



ICON Database Reference Manual

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History of versions

Version	Date	Author(s)	Changes
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 parameter 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

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Chapter 1

Grid geometry

1.1 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 1.1a) which is projected onto a sphere. The spherical icosahedron (Figure 1.1b) 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 1.1c, 1.1d).

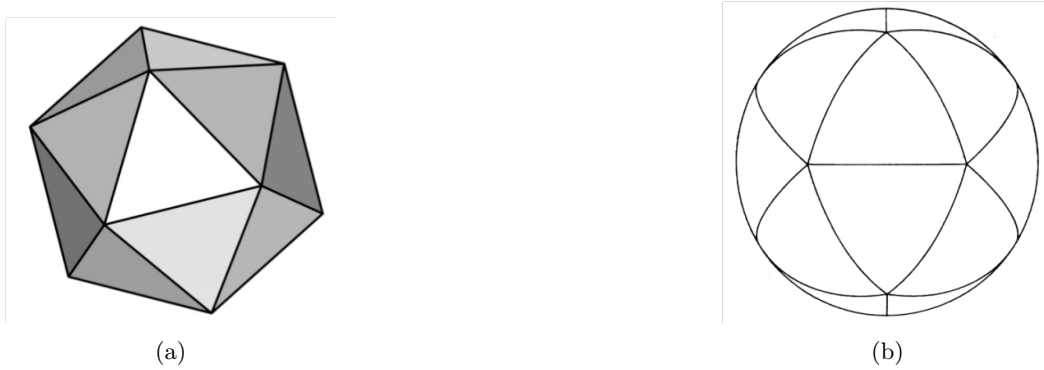


Figure 1.1: Icosahedron before (a) and after (b) projection onto a sphere

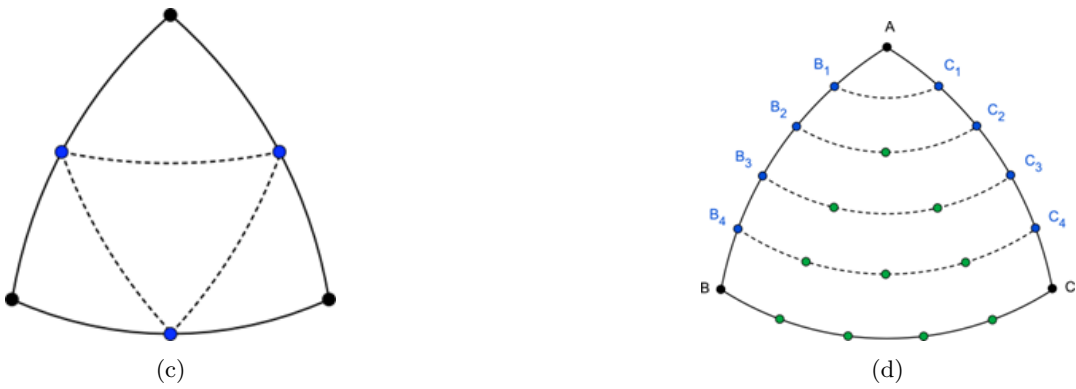


Figure 1.2: (a) Bisection of the original triangle edges (b) More general division into n equal sections

ICON grids are constructed by an initial root division into n sections (\mathbf{R}_n) followed by k bisection steps (\mathbf{B}_k), resulting in a $\mathbf{R}_n\mathbf{B}_k$ grid. Figures 1.3a and 1.3b show $\mathbf{R}_2\mathbf{B}_0$ and $\mathbf{R}_2\mathbf{B}_2$ ICON grids. Such grids avoid polar singularities of latitude-longitude grids (Figure 1.3c) and allow a high uniformity in resolution over the whole sphere.



Figure 1.3: (a) $\mathbf{R}_2\mathbf{B}_0$ grid. (b) $\mathbf{R}_2\mathbf{B}_2$ grid. (c) traditional regular latitude-longitude grid with polar singularities

Throughout this document, the grid is referred to as the “ $\mathbf{R}_n\mathbf{B}_k$ grid” or “ $\mathbf{R}_n\mathbf{B}_k$ resolution”. For a given resolution $\mathbf{R}_n\mathbf{B}_k$, 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. Based on $\overline{\Delta A}$ one can derive an estimate of the average grid resolution $\overline{\Delta x}$:

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

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

In Table 1.1, some characteristics of frequently used ICON grids are given. The table contains information about the total number of triangles (n_c), the average resolution $\overline{\Delta x}$, and the maximum/minimum cell area. The latter may be interpreted as the area for which the prognosed meteorological quantities (like temperature, pressure, ...) are representative. Some additional information about ICON’s horizontal grid can be found in Wan et al. (2013).

Table 1.1: Characteristics of frequently used ICON grids. ΔA_{max} and ΔA_{min} refer to the maximum and minimum area of the grid cells, respectively.

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

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

1.1.1 Local grid refinement

1.2 Vertical grid

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

To improve simulations of flow past complex topography, the ICON model employs a smooth level vertical (SLEVE) coordinate [Leuenberger et al. \(2010\)](#). It allows for a faster transition to smooth levels in the upper troposphere and lower stratosphere, as compared to the classical height-based Gal-Chen coordinate. In the operational setup, the transition from terrain following levels in the lower atmosphere to constant height levels is completed at $z = 16$ km. Model levels above are flat. The required smooth large-scale contribution of the model topography is generated by digital filtering with a ∇^2 -diffusion operator. Figure 1.4 shows the (half) levels of the planned operational ICON setup with 90 vertical levels. The table to the right shows the height above ground of selected half levels (for zero height topography) and the corresponding pressure, assuming the US standard atmosphere. Standard heights for all 91 half levels are given in Table A.1.

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

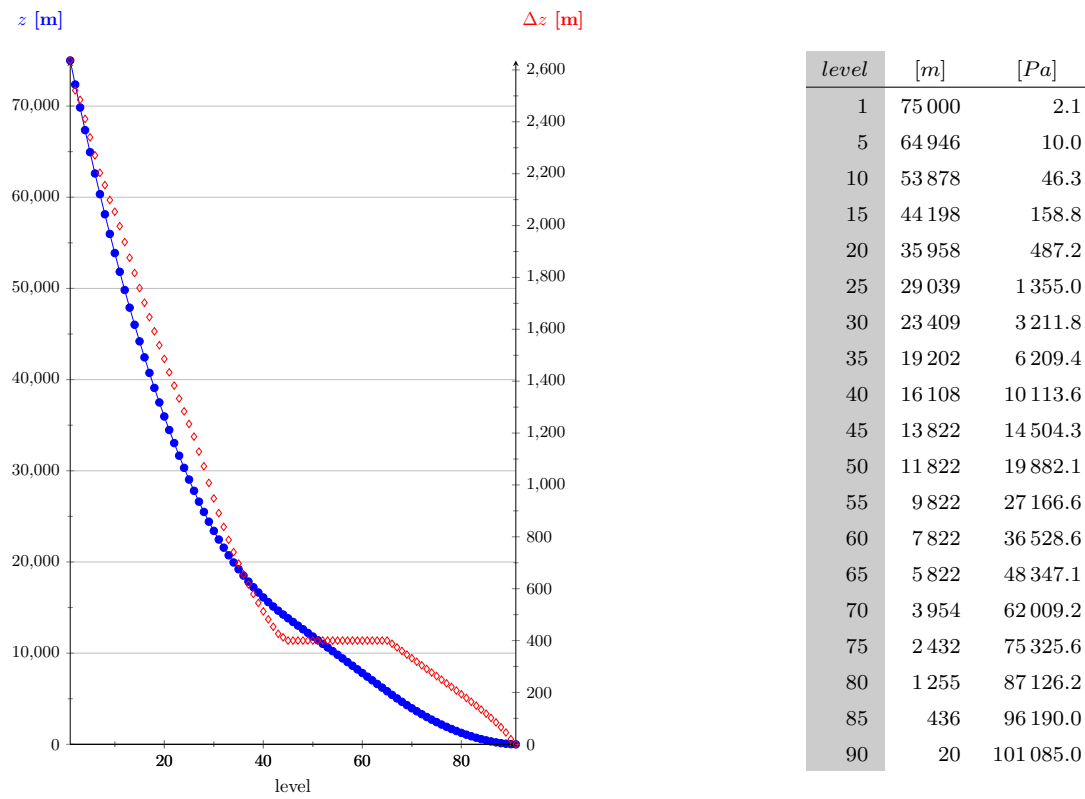


Figure 1.4: Vertical (half) levels of the ICON model (planned operational setup). The table of selected pressure values (for zero height) is based on the 1976 US standard atmosphere.

Chapter 2

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). The latter will be described in Chapter 3.

2.1 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. The most important data entries 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 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 triangle vertices that belong to the triangle **i**.
- **edge_of_cell** (INTEGER array, dimensions: [2, #triangles])
The indices **edge_of_cell(:,i)** denote the triangle edges that belong to the triangle **i**.

2.2 External parameter

External parameters are used to describe the properties of the earth’s surface. These data include the orography and the land-sea-mask. Also, several parameters are needed to specify the dominant land use of a grid box like the soiltype or the plant cover fraction.

The ExtPar software (ExtPar – External parameter for Numerical Weather Prediction and Climate Application) is able to generate external parameters for the ICON model. The generation is based on a set of raw-datafields which are listed in Table 2.1. For a more detailed overview of ExtPar, the reader is referred to the *User and Implementation Guide* of Extpar.

Table 2.1: Raw datasets from which the ICON external parameter fields are derived.

Dataset	Source	Resolution
GLOBE orography	NOAA/NGDC	30"
GlobCover 2009	ESA	10"
GLCC land use	USGS	30"
HWSD Harmonized World Soil Database	FAO/IIASA/ISRIC/ISSCAS/JRC	30"
NDVI Climatotology, SeaWiFS	NASA/GSFC	2.5'
CRU near surface climatology	CRU University of East Anglia	0.5°
GACP Aerosol Optical thickness	NASA/GISS (Global Aerosol Climatology Project)	4x5°
GLDB Global lake database	DWD/RSHU/MeteoFrance	30"
MODIS albedo	NASA	5'

GlobCover 2009 is a land cover database covering the whole globe, except for Antarctica. Therefore, we make use of *GlobCover 2009* for $90^\circ > \phi > -65^\circ$ (with ϕ denoting latitude) and switch to the coarser, however globally available dataset *GLCC* for $-65^\circ > \psi > -90^\circ$.

The products generated by the ExtPar software package are listed in Table 2.2 together with the underlying raw dataset. Note that these are mandatory input fields for assimilation- and forecast runs.

Table 2.2: External parameter fields for ICON, produced by the ExtPar software package (in alphabetical order)

ShortName	Description	Raw dataset
AER.SS12	Sea salt aerosol climatology (monthly fields)	GACP
AER.DUST12	Total soil dust aerosol climatology (monthly fields)	GACP
AER.ORG12	Organic aerosol climatology (monthly fields)	GACP
AER.SO412	Total sulfate aerosol climatology (monthly fields)	GACP
AER.BC12	Black carbon aerosol climatology (monthly fields)	GACP
ALB.DIF12	Shortwave (0.3 – 5.0 μm) albedo for diffuse radiation (monthly fields)	MODIS

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Table 2.2: *continued*

ALB_UV12	UV-visible ($0.3 - 0.7 \mu\text{m}$) albedo for diffuse radiation (monthly fields)	MODIS
ALB_NI12	UV-visible ($0.7 - 5.0 \mu\text{m}$) albedo for diffuse radiation (monthly fields)	MODIS
DEPTH_LK	Lake depth	GLDB
EMIS_RAD	Surface longwave (thermal) emissivity	GlobCover 2009
FOR_D (*)	Fraction of deciduous forest	GlobCover 2009
FOR_E (*)	Fraction of evergreen forest	GlobCover 2009
FR_LAKE	Lake fraction (fresh water)	GLDB
FR_LAND	Land fraction (excluding lake fraction but including glacier fraction)	GlobCover2009
FR_LUC	Landuse class fraction	
HSURF	Orography height at cell centres	GLOBE
LAI_MX	Leaf area index in the vegetation phase	GlobCover 2009
NDVI_MAX	Normalized differential vegetation index	SeaWiFS
NDVI_MRAT	proportion of monthly mean NDVI to yearly maximum (monthly fields)	SeaWiFS
PLCOV_MX	Plant covering degree in the vegetation phase	GlobCover 2009
ROOTDP	Root depth	GlobCover 2009
RSMIN	Minimum stomatal resistance	GlobCover 2009
SOILTYP	Soil type	HWSD
SSO_STDH	Standard deviation of sub-grid scale orographic height	GLOBE
SSO_THETA	Principal axis-angle of sub-grid scale orography	GLOBE
SSO_GAMMA	Horizontal anisotropy of sub-grid scale orography	GLOBE
SSO_SIGMA	Average slope of sub-grid scale orography	GLOBE
T_2M_CL	Climatological 2m temperature (serves as lower boundary condition for soil model)	CRU
Z0 (*)	Surface roughness length (over land)	GlobCover 2009

Note that fields marked with (*) are not required in operational model runs. I.e. **FOR_D** and **FOR_E** are only required *without* tile approach, if tabulated albedo values are used instead of MODIS albedo. Similarly, the surface roughness **Z0** is only needed, if the additional contribution from sub-grid scale orography is taken into account (i.e. for `itype_z0=1`). Otherwise, land-use specific roughness lengths are used, which are based on a GlobCover-based lookup table. However, due to technical reasons, all 3 fields must be provided as input, irrespective of the options chosen.

Remarks on post-processing

Some of the external parameter fields produced by ExtPar are modified by ICON. The following fields are affected: **HSURF**, **FR_LAND**, **FR_LAKE**, **Z0**. Thus, for consistency reasons, the modified fields should be

used for post-processing tasks rather than the original external parameter fields.

Chapter 3

Analysis fields

The 3-hourly first guess output of ICON contains the following fields:

Table 3.1: Available 3h first guess output fields

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

Atmospheric analysis fields are computed every 3 hours (00, 03, 06,... 21 UTC) by the 3DVar data assimilation system. Sea surface temperature `T_SO(0)` and sea ice cover `FR_ICE` are provided once per day (00 UTC) by the SST-Analysis. A snow analysis is conducted every 3 hours. 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 analysis cycle, ICON must be provided with 2 input files, containing First Guess (FG) and analysis (AN) fields, respectively. Variables for which no analysis is available are always read from the first guess file (e.g. `TKE`). Other variables may be either read from the first guess or the analysis file, depending on the starting time. E.g. for `T_SO(0)` the first guess is read at 03, 06, 09, 12, 15, 18, 21 UTC, however, the analysis is read at 00 UTC. In Table 3.2 the available and employed first guess and analysis fields are listed as a function of starting time.

Table 3.2: 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)	Ana_SST	AN	FG	FG	FG	FG	FG	FG	FG
T_SO(1:nlevsoil)	–	FG	FG	FG	FG	FG	FG	FG	FG
W_SO_ICE	–	FG	FG	FG	FG	FG	FG	FG	FG
W_SO	SMA	AN	FG	FG	FG	FG	FG	FG	FG
W_I	–	FG	FG	FG	FG	FG	FG	FG	FG
W_SNOW ¹	Ana_SNOW	AN	AN	AN	AN	AN	AN	AN	AN
T_SNOW	Ana_SNOW	AN	AN	AN	AN	AN	AN	AN	AN
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
Sea ice/Lake									
T_ICE	Ana_SST	AN	FG	FG	FG	FG	FG	FG	FG
H_ICE	Ana_SST	AN	FG	FG	FG	FG	FG	FG	FG
FR_ICE	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

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Table 3.2: 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
H_ML_LK	–	FG	FG	FG	FG	FG	FG	FG	FG
T_BOT_LK	–	FG	FG	FG	FG	FG	FG	FG	FG
C_TLK	–	FG	FG	FG	FG	FG	FG	FG	FG
T_B1_LK	–	FG	FG	FG	FG	FG	FG	FG	FG
H_B1_LK	–	FG	FG	FG	FG	FG	FG	FG	FG

3.1 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 3.1).

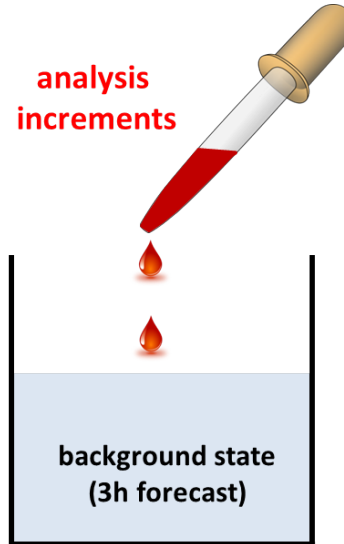


Figure 3.1: Incremental Analysis Update. Analysis increments are added to the background state (FG) in small drips over some time interval rather than in one go. Currently, increments for U , V , P , T , QV are treated in this way.

¹Note that w_{snow} and ρ_{snow} are actually not read from the analysis but from the first guess. w_{snow} and ρ_{snow} do not contain any new/independent information, they are simply re-diagnosed from the analysed field h_{snow} . This diagnosis is performed within the ICON-code based on the first guess fields of w_{snow} and ρ_{snow} and the analyzed field h_{snow} .

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

$$\frac{d\mathbf{x}}{dt} = A\mathbf{x} + g(t)\Delta\mathbf{x}^A \quad , \text{ with } \int g(t) dt = 1 \quad (3.1)$$

\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 .

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 3.2 shows how the IAU-method is implemented in ICON for a 3h assimilation run starting at midnight. Analysis increments are applied over a 3h hour time window, centered at the actual model start time. As indicated by the blue line, constant weights are used:

$$g(t) = \frac{\Delta t}{T} \quad , \text{ for } -T/2 < t < T/2 \quad (3.2)$$

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 CET first guess. The analysis increments for U, V, P, T, QV, whose validity time is 00:00 CET 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 CET, which will be used for starting the next 3h assimilation run, and a second one at 3:00 CET, which is required as input for the assimilation system itself. Thus in general, using the IAU method requires some care in terms of reading and writing the right fields at the right times.

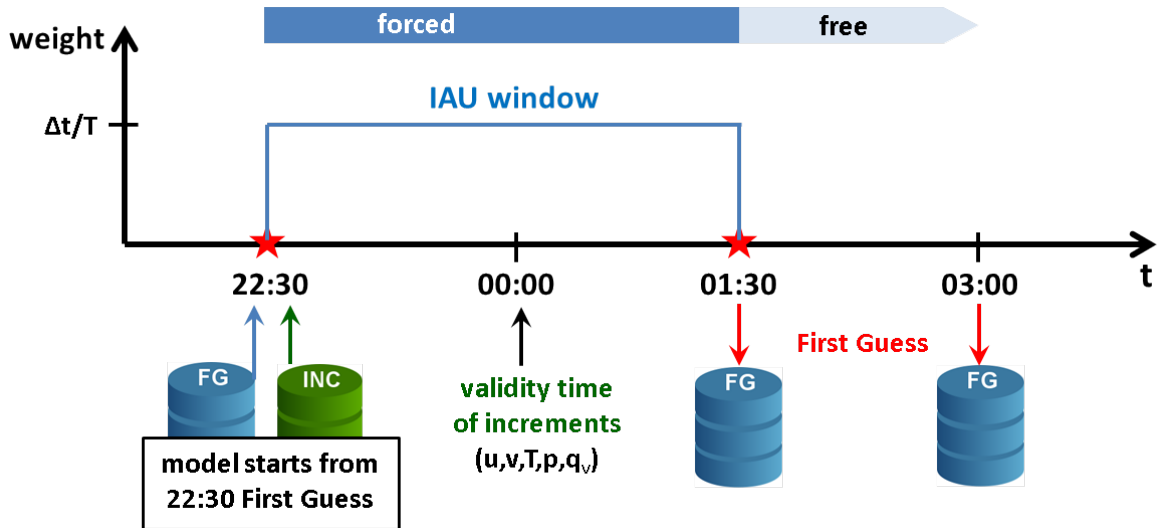


Figure 3.2: Time line for an ICON assimilation run starting at 00:00 CET.

Chapter 4

Available output fields in GRIB2-format

In GRIB2, a variable is uniquely defined by the following set of metadata:

- *Discipline* (see GRIB2 code table 4.2)
- *ParameterCategory* (see GRIB2 code table 4.2)
- *ParameterNumber* (see GRIB2 code table 4.2)
- *typeOfFirstFixedSurface* and *typeOfSecondFixedSurface* (see GRIB2 code table 4.5)
- *stepType* (instant, accum, avg, max, min, diff, rms, sd, cov, ...)

A documentation of the official WMO GRIB2 code tables can be found here: http://www.wmo.int/pages/prog/www/WMOCodes/WM0306_vI2/LatestVERSION/WM0306_vI2_GRIB2_CodeFlag_en.pdf

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

4.1 Deprecated output fields

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

- **BAS_CON** [-]: Level index of convective cloud base. Instead, **HBAS_CON** [m] should be used.
- **TOP_CON** [-]: Level index of convective cloud top. Instead, **HTOP_CON** [m] should be used.
- **T_S** [K]: Temperature at the soil-atmosphere-, or soil-snow-interface. Note that $T_S = T_SO(0)$, thus **T_S** is redundant.
- **W_G1**, **W_G2** [mm H₂O]: Soil water content in upper layer (0 to 10 cm) and middle layer (10 to 100 cm), respectively. If needed, these fields can be derived from **W_SO**.
- **FIS** [m² s⁻¹]: Surface Geopotential. Instead, **HSURF** [m] should be used (see Section 4.2).
- **O3** [kg/kg], **TO3** [Dobson]: Ozone mixing ratio and corresponding total ozone concentration. No longer available; no substitution

4.2 New output fields

Table 4.1 contains a list of new output fields that will become available with the launch of ICON (compared to GME). A more thorough description of these fields is provided in Section 4.3.

Table 4.1: *Newly available output fields*

ShortName	Unit	Description
W	m/s	vertical velocity in height coordinates $w = \frac{dz}{dt}$ (3D field)
DEN	kg/m ³	density of moist air (3D field)
TKE	m ² /s ²	Turbulent kinetic energy (3D field)
DTKE_CON	m ² /s ³	Buoyancy-production of TKE due to sub grid scale convection (3D field)
HSURF	m	Geometric Height of the earths surface above sea level (2D field)
HHL	m	Geometric Height of model half levels above sea level (3D field)
CLON,CLAT	deg	Geographical longitude/latitude of native grid triangle cell center
ELON,ELAT	deg	Geographical longitude/latitude of native grid triangle edge mid-point
VLON,VLAT	deg	Geographical longitude/latitude of native grid triangle vertex

4.3 Available output fields

ICON output is available on two distinct horizontal grids: The native triangular grid with an average resolution of 13 km, and a regular latitude-longitude grid with a resolution of $\Delta\lambda = \Delta\Phi = 0.25^\circ$. On the native grid most output fields are defined on triangle cell centers, except for VN , which is defined on cell edges. On the lat-lon grid, all fields are defined on cell centers. A single 2D GRIB2 field on the native and regular lat-lon grid contains 2949120 and 1036800 grid points, respectively.

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

4.3.1 Time-constant (external parameter) fields

Table 4.2: *Time-constant fields (Date D=000000)*

ShortName	Description	Discipline	Category	Number	Lev-Typ 1/2	stepType	Unit
HSURF	Geometric height of the earth's surface above msl	0	3	6	1/101	inst	m
HHL	Geometric height of model half levels above msl	0	3	6	150/101	inst	m
RLAT	Geographical latitude	0	191	1	1/–	inst	Deg. N
RLON	Geographical longitude	0	191	2	1/–	inst	Deg. E
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
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
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
FR.LAND	Land fraction (possible range [0, 1])	2	0	0	1/–	inst	1
ROOTDP	Root depth of vegetation	2	0	32	1/–	inst	m
EMIS_RAD	Longwave surface emissivity	2	3	199	1/–	inst	1
RSMIN	Minimum stomatal resistance	2	0	16	1/–	inst	s m ⁻¹
SSO.STDH	Standard deviation of sub-grid scale orography	0	3	20	1/–	inst	m
SSO.GAMMA	Anisotropy of sub-gridscale orography	0	3	24	1/–	inst	1
SSO.THETA	Angle of sub-gridscale orography	0	3	21	1/–	inst	rad
SSO.SIGMA	Slope of sub-gridscale orography	0	3	22	1/–	inst	1
PLCOV_MX	Plant covering degree in the vegetation phase	2	0	4	1/–	max	1
T_2M.CL	Climatological 2m temperature (used as lower bc. for soil model)	0	0	0	103/–	inst	K
NDVLMRAT	ratio of monthly mean NDVI (normalized differential vegetation index) to annual max	0	0	192	1/–	avg	1

4.3.2 Multi-level fields on native hybrid vertical levels

Table 4.3: Hybrid multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products

ShortName	Description	Discipline	Category	Number	Lev-Typ 1/2	stepType	Unit
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}
T	Temperature	0	0	0	150/150	inst	K
DEN	Density of moist air	0	3	10	150/150	inst	kg m^{-3}
QV	Specific humidity	0	1	0	150/150	inst	kg kg^{-1}
QC	Cloud mixing ratio ²	0	1	22	150/150	inst	kg kg^{-1}
QI	Cloud ice mixing ratio ²	0	1	82	150/150	inst	kg kg^{-1}
QR	Rain mixing ratio ²	0	1	24	150/150	inst	kg kg^{-1}
QS	Snow mixing ratio ²	0	1	25	150/150	inst	kg kg^{-1}
CLC	Cloud cover	0	6	22	150/150	inst	%
TKE	Turbulent kinetic energy	0	19	11	150/–	inst	$\text{m}^2 \text{s}^{-2}$
DTKE_CON	Buoyancy-production of TKE due to sub grid scale convection	0	19	219	150/–	inst	$\text{m}^2 \text{s}^{-3}$

4.3.3 Multi-level fields interpolated to pressure levels

The following pressure levels are available: 1000, 950, 925, 900, 850, 800, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10, 7, 5, 3, 2, 1, 0.3, 0.1 hPa. Newly available pressure levels (as compared to GME) are highlighted in red. I.e. note that all 17 WMO standard pressure levels are included.

²for the time being, erroneously encoded as mixing ratios instead of specific quantities

Table 4.4: 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	Unit
FI	Geopotential	0	3	4	100/–	inst	$\text{m}^2 \text{s}^{-2}$
OMEGA	Vertical velocity in pressure co-ordinates ($\omega = dp/dt$)	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	K
U	Zonal wind	0	2	2	100/–	inst	m s^{-1}
V	Meridional wind	0	2	3	100/–	inst	m s^{-1}
W	Vertical wind	0	2	9	100/–	inst	m s^{-1}

4.3.4 Single-level fields

Table 4.5: Single-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products

ShortName	Description	Discipline	Category	Number	Lev-Typ 1/2	stepType	Unit
PS	Surface pressure (not reduced)	0	3	0	1/–	inst	Pa
T.SNOW	Temperature of the snow surface	0	0	18	1/–	inst	K
T.G	Ground temperature (temperature at sfc-atm interface)	0	0	0	1/–	inst	K
QV_S	Surface specific humidity	0	1	0	1/–	inst	kg kg^{-1}
W.SNOW	Snow depth water equivalent	0	1	60	1/–	inst	kg m^{-2}
W.I	Plant canopy surface water	2	0	13	1/–	inst	kg m^{-2}
TCM	Turbulent transfer coefficient for momentum (surface)	0	2	29	1/–	inst	1
TCH	Turbulent transfer coefficient for heat and moisture (surface)	0	0	19	1/–	inst	1
ASOB_S	Net short-wave radiation flux at surface (average since model start)	0	4	9	1/–	avg	W m^{-2}

Continued on next page

Table 4.5: *continued*

ATHB_S	Net long-wave radiation flux at surface (average since model start)	0	5	5	1/–	avg	W m^{-2}
APAB_S ³	Photosynthetically active radiation flux at surface (average since model start)	0	4	10	1/–	avg	W m^{-2}
ASOB_T	Net short-wave radiation flux at TOA (average since model start)	0	4	9	8/–	avg	W m^{-2}
ATHB_T	Net long-wave radiation flux at TOA (average since model start)	0	5	5	8/–	avg	W m^{-2}
ASWDIR_S	Surface down solar direct radiation (average since model start)	0	4	198	1/–	avg	W m^{-2}
ASWDIFD_S	Surface down solar diffuse radiation (average since model start)	0	4	199	1/–	avg	W m^{-2}
ASWDIFU_S	Surface up solar diffuse radiation (average since model start)	0	4	8	1/–	avg	W m^{-2}
ALB_RAD	Surface albedo for visible range, diffuse	0	19	1	1/–	inst	%
RAIN_GSP ⁴	Large scale rain (accumulated since model start)	0	1	77	1/–	accu	kg m^{-2}
SNOW_GSP ⁴	Large snowfall water equivalent (accumulated since model start)	0	1	56	1/–	accu	kg m^{-2}
RAIN_CON ⁴	Convective rain (accumulated since model start)	0	1	76	1/–	accu	kg m^{-2}
SNOW_CON ⁴	Convective snowfall water equivalent (accumulated since model start)	0	1	55	1/–	accu	kg m^{-2}
TOT_PREC ⁴	Total precipitation (accumulated since model start)	0	1	52	1/–	accu	kg m^{-2}
RUNOFF_S	Surface water runoff (accumulated since model start)	2	0	5	106/–	accu	kg m^{-2}
RUNOFF_G	Soil water runoff (accumulated since model start)	2	0	5	106/–	accu	kg m^{-2}
U_10M	Zonal wind at 10m above ground	0	2	2	103/–	inst	m s^{-1}
V_10M	Meridional wind at 10m above ground	0	2	3	103/–	inst	m s^{-1}
T_2M	Temperature at 2m above ground	0	0	0	103/–	inst	K
TD_2M	Dew point temperature at 2m above ground	0	0	6	103/–	inst	K

Continued on next page

Table 4.5: *continued*

■ 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
■ VMAX_10M	Maximum wind at 10m above ground	0	2	22	103/-	max	m s ⁻¹
■ Z0	Surface roughness (above land and water)	2	0	1	1/-	inst	m
■ 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
■ CLCH	High level clouds	0	6	22	100/100	inst	%
■ CLCM	Mid level clouds	0	6	22	100/100	inst	%
■ CLCL	Low level clouds	0	6	22	100/1	inst	%
■ TQV	Total column integrated water vapour	0	1	64	1/-	inst	kg m ⁻²
■ TQC	Total column integrated cloud water	0	1	69	1/-	inst	kg m ⁻²
■ TQI	Total column integrated cloud ice	0	1	70	1/-	inst	kg m ⁻²
■ TQR	Total column integrated rain	0	1	45	1/-	inst	kg m ⁻²
■ TQS	Total column integrated snow	0	1	46	1/-	inst	kg m ⁻²
■ HBAS_CON	Height of convective cloud base above msl	0	6	26	2/101	inst	m
■ HTOP_CON	Height of convective cloud top above msl	0	6	27	3/101	inst	m
■ HTOP_DC	Height of top of dry convection above msl	0	6	196	3/101	inst	m
■ HZEROCL	Height of 0 degree Celsius isotherm above msl	0	3	6	4/101	inst	m
■ AUMFLS	U-momentum flux at surface $\overline{u'w'}^{1/2}$ (average since model start)	0	2	17	1/-	avg	m
■ AVMFLS	V-momentum flux at surface $\overline{v'w'}^{1/2}$ (average since model start)	0	2	18	1/-	avg	m
■ ASHFLS	Sensible heat net flux at surface (average since model start)	0	0	11	1/-	avg	W m ⁻²

Continued on next page

Table 4.5: *continued*

ALHFLS	Latent heat net flux at surface (average since model start)	0	0	10	1/–	avg	W m^{-2}
FR_ICE	Sea/lake ice cover (possible range: [0, 1])	10	2	0	1/–	inst	1
T_ICE	Sea ice temperature (at ice-atm interface)	10	2	8	1/–	inst	K
H_ICE	Sea ice thickness (Max: 3 m)	10	2	1	1/–	inst	m
FRESHSNW	Fresh snow factor (weighting function for albedo indicating freshness of snow)	0	1	203	1/–	inst	1
RHO_SNOW	Snow density	0	1	61	1/–	inst	kg m^{-3}
H_SNOW	Snow depth	0	1	11	1/–	inst	m
PLCOV	Plant cover	2	0	4	1/–	inst	%
LAI	Leaf area index	2	0	28	1/–	inst	1
NDVIRATIO	ratio of current NDVI (normalized differential vegetation index) to annual max	2	0	192	1/–	inst	1
WW	Weather interpretation (WMO)	0	19	25	1/–	inst	1

³Not yet available.

Table 4.6: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products of the soil model

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

Soil temperature is defined at the soil depths given in Table 4.7 (column 2). Levels 1 to 8 define the full levels of the soil model. A zero gradient condition is assumed between levels 0 and 1, meaning that temperatures at the surface-atmosphere interface are set equal to the temperature at the first full level

⁴Note that the unit which is displayed, when inspecting the GRIB2 message with *grib_dump* is $\text{kg m}^{-2} \text{s}^{-1}$ 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.

Table 4.7: *Soil model: vertical distribution of levels and layers*


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

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_S0 is prognosed for layers 1 to 6. In the two lowermost layers W_S0 is filled with W_S0(6) (zero gradient condition).

4.3.5 Surface fields interpolated to msl

Table 4.8: *Forecast ($VV > 0$) and initialised analysis ($VV = 0$) products interpolated to msl*

ShortName	Description	Discipline	Category	Number	Lev-Typ 1/2	stepType	Unit
 PMSL	Surface pressure reduced to msl	0	3	1	101/–	inst	Pa

4.4 Extended description of available output fields

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

4.4.1 Cloud products

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

CLDEPTH	Modified cloud depth ($0 \leq \text{CLDEPTH} \leq 1$). Used for visualization purpose (i.e. gray-scale figures) in the media. A cloud reaching a vertical extent of 700 hPa or more, has CLDEPTH = 1.
HBAS_CON	Height of the convective cloud base in m above msl. HBAS_CON is initialized with -500 m at points where no convection is diagnosed.
HTOP_CON	Same, but for cloud top.

4.4.2 Near surface products

TMIN_2M	Minimum temperature at 2 m above ground, computed over 3-hourly intervals.
TMAX_2M	Same, but for maximum 2 m temperature.
VMAX_10M	Maximum wind gust at 10 m above ground, computed over 3-hourly intervals. It is diagnosed from the turbulence state in the atmospheric boundary layer. In the presence of deep convection, it contains an additional contribution due to convective gusts.

General comment on statistically processed fields

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

The beginning of the overall time interval is defined by **referenceTime** + **forecastTime**, whereas the end of the overall time interval is given by **referenceTime** + **forecastTime** + **lengthOfTimeRange**.

4.4.3 Surface products

FR_ICE	Sea and lake ice cover. Currently, the only possible values are 0 (no ice cover) and 1 (ice covered grid point). For lake points, FR_ICE is synchronized with H_ICE meaning that FR_ICE is set to 1 (0), where the lake model indicates H_ICE > 0 (H_ICE = 0).
T_ICE	Ice temperature over sea-ice and frozen lake points. Ice-free points over land, sea and lakes are set to T_S0 (0).

4.4.4 Soil products

T_SO	Temperature of the soil and earth surface (uppermost level). The soil full level depths at which the the soil temperature is defined are given in Table 4.7. The temperature at the uppermost level T_SO (0) is not prognostic. It is rather set equal to the temperature at the first prognostic level T_SO (1). The temperature at the lowermost level T_SO (8) is set to the climatological 2 m temperature T_2M_CL . At sea-points, T_SO (0:7) is filled with the sea-surface temperature. Note that T_SO (0) does not necessarily represent the temperature at the interface soil-atmosphere. I.e. Over snow/ice covered surfaces, T_SO (0) represents the temperature below snow/ice.
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Chapter 5

ICON data in the SKY data bases of DWD

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

5.1 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.
- **type:** **an** for analysis data, **fc** for forecast data, **const** for invariant data.
- **suite:** **rout** for operational data in `db=roma`, **para** for pre-operational data in `db=parma`, **exp** or **exp1** for data from experiments in `db=numex`. The category extension `exp1` is used for experiments of the NUMEX wizard, a special NUMEX user.

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

The categories for ICON start with the string **ico** for ICON data on the native ICON grid, or with **icr** for data on a regular lat-lon grid. Next follows a two-letter string to identify the domain of ICON; **gl** for the global domain, **eu** for the nest over Europe. After the domain follows the mesh width of the model in units of 100 m, and then the number of levels after the letter `l`. As an example `icogl130l90` is on the native grid from a global model with a mesh width 13 km (grid R3B07) and 90 levels. `icrgl400l90` is data on a regular grid from a global model with mesh width 40 km (R2B06) and 90 levels. `icreu065l50` is an ICON nest over Europe with a mesh width of 6.5 km and 50 levels and interpolated to a regular lat-lon grid.

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

Since 2014-08-12 12 UTC ICON is running pre-operationally at DWD. Hence, forecast data is available in the sky database **db=parma** in categories **icogl130l90_main_fc_para** and **icrgl130l90_main_fc_para**.

5.2 Retrieving ICON data from SKY

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

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

```
read db=parma cat=icrgl130l90_main_fc_para d=t00 s[h]=3/to/78/by/3 p=t_2m,td_2m
bin f=icon2mdat
```

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

```
read db=parma cat=icogl130l90_main_an_para d=t18-1d p=T gptype=0 bin f=t_icon_ana
```

- Retrieve the 6, 12, 18, and 24 hour forecast of the 2m temperature from a forecast run on 2012-06-28 at 00 UTC on the global domain from an ICON run on a R3B07 grid with 90 levels:

```
read db=numex cat=icrgl130l90_main_fc_exp1 exp=901 d=2012062800 s[h]=6,12,18,24
p=t_2m bin f=t_2m_fc.grb
```

- Retrieve wind components U and V at 300 hPa on the regular grid from a 24 hour forecast on 2013-10-03 at 00 UTC. *lv=P* specifies the level type as pressure levels:

```
read db=numex cat=icrgl130l90_main_fc_exp1 exp=907 d=2013100300 s[h]=24 p=U,V
lv=P lv1=30000 bin f=uvReg300hPa
```

- Retrieve the analysis of U on the native grid:

```
read db=numex cat=icogl130l90_main_an_exp1 exp=907 d=2013100300 p=U bin f=u_icon_ana
```

- Retrieve temperature forecasts from 7 to 9 hours on the native grid:

```
read db=numex cat=icogl130l90_main_fc_exp1 exp=907 d=2013100300 s[h]=7/to/9 p=T
bin f=T_icon_07-09
```

- Retrieve a 6 hour forecast on a regular grid on pressure levels. ICON was run on a 40 km grid (R2B06). 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=numex cat=icrgl400l90_main_fc_exp exp=9323 d=2012010100 step[h]=6 lv=P
f=icr06p bin info=metaData metaArray=d,s,p,lv,lv1,dedat,stdat sort=d,s,p,lv,lv1 in-
fof=icr.info
```

- Retrieve temperature in 850 hPa from a forecast on 2013-10-05 at 12 UTC:

```
read db=numex cat=icrgl400l90_main_fc_exp1 exp=906 d=2013100512 p=T lv1=85000
lv=P bin f=t850_iconr
```


Appendix A

ICON standard half level heights

Table A.1: *Standard heights (i.e. for zero topography height) for all 91 vertical half levels.*

level index	height [m]	level index	height [m]	level index	height [m]
1	75000.000	32	21569.375	63	6621.524
2	72363.546	33	20731.107	64	6221.524
3	69842.381	34	19942.837	65	5821.524
4	67357.797	35	19201.585	66	5421.524
5	64946.444	36	18504.545	67	5033.731
6	62606.299	37	17849.081	68	4659.952
7	60335.466	38	17232.713	69	4300.121
8	58132.167	39	16653.108	70	3954.183
9	55976.216	40	16108.074	71	3622.092
10	53877.930	41	15595.549	72	3303.815
11	51824.685	42	15113.594	73	2999.329
12	49826.951	43	14660.386	74	2708.624
13	47890.748	44	14234.210	75	2431.707
14	46014.776	45	13821.524	76	2168.596
15	44197.795	46	13421.524	77	1919.330
16	42438.627	47	13021.524	78	1683.966
17	40736.151	48	12621.524	79	1462.584
18	39089.298	49	12221.524	80	1255.291
19	37497.048	50	11821.524	81	1062.224
20	35958.428	51	11421.524	82	883.557
21	34472.507	52	11021.524	83	719.514
22	33038.397	53	10621.524	84	570.373
23	31655.249	54	10221.524	85	436.493
24	30322.249	55	9821.524	86	318.336
25	29038.622	56	9421.524	87	216.516
26	27803.623	57	9021.524	88	131.880
27	26617.350	58	8621.524	89	65.677
28	25488.963	59	8221.524	90	20.000
29	24416.908	60	7821.524	91	0.000
30	23408.796	61	7421.524		
31	22460.814	62	7021.524		

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