4	11.01.16	HF	Updated examples how to retrieve ICON data from SKY.
1.1.5	22.01.16	AR	Description of En-Var.
1.1.6	28.01.16	DR	Extend tables by field specific lat-lon interpolation method.
1.1.7	11.04.16	DR, FP	Add timeline of model changes.
1.1.8	06.07.16	HF	Add DTKE_HSH and other minor corrections.
1.1.9	27.09.16	DR	Update intro and timeline.
1.1.10	03.02.17	DR	update lat-lon interpolation methods and timeline.
1.1.11	08.05.17	DR	update version history.
1.1.12	13.07.17	DR	Update description for output variable `SOILTYP`.
1.1.13	25.10.17	FP, DR	Remove references to COSMO-EU
1.1.14	10.01.18	DR	Bug fix regarding availability of `CLCT_MOD` on global domain
1.2.0	26.01.18	MD	Documentation for ICON-EPS products added
1.2.1	31.01.18	FP	Updated height tables (appendix)
1.2.2	12.03.18	DR	Added new output fields `EVAP_PL`, and `SMI`. Further adaptions to the list of available fields and updated timeline; info on download of grids.
1.2.3	07.07.18	FP	Added output field `CAPE_ML`, `EVAP_PL`, `SMI` for global domain, native grid. Added output field `ALB_SEAICE`.
1.2.4	31.08.18	MD	Updated table of probability products.

Simulations are believed by no one except those who conducted them.

Experimental results are believed by everyone except those who conducted them.

ANONYMOUS

Contents

1. Introduction

The **ICO**sahedral **N**onhydrostatic model ICON is the global and regional numerical weather prediction model at DWD. It became operational at 2015-01-20, replacing the former operational global model GME. In June 2015 a refined subregion (*nest*) over Europe was activated, in order to replace the regional model COSMO-EU.

The ICON modelling system as a whole is developed jointly by DWD and the Max-Planck Institute for Meteorology in Hamburg (MPI-M). While ICON is the new working horse for short and medium range global weather forecast at DWD, it embodies the core of a new climate modelling system at MPI-M.

ICON analysis and forecast fields serve as initial and boundary data for a couple of different limited area models: Since 2015-01-20, analysis and forecast fields of the deterministic forecast run at 13 km horizontal resolution serve as initial and boundary data for

- RLMs (**R**elocatable **L**ocal **M**odel) of the German armed forces,
- DWD's wave models.

In addition, deterministic forecasts of the regional model COSMO-DE are driven by deterministic forecasts of the ICON-EU nest (since 2016-07-13). Forecasts of the regional ensemble prediction system COSMO-DE-EPS are driven by ICON-EPS forecasts (since 2017-03-21).

This document provides some basic information about ICON's horizontal and vertical grid structure, numerical algorithms (see also Zängl et al. (2015)) and physical parameterizations (the latter two are planned but not yet available). Furthermore, it provides an overview about the ICON analysis and forecast fields stored in the database SKY at DWD. Some examples on how to read these data from the database are given as well.

If you encounter bugs or inconsistencies, or if you have suggestions for improving this document, please contact one of the following colleagues:

Daniel Reinert, FE13	**Helmut Frank**, FE13	**Florian Prill**, FE13
Tel: +49 (69) 8062-2060	Tel: +49 (69) 8062-2742	Tel: +49 (69) 8062-2727
Mail: daniel.reinert@dwd.de	Mail: helmut.frank@dwd.de	Mail: florian.prill@dwd.de

2. History of model changes

The forecasting environment, which is composed of the ICON model and the data assimilation system, is subject to continuous improvements and modifications. The most important ones in terms of forecast quality and output products are depicted below. For additional information, the reader is referred to the official change notifications which are available from

```
http://www.dwd.de/DE/fachnutzer/forschung_lehre/numerische_wettervorhersage/nwv_
aenderungen/nwv_aenderungen_node.html
```

Alternatively you can click on the timeline-date to see the corresponding change notification.

2015-01-20 First operational ICON forecast run at a horizontal resolution of 13 km and 90 vertical levels. Model top at 75 km

2015-02-25 4 additional forecast runs 03, 09, 15, 21 UTC up to 30 h lead time. Maximum forecast lead times for 06 and 18 UTC runs extended to 120 h

2015-03-04 Improved wind gust diagnostic for mountainous regions

2015-07-07 Time interval over which max/min temperatures `TMAX_2M`, `TMIN_2M` are collected changed to 6 h (formerly 3 h). Time interval over which maximum wind gusts `VMAX_10M` are collected changed to 1 h (formerly 3 h).

2015-07-21 Launch of the ICON-EU nest with a horizontal resolution of 6.5 km and 50 vertical levels. Model top at 50 km.

2015-09-02 Assimilation of selected microwave satellite radiance channels over land (AMSU-A and ATMS), which have so far been assimilated only over the oceans.

2015-12-01 Surface tile approach for land, sea-ice and lake points, including snow-tiles. Each grid point can have up to 5 tiles consisting of 3 land tiles (dominant land-use types), a lake tile or a sea-water plus sea-ice tile. Land tiles may have additional snow tiles.

2016-01-20 Launch of the ensemble data assimilation system (LETKF, Localized Ensemble Transform Kalman Filter), providing a 40 member analysis ensemble at R2B6N7. For deterministic forecasts the 3D-Var assimilation system is replaced by En-Var (Ensemble Variational analysis system) which makes use of the ensemble-based model error covariances.

2016-04-13 Improved version of the ICON model which

- accounts for oceanic salt content in the saturation vapor pressure computation.
- contains modifications to the detrainment tendencies from the convection parameterization in order to reduce spurious drizzle.
- makes use of the aerosol climatology for the computation of cloud droplet number concentrations in the radiation parameterization.

2016-04-20 The pressure levels for regular grid output have been revised. Newly available levels: 650, 550, 450, 350, 275, 225, 175, 125 hPa. Deprecated levels: 725, 20, 7, 3, 0.3 hPa.

2016-09-28 New version of the ICON model in which

- the convection parameterization has been improved with respect to mixed-phase cloud processes
- the process of rain water evaporation below cloud base has been updated.

2016-11-30 New version of the ICON model in which

- the incremental analysis update (IAU) scheme has been improved
- the diagnostic relative humidity at 2 m above ground is used in the assimilation system instead of the prognostic one at 10 m above ground.

2017-01-31 Modifications to the ICON-internal lat-lon interpolation for temperature and specific humidity. Changes to the data assimilation system, i.e.

- bias correction for scatterometer data
- improvements regarding the usage of wind measurements from buoys

2017-03-15 New version of the ICON model:

- updated set of external parameters w.r.t. model orography
- reduced orography filtering for global domain
- new surface evaporation scheme and activation of interception storage
- regular update of the sea surface temperature (SST) by climatological increments
- a limiter is applied to SSO-scheme wind tendencies from the middle stratosphere onwards

Updates to the data assimilation scheme:

- Usage of Meteosat-8 Atmospheric motion vector (AMV) winds (instead of Meteosat-7 AMVs)

2017-05-10 New version of the ICON model, which includes

- prognostic sea-ice albedo
- new ozone climatology over antarctica
- SSO scheme retuning
- usage of ice-coverage observations for the great lakes
- improved snow-analysis w.r.t. to small-scale structures

2017-09-29 Usage of high-resolution (0.083°) NCEP sea surface temperature SST analysis

2017-10-11 Updated weather interpretation (WW) code tables

2017-10-25 Modifications w.r.t. the usage of 2 m relative humidity and 10 m winds from SYNOP stations over land in the global data assimilation system.

2017-11-29 Usage of Dual-Metop Atmospheric Motion Vector (AMV) winds in the global data assimilation system.

2018-01-17 Launch of the global ICON-EPS (Ensemble Prediction System) with 40 members and 40(20) km horizontal resolution globally (over Europe).

2018-03-14 New version of the ICON model and improvements of the assimilation system, which include

- assimilation of satellite moisture channels (IASI and MHS)
- updated RTTOV library (RTTOV12)
- new output fields `EVAP_PL`, `SMI`
- migration from GRIB Master Tables Version 11 to Version 19
- updated model topography
- several measures for reducing the model bias for 2 m humidity and temperature.

3. Grid geometry

3.1. Horizontal grid

The horizontal ICON grid consists of a set of spherical triangles that seamlessly span the entire sphere. The grid is constructed from an icosahedron (see Figure 3.1a) which is projected onto a sphere. The spherical icosahedron (Figure 3.1b) consists of 20 equilateral spherical triangles. The edges of each triangle are bisected into equal halves or more generally into n equal sections. Connecting the new edge points by great circle arcs yields 4 or more generally n^2 spherical triangles within the original triangle (Figure 3.2a, 3.2b).

Figure 3.1.: Icosahedron before (a) and after (b) projection onto a sphere

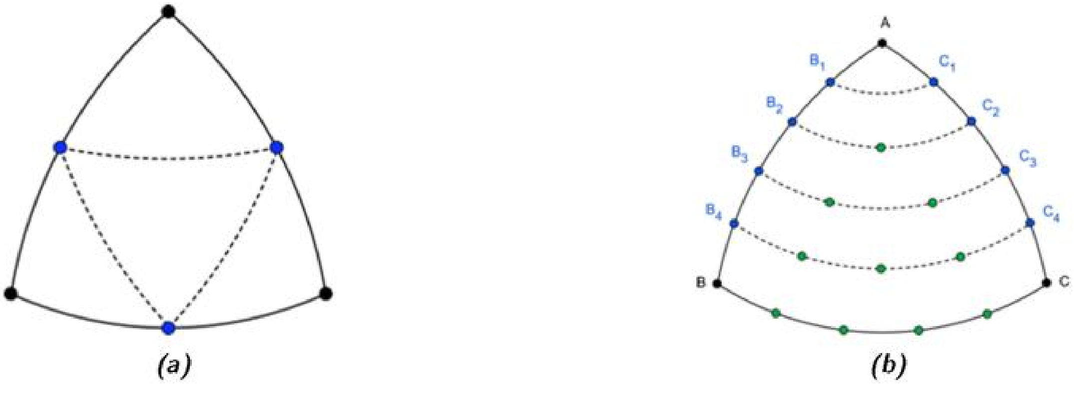


Figure 3.2.: (a) Bisection of the original triangle edges (b) More general division into n equal sections

ICON grids are constructed by an initial root division into n sections (**R**n) followed by k bisection steps (**B**k), resulting in a **R**n**B**k grid. Figures 3.3a and 3.3b show **R**2**B**00 and **R**2**B**02 ICON grids. Such grids avoid polar singularities of latitude-longitude grids (Figure 3.3c) and allow a high uniformity in resolution over the whole sphere.

Throughout this document, the grid is referred to as the "**R**n**B**k grid" or "**R**n**B**k resolution". For a

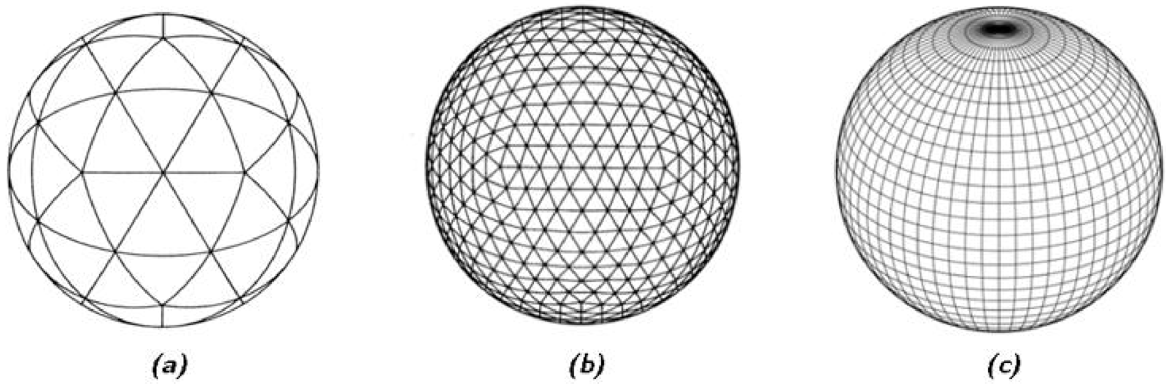


Figure 3.3.: (a) R2B00 grid. (b) R2B02 grid. (c) traditional regular latitude-longitude grid with polar singularities

given resolution **R**n**B**k, the total number of cells, edges, and vertices can be computed from

$$\begin{aligned} n_c &= 20\, n^2\, 4^k \\ n_e &= 30\, n^2\, 4^k \\ n_v &= 10\, n^2\, 4^k + 2 \end{aligned}$$

The average cell area $\overline{\Delta A}$ can be computed from

$$\overline{\Delta A} = \frac{4\pi\, r_e^2}{n_c}\,,$$

with the earth radius r_e, and n_c the total number of cells. ICON uses an earth radius of

$$r_e = 6.371229 \cdot 10^6\,\mathrm{m}.$$

Based on $\overline{\Delta A}$ one can derive an estimate of the average grid resolution $\overline{\Delta x}$:

$$\overline{\Delta x} = \sqrt{\overline{\Delta A}} = \sqrt{\frac{\pi}{5}}\frac{r_e}{n\,2^k}$$

Visually speaking, $\overline{\Delta x}$ is the edge length of a square which has the same area as our triangular cell.

In Table 3.1, some characteristics of frequently used ICON grids are given. The table contains information about the total number of triangles (n_c), the average resolution $\overline{\Delta x}$, and the maximum/minimum cell area. The latter may be interpreted as the area for which the prognosed meteorological quantities (like temperature, pressure, ...) are representative. Some additional information about ICON's horizontal grid can be found in Wan et al. (2013).

Table 3.1.: Characteristics of frequently used ICON grids. ΔA_{max} and ΔA_{min} refer to the maximum and minimum area of the grid cells, respectively.

Grid	number of cells (n_c)	avg. resolution [km]	ΔA_{max} [km^2]	ΔA_{min} [km^2]
R2B04	20480	157.8	25974.2	18777.3
R2B05	81920	78.9	6480.8	4507.5
R2B06	327680	39.5	1618.4	1089.6
R2B07	1310720	19.7	404.4	265.1
R3B07	2949120	13.2	179.7	116.3

The first operational version of ICON is based on the R3B07 grid, thus, having a horizontal resolution of about 13 km!

3.2. Vertical grid

The vertical grid consists of a set of vertical layers with height-based vertical coordinates. Each of these layers carries the horizontal *2D* grid structure, thus forming the *3D* structure of the grid. The ICON grid employs a Lorenz-type staggering with the vertical velocity defined at the boundaries of layers (half levels) and the other prognostic variables in the center of the layer (full levels).

To improve simulations of flow past complex topography, the ICON model employs a smooth level vertical (SLEVE) coordinate (Leuenberger et al., 2010). It allows for a faster transition to smooth levels in the upper troposphere and lower stratosphere, as compared to the classical height-based Gal-Chen coordinate. In the operational setup, the transition from terrain following levels in the lower atmosphere to constant height levels is completed at $z = 16$ km. Model levels above are flat. The required smooth large-scale contribution of the model topography is generated by digital filtering with a ∇^2-diffusion operator. Figure 3.4 shows the (half) levels of the operational ICON setup with 90 vertical levels. The table to the right shows the height above ground of selected half levels (for zero height topography) and the corresponding pressure, assuming the US standard atmosphere. Standard heights for all 91 half levels are given in Table A.1.

Please note that for grid cells with non-zero topography these values only represent rough estimates of the true level height. Actual heights and layer thicknesses may vary considerably from location to location, due to grid level stretching/compression over non-zero topography.

3.3. Refined subregion over Europe ("local nest")

ICON has the capability for running global simulations with refined domains (so called *nests*). The triangular mesh of the refined area is generated by bisection of triangles in the global "parent" grid, see Fig. 3.5. In the vertical the global grid extends into the mesosphere (which greatly facilitates the assimilation of satellite data) whereas the nested domains extend only into the lower stratosphere in order to save computing time. For the same orography the heights of levels 1–60 of the Europe nest are the same as those of levels 31–90 of the global grid. In practice, however, near surface level heights of nests and the global domain differ due to the fact that the underlying orography differs, with deeper slopes and higher summits in the high resolution nests.

For each nesting level, the time step is automatically divided by a factor of two. Note that the grid nests are computed in a concurrent fashion:

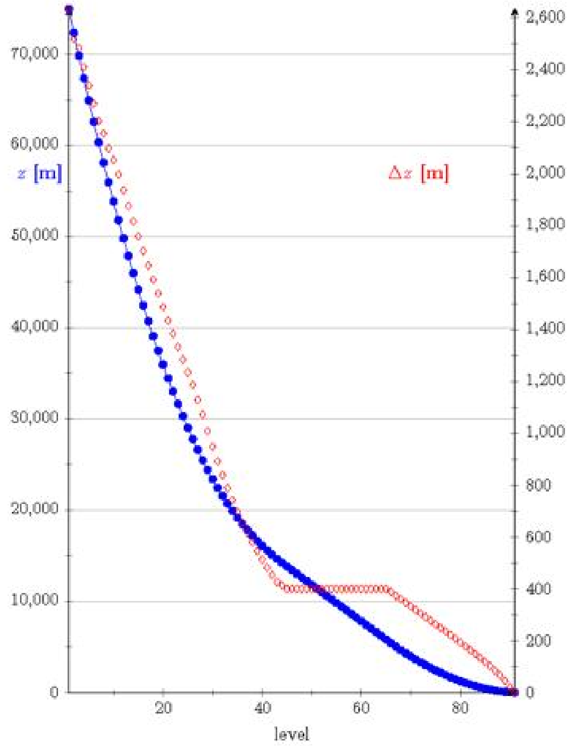
- Points that are covered by the refined subdomain additionally contain data for the global grid state.
- The data points on the triangular grid are the cell circumcenters. Therefore the global grid data points are closely located to nest data sites, but they *do not coincide* exactly (see Fig. 3.5).

ICON's refined subregion over Europe is comparable to the COSMO-EU region of DWD's COSMO model. Key figures like edge coordinates and mesh size of the COSMO-EU region and the ICON-EU nest are given in Table 3.2. The geographical location of the nest is visualized in Fig. 3.6a and Fig. 3.6b.

Model simulations including the nesting region over Europe are running regularly, starting from

2015-07-21, 06 UTC (`roma`).

Main forecasts starting at 00, 06, 12, 18 UTC **reach out to** 120 h, **while additional short-range forecasts starting at** 03, 09, 15, 21 UTC **provide data until** +30 h.



level	[*m*]	[*Pa*]
1	75 000	2.1
5	64 946	10.0
10	53 878	46.3
15	44 198	158.8
20	35 958	487.2
25	29 039	1 355.0
30	23 409	3 211.8
35	19 202	6 209.4
40	16 108	10 113.6
45	13 822	14 504.3
50	11 822	19 882.1
55	9 822	27 166.6
60	7 822	36 528.6
65	5 822	48 347.1
70	3 954	62 009.2
75	2 432	75 325.6
80	1 255	87 126.2
85	436	96 190.0
90	20	101 085.0

Figure 3.4.: Vertical half levels (blue) and layer thickness (red) of the ICON operational setup. The table of selected pressure values (for zero height) is based on the 1976 US standard atmosphere.

Simulation on the global grid and the regional (Europe) domain are tightly coupled (*two-way nesting*): Boundary data for the nest area is updated every time step (120 s). Feedback of atmospheric prognostic variables (except precipitation) is computed via relaxation on a 3 h time scale.

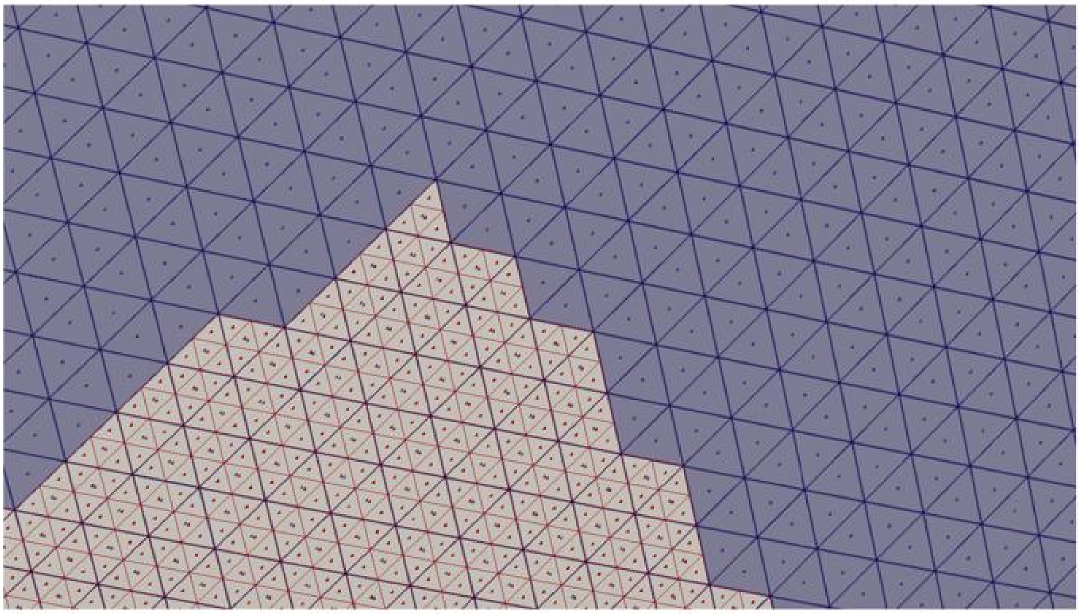


Figure 3.5.: ICON grid refinement (zoom view). Blue and red dots indicate the cell circumcenters for the global ("parent") and the refined ("child") domain, respectively.

Table 3.2.: Key figures of the ICON-EU nest and the COSMO-EU region.

	ICON-EU nest	**COSMO-EU**
geogr. coordinates	23.5° W – 62.5° E	$\lambda_N = 170°$ W, $\phi_N = 40°$ N,
	29.5° N – 70.5° N	18.0° W – 23.5° E
		20.0° S – 21.0° N
mesh size	≈ 6.5 km (R3B08)	0.0625° (≈ 7 km)
	659156 triangles	665 × 657 = 436905 grid points
vertical levels	60 levels	40 levels
upper boundary	22.5 km	22.5 km

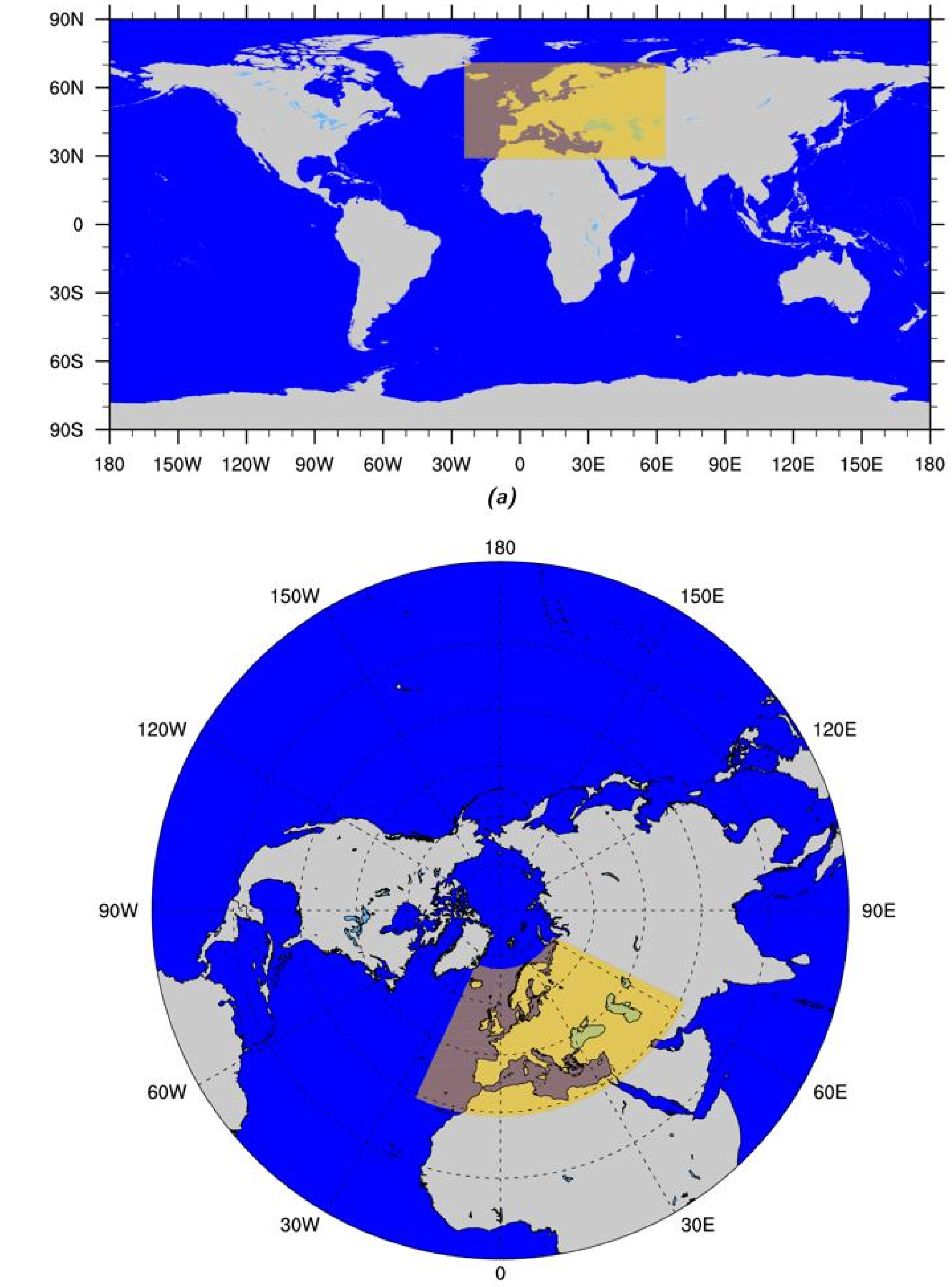


Figure 3.6.: 3.6a: Horizontal extent of the ICON-EU nest (orange shaded area) in a cylindrical equidistant projection. 3.6b: Same as 3.6a but in a polar stereographic projection.

4. Mandatory input fields

Several input files are needed to perform runs of the ICON model. These can be divided into three classes: Grid files, external parameters, and initialization (analysis) files. The latter will be described in Chapter 5.

4.1. Grid Files

In order to run ICON, it is necessary to load the horizontal grid information as an input parameter. This information is stored within so-called grid files. For an ICON run, at least one global grid file is required. For model runs with nested grids, additional files of the nested domains are necessary. Optionally, a reduced radiation grid for the global domain may be used.

The unstructured triangular ICON grid resulting from the grid generation process is represented in NetCDF format. This file stores coordinates and topological index relations between cells, edges and vertices.

The most important data entries of the main grid file are

- `cell` (INTEGER dimension)
  number of (triangular) cells
- `vertex` (INTEGER dimension)
  number of triangle vertices
- `edge` (INTEGER dimension)
  number of triangle edges
- `clon`, `clat` (double array, dimension: #triangles, given in radians)
  longitude/latitude of the midpoints of triangle circumcenters
- `vlon`, `vlat` (double array, dimension: #triangle vertices, given in radians)
  longitude/latitude of the triangle vertices
- `elon`, `elat` (double array, dimension: #triangle edges, given in radians)
  longitude/latitude of the edge midpoints
- `cell_area` (double array, dimension: #triangles)
  triangle areas
- `vertex_of_cell` (INTEGER array, dimensions: [3, #triangles])
  The indices `vertex_of_cell(:,i)` denote the vertices that belong to the triangle `i`. The `vertex_of_cell` index array is ordered counter-clockwise for each cell.
- `edge_of_cell` (INTEGER array, dimensions: [3, #triangles])
  The indices `edge_of_cell(:,i)` denote the edges that belong to the triangle `i`.
- `clon/clat_vertices` (double array, dimensions: [#triangles, 3], given in radians)
  `clon/clat_vertices(i,:)` contains the longitudes/latitudes of the vertices that belong to the triangle `i`.
- `neighbor_cell_index` (INTEGER array, dimensions: [3, #triangles])
  The indices `neighbor_cell_index(:,i)` denote the cells that are adjacent to the triangle `i`.

Figure 4.1.: Screenshots of the ICON download server hosted by the Max Planck Institute for Meteorology in Hamburg.

- `zonal/meridional_normal_primal_edge`: (INTEGER array, #triangle edges) components of the normal vector at the triangle edge midpoints.
- `zonal/meridional_normal_dual_edge`: (INTEGER array, #triangle edges) These arrays contain the components of the normal vector at the facets of the dual control volume. Note that each facet corresponds to a triangle edge and that the dual normal matches the direction of the primal tangent vector but signs can be different.

4.1.1. Download of Predefined Grids

For fixed domain sizes and resolutions a list of grid files has been pre-built for the ICON model together with the corresponding reduced radiation grids and the external parameters.

The contents of the primary storage directory are regularly mirrored to a public web site for download, see Figure 4.1 for a screenshot of the ICON grid file server. The download server can be accessed via

`http://icon-downloads.mpimet.mpg.de`

The pre-defined grids are identified by a *centre number*, a *subcentre number* and a *numberOfGridUsed*, the latter being simply an integer number, increased by one with every new grid that is registered in the download list. Also contained in the download list is a tree-like illustration which provides information on parent-child relationships between global and local grids, and global and radiation grids, respectively.

Note that the grid information of some of the older grids (no. 23 – 40) is split over two files: The users need to download the main grid file itself *and* a *grid connectivity* file (suffix `-grfinfo.nc`).

4.2. External Parameters

External parameters are used to describe the properties of the earth's surface. These data include e.g. the orography, the land-sea-mask as well as parameters describing soil and surface properties, like the soiltype or the plant cover fraction.

The ExtPar software (ExtPar – External parameter for Numerical Weather Prediction and Climate Application) is able to generate external parameters for the ICON model. The generation is based on a set of raw datafields which are listed in Table 4.1. For a more detailed overview of ExtPar, the reader is referred to the *User and Implementation Guide* of Extpar.

Table 4.1.: Raw datasets from which the ICON external parameter fields are derived.

Dataset	Source	Resolution
Global Land One-km Base Elevation Project (GLOBE)	NGDC	30"
Global Land Cover Map for 2009 (GlobCover 2009)	ESA	10"
Global Land Cover Characteristics (GLCC)	USGS	30"
Digital Soil Map of the World (DSMW)	FAO	5'
Sea-viewing Wide Field-of-view Sensor (SeaWIFS) NDVI Climatotology	NASA/GSFC	2.5'
Climate Research Unit - Gridded climatology of 1961-1990 monthly means (CRU-CL)	CRU-UEA	0.5°
Global Aerosol Climatology Project (GACP) Aerosol Optical thickness	NASA/GISS	$4x5°$
Global Lake Database (GLDB)	DWD/RSHU/MeteoFrance	30"
Moderate Resolution Imaging Spectroradiometer (MODIS) albedo	NASA	5'

GlobCover 2009 is a land cover database covering the whole globe, except for Antarctica. Therefore, we make use of GlobCover 2009 for $90° > \phi > -56°$ (with ϕ denoting latitude) and switch to the coarser, however globally available dataset GLCC for $-56° \geq \psi > -90°$.

The products generated by the ExtPar software package are listed in Table 4.2 together with the underlying raw dataset. These are mandatory input fields for assimilation- and forecast runs.

Table 4.2.: External parameter fields for ICON, produced by the ExtPar software package (in alphabetical order)

ShortName	Description	Raw dataset
AER_SS12	Sea salt aerosol climatology (monthly fields)	GACP
AER_DUST12	Total soil dust aerosol climatology (monthly fields)	GACP
AER_ORG12	Organic aerosol climatology (monthly fields)	GACP
AER_SO412	Total sulfate aerosol climatology (monthly fields)	GACP
AER_BC12	Black carbon aerosol climatology (monthly fields)	GACP
ALB_DIF12	Shortwave ($0.3 - 5.0\,\mu$m) albedo for diffuse radiation (monthly fields)	MODIS
ALB_UV12	UV-visible ($0.3 - 0.7\,\mu$m) albedo for diffuse radiation (monthly fields)	MODIS
ALB_NI12	Near infrared ($0.7 - 5.0\,\mu$m) albedo for diffuse radiation (monthly fields)	MODIS
DEPTH_LK	Lake depth	GLDB

Continued on next page

Table 4.2.: *continued*

EMIS_RAD	Surface longwave (thermal) emissivity	GlobCover 2009
FOR_D (*)	Fraction of deciduous forest	GlobCover 2009
FOR_E (*)	Fraction of evergreen forest	GlobCover 2009
FR_LAKE	Lake fraction (fresh water)	GLDB
FR_LAND	Land fraction (excluding lake fraction but including glacier fraction)	GlobCover 2009
FR_LUC	Landuse class fraction	
HSURF	Orography height at cell centres	GLOBE
LAI_MX (*)	Leaf area index in the vegetation phase	GlobCover 2009
NDVI_MAX	Normalized differential vegetation index	SeaWIFS
NDVI_MRAT	proportion of monthly mean NDVI to yearly maximum (monthly fields)	SeaWIFS
PLCOV_MX (*)	Plant covering degree in the vegetation phase	GlobCover 2009
ROOTDP (*)	Root depth	GlobCover 2009
RSMIN (*)	Minimum stomatal resistance	GlobCover 2009
SOILTYP	Soil type	DSMW
SSO_STDH	Standard deviation of sub-grid scale orographic height	GLOBE
SSO_THETA	Principal axis-angle of sub-grid scale orography	GLOBE
SSO_GAMMA	Horizontal anisotropy of sub-grid scale orography	GLOBE
SSO_SIGMA	Average slope of sub-grid scale orography	GLOBE
T_2M_CL	Climatological 2m temperature (serves as lower boundary condition for soil model)	CRU-CL
Z0 (*)	Surface roughness length (over land), containing a contribution from subgrid-scale orography	GlobCover 2009

Note that fields marked with (*) are not required in operational model runs. I.e. the surface roughness `Z0` is only required, if the additional contribution from sub-grid scale orography shall be taken into account (i.e. for `itype_z0=1`). In operational runs this is not the case. Instead, land-cover class specific roughness lengths are taken from a GlobCover-based lookup table. `FOR_D`, `FOR_E`, `LAI_MX`, `PLCOV_MX`, `RSMIN`, and `ROOTDP` became obsolete with the activation of the surface tile approach (2015-03-04). The latter 4 fields are replaced by land-cover class specific values taken from lookup tables.

Remarks on post-processing

Some of the external parameter fields are further modified by ICON. The following fields are affected:

`DEPTH_LK` `HSURF` `FR_LAND` `FR_LAKE` `Z0`

Thus, for consistency, the modified fields should be used for post-processing tasks rather than the original external parameter fields. See Section 6.3.1 for more details.

5. Analysis fields

Numerical weather prediction (NWP) is an initial value problem. The ability to make a skillful forecast relies heavily on an accurate estimate of the present atmospheric state, known as the analysis. In general, an analysis is generated by optimally combining all available observations with a short-range model forecast, known as *first guess* (FG) or *background*. Currently an atmospheric analysis is created every 3 h. The 3-hourly first guess output provided by ICON comprises the following fields:

Table 5.1.: Available 3 h first guess output fields from the forecast database `CAT_NAME=$model_ass_fc_$suite`

Type	GRIB shortName
Atmosphere	VN, U, V, W, DEN, THETA_V, T, QV, QC, QI, QR, QS, TKE, P
Surface (general)	T_G, T_SO(0), QV_S, T_2M, TD_2M, U_10M, V_10M, PS, Z0
Land specific	W_SNOW, T_SNOW, RHO_SNOW, H_SNOW, FRESHSNW, W_I, T_SO(1:nlev_soil), W_SO, W_SO_ICE
Lake/sea ice specific	T_MNW_LK, T_WML_LK, H_ML_LK, T_BOT_LK, C_T_LK, T_B1_LK, H_B1_LK, T_ICE, H_ICE, FR_ICE
Time invariant	FR_LAND, HHL, CLON, CLAT, ELON, ELAT, VLON, VLAT

Atmospheric analysis fields are computed every 3 hours (00, 03, 06,... 21 UTC) by the 3DVar data assimilation system, which has recently been upgraded to an En-Var system (see Section 5.1). Sea surface temperature `T_SO(0)` and sea ice cover `FR_ICE` are provided once per day (00 UTC) by the SST-Analysis. A snow analysis is conducted every 3 hours, providing updated information on the snow height `H_SNOW` and snow age `FRESHSNW`. In addition a soil moisture analysis (SMA) is conducted once per day (00 UTC). It basically modifies the soil moisture content `W_SO`, in order to improve the 2 m temperature forecast.

For the 3-hourly assimilation cycle and forecast runs, ICON must be provided with 2 input files: One containing the First Guess (FG) and the other containing analysis (AN) fields, only. Variables for which no analysis is available are always read from the first guess file (e.g. TKE). Other variables may be read either from the first guess or the analysis file, depending on the starting time. E.g. for T_SO(0) the first guess is read at 03, 06, 09, 12, 15, 18, 21 UTC, however, the analysis is read at 00 UTC when a new SST analysis is available. In Table 5.2 the available and employed first guess and analysis fields are listed as a function of starting time.

Table 5.2.: The leftmost column shows variables that are mandatory for the assimilation cycle and forecast runs. Column 2 indicates, whether or not an analysis is performed for these variables. Columns 3 to 10 show the origin of these variables (analysis or first guess), depending on the starting time.

ShortName	Analysis	00	03	06	09	12	15	18	21
Atmosphere									
VN	–	FG	FG	FG	FG	FG	FG	FG	FG
THETA_V	–	FG	FG	FG	FG	FG	FG	FG	FG
DEN	–	FG	FG	FG	FG	FG	FG	FG	FG
W	–	FG	FG	FG	FG	FG	FG	FG	FG
TKE	–	FG	FG	FG	FG	FG	FG	FG	FG
QC, QI, QR, QS	–	FG	FG	FG	FG	FG	FG	FG	FG
QV	3DVar	AN	AN	AN	AN	AN	AN	AN	AN
T	3DVar	AN	AN	AN	AN	AN	AN	AN	AN
P	3DVar	AN	AN	AN	AN	AN	AN	AN	AN
U, V	3DVar	AN	AN	AN	AN	AN	AN	AN	AN
Surface									
Z0	–	FG	FG	FG	FG	FG	FG	FG	FG
T_G	–	FG	FG	FG	FG	FG	FG	FG	FG
QV_S	–	FG	FG	FG	FG	FG	FG	FG	FG
T_SO(0) (SST only)	Ana_SST	AN	FG	FG	FG	FG	FG	FG	FG
T_SO(0:nlevsoil)	–	FG	FG	FG	FG	FG	FG	FG	FG
W_SO_ICE	–	FG	FG	FG	FG	FG	FG	FG	FG
W_SO	SMA	AN	FG	FG	FG	FG	FG	FG	FG
W_I	–	FG	FG	FG	FG	FG	FG	FG	FG
W_SNOW[1]	Ana_SNOW	AN	AN	AN	AN	AN	AN	AN	AN
T_SNOW	–	FG	FG	FG	FG	FG	FG	FG	FG
RHO_SNOW[1]	Ana_SNOW	AN	AN	AN	AN	AN	AN	AN	AN
H_SNOW	Ana_SNOW	AN	AN	AN	AN	AN	AN	AN	AN
FRESHSNW	Ana_SNOW	AN	AN	AN	AN	AN	AN	AN	AN
SNOWC	–	FG	FG	FG	FG	FG	FG	FG	FG
Sea ice/Lake									
T_ICE	–	FG	FG	FG	FG	FG	FG	FG	FG
H_ICE	–	FG	FG	FG	FG	FG	FG	FG	FG
FR_ICE	Ana_SST	AN	FG	FG	FG	FG	FG	FG	FG

Continued on next page

Table 5.2.: The leftmost column shows variables that are mandatory for the assimilation cycle and forecast runs. Column 2 indicates, whether or not an analysis is performed for these variables. Columns 3 to 10 show the origin of these variables (analysis or first guess), depending on the starting time.

ShortName	Analysis	00	03	06	09	12	15	18	21
T_MNW_LK	–	FG	FG	FG	FG	FG	FG	FG	FG
T_WML_LK	–	FG	FG	FG	FG	FG	FG	FG	FG
H_ML_LK	–	FG	FG	FG	FG	FG	FG	FG	FG
T_BOT_LK	–	FG	FG	FG	FG	FG	FG	FG	FG
C_T_LK	–	FG	FG	FG	FG	FG	FG	FG	FG
T_B1_LK	–	FG	FG	FG	FG	FG	FG	FG	FG
H_B1_LK	–	FG	FG	FG	FG	FG	FG	FG	FG

5.1. Ensemble Data Assimilation

Until 2016-01-20 the analyses were derived by a 3-hourly cycled 3-dimensional data assimilation system (3D-Var).

From 2016-01-20 on the analysis system consists of the 3-hourly cycled Ensemble Variational Data assimilation system (En-Var) providing initial fields for the deterministic ICON forecasts at 13 km resolution, based on the 3-hour short range forecast (first guess) and the observations at the actual analysis time. In the En-Var a part of the background error covariance matrix is derived from the statistics of a 3-hour short range ensemble forecast at lower resolution (currently 40 members at 40 km R2B06 resolution with a 20 km nest over Europe). The En-Var deterministic analysis system is complemented by an Ensemble Data Assimilation system (EDA), in the specific implementation of a Localized Ensemble Transform Kalman Filter (LETKF). The EDA provides the initial fields for the 3-hourly cycled ICON short range ensemble forecasts.

Both the deterministic and the ensemble data assimilation provide atmospheric analyses and analysis increments as described in Table 5.2 and Section 5.2. However, The Ensemble Data assimilation currently does not run separate analyses for sea surface temperature, snow, and soil moisture. Instead these fields are derived from the deterministic forecast and provided 3-hourly by the EDA in the following way:

Sea Surface Temperature The sea surface temperature at ensemble resolution is interpolated (taking the nearest neighbor) from the deterministic sea surface temperature. Ice fraction, ice height, and ice temperature are taken from the deterministic first guess as well. As a SST analysis is run once a day in the deterministic forecast system this mechanism ensures that the ensemble sea surface temperature stays close to the observed one.

In addition the interpolated sea surface temperature is perturbed individually for each ensemble member with prescribed spacial and temporal correlation length scales to account for the uncertainties in the SST analysis.

[1]Note that RHO_SNOW is read from the analysis, however it does not contain any new/independent information compared to the model first guess, except for an initialization of newly generated snow points and a limitation over glacier points. W_SNOW is read from the analysis, too, however it is re-diagnosed within the ICON-code based on the analyzed snow height H_SNOW and the former mentioned snow density RHO_SNOW.

Soil Moisture

The ensemble mean of soil moisture is adjusted to its value in the deterministic run. This procedure ensures that the mean ensemble soil moisture stays close to the analyzed one, as a soil moisture analysis is run once a day in the deterministic forecast system. By adjusting only the ensemble mean the ensemble spread is preserved.

Snow

For each ensemble member the mean ensemble snow cover is adjusted to its deterministic value.

The data assimilation system also provides a couple of fields, which are not modified with respect to their guess values, so that a full set of nominal analysis fields is available.

Table 5.3.: Fields provided by the ensemble analysis system. The column **Increment** indicates if an analysis increment is provided. **Analysis** indicates if the field is analysed by the LETKF (letkf), taken from the first guess (fg), interpolated (det) from, or (mean) adjusted to the respective deterministic quantity, or additionally perturbed (per).

ShortName	Type	Increment	Analysis	
T	Atmosphere	yes	letkf	Temperature
U	"	yes	letkf	U-Component of Wind
V	"	yes	letkf	V-Component of Wind
QV	"	yes	letkf	Specific Humidity
P	"	yes	letkf	Pressure
QC	"		letkf	Cloud Mixing Ratio
QI	"		letkf	Cloud Ice Mixing Ratio
QR	"		fg	Rain Mixing Ratio
QS	"		fg	Snow Mixing Ratio
H_SNOW	Snow	yes	mean	Snow Depth
FRESHSNW	"	yes	mean	Fresh snow factor
QV_S	Surface		fg	Surface Specific Humidity
W_I	"		fg	Plant Canopy Surface Water
Z0	"		fg	Surface Roughness length
T_SO(0)	Sea surface		det+per	Sea Surface Temperature
H_ICE	"		det	Sea Ice Thickness
FR_ICE	"		det	Sea Ice Cover
W_SO	Soil	yes	mean	Soil moisture
W_SO_ICE	"		fg	Soil ice content
T_SO	"		fg	Soil temperature

5.2. Incremental analysis update

Analysis fields provided by the data assimilation system are usually not perfectly balanced, leading to e.g. the generation of spurious gravity waves. Thus, atmospheric models generally require some initialization procedure in order to minimize spin-up effects and to prevent the accumulation of noise. In ICON, a method known as **I**ncremental **A**nalysis **U**pdate (IAU) (Bloom et al., 1996, Polavarapu et al., 2004) is applied. The basic idea is quite simple: Rather than adding the analysis increments $\Delta\mathbf{x}^A = \mathbf{x}^A - \mathbf{x}^{FG}$ (i.e. the difference between the analysis $\mathbf{x}^A$ and the model first guess $\mathbf{x}^{FG}$) in one go, they are incorporated into the model in small drips over many timesteps (see Figure 5.1).

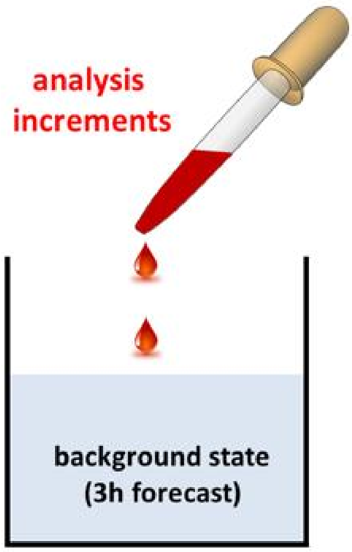


Figure 5.1.: Incremental **A**nalysis **U**pdate. Analysis increments are added to the background state (FG) in small drips over some time interval rather than in one go. Currently, increments for `U`, `V`, `P`, `T`, `QV` are treated in this way.

Mathematically speaking, during forward integration the model is forced with appropriately weighted analysis increments:

$$\frac{\mathrm{d}\mathbf{x}}{\mathrm{d}t} = A\mathbf{x} + g(t)\Delta\mathbf{x}^A \qquad \text{, with} \quad \int g(t)\,\mathrm{d}t = 1 \tag{5.1}$$

$\mathbf{x}$ is the discrete model state, A is a matrix representing the (non)-linear dynamics of the system and $g(t)$ is a weighting function, which is non-zero over some time-interval Δt.

This drip by drip incorporation acts as a low pass filter in frequency domain on the analysis increments such that small scale unbalanced modes are effectively filtered (see Bloom et al. (1996)). The filter characteristic depends on the weighting function $g(t)$. It should be noted that IAU only filters the increments and not the backgound state, such that regions where analysis increments are zero remain unaffected. This method is currently applied to the prognostic atmospheric fields π, ρ, v_n, q_v, based on analysis increments provided for u, v, p, t and q_v. π denotes the Exner pressure.

The method sounds incredibly simple, however there are a few technical aspects to be taken care of when implementing this into an operational system: Figure 5.2 shows how the IAU-method is implemented in ICON for a 3 h assimilation run starting at midnight. Analysis increments are applied over a 3 h time window, centered at the actual model start time. As indicated by the blue line, constant weights are used:

$$g(t) = \frac{\Delta t}{T} \qquad \text{, for} \quad -T/2 < t < T/2 \tag{5.2}$$

T is the window width and Δt is the fast physics time step. The key point in terms of technical implementation is that the model must be started 90 minutes prior to the actual starting time of the assimilation run. The model is started from the 22:30 UTC first guess. The analysis increments for U, V, P, T, QV, whose validity time is 00:00 UTC are added over 3 hours until at 1:30 the free forecast starts. Then, two first guess data sets are written into the database. One at 1:30 UTC, which will be used for starting the next 3 h assimilation run, and a second one at 3:00 UTC, which serves as input for the assimilation system itself. Thus in general, using the IAU method requires some care in terms of reading and writing the right fields at the right times.

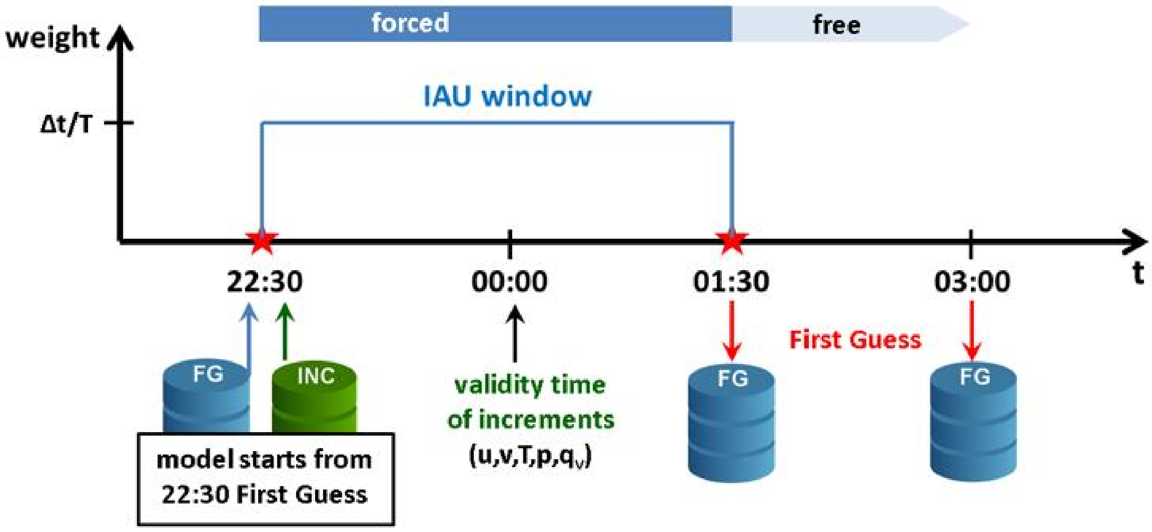


Figure 5.2.: Time line for an ICON assimilation run starting at 00:00 UTC.

This method is not restricted to atmospheric fields, but also applicated to assimilated soil and surface fields, specifically soil moisture W_SO, and snow quantities H_SNOW and FRESHSNW.

6. Global output fields: Deterministic forecast runs

ICON output fields are exclusively available in Gridded Binary Format, 2nd edition (GRIB2), with the exception of meteogram data (NetCDF). GRIB is a bit-oriented data storage format which was developed by World Meteorological Organization (WMO) to facilitate the exchange of large volumes of gridded data between weather prediction centres. For decoding and encoding GRIB2 messages, the DWD in general and ICON in particular makes use of the ECMWF GRIB API. The current operational version at DWD is 1.23.1.

In GRIB2, a product (i.e. a variable/field) is identified by a set of three parameters

- *Discipline* (see GRIB2 code table 0.0)
- *ParameterCategory* (see GRIB2 code table 4.1)
- *ParameterNumber* (see GRIB2 code table 4.2),

augmented by a large number of additional metadata in order to uniquely describe the nature of the data. Noteworthy examples of additional metadata are

- *typeOfFirstfixedSurface* and *typeOfSecondFixedSurface* (see GRIB2 code table 4.5)
- *typeOfStatisticalProcessing*, former known as *stepType* (instant, accum, avg, max, min, diff, rms, sd, cov, ...), describing the statistical process used to calculate the field

just to name a few.

A documentation of the official WMO GRIB2 code tables can be found here:
`http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI2/LatestVERSION/WMO306_vI2_GRIB2_CodeFlag_en.pdf`

In the following tables *typeOfFirstFixedSurface* and *typeOfSecondFixedSurface* will be abbreviated by *Lev-Typ 1/2*.

6.1. Deprecated output fields

With the launch of ICON, the following former GME output fields are no longer available:

- **BAS_CON** [–]: Level index of convective cloud base. Instead, **HBAS_CON** [m] should be used.
- **TOP_CON** [–]: Level index of convective cloud top. Instead, **HTOP_CON** [m] should be used.
- **W_G1, W_G2** [mm H2O]: Soil water content in upper layer (0 to 10 cm) and middle layer (10 to 100 cm), respectively. If needed, these fields can be derived from **W_SO**.
- **FIS** [$m^2 s^{-1}$]: Surface Geopotential. Instead, **HSURF** [m] should be used (see Section 6.2).
- **O3** [kg/kg], **TO3** [Dobson]: Ozone mixing ratio and corresponding total ozone concentration. No longer available; no substitution

6.2. New output fields

Table 6.1 contains a list of new output fields that became available with the launch of ICON (compared to GME). A more thorough description of these fields is provided in Section 6.3.

Table 6.1.: Newly available output fields

ShortName	Unit	Description
		Atmosphere
DEN	$\mathrm{kg\,m^{-3}}$	Density of moist air (3D field)
TKE	$\mathrm{m^2\,s^{-2}}$	Turbulent kinetic energy (3D field)
DTKE_CON	$\mathrm{m^2\,s^{-3}}$	Buoyancy-production of TKE due to sub grid scale convection (3D field)
DTKE_HSH	$\mathrm{m^2\,s^{-3}}$	Production of TKE due to horizontal shear (3D field)
W	$\mathrm{m\,s^{-1}}$	Vertical velocity in height coordinates $w = \frac{dz}{dt}$ (3D field)
P	Pa	Pressure (3D field)
		Surface
CAPE_CON	$\mathrm{J\,kg^{-1}}$	Convective available potential energy (2D field)
QV_2M	$\mathrm{kg\,kg^{-1}}$	Specific humidity at 2m above ground (2D field)
RELHUM_2M	%	Relative humidity at 2m above ground (2D field)
SOBS_RAD	$\mathrm{W\,m^{-2}}$	Net short-wave radiation flux at surface (instantaneous)
THBS_RAD	$\mathrm{W\,m^{-2}}$	Net long-wave radiation flux at surface (instantaneous)
		Lake
C_T_LK	1	Shape factor with respect to the temperature profile in the thermocline (2D field)
H_ML_LK	m	Mixed-layer depth (2D field)
T_BOT_LK	K	Temperature at the water-bottom sediment interface (2D field)
T_MNW_LK	K	Mean temperature of the water column (2D field)
T_WML_LK	K	Mixed-layer temperature (2D field)
		Geometry
HSURF	m	Geometric Height of the earths surface above sea level (2D field)
HHL	m	Geometric Height of model half levels above sea level (3D field)
CLON,CLAT	deg	Geographical longitude/latitude of native grid triangle cell center
ELON,ELAT	deg	Geographical longitude/latitude of native grid triangle edge midpoint

6.3. Available output fields

ICON forecasts are performed multiple times a day with varying forecast periods. An overview of the forecast runs, including its forecast period and output intervals is provided in Figure 6.1.

Main forecasts are performed 4 times a day at 0, 6, 12, 18 UTC, covering a forecast time span of 180 h

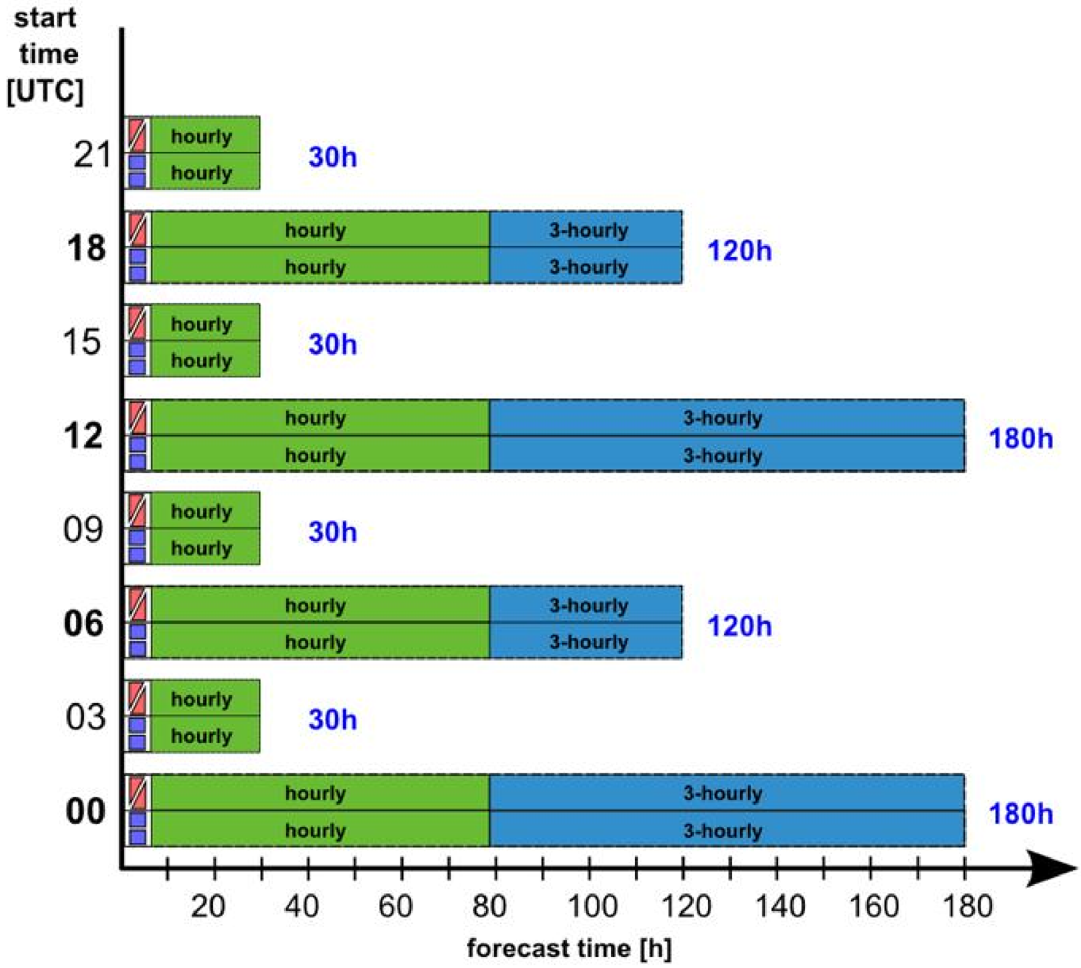


Figure 6.1.: Time span covered by the various global ICON forecasts which are launched every three hours. Output on the native (triangular) grid (▨) and the regular grid (▦) is generally available until forecast end, as indicated by the lenght of the two bars shown for each forecast run. Output fields are available hourly up to $VV = 78$ h and 3-hourly for larger forecast times.

for the 0 und 12 UTC runs and 120 h for the 6 und 18 UTC runs. Prior to 2015-02-25 the 6 and 18 UTC runs were restricted to 78 h. Additional short-range forecasts are performed at 3, 9, 15 and 21 UTC. The ICON nest will provide boundary data for the high resolution COSMO-DE runs. The forecast time covered by these runs is limited to 30 h. See Chapter 7 for more details on the ICON nest and the available output fields.

All time-dependent output fields are available hourly up to $VV = 78$ h and 3-hourly for larger forecast times[2]. Please note that for ICON fields the time unit is minutes rather than hours, and thus differs from GME (hours).

Output is available on two distinct horizontal grids:

- The native triangular grid with an average resolution of 13 km, and
- a regular latitude-longitude grid with a resolution of $\Delta\lambda = \Delta\Phi = 0.25°$.

On the native grid most output fields are defined on triangle cell (circum-)centers, except for `VN`, which is defined on cell edges. On the lat-lon grid, all fields are defined on cell centers. A single 2D GRIB2 field on the native and regular lat-lon grid contains 2949120 and 1038240 (721 × 1440) grid points, respectively.

For details regarding the available fields, please see the tables below. Note that the vertical rules in the leftmost column indicate whether the field is available on the native grid (), on the lat-lon grid(), or on both grids().

For details regarding the algorithm for interpolation onto the lat-lon grid, see Section 11.2. In the tables below, the specific algorithm used for lat-lon interpolation is indicated in the column `LL IntpType`. If nothing is specified, then an RBF-based interpolation method is used.

6.3.1. Time-constant (external parameter) fields

Table 6.2 provides an overview of the available time invariant fields. They are available from the database category `CAT_NAME=$model_const_an_$suite`. As mentioned in Section 4.2, `DEPTH_LK`, `HSURF`, `FR_LAND`, `FR_LAKE` and `Z0` are modified by ICON. Thus, the latter should not be taken from the *const_an* database category, unless you definitely know what you are doing. For convenience, the modified invariant fields (and some more) are stored in the *forecast* database categories for step $s[h] = 0$ (`CAT_NAME=$model_$run_fc_$suite`). Table 6.3 provides a list of all fields which are exclusively written for $s[h] = 0$.

See Section 12.1 for more details on the database categories and Section 12.2 for sample retrievals.

Table 6.2.: Time-constant fields (`CAT_NAME=$model_const_an_$suite`)

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
	Date/Time (YYYY-MM-DDThh) **D=0001-01-01T00**					
CLAT	Geographical latitude of native grid triangle cell center	0/191/1	1/–	inst	–	Deg. N
CLON	Geographical longitude of native grid triangle cell center	0/191/2	1/–	inst	–	Deg. E
DEPTH_LK	Lake depth	1/2/0	1/162	inst	–	m
EMIS_RAD	Longwave surface emissivity	2/3/199	1/–	inst	–	1
FOR_D	Fraction of deciduous forest (possible range [0, 1])	2/0/30	1/–	inst	–	1
FOR_E	Fraction of evergreen forest (possible range [0, 1])	2/0/29	1/–	inst	–	1
FR_LAKE	Fresh water lake fraction (possible range [0, 1])	1/2/2	1/–	inst	–	1
FR_LAND	Land fraction (possible range [0, 1])	2/0/0	1/–	inst	–	1

Continued on next page

[2] An exception here are the output fields `VMAX_10M`, `U_10M` and `V_10M`, which are available hourly throughout the forecast. For the latter two this is because `U_10M` and `V_10M` are needed as input by the wave models.

Table 6.2.: *continued*

FR_LUC	Land use class fraction (possible range [0, 1])	2/0/36	1/–	inst	–	1
HSURF	Geometric height of the earths surface above msl	0/3/6	1/101	inst	–	m
LAI_MX	Leaf area index in the vegetation phase	2/0/28	1/–	max	–	1
NDVI_MAX	Normalized differential vegetation index	2/0/31	1/–	max	–	1
PLCOV_MX	Plant covering degree in the vegetation phase	2/0/4	1/–	max	–	1
ROOTDP	Root depth of vegetation	2/0/32	1/–	inst	–	m
RSMIN	Minimum stomatal resistance	2/0/16	1/–	inst	–	$s\,m^{-1}$
SOILTYP	Soil type of land fraction (9 types [1, . . . , 9])	2/3/196	1/–	inst	–	1
SSO_GAMMA	Anisotropy of sub-gridscale orography	0/3/24	1/–	inst	–	1
SSO_SIGMA	Slope of sub-gridscale orography	0/3/22	1/–	inst	–	1
SSO_STDH	Standard deviation of sub-grid scale orography	0/3/20	1/–	inst	–	m
SSO_THETA	Angle of sub-gridscale orography	0/3/21	1/–	inst	–	rad
T_2M_CL	Climatological 2 m temperature (used as lower bc. for soil model)	0/0/0	103/–	inst	–	K
Z0	Surface roughness length (over land)	2/0/1	1/–	inst	–	m
Date/Time (YYYY-MM-DDThh) **D=1111-01-11T11**						
AER_SS12	Sea salt aerosol climatology (monthly fields)	0/20/102	1/–	avg	–	1
AER_DUST12	Total soil dust aerosol climatology (monthly fields)	0/20/102	1/–	avg	–	1
AER_ORG12	Organic aerosol climatology (monthly fields)	0/20/102	1/–	avg	–	1
AER_SO412	Total sulfate aerosol climatology (monthly fields)	0/20/102	1/–	avg	–	1
AER_BC12	Black carbon aerosol climatology (monthly fields)	0/20/102	1/–	avg	–	1

Continued on next page

Table 6.2.: *continued*

ALB_DIF12	Shortwave ($0.3 - 5.0\,\mu$m) albedo for diffuse radiation (monthly fields)	0/19/18	1/–	avg	–	1
ALB_UV12	UV-visible ($0.3 - 0.7\,\mu$m) albedo for diffuse radiation (monthly fields)	0/19/222	1/–	avg	–	1
ALB_NI12	Near infrared ($0.7 - 5.0\,\mu$m) albedo for diffuse radiation (monthly fields)	0/19/223	1/–	avg	–	1
NDVI_MRAT	ratio of monthly mean NDVI (normalized differential vegetation index) to annual max	0/0/192	1/–	avg	–	1

Table 6.3.: Variables exclusively available for $VV = 0$ from the forecast databases (`CAT_NAME=$model_$run_fc_$suite`, $s[h] = 0$)

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
ALB_SEAICE	Sea ice albedo	0/19/234	1/–	inst	–	%
CLAT	Geographical latitude of native grid triangle cell center	0/191/1	1/–	inst	–	Deg. N
CLON	Geographical longitude of native grid triangle cell center	0/191/2	1/–	inst	–	Deg. E
DEPTH_LK	Lake depth	1/2/0	1/162	inst		m
ELAT	Geographical latitude of native grid triangle edge midpoint	0/191/1	1/–	inst	–	Deg. N
ELON	Geographical longitude of native grid triangle edge midpoint	0/191/2	1/–	inst	–	Deg. E
EVAP_PL	Evaporation of plants (integrated since "nightly reset")	2/0/198	1/–	acc		$\mathrm{kg\,m^{-2}}$
FR_LAKE	Fresh water lake fraction (possible range [0, 1])	1/2/2	1/–	inst		1
FR_LAND	Land fraction (possible range [0, 1])	2/0/0	1/–	inst		1

Continued on next page

Table 6.3.: *continued*

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
HHL	Geometric height of model half levels above msl	0/3/6	150/101	inst		m
HSURF	Geometric height of the earths surface above msl	0/3/6	1/101	inst		m
LAI	Leaf area index	2/0/28	1/–	inst		1
NDVIRATIO	ratio of current NDVI (normalized differential vegetation index) to annual max	2/0/192	1/–	inst	–	1
PLCOV	Plant cover	2/0/4	1/–	inst		%
RLAT	Geographical latitude of regular lat-lon grid cell centers	0/191/1	1/–	inst		Deg. N
RLON	Geographical longitude of regular lat-lon grid cell centers	0/191/2	1/–	inst		Deg. E
ROOTDP	Root depth of vegetation	2/0/32	1/–	inst		m
SMI	Soil moisture index	2/3/200	106/106	inst		1
SOILTYP	Soil type of land fraction (9 types $[1, \ldots, 9]$)	2/3/196	1/–	inst	NNB	1

6.3.2. Multi-level fields on native hybrid vertical levels

Table 6.4.: Hybrid multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
CLC	Cloud cover	0/6/22	150/150	inst		%
DEN	Density of moist air	0/3/10	150/150	inst	–	$kg\,m^{-3}$
DTKE_CON	Buoyancy-production of TKE due to sub grid scale convection	0/19/219	150/–	inst	–	$m^2\,s^{-3}$
DTKE_HSH	Production of TKE due to horizontal shear	0/19/220	150/–	inst	–	$m^2\,s^{-3}$

Continued on next page

Table 6.4.: *continued*

P	Pressure	0/3/0	150/150	inst		Pa
QC	Cloud mixing ratio[3]	0/1/22	150/150	inst		$kg\,kg^{-1}$
QI	Cloud ice mixing ratio[3]	0/1/82	150/150	inst		$kg\,kg^{-1}$
QR	Rain mixing ratio[3]	0/1/24	150/150	inst	–	$kg\,kg^{-1}$
QS	Snow mixing ratio[3]	0/1/25	150/150	inst	–	$kg\,kg^{-1}$
QV	Specific humidity	0/1/0	150/150	inst	BCT	$kg\,kg^{-1}$
T	Temperature	0/0/0	150/150	inst	BCT	K
TKE	Turbulent kinetic energy	0/19/11	150/–	inst		$m^2\,s^{-2}$
U	Zonal wind	0/2/2	150/150	inst		$m\,s^{-1}$
V	Meridional wind	0/2/3	150/150	inst		$m\,s^{-1}$
W	Vertical wind	0/2/9	150/–	inst		$m\,s^{-1}$

6.3.3. Multi-level fields interpolated to pressure levels

For regular grid output the following 36 pressure levels are available:

1000, 975, 950, 925, 900, 875, 850, 825, 800, 775,
750, 700, 650, 600, 550, 500, 450, 400, 350, 300,
275, 250, 225, 200, 175, 150, 125, 100, 70, 50, 30,
10, 5, 2, 1, 0.1 hPa.

The output fields are listed in Table 6.5. Note that the fields `CLC`, `OMEGA`, and `RELHUM` are only available from 1000 hPa down to 5 hPa, i.e. they are not available on the levels highlighted in blue.

[3] for the time being, erroneously encoded as mixing ratios instead of specific quantities

Table 6.5.: Regular grid output: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products interpolated to pressure levels 1000, 975, 950, 925, 900, 875, 850, 825, 800, 775, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 275, 250, 225, 200, 175, 150, 125, 100, 70, 50, 30, 10, 5, 2, 1, 0.1 hPa. The fields `CLC`, `OMEGA`, and `RELHUM` are not available for the pressure levels highlighted in blue.

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
CLC	Cloud cover	0/6/22	100/–	inst		%
FI	Geopotential	0/3/4	100/–	inst		$m^2 s^{-2}$
OMEGA	Vertical velocity in pressure coordinates ($\omega = dp/dt$)	0/2/8	100/–	inst		$Pa s^{-1}$
RELHUM	Relative humidity (with respect to water)	0/1/1	100/–	inst		%
T	Temperature	0/0/0	100/–	inst	BCT	K
U	Zonal wind	0/2/2	100/–	inst		$m s^{-1}$
V	Meridional wind	0/2/3	100/–	inst		$m s^{-1}$

On the native (triangular) grid, output is generated for levels

1000, 950, 850, 700, 500, 300 hPa.

The output fields are listed in Table 6.6.

Table 6.6.: Native (triangular) grid output: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products interpolated to pressure levels 1000, 950, 850, 700, 500, 300 hPa.

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
FI	Geopotential	0/3/4	100/–	inst	–	$m^2 s^{-2}$
RELHUM	Relative humidity (with respect to water)	0/1/1	100/–	inst	–	%
T	Temperature	0/0/0	100/–	inst	–	K
U	Zonal wind	0/2/2	100/–	inst	–	$m s^{-1}$

Continued on next page

Table 6.6.: *continued*

V	Meridional wind	0/2/3	100/–	inst	–	$m\,s^{-1}$

6.3.4. Single-level fields

Table 6.7.: Single-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
ALB_RAD	Shortwave broadband albedo for diffuse radiation	0/19/1	1/–	inst		%
ALHFL_S	Latent heat net flux at surface (average since model start)	0/0/10	1/–	avg		$\mathrm{W\,m^{-2}}$
APAB_S	Photosynthetically active radiation flux at surface (average since model start)	0/4/10	1/–	avg		$\mathrm{W\,m^{-2}}$
ASHFL_S	Sensible heat net flux at surface (average since model start)	0/0/11	1/–	avg		$\mathrm{W\,m^{-2}}$
ASOB_S	Net short-wave radiation flux at surface (average since model start)	0/4/9	1/–	avg		$\mathrm{W\,m^{-2}}$
ASOB_T	Net short-wave radiation flux at top of atmosphere (TOA) (average since model start)	0/4/9	8/–	avg		$\mathrm{W\,m^{-2}}$
ASWDIFD_S	Surface down solar diffuse radiation (average since model start)	0/4/199	1/–	avg		$\mathrm{W\,m^{-2}}$
ASWDIFU_S	Surface up solar diffuse radiation (average since model start)	0/4/8	1/–	avg		$\mathrm{W\,m^{-2}}$
ASWDIR_S	Surface down solar direct radiation (average since model start)	0/4/198	1/–	avg		$\mathrm{W\,m^{-2}}$
ATHB_S	Net long-wave radiation flux at surface (average since model start)	0/5/5	1/–	avg		$\mathrm{W\,m^{-2}}$
ATHB_T	Net long-wave radiation flux at TOA (average since model start)	0/5/5	8/–	avg		$\mathrm{W\,m^{-2}}$
AUMFL_S	U-momentum flux at surface $\overline{u'w'}^{1/2}$ (average since model start)	0/2/17	1/–	avg		m
AVMFL_S	V-momentum flux at surface $\overline{v'w'}^{1/2}$ (average since model start)	0/2/18	1/–	avg		m
CAPE_CON	Convective available potential energy	0/7/6	1/–	inst	–	$\mathrm{J\,kg^{-1}}$
CAPE_ML	Mixed layer CAPE	0/7/6	192/–	inst	NNB	$\mathrm{J\,kg^{-1}}$

Continued on next page

Table 6.7.: *continued*

CIN_ML	Mixed layer convective inhibition	0/7/7	192/–	inst	NNB	$\mathrm{J\,kg^{-1}}$
CLCH	High level clouds	0/6/22	100/100	inst		%
CLCM	Mid level clouds	0/6/22	100/100	inst		%
CLCL	Low level clouds	0/6/22	100/1	inst		%
CLCT	Total cloud cover	0/6/1	1/–	inst		%
CLCT_MOD	Modified total cloud cover for media	0/6/199	1/–	inst		1
CLDEPTH	Modified cloud depth for media	0/6/198	1/–	inst		1
FRESHSNW	Fresh snow factor (weighting function for albedo indicating freshness of snow)	0/1/203	1/–	inst	–	1
FR_ICE	Sea/lake ice cover (possible range: [0, 1])	10/2/0	1/–	inst		1
HBAS_CON	Height of convective cloud base above msl	0/6/26	2/101	inst	NNB	m
H_ICE	Sea/Lake ice thickness (Max: 3 m)	10/2/1	1/–	inst		m
H_SNOW	Snow depth	0/1/11	1/–	inst		m
HTOP_CON	Height of convective cloud top above msl	0/6/27	3/101	inst	NNB	m
HTOP_DC	Height of top of dry convection above msl	0/6/196	3/101	inst	NNB	m
HZEROCL	Height of 0 degree Celsius isotherm above msl	0/3/6	4/101	inst	NNB	m
PMSL	Surface pressure reduced to msl	0/3/1	101/–	inst		Pa
PS	Surface pressure (not reduced)	0/3/0	1/–	inst		Pa
QV_2M	Specific humidity at 2m above ground	0/1/0	103/–	inst		$\mathrm{kg\,kg^{-1}}$
QV_S	Surface specific humidity	0/1/0	1/–	inst		$\mathrm{kg\,kg^{-1}}$
RAIN_CON[4]	Convective rain (accumulated since model start)	0/1/76	1/–	accu	BCT	$\mathrm{kg\,m^{-2}}$

Continued on next page

Table 6.7.: *continued*

RAIN_GSP[4]	Large scale rain (accumulated since model start)	0/1/77	1/–	accu	BCT	$\mathrm{kg\,m^{-2}}$
RELHUM_2M	Relative humidity at 2m above ground	0/1/1	103/–	inst		%
RHO_SNOW	Snow density	0/1/61	1/–	inst		$\mathrm{kg\,m^{-3}}$
RUNOFF_G	Soil water runoff (accumulated since model start)	2/0/5	106/–	accu		$\mathrm{kg\,m^{-2}}$
RUNOFF_S	Surface water runoff (accumulated since model start)	2/0/5	106/–	accu		$\mathrm{kg\,m^{-2}}$
SNOW_CON[4]	Convective snowfall water equivalent (accumulated since model start)	0/1/55	1/–	accu	BCT	$\mathrm{kg\,m^{-2}}$
SNOW_GSP[4]	Large snowfall water equivalent (accumulated since model start)	0/1/56	1/–	accu	BCT	$\mathrm{kg\,m^{-2}}$
SOBS_RAD	Net short-wave radiation flux at surface (instantaneous)	0/4/9	1/–	inst		$\mathrm{W\,m^{-2}}$
T_2M	Temperature at 2m above ground	0/0/0	103/–	inst		K
TCH	Turbulent transfer coefficient for heat and moisture (surface)	0/0/19	1/–	inst		1
TCM	Turbulent transfer coefficient for momentum (surface)	0/2/29	1/–	inst		1
TD_2M	Dew point temperature at 2m above ground	0/0/6	103/–	inst		K
T_G	Ground temperature (temperature at sfc-atm interface)	0/0/0	1/–	inst		K
THBS_RAD	Net long-wave radiation flux at surface (instantaneous)	0/5/5	1/–	inst		$\mathrm{W\,m^{-2}}$
T_ICE	Sea/Lake ice temperature (at ice-atm interface)	10/2/8	1/–	inst		K
TMAX_2M	Maximum temperature at 2m above ground	0/0/0	103/–	max		K
TMIN_2M	Minimum temperature at 2m above ground	0/0/0	103/–	min		K
TOT_PREC[4]	Total precipitation (accumulated since model start)	0/1/52	1/–	accu	BCT	$\mathrm{kg\,m^{-2}}$
TQC	Column integrated cloud water (grid scale)	0/1/69	1/–	inst		$\mathrm{kg\,m^{-2}}$

Continued on next page

Table 6.7.: *continued*

TQC_DIA	Total column integrated cloud water (including sub-grid-scale contribution)	0/1/215	1/–	inst		$kg\,m^{-2}$
TQI	Column integrated cloud ice (grid scale)	0/1/70	1/–	inst		$kg\,m^{-2}$
TQI_DIA	Total column integrated cloud ice (including sub-grid-scale contribution)	0/1/216	1/–	inst		$kg\,m^{-2}$
TQR	Column integrated rain (grid scale)	0/1/45	1/–	inst		$kg\,m^{-2}$
TQS	Column integrated snow (grid scale)	0/1/46	1/–	inst		$kg\,m^{-2}$
TQV	Column integrated water vapour (grid scale)	0/1/64	1/–	inst		$kg\,m^{-2}$
T_S [5]	Temperature of the soil surface (equivalent to T_SO(0))	2/3/18	1/–	inst		K
T_SNOW	Temperature of the snow surface	0/0/18	1/–	inst		K
U_10M	Zonal wind at 10m above ground	0/2/2	103/–	inst		$m\,s^{-1}$
V_10M	Meridional wind at 10m above ground	0/2/3	103/–	inst		$m\,s^{-1}$
VMAX_10M	Maximum wind at 10 m above ground	0/2/22	103/–	max		$m\,s^{-1}$
W_I	Plant canopy surface water	2/0/13	1/–	inst	–	$kg\,m^{-2}$
W_SNOW	Snow depth water equivalent	0/1/60	1/–	inst		$kg\,m^{-2}$
WW	Weather interpretation (WMO), see Table 6.8 for details.	0/19/25	1/–	inst	NNB	1
Z0	Surface roughness (above land and water)	2/0/1	1/–	inst		m

[4] Note that the unit which is displayed, when inspecting the GRIB2 message with *grib_dump* is $kg\,m^{-2}\,s^{-1}$ rather than $kg\,m^{-2}$. Mathematically this is wrong, however, it is in accordance with the GRIB2 standard. To get the mathematically correct unit for accumulated fields (*typeOfStatisticalProcessing*=1), the unit displayed by *grib_dump* must be multiplied by s.

[5] T_S is identical to T_SO at level 0. It will no longer be available in the future. Use T_SO(0) instead of T_S.

WW	weather interpretation	WW	weather interpretation
45	Fog	**48**	Fog, depositing rime
51	Slight drizzle	**53**	Moderate drizzle
55	Heavy drizzle	**56**	Drizzle, freezing, slight
57	Drizzle, freezing, moderate or heavy	**61**	Slight rain, not freezing
63	Moderate rain, not freezing	**65**	Heavy rain, not freezing
66	Rain, freezing, slight	**67**	Rain, freezing, moderate or heavy
71	Slight fall of snowflakes	**73**	Moderate fall of snowflakes
75	Heavy fall of snowflakes	**77**	Snow grains
80	Rain shower(s), slight	**81**	Rain shower(s), moderate or heavy
82	Rain shower(s), violent	**85**	Snow shower(s), slight
86	Snow shower(s), moderate or heavy	**95**	Thunderstorm, slight or moderate
96	Thunderstorm with hail, or heavy thunderstorm		

Table 6.8.: Weather interpretation (WW) code table for the ICON model. This table is a subset of the WMO code table *FM 94 BUFR/FM 95 CREX code table 0 20 003 – present weather*. In the case that none of the values provided in Table 6.8 is returned, the WW output contains the total cloud cover, encoded in the following form: **0**: clear sky **1**: mainly clear **2**: partly/generally cloudy **3**: cloudy/overcast.

6.3.5. Soil-specific multi-level fields

Table 6.9.: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products of the soil model

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
T_SO	Soil temperature	2/3/18	106/–	inst		K
W_SO	Soil moisture integrated over individual soil layers (ice + liquid)	2/3/20	106/106	inst		$\mathrm{kg\,m^{-2}}$
W_SO_ICE	Soil ice content integrated over individual soil layers	2/3/22	106/106	inst	NNB	$\mathrm{kg\,m^{-2}}$

Soil temperature is defined at the soil depths given in Table 6.10 (column 2). Levels 1 to 8 define the full levels of the soil model. A zero gradient condition is assumed between levels 0 and 1, meaning that temperatures at the surface-atmosphere interface are set equal to the temperature at the first full level depth (0.5 cm). Temperatures are prognosed for layers 1 to 7. At the lowermost layer (mid-level height 1458 cm) the temperature is fixed to the climatological average 2 m-temperature.

Soil moisture `W_SO` is prognosed for layers 1 to 6. In the two lowermost layers `W_SO` is filled with `W_SO(6)` (zero gradient condition).

Table 6.10.: Soil model: vertical distribution of levels and layers

level no.	depth [cm]	layer no.	upper/lower bounds [cm]
0	0.0		
1	0.5	1	0.0 — 1.0
2	2.0	2	1.0 — 3.0
3	6.0	3	3.0 — 9.0
4	18.0	4	9.0 — 27.0
5	54.0	5	27.0 — 81.0
6	162.0	6	81.0 — 243.0
7	486.0	7	243.0 — 729.0
8	1458.0	8	729.0 — 2187.0

6.3.6. Lake-specific single-level fields

Table 6.11.: Single-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products of the lake model model

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
C_T_LK	Shape factor with respect to the temperature profile in the thermocline	1/2/10	162/166	inst	–	1
H_ML_LK	Mixed-layer depth	1/2/0	1/166	inst	–	m
T_BOT_LK	Temperature at the water-bottom sediment interface	1/2/1	162/–	inst	–	K
T_MNW_LK	Mean temperature of the water column	1/2/1	1/162	inst	–	K
T_WML_LK	Mixed-layer temperature	1/2/1	1/166	inst	–	K

7. EU Nest output fields: Deterministic forecast runs

7.1. Available output fields

This section contains a list of output fields that are available with the launch of the ICON-EU nest. See Fig. 3.6a on page 12 for details regarding the nest location and extent. Forecasts on the EU-nest are performed multiple times a day with varying forecast periods. Forecasts reaching out to 120 h are performed at 00, 06, 12, and 18 UTC. Additional short-range forecasts reaching out to 30 h are performed at 03, 09, 15 and 21 UTC. Its main purpose is to provide boundary data for the high resolution COSMO-DE runs. A schematic overview of the various forecasts, including its forecast period and output intervals is provided in Figure 7.1.

Output is available on two distinct horizontal grids:

- a native triangular grid with an average resolution of 6.5 km, and
- a regular latitude-longitude grid with a resolution of $\Delta\lambda = \Delta\Phi = 0.0625°$.
  See Table 7.1 for a summary.

Output on the native (triangular) grid is hourly to 48 h, and every 6 hours for verfication until the forecast end at 120 h. Output on the regular grid is hourly to 78 h, and every 3 hours until forecast end. See also Figure 7.1.

Again, in the subsequent tables the availability of specific fields on the native grid ( ), on the lat-lon grid( ), or on both grids ( ) is marked in the leftmost column. The method used for lat-lon interpolation is indicated in the column `LL IntpType`.

	global lat-lon	EU nest lat-lon
geogr. coordinates	0.0° – 359.75°	23.5° W – 62.5° E,
	90.0° S – 90.0° N	29.5° N – 70.5° N
mesh size	0.25°	0.0625°

Table 7.1.: Summary of the latitude-longitude grids for ICON global and ICON-EU nest output.

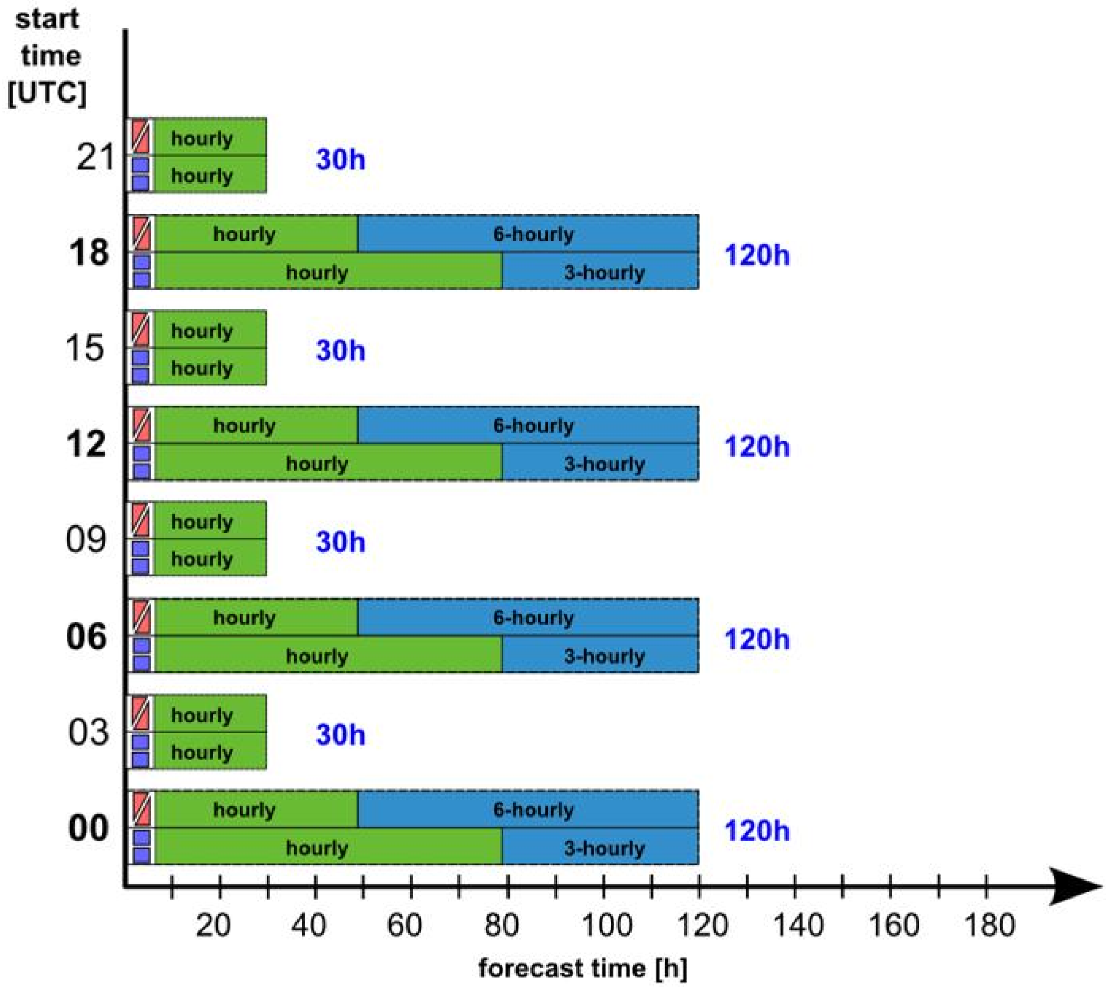


Figure 7.1.: Time span covered by the various EU nest forecasts which are launched every three hours. Output on the native (triangular) grid (▨) and the regular grid (▦) is generally available until forecast end, as indicated by the lenght of the two bars shown for each forecast run. Output on the native grid is available hourly to 48 h, and every 6 hours for later forecast times. Output on the regular grid is available hourly to 78 h, and every 3 hours for later forecast times.

7.1.1. Time-constant (external parameter) fields for the EU nest

Table 7.2.: Variables exclusively available for $VV = 0$ from the forecast databases (CAT_NAME=$model_$run_fc_$suite, $s[h] = 0$)

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit

Continued on next page

Table 7.2.: *continued*

ALB_SEAICE	Sea ice albedo	0/19/234	1/–	inst	–	%
CLAT	Geographical latitude of native grid triangle cell center	0/191/1	1/–	inst	–	Deg. N
CLON	Geographical longitude of native grid triangle cell center	0/191/2	1/–	inst	–	Deg. E
DEPTH_LK	Lake depth	1/2/0	1/162	inst		m
ELAT	Geographical latitude of native grid triangle edge midpoint	0/191/1	1/–	inst	–	Deg. N
ELON	Geographical longitude of native grid triangle edge midpoint	0/191/2	1/–	inst	–	Deg. E
EVAP_PL	Evaporation of plants (integrated since "nightly reset")	2/0/198	1/–	acc		$\mathrm{kg\,m^{-2}}$
FR_LAKE	Fresh water lake fraction (possible range [0, 1])	1/2/2	1/–	inst		1
FR_LAND	Land fraction (possible range [0, 1])	2/0/0	1/–	inst		1
HHL	Geometric height of model half levels above msl	0/3/6	150/101	inst		m
H_SNOW	Snow depth	0/1/11	1/–	inst		m
HSURF	Geometric height of the earths surface above msl	0/3/6	1/101	inst		m
LAI	Leaf area index	2/0/28	1/–	inst		1
PLCOV	Plant cover	2/0/4	1/–	inst		%
RLAT	Geographical latitude of regular lat-lon grid cell centers	0/191/1	1/–	inst		Deg. N
RLON	Geographical longitude of regular lat-lon grid cell centers	0/191/2	1/–	inst		Deg. E
ROOTDP	Root depth of vegetation	2/0/32	1/–	inst		m
SMI	Soil moisture index	2/3/200	106/106	inst		1
SOILTYP	Soil type of land fraction (9 types $[1, \ldots, 9]$)	2/3/196	1/–	inst	NNB	1
Z0	Surface roughness (above land and water)	2/0/1	1/–	inst		m

7.1.2. Multi-level fields on native hybrid vertical levels for the EU nest

Table 7.3.: Hybrid multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
CLC	Cloud cover	0/6/22	150/150	inst		%
DTKE_CON	Buoyancy-production of TKE due to sub grid scale convection	0/19/219	150/–	inst	–	$m^2 s^{-3}$
DTKE_HSH	Production of TKE due to horizontal shear	0/19/220	150/–	inst	–	$m^2 s^{-3}$
P	Pressure	0/3/0	150/150	inst		Pa
QC	Cloud mixing ratio[3]	0/1/22	150/150	inst		$kg\,kg^{-1}$
QI	Cloud ice mixing ratio[3]	0/1/82	150/150	inst		$kg\,kg^{-1}$
QR	Rain mixing ratio[3]	0/1/24	150/150	inst	–	$kg\,kg^{-1}$
QS	Snow mixing ratio[3]	0/1/25	150/150	inst	–	$kg\,kg^{-1}$
QV	Specific humidity	0/1/0	150/150	inst	BCT	$kg\,kg^{-1}$
T	Temperature	0/0/0	150/150	inst	BCT	K
TKE	Turbulent kinetic energy	0/19/11	150/–	inst		$m^2 s^{-2}$
U	Zonal wind	0/2/2	150/150	inst		$m\,s^{-1}$
V	Meridional wind	0/2/3	150/150	inst		$m\,s^{-1}$
W	Vertical wind	0/2/9	150/–	inst		$m\,s^{-1}$

[3] for the time being, erroneously encoded as mixing ratios instead of specific quantities

7.1.3. Multi-level fields interpolated to pressure levels

For regular grid output the following 30 pressure levels are available:

1000, 975, 950, 925, 900, 875, 850, 825, 800, 775,
750, 700, 650, 600, 550, 500, 450, 400, 350, 300,
275, 250, 225, 200, 175, 150, 125, 100, 70, 50 hPa.

The output fields are listed in Table 7.4.

On the native (triangular) grid no output is generated for pressure levels.

Table 7.4.: Regular grid output on the ICON EU Nest: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products interpolated to pressure levels 1000, 975, 950, 925, 900, 875, 850, 825, 800, 775, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 275, 250, 225, 200, 175, 150, 125, 100, 70, 50 hPa.

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
CLC	Cloud cover	0/6/22	100/–	inst		%
FI	Geopotential	0/3/4	100/–	inst		$m^2 s^{-2}$
OMEGA	Vertical velocity in pressure coordinates ($\omega = dp/dt$)	0/2/8	100/–	inst		$Pa s^{-1}$
RELHUM	Relative humidity (with respect to water)	0/1/1	100/–	inst		%
T	Temperature	0/0/0	100/–	inst	BCT	K
U	Zonal wind	0/2/2	100/–	inst		$m s^{-1}$
V	Meridional wind	0/2/3	100/–	inst		$m s^{-1}$

7.1.4. Single-level fields

Table 7.5.: Single-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products on the ICON EU Nest

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit

Continued on next page

Table 7.5.: *continued*

ALB_RAD	Shortwave broadband albedo for diffuse radiation	0/19/1	1/–	inst		%
ALHFL_S	Latent heat net flux at surface (average since model start)	0/0/10	1/–	avg		$W\,m^{-2}$
APAB_S	Photosynthetically active radiation flux at surface (average since model start)	0/4/10	1/–	avg		$W\,m^{-2}$
ASHFL_S	Sensible heat net flux at surface (average since model start)	0/0/11	1/–	avg		$W\,m^{-2}$
ASOB_S	Net short-wave radiation flux at surface (average since model start)	0/4/9	1/–	avg		$W\,m^{-2}$
ASOB_T	Net short-wave radiation flux at TOA (average since model start)	0/4/9	8/–	avg		$W\,m^{-2}$
ASWDIFD_S	Surface down solar diffuse radiation (average since model start)	0/4/199	1/–	avg		$W\,m^{-2}$
ASWDIFU_S	Surface up solar diffuse radiation (average since model start)	0/4/8	1/–	avg		$W\,m^{-2}$
ASWDIR_S	Surface down solar direct radiation (average since model start)	0/4/198	1/–	avg		$W\,m^{-2}$
ATHB_S	Net long-wave radiation flux at surface (average since model start)	0/5/5	1/–	avg		$W\,m^{-2}$
ATHB_T	Net long-wave radiation flux at TOA (average since model start)	0/5/5	8/–	avg		$W\,m^{-2}$
AUMFL_S	U-momentum flux at surface $\overline{u'w'}^{1/2}$ (average since model start)	0/2/17	1/–	avg		m
AVMFL_S	V-momentum flux at surface $\overline{v'w'}^{1/2}$ (average since model start)	0/2/18	1/–	avg		m
CAPE_CON	Convective available potential energy	0/7/6	1/–	inst	NNB	$J\,kg^{-1}$
CAPE_ML	Mixed layer CAPE	0/7/6	192/–	inst	NNB	$J\,kg^{-1}$
CIN_ML	Mixed layer convective inhibition	0/7/7	192/–	inst	NNB	$J\,kg^{-1}$
CLCH	High level clouds	0/6/22	100/100	inst		%
CLCM	Mid level clouds	0/6/22	100/100	inst		%
CLCL	Low level clouds	0/6/22	100/1	inst		%
CLCT	Total cloud cover	0/6/1	1/–	inst		%

Continued on next page

Table 7.5.: *continued*

CLCT_MOD	Modified total cloud cover for media	0/6/199	1/–	inst		1
CLDEPTH	Modified cloud depth for media	0/6/198	1/–	inst		1
FRESHSNW	Fresh snow factor (weighting function for albedo indicating freshness of snow)	0/1/203	1/–	inst	–	1
FR_ICE	Sea/lake ice cover (possible range: [0, 1])	10/2/0	1/–	inst	–	1
HBAS_CON	Height of convective cloud base above msl	0/6/26	2/101	inst	NNB	m
H_ICE	Sea/Lake ice thickness (Max: 3 m)	10/2/1	1/–	inst		m
H_SNOW	Snow depth	0/1/11	1/–	inst		m
HTOP_CON	Height of convective cloud top above msl	0/6/27	3/101	inst	NNB	m
HTOP_DC	Height of top of dry convection above msl	0/6/196	3/101	inst	NNB	m
HZEROCL	Height of 0 degree Celsius isotherm above msl	0/3/6	4/101	inst	NNB	m
PMSL	Surface pressure reduced to msl	0/3/1	101/–	inst		Pa
PS	Surface pressure (not reduced)	0/3/0	1/–	inst		Pa
QV_2M	Specific humidity at 2m above ground	0/1/0	103/–	inst		$kg\,kg^{-1}$
QV_S	Surface specific humidity	0/1/0	1/–	inst		$kg\,kg^{-1}$
RAIN_CON	Convective rain (accumulated since model start)	0/1/76	1/–	accu	BCT	$kg\,m^{-2}$
RAIN_GSP	Large scale rain (accumulated since model start)	0/1/77	1/–	accu	BCT	$kg\,m^{-2}$
RELHUM_2M	Relative humidity at 2m above ground	0/1/1	103/–	inst		%
RHO_SNOW	Snow density	0/1/61	1/–	inst		$kg\,m^{-3}$
RUNOFF_G	Soil water runoff (accumulated since model start)	2/0/5	106/–	accu		$kg\,m^{-2}$
RUNOFF_S	Surface water runoff (accumulated since model start)	2/0/5	106/–	accu		$kg\,m^{-2}$
SNOW_CON	Convective snowfall water equivalent (accumulated since model start)	0/1/55	1/–	accu	BCT	$kg\,m^{-2}$

Continued on next page

Table 7.5.: *continued*

SNOW_GSP	Large snowfall water equivalent (accumulated since model start)	0/1/56	1/–	accu	BCT	$kg\,m^{-2}$
SNOWLMT	Height of snowfall limit above MSL	0/1/204	4/101	inst	NNB	m
SYNMSG_BT_CL_IR10.8	Synthetic MSG SEVIRI image brightness temp. at 10.8μm	3/1/14	–/–	inst		K
SYNMSG_BT_CL_WV6.2	Synthetic MSG SEVIRI image brightness temp. at 6.2μm	3/1/14	–/–	inst		K
T_2M	Temperature at 2m above ground	0/0/0	103/–	inst		K
TCH	Turbulent transfer coefficient for heat and moisture (surface)	0/0/19	1/–	inst		1
TCM	Turbulent transfer coefficient for momentum (surface)	0/2/29	1/–	inst		1
TD_2M	Dew point temperature at 2m above ground	0/0/6	103/–	inst		K
T_G	Ground temperature (temperature at sfc-atm interface)	0/0/0	1/–	inst		K
T_ICE	Sea/Lake ice temperature (at ice-atm interface)	10/2/8	1/–	inst		K
TMAX_2M	Maximum temperature at 2m above ground	0/0/0	103/–	max		K
TMIN_2M	Minimum temperature at 2m above ground	0/0/0	103/–	min		K
TOT_PREC	Total precipitation (accumulated since model start)	0/1/52	1/–	accu	BCT	$kg\,m^{-2}$
TQC	Column integrated cloud water (grid scale)	0/1/69	1/–	inst		$kg\,m^{-2}$
TQI	Column integrated cloud ice (grid scale)	0/1/70	1/–	inst		$kg\,m^{-2}$
TQR	Column integrated rain (grid scale)	0/1/45	1/–	inst		$kg\,m^{-2}$
TQS	Column integrated snow (grid scale)	0/1/46	1/–	inst		$kg\,m^{-2}$
TQV	Column integrated water vapour (grid scale)	0/1/64	1/–	inst		$kg\,m^{-2}$
T_S [5]	Temperature of the soil surface (equivalent to T_SO(0))	2/3/18	1/–	inst		K
T_SNOW	Temperature of the snow surface	0/0/18	1/–	inst		K
U_10M	Zonal wind at 10m above ground	0/2/2	103/–	inst		$m\,s^{-1}$

Continued on next page

Table 7.5.: *continued*

V_10M	Meridional wind at 10m above ground	0/2/3	103/–	inst		$m\,s^{-1}$
VMAX_10M	Maximum wind at 10 m above ground	0/2/22	103/–	max		$m\,s^{-1}$
W_I	Plant canopy surface water	2/0/13	1/–	inst	–	$kg\,m^{-2}$
W_SNOW	Snow depth water equivalent	0/1/60	1/–	inst		$kg\,m^{-2}$
WW	Weather interpretation (WMO), see Table 6.8 for details.	0/19/25	1/–	inst	NNB	1
Z0	Surface roughness (above land and water)	2/0/1	1/–	inst		m

7.1.5. Soil-specific multi-level fields

Table 7.6.: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products of the soil model

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
T_SO	Soil temperature	2/3/18	106/–	inst		K
W_SO	Soil moisture integrated over individual soil layers (ice + liquid)	2/3/20	106/106	inst		$kg\,m^{-2}$
W_SO_ICE	Soil ice content integrated over individual soil layers	2/3/22	106/106	inst	NNB	$kg\,m^{-2}$

Soil temperature is defined at the soil depths given in Table 7.7 (column 2). Levels 1 to 8 define the full levels of the soil model. A zero gradient condition is assumed between levels 0 and 1, meaning that temperatures at the surface-atmosphere interface are set equal to the temperature at the first full level depth. (0.5 cm). Temperatures are prognosed for layers 1 to 7. At the lowermost layer (mid-level height 1458 cm) the temperature is fixed to the climatological average 2 m-temperature.

Soil moisture `W_SO` is prognosed for layers 1 to 6. In the two lowermost layers `W_SO` is filled with `W_SO(6)` (zero gradient condition).

[5]T_S is identical to T_SO at level 0. It will no longer be available in the future. Use T_SO(0) instead of T_S.

Table 7.7.: Soil model: vertical distribution of levels and layers

level no.	depth [cm]	layer no.	upper/lower bounds [cm]
0	0.0		
1	0.5	1	0.0 — 1.0
2	2.0	2	1.0 — 3.0
3	6.0	3	3.0 — 9.0
4	18.0	4	9.0 — 27.0
5	54.0	5	27.0 — 81.0
6	162.0	6	81.0 — 243.0
7	486.0	7	243.0 — 729.0
8	1458.0	8	729.0 — 2187.0

7.1.6. Lake-specific single-level fields

Table 7.8.: Single-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products of the lake model model on the ICON EU nest.

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
C_T_LK	Shape factor with respect to the temperature profile in the thermocline	1/2/10	162/166	inst	–	1
H_ML_LK	Mixed-layer depth	1/2/0	1/166	inst	–	m
T_BOT_LK	Temperature at the water-bottom sediment interface	1/2/1	162/–	inst	–	K
T_MNW_LK	Mean temperature of the water column	1/2/1	1/162	inst	–	K
T_WML_LK	Mixed-layer temperature	1/2/1	1/166	inst	–	K

8. Output fields for soil moisture analysis SMA

The soil moisture analysis, SMA, requires the following fields from the main run at 00 UTC. They are written only by this run and from forecast hour 2 to 24. As a soil moisture analysis is made for the global and the nest domain, these fields are available for both domains, but only on the native grid.

Table 8.1.: Fields for SMA from 00 UTC run for forecast hours 2 to 24.

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
ALHFL_BS	Latent heat flux from bare soil	2/0/193	1/–	avg	–	$W\,m^{-2}$
ALHFL_PL	Latent heat flux from plants	2/0/194	106/106	avg	–	$W\,m^{-2}$
RSTOM	Stomatal resistance	2/0/195	1/–	inst	–	$s\,m^{-1}$

The latent heat flux from plants is defined at the same soil layers as the soil moisture `W_SO`.

9. Ensemble (ICON-EPS)

The operational ICON ensemble suite generates 40 short to medium range forecasts at approx. 40 km (R2B06) horizontal resolution on the global scale with a 20 km nesting area over Europe. It runs 8 times a day providing boundary conditions for the COSMO-DE-EPS, where at 03/09/15/21 UTC the maximum forecast time is limited to +30 h lead time. Otherwise, the EU-nest runs within the global model up to 120h. At 00/12 UTC only the global system is further integrated up to 180 h lead time. The main purpose of an ensemble system is to estimate forecast uncertainty by running a number of possible physically consistent scenarios of future development. The different scenarios arise from uncertainties in initial conditions and model error. In the following sections we explain the techniques used in the ICON-EPS to simulate the effects of both error sources on the forecast and describe its output data.

9.1. Initial Perturbations

In the ICON-EPS the initial perturbations are set by the EDA system at DWD, which is based on a Local Ensemble Transform Kalman Filter (LETKF). The implementation of the filter follows the paper of Hunt et al. (2007). The algorithm establishes an assimilation cycle of 3 hours and solves the underlying equations in ensemble space spanned by a background ensemble of 40 members. More details of the implementation can be found in Schraff et al. (2004) and Section 5 of this document.

In the context of ensemble forecasting it is important to note that the LETKF establishes a square root filter with multiple variance inflation techniques (see Anlauf et al. (2017), Freitag and Potthast (2013)). The "Kalman gain" from adding observations reduces the uncertainty in the analysis and thus the variance in the analysis ensemble. By the time this would lead to underestimation of the true background error compared to the observation error and the analysis ensemble must be re-inflated in each analysis step to stabilize the ensemble variance. The analysis increments as well as the partly random variance inflation techniques introduce imbalances in the initial states of the forecast ensemble, which are damped using an incremental analysis update scheme (IAU; Section 5.2). All the modifications from the analysis cycle lead to a new analysis ensemble. The new properties and relative arrangements of the analysis members determine the spread growth and thus the quality of the forecast uncertainty estimation. For a detailed analysis of the ICON-EPS performance see Denhard et al. (2018).

9.2. Ensemble Physics Perturbations

To simulate model error a simple methodology for perturbing various physics tuning parameters has been implemented in the ICON-EPS. At the beginning of each forecast the actual values of a predefined set of tuning parameters are calculated using a random number generator depending on the ensemble member ID. The user can specify a range within each parameter may vary. For most parameters, the perturbation is applied in an additive symmetric way by setting

$$pert\_param = ref\_param + 2. * (rand\_num - 0.5) * range\,,$$

where $rand\_num = [0, 1]$. Exceptions are `capdcfac_et`, for which only positive variations are retained (implying that no perturbations are applied for random numbers below 0.5), and `rlam_heat`, for which the perturbation is multiplicative. Currently, the following tuning parameters are affected:

`gkwake`, `gkdrag`: These parameters control the magnitude of low-level blocking and atmospheric gravity-wave momentum deposition in the SSO scheme. They are forced to vary inversely to each other in order to keep the vertically integrated gravity-wave forcing approximately the same.

`entrorg`, `zvz0i`: While `entrorg` controls the entrainment rate in organized deep convection, `zvz0i` controls the terminal sedimentation speed of cloud ice. These parameters are again forced to vary inversely to each other in order to keep the systematic impact on the model climate small. Briefly spoken, less entrainment increases the tops of tropical convection and thus the production of cloud ice in the upper tropical troposphere. It needs to be accompanied by faster cloud ice sedimentation in order to keep the radiative forcing at a similar level.

`gfluxlaun`: This parameter controls the momentum forcing of the non-orographic gravity-wave drag scheme, which primarily affects the intensity of the stratospheric meridional circulation.

`capdcfac_et`: This parameter controls the intensity of the extratropical CAPE diurnal cycle correction in the convection scheme. By default, the correction is applied in the tropics only, i.e. at latitudes $< 25°$ with a linear transition to zero between $25°$ and $30°$. The value set in `capdcfac_et` is the fractional correction applied in the extratropics.

`rhebc_land`, `rhebc_ocean`, `rcucov`: The first two of these parameters set the relative humidity thresholds below which evaporation of rain (or snow) below the cloud base starts in the convection scheme, while `rcucov` specifies the fractional area coverage of convective precipitation assumed in this context. Positive perturbations of the RH thresholds are accompanied by negative perturbations of the convective area fraction (and vice versa) in order to approximately maintain the model's precipitation efficiency.

`texc`, `qexc`: These parameters specify the so-called excess values of temperature and QV assumed in the test parcel ascent of the convection scheme, where a preselection of grid points eligible for convection is made. Perturbations of these parameters are opposite to each other in order to minimize systematic changes in the fraction of convective precipitation.

`box_liq`: This parameter affects the width of the subgrid-scale moisture distribution assumed in the cloud cover scheme for water clouds. Increasing this width reduces the RH threshold at which subgrid-scale clouds start to form.

`tkhmin`: The minimum vertical diffusion coefficient for heat/moisture in the turbulence scheme.

`tkmmin`: The minimum vertical diffusion coefficient for momentum in the turbulence scheme.

`rlam_heat`: A scaling parameter for the laminar transport resistance in the transfer scheme. The change in `rlam_heat` is accompanied by an inverse change of `rat_sea` in order to keep the evaporation over water (controlled by `rlam_heat` ∗ `rat_sea`) the same.

9.3. ICON-EPS output fields in DWD databases

In SKY the data is stored in different categories and data base subsystems. These are identified by the cat=CAT_NAME parameter. The ICON-EPS categories start with the string **ico** for ICON data on its native grid. Next follows a two-letter string to identify the domain of ICON: **gl** for the global domain, **eu** for the nest over Europe. The ensemble data is further characterized by a final **e**. The category parameters run, type, and suite have the same meaning for all forecast models of DWD. See section 12.1 for an explanation and available values. Hence, the full category name for data from an operational ensemble forecast run of the ICON-EPS is **icogle_main_fc_rout** for a global field and **icoeue_main_fc_rout** for the nesting area over Europe. The ensemble output data is stored exclusively on the native grid. For interpolation to other grid types, please use postprocessing software like CDO (or fieldextra), which are able to read native ICON grids. The instructions manual for interpolating ICON model fields with CDO can be found on the DWD web pages `https://www.dwd.de` by typing **CDO** in the search tool of the web page.

Ensemble members or ranges of ensemble members are specified in the SKY language by the parameter *enum=NUM* or *enum=NUM1 − NUM2* where *NUM* is the member id. See Section 12.2 for SKY retrieval examples.

9.3.1. Model Output

ICON-EPS output contains the following fields:

Model Levels

Table 9.1.: Available output fields for ICON-EPS on **Model Levels**. Numbers in brackets refer to shorter model runs with reduced maximum forecast times.

Domain	GRIB shortName	freq	forecast times
global	P, T, U, V, QV, QC, QI	6h	0-180(120)
global: levels 44-75	P, TKE, DTKE_CON, DTKE_HSH	1h	0-36
EU-nest	P, T, U, V, W, QV, QC, QI, QR, QS	1h	0-48(30)
	P, T, QV, QC	3h	51(33)-78
	T_SO, W_SO	1h	0-48(30)
EU-nest: levels 14-60	P, TKE, DTKE_CON, DTKE_HSH	1h	0-36

Pressure Levels

Levels for global fields are: 1, 2, 5, 10, 30, 50, 70, 100, 200, 250, 300, 500, 700, 850, 925, 1000 hPa. For the EU domain only levels from bottom up to 70 hPa are available in the databases.

Table 9.2.: Available output fields for ICON-EPS on **Pressure Levels**. Numbers in brackets refer to shorter model runs with reduced maximum forecast times.

Domain	GRIB shortName	freq	forecast times
global/EU-nest	FI, T, U, V, RELHUM	1h	0-48(30)
	FI, T, U, V, RELHUM	3h	51(33)-72
	FI, T, U, V, RELHUM	6h	78-120
global	FI, T, U, V, RELHUM	12h	132-180

Surface fields

The output frequencies and the forecast time ranges are the same as in table 9.2

Table 9.3.: Available output fields for ICON-EPS: **Surface**.

Domain	GRIB shortName
global/EU-nest	ASOB_S, ASOB_T, ASWDIFD_S, ASWDIFU_S, ASWDIR_S, ATHB_S, ATHB_T
	CAPE_ML, CLCT, CLCL, CLCM, CLCH, CLCT_MOD
	FR_ICE, H_ICE, H_SNOW, PS, QV_S, RAIN_CON, RAIN_GSP, SNOW_CON, SNOW_GSP, W_SNOW, SOBS_RAD
	T_G, T_SNOW, THBS_RAD, TOT_PREC, TQC, TQI, TQR, TQS, TQV
	Z0, RELHUM_2M, T_2M, TD_2M, TMAX_2M, TMIN_2M, U_10M, V_10M, VMAX_10M, PMSL, HBAS_CON, HTOP_CON

9.3.2. Ensemble Products

The ICON-EPS products are stored in the **roma** database and can be identified by the category type **fcprod**. This leads to the category name **icreue_main_fcprod_rout** for ensemble products on the EU domain and **icrgle_main_fcprod_rout** for global products. The products are generated with fieldextra on regular latitude/longitude grids with resolutions of 0.25° and 0.5°, respectively. The ICON-EPS provides ensemble products in three different categories, which can be accessed by using the SKY bank parameters derivedForecast (**deriv**), percentile (**perc**) and exceedance probability (**probt**):

1. **Mean and extreme values**

Unweighted mean of all members	(deriv = 0)
Spread of all members	(deriv = 4)
Minimum of all ensemble members	(deriv = 8)
Maximum of all ensemble members	(deriv = 9)

2. **Percentiles,**
   i.e. physical values of a forecast parameter (e.g. `T_2M`,...), which define the perc=10,25,50,75,90 [%] parts of the ensemble distribution.

3. **Exceedance Probabilities**
   Probability of event above lower limit (probt=3)
   Probability of event below upper limit (probt=4)

The thresholds for the exceedance probabilities are given by the DWD alert thresholds which are used for issuing weather warnings[1] and follow the WMO recommendations[2] for the global fields. Ensemble products are generated every 6 hours up to 120 h lead time on the EU domain and for the global fields up to 180 h twice a day (00/12 UTC). Tis is done for different accumulation periods depending on the forecast parameter. The following parameters are available:

[1] https://www.dwd.de/DE/wetter/warnungen_aktuell/kriterien/warnkriterien.html
[2] http://www.wmo.int/pages/prog/www/DPS/Publications/WMO_485_Vol_I.pdf

Table 9.4.: Available output fields for ICON-EPS: **Probability Products**.

Parameter	Description	
T_2M	2m Temperature	
TD_2M	2m Dew Point Temperature	
SP_10M	Wind Speed at 10m	
PMSL	Mean Sea Level Pressure	
CAPE_ML	Convective Available Potential Energy	
CLC*	Cloud Cover (*=T/L/M/H)	
Parameter	**Description**	**Height Level**
FI	Geopotential	500Pa
SP	Wind Speed	250/500/850hPa
T	Temperature	500/850hPa
T $\pm1/\pm1.5/\pm2$	Temperature Anomaly	850hPa
Parameter	**Description**	**Accumulation**
T_G/T_SO	Ground temperature (temperature at sfc-atm interface)	12h
TMAX_2M/TMIN_2M	Max/Min Temperatures	12h, 24h
VMAX_10M	Maximum wind speed at 10m above ground	6h, 12h, 24h
TOT_PREC	Total Precipitation	6h, 12h, 24h, 48h, 72h
TOT_SNOW	Total snowfall water equivalent	6h, 12h, 24h

Most of the parameters are available on both domains, but there are exceptions: SP250, FI500,T_SO and the temerature anomaly are available on the global domain only. The latter is calculated for thresholds of ±1, ±1.5 and ±2 standard deviations with respect to the reanalysis climatology ERA_INTERIM[3]. The global products are available via the WMO WIS/WMS system or directly as grib files and charts on the opendata server of DWD[4] in /weather/wmc/icon-eps. A graphical user interface for direct access to the charts is available on the DWD website[5]. The dissemination of the EU-Nest ensemble product grib files via the opendata server of DWD is planned to start in October 2018.

[3] https://www.ecmwf.int/en/forecasts/datasets/archive-datasets/reanalysis-datasets/era-interim
[4] https://www.dwd.de/opendata
[5] https://www.dwd.de/EN/ourservices/wmc/wmc.html

10. Extended description of available output fields

In order to facilitate the selection and interpretation of fields and to guard against possible mis-interpretation or mis-usage, the following section provides a more thorough description of the available output fields.

10.1. Cloud products

CLCT_MOD Modified total cloud cover ($0 \leq$ `CLCT_MOD` ≤ 1). Used for visualization purpose (i.e. gray-scale figures) in the media. It is derived from `CLC`, neglecting cirrus clouds if there are only high clouds present at a given grid point. The reason for this treatment is that the general public does not regard transparent cirrus clouds as 'real' clouds.

CLDEPTH Modified cloud depth ($0 \leq$ `CLDEPTH` ≤ 1). Used for visualization purpose (i.e. gray-scale figures) in the media. A cloud reaching a vertical extent of 700 hPa or more, has `CLDEPTH`$= 1$.

HBAS_CON Height of the convective cloud base in m above msl. `HBAS_CON` is initialized with -500 m at points where no convection is diagnosed.

HTOP_CON Same, but for cloud top.

10.2. Atmospheric products

HZEROCL Height of the 0° C isotherm above MSL. At points where the temperature is below 0° C within the entire atmospheric column, `HZEROCL` is undefined and set to -999.

SNOWLMT Height of snow fall limit above MSL. It is defined as the height where the wet bulb temperature T_w first exceeds 1.3°C (scanning mode from top to bottom). If this threshold is never reached within the entire atmospheric column, `SNOWLMT` is undefined (GRIB2 bitmap).

10.3. Near surface products

TD_2M Dew point temperature at 2 m above ground, i.e. the temperature to which the air must be cooled, keeping its vapour pressure e constant, such that e equals the saturation (or equilibrium) vapour pressure e_s.

$$e_s(T_d) = e$$

TMIN_2M Minimum temperature at 2 m above ground. Minima are collected over 6-hourly intervals on all domains. (Prior to 2015-07-07 minima were collected over 3-hourly intervals on the global grid.)

TMAX_2M Same, but for maximum 2 m temperature.

VMAX_10M Maximum wind gust at 10 m above ground. It is diagnosed from the turbulence state in the atmospheric boundary layer, including a potential enhancement by the SSO parameterization over mountainous terrain. In the presence of deep convection, it contains an additional contribution due to convective gusts.

Maxima are collected over hourly intervals on all domains. (Prior to 2015-07-07 maxima were collected over 3-hourly intervals on the global grid.)

10.3.1. General comment on statistically processed fields

In GRIB2, the overall time interval over which a statistical process (like averaging, computation of maximum/minimum) has taken place is encoded as follows:

The beginning of the overall time interval is defined by `referenceTime + forecastTime`, whereas the end of the overall time interval is given by `referenceTime + forecastTime + lengthOfTimeRange`. See Section 11.1 for more details on statistically processed fields.

10.4. Surface products

ASWDIFD_S Downward solar diffuse radiation flux at the surface, averaged over forecast time. See Section 11.1 for more information on time averaging.

ASWDIR_S Downward solar direct radiation flux at the surface. See Section 11.1 for more information on time averaging.

ALB_RAD Ratio of upwelling to downwelling diffuse radiative flux for wavelength interval $[0.3\,\mu\text{m}, 5.0\,\mu\text{m}]$. Values over snow-free land points are based on a monthly mean MODIS climatology. MODIS values have been limited to a minimum value of 2 %.

From `ASWDIFD_S` and `ASWDIR_S` the time averaged global radiation at the surface `GLOB` can easily be computed as follows:

$$\texttt{GLOB} = \texttt{ASWDIFD\_S} + \texttt{ASWDIR\_S}$$

An estimate of `GLOB` can also be derived from the net solar radiation flux at the surface `ASOB_S` and the albedo `ALB_RAD`:

$$\texttt{GLOB} = \frac{\texttt{ASOB\_S}}{1 - 0.01\,\texttt{ALB\_RAD}}$$

However be aware that this is only approximately true, because `ALB_RAD` is an instantaneous field, and it only constitutes the albedo for the diffuse component of the incoming solar radiation ("white sky" albedo). However, `ASOB_S` contains both diffuse and direct components. As a consequence, the reflection of the incoming direct radiation, which is dependent on the solar zenith angle (and described by the so called "black sky" albedo), is not correctly taken into account.

FR_ICE Sea and lake ice cover. This is the fraction of water covered by ice. I.e. if a grid cell contains land and water `FR_ICE` = 1 if the whole fraction of water of this grid cell is covered by ice. At lake points no fractional ice cover is allowed, meaning that `FR_ICE` is either 1 or 0.

H_ICE Ice thickness over sea and frozen fresh water lakes. The maximum allowable ice thickness is limited to 3 m. New sea-ice points generated by the analysis are initialized with `H_ICE` = 0.5 m.

H_SNOW Snow depth in m. It is diagnosed from RHO_SNOW and W_SNOW according to

$$\text{H\_SNOW} = \frac{\text{W\_SNOW}}{\text{RHO\_SNOW}}$$

and is limited to H_SNOW $\leq 40\,\text{m}$.

RHO_SNOW Snow density in kg/m^3. It can vary between $50\,\text{kg/m}^3$ for fresh snow and $400\,\text{kg/m}^3$ for compacted old snow. At snow-free points over land RHO_SNOW is set to $50\,\text{kg/m}^3$, while over water it is set to $0\,\text{kg/m}^3$.

T_ICE Ice temperature over sea-ice and frozen lake points. Melting ice has a temperature of 273.15 K. Ice-free points over land, sea, and lakes are set to T_SO(0).

T_G Temperature at the atmosphere-surface interface. It is the temperature that is crucial for the computation of surface fluxes. T_G is equal to T_SO(0) over open water and snow-free land. At other grid points one has

- T_G = T_SNOW+(1−f_snow)∗(T_SO(0)−T_SNOW) over (partially) snow covered grid points. f_snow is the grid point fraction that is snow covered.
- T_G = T_ICE over frozen sea and fresh water lakes

TOT_PREC Total precipitation accumulated since model start.
TOT_PREC = RAIN_GSP + SNOW_GSP + RAIN_CON + SNOW_CON

T_SNOW Temperature of snow surface. At snow-free points (H_SNOW = 0), T_SNOW contains the temperature of the soil surface T_SO(0).

W_I Water content of interception layer, i.e. the amount of precipitation intercepted by vegetation canopies. The maximum capacity of the interception reservoir is currently limited to $6.0E{-}3\,\text{kg}\,\text{m}^{-2}$ due to numerical reasons and thus almost negligible. Over water points, W_I is set to 0.

W_SNOW Snow depth water equivalent in kg/m^2. Set to 0 above water surfaces and snow-free land points.

Z0 Surface roughness length. Constant over land, where it depends only on the type of land cover. I.e. it does not contain any contribution from subgrid-scale orography. Over water, the roughness length usually varies with time. It is computed by the so called Charnock-formula, which parameterizes the impact of waves on the roughness length. Note that this field differs significantly from the external parameter field Z0 (see Table 4.2 or 6.2).

10.5. Soil products

RUNOFF_G Water runoff from soil layers. Sum over forecast.

RUNOFF_S Surface water runoff from interception and snow reservoir and from limited infiltration rate. Sum over forecast.

SOILTYP Characterizes the dominant soiltype in a grid cell. The soiltype is assumed to be the same for all soil levels. Currently 9 soiltypes are distinguished and encoded by 1-digit integers 1-9. The mapping between these integer numbers and soiltype short names is given in Table 10.1, together with some soil-dependent hydraulic parameters. For the full list of hydraulic and thermal parameters, the reader is referred to Doms et al. (2011).

Table 10.1.: Mapping between the the soiltype index stored in the field `SOILTYP` and soiltype short names. The hydraulic parameters *porosity* and *field capacity*, currently used by ICON, are given in terms of volume fractions.

index	soiltype	porosity	field capacity
1	ice	–	–
2	rock	–	–
3	sand	0.364	0.196
4	sandyloam	0.445	0.260
5	loam	0.455	0.340
6	clayloam	0.475	0.370
7	clay	0.507	0.463
8	peat	0.863	0.763
9	sea water	–	–

T_SO Temperature of the soil and earth surface (uppermost level). The soil full level depths at which the the soil temperature is defined are given in Table 6.10. The temperature at the uppermost level `T_SO(0)` is not prognostic. It is rather set equal to the temperature at the first prognostic level `T_SO(1)`. The temperature at the lowermost level `T_SO(8)` is set to the climatological 2 m temperature `T_2M_CL`. At sea-points, `T_SO(0:7)` is filled with the sea-surface temperature. Note that `T_SO(0)` does not necessarily represent the temperature at the interface soil-atmosphere. I.e. over snow/ice covered surfaces, `T_SO(0)` represents the temperature below snow/ice.

10.6. Vertical Integrals

TQX Column integrated water species `X`, derived from the 3D grid-scale prognostic quantities `QX`, with $\mathtt{X} \in \{\mathtt{V},\mathtt{C},\mathtt{I},\mathtt{R},\mathtt{S}\}$. `TQX` is based on the assumption that there would be no sub-grid-scale variability. That assumption is particularly problematic for precipitation generation, moist turbulence and radiation.

TQX_DIA Total column integrated water species `X`, with $\mathtt{X} \in \{\mathtt{C},\mathtt{I}\}$. Takes into account the sub-grid-scale variability that includes simple treatments of turbulent motion and convective detrainment. These cloud variables attempt to represent all model included physical processes. They are also consistent with the cloud cover variables `CLC`, `CLCT`, `CLCH`, `CLCM` and `CLCL`.

11. Remarks on statistical processing and horizontal interpolation

11.1. Statistically processed output fields

11.1.1. Time-averaged fields

The quantities

ALHFL_S	ASHFL_S	AUMFL_S	AVMFL_S
APAB_S	ASOB_S	ASOB_T	ATHB_S
ATHB_T	ASWDIR_S	ASWDIFS_S	ASWDIFU_S

constitute time averages over the respective forecast time. The averaging process is performed from forecast start ($t_0 = 0\,\text{s}$) till forecast end. Thus, time averaged fields which are written to the database at $t = t_i$ contain averages for the elapsed time interval $[t_0, t_i]$.

Let Ψ denote the instantaneous value of one of the above fields. The time average $\overline{\Psi}$ at time t stored in the database is given as

$$\overline{\Psi}(t) = \frac{1}{t}\int_0^t \Psi \, \mathrm{d}t \quad , \text{for } t > 0.$$

For $t = 0$, the average $\overline{\Psi}$ is equal to 0. If time averages are required for other time intervals $[t_1, t_2]$, with $t_1 > 0$, these can be computed as follows:

$$\begin{aligned}
\overline{\Psi}(t_2 - t_1) &= \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} \Psi \, \mathrm{d}t \\
&= \frac{1}{t_2 - t_1}\left[\int_0^{t_2} \Psi \, \mathrm{d}t - \int_0^{t_1} \Psi \, \mathrm{d}t\right] \\
&= \frac{1}{t_2 - t_1}\left[t_2\overline{\Psi}(t_2) - t_1\overline{\Psi}(t_1)\right]
\end{aligned}$$

For this equation to work, it is of course necessary that the fields $\overline{\Psi}(t_1)$ and $\overline{\Psi}(t_2)$ are available from the database.

The averaging process is fully reflected by the field's GRIB2 metainfo. In order to check whether a field contains the desired time average, it is advisable to check the content of the GRIB2 keys listed in Table 11.1. I.e. `productDefinitionTemplateNumber=8` indicates that the field in question is statistically processed. The statistical process itself is specified by the key `typeOfStatisticalProcessing`. The averaging interval (relative to the start of the forecast) is given by

[`forecastTime`, `forecastTime+lengthOfTimeRange`].

Since the averaging process starts at $t = 0$, the key `forecastTime` is set to 0.

Table 11.1.: List of GRIB2 keys which provide information about the *averaging* process

Octet(s)	Key	Value	Meaning
8-9	`productDefinitionTemplateNumber`	8	Average, accumulation, extreme values or other statistically processed values at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval
19-22	`forecastTime`	0	Starting time of the averaging process relative to the reference time.
47	`typeOfStatisticalProcessing`	0	Average
50-53	`lengthOfTimeRange`	*variable*	Time range over which statistical processing is done

11.1.2. Accumulated fields

The quantities

RAIN_GSP	SNOW_GSP	RAIN_CON	SNOW_CON
TOT_PREC	RUNOFF_S	RUNOFF_G	

are accumulated over the respective forecast time. The accumulation process is performed from forecast start ($t_0 = 0\,\mathrm{s}$) till forecast end. Thus, fields which are written to the database at $t = t_i$ are accumulated for the elapsed time interval $[t_0, t_i]$.

Let Ψ denote the instantaneous value of one of the above fields. The accumulation $\hat{\Psi}$ at time t stored in the database is given as

$$\hat{\Psi}(t) = \int_0^t \Psi \,\mathrm{d}t \quad , \text{for } t > 0.$$

For $t = 0$, the accumulation $\hat{\Psi}$ is equal to 0. If accumulations are required for other time intervals $[t_1, t_2]$, with $t_1 > 0$, these can be computed as follows:

$$\begin{aligned}\hat{\Psi}(t_2 - t_1) &= \int_{t_1}^{t_2} \Psi \,\mathrm{d}t \\ &= \int_0^{t_2} \Psi \,\mathrm{d}t - \int_0^{t_1} \Psi \,\mathrm{d}t \\ &= \hat{\Psi}(t_2) - \hat{\Psi}(t_1)\end{aligned}$$

For this equation to work, it is of course necessary that the fields $\hat{\Psi}(t_1)$ and $\hat{\Psi}(t_2)$ are available from the database.

The accumulation process is fully reflected by the field's GRIB2 metainfo. In order to check whether a field contains the desired accumulation, it is advisable to check the content of the GRIB2 keys listed in Table 11.2. I.e. `productDefinitionTemplateNumber=8` indicates that the field in question is statistically processed. The statistical process itself is specified by the key `typeOfStatisticalProcessing`. The accumulation interval (relative to the start of the forecast) is given by

[`forecastTime`, `forecastTime+lengthOfTimeRange`].

Since the accumulation process starts at $t = 0$, the key `forecastTime` is set to 0.

Table 11.2.: List of GRIB2 keys which provide information about the *accumulation* process

Octet(s)	Key	Value	Meaning
8-9	`productDefinitionTemplateNumber`	8	Average, accumulation, extreme values or other statistically processed values at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval
19-22	`forecastTime`	0	Starting time of the accumulation process relative to the reference time.
47	`typeOfStatisticalProcessing`	1	Accumulation
50-53	`lengthOfTimeRange`	variable	Time range over which statistical processing is done

11.1.3. Extreme value fields

The quantities

VMAX_10M TMAX_2M TMIN_2M

represent extreme values, which are collected over certain time intervals χ, starting from the beginning of the forecast. The interval χ differs temperatures and gusts:

- $\chi = 6\,\text{h}$ for temperatures, TMAX_2M and TMIN_2M,
- $\chi = 1\,\text{h}$ for gusts, VMAX_10M.

After χ hours of forecast the fields are re-initialized with 0 for the first time and the next χ-hourly collection phase is started. This procedure is repeated till the end of the forecast.

Let Ψ denote the instantaneous value of one of the above fields. The maximumu value Ψ_{max} at time t stored in the database is given as

$$\Psi_{max}(t) = \max(\Psi(t), \Psi_{max}(t)) \quad , \text{for } t_i < t < t_i + \chi$$

Here, t_i indicates the time when Ψ_{max} was (re)-initialized the last time. For $t = 0$, the extreme value Ψ_{max} is equal to the instantaneous value Ψ.

Please note: Even though a 6 hour time window is used for temperatures, the database contains hourly, 2-hourly, etc. extreme temperatures. This is because the extreme temperatures are written to the database hourly, irrespective of the start/end of the 6-hourly time windows. Example: Extreme temperatures which are written into the database after a forecast time of 8 hours, contain extreme values collected over the last 2 hours. On the other hand, extreme temperatures written into the database after 12 hours contain values collected over the last 6 hours. Thus, when dealing with those fields it is very important to check the GRIB2 keys listed in Table 11.3.

`productDefinitionTemplateNumber=8` indicates that the field in question is statistically processed. The statistical process itself is specified by the key `typeOfStatisticalProcessing`. The time interval (relative to the start of the forecast) over which the extreme value collection was performed is given by [`forecastTime`, `forecastTime+lengthOfTimeRange`]. Since the collection process is restarted every χ hours, the key `forecastTime` can differ from 0.

Table 11.3.: List of GRIB2 keys which provide information about the *extreme value* process

Octet(s)	Key	Value	Meaning
8-9	`productDefinitionTemplateNumber`	8	Average, accumulation, extreme values or other statistically processed values at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval
19-22	`forecastTime`	*variable*	Starting time of the statistical process relative to the reference time.
47	`typeOfStatisticalProcessing`	2,3	Maximum/Minimum
50-53	`lengthOfTimeRange`	*variable*	Time range over which statistical processing is done

11.2. Technical Details of the Horizontal Interpolation

ICON currently supports three different methods for interpolating data horizontally from the native triangular grid onto a regular lat-lon grid:

RBF Radial basis functions

BCT Barycentric interpolation

NNB Nearest-neighbor interpolation

The interpolation selected for a particular field is indicated in the previous tables which list all available output fields.

Most of the output data on regular grids is processed using an *RBF-based interpolation method*. The algorithm approximates the input field with a linear combination of radial basis functions (RBF) located at the data sites, see, for example, Ruppert (2007). RBF interpolation typically produces over- and undershoots at position where the input field exhibits steep gradients. Therefore, the internal interpolation algorithm performs a cut-off by default. Note that RBF-based interpolation is *not conservative*.

Barycentric interpolation is a two-dimensional generalization of linear interpolation. This method uses just three near-neighbors to interpolate and avoids over- and undershoots, since extremal values are taken only in the data points. This interpolation makes sense for fields where the values change in a roughly piecewise linear way.

A small number of output fields is treated differently, with a *nearest-neighbor interpolation* (NNB). The nearest neighbor algorithm selects the value of the nearest point and does not consider the values of neighboring points at all, yielding a piecewise-constant interpolant.

12. ICON data in the SKY data bases of DWD

GRIB data of the numerical weather prediction models are stored in the data base SKY at DWD. Documentation on the SKY system is available in the intranet of DWD at `IT/Messnetz/Technik` → `Datenmanagement (technisch)` → `Management der DWD Fachdaten -Dokumentation` → `SKY`. Here, some remarks are given on the SKY categories for ICON data, and some examples are given how to retrieve data from the data base.

12.1. SKY categories for ICON

In SKY the data is stored in different categories and data base subsystems. These are identified by the cat=CAT_NAME parameter. The name of a category is made up of 4 parts:

$model_$run_$type_$suite

run, type, and suite are general for all forecast models of DWD. They can have the following values:

- **run**: **main** for main forecast runs, **ass** for assimilation runs, **pre** for pre-assimilation runs, **const** for invariant data.
- **type**: **an** for analysis data, **fc** for forecast data, **fcprod** for EPS products
- **suite**:
  - **rout** for operational data in *db=roma,*
  - **para1** for pre-operational data in *db=parma*, or **vera** for pre-operational data in *db=vera*.
  - **exp** or **exp1** for data from experiments in *db=numex*. The category extension exp1 is used for experiments of the NUMEX wizard, a special NUMEX user.

    Data from experiments is additionally identified by the parameter *exp=NUM* where *NUM* is the experiment number.

The ICON categories start with the string **ico** for ICON data on the native ICON grid, or with **icr** for data on a regular lat-lon grid. Next follows a two-letter string to identify the domain of ICON; **gl** for the global domain, **eu** for the nest over Europe. Further particulars of the category name differ for the global and nested domain. In case of deterministic runs of the global domain, **gl** is followed by the mesh width of the model in units of 100 m, and then the number of levels preceeded by the letter l. As an example **icogl130l90** is on the native grid from a global model with a mesh width 13 km (grid R3B07) and 90 levels. **icrgl400l90** is data on a regular grid from a global model with mesh width 40 km (R2B06) and 90 levels. For the nested domain, the specification of the mesh width and number of levels is omitted. As an example, **icreu** is the ICON nest over Europe (with a mesh width of 6.5 km and 60 levels), interpolated to a regular lat-lon grid.

For ensemble forecasts or ensemble analyses the first part of the category is extended by an **e** (for instance **icogle** or **icrgle**). Ensemble members or ranges of ensemble members are specified by the parameter *enum=NUM* or *enum=$NUM1 - NUM2$* where *NUM* is the member id.

Hence, the full category name for data from a global operational deterministic forecast run of ICON on a regular grid will be **icrgl130l90_main_fc_rout**. The initial analysis for this run is in category **icogl130l90_main_an_rout**.

> Since 2015-01-20 06 UTC the *global* ICON model is running operationally at DWD. Forecast data is available in the sky database **db=roma** in categories **icogl130l90_main_fc_rout** and **icrgl130l90_main_fc_rout**.

> Since 2016-01-20 06 UTC an ensemble data assimilation for ICON is running operationally at DWD. Analysis data is available in the sky database **db=roma** in the ensemble categories **icogle_main_an_rout** and **icoeue_main_an_rout**. First guess data is in **icogle_pre_fc_rout** and **icogle_pre_fc_rout**.

> Since 2018-01-17 06 UTC the global ICON-EPS is running operationally at DWD. Forecast data is available in the sky database **db=roma** in categories **icogle_main_fc_rout** and **icoeue_main_fc_rout** for the EU domain.

12.2. Retrieving ICON data from SKY

Here we shall give several examples how to retrieve ICON data from SKY. The parameter d specifies the reference or initial date, s is the forecast step, p the parameter, and f the name of the GRIB data file.

12.2.1. Deterministic products

- Retrieve the 2m temperature and dew point temperature for forecast hours 3 to 78 every 3 hours of today's run at 00 UTC on the global domain from an ICON run on a R3B07 grid with 90 levels to file icon2mdat

```
read db=roma cat=icrgl130l90_main_fc_rout d=t00 s[h]=3/to/78/by/3 p=t_2m,td_2m bin
    f=icon2mdat
```

- Retrieve the analysis of T on the native grid from yesterday 18 UTC:

```
read db=roma cat=icogl130l90_main_an_rout d=t18-1d p=T gptype=0 bin f=t_icon_ana
```

- Retrieve the 6, 12, 18, and 24 hour forecast of the 2m temperature from a forecast in experiment 10096 on 2015-09-05 at 00 UTC on the global domain from an ICON run on a R3B07 grid with 90 levels:

```
read db=numex cat=icrgl130l90_main_fc_exp exp=10096 d=2015090500 s[h]=6,12,18,24 p=
    t_2m bin f=t_2m_fc.grb
```

- Retrieve accumulated precipiation of the ICON-EU nest on the regular grid every 6 hours to 72 hours from the yesterday's operational run at 12 UTC:

```
read db=roma cat=icreu_main_fc_rout d=t12-1d s[h]=6/to/72/by/6 p=tot_prec bin f=
    tot_prec_ieu
```

- List the data on pressure levels of the 18 hours forecast from 06 UTC of ICON-EU nest on the regular grid. Write reference date (d), forecast step (s), level type (lv), value of first level (lv1), decoding date (dedat), and store date (stdat) in information file icr.info.

```
read db=roma cat=icreu_main_fc_rout d=06 step[h]=18 lv=P info=metaData metaArray=d,
    s,p,lv,lv1,dedat,stdat sort=d,s,p,lv,lv1 infof=icr.info
```

- Retrieve all available time-invariant (constant) fields on the native grid and store them in the file const_icongl. Write reference date (d), forecast step (s), level type (lv), value of first level (lv1), decoding date (dedat), store date (stdat), and validity date (valdat) in information file icr.info. It is important to set **invar=true**.

```
read db=roma cat=icogl130190_const_an_rout invar=true info=metaData metaArray=d,s,p
    ,lv,lv1,dedat,stdat bin infof=icr.info f=const_icongl
```

12.2.2. Ensemble products

- ICON-EPS: Retrieve the 2m temperature and dew point temperature for forecast hours 3 to 78 every 3 hours of today's run at 00 UTC on the global domain from an ICON-EPS run on a R2B06 grid to file iconEPS2mdat

```
read db=roma cat=icogle_main_fc_rout d=t00 s[h]=3/to/78/by/3 p=t_2m,td_2m bin f=
    iconEPS2mdat
```

- ICON-EPS: Retrieve 90% percentile (on regular lat/lon grid) of accumulated precipitation (available accumulation periods) at forecast hour 72 of today's run at 06 UTC on the EU domain.

```
read db=roma cat=icreue_main_fcprod_rout d=t00 s[h]=24/to/120/by/6 perc=90 p=
    TOT_PREC bin f=iconEPS_RR24_90
```

- Retrieve ensemble spread (on regular lat/lon grid) of CAPE for forecast hours 6 to 120 every 6 hours of today's run at 00 UTC on the EU domain.

```
read db=roma cat=icreue_main_fcprod_rout d=t00 s[h]=6/to/120/by/6 deriv=4 p=CAPE_ML
     bin f=iconEPS_CAPE_spread
```

- Retrieve probabilities of `TMIN_2M` of the last 12 h and 24 h for any available threshold, where the probability of event is above lower limit (probt=3), for all available forecast hours of today's run at 00 UTC on the EU domain.

```
read db=roma cat=icreue_main_fcprod_rout d=t00 probt=3 p=TMIN_2M bin f=
    iconEPS_TMIN_2M_probt3
```

- Retrieve temperature in 850 hPa from the first guess of the 40 ensemble members of the EDA on the 40 km grid in the parallel suite yesterday at 21 UTC. Sort the data by ensemble member.

```
read db=parma cat=icrgle_ass_fc_para1 enum=1/to/ d=t21-1d s=3 p=T lv=P lv1=85000
    info=epsInfo sort=enum
```

A. ICON standard level heights

A.1. Level heights for zero topography height

ICON standard *half level* heights z^{h0} are listed in Table A.1. Please note that these values correspond to the actual level heights only at grid points with zero topography height, e. g. at ocean grid points.

If *full level* heights z^{f0} are required, these can be deduced as follows: Let i denote the full level index for which the height is wanted. Then the full level height z_i^{f0} is given by

$$z_i^{f0} = \frac{z_i^{h0} + z_{i+1}^{h0}}{2}.$$

See Table A.2 for a list of all full level heights of the operational setup.

A.2. Non-zero topography heights

The prerequisite "zero topography height" is seldom met in real applications. Instead the user has to compute the model level height for each grid point separately. To this end the invariant fields `HSURF` and `HHL` are provided where `HHL` is the geometric height of model half levels above sea level. The level height above ground can therefore be computed by the following formula:

$$z_i^h(x) = \mathtt{HHL}(x) - \mathtt{HSURF}(x)$$

$$z_i^f(x) = \frac{z_i^h(x) + z_{i+1}^h(x)}{2}$$

Table A.1.: Standard heights z_i^{h0} (i.e. for zero topography height) for all 91 vertical *half levels* of the global 13 km domain and the 61 vertical half levels for the 6.5 km EU nest.

level index global	level index EU nest	height [m]	level index global	level index EU nest	height [m]	level index global	level index EU nest	height [m]
1	-	75 000.000	32	2	21 569.375	63	33	6 621.524
2	-	72 363.546	33	3	20 731.107	64	34	6 221.524
3	-	69 842.381	34	4	19 942.837	65	35	5 821.524
4	-	67 357.797	35	5	19 201.585	66	36	5 421.524
5	-	64 946.444	36	6	18 504.545	67	37	5 033.731
6	-	62 606.299	37	7	17 849.081	68	38	4 659.952
7	-	60 335.466	38	8	17 232.713	69	39	4 300.121
8	-	58 132.167	39	9	16 653.108	70	40	3 954.183
9	-	55 976.216	40	10	16 108.074	71	41	3 622.092
10	-	53 877.930	41	11	15 595.549	72	42	3 303.815
11	-	51 824.685	42	12	15 113.594	73	43	2 999.329
12	-	49 826.951	43	13	14 660.386	74	44	2 708.624
13	-	47 890.748	44	14	14 234.210	75	45	2 431.707
14	-	46 014.776	45	15	13 821.524	76	46	2 168.596
15	-	44 197.795	46	16	13 421.524	77	47	1 919.330
16	-	42 438.627	47	17	13 021.524	78	48	1 683.966
17	-	40 736.151	48	18	12 621.524	79	49	1 462.584
18	-	39 089.298	49	19	12 221.524	80	50	1 255.291
19	-	37 497.048	50	20	11 821.524	81	51	1 062.224
20	-	35 958.428	51	21	11 421.524	82	52	883.557
21	-	34 472.507	52	22	11 021.524	83	53	719.514
22	-	33 038.397	53	23	10 621.524	84	54	570.373
23	-	31 655.249	54	24	10 221.524	85	55	436.493
24	-	30 322.249	55	25	9 821.524	86	56	318.336
25	-	29 038.622	56	26	9 421.524	87	57	216.516
26	-	27 803.623	57	27	9 021.524	88	58	131.880
27	-	26 617.350	58	28	8 621.524	89	59	65.677
28	-	25 488.963	59	29	8 221.524	90	60	20.000
29	-	24 416.908	60	30	7 821.524	91	61	0.000
30	-	23 408.796	61	31	7 421.524			
31	1	22 460.814	62	32	7 021.524			

Table A.2.: Standard heights z_i^{f0} (i.e. for zero topography height) for all 90 vertical *full levels* of the global 13 km domain.

level index	height $[m]$	level index	height $[m]$	level index	height $[m]$
1	73 681.773	31	22 015.095	61	7 221.524
2	71 102.963	32	21 150.241	62	6 821.524
3	68 600.089	33	20 336.972	63	6 421.524
4	66 152.120	34	19 572.211	64	6 021.524
5	63 776.371	35	18 853.065	65	5 621.524
6	61 470.883	36	18 176.813	66	5 227.628
7	59 233.817	37	17 540.897	67	4 846.842
8	57 054.191	38	16 942.910	68	4 480.037
9	54 927.073	39	16 380.591	69	4 127.152
10	52 851.308	40	15 851.812	70	3 788.138
11	50 825.818	41	15 354.572	71	3 462.954
12	48 858.849	42	14 886.990	72	3 151.572
13	46 952.762	43	14 447.298	73	2 853.976
14	45 106.285	44	14 027.867	74	2 570.165
15	43 318.211	45	13 621.524	75	2 300.151
16	41 587.389	46	13 221.524	76	2 043.963
17	39 912.725	47	12 821.524	77	1 801.648
18	38 293.173	48	12 421.524	78	1 573.275
19	36 727.738	49	12 021.524	79	1 358.938
20	35 215.467	50	11 621.524	80	1 158.757
21	33 755.452	51	11 221.524	81	972.891
22	32 346.823	52	10 821.524	82	801.536
23	30 988.749	53	10 421.524	83	644.943
24	29 680.436	54	10 021.524	84	503.433
25	28 421.123	55	9 621.524	85	377.415
26	27 210.487	56	9 221.524	86	267.426
27	26 053.157	57	8 821.524	87	174.198
28	24 952.936	58	8 421.524	88	98.779
29	23 912.852	59	8 021.524	89	42.839
30	22 934.805	60	7 621.524	90	10.000

Table A.3.: Height above ground $z_i^h(x)$ (half levels) for the grid point with maximum topography height in the operational setup R03B07, 13 km spatial resolution.

Example: Height above ground HHL - HSURF

Location with max. surface height

CLON/CLAT = 88.180 / 27.938

HSURF = 6521.735 m

level idx.	height [m]	level idx.	height [m]	level idx.	height [m]	level idx.	height [m]
1	68 478.265	26	21 281.888	51	5 327.376	76	866.489
2	65 841.812	27	20 095.614	52	5 131.536	77	758.180
3	63 320.647	28	18 967.228	53	4 935.699	78	657.641
4	60 836.062	29	17 895.173	54	4 739.875	79	564.832
5	58 424.710	30	16 887.062	55	4 544.039	80	479.667
6	56 084.562	31	15 939.079	56	4 348.198	81	402.130
7	53 813.730	32	15 047.640	57	4 152.369	82	332.014
8	51 610.433	33	14 209.372	58	3 956.552	83	269.290
9	49 454.480	34	13 421.103	59	3 760.682	84	213.850
10	47 356.194	35	12 679.851	60	3 564.867	85	165.505
11	45 302.948	36	11 982.810	61	3 369.022	86	124.377
12	43 305.214	37	11 327.347	62	3 173.185	87	90.297
13	41 369.015	38	10 710.978	63	2 977.389	88	62.129
14	39 493.042	39	10 131.372	64	2 781.538	89	40.050
15	37 676.058	40	9 586.339	65	2 585.719	90	20.103
16	35 916.890	41	9 102.469	66	2 389.888	91	0.000
17	34 214.417	42	8 626.524	67	2 201.043		
18	32 567.562	43	8 180.073	68	2 020.364		
19	30 975.312	44	7 761.408	69	1 847.844		
20	29 436.690	45	7 357.246	70	1 683.365		
21	27 950.772	46	6 966.873	71	1 527.137		
22	26 516.663	47	6 578.056	72	1 378.952		
23	25 133.513	48	6 191.036	73	1 238.808		
24	23 800.515	49	5 852.974	74	1 106.748		
25	22 516.886	50	5 567.850	75	982.565		

Table A.4.: Height above ground $z_i^f(x)$ (full levels) for the grid point with maximum topography height in the operational setup R03B07, 13 km spatial resolution.

Example: Height above ground, full levels

Location with max. surface height

CLON/CLAT = 88.180 / 27.938

HSURF = 6521.735 m

level idx.	height [m]	level idx.	height [m]	level idx.	height [m]	level idx.	height [m]
1	67 160.038	25	21 899.387	49	5 710.412	73	1 172.778
2	64 581.230	26	20 688.751	50	5 447.613	74	1 044.657
3	62 078.355	27	19 531.421	51	5 229.456	75	924.527
4	59 630.386	28	18 431.200	52	5 033.618	76	812.334
5	57 254.636	29	17 391.117	53	4 837.787	77	707.911
6	54 949.146	30	16 413.070	54	4 641.957	78	611.237
7	52 712.081	31	15 493.359	55	4 446.119	79	522.250
8	50 532.456	32	14 628.506	56	4 250.284	80	440.899
9	48 405.337	33	13 815.237	57	4 054.460	81	367.072
10	46 329.571	34	13 050.477	58	3 858.617	82	300.652
11	44 304.081	35	12 331.330	59	3 662.774	83	241.570
12	42 337.114	36	11 655.078	60	3 466.944	84	189.678
13	40 431.028	37	11 019.162	61	3 271.103	85	144.941
14	38 584.550	38	10 421.175	62	3 075.287	86	107.337
15	36 796.474	39	9 858.855	63	2 879.463	87	76.213
16	35 065.653	40	9 344.404	64	2 683.628	88	51.090
17	33 390.989	41	8 864.497	65	2 487.803	89	30.077
18	31 771.437	42	8 403.299	66	2 295.465	90	10.052
19	30 206.001	43	7 970.741	67	2 110.703		
20	28 693.731	44	7 559.327	68	1 934.104		
21	27 233.718	45	7 162.060	69	1 765.604		
22	25 825.088	46	6 772.464	70	1 605.251		
23	24 467.014	47	6 384.546	71	1 453.044		
24	23 158.700	48	6 022.005	72	1 308.880		

Bibliography

Anlauf, H., A. Rhodin, A. Cress, R. Faulwetter, M. Lange, G. Paul, C. Kopken-Watts, O. O. Stiller, and R. Potthast, 2017: Deterministic global data assimilation for the ICON model - system suite and evaluation. *Mon. Wea. Rev.*, **in preparation**.

Bloom, S. C., L. L. Takacs, A. M. D. Silva, and D. Ledvina, 1996: Data assimilation using incremental analysis updates. *Mon. Wea. Rev.*, **124**, 1256–1270.

Denhard, M., C. Primo, A. Rhodin, J. T. Ambadan, H. Anlauf, H. Frank, A. F. del Rio, A. Cress, G. Zängl, R. Potthast, and M. Buchhold, 2018: The spread skill properties of the global icon ensemble. **in preparation**.

Doms, G., J. Förstner, E. Heise, H.-J. Herzog, D. Mironov, M. Raschendorfer, T. Reinhardt, B. Ritter, R. Schrodin, J.-P. Schulz, and G. Vogel, 2011: A description of the nonhydrostatic regional COSMO model. Part II: Physical parameterization. Technical report, Deutscher Wetterdienst. Available at http://www.cosmo-model.org/.

Freitag, M. and R. Potthast, 2013: *Large Scale Inverse Problems Computational Methods and Applications In the Earth Sciences*. De Gruyter.

Hunt, B. R., E. J. Kostelich, and I. Szunyogh, 2007: Efficient data assimilation for spatiotemporal chaos: A local ensemble transform Kalman filter. *Physica D: Nonlinear Phenomena*, **230**, 112–126.

Leuenberger, D., M. Koller, and C. Schär, 2010: A generalization of the sleve vertical coordinate. *Mon. Wea. Rev.*, **138**, 3683–3689.

Polavarapu, S., S. Ren, A. M. Clayton, D. Sankey, and Y. Rochon, 2004: On the relationship between incremental analysis updating and incremental digital filtering. *Mon. Wea. Rev.*, **132**, 2495–2502.

Ruppert, T., 2007: Diplomarbeit: Vector field reconstruction by radial basis functions. Master's thesis, Technical University Darmstadt, Department of Mathematics.

Schraff, C., H. Reich, A. Rhodin, A. Schomburg, K. Stephan, A. Perianez, and R. Potthast, 2004: Kilometre-scale ensemble data assimilation for the COSMO model (KENDA). *Q.J.R. Meteorol. Soc.*, **142**, 1453–1472.

Wan, H., M. A. Giorgetta, G. Zängl, M. Restelli, D. Majewski, L. Bonaventura, K. Fröhlich, D. Reinert, P. Ripodas, L. Kornblueh, and J. Förstner, 2013: The ICON-1.2 hydrostatic atmospheric dynamical core on triangular grids – Part 1: Formulation and performance of the baseline version. *Geosci. Model Dev.*, **6**, 735–763.

Zängl, G., D. Reinert, P. Ripodas, and M. Baldauf, 2015: The ICON (ICOsahedral Non-hydrostatic) modelling framework of DWD and MPI-M: Description of the non-hydrostatic dynamical core. *Q.J.R. Meteorol. Soc.*, **141**, 563–579.

Glossary

CRU-CL Climate Research Unit - Gridded climatology of 1961-1990 monthly means. 15, 16

CRU-UEA Climate Research Unit - University of east Anglia. 15

DSMW Digital Soil Map of the World. 15, 16

ESA European Space Agency. 15

FAO Food and Agricultural Organization. 15

GACP Global Aerosol Climatology Project. 15

GLCC Global Land Cover Characteristics. 15

GLDB Global Lake Database. 15, 16

GlobCover 2009 Global Land Cover Map for 2009. 15, 16

GLOBE Global Land One-km Base Elevation Project. 15, 16

GRIB2 Gridded Binary Format, 2^{nd} edition. 23, 57

GSFC Goddard Space Flight Center. 15

MODIS Moderate Resolution Imaging Spectroradiometer. 15

NASA National Aeronautics and Space Administration. 15

NGDC NOAA National Geophysical Data Center. 15

SeaWIFS Sea-viewing Wide Field-of-view Sensor. 15, 16

TOA top of atmosphere. 33, 44

USGS U.S. Geological Service. 15

WMO World Meteorological Organization. 23

Deutscher Wetterdienst
Business Area "Research and Development"
Frankfurter Straße 135
63067 Offenbach
Germany