



ICON Database Reference Manual

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

Deutscher Wetterdienst
Research and development (FE13)



Version: 1.0.2

Last changes: March 12, 2015

Offenbach am Main, Germany

This document is based on Revision 21269 of the ICON code,
Last changed on 2015-02-27.

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. <code>AUMFL_S</code> , <code>AVMFL_S</code> 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 <code>OMEGA</code> |
| 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 <code>ASWDIR_S</code> , <code>ASWDIFD_S</code> , <code>ASWDIFU_S</code> , <code>DTKE_CON</code> |
| 0.4.2 | 10.09.14 | DR | New output fields <code>CLCT_MOD</code> , <code>CLDEPTH</code> |
| 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 <code>APAB_S</code> |
| 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. |

Contents

| | | |
|----------|---|-----------|
| 1 | Introduction | 1 |
| 2 | Grid geometry | 3 |
| 2.1 | Horizontal grid | 3 |
| 2.2 | Vertical grid | 5 |
| 3 | Mandatory input fields | 7 |
| 3.1 | Grid Files | 7 |
| 3.2 | External parameter | 8 |
| 4 | Analysis fields | 11 |
| 4.1 | Incremental analysis update | 13 |
| 5 | Available output fields: Forecast runs | 15 |
| 5.1 | Deprecated output fields | 15 |
| 5.2 | New output fields | 16 |
| 5.3 | Available output fields | 17 |
| 5.3.1 | Time-constant (external parameter) fields | 18 |
| 5.3.2 | Multi-level fields on native hybrid vertical levels | 21 |
| 5.3.3 | Multi-level fields interpolated to pressure levels | 22 |
| 5.3.4 | Multi-level fields interpolated to height levels | 23 |
| 5.3.5 | Single-level fields | 23 |
| 5.3.6 | Surface fields interpolated to msl | 27 |
| 5.3.7 | Soil-specific multi-level fields | 27 |
| 5.3.8 | Lake-specific single-level fields | 28 |
| 5.4 | Extended description of available output fields | 29 |
| 5.4.1 | Cloud products | 29 |
| 5.4.2 | Near surface products | 29 |
| | General comment on statistically processed fields | 30 |
| 5.4.3 | Surface products | 30 |
| 5.4.4 | Soil products | 31 |

| | | |
|---------------------|---|-----------|
| 5.4.5 | Vertical Integrals | 31 |
| 5.4.6 | Technical Details of the Horizontal Interpolation | 31 |
| 5.5 | Statistically processed output fields | 32 |
| 5.5.1 | Time averaged fields | 32 |
| 5.5.2 | Accumulated fields | 33 |
| 5.5.3 | Extreme value fields | 34 |
| 6 | ICON data in the SKY data bases of DWD | 37 |
| 6.1 | SKY categories for ICON | 37 |
| 6.2 | Retrieving ICON data from SKY | 38 |
| Appendix A | ICON standard level heights | 41 |
| A.1 | Level heights for zero topography height | 41 |
| A.2 | Non-zero topography heights | 41 |
| Bibliography | | 47 |

Chapter 1

Introduction

The **ICO**sahedral **N**onhydrostatic model **ICON** is the new global numerical weather prediction model at DWD. It became operational at 2015-01-20, replacing the former operational global model GME. The ICON modelling system as a whole is developed jointly by DWD and the Max-Planck Institute for Meteorology in Hamburg (MPI-M). While ICON is the new working horse for short and medium range global weather forecast at DWD, it will serve as the core of a new climate modelling system at MPI-M.

Since 2015-01-20, ICON analysis and forecast fields serve as initial and boundary data for

- the regional model COSMO-EU
- RLMs (**R**elocatable **L**ocal **M**odel) of the German armed forces
- DWD's wave models

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

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

Daniel Reinert, FE13

Tel: +49 (69) 8062-2060

Mail: daniel.reinert@dwd.de

Helmut Frank, FE13

Tel: +49 (69) 8062-2742

Mail: helmut.frank@dwd.de

Florian Prill, FE13

Tel: +49 (69) 8062-2727

Mail: florian.prill@dwd.de

Chapter 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).



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



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 (\mathbf{R}_n) followed by k bisection steps (\mathbf{B}_k), resulting in a $\mathbf{R}_n\mathbf{B}_k$ grid. Figures 2.3a and 2.3b 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 2.3c) and allow a high uniformity in resolution over the whole sphere.



Figure 2.3: (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 2.1, 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 2.1: Characteristics of frequently used ICON grids. ΔA_{max} and ΔA_{min} refer to the maximum and minimum area of the grid cells, respectively.

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

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

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. 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 2.4 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.

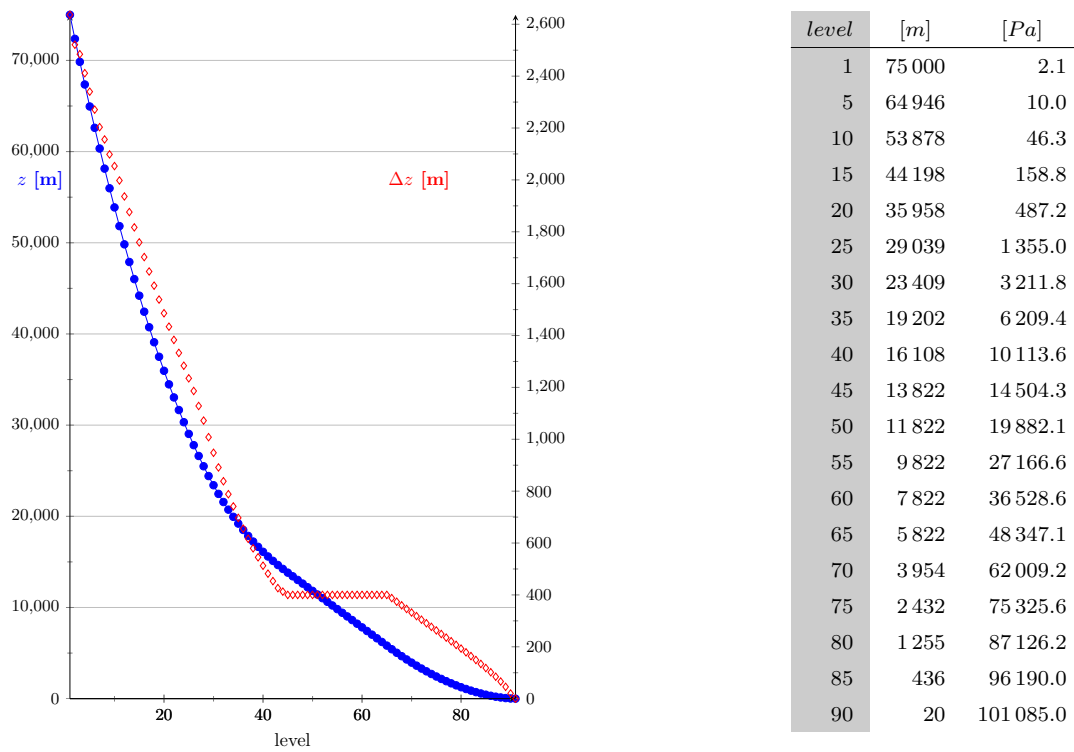


Figure 2.4: Vertical half levels (blue) and layer thickness (red) of the ICON operational setup. The table of selected pressure values (for zero height) is based on the 1976 US standard atmosphere.

Chapter 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). 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. 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**.

3.2 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 3.1. For a more detailed overview of ExtPar, the reader is referred to the *User and Implementation Guide* of Extpar.

Table 3.1: 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 $90^\circ > \phi > -56^\circ$ (with ϕ denoting latitude) and switch to the coarser, however globally available dataset *GLCC* for $-56^\circ > \psi > -90^\circ$.

The products generated by the ExtPar software package are listed in Table 3.2 together with the underlying raw dataset. Note that these are mandatory input fields for assimilation- and forecast runs.

Table 3.2: 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 |

Continued on next page

Table 3.2: *continued*

| | | |
|-----------|--|----------------|
| ALB_UV12 | UV-visible ($0.3 - 0.7 \mu\text{m}$) albedo for diffuse radiation (monthly fields) | MODIS |
| ALB_NI12 | Near infrared ($0.7 - 5.0 \mu\text{m}$) 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), containing a contribution from subgrid-scale orography | GlobCover 2009 |

Note that fields marked with (*) are not required in operational model runs. I.e. the surface roughness Z0 is only needed, if the additional contribution from sub-grid scale orography is taken into account (i.e. for `itype_z0=1`). In operational runs, land-use specific roughness lengths are taken from a GlobCover-based lookup table. `FOR_D` and `FOR_E` will become obsolete, as soon as the surface tile approach (which is currently under development) is activated. However, due to technical reasons, all the above 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 4

Analysis fields

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

Table 4.1: 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. It provides updated information on the snow height **H_SNOW** and snow age **FRESHSNW**. In addition a soil moisture analysis (SMA) is conducted once per day (00 UTC). It basically modifies the soil moisture content **W_SO**, in order to improve the 2 m temperature forecast.

For the 3-hourly assimilation cycle and forecast runs, ICON must be provided with 2 input files: One containing the First Guess (FG) and the other containing analysis (AN) fields, only. Variables for which no analysis is available are always read from the first guess file (e.g. TKE). Other variables may be read either from the first guess or the analysis file, depending on the starting time. E.g. for **T_SO(0)** the first guess is read at 03, 06, 09, 12, 15, 18, 21 UTC, however, the analysis is read at 00 UTC. 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) (SST only) | Ana_SST | AN | FG | FG | FG | FG | FG | FG | FG |
| T_SO(0:nlevsoil) | – | FG | FG | FG | FG | FG | FG | FG | FG |
| W_SO_ICE | – | FG | FG | FG | FG | FG | FG | FG | FG |
| W_SO | SMA | AN | FG | FG | FG | FG | FG | FG | FG |
| W_I | – | FG | FG | FG | FG | FG | FG | FG | FG |
| W_SNOW ¹ | Ana_SNOW | AN | AN | AN | AN | AN | AN | AN | AN |
| T_SNOW | – | FG | FG | FG | FG | FG | FG | FG | FG |
| RHO.SNOW ¹ | Ana_SNOW | AN | AN | AN | AN | AN | AN | AN | AN |
| H_SNOW | Ana_SNOW | AN | AN | AN | AN | AN | AN | AN | AN |
| FRESHSNW | Ana_SNOW | AN | AN | AN | AN | AN | AN | AN | AN |
| Sea ice/Lake | | | | | | | | | |
| T_ICE | – | FG | FG | FG | FG | FG | FG | FG | FG |
| H_ICE | – | FG | FG | FG | FG | FG | FG | FG | FG |
| FR_ICE | Ana_SST | AN | FG | FG | FG | FG | FG | FG | FG |
| T_MNW_LK | – | FG | FG | FG | FG | FG | FG | FG | FG |
| T_WML_LK | – | FG | FG | FG | FG | FG | FG | FG | FG |

Continued on next page

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 |
|-----------|----------|----|----|----|----|----|----|----|----|
| H.ML.LK | – | FG | FG | FG | FG | FG | FG | FG | FG |
| T.BOT.LK | – | FG | FG | FG | FG | FG | FG | FG | FG |
| C.T.LK | – | FG | FG | FG | FG | FG | FG | FG | FG |
| T.B1.LK | – | FG | FG | FG | FG | FG | FG | FG | FG |
| H.B1.LK | – | FG | FG | FG | FG | FG | FG | FG | FG |

4.1 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 4.1).



Figure 4.1: 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 ρ_{snow} is read from the analysis, however it does not contain any new/independent information compared to the model first guess, except for an initialization of newly generated snow points and a limitation over glacier points. w_{snow} is read from the analysis, too, however it is re-diagnosed within the ICON-code based on the analyzed snow height h_{snow} and the former mentioned snow density ρ_{snow} .

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

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

\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 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:

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

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 3h assimilation run, and a second one at 3:00 UTC, 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 4.2: Time line for an ICON assimilation run starting at 00:00 UTC.

Chapter 5

Available output fields: Forecast runs

ICON output fields are exclusively available in GRIB2 format (**GR**Idded **B**inary Edition **2**), with the exception of meteogram data (NetCDF). GRIB is a bit-oriented data storage format which was developed by WMO to facilitate the exchange of large volumes of gridded data between weather prediction centres. For decoding and encoding GRIB2 messages, the DWD in general and ICON in particular makes use of the ECMWF GRIB API. The current operational version at DWD is 1.12.3.

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, ...): describes the statistical process used to calculate the field

just to name a few.

A documentation of the official WMO GRIB2 code tables can be found here:

http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI2/LatestVERSION/WMO306_vI2_GRIB2_CodeFlag_en.pdf

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

5.1 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.
- **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 5.2).
- **O3** [kg/kg], **TO3** [Dobson]: Ozone mixing ratio and corresponding total ozone concentration. No longer available; no substitution

5.2 New output fields

Table 5.1 contains a list of new output fields that became available with the launch of ICON (compared to GME). A more thorough description of these fields is provided in Section 5.3.

Table 5.1: Newly available output fields

| ShortName | Unit | Description |
|-------------------|--------------------------------|--|
| Atmosphere | | |
| 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) |
| W | m s ⁻¹ | vertical velocity in height coordinates $w = \frac{dz}{dt}$ (3D field) |
| P | Pa | pressure (3D field) |
| Surface | | |
| CAPE_CON | J kg ⁻¹ | Convective available potential energy (2D field) |
| QV_2M | kg kg ⁻¹ | Specific humidity at 2m above ground (2D field) |
| RELHUM_2M | % | Relative humidity at 2m above ground (2D field) |
| SOBS_RAD | W m ⁻² | Net short-wave radiation flux at surface (instantaneous) |
| THBS_RAD | W m ⁻² | Net long-wave radiation flux at surface (instantaneous) |
| Lake | | |
| C_T_LK | 1 | Shape factor with respect to the temperature profile in the thermocline (2D field) |
| H_ML_LK | m | Mixed-layer depth (2D field) |
| T_BOT_LK | K | Temperature at the water-bottom sediment interface (2D field) |
| T_MNW_LK | K | Mean temperature of the water column (2D field) |
| T_WML_LK | K | Mixed-layer temperature (2D field) |
| Geometry | | |

Continued on next page

Table 5.1: *continued*

| | | |
|------------------|-----|--|
| 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 |

5.3 Available output fields

ICON forecasts are performed multiple times a day with varying forecast times. An overview of the various forecasts, including its forecast time and output intervals is provided in Figure 5.1.

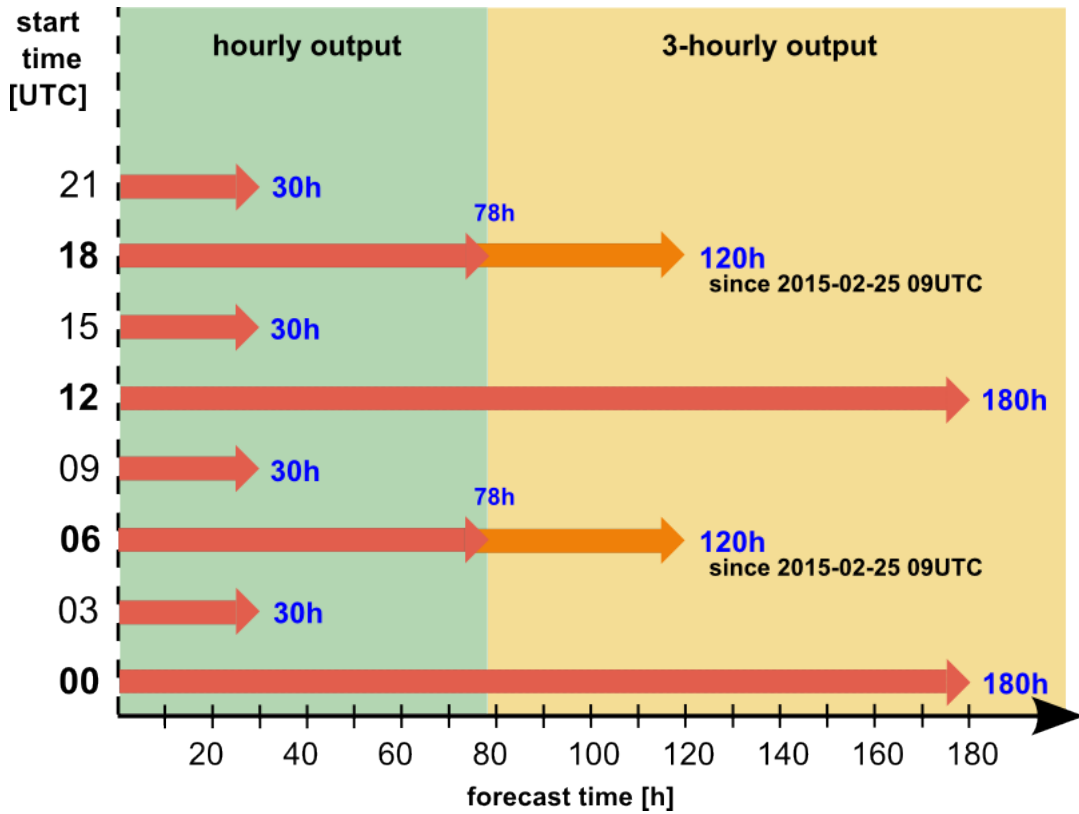


Figure 5.1: Time span covered by the various ICON forecasts. An ICON forecast run is launched every three hours.

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 and 12 UTC runs and 120 h for the 6 and 18 UTC runs. Prior to 2015-02-25 the 6 and 18 UTC runs were restricted to 78 h. In preparation for the replacement of COSMO-EU by a high resolution ICON nest, additional short forecasts are performed at 3, 9, 15 and 21 UTC. These will provide boundary data for the high resolution COSMO-DE runs, once COSMO-EU has been switched off. The forecast time covered by these runs is limited to 30 h.

All time-dependent output fields are available hourly up to $VV = 78$ h and 3-hourly for larger forecast times².

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.

Please note that for ICON fields the time unit is minutes rather than hours, and thus differs from GME (hours).

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

For details regarding the algorithm for interpolation onto the lat-lon grid, see Section 5.4.6

5.3.1 Time-constant (external parameter) fields

Table 5.2 provides an overview of the available time invariant fields. They are available from the database category `CAT_NAME=$model_const_an.$suite`. As mentioned in Section 3.2, HSURF, FR_LAND, FR_LAKE and Z0 are modified by ICON. Thus, the latter should not be taken from the `const_an` database categorie, unless you definitely know what you are doing. For convenience, the modified invariant fields (and some more) are stored in the `forecast` database categories for step $s[h] = 0$ (`CAT_NAME=$model.$run_fc.$suite`). Table 5.3 provides a list of all fields which are exclusively written for $s[h] = 0$.

See Section 6.1 for more details on the database categories and Section 6.2 for sample retrievals.

Table 5.2: Time-constant fields (`CAT_NAME=$model_const_an.$suite`)

| ShortName | Description | Discipline | Category | Number | Lev-Typ 1/2 | stepType | Unit |
|--|--|------------|----------|--------|-------------|----------|--------|
| Date/Time (YYYY-MM-DDThh) D=0001-01-01T00 | | | | | | | |
| ■ HSURF | Geometric height of the earths surface above msl | 0 | 3 | 6 | 1/101 | inst | m |
| ■ 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 |
| ■ FOR_E | Fraction of evergreen forest (possible range [0, 1]) | 2 | 0 | 29 | 1/– | inst | 1 |
| ■ FOR_D | Fraction of deciduous forest (possible range [0, 1]) | 2 | 0 | 30 | 1/– | inst | 1 |

Continued on next page

²An exception here are the lat-lon output fields U_10M and V_10M, which are available hourly throughout the forecast. This is because U_10M and V_10M are needed as input by the wave models.

Table 5.2: *continued*

| | | | | | | | |
|--|---|---|----|-----|-------|------|-------------------|
| FR_LAND | Land fraction (possible range [0, 1]) | 2 | 0 | 0 | 1/– | inst | 1 |
| FR_LAKE | Fresh water lake fraction (possible range [0, 1]) | 1 | 2 | 2 | 1/– | inst | 1 |
| FR_LUC | Land use class fraction (possible range [0, 1]) | 2 | 0 | 36 | 1/– | inst | 1 |
| DEPTH_LK | Lake depth | 1 | 2 | 0 | 1/162 | inst | m |
| ROOTDP | Root depth of vegetation | 2 | 0 | 32 | 1/– | inst | m |
| RSMIN | Minimum stomatal resistance | 2 | 0 | 16 | 1/– | inst | s m ⁻¹ |
| EMIS_RAD | Longwave surface emissivity | 2 | 3 | 199 | 1/– | inst | 1 |
| SOILTYP | Soil type of land fraction (9 types [1, ..., 9]) | 2 | 3 | 196 | 1/– | inst | 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 |
| LAI_MX | Leaf area index in the vegetation phase | 2 | 0 | 28 | 1/– | max | 1 |
| NDVI_MAX | Normalized differential vegetation index | 2 | 0 | 31 | 1/– | max | 1 |
| PLCOV_MX | Plant covering degree in the vegetation phase | 2 | 0 | 4 | 1/– | max | 1 |
| T_2M_CL | Climatological 2 m temperature (used as lower bc. for soil model) | 0 | 0 | 0 | 103/– | inst | K |
| Z0 | Surface roughness length (over land) | 2 | 0 | 1 | 1/– | inst | m |
| Date/Time (YYYY-MM-DDThh) D=1111-01-11T11 | | | | | | | |
| AER_SS12 | Sea salt aerosol climatology (monthly fields) | 0 | 20 | 102 | 1/– | avg | 1 |
| AER_DUST12 | Total soil dust aerosol climatology (monthly fields) | 0 | 20 | 102 | 1/– | avg | 1 |
| AER_ORG12 | Organic aerosol climatology (monthly fields) | 0 | 20 | 102 | 1/– | avg | 1 |
| AER_SO412 | Total sulfate aerosol climatology (monthly fields) | 0 | 20 | 102 | 1/– | avg | 1 |

Continued on next page

Table 5.2: *continued*

| | | | | | | | |
|-------------|--|---|----|-----|-----|-----|---|
| ■ AER_BC12 | Black carbon aerosol climatology (monthly fields) | 0 | 20 | 102 | 1/– | avg | 1 |
| ■ ALB_DIF12 | Shortwave (0.3 – 5.0 μm) albedo for diffuse radiation (monthly fields) | 0 | 19 | 18 | 1/– | avg | 1 |
| ■ ALB_UV12 | UV-visible (0.3 – 0.7 μm) albedo for diffuse radiation (monthly fields) | 0 | 19 | 222 | 1/– | avg | 1 |
| ■ ALB_NI12 | Near infrared (0.7 – 5.0 μm) albedo for diffuse radiation (monthly fields) | 0 | 19 | 223 | 1/– | avg | 1 |
| ■ NDVLMRAT | ratio of monthly mean NDVI (normalized differential vegetation index) to annual max | 0 | 0 | 192 | 1/– | avg | 1 |

Table 5.3: Variables exclusively available for $VV = 0$ from the forecast databases (CAT_NAME=\$model.\$run.fc-\$suite, $s[h] = 0$)

| ShortName | Description | Discipline | Category | Number | Lev-Typ 1/2 | stepType | Unit |
|------------|--|------------|----------|--------|-------------|----------|--------|
| ■ 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 |
| ■ DEPTH.LK | Lake depth | 1 | 2 | 0 | 1/162 | inst | m |
| ■ FR.LAND | Land fraction (possible range [0, 1]) | 2 | 0 | 0 | 1/– | inst | 1 |
| ■ FR.LAKE | Fresh water lake fraction (possible range [0, 1]) | 1 | 2 | 2 | 1/– | inst | 1 |

Continued on next page

Table 5.3: *continued*

| | | | | | | | |
|-------------|--|---|---|-----|---------|------|---|
| ■ HHL | Geometric height of model half levels above msl | 0 | 3 | 6 | 150/101 | inst | m |
| ■ HSURF | Geometric height of the earths surface above msl | 0 | 3 | 6 | 1/101 | inst | m |
| ■ LAI | Leaf area index | 2 | 0 | 28 | 1/– | inst | 1 |
| ■ NDVIRATIO | ratio of current NDVI (normalized differential vegetation index) to annual max | 2 | 0 | 192 | 1/– | inst | 1 |
| ■ PLCOV | Plant cover | 2 | 0 | 4 | 1/– | inst | % |
| ■ ROOTDP | Root depth of vegetation | 2 | 0 | 32 | 1/– | inst | m |
| ■ SOILTYP | Soil type of land fraction (9 types [1, . . . , 9]) | 2 | 3 | 196 | 1/– | inst | 1 |

5.3.2 Multi-level fields on native hybrid vertical levels

Table 5.4: *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 |
| ■ P | Pressure | 0 | 3 | 0 | 150/150 | inst | Pa |
| ■ 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 | $\text{m}^2 \text{s}^{-3}$ |

Table 5.5: Regular grid output: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products interpolated to pressure levels 1000, 975, 950, 925, 900, 875, 850, 825, 800, 775, 750, 725, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10, 7, 5, 3, 2, 1, 0.3, 0.1 hPa.

| 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} |

5.3.3 Multi-level fields interpolated to pressure levels

For regular grid output the following pressure levels are available:

1000, 975, 950, 925, 900, 875, 850, 825, 800, 775, 750, 725, 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. The output fields are listed in Table 5.5. I.e. note that all 17 WMO standard pressure levels are included.

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

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

The output fields are listed in Table 5.6.

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

Table 5.6: Native (triangular) grid output: Multi-level forecast ($VV > 0$) and initialised analysis ($VV = 0$) products interpolated to pressure levels 1000, 950, 850, 700, 500, 300 hPa.

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

5.3.4 Multi-level fields interpolated to height levels

Table 5.7: Regular grid output: Multi-level forecast ($VV > 0$) and initialised analysis ($VV > 0$) products interpolated to height levels 10000, 5000, 3000, 2000, 1500, 1000, 500, 100 m (above mean sea level).

| ShortName | Description | Discipline | Category | Number | Lev-Typ 1/2 | stepType | Unit |
|-----------|-----------------|------------|----------|--------|-------------|----------|-------------------|
| 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 | 150/– | inst | m s^{-1} |
| T | Temperature | 0 | 0 | 0 | 100/– | inst | K |
| P | Pressure | 0 | 3 | 0 | 150/150 | inst | Pa |

5.3.5 Single-level fields

Table 5.8: 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 |
| T_S | Temperature of the soil surface (equivalent to T_SO(0)) | 2 | 3 | 18 | 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 |
| SOBS_RAD | Net short-wave radiation flux at surface (instantaneous) | 0 | 4 | 9 | 1/– | inst | W m ⁻² |
| THBS_RAD | Net long-wave radiation flux at surface (instantaneous) | 0 | 5 | 5 | 1/– | inst | W m ⁻² |
| ASOB_S | Net short-wave radiation flux at surface (average since model start) | 0 | 4 | 9 | 1/– | avg | W m ⁻² |
| ATHB_S | Net long-wave radiation flux at surface (average since model start) | 0 | 5 | 5 | 1/– | avg | W m ⁻² |
| APAB_S | 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 |

Continued on next page

Table 5.8: *continued*

| | | | | | | | |
|-----------------------|--|---|----|-----|-------|------|---------------------|
| 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} |
| RSTOM | Stomatal resistance | 2 | 0 | 195 | 1/– | inst | s m^{-1} |
| U_10M | Zonal wind at 10m above ground | 0 | 2 | 2 | 103/– | inst | m s^{-1} |
| V_10M | Meridional wind at 10m above ground | 0 | 2 | 3 | 103/– | inst | m s^{-1} |
| VMAX_10M | Maximum wind at 10m above ground | 0 | 2 | 22 | 103/– | max | m s^{-1} |
| QV_2M | Specific humidity at 2m above ground | 0 | 1 | 0 | 103/– | inst | kg kg^{-1} |
| RELHUM_2M | Relative humidity at 2m above ground | 0 | 1 | 1 | 103/– | inst | % |
| 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 |
| 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 |
| Z0 | Surface roughness (above land and water) | 2 | 0 | 1 | 1/– | inst | m |

Continued on next page

Table 5.8: *continued*

| | | | | | | | |
|----------|--|---|---|-----|---------|------|--------------------|
| CAPE_CON | Convective available potential energy | 0 | 7 | 6 | 1/– | inst | J kg^{-1} |
| 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 | Column integrated water vapour (grid scale) | 0 | 1 | 64 | 1/– | inst | kg m^{-2} |
| TQC | Column integrated cloud water (grid scale) | 0 | 1 | 69 | 1/– | inst | kg m^{-2} |
| TQI | Column integrated cloud ice (grid scale) | 0 | 1 | 70 | 1/– | inst | kg m^{-2} |
| TQR | Column integrated rain (grid scale) | 0 | 1 | 45 | 1/– | inst | kg m^{-2} |
| TQS | Column integrated snow (grid scale) | 0 | 1 | 46 | 1/– | inst | kg m^{-2} |
| TQC_DIA | Total column integrated cloud water (including sub-grid-scale contribution) | 0 | 1 | 215 | 1/– | inst | kg m^{-2} |
| TQLDIA | Total column integrated cloud ice (including sub-grid-scale contribution) | 0 | 1 | 216 | 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 |

Continued on next page

Table 5.8: *continued*

| | | | | | | | |
|----------|--|----|----|-----|-----|------|--------------------|
| ASHFLS | Sensible heat net flux at surface (average since model start) | 0 | 0 | 11 | 1/– | avg | W m^{-2} |
| 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/Lake ice temperature (at ice-atm interface) | 10 | 2 | 8 | 1/– | inst | K |
| H_ICE | Sea/Lake 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 |
| WW | Weather interpretation (WMO) | 0 | 19 | 25 | 1/– | inst | 1 |

5.3.6 Surface fields interpolated to msl




Table 5.9: *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 |

5.3.7 Soil-specific multi-level fields

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 5.10: 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 5.11 (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 5.11: *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 |

5.3.8 Lake-specific single-level fields

Table 5.12: 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 | 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 |

5.4 Extended description of available output fields

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

5.4.1 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. |

5.4.2 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 10m above ground, computed over 3-hourly intervals. 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.

General comment on statistically processed fields

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

The beginning of the overall time interval is defined by `referenceTime + forecastTime`, whereas the end of the overall time interval is given by `referenceTime + forecastTime + lengthOfTimeRange`. See Section 5.5 for more details on statistically processed fields.

5.4.3 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).

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

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_S0(0).

T_G Temperature at the atmosphere-surface interface. It is the temperature that is crucial for the computation of surface fluxes. T_G is equal to T_S0(0) over open water and snow-free land. At other grid points one has

- $T_G = T_{SNOW} + (1 - f_{snow}) * (T_{S0}(0) - T_{SNOW})$ over (partially) snow covered grid points. f_{snow} is the grid point fraction that is snow covered.
- $T_G = T_{ICE}$ over frozen sea and fresh water lakes

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

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

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 3.2 or 5.2).

5.4.4 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. |
| 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 5.11. 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 2m 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. |

5.4.5 Vertical Integrals

| | |
|----------------|---|
| TQX | Column integrated water species X , derived from the 3D grid-scale prognostic quantities QX , with $X \in \{V, C, I, R, S\}$. TQX is based on the assumption that there would be no sub-grid-scale variability. That assumption is particularly problematic for precipitation generation, moist turbulence and radiation. |
| TQX_DIA | Total column integrated water species X , with $X \in \{C, I\}$. Takes into account the sub-grid-scale variability that includes simple treatments of turbulent motion and convective detrainment. These cloud variables attempt to represent all model included physical processes. They are also consistent with the cloud cover variables CLC , $CLCT$, $CLCH$, $CLCM$ and $CLCL$. |

5.4.6 Technical Details of the Horizontal Interpolation

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

A small number of output fields is treated differently, with a nearest-neighbor interpolation:

| | | |
|----------|----------|----------|
| RAIN_CON | RAIN_GSP | SNOW_CON |
| SNOW_GSP | SOILTYP | TOT_PREC |
| W_SO_ICE | WW | |

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.

5.5 Statistically processed output fields

5.5.1 Time averaged fields

The quantities

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

constitute time averages over the respective forecast time. The averaging process is performed from forecast start ($t_0 = 0$ 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 $\bar{\Psi}$ at time t stored in the database is given as

$$\bar{\Psi}(t) = \frac{1}{t} \int_0^t \Psi dt \quad , \text{ for } t > 0 \quad (5.1)$$

For $t = 0$, the average $\bar{\Psi}$ 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:

$$\bar{\Psi}(t_2 - t_1) = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \Psi dt \quad (5.2)$$

$$= \frac{1}{t_2 - t_1} \left[\int_0^{t_2} \Psi dt - \int_0^{t_1} \Psi dt \right] \quad (5.3)$$

$$= \frac{1}{t_2 - t_1} [t_2 \bar{\Psi}(t_2) - t_1 \bar{\Psi}(t_1)] \quad (5.4)$$

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

The averaging process is fully reflected in 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 5.13. 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 5.13: 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 |

Continued on next page

Table 5.13: List of GRIB2 keys which provide information about the **averaging** process

| Octet(s) | Key | Value | Meaning |
|----------|-------------------|----------|--|
| 50-53 | lengthOfTimeRange | variable | Time range over which statistical processing is done |

5.5.2 Accumulated fields

The quantities

| | | | |
|----------|----------|----------|----------|
| RAIN_GSP | SNOW_GSP | RAIN_CON | SNOW_CON |
| TOT_PREC | RUNOFF_S | RUNOFF_G | |

are accumulated over the respective forecast time. The accumulation process is performed from forecast start ($t_0 = 0$ 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

$$\hat{\Psi}(t) = \int_0^t \Psi \, dt \quad , \text{ for } t > 0 \quad (5.5)$$

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:

$$\hat{\Psi}(t_2 - t_1) = \int_{t_1}^{t_2} \Psi \, dt \quad (5.6)$$

$$= \int_0^{t_2} \Psi \, dt - \int_0^{t_1} \Psi \, dt \quad (5.7)$$

$$= \hat{\Psi}(t_2) - \hat{\Psi}(t_1) \quad (5.8)$$

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 in 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 5.14. 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 5.14: List of GRIB2 keys which provide information about the **accumulation** process

| Octet(s) | Key | Value | Meaning |
|----------|-------------------------------|----------|--|
| 8-9 | productDefinitionTemplateName | 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 |

5.5.3 Extreme value fields

The quantities

| | | |
|----------|---------|---------|
| VMAX_10M | TMAX_2M | TMIN_2M |
|----------|---------|---------|

contain extreme values, which are collected over 3-hourly time windows, starting from the beginning of the forecast. After 3 hours of forecast the fields are re-initialized with 0 for the first time and the next 3-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

$$\Psi_{max}(t) = \max(\Psi(t), \Psi_{max}(t)) \quad , \text{ for } t_i < t < t_i + 3h \quad (5.9)$$

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 3 hour time window is used, the database contains hourly, 2-hourly and 3-hourly extreme value fields. This is because the extreme value fields are written to the database hourly, irrespective of the start/end of the 3-hourly time windows. Example: Extreme value fields which are written into the database after a forecast time of 5 hours, contain extreme values collected over the last 2 hours. On the other hand, extreme value fields written into the database after 6 hours contain values collected over the last 3 hours. Thus, when dealing with those fields it is very important to check the GRIB2 metainfo listed in Table 5.15.

productDefinitionTemplateName=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 3 hours, the key **forecastTime** can differ from 0.

Table 5.15: 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 | <i>variable</i> | Starting time of the statistical process relative to the reference time. |
| 47 | typeOfStatisticalProcessing | 2,3 | Maximum/Minimum |
| 50-53 | lengthOfTimeRange | <i>variable</i> | Time range over which statistical processing is done |

Chapter 6

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.

6.1 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.
- **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**.

6.2 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. **lv1=30000** specifies the level in Pa.

```
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
infof=icr.info
```

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

```
read db=numex cat=icrgl400190_main_fc_exp1 exp=906 d=2013100512 p=T lv1=85000 lv=P  
bin f=t850_iconr
```

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

```
read db=parma cat=icogl130190_const_an_para invar=true info=metaData metaArray=d,s,  
p,lv,lv1,dedat,stdat bin infof=icr.info f=const_icongl
```


Appendix A

ICON standard level heights

A.1 Level heights for zero topography height

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

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

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

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

A.2 Non-zero topography heights

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

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

Table A.1: Standard heights z_i^{h0} (i.e. for zero topography height) for all 91 vertical half levels.

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

Table A.2: Standard heights z_i^{f0} (i.e. for zero topography height) for all 90 vertical full levels.

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

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



| <p>Example: Height above ground HHL - HSURF</p> <p>Location with max. surface height</p> <p>CLON/CLAT = 88.180 / 27.938</p> <p>HSURF = 6425.974 m</p>  | | | | | | | |
|--|------------|------------|------------|------------|------------|------------|------------|
| level idx. | height [m] | level idx. | height [m] | level idx. | height [m] | level idx. | height [m] |
| 1 | 68 574.026 | 26 | 21 377.649 | 51 | 5 327.293 | 76 | 866.370 |
| 2 | 65 937.573 | 27 | 20 191.375 | 52 | 5 131.465 | 77 | 758.050 |
| 3 | 63 416.409 | 28 | 19 062.989 | 53 | 4 935.623 | 78 | 657.498 |
| 4 | 60 931.823 | 29 | 17 990.934 | 54 | 4 739.792 | 79 | 564.784 |
| 5 | 58 520.471 | 30 | 16 982.823 | 55 | 4 543.948 | 80 | 479.555 |
| 6 | 56 180.323 | 31 | 16 034.840 | 56 | 4 348.128 | 81 | 402.027 |
| 7 | 53 909.491 | 32 | 15 143.401 | 57 | 4 152.290 | 82 | 331.853 |
| 8 | 51 706.194 | 33 | 14 305.133 | 58 | 3 956.454 | 83 | 269.111 |
| 9 | 49 550.241 | 34 | 13 516.864 | 59 | 3 760.637 | 84 | 213.679 |
| 10 | 47 451.955 | 35 | 12 775.612 | 60 | 3 564.822 | 85 | 165.480 |
| 11 | 45 398.709 | 36 | 12 078.571 | 61 | 3 368.960 | 86 | 124.372 |
| 12 | 43 400.975 | 37 | 11 423.108 | 62 | 3 173.123 | 87 | 90.304 |
| 13 | 41 464.776 | 38 | 10 806.739 | 63 | 2 977.288 | 88 | 62.007 |
| 14 | 39 588.803 | 39 | 10 227.133 | 64 | 2 781.490 | 89 | 40.029 |
| 15 | 37 771.819 | 40 | 9 682.100 | 65 | 2 585.635 | 90 | 19.913 |
| 16 | 36 012.651 | 41 | 9 198.296 | 66 | 2 389.814 | 91 | 0.000 |
| 17 | 34 310.178 | 42 | 8 722.363 | 67 | 2 200.963 | | |
| 18 | 32 663.323 | 43 | 8 275.923 | 68 | 2 020.269 | | |
| 19 | 31 071.073 | 44 | 7 857.270 | 69 | 1 847.760 | | |
| 20 | 29 532.451 | 45 | 7 453.121 | 70 | 1 683.296 | | |
| 21 | 28 046.534 | 46 | 7 062.759 | 71 | 1 527.009 | | |
| 22 | 26 612.424 | 47 | 6 673.955 | 72 | 1 378.876 | | |
| 23 | 25 229.274 | 48 | 6 286.946 | 73 | 1 238.770 | | |
| 24 | 23 896.276 | 49 | 5 911.315 | 74 | 1 106.582 | | |
| 25 | 22 612.647 | 50 | 5 594.500 | 75 | 982.521 | | |

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

| <p>Example: Height above ground, full levels</p> <p>Location with max. surface height</p> <p>CLON/CLAT = 88.180 / 27.938</p> <p>HSURF = 6425.974 m</p> | | | | | | | |
|---|------------|------------|------------|------------|------------|------------|------------|
|  | | | | | | | |
| level idx. | height [m] | level idx. | height [m] | level idx. | height [m] | level idx. | height [m] |
| 1 | 67 255.799 | 25 | 21 995.148 | 49 | 5 752.908 | 73 | 1 172.676 |
| 2 | 64 676.991 | 26 | 20 784.512 | 50 | 5 460.897 | 74 | 1 044.552 |
| 3 | 62 174.116 | 27 | 19 627.182 | 51 | 5 229.379 | 75 | 924.446 |
| 4 | 59 726.147 | 28 | 18 526.961 | 52 | 5 033.544 | 76 | 812.210 |
| 5 | 57 350.397 | 29 | 17 486.878 | 53 | 4 837.708 | 77 | 707.774 |
| 6 | 55 044.907 | 30 | 16 508.831 | 54 | 4 641.870 | 78 | 611.141 |
| 7 | 52 807.842 | 31 | 15 589.120 | 55 | 4 446.038 | 79 | 522.169 |
| 8 | 50 628.217 | 32 | 14 724.267 | 56 | 4 250.209 | 80 | 440.791 |
| 9 | 48 501.098 | 33 | 13 910.998 | 57 | 4 054.372 | 81 | 366.940 |
| 10 | 46 425.332 | 34 | 13 146.238 | 58 | 3 858.546 | 82 | 300.482 |
| 11 | 44 399.842 | 35 | 12 427.091 | 59 | 3 662.730 | 83 | 241.395 |
| 12 | 42 432.875 | 36 | 11 750.839 | 60 | 3 466.891 | 84 | 189.580 |
| 13 | 40 526.789 | 37 | 11 114.923 | 61 | 3 271.042 | 85 | 144.926 |
| 14 | 38 680.311 | 38 | 10 516.936 | 62 | 3 075.206 | 86 | 107.338 |
| 15 | 36 892.235 | 39 | 9 954.617 | 63 | 2 879.389 | 87 | 76.155 |
| 16 | 35 161.414 | 40 | 9 440.198 | 64 | 2 683.563 | 88 | 51.018 |
| 17 | 33 486.750 | 41 | 8 960.329 | 65 | 2 487.724 | 89 | 29.971 |
| 18 | 31 867.198 | 42 | 8 499.143 | 66 | 2 295.388 | 90 | 9.956 |
| 19 | 30 301.762 | 43 | 8 066.596 | 67 | 2 110.616 | | |
| 20 | 28 789.492 | 44 | 7 655.196 | 68 | 1 934.015 | | |
| 21 | 27 329.479 | 45 | 7 257.940 | 69 | 1 765.528 | | |
| 22 | 25 920.849 | 46 | 6 868.357 | 70 | 1 605.152 | | |
| 23 | 24 562.775 | 47 | 6 480.451 | 71 | 1 452.942 | | |
| 24 | 23 254.461 | 48 | 6 099.130 | 72 | 1 308.823 | | |

Bibliography

- Bloom, S. C., L. L. Takacs, A. M. D. Silva, and D. Ledvina, 1996: Data assimilation using incremental analysis updates. *Mon. Wea. Rev.*, **124**, 1256–1270.
- Leuenberger, D., M. Koller, and C. Schär, 2010: A generalization of the sleeve vertical coordinate. *Mon. Wea. Rev.*, **138**, 3683–3689.
- Polavarapu, S., S. Ren, A. M. Clayton, D. Sankey, and Y. Rochon, 2004: On the relationship between incremental analysis updating and incremental digital filtering. *Mon. Wea. Rev.*, **132**, 2495–2502.
- Ruppert, T., 2007: Diplomarbeit: Vector field reconstruction by radial basis functions. Master’s thesis, Technical University Darmstadt, Department of Mathematics.
- Wan, H., M. A. Giorgetta, G. Zängl, M. Restelli, D. Majewski, L. Bonaventura, K. Fröhlich, D. Reinert, P. Ripodas, L. Kornblueh, and J. Förstner, 2013: The ICON-1.2 hydrostatic atmospheric dynamical core on triangular grids – Part 1: Formulation and performance of the baseline version. *Geosci. Model Dev.*, **6**, 735–763.