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Research and Development at DWD

DWD Database Reference for the Global and Regional ICON and ICON-EPS Forecasting System

Version 2.5.0

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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 6.1.
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.
1.2.5	09.10.18	DR	Updated history of model changes; updated description of output products; added output fields SNOAG and HSNOW_MAX
1.2.6	01.11.18	HF	Updated section on Sky database examples.
1.2.7	27.02.19	DR	Updated history of model changes.
1.2.8	01.04.19	HF	Updated list of pressure levels of EPS output.
1.2.9	30.04.19	HF	Updated list of pressure levels of deterministic global ICON on triangular grid; hourly output of 5 fields of ICON-EU on regular grid until the end of the forecast.
1.2.10	08.08.19	DR	Updated history of model changes and description for HZEROCL
1.2.11	30.09.19	HF, DR	Updated output list of ICON-EPS. Updated description of T_G and T_SO
1.2.12	20.04.20	DR	Updated history of model changes and added new diagnostic output field CEILING
1.2.13	10.06.20	DR	Updated history of model changes

2.0.0	21.01.20	MB, FP, DR, MD, CS, CG	Common database reference for all models ICON global/-EU/-D2; partly restructured chapters about output variables
2.0.1	17.02.20	MD, CG, FP, DR, MB	Ensemble model output is now contained in chapters 10-12
2.1.0	15.05.20	MD, CM, MB, FP	New tables for all EPS products
2.1.1	05.06.20	MB, DR	New native grid for ICON-D2
2.1.2	19.01.21	DR, CG, MB	Update a few product descriptions; hints about the rotated lat-lon grid output
2.1.3	16.02.21	DR	Add description for `DBZ_850`, `DBZ_CMAX`
2.1.4	30.06.21	FP,DR	Updated forecast range for ICON-D2(-EPS)
2.1.5	09.09.21	HF	New output field `LPI_CON_CI_MAX` for ICON-EU(-EPS)
2.1.6	20.10.21	HF	Output of ICON-EU runs to 51 h
2.1.7	17.11.21	HF	Output of `LPI_CON_CI_MAX` for ICON-EU also on regular grid
2.1.8	15.08.22	DR	Fix units of `AUMFL_S` and `AVMFL_S` and remove non-existing DOI
2.2.0	23.11.22	HF	Adapted for ICON with 120 levels. Output of `LPI_CON_MAX` instead of `LPI_CON_CI_MAX` for ICON-EU on regular grid
2.2.1	12.01.23	HF	Added `LPI_CON_MAX` to output of global ICON. Corrected several time ranges, resolution of MODIS data.
2.2.2	03.04.23	HF	Added `ASOB_S_CS` to output of global ICON and ICON-EU.
2.3.0	27.03.24	LS, JF, DR	Added ICON-ART mixed ensemble and related variables plus ICON-EU-NA^2 domain.
2.3.1	23.04.24	HF	Added `VIS` to output of ICON-EU and ICON-D2.
2.3.2	12.02.25	LS	Update regarding start dates of ICON-ART mineral dust forecasts.
2.4.0	13.02.25	CW, UB, DR	Added informations about the new `ICON-D2-RUC` (Rapid Update Cycle) at various places.
2.5.0	21.02.25	MB, DR, GZ	Added informations about the new operational `ICON-D05`.

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 (Zängl et al., 2015, Zängl et al., 2022) 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 sub-region (*nest*) over Europe was activated (**ICON-EU**), in order to replace the regional model **COSMO-EU**. On 2021-02-10 the convection-permitting model setup **ICON-D2** (i.e. using the *limited-area mode* of ICON) has replaced **COSMO-D2**. Since that date, the entire NWP system at DWD is based on ICON.

As a fraternal twin of ICON-D2, the new Rapid Update Cycle **ICON-D2-RUC** has been implemented operationally on 2024-07-12. While ICON-D2 initiates new forecasts every 3 hours up to 48 h lead time, the ICON-D2-RUC provides new forecasts every hour with 14 h lead time. It applies the more advanced two-moment bulk microphyscial scheme of Seifert and Beheng (Noppel et al., 2010, Seifert and Beheng, 2006) including prognostic hail hydrometeors.

The first sub-km application **ICON-D05** with a grid spacing of 500 m has been started operationally on 2025-02-27. Due to the enormous increase in computational cost it only runs as a deterministic model (no EPS available). ICON-D05 mainly covers Germany and, as ICON-D2, is started every 3 h and delivers 48 h forecasts. In contrast to the other model setups, ICON-D05 has no own data assimilation, but is initialized by an interpolated ICON-D2 analysis.

The ICON modelling system as a whole is developed jointly by DWD, the Max-Planck Institute for Meteorology (MPI-M), the German Climate Computing Center (DKRZ), MeteoSwiss, and the Karlsruhe Institute for Technology (KIT). While ICON is the new working horse for short and medium range weather forecast at DWD and MeteoSwiss, 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.

ICON-D2 (-EPS) and ICON-D2-RUC (-EPS) are driven by the deterministic (ensemble) forecasts of the ICON-EU nest.

This document provides an overview of all ICON analysis and forecast fields that are stored in the database SKY at DWD. A subset of these data is publicly available on DWD's Open Data Server

`https://opendata.dwd.de`

For additional information on the Open Data Server, we refer to this webpage. The document at hand also provides some selected information on ICON's grid structure and the data assimilation system. For more detailed information, in particular regarding ICON's numerical algorithms and physical parameterizations, the reader is referred to the ICON Tutorial (Prill et al., 2024).

1.1. 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 modifications in terms of forecast quality and output products are summarized in so called *change notifications*, which are available from the following website:

http://www.dwd.de/DE/fachnutzer/forschung_lehre/numerische_wettervorhersage/nwv_aenderungen/nwv_aenderungen_node.html

You can receive regular information about changes to the forecasting environment by subscribing to this mailinglist.

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

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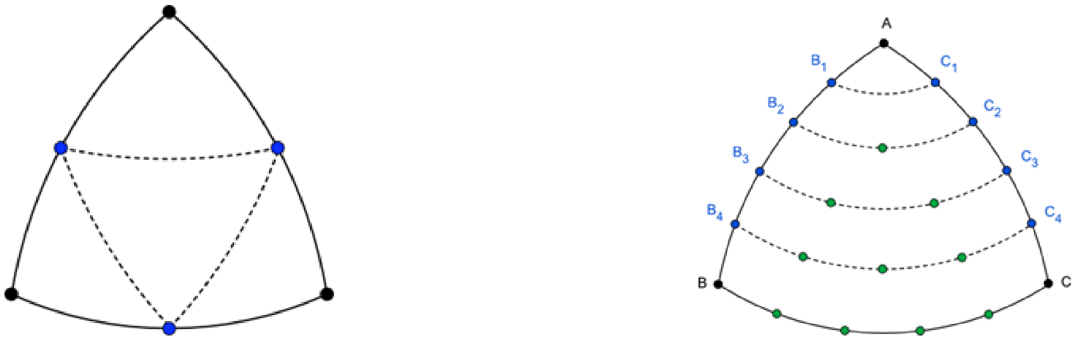
2. Grid geometry

2.1. 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 2.1a) which is projected onto a sphere. The spherical icosahedron (Figure 2.1b) 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 2.2a, 2.2b).

(a) ***(b)***

Figure 2.1.: Icosahedron before (a) and after (b) projection onto a sphere

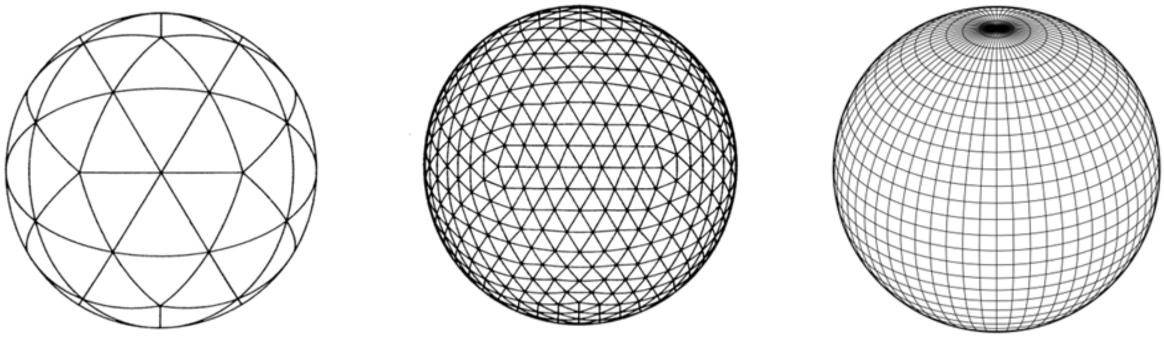


(a) ***(b)***

Figure 2.2.: (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 2.3a and 2.3b show **R**2**B**00 and **R**2**B**02 ICON grids. Such grids avoid polar singularities of latitude-longitude grids (Figure 2.3c) 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



(a) (b) (c)

Figure 2.3.: (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 $\overline{\Delta x}$:

$$\overline{\Delta x} = \sqrt{\overline{\Delta A}} = \sqrt{\frac{\pi}{5}}\frac{r_e}{n\, 2^k} \approx \frac{5050 \cdot 10^3}{n\, 2^k} \quad [m]$$

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

In Table 2.1, some characteristics of frequently used global 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 2.1.: Characteristics of frequently used global 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
R3B06	737280	26.5	719.2	476.1
R2B07	1310720	19.7	404.4	265.1
R3B07	2949120	13.2	179.7	116.3

> **The operational deterministic version of ICON is based on the R3B07 grid ($\overline{\Delta x} \approx$ 13 km), while the ensemble version (ICON-EPS) is based on the R3B06 grid ($\overline{\Delta x} \approx$ 26 km)** Until 2022-11-22 the ensemble version was based on the R2B06 grid ($\overline{\Delta x} \approx 40$ km)

2.2. 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. Close to the surface the vertical layers are terrain following, while with increasing distance from the surface the terrain signal is smoothed out and they gradually evolve into layers of constant height. 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) (see Figure 2.4).

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 (deterministic and ensemble), 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 2.5 shows the (half) level heights and layer thicknesses of the operational ICON setup with 120 vertical levels. This figure applies to the deterministic and the ensemble system, as both share the same vertical grid.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 121 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 (see e.g. the layer compression which is visible in Figure 2.4).

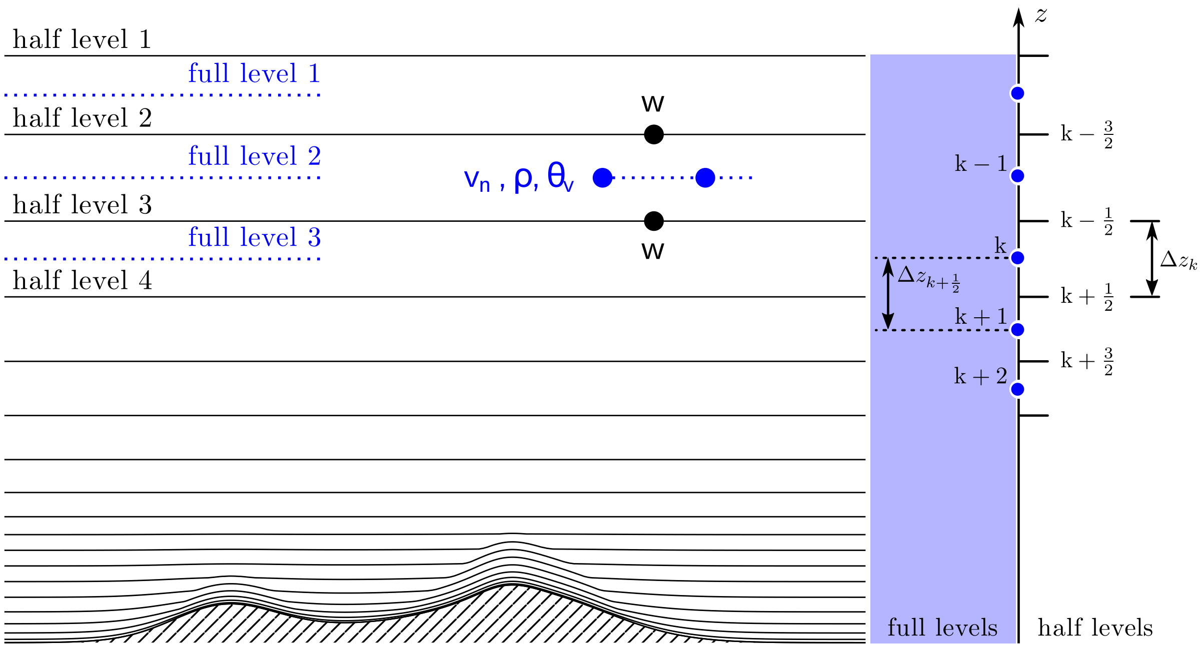


Figure 2.4.: Illustration of ICON's vertical levels. With `num_lev` layers, there are `num_lev` + 1 so-called *half levels*. The half levels $k - 1/2$, $k + 1/2$ enclose layer k at the centers of which are the corresponding full levels k, for $k = 1, \ldots,$ `num_lev`. Layer 1 is at the top of the atmosphere and layer n at the bottom of the atmosphere. Half level `num_lev`+1 coincides with the Earth's surface.

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

ICON has the capability for running global simulations with refined domains - so called *nests* (Zängl et al., 2022). The triangular mesh of the refined area is generated by bisection of triangles in the global "parent" grid, see Fig. 2.6. 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 1–74 of the Europe nest are the same as those of levels 47–120 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.

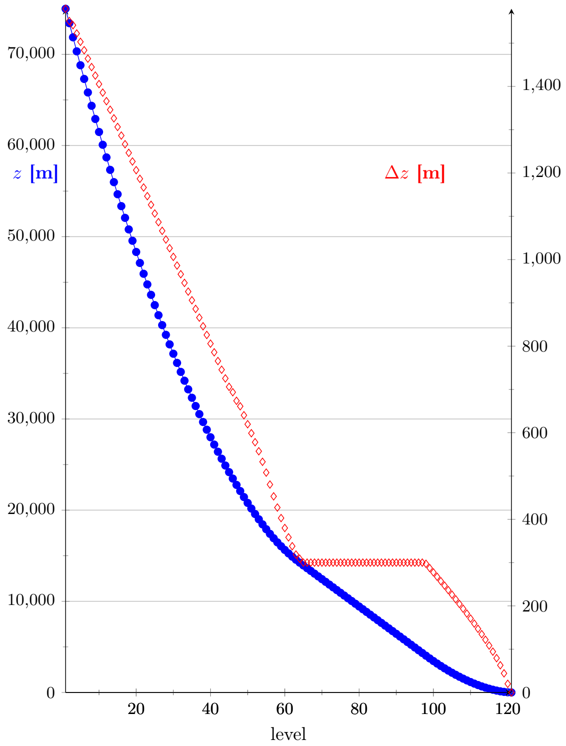
For each nesting level, the time step is automatically divided by a factor of two. Note that the grid nests are computed in a concurrent fashion:

- 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. 2.6).

Simulation on the global grid and the nested domain(s) are tightly coupled (*two-way nesting*): Boundary data for the nest area is updated every time step (120 s/240 s in case of the operational deterministic/ensemble system). Feedback of atmospheric prognostic variables (except precipitation) is computed via relaxation on a 3 h time scale.

2.3.1. ICON-EU

The operational ICON has one refined subregion over Europe (ICON-EU). Key figures like edge coordinates and mesh size of the ICON-EU nest are given in Table 2.2. The geographical location of the



level	[*m*]	[*Pa*]
1	75 000	2.1
5	68 806	5.6
10	61 485	16.5
15	54 656	41.8
20	48 323	93.8
25	42 491	198.7
30	37 159	411.1
35	32 328	826.6
40	27 998	1 586.7
45	24 170	2 854.4
50	20 795	4 830.8
55	17 908	7 614.0
60	15 637	10 893.4
65	13 933	14 251.2
70	12 433	18 054.1
75	10 933	22 871.6
80	9 433	28 812.4
85	7 933	35 945.4
90	6 433	44 445.2
95	4 933	54 504.1
100	3 449	66 200.5
105	2 164	77 893.2
110	1 142	88 332.9
115	409	96 507.3
120	20	101 085.0

Figure 2.5.: Vertical half levels (blue) and layer thickness (red) of the ICON operational setup (deterministic and ensemble). The table of selected pressure values (for zero height) is based on the 1976 US standard atmosphere.

nest is visualized in Fig. 2.7 (top).

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

2015-07-21, 06 UTC (roma) **for ICON-EU**

2018-01-17, 06 UTC (roma) **for ICON-EU-EPS**

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** +51 h**.**

2.3.2. ICON-EU-NA^2

The deterministic forecast and the ensemble members that include prognostic mineral dust have a refined subregion over Europe, Northern Africa and the North Atlantic (ICON-EU-NA^2) instead of the ICON-EU domain. This refined subregion is considerably larger than the ICON-EU domain. Key figures like edge coordinates and mesh size of the ICON-EU-NA^2 nest are given in Table 2.4. The geographical location of the nest is visualized in Fig. 2.7 (bottom).

Model simulations including prognostic mineral dust are running regularly, starting from

2023-11-27, 00 UTC (roma) **for ICON global and ICON-EU-NA^2**

2023-11-27, 00 UTC (roma) **for ICON-EPS global and ICON-EU-NA^2-EPS**

Main forecasts starting at 00 **and** 12 UTC **reach out to** 180 h **on the global and to** 120 h **in the ICON-EU-NA^2 domain. Main forecasts starting at** 06 **and** 18 UTC **provide data until** +120 h**, and the additional short-range forecasts starting at** 03, 09, 15, 21 UTC **until** +51 h**.**

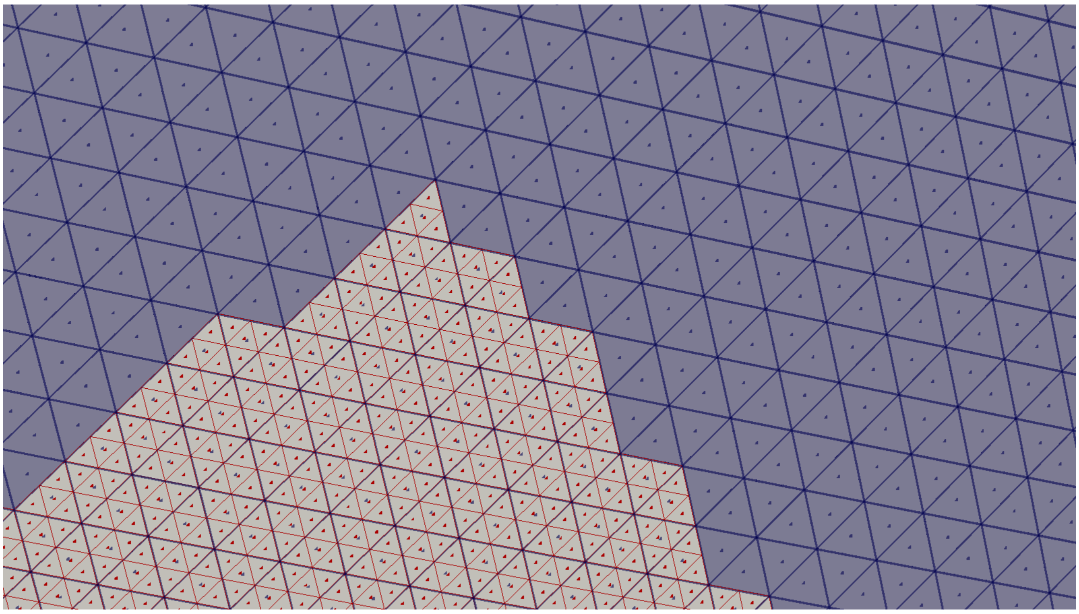


Figure 2.6.: ICON grid refinement (zoom view). Blue and red dots indicate the cell circumcenters for the global ("parent") and the refined ("child") domain, respectively.

Table 2.2.: Key figures of the ICON-EU and ICON-EU-EPS nest.

	ICON-EU nest	**ICON-EU-EPS nest**
geogr. coordinates	23.5° W – 62.5° E	23.5° W – 62.5° E
	29.5° N – 70.5° N	29.5° N – 70.5° N
mesh size	≈ 6.5 km (R3B08)	≈ 13 km (R3B07)
	659156 triangles	164984 triangles
vertical levels	74 levels	74 levels
upper boundary	22.8 km	22.8 km

Table 2.4.: Key figures of the ICON-NA^2 and ICON-NA^2-EPS nest.

	ICON-EU-NA^2 nest	**ICON-EU-NA^2-EPS nest**
geogr. coordinates	70° W – 70° E	70° W – 70° E
	0° N – 82° N	0° N – 82° N
mesh size	≈ 13 km (R3B07)	≈ 13 km (R3B07)
	571088 triangles	571088 triangles
vertical levels	74 levels	74 levels
upper boundary	22.8 km	22.8 km

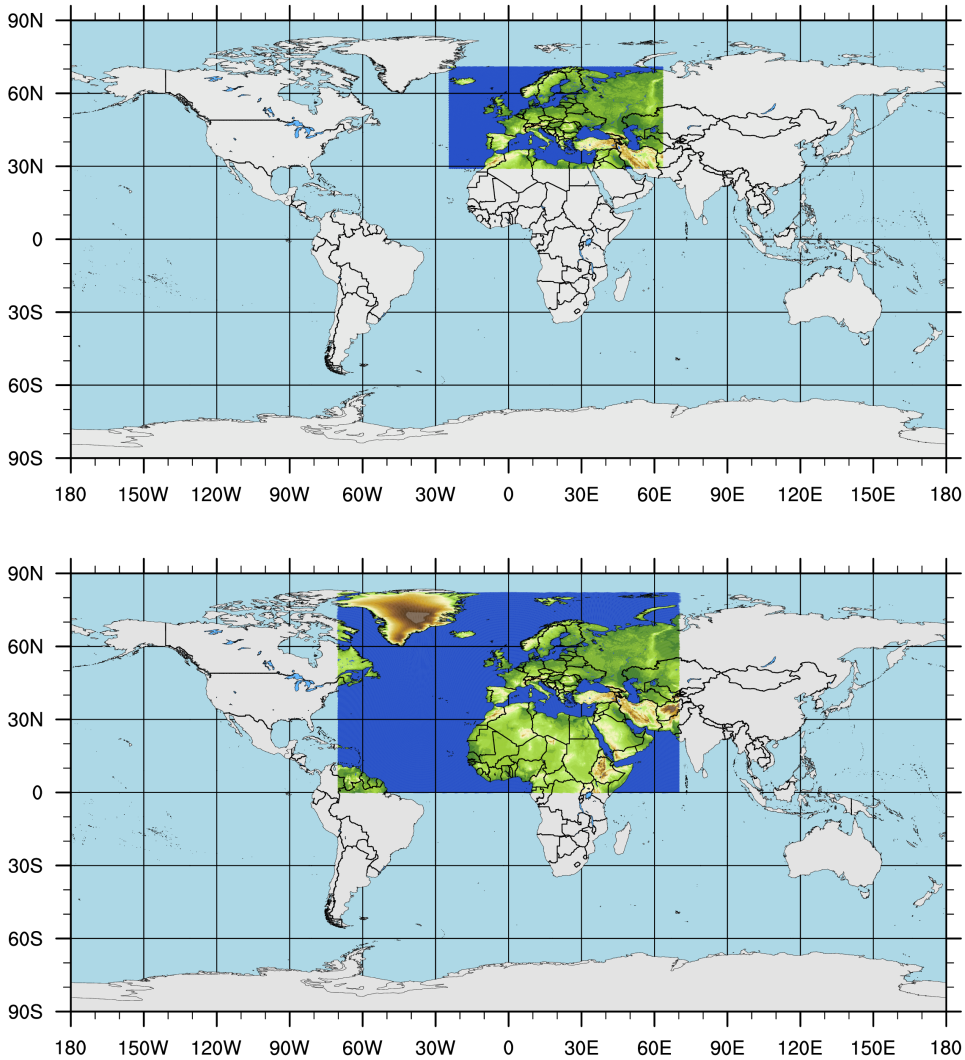


Figure 2.7.: Horizontal extent of the R3B8/R3B7 ($\overline{\Delta x} \approx 6.5/13\,\mathrm{km}$) **ICON-EU/ICON-EU-EPS nest** (top; greenish blue area) and the R3B7 ($\overline{\Delta x} \approx 13\,\mathrm{km}$) **ICON-EU-NA^2/ICON-EU-NA^2-EPS nest** (bottom) in a cylindrical equidistant projection.

2.4. ICON-D2

The horizontal domain of the regional model system ICON-D2 is depicted in Fig. 2.8. It is a regional R19B07 grid with 542040 cells and a horizontal resolution of $\overline{\Delta x} \approx 2\,\mathrm{km}$. The model domain completely covers the areas of Germany, Switzerland, Austria, Denmark, Belgium and the Netherlands and parts of the neighboring countries. The same horizontal grid is used for the ensemble system ICON-D2-EPS.

The grid frame which is highlighted in Fig. 2.8 depicts the *lateral boundary zone* where the model is forced by externally specified data. The lateral boundary zone has a total width of 14 cell rows. It consists of two sub-zones which are named *interpolation zone* (rows 1-4) and *nudging zone* (rows 5-14). Rows are counted positive towards the model interior. The interpolation zone provides the necessary boundary conditions and contains interpolated forcing data of the driving model. In other words, no prognostic computations are performed in the outermost 4 cell rows. In the nudging zone, the interior flow (i.e. the prognostic solution) is nudged towards the data of the driving model (ICON-EU in our case).

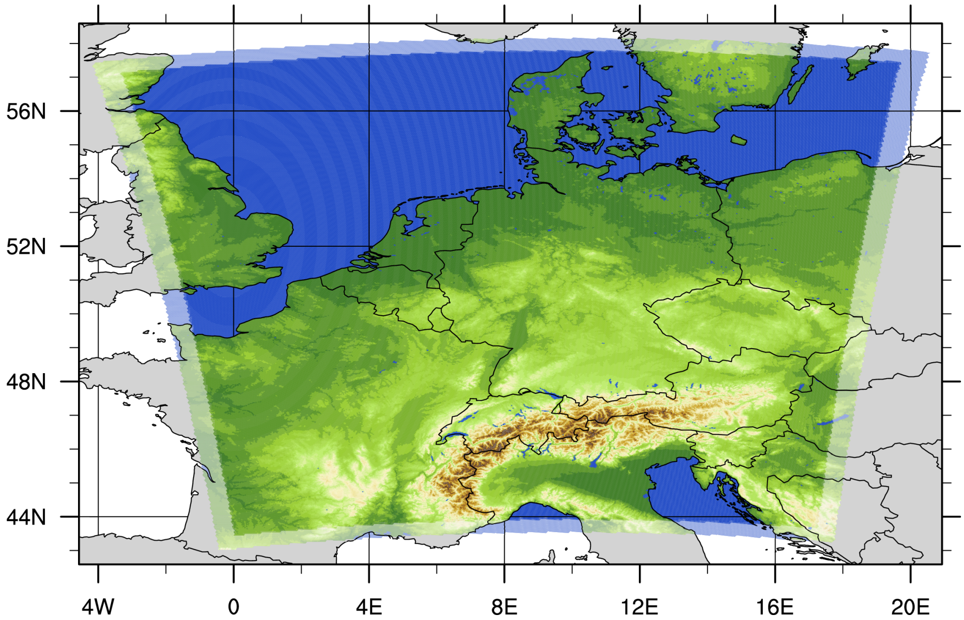


Figure 2.8.: ICON-D2 domain in cylindrical equidistant projection. It is comprised of a regional R19B07 grid with 542040 cells and a horizontal resolution of $\overline{\Delta x} \approx 2\,\mathrm{km}$. The highlighted frame depicts the *lateral boundary zone* where the model is forced by externally specified data sets. It has a total width of 14 cell rows and consists of two sub-zones named *interpolation zone* (rows 1-4) and *nudging zone* (rows 5-14). The prognostic region starts at cell row 5. In the nudging zone the prognostic solution is nudged towards the data of the driving model.

Figure 2.9 shows the (half) level heights and layer thicknesses of the operational ICON-D2 setup.

2.5. ICON-D2-RUC

The horizontal domain and vertical levels of the ICON-D2-RUC are exactly the same as for the ICON-D2, which has been described in the previous Section 2.4.

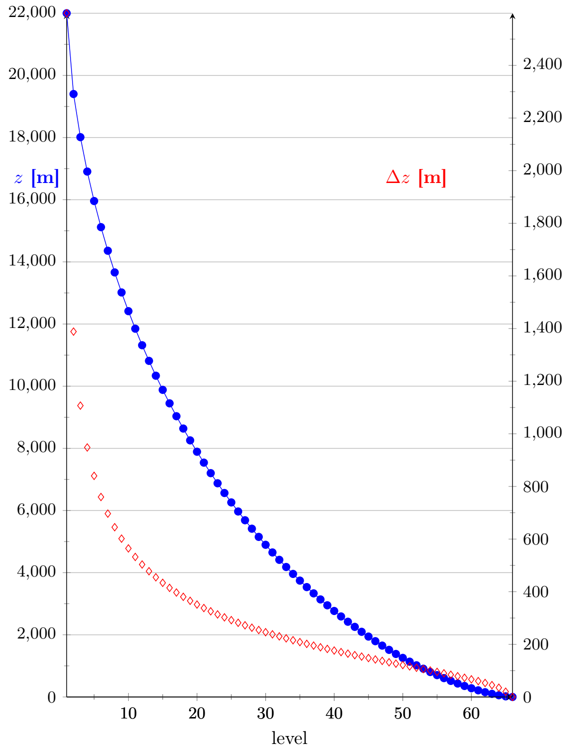


Figure 2.9.: Vertical half levels (blue) and layer thickness (red) of the ICON-D2 operational setup (deterministic and ensemble).

2.6. ICON-D05

ICON-D05 uses a regional R19B09 grid with a horizontal resolution of $\overline{\Delta x} \approx 500\,\mathrm{m}$ (on 2857428 horizontal grid cells) and therefore is the first sub-km NWP application of ICON at DWD. It mainly covers Germany, see Fig. 2.10. Technically it is two-way nested in a regional R19B08 grid with a horizontal resolution of $\overline{\Delta x} \approx 1\,\mathrm{km}$ and finally in an ICON-D2 R19B07 grid (however, these two driving model domains do not deliver output fields). Vertical levels of the ICON-D05 are exactly the same as for the ICON-D2 (see Figure 2.9).

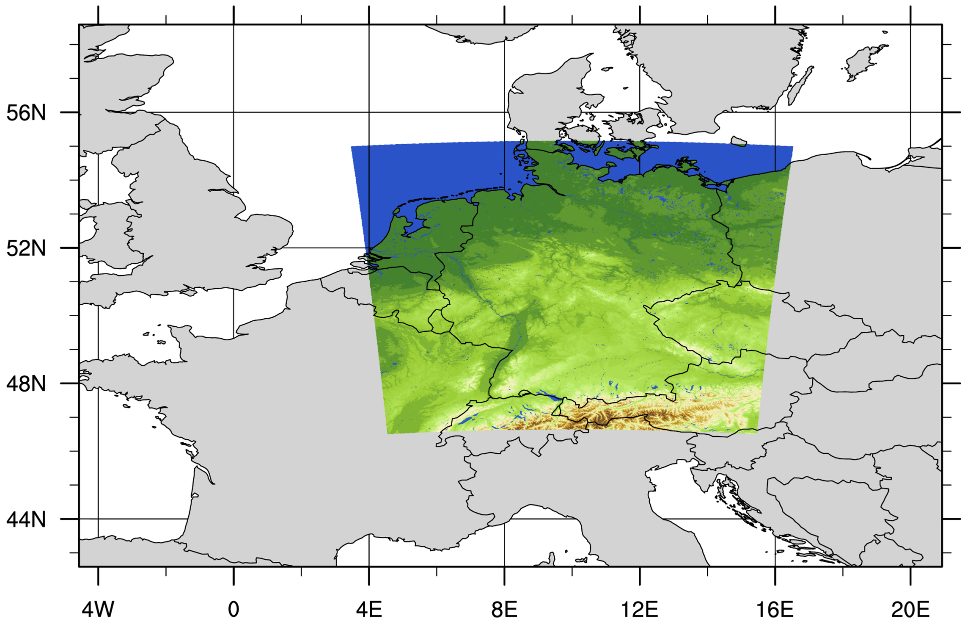


Figure 2.10.: ICON-D05 domain in cylindrical equidistant projection.

3. 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 4.

3.1. 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`.

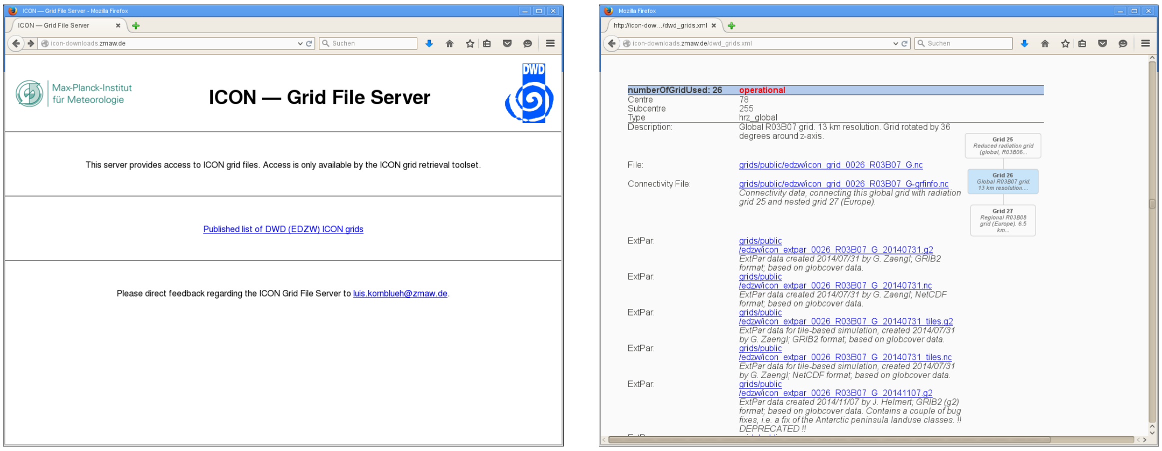


Figure 3.1.: Screenshots of the ICON download server hosted by the Max Planck Institute for Meteorology in Hamburg.

- `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.

3.1.1. 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 3.1 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`).

3.2. 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

Table 3.1.: Raw datasets from which the ICON external parameter fields are derived.

Dataset	Source	Resolution
GLOBE	NGDC	30”
MERIT (limited domain: 90 N - 60 S)	IIS	3”
REMA (limited domain: 62 S - 90 S)	PGC	200 m
ASTER (limited domain: 60 N - 60 S)	METI/NASA	1”
GlobCover 2009	ESA	10”
GLCC	USGS	30”
DSMW	FAO	5’
HWSD	FAO/IIASA/ISRIC /ISSCAS/ISRIC /ISSCAS/JRC	30”
HWSD_USDA	FAO/IIASA/ISRIC /ISSCAS/JRC	30”
SeaWIFS NDVI Climatotology	NASA/GSFC	2.5’
CRU-CL	CRU-UEA	0.5°
GACP Aerosol Optical thickness	NASA/GISS	$4x5°$
GLDB	DWD/RSHU/MeteoFrance	30”
MODIS albedo	NASA	3’

set of raw datafields which are listed in Table 3.1. For a more detailed overview of ExtPar, the reader is referred to the *User and Implementation Guide* of Extpar.

Multi-Error-Removed Improved-Terrain (MERIT) DEM (MERIT) and The Reference Elevation Model of Antarctica (REMA) are used for ICON, and Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER) is used for ICON-D2. Global Land Cover Map for 2009 (GlobCover 2009) is a land cover database covering the whole globe, except for Antarctica. Therefore, we make use of GlobCover 2009 for latitudes $90° > \phi > -56°$ and switch to the coarser, however globally available dataset Global Land Cover Characteristics (GLCC) for $-56° \geq \phi > -90°$.

The products generated by the ExtPar software package are listed in Table 3.3 together with the underlying raw dataset. These are mandatory input fields for assimilation- and forecast runs.

Table 3.3.: 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 $(0.3 - 5.0\,\mu\mathrm{m})$ albedo for diffuse radiation (monthly fields)	MODIS
ALB_UV12	UV-visible $(0.3 - 0.7\,\mu\mathrm{m})$ albedo for diffuse radiation (monthly fields)	MODIS
ALB_NI12	Near infrared $(0.7 - 5.0\,\mu\mathrm{m})$ albedo for diffuse radiation (monthly fields)	MODIS
DEPTH_LK	Lake depth	GLDB
EMIS_RAD	Surface longwave (thermal) emissivity	GlobCover 2009
EMISS	monthly mean EMISS climatology 1998-2003	CAMEL (combined ASTER and MODIS)
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	MERIT, REMA, ASTER, 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	MERIT, REMA, ASTER

Continued on next page

Table 3.3.: *continued*

SSO_THETA	Principal axis-angle of sub-grid scale orography	MERIT, REMA, ASTER
SSO_GAMMA	Horizontal anisotropy of sub-grid scale orography	MERIT, REMA, ASTER
SSO_SIGMA	Average slope of sub-grid scale orography	MERIT, REMA, ASTER
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
FR_HCLA	Fraction of Heavy Clay	HWSD_USDA
FR_SILC	Fraction of Silty Clay	HWSD_USDA
FR_LCLA	Fraction of Light Clay	HWSD_USDA
FR_SICL	Fraction of Silty Clay Loam	HWSD_USDA
FR_CLOA	Fraction of Clay Loam	HWSD_USDA
FR_SILT	Fraction of Silt	HWSD_USDA
FR_SILO	Fraction of Silty Loam	HWSD_USDA
FR_SCLA	Fraction of Sandy Clay	HWSD_USDA
FR_LOAM	Fraction of Loam	HWSD_USDA
FR_SCLO	Fraction of Sandy Clay Loam	HWSD_USDA
FR_SLOA	Fraction of Sandy Loam	HWSD_USDA
FR_LSAN	Fraction of Loamy Sand	HWSD_USDA
FR_SAND	Fraction of Sand	HWSD_USDA
FR_UDEF	Fraction of Undefined or Water	HWSD_USDA

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`

Hence, for post-processing tasks the modified external parameter fields should be used rather than the original fields, for consistency. See Section 5.1.1 for more details.

4. 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 4.1.: 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, SKT, Z0, RELHUM_LML_FILTINC, SP_LML_FILTINC, T_LML_FILTINC, T_LML_COSWGT_FILTINC
Land specific	T_SNOW, RHO_SNOW, H_SNOW, HSNOW_MAX, FRESHSNW, SNOWC, SNOAG, W_I, T_SO(1:nlev_soil), W_SO, W_SO_ICE, EVAP_PL
Lake/sea ice specific	T_MNW_LK, T_WML_LK, H_ML_LK, T_BOT_LK, C_T_LK, T_SEA, T_ICE, H_ICE, FR_ICE, ALB_SEAICE
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 4.1). Sea surface temperature `T_SEA` 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 fresh snow factor `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_SEA 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 4.2 the available and employed first guess and analysis fields are listed as a function of starting time.

Table 4.2.: 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: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
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
HSNOW_MAX	–	FG	FG	FG	FG	FG	FG	FG	FG
W_I	–	FG	FG	FG	FG	FG	FG	FG	FG
EVAP_PL	–	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

Continued on next page

Table 4.2.: *continued*

FR_ICE	Ana_SST	AN	FG	FG	FG	FG	FG	FG	FG
ALB_SEAICE	–	FG	FG	FG	FG	FG	FG	FG	FG
T_SEA	Ana_SST	AN	FG	FG	FG	FG	FG	FG	FG
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

4.1. 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 4.2 and Section 4.2. 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.

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 analysed one, as a soil moisture

[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 re-diagnosed within the ICON-code based on the analysed snow height `H_SNOW` and the former mentioned snow density `RHO_SNOW`.

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 4.3.: 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_SEA	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

4.2. 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 4.1).

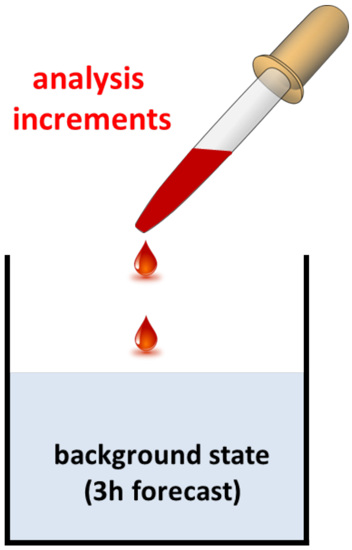


Figure 4.1.: **I**ncremental **A**nalysis **U**pdate. Analysis increments are added to the background state (FG) in small drips over some time interval rather than in one go. Currently, increments for `U`, `V`, `P`, `T`, `QV` are treated in this way.

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

$$\frac{\mathrm{d}\mathbf{x}}{\mathrm{d}t} = A\mathbf{x} + g(t)\Delta\mathbf{x}^A \qquad \text{, with} \quad \int g(t)\,\mathrm{d}t = 1 \tag{4.1}$$

$\mathbf{x}$ 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 background 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 4.2 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:

$$g(t) = \frac{\Delta t}{T} \qquad \text{, for} \quad -T/2 < t < T/2 \tag{4.2}$$

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

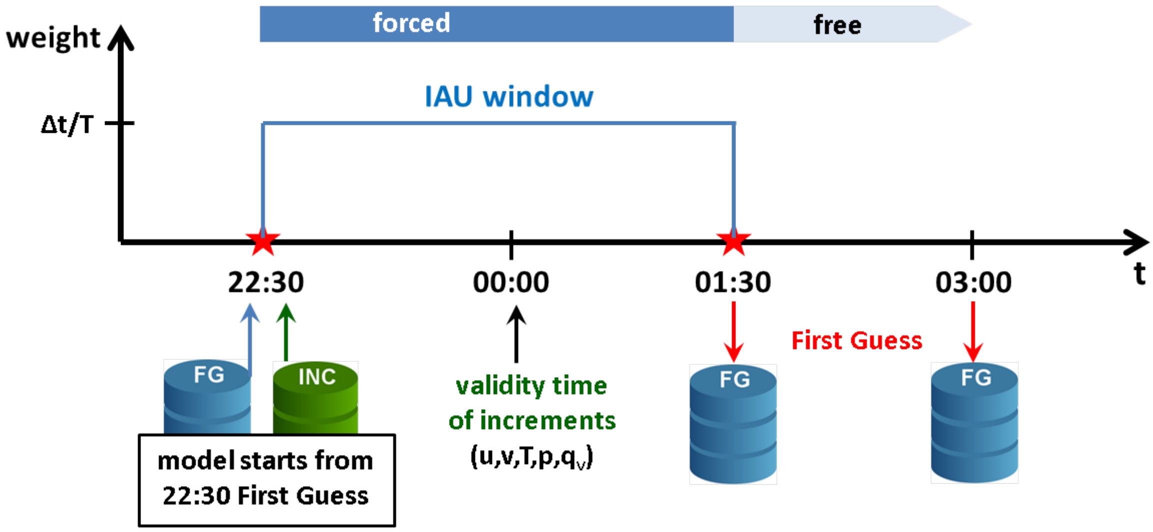


Figure 4.2.: Time line for an ICON assimilation run starting at 00:00 UTC.

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.

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

4.3. Initial state for the convection-resolving ICON-D2 and ICON-D2-RUC

4.3.1. Interpolated initial conditions and initialisation

For experimental predictions and simulations with the ICON-D2 the initial state can be determined by interpolation from the analysis of a driving model (normally ICON / ICON-EU, or also the IFS). With interpolated initial conditions one should generally note that the calculated initial state is not very well defined due to the difference in the horizontal and vertical resolution. Therefore, a settling period occurs (spin-up, approx. 3–6 hours), during which the flow adjusts to the high-resolution topography[1].

4.3.2. Data assimilation

KENDA-LETKF

The initial conditions are generated with the data assimilation system KENDA ('Kilometer-scale Ensemble Data Assimilation', Schraff et al. (2016)) which is based on the method of the "Local Ensemble Transform Kalman Filter" (LETKF, Hunt et al. (2007)). With this method, one can simultaneously and consistently provide initial conditions both for the deterministic ICON-D2 / ICON-D2-RUC in the form of a deterministic analysis as well as for the ICON-D2-EPS (COSMO-D2-EPS before 2021-02-10) and ICON-D2-RUC-EPS using a whole ensemble of suitably disturbed analyses.

[1] The digital filter initialization (DFI) by Lynch (1997) used earlier, is difficult to adapt for the 2-time-level based integration used in ICON-D2 according to previous experience.

For the calculation of the analysis, the information is combined from the current observations and the previous short-term forecast, in the case of the current configuration of KENDA this is a 1-hour forecast. The weighting of these components is based on the estimation of the respective uncertainties, where the errors of the predictions in particular on the convective scale depends to a high degree on the situation and weather. In KENDA, these forecasting uncertainties can be estimated with the help of an ensemble from (currently) 40 appropriately slightly different 1-hour forecasts. The analysis procedure allows not only to estimate the most likely actual state of the atmosphere, but also the analysis error. This estimate is used in the generation of an entire ensemble of different analyses (with the same number as the incoming prediction Ensemble) in such a way that the analysis ensemble mean corresponds to the most likely current state and that the spread of the analysis ensemble corresponds to the estimated analysis error. As a result, the estimation of the analysis error influences directly the spread of the subsequent ensemble forecasts (in the data assimilation cycle or as an actual short-term forecast ICON-D2-EPS / ICON-D2-RUC-EPS), which in turn serves as a measure of the forecasting uncertainty. However, it should be mentioned that the ensemble spread generally only describes random errors, but not the systematic analysis errors or forecast errors.

To sufficiently take into account the uncertainty in the heat flux from the surface of the earth into the atmosphere, additional explicit random errors in the sea surface temperature and soil moisture are applied, so that ensemble members have a spread of 1 K or approx. 15 % relative soil moisture (between wilting point and field capacity). Without these disturbances, the ensemble spread and thus the estimate of the uncertainty of analysis and prediction in the planetary boundary layer would become underestimated.

Because the analysis ensemble mean in the atmosphere is not a very well balanced model state, and, as used as an initial state for a deterministic forecast, would lead to a slightly increased spin-up in the first forecast hours, an additional undistorted model run ('Control Run' or 'deterministic run') is determined. Based on this 1 hour forecast ('deterministic first guess'), the deviations of the observations from this run, and the estimation of the forecast errors from the LETKF (in the form of the 'Kalman Gain' for the ensemble mean) a 'deterministic' analysis is calculated. This serves as the initial condition for the subsequent 'Control Run' or for the actual deterministic short-term prediction.

The so-called 'control variables' of the LETKF, i.e. the variables which are changed ('analysed') by LETKF are currently: 3-D wind components, temperature, specific humidity, cloud water, and cloud ice (additionally rain, snow, graupel and hail for the ICON-D2-RUC) on all model levels, as well as pressure at the bottom model surface. In the areas above it, the pressure is adjusted in such a way that the entire analysis corrections (analysis increments) are hydrostatically balanced. For all other model variables, the analysis is just the 1 hour forecast ('First Guess').

The Incremental analysis update (IAU) is applied during a time window of 10 min at the beginning of each forecast.

In the LETKF, we currently assimilate at hourly intervals for ICON-D2 and ICON-D2-RUC:

- "conventional" observations, which are data from radio sondes, aircraft (temperature, moisture, wind from MODE-S), wind profilers, ground stations,
- remote sensing data from radar 3D volume scans of reflectivity and radial wind from 17 DWD stations and some surrounding countries
- remote sensing data from Meteosat, 1 visible and 2 infrared channels.

To additionally assimilate 2D precipitation rates estimated in 5 min intervals from radar composites during the first guess runs inbetween the hourly analysis steps, the LETKF is combined with the traditional 'Latent Heat Nudging' (LHN). This is also done at the beginning of the forecasts during the short time interval which is already in the past, e.g., computations for the 15 UTC run start at 15:30 or so and there are already radar observations for that half hour.

3D radar volume data

Starting in 2020, the 3D volume scans of radar reflectivity and radial winds from the 17 DWD radar stations are assimilated directly at hourly intervals in ICON-D2. Since March 2024, some more stations of surrounding countries (data provided via OPERA) have been added. The same data are also assimilated in ICON-D2-RUC.

Each station provides area-wide radar data for a set of conical fixed-elevation scans (10 for Germany) in polar coordinates, with a typical range resolution of 250 - 1000 m and an azimutal resolution of 1°. As described in Bick et al. (2016), Waller et al. (2019), the assimilation is done in observation space, and the Efficient Modular VOlume scan RADar Operator EMVORADO (Blahak, 2016, Blahak and de Lozar, 2021, Zeng et al., 2016) is applied to derive the synthetic model equivalents for each volume scan. Only a certain subset of the elevations are used and the raw data are averaged to a scale of about $10 \times 10\,\mathrm{km}^2$ prior to assimilation ("superobservations").

Meteosat VIS/IR

Since end of 2022, cloudy satellite observations (reflectances) of the $0.6\,\mu m$ visible channel from the geostationary Meteosat are assimilated during the day in hourly intervals. As described in Scheck et al. (2020), the assimilation is again done in observation space, with model equivalents computed by the Method for FAst Satellite Image Synthesis MFASIS (Scheck et al., 2016) and involving superobservations and/or thinning of the data prior to assimilation.

At beginning of 2024, cloudy brightness temperatures of two additional IR channels have been added using similar methodologies, with model equivalents computed by the well-established RTTOV satellite forward operator. MFASIS is technically integrated into the RTTOV framework as well.

Latent Heat Nudging

In order to have a sufficiently good forecast quality of precipitation, especially in the short range, the use of radar-based precipitation information is essential for the determination of a reasonable initial condition. Currently, quality proven products of near-ground precipitation rates are used in a temporal resolution of 5 minutes and a horizontal resolution of $1\,\mathrm{km} \times 1\,\mathrm{km}$ from the DWD radar network and foreign radar stations. These data are aggregated to the ICON-D2 model grid and are brought in GRIB format as precipitation analyses into the database. With the help of the "latent heat nudging" method these radar precipitation data are assimilated during the forward integration of the (ICON) model into the model state (Stephan et al., 2008). To do this, one determines temperature increments from the ratio between observed and modeled precipitation as well as from model based latent heating rates. The temperature changes take place while maintaining the relative humidity, whereby the specific humidity is adjusted accordingly. The increments introduced influence the dynamics of the model in that the model precipitation adjusts to the observation.

Soil moisture analysis

The soil moisture is adapted by relaxing the soil moisture index (SMI) of ICON-D2 and ICON-D2-RUC towards the SMI of ICON-EU (which uses a soil moisture analysis, see above).

Further external analysis

Once a day there is an analysis of the sea surface temperature carried out. Based on the previous analysis as 'first guess', the new analysis is produced by using all observations from ships and buoys of the previous 2 days with the aid of a correction procedure. In low data areas this is complemented through the global analysis, based on the analysis by NCEP, which is also based on satellite data.

Furthermore, a snow depth analysis is carried out every 6 hours. It is based on a simple weighted averaging of SYNOP snow depth observations. The weighting depends on the horizontal and vertical distances the target grid points. In areas with low data density, an attempt is made to derive the snow depth increments from SYNOP precipitation and temperatures.

Coupling ICON-D2-RUC to ICON-D2 assimilation cycle

While the observation data sources of ICON-D2 and ICON-D2-RUC are essentially the same, ICON-D2-RUC needs to complete it's forecasts earlier and consequently cannot wait as long for the observations to become available. Due to this shorter cut-off time, systematically less observations may be assimilated in ICON-D2-RUC compared to ICON-D2, potentially penalizing the forecast quality of the ICON-D2-RUC. To mitigate this adverse effect and to avoid a possible systematic quality drift of ICON-D2-RUC away from ICON-D2, the data assimilation cycle of the ICON-D2-RUC is reset every morning at 3 UTC to the best available analysis of ICON-D2 having a very long cutoff time.

Followed by a 3 h pre-assimilation cycle with hourly assimilation to allow the model fields to adjust to the different cloud microphysics, the 7 UTC init is the first ICON-D2-RUC forecast of the day profiting from the newly branched assimilation cycle. This 7 UTC forecast of the ICON-D2-RUC is, as any other ICON-D2-RUC forecast, preceded by an assimilation cycle with very short cut-off time. The last forecast in this cycle is the 6 UTC of the next day.

ICON-D05

In contrast to the other model setups, ICON-D05 has no own data assimilation, but is initialized by the interpolated ICON-D2 deterministic analysis. This is a commonly accepted approach for very highly resolved sub-km model setups. The most important reason is that it saves the expensive ensemble forecast runs needed for an LETKF system. Specifically, we use a two-step two-way nesting approach in which the nested domains are started during the forecast after the end of the latent-heat nudging phase. The intermediate 1-km domain, for which no output is written, starts at +40 min, and the D05 domain 10 min later at +50 min. Consequently, the first output is written at a forecast lead time of 1 hour.

5. Output fields of the ICON model: General description

ICON output fields are exclusively available in the General Regularly-distributed Information in Binary Form, 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.

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 on the official WMO GRIB2 data standard is available from:

https://community.wmo.int/activity-areas/wis/latest-version

For decoding and encoding GRIB2 messages, the DWD in general and ICON in particular makes use of the **ecCodes** package developed by ECMWF. ecCodes includes both programming interfaces for reading and writing GRIB2- (and the older GRIB1-) data in Fortran-, C-, and Python-programs and command line tools for analysing and further processing of GRIB-fields. Examples for the latter are

> `grib_ls` gribfile

for a listing of the repository of a gribfile, or

> `grib_dump` gribfile

for extensive information about the single grib fields. To see the meta data in 'pure' form (i.e. only so-called 'coded keys' are displayed) and ordered by GRIB sections then

> `grib_dump -O` gribfile

should be used.

Further information can be found at

https://confluence.ecmwf.int/display/ECC/ecCodes+Home

5.1. Available output fields

All available output variables of the ICON model are listed in the following tables, together with the most important GRIB keys for their identification. These tables are of interest in particular for those users, who *don't use* the ecCodes software together with the national DWD GRIB tables. Please note that the individual models (ICON global, ICON-EU/EU-NA[2] nest, ICON-D2, ICON-D2-RUC) deliver only a subset of these output fields. The concrete output for each model is described in Sections 8, 9, and 10.

In the tables below the GRIB keys `typeOfFirstFixedSurface` and `typeOfSecondFixedSurface` are abbreviated by `Lev-Typ 1/2`. Furthermore, the specific algorithm used for interpolation to regular lat-lon grids is indicated in the column `LL IntpType`. If nothing is specified, then an RBF-based interpolation method is used. `LL IntpType='-'` indicates that the respective field is not available on lat-lon grids. For details regarding the available interpolation methods, see Section 7.2.

5.1.1. Time-constant (external parameter) fields

Table 5.1 provides an overview of the available time-constant fields. As mentioned in Section 3.2, there are two types of such variables. The one type is delivered as an external (invariant) field; such fields are available from the database category `CAT_NAME=$model_const_an_$suite`. In the later tables 8.1, 9.2, and 10.2 they are denoted by 'invar'. The other type of variables (in particular `DEPTH_LK`, `HSURF`, `FR_LAND`, `FR_LAKE` and `Z0`) is 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`) (such variables are denoted by 't=0' in the above mentioned tables).

See Section 14.1 for more details on the database categories and Section 14 for sample retrievals.

Table 5.1.: Time-constant fields or variables exclusively available for $VV = 0$ from the forecast databases

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
	Date/Time (YYYY-MM-DDThh) **D=0001-01-01T00**					
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

Continued on next page

Table 5.1.: *continued*

EMIS_RAD	Longwave surface emissivity	2/3/199	1/–	inst	–	1
EVAP_PL	Evaporation of plants (integrated since "nightly reset")	2/0/198	1/–	acc		$kg\,m^{-2}$
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
FR_LUC	Land use class fraction (possible range [0, 1])	2/0/36	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
HSNOW_MAX	Maximum snow height during contiguous accumulating snow period	0/1/235	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
LAI_MX	Leaf area index in the vegetation phase	2/0/28	1/–	max	–	1
NDVIRATIO	ratio of current NDVI (normalized differential vegetation index) to annual max	2/0/192	1/–	inst	–	1
NDVI_MAX	Normalized differential vegetation index	2/0/31	1/–	max	–	1
PLCOV	Plant cover	2/0/4	1/–	inst		%
PLCOV_MX	Plant covering degree in the vegetation phase	2/0/4	1/–	max	–	1
RLAT	Geographical latitude of rotated lat-lon grid cell centers	0/191/1	1/–	inst		Deg. N
RLON	Geographical longitude of rotated lat-lon grid cell centers	0/191/2	1/–	inst		Deg. E
ROOTDP	Root depth of vegetation	2/0/32	1/–	inst		m
RSMIN	Minimum stomatal resistance	2/0/16	1/–	inst	–	$s\,m^{-1}$
SMI	Soil moisture index	2/3/200	106/106	inst		1
SNOAG	Snow age	0/1/17	1/–	inst		d

Continued on next page

Table 5.1.: *continued*

SOILTYP	Soil type of land fraction (9 types [1, . . . , 9])	2/3/196	1/–	inst	NNB	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
VLAT	Geographical latitude of native grid triangle vertex	0/191/1	1/–	inst		Deg. N
VLON	Geographical longitude of native grid triangle vertex	0/191/2	1/–	inst		Deg. E
Z0	Surface roughness (above land and water)	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
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

5.1.2. Multi-level fields on native hybrid vertical levels

Fields from standard forecasts

Table 5.2.: 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		%
DBZSCAN_SIM	Reflectivity (Radar volume scans on native polar coordinates)	0/6/4	198/–	inst		dB
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	–	$m^2\,s^{-3}$
NCCLOUD	Number of cloud droplets per unit mass of air	0/6/28	150/150	inst		kg^{-1}
NCGRAUPEL	Specific number concentration of graupel	0/1/102	150/150	inst		kg^{-1}
NCHAIL	Specific number concentration of hail	0/1/103	150/150	inst		kg^{-1}
NCICE	Number of cloud ice particles per unit mass of air	0/6/29	150/150	inst		kg^{-1}
NCRAIN	Specific number concentration of rain	0/1/100	150/150	inst		kg^{-1}
NCSNOW	Specific number concentration of snow	0/1/101	150/150	inst		kg^{-1}
P	Pressure	0/3/0	150/150	inst		Pa
QC	Cloud mixing ratio[3]	0/1/22	150/150	inst		$kg\,kg^{-1}$
QC_DIA	Specific cloud water content (diagnostic)	0/1/212	150/150	inst		$kg\,kg^{-1}$
QG	Graupel mixing ratio[3]	0/1/32	150/150	inst		$kg\,kg^{-1}$
QH	Hail mixing ratio[3]	0/1/71	150/150	inst		$kg\,kg^{-1}$
QI	Cloud ice mixing ratio[3]	0/1/82	150/150	inst		$kg\,kg^{-1}$
QI_DIA	Specific cloud ice content (diagnostic)	0/1/213	150/150	inst		$kg\,kg^{-1}$
QR	Rain mixing ratio[3]	0/1/24	150/150	inst	–	$kg\,kg^{-1}$

Continued on next page

Table 5.2.: *continued*

QS	Snow mixing ratio[3]	0/1/25	150/150	inst	–	$kg\,kg^{-1}$
QV	Specific humidity	0/1/0	150/150	inst	BCT	$kg\,kg^{-1}$
Q_SEDIM	Specific mass of sedimenting particles	0/1/196	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		$m\,s^{-1}$

Fields from forecasts employing prognostic mineral dust

Table 5.3.: Hybrid multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products for forecasts employing prognostic mineral dust

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
DUST_TOTAL_MC	Diagnostic total mass concentration of mineral dust aerosol	0/20/0	150/150	inst	–	$kg\,m^{-3}$
SAT_BSC_DUST	Attenuated backscatter from satellite for dust (for given wave length)	0/20/107	150/150	inst	–	$m^{-1}\,sr^{-1}$
SAT_BSC_DUST	Attenuated backscatter from satellite for dust (for given wave length)	0/20/107	150/150	inst	–	$m^{-1}\,sr^{-1}$
CEIL_BSC_DUST	Attenuated backscatter from ground (ceilometer) for dust (for given wave length)	0/20/108	150/150	inst	–	$m^{-1}\,sr^{-1}$
CEIL_BSC_DUST	Attenuated backscatter from ground (ceilometer) for dust (for given wave length)	0/20/108	150/150	inst	–	$m^{-1}\,sr^{-1}$

Continued on next page

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

Table 5.3.: *continued*

DUSTA	Modal prognostic mass mixing ratio of mineral dust particles (fine mode)[4]	0/20/2	150/150	inst	–	$kg\,kg^{-1}$
DUSTB	Modal prognostic mass mixing ratio of mineral dust particles (medium mode)[4]	0/20/2	150/150	inst	–	$kg\,kg^{-1}$
DUSTC	Modal prognostic mass mixing ratio of mineral dust particles (coarse mode)[4]	0/20/2	150/150	inst	–	$kg\,kg^{-1}$
DUSTA0	Modal prognostic specific number concentration of mineral dust particles (fine mode)	0/20/60	150/150	inst	–	kg^{-1}
DUSTB0	Modal prognostic specific number concentration of mineral dust particles (medium mode)	0/20/60	150/150	inst	–	kg^{-1}
DUSTC0	Modal prognostic specific number concentration of mineral dust particles (coarse mode)	0/20/60	150/150	inst	–	kg^{-1}
AOD_DUST	Diagnostic mineral dust optical depth	0/20/102	150/150	inst	–	-

The variables `SAT_BSC_DUST` and `CEIL_BSC_DUST` share the same grib key triplet for `discipline`, `parameterCategory` and `parameterNumber`, but are available for different wavelengths, 532 and 1064 nm. They can be distinguished by the grib key `scaledValueOfFirstWavelength` = 532/1064. The variables `DUSTA`, `DUSTB` and `DUSTC`, and likewise `DUSTA0`, `DUSTB0` and `DUSTC0` also share the same grib key triplet, but represent different modes. They can be distinguished by the additional grib keys `numberOfModeOfDistribution`, that indicates the number of modes used, and `modeNumber` = 1,2,3 that indicates which mode number (A: 1=fine, B: 2=medium, C: 3=coarse) is encoded.

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

5.1.3. Multi-level fields interpolated to pressure levels

Fields from standard forecasts

Table 5.4.: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products interpolated to pressure levels

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		$m s^{-1}$

Fields from forecasts employing prognostic mineral dust

Table 5.5.: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products from forecasts employing prognostic mineral dust

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
DUST_MAX_TOTAL_MC_LAYER	Vertical maximum total mass concentration of mineral dust aerosol in a layer	0/20/61	100/100	inst		$kg m^{-3}$

Currently output for seven different layers is generated. The first layer starts at the surface (SFC). Further above the bottom and top of each layer is a certain flight level (FL). Since the FLs are defined as the heights of pressure levels in the ICAO standard atmosphere, these are encoded as the values of `scaledValueOfFirstFixedSurface` and `scaledValueOfSecondFixedSurface`. The following levels are used to define the layers: SFC: 101325, FL050: 84307, FL100: 69682, FL140: 59524, FL180: 50600, FL250: 37601, FL350: 23842, FL450: 14748 Pa.

5.1.4. Single-level fields

Table 5.6.: 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	BCT	$\mathrm{W\,m^{-2}}$
APAB_S	Photosynthetically active radiation flux at surface (average since model start)	0/4/10	1/–	avg	BCT	$\mathrm{W\,m^{-2}}$
ASHFL_S	Sensible heat net flux at surface (average since model start)	0/0/11	1/–	avg	BCT	$\mathrm{W\,m^{-2}}$
ASOB_S	Net short-wave radiation flux at surface (average since model start)	0/4/9	1/–	avg	BCT	$\mathrm{W\,m^{-2}}$
ASOB_S_OS	Net short wave radiation flux at surface on horizontal plane including orographic shading	0/4/9	208/–	avg		$\mathrm{W\,m^{-2}}$
ASOB_S_TAN_OS	Net short wave radiation flux at surface on tangent plane to terrain including orographic shading	0/4/9	209/–	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	BCT	$\mathrm{W\,m^{-2}}$
ASOB_S_CS	Net clear sky short-wave radiation flux at surface (average since model start)	0/4/11	1/–	avg	BCT	$\mathrm{W\,m^{-2}}$
ASWDIFD_S	Surface down solar diffuse radiation (average since model start)	0/4/199	1/–	avg	BCT	$\mathrm{W\,m^{-2}}$
ASWDIFU_S	Surface up solar diffuse radiation (average since model start)	0/4/8	1/–	avg	BCT	$\mathrm{W\,m^{-2}}$
ASWDIR_S	Surface down solar direct radiation (average since model start)	0/4/198	1/–	avg	BCT	$\mathrm{W\,m^{-2}}$
ASWDIR_S_OS	Downward direct short wave radiation flux at surface on horizontal plane including orographic shading	0/4/198	208/–	avg		$\mathrm{W\,m^{-2}}$

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Table 5.6.: *continued*

ATHB_S	Net long-wave radiation flux at surface (average since model start)	0/5/5	1/–	avg	BCT	$\mathrm{W\,m^{-2}}$
ATHB_T	Net long-wave radiation flux at TOA (average since model start)	0/5/5	8/–	avg	BCT	$\mathrm{W\,m^{-2}}$
AUMFL_S	U-momentum flux at surface $\overline{\rho u'w'}$ (average since model start)	0/2/17	1/–	avg	BCT	$\mathrm{N\,m^{-2}}$
AVMFL_S	V-momentum flux at surface $\overline{\rho v'w'}$ (average since model start)	0/2/18	1/–	avg	BCT	$\mathrm{N\,m^{-2}}$
CAPE_CON	Convective available potential energy	0/7/6	1/–	inst	NNB	$\mathrm{J\,kg^{-1}}$
CAPE_ML	Convective Available Potential Energy, mean layer	0/7/6	192/–	inst	NNB	$\mathrm{J\,kg^{-1}}$
CAPE_MU	Convective Available Potential Energy, most unstable	0/7/6	193/–	inst	NNB	$\mathrm{J\,kg^{-1}}$
CEILING	Ceiling height (above MSL)	0/6/13	2/101	inst		m
CIN_ML	Convective Inhibition, mean layer	0/7/7	192/–	inst	NNB	$\mathrm{J\,kg^{-1}}$
CIN_MU	Convective Inhibition, most unstable	0/7/7	193/–	inst	NNB	$\mathrm{J\,kg^{-1}}$
CLCH	High level clouds	0/6/22	100/100	inst		%
CLCL	Low level clouds	0/6/22	100/1	inst		%
CLCM	Mid level clouds	0/6/22	100/100	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
DBZCMP_SIM	Composite reflectivity from simulated low-elevation radar scans	0/16/5	-/-	inst	–	dBZ
DBZLMX_LOW	Radar reflectivity maximum in the layer $1000-2000\,\mathrm{m}$ AGL	0/15/4	103/103	inst	–	dBZ
DBZ_850	Radar Reflectivity in approx. 850 hPa	0/15/1	1/–	inst	–	dBZ
DBZ_CMAX	Column Maximum Radar Reflectivity	0/15/1	1/8	inst	–	dBZ
DBZ_CTMAX	Column Maximum Radar Reflectivity, maximum over last hour	0/15/1	1/8	max	–	dBZ
ECHOTOP	Echotop-pressure: smallest pressure where radar reflectivity above a threshold is present	0/3/0	25/–	accu		Pa

Continued on next page

Table 5.6.: *continued*

ECHOTOPINM	Echotop-height: largest height where radar reflectivity above a threshold is present	0/3/6	25/–	accu		Pa
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
GRAU_GSP[5]	Large scale graupel (accumulated since model start)	0/1/75	1/–	accu	BCT	$kg\,m^{-2}$
HBAS_CON	Height of convective cloud base above MSL	0/6/26	2/101	inst	NNB	m
HBAS_SC	Height of shallow convective cloud base above MSL	0/6/192	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
HTOP_SC	Height of shallow convective cloud top above MSL	0/6/193	3/101	inst	NNB	m
HZEROCL	Height of 0 degree Celsius isotherm above MSL	0/3/6	4/101	inst	NNB	m
LPI	Lightning Potential Index	0/17/192	1/–	inst	NNB	$J\,kg^{-1}$
LPI_MAX	Maximum Lightning Potential Index	0/17/192	1/–	max	NNB	$J\,kg^{-1}$
LPI_CON_MAX	Maximum Lightning Potential Index from convection scheme	0/17/5	1/–	max	BCT	$J\,kg^{-1}$
MCONV	Horizontal moisture convergence	0/1/26	103/103	inst		$kg\,kg^{-1}\,s^{-1}$
PMSL	Surface pressure reduced to MSL	0/3/1	101/–	inst		Pa
PRG_GSP	Precipitation rate of large scale graupel	0/1/75	1/–	inst	BCT	$kg\,m^{-2}\,s^{-1}$
PRR_GSP	Precipitation rate of large scale rain	0/1/77	1/–	inst	BCT	$kg\,m^{-2}\,s^{-1}$
PRS_GSP	Precipitation rate of large scale snow	0/1/56	1/–	inst	BCT	$kg\,m^{-2}\,s^{-1}$
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		$kg\,kg^{-1}$

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Table 5.6.: *continued*

RAIN_CON[5]	Convective rain (accumulated since model start)	0/1/76	1/–	accu	BCT	kg m^{-2}
RAIN_GSP[5]	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	BCT	kg m^{-2}
RUNOFF_S	Surface water runoff (accumulated since model start)	2/0/5	106/–	accu	BCT	kg m^{-2}
SDI2	Supercell Detection Index 2	0/7/193	1/–	inst	NNB	s^{-1}
SNOWC	Snow cover	0/1/42	1/–	inst		%
SNOW_CON[5]	Convective snowfall water equivalent (accumulated since model start)	0/1/55	1/–	accu	BCT	kg m^{-2}
SNOW_GSP[5]	Large scale 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
SOBS_RAD	Net short-wave radiation flux at surface (instantaneous)	0/4/9	1/–	inst		W m^{-2}
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	BCT	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
TCOND_MAX	column integrated condensate, maximum over the last hour	0/1/81	1/8	max		kg m^{-2}
TCOND10_MAX	as TCOND_MAX, but integration only above $z(T = -10°C)$	0/1/81	20/8	max		kg m^{-2}
TD_2M	Dew point temperature at 2m above ground	0/0/6	103/–	inst	BCT	K
T_G	Ground temperature (temperature at sfc-atm interface)	0/0/0	1/–	inst		K

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Table 5.6.: *continued*

THBS_RAD	Net long-wave radiation flux at surface (instantaneous)	0/5/5	1/–	inst		$W\,m^{-2}$
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_PR	Total precipitation rate	0/1/52	1/–	inst		$kg\,m^{-2}\,s^{-1}$
TOT_PR_MAX	Total precipitation rate (maximum)	0/1/52	1/–	max		$kg\,m^{-2}\,s^{-1}$
TOT_PREC[5]	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		$kg\,m^{-2}$
TQC_DIA	Total column integrated cloud water (including sub-grid-scale contribution)	0/1/215	1/–	inst		$kg\,m^{-2}$
TQG	Column integrated graupel (grid scale)	0/1/74	1/–	inst		$kg\,m^{-2}$
TQH	Column integrated hail (grid scale)	0/1/72	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		$kg\,m^{-2}$
TQV_DIA	Total column integrated water vapour (including sub-grid-scale contribution)	0/1/214	1/–	inst		$kg\,m^{-2}$
TWATER	Column integrated water (grid scale)	0/1/78	1/–	inst		$kg\,m^{-2}$
T_S[6]	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 5.6.: *continued*

U_10M_AV	Zonal wind at 10m above ground - 10 min. time average	0/2/2	103/–	avg		$m\,s^{-1}$
UH_MAX	updraft helicity (vertically averaged over the interval [2 km, 8 km]), maximum over last hour	0/7/15	102/102	max		$m^2\,s^{-2}$
UH_MAX_LOW	updraft helicity (vertically averaged over the interval [0 km, 3 km]), maximum over last hour	0/7/15	102/102	max		$m^2\,s^{-2}$
UH_MAX_MED	updraft helicity (vertically averaged over the interval [2 km, 5 km]), maximum over last hour	0/7/15	102/102	max		$m^2\,s^{-2}$
USTAR	Friction velocity	0/2/30	1/–	inst		$m\,s^{-1}$
USTAR_THRES	Threshold friction velocity	0/2/203	1/–	inst		$m\,s^{-1}$
V_10M	Meridional wind at 10m above ground	0/2/3	103/–	inst		$m\,s^{-1}$
V_10M_AV	Meridional wind at 10m above ground - 10 min. time average	0/2/3	103/–	avg		$m\,s^{-1}$
VIS	Visibility	0/19/0	1/–	inst		m
VMAX_10M	Maximum wind at 10 m above ground	0/2/22	103/–	max		$m\,s^{-1}$
VORW_CTMAX	vorticity (vertically averaged), maximum of absolute value over last hour	0/2/206	102/102	max		s^{-1}
W_CTMAX	vertical velocity (maximum value), maximum over last hour	0/2/207	102/102	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 6.1 for details.	0/19/25	1/–	inst	NNB	1
Z0	Surface roughness (above land and water)	2/0/1	1/–	inst		m

[5] 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.

[6] 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.

5.1.5. Lake-specific single-level fields

Table 5.7.: 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

5.1.6. Dust-specific single-level fields

Table 5.8.: Single-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products of the ensemble members with prognostic dust

ShortName	Description	Discipline Category Number	Lev-Typ 1/2	stepType	LL IntpType	Unit
DUST_TOTAL _MC_VI	Column integrated mineral dust aerosol	0/20/1	10/-	inst	–	$kg\,m^{-2}$
TAOD_DUST	Total atmosphere optical depth due to mineral dust aerosol	0/20/102	10/-	inst	–	-
ACCEMISS _DUSTA	Accumulated dust Emission for mode A [7]	0/20/3	1/–	accu	–	$kg\,m^{-2}$
ACCEMISS _DUSTB	Accumulated dust Emission for mode B [7]	0/20/3	1/–	accu	–	$kg\,m^{-2}$
ACCEMISS _DUSTC	Accumulated dust Emission for mode C [7]	0/20/3	1/–	accu	–	$kg\,m^{-2}$
ACCDRYDEPO _DUSTA	Accumulated dry deposition for mode A [7]	0/20/6	1/–	accu	–	$kg\,m^{-2}$

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Table 5.8.: *continued*

ACCDRYDEPO _DUSTB	Accumulated dry deposition for mode B [7]	0/20/6	1/–	accu	–	$kg\,m^{-2}$
ACCDRYDEPO _DUSTC	Accumulated dry deposition for mode C [7]	0/20/6	1/–	accu	–	$kg\,m^{-2}$
ACCWETDEPO _GSP_DUSTA	Accumulated wet deposition by grid scale precipitation of dust for mode A [7]	0/20/9	1/–	accu	–	$kg\,m^{-2}$
ACCWETDEPO _GSP_DUSTB	Accumulated wet deposition by grid scale precipitation of dust for mode B [7]	0/20/9	1/–	accu	–	$kg\,m^{-2}$
ACCWETDEPO _GSP_DUSTC	Accumulated wet deposition by grid scale precipitation of dust for mode C [7]	0/20/9	1/–	accu	–	$kg\,m^{-2}$
ACCWETDEPO _CON_DUSTA	Accumulated wet deposition by convective precipitation of dust for mode A [7]	0/20/10	1/–	accu	–	$kg\,m^{-2}$
ACCWETDEPO _CON_DUSTB	Accumulated wet deposition by convective precipitation of dust for mode B [7]	0/20/10	1/–	accu	–	$kg\,m^{-2}$
ACCWETDEPO _CON_DUSTC	Accumulated wet deposition by convective precipitation of dust for mode C [7]	0/20/10	1/–	accu	–	$kg\,m^{-2}$
ACCSEDIM _DUSTA	Accumulated sedimentation for mode A [7]	0/20/11	1/–	accu	–	$kg\,m^{-2}$
ACCSEDIM _DUSTB	Accumulated sedimentation for mode B [7]	0/20/11	1/–	accu	–	$kg\,m^{-2}$
ACCSEDIM _DUSTC	Accumulated sedimentation for mode C [7]	0/20/11	1/–	accu	–	$kg\,m^{-2}$

[7] The grib key `modeNumber` is used as additional identifier to distinguish the different modes, with A: 1, B: 2, C: 3.

5.1.7. Soil-specific multi-level fields

Table 5.9.: 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 5.10 (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 5.10.: 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

5.1.8. 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 5.11.: 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	–	$\mathrm{W\,m^{-2}}$
ALHFL_PL	Latent heat flux from plants	2/0/194	106/106	avg	–	$\mathrm{W\,m^{-2}}$
RSTOM	Stomatal resistance	2/0/195	1/–	inst	–	$\mathrm{s\,m^{-1}}$

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

6. Extended description of available output fields

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

6.1. Cloud products

CEILING Ceiling is that height above MSL (in m), where the large scale cloud coverage (more precise: scale and sub-scale, but without the convective contribution) first exceeds 50% when starting from ground.

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

ICON-D2:
DBZ_850
DBZ_CMAX
DBZ_CTMAX
Synthetic Rayleigh-type approximation of radar reflectivity in dBZ, as a function of the model variables rain water `QR`, snow water content `QR`, graupel content `QG` and temperature `T`. `DBZ_850` is the radar reflectivity at approximately 850 hPa, `DBZ_CMAX` is the maximum within the entire grid column, and `DBZ_CTMAX` is the maximum within the entire grid column over the last hour.

ICON-D2-RUC:
DBZ_850
DBZLMX_LOW
DBZ_CMAX
DBZ_CTMAX
DBZCMP_SIM
DBZSCAN_SIM
Synthetic radar reflectivity using Mie-scattering methods of EMVORADO including a detailed scheme for simulating effects of partially melted particles like melting snow, graupel and hail, known as "bright band" (Blahak, 2016, Blahak and de Lozar, 2021, Zeng et al., 2016). It is based on the mass- and number densities of all hydrometeor types including hail as well as temperature. `DBZ_850`, `DBZ_CMAX` and `DBZ_CTMAX` are defined as above. `DBZLMX_LOW` is the maximum reflectivity in the layer $1000-2000$ m AGL. `DBZCMP_SIM` is a composite of simulated near-surface radar scans (the so-called precipitation scans of all DWD radars) and is a better approximation of the usual radar observation composites as `DBZ_850` and `DBZLMX_LOW`. It comprises effects of the measuring height, propagation effects (attenuation, beam broadening) and effects of compositing in regions of overlapping measuring ranges. On the other hand, `DBZCMP_SIM` is only available for the measuring ranges of the German radars and is set to "no data" (-999.99) elsewhere. `DBZSCAN_SIM` are the radar volume scans on native polar coordinates. As `DBZCMP_SIM` the quantity `DBZSCAN_SIM` is only available within the specifications (range, elevations, resolution) of the German radars.

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

HBAS_SC Height of the convective cloud base in m above MSL, but only the shallow convection part is active.

HTOP_CON Same as HBAS_CON, but for cloud top.

HTOP_SC Same as HBAS_SC, but for cloud top.

6.2. Atmospheric products

HTOP_DC Height of the top of dry convection above MSL. It is the upper limit of dry thermals rising from near the surface. At grid points without dry convection the value is zero, or the surface height at points below MSL.

HZEROCL Height of the 0° C isotherm above MSL. In case of multiple 0° C isotherms, `HZEROCL` contains the *uppermost* one. If the temperature is below 0° C throughout the entire atmospheric column, `HZEROCL` is set equal to the topography height (fill value).

Note that prior to 2019-07-30, `HZEROCL` contains the height of the *lowermost* 0° C isotherm. At grid points where no 0° C isotherm could be diagnosed, a fill value of 0 is used.

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).

6.3. Radiation products

Some of the products listed below have undergone time-averaging. For more details on the averaging process we refer to Section 7.1.

ALB_RAD $\widehat{=} \alpha$ Ratio of upwelling to downwelling diffuse radiative flux for wavelength interval [0.3 μm, 5.0 μm]. 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 %.

ASOB_S $\widehat{=} \overline{F}^{net}_{sw,s}$ Shortwave net radiation flux at the surface, averaged over forecast time.

ASOB_T Shortwave net radiation flux at the top of the model atmosphere, averaged over forecast time.

ASOB_S_CS Clear sky shortwave net radiation flux at the surface, averaged over forecast time.

ASOB_S_OS Net short wave radiation flux at surface on horizontal plane including orographic shading.

ASOB_S_TAN_OS Net short wave radiation flux at surface on tangent plane to terrain including orographic shading.

ASWDIFD_S $\widehat{=} \overline{F}^{\downarrow dif}_{sw,s}$ Downward solar diffuse radiation flux at the surface, averaged over forecast time.

ASWDIFU_S $\widehat{=} \overline{F}^{\uparrow dif}_{sw,s}$ Upward solar diffuse radiation flux at the surface, averaged over forecast time.

ASWDIR_S $\widehat{=} \overline{F}^{\downarrow dir}_{sw,s}$ Downward solar direct radiation flux at the surface, averaged over forecast time. This quantity is not directly provided by the radiation scheme. It is a-posteriori diagnosed from the definition of the surface net shortwave radiation flux $F^{net}_{sw,s}$

$$F^{net}_{sw,s} = F^{\downarrow dir}_{sw,s} + F^{\downarrow dif}_{sw,s} - F^{\uparrow dif}_{sw,s} .$$

Solving this equation for $F^{\downarrow dir}_{sw,s}$, one arrives at

$$\overline{F}^{\downarrow dir}_{sw,s} = \overline{F}^{net}_{sw,s} - \overline{F}^{\downarrow dif}_{sw,s} + \overline{F}^{\uparrow dif}_{sw,s} .$$

The overbar denotes a time average over the forecast time.

ASWDIR_S_OS Downward direct short wave radiation flux at surface on horizontal plane including orographic shading.

From $\overline{F}^{\downarrow dif}_{sw,s}$ and $\overline{F}^{\downarrow dir}_{sw,s}$ the time averaged global radiation at the surface $\overline{F}^{\downarrow tot}_{sw,s}$ can easily be computed as follows:

$$\overline{F}^{\downarrow tot}_{sw,s} = \overline{F}^{\downarrow dif}_{sw,s} + \overline{F}^{\downarrow dir}_{sw,s}$$

An estimate of $\overline{F}^{\downarrow tot}_{sw,s}$ can also be derived from the surface net solar radiation flux $\overline{F}^{net}_{sw,s}$ and albedo α:

$$\overline{F}^{\downarrow tot}_{sw,s} = \frac{\overline{F}^{net}_{sw,s}}{1 - 0.01\,\alpha}$$

However be aware that this is only approximately true, as α (`ALB_RAD`) is an instantaneous field. In addition α only constitutes the albedo for the diffuse component of the incoming solar radiation ("white sky" albedo). $\overline{F}^{net}_{sw,s}$, however, 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.

6.4. 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.) Especially in situations with partial snow cover the minimum temperature `TMIN_2M` of a grid point and time interval can be much lower than any instantaneous 2 m temperature `T_2M` during that time interval. The reason is that `T_2M` is defined as the average over all tiles of a grid point, while `TMIN_2M` is based on the minimum temperature of all tiles.

TMAX_2M Same, but for maximum 2 m temperature.

VIS Near surface visibility in m.

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.)

6.5. Surface products

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 initialised with H_ICE $= 0.5$ m.

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

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

and is limited to H_SNOW ≤ 40 m.

LPI The Lightning Potential Index after Lynn and Yair (2010). It is calculated as a vertical integral of the squared updraft velocity weighted by a function that essentially contains the graupel concentration. Therefore, the graupel scheme must be necessarily switched on and consequently the LPI can be calculated only in a convection-permitting model setup.

LPI_MAX as LPI, but the maximum value over the last hour is delivered.

LPI_CON_MAX The Maximum Lightning Potential Index from convection scheme is based on Lynn and Yair (2010) and Lopez (2016). It is calculated in a similar way as the LPI, only that the updraft velocity and hydrometeors are taken from the Bechtold-Tiedke convection scheme. The variable contains the maximum since the last output.

RHO_SNOW Snow density in kg/m^3. It can vary between $50\,kg/m^3$ for fresh snow and $400\,kg/m^3$ for compacted old snow. At snow-free points over land and over water RHO_SNOW is set to $0\,kg/m^3$. Note that prior to 2019-07-30 RHO_SNOW was set to $50\,kg/m^3$ over snow-free land points.

SDI2 The supercell detection index detects the mesocyclone of a supercell. It is based on the product of a correlation between vertical velocity and vorticity and the local vorticity Wicker et al. (2005).

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, i.e. the temperature of those parts of the ground which are in direct contact with the atmosphere. E.g. at snow-free land points it is the temperature of the soil surface, whereas at snow covered land points it is the temperature of the snow surface.

At snow-free land points T_G is equal to T_SO(0). Likewise, at open water points T_G is equal to T_SO(0), and represents the sea-surface temperature SST (for more details on SST see description of T_SO(0) in Section 6.6). 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. In global simulations (with and without nests) it is
`TOT_PREC = RAIN_GSP + SNOW_GSP + RAIN_CON + SNOW_CON`,
whereas for ICON-D2 it is
`TOT_PREC = RAIN_GSP + SNOW_GSP + GRAU_GSP + RAIN_CON + SNOW_CON`.

TOT_PR_MAX Total precipitation rate maximum. Tracking variable, hence maximum is the maximum in the intervall defined by the Namelist variable `celltracks_intervall` (default: 1 h, RUC: 900 s).

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).

WW Significant weather of the last hour. The predicted weather will be diagnosed hourly at each model grid point and coded as a key number. The latter is called ww-code and represents weather phenomena within the last hour. The interpretation of such weather phenomena from raw model output relies on an independent post-processing method. This technique applies a number of thresholding processes based on WMO criteria. Therefore, a couple of ww-codes may differ from the direct model output (e.g. ww-category snow vs. SNOW_GSP/SNOW_CON). Due to limitations in temporal and spatial resolution, not all ww-codes as defined by the WMO criteria can be determined. However, the simulated ww-code is able to take the following values:
no significant weather/ cloud cover (0, 1, 2, 3), fog (45, 48), drizzle (51, 53, 55, 56, 57), rain (61, 63, 65, 66, 67), solid precip not in showers (71, 73, 75, 77), showery precip (liquid & solid) (80, 81, 82, 85, 86), thunderstorm (95, 96, 99 (only ICON-D2)) (see also Table 6.1).

W_I Water content of interception layer, i.e. the amount of precipitation intercepted by vegetation canopies. 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.

W_CTMAX updraft velocity; delivered is the maximum value between ground and 10 km above ground and during the last hour.

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 3.3 or 8.1).

6.6. 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 6.2, 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).

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 6.1.: 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 6.1 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.

Table 6.2.: 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 sea water. At land points `T_SO(1:7)` provides the prognostic temperature of the soil. The full level depths at which the soil temperature is defined are given in Table 5.10. 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) provides the sea-surface temperature SST (same value at all levels). So far, the SST in ICON is not prognostic. It is read from the analysis at model start and is updated incrementally each day at 00 UTC based on its annual climatological cycle.

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.

6.7. Vertical Integrals

DUST_TOTAL_MC_VI Vertical integral of the mineral dust aerosol mass. Only calculated in forecasts with prognostic mineral dust.

TCOND_MAX The column integrated condensate (i.e. C, I, R, S, G), delivered is the maximum over the last hour.

TCOND10_MAX As TCOND_MAX, but the vertical integration is restricted to heights above $z(T = -10°C)$.

TQx Column integrated water species x, derived from the 3D grid-scale prognostic quantities Qx, with $\mathtt{x} \in \{\mathtt{V}, \mathtt{C}, \mathtt{I}, \mathtt{R}, \mathtt{S}, \mathtt{G}\}$. 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 $\mathtt{x} \in \{\mathtt{C}, \mathtt{I}, \mathtt{V}\}$. 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.

TWATER This is just the sum over all TQx (but can be independently calculated).

UH_MAX Updraft helicity (i.e. the product of vertical velocity and vorticity) that is vertically averaged between 2000 m and 8000 m above ground. Delivered is its maximum value (either positive or negative) over the last hour.

UH_MAX_LOW same as UH_MAX but vertically averaged over the interval $[0\,\mathrm{m}, 3000\,\mathrm{m}]$

UH_MAX_MED same as UH_MAX but vertically averaged over the interval $[2000\,\mathrm{m}, 5000\,\mathrm{m}]$

VORW_CTMAX Vorticity, vertically averaged between the surface and 1500 m above ground. Delivered is its maximum value (either positive or negative) over the last hour.

7. Remarks on statistical processing and horizontal interpolation

7.1. Statistically processed output 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`. More details will be provided in the sections below.

7.1.1. Time-averaged fields

The quantities

ALHFL_S	ASHFL_S	AUMFL_S	AVMFL_S
APAB_S	ASOB_S	ASOB_S_CS	ASOB_S_OS
ASOB_S_TAN_OS	ASOB_T	ATHB_S	ATHB_T
ASWDIR_S	ASWDIR_S_OS	ASWDIFD_S	ASWDIFU_S

constitute time averages over the respective forecast time. The averaging process is performed from forecast start ($t_0 = 0\,\mathrm{s}$) 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 7.1. 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 7.1.: 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

7.1.2. Time-averaged fields over a limited time range

The quantities

U_10M_AV V_10M_AV

constitute time averages over a limited time range, here of a 10 minute interval; more precisely, the 10-min interval ending at the time given in the time stamp (use the additional GRIB2 descriptors indicatorOfUnitForTimeRange=0 (i.e. minute) and lengthOfTimeRange=10).

7.1.3. Accumulated fields

The quantities

RAIN_GSP SNOW_GSP GRAU_GSP RAIN_CON
SNOW_CON TOT_PREC RUNOFF_S RUNOFF_G

as well as

ACCEMISS_DUST[ABC] ACCDRYDEPO_DUST[ABC]
ACCWETDEPO_GSP_DUST[ABC] ACCWETDEPO_CON_DUST[ABC]
ACCSEDIM_DUST[ABC]

for the forecasts including prognostic mineral dust

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 7.2. 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 7.2.: 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

7.1.4. Extreme value fields

The quantities

LPI_MAX	LPI_CON_MAX	TCOND_MAX	TCOND10_MAX
TMAX_2M	TMIN_2M	UH_MAX	UH_MAX_LOW
UH_MAX_MED	VMAX_10M	VORW_CTMAX	W_CTMAX

DBZ_CTMAX

represent extreme values, which are collected over certain time intervals χ, starting from the beginning of the forecast. The interval χ is variable dependent:

- $\chi = 6\,\text{h}$ for TMAX_2M, TMIN_2M
- $\chi = 1\,\text{h}$ for LPI_MAX, TCOND_MAX, TCOND10_MAX, UH_MAX, UH_MAX_LOW, UH_MAX_MED, VMAX_10M, VORW_CTMAX, W_CTMAX, DBZ_CTMAX
- $\chi = 1$, 3, or 6 h, depending on the forecast hour for LPI_CON_MAX

After χ hours of forecast the fields are re-initialized with 0 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 maximum 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 7.3.

`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 7.3.: 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

7.2. Technical Details of the Horizontal Interpolation

To facilitate the practical use of ICON output files, many fields are additionally delivered as interpolated fields on a regular (i.e. geographical) lat-lon or a rotated lat-lon grid. Of course, this means a minimal loss of information on the smallest scales. ICON currently supports three different methods for interpolating data horizontally from the native triangular grid onto a 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 lat-lon 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 (BCT) 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.

8. Global 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 8.1.

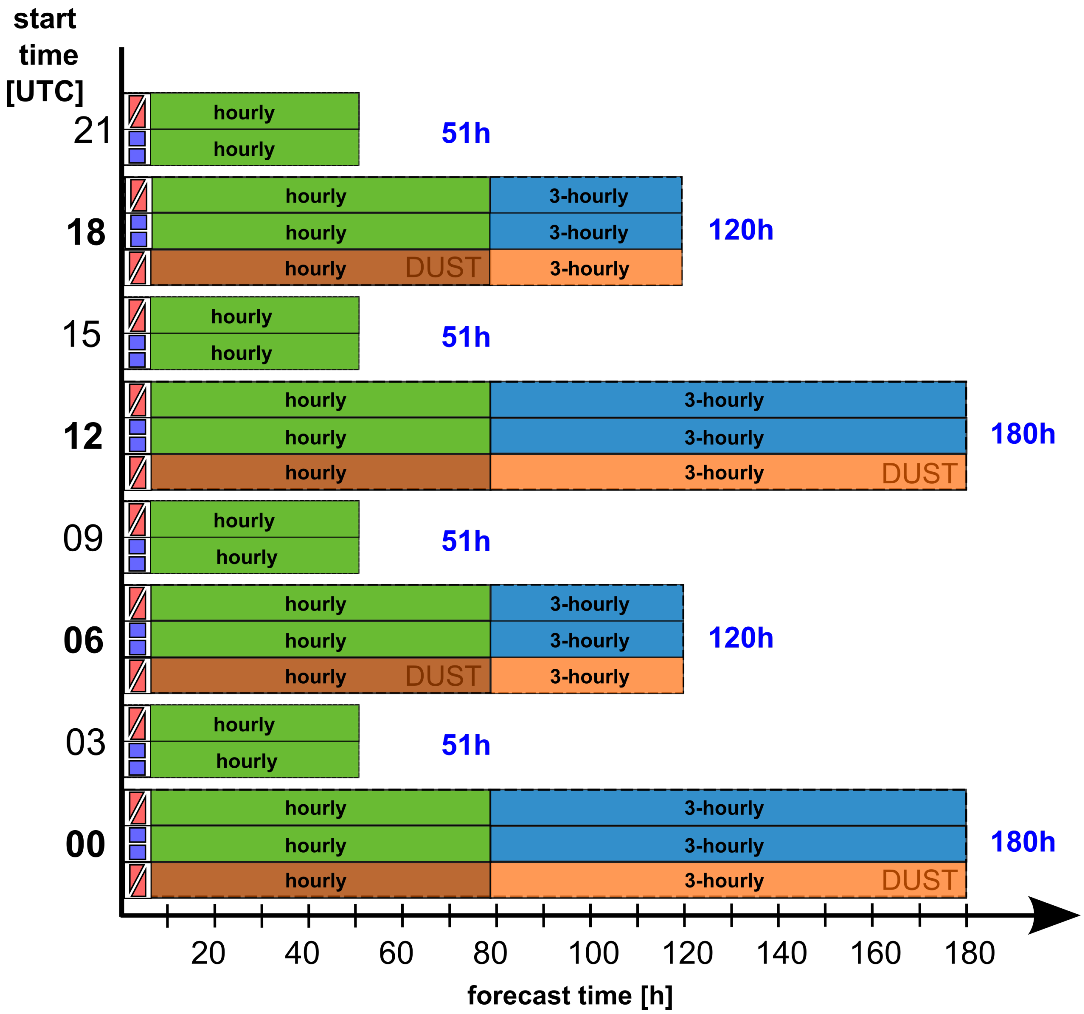

Figure 8.1.: Time span covered by the various global ICON forecasts which are launched every three hours. Output on the native (triangular) grid (▨) and the regular grid (▤) is generally available until forecast end, as indicated by the lenght of the two bars shown for each forecast run. Output fields are available hourly up to $VV = 78\,\mathrm{h}$ and 3-hourly for larger forecast times (for exceptions see the following tables). Forecasts with prognostic mineral dust (indicated by the brown colorbars) are launched every six hours, and are available only on the native (triangular) grid.

Main forecasts are performed 4 times a day at 0, 6, 12, 18 UTC, covering a forecast time span of 180 h 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 forecast time covered by these runs is limited to 51 h since one main purpose of these runs is to provide boundary data for the high resolution ICON-D2 runs from the ICON nest. These short-range forecasts are not available for forecasts employing prognostic mineral dust. Furthermore, output by the forecasts employing prognostic mineral dust is available on the native (triangular) grid only.

See Chapter 9 for more details on the ICON nest and the available output fields.

In general, 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 the previously used global model GME (hours).

Output is available on two distinct horizontal grids:

- The *native triangular grid* with an average resolution of 13 km that covers the earth with 2949120 triangles
- a *regular latitude-longitude grid* with a resolution of $\Delta\lambda = \Delta\Phi = 0.25°$ (see table 8.1)

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.

	global lat-lon
geogr. coordinates	0.0° – 359.75°
	90.0° S – 90.0° N
mesh size	0.25°
no. of grid points	1038240 (= 721 × 1440)

Table 8.1.: Summary of the latitude-longitude grid for ICON global output.

For details regarding the available fields, please see the tables below. A few remarks about the column 'Time range': listed is the output time range in hours, followed by the output intervall (also in hours). The time range is given for the longest runs (i.e. the 00 and 12 UTC runs); of course, for the shorter runs at 03, 06, 09, 15, 18, 21 UTC, output is only available until the end of the forecast range.

8.1. Time-constant (external parameter) fields

One should distinguish between **time-constant** or **invariant** fields that can be extracted from the database by means of the sky-category parameter (`CAT_NAME=$model_const_an_$suite`) and **variables exclusively available for** $VV = 0$ that can be extracted via (`CAT_NAME=$model_$run_fc_$suite`, $s[h] = 0$) .

Table 8.2.: Time-constant (external parameter) fields

ShortName	Time range	Det.	EPS	latlon	native	level type
ALB_SEAICE	t=0	✓			✓	
CLAT	t=0	✓			✓	

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 8.2.: *continued*

	t=0		✓		✓	
CLON	t=0	✓			✓	
	t=0		✓		✓	
C_T_LK	t=0	✓			✓	
DEPTH_LK	t=0	✓		✓	✓	
ELAT	t=0	✓			✓	
	t=0		✓		✓	
ELON	t=0	✓			✓	
	t=0		✓		✓	
EVAP_PL	t=0	✓			✓	
FRESHSNW	t=0	✓			✓	
FR_ICE	t=0	✓			✓	
FR_LAKE	t=0	✓		✓	✓	
FR_LAND	t=0	✓		✓	✓	
	t=0		✓		✓	
HHL	t=0	✓		✓	✓	m
	t=0		✓		✓	m
HSNOW_MAX	t=0	✓			✓	
HSURF	t=0	✓		✓	✓	
	t=0		✓		✓	
H_ICE	t=0	✓			✓	
H_ML_LK	t=0	✓			✓	
H_SNOW	t=0	✓			✓	
LAI	t=0	✓		✓	✓	
NDVIRATIO	t=0	✓			✓	
P	t=0	✓			✓	m
PLCOV	t=0	✓		✓	✓	
QC	t=0	✓			✓	m
QI	t=0	✓			✓	m
QR	t=0	✓			✓	m
QS	t=0	✓			✓	m
QV	t=0	✓			✓	m
QV_S	t=0	✓			✓	
RHO_SNOW	t=0	✓			✓	

Continued on next page

Table 8.2.: *continued*

RLAT	t=0	✓		✓		
RLON	t=0	✓		✓		
ROOTDP	t=0	✓		✓	✓	
SMI	t=0	✓			✓	soil
SNOAG	t=0	✓			✓	
SOILTYP	t=0	✓		✓	✓	
T	t=0	✓			✓	m
T_BOT_LK	t=0	✓			✓	
T_G	t=0	✓			✓	
T_ICE	t=0	✓			✓	
T_MNW_LK	t=0	✓			✓	
T_SNOW	t=0	✓			✓	
T_SO	t=0	✓			✓	soil
T_WML_LK	t=0	✓			✓	
U	t=0	✓			✓	m
V	t=0	✓			✓	m
W	t=0	✓			✓	m
W_I	t=0	✓			✓	
W_SNOW	t=0	✓			✓	
W_SO	t=0	✓			✓	soil
W_SO_ICE	t=0	✓			✓	soil
Z0	t=0	✓			✓	

Table 8.3.: Time-constant (external parameter) fields

ShortName	Time range	Det.	EPS	latlon	native	level type
AER_BC12	invar	✓		✓	✓	
AER_DIF12	invar	✓		✓	✓	
AER_DUST12	invar	✓		✓	✓	
AER_MRAT	invar	✓		✓	✓	
AER_NI12	invar	✓		✓	✓	
AER_ORG12	invar	✓		✓	✓	

Continued on next page

Table 8.3.: *continued*

AER_SO412	invar	✓		✓	✓
AER_SS12	invar	✓		✓	✓
AER_UV12	invar	✓		✓	✓
CLAT	invar	✓			✓
CLON	invar	✓			✓
DEPTH_LK	invar	✓		✓	✓
EMIS_RAD	invar	✓		✓	✓
FOR_D	invar	✓		✓	✓
FOR_E	invar	✓		✓	✓
FR_LAKE	invar	✓		✓	✓
FR_LAND	invar	✓		✓	✓
FR_LUC	invar	✓		✓	✓
HSURF	invar	✓		✓	✓
LAI_MX	invar	✓		✓	✓
NDVI_MAX	invar	✓		✓	✓
PLCOV_MX	invar	✓		✓	✓
ROOTDP	invar	✓		✓	✓
RSMIN	invar	✓		✓	✓
SOILTYP	invar	✓		✓	✓
SSO_GAMMA	invar	✓		✓	✓
SSO_SIGMA	invar	✓		✓	✓
SSO_STDH	invar	✓		✓	✓
SSO_THETA	invar	✓		✓	✓
T_2M_CL	invar	✓		✓	✓
Z0	invar	✓		✓	✓

8.2. Multi-level fields on native hybrid vertical levels

In the following table 8.4 the denotations in the 'level types' mean:

- 'm': output on all model levels (either 90 on main levels or 91 on half (interface) levels)
- 'm39-ke1': output on model levels 39 ... nlev+1 (=lowest level near the ground)
- 'm61-ke1': output on model levels, k=61... nlev+1
- 'm_3': output on model levels 42 - 75

8.2.1. Standard Forecasts

Table 8.4.: Multi-level fields on native hybrid vertical levels

ShortName	Time range	Det.	EPS	latlon	native	level type
CLC	0–78, 1 h	✓		✓	✓	m
	81–180, 3 h	✓		✓	✓	m
DEN	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
DTKE_CON	0–180, 1 h	✓			✓	m61-ke1
	0–36, 1 h		✓		✓	m_3
DTKE_HSH	0–180, 1 h	✓			✓	m61-ke1
	0–36, 1 h		✓		✓	m_3
P	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
	0–78, 1 h	✓		✓		m39-ke1
	81–180, 3 h	✓		✓		m39-ke1
	0–180, 6 h		✓		✓	m
QC	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
	0–78, 1 h	✓		✓		m39-ke1
	81–180, 3 h	✓		✓		m39-ke1
	0–180, 6 h		✓		✓	m
QI	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
	0–78, 1 h	✓		✓		m39-ke1
	81–180, 3 h	✓		✓		m39-ke1
	0–180, 6 h		✓		✓	m
QR	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
QS	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
QV	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
	0–78, 1 h	✓		✓		m39-ke1

Continued on next page

Table 8.4.: *continued*

	81–180, 3 h	✓		✓		m39-ke1
	0–180, 6 h		✓		✓	m
T	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
	0–78, 1 h	✓		✓		m39-ke1
	81–180, 3 h	✓		✓		m39-ke1
	0–180, 6 h		✓		✓	m
TKE	0–180, 1 h	✓			✓	m61-ke1
	0–36, 1 h		✓		✓	m_3
U	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
	0–78, 1 h	✓		✓		m39-ke1
	81–180, 3 h	✓		✓		m39-ke1
	0–180, 6 h		✓		✓	m
V	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
	0–78, 1 h	✓		✓		m39-ke1
	81–180, 3 h	✓		✓		m39-ke1
	0–180, 6 h		✓		✓	m
W	0–78, 1 h	✓			✓	m
	81–180, 3 h	✓			✓	m
	0–78, 1 h	✓		✓		m39-ke1
	81–180, 3 h	✓		✓		m39-ke1

8.2.2. Forecasts employing prognostic mineral dust

> Forecasts employing prognostic mineral dust also provide the “standard” meteorological variables. However, they are only made available on the native grid, there is no interpolation to lat-lon.

Table 8.5.: Dust-specific multi-level fields on native hybrid vertical levels

ShortName	Time range	Det.	EPS	latlon	native	level type
AOD_DUST	0–48, 6 h	✓			✓	m

Continued on next page

Table 8.5.: *continued*

	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
CEIL_BSC_DUST					
(1064 nm)	0–48, 6 h	✓		✓	m
	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
CEIL_BSC_DUST					
(532 nm)	0–48, 6 h	✓		✓	m
	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
CLC	0–78, 1 h	✓		✓	m39-ke1
	81–180, 3 h	✓		✓	m39-ke1
DEN	0–78, 1 h	✓		✓	m39-ke1
	81–180, 3 h	✓		✓	m39-ke1
DTKE_CON	0–48, 1 h	✓		✓	m61-ke1
	0–36, 1 h		✓	✓	m_3
DTKE_HSH	0–48, 1 h	✓		✓	m61-ke1
	0–36, 1 h		✓	✓	m_3
DUSTA	0–48, 6 h	✓		✓	m
	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
DUSTA0	0–48, 6 h	✓		✓	m
	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
DUSTB	0–48, 6 h	✓		✓	m
	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
DUSTB0	0–48, 6 h	✓		✓	m

Continued on next page

Table 8.5.: *continued*

	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
DUSTC	0–48, 6 h	✓		✓	m
	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
DUSTC0	0–48, 6 h	✓		✓	m
	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
DUST_TOTAL_MC	0–180, 3 h	✓		✓	m
	0–180, 3 h		✓	✓	m
P	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m
	0–180, 6 h		✓	✓	m
QC	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m
	0–180, 6 h		✓	✓	m
QI	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m
	0–180, 6 h		✓	✓	m
QR	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m
QS	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m
QV	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m
	0–180, 6 h		✓	✓	m
SAT_BSC_DUST					
(1064 nm)	0–48, 6 h	✓		✓	m
	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m

Continued on next page

Table 8.5.: *continued*

SAT_BSC_DUST					
(532 nm)	0–48, 6 h	✓		✓	m
	60–180, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–180, 12 h		✓	✓	m
T	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m
	0–180, 6 h		✓	✓	m
TKE	0–48, 1 h	✓		✓	m61-ke1
	0–36, 1 h		✓	✓	m_3
U	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m
	0–180, 6 h		✓	✓	m
V	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m
	0–180, 6 h		✓	✓	m
W	0–78, 1 h	✓		✓	m
	81–180, 3 h	✓		✓	m

8.3. Multi-level fields interpolated to pressure levels

There are several 'level types' for output on pressure levels. In the following table 8.6 they are denoted as

- p2: output on pressure levels 30, 50, 70, 100, 150, 200, 250, 300, 400, 500, 600, 700, 800, 850, 900, 925, 950, 1000 hPa
- p3: output on pressure levels 5, 10, 30, 50, 70, 100, 125, 150, 175, 200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 775, 800, 825, 850, 875, 900, 925, 950, 975, 1000 hPa
- p4: output on pressure levels 0.1, 1, 2 hPa
- pe1: output on pressure levels 1, 2, 5, 10, 30, 50, 70, 100, 200 hPa
- pe2: output on pressure levels 250 hPa
- pe3: output on pressure levels 300, 400, 500, 700, 850, 900, 925, 950, 1000 hPa
- pe4: output on pressure levels 500 hPa
- pd7: output of the maximum in a layer defined by certain flight levels (FL), which correspond to pressure levels in the ICAO standard atmosphere
  SFC: 101325, FL050: 84307, FL100: 69682, FL140: 59524, FL180: 50600, FL250: 37601, FL350: 23842, FL450: 14748 Pa

8.3.1. Standard Forecasts

Table 8.6.: Multi-level fields interpolated to pressure levels

ShortName	Time range	Det.	EPS	latlon	native	level type
CLC	0–78, 1 h	✓		✓		p3
	81–180, 3 h	✓		✓		p3
FI	0–78, 1 h	✓			✓	p2
	81–180, 3 h	✓			✓	p2
	0–78, 1 h	✓		✓		p3, p4
	81–180, 3 h	✓		✓		p3, p4
	0–75, 1 h		✓		✓	pe3
	75–180, 3 h		✓		✓	pe3
	0–180, 6 h		✓		✓	pe2
	0–72, 6 h		✓		✓	pe1
	72–180, 12 h		✓		✓	pe1
OMEGA	0–78, 1 h	✓		✓		p3
	81–180, 3 h	✓		✓		p3
	0–75, 1 h		✓		✓	pe4
	75–180, 3 h		✓		✓	pe4
RELHUM	0–78, 1 h	✓			✓	p2
	81–180, 3 h	✓			✓	p2
	0–78, 1 h	✓		✓		p3
	81–180, 3 h	✓		✓		p3
	0–75, 1 h		✓		✓	pe3
	75–180, 3 h		✓		✓	pe3
	0–180, 6 h		✓		✓	pe2
	0–72, 6 h		✓		✓	pe1
	72–180, 12 h		✓		✓	pe1
T	0–78, 1 h	✓			✓	p2
	81–180, 3 h	✓			✓	p2
	0–78, 1 h	✓		✓		p3, p4
	81–180, 3 h	✓		✓		p3, p4
	0–75, 1 h		✓		✓	pe3
	75–180, 3 h		✓		✓	pe3

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Table 8.6.: *continued*

	0–180, 6 h		✓		✓	pe2
	0–72, 6 h		✓		✓	pe1
	72–180, 12 h		✓		✓	pe1
U	0–78, 1 h	✓			✓	p2
	81–180, 3 h	✓			✓	p2
	0–78, 1 h	✓		✓		p3, p4
	81–180, 3 h	✓		✓		p3, p4
	0–75, 1 h		✓		✓	pe3
	75–180, 3 h		✓		✓	pe3
	0–180, 6 h		✓		✓	pe2
	0–72, 6 h		✓		✓	pe1
	72–180, 12 h		✓		✓	pe1
V	0–78, 1 h	✓			✓	p2
	81–180, 3 h	✓			✓	p2
	0–78, 1 h	✓		✓		p3, p4
	81–180, 3 h	✓		✓		p3, p4
	0–75, 1 h		✓		✓	pe3
	75–180, 3 h		✓		✓	pe3
	0–180, 6 h		✓		✓	pe2
	0–72, 6 h		✓		✓	pe1
	72–180, 12 h		✓		✓	pe1

8.3.2. Forecasts employing prognostic mineral dust

Table 8.7.: Multi-level fields interpolated to pressure levels

ShortName	Time range	Det.	EPS	latlon	native	level type
DUST_MAX_TOTAL						
_MC_LAYER	0–180, 3 h	✓			✓	pd7
FI	0–78, 1 h	✓			✓	p2
	81–180, 3 h	✓			✓	p2
	0–75, 1 h		✓		✓	pe3
	75–180, 3 h		✓		✓	pe3

Continued on next page

Table 8.7.: *continued*

	0–180, 6 h		✓	✓	pe2
	0–72, 6 h		✓	✓	pe1
	72–180, 12 h		✓	✓	pe1
OMEGA	0–75, 1 h		✓	✓	pe4
	75–180, 3 h		✓	✓	pe4
RELHUM	0–78, 1 h	✓		✓	p2
	81–180, 3 h	✓		✓	p2
	0–75, 1 h		✓	✓	pe3
	75–180, 3 h		✓	✓	pe3
	0–180, 6 h		✓	✓	pe2
	0–72, 6 h		✓	✓	pe1
	72–180, 12 h		✓	✓	pe1
T	0–78, 1 h	✓		✓	p2
	81–180, 3 h	✓		✓	p2
	0–75, 1 h		✓	✓	pe3
	75–180, 3 h		✓	✓	pe3
	0–180, 6 h		✓	✓	pe2
	0–72, 6 h		✓	✓	pe1
	72–180, 12 h		✓	✓	pe1
U	0–78, 1 h	✓		✓	p2
	81–180, 3 h	✓		✓	p2
	0–75, 1 h		✓	✓	pe3
	75–180, 3 h		✓	✓	pe3
	0–180, 6 h		✓	✓	pe2
	0–72, 6 h		✓	✓	pe1
	72–180, 12 h		✓	✓	pe1
V	0–78, 1 h	✓		✓	p2
	81–180, 3 h	✓		✓	p2
	0–75, 1 h		✓	✓	pe3
	75–180, 3 h		✓	✓	pe3
	0–180, 6 h		✓	✓	pe2
	0–72, 6 h		✓	✓	pe1
	72–180, 12 h		✓	✓	pe1

8.4. Single-level fields

8.4.1. Standard Forecasts

Table 8.8.: Single-level fields

ShortName	Time range	Det.	EPS	latlon	native
AER_BC12	invar, 0 h	✓		✓	✓
AER_DIF12	invar, 0 h	✓		✓	✓
AER_DUST12	invar, 0 h	✓		✓	✓
AER_MRAT	invar, 0 h	✓		✓	✓
AER_NI12	invar, 0 h	✓		✓	✓
AER_ORG12	invar, 0 h	✓		✓	✓
AER_SO412	invar, 0 h	✓		✓	✓
AER_SS12	invar, 0 h	✓		✓	✓
AER_UV12	invar, 0 h	✓		✓	✓
ALB_RAD	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
ALHFL_BS	2–24, 1 h	✓			✓
ALHFL_PL	2–24, 1 h	✓			✓
ALHFL_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	6–180, 6 h		✓		✓
APAB_S	0–78, 1 h	✓		✓	
	81–180, 3 h	✓		✓	
ASHFL_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	6–180, 6 h		✓		✓
ASOB_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
ASOB_S_CS	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓

Continued on next page

Table 8.8.: *continued*

ASOB_T	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
ASWDIFD_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	3–180, 3 h		✓		✓
ASWDIFU_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	6–180, 6 h		✓		✓
ASWDIR_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	3–180, 3 h		✓		✓
ATHB_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
ATHB_T	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
AUMFL_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
AVMFL_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
CAPE_CON	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
CAPE_ML	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
CIN_ML	0–78, 1 h	✓		✓	
	81–180, 3 h	✓		✓	
CLAT	invar, 0 h	✓			✓
CLCH	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓

Continued on next page

Table 8.8.: *continued*

	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
CLCL	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
CLCM	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
CLCT	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
CLCT_MOD	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–180, 6 h		✓		✓
CLDEPTH	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
CLON	invar, 0 h	✓			✓
C_T_LK	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
DEPTH_LK	invar, 0 h	✓		✓	✓
EMIS_RAD	invar, 0 h	✓		✓	✓
FOR_D	invar, 0 h	✓		✓	✓
FOR_E	invar, 0 h	✓		✓	✓
FRESHSNW	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
FR_ICE	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–72, 6 h		✓		✓
	72–180, 12 h		✓		✓
FR_LAKE	invar, 0 h	✓		✓	✓
FR_LAND	invar, 0 h	✓		✓	✓

Continued on next page

Table 8.8.: *continued*

FR_LUC	invar, 0 h	✓		✓	✓
HBAS_CON	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
HSURF	invar, 0 h	✓		✓	✓
HTOP_CON	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
HTOP_DC	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
HZEROCL	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
H_ICE	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–72, 6 h		✓		✓
	72–180, 12 h		✓		✓
H_ML_LK	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
H_SNOW	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–72, 6 h		✓		✓
	72–180, 12 h		✓		✓
LAI_MX	invar, 0 h	✓		✓	✓
LPI_CON_MAX	0–48, 1 h	✓			✓
	0–48, 1 h		✓		✓
NDVI_MAX	invar, 0 h	✓		✓	✓
PLCOV_MX	invar, 0 h	✓		✓	✓
PMSL	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
PS	0–78, 1 h	✓		✓	✓

Continued on next page

Table 8.8.: *continued*

	81–180, 3 h	✓		✓	✓
	0–180, 6 h		✓		✓
QV_2M	0–78, 1 h	✓		✓	
	81–180, 3 h	✓		✓	
QV_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
RAIN_CON	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
RAIN_GSP	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
RELHUM_2M	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–180, 6 h		✓		✓
RHO_SNOW	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
ROOTDP	invar, 0 h	✓		✓	✓
RSMIN	invar, 0 h	✓		✓	✓
RSTOM	2–24, 1 h	✓			✓
RUNOFF_G	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
RUNOFF_S	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
SNOW_CON	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
SNOW_GSP	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓

Continued on next page

Table 8.8.: *continued*

SOBS_RAD	0–78, 1 h	✓		✓	
	81–180, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
SOILTYP	invar, 0 h	✓		✓	✓
SSO_GAMMA	invar, 0 h	✓		✓	✓
SSO_SIGMA	invar, 0 h	✓		✓	✓
SSO_STDH	invar, 0 h	✓		✓	✓
SSO_THETA	invar, 0 h	✓		✓	✓
TCH	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
TCM	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
TD_2M	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
THBS_RAD	0–78, 1 h	✓		✓	
	81–180, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
TMAX_2M	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	6–180, 6 h		✓		✓
TMIN_2M	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	6–180, 6 h		✓		✓
TOT_PREC	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
TQC	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓

Continued on next page

Table 8.8.: *continued*

	75–180, 3 h		✓		✓
TQC_DIA	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
TQI	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
TQI_DIA	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
TQR	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
TQS	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
TQV	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
T_2M	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
T_2M_CL	invar, 0 h	✓		✓	✓
T_BOT_LK	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
T_G	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
T_ICE	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
T_MNW_LK	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
T_S	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓

Continued on next page

Table 8.8.: *continued*

T_SNOW	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–72, 6 h		✓		✓
	72–180, 12 h		✓		✓
T_SO	0–180, 6 h		✓		✓
T_WML_LK	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
U_10M	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
	0–180, 1 h	✓		✓	
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
VMAX_10M	1–180, 1 h	✓			✓
	0–180, 1 h	✓		✓	
	1–180, 1 h		✓		✓
V_10M	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
	0–180, 1 h	✓		✓	
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
WW	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
W_I	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
W_SNOW	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
W_SO	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
W_SO_ICE	81–180, 3 h	✓		✓	✓
Z0	invar, 0 h	✓		✓	✓
	0–78, 1 h	✓		✓	✓
	81–180, 3 h	✓		✓	✓

Continued on next page

Table 8.8.: *continued*

	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓

8.4.2. Forecasts employing prognostic mineral dust

Table 8.9.: Single-level fields from forecasts employing prognostic mineral dust

ShortName	Time range	Det.	EPS	latlon	native
ACCDRYDEPO_DUSTA	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCDRYDEPO_DUSTB	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCDRYDEPO_DUSTC	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCEMISS_DUSTA	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCEMISS_DUSTB	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCEMISS_DUSTC	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCSEDIM_DUSTA	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCSEDIM_DUSTB	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCSEDIM_DUSTC	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCWETDEPO					
_CON_DUSTA	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCWETDEPO					
_CON_DUSTB	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
ACCWETDEPO					

Continued on next page

Table 8.9.: *continued*

_CON_DUSTC	0–180, 3 h	✓		✓
	0–180, 3 h		✓	✓
ACCWETDEPO				
_GSP_DUSTA	0–180, 3 h	✓		✓
	0–180, 3 h		✓	✓
ACCWETDEPO				
_GSP_DUSTB	0–180, 3 h	✓		✓
	0–180, 3 h		✓	✓
ACCWETDEPO				
_GSP_DUSTC	0–180, 3 h	✓		✓
	0–180, 3 h		✓	✓
AER_BC12	invar, 0 h	✓		✓
AER_DIF12	invar, 0 h	✓		✓
AER_DUST12	invar, 0 h	✓		✓
AER_NI12	invar, 0 h	✓		✓
AER_ORG12	invar, 0 h	✓		✓
AER_SO412	invar, 0 h	✓		✓
AER_SS12	invar, 0 h	✓		✓
AER_UV12	invar, 0 h	✓		✓
ALB_RAD	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
ALHFL_BS	2–24, 3 h	✓		✓
ALHFL_PL	2–24, 3 h	✓		✓
ALHFL_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	6–180, 6 h		✓	✓
ASHFL_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	6–180, 6 h		✓	✓
ASOB_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
ASOB_S_CS	0–78, 1 h	✓		✓

Continued on next page

Table 8.9.: *continued*

	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
ASOB_T	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
ASWDIFD_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	3–180, 3 h		✓	✓
ASWDIFU_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	6–180, 6 h		✓	✓
ASWDIR_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	3–180, 3 h		✓	✓
ATHB_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
ATHB_T	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
AUMFL_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
AVMFL_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
CAPE_CON	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
CAPE_ML	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓

Continued on next page

Table 8.9.: *continued*

CLAT	invar, 0 h	✓			✓
CLCH	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
CLCL	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
CLCM	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
CLCT	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
	0–75, 1 h		✓		✓
	75–180, 3 h		✓		✓
CLCT_MOD	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
	0–180, 6 h		✓		✓
CLDEPTH	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
CLON	invar, 0 h	✓			✓
C_T_LK	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
DEPTH_LK	invar, 0 h	✓			✓
DUST_TOTAL_MC_VI	0–180, 3 h	✓			✓
	0–180, 3 h		✓		✓
EMIS_RAD	invar, 0 h	✓			✓
FOR_D	invar, 0 h	✓			✓
FOR_E	invar, 0 h	✓			✓
FRESHSNW	0–78, 1 h	✓			✓
	81–180, 3 h	✓			✓
FR_ICE	0–78, 1 h	✓			✓

Continued on next page

Table 8.9.: *continued*

	81–180, 3 h	✓		✓
	0–72, 6 h		✓	✓
	72–180, 12 h		✓	✓
FR_LAKE	invar, 0 h	✓		✓
FR_LAND	invar, 0 h	✓		✓
FR_LUC	invar, 0 h	✓		✓
HBAS_CON	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
HSURF	invar, 0 h	✓		✓
HTOP_CON	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
HTOP_DC	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
HZEROCL	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
H_ICE	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–72, 6 h		✓	✓
	72–180, 12 h		✓	✓
H_ML_LK	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
H_SNOW	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–72, 6 h		✓	✓
	72–180, 12 h		✓	✓
LAI_MX	invar, 0 h	✓		✓
LPI_CON_MAX	0–48, 1 h	✓		✓
	0–48, 1 h		✓	✓
NDVI_MAX	invar, 0 h	✓		✓
NDVI_MRAT	invar, 0 h	✓		✓

Continued on next page

Table 8.9.: *continued*

PLCOV_MX	invar, 0 h	✓		✓
PMSL	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
PS	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–180, 6 h		✓	✓
QV_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
RAIN_CON	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
RAIN_GSP	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
RELHUM_2M	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–180, 6 h		✓	✓
RHO_SNOW	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
ROOTDP	invar, 0 h	✓		✓
RSMIN	invar, 0 h	✓		✓
RSTOM	2–24, 3 h	✓		✓
RUNOFF_G	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
RUNOFF_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
SKD	invar, 0 h	✓		✓
SNOW_CON	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓

Continued on next page

Table 8.9.: *continued*

	75–180, 3 h		✓	✓
SNOW_GSP	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
SOBS_RAD	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
SOILTYP	invar, 0 h	✓		✓
SSO_GAMMA	invar, 0 h	✓		✓
SSO_OROMAX	invar, 0 h	✓		✓
SSO_OROMIN	invar, 0 h	✓		✓
SSO_SIGMA	invar, 0 h	✓		✓
SSO_STDH	invar, 0 h	✓		✓
SSO_THETA	invar, 0 h	✓		✓
TAOD_DUST	0–180, 3 h	✓		✓
	0–180, 3 h		✓	✓
TCH	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
TCM	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
TD_2M	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
THBS_RAD	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
TMAX_2M	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	6–180, 6 h		✓	✓
TMIN_2M	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	6–180, 6 h		✓	✓
TOT_PREC	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓

Continued on next page

Table 8.9.: *continued*

	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
TQC	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
TQC_DIA	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
TQI	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
TQI_DIA	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
TQR	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
TQS	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
TQV	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
T_2M	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
T_2M_CL	invar, 0 h	✓		✓
T_BOT_LK	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
T_G	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
T_ICE	0–78, 1 h	✓		✓

Continued on next page

Table 8.9.: *continued*

	81–180, 3 h	✓		✓
T_MNW_LK	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
T_S	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
T_SEA	invar, 0 h	✓		✓
T_SNOW	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–72, 6 h		✓	✓
	72–180, 12 h		✓	✓
T_SO	0–180, 6 h		✓	✓
T_WML_LK	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
USTAR	0–180, 3 h	✓		✓
USTAR_THRES	0–180, 3 h	✓		✓
U_10M	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
VMAX_10M	1–180, 1 h	✓		✓
	1–180, 1 h		✓	✓
V_10M	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
WW	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
W_I	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
W_SNOW	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
W_SO	0–75, 1 h		✓	✓

Continued on next page

Table 8.9.: *continued*

	75–180, 3 h		✓	✓
W_SO_ICE	81–180, 3 h	✓		✓
Z0	invar, 0 h	✓		✓
	0–78, 1 h	✓		✓
	81–180, 3 h	✓		✓
	0–75, 1 h		✓	✓
	75–180, 3 h		✓	✓
fr_cloa	invar, 0 h	✓		✓
fr_hcla	invar, 0 h	✓		✓
fr_lcla	invar, 0 h	✓		✓
fr_loam	invar, 0 h	✓		✓
fr_lsan	invar, 0 h	✓		✓
fr_sand	invar, 0 h	✓		✓
fr_scla	invar, 0 h	✓		✓
fr_sclo	invar, 0 h	✓		✓
fr_sicl	invar, 0 h	✓		✓
fr_silc	invar, 0 h	✓		✓
fr_silo	invar, 0 h	✓		✓
fr_silt	invar, 0 h	✓		✓
fr_sloa	invar, 0 h	✓		✓
fr_udef	invar, 0 h	✓		✓

8.5. Soil-specific multi-level fields

- soil: soil levels = 0, 1, 3, 9, 27, 81, 243, 729 cm

8.5.1. Standard Forecasts

Table 8.10.: Soil-specific multi-level fields

ShortName	Time range	Det.	EPS	latlon	native	level type
T_SO	0–78, 1 h	✓		✓	✓	soil
	81–180, 3 h	✓		✓	✓	soil

Continued on next page

Table 8.10.: *continued*

ShortName	Time range	Det.	EPS	latlon	native	level type
W_SO	0–78, 1 h	✓		✓	✓	soil
	81–180, 3 h	✓		✓	✓	soil
W_SO_ICE	0–78, 1 h	✓		✓	✓	soil

8.5.2. Forecasts employing prognostic mineral dust

Table 8.11.: Soil-specific multi-level fields from forecasts employing prognostic mineral dust

ShortName	Time range	Det.	EPS	latlon	native	level type
T_SO	0–78, 1 h	✓			✓	soil
	81–180, 3 h	✓			✓	soil
W_SO	0–78, 1 h	✓			✓	soil
	81–180, 3 h	✓			✓	soil
W_SO_ICE	0–78, 1 h	✓			✓	soil

9. EU Nest output fields

This section contains a list of output fields that are available with the launch of the ICON-EU nest. See Fig. 2.7 (top) on page 9 for details regarding the nest location and extent. In the forecasts employing prognostic mineral dust a bigger nest domain ICON-EU-NA[2] is used. For details see Fig. 2.7 (bottom) on page 9.

Forecasts on the EU-nest or respectivly the EU-NA[2]-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 51 h are performed at 03, 09, 15 and 21 UTC. Its main purpose is to provide boundary data for the high resolution ICON-D2 (formerly: COSMO-D2 or COSMO-DE) runs. A schematic overview of the various forecasts, including its forecast period and output intervals is provided in Figure 9.1.

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 9.1 for a summary.

Output on the native (triangular) grid is hourly to 51 h, and every 6 hours for verification from forecast time $\geq$ 54 h 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 9.1. Output of the 10m wind U_10M, V_10M, VMAX_10M and the solar radiation ASWDIR_S and ASWDIFD_S on the regular grid is hourly until the end of the forecast.

Output by the forecasts employing prognostic mineral dust is available on the native (triangular) grid only.

In the subsequent tables the availability of specific fields on the native grid, on the lat-lon grid, or on both grids is denoted. A few remarks about the column 'Time range': listed is the output time range in hours, followed by the output intervall (also in hours). The time range is given for the longest runs (i.e. the 00 and 12 UTC runs); of course, for the shorter runs at 03, 06, 09, 15, 18, 21 UTC, output is only available until the end of the forecast range.

	EU nest lat-lon
geogr. coordinates	23.5° W – 62.5° E,
	29.5° N – 70.5° N
mesh size	0.0625°

Table 9.1.: Summary of the latitude-longitude grid for the ICON-EU nest output.

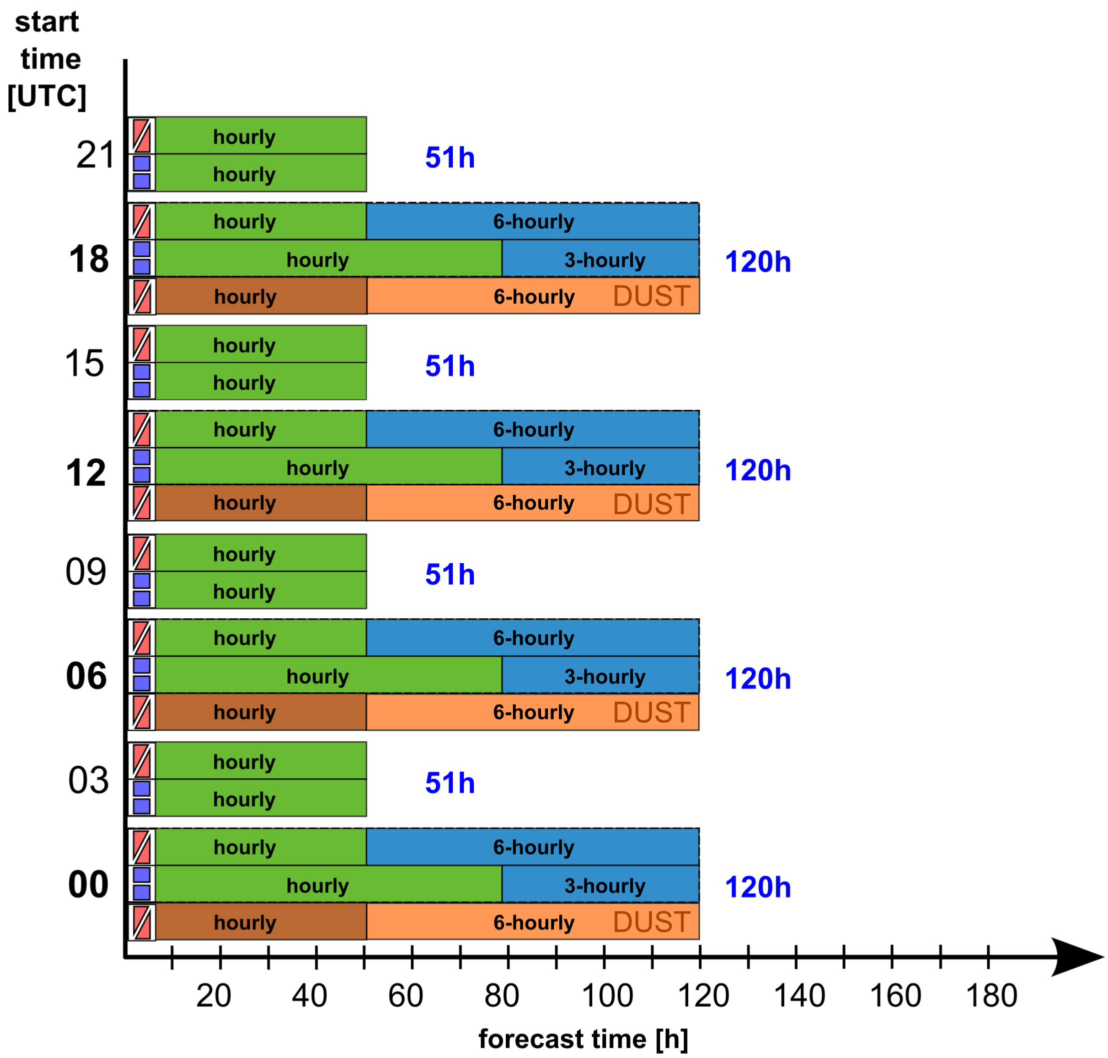

Figure 9.1.: Time span covered by the various EU-nest (or EU-NA^2-nest) forecasts which are launched every three hours. Output on the native (triangular) grid (▨) and the regular grid (▤) is generally available until forecast end, as indicated by the lenght of the two bars shown for each forecast run. Output on the native grid is available hourly to $51\,\mathrm{h}$, and every 6 hours for later forecast times (forecast time $\geq 54\,\mathrm{h}$). Output on the regular grid is available hourly to $78\,\mathrm{h}$, and every 3 hours for later forecast times. Mineral dust forecasts (indicated by brown colorbars) are launched every six hours and are available only on the native (triangular) grid.

9.1. Time-constant (external parameter) fields

9.1.1. Standard Forecasts

Table 9.2.: Time-constant (external parameter) fields

ShortName	Time range	Det.	EPS	latlon	native	level type
ALB_SEAICE	t=0	✓			✓	
CLAT	t=0	✓			✓	
	t=0		✓		✓	
CLON	t=0	✓			✓	
	t=0		✓		✓	
DEPTH_LK	t=0	✓		✓	✓	
ELAT	t=0	✓			✓	
	t=0		✓		✓	
ELON	t=0	✓			✓	
	t=0		✓		✓	
EVAP_PL	t=0	✓			✓	
FR_LAKE	t=0	✓		✓	✓	
FR_LAND	t=0	✓		✓	✓	
	t=0		✓		✓	
HHL	t=0	✓		✓	✓	m
	t=0		✓		✓	m_5
HSNOW_MAX	t=0	✓			✓	
HSURF	t=0	✓		✓	✓	
	t=0		✓		✓	
H_SNOW	t=0	✓			✓	
LAI	t=0	✓		✓	✓	
PLCOV	t=0	✓		✓	✓	
RLAT	t=0	✓		✓		
RLON	t=0	✓		✓		
ROOTDP	t=0	✓		✓	✓	
SMI	t=0	✓			✓	soil
SNOAG	t=0	✓			✓	
SOILTYP	t=0	✓		✓	✓	
Z0	t=0	✓			✓	

Continued on next page

Table 9.2.: *continued*

9.1.2. Forecasts employing prognostic mineral dust

Table 9.3.: Time-constant (external parameter) fields in forecasts employing prognostic mineral dust

ShortName	Time range	Det.	EPS	latlon	native	level type
ALB_SEAICE	t=0	✓			✓	
CLAT	t=0	✓			✓	
	t=0		✓		✓	
CLON	t=0	✓			✓	
	t=0		✓		✓	
DEPTH_LK	t=0	✓			✓	
ELAT	t=0	✓			✓	
	t=0		✓		✓	
ELON	t=0	✓			✓	
	t=0		✓		✓	
EVAP_PL	t=0	✓			✓	
FR_LAKE	t=0	✓			✓	
FR_LAND	t=0	✓			✓	
	t=0		✓		✓	
HHL	t=0	✓			✓	m
	t=0		✓		✓	m
HSNOW_MAX	t=0	✓			✓	
HSURF	t=0	✓			✓	
	t=0		✓		✓	
H_SNOW	t=0	✓			✓	
	t=0		✓		✓	
LAI	t=0	✓			✓	
PLCOV	t=0	✓			✓	
ROOTDP	t=0	✓			✓	
SMI	t=0	✓			✓	soil
SNOAG	t=0	✓			✓	
SOILTYP	t=0	✓			✓	

Continued on next page

Table 9.3.: *continued*

SSO_STDH	t=0	✓			✓	
	t=0		✓		✓	
Z0	t=0	✓			✓	
	t=0		✓		✓	

9.2. Multi-level fields on native hybrid vertical levels

In the following table 9.4 the denotations in the 'level types' mean:

- 'm': output on all model levels
- 'm15-ke1': output on model levels 15 ... nlev+1 (=lowest level near the ground)
- 'm_4': output on model levels 1 - 60
- 'm_5': output on model levels 1 - 61
- 'm_6': output on model levels 12 - 61

9.2.1. Standard Forecasts

Table 9.4.: Multi-level fields on native hybrid vertical levels

ShortName	Time range	Det.	EPS	latlon	native	level type
CLC	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m
DTKE_CON	0–48, 1 h	✓			✓	m15-ke1
	0–36, 1 h		✓		✓	m_6
DTKE_HSH	0–48, 1 h	✓			✓	m15-ke1
	0–36, 1 h		✓		✓	m_6
P	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m
	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m
	0–51, 1 h		✓		✓	m_4
	54–78, 3 h		✓		✓	m_4
	78–120, 6 h		✓		✓	m_4
QC	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m

Continued on next page

Table 9.4.: *continued*

	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m
	0–51, 1 h		✓		✓	m_4
	54–78, 3 h		✓		✓	m_4
	78–120, 6 h		✓		✓	m_4
QI	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m
	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m
	0–51, 1 h		✓		✓	m_4
	51–120, 6 h		✓		✓	m_4
QR	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m
	0–51, 1 h		✓		✓	m_4
QS	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m
	0–51, 1 h		✓		✓	m_4
QV	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m
	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m
	0–51, 1 h		✓		✓	m_4
	54–78, 3 h		✓		✓	m_4
	78–120, 6 h		✓		✓	m_4
T	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m
	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m
	0–51, 1 h		✓		✓	m_4
	54–78, 3 h		✓		✓	m_4
	78–120, 6 h		✓		✓	m_4
TKE	0–48, 1 h	✓			✓	m15-ke1
	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m

Continued on next page

Table 9.4.: *continued*

	0–36, 1 h		✓		✓	m_6
U	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m
	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m
	0–51, 1 h		✓		✓	m_4
	54–120, 6 h		✓		✓	m_4
V	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m
	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m
	0–51, 1 h		✓		✓	m_4
	54–120, 6 h		✓		✓	m_4
W	0–51, 1 h	✓			✓	m
	54–120, 6 h	✓			✓	m
	0–78, 1 h	✓		✓		m
	81–120, 3 h	✓		✓		m
	0–3, 3 h		✓		✓	m_5

9.2.2. Forecasts employing prognostic mineral dust

Table 9.5.: Multi-level fields on native hybrid vertical levels in forecasts employing prognostic mineral dust

ShortName	Time range	Det.	EPS	latlon	native	level type
AOD_DUST	0–48, 6 h	✓			✓	m
	60–120, 12 h	✓			✓	m
	0–48, 6 h		✓		✓	m
	60–120, 12 h		✓		✓	m
CEIL_BSC_DUST						
(1064 nm)	0–48, 6 h	✓			✓	m
	60–120, 12 h	✓			✓	m
	0–48, 6 h		✓		✓	m
	60–120, 12 h		✓		✓	m

Continued on next page

Table 9.5.: *continued*

CEIL_BSC_DUST					
(532 nm)	0–48, 6 h	✓		✓	m
	60–120, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–120, 12 h		✓	✓	m
DTKE_CON	0–48, 1 h	✓		✓	m15-ke1
	0–36, 1 h		✓	✓	m_6
DTKE_HSH	0–48, 1 h	✓		✓	m15-ke1
	0–36, 1 h		✓	✓	m_6
DUSTA	0–48, 6 h	✓		✓	m
	60–120, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–120, 12 h		✓	✓	m
DUSTA0	0–48, 6 h	✓		✓	m
	60–120, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–120, 12 h		✓	✓	m
DUSTB	0–48, 6 h	✓		✓	m
	60–120, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–120, 12 h		✓	✓	m
DUSTB0	0–48, 6 h	✓		✓	m
	60–120, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–120, 12 h		✓	✓	m
DUSTC	0–48, 6 h	✓		✓	m
	60–120, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–120, 12 h		✓	✓	m
DUSTC0	0–48, 6 h	✓		✓	m
	60–120, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–120, 12 h		✓	✓	m
DUST_TOTAL_MC	0–120, 3 h	✓		✓	m

Continued on next page

Table 9.5.: *continued*

	0–120, 3 h		✓	✓	m
P	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–51, 1 h		✓	✓	m_4
	54–78, 3 h		✓	✓	m_4
	78–120, 6 h		✓	✓	m_4
QC	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–51, 1 h		✓	✓	m_4
	54–78, 3 h		✓	✓	m_4
	78–120, 6 h		✓	✓	m_4
QI	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–51, 1 h		✓	✓	m_4
	51–120, 6 h		✓	✓	m_4
QR	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–51, 1 h		✓	✓	m_4
QS	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–51, 1 h		✓	✓	m_4
QV	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–51, 1 h		✓	✓	m_4
	54–78, 3 h		✓	✓	m_4
	78–120, 6 h		✓	✓	m_4
SAT_BSC_DUST					
(1064 nm)	0–48, 6 h	✓		✓	m
	60–120, 12 h	✓		✓	m
	0–48, 6 h		✓	✓	m
	60–120, 12 h		✓	✓	m
SAT_BSC_DUST					
(532 nm)	0–48, 6 h	✓		✓	m
	60–120, 12 h	✓		✓	m

Continued on next page

Table 9.5.: *continued*

	0–48, 6 h		✓	✓	m
	60–120, 12 h		✓	✓	m
T	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–51, 1 h		✓	✓	m_4
	54–78, 3 h		✓	✓	m_4
	78–120, 6 h		✓	✓	m_4
TKE	0–48, 1 h	✓		✓	m15-ke1
	0–36, 1 h		✓	✓	m_6
U	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–51, 1 h		✓	✓	m_4
	54–120, 6 h		✓	✓	m_4
V	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–51, 1 h		✓	✓	m_4
	54–120, 6 h		✓	✓	m_4
W	0–51, 1 h	✓		✓	m
	54–120, 6 h	✓		✓	m
	0–3, 3 h		✓	✓	m_5

9.3. Multi-level fields interpolated to pressure levels

In the following table 9.6, the 'level type' means

- p5: output on pressure levels 50, 70, 100, 125, 150, 175, 200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 775, 800, 825, 850, 875, 900, 925, 950, 975, 1000 hPa
- pe4: output on pressure level 500 hPa
- pe5: output on pressure levels 300, 400, 500, 700, 850, 900, 925, 950, 1000 hPa

9.3.1. Standard Forecasts

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

Table 9.6.: Multi-level fields interpolated to pressure levels

ShortName	Time range	Det.	EPS	latlon	native	level type
CLC	0–78, 1 h	✓		✓		p5
	81–120, 3 h	✓		✓		p5
FI	0–78, 1 h	✓		✓		p5
	81–120, 3 h	✓		✓		p5
	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5
OMEGA	0–78, 1 h	✓		✓		p5
	81–120, 3 h	✓		✓		p5
	0–75, 1 h		✓		✓	pe4
	75–120, 3 h		✓		✓	pe4
RELHUM	0–78, 1 h	✓		✓		p5
	81–120, 3 h	✓		✓		p5
	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5
T	0–78, 1 h	✓		✓		p5
	81–120, 3 h	✓		✓		p5
	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5
U	0–78, 1 h	✓		✓		p5
	81–120, 3 h	✓		✓		p5
	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5
V	0–78, 1 h	✓		✓		p5
	81–120, 3 h	✓		✓		p5
	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5

9.3.2. Forecasts employing prognostic mineral dust

Table 9.7.: Multi-level fields interpolated to pressure levels

ShortName	Time range	Det.	EPS	latlon	native	level type
DUST_MAX_TOTAL						
_MC_LAYER	0–120, 3 h	✓			✓	pd7
FI	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5
OMEGA	0–75, 1 h		✓		✓	pe4
	75–120, 3 h		✓		✓	pe4
RELHUM	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5
T	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5
U	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5
V	0–75, 1 h		✓		✓	pe5
	75–120, 3 h		✓		✓	pe5

9.4. Single-level fields

9.4.1. Standard Forecasts

Table 9.8.: Single-level fields

ShortName	Time range	Det.	EPS	latlon	native
ALB_RAD	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
ALHFL_BS	2–24, 1 h	✓			✓
ALHFL_PL	2–24, 1 h	✓			✓
ALHFL_S	0–51, 1 h	✓			✓

Continued on next page

Table 9.8.: *continued*

	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
APAB_S	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
ASHFL_S	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
ASOB_S	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
ASOB_S_CS	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
ASOB_T	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
ASWDIFD_S	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–120, 1 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
ASWDIFU_S	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓

Continued on next page

Table 9.8.: *continued*

	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	6–120, 6 h		✓		✓
ASWDIR_S	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–120, 1 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
ATHB_S	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
ATHB_T	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
AUMFL_S	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
AVMFL_S	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
CAPE_CON	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
CAPE_ML	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
CEILING	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	

Continued on next page

Table 9.8.: *continued*

CIN_ML	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
CLCH	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
CLCL	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
CLCM	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
CLCT	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
CLCT_MOD	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
CLDEPTH	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	

Continued on next page

Table 9.8.: *continued*

C_T_LK	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
FRESHSNW	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–3, 3 h		✓		✓
FR_ICE	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–120, 6 h		✓		✓
HBAS_CON	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
HTOP_CON	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
HTOP_DC	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
HZEROCL	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
HZERO_CL	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
H_ICE	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–6, 3 h		✓		✓
	6–120, 6 h		✓		✓

Continued on next page

Table 9.8.: *continued*

H_ML_LK	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
H_SNOW	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–120, 6 h		✓		✓
LPI_CON_MAX	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–48, 1 h	✓		✓	
	51–72, 3 h	✓		✓	
	78–120, 6 h	✓		✓	
	0–48, 1 h		✓		✓
	51–72, 3 h		✓		✓
	78–120, 6 h		✓		✓
PMSL	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
PS	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
QV_2M	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
QV_S	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–51, 1 h		✓		✓

Continued on next page

Table 9.8.: *continued*

RAIN_CON	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
RAIN_GSP	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
RELHUM_2M	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–120, 6 h		✓		✓
RHO_SNOW	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
RSTOM	2–24, 1 h	✓			✓
RUNOFF_G	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
RUNOFF_S	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
SNOWLMT	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
SNOW_CON	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓

Continued on next page

Table 9.8.: *continued*

SNOW_GSP	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
SOBS_RAD	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
SYNMSG_BT_CL_IR10.8	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
SYNMSG_BT_CL_WV6.2	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
TCH	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
TCM	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
TD_2M	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
THBS_RAD	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
TMAX_2M	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	6–120, 6 h		✓		✓
TMIN_2M	0–51, 1 h	✓			✓

Continued on next page

Table 9.8.: *continued*

	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	6–120, 6 h		✓		✓
TOT_PREC	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
TQC	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
TQI	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
TQR	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
TQS	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
TQV	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	

Continued on next page

Table 9.8.: *continued*

	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
T_2M	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
T_BOT_LK	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
T_G	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
T_ICE	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–3, 3 h		✓		✓
T_MNW_LK	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
T_SNOW	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–51, 1 h		✓		✓
T_SO	0–51, 1 h		✓		✓
T_WML_LK	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
U_10M	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–120, 1 h	✓		✓	

Continued on next page

Table 9.8.: *continued*

	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
VIS	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
VMAX_10M	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–120, 1 h	✓		✓	
	1–120, 1 h		✓		✓
V_10M	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–120, 1 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
WW	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
W_I	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
	0–3, 3 h		✓		✓
W_SNOW	0–51, 1 h	✓			✓
	54–120, 3 h	✓			✓
	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
W_SO	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓
W_SO_ICE	0–51, 1 h	✓			✓
	54–120, 6 h	✓			✓
Z0	0–78, 1 h	✓		✓	
	81–120, 3 h	✓		✓	
	0–75, 1 h		✓		✓
	75–120, 3 h		✓		✓

Continued on next page

Table 9.8.: *continued*

9.4.2. Forecasts employing prognostic mineral dust

Table 9.9.: Single-level fields

ShortName	Time range	Det.	EPS	latlon	native
ACCDRYDEPO_DUSTA	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCDRYDEPO_DUSTB	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCDRYDEPO_DUSTC	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCEMISS_DUSTA	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCEMISS_DUSTB	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCEMISS_DUSTC	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCSEDIM_DUSTA	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCSEDIM_DUSTB	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCSEDIM_DUSTC	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCWETDEPO_CON_DUSTA	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCWETDEPO_CON_DUSTB	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓
ACCWETDEPO_CON_DUSTC	0–120, 3 h	✓			✓
	0–120, 3 h		✓		✓

Continued on next page

Table 9.9.: *continued*

ACCWETDEPO				
_GSP_DUSTA	0–120, 3 h	✓		✓
	0–120, 3 h		✓	✓
ACCWETDEPO				
_GSP_DUSTB	0–120, 3 h	✓		✓
	0–120, 3 h		✓	✓
ACCWETDEPO				
_GSP_DUSTC	0–120, 3 h	✓		✓
	0–120, 3 h		✓	✓
ALB_RAD	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
ALHFL_BS	2–24, 1 h	✓		✓
ALHFL_PL	2–24, 1 h	✓		✓
ALHFL_S	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
ASHFL_S	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
ASOB_S	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
ASOB_S_CS	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
ASOB_T	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
ASWDIFD_S	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
ASWDIFU_S	6–120, 6 h		✓	✓
ASWDIR_S	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓

Continued on next page

Table 9.9.: *continued*

	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
ATHB_S	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
ATHB_T	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
CEILING	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
CLCH	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
CLCL	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
CLCM	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
CLCT	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
C_T_LK	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
DUST_TOTAL_MC_VI	0–120, 3 h	✓		✓
	0–120, 3 h		✓	✓
FRESHSNW	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–3, 3 h		✓	✓
FR_ICE	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–120, 6 h		✓	✓

Continued on next page

Table 9.9.: *continued*

HBAS_CON	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
HTOP_CON	0–48, 1 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
H_ICE	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–6, 3 h		✓	✓
	6–120, 6 h		✓	✓
H_ML_LK	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
H_SNOW	0–120, 6 h		✓	✓
LPI_CON_MA	0–48, 1 h		✓	✓
LPI_CON_MAX	0–48, 1 h	✓		✓
	51–72, 3 h	✓		✓
	78–120, 6 h	✓		✓
	51–72, 3 h		✓	✓
	78–120, 6 h		✓	✓
PMSL	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
PS	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
QV_S	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–51, 1 h		✓	✓
RAIN_CON	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
RAIN_GSP	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
RELHUM_2M	0–120, 6 h		✓	✓
RHO_SNOW	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓

Continued on next page

Table 9.9.: *continued*

RSTOM	2–24, 1 h	✓		✓
SNOW_CON	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
SNOW_GSP	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
SOBS_RAD	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
TAOD_DUST	0–120, 3 h	✓		✓
	0–120, 3 h		✓	✓
TCH	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
TCM	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
TD_2M	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
THBS_RAD	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
TMAX_2M	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	6–120, 6 h		✓	✓
TMIN_2M	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	6–120, 6 h		✓	✓
TOT_PREC	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
TQC	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
TQI	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
TQV	0–75, 1 h		✓	✓

Continued on next page

Table 9.9.: *continued*

	75–120, 3 h		✓	✓
T_2M	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
T_BOT_LK	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
T_G	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
T_ICE	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–3, 3 h		✓	✓
T_MNW_LK	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
T_SNOW	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–51, 1 h		✓	✓
T_SO	0–51, 1 h		✓	✓
T_WML_LK	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
USTAR	0–120, 3 h	✓		✓
	0–120, 3 h		✓	✓
USTAR_THRES	0–120, 3 h	✓		✓
	0–120, 3 h		✓	✓
U_10M	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
VMAX_10M	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	1–120, 1 h		✓	✓
V_10M	0–51, 1 h	✓		✓

Continued on next page

Table 9.9.: *continued*

	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
W_I	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–3, 3 h		✓	✓
W_SNOW	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
W_SO	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓
W_SO_ICE	0–51, 1 h	✓		✓
	54–120, 6 h	✓		✓
Z0	0–75, 1 h		✓	✓
	75–120, 3 h		✓	✓

9.5. Soil-specific multi-level fields

The output of soil variables is identical for standard forecasts and forecasts employing prognostic mineral dust.

- soil: soil levels = 0, 1, 3, 9, 27, 81, 243, 729 cm

Table 9.10.: Soil-specific multi-level fields

ShortName	Time range	Det.	EPS	latlon	native	level type
T_SO	0–51, 1 h	✓			✓	soil
	54–120, 6 h	✓			✓	soil
	0–78, 1 h	✓		✓		soil
	81–120, 3 h	✓		✓		soil
W_SO	0–51, 1 h	✓			✓	soil
	54–120, 6 h	✓			✓	soil
	0–78, 1 h	✓		✓		soil
	81–120, 3 h	✓		✓		soil

Continued on next page

Table 9.10.: *continued*

W_SO_ICE	0–78, 1 h	✓	✓	soil
	81–120, 3 h	✓	✓	soil

10. ICON-D2 output fields

This section contains a list of output fields that are available with the launch of ICON-D2. See Fig. 2.8 for details regarding its location and extent. Forecasts of ICON-D2 are performed 8 times a day for the forecast times 00, 03, 06, 09, 12, 15, 18, 21 UTC, with a forecast range of 48h. Prior to 2021-06-23, the forecast range was limited to 27h with the exception of the 03 UTC run which reached 45h. During the pre-operational phase (i.e. prior to 2021-02-10) forecasts of ICON-D2 have been performed 2 times a day for the forecast times 00 and 12 UTC, with a forecast range of 27h.

Output is available on two distinct horizontal grids:

- a *native triangular grid* with an average grid spacing of about 2.1 km, and
- a *rotated (!) latitude-longitude* grid with a grid spacing of $\Delta\lambda = \Delta\Phi = 0.02°$ (remark: this horizontal lat-lon grid is exactly the same as for the former COSMO-D2!). See Table 10.1 for a summary.

  The geographical coordinates of every rotated grid point can be found in the fields `RLON` and `RLAT`. This information should be sufficient for the most users (otherwise some more details can be found in appendix B).

  Note that there are a few differences to some of the former COSMO-D2 fields:

  - although the velocity components u and v are given on the rotated lat-lon grid points, too, their components now are the purely (i.e. unrotated) zonal and meridional components, respectively (in the Grib-Metadata `ResolutionAndComponentFlags` the 5th bit is 0, whereas in the former COSMO it was 1).
  - Now every variable is interpolated to the same cell center point (whereas in the former COSMO again the velocity components have been staggered by the half grid mesh size) (in the Grib-Metadata `scanningMode` the last four bits are all zero, i.e. no staggering).
  - The vertical model levels for 3D fields are slightly different to COSMO. In any case the height values are given by the vertical averaging of the two neighbouring `HHL`-values (`HHL`-fields are delivered on the rotated lat-lon grid, too).

The output of the most variables takes place hourly. A few variables, which are of particular interest in the cases of deep convection, are delivered every 15 min.

The model area of ICON-D2 (Fig. 2.8) completely contains the areas of Germany, Switzerland and Austria and also parts of the neighbouring coutries.

The rotated latitude-longitude output grid contains $651 \times 716 = 466116$ grid points with a grid mesh size of 0.02° ($\sim$ 2,2 km).

Left bottom (SW) corner:	$\lambda = 07.50°$W	$\varphi = 06.30°$S	$\lambda_g = 00.25°$W	$\varphi_g = 43.19°$N
Right bottom (SE) corner:	$\lambda = 05.50°$E	$\varphi = 06.30°$S	$\lambda_g = 17.54°$E	$\varphi_g = 43.42°$N
Left top (NW) corner:	$\lambda = 07.50°$W	$\varphi = 08.00°$N	$\lambda_g = 03.84°$W	$\varphi_g = 57.31°$N
Right top (NE) corner:	$\lambda = 05.50°$E	$\varphi = 08.00°$N	$\lambda_g = 20.21°$E	$\varphi_g = 57.62°$N

Table 10.1.: Rotated coordinates (λ, φ) and geographical coordinates (λ_g, φ_g) of the four corner points of the lat-lon grid.

In the subsequent tables the availability of specific fields on the native grid, on the lat-lon grid, or on both grids is denoted.

10.1. Time-constant fields

Table 10.2.: Time-constant fields

ShortName	Time range	Det.	EPS	latlon	native	level type
CLAT	t=0	✓			✓	
	t=0		✓		✓	
CLON	t=0	✓			✓	
	t=0		✓		✓	
DEPTH_LK	t=0	✓		✓	✓	
	t=0		✓		✓	
ELAT	t=0	✓			✓	
	t=0		✓		✓	
ELON	t=0	✓			✓	
	t=0		✓		✓	
FR_ICE	t=0	✓		✓	✓	
	t=0		✓		✓	
FR_LAKE	t=0	✓		✓	✓	
	t=0		✓		✓	
FR_LAND	t=0	✓		✓	✓	
	t=0		✓		✓	
HHL	t=0	✓		✓	✓	m
	t=0		✓		✓	m
HSURF	t=0	✓		✓	✓	
	t=0		✓		✓	
LAI	t=0	✓		✓	✓	
	t=0		✓		✓	
PLCOV	t=0	✓		✓	✓	
	t=0		✓		✓	
RLAT	t=0	✓		✓		
RLON	t=0	✓		✓		
ROOTDP	t=0	✓		✓	✓	
	t=0		✓		✓	
SOILTYP	t=0	✓		✓	✓	
	t=0		✓		✓	

Continued on next page

Table 10.2.: *continued*

10.2. Multi-level fields on native hybrid vertical levels

In the following table 10.3, the denotation 'm' in the 'level types' means: output on all model levels.

Table 10.3.: Multi-level fields on native hybrid vertical levels

ShortName	Time range	Det.	EPS	latlon	native	level type
CLC	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
P	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
QC	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
QG	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
QI	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
QR	0–48, 1 h	✓		✓	✓	m
QS	0–48, 1 h	✓		✓	✓	m
QV	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
Q_SEDIM	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
T	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
TKE	0–48, 1 h	✓		✓	✓	m
U	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
V	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m
W	0–48, 1 h	✓		✓	✓	m
	0–48, 1 h		✓		✓	m

10.3. Multi-level fields interpolated to pressure levels

In the following table, the 'level type' p1 means output on the pressure levels 200, 250, 300, 400, 500, 600, 700, 850, 950, 975, 1000 hPa.

Table 10.4.: Multi-level fields interpolated to pressure levels

ShortName	Time range	Det.	EPS	latlon	native	level type
FI	0–48, 1 h	✓		✓	✓	p1
	0–48, 1 h		✓		✓	p1
OMEGA	0–48, 1 h	✓		✓	✓	p1
	0–48, 1 h		✓		✓	p1
RELHUM	0–48, 1 h	✓		✓	✓	p1
	0–48, 1 h		✓		✓	p1
T	0–48, 1 h	✓		✓	✓	p1
	0–48, 1 h		✓		✓	p1
U	0–48, 1 h	✓		✓	✓	p1
	0–48, 1 h		✓		✓	p1
V	0–48, 1 h	✓		✓	✓	p1
	0–48, 1 h		✓		✓	p1

10.4. Single-level fields

Table 10.5.: Single-level fields

ShortName	Time range	Det.	EPS	latlon	native
ALB_RAD	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
ALHFL_S	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
APAB_S	0–48, 1 h	✓		✓	✓
ASHFL_S	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
ASOB_S	0–48, 1 h	✓		✓	✓

Continued on next page

Table 10.5.: *continued*

	0–48, 1 h		✓		✓
ASOB_T	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
ASWDIFD_S	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
ASWDIFU_S	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
ASWDIR_S	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
ATHB_S	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
ATHB_T	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
AUMFL_S	0–48, 1 h	✓		✓	✓
AVMFL_S	0–48, 1 h	✓		✓	✓
CAPE_CON	0–48, 1 h		✓		✓
CAPE_ML	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
CEILING	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
CIN_ML	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
CLCH	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
CLCL	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
CLCM	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
CLCT	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
CLCT_MOD	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
CLDEPTH	0–48, 1 h	✓		✓	✓
C_T_LK	0–48, 1 h	✓			✓

Continued on next page

Table 10.5.: *continued*

DBZ_850	0–48, 0.25 h	✓			✓
	0–48, 0.25 h		✓		✓
DBZ_CMAX	0–48, 0.25 h	✓			✓
	0–48, 0.25 h		✓		✓
	0–48, 1 h		✓	✓	
DBZ_CTMAX	0–48, 1 h	✓			✓
	0–48, 1 h		✓		✓
ECHOTOP	0–48, 0.25 h	✓			✓
	0–48, 0.25 h		✓		✓
FRESHSNW	0–48, 1 h	✓			✓
	0–48, 1 h		✓		✓
GRAU_GSP	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
HBAS_SC	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
HTOP_DC	0–48, 1 h	✓		✓	✓
HTOP_SC	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
HZEROCL	0–48, 0.25 h	✓		✓	✓
H_ICE	0–48, 1 h	✓		✓	✓
H_ML_LK	0–48, 1 h	✓			✓
H_SNOW	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
LPI	0–48, 0.25 h	✓		✓	✓
	0–48, 0.25 h		✓		✓
	0–48, 1 h		✓	✓	
LPI_MAX	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
PMSL	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
PRG_GSP	0–48, 0.25 h	✓		✓	✓
PRR_GSP	0–48, 0.25 h	✓		✓	✓
PRS_GSP	0–48, 0.25 h	✓		✓	✓
PS	0–48, 1 h	✓		✓	✓

Continued on next page

Table 10.5.: *continued*

	0–48, 1 h		✓		✓
QV_S	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
RAIN_CON	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
RAIN_GSP	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
RELHUM_2M	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
RHO_SNOW	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
RUNOFF_G	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
RUNOFF_S	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
SDI_2	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓	✓	✓
SNOWC	0–48, 1 h	✓			✓
	0–48, 1 h		✓		✓
SNOWLMT	0–48, 0.25 h	✓		✓	✓
SNOW_CON	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
SNOW_GSP	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
SYNMSG_BT_CL_IR10.8	0–48, 0.25 h	✓		✓	✓
SYNMSG_BT_CL_WV6.2	0–48, 0.25 h	✓		✓	✓
TCH	0–48, 1 h	✓		✓	
TCM	0–48, 1 h	✓		✓	
TCOND10_MAX	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
TCOND_MAX	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
TD_2M	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓

Continued on next page

Table 10.5.: *continued*

TMAX_2M	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
TMIN_2M	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
TOT_PREC	0–48, 0.25 h	✓		✓	✓
	0–48, 0.25 h		✓	✓	✓
	0–48, 1 h		✓	✓	
TQC	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
TQC_DIA	0–48, 1 h	✓			✓
	0–48, 1 h		✓		✓
TQG	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
TQI	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
TQI_DIA	0–48, 1 h	✓			✓
	0–48, 1 h		✓		✓
TQR	0–48, 0.25 h	✓		✓	✓
TQS	0–48, 0.25 h	✓		✓	✓
TQV	0–48, 0.25 h	✓		✓	✓
	0–48, 1 h		✓		✓
TQV_DIA	0–48, 1 h	✓			✓
	0–48, 1 h		✓		✓
TWATER	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
T_2M	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
T_BOT_LK	0–48, 1 h	✓			✓
T_G	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
T_ICE	0–48, 1 h	✓		✓	✓
T_MNW_LK	0–48, 1 h	✓			✓
T_SNOW	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓

Continued on next page

Table 10.5.: *continued*

T_WML_LK	0–48, 1 h	✓			✓
UH_MAX	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
UH_MAX_LOW	0–48, 1 h	✓		✓	✓
UH_MAX_MED	0–48, 1 h	✓		✓	✓
U_10M	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
VIS	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
VMAX_10M	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓	✓	✓
VORW_CTMAX	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
V_10M	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
WW	0–48, 1 h	✓		✓	✓
W_CTMAX	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
W_I	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
W_SNOW	0–48, 1 h	✓		✓	✓
	0–48, 1 h		✓		✓
Z0	0–48, 1 h	✓		✓	✓

10.5. Soil-specific multi-level fields

- soil: soil levels = 0, 1, 3, 9, 27, 81, 243, 729 cm

Table 10.6.: Soil-specific multi-level fields

ShortName	Time range	Det.	EPS	latlon	native	level type
SMI	0–48, 1 h	✓		✓	✓	soil
	0–48, 1 h		✓		✓	soil

Continued on next page

Table 10.6.: *continued*

T_SO	0–48, 1 h	✓		✓	✓	soil
	0–48, 1 h		✓		✓	soil
W_SO	0–48, 1 h	✓		✓	✓	soil
	0–48, 1 h		✓		✓	soil
W_SO_ICE	0–48, 1 h	✓		✓	✓	soil
	0–48, 1 h		✓		✓	soil

11. ICON-D2-RUC output fields

This section contains the list of output fields that are available for the ICON-D2-RUC. See Fig. 2.8 for details regarding its location and extent. Forecasts of ICON-D2-RUC are initialized 24 times a day at every full hour (00, 01, ..., 23 UTC) with a forecast range of 14 h.

- Most output is available only on the *native triangular grid*. The triangular grid is exactly the same as for ICON-D2 and has an average resolution of about 2.1 km.
- The only output on the rotated (!) latitude-longitude grid (the former COSMO-D2 grid, see Section 10) are simulated radar reflectivity composites (`DBZCMP_SIM`) from the radar forward operator EMVORADO.

The vertical levels are exactly the same as for the ICON-D2.

The output of most of the variables takes place every 15 min. Precipitation related variables and simulated radar reflectivity (volume scans and radar composites) are available at 5 min intervals.

11.1. Time-constant fields

Table 11.1.: Time-constant fields

ShortName	Time range	Det.	EPS	latlon	RadVol	native	level type
CLAT	t=0	✓				✓	
	t=0		✓			✓	
CLON	t=0	✓				✓	
	t=0		✓			✓	
DEPTH_LK	t=0	✓				✓	
	t=0		✓			✓	
ELAT	t=0	✓				✓	
	t=0		✓			✓	
ELON	t=0	✓				✓	
	t=0		✓			✓	
FR_ICE	t=0	✓				✓	
	t=0		✓			✓	
FR_LAKE	t=0	✓				✓	
	t=0		✓			✓	

Continued on next page

Table 11.1.: *continued*

FR_LAND	t=0	✓				✓	
	t=0		✓			✓	
HHL	t=0	✓				✓	m
	t=0		✓			✓	m
HSURF	t=0	✓				✓	
	t=0		✓			✓	
LAI	t=0	✓				✓	
	t=0		✓			✓	
PLCOV	t=0	✓				✓	
	t=0		✓			✓	
ROOTDP	t=0	✓				✓	
	t=0		✓			✓	
SOILTYP	t=0	✓				✓	
	t=0		✓			✓	

11.2. Multi-level fields on native hybrid vertical levels

In the following table, the 'level type' denotes output on hybrid model levels ("1"= model top, "65"=lowest level, approx. terrain-following) and has the following meaning:

m all model levels

m_7 level 63 (third-lowest level)

Table 11.2.: Multi-level fields on native hybrid vertical levels

ShortName	Time range	Det.	EPS	latlon	RadVol	native	level type
CLC	0–14, 60 min	✓				✓	m
	0–14, 60 min		✓			✓	m
P	0–14, 60 min	✓				✓	m
	0–14, 60 min		✓			✓	m
QC	0–14, 60 min	✓				✓	m
	0–14, 60 min		✓			✓	m
QC_DIA	0–14, 60 min	✓				✓	m
	0–14, 60 min		✓			✓	m
QI_DIA	0–14, 60 min	✓				✓	m

Continued on next page

Table 11.2.: *continued*

	0–14, 60 min		✓			✓	m
QV	0–14, 60 min	✓				✓	m
	0–14, 15 min	✓				✓	m_7
	0–14, 60 min		✓			✓	m
	0–14, 15 min		✓			✓	m_7
T	0–14, 60 min	✓				✓	m
	0–14, 60 min		✓			✓	m
U	0–14, 60 min	✓				✓	m
	0–14, 60 min		✓			✓	m
V	0–14, 60 min	✓				✓	m
	0–14, 60 min		✓			✓	m

11.3. Multi-level fields interpolated to pressure levels

In the following table, the 'level type' denotes pressure levels in hPa and has the following meaning:

p6 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 775, 800, 825, 850, 875, 900, 925, 950, 975, 1000

p7 500, 700

Table 11.3.: Multi-level fields interpolated to pressure levels

ShortName	Time range	Det.	EPS	latlon	RadVol	native	level type
FI	0–14, 60 min	✓				✓	p6
QV	0–14, 60 min	✓				✓	p6
RELHUM	0–14, 15 min	✓				✓	p7
	0–14, 15 min		✓			✓	p7
T	0–14, 60 min	✓				✓	p6
	0–14, 15 min	✓				✓	p7
	0–14, 15 min		✓			✓	p7
U	0–14, 60 min	✓				✓	p6
	0–14, 15 min	✓				✓	p7
	0–14, 15 min		✓			✓	p7
V	0–14, 60 min	✓				✓	p6

Continued on next page

Table 11.3.: *continued*

	0–14, 15 min	✓				✓	p7
	0–14, 15 min		✓			✓	p7
W	0–14, 15 min	✓				✓	p7
	0–14, 15 min		✓			✓	p7

11.4. Single-level fields

Table 11.4.: Single-level fields

ShortName	Time range	Det.	EPS	latlon	RadVol	native
ASOB_S	0–14, 15 min	✓				✓
	0–14, 15 min		✓			✓
ASWDIFD_S	0–14, 15 min	✓				✓
	0–14, 60 min		✓			✓
	0–14, 15 min		✓			✓
ASWDIR_S	0–14, 15 min	✓				✓
	0–14, 60 min		✓			✓
	0–14, 15 min		✓			✓
CAPE_ML	0–14, 15 min	✓				✓
	0–14, 15 min		✓			✓
CAPE_MU	0–14, 60 min	✓				✓
	0–14, 60 min		✓			✓
CEILING	0–14, 15 min	✓				✓
	0–14, 15 min		✓			✓
CIN_ML	0–14, 15 min	✓				✓
	0–14, 15 min		✓			✓
CIN_MU	0–14, 60 min	✓				✓
	0–14, 60 min		✓			✓
CLCH	0–14, 60 min	✓				✓
	0–14, 60 min		✓			✓
CLCL	0–14, 60 min	✓				✓
	0–14, 60 min		✓			✓

Continued on next page

Table 11.4.: *continued*

CLCM	0–14, 60 min	✓			✓
	0–14, 60 min		✓		✓
CLCT	0–14, 60 min	✓			✓
	0–14, 60 min		✓		✓
DBZCMP_SIM	0–14, 5 min	✓		✓	
	0–14, 5 min		✓	✓	
DBZLMX_LOW	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
DBZ_850	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
DBZ_CMAX	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
DBZ_CTMAX	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
ECHOTOP	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
ECHOTOPINM	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
GRAU_GSP	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
HAIL_GSP	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
HZEROCL	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
H_SNOW	0–14, 60 min	✓			✓
	0–14, 60 min		✓		✓
LAPSE_RATE	0–14, 60 min	✓			✓
	0–14, 60 min		✓		✓
LPI	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
LPI_MAX	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓
MCONV	0–14, 15 min	✓			✓
	0–14, 15 min		✓		✓

Continued on next page

Table 11.4.: *continued*

PMSL	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
PREC_GSP	0–14, 5 min	✓		✓
	0–14, 5 min		✓	✓
PRG_GSP	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
PRH_GSP	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
PRS_GSP	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
PR_GSP	0–14, 5 min	✓		✓
	0–14, 5 min		✓	✓
PS	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
QV_2M	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
RAIN_GSP	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
RELHUM_2M	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
SDI_2	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
SNOWLMT	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
SNOW_GSP	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
SRH	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
SYNMSG_BT_CL_IR10.8	0–14, 15 min	✓		✓
SYNMSG_BT_CL_WV6.2	0–14, 15 min	✓		✓
TCOND10_MAX	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TCOND_MAX	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓

Continued on next page

Table 11.4.: *continued*

TD_2M	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
TOT_PR	0–14, 15 min	✓		✓
	0–14, 5 min	✓		✓
	0–14, 15 min		✓	✓
	0–14, 5 min		✓	✓
TOT_PREC	0–14, 5 min	✓		✓
	0–14, 5 min		✓	✓
TOT_PREC_D	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
TQC	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TQC_DIA	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TQG	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TQH	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TQI	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TQI_DIA	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TQR	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TQS	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TQV	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
TQV_DIA	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
T_2M	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
T_G	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓

Continued on next page

Table 11.4.: *continued*

UH_MAX	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
UH_MAX_LOW	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
UH_MAX_MED	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
U_10M	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
VIS	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
VMAX_10M	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
VORW_CTMAX	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓
V_10M	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
WSHEAR_U	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
WSHEAR_V	0–14, 60 min	✓		✓
	0–14, 60 min		✓	✓
W_CTMAX	0–14, 15 min	✓		✓
	0–14, 15 min		✓	✓

The simulated radar reflectivity composites (`DBZCMP_SIM`) from EMVORADO are on the rotated latitude-longitude grid (see Section 10).

11.5. Radar volume scans on native polar coordinates

Table 11.5.: Simulated 3D radar volume scans (range, azimut, elevation)

ShortName	Time range	Det.	EPS	latlon	RadVol	native	level type
DBZSCAN_SIM	0–14, 5 min	✓			✓		radDE
	0–14, 5 min		✓		✓		radDE

Continued on next page

Table 11.5.: *continued*

11.6. Soil-specific multi-level fields

Soil fields are not yet in the output of ICON-RUC.

12. ICON-D05 output fields

This section contains a list of output fields that are available with the launch of ICON-D05. See Fig. 2.10 for details regarding its geographic location and extent. Forecasts of ICON-D05 are performed 8 times a day for the forecast times 00, 03, 06, 09, 12, 15, 18, 21 UTC, with a forecast range of 48 h.

In contrast to ICON-D2, output is available *only* on a *native triangular grid* with an average grid spacing of about 500 m. Additionally, there is only output from the deterministic run (no ensemble output available).

The output of most variables takes place hourly. A few variables, which are of particular interest in the cases of deep convection, are delivered every 15 min. Generally spoken, most output variables are the same as for ICON-D2 (see Section 10) with the following exceptions: ICON-D05 additionally delivers the single-level variables `ASOB_S_OS`, `ASOB_S_TAN_OS`, `ASWIR_S_OS`, `U_10M_AV`, `V_10M_AV`, and the 3D fields `QC_DIA` and `QI_DIA`, however it does not deliver the 3D output fields `QR`, `QS`, `QG`, `Q_SEDIM`.

There is another important difference to the ICON-D2 or ICON-D2-RUC output: the *first output timestep* is `vv=1` and the time-constant fields are written at `vv=1` as well (this is simply because the nests are started only after the end of the latent-heat nudging phase of ICON-D2, i.e. the first nest D1 starts at +40 min and ICON-D05 at +50 min.).

12.1. Time-constant fields

In the following table 12.1, the denotation 'm' in the 'level types' means: output on all model levels.

Table 12.1.: Time-constant fields

ShortName	Time range	Det.	EPS	latlon	native	level type
CLAT	t=1	✓			✓	
CLON	t=1	✓			✓	
DEPTH_LK	t=1	✓			✓	
ELAT	t=1	✓			✓	
ELON	t=1	✓			✓	
FR_ICE	t=1	✓			✓	
FR_LAKE	t=1	✓			✓	
FR_LAND	t=1	✓			✓	
HHL	t=1	✓			✓	m
HSURF	t=1	✓			✓	
LAI	t=1	✓			✓	
PLCOV	t=1	✓			✓	

Continued on next page

Table 12.1.: *continued*

ROOTDP	t=1	✓			✓	
SOILTYP	t=1	✓			✓	

12.2. Multi-level fields on native hybrid vertical levels

In the following table 12.2, the denotation 'm' in the 'level types' means: output on all model levels.

Table 12.2.: Multi-level fields on native hybrid vertical levels

ShortName	Time range	Det.	EPS	latlon	native	level type
CLC	1–48, 1 h	✓			✓	m
P	1–48, 1 h	✓			✓	m
QC	1–48, 1 h	✓			✓	m
QC_DIA	1–48, 1 h	✓			✓	m
QI	1–48, 1 h	✓			✓	m
QI_DIA	1–48, 1 h	✓			✓	m
QV	1–48, 1 h	✓			✓	m
T	1–48, 1 h	✓			✓	m
TKE	1–48, 1 h	✓			✓	m
U	1–48, 1 h	✓			✓	m
V	1–48, 1 h	✓			✓	m
W	1–48, 1 h	✓			✓	m

12.3. Multi-level fields interpolated to pressure levels

In the following table, the 'level type' p1 means output on the pressure levels 200, 250, 300, 400, 500, 600, 700, 850, 950, 975, 1000 hPa.

Table 12.3.: Multi-level fields interpolated to pressure levels

ShortName	Time range	Det.	EPS	latlon	native	level type
FI	1–48, 1 h	✓			✓	p1

Continued on next page

Table 12.3.: *continued*

OMEGA	1–48, 1 h	✓			✓	p1
RELHUM	1–48, 1 h	✓			✓	p1
T	1–48, 1 h	✓			✓	p1
U	1–48, 1 h	✓			✓	p1
V	1–48, 1 h	✓			✓	p1

12.4. Single-level fields

Table 12.4.: Single-level fields

ShortName	Time range	Det.	EPS	latlon	native
ALB_RAD	1–48, 1 h	✓			✓
ALHFL_S	1–48, 1 h	✓			✓
APAB_S	1–48, 1 h	✓			✓
ASHFL_S	1–48, 1 h	✓			✓
ASOB_S	1–48, 1 h	✓			✓
ASOB_S_OS	1–48, 1 h	✓			✓
ASOB_S_TAN_OS	1–48, 1 h	✓			✓
ASOB_T	1–48, 1 h	✓			✓
ASWDIFD_S	1–48, 0.25 h	✓			✓
ASWDIFU_S	1–48, 1 h	✓			✓
ASWDIR_S	1–48, 0.25 h	✓			✓
ASWDIR_S_OS	1–48, 0.25 h	✓			✓
ATHB_S	1–48, 1 h	✓			✓
ATHB_T	1–48, 1 h	✓			✓
AUMFL_S	1–48, 1 h	✓			✓
AVMFL_S	1–48, 1 h	✓			✓
CAPE_ML	1–48, 0.25 h	✓			✓
CEILING	1–48, 1 h	✓			✓
CIN_ML	1–48, 0.25 h	✓			✓
CLCH	1–48, 1 h	✓			✓
CLCL	1–48, 1 h	✓			✓

Continued on next page

Table 12.4.: *continued*

CLCM	1–48, 1 h	✓	✓
CLCT	1–48, 1 h	✓	✓
CLCT_MOD	1–48, 1 h	✓	✓
CLDEPTH	1–48, 1 h	✓	✓
C_T_LK	1–48, 1 h	✓	✓
DBZ_850	1–48, 0.25 h	✓	✓
DBZ_CMAX	1–48, 0.25 h	✓	✓
DBZ_CTMAX	1–48, 1 h	✓	✓
ECHOTOP	1–48, 0.25 h	✓	✓
FRESHSNW	1–48, 1 h	✓	✓
GRAU_GSP	1–48, 0.25 h	✓	✓
HBAS_SC	1–48, 0.25 h	✓	✓
HTOP_DC	1–48, 1 h	✓	✓
HTOP_SC	1–48, 0.25 h	✓	✓
HZEROCL	1–48, 0.25 h	✓	✓
H_ICE	1–48, 1 h	✓	✓
H_ML_LK	1–48, 1 h	✓	✓
H_SNOW	1–48, 1 h	✓	✓
LPI	1–48, 0.25 h	✓	✓
LPI_MAX	1–48, 1 h	✓	✓
PMSL	1–48, 1 h	✓	✓
PRG_GSP	1–48, 0.25 h	✓	✓
PRR_GSP	1–48, 0.25 h	✓	✓
PRS_GSP	1–48, 0.25 h	✓	✓
PS	1–48, 1 h	✓	✓
QV_S	1–48, 1 h	✓	✓
RAIN_CON	1–48, 0.25 h	✓	✓
RAIN_GSP	1–48, 0.25 h	✓	✓
RELHUM_2M	1–48, 1 h	✓	✓
RHO_SNOW	1–48, 1 h	✓	✓
RUNOFF_G	1–48, 1 h	✓	✓
RUNOFF_S	1–48, 1 h	✓	✓
SDI_2	1–48, 0.25 h	✓	✓
SNOWC	1–48, 1 h	✓	✓

Continued on next page

Table 12.4.: *continued*

SNOWLMT	1–48, 0.25 h	✓	✓
SNOW_CON	1–48, 0.25 h	✓	✓
SNOW_GSP	1–48, 0.25 h	✓	✓
SYNMSG_BT_CL_IR10.8	1–48, 0.25 h	✓	✓
SYNMSG_BT_CL_WV6.2	1–48, 0.25 h	✓	✓
TCH	1–48, 1 h	✓	
TCM	1–48, 1 h	✓	
TCOND10_MAX	1–48, 1 h	✓	✓
TCOND_MAX	1–48, 1 h	✓	✓
TD_2M	1–48, 1 h	✓	✓
TMAX_2M	1–48, 1 h	✓	✓
TMIN_2M	1–48, 1 h	✓	✓
TOT_PREC	1–48, 0.25 h	✓	✓
TQC	1–48, 0.25 h	✓	✓
TQC_DIA	1–48, 1 h	✓	✓
TQG	1–48, 0.25 h	✓	✓
TQI	1–48, 0.25 h	✓	✓
TQI_DIA	1–48, 1 h	✓	✓
TQR	1–48, 0.25 h	✓	✓
TQS	1–48, 0.25 h	✓	✓
TQV	1–48, 0.25 h	✓	✓
TQV_DIA	1–48, 1 h	✓	✓
TWATER	1–48, 1 h	✓	✓
T_2M	1–48, 1 h	✓	✓
T_BOT_LK	1–48, 1 h	✓	✓
T_G	1–48, 1 h	✓	✓
T_ICE	1–48, 1 h	✓	✓
T_MNW_LK	1–48, 1 h	✓	✓
T_SNOW	1–48, 1 h	✓	✓
T_WML_LK	1–48, 1 h	✓	✓
UH_MAX	1–48, 1 h	✓	✓
UH_MAX_LOW	1–48, 1 h	✓	✓
UH_MAX_MED	1–48, 1 h	✓	✓
U_10M	1–48, 1 h	✓	✓

Continued on next page

Table 12.4.: *continued*

U_10M_AV	1–48, 1 h	✓	✓
VIS	1–48, 1 h	✓	✓
VMAX_10M	1–48, 1 h	✓	✓
VORW_CTMAX	1–48, 1 h	✓	✓
V_10M	1–48, 1 h	✓	✓
V_10M_AV	1–48, 1 h	✓	✓
WW	1–48, 1 h	✓	✓
W_CTMAX	1–48, 1 h	✓	✓
W_I	1–48, 1 h	✓	✓
W_SNOW	1–48, 1 h	✓	✓
Z0	1–48, 1 h	✓	✓

12.5. Soil-specific multi-level fields

- soil: soil levels = 0, 1, 3, 9, 27, 81, 243, 729 cm

Table 12.5.: Soil-specific multi-level fields

ShortName	Time range	Det.	EPS	latlon	native	level type
SMI	1–48, 1 h	✓			✓	soil
T_SO	1–48, 1 h	✓			✓	soil
W_SO	1–48, 1 h	✓			✓	soil
W_SO_ICE	1–48, 1 h	✓			✓	soil

13. Ensemble forecasts with ICON (global, nested, and limited area mode)

Two ensemble systems based on ICON are running under operational conditions at DWD. The global ICON ensemble suite started operational in January 2018 now providing short to medium range forecasts at approx. 26, 5 km (R3B06) horizontal resolution on the global scale with a 13, 2 km (R3B07) nesting area over Europe. The number of vertical model levels in the actual version is 120. Before 2022-11-23, the ensemble used a grid resolution of 40 km (R2B06) for the global domain and 20 km (R2B07) for the nest, both on 90 levels.

The ICON-EPS with its EU-nest runs 8 times a day providing boundary conditions for the ICON-D2-EPS. At 00/06/12/18 UTC, the whole system including the EU-nest is integrated up to 120h. In addition, at 00/12 UTC, the global system (without nest) is further integrated to 180 h lead time. At 03/09/15/21 UTC the forecast lead time is limited to +51 h for both, the global domain and the EU nest.

With the operational start of ICON-D2 (2021-02-10), a convection-permitting ensemble ICON-D2-EPS (analogous to the former COSMO-D2-EPS) with 20 members and the same resolution and grid as the deterministic ICON-D2 ($\approx$ 2 km, R19B07) is performed. It runs 8 times a day with 48 hours of forecasts for the 00, 06, 09, 12, 15, 18, 21 UTC runs. Prior to 2021-06-23 the forecast range was limited to 27 hours, with the exception of the 03 UTC run (45 hours).

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. For limited area ensembles, an additional source of forecast uncertainty is the uncertainty in the boundary conditions. In the following sections we explain the techniques used in the ICON-EPS to simulate the effects of those error sources on the forecast and describe its output data.

13.1. Initial Perturbations

In the ICON ensembles the initial perturbations are set by the EDA system for the ICON EPS (global domain and EU nest, Section 4.1) and the KENDA system for ICON-D2-EPS (Section 4.3.2). Both systems are 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 (1 hour for KENDA) and solves the underlying equations in ensemble space spanned by a background ensemble of 40 members.
Since the ICON-D2-EPS runs with 20 forecast members, only the first 20 of the 40 KENDA members are used as initial conditions for ICON-D2-EPS. Over a large number of ICON-D2-EPS runs, this is statistically equivalent to a random selection of 20 members as there are no statistically distinguishable members in KENDA by construction. More details of the implementation can be found in Schraff et al. (2016) and Section 4 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, Schraff et al., 2016) 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 stabilise 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 4.2). 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.

13.2. Ensemble Physics Perturbations

To simulate the model error a simple methodology for perturbing various physics tuning parameters has been implemented in ICON for the ensemble mode.
At the beginning of each forecast the actual values of a predefined set of tuning parameters are calculated using a random number generator. The user can specify a range for the variation of each parameter in the namelist `ensemble_pert_nml`. The randomised perturbation of physics is activated by setting the parameter *use_ensemble_pert=.true.* in the same namelist.
For most parameters, the perturbation is applied in an additive symmetric way:

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

where $rand\_num \in [0, 1]$ is drawn from a uniform distribution.
For a few exceptions, only positive variations are retained (implying that no perturbations are applied for random numbers below 0.5, e.g. `capdcfac_et`) or the perturbation is multiplicative.
There are two options to control the randomisation using parameters in the same namelist:

timedep_pert: The randomisation depends on the member ID with *timedep_pert=0*. With *timedep_pert=1*, it depends on the forecast start time (not taking into account time differences finer than hours) and the member ID. A value of *timedep_pert=2* results in time-dependent perturbations varying sinusoidally within their range. The randomisation is accomplished by a phase shift of the sinusoidal wave depending on the member ID. N.B., parameters related to latent heat nudging in the nudgecast mode of ICON-D2-EPS use the sinusoidal perturbation hard-coded, i.e. even with *timedep_pert=1* (see Table 13.1).

itype_pert_gen: The random number *rand_num* is used at face value (*itype_pert_gen=1*) or is set to 0 for $rand\_num < 0.25$, to 1 for $rand\_num > 0.75$ or to 0.5 otherwise ensuring that each parameter is perturbed in 50% of the members statistically (*itype_pert_gen=2*).

In the current implementation, the set-up is *timedep_pert=2* and *itype_pert_gen=1* for the global ICON-EPS and its EU-nest whereas the set-up is *timedep_pert=1* and *itype_pert_gen=2* for ICON-D2-EPS, i.e. only the boundary values of the specified range of a parameter are used besides its default value.
Table 13.1 lists the parameters which are perturbed. Parameter ranges can be slightly different between EPS set-ups:

Table 13.1.: List of parameters which are perturbed in the global/EU ICON-EPS (**glo**) and/or ICON-D2-EPS (**D2**). The perturbation mode is either additive (a), multiplicative (m), or hard-coded sinusoidal (s), possibly limited to positive (+) deviations from the default value.

Parameter	Description	glo	D2	mode
`gkwake`	Low level wake drag constant	✓	✓	a
`gkdrag`	Gravity wake drag constant	✓		a
`gfrcrit`	Critical Froude number	✓	✓	a

Continued on next page

Table 13.1.: *continued*

Parameter	Description	glo	D2	mode
`entrorg`	Entrainment parameter in convection scheme valid for dx=20 km (depends on model resolution)	✓	✓	a
`q_crit`	Critical value for normalised super-saturation	✓	✓	a
`zvz0i`	Terminal fall velocity of ice	✓	✓	a
`rprcon`	Coefficient for conversion of cloud water into precipitation. If perturbed, its perturbation is forced to be anticorrelated to the perturbation of `zvzi0` to compensate for a temperature bias in the upper tropical troposphere.	✓		a
`rdepths`	Maximum allowed depth of shallow convection	✓	✓	a
`rain_n0fac`	Intercept parameter of raindrop size distribution	✓	✓	m
`gfluxlaun`	Variability range for non-orographic gravity wave launch momentum flux	✓		a
`capdcfac_et`	Maximum fraction of CAPE diurnal cycle correction applied in the extratropics	✓		a+
`capdcfac_tr`	Maximum fraction of CAPE diurnal cycle correction applied in the tropics	✓		a+
`lowcapefac`	Tuning parameter for diurnal-cycle correction in convection scheme: reduction factor for low-cape situations.	✓		a
`negpblcape`	Tuning parameter for diurnal-cycle correction in convection scheme: maximum negative PBL CAPE allowed in the modified CAPE closure.	✓		a
`rhebc_land`	RH threshold for onset of evaporation below cloud base over land	✓		a
`rhebc_ocean`	RH threshold for onset of evaporation below cloud base over sea	✓		a
`rcucov`	Convective area fraction used for computing evaporation below cloud base	✓		a
`texc`	Excess value for temperature used in test parcel ascent	✓	✓	a
`qexc`	Excess fraction of grid-scale QV used in test parcel ascent	✓	✓	a
`box_liq`	Box width for liquid cloud diagnostic in cloud cover scheme	✓	✓	a
`box_liq_asy`	Asymmetry factor for liquid cloud cover diagnostic	✓	✓	a

Continued on next page

Table 13.1.: *continued*

Parameter	Description	glo	D2	mode
tur_len	Asymptotic maximal turbulent distance	✓	✓	a
tkhmin	Scaling factor for minimum vertical diffusion coefficient (proportional to $Ri^{-2/3}$) for heat and moisture	✓	✓	a
tkmmin	Scaling factor for minimum vertical diffusion coefficient (proportional to $Ri^{-2/3}$) for momentum	✓	✓	a
rlam_heat	Scaling factor of the laminar boundary layer for heat (scalars). 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.	✓	✓	a
a_hshr	Length scale factor for the separated horizontal shear mode	✓	✓	a
a_stab	Factor for stability correction of turbulent length scale	✓	✓	a+
c_diff	Length scale factor for vertical diffusion of TKE	✓	✓	m
c_soil	Evaporating fraction of soil	✓		a
minsnowfrac	Lower limit of snow cover fraction to which melting snow is artificially reduced in the context of the snow-tile approach	✓		a
cwimax_ml	Scaling parameter for maximum interception storage	✓		m
charnock	Upper and lower bound of wind-speed-dependent Charnock parameter	✓		m
alpha0	Lower bound of velocity-dependent Charnock parameter	✓		a/m
lhn_coef	Nudging coefficient of adding the increments		✓	s
fac_lhn_artif_tune	Tuning factor to optimize the effectiveness of the artificial profile		✓	s
fac_lhn_down	Lower limit of the scaling factor of the relevant profile		✓	s
fac_lhn_up	Upper limit of the scaling factor of the relevant profile		✓	s

13.3. Lateral boundary perturbations (limited area EPS)

For models running in limited area mode, the provision of lateral boundaries is an additional source of forecast uncertainty.
This is accounted for in ICON-D2-EPS by using as hourly lateral boundary conditions forecast mem-

bers of the ICON-EU-EPS which have started 3 hours before the start of the respective ICON-D2-EPS. Only the members 1–20 of the 40 members of ICON-EU-EPS are used for driving the 20 members of ICON-D2-EPS. As for the reduction to KENDA members 1–20 for the perturbation of initial conditions (Section 13.1), this is statistically equivalent to a random selection of 20 members of ICON-EU-EPS over a large number of ICON-D2-EPS runs. However, there are promising approaches in the research community to select a suitable subset of 20 out of 40 members at each forecast following certain optimisation criteria. The application and suitability of such methods has not yet been tested for the combination of ICON-EU-EPS and ICON-D2-EPS.

13.4. ICON Ensemble 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 ensemble 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, **la** for the limited area domain. The ensemble data is further characterised by a final **e**. The category parameters run, type, and suite have the same meaning for all forecast models of DWD. See section 14.1 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. For ICON-D2-EPS the full category name is **icolae_main_fc_rout**. 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 14 for SKY retrieval examples.

13.4.1. Model Output

The model output fields are collected in the tables of chapter 8 (ICON global), 9 (ICON-EU nest), and 10 (for ICON-D2).

13.4.2. Ensemble Products for the ICON-EPS (global) and ICON-EU-EPS

The 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 0.125° and 0.25°, respectively (0.25° and 0.5° before 2022-11-23 09 UTC). 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). This is done for different accumulation periods depending on the forecast parameter. In the following tables, the accumulation time range is given in hours. The meaning of the level types is:

- (no key): 2D field
- pe4: pressure level 500 hPa
- pe7: pressure level 850 hPa
- pe8: pressure levels 500, 850 hPa
- pe9: pressure levels 250, 500, 850 hPa

All products are delivered only on the lat/lon grid (i.e. *not* on the ICON native grid).

Table 13.2.: EPS products from ICON global. See table 13.4 for a description of the various product types.

ShortName	Time range	level type	Accum. timerange	Product type
CAPE_ML	6–180, 6 h			perct_1
	6–180, 6 h			probt_12
CLCH	6–180, 6 h			perct_1
	6–180, 6 h			probt_13
CLCL	6–180, 6 h			perct_1
	6–180, 6 h			probt_13
CLCM	6–180, 6 h			perct_1
	6–180, 6 h			probt_13
CLCT	6–180, 6 h			perct_1
	6–180, 6 h			probt_13
FI	6–180, 6 h	pe4		perct_1
PMSL	6–180, 6 h			perct_1
SP	6–180, 6 h	pe9		perct_1
SP_10M	6–180, 6 h			perct_1
	6–180, 6 h			probt_8

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[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 13.2.: *continued*

T	6–180, 6 h	pe8		perct_1
	6–180, 6 h	pe7		probt_14
TD_2M	6–180, 6 h			perct_1
TMAX_2M	12–180, 6 h		720	perct_1
	12–180, 6 h		720	probt_11
	12–180, 6 h		1440	perct_1
	12–180, 6 h		1440	probt_11
TMIN_2M	12–180, 6 h		720	perct_1
	12–180, 6 h		720	probt_10
	12–180, 6 h		1440	perct_1
	12–180, 6 h		1440	probt_10
TOT_PREC	6–180, 6 h		360	perct_1
	6–180, 6 h		360	probt_4
	6–180, 6 h		720	perct_1
	6–180, 6 h		720	probt_5
	6–180, 6 h		1440	perct_1
	6–180, 6 h		1440	probt_3
	6–180, 6 h		2880	perct_1
	6–180, 6 h		2880	probt_6
	6–180, 6 h		4320	perct_1
	6–180, 6 h		4320	probt_7
TOT_SNOW	6–180, 6 h		360	perct_1
	6–180, 6 h		360	probt_1
	6–180, 6 h		720	perct_1
	6–180, 6 h		720	probt_2
	6–180, 6 h		1440	perct_1
	6–180, 6 h		1440	probt_2
T_2M	6–180, 6 h			perct_1
T_G	12–180, 6 h		720	perct_1
	12–180, 6 h		720	probt_9
VMAX_10M	6–180, 6 h		360	perct_1
	6–180, 6 h		360	probt_8
	6–180, 6 h		720	perct_1
	6–180, 6 h		720	probt_8

Continued on next page

Table 13.2.: *continued*

	6–180, 6 h		1440	perct_1
	6–180, 6 h		1440	probt_8

Table 13.3.: EPS products from ICON-EU. See table 13.4 for a description of the various product types.

ShortName	Time range	level type	Accum. timerange	Product type
CAPE_ML	6–120, 6 h			perct_1
	6–120, 6 h			probt_12
CLCH	6–120, 6 h			perct_1
	6–120, 6 h			probt_13
CLCL	6–120, 6 h			perct_1
	6–120, 6 h			probt_13
CLCM	6–120, 6 h			perct_1
	6–120, 6 h			probt_13
CLCT	6–120, 6 h			perct_1
	6–120, 6 h			probt_13
FI	6–120, 6 h	pe4		perct_1
PMSL	6–120, 6 h			perct_1
SP	6–120, 6 h	pe9		perct_1
SP_10M	6–120, 6 h			perct_1
	6–120, 6 h			probt_8
T	6–120, 6 h	pe8		perct_1
TD_2M	6–120, 6 h			perct_1
TMAX_2M	12–120, 6 h		720	perct_1
	12–120, 6 h		720	probt_11
	12–120, 6 h		1440	perct_1
	12–120, 6 h		1440	probt_11
TMIN_2M	12–120, 6 h		720	perct_1
	12–120, 6 h		720	probt_10
	12–120, 6 h		1440	perct_1
	12–120, 6 h		1440	probt_10

Continued on next page

Table 13.3.: *continued*

TOT_PREC	6–120, 6 h	360	perct_1
	6–120, 6 h	360	probt_4
	6–120, 6 h	720	perct_1
	6–120, 6 h	720	probt_5
	6–120, 6 h	1440	perct_1
	6–120, 6 h	1440	probt_3
	6–120, 6 h	2880	perct_1
	6–120, 6 h	2880	probt_6
	6–120, 6 h	4320	perct_1
	6–120, 6 h	4320	probt_7
TOT_SNOW	6–120, 6 h	360	perct_1
	6–120, 6 h	360	probt_1
	6–120, 6 h	720	perct_1
	6–120, 6 h	720	probt_2
	6–120, 6 h	1440	perct_1
	6–120, 6 h	1440	probt_2
T_2M	6–120, 6 h		perct_1
T_G	12–120, 6 h	720	perct_1
	12–120, 6 h	720	probt_9
VMAX_10M	6–120, 6 h	360	perct_1
	6–120, 6 h	360	probt_8
	6–120, 6 h	720	perct_1
	6–120, 6 h	720	probt_8
	6–120, 6 h	1440	perct_1
	6–120, 6 h	1440	probt_8

Most of the parameters are available on both domains, but there are exceptions: SP250, FI500,T_SO and the temperature 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

Table 13.4.: Meaning of the 'product type' key for EPS-products from ICON (global) and ICON-EU EPS.

Product type	Description
perct_1	perct; mean; spread; min; max; 10; 25; 50; 75; 90 (ensemble distribution)
probt_1	1.0; 5.0; 10.0 (precipitation thresholds (in mm))
probt_2	1.0; 5.0; 10.0; 15.0; 20.0; 25.0; 30.0; 50.0 (precipitation thresholds (in mm))
probt_3	1.0; 5.0; 10.0; 20.0; 25.0; 30.0; 50.0; 80.0; 100.0 (precipitation thresholds (in mm))
probt_4	20.0; 35.0; 60.0 (precipitation thresholds (in mm))
probt_5	25.0; 40.0; 70.0 (precipitation thresholds (in mm))
probt_6	40.0; 60.0; 90.0; 150.0 (precipitation thresholds (in mm))
probt_7	50.0; 100.0; 150.0; 250.0 (precipitation thresholds (in mm))
probt_8	11.0; 12.5; 14.0; 18.0; 21.0; 25.0; 29.0; 33.0; 39.0 (wind speed thresholds (in m/s))
probt_9	273.15 (temperature thresholds (in K))
probt_10	253.15; 263.15; 273.15; 293.15 (temperature thresholds (in K))
probt_11	263.15; 273.15; 298.15; 303.15; 308.15 (temperature thresholds (in K))
probt_12	750.0; 1000.0; 1500.0; 2000.0; 3000.0; 4000.0 (CAPE thresholds)
probt_13	50.0; 87.5 (cloud cover thresholds (in %))
probt_14	-1.0; -1.5; -2.0; 1.0; 1.5; 2.0 (temperature anomalie thresholds)

13.4.3. Ensemble Products for the ICON-D2-EPS

The ICON-D2-EPS products are stored in the **roma** database and can be identified by the category type **fcprod**. This leads to the category name **icrlae_main_fcprod_rout**. The products are generated with fieldextra on the COSMO-D2 grid (rotated latlon grid). The ICON-D2-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 (Standard Deviation)	(deriv = 4)
Spread of all members (Interquartile Range)	(deriv = 7)
Minimum of all ensemble members	(deriv = 8)
Maximum of all ensemble members	(deriv = 9)

   i.e. 'spread' is computed as interquartile range for `TOT_PREC` and `TOT_SNOW` and as standard deviation for all the other products.

2. **Percentiles**,
   i.e. physical values of a forecast parameter (e.g. `T_2M`,...), which define the perc=10,25,30,50,75,90 [%] parts of the ensemble distribution.

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

4. **Grid specification**
   Products on the rotated latlon COSMO-D2 grid (`localTypeOfEnsembleProductGeneration=1`)

Products on the upscaled (10x10 grid point) grid (`localTypeOfEnsembleProductGeneration=101`)

The thresholds for the exceedance probabilities are given by the DWD alert thresholds which are used for issuing weather warnings[6] and follow the WMO recommendations[7].

In addition, exceedance probability products for `TOT_PREC` and `LPI` are generated on an upscaled grid, 10x10 grid points. In order to distinguish the products on the upscaled grid from the ones on the COSMO-D2 grid, the grib parameter `localTypeOfEnsembleProductGeneration` is used.

Ensemble products are generated every 1 hour (not for all parameters, see the tables) up to 48 h lead time eight times per day (00/03/06/09/12/15/18/21 UTC). This is done for different accumulation periods, depending on the forecast parameter. In the following tables, the accumulation time range is given in minutes.

Table 13.5.: EPS products from ICON-D2. See table 13.6 for a description of the various product types.

ShortName	Time range	level type	Accum. timerange	Product type
CAPE_ML	6–24, 6 h		360	perct_1d
	6–24, 6 h		360	probt_7d
CLCL	1–48, 1 h			perct_1d
	1–48, 1 h			probt_6d
CLCT	1–48, 1 h			perct_1d
	1–48, 1 h			probt_6d
DBZ_CMAX	1–48, 1 h			perct_1d
	1–48, 1 h			probt_13d
LPI	1–48, 1 h			perct_1d
	1–48, 1 h			probt_14d
	1–48, 1 h			probt_14d_ups
TMAX_2M	6–24, 6 h		360	perct_1d
	6–24, 6 h		360	probt_12d
	12–24, 12 h		720	perct_1d
	12–24, 12 h		720	probt_12d
TMIN_2M	6–24, 6 h		360	perct_1d
	6–24, 6 h		360	probt_11d
	12–24, 12 h		720	perct_1d
	12–24, 12 h		720	probt_11d

Continued on next page

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

Table 13.5.: *continued*

TOT_PREC	6–48, 1 h	360	perct_1d
	6–48, 1 h	360	probt_3d
	1–48, 1 h	60	perct_1d
	1–48, 1 h	60	probt_1d
	12–48, 1 h	720	perct_1d
	12–48, 1 h	720	probt_9d
	12–48, 1 h	720	probt_9d_ups
	1–48, 1 h	60	probt_1d_ups
	6–48, 1 h	360	probt_3d_ups
TOT_SNOW	6–48, 1 h	360	perct_1d
	6–48, 1 h	360	probt_5d
	1–48, 1 h	60	perct_1d
	1–48, 1 h	60	probt_4d
	12–48, 1 h	720	perct_1d
	12–48, 1 h	720	probt_2d
T_2M	1–48, 1 h		perct_1d
	1–48, 1 h		probt_11d
T_G	1–48, 1 h		perct_1d
	1–48, 1 h		probt_10d
VMAX_10M	6–24, 6 h	360	perct_1d
	6–24, 6 h	360	probt_8d
	1–48, 1 h	60	perct_1d
	1–48, 1 h	60	probt_8d
	12–24, 12 h	720	perct_1d
	12–24, 12 h	720	probt_8d

13.4.4. Ensemble Products for the ICON-D2-RUC-EPS

The ICON-D2-RUC-EPS products are stored in the **roma** database and can be identified by the category type **fcprod**. This leads to the category name **rucrlae_main_fcprod_rout**. The products are generated with fieldextra on the COSMO-D2 grid (rotated latlon grid). The ICON-D2-RUC-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 (Standard Deviation)	(deriv = 4)
Spread of all members (Interquartile Range)	(deriv = 7)
Minimum of all ensemble members	(deriv = 8)
Maximum of all ensemble members	(deriv = 9)

i.e. 'spread' is computed as interquartile range for TOT_PREC and as standard deviation for all the other products.

2. **Percentiles**,
   i.e. physical values of a forecast parameter (e.g. T_2M,...), which define the perc=10,25,30,50,75,90 [%] parts of the ensemble distribution.
3. **Exceedance Probabilities**
   Probability of event above lower limit (probt=3)
   Probability of event below upper limit (probt=4)
4. **Grid specification**
   Products on the rotated latlon COSMO-D2 grid (localTypeOfEnsembleProductGeneration=1)

The thresholds for the exceedance probabilities are given by the DWD alert thresholds which are used for issuing weather warnings[8] and follow the WMO recommendations[9].

Ensemble products are generated every 15 minutes (not for all parameters, see the tables) up to 14 h lead time 24 times per day. This is done for different accumulation periods, depending on the forecast parameter. In the following tables, the accumulation time range is given in minutes.

Table 13.7.: EPS products from ICON-D2-RUC. See table 13.6 for a description of the various product types.

ShortName	Time range	level type	Accum. timerange	Product type
CAPE_ML	1–14, 60 min		60	perct_1d
	1–14, 60 min		60	probt_7d
CAPE_MU	1–14, 60 min		60	perct_1d
	1–14, 60 min		60	probt_7d
CLCL	1–14, 60 min			perct_1d
	1–14, 60 min			probt_6d
CLCT	1–14, 60 min			perct_1d
	1–14, 60 min			probt_6d
DBZ_850	1–14, 15 min			perct_2d

Continued on next page

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

Table 13.7.: *continued*

	1–14, 15 min		probt_13d
DBZ_CMAX	1–14, 15 min	15	perct_2d
	1–14, 15 min	15	probt_13d
DBZ_CTMAX	1–14, 15 min	15	perct_2d
	1–14, 15 min	15	probt_13d
	1–14, 60 min	60	perct_2d
	1–14, 60 min	60	probt_13d
ECHOTOP	0–14, 15 min	15	perct_2d
	0–14, 15 min	15	probt_16d
ECHOTOPINM	0–14, 15 min	15	perct_2d
	0–14, 15 min	15	probt_15d
	0–14, 60 min	60	perct_2d
	0–14, 60 min	60	probt_15d
LPI	1–14, 15 min		perct_2d
	1–14, 15 min		probt_14d
LPI_MAX	1–14, 15 min	15	perct_2d
	1–14, 15 min	15	probt_14d
	1–14, 60 min	60	perct_2d
	1–14, 60 min	60	probt_14d
TCOND10_MX	1–14, 15 min	15	perct_2d
	1–14, 15 min	15	probt_14d
	1–14, 60 min	60	perct_2d
	1–14, 60 min	60	probt_14d
TCOND_MAX	1–14, 15 min	15	perct_2d
	1–14, 15 min	15	probt_14d
	1–14, 60 min	60	perct_2d
	1–14, 60 min	60	probt_14d
TOT_PREC	1–14, 60 min	60	perct_1d
	1–14, 60 min	60	probt_1d
	3–14, 60 min		perct_1d
	3–14, 60 min		probt_1d
	6–14, 60 min	360	perct_1d
	6–14, 60 min	360	probt_3d

Continued on next page

Table 13.7.: *continued*

	12–14, 60 min	720	perct_1d
	12–14, 60 min	720	probt_9d
T_2M	1–14, 60 min		perct_1d
	1–14, 60 min		probt_11d
UH_MAX	1–14, 15 min	15	perct_1d_abs
	1–14, 15 min	15	probt_17d
	1–14, 15 min	15	probt_18d_abs
	1–14, 60 min	60	perct_1d_abs
	1–14, 60 min	60	probt_17d
	1–14, 60 min	60	probt_18d_abs
VMAX_10M	1–14, 60 min	60	perct_1d
	1–14, 60 min	60	probt_8d

Table 13.6.: Meaning of the 'product type' key for EPS-products from ICON-D2-EPS and ICON-D2-EPS-RUC.

Product type	Description
perct_1d	perct; mean; spread; min; max; 10; 25; 30; 50; 75; 90 (ensemble distribution)
perct_1d_abs	as perct_1d, but for absolute value
probt_1d_ups	as probt_1d, but upscaled to 10x10 gridpoints
perct_2d	perct; mean; spread; min; max; 10; 30; 50; 90 (ensemble distribution)
probt_1d	> 0.1; > 1.0; > 2.0; > 5.0; > 10.0; > 15.0; > 25.0; > 40.0 (probability thresholds)
probt_2d	> 0.1; > 1.0; > 5.0; > 10.0; > 15.0; > 20.0; > 25.0; > 30.0; > 50.0 (probability thresholds)
probt_3d	> 0.1; > 1.0; > 2.0; > 5.0; > 10.0; > 20.0; > 35.0; > 60.0 (probability thresholds)
probt_3d_ups	as probt_3d, but upscaled to 10x10 gridpoints
probt_4d	> 0.1; > 1.0; > 2.0; > 5.0 (probability thresholds)
probt_5d	> 0.1; > 5.0; > 10.0 (probability thresholds)
probt_6d	< 50.0; > 87.5 (probability thresholds)
probt_7d	> 750.0; > 1000.0; > 1500.0; > 2000.0 (probability thresholds)
probt_8d	> 11.0; > 12.5; > 14.0; > 18.0; > 21.0; > 25.0; > 29.0; > 33.0; > 39.0 (probability thresholds)
probt_9d	> 25.0; > 40.0; > 70.0 (probability thresholds)
probt_9d_ups	as probt_9d, but upscaled to 10x10 gridpoints
probt_10d	< 273.15 (probability thresholds)
probt_11d	< 253.15; < 263.15; < 273.15; >= 293.15; >= 298.15; >= 303.15; >= 308.15 (probability thresholds)
probt_12d	< 263.15; < 273.15; >= 298.15; >= 303.15; >= 308.15 (probability thresholds)
probt_13d	> 28.0; > 37.0; > 46.0; > 54.0 (probability thresholds)
probt_14d	> 0.1; > 1.0; > 5.0; > 10.0; > 20.0 (probability thresholds)
probt_14d_ups	as probt_14d, but upscaled to 10x10 gridpoints
probt_15d	> 1000.0; > 3000.0; > 5000.0; > 8000.0; > 10000.0; > 12000.0 (probability thresholds)
probt_16d	< 900.0; < 700.0; < 500.0; < 300.0; < 250.0; < 200.0 (probability thresholds)
probt_17d	> 50.0; < -50.0 (probability thresholds)
probt_18d	> 100.0; > 200.0; > 400.0; > 800.0 (probability thresholds)
probt_18d_abs	> as probt_17d, but for absolute value

14. 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 under this link. Below, some remarks are given on the SKY categories for ICON data, and some examples are given how to retrieve data from the data base.

14.1. 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

For forecasts employing prognostic mineral dust, the suffix *aero* is added, i.e. we have **anaero**, **fcaero** and **fcprodaero** respectively.

suite

- **rout** for operational data in *db=roma,*
- **para1** for pre-operational data in *db=parma*
- **vera** for pre-operational data in *db=vera*
- **exp**
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 **model** part of the sky-categories for ICON itself is constructed by several substrings. It starts with a substring indicating standard icon runs or runs of the Rapid Update Cycle (*RUC*):

- with the string **ic** for standard ICON data, or

- with **ruc** for data of the RUC.

This is followed by a substring of one letter indicating the output grid

- **o** for ICON data on the native ICON grid
- **r** for data on a regular lat-lon or a rotated lat-lon grid
- **e** for radar data: volume and precipitation scans (DBZSCAN_SIM) as well as radar composites on rotated lat-lon (DBZCMP_SIM).

Next follows a two- or three-letter string to identify the domain of ICON;

- **gl** for the global domain,
- **eu** for the nest over Europe,
- **la** for the limited-area models ICON-D2 and ICON-D2-RUC.
- **ln2** for the limited-area model ICON-D05 ('n2' stands for **n**esting step **2**).

Until 2022-11-22 the category names for the deterministic runs of the global domain included the resolution and the number of levels, i.e. **icogl130l90** or **icrgl130l90**.

For ensemble forecasts or ensemble analyses the first part of the category is extended by an **e** (for instance **icogle**). Except for 5 fields for ICON-D2 there is no output of ensemble forecasts on the regular grid. For the RUC there is no output on regular grid apart fromt the radar composites, neither for the deterministic run nor for the ensemble. Ensemble members or ranges of ensemble members are specified by the parameter *enum*=NUM or *enum*=$NUM1/to/NUM2$ where NUM is the member id. *enum* must be given to get output from the ensemble categories. To get all members use *enum*=$1/to/$. Ensemble products are available only on a regular grid.

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

> Since 2014-08-12 12 UTC ICON is running pre-operationally at DWD. Hence, forecast data was available in the sky database **db=parma** in categories **icogl130l90_main_fc_para** and **icrgl_main_fc_para**. Data of the present pre-operational ICON runs is in **db=parma** in categories **icogl_main_fc_para1** and **icrgl_main_fc_para1**.

> Since 2015-01-20 06 UTC the *global* ICON model is running operationally at DWD. Forecast data was available in the sky database **db=roma** in categories **icogl130l90_main_fc_rout** and **icrgl130l90_main_fc_rout**. Analysis data is available in **icogl130l90_ass_an_rout**. Present analysis data is in **icogl_ass_an_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**. The ensemble runs of ICON write data only on the native ICON grid. Data on regular grids must be interpolated from the native grid.

> 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.

Since 2021-02-10 09 UTC the limited-area model ICON-D2 is running operationally at DWD. The same applies to the EPS mode ICON-D2-EPS. Forecast data is available in the sky database **db=roma** in categories **icola_main_fc_roma**, **icrla_main_fc_roma**, **icolae_main_fc_roma**, **icrlae_main_fc_roma**.

Since 2023-11-27 00 UTC the *global* ICON(-ART) model employing prognostic mineral dust is running operationally at DWD. This includes an ensemble data assimilation and the deterministic as well as ensemble forecast runs for a ten member ensemble. Data of the operational routine is saved in the sky database **db=roma**.
Global deterministic forecast data is available in the category **icogl_main_fcaero_rout**. Analysis data is available in **icogl_ass_anaero_rout**.
Data for the ICON-EU-NA[2] nest is available in the categories **icoeu_main_fcaero_rout** and **icoeu_ass_anaero_rout** respectively.
Forecast data of the ten member ensemble employing prognostic mineral dust is available in the categories **icogle_main_fcaero_rout** for the global domain and **icoeue_main_fcaero_rout** for the nest domain. Analysis data is avalable in the global **icogle_main_anaero_rout** and nest **icoeue_main_anaero_rout** ensemble categories. Likewise first guess data is in **icogle_pre_fcaero_rout** and **icogle_pre_fcaero_rout**. All output for the runs with prognostic mineral dust write data only on the native ICON grid. Data on regular grids must be interpolated from the native grid.

Data from the operational forecast runs of ICON on the native ICON grid, **cat** = **ico*_main_fc_rout**, is kept in the database **roma** only for 15 months! Analysis and first guess data is kept forever.

Since 2024-07-10 07 UTC the ICON-D2-RUC is running technically operational at DWD. This includes an ensemble data assimilation and the deterministic as well as ensemble forecast runs for a twenty member ensemble. Data of the operational routine is saved in the sky database **db=roma**.
Forecast data is available in the categories **ruc[oe]la_main_fc_rout** (deterministic), **ruc[oe]lae_main_fc_rout** (ensemble) and **rucrlae_main_fcprod_rout** (ensemble products). Analysis data is available in **rucola_ass_an_rout** and **rucolae_ass_an_rout** (only analysis increments).

Since 2025-02-27 09 UTC the ICON-D05 is running operationally at DWD, consisting of a deterministic forecast run every 3 hours. Data of this operational routine is saved in the sky database **db=roma**.
Forecast data is available in the categories **icoln2_main_fc_rout**.

14.2. 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 or variable name, and f the name of the GRIB data file.

14.2.1. Deterministic products

ICON global

- Retrieve the 2 m 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 120 levels to file icon2mdat

```
read db=roma cat=icogl_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 and model levels (lv=genv) from yesterday 18 UTC:

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

- Get the 6, 12, 18, and 24 hour forecast of the 2 m temperature from a forecast in experiment 11503 on 2022-08-29 at 00 UTC from an ICON run on a R3B07 grid with 120 levels. Retrieve data on the regular lat/lon grid:

```
read db=numex cat=icrgl_main_fc_exp exp=11503 d=2022082900 s[h]=6,12,18,24 p=t_2m
    bin f=t_2m_fc.grb
```

- Retrieve the 12 hour forecast on 2024-03-13 at 00 UTC of the column integrated mineral dust optical depth (for a wavelength of 550 nm) and the total mineral dust mass concentration on model levels to file icon-art_dust:

```
read db=roma cat=icogl_main_fcaero_rout d=2024031300 s[h]=12 p=taod_dust,
    dust_total_mc bin f=icon-art_dust
```

ICON-EU

- Retrieve accumulated precipitation of the ICON-EU nest on the regular grid every 6 hours to 72 hours from 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=p,lv1 infof=icr.info
```

- Retrieve the 12 hour forecast of the 00 UTC run yesterday for the ICON-EU-NA[2] domain of the attenuated backscatter for mineral dust seen from the ground for a wavelength of 1064 nm on model levels to file icon-euna2-art_ceil_bsc_dust:

```
read db=roma cat=icoeu_main_fcaero_rout d=t00-1d s[h]=12 p=ceil_bsc_dust wvl1
    =1.064E-6 bin f=icon-euna2-art_ceil_bsc_dust
```

ICON-D2

- Retrieve accumulated precipitation of the operational ICON-D2 on the rotated lat-lon grid every 3 hours to 27 hours from the 12 UTC run two days ago:

```
read db=roma cat=icrla_main_fc_rout d=t12-2d s[h]=3/to/27/by/3 p=tot_prec bin f=
    tot_prec_id2
```

- Retrieve the surface net short-wave radiation flux (averaged since model start) of the operational ICON-D2 on the native grid every hour to 12 hours for today's run at 00 UTC:

```
read db=roma cat=icola_main_fc_rout d=t00 s[h]=0/to/12/by/1 p=asob_s bin f=
    asob_s_id2
```

ICON-D2-RUC

- Retrieve accumulated precipitation of the operational ICON-D2-RUC on the ICON grid every 5 minutes up to 4 hours of the 11 UTC run yesterday:

```
read db=roma cat=rucola_main_fc_rout d=t11-1d s[m]=0/to/240/by/5 p=tot_prec bin f=
    tot_prec_ruc
```

- Retrieve the radar forecasts of the operational ICON-D2-RUC of the full forecast (up to 14 hours) for yesterday's run at 07 UTC:

```
read db=roma cat=rucela_main_fc_rout d=t07-1d s[m]=0/to/840/by/5 p=DBZSCAN_SIM bin
    f=dbzscan_sim_ruc
```

ICON-D05

- Retrieve accumulated precipitation of the operational ICON-D05 on the ICON grid every hour for the first 4 output times of the 12 UTC run at 2025-02-28:

```
 read db=roma cat=icoln2_main_fc_rout d=2025022812 STEP[h]=1/to/4/by/1 p=tot_prec
     bin f=tot_prec_d05
```

14.2.2. Ensemble products

ICON global

- ICON-EPS: Retrieve the 2 m 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 R3B06 grid to file iconEPS2mdat (use `cat=icoeue_main_fc_rout` for corresponding forecasts of ICON-EU-EPS on R3B07)

```
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
```

- Retrieve temperature in 850 hPa from the forecast of the 40 ensemble members on the 26 km grid in the parallel suite yesterday at 12 UTC. Sort the data by ensemble member.

```
read db=parma cat=icogle_main_fc_para1 enum=1/to/ d=t12-1d s=3 p=T lv=P lv1=85000
    bin f=T850_eps sort=enum
```

ICON-EU

- 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=t06 s[h]=72 perc=90 p=TOT_PREC bin f=
    iconEPS_RR72_90
```

- Retrieve ensemble spread (deriv=4) of CAPE for forecast hours 6 to 120 every 6 hours of today's run at 00 UTC on the EU domain (on regular lat/lon grid).

```
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
```

ICON-D2

- Retrieve ensemble spread (deriv=4) of T_2M for all forecast hours (from 0 to 48 every hour) of a run starting at 00 UTC.

```
read db=roma cat=icrlae_main_fcprod_rout d=t00-1d s[h]=0/to/48/by/1 deriv=4 p=T_2M
    bin f=icolae_T2M_spread
```

- Retrieve probabilities of TOT_PREC for any available threshold, where the probability of event is above lower limit (probt=3), for the forecast hours between 0 and 24 with 6-hourly step, all available accumulations (1h, 6h, 12h), of one run at 00 UTC.

```
read db=roma cat=icrlae_main_fcprod_rout d=t00-2d s[h]=0/to/24/by/6 probt=3 p=
    TOT_PREC bin f=icolae_TP_prob
```

- Retrieve 90% percentile of CAPE_ML (6h accumulation period) at forecast hour 12 of today's run at 00 UTC.

```
read db=roma cat=icrlae_main_fcprod_rout d=t00 s[h]=12 perc=90 p=CAPE_ML bin f=
    icolae_CAPE_perc
```

- The corresponding request to retrieve ICON-D2-EPS products from the parallel suite is

```
read db=vera cat=icrlae_main_fcprod_vera d=t00 s[h]=12 perc=90 p=CAPE_ML bin f=
    icolae_CAPE_perc
```

ICON-D2-RUC

- Retrieve ensemble spread (deriv=4) of LPI for all forecast hours (from 0 to 14 every hour) of a run starting at 02 UTC.

```
read db=roma cat=rucrlae_main_fcprod_rout d=t02 s[h]=0/to/14/by/1 deriv=4 p=LPI bin
     f=rucolae_LPI_spread
```

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 for ICON global/ICON-EU and in Table A.3 for ICON-D2. 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 for ICON global/ICON-EU and Table A.4 for ICON-D2.

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:

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

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

As an example, Tables A.5 and A.6 show these model heights for a special grid point over India with a quite high surface elevation.

Table A.1.: Standard heights z_i^{h0} (i.e. for zero topography height) for all 121 vertical *half levels* of the global 13 km domain and the 75 vertical half levels for the 6.5 km EU nest.

level index		height	level index		height	level index		height
global	EU nest	$[m]$	global	EU nest	$[m]$	global	EU nest	$[m]$
1	-	75 000.000	42	-	26 406.667	83	37	8 533.170
2	-	73 420.604	43	-	25 640.990	84	38	8 233.170
3	-	71 869.610	44	-	24 895.393	85	39	7 933.170
4	-	70 328.192	45	-	24 169.889	86	40	7 633.170
5	-	68 805.917	46	-	23 463.917	87	41	7 333.170
6	-	67 302.897	47	1	22 770.331	88	42	7 033.170
7	-	65 819.234	48	2	22 096.568	89	43	6 733.170
8	-	64 355.018	49	3	21 435.487	90	44	6 433.170
9	-	62 910.329	50	4	20 795.107	91	45	6 133.170
10	-	61 485.239	51	5	20 175.457	92	46	5 833.170
11	-	60 079.812	52	6	19 576.575	93	47	5 533.170
12	-	58 694.107	53	7	18 998.498	94	48	5 233.170
13	-	57 328.172	54	8	18 441.271	95	49	4 933.170
14	-	55 982.053	55	9	17 908.405	96	50	4 633.170
15	-	54 655.788	56	10	17 400.463	97	51	4 333.170
16	-	53 349.411	57	11	16 920.113	98	52	4 033.170
17	-	52 062.951	58	12	16 467.114	99	53	3 735.917
18	-	50 796.435	59	13	16 039.909	100	54	3 448.582
19	-	49 549.882	60	14	15 637.031	101	55	3 171.241
20	-	48 323.311	61	15	15 257.093	102	56	2 903.980
21	-	47 116.737	62	16	14 898.789	103	57	2 646.890
22	-	45 930.172	63	17	14 560.888	104	58	2 400.076
23	-	44 763.626	64	18	14 242.227	105	59	2 163.652
24	-	43 617.107	65	19	13 933.170	106	60	1 937.746
25	-	42 490.621	66	20	13 633.170	107	61	1 722.498
26	-	41 384.171	67	21	13 333.170	108	62	1 518.070
27	-	40 297.761	68	22	13 033.170	109	63	1 324.640
28	-	39 231.393	69	23	12 733.170	110	64	1 142.413
29	-	38 185.067	70	24	12 433.170	111	65	971.624
30	-	37 158.783	71	25	12 133.170	112	66	812.540
31	-	36 152.542	72	26	11 833.170	113	67	665.478
32	-	35 166.342	73	27	11 533.170	114	68	530.811
33	-	34 200.183	74	28	11 233.170	115	69	408.988
34	-	33 254.064	75	29	10 933.170	116	70	300.565
35	-	32 327.985	76	30	10 633.170	117	71	206.253
36	-	31 421.947	77	31	10 333.170	118	72	126.999
37	-	30 535.948	78	32	10 033.170	119	73	64.166
38	-	29 669.993	79	33	9 733.170	120	74	20.000
39	-	28 824.082	80	34	9 433.170	121	75	0.000
40	-	27 998.221	81	35	9 133.170			
41	-	27 192.413	82	36	8 833.170			

Table A.2.: Standard heights z_i^{f0} (i.e. for zero topography height) for all 120 vertical *full levels* of the global 13 km domain and the 74 full levels of the 6.5 km EU nest.

level index		height	level index		height	level index		height
global	EU nest	height $[m]$	global	EU nest	height $[m]$	global	EU nest	height $[m]$
1	-	74 210.302	41	-	26 799.540	81	35	8 983.170
2	-	72 645.107	42	-	26 023.829	82	36	8 683.170
3	-	71 098.901	43	-	25 268.192	83	37	8 383.170
4	-	69 567.054	44	-	24 532.641	84	38	8 083.170
5	-	68 054.407	45	-	23 816.903	85	39	7 783.170
6	-	66 561.065	46	-	23 117.124	86	40	7 483.170
7	-	65 087.126	47	1	22 433.449	87	41	7 183.170
8	-	63 632.673	48	2	21 766.028	88	42	6 883.170
9	-	62 197.784	49	3	21 115.297	89	43	6 583.170
10	-	60 782.526	50	4	20 485.282	90	44	6 283.170
11	-	59 386.959	51	5	19 876.016	91	45	5 983.170
12	-	58 011.140	52	6	19 287.537	92	46	5 683.170
13	-	56 655.113	53	7	18 719.885	93	47	5 383.170
14	-	55 318.921	54	8	18 174.838	94	48	5 083.170
15	-	54 002.599	55	9	17 654.434	95	49	4 783.170
16	-	52 706.181	56	10	17 160.288	96	50	4 483.170
17	-	51 429.693	57	11	16 693.613	97	51	4 183.170
18	-	50 173.158	58	12	16 253.512	98	52	3 884.543
19	-	48 936.596	59	13	15 838.470	99	53	3 592.249
20	-	47 720.024	60	14	15 447.062	100	54	3 309.912
21	-	46 523.454	61	15	15 077.941	101	55	3 037.610
22	-	45 346.899	62	16	14 729.839	102	56	2 775.435
23	-	44 190.367	63	17	14 401.558	103	57	2 523.483
24	-	43 053.864	64	18	14 087.699	104	58	2 281.864
25	-	41 937.396	65	19	13 783.170	105	59	2 050.699
26	-	40 840.966	66	20	13 483.170	106	60	1 830.122
27	-	39 764.577	67	21	13 183.170	107	61	1 620.284
28	-	38 708.230	68	22	12 883.170	108	62	1 421.355
29	-	37 671.925	69	23	12 583.170	109	63	1 233.526
30	-	36 655.663	70	24	12 283.170	110	64	1 057.019
31	-	35 659.442	71	25	11 983.170	111	65	892.082
32	-	34 683.262	72	26	11 683.170	112	66	739.009
33	-	33 727.124	73	27	11 383.170	113	67	598.144
34	-	32 791.024	74	28	11 083.170	114	68	469.899
35	-	31 874.966	75	29	10 783.170	115	69	354.776
36	-	30 978.948	76	30	10 483.170	116	70	253.409
37	-	30 102.970	77	31	10 183.170	117	71	166.626
38	-	29 247.037	78	32	9 883.170	118	72	95.582
39	-	28 411.151	79	33	9 583.170	119	73	42.083
40	-	27 595.317	80	34	9 283.170	120	74	10.000

Table A.3.: Standard heights z_i^{h0} (i.e. for zero topography height) for all 66 vertical *half levels* of ICON-D2.

level idx.	height $[m]$	level idx.	height $[m]$	level idx.	height $[m]$	level idx.	height $[m]$
1	22 000.000	19	8 256.329	37	3 333.549	55	702.132
2	19 401.852	20	7 890.952	38	3 138.402	56	606.827
3	18 013.409	21	7 539.748	39	2 949.656	57	516.885
4	16 906.264	22	7 201.825	40	2 767.143	58	432.419
5	15 958.169	23	6 876.388	41	2 590.708	59	353.586
6	15 118.009	24	6 562.725	42	2 420.213	60	280.598
7	14 358.139	25	6 260.200	43	2 255.527	61	213.746
8	13 661.439	26	5 968.239	44	2 096.537	62	153.438
9	13 016.363	27	5 686.321	45	1 943.136	63	100.277
10	12 414.654	28	5 413.976	46	1 795.234	64	55.212
11	11 850.143	29	5 150.773	47	1 652.748	65	20.000
12	11 318.068	30	4 896.323	48	1 515.610	66	0.000
13	10 814.653	31	4 650.265	49	1 383.761		
14	10 336.841	32	4 412.272	50	1 257.155		
15	9 882.112	33	4 182.043	51	1 135.760		
16	9 448.359	34	3 959.301	52	1 019.556		
17	9 033.796	35	3 743.791	53	908.539		
18	8 636.893	36	3 535.279	54	802.721		

Table A.4.: Standard heights z_i^{f0} (i.e. for zero topography height) for all 65 vertical *full levels* of ICON-D2.

level idx.	height $[m]$	level idx.	height $[m]$	level idx.	height $[m]$	level idx.	height $[m]$
1	20 700.926	18	8 446.611	35	3 639.535	52	964.048
2	18 707.630	19	8 073.640	36	3 434.414	53	855.630
3	17 459.836	20	7 715.350	37	3 235.976	54	752.427
4	16 432.216	21	7 370.787	38	3 044.029	55	654.479
5	15 538.089	22	7 039.106	39	2 858.399	56	561.856
6	14 738.074	23	6 719.557	40	2 678.926	57	474.652
7	14 009.789	24	6 411.462	41	2 505.461	58	393.002
8	13 338.901	25	6 114.219	42	2 337.870	59	317.092
9	12 715.508	26	5 827.280	43	2 176.032	60	247.172
10	12 132.398	27	5 550.148	44	2 019.836	61	183.592
11	11 584.105	28	5 282.374	45	1 869.185	62	126.857
12	11 066.360	29	5 023.548	46	1 723.991	63	77.745
13	10 575.747	30	4 773.294	47	1 584.179	64	37.606
14	10 109.477	31	4 531.269	48	1 449.686	65	10.000
15	9 665.235	32	4 297.157	49	1 320.458		
16	9 241.077	33	4 070.672	50	1 196.457		
17	8 835.344	34	3 851.546	51	1 077.658		

Table A.5.: 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 = 81.016 / 35.333

HSURF = 6220.215 m

level idx.	height $[m]$	level idx.	height $[m]$	level idx.	height $[m]$	level idx.	height $[m]$
1	68 779.785	32	28 946.129	63	8 390.156	94	2 225.703
2	67 200.387	33	27 979.969	64	8 078.022	95	2 088.177
3	65 649.395	34	27 033.848	65	7 776.084	96	1 950.706
4	64 107.981	35	26 107.772	66	7 483.826	97	1 813.210
5	62 585.699	36	25 201.733	67	7 192.479	98	1 675.732
6	61 082.684	37	24 315.734	68	6 902.146	99	1 539.776
7	59 599.020	38	23 449.777	69	6 612.939	100	1 409.701
8	58 134.805	39	22 603.867	70	6 324.984	101	1 285.344
9	56 690.113	40	21 778.006	71	6 038.416	102	1 166.802
10	55 265.024	41	20 972.199	72	5 753.389	103	1 054.064
11	53 859.598	42	20 186.453	73	5 470.070	104	947.087
12	52 473.891	43	19 420.775	74	5 188.639	105	845.981
13	51 107.957	44	18 675.178	75	4 941.922	106	750.672
14	49 761.840	45	17 949.674	76	4 735.653	107	661.273
15	48 435.574	46	17 243.703	77	4 563.203	108	577.713
16	47 129.195	47	16 550.117	78	4 425.707	109	499.860
17	45 842.738	48	15 876.354	79	4 288.199	110	427.890
18	44 576.219	49	15 215.272	80	4 150.699	111	361.787
19	43 329.668	50	14 574.893	81	4 013.218	112	301.589
20	42 103.098	51	13 955.242	82	3 875.690	113	247.134
21	40 896.524	52	13 356.359	83	3 738.201	114	198.440
22	39 709.957	53	12 778.283	84	3 600.717	115	155.705
23	38 543.410	54	12 221.057	85	3 463.198	116	118.833
24	37 396.891	55	11 688.190	86	3 325.699	117	87.462
25	36 270.406	56	11 180.248	87	3 188.214	118	61.043
26	35 163.957	57	10 699.899	88	3 050.701	119	40.010
27	34 077.547	58	10 246.899	89	2 913.215	120	19.982
28	33 011.180	59	9 819.694	90	2 775.681	121	0.000
29	31 964.852	60	9 449.262	91	2 638.213		
30	30 938.570	61	9 074.562	92	2 500.675		
31	29 932.328	62	8 721.942	93	2 363.176		

Table A.6.: 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 = 81.016 / 35.333

HSURF = 6220.215 m

level idx.	height [m]	level idx.	height [m]	level idx.	height [m]	level idx.	height [m]
1	67 990.086	31	29 439.229	61	8 898.252	91	2 569.444
2	66 424.891	32	28 463.049	62	8 556.049	92	2 431.926
3	64 878.688	33	27 506.909	63	8 234.089	93	2 294.439
4	63 346.840	34	26 570.810	64	7 927.053	94	2 156.940
5	61 834.192	35	25 654.753	65	7 629.955	95	2 019.441
6	60 340.852	36	24 758.734	66	7 338.153	96	1 881.958
7	58 866.912	37	23 882.755	67	7 047.312	97	1 744.471
8	57 412.459	38	23 026.822	68	6 757.542	98	1 607.754
9	55 977.568	39	22 190.936	69	6 468.962	99	1 474.738
10	54 562.311	40	21 375.103	70	6 181.700	100	1 347.523
11	53 166.745	41	20 579.326	71	5 895.903	101	1 226.073
12	51 790.924	42	19 803.614	72	5 611.729	102	1 110.433
13	50 434.898	43	19 047.977	73	5 329.354	103	1 000.576
14	49 098.707	44	18 312.426	74	5 065.280	104	896.534
15	47 782.385	45	17 596.689	75	4 838.788	105	798.327
16	46 485.966	46	16 896.910	76	4 649.428	106	705.973
17	45 209.478	47	16 213.235	77	4 494.455	107	619.493
18	43 952.943	48	15 545.813	78	4 356.953	108	538.786
19	42 716.383	49	14 895.083	79	4 219.449	109	463.875
20	41 499.811	50	14 265.068	80	4 081.958	110	394.838
21	40 303.240	51	13 655.801	81	3 944.454	111	331.688
22	39 126.683	52	13 067.321	82	3 806.945	112	274.361
23	37 970.151	53	12 499.670	83	3 669.459	113	222.787
24	36 833.649	54	11 954.624	84	3 531.957	114	177.072
25	35 717.182	55	11 434.219	85	3 394.448	115	137.269
26	34 620.752	56	10 940.073	86	3 256.957	116	103.148
27	33 544.363	57	10 473.399	87	3 119.457	117	74.252
28	32 488.016	58	10 033.297	88	2 981.958	118	50.526
29	31 451.711	59	9 634.478	89	2 844.448	119	29.996
30	30 435.449	60	9 261.912	90	2 706.947	120	9.991

B. Output on rotated latitude-longitude grids in ICON-D2

The output on the structured lat-lon grid of ICON-D2 takes place on a *rotated latitude-longitude* grid, i.e. in comparison to the standard latitude-longitude output of ICON global or ICON-EU, this spherical coordinate system has rotated poles. The reason for this is to achieve a relatively constant grid mesh size on the sphere[1], which saves storage space by avoiding senseless high spatial sampling in the northern (i.e. close to the pole) part of the domain.

For most of the users it may be sufficient just to read the two fields `RLON` and `RLAT`, which contain the geographical coordinates (longitude and latitude, respectively) of every rotated grid point.

For those who are interested in the underlying transformations or need them for some reason, we list here the transformation formulas between the rotated and the geographical coordinates. First, the north pole of the rotated output grid for ICON-D2 is shifted to the position $\lambda_N = 170°$W and $\varphi_N = 40°$N. (i.e. somewhere into the pacific), Therefore, the equator of the rotated grid goes roughly through the center of the output domain (i.e. through the center of Germany).

The 'rotated latitude/longitude grid' is coded in the Grid Description Section (GDS=section 3) of the ICON-D2 output GRIB-files by `gridDefinitionTemplateNumber=1` and `gridType=rotated_ll`.

It should be noted, that ICON still assumes a perfect sphere of the earth with a radius of 6371,229 km.

The transformation relations between the geographical coordinates (λ_g, φ_g) and the rotated coordinates (λ, φ) can be derived from simple geometric relations of spherical geometry. They are:

- From rotated to geographical coordinates

$$\begin{aligned}\lambda_g &= \lambda_N - \arctan\left\{\frac{\cos\varphi\sin\lambda}{\sin\varphi\cos\varphi_N - \sin\varphi_N\cos\varphi\cos\lambda}\right\}\,,\\ \varphi_g &= \arcsin\left\{\sin\varphi\sin\varphi_N + \cos\varphi\cos\lambda\cos\varphi_N\right\}\,,\end{aligned}$$

- and for the backtransformation from geographical to rotated coordinates

$$\begin{aligned}\lambda &= \arctan\left\{\frac{-\cos\varphi_g\sin(\lambda_g-\lambda_N)}{-\cos\varphi_g\sin\varphi_N\cos(\lambda_g-\lambda_N)+\sin\varphi_g\cos\varphi_N}\right\}\,,\\ \varphi &= \arcsin\left\{\sin\varphi_g\sin\varphi_N + \cos\varphi_g\cos\varphi_N\cos(\lambda_g-\lambda_N)\right\}\,.\end{aligned}$$

Note, that all angles are given in arcs (not in degrees). To get the angle in degrees, one has to multiply by $180/\pi \approx 57,2957795$. Take care that the arctan is correctly evaluated in all 4 quadrants.[2].

In the `dwdlib` (in particular in the library `libmisc.a`) the four Fortran functions `RLSTORL`, `PHSTOPH`, `RLTORLS` and `PHTOPHS` are contained, which calculate the transformtions. These programs give and expect angles in degrees.

[1] In former models that used a spherical coordinate system, not only for output but as the base for their numerical grid (e.g. the COSMO model), the use of a rotated grid was necessary to avoid too narrow grid cells near the poles (the so called 'pole problem'). Narrow grid cells induce strong time step restrictions and therefore would result in inefficient code.

[2] Most programming languages have an extension of the standard arctan-function, e.g. in Fortran the function `ATAN2(numerator, denominator)`, which takes into account the corrct quadrant.

- `RLSTORL` calculates geographic longitude (RL) from rotated longitude and latitude.
- `PHSTOPH` calculates geographic latitude (PH) from rotated longitude and latitude.
- `RLTORLS` calculates rotated longitude (RLS) from geographic longitude and latitude.
- `PHTOPHS` calculates rotated latitude (PHS) from geographic longitude and latitude.

For the transformation of many points or even whole fields `dwdlib` also contains the better optimized routines `PLSTOPL`, `PLTOPLS`, `APLSTPL`, and `APLTPLS`. An online description can be get via `disdwd PLSTOPL` or `man libmisc`.

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Glossary

ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model. 15–17

CRU-CL Climate Research Unit – Gridded climatology of 1961-1990 monthly means. 15, 17

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, 16

GLCC Global Land Cover Characteristics. 15

GLDB Global Lake Database. 15, 16

GlobCover 2009 Global Land Cover Map for 2009. 15–17

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

GRIB2 General Regularly-distributed Information in Binary Form, 2^{nd} edition. 29, 48

GSFC Goddard Space Flight Center. 15

HWSD Harmonized World Soil Database. 15

HWSD_USDA Harmonized World Soil Database in USDA (United States Department of Agriculture) soil classification system. 15, 17

IIASA International Institute for Applied Systems Analysis. 15

IIS Institute of Industrial Sciences, The University of Tokyo. 15

ISRIC World Soil Information. 15

ISSCAS Chinese Academy of Sciences. 15

JRC Joint Research Centre – European Commission. 15

MERIT Multi-Error-Removed Improved-Terrain (MERIT) DEM. 15–17

METI Ministry of Economy, Trade, and Industry. 15

MODIS Moderate Resolution Imaging Spectroradiometer. 15, 16

NASA National Aeronautics and Space Administration. 15

NGDC NOAA National Geophysical Data Center. 15

PGC U. S. Polar Geospatial Center. 15

REMA The Reference Elevation Model of Antarctica. 15–17

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

TOA top of atmosphere. 37, 38

USGS U. S. Geological Service. 15

WMO World Meteorological Organization. 29

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