Consortium for Small-Scale Modelling

A Description of the

Nonhydrostatic Regional COSMO-Model

Model Output and Data Formats for I/O

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www.cosmo-model.org

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Section 1

Overview on the Model System

1.1 General Remarks

The *COSMO-Model* is a nonhydrostatic limited-area atmospheric prediction model. It has been designed for both operational numerical weather prediction (NWP) and various scientific applications on the meso-β and meso-γ scale. The COSMO-Model is based on the primitive thermo-hydrodynamical equations describing compressible flow in a moist atmosphere. The model equations are formulated in rotated geographical coordinates and a generalized terrain following height coordinate. A variety of physical processes are taken into account by parameterization schemes.

Besides the forecast model itself, a number of additional components such as data assimilation, interpolation of boundary conditions from a driving host model, and postprocessing utilities are required to run the model in NWP-mode, climate mode or for case studies. The purpose of the *Description of the Nonhydrostatic Regional COSMO-Model* is to provide a comprehensive documentation of all components of the system and to inform the user about code access and how to install, compile, configure and run the model.

The basic version of the COSMO-Model (formerly known as *Lokal Modell (LM)*) has been developed at the *Deutscher Wetterdienst* (DWD). The COSMO-Model and the triangular mesh global gridpoint model ICON form – together with the corresponding data assimilation schemes – the NWP-system at DWD. The subsequent developments related to the COSMO-Model have been organized within COSMO, the *Consortium for Small-Scale Modeling*. COSMO aims at the improvement, maintenance and operational application of a nonhydrostatic limited-area modeling system, which is now consequently called the COSMO-Model. The meteorological services participating to COSMO at present are listed in Table 1.1.

For more information about COSMO, we refer to the web-site at `www.cosmo-model.org`.

The COSMO-Model is available free of charge for scientific and educational purposes, especially for cooperational projects with COSMO members. However, all users are required to sign an agreement with a COSMO national meteorological service and to respect certain conditions and restrictions on code usage. For questions concerning the request and the agreement, please contact the chairman of the COSMO Steering Committee. In the case of a planned operational or commercial use of the COSMO-Model package, special regulations

Table 1.1: COSMO: Participating Meteorological Services

DWD	Deutscher Wetterdienst, Offenbach, Germany
MeteoSwiss	Meteo-Schweiz, Zürich, Switzerland
ITAF-ReMet	Ufficio Generale Spazio Aero e Meteorologia, Roma, Italy
HNMS	Hellenic National Meteorological Service, Athens, Greece
IMGW	Institute of Meteorology and Water Management, Warsaw, Poland
ARPA-SIMC	Agenzia Regionale per la Protezione Ambientale dell Emilia-Romagna Servizio Idro Meteo Clima Bologna, Italy
ARPA-Piemonte	Agenzia Regionale per la Protezione Ambientale, Piemonte, Italy
CIRA	Centro Italiano Ricerche Aerospaziali, Italy
ZGeoBW	Zentrum für Geoinformationswesen der Bundeswehr, Euskirchen, Germany
NMA	National Meteorological Administration, Bukarest, Romania
RosHydroMet	Hydrometeorological Centre of Russia, Moscow, Russia
IMS	Israel Meteorological Service, Bet-Dagan, Israel

will apply.

The further development of the modeling system within COSMO is organized in Working Groups which cover the main research and development activities: data assimilation, numerical aspects, upper air physical aspects, soil and surface physics aspects, interpretation and applications, verification and case studies, reference version and implementation and predictability and ensemble methods. In 2005, the COSMO Steering Committee decided to define *Priority Projects* with the goal to focus the scientific activities of the COSMO community on some few key issues and support the permanent improvement of the model. For contacting the Working Group Coordinators or members of the Working Groups or Priority Projects, please refer to the COSMO web-site.

The COSMO meteorological services are not equipped to provide extensive support to external users of the model. If technical problems occur with the installation of the model system or with basic questions how to run the model, questions could be directed via email to `cosmo-support@cosmo-model.org`. If further problems occur, please contact the members of an appropriate Working Group. We try to assist you as well as possible.

The authors of this document recognize that typographical and other errors as well as dis-

crepancies in the code and deficiencies regarding the completeness may be present, and your assistance in correcting them is appreciated. All comments and suggestions for improvement or corrections of the documentation and the model code are welcome and may be directed to the authors.

1.2   Basic Model Design and Features

The nonhydrostatic fully compressible COSMO-Model has been developed to meet high-resolution regional forecast requirements of weather services and to provide a flexible tool for various scientific applications on a broad range of spatial scales. When starting with the development of the COSMO-Model, many NWP-models operated on hydrostatic scales of motion with grid spacings down to about 10 km and thus lacked the spatial resolution required to explicitly capture small-scale severe weather events. The COSMO-Model has been designed for meso-β and meso-γ scales where nonhydrostatic effects begin to play an essential role in the evolution of atmospheric flows.

By employing 1 to 3 km grid spacing for operational forecasts over a large domain, it is expected that deep moist convection and the associated feedback mechanisms to the larger scales of motion can be explicitly resolved. Meso-γ scale NWP-models thus have the principle potential to overcome the shortcomings resulting from the application of parameterized convection in current coarse-grid hydrostatic models. In addition, the impact of topography on the organization of penetrative convection by, e.g. channeling effects, is represented much more realistically in high resolution nonhydrostatic forecast models.

In the beginning, the operational application of the model within COSMO were mainly on the meso-β scale using a grid spacing of 7 km. The key issue was an accurate numerical prediction of near-surface weather conditions, focusing on clouds, fog, frontal precipitation, and orographically and thermally forced local wind systems. Since April 2007, a meso-γ scale version is running operationally at DWD by employing a grid spacing of 2.8 km. In May 2018, the resolution has further been enhanced to 2.2 km. Applications with similar resolutions are now run by most COSMO partners. We expect that this will allow for a direct simulation of severe weather events triggered by deep moist convection, such as supercell thunderstorms, intense mesoscale convective complexes, prefrontal squall-line storms and heavy snowfall from wintertime mesocyclones.

The requirements for the data assimilation system for the operational COSMO-Model are mainly determined by the very high resolution of the model and by the task to employ it also for nowcasting purposes in the future. Hence, detailed high-resolution analyses have to be able to be produced frequently and quickly, and this requires a thorough use of asynoptic and high-frequency observations such as aircraft data and remote sensing data. Since both 3-dimensional and 4-dimensional variational methods tend to be less appropriate for this purpose, a scheme based on the observation nudging technique has been chosen for data assimilation from the beginning of the development. But in March 2017 the nudging scheme has been replaced by a new, more modern, ensemble-based method, called KENDA: Km-scale ENsemble Data Assimilation. Note, that KENDA, unlike the nudging scheme, is not available within the source code of the COSMO-Model.

Besides the operational application, the COSMO-Model provides a nonhydrostatic modeling framework for various scientific and technical purposes. Examples are applications of

the model to large-eddy simulations, cloud resolving simulations, studies on orographic flow systems and storm dynamics, development and validation of large-scale parameterization schemes by fine-scale modeling, and tests of computational strategies and numerical techniques. For these types of studies, the model should be applicable to both real data cases and artificial cases using idealized test data. Moreover, the model has been adapted by other communities for applications in climate mode (CCLM) and / or running an online coupled module for aerosols and reactive trace gases (ART).

Such a wide range of applications imposes a number of requirements for the physical, numerical and technical design of the model. The main design requirements are:

(i) use of nonhydrostatic, compressible dynamical equations to avoid restrictions on the spatial scales and the domain size, and application of an efficient numerical method of solution;

(ii) provision of a comprehensive physics package to cover adequately the spatial scales of application, and provision of high-resolution data sets for all external parameters required by the parameterization schemes;

(iii) flexible choice of initial and boundary conditions to accommodate both real data cases and idealized initial states, and use of a mesh-refinement technique to focus on regions of interest and to handle multi-scale phenomena;

(iv) use of a high-resolution analysis method capable of assimilating high-frequency asynoptic data and remote sensing data;

(v) use of pure Fortran constructs to render the code portable among a variety of computer systems, and application of the standard MPI-software for message passing on distributed memory machines to accommodate broad classes of parallel computers.

The development of the COSMO-Model was organized along these basic guidelines. However, not all of the requirements are fully implemented, and development work and further improvement is an ongoing task. The main features and characteristics of the present release are summarized below.

Dynamics

- **Model Equations** – Nonhydrostatic, full compressible hydro-thermodynamical equations in advection form. Subtraction of a hydrostatic base state at rest.

- **Prognostic Variables** – Horizontal and vertical Cartesian wind components, pressure perturbation, temperature, specific humidity, cloud water content. Optionally: cloud ice content, turbulent kinetic energy, specific water content of rain, snow and graupel.

- **Diagnostic Variables** – Total air density, precipitation fluxes of rain and snow.

- **Coordinate System** – Generalized terrain-following height coordinate with rotated geographical coordinates and user defined grid stretching in the vertical. Options for (i) base-state pressure based height coordinate, (ii) Gal-Chen height coordinate and (iii) exponential height coordinate (SLEVE) according to Schaer et al. (2002) and (iv) in a modified version (SLEVE2) according to Leuenberger et al. (2010).

Numerics

- **Grid Structure** – Arakawa C-grid, Lorenz vertical grid staggering.

- **Spatial Discretization** – Second-order finite differences. For the two time-level scheme also 1st and 3rd to 6th order horizontal advection (default: 5th order). Option for explicit higher order vertical advection.

- **Time Integration** – Two time-level 2nd and 3rd order Runge-Kutta split-explicit scheme after Wicker and Skamarock (2002) and a TVD-variant (Total Variation Diminishing) of a 3rd order Runge-Kutta split-explicit scheme. Option for a second-order leapfrog HE-VI (horizontally explicit, vertically implicit) time-split integration scheme, including extensions proposed by Skamarock and Klemp (1992). Option for a three time-level 3-d semi-implicit scheme (Thomas et al. (2000)) based on the leapfrog scheme.

- **Numerical Smoothing** – 4th-order linear horizontal diffusion with option for a monotonic version including an orographic limiter. Rayleigh damping in upper layers. 2-d divergence damping and off-centering in the vertical in split time steps.

Initial and Boundary Conditions

- **Initial Conditions** – Interpolated initial data from various coarse-grid driving models (ICON (and former GME), ECMWF, COSMO-Model) or from the continuous data assimilation stream (see below). Option for user-specified idealized initial fields.

- **Lateral Boundary Conditions** – 1-way nesting by Davies-type lateral boundary formulation. Data from several coarse-grid models can be processed (ICON (and former GME), IFS, COSMO-Model). Option for periodic boundary conditions.

- **Top Boundary Conditions** – Options for rigid lid condition and Rayleigh damping layer.

- **Initialization** – Digital-filter initialization of unbalanced initial states (Lynch et al. (1997)) with options for adiabatic and diabatic initialization.

Physical Parameterizations

- **Subgrid-Scale Turbulence** – Prognostic turbulent kinetic energy closure at level 2.5 including effects from subgrid-scale condensation and from thermal circulations. Option for a diagnostic second order K-closure of hierarchy level 2 for vertical turbulent fluxes. Preliminary option for calculation of horizontal turbulent diffusion in terrain following coordinates (3D Turbulence).

- **Surface Layer Parameterization** – A Surface layer scheme (based on turbulent kinetic energy) including a laminar-turbulent roughness layer. Option for a stability-dependent drag-law formulation of momentum, heat and moisture fluxes according to similarity theory (Louis (1979)).

- **Grid-Scale Clouds and Precipitation** – Cloud water condensation and evaporation by saturation adjustment. Precipitation formation by a bulk microphysics parameterization including water vapour, cloud water, cloud ice, rain and snow with 3D transport for the precipitating phases. Option for a new bulk scheme including graupel. Option for a simpler column equilibrium scheme.

- **Subgrid-Scale Clouds** – Subgrid-scale cloudiness is interpreted by an empirical function depending on relative humidity and height. A corresponding cloud water content is also interpreted. Option for a statistical subgrid-scale cloud diagnostic for turbulence.

- **Moist Convection** – Tiedtke (1989) mass-flux convection scheme with equilibrium closure based on moisture convergence. Option for the current IFS Tiedtke-Bechtold convection scheme.

- **Shallow Convection** – Reduced Tiedtke scheme for shallow convection only.

- **Radiation** – δ two-stream radiation scheme after Ritter and Geleyn (1992) short and longwave fluxes (employing eight spectral intervals); full cloud-radiation feedback.

- **Soil Model** – Multi-layer version of the former two-layer soil model after Jacobsen and Heise (1982) based on the direct numerical solution of the heat conduction equation. Snow and interception storage are included.

- **Fresh-Water Lake Parameterization** – Two-layer bulk model after Mironov (2008) to predict the vertical temperature structure and mixing conditions in fresh-water lakes of various depths.

- **Sea-Ice Scheme** – Parameterization of thermodynamic processes (without rheology) after Mironov and B. (2004). The scheme basically computes the energy balance at the ices surface, using one layer of sea ice.

- **Terrain and Surface Data** – All external parameters of the model are available at various resolutions for a pre-defined region covering Europe. For other regions or grid-spacings, the external parameter file can be generated by a preprocessor program using high-resolution global data sets.

Data Assimilation

- **Former Method** – Continuous four-dimensional data assimilation based on observation nudging (Schraff (1996), Schraff (1997)), with lateral spreading of upper-air observation increments along horizontal surfaces. Explicit balancing by a hydrostatic temperature correction for surface pressure updates, a geostrophic wind correction, and a hydrostatic upper-air pressure correction.

- **Actual Method** – Ensemble data assimilation based on the LETKF (Local Ensemble Transform Kalman Filter) (Schraff et al. (2016))

- **Assimilated Atmospheric Observations** – Radiosonde (wind, temperature, humidity), aircraft (wind, temperature), wind profiler (wind), and surface-level data (SYNOP, SHIP, BUOY: pressure, wind, humidity). Optionally RASS (temperature), radar VAD wind, and ground-based GPS (integrated water vapour) data. Surface-level temperature is used for the soil moisture analysis only.

- **Radar derived rain rates** – Assimilation of near surface rain rates based on latent heat nudging (Stephan et al. (2008)). It locally adjusts the three-dimensional thermodynamical field of the model in such a way that the modelled precipitation rates should resemble the observed ones.

- **Surface and Soil Fields** – Additional two-dimensional intermittent analysis:
    - **Soil Moisture Analysis** – Daily adjustment of soil moisture by a variational method (Hess (2001)) in order to improve 2-m temperature forecasts; use of a Kalman-Filter-like background weighting.
    - **Sea Surface Temperature Analysis** – Daily Cressman-type correction, and blending with global analysis. Use of external sea ice cover analysis.
    - **Snow Depth Analysis** – 6-hourly analysis by weighted averaging of snow depth observations, and use of snowfall data and predicted snow depth.

Code and Parallelization

- **Code Structure** – Modular code structure using standard Fortran constructs.

- **Parallelization** – The parallelization is done by horizontal domain decomposition using a soft-coded gridline halo (2 lines for Leapfrog, 3 for the Runge-Kutta scheme). The *Message Passing Interface* software (MPI) is used for message passing on distributed memory machines.

- **Compilation of the Code** – For all programs a Makefile is provided for the compilation which is invoked by the Unix *make* command. Two files are belonging to the Makefile: `ObjFiles` is a list of files that have to be compiled and `ObjDependencies` contains all file dependencies. In addition it reads the file `Fopts`, which has to be adapted by the user to specify the compiler, compiler options and necessary libraries to link.

Table 1.2: COSMO Documentation: A Description of the Nonhydrostatic Regional COSMO-Model

Part I:	Dynamics and Numerics
Part II:	Physical Parameterization
Part III:	Data Assimilation
Part IV:	Special Components and Implementation Details
Part V:	Preprocessing: Initial and Boundary Data for the COSMO-Model
Part VI:	Model Output and Data Formats for I/O
Part VII:	User's Guide

- **Portability** – The model can be easily ported to various platforms; current applications are on conventional scalar machines (UNIX workstations, LINUX and Windows-NT PCs), on vector computers (NEC SX series) and MPP machines (CRAY, IBM, SGI and others).

- **Model Geometry** – 3-d, 2-d and 1-d model configurations. Metrical terms can be adjusted to represent tangential Cartesian geometry with constant or zero Coriolis parameter.

- **New Architectures** – In the last years our swiss colleagues implemented a model version, which can exploit also GPUs. While the dynamical core has been implemented using a new domain specific language (DSL), the rest of the model has been ported using OpenACC. Since Version 5.06, all modifications have been implemented into the official model version.

1.3 Organization of the Documentation

For the documentation of the model we follow closely the *European Standards for Writing and Documenting Exchangeable Fortran 90-Code*. These standards provide a framework for the use of Fortran-90 in European meteorological organizations and weather services and thereby facilitate the exchange of code between these centres. According to these standards, the model documentation is split into two categories: external documentation (outside the code) and internal documentation (inside the code). The model provides extensive documentation within the codes of the subroutines. This is in form of procedure headers, section comments and other comments. The external documentation is split into seven parts, which are listed in Table 1.2.

Parts I - III form the scientific documentation, which provides information about the theoretical and numerical formulation of the model, the parameterization of physical processes and the four-dimensional data assimilation. The scientific documentation is independent of (i.e. does not refer to) the code itself. Part IV will describe the particular implementation of the methods and algorithms as presented in Parts I - III, including information on the basic code design and on the strategy for parallelization using the MPI library for message passing on distributed memory machines (not available yet). The generation of initial and boundary conditions from coarse grid driving models is described in Part V. This part is a description of the interpolation procedures and algorithms used (not yet complete) as well as a User's Guide for the interpolation program INT2LM. In Part VI we give a description of the data formats, which can be used in the COSMO-Model, and describe the output

from the model and from data assimilation. Finally, the User's Guide of the COSMO-Model provides information on code access and how to install, compile, configure and run the model. The User's Guide contains also a detailed description of various control parameters in the model input file (in NAMELIST format) which allow for a flexible model set-up for various applications. All parts of the documentation are available at the COSMO web-site (http://www.cosmo-model.org/content/model/documentation/core/default.htm).

Section 2

Introduction

42. Since Douglas Adams (1982) wrote *The Hitchhiker's Guide to the Galaxy* books, this short and condense *answer to the ultimate question of life, the universe, and everything* is a synonym for a precise but not understandable and therefore useless supercomputer result. Knowing that the answers from the COSMO-Model are perhaps less precise, this Output Guide has been written in order to make the results at least more understandable.

To inform the users about its simulation results, the COSMO-Model provides three kinds of output:

- The model fields resulting from the model integration can be written in GRIB 1, GRIB 2 or in NetCDF output. Both, GRIB and NetCDF are international binary formats, GRIB mainly used within the WMO, NetCDF mainly used within the climate community. Chapter 3 gives short introductions to all these formats. The fields themselves are explained in detail in Chapter 4.

- For a quick monitoring and diagnostic output, several ASCII files are written. These are described in Chapter 5 and 6.1.

- For data assimilation or verification purposes, a special NetCDF 'feedobs' file (sometimes also (mis)called 'feedback' file) can be written. Section 6.2 provides some information on it. A comprehensive description of the format of 'feedback' files (which are extended 'feedobs' files) is given in an extra documentation *Feedback File Definition*, which can also be found on the COSMO web site (www.cosmo-model.org).

Section 3

Data Formats for I/O

3.1 Introduction

All input and output fields of the COSMO-Model and the preprocessor program providing interpolated initial and boundary conditions can be stored in GRIB or in NetCDF format. Restart files are always written in pure binary format. Writing restart files in NetCDF has been implemented by the CLM community lately; this work will be included into the official version with the next code re-unification.

GRIB

GRIB is designed for the international exchange of processed data in the form of grid-point values expressed in binary form. The GRIB-code is part of the FM-system of binary codes of the World Meteorological Organization (WMO). For coding details, see the *Manual on Codes, International Codes, Volume 1.2* of WMO (WMO Publication No. 306). In this section, we describe only the basic features of the GRIB code which are relevant for the I/O of the COSMO-system.

Each GRIB-coded record (analysis or forecast field) consists of a continuous bit-stream which is made up of a sequence of octets (1 octet = 8 bits). The representation of data by means of series of bits is independent of any particular machine representation. There are two flavors of GRIB, Edition 1 and 2.

GRIB 1 was the first data format implemented in the COSMO-Model system using DWD's `libgrib1.a`. To deal with GRIB 2, the application programmers interface, `grib_api`, from ECMWF has been implemented. A full implementation is only available since versions INT2LM 2.02 and COSMO-Model 5.03. Lately, ECMWF integrated `grib_api` and `bufr` into one package, called `ecCodes`. In the following we will use the new term `ecCodes` when referring to this application programmers interface.

The approach, how data is coded to / decoded from GRIB messages is different than in the DWD GRIB 1 library. While the GRIB 1 library provides interfaces to code / decode the full GRIB message in one step, `ecCodes` uses a *key / value* approach to write or read single meta data. Each meta datum, called a key, has a special name. Values for the keys can be read or written by special `ecCodes` commands. Please refer to the `ecCodes` manual for further information.

To use `ecCodes` properly, also a set of definition files is necessary. The COSMO-Model system uses the concept of the *short names*, and for that additional definition files are necessary, which are provided by DWD. While `ecCodes` can handle both GRIB editions, DWD only guarantees maintenance of its definition files for GRIB 2. Therefore it is strongly recommended to use DWD's `libgrib1.a` when working with GRIB 1!

NetCDF

Unidatas Network Common Data Form (*netCDF*) is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. It is also a community standard for sharing scientific data.

NetCDF has been implemented into the COSMO-Model system by the CLM Community in the version INT2LM 1.06 and COSMO-Model 3.18.

How to choose the data format

The basic namelist settings to control the format in the COSMO-Model are `yform_read=`*string* and `yform_write=`*string*. Table 3.1 lists the possible options for *string* for both variables:

yform_read	yform_write
'grb1'	'grb1'
'ncdf'	'ncdf'
'apix'	'api1'
	'api2'

Table 3.1: *Options for Data Formats*

The same values are possible for corresponding namelist variables in the INT2LM. Note that with `yform_read='apix'` it is possible to read records from one file, even if they are coded in different editions.

The next sections explain the GRIB (Edition 1 and 2) and NetCDF format in more detail, but without claiming to be a full reference hand book. Therefore we refer also to the original documentation of these formats. Section 3.4 of this chapter will highlight some modifications in INT2LM and the COSMO-Model regarding GRIB2.

3.2 GRIB Edition 1

For Edition 1, GRIB means "gridded binary". The octets of a GRIB 1 message are grouped in sections (see Table 3.2), where the length of the record and the length of the sections are expressed in octets. Section 0 has a fixed length of 8 octets and Section 5 has a fixed length of 4 octets. Sections 1, 2, 3 and 4 have a variable length which is included in the first three octets of each section.

Code Structure

Section	Name	Contents
0	Indicator Section	"GRIB"; length of record; GRIB edition number
1	Product Definition Section	Length of section; identification of the coded analysis/forecast field
2	Grid Description Section (optional)	Length of section; horizontal grid geometry; vertical coordinate parameters (optional)
3	Bit-map Section (optional)	Length of section; one bit per grid-point, placed in suitable sequence
4	Binary Data Section	Length of section; packed data values
5	End Section	7777

Table 3.2: *Form of GRIB 1-code*

Octets are numbered 1, 2, 3, etc., starting at the beginning of each section. Bit positions within octets are referred to as bit 1 to 8, where bit 1 is the most significant bit and bit 8 is the least significant bit, as in big endian UNIX computers. Thus, an octet with only bit 8 set to 1 would have the integer value 1.

Indicator and End Section

The Indicator Section has a fixed length of 8 octets. The first four octets shall always be character coded in a human readable form as "GRIB" (according to the CCITT International Alphabet No. 5). The remainder of the section shall contain the length of the entire GRIB-record (including the Indicator Section) expressed in binary form over the left-most 3 octets (i.e. 24 bits in octet 5-7), followed by the GRIB edition number (here: 1), in binary, in the remaining octet 8. Note that the length of GRIB 1 records therefore is limited to a value of $2^{24} - 1 = 16777215$ bytes! The End Section has a fixed length of 4 octets. These octets are character coded as "7777" according to the International Alphabet No. 5.

Thus, the beginning and the end of a GRIB-record can be identified by the character coded words "GRIB" and "7777". All other octets included in the code represent data in binary form. Each input or output array defined on the rotated lat/lon grid of the COSMO-model (e.g the surface pressure or the temperature at a specified model level) is coded as a GRIB-record. Various records can be combined in a single GRIB-file.

Product Definition Section

The Product Definition Section (PDS) contains the necessary information to identify the binary coded field contained in the GRIB 1 record. The most important octet in this section is the indicator of the meteorological parameter. The indicator relates a specific meteorological element to an integer number. This indicator number is also referred to as *GRIB-number* or *element-number* and is defined in a separate code table. The COSMO-Model system uses more than one of these code tables. Thus, one can have the same element-number but different code table numbers for various fields. Every I/O-field of the COSMO-Model is uniquely mapped to a pair of numbers *(element number, code table)*. These numbers are coded in the COSMO module `src_setup_vartab.f90`.

The program `grbin1` of the supplementary GRIB 1-library `libgrib1` can be used to decode GRIB 1 binary code. Besides the decoded data set, this program does also retrieve the contents of the octets of the PDS in an integer array `ipds`. To illustrate the structure of the PDS, Table 3.7 shows the contents of the product definition section of a binary coded output array, the total cloud cover (CLCT). The GRIB 1-record for this field is valid for 28.10.1998 00 UTC + 11 h and was created at 28.10.1998 7.04 UTC by a forecast of the COSMO-Model.

Octet 4 (ipds(2)) assigns a table number to the parameter indicator number given in octet 9. Besides the official WMO table 2, we use some additional local tables, 201 to 205. A full list of variables defined by these tables is available from DWD.

Octet 6 (ipds(4)) indicates the generating process identification number which is allocated by the originating centre. The process numbers used for the COSMO applications at DWD are shown in Table 3.3. At DWD this number is strongly connected to the data base system, because it also specifies the different application and whether it is a forecast or an analysis.

process id; ipds(4)	Comment
131	Analyses from data assimilation cycle for former model domain
132	Forecasts and initialized analyses for former model domain
134	Analyses from data assimilation cycle for COSMO_EU
135	Forecasts and initialized analyses for COSMO_EU
137	Analyses from data assimilation cycle for COSMO_DE
138	Forecasts and initialized analyses for COSMO_DE
139	Forecasts and initialized analyses for COSMO_D2

Table 3.3: *Process identification numbers*

The level or layer for which the data are included in the GRIB 1-record is coded in octets 10 - 12 (ipds(8) - ipds(9)), where octet 10 indicates the type of level and octets 11 and 12 indicate the value of this level. Table 3.4 shows the level types used for the COSMO-Model. For reserved values, or if not defined, octets 11 and 12 shall contain zero.

Most 3-D variables are defined on terrain-following main levels. In GRIB 1, these main levels are coded as level-type 110: hybrid layers between two adjacent hybrid levels - which are the half levels in the COSMO-Model, i.e. the layer interfaces. In this case, octet 11 contains

level type ipds(8)	Meaning	ipds(9)	ipds(10)
1	Ground or water surface	0	0
2	Cloud base level	0	0
3	Level of cloud tops	0	0
4	Level of $0°C$ isotherm	0	0
8	Top of atmosphere	0	0
100	Pressure (isobaric) level	0	Pressure in hPa
102	Mean sea level	0	0
103	Specified height above mean sea level	0	Height in m
105	Specified height level above ground	0	Height in m
109	Hybrid level (half levels)	0	Level number (k)
110	Hybrid layer (main level) between two hybrid levels	Level number of top (k)	Level number of bottom (k+1)
111	Depth below land surface	0	Depth in cm
112	Layer between two depths below land surface	Depth of upper surface in cm	Depth of lower surface in cm

Table 3.4: *Types of fixed levels or layers used by the COSMO-Model*

the level index of the upper half level and octet 12 contains the level index of the lower half level. Only few variables (as the vertical velocity or the height of the half levels) are coded as level type 109: hybrid levels, i.e. the model half levels. In this case, octet 11 contains zero and octet 12 contains the level index of the model half level. Pressure levels (ipds(8) = 100) and height levels (ipds(8) = 105) are used when the interpolation from model to specified p- or z-surfaces is switched on for model output.

Octets 13-17 contain the reference time of the data: the start of a forecast, the time for which an analysis is valid or the start of an averaging or accumulation period. The year of the century is coded in octet 13 and the century (100 years) in octet 25. For a reference time within the year 2000, octet 13 will contain the integer value 100 and octet 25 will contain the integer value 20.

The time or time interval for which the data are valid with respect to the reference time is coded in octets 18-21 (ipds(16)-ipds(19)). Octets 19 and 20 contain two periods of time, P1 and P2. The units of the values of P1 and P2 are defined in octet 18. Normally, we use hours as the time unit, but other values may be more appropriate for special applications of the model as the maximum integer number in an octet is 256. Thus, for long-term climate runs or short-term cloud simulations, other time units must be chosen. In the COSMO-DE we use *quarter of an hour* or *half an hour* for writing special variables more often than hourly. Note that the corresponding values for the unit of time (13 and 14) have only been lately adopted by WMO as official numbers. The WMO code-table for the unit of time in P1 and P2 is given in Table 3.5.

The meaning of the time period P1 in octet 19 (ipds(17)) and of the time period P2 in octet 20 (ipds(18)) - given in the units coded in octet 18 - depends on the time-range indicator,

ipds(16)	Meaning
0	Minute
1	Hour
2	Day
3	Month
4	Year
5	Decade
6	Normal
7	Century
8-9	Reserved
10	3 hours
11	6 hours
12	12 hours
13	Quarter of an hour
14	Half an hour
254	Second

Table 3.5: *Code table for unit of time*

which is contained in octet 21 (ipds(19)). The WMO code-table allows for a large number of indicators including averages and accumulation over a number of forecasts and analyses. For the COSMO-system, we use only a few standard indicators as shown in Table 3.6.

ipds(19)	Meaning
0	Forecast product valid for reference time + P1 (if P1 > 0) or uninitialized analysis product valid for reference time (P1 = 0)
1	initialized analysis product valid for reference time (P1 = 0)
2	Product with a valid time ranging between reference time + P1 and reference time + P2
3	Average from reference time + P1 to reference time + P2
4	Accumulation from reference time + P1 to reference time + P2; product valid for reference time + P2

Table 3.6: *Time range indicators used by the COSMO-Model*

Table 3.7: *Contents of the Product Definition Section*

array ipds(i)	Octet number	Value	Remarks
			Contents of PDS
1	1-3	54	Length of the PDS (in octets)
2	4	2	Version number of the GRIB 1 indicator table
3	5	78	Identification of originating/generating centre (DWD has WMO number 78)
4	6	132	Generating process identification number (allocated by originating centre, see Table 3.3)
5	7	255	Number of grid used - from catalogue defined by the originating centre. Octet 7 set to 255 indicates a non-cataloged grid, in which case the grid is defined in the grid description section.
6	8	128	Block-flag; the value 128 indicates that the grid description section is included.
7	9	71	Indicator of parameter (element number) from GRIB 1-table in ipds(2).
8	10	1	Indicator of type of level, see Table 3.4
9-10	11-12	0	Value of level (height, pressure, etc.) for which the data are included (see Table 3.4)
11	13	98	Year (start time of forecast; analysis time)
12	14	10	Month (start time of forecast; analysis time)
13	15	28	Day (start time of forecast; analysis time)
14	16	0	Hour (start time of forecast; analysis time)
15	17	0	Minute (start time of forecast; analysis time)
16	18	1	Indicator of unit of time range (see Table 3.5)
17	19	11	P1 - period of time (number of time units); time units given by octet 18 (ipds(16))
18	20	0	P2 - period of time (number of time units); time units given by octet 18 (ipds(16))
19	21	0	Time range indicator (see Table 3.6)
20	22-23	0	Number of forecasts included in average, when octet 21 (ipds(19)) indicates an average or accumulation of forecasts (or analyses); otherwise set to zero.
21	24	0	Number of forecasts missing from averages or accumulations.
22	25	20	Century of reference time of data given by octets 13- 17
23	26	255	Sub-centre identification, national use
24	27-28	0	Units decimal scale factor (D)
25-36	29-40	0	Reserved: need not to be present
37	41	254	Octets 41-54 are reserved for the originating centre (local use). The integer value 254 indicates that additional data follow. We use this part as follows:
38	42	0	Not used
39	43-45	0	Not used
40	46	0	Not used
41	47	0	Additional indicator for a GRIB 1 element number
42	48	98	Year of production of GRIB 1-record
43	49	98	Month of production of GRIB 1-record
44	50	11	Day of production of GRIB 1-record
45	51	2	Hour of production of GRIB 1-record
46	52	0	Minute of production of GRIB 1-record
47	53-54	1	Version number, currently 1

Grid Description Section

Section 2 of a GRIB 1-record, the grid description section GDS, contains all information about the horizontal and vertical geometry of the grid on which the data are defined. For all input and output files of the model, this section is coded completely for every field contained in the file. The program `grbin1` of the supplementary GRIB 1-library `libgrib1` retrieves the contents of the GDS in an integer array `igds`.

The contents of the grid description section of a COSMO-EU GRIB 1-record is illustrated in Table 3.8 for the model domain used operationally at DWD. The octets corresponding to the integer array `igds` are numbered relative to this section.

Bit-map Section

This section is optional, and provides the possibility to include only some grid points of the grid defined in the Grid Description Section. The bit-map is a sequence of bits with a bit-to-grid point correspondence, ordered as defined in the grid definition (1: value is included; 0: value is excluded).

DWD uses bit-maps to send only those data from the global model ICON (or the older model GME) to the national weather services running the COSMO-Model, that are needed for the corresponding domain.

Binary Data Section

This section contains all values of the defined grid, usually in a packed format. At DWD typically 16 bits are used to store a packed value.

Table 3.8: *Contents of the Grid Description Section*

array igds(i)	Octet number	Contents of GDS	
		Value	Meaning
1	1-3	250	Length of GDS (in octets) including the vertical coordinate parameters. (here for $ke = 40$ layers, i.e. $ke + 1 = 41$ half levels)
2	4	52	NV: Number of vertical coordinate parameters (four base state parameters $+ (ke + 1)$ values of the vertical coordinates of the half levels + poss. other parameters)
3	5	43	PV: Location (octet number) of the list of vertical coordinate parameters
4	6	10	Data representation type according to WMO code-table 6; '10' assigns a rotated latitude/longitude grid
5	7-8	665	Number of gridpoints in 'zonal' direction
6	9-10	657	Number of gridpoints in 'meridional' direction
7	11-13	-18000	Rotated latitude of the first gridpoint in millidegrees
8	14-16	-20000	Rotated longitude of the first gridpoint in millidegrees
9	17	0	Resolution flag according to WMO code-table 7; '0' means that the grid spacing is not given
10	18-20	23500	Rotated latitude of the last gridpoint in millidegrees
11	21-23	21000	Rotated longitude of the last gridpoint in millidegrees
12	24-25	0	Longitudinal direction increment (grid spacing in λ-direction, not given)
13	26-27	0	Meridional direction increment (grid spacing in ϕ-direction, not given)
14	28	64	Scanning mode flag according to WMO code-table 8 '64' means that points scan in +i and +j direction and adjacent points in i-direction are consecutive
15-19	29-32	0	Reserved (set to zero)
20	33-35	-40000	Geographical latitude of rotated southern pole in millidegrees
21	36-38	10000	Geographical longitude of rotated southern pole in millidegrees
22	39-42	0	Angle of rotation
26-65	43-202	.....	List of vertical coordinate parameters, each packed on 4 octets (length = 4 x NV octets). first the three parameters defining the base state: `igds(26)=p0sl, igds(27)=t0sl, igds(28)=dt0lp;` then the parameter `igds(29)=vcflat` of the hybrid coordinate system; and finally the $ke + 1$ values of the vertical coordinate $\eta(k)$ of the model half levels for $k = 1, \ldots, ke + 1$ in `igds(30)`,..., `igds(65)`.

3.3   GRIB Edition 2

Due to some weaknesses and limitations of GRIB 1 (see the limited size of GRIB 1 messages) a new Edition 2 has been developed. This new edition has been approved already in November 2001, but only about 10 years later several weather centers started to adopt and use it. DWD started to use GRIB Edition 2 for all operational products in June 2014.

For Edition 2, GRIB means "General Regularly distributed Information in Binary Form". The octets of a GRIB 2 message are also grouped in sections, where the length of the record and the length of the sections are expressed in octets, as it is done in Edition 1.

Because GRIB Edition 2 (also called GRIB 2) is much more complex than Edition 1, we cannot describe it here in the same details. We refer to additional introductory reading in http://www.wmo.int/pages/prog/www/WMOCodes/Guides/GRIB/GRIB2_062006.pdf.

We refer also to a special page on the COSMO web-site, where you can get additional information on GRIB 2, its structure and how it is used in the COSMO-Model. You can also find a short summary useful for migrating from GRIB 1 to GRIB 2 and comments on how to set up operational COSMO runs using GRIB 2:
http://www.cosmo-model.org/content/model/documentation/grib/default.htm.

The following short documentation should serve as a rapid introduction to GRIB 2. We start with a number of remarkable differences to GRIB 1 and will then describe the single sections briefly.

Differences between the two GRIB Editions

The structure of GRIB 2 is more modular than Edition 1. It enables the representation of new products and provides an easy way for expansion and additions by extensively using *code tables* and *templates*. In this way the definition of parameters or attributes are separated in functionality so that items related to time, purpose or production method are independent. This makes maintenance easier when descriptions of new products or new parameters are required.

GRIB 2 permits the coding of ensemble data, probability and percentile forecasts, forecast error fields, satellite image data, radar data, the analysis and forecast of accumulated and averaged parameters and offers enhanced capability to describe fields involving multiple time periods. Also it supports more compression schemes, for example JPEG2000, PNG and CCSDS (Consultative Committee for Space Data Systems).

Templates and Table Driven Code

A template is a standard list of descriptive information, which also includes some coded values. While the *product definition section* in GRIB 1 only was one unique standard template, the *product definition section* in GRIB 2 contains a coded value for the *product definition template number*. Possible values for this template number are described in *Code Table 4.0* and include for example

  0: Analysis or forecast at a horizontal level or in a horizontal layer at a point in time.

  1: Individual ensemble forecast, control and perturbed, at a horizontal level or in a hori-

zontal layer at a point in time.

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 interval.

This demonstrates how new products or different representations can be added by defining new templates and adding new elements to the set of tables in the official Manual without changing existing definitions.

Representation of Meteorological Variables

While meteorological variables in GRIB 1 were mainly specified by two numbers, the *table* and the *element number*, GRIB 2 requires to specify a triple of numbers: the *discipline*, the *category* and the *parameter number*. Here are the specifications for some temperature products:

Product	GRIB 1		GRIB 2			
	Element	Table	Discipline	Category	Parameter	Product Definition Template Number
T	11	2	0	0	0	0
TMIN_2M	16	2	0	0	0	8

Table 3.9: *GRIB 1/2 Specifications of Temperature Products*

Both products shown are temperatures, the first one is the usual temperature without any specialities, so it uses the *product definition template number* 0. The second one is the minimum temperature two meters above ground. This is a statistically processed product, so the *product definition template number* to use is 8. Note, that for this product TMIN_2M, additional meta data have to be specified. The first one of the list below is only contained in the *product definition template number* 8.

- type of statistical processing = 3: specifies the minimum;

- type of first fixed surface = 103: specifies a height level above ground;

- scale vactor of first fixed surface = 0;

- scaled value of first fixed surface = 2: specifies the 2 meter.

Code Structure

Also a GRIB 2 message consists of a bit stream and a number of octets. Again there are sections at the beginning, which describe the data contained in the message. These sections contain pointers towards elements in predefined and internationally agreed tables (stored in the official WMO Manual on Codes). By reading and decoding these sections, the following part of the message containing the data (the data section) can be understood. The characteristics (name, unit, etc.) of the parameters to be transmitted must already be defined in the tables of the WMO Manual on Codes. The *pointers* in the description sections are in fact numbers, which correspond to entries in the GRIB code tables of the WMO Manual.

The layout of a GRIB 2 message is shown in Table 3.10. The GRIB 2 indicator, grid definition, bit-map, data, and end sections map directly to their counterparts in GRIB 1, although their contents in GRIB 2 are somewhat different than in GRIB 1. However, the GRIB 2 identification, product definition, and data representation sections all map into the GRIB 1 product definition section, and the GRIB 2 sections contain substantially more information than in GRIB 1. The GRIB 2 local use section is not present in GRIB 1.

Section number	Name	Contents
0	Indicator Section	"GRIB"; discipline; edition number; length of record
1	Identification Section	Length of section; section number; characteristics that apply to all processed data in the GRIB message
2	Local Use Section	Length of section; section number; items for local use by originating center (optional)
3	Grid Description Section	Length of section; section number; grid surface and geometry of data values within the surface
4	Product Definition Section	Length of section; section number; description of the nature of the data
5	Data Representation Section	Length of section; section number; description of how the data values are represented
6	Bit-Map Section	Length of section; section number; indication of presence or absence of data at each grid point, as applicable (optional)
7	Data Section	Length of section; section number; data values
8	End Section	7777

Table 3.10: *Form of GRIB 2-code*

Indicator Section

Section 0 identifies the start of the GRIB 2 message in a human readable form. (`"GRIB"`. It already contains the first product identifying value, the *discipline*, and specifies the Edition Number of GRIB used to encode the message. The total length of the message is coded in octets 9-16. Having 8 octets available for the length, a message can now have up to $2^{64} - 1 = 1.84 \cdot 10^{19}$ bytes (= octets).

To illustrate the usage of keys (in `ecCodes`) and code tables (in GRIB 2), Table 3.11 shows the contents of the Indicator Section for the 2 meter minimum temperature `TMIN_2M` for COSMO-EU. Besides the identifier `GRIB` it contains the number of the discipline, the edition number and the total length of the GRIB message. The key names are the names, by which `ecCodes` identifies the corresponding GRIB meta data. For the *discipline* also Code Table 0.0 is shown, which contains the different disciplines defined up to now.

Note that from this section you can only identify that it is a meteorological product coded in GRIB 2, and that the length of the total message is 874052 octets. The 2 meter minimum temperature cannot be identified here.

Octet	Key Name	Contents	
		Value	Comments
1-4	identifier	GRIB	coded according to the International Alphabet No. 5
5-6	-	MISSING	Reserved
7	discipline	0	Discipline according to GRIB master table number Code Table 0.0:
			0 Meteorological products
			1 Hydrological products
			2 Land surface products
			3 Space products
			4-9 Reserved
			10 Oceanic products
			11-191 Reserved
			192-254 Reserved for local use
			255 Missing
8	editionNumber	2	GRIB edition number
9-16	totalLength	874052	Total length of GRIB message in octets (incl. Section 0)

Table 3.11: *Contents of the Indicator Section*

Identification Section

The identification section contains characteristics that apply to all processed data in the GRIB message. These characteristics identify the originating centre and sub-centre, indicate the GRIB master table and local table versions used, and give the reference time, the production status, and the type of processed data contained in this GRIB message.

Local Use Section

The purpose of the local use section is just what the section name implies: information for local use by the originating / generating center. The originating / generating center can put anything it desires in this Section.

The COSMO community agreed that all applications will employ a local use section and that all different sections are coordinated between the partners. The following sections are already defined. The number refers to the *local definition number* of the section:

  28: COSMO-LEPS

250: basic section layout defined by COSMO

252: DWD: used for ensemble system incl. postprocessing

253: DWD: used for ensemble system

254: DWD: used for deterministic system

Grid Definition Section

The purpose of the grid definition section is to define the grid surface and geometry of the data values within the surface for the data contained in the next occurrence of the data section. Already GRIB 1 contained the concept of templates in the grid description section and it is again used here. Use of a template means there are very few values common to all grid definition sections possible in GRIB 2. Rather, the number of the *grid definition template* used is encoded. The values that must follow are those required by that particular grid definition template.

For the COSMO-Model we use the grid definition template 1, which defines a rotated latitude / longitude grid. This template is rather similar to the GRIB 1 template. The most significant change is, that the number of vertical coordinate parameters (`NV`) and the parameters as well have been moved to the product definition section for GRIB 2.

Product Definition Section

The purpose of the product definition section is to describe the nature of the data contained in the next occurrence of the data section. The generic content of this section is rather short, containing the length and the number of the section, the number of coordinate values (`NV`) and the *product definition template number*. Depending on this number, more information on the data is contained in the template chosen. The optional list of vertical coordinate parameters then is given at the end of the section.

A new feature in this section, which is used by the COSMO-Model, is the new vertical coordinate type, coded with value 150, the *generalized vertical coordinate*. If the algorithm to compute the vertical levels for a model is too complicated, it is now possible to specify the vertical grid as a three-dimensional field. For the COSMO-Model, this 3D field is the `HHL`, a field that specifies the height of the half levels. All atmospheric fields that are defined on these half levels (or the corresponding full levels, which are the arithmetic mean of the half levels) have to code the level type as 150. This new level type contains only 6 vertical coordinate parameters describing the generalized vertical coordinate.

As a consequence the meta data describing the reference atmosphere and the vertical grid used cannot be coded in GRIB 2 any more. Of course coding these values within the vertical coordinates in GRIB 1 already was a mis-use of GRIB 1. How this is handled in the COSMO-Model when using GRIB 2 is explained in detail in Sect. 3.4.2.

Data Representation Section

The purpose of the data representation section is to describe how the data values are represented in the next occurrence of the data section. Again, there are only few coded values (e.g. number of data points) together with the data representation template number. This number specifies the template to use, which could for example be *grid point data - simple packing* or *spherical harmonics data - complex packing*.

New to GRIB 2 is the possibility to use some special packing (JPEG 2000, PNG, CCSDS) or even IEEE floating point data.

Bit-Map Section

The purpose of the bit-map section is to indicate the presence or absence of data at each of the grid points, as applicable, in the next occurrence of the data section. Whether a bit-map is present or not is set in octet 6 of this section:

0: A bit-map applies to this product and is specified in this section.

1-253: A bit-map pre-determined by the originating/generating center applies to this product and is not specified in this section.

254: A bit-map defined previously in the same "GRIB" message applies to this product.

255: A bit-map does not apply to this product.

If present, the bit-map follows as a series of contiguous bits, ordered as defined in the grid description section (Section 3). A bit is set to 1, if a data value is present and it is set to 0, if it is not present.

Data Section

The data section contains the data value themselves in a format described in the data representation template in Section 5.

End Section

The end section serves to identify the end of the GRIB 2 message in a human readable form: "7777"

3.4 Modifications in the COSMO-Model System for GRIB 2

When using GRIB 1, several values were coded together with the *vertical coordinate parameters* in the grid description section, which are not really vertical coordinate parameters, but additional information necessary to construct the vertical grid and the reference atmosphere of the COSMO-Model. This was a mis-use of GRIB 1 and is no more possible in GRIB 2. Therefore we had to change several things in INT2LM and the COSMO-Model when using GRIB 2.

3.4.1 Vertical Coordinates, Reference Atmosphere and Misuse of GRIB 1

To put up the vertical grid, INT2LM and the COSMO-Model need to know the vertical coordinate parameters `vcoord` and a coordinate value `vcflat`, where the vertical levels change from terrain-following to flat z-levels. If the SLEVE (smooth level vertical) coordinate is used, additional parameters are necessary, to compute the filtering for splitting the orography: `nfltvc`, `svc1` and `svc2`. Which type of vertical coordinate is used is coded in the

value `ivctype`. We refer to all these values as the *vertical coordinate parameters*. Table 3.12 summarizes the vertical coordinate parameters.

`ivctype`	Type of the vertical coordinate
	1: Pressure based hybrid coordinate η
	2: Height based hybrid coordinate μ
	3: Height based hybrid SLEVE coordinate μ_s
	4: Variant of the SLEVE coordinate μ_s
`ke`	Number of vertical main levels
`vcflat`	Coordinate value where system changes back to z-levels
`svc1, svc2, nfltvc`	decay rates and number of filtering steps for splitting the orography for the SLEVE coordinate
`vcoord`	list of the vertical parameters

Table 3.12: Vertical Coordinate Parameters

For computing the reference atmosphere, also some special parameters are necessary, namely the reference pressure and temperature on sea level, `p0sl` and `t0sl`. For the COSMO-Model there are two different types of reference atmospheres, coded with `irefatm=1` or `irefatm=2`. Depending on the type, additional values are necessary: For `irefatm=1`, a constant rate for the temperature increase with the logarithm of pressure is prescribed, which is $dt0lp = \partial T_0 / \partial \ln p_0$. For `irefatm=2`, a temperature difference between sea level and the stratosphere, `delta_t`, and a scale height `h_scal`, have to be specified. These values are the *reference atmosphere parameters*. Table 3.13 summarizes the reference atmosphere parameters.

`p0sl, t0sl`	Reference pressure and temperature on sea-level
`dt0lp`	d (t0) / d (ln p0) ("old" reference atmosphere)
`delta_t`	temperature difference between sea level and stratosphere ("new" reference atmosphere)
`h_scal`	scale height ("new" reference atmosphere)

Table 3.13: Reference Atmosphere Parameters

All these values can be specified via namelist variables in the INT2LM. INT2LM then computes the vertical grid and the reference pressure p_0 on that grid, i.e. the three-dimensional variables `HHL` and `P0`. When using GRIB 1 or NetCDF, the vertical coordinate and the reference atmosphere parameters are encoded in the meta data of the initial and boundary fields for the COSMO-Model. The atmospheric pressure variable passed to the COSMO-Model as initial field is not the full pressure P, but only the pressure deviation PP (with PP = P - P0) because it suffers less from a precision loss due to GRIB packing.

The COSMO-Model reads the values for these parameters from the meta data and therefore is able to re-compute the fields HHL and P0 in the same way as the INT2LM does. But coding the reference atmosphere parameters and the additional vertical coordinate parameter vcflat in the GRIB 1 meta data for the *vertical coordinates* is a violation of the GRIB 1 standard and cannot be done in GRIB 2 any more.

NOTE:
Not all COSMO vertical coordinate parameters and reference atmosphere parameters can be coded in GRIB 2 anymore! This has consequences for INT2LM, the COSMO-Model and eventually also for post-processing programs.

In the following we describe the methods now implemented for GRIB 2 in INT2LM and the COSMO-Model.

3.4.2   GRIB 2 and the generalized vertical coordinate

The GRIB 1 standard referred to the vertical coordinate parameters always as *pairs of coordinates* a_k, b_k, where for example the pressure on level k is given by a simple formula $p_{ijk} = a_k + b_k \cdot p_{sij}$, where p_{sij} is the surface pressure at a special horizontal grid point ij.

Not all type of vertical grids, which are possible in the COSMO-Model, can be computed by such an easy formula. Therefore we introduced a new *type of vertical level* for GRIB 2, which has been accepted by WMO. This new type of vertical level is specified as *generalized vertical coordinate* and has the value 150 in GRIB 2.

To define the generalized vertical coordinate, some additional meta data have to be specified:

- Number of vertical levels (nlev): This corresponds to the number of half (!) levels ke+1

- Number of vertical grid used (numberOfVGridUsed): This corresponds to ivctype

- A universally unique identifier for the vertical grid (uuidOfVGrid): This is a special identifier, which should ensure that INT2LM and the COSMO-Model always use the same grid. As hexadecimal value it takes 16 bytes (or octets).

These meta data (the names in brackets are the ecCodes keys) are encoded in the list of coordinate values. But depending on which ivctype is used, additional parameters are necessary to construct the three-dimensional grid (the HHL) for the COSMO-Model, mainly the vertical coordinate values vcoord. These parameters are only known to INT2LM via namelist variables and not to the COSMO-Model. Therefore the 3D-field HHL is written to the laf-file with the initial fields. This is done from INT2LM and also from the COSMO-Model itself, if it is running in analysis mode. This field is written with a grib-packing to 24 bits, which gives a higher precision than the packing to 16 bits, which is used for most other fields. The COSMO-Model then does not need to recompute the grid.

But there are some other tasks, mainly in the data assimilation, that require the knowledge of the vertical coordinate parameters (which for ivctype=2/3/4 just give the heights of the levels over the sea surface, where no orography is present.) Therefore we code these vertical coordinate parameters in the meta data for the HHL-file, which is defined on half levels. For such variables, the meta data for the *second fixed surface* usually are not set and we

can use them to code the vertical coordinate parameters `vcoord`. The value for the vertical coordinate parameter of level k is coded in the `scaleFactorOfSecondFixedSurface` and the `scaledValueOfSecondFixedSurface` of the corresponding level of `HHL`.

The coordinate value, where the system changes back to z-levels (`vcflat`), is not available in GRIB 2 anymore. In case of `ivctype=2`, it can be reconstructed from the values of `HHL`. For `ivctype=3/4`, this is not possible. Only an approximation can be computed by using the method from `ivctype=2`. For `ivctype=1`, the pressure based coordinate parameters, this is not possible at all. Therefore, the use of `ivctype=1` is deprecated when using GRIB 2.

Also the additional parameters, which are necessary to compute the filtering for the SLEVE coordinate (`svc1, svc2, nfltvc`), are not available in GRIB 2. But they are only needed for the computation of `HHL`, which is not necessary in the COSMO-Model, when reading the `HHL` from the laf-file.

3.4.3   GRIB 2 and the reference atmosphere parameters

The information about the reference atmosphere parameters is necessary for the COSMO-Model, if it has to process the pressure deviation `PP` as input field. Because then it has to compute the reference pressure `P0` to get the full pressure `P`. The pressure deviation has been chosen as the transfer parameter between the INT2LM and the COSMO-Model and also between the assimilation cycle and the forecast, when using GRIB 1, because it minimizes the loss in precision, when using the GRIB packing.

For GRIB 2, we are now transfering the full pressure field, but with a higher precision, using 24 bits for GRIB packing (same as for `HHL`).

Nevertheless, the COSMO-Model still needs the reference atmosphere parameters to compute `P0` and `PP`, because the prognostic variable used in the COSMO-Model is `PP`. But the reference atmosphere used in the COSMO-Model is independent from the one used in INT2LM or in other programs processing the full pressure `P`.

New namelist variables have therefore been introduced for the reference atmosphere parameters in the COSMO-Model (in group `/LMGRID/`) to compute an own reference atmosphere. The only restriction is, that the new reference atmosphere (`irefatm=2`) has to be chosen, if the model height is higher than 27000 meters. `irefatm=1` will not work then.

3.4.4   The UUID and a special HHL-file for INT2LM

The universally unique identifier (UUID) is a speciality about the new generalized vertical coordinate in GRIB 2. It serves as an identifier for a certain vertical grid and is used to check, that all three-dimensional variables are using the same grid. Only the INT2LM, which computes the `HHL`, can set a valid UUID.

All atmospheric (3D) variables computed by INT2LM get the same UUID as the `HHL`-field. The COSMO-Model then ensures that an atmospheric variable really belongs to the vertical grid specified by `HHL` by comparing the UUIDs of both fields.

This is controlled by the INT2LM namelist variable `lnewVGrid`.

```
lnewVGrid = .TRUE.
```

Then a new vertical grid `HHL` is computed using the vertical coordinate parameters from namelist input and a new UUID is set for this field. If this variable is always set to `.TRUE.`, every run will have a new UUID. This is only possible, if INT2LM computes both, the initial and the boundary values for a COSMO forecast.

`lnewVGrid = .FALSE.`
Then the vertical grid is read from an extra file, specified by the namelist variable `ylm_hhl` and the UUID from this `HHL`-field is taken for further use. We recommend to produce such a special `HHL`-file for INT2LM. It can be extracted out of the laf-file, for example, and can then be used again for the next runs. This is absolutely necessary when running a data assimilation cycle, because the `HHL`-file then is used from the COSMO assimilation run, while all atmospheric variables for initial or boundary values are produced by the INT2LM, but have to have the same UUIDs than the `HHL`-file from the COSMO run.

3.4.5 Summary for vertical coordinate and reference atmosphere parameters

Table 3.14 gives a summary of the vertical coordinate and the reference atmosphere parameters in INT2LM and the COSMO-Model, and where they can be found. All these parameters are namelist variables in INT2LM, which computes the three-dimensional vertical COSMO grid, the `HHL`, and a reference atmosphere. Only the reference atmosphere parameters are also namelist variables in the COSMO-Model

Parameter	GRIB 1	GRIB 2
`ivctype`	`pv(1)`	`numberOfVGridUsed`
`ke`	`pv(2)`	`nlev (=ke+1!)`
`vcflat`	`pv(6)`	not available
`svc1`	`pv(6+ke1+1)`	not available
`svc2`	`pv(6+ke1+2)`	not available
`nfltvc`	`pv(6+ke1+3)`	not available
`vcoord`	`pv(6+ke1)`	`scaleFactorOfSecondFixedSurface` `scaledValueOfSecondFixedSurface`
`p0sl`	`pv(3)`	namelist variable in COSMO
`t0sl`	`pv(4)`	namelist variable in COSMO
`dt0lp`	`pv(5)`	namelist variable in COSMO
`delta_t`	`pv(6+ke1+4)`	namelist variable in COSMO
`h_scal`	`pv(6+ke1+5)`	namelist variable in COSMO

Table 3.14: Vertical Coordinate and Reference Atmosphere Parameters

3.5 The NetCDF Data Format

netCDF (network Common Data Form) is an interface for array-oriented data access and a library that provides an implementation of the interface. The netCDF of the COSMO-Model is self explaining, i.e. no additional tables are needed. The contents of an output file can be listed with the program `ncdump` which installs automatically along with the netCDF library. The netCDF library also defines a machine-independent format for representing scientific data. Together, the interface, library, and format support the creation, access, and sharing of scientific data. The netCDF software was developed at the Unidata Program Center in Boulder, Colorado. The freely available source can be obtained as a compressed tar-file or a zip-file from Unidata or from other mirror sites.

http://www.unidata.ucar.edu/packages/netcdf/index.html.

Information on the F90 implementation can also be obtained from

http://www.unidata.ucar.edu/packages/netcdf/f90/index.htm.

In the current implementation of netCDF I/O data are in 32bit accuracy. For GRIB format, an additional packing can be done (usually using 16 bit accuracy). But this packing will lose information.

NetCDF I/O can be turned on via the `yform_read` and the `yform_write` parameters in the namelist `IOCTL`. The parameters can be chosen independently, e.g. it is also possible to have GRIB as input and netCDF as output format and vice versa.

Name	Type	Definition / Purpose / Comments	Default
yform_read	CHAR	Format of input data	'grb1'
		'grb1' = GRIB formatted input	
		'ncdf' = netCDF formatted input	
yform_write	CHAR	Format of output data	'grb1'
		'grb1' = GRIB formatted output	
		'ncdf' = netCDF formatted output	

3.5.1 CF Conventions

The basic conventions for netCDF Output in COSMO are the Climate and Forecast (CF) conventions. These define standards on the naming and structuring of the netCDF output. The latest description of the CF conventions can be found on the Lawrence Livermore WEB page http://cf-pcmdi.llnl.gov/.

The values for `units` and `standard_name` have fixed values and are defined by the CF conventions. Values for `long_name` and the name of the parameter field can be freely chosen by the user. The `long_name` is often used by graphic programs in creating the legend of figures. The `_FillValue` attribute holds the value set for missing data. The name of the parameter is used to extract a certain field from the output file.

3.5.2 Namelist Input

The netCDF I/O can be controlled via the Namelist `IOCTL`. In addition to the parameters `yform_read` and the `yform_write` described above global attributes can be defined to describe the model simulation.

`yncglob_institution`	CHAR	originating center name	'–'
`yncglob_title`	CHAR	title string for the output	'–'
`yncglob_source`	CHAR	program name and version	'–'
`yncglob_contact`	CHAR	identification of the project of the simulation	'–'
`yncglob_project_id`	CHAR	identification of the experiment of the simulation	'–'
`yncglob_experiment_id`	CHAR	contact e.g. email address	'–'
`yncglob_references`	CHAR	URL, report etc.	'–'
`ncglob_realization`	INT	number of the realisation of the experiment	1

The "`yncglob_...`" parameters are written into the netCDF output as global attributes (see example header output below).

3.5.3 netCDF Header Section

The following is a typical content of the header section of a netCDF formatted output file. Such a listing can be produced by using the `ncdump` command

<div align="center">

`ncdump -h lffd1979010200.nc.`

</div>

The dimensions of the variables are written in the C language order, i.e. the last coordinate comes first (Example: `float T(time, level, rlat, rlon)` in C reads `float T(rlon, rlat, level, time)` in F90).

```
netcdf lffd1979010200 {
dimensions:
        rlon = 101 ;
        rlat = 107 ;
        srlon = 101 ;
        srlat = 107 ;
        level = 20 ;
        level1 = 21 ;
        height_2m = 1 ;
        height_10m = 1 ;
        soil = 9 ;
        soil1 = 10 ;
        time = UNLIMITED ; // (1 currently)
        bnds = 2 ;
variables:
        char rotated_pole ;
                rotated_pole:long_name = "coordinates of the rotated North Pole" ;
                rotated_pole:grid_mapping_name = "rotated_latitude_longitude" ;
                rotated_pole:grid_north_pole_latitude = 32.5f ;
                rotated_pole:grid_north_pole_longitude = -170.f ;
        float rlon(rlon) ;
                rlon:standard_name = "grid_longitude" ;
                rlon:long_name = "rotated longitude" ;
                rlon:units = "degrees" ;
        float rlat(rlat) ;
                rlat:standard_name = "grid_latitude" ;
                rlat:long_name = "rotated latitude" ;
                rlat:units = "degrees" ;
        float srlon(srlon) ;
                srlon:standard_name = "grid_longitude" ;
                srlon:long_name = "staggered rotated longitude" ;
                srlon:units = "degrees" ;
        float srlat(srlat) ;
                srlat:standard_name = "grid_latitude" ;
                srlat:long_name = "staggered rotated latitude" ;
                srlat:units = "degrees" ;
        float lon(rlat, rlon) ;
```

```
                lon:standard_name = "longitude" ;
                lon:long_name = "longitude" ;
                lon:units = "degrees_east" ;
        float lat(rlat, rlon) ;
                lat:standard_name = "latitude" ;
                lat:long_name = "latitude" ;
                lat:units = "degrees_north" ;
        float slonu(rlat, srlon) ;
                slonu:standard_name = "longitude" ;
                slonu:long_name = "staggered U-wind longitude" ;
                slonu:units = "degrees_east" ;
        float slatu(rlat, srlon) ;
                slatu:standard_name = "latitude" ;
                slatu:long_name = "staggered U-wind latitude" ;
                slatu:units = "degrees_north" ;
        float slonv(srlat, rlon) ;
                slonv:standard_name = "longitude" ;
                slonv:long_name = "staggered V-wind longitude" ;
                slonv:units = "degrees_east" ;
        float slatv(srlat, rlon) ;
                slatv:standard_name = "latitude" ;
                slatv:long_name = "staggered V-wind latitude" ;
                slatv:units = "degrees_north" ;
        float vcoord(level1) ;
                vcoord:long_name = "terrain following coordinate" ;
                vcoord:units = "Pa" ;
                vcoord:p0sl = 100000. ;
                vcoord:t0sl = 288.15 ;
                vcoord:dt0lp = 42. ;
                vcoord:vcflat = 0.22 ;
        float height_2m(height_2m) ;
                height_2m:standard_name = "height" ;
                height_2m:long_name = "height above the surface" ;
                height_2m:units = "m" ;
                height_2m:positive = "up" ;
        float height_10m(height_10m) ;
                height_10m:standard_name = "height" ;
                height_10m:long_name = "height above the surface" ;
                height_10m:units = "m" ;
                height_10m:positive = "up" ;
        float soil1(soil1) ;
                soil1:standard_name = "depth" ;
                soil1:long_name = "depth of soil layers" ;
                soil1:units = "m" ;
                soil1:positive = "down" ;
                soil1:bounds = "soil1_bnds" ;
        float soil1_bnds(soil1, sbnds) ;
                soil1_bnds:long_name = "boundaries of soil layers" ;
        double time(time) ;
                time:standard_name = "time" ;
                time:long_name = "time" ;
                time:units = "seconds since 1979-01-01 00:00:00" ;
                time:calendar = "proleptic_gregorian" ;
                time:bounds = "time_bnds" ;
        double time_bnds(time, tbnds) ;
                time_bnds:long_name = "time bounds" ;
                time_bnds:units = "seconds since 1979-01-01 00:00:00" ;
        float P(time, level, rlat, rlon) ;
                P:standard_name = "air_pressure" ;
                P:long_name = "pressure" ;
                P:units = "Pa" ;
                P:grid_mapping = "rotated_pole" ;
                P:coordinates = "lon lat" ;
        float PS(time, rlat, rlon) ;
                PS:standard_name = "surface_air_pressure" ;
                PS:long_name = "surface pressure" ;
                PS:units = "Pa" ;
                PS:grid_mapping = "rotated_pole" ;
                PS:coordinates = "lon lat" ;
        float T(time, level, rlat, rlon) ;
                T:standard_name = "air_temperature" ;
                T:long_name = "temperature" ;
                T:units = "K" ;
                T:grid_mapping = "rotated_pole" ;
                T:coordinates = "lon lat" ;
        float U(time, level, rlat, srlon) ;
                U:standard_name = "grid_eastward_wind" ;
                U:long_name = "U-component of wind" ;
                U:units = "m s-1" ;
                U:grid_mapping = "rotated_pole" ;
                U:coordinates = "slonu slatu" ;
        float V(time, level, srlat, rlon) ;
                V:standard_name = "grid_northward_wind" ;
                V:long_name = "V-component of wind" ;
                V:units = "m s-1" ;
                V:grid_mapping = "rotated_pole" ;
                V:coordinates = "slonv slatv" ;
        float TOT_PREC(time, rlat, rlon) ;
                TOT_PREC:standard_name = "precipitation_amount" ;
                TOT_PREC:long_name = "total precipitation amount" ;
                TOT_PREC:units = "kg m-2" ;
                TOT_PREC:grid_mapping = "rotated_pole" ;
                TOT_PREC:coordinates = "lon lat" ;
                TOT_PREC:cell_methods = "time: sum" ;
        float ASOB_S(time, rlat, rlon) ;
```

```
              ASOB_S:standard_name = "surface_net_downward_shortwave_flux" ;
              ASOB_S:long_name = "surface net downward shortwave radiation" ;
              ASOB_S:units = "W m-2" ;
              ASOB_S:grid_mapping = "rotated_pole" ;
              ASOB_S:coordinates = "lon lat" ;
              ASOB_S:cell_methods = "time: mean" ;
       float VMAX_10M(time, height_10m, rlat, rlon) ;
              VMAX_10M:standard_name = "wind_speed" ;
              VMAX_10M:long_name = "maximum 10m wind speed" ;
              VMAX_10M:units = "m s-1" ;
              VMAX_10M:grid_mapping = "rotated_pole" ;
              VMAX_10M:coordinates = "lon lat" ;
              VMAX_10M:cell_methods = "time: maximum" ;

// global attributes:
              :title = "Simulation in the EU project ENSEMBLES" ;
              :institution = "GKSS" ;
              :source = "CCLM4" ;
              :project_id = "ENSEMBLES" ;
              :experiment_id = "ERA40@50km" ;
              :realization = 1 ;
              :Conventions = "CF-1.0" ;
              :conventionsURL = "http://www.unidata.ucar.edu/packages/netcdf/conventions.html" ;
              :contact = "John.Somebody@somewhere.de" ;
              :references = "http://www.ensembles-eu.org" ;
              :creation_date = "2005-09-16 20:50:38" ;
}
```

The header is divided in three parts :

1. Dimensions

netCDF dimension	COSMO dimension	Description
rlon	ie	number of grid points in rotated longitudinal direction (mass points)
rlat	je	number of grid points in rotated latitudinal direction (mass points)
srlon	ie	number of grid points in rotated longitudinal direction (flux points)
srlat	je	number of grid points in rotated latitudinal direction (flux points)
level	ke	number of vertical full levels
level1	ke1	number of vertical half levels
height_2m	–	= 1 (single atmosphere level)
height_10m	–	= 1 (single atmosphere level)
soil	ke_soil	number of soil layers
soil1	ke_soil1	number of soil layers +1
bnds	–	=2 (bounds of variables soil_bounds and time_bounds)
time	–	=1 (dimension for time series)

The *time* dimension is different from the other dimensions since it is declared as "unlimited". This makes it possible to cat together several output files and construct time series and animations.

2. Variables

Variables can be divided in two categories: coordinate variables and the meteorological quantities. Coordinate variables have the same name as their dimension. All variables are in 32bit (i.e. float) except of *time* which is in 64bit (i.e. double) and *rotated_pole* which is defined as a character variable.

3. Global attributes

   The global attributes contain general information about the data. The attributes `conventions`, `conventionsURL`, and `creation_date` are set within the model itself. The other global attributes can be set by the user via namelist `IOCTL` (see above).

3.5.4 Useful Post-Processing Utilities

- *ncdump (Freeware)* Shows information about the contents of a netCDF file. This program is part of the netCDF standard software package.

- *ncview (freeware)* Visual browser for netCDF.
  http://meteora.ucsd.edu/ pierce/ncview_home_page.html

- *NCO (freeware)* Software package including several programs to manipulate netCDF data. http://nco.sourceforge.net/

- *CDO (freeware)* Software package including several programs to manipulate grib and netCDF data. This is the successor of the PINGO package at the German Climate Research Centre (DKRZ). http://www.mpimet.mpg.de/∼cdo

- *Others* An extensive listing of software that uses netCDF is available from
  http://www.unidata.ucar.edu/packages/netcdf/software.html

Section 4

Output Fields of the COSMO-Model

4.1 Specifying Model Output

The output of the forecast fields is controlled by the `NAMELIST`-group `GRIBOUT` (the name of this group comes from the time, when only Grib was implemented, but it it also valid for NetCDF output). It is possible to specify several instances of this group. The `NAMELIST` parameter `ngribout` in the group `IOCTL` has to be set accordingly. For every instance you can set several variables. Here we only explain the most important variables. For a complete list of all variables in this group see the COSMO User Guide.

The results of the model forecast can be written to Grib (Edition 1 or 2) or to NetCDF files. The Grib Code is explained in Section 3.2 (Edition 1) and 3.3 (Edition 2) in more detail. The files, to which the forecast fields are written, obey to the *File Name Conventions* explained in the User Guide of the INT2LM. Depending on the type of data, the filenames get a certain extension:

'p' Forecast fields on pressure levels.

'z' Forecast fields on geometric z-levels.

's' Synthetic satellite images.

     All fields on model levels, soil and surface fields are written to a file without extension.

In addition, a file with the extension 'c' can be written, which contains a list of constant fields (external parameters). Which fields are written to this file is determined by the model depending on the chosen configuration. Whether this field is written or not is controlled by the namelist switch `lwrite_const`.

All fields can be written either for the full domain or a subdomain, if the `NAMELIST` parameters `ydomain = 's'` and `slon, slat, elon, elat` in the group `/GRIBOUT/` are specified. To distinguish NetCDF from Grib files, the NetCDF files contain the suffix `.nc`.

- Specifying the list of variables for output:

- yvarml(:): Variables on model levels.
  e.g. yvarml = 'U', 'V', 'HSURF'.
- yvarpl(:): Variables on pressure levels.
- plev(:): A list of pressure levels to which the model variables are interpolated.
- yvarzl(:): Variables on z-levels.
- zlev(:): A list of z-levels to which the model variables are interpolated.
- yvarsl(:): Variables that contain artificial images for channels of selected satellites, which are derived from the forecast fields of the COSMO-Model.

By specifying yvarxl = 'default' (x ∈ {m, p, z, s}), a predefined list of variables is written.

- Specifying the time steps, when these variables shall be written:
  There are two ways of specifying the output steps:

  - With a list of time steps (ngrib(:)) or alternatively a list of hours (hgrib(:)),
    e.g.
    ngrib = 0, 2, 4, 24, 138, 400
    hgrib = 0.0, 0.5, 1.0, 1.75, 4.3
    Up to 100 different output steps can be specified.
  - With a list of begin-, end- and increment steps given in time steps (ncomb(:)) or
    in hours (hcomb(:)). The values have to be given in triples, e.g.

        hcomb = 0.0, 12.0, 1.0, 12.0, 24.0, 0.5, 24.0, 48.0, 2.0

    With this specification, the following output is performed:
    * From forecast hour 0.0 to 12.0 results are written every hour.
    * From forecast hour 12.0 to 24.0 results are written every 30 Minutes.
    * From forecast hour 24.0 to 48.0 results are written every 2 hours.

If nothing is specified for these variables, results will be written every hour starting with the beginning of the forecast.

- Specifying the domain for which these variables shall be written:
  With the variable ydomain you can specify whether the variables are written for the full domain (ydomain = 'f': default) or for a subdomain (ydomain = 's'). In case of a subdomain you also have to define the start- and endpoints of this subdomain (slon, slat, elon and elat) in rotated geographical coordinates.

- Specifying the time unit of the forecast range:
  With the variable ytunit the time unit of the forecast range (form of the output file name) can be specified. The two mostly used formats are

  - ytunit = 'f': forecast mode: the forecast range is given in the form ddhhmmss,
    where dd: day, hh: hour, mm: minute, ss: second (only possibility for ICON!)
  - ytunit = 'd': day mode: the full date is given in the form 'yyyymmddhh', where
    yyyy: year; mm: month; dd: day; hh: hour

- Specifying control output:
  If lcheck = .TRUE., minimum, maximum and mean values of the fields are calculated and written to file YUCHKDAT.

In the following sections most of the COSMO-MOdel output fields are listed. The tables have several columns, specifying

- the name of the field (`shortName`);

- a short description;

- the unit of the field;

- the GRIB 2 triple: Discipline (D), Category (C), Parameter (P);

- the type of first (L1) and second (L2) fixed surface.

Some fields have not yet been inserted into the DWD definition files for GRIB 2, therefore a triple (D,C,P) is not available. Note that these fields cannot be written in GRIB 2 then.

4.2 Constant fields

shortName	Description	Unit	D	C	P	L1	L2
HHL	Geometrical height of half levels	m	0	3	6	150	101
FIS	Geopotential of surface topography	m^2/s^2	0	3	4	1	
HSURF	Geometrical height of surface topography	m	0	3	6	1	101
FR_LAND	Fraction of land in a grid element	1	2	0	0	1	
FR_LAKE	Lake fraction in a grid element	1	1	2	2	1	
SOILTYP	Type of the soil (keys 0-9)	-	2	3	196	1	
RLAT	Geographical latitude	°N	0	191	1	1	
RLON	Geographical longitude	°E	0	191	2	1	
ROOTDP	Depth of the roots	m	2	0	32	1	
PLCOV	Fraction of plant cover	%	2	0	4	1	
LAI	Leaf area index of plants	1	2	0	28	1	
HMO3	Ozone maximum	Pa	0	14	192	1	
VIO3	Vertical integrated ozone contents	Pa	0	14	193	1	
FOR_E	Ground fraction covered by evergreen forest	1	2	0	29	1	
FOR_D	Ground fraction covered by deciduous forest	1	2	0	30	1	
RSTOM	Stomata resistance	s/m	2	0	195	1	
RSMIN	Minimum stomata resistance	s/m	2	0	16	1	
EMIS_RAD	Thermal surface emissivity	1	2	3	199	1	
SKC	Skin conductivity	W/(m^{2}K)	2	0	199	1	
DEPTH_LK	Lake depth	m	1	2	0	1	162
FETCH_LK	Wind fetch over lake	m	0	2	33	1	
C_T_LK	Shape factor of temperature profile in lake thermocline	1	1	2	10	166	162
GAMSO_LK	Attenuation coefficient for solar radiation in lake water	m−1	1	2	11	1	162

shortName	Description	Unit	D	C	P	L1	L2
DP_BS_LK	Thickness of thermally active layer of bottom sediments	m	1	2	3	162	164
H_B1_LK	Thickness of the upper layer of bottom sediments	m	1	2	3	162	165
H_ML_LK	Thickness of mixed layer	m	1	2	0	1	166
SSO_STDH	Standard deviation of sub-grid scale orography scale orography	m	0	3	20	1	
SSO_GAMMA	Anisotropy of sub-grid scale orography	1	0	3	24	1	
SSO_THETA	Angle between principal axis of orography and east	rad	0	3	21	1	
SSO_SIGMA	Mean slope of sub-grid scale orography	1	0	3	22	1	
SLO_ANG	Slope angle - topography	1	0	199	2	1	
SLO_ASP	Slope aspect - topography	1	0	199	3	1	
SKYVIEW	Sky-view factor	1	0	199	0	1	
AER_SO4 (1)	Aerosol sulfat	1	0	20	102	1	
AER_DUST	Aerosol dust	1	0	20	102	1	
AER_ORG	Aerosol organic	1	0	20	102	1	
AER_BC	Aerosol black carbon	1	0	20	102	1	
AER_SS	Aerosol sea salt	1	0	20	102	1	
ALB_RAD	Surface albedo	%	0	19	1	1	
ALB_DIF	Diffuse solar albedo	%	0	19	18	1	
ALB_DRY	Dry soil albedo	1	0	19			
ALB_SAT	Saturated soil albedo	1	0	19			

Notes:

1. The aerosol fields use product definition template 4.40 and are distinguished by their atmospheric chemical constituent type.

4.3   Atmospheric fields

*t*o be updated and completed

Table 4.2: Basic output fields for the COSMO-Model

Field	defaults	Meaning
U	mpz	zonal wind speed
V	mpz	meridional wind speed
W	m z	vertical wind speed
T	mpz	temperature
QV	m	specific water vapor content
QC	m	specific cloud water content

QI	m	specific cloud ice content
QR	m	specific rain content
QS	m	specific snow content
QG		specific snow content
PP		deviation from reference pressure
P	m z	pressure
PS	m	surface pressure
PMSL	m	surface pressure on mean sealevel
HHL	m	geometrical height of half levels
HSURF	m	height of surface topography
T_S	m	temperature of surface
T_SNOW	m	temperature of snow surface
T_G	m	temperature at the boundary soil-atmosphere
T_M	m	temperature between upper and medium soil layer
T_SO	m	temperature of (multi-layer) soil levels
QV_S	m	specific water vapor content at the surface
WG_1	m	water content of the upper soil layer
WG_2	m	water content of the medium soil layer
WG_3		water content of the lower soil layer
W_SO	m	water content of (multi-layer) soil levels
TKVM		turbulent diffusion coefficients for momentum in the atmosphere
TKVH		turbulent diffusion coefficients for heat and moisture in the atmosphere
W_I	m	water content of interception water
W_SNOW	m	water content of snow
T_CL	m	temperature between medium and lower soil layer
W_CL	m	climatological water content of the lowest soil layer
TCM	m	turbulent diffusion coefficients for momentum at the surface
TCH	m	turbulent diffusion coefficients for heat and moisture at the surface
CLCT	m	total cloud cover
CLCH	m	cloud cover with high clouds
CLCM	m	cloud cover with medium clouds
CLCL	m	cloud cover with low clouds
DPSDT		tendency of the surface pressure
BAS_CON	m	index of lower boundary of convective clouds
TOP_CON	m	index of upper boundary of convective clouds
HBAS_CON	m	height of lower boundary of convective clouds
HTOP_CON	m	height of upper boundary of convective clouds

ASOB_S	m	average solar radiation budget (surface) (mean value over forecast)
ATHB_S	m	average thermal radiation budget (surface) (mean value over forecast)
APAB_S	m	average photosynthetic active radiation (surface) (mean value over fcast.)
ASOB_T	m	average solar radiation budget (model top) (mean value over forecast)
ATHB_T	m	average thermal radiation budget (model top) (mean value over forecast)
VIO3		vertical integrated ozone content
HMO3		ozone maximum
Z0	m	roughness length * g
FR_LAND	m	part of land in the grid cell
SOILTYP	m	soil type of the land
PLCOV		degree of plant covering
LAI		leaf area index
ROOTDP		root depth
ALB_RAD	m	albedo of the ground
RLAT	m	geographical latitude
RLON	m	geographical longitude
FC		Coriolisparameter
RAIN_GSP	m	rain, precipitation (sum over forecast)
SNOW_GSP	m	snow, precipitation (sum over forecast)
RAIN_CON	m	rain, convective (sum over forecast)
SNOW_CON	m	snow, convective (sum over forecast)
U_10M	m	zonal wind in 10m
V_10M	m	meridional wind in 10m
T_2M	m	temperature in 2m
TD_2M	m	dew-point in 2m
TMIN_2M	m	minimum temperature in 2m
TMAX_2M	m	maximum temperature in 2m
PRR_CON		rate of precipitation, convective rain
PRS_CON		rate of precipitation, convective snow
PRR_GSP		rate of precipitation, scale rain
PRS_GSP		rate of precipitation, scale snow
AUMFL_S	m	average u-momentum flux (surface)
AVMFL_S	m	average v-momentum flux (surface)
ASHFL_S	m	average sensible heat flux (surface)
ALHFL_S	m	average latent heat flux (surface)

RUNOFF_S	m	surface water drainage; (sum over forecast)
RUNOFF_G	m	soil water drainage; (sum over forecast)
VMAX_10M	m	maximal windspeed in 10m
FI	p	geopotential height
OMEGA	p	vertical velocity p-dot in pressure coordinate system
RELHUM	pz	relative humidity
TOT_PREC	m	total precipitation

Section 5

ASCII Output for the Forecast Model

For a quick forecast monitoring the model writes various control output to ASCII files. These files are:

- `YUSPECIF`: `NAMELIST`-parameters

- `YUCHKDAT`: Checking the input/output data from GRIB / NetCDF

- `YUPRMASS`: Protocolling the forecast with selected mean values for mass variables

- `YUPRHUMI`: Protocolling the forecast with selected mean values for humidity variables

- `YUDEBUG`: More detailed information for debugging purposes

- `YUTIMING`: Timings for the different parts of the forecast

In addition, output for meteographs (grid point output) can also be done. For every selected grid point a file M_*stationname* is written.

5.1   M_*stationname* — **Grid point output**

The files M_*stationname* provide a monitoring of model variables at single grid points. There is a short form (NAMELIST-variable `lgpshort = .TRUE.`) or a long form (`lgplong = .TRUE.`). Only one of these two forms can be chosen. If none of the two variables is set to `.TRUE.`, the meteograph files are not printed.

The number of grid points considered are limited because of memory reasons. Up to `nmaxgp` grid points can be chosen. The parameter `nmaxgp` is contained in `data_runcontrol.f90` (`nmaxgp = 100`). If more grid points should be considered, this parameter has to be changed and the program has to be recompiled.

With `n0gp` and `nincgp`, the first output and the interval of outputs in time steps can be controlled (alternatively `h0gp` and `hincgp` for specifying these values in hours).

Figure 5.1 shows an example of a file M_*stationname* with the short form of the grid point output. This short form contains the following information for every grid point:

A header specifying the initial date of the forecast and the i- and j-indices of the model domain, the model orography (m), the fraction of land (%) within the grid cell, the geographical latitude (φ) and the geographical longitude (λ). For every time step, the following quantities are listed in one line:

HH	date
PS	surface pressure reduced to sea-level
DF10M	wind direction (°) and speed (kn, where $1\,m/s \approx 2\,kn$) at 10m above surface
DF500M	wind direction (°) and speed (kn) at 500m above surface
DF850	wind direction (°) and speed (kn) at 850 hPa
DF700	wind direction (°) and speed (kn) at 700 hPa
DF500	wind direction (°) and speed (kn) at 500 hPa
TG	surface temperature (°C)
T2M	temperature (°C) 2m above surface
TD2M	dew point (°C) 2m above surface
T30M	temperature (°C) 30m above surface
T850	temperature (°C) at 850 hPa
T700	temperature (°C) at 700 hPa
T500	temperature (°C) at 500 hPa
HML	cloud cover (high, medium, low) (range $0\ldots8$)
=	ground fog (range $0\ldots8$)
HBAS	base height of convective cloud above msl
HTOP	top height of convective cloud above msl
RR	rain (grid scale and convection)
RS	snow (grid scale and convection)
WS	water content of snow

Figure 5.2 shows an example of a file M_*stationname* with the long form of the grid point output. This long form contains the following information for every grid point:

HSURF	height of model orography (in m)
FR_LAND	land fraction (%)
LAT	geographical latitude (in °) of the grid point
LON	geographical longitude (in °) of the grid point
FC	Coriolisparameter (in $10^{-4} s^{-1}$)
SOIL TYPE	type of the soil (keys 0-9)
PS	unreduced surface pressure (in hPa)
DPSDT	tendency of surface pressure (in hPa/h)

For all main levels k=1,...,ke_tot the following parameters are printed:

Pmain	pressure (in hPa) of the main levels
T	temperature (in °C)
QV	specific water vapor content (in g/kg)
QC	specific cloud water content (in g/kg)
QI	specific cloud ice content (in g/kg)
REL_HUM	relative humidity (in %)
CLC	cover with grid scale clouds (in %)
CLC_CON	cover with convective clouds (in %)
U	zonal wind component (in m/s)
V	meridional wind component (in m/s)
SPEED	wind speed (in m/s)
HML	height of model main levels (in m)

For the half levels the following parameters are printed:

Phalf	pressure (in hPa) of the half levels
W	vertical velocity
TKVM	turbulent diffusion coefficients for momentum
TKVH	turbulent diffusion coefficients for heat and moisture
HHL	height of model half levels (in m)

In addition the values of several near surface and soil parameters are printed.

5.2   YUSPECIF — NAMELIST-parameters

YUSPECIF contains all NAMELIST-variables, their default and their actual values. At the end of this file, the vertical coordinate parameters sigma(k) and the values of the reference atmosphere are printed. YUSPECIF is always written.

```
*** Model: LM ***                  Start of the forecast: SUN 17.02.2008 18 UTC
Short meteograph of the LM at selected grid points

Meaning of the parameters:
HH:    forecast hour                                        (hours)
PS:    mean sea level pressure                              (hpa)
DF10M: wind direction and speed at 10m                      (degree/knots)
DF500M:wind direction and speed at 950 hPa                  (degree/knots)
DF850: wind direction and speed at 850 hPa                  (degree/knots)
DF700: wind direction and speed at 700 hPa                  (degree/knots)
DF500  wind direction and speed at 500 hPa                  (degree/knots)

TG:    ground temperature                                   (C)
T2M:   temperature at 2m                                    (C)
TD2M:  dew point temperature at 2m                          (C)
T30M:  temperature at ~ 30m (lowest level)                  (C)
T850:  temperature at 850 hpa                               (C)
T700:  temperature at 700 hpa                               (C)
T500:  temperature at 500 hpa                               (C)

HML:   cloud cover (high, medium, low)                      (0..8)
=  :   ground fog                                           (0..8)
HBAS:  base height of con. cloud above msl                  (hpa)
HTOP:  top height of con. cloud above msl                   (hpa)
RR:    rain amount (grid scale and convective)              (mm)
RS:    snow amount (grid scale and convective)              (mm)
WS:    water content of snow                                (m)

GRID POINT:
Initial Date:    SUN 17.02.2008 18 UTC
                 Frankfurt-Flughafen     I:    23    J:    70
HSURF   ( m ):   111.208
FR_LAND ( % ):   100.000
LAT     (dgr):    50.055
LON     (dgr):     8.637
SOIL TYPE : sandy loam      4

HH   PMSL   DF10M  DF500M DF850  DF700  DF500   TG   T2M  TD2M  T30M  T850  T700  T500  HML   HBAS HTOP  RR    RS    WS
h    hpa    dgr m/s dgr m/s dgr m/s dgr m/s dgr m/s        degree centigrade              octas = 10*m  mm           m
18.0 1039.60 234/ 1 271/ 4 342/ 5 344/ 7 343/ 13 -0.5  1.2 -9.6  2.7  0.3  -7.1 -21.9 000 0   0   0  0.00  0.00  0.000
19.0 1039.67 244/ 1 271/ 4 332/ 6 341/ 7 348/ 14 -1.0 -0.5 -8.9  2.5  0.3  -7.0 -22.0 100 0   0   0  0.00  0.00  0.000
20.0 1039.35 241/ 2 276/ 4 332/ 6 338/ 8 349/ 14 -1.4 -1.1 -8.3  0.8  0.1  -6.6 -21.8 100 0   0   0  0.00  0.00  0.000
21.0 1039.12 237/ 2 280/ 4 327/ 6 346/ 9 349/ 15 -2.0 -1.8 -7.6 -0.5  0.1  -6.5 -22.0 100 0   0   0  0.00  0.000 0.000
```

Figure 5.1: Example file M_*stationname* with short grid point output.

```
GRID POINT:       Frankfurt-Flughafen    I:    23   J:    70
Initial Date:     SUN 17.02.2008  18 UTC
   HSURF   ( m ):   111.208
   FR_LAND ( % ):   100.000
   LAT    (dgr):    50.055
   LON    (dgr):     8.637
   FC   (1E4/s):     1.119
   SOIL TYPE   : sandy loam    4

      Actual date:           SUN 17.02.2008  18 UTC +  0.0    (time step:      0)
   PS(hpa): 1025.3   DPSDT(hpa/h):   -4.2

  K    Pmain    T     QV      QC      QI  REL_HUM   CLC   CLC_CON      U       V    SPEED    HML
        hPa   Grd C  g/kg      mg/kg          %      %       %             m/s               m

  1   34.19 -76.61  0.004   0.000   0.000   15.01   0.00    0.00   42.73   -1.29   42.75  22184.5
  2   51.27 -78.10  0.004   0.000   0.000   25.42   0.00    0.00   30.44  -13.05   33.12  19807.4
  3   69.20 -74.72  0.004   0.000   0.000   20.32   0.00    0.00   22.42  -14.96   26.95  18062.0
  4   88.30 -73.62  0.004   0.000   0.000   21.87   0.00    0.00   13.30  -14.65   19.79  16634.0
..........
 37 1010.77   3.46  1.696   0.000   0.000   35.13   0.00    0.00    1.73    1.37    2.21    226.7
 38 1016.66   3.24  1.722   0.000   0.000   36.43   0.00    0.00    1.33    0.99    1.66    179.6
 39 1020.97   2.95  1.740   0.000   0.000   37.73   0.00    0.00    1.06    0.76    1.30    145.4
 40 1024.03   2.71  1.759   0.000   0.000   38.93   0.00    0.00    0.85    0.60    1.04    121.2

  K    Phalf      W      TKVM    TKVH     HHL
        hPa     cm/s        m**2/s         m

  1   19.91    0.000                     23588.5
  2   42.73   -0.741    1.000   1.000    20780.5
  3   60.24   -1.355    1.000   1.000    18834.3
  4   78.75   -1.979    1.000   1.000    17289.8
..........
 38 1013.71    0.338    1.000   1.000     199.7
 39 1018.82    0.269    1.000   1.000     159.6
 40 1022.50    0.186    1.000   1.000     131.1
 41 1025.29    0.168                      111.2

   Surface variables:       TCM    :     0.00000
             ( m/s )        TCH    :     0.00000
             ( m  )         Z0     :     0.75001
             ( w/m2)        SHFL   :     0.007        ( N/m2)    UMFL   :      0.000
                            LHFL   :    -0.002        ( N/m2)    VMFL   :      0.001
             ( g/kg)        QV_S   :     2.125
             (kg/m2)        RUNOFF_S:    0.000
                            RUNOFF_G:    0.000
   Plants:                  LAI    :     1.060    Ozone:         VIO3   :      0.078
                            PLCOV  :     0.670                   HMO3   :   5477.051
                            ROOTDP :     0.120

   Soil temperatures        T_SNOW :    -0.460    Soil moistures/Snow  W_SNOW :     0.000
             (dgr C)        T_S    :    -0.460         (mm H2O)    W_I    :      0.000
                            T_G    :    -0.460                     FRESHSNW:      1.000
                                                       (kg/m3)    RHO_SNOW:     50.000
                                                       (m)        H_SNOW :      0.000
                            T_SO( 0):   -0.460
                            T_SO( 1):   -0.460    W_SO( 1):     1.338 W_SO_ICE( 1):    0.234
                            T_SO( 2):   -0.181    W_SO( 2):     2.710 W_SO_ICE( 2):    0.000
                            T_SO( 3):    0.545    W_SO( 3):     8.211 W_SO_ICE( 3):    0.000
                            T_SO( 4):    0.678    W_SO( 4):    25.668 W_SO_ICE( 4):    0.000
                            T_SO( 5):    2.592    W_SO( 5):    26.953 W_SO_ICE( 5):    0.000
                            T_SO( 6):    5.600    W_SO( 6):   353.938 W_SO_ICE( 6):    0.000
                            T_SO( 7):    8.717    W_SO( 7):  1061.812 W_SO_ICE( 7):    0.000
                            T_SO( 8):    9.795    W_SO( 8):  3185.500 W_SO_ICE( 8):    0.000

   Temperatures             T2M    :     1.191    Winds          U10M   :      0.832
             (dgr C)        TD2M   :    -9.592         ( m/s )    V10M   :      0.584
                            TMIN2M :     1.191                    VBMAX10M:     1.206
                            TMAX2M :     1.191

   Solar radiation          SOBT   :     0.000    Thermal radiation    THBT   :  -232.998
             (w/m**2)       SOBS   :     0.000         (w/m**2)    THBS   :  -104.491
   Photosynt. active Rad.   PABS   :     0.000    Surface albedo (%)   ALB    :     17.108

   Precipitation      rates   and   amount         Cloud Cover
                      (mm/d)         (mm)              (%)
         RAIN_GSP:    0.000          0.000         CLCH   :      4.701
         SNOW_GSP:    0.000          0.000         CLCM   :      0.000
         RAIN_CON:    0.000          0.000         CLCL   :      0.000
         SNOW_CON:    0.000          0.000         CLCT   :      4.701
         TOTAL:       0.000          0.000
```

Figure 5.2: Example file M_*stationname* with long grid point output.

5.3   YUCHKDAT — Checking the Grib input/output data

YUCHKDAT contains information about fields that are read from or written to GRIB files. For every field the maximum value, the minimum value (together with the corresponding indices) and the mean value are written. This output can be controlled with the NAMELIST-parameters

- lchkini (in gribin): check the initial data

- lchkbd (in gribin): check the boundary data

- lcheck (in gribout): check the output data

If none of these variables is set to .TRUE., YUCHKDAT is not written.

5.4   YUPRMASS — Protocolling the forecast with mass variables

YUPRMASS contains meanvalues of model variables related to mass and deviations from initial mean values. First, the initial values of the following variables are written:

- area mean value of the surface pressure (in hPa) for the total model domain without boundary zone.

- volume mean values of dry static, moist static and kinetic energy (in J/kg).

In the next lines, the following values are written:

ntstep	actual time step.
Real	elapsed time since the last line was printed.
dpsdt	area mean value of the tendency of the surface pressure.
	(This is a good measure for the noise in the model.)
ps	area mean value of the surface pressure.
dse	deviation of the volume mean value of dry static energy from the initial value.
mse	deviation of the volume mean value of moist static energy from the initial value.
ke	deviation of the volume mean value of kinetic energy from the initial value.
vamx	maximum of the horizontal velocity.
wamx	maximum of the absolute vertical velocity.
waxxx	area mean values of the absolute vertical velocity for three model layers in about 850, 500 and 300 hPa.

The file YUPRMASS is always written. With the NAMELIST-parameters n0meanval and nincmeanval of /diactl/ the first output and the interval of the outputs in time steps can be controlled. With ldump_ascii = .TRUE. / .FALSE., the flushing of YUPRMASS to disk in every time step can be switched on/off.

An example of YUPRMASS is shown in Figure .

Experiment: LM   Number: 1   SUN 17.02.2008 18 UTC + 0 H (SUN 17.02.2008 18 UTC)   19.02.2008 15.21.47

Elapsed time for providing initial and boundary values: REAL (S):   1.12

Initial mean values for nstart = 0 for several variables:

surface pressure (hPa)	dry static energy (J/kg)	moist static energy (J/kg)	kinetic energy (J/kg)
967.278	313977.93	314962.08	207.08

Experiment: LM   Number: 1   SUN 17.02.2008 18 UTC + 0 H (SUN 17.02.2008 18 UTC)   19.02.2008 15.21.47

ntstep	Real s	dpsdt Pa/s E-2	ps hPa	dse J/kg E+3	mse J/kg E+3	ke J/kg	vamx m/s	wamx m/s	wa850 cm/s	wa500 cm/s	wa300 cm/s
0	3.680	22.809	967.195	-0.005	-0.002	-0.621	47.647	0.800	3.231	3.940	5.151
1	1.200	25.425	967.324	0.001	0.012	-0.924	47.693	0.801	3.763	5.798	7.087
2	0.360	17.142	967.265	0.000	0.014	-1.220	47.724	0.810	3.782	4.657	5.440
3	0.370	14.223	967.289	0.003	0.020	-1.463	47.749	0.828	3.946	4.945	5.979
4	1.250	11.841	967.284	0.005	0.023	-1.679	47.769	0.845	4.025	4.739	5.595
5	0.370	12.827	967.289	0.006	0.027	-1.872	47.784	0.860	4.151	4.887	5.730
6	0.360	11.485	967.299	0.008	0.030	-2.044	47.797	0.869	4.216	4.806	5.588
7	0.360	11.888	967.294	0.009	0.032	-2.202	47.807	0.874	4.292	4.855	5.617
8	1.260	10.977	967.303	0.010	0.035	-2.338	47.817	0.877	4.342	4.819	5.595
9	0.400	11.277	967.297	0.011	0.038	-2.464	47.826	0.880	4.388	4.814	5.567
10	0.360	10.802	967.301	0.013	0.040	-2.573	47.834	0.883	4.415	4.815	5.583
11	1.270	10.548	967.297	0.014	0.042	-2.671	47.842	0.883	4.432	4.823	5.581
12	0.360	10.328	967.298	0.015	0.045	-2.755	47.850	0.881	4.448	4.814	5.563
13	0.360	10.335	967.295	0.016	0.047	-2.828	47.859	0.885	4.453	4.822	5.574
14	0.360	9.545	967.294	0.017	0.049	-2.889	47.868	0.885	4.455	4.836	5.592
15	1.260	8.093	967.291	0.019	0.051	-2.937	47.879	0.917	4.460	4.844	5.586
16	0.360	8.277	967.288	0.020	0.053	-2.975	47.894	0.946	4.465	4.859	5.597
17	0.360	8.472	967.284	0.021	0.055	-3.002	47.910	0.975	4.471	4.877	5.600
18	0.360	8.484	967.281	0.022	0.057	-3.020	47.917	1.002	4.478	4.898	5.617
19	1.360	8.104	967.277	0.024	0.060	-3.031	47.921	1.029	4.485	4.918	5.641
20	0.360	7.968	967.272	0.025	0.062	-3.035	47.926	1.056	4.494	4.935	5.661
21	0.370	8.029	967.267	0.026	0.064	-3.032	47.933	1.084	4.504	4.957	5.680
22	1.250	7.658	967.262	0.027	0.065	-3.025	47.941	1.111	4.513	4.981	5.696
23	0.370	7.442	967.257	0.028	0.067	-3.013	47.948	1.138	4.522	5.003	5.708
24	0.360	7.288	967.252	0.029	0.069	-2.997	47.955	1.164	4.532	5.027	5.716
25	0.360	7.210	967.246	0.030	0.071	-2.977	47.963	1.189	4.541	5.054	5.728
26	1.260	6.887	967.240	0.031	0.072	-2.953	47.971	1.212	4.550	5.080	5.744
27	0.370	6.880	967.233	0.032	0.074	-2.926	47.980	1.233	4.559	5.104	5.768
28	0.360	6.796	967.226	0.033	0.076	-2.894	47.990	1.249	4.566	5.125	5.792
29	0.390	6.489	967.220	0.034	0.077	-2.854	47.997	1.264	4.574	5.144	5.809
30	1.280	5.797	967.214	0.035	0.079	-2.807	48.001	1.275	4.582	5.159	5.811
31	0.360	5.203	967.208	0.036	0.080	-2.750	48.005	1.285	4.587	5.169	5.804
32	0.360	4.570	967.200	0.037	0.082	-2.686	48.017	1.291	4.593	5.177	5.803
33	1.290	4.018	967.190	0.037	0.083	-2.615	48.033	1.296	4.598	5.185	5.813
34	0.360	3.653	967.180	0.038	0.084	-2.539	48.045	1.300	—	5.191	5.828

Figure 5.3: Example file YUPRMASS

5.5 `YUPRHUMI` — Protocolling the forecast with humidity variables

`YUPRHUMI` contains meanvalues of model variables related to humidity and rain rates. First, the initial values of the humidity variables are written.

In the next lines, the following values are written:

`ntstep`	actual time step.
`Real`	elapsed time since the last line was printed.
`qc`	area mean value of cloud water.
`qi`	area mean value of cloud ice.
`qr`	area mean value of rain.
`qs`	area mean value of snow.
`qg`	area mean value of graupel.
`prrs`	precipitation rate for grid scale rain.
`prss`	precipitation rate for grid scale snow.
`prrk`	precipitation rate for convective rain
`prsk`	precipitation rate for convective snow.
`rrn`	sum of precipitation (rain) since start of the forecast.
`rsn`	sum of precipitation (snow) since start of the forecast.

The file `YUPRHUMI` is always written. With the `NAMELIST`-parameters `n0meanval` and `nincmeanval` of `/diactl/` the first output and the interval of the outputs in time steps can be controlled. With `ldump_ascii = .TRUE. / .FALSE.`, the flushing of `YUPRHUMI` to disk in every time step can be switched on/off.

An example of `YUPRHUMI` is shown in Figure 5.4.

```
Experiment: LM     Number:   1   SUN 17.02.2008  18 UTC +   0 H   (SUN 17.02.2008  18 UTC)                    19.02.2008  15.21.47
Elapsed time for providing initial and boundary values:     REAL (S):  1.12

Initial mean values for nstart =    1   SUN 17.02.2008  18 UTC +   0 H   (SUN 17.02.2008  18 UTC)            19.02.2008  15.21.47
cloud water   cloud ice      rain        snow      graupel   (all: g/kg)
   0.000        0.000        0.000       0.000      0.000

Experiment: LM     Number:   1   SUN 17.02.2008  18 UTC +   0 H   (SUN 17.02.2008  18 UTC)                    19.02.2008  15.21.47
```

ntstep	qc	qi	qr	qs	qg	prrs	prss	prrk	prsk	rrn	rsn
		kg/kg (1E-5)				mm/D				mm	
0	0.000	0.085	0.000	0.386	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.000	0.076	0.000	0.385	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.072	0.000	0.383	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.069	0.000	0.382	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.067	0.000	0.380	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.065	0.000	0.379	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.064	0.000	0.377	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.062	0.000	0.376	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.061	0.000	0.374	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.060	0.000	0.373	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.059	0.000	0.371	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.059	0.000	0.370	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.058	0.000	0.369	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.057	0.000	0.367	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.057	0.000	0.366	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.056	0.000	0.365	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.056	0.000	0.364	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.055	0.000	0.362	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.055	0.000	0.361	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.055	0.000	0.360	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.054	0.000	0.359	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.054	0.000	0.358	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.054	0.000	0.357	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.054	0.000	0.357	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.054	0.000	0.356	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.054	0.000	0.355	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.054	0.000	0.354	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.000	0.054	0.000	0.353	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28	0.000	0.054	0.000	0.353	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29	0.000	0.054	0.000	0.352	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.000	0.054	0.000	0.352	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.054	0.000	0.351	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	0.000	0.054	0.000	0.350	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33	0.000	0.054	0.000	0.350	0.000	0.000	0.000	0.000	0.000	0.000	0.000
34	0.000	0.054	0.000	0.349	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	0.000	0.054	0.000	0.349	0.000	0.000	0.000	0.000	0.000	0.000	0.000
36	0.000	0.054	0.000	0.348	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 5.4: Example file YUPRHUMI

Section 6

Output for Data Assimilation

6.1   ASCII Output Related to the Use of Observations

The ASCII output described in this section is produced only if the compile option `-DNUDGING` is used for the production of the COSMO binary, and the `NAMELIST` variable `luseobs` is set to `.TRUE.`. For some of the files, additional prerequisites exist. The ASCII files provide a helpful tool for a quick monitoring and diagnosis of the tasks related to the use of observations, such as data assimilation, input for verification, and production of 2-dimensional analyses based on observations. These files are:

- `YUAOFEX`: Nudging, observation input AOF

- `YUOBSDR`: Nudging, list of active and passive reports

- `YUREJCT`: Nudging, list of rejected reports

- `YUQUCTL`: Nudging, list of data rejected by quality control

- `YUSTATS`: Nudging, statistics on observation processing

- `YUCAUTN`: Nudging, warning messages indicating insufficient array sizes

- `YUVERIF`: Nudging, verification file VOF

- `YUPRINT`: Nudging, other, various aspects

- `YUSURF` : 2-D surface analyses

- `YULHN` : Latent Heat Nudging (description not yet available)

Note that the `NAMELIST`-parameters related to the tasks which use observations are also written to file `YUSPECIF`. This has already been described in Section 5. Furthermore, the file `YUTIMING` is also extended with parts that consider the nudging (or production of the `YUVERIF` and / or NetCDF feedobs files) and the latent heat nudging.

6.1.1 `YUAOFEX` — Nudging: Observation Input AOF

File `YUAOFEX` is written only if the observations for the nudging scheme are read from an 'AOF' file (see variable 'itype_obfile' in NAMELIST 'NUDGING') and if NAMELIST variable 'lpraof' is set to '.TRUE.'. `YUAOFEX` then prints the complete observations that are read from the AOF file. In this case, the AOF file contains all the observations (except for the GPS data) that made available to the COSMO Model either for the purpose of nudging, verification, or production of two-dimensional surface analyses. Figure 6.1 shows an example of a file `YUAOFEX` which includes an aircraft report, a SYNOP report, and the beginning of a TEMP report. For each report, the first four lines contain the 19 items of the report header:

1	length of record for whole report
2	length of preliminary array
3 - 5	missing (length of next record; record number; analysis box number)
6 / 7	observation type / code type (see Figure 6.8)
8	station latitude, in [degree * 100 + 9000]
9	station longitude, in [degree * 100 + 18000]
10	date of observation, in [yyyymmdd] (yyyy=year; mm=month; dd=day)
11 / 12	synoptic / exact time of observation, in [hh ''] (hh=hour; '' = minutes)

```
****************************************************** A O F   R E P O R T *****
0        27           4  2147483647  2147483647  2147483647
          2         144       14425       18863    20020109
       1100        1158    88773930    88773930  2147483647
 2147483647     1032192          22           0
         33           4 17777777777 17777777777 17777777777
          2         220       34131       44657   114275615
       2114        2206   522512452   522512452 17777777777
17777777777     3740000          26           0
0      2381         212          40        2140  2147483647
          0           0
       4515         324          50        4134 17777777777
          0           0
****************************************************** A O F   R E P O R T *****
0        35           4  2147483647  2147483647  2147483647
          1          11       13552       18867    20020109
       1200        1200   103651382   109580320       16166
       1169          65          32           0
         43           4 17777777777 17777777777 17777777777
          1          13       32360       44663   114275615
       2260        2260   613314066   642010040       37446
       2221         101          40           0
0     10160         999           0        2692        2678
        502  2147483647   131073280   133757695          64
          0           0         256         127           0

      23660        1747           0        5204        5166
        766 17777777777   764002400   776175377         100
          0           0         400         177           0

****************************************************** A O F   R E P O R T *****
0       332           4  2147483647  2147483647  2147483647
          5          35       14057       19038    20020109
       1200        1200   103553716   117968928          56
       1450         768         127           0
        514           4 17777777777 17777777777 17777777777
          5          43       33351       45136   114275615
       2260        2260   613015264   702010040          70
       2652        1400         177           0
0      9830         150           1        2679        2676
       1453      507904           0
      23146         226           1        5167        5164
       2655     1740000           0
.................................................................................
```

Figure 6.1: Example file `YUAOFEX`.

13 , 14	station identity (for characters 1 - 4 resp. 5 - 8, ASCII allocating sequence)
15	data base key
16	station altitude, in [m + 1000]
17 / 18	station characteristics / instrument specifications
19	flags on latitude/longitude/date/time/altitude

Further details related to these elements are given in the AOF documentation in appendix A of Documentation Part IV (Implementation Guide).

In file `YUAOFEX`, the header is repeated in octal numbers. Then each observation level of the report body is also given first in digital numbers and then in octal numbers. For each observation type used currently, the first elements are pressure (in [0.1 hPa], or geopotential [m]), wind direction ([°]), wind speed ([m/s]), and temperature ([0.1 K]). For TEMP radiosonde reports, this is followed by dew point ([0.1 K]), height ([m+1000]), and two flag words. For PILOT and aircraft reports, the same applies except that there is no value for dew point. For SYNOP reports, dew point is followed by pressure tendency ([0.1 hPa / 3 h]), sea surface temperature ([0.1 K]), the weather group word and general cloud group word, a pressure level code flag and two further flag words, and optional groups.

6.1.2   `YUOBSDR` — **Nudging: Active and Passive Reports**

File `YUOBSDR` lists the active reports. It is written only if the `NAMELIST` parameter 'lprodr' is set to '.TRUE.'. The passive reports are also listed if 'lverif=.TRUE.' and 'lverpas=.TRUE.'. The criteria to distinguish between passive and fully rejected (i.e. omitted) reports are given in Figure 6.9. In addition, a message is also written if a report or a single observation level within a multi-level report is redundant.

The first three lines in Figure 6.2 relate to redundant surface-level reports. At first, the station identity and code type (see Figure 6.8) of the redundant report are given. This is followed by a list of properties of the (resulting) active report, consisting of the (rotated) wind components, temperature, relative humidity, pressure, station identity, code type, longitude, latitude, order index, station correction flag, replacement indicator, and report time (relative to the initial time of the model run). The replacement indicator is organized in the same

```
 --> REDUNDANT: 60571      35  / ACTIVE:    -1.3   -1.6  290.2 0.39******** 60571      35 -2.3 31.5 1 F   0  2.0
 --> REDUNDANT: 11520      14  / ACTIVE:     2.1   -2.2  273.4 0.91 98300. 11520      11 14.5 50.0 2 T   0  0.0
 --> REDUNDANT: 11520      35  / ACTIVE:     1.0   -2.9  274.0 0.91******** 11520      35 14.5 50.0 1 F  32  2.3
 11520      Z: ACT/REJ: P/ZERR/Z: 39900.  40000.******  9.8****** 6970.
 11520      T: ACT/REJ: P/T/FLAG: 39900.  40000.******  0.4 0 0
 11520      Q: ACT/REJ: P/Q/FLAG: 39900.  40000.******  0.2 0 0
TEMP  11520        0.9  -2.8 274.0 0.90*************** 302***** 1.2 0.40*****   0(335,322) 14.44  50.02  35 5  2.25
TEMP  11520     P  0.9  -2.8 274.0 0.90*************** 302***** 1.2 0.40*****   0(335,322) 14.44  50.02  35 5  2.25
SYNOP 11520     P  2.1  -2.2 273.4 0.91  983.00  303.  303***** 1.0 0.10  7.5   1(335,322) 14.44  50.02  11 1  0.00
SYNOP 11520        2.1  -2.2 273.4 0.91  983.00  303.  303***** 1.0 0.10  7.5   1(335,322) 14.44  50.02  11 1  0.00
SYNOP 11520        2.1  -2.2 273.6 0.92  983.70  303.  303***** 1.0 0.10  7.5   1(335,322) 14.44  50.02  11 1  1.00
SYNOP 11520        1.2  -2.8 274.0 0.90  984.40  303.  303***** 1.0 0.10  7.5   1(335,322) 14.44  50.02  11 1  2.00
TEMP  11520        OBS/CODE TYPE: 5  35  STA/MOD HEIGHT: 302  301  LON= 14.44 LAT= 50.02  G.P.=(335,322)  HOUR=  2.3
      u      v     t    rh     p      z  v-err t-er rh-er z-er lev
     0.9   -2.8  274.0 0.90   985.0  302.************** 4.3  64
     2.8   -6.4************ 958.0******  2.1************** 128
*************** 271.0 1.00   945.0************ 1.1 0.10***** 256
     1.2   -7.9  269.9 1.00   925.0  803.  2.2  1.1 0.10  4.3  32
    -2.0   -9.8  266.3 0.93   850.0 1468.  2.4  1.0 0.10  4.4  32
    -3.3   -8.4************ 800.0******  2.4************** 32
    -4.7   -7.7************ 765.0******  2.5************** 128
*************** 258.5 0.90   738.0************ 0.8 0.10***** 256
*************** 259.9 0.89   732.0************ 0.8 0.10***** 256
    -5.4  -10.7  257.3 0.59   700.0 2956.  2.5  0.7 0.10  5.2  32
   -10.0  -11.2************ 600.0******  2.9************** 32
*************** 247.3 0.25   568.0************ 0.5 0.10***** 256
   -14.3  -19.3  241.4 0.14   500.0 5410.  3.4  0.4 0.15  8.4  32
*************** 240.9 0.09   473.0************ 0.4 0.15***** 256
*************** 241.1 0.11   469.0************ 0.4 0.15***** 256
   -17.8  -29.0  233.4 0.12   400.0 6970.  3.5  0.4 0.15  9.8  33
*************** 226.3 0.20   344.0************ 0.5 0.20***** 256
   -13.6  -22.1  222.9 0.09   300.0 8880.  3.7  0.5 0.20 10.7  32
   -14.7  -23.9  218.3 0.06   259.0******  3.5  0.5********   2
   -13.6  -22.1  218.3 0.05   250.0 10060.  3.5  0.5***** 11.8  32
   -12.1  -24.1************ 206.0******  3.5************** 128
   -12.1  -24.1  217.9 0.02   200.0 11480.  3.5  0.6***** 13.2  32
*************** 219.6 0.01   155.0************ 0.7********** 256
    -7.3  -11.9  218.6 0.01   150.0 13320.  3.4  0.7***** 15.2  32
    -0.3  -11.0  215.6 0.01   100.0******  3.3  0.8*********** 384
    -2.4  -11.8  214.3 0.01    70.0 18140.  3.2  0.8***** 19.5   8
    -3.6   -3.4  214.1 0.01    50.0 20250.  3.2  0.9***** 22.5   8
    -0.6   -1.9  212.4 0.01    30.0 23430.  3.3  0.9***** 25.0   8
     2.9    0.7  212.1 0.01    20.0 25940.  3.6  1.0***** 32.0   8
    11.0   -0.3  220.6 0.01    10.0******  4.5  1.2*********** 128
PILOT 10266        OBS/CODE TYPE: 6 132  STA/MOD HEIGHT:  57   56  LON= 11.84 LAT= 53.31  G.P.=(306,374)  HOUR=  0.5
      u      v     t    rh     p      z  v-err t-er rh-er z-er lev
    -1.1   -2.5************ 958.9  525.  2.1**************   0
    -0.8   -2.3************ 941.6  669.  2.1**************   0
    -1.0   -2.1************ 924.5  814.  2.2**************   0
    -0.6   -2.5************ 907.9  958.  2.2**************   0
     0.8   -3.4************ 891.4 1103.  2.3**************   0
PILOT 10266     P  OBS/CODE TYPE: 6 133  STA/MOD HEIGHT:  57   56  LON= 11.84 LAT= 53.31  G.P.=(306,374)  HOUR=  0.5
      u      v     t    rh     p      z  v-err t-er rh-er z-er lev
*************** 270.4***** 956.9  542.********************   0
*************** 269.7***** 940.4  679.********************   0
*************** 269.0***** 924.3  816.********************   0
*************** 269.1***** 908.3  954.********************   0
*************** 270.3***** 892.8 1091.********************   0
SYNOP Q671         0.7  -1.9 272.6 1.00********  750.  750***** 1.0 0.10*****   1(284,295)  9.48  48.38  14 1  2.00
SYNOP 07497     P -1.0   0.2 278.5 0.52  917.90  868.  868******************* -781(253,252)  6.76  45.61  11 1  2.00
SYNOP 02868     P  5.1   7.4 262.0 0.92 1002.60    0.  488*******************  156(417,596) 29.14  66.16  14 1  2.00
SYNOP 02876        4.3   5.5 271.1 0.80 1003.40    5.    5  3.6 1.0 0.10  7.4   2(396,571) 25.39  65.00  14 1  2.00
SYNOP 63108        6.0  -3.0 280.0 0.94 1017.50    0.    0  3.6 1.0 0.10 14.5   0(223,497)  1.70  60.79  24 1  2.00
SYNOP DBFC         2.0  -2.2 273.9 0.73 1024.30    0.    0  3.6 1.0 0.10 14.5   0(320,402) 13.39  55.00  21 1  2.00
DRIBU 63551       ********************* 1014.50    0.    0************** 14.5   0(230,605)  0.84  67.53 165 4  0.00
DRIBU 64071       -0.5  -5.0 265.3 1.00********    0.    0  5.4 1.0**********   0(171,632) -9.25  68.46 165 4  2.00
Scatt 004          4.7   0.5******************    0.    0  7.0**********      0(227,395)  3.36  54.46 123 9  1.63
Scatt 004          4.3  -0.1******************    0.    0  7.0**********      0(235,395)  4.23  54.48 123 9  1.63
```

Figure 6.2: Example file `YUOBSDR`, first part.

way as the finite observation error indicator of the VOF (see section 6.1.7). It reveals which observations of the active report have been missing and were replaced by data from the rejected report. Rejected multi-level reports are written to file YUOBSDR in a format very similar to that for the active reports (see below).

The next three lines inform about an observation level being redundant within a multi-level report. Pressure level, observation error, and observed value for height resp. quality flags for other variables are provided both from the active and the redundant level.

The following information is given for each (active or passive) single-level report (stars ' *** ' always indicate missing values):

-   observation type , and station identity
-   status indicator: ' ': active, 'P': passive, 'M': used as part of a multi-level report
-   zonal and meridional wind components u, v [m/s]
-   temperature T [K], and relative humidity rh [ ]
-   pressure level p [hPa]
-   height z at observation level [m], and station height [m]
-   observation errors assigned to wind, temperature, humidity, and height data
-   station altitude minus height of model orography
-   coordinates of the grid point to which the report is assigned
-   longitude and latitude [°]
-   code type , and observation type (see Figure 6.8)
-   reported observation time [h] relative to the initial model time

```
AIREP EU5331      M  0.4  -5.1 265.5 0.66  840.38  1550.*****  2.5 1.0 0.10**********(313,297)  12.27  48.50 244 2  2.51
AIREP EU5331      M  0.2  -4.1 266.5 0.62  848.67  1470.*****  2.5 1.0 0.10**********(313,297)  12.25  48.47 244 2  2.51
AIREP EU5331      M -0.1  -3.1 267.0 0.63  858.08  1380.*****  2.5 1.0 0.10**********(313,297)  12.23  48.45 244 2  2.51
AIREP EU5331      M  0.7  -3.5 268.0 0.56  869.69  1270.*****  2.5 1.0 0.10**********(313,296)  12.21  48.43 244 2  2.53
AIREP EU5331         0.1  -2.6 268.5 0.65  882.51  1150.*****  2.5 1.0 0.10**********(312,296)  12.15  48.41 244 2  2.53
AIREP EU5331      P  1.1  -4.5 268.8 0.50  879.29  1180.*****  2.5 1.0 0.10**********(312,296)  12.18  48.42 244 2  2.53
AIREP EU5331      P  0.2  -2.1 268.8 0.63  882.51  1150.*****  2.5 1.0 0.10**********(312,296)  12.12  48.40 244 2  2.54
AIREP EU5331      M  0.3  -2.6 269.0 0.62  881.43  1160.*****  2.5 1.0 0.10**********(311,296)  12.10  48.40 244 2  2.54
AIREP EU5331      M  0.6  -3.5 269.3 0.58  882.51  1150.*****  2.5 1.0 0.10**********(311,295)  12.06  48.38 244 2  2.54
AIREP EU5331      P  0.2  -3.1 269.3 0.55  882.51  1150.*****  2.5 1.0 0.10**********(311,295)  12.03  48.38 244 2  2.56
AIREP EU5331      M -0.1  -3.1 269.5 0.54  882.51  1150.*****  2.5 1.0 0.10**********(310,295)  12.01  48.37 244 2  2.56
AIREP EU5331      M -0.4  -2.6 270.0 0.52  890.05  1080.*****  2.5 1.1 0.10**********(310,295)  11.98  48.37 244 2  2.56
AIREP EU5331      M -0.6  -2.5 270.8 0.53  902.01   970.*****  2.5 1.1 0.10**********(310,295)  11.95  48.37 244 2  2.58
AIREP EU5331      M -0.3  -2.1 270.8 0.62  913.00   870.*****  2.5 1.1 0.10**********(310,295)  11.93  48.37 244 2  2.58
AIREP EU5331      M -0.5  -2.5 272.5 0.58  922.98   780.*****  2.5 1.1 0.10**********(309,295)  11.91  48.37 244 2  2.58
AIREP EU5331      M -0.4  -2.6 272.8 0.60  930.81   710.*****  2.5 1.1 0.10**********(309,295)  11.89  48.37 244 2  2.60
AIREP EU5331      M -0.3  -2.6 273.2 0.56  938.69   640.*****  2.5 1.1 0.10**********(309,295)  11.87  48.37 244 2  2.60
AIREP EU5331      M -0.1  -2.6 273.3 0.58  946.62   570.*****  2.5 1.1 0.10**********(309,295)  11.86  48.37 244 2  2.60
AIREP EU5331      M  0.2  -1.5 273.8 0.59  955.75   490.*****  2.5 1.1 0.10**********(309,295)  11.85  48.37 244 2  2.61
AIREP EU5331      M  0.3  -0.4 274.3 0.60  963.80   420.*****  2.5 1.2 0.10**********(308,295)  11.82  48.36 244 2  2.61
AIREP EU5331         OBS/CODE TYPE: 2 244  STA/MOD HEIGHT:****  443  LON= 11.82 LAT= 48.36  G.P.=(308,295)  HOUR=  2.6
      u      v    t    rh     p      z  v-err t-er rh-er z-er lev
    0.3   -0.4 274.3 0.60  963.8   420.  2.5  1.2 0.10***** 384
    0.2   -1.5 273.8 0.59  955.8   490.  2.5  1.1 0.10***** 384
   -0.1   -2.6 273.3 0.58  946.6   570.  2.5  1.1 0.10***** 384
   -0.3   -2.6 273.2 0.56  938.7   640.  2.5  1.1 0.10***** 384
   -0.4   -2.6 272.8 0.60  930.8   710.  2.5  1.1 0.10***** 384
   -0.5   -2.5 272.5 0.58  923.0   780.  2.5  1.1 0.10***** 384
   -0.3   -2.1 270.8 0.62  913.0   870.  2.5  1.1 0.10***** 384
   -0.6   -2.5 270.8 0.53  902.0   970.  2.5  1.1 0.10***** 384
   -0.4   -2.6 270.0 0.52  890.1  1080.  2.5  1.1 0.10***** 384
   -0.1   -3.1 269.5 0.54  882.5  1150.  2.5  1.0 0.10***** 384
AIREP EU5331         OBS/CODE TYPE: 2 244  STA/MOD HEIGHT:****  481  LON= 12.06 LAT= 48.38  G.P.=(311,295)  HOUR=  2.5
      u      v    t    rh     p      z  v-err t-er rh-er z-er lev
    0.6   -3.5 269.3 0.58  882.5  1150.  2.5  1.0 0.10***** 384
    0.3   -2.6 269.0 0.62  881.4  1160.  2.5  1.0 0.10***** 384
    0.7   -3.5 268.0 0.56  869.7  1270.  2.5  1.0 0.10***** 384
   -0.1   -3.1 267.0 0.63  858.1  1380.  2.5  1.0 0.10***** 384
    0.2   -4.1 266.5 0.62  848.7  1470.  2.5  1.0 0.10***** 384
    0.4   -5.1 265.5 0.66  840.4  1550.  2.5  1.0 0.10***** 384
GPS     COMO-METO P  6.5  42.1******************** 2286.0  247 1.4   0.00       -46(279,253)  9.09  45.80 80012  0.50
GPS     COMO-METO P  6.4  41.2******************** 2285.1  247 1.7   0.00       -46(279,253)  9.09  45.80 80012  0.75
GPS     COMO-ROB_ P**************************** 2279.8  247 1.7  *****       -46(279,253)  9.09  45.80 83712  0.50
GPS     COMO-ROB_ P**************************** 2278.1  247 1.8  *****       -46(279,253)  9.09  45.80 83712  0.75
GPS     COMO-ASI_ P**************************** 2272.6  247 2.4  *****       -46(279,253)  9.09  45.80 82112  0.50
GPS     COMO-ASI_ P**************************** 2261.2  247 2.6  *****       -46(279,253)  9.09  45.80 82112  0.75
GPS     COMO-SGN_ P**************************** 2275.0  247 2.2  *****       -46(279,253)  9.09  45.80 82912  0.50
GPS     COMO-SGN_   **************************** 2273.4  247 2.5  *****       -46(279,253)  9.09  45.80 82912  0.75
GPS     COMO-SGN1 P**************************** 2274.3  247 2.3  *****       -46(279,253)  9.09  45.80 92912  0.50
GPS     COMO-SGN1 P**************************** 2272.6  247 2.6  *****       -46(279,253)  9.09  45.80 92912  0.75
GPS     COMO-BKG_   **************************** 2273.6  247 1.0  *****       -46(279,253)  9.09  45.80 83012  0.50
```

Figure 6.3: Example file YUOBSDR, second part.

Figure 6.2 provides examples of a TEMP radiosonde, a wind profiler, and a RASS multi-level report. For multi-level reports, a self-explanatory header line is followed by lines each providing the following information for one observation level: horizontal wind components, temperature, relative humidity, pressure, height, observation errors for wind, temperature, humidity, and height, and level identity. The latter is a bit pattern as specified for the VOF (see section 6.1.7). Figure 6.2 also includes examples for drifting buoy, scatterometer wind, Synop ship, and Synop surface land reports. Two of the latter reports are set passive since all their observations are passive due to large differences between observation level and model orography.

Figure 6.3 shows an example of an descending aircraft before landing. The process of deriving a multi-level report from the original single-level reports is interrupted at a level where the aircraft had to stay on hold before it was allowed for the final landing. As a result, two instead of one multi-level reports are created, and at the holding altitude (of 882 hPa), several single-level reports remain, all of which except for one are set passive due to redundancy.

Figure 6.3 is completed by examples of ground-based GPS reports. Compared to other single-level reports, the values for wind are replaced here by integrated water vapour and zenith wet delay values (in [mm]), height by zenith total delay (ZTD, in [mm]), and the observation errors by the ZTD error and the bias correction (in [mm]). All reports shown here are from one station (COMO), but the raw data have been processed by different processing centres in order to obtain ZTD. In such cases, all except for one report have to be set to passive due to redundancy according to the preference given by `NAMELIST` parameter 'igpscen'. In the example, the reports processed by 'BKG' for observation time 0.5 and by 'SGN' for time 0.75 are active.

6.1.3   `YUREJCT` — **Nudging: Rejected Reports**

`YUREJCT` (see Figure 6.4) lists the station identities of the rejected (or passive) reports and indicates the reasons for their rejection. For instance, the station height and its difference to the model orography is provided if this difference is so large that every observed quantity from that report is excluded from use. Most of the messages are self-explanatory.

The 'FLIGHT TRACK' messages all deliver station identity, observation time (relative to the model initial time), and pressure of observation level. They are complemented by position confidences (in [%]) with original resp. reversed sign for longitude (if the line includes "LON SIGN") or position confidences for the foreward resp. backward trajectory of the report sequence.

The 'BLACKLISTED' messages indicate in general rejection of certain parts rather than complete reports. Observation types 'OBTYP' are as specified in Figure 6.8, and the 4 pairs of numbers at the end of the lines indicate the lower and upper limit in [hPa] of the blacklisted vertical range for height (geopotential) or pressure, wind, temperature, resp. humidity.

The last 12 lines in Figure 6.4 relate to single observed quantities or to single observation levels of multi-level reports. The lapse rate and wind shear messages deliver station identity, observation time, threshold value, actual value (in [K] resp. [m/s]), and the pressure range of the rejected levels. By default (see `NAMELIST` parameter 'maxmlv'), a maximum of 100 observation levels are allowed in a multi-level report (see second but last message).

```
 STATION 04339       : OBS. LOCATION OUT OF DOMAIN    -22.0   70.5 ,    2.0 HRS
 STATION 004         : OBS. LOCATION OUT OF DOMAIN     10.5   70.8 ,   -0.1 HRS
 STATION EU0324      : OBSERVATION TOO OLD:    âˆ'0.6 [FORECAST HRS]
 STATION 11142       : HEIGHT  647. DIFF. TO MODEL  937. TOO LARGE,     0.0 HRS
 STATION 11916       : HEIGHT 2007. DIFF. TO MODEL 1294. TOO LARGE,     0.0 HRS
 STATION 01455       : HEIGHT  255. DIFF. TO MODEL  410. TOO LARGE,     0.0 HRS
 STATION LCAR-METO   : HEIGHT   16. DIFF. TO MODEL  172. TOO LARGE,     1.0 HRS
 STATION ARDE-LPT_   : HEIGHT 1497. DIFF. TO MODEL 2033. TOO LARGE,     1.0 HRS
 STATION ASDE09      : SEA OBS. IS LOCATED OVER (MODEL) LAND AT   10.0   53.0 ,   1.6 HRS
STATION ASDE09       : NO SURFACE-LEVEL REPORT DERIVED FROM TEMP / PILOT
 STATION DBBI        : SEA OBS. IS LOCATED OVER (MODEL) LAND AT    8.5   53.5 ,   0.0 HRS
 STATION 61933       : STA HEIGHT FLAGGED,    -0.5 HRS
 STATION 62934       : STA HEIGHT FLAGGED,     1.3 HRS
STATION 11164        : NO SURFACE-LEVEL REPORT DERIVED FROM TEMP / PILOT
 STATION 06620     CODE TYPE 132 NOT ON WHITELIST,     0.0 HRS
 STATION 07145     CODE TYPE 137 NOT ON WHITELIST,     0.5 HRS
 FLIGHT TRACK THINNING  EU4611   ,  3.73,  393.: (TOO) CLOSE TO OBS. TIME  3.72
 FLIGHT TRACK THINNING  EU4611   ,  3.80,  330.: (TOO) CLOSE TO OBS. TIME  3.77
 FLIGHT TRACK THINNING  EU4611   ,  3.83,  330.: (TOO) CLOSE TO OBS. TIME  3.77
 FLIGHT TRACK CHECK  EU6363  , 0.80  216.: HORIZONTAL CONFIDENCES:  83.9  57.9
 FLIGHT TRACK CHECK  EU3311  ,-0.07  344.: HORIZONTAL CONFIDENCES: 101.0  58.5
 FLIGHT TRACK CHECK  EU1234  , 3.52  238.: HORIZONTAL CONFIDENCES:  59.2 101.0
 EXAGGERATED HORIZONTAL COLOCATION EU0350   :  28 REPORTS FROM  1.68 TO  3.70
 FLIGHT TRACK CHECK  LHEU0456 , 4.80  780.: HORIZONTAL CONFIDENCES:  19.0   0.0
 FLIGHT TRACK CHECK  EU3268  , 2.70  376.: VERTICAL CONFIDENCES:  59.0  81.2
 FLIGHT TRACK CHECK  EU9145  , 3.88  290.: LON SIGN, FOREWARD CONFIDENCE:  54  89
 FLIGHT TRACK CHECK  EU8969  , 1.61  376.: LON SIGN, FOREWARD CONFIDENCE:  29  89

 STA 62023      OBTYP 1 BLACKLISTED (Z,V,T,Q):    0    0 1100    0    0    0    0    0
 STA 16115      OBTYP 1 BLACKLISTED (Z,V,T,Q): 1100    0    0    0    0    0    0    0
 STA EU8742     OBTYP 2 BLACKLISTED (Z,V,T,Q):    0    0    0    0 1100    0    0    0
 STA KLM791     OBTYP 2 BLACKLISTED (Z,V,T,Q):    0    0 1100    0    0    0    0    0
 STA RCH7440    OBTYP 2 BLACKLISTED (Z,V,T,Q):    0    0 1100    0 1100    0    0    0
 STA 62337      OBTYP 5 BLACKLISTED (Z,V,T,Q):   30    0 1100    0   30    0    0    0
 STA 34247      OBTYP 5 BLACKLISTED (Z,V,T,Q):  150    0    0    0  150    0    0    0
 STA 22522      OBTYP 5 BLACKLISTED (Z,V,T,Q): 1100    0    0    0 1100    0    0    0
 STA 08007      OBTYP 6 BLACKLISTED (Z,V,T,Q):    0    0 1100  900    0    0    0    0
 STA 08007      OBTYP 6 BLACKLISTED (Z,V,T,Q):    0    0  600    0    0    0    0    0
 STA 10678      OBTYP 6 BLACKLISTED (Z,V,T,Q):    0    0  200    0 1100    0    0    0

 PRECIPITATION AMOUNT EXCEEDS LIMIT âˆ'    DATUM REJECTED.  STID=08226    RR=914.0 TR=12.
 PRECIPITATION AMOUNT EXCEEDS LIMIT âˆ'    DATUM REJECTED.  STID=07649    RR= 18.0 TR= 1.
 03507   : Fog with precip.: weather:127 ,vis.:   300 ,flags:  0  0
 10488   : Fog with precip.: weather: 51 ,vis.:   200 ,flags:  0  0
 10544   : Fog with precip.: weather: 77 ,vis.:   300 ,flags:  0  0
 LAPSE RATE  EU8943  ,  0.8: THRESHOLD , VALUE: -0.5 -0.69 , P:  332. -  331.
 LAPSE RATE  22550   ,  2.5: THRESHOLD , VALUE: -1.5 -2.10 , P:  565. -  549.
 WIND SPEED SHEAR  03920   ,  3.0: THRESH, VALUE: 42.6  44.0 , P:  250. âˆ'  200.
 WIND SPEED SHEAR  03496   ,  3.0: THRESH, VALUE: 39.9  50.0 , P:  400. âˆ'  300.
 SINGLE LEV REP  06458    : PRESSURE TENDENCY:  4506 ,  FLAG:  0
 SINGLE LEV REP 07600     : NO ACCEPTED DATA IN REPORT
 MULTI LEV REP  03501    :   130th LEVEL, BUT ODR SIZE IS   100
```

Figure 6.4: Example file `YUREJCT`.

6.1.4   `YUQUCTL` — Nudging: Data Rejected by Quality Control

`YUQUCTL` (see Figure 6.5) lists the data which are rejected by the quality control at the observation time. Note that as the quality control procedures are applied to each observation several times during the individual assimilation time window, the messages do not imply automatically that all of these observations are never used. It only means that these data are rejected at least at the individual observation time itself, when the checks give the best estimation about the data quality, and when the nudging weights would be largest.

The entries for each line denote the type of rejection. The entries 'uv', 'uv-10m', 'T', 'T-2m', 'RH', and 'RH-2m' indicate that an upper-air resp. surface-level wind, temperature, resp. humidity observation is rejected by the individual threshold quality control. The same applies to the entries 'p-TEMP' and 'ps' for pressure, except that 'p-TEMP' refers to a single pressure datum at the lowest model level as derived from radiosonde geopotential data. The entry 'IWV' relates to an integrated water vapour value (in [mm]), which is derived

from a ground-based GPS report (and possibly bias-corrected), and which is either rejected by the threshold quality control or is smaller than an absolute minimum threshold value (2 mm). For each entry, the following properties are given: station identity, code type (see Figure 6.8), observation time (relative to the model initial time, in [h]), pressure (in [hPa]) at the observation level, latitude and longitude (in [°]), threshold value for the difference, observed value, model value, and in some cases the difference between observed and model value. For wind, both the zonal and meridional value components are given, complemented

```
List of Observations Rejected by the Threshold Quality Control at the Observation Time
========================================================================================
                                                                                 Obs.
      Station ID Code Time Pressure Lat. Lon. Thresh. Var: Obs /Model  Var: Obs /Model  Diff Op.

uv    : 08019     137  0.0  893.9  43.5  -6.3 10.4 : u     5.5   -7.1 , v    -2.3    2.3  13.5
V-mult: 08019     137  0.0  915.8  43.5  -6.3        p-top: 367.6
T -2m : 62144      24  0.0 1000.1  53.4   1.7 12.0 : T   250.7  287.4  -36.6
uv-10m: 06012      14  0.0  995.7  62.3  -6.3 12.0 : u     2.9  -11.3 , v    -1.2  -10.0  16.7
RH    : EU6564    244  0.0  815.9  48.2  12.2  0.45: RH    0.46   0.96
RH    : EU6564    244  0.1  857.0  48.3  12.1  0.44: RH    0.48   0.95
RH    : EU6564    244  0.1  883.6  48.3  12.0  0.44: RH    0.46   0.94
RH    : EU6564    244  0.1  846.6  48.3  12.1  0.44: RH    0.48   0.96
RH    : EU6564    244  0.1  838.3  48.3  12.1  0.47: RH    0.50   0.97
q-mult: EU6564    244  0.1  846.6  48.3  12.1        p-top: 815.9
T-mult: EU9734    144  0.1  959.5  50.2  14.3        p-top: 729.9
T-mult: EU9734    144  0.2  694.2  50.3  14.1        p-top: 578.7
T-mult: EU9734    144  0.2  555.9  50.3  13.8        p-top: 483.4
T-mult: EU9734    144  0.3  465.6  50.2  13.5        p-top: 406.5
uv    : RCH7440   141  0.3  206.5  60.0 -20.3 16.1 : u    21.8   18.0 , v     7.8   13.8   7.1
T     : RCH7440   141  0.3  206.5  60.0 -20.3  6.9 : T   233.1  223.4
uv    : EU5261    244  0.7  507.1  51.2  11.6 14.0 : u    19.8   18.7 , v    15.6   14.3   1.7
T     : EU5261    244  0.7  507.1  51.2  11.6  5.1 : T   267.0  260.8
dz    : EU5261    244  0.6  984.7  51.4  12.2 26.1  p-top: 750.6  : dz   45.9, dT-mean   5.8
uv    : EU0350    244  0.7  197.0  50.1   8.6 16.1 : u   -15.9  -12.7 , v   -18.2  -37.0  19.1
T     : EU0350    244  0.7  197.0  50.1   8.6  7.1 : T   221.7  213.6
uv    : RCH8125   141  0.8  196.8  57.5 -17.6 16.1 : u    21.7   23.5 , v    15.7   12.8   3.4
T     : RCH8125   141  0.8  196.8  57.5 -17.6  7.1 : T   229.1  218.8
ps-scc: SKEC       24  1.0  994.6  56.1  16.6  3.3 : ps  994.6  998.5 , bias|w2:  -0.1   8.5
z-mult: 40179      35  1.5 1000.0  32.0  34.8        p-top:  50.0
RH    : 60571      35  1.8  604.0  31.5  -2.2  0.58: RH    0.02   0.66
RH    : 60571      35  1.8  500.0  31.5  -2.2  0.56: RH    0.11   0.86
RH    : 60571      35  1.8  485.0  31.5  -2.2  0.56: RH    0.10   0.82
IWV-sc: 60571      35  1.8  371.0  31.5  -2.2  5.2 :IWV    5.6   11.7 , bias|w2:   0.0   0.0
uv    : 16080      35  1.9   10.0  45.4   9.3 22.7 : u    19.4   -3.9 , v     1.5    3.6  23.5
T     : 16080      35  1.9   10.0  45.4   9.3 12.1 : T   226.9  211.1
z-mult: 17609      32  2.0  977.6  34.9  33.6        p-top: 783.1
z-mult: 17600      32  2.0  977.7  34.7  32.5        p-top: 844.1
ps    : 16080      35  2.0  985.0  45.4   9.3  5.0 : ps  985.0  990.0
ps-scc: 16080      35  2.0  985.0  45.4   9.3  5.5 : ps  985.0  987.0 , bias|w2:  -3.0  17.5
IWV   : TRYN-NGAA 834  2.2 ****** 61.4  12.4  2.82:IWV    6.87   9.73
IWV   : NYKO-NGAA 834  2.2 ****** 55.9  11.7  3.47:IWV    4.98   8.60
IWV   : OSV2-NGAA 834  2.2 ****** 60.2  17.2  3.05:IWV    5.24   9.08
IWV-sc: NYKO-NGAA 834  2.2 ****** 55.9  11.7  3.9 :IWV    5.0    8.6 , bias|w2:  -1.6   2.7
IWV-sc: TRYN-NGAA 834  2.2 ****** 61.4  12.4  3.0 :IWV    6.9    9.8 , bias|w2:  -0.7   1.2
RH-2m : 01415      35  2.4 1012.0  58.9   5.7  0.70: RH    0.05   0.80  -0.76
RH    : 01415      35  2.4  560.0  58.9   5.7  0.51: RH    0.22   0.76
q-mult: EU5331    244  2.4  618.0  48.9  12.5        p-top: 538.0
q-mult: EU5331    244  2.5  707.3  48.7  12.4        p-top: 639.2
z-mult: 17220      35  2.5 1000.0  38.4  27.2        p-top:  50.0
z     : 17220      35  2.5   10.0  38.4  27.2 312.1 (p-top:  10.0)    : z                324.2
RH    : 60571      35  3.0  500.0  31.5  -2.2  0.56: RH    0.11   0.88
IWV-sc: 60571      35  3.0  400.0  31.5  -2.2  5.2 :IWV    5.1   12.0 , bias|w2:   0.0   0.0
p-TEMP: 02527      35  3.0  948.4  57.7  12.5  5.0 : ps  948.4  955.0
ps    : 02527      11  3.0  953.0  57.7  12.5  5.0 : ps  953.0  959.5
ps    : 02527      35  3.0  953.0  57.7  12.5  5.0 : ps  953.0  959.6
z-mult: 02527      35  3.0  953.0  57.7  12.5        p-top: 500.0
T     : 26038      35  3.0  250.0  59.4  24.6  5.0 : T   207.1  212.4
T     : 26038      35  3.0  245.0  59.4  24.6  5.1 : T   206.7  212.5
T-mult: 26038      35  3.0  250.0  59.4  24.6        p-top: 150.0
dz    : 26038      35  3.0  250.0  59.4  24.6 96.9  p-top: 100.0  : dz -119.9, dT-mean  -4.5
ps-scc: 14427      11  3.0 1011.8  43.8  15.2  3.4 : ps 1011.8 1015.3 , bias|w2:   0.1  12.0
ps-scc: 16584      14  3.0 1011.9  41.1  16.8  3.6 : ps 1011.9 1008.3 , bias|w2:  -0.3   9.3
```

Figure 6.5: Example file `YUQUCTL`.

by the absolute value of the difference vector (in [m/s]). For relative humidity (in [ ]), the temperature values (in [K]) are also provided if the humidity observation is rejected only due to the rejection of the corresponding temperature observation. The same applies to aircraft temperature, if it is rejected due to the rejection of the wind observations, and vice versa.

The entry 'ps-scc' usually denotes a (surface) pressure report which after passing the individual threshold quality control is rejected by the spatial consistency check. However, if the entry follows immediately the entry 'ps' for the same report (e.g. report '16080' in Figure 6.5), it implies that the spatial consistency check accepts the observation by cancelling the rejection suggested by the individual threshold quality control. The 'ps-scc' lines are always complemented with the value for the bias correction applied to the model value used in the check, and with the total weight of the observations used to determine this bias. The same as for 'ps-scc' applies to entry 'IWV-sc', if it is related to a ground-based GPS observation. 'IWV-sc' can also occur for a radiosonde report − in this case, this means that the whole humidity profile report is rejected.

In the case of the entry 'z', the height observation increment as derived hydrostatically from multi-level temperature increments (and possibly a surface pressure increment) exceeds the threshold at the given pressure level. This implies that all temperature, humidity, and geopotential data from that level up to the top level 'p-top' of the multi-level profile are set passive. Similarly, the entry 'dz' means that these types of data are rejected due to the hydrostatic thickness check between the given pressure level and the pressure level 'p-top' which in this case does not coincide with the top level of the report in general. The specification of the threshold and the thickness increment is complemented here by the mean temperature increment 'dT-mean' corresponding to the thickness increment within the given vertical range.

Finally, the entries 'V-mult', 'T-mult', 'q-mult', and 'z-mult' indicate that the corresponding observations are set passive in the given pressure range due to the multi-level check. While rejection of temperature implies rejection of humidity, rejection of height does not imply rejection of temperature here.

6.1.5   YUCAUTN — Nudging: Warning Messages on Insufficient Array Sizes

The size of arrays which are used to store non-gridded observational information are a function of several NAMELIST parameters. This means that the values of these NAMELIST parameters determine the size of these arrays. If the values are too small, there are various places in the program, where such arrays may fail to accommodate all the available data. In such a case, the program will not crash or stop, but it will simply omit the surplus data and issue warning messages which always contain the label 'CAUTION'. This allows to 'grep' for it (yet there may be also other types of messages containing the word 'CAUTION'). Messages on short array sizes related to individual observational reports are written to the files YUREJCT (see section 6.1.3), YUPRINT (section 6.1.8), and / or to the standard output. The messages on YUPRINT are written by one processing unit and often take into account only one sub-domain on distributed-memory machines. In contrast, the whole model domain is considered by the messages on YUREJCT and the standard output. In addition, there are summary 'CAUTION' messages related to insufficient array size occurring in any of the sub-domains written to the files YUSTATS (section 6.1.6) and YUCAUTN.

In an operational setting, it is important that the model does not crash due to insufficient

```
CAUTION !!!!! t=     0: 1923 LOCAL SINGLE-LEVEL OBS. BEYOND maxsgl  5573
   ==>  INCREASE NAMELIST VARIABLE maxsgo BY AT LEAST  1381
CAUTION !!!!! t=     0:    88 LOC MULTI-LEV. AIRCRAFT REPORTS BEYOND ARRAY SIZE
CAUTION !!!!! t=     0:   203 LOCAL MULTI-LEVEL OBS. BEYOND maxmll   244
   ==>  INCREASE NAMELIST VARIABLE maxmlo BY AT LEAST   292
CAUTION !!!!! t=     0:   980 LOCAL GPS (IWV) OBS. BEYOND maxgpl  3344
   ==>  INCREASE NAMELIST VARIABLE maxgpo BY AT LEAST   587
...
CAUTION !!!!! t=    90: 2617 UPPER-AIR SINGLE-LEVEL OBS. INCR., ARRAY SIZE  2500
   ==>  INCREASE NAMELIST VARIABLE maxuso BY AT LEAST   117
CAUTION !!!!! t=   162: 4372 SURFACE PRESSURE OBS. INCREMENTS, ARRAY SIZE  4350
   ==>  INCREASE NAMELIST VARIABLE maxsgo BY AT LEAST    22
CAUTION !!!!! t=   270: 1374 MULTI-LEVEL STATIONS OF OBS. INCR., ARRAY SIZE  1351
   ==>  INCREASE NAMELIST VARIABLE maxmlo, maxgpo OR maxtvo BY AT LEAST    23
...
CAUTION !!!!! t=   252: 2452 IWV INCREMENTS FOR HUMIDITY CHECK, ARRAY SIZE  2350
   ==>  INCREASE NAMELIST VARIABLE maxmlo OR maxgpo BY AT LEAST   102
...
CAUTION !!!!! total number of reports  35088 > FOF size max_rep = 25056
   ==>  INCREASE SUM OF NAMELIST VARIABLES maxmlo + maxsgo + 2*maxgpo + 2*maxtvo
        BY AT LEAST   3344 FOR NetCDF FEEDOBS FILE fof_*
...
```

Figure 6.6: Example file YUCAUTN.

array size. Otherwise, any simple increase from one day to the next of the number of observations that are input to the data assimilation scheme could potentially cause a crash of the operational suite. Omitting the (presumably rather small number of) surplus observations will usually lead only to a minor degradation of the analysis, if at all. On the other hand, it should be made sure that the data assimilation does not run for weeks or months with too small array sizes.

The file 'YUCAUTN' serves this purpose. It is not created at all, except if one of the following two events occurs. Either there is an insufficient array size related to observational information, or an observation with unknown observation type has been read. Thus, if the file YUCAUTN is produced by the COSMO model, this implies that action needs to be taken to ensure an optimal use of the data in subsequent data assimilation cylces. (At DWD, e-mails are sent automatically to responsible persons if the file YUCAUTN is created in the operational suite or even in an experiment by the experimentation system NUMEX.)

If an unknown observation type is found, the reason has to be investigated. The event may indicate that there is a problem with the observation data base or with a pre-processing step before the data are read by the COSMO model. If an array size is too small, the value(s) of some NAMELIST parameter(s) have to be increased appropriately (this requires testing that there is enough memory available on the processors of the computer). File YUCAUTN also provides recommendations on how much to increase the value of which NAMELIST parameter. Even though the recommended increase is often sufficient to obtain appropriate array sizes everywhere, this is not always the case, particularly in situations where several arrays are too small for several reasons and the surplus data add to each other. Note that similar types of messages and recommendations are also given in file YUSTATS (see Section 6.1.6).

Figure 6.6 shows excerpts of an example file. Each message contains the model timestep (after 't ='), at which the message was issued. While in a real YUCAUTN file, the messages are ordered according to the timestep, they have been ordered thematically in the example shown here for convenience.

The first group of 4 messages relates to the observation reports themselves. After reading, the observations to be used at a certain timestep or later on are stored in arrays called 'observation data record' (ODR). The ODR is a local array, i.e. at each local node on a distributed-memory computing platform, only the data related to the respective model sub-domain are stored. The size of the ODR arrays depends on the `NAMELIST` parameters 'maxsgo' for single-level reports, 'maxmlo' for multi-level reports, and 'maxgpo' for GPS ZTD (or IWV) reports. The second message in Figure 6.6 simply means that the ODR size for multi-level reports is too small in order to accommodate all multi-level aircraft reports which could have been created from the input single-level reports. In this case, the aircraft reports do not have to be omitted (unless 'maxsgo' is also too small), but they are assimilated as single-level reports rather than multi-level reports as preferred.

The second group of 3 messages relates to the arrays containing the observation increments from the total model domain used at a certain timestep. There are four types of sets of increments in the scheme and hence four types of families of arrays in the code: multi-level, upper-air single-level, surface-level, and surface pressure increments. The length of the respective arrays correspond to the number of stations (in case of temporal linear interpolation) or reports (otherwise) with active observation increments (or reports to be written to the `YUVERIF` or NetCDF feedobs files). These lengths are given by the `NAMELIST` parameters 'maxmlo + maxgpo/2 + 1' for multi-level, 'maxuso' for upper-air single-level, 'maxsgo' for surface level, and 'maxsgo + maxmlo' for surface pressure increment arrays. Note that e.g. from the GPS ZTD observations, profiles of humidity increments are derived. Therefore, the size of the multi-level increment arrays also depends on 'maxgpo'.

The next message relates to an array that is used purely for the spatial consistency quality check for integrated water vapour (IWV) derived from GPS ZTD and from radiosonde humidity profile data. The final message in Figure 6.6 indicates that there is insufficient space in the NetCDF feedobs file to write all the observations onto that file.

6.1.6 `YUSTATS` — Nudging: Statistics on Observation Processing

`YUSTATS` provides statistics on the processed observations and on the analysis increments accumulated over time. It consists of several parts.

In the first part (Figure 6.7), the domain-averaged analysis increments integrated over time since the beginning of the model integration are provided once every hour (the last hour is written almost at the end of the file). For the 3-dimensional variables wind speed '|v|', wind direction, temperature 'T', pressure 'p', geopotential 'FI', specific water vapour content 'qv', and specific cloud water content 'qc', this information is given for each vertical model level separately, and this results in vertical profiles of the domain averaged analysis increments. Note that the time integrated values are obtained by updating them with the analysis increments from the nudging (without the latent heat nudging) at each model timestep, i.e. it is the sum over the nudging increments from every timestep. This can be very different from the difference 'analysis minus first guess', if 'first guess' is e.g. a 3-hour free forecast. The reason is that the model dynamics and physics can react to the changes of the model state from the nudging by producing modfied dynamics and physics tendencies in the subsequent timestep(s).

The second part of `YUSTATS` (Figure 6.8) shows the number of processed, active, passive, and rejected reports for each observation type and code type. The meaning of the type

numbers is also specified. The third part (Figure 6.9) first mentions the conditions for a report to be set passive rather than rejected. In contrast to rejected reports, passive reports are processed further for being written to the VOF file `YUVERIF` and / or the NetCDF feedobs file for verification purposes (if `NAMELIST` variable 'lverpas' is set to '.TRUE.'). The subsequent 'REPORT EVENTS' table declares the reasons in a statistical sense (rather than for each individual report), why a certain number of the reports of a certain code type is set passive or rejected. Further report events relate mainly to the processing of aircraft reports. The 'DATA EVENTS' tables in the forth part (Figure 6.10) provide similar statistical information on the reasons for rejecting parts of reports, i.e. either complete observation levels or single observations.

The fifth part (Figure 6.11) finally delivers the hourly maximum total number of stations (in case of temporal linear interpolation) or reports (otherwise) with active observation increments. There are four types of sets of increments in the scheme and hence four types of families of arrays in the code: multi-level, upper-air single-level, surface-level, and surface pressure increments. The length of the corresponding arrays, listed in the table as 'array bounds', are a function of `NAMELIST` parameters: 'maxmlo + maxgpo/2 + 1' for multi-level, 'maxuso' for upper-air single-level, 'maxsgo' for surface level, and 'maxsgo + maxmlo' for surface pressure increment reports.

If the array lengths which depend on the selected values of these `NAMELIST` parameters are not sufficiently large, there are various places in the program, where arrays may fail to accommodate all the available data. The program will not crash or stop in such a case, but it will simply omit the surplus data and issue warning messages which always contain the label 'CAUTION'. For more information on this concept, see Section 6.1.5. As already mentioned there, summary messages are also written to `YUSTATS`. As shown in Figure 6.12, there are two types of messages. The first one relates to the arrays which store internally the observation

```
1      Diagnostics on time-integrated analysis increments
       2009022409 + 2 h: horizontal mean of  2-hourly sums of analysis increments
                       TQV [g/m2]     TQC [mg/m2]      Dry Static Energy [J/kg]
                       -389.070        7539.854           0.003 (volumn mean)
       level p0(k)      |v|     wind dir      T         p         FI       qv       qc
             hPa        m/s       deg         K        hPa      m2/s2     g/kg     mg/kg
         1    30.00    -0.174    -14.29     0.728      0.13     211.7     0.000    0.000
         2    50.18    -0.074    -73.22     1.228      0.08      88.7     0.000    0.000
         3    70.87    -0.025   -124.75    -0.064      0.04      32.7     0.000    0.000
         4    92.35     0.241    -46.38    -0.176      0.06      41.5     0.000    0.000
         5   114.84     0.150     -5.74     0.186      0.07      41.1     0.000    0.000
         6   138.49     0.096      8.00     0.267      0.06      28.1     0.000    0.000
         7   163.43     0.247     -5.58     0.695      0.01       3.9     0.000    0.000
         8   189.73     0.377    -23.58     0.051     -0.04     -13.5     0.000    0.000
         9   217.42     0.302      7.52    -0.379     -0.02      -6.9     0.000    0.000
        10   246.48     0.227    -10.69    -0.273      0.02       4.5     0.000    0.000
        11   276.87     0.144     -8.65    -0.221      0.06      12.4    -0.001    0.000
        12   308.52     0.109     -6.54    -0.232      0.10      19.8    -0.002    0.002
...
        29   867.95    -0.017     37.67     0.046      0.18      16.2    -0.067    4.879
        30   890.50    -0.021     44.06     0.045      0.18      15.9    -0.084    7.029
        31   910.85    -0.021     38.69     0.109      0.18      15.5    -0.122    3.819
        32   928.96    -0.031     69.08     0.146      0.18      14.9    -0.109    1.592
        33   944.79    -0.092     76.08     0.138      0.17      14.3    -0.101    0.094
        34   958.36    -0.207     50.72     0.138      0.17      13.9    -0.083   -0.338
        35   969.73    -0.301     20.85     0.175      0.16      13.5    -0.075   -0.007
        36   979.00    -0.339     -1.08     0.216      0.16      13.0    -0.069    0.544
        37   986.31    -0.353    -19.18     0.249      0.15      12.6    -0.070    0.494
        38   991.87    -0.366    -37.67     0.255      0.15      12.2    -0.088    0.447
        39   995.93    -0.375    -51.05     0.251      0.15      12.0    -0.092    0.369
        40   998.82    -0.377    -63.93     0.251      0.10       8.0     0.095   -0.121
```

Figure 6.7: Example file `YUSTATS`, first part (incomplete).

```
1
0 ---DISTRIBUTION OF PROCESSED/ACTIVE/PASSIVE/REJECTED REPORTS FOR ASSIMILATION
0                                       processed    active   passive rejected
0
0 --- total number of reports              59556     38808     14041    11437
      reports with unknown obs/code type       0         0         0        0
0 --- observation type 1     SYNOP          16011     11860      1025     4959
      code type  11      SYNOP Manual Land    5955      4951       457     1025
      code type  14      SYNOP Automatic Land 9430      6418       537     3830
      code type  21      SHIP                  126        90         6       30
      code type  22      SHIP Abbreviated        0         0         0        0
      code type  23      SHIP Reduced SHRED      0         0         0        0
      code type  24      SHIP Automatic        500       401        25       74
      code type 140      METAR                   0         0         0        0
0 --- observation type 2     AIREP          11716     10214       926      576
      code type  41      CODAR                   0         0         0        0
      code type 141      AIREP Aircraft        386       178         9      199
      code type 144      AMDAR                4721      4167       321      233
      code type 244      ACARS                6609      5869       596      144
      code type 241      COLBA Const Lev Ball    0         0         0        0
0 --- observation type 3     SATOB              0         0         0        0
0 --- observation type 4     DRIBU            778       138         0      640
      code type  63      BATHY                   0         0         0        0
      code type 165      DRIBU Drifting Buoy   778       138         0      640
0 --- observation type 5     TEMP             549       114         1      434
      code type  35      TEMP Land             531       111         0      420
      code type  36      TEMP SHIP              18         3         1       14
      code type  37      TEMP Mobile             0         0         0        0
      code type  39      ROCOB Land              0         0         0        0
      code type  40      ROCOB SHIP              0         0         0        0
      code type 135      TEMP DROP               0         0         0        0
0 --- observation type 6     PILOT           1389       601       740      262
      code type  32      PILOT Land             25         2         3       20
      code type  33      PILOT SHIP              0         0         0        0
      code type  38      PILOT Mobile            0         0         0        0
      code type 132      Wind Profiler (Eur)   235       107       128        0
      code type 133      RASS / SODAR   (Eur)   40         4        36        0
      code type 136      Wind Prof/RASS (US)     0         0         0        0
      code type 137      RADAR VAD Wind Prof. 1089       488       573      242
0 --- observation type 7     SATEM              0         0         0        0
0 --- observation type 9     Scatterometer   1322      1145         0      177
      code type 123      ASCAT scatterometer  1322      1145         0      177
      code type 122      QuickScat scatterom.    0         0         0        0
0 --- observation type12     GPS            27791     14736     11349     4389
      code type 800      GPS by METO          4270      2127      2097      347
      code type 900      GPS by MET_             0         0         0        0
      code type 821      GPS by ASI_           939       152       727      162
      code type 823      GPS by GFZ_             0         0         0        0
      code type 824      GPS by GOP_           352       153       199       46
      code type 924      GPS by GOPE             0         0         0        0
      code type 825      GPS by IEEC             0         0         0        0
      code type 826      GPS by LPT_           802       406       188      308
      code type 926      GPS by LPTR          1800       722       607      833
      code type 829      GPS by SGN_          3581      2483       906      519
      code type 929      GPS by SGN1          3335       600      2567      377
      code type 830      GPS by BKG_           564       548         4      143
      code type 930      GPS by BKGH             0         0         0        0
      code type 832      GPS by ROB_             0         0         0        0
      code type 833      GPS by KNMI          1122       683       439      228
      code type 933      GPS by KNM1           621       376       245      106
      code type 834      GPS by NGAA          4602      4094       400      184
      code type 934      GPS by NGA_             0         0         0        0
      code type 835      GPS by IGE_          2424      1228       917      579
      code type 837      GPS by ROB_          3379      1164      2053      557
      code type 899      GPS by XXX_             0         0         0        0
0
  --- Notes on the table above:
      "Rejected"/"passive" means that the whole report is rejected /set passive.
      Partly rejected and partly passive reports are labeled "active".
      A report can be labeled "active" even if part of its data is black listed.
```

Figure 6.8: Example file YUSTATS, second part.

```
        Reports may only be rejected or set passive for reasons given by report
          events 1 - 13 , except for events 3 and 5 (on station altitude) for
          TEMPs and PILOTs. Hence, the number of these events must equal the
          number of rejected and passive reports.
        In the verification mode (i.e if data are written to the VOF), reports are
          rejected in case of report events 1 - 3, 8 - 13, and event 4 if the re-
          port is outside the model domain. Otherwise the reports are set passive,
          except that already passive reports are also rejected if they do not
          contain any data or if they are redundant and a subset of an active
          report.
        Without verification, reports are always rejected for events 1 to 13.
0
1 *** REPORT EVENTS DEFINITIONS (THEIR ORDER MATCHES THE ORDER OF THE CHECKS):
          1 = DATA BASE FLAG ON LOCATION / TIME / ALTITUDE HIGH
          2 = OBSERVATION TIME OUT OF RANGE (TOO OLD) (OR TIME MISSING)
          3 = STATION ALTITUDE MISSING
          4 = STATION LOCATION OUT OF DOMAIN OR OUT OF USER-SPECIFIED AREA
          5 = DISTANCE "MODEL OROGRAPHY - STATION ALTITUDE" TOO LARGE
          6 = BLACKLISTED SHIP
          7 = OBSERVATION OR CODE TYPE EXCLUDED IN AREA AROUND STATION LOCATION
          8 = REPORT NUMBER EXCEEDING SIZE OF ODR (==> ADJUST NAMELIST !!!)
          9 = NO ACCEPTED DATA IN REPORT
         10 = PRESSURE TOO SMALL ( < 9 HPA), OR MISSING WITH AIRCRAFT REPORT
         11 = REDUNDANCY BETWEEN 2 MULTI-LEVEL, OR 2 SINGLE-LEVEL REPORTS
         12 = FLIGHT TRACK SUSPICIOUS, OR EXAGGERATED COLOCATION
         13 = THINNING OF DENSE AIRCRAFT FLIGHT TRACK
         14 = SURFACE LEVEL FROM MULTI-LEVEL REP. REDUNDANT AGAINST OTHER REPORT
         15 = ONE MULTI-LEVEL REPORT MADE FROM SINGLE-LEVEL REPORTS
         16 = SINGLE-LEVEL REPORT PUT IN MULTI-LEVEL REPORT AND SET PASSIVE
         17 = MULTI-LEVEL REPORT NOT BUILT DUE TO ODR SIZE LIMIT: ADJUST NAMELIST
0
     events      1  2  3    4    5  6    7  8    9 10    11 12    13 14   15    16 17
     ------
0 *SYNOP
SYNOP Manual Land 0  0  0  496 329  0    0508   54  0  125  0     0  0    0     0  0
SYNOP Automatic L 0  0  0   81 415  0    0***  2439 0   77  0     0  0    0     0  0
SHIP              0  0  0   30   6  0    0  0    0  0    0  0     0  0    0     0  0
...
SHIP Automatic    0  0  0   15   7  0    0  0   59  0   18  0     0  0    0     0  0
0 *AIREP
CODAR             0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
AIREP Aircraft    0  0  0  199   0  0    0  0    4  0    3  0     2  0    0     0  0
AMDAR             0  0  0  233  67  0    0  0    0  0  185  0    69  0  342  2359 38
ACARS             0  0  0  144  50  0    0  0    3  0  109 40   394  0  148  1632 87
COLBA Const Lev B 0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
0 *SATOB
SATOB             0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
High-res VIS Wind 0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
AMV               0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
SST as DRIBU      0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
0 *DRIBU
BATHY             0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
DRIBU Drifting Bu 18 0  0  399   0  0    0  0  223  0    0  0     0  0    0     0  0
0 *TEMP
TEMP Land         0  0  0  116   0  0    0  0   71  0    7  0     0139   0   226  0
TEMP SHIP         0  0 18    4   2  0    0  0    3  0    0  0     0  0    0     6  0
...
0 *PILOT
PILOT Land        0  0  0   12   0  0    0  0    5  0    4  0     0  0    0     2  0
PILOT SHIP        0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
PILOT Mobile      0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
Wind Profiler (Eu 0  0  0    0   7  0    0  0   87  0   41  0     0  0    0     0  0
RASS / SODAR  (Eu 0  0  0    0   0  0    0  0   36  0    0  0     0  0    0     0  0
Wind Prof/RASS (U 0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
RADAR VAD Wind Pr 0  0  0    0  96  0    0214  584  0   17  0     0  0    0     0  0
0 *SATEM
...
0 *Scatterometer
ASCAT scatteromet 0  0  0  177   0  0    0  0    0  0    0  0     0  0    0     0  0
QuickScat scatter 0  0  0    0   0  0    0  0    0  0    0  0     0  0    0     0  0
0 *GPS
GPS by METO       0  0  0   46  92  0    0301    0  0 2005  0     0  0    0     0  0
...
GPS by LPT_       0  0  0   36 144  0    0116   28  0  188  0     0  0    0     0  0
GPS by LPTR       0  0  0    0 400  0    0425   71  0  607  0     0  0    0     0  0
GPS by BKG_       0  0  0    0  12  0    0133    0  0    4  0     0  0    0     0  0
...
```

Figure 6.9: Example file YUSTATS, third part (incomplete).

reports themselves from the local sub-domain, and the second one to arrays containing the observation increments from the total model domain that are used at a certain timestep. Both types of events, the relation to certain `NAMELIST` parameters, and considerations on the recommendations on how much to increase the values of these parameters are already decribed in detail in Section 6.1.5.

```
1 *** DATA EVENTS DEFINITIONS (LEVEL EVENTS APPLY TO MULTI-LEVEL DATA ONLY,
                        THE ORDER OF ALL EVENTS MATCHES THE ORDER OF
                        THE CHECKS EXCEPT FOR EVENT 8
        1 = LEVEL REJECTED: NUMBER OF LEVELS EXCEEDING ODR SIZE
        2 = LEVEL REJECTED: PRESSURE (PILOT: PRESSURE AND HEIGHT) MISSING
        3 = LEVEL REJECTED: PRESSURE (PILOT: HEIGHT) FLAGGED
        4 = LEVEL REJECTED: TOO MANY SURFACE LEVELS
        5 = LEVEL REJECTED: PILOT HEIGHT LEVEL OUTSIDE RANGE OF MODEL LEVELS
        6 = LEVEL REJECTED: PRESSURE < 9 HPA, OR LEVEL BELOW STATION HEIGHT
        7 = LEVEL REJECTED: SIGNIFICANT LEVEL ABOVE A SPECIFIED LIMIT
        8 = LEVEL REJECTED: REDUNDANT LEVEL IN REPORT  (NOT ACTIVE YET)
        9 = PRESSURE (TEMP: HEIGHT): MISSING
       10 = PRESSURE (TEMP: HEIGHT): FLAGGED
       11 = PRESSURE: BAD REPORTING PRACTICE
       12 = PRESSURE: HEIGHT DISTANCE TO OROGRAPHY OR STATION HEIGHT TOO LARGE
       13 = PRESSURE TENDENCY: FLAGGED, OR ABSOLUTE VALUE > 40 HPA/3H
       14 = TEMPERATURE: MISSING (TEMP: AT SIGNIFICANT TEMPERATURE LEVELS ONLY)
       15 = TEMPERATURE: FLAGGED
       16 = TEMPERATURE: < -90 C,  OR  > +60 C  (P < 700HPA: > +20 C , ETC)
       17 = TEMPERATURE AT 2M: HEIGHT OR HEIGHT DISTANCE TO OROGRAPHY TOO LARGE
       18 = TEMPERATURE (TEMP ONLY): LAPSE RATE TOO LARGE
0
    events          1  2  3 4  5   6     7  8     9   10 11  12 13   14 15 16   17 18
    ------
0 *SYNOP
SYNOP Manual Lan   0  0  0 0  0   0     0  0   129   20  2 257  0   36  0  0  200  0
SYNOP Automatic    0  0  0 0  0   0     0  0  4303   13  0 111  0 2569  0  0  119  0
SHIP               0  0  0 0  0   0     0  0     1    4  0   0  0    0  0  0    0  0
...
TEMP Land         38  1  0 0  0 216  3402  0  4212   77  0   0  0  519 93  0    0 18
...
GPS by LPTR        0  0  0 0  0   0     0  0  1038    0  0   0  0 1038  0  0    0  0
...
...
1 *** DATA EVENTS DEFINITIONS (CONTINUED):
       19 = HUMIDITY: MISSING (TEMP: AT SIGNIFICANT LEVELS BELOW 300 HPA LEVEL)
       20 = HUMIDITY: FLAGGED
       21 = HUMIDITY: DEWPOINT < -150 C (SURFACE-LEV OBS: < -90 C), OR > +40 C
       22 = HUMIDITY: ABOVE 300 HPA LEVEL
       23 = HUMIDITY: EXCEEDING ALLOWED VALUE (120%)
       24 = HUMIDITY: FORCED TO BE SATURATED (T>O)
       25 = HUMIDITY: FORCED TO BE SATURATED (T<O)
       26 = HUMIDITY: FORCED TO BE <= 100% (T>0)
       27 = HUMIDITY: FORCED TO BE <= 100% (T<0)
       28 = HUMIDITY AT 2M: HEIGHT OR HEIGHT DISTANCE TO OROGRAPHY TOO LARGE
       29 = WIND DIRECTION: MISSING
       30 = WIND SPEED: MISSING
       31 = WIND DIRECTION: FLAGGED , OR ABSOLUTE VALUE > 360 DEGREES
       32 = WIND SPEED: FLAGGED
       33 = WIND SPEED: < 0 (DRIBU: <= 0) , OR > 150 M/S (P > 700HPA: > 90 M/S)
       34 = WIND AT 10M: HEIGHT OR HEIGHT DISTANCE TO OROGRAPHY TOO LARGE
       35 = WIND SPEED: SHEAR TOO LARGE
       36 = WIND DIRECTION: SHEAR TOO LARGE
       37 = PRECIPITATION: AMOUNT EXCEEDING THRESHOLD LIMIT
       38 = ZENITH PATH DELAY MISSING OR TOO SMALL
0
   events         19 2021   22 23   24  2526  27  28   29     30 31 32 33   3435 36 37   38
   ------
0 *SYNOP
SYNOP Manual La  67  1 0    0 16  178   49 0    0  200   47 58  0  0  0 2739 0  0  0    0
SYNOP Automatic2623  1 0    0  0  190  102 1    1 11435573559  0  0  0 1851 0  0  0    0
SHIP             13  0 0    0  0    3    0 0    0    0    0  0  0  0  0    3 0  0  0    0
...
TEMP Land         0 43 0 1214  0   23   69 0    0    0   95 95 24 24  0   99 1  0  0    0
...
GPS by LPTR       0  0 0    0  0    0    0 0    0    0    0  0  0  0  0    0 0  0  0   71
...
```

Figure 6.10: Example file `YUSTATS`, forth part (incomplete).

```
1
0 ---HOURLY MAX. TOTAL NUMBER OF STATIONS WITH ACTIVE OBSERVATION INCREMENTS
+              (only for MPP applications)
+ ---                   multi-   |  upper-air   | surface- | surface
+                       level    | single-level |  level   | pressure
+      1. hour :         1224         2608           3589      3960
+      2. hour :         1331         2617           3995      4372
+      3. hour :         1293         2550           3995      4439
+      4. hour :         1374         2531           3428      4115
+      total max.  :     1374         2617           3995      4439
+      array bounds:     1351         2500           4000      4350
```

Figure 6.11: Example file `YUSTATS`, fifth part.

6.1.7 `YUVERIF` — Nudging: Verification File VOF

`YUVERIF` is called 'Verification Observation File' VOF and lists all the active observations, of which the observation time lies within a selected period between the beginning and the end of the model integration time. It is important to note that under normal circumstances it never lists all the observations which are used actively in the nudging (and which e.g. enter the statistics shown in file `YUSTATS`). This is due to the use of a finite temporal weight function for the relaxation, so that the nudging also uses data that are older than the beginning of the model integration time. In a data assimilation cycle, moreover, it normally also uses data with observation time later than the end of the model run. These data outside the model integration time are never written to `YUVERIF`.

`YUVERIF` is written only if the `NAMELIST` variables 'lverif = .TRUE.' and 'mveripr $\geq$ 2'. Passive reports and the deviations of the observed values from the model values, i.e. the observation increments, are optionally included. Furthermore, `YUVERIF` can be post-processed

```
+      !!! CAUTION !!!!! CAUTION !!!!! CAUTION !!!!! CAUTION !!!!! CAUTION !!!!!
+      ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
0      WARNING: array size for multi-level observations is too small
       ======  to accommodate all observations
        --> Increase "MAXMLO" (namelist) by  312: usually ok for local obs. array
            ================                      (possibly still insufficient for
                                                   the global obs increment array!)
...
0      WARNING: array size for GPS observations is too small
       ======  to accommodate all observations
        --> Increase "MAXGPO" (namelist) by 1190: usually ok for local obs. array
            ================                      (possibly still insufficient for
                                                   the global obs increment array!)
...
1
0      !!! CAUTION !!!!! CAUTION !!!!! CAUTION !!!!! CAUTION !!!!! CAUTION !!!!!
+      ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
+      WARNING: array size for multi-level obs. increments is
       ======  too small to accommodate all obs. increments
        -->  Increase "MAXMLO" (namelist) from 350 to at least 373
          or increase "MAXGPO" (namelist) from2000 to at least2046
          or increase "MAXTVO" (namelist) from   1 to at least  24
              ================
+      WARNING: array size for upper-air single-level obs. increments is
       ======  too small to accommodate all obs. increments
        -->  Increase "MAXUSO" (namelist) from 2500 to at least 2617
              ================
+      WARNING: array size for surface-level obs. increments is
       ======  too small to accommodate all obs. increments
        -->  Increase "MAXSGO" (namelist) from 4000 to at least 4089
              ================
```

Figure 6.12: Example file `YUSTATS`, warning messages related to specified array sizes.

```
VOF: Verification Observation File: Version 3
Verification period: initial date and hour 2009022409
                     start: 0.0000 , end:  3.0000
Set-up of the reference model run, used for threshold quality control (QC):
- LM-grid: pole:  40.00 -170.00 , lower left corner:  -20.000  -18.000
           resolution: 0.06250 0.06250 , upper right:  21.000   23.500
           domain size:  665  657  40
- Initial date and time: 2009022409
- QC time step :    720. [s]
- QC thresholds: upper-air, vertical table:    5.00    1.00   10.00    1.00
                 upper-air, constant part :    0.00  500.00    0.00    0.00
                 upper-air, time factor   :    0.10    0.20    0.10    0.03
                 surface  , constant part :   12.00  500.00   12.00    0.70
                 surface  , time factor   :    0.10    0.20    0.10    0.03

Number of model runs to compare with observations: 1
Domain used for verification (rotated pole: see above):
     lower left corner: -20.000 -18.000 , upper right:  21.000   23.500
     domain size:  665  657
Types assigned to "model runs" in table below:
     = 0: the "model run" is one straightforward model integration
     > 0: the "model run" comprises of x-hourly periods from a series of cycled
          integrations starting at x-hour intervals (x = 6, 12 or 24), and
          the initial date and time relates to the latest of these integrations
     = 2: the "model run" is a series of analyses
          |               |forecast time | horiz. | number |
 model    |   initial     |at the end of | mesh   |  of    |
  run     |date and hour  | verification | width  |vertical| description of
no.|type| of the run    | period [hrs] |[1/deg.]| levels | the model run
 1   02   2009022412          0.0000       16.00    40      analysis

  -4 COMO-METO    910 4580    30   247   293 12 800        102         2000 2 0  279  253
 603 650   -9   -9    -9 2286  32   0           0 64  42
   78
  -4 COMO-SGN_    910 4580    30   247   293 12 829        102         2000 2 0  279  253
 433 9999   -9   -9    -9 2275  32   0           0 64  -9
  -92
  -4 COMO-BKG_    910 4580    30   247   293 12 830          0           0 0 0  279  253
 411 9999   -9   -9    -9 2274  32   0           0 64  -9
 -114
  -1 004          337 5446    98     0     0  9 123        200           0 0 0  227  395
  47    5   -9   -9    -9    0   1   0           0 64  -9 -9   -9 17777777777 17777777777   -9
  -30  117 9999 9999  9999  -9  -9  -9    -9
  -1 63551         84 6746   120     0     0  4 165        200           0 0 0  230  604
9999 9999   -9   -9 101510    0   8   0           0 64 510 -9   -9 17777777777  1777777777   -9
9999 9999 9999 9999   -58  -9  -9  -9    -9
   0 07497        677 4562   120   868  1649  1 11        412          40 2 2  253  252
 -10    2 2785  522 91790  868   0   0   203004020  1 501  3 2500 17714653400 1766252774   -9
  -9   -9   -9    2  -9    -9
  -90    9  692  -27    48   13   0  -9    -9 9999 9999 9999 9999 9999
  -1 Q671         948 4839   120   750   749  1 14          0           0 0 0  284  295
   7  -19 2726 1000    -9   750   6   0          20  1 -9 -9   -9 17777777777  1762277775   -9
 -174  211  -40   15  9999  -9  -9  -9    -9
  -3 EU5331      1215 4842   152  -999   495  2 244 140000000           0 0 0  312  296
   1  -26 2685  655 88251 1150   7   0  400140600 384  -9
  156   91  -18 -118
  -3 EU5331      1207 4839   153  -999   481  2 244 140000001       10000 1 0  311  295
   6  -35 2693  585 88251 1150   7   0  400140600 384  -9
  158  -18   69 -240
   6 EU5331      1207 4839   153  -999   481  2 244 140000000           0 0 4  311  295
   6  -35 2693  585 88251 1150   7   0  400140600 384
   3  -26 2690  629 88144 1160   7   0  400140600 384
   7  -35 2680  570 86970 1270   7   4  400140600 384
  -1  -31 2670  639 85808 1380   7   4  400140600 384
   2  -41 2665  624 84868 1470   7   4  400140600 384
   4  -51 2655  667 84038 1550   7   4  400140600 384
  158  -18   69 -240 9999
  129   75   45 -199 9999
  191  -20   22 -291 9999
  135   63    6 -257 9999
  140   -6   18 -295 9999
  120  -78  -29 -270 9999
  9999
  -3 EU5331      1210 4840   153  -999   477  2 244 140000001       10000 1 0  311  296
   3  -26 2690  629 88144 1160   7   0  400140600 384  -9
  151   75   47 -178
  -3 EU5331      1212 4840   153  -999   495  2 244 140000102        2000 2 0  312  296
   2  -21 2688  640 88251 1150   7   0  400140600 384  -9
  173  142   12 -133
  -3 EU5331      1202 4837   154  -999   458  2 244 140000001       10000 1 0  310  295
  -1  -31 2695  543 88251 1150   7   0  400140600 384  -9
   56   16   95 -317
  -3 EU5331      1204 4839   154  -999   481  2 244 140000102        2000 2 0  311  295
   2  -31 2693  552 88251 1150   7   0  400140600 384  -9
  122   28   69 -274
  -9 xxxxx          0    0     0     0     0  0  0           0         0 0 0    0    0
```

Figure 6.13: Example file `YUVERIF`.

by means of additional programs to include also the deviations e.g. from different forecast runs and to derive statistical quantities. Thus, it can be used for monitoring, validation, and verification purposes.

Figure 6.13 shows a short example for `YUVERIF`. The file begins with a header part which is mostly self-explanatory. Note that the 'initial date and hour of the run' entry in the table at the end of the file header relates to the formal initial time of the forecast, which is set to the final model integration time for an assimilating run. Then, the file body with the list of reports follows. In the current example, it consists of a subset of the reports already shown in Figures 6.2 and 6.3 for `YUOBSDR`, namely 3 GPS ZTD (IWV), 1 scatterometer, 1 buoy, 2 Synop, 6 aircraft single-level, and 1 aircraft multi-level report. The last line of the file has always the same form in order to indicate the end of file.

Each report consists of a report header, a regular report body, and an optional report body extension which contains the devations of the observed values from the model values. In the report header und regular body, there are entries consisting of long bit patterns. These entries are written to `YUVERIF` as octal numbers, so that each digit consists of 3 bits. This makes it easy to directly make out in the formatted ASCII file, which bits are set.

The following description details the VOF file body for the case that the observations are read from NetCDF observation input files. If the observations are read from an AOF file, not all the details are exactly as described here, particularly the flags.

Report Header

For each type of report, the header has the same format and consists of 15 entries in one line:

report header

1. basic report type: > 0 : multi-level report : number of vertical levels
   = 0 : complete synoptic surface-level report (SYNOP)
   = −1 : short surface-level report (with cloud and precipitation)
   = −2 : very short surface-level report (without cloud and precip)
   = −3 : upper-air single-level report
   = −4 : GPS report on integrated water vapour (IWV)
2. station identity
3. longitude of observing station   [1/100 deg]
4. latitude of observing station   [1/100 deg]
5. observation time, relative to initial verification hour (see VOF header)   [min]
6. station altitude   [m]
7. height of model orography at station location   [m]
8. observation type   (see Figure 6.8)
9. code type   (see Figure 6.8)
10. station characteristics   (bit pattern as octal number, see below)
11. report flag word (reasons for status ≥ 1)   (bit pattern as octal number, see below)
12. report status   = 0 : active report, i.e. used by nudging (or LETKF)
    = 1 : single-level aircraft set passive because used as part of a multi-level rep.
    = 2 : passive report, i.e. not used by nudging (or LETKF)
13. threshold quality control (QC) flag for extrapolated surface pressure from multi-level
    radiosonde report = 0 : active data used, value ok
    = 1 : active data used, value not ok
    = 2 : only passive data used, value ok
    = 3 : only passive data used, value not ok
    = 4 : no data at all usable
14. , 15. x- resp. y- coordinate of model grid point to which report is assigned

The station characteristics is given by the following bit pattern (the description related to a
bit number is true only if that bit takes the value of 1):

  bit numbers of : **station characteristics**
   0 : single-level report set passive because it is used as part of a multi-level report
   1 : report set passive because at least 1 flag at positions 2−6 or 20−21 is set
   2 : flag: station location outside of user-specified area
   3 : flag: distance between model orography and station altitude too large
   4 : flag: suspicious aircraft identity
   5 : flag: observation or code type excluded at station location (user-specified)
   6 : flag: redundant report
   7 : report located at sea grid point
   8 : station correction indicator
   9 / 10 : station suspicion indicator / important station indicator
  13−19 : instrument specification word (only for obs reports read from AOF file)
  20 : flight track error flag
  21 : flight thinning flag
  22−25 : indicator for phase of flight (aircraft), code table WMO descriptor '0 08 004':
       = 2 : unsteady   = 3 , 4 : level flight
       = 5 : ascending   = 6 : descending   = 7 : missing value
  26−27 : aircraft roll angle (WMO descriptor '0 02 064', not used for report status)

The report flag word indicates all reasons why a whole report is not used actively in the assimilation (nudging or LETKF). This flag word is given by the following bit pattern (a flag is true if the bit is set to 1; the report flag is equal to the quality check flags for reports in the NetCDF feedobs file, see 'Feedback File Description'):

    bit numbers of : **report flag word**
     0 : passive report type (at observation location)
     1 : blacklisted (or not on whitelist)
     2 : suspicious location or date/time
     4 : location not in valid area
     5 : location not in valid height range
     6 : incorrect surface (land, ice, etc.)
   10 : redundant report
   11 : flight track error flag
   12 : report merged into another report (e.g. aircraft single-level into multi-level report)
   13 : thinning
   19 : no active observations in report

Note that the report flag word is written only if the observations are read from NetCDF observation input files. If the observations are read from an AOF file, a different flag word (not described here) is used.

Report Body

The regular report body contains all the observed values and the quality flags for the individual data. It has 22 entries for complete synoptic surface-level reports, the last 6 of which are written to the VOF in a second line. For the other basic types of reports, the last few entries are omitted in such a way that the body length is as follows:

body length = 22 : for complete synoptic surface-level reports
          = 16 : for short surface-level reports (see also report header)
          = 11 : for upper-air single-level or very short surface-level reports
          = 10 : for (each observation level of) multi-level reports
          = 11 : for ground-based GPS reports on ZTD / IWV (integ. water vapour)

For multi-level reports, the regular report body consists of as many lines with 10 entries each as there are observation levels. The following list declares the complete set of 22 entries:

regular report body
1.   zonal wind component   [1/10 m/s]
      (for GPS reports : derived IWV (ice-to-water saturat. + bias adjusted) [1/100 mm])
2.   meridional wind component   (GPS: reported IWV [1/100 mm])   [1/10 m/s]
3.   temperature   [1/10 K]
4.   relative humidity (ice-to-water saturation adjusted)   [1/10 %]
5.   pressure   [Pa]
6.   height   (GPS: zenith total delay (ZTD) [mm])   [m]
7.   observation status flag   (bit pattern as decimal number, see below)
      (if bit is set to 1 then the obs is *active unless* − the QC flag is set, or
                                      − status $\neq$ 0 in report header)
8.   QC flag   (bit pattern as decimal number, see below)
      (if bit is set to 1 then the obs is *rejected* by the threshold quality control;
        bit 3 for height is also set if upper-air obs is below model orography)

9. main flag word for wind, temperat., humidity, pressure   (as octal number, see below)
10. level identity (bit pattern) or pressure code (SYNOP) (as decimal number, see below)
11. (3-hourly) pressure tendency   (GPS: zenith wet delay [mm])   [10 Pa/3h + 500]
12. low cloud cover   [octas]
13. (horizontal) visibility   [10 m]
14. combined cloud and weather group   (code tables as octal number, see below)
15. SYNOP: combined weather & ground group (code tables as octal number, see below)
    single-level aircraft: degree of turbulence (WMO decriptor '0 11 031' as octal number)
16. precipitation amount rr over 12 hrs ('-1' denotes: $0 < rr < 0.1$ mm)   [1/10 mm]
17. minimum temperature (at 2 m during past 12 hrs)   [1/10 K]
18. maximum temperature (at 2 m during past 12 hrs)   [1/10 K]
19. (only for AOF read :) min. ground temperature (at 5 cm in past 12 hrs)   [1/10 K]
20. maximum wind speed of gusts over 1 hour   [m/s]
21. maximum wind speed of gusts over 6 hrs   [m/s]
22. (only for AOF read :) global radiation, sum over 1 hour   [10 kJ/m2]

Missing values are denoted by $'-9'$ for quantities which do not take negative values, by $'-999'$ for height, and by $'9999'$ otherwise. Entries 7, 8, 9, 10, 14, and 15 are detailed by the following lists:

main flag word (entry 9)
    main flag groups on :   horiz. wind / temperature / humidity / pressure or geopot.
        bit position for flag groups: 0   ,   7   ,   14   ,   21
    bit position within flag groups of 7 bits each (a 1-bit flag is set if the bit set to 1):
        0 : − aircraft wind   : roll angle (code table, WMO descriptor '0 02 064')
            − otherwise   : 2-bit dataset quality flag (WMO descriptor '0 33 002' :
                                        0 : data ok ,   1 : data suspect ,   3 : missing info ,
                                        set for aircraft, wind profiler, RASS data)
        2 : blacklisted
        3 : gross error
        4 : not in valid height range :
            − surface-level data : height or height distance to orography too large
            − upper-air humidity: above 300 hPa level
        5 : bad reporting practice :
            − SYNOP pressure   : bad reporting practice
            − aircraft height   : not measured, derived from p using std. atmosphere
            − upper-air height   : without temperature obs
            − buoy wind   : zero wind speed
            − radar VAD wind   : small wind speed
            − aircraft wind   : bad roll angle quality
            − dew point   : temperature not active
            − mixing ratio   : temperature or pressure not active
            − relative humidity : temperature not active (if needed)
            − generally   : sensor not at appropriate height, or
                                  : measurement duration not appropriate
        6 : − gross error for multi-level temperature or wind found in special check :
                - temperature : lapse rate check
                - horiz. wind   : wind speed shear or directional shear check
            − (rel.) humidity   : $> 96\%$ and bias-corrected to saturation
            − upper-air pressure : derived from reported height using model atmosphere
    bit 28 (of main flag word): flag indicating observation level is below surface

bit numbers for : **observation status flag** (entry 7) and **QC flag** (entry 8)
0 : horizontal wind
1 : temperature
2 : humidity
3 : pressure (surface-level obs) / height (upper-air obs)
5 : IWV (vertically integrated water vapour)
6 : ZTD (zenith total delay of GPS signal)

level identity / **pressure code** (entry 10)

level identity (for non-SYNOP observations)		pressure code (for SYNOP observations)
bit : meaning		code : meaning
0 : maximum wind level		0 : sea level
1 : tropopause		1 : station level pressure
2 : TEMP D part		2 : 850 hPa level geopotential
3 : TEMP C part		3 : 700 hPa level geopotential
4 : TEMP B part		4 : 500 gpm level pressure
5 : TEMP A part		5 : 1000 gpm level pressure
6 : surface level		6 : 2000 gpm level pressure
7 : significant wind level		7 : 3000 gpm level pressure
8 : significant temperature level		8 : 8000 gpm level pressure
(several bits can be set at the same time)		9 : 900 hPa level geopotential
		10 : 1000 hPa level geopotential
		11 : 500 hPa level geopotential

combined cloud and weather group (entry 14)

bits	: meaning	
$0 - 3$	: type of high cloud	[VUB WMO Code table 0509]
$4 - 7$	: type of middle cloud	[VUB WMO Code table 0515]
$8 - 11$	: cloud base height	[VUB WMO Code table 1600]
$12 - 15$	: type of low cloud	[VUB WMO Code table 0513]
$16 - 19$	: cover of low cloud if > 0, else of middle cloud	[VUB WMO Code table 2700]
$20 - 23$	: total cloud cover	[VUB WMO Code table 2700]
$24 - 30$	: present weather	[VUB WMO Code table 4677]

combined weather and ground group (entry 15, for SYNOP obs)

bits	: meaning	
$0 - 8$	: present weather	[WMO descriptor '0 02 003']
$9 - 13$	: past weather	[WMO descriptor '0 02 004']
$14 - 19$	: time period of past weather	[VUB WMO Code table 4019, keys $0 - 7$]
	(1 : 6 h, 2 : 12 h, 3 : 18 h, 4 : 24 h , 5 : 1 h, 6 : 2 h, 7 : 3 h)	
$20 - 21$	: accuracy flag for low cloud cover	(0 : high accuracy , 1 : low accuracy)
$22 - 27$	: state of ground	[WMO descriptor '0 02 062']
$28 - 30$	: (precip obs duration	(2 : 12 hrs , 0 : otherwise))

Some VUB WMO Code tables relate to WMO descriptors in the following way:

VUB WMO table 0509 $\approx$ (code figures $10 - 19$ of WMO decriptor '0 20 012') $- 10$
VUB WMO table 0513 $\approx$ (code figures $20 - 29$ of WMO decriptor '0 20 012') $- 20$
VUB WMO table 0515 $\approx$ (code figures $30 - 39$ of WMO decriptor '0 20 012') $- 30$
VUB WMO table 4677 $\approx$ code figures $00 - 99$ of WMO decriptor '0 20 003'

In VUB WMO Code table 2700, code figures $0 - 8$ indicate the cloud cover in octas, and code figure 9 indicates sky or clouds invisible. VUB WMO Code table 1600 is defined as follows:

$0 : < \quad 50\,\text{m}, \quad 1 : < \; 100\,\text{m}, \quad 2 : < \; 200\,\text{m}, \quad 3 : < \; 300\,\text{m}, \quad 4 : < 600\,\text{m}, \quad 5 : < 1000\,\text{m},$
$6 : < 1500\,\text{m}, \quad 7 : < 2000\,\text{m}, \quad 8 : < 2500\,\text{m}, \quad 9 : \geq 2500\,\text{m or cloud-free}, \quad 15 : \text{undefined}.$

Report Body Extension for Increments

The regular report body is followed by an optional report body extension if the `NAMELIST` variable 'mruntyp ≥ 0'. It consists of observation increments or full model values of the (assimilating) model run which writes `YUVERIF`. This part can be extended by analogous increments from several other model runs, e.g. forecasts, by use of a post-processing program `lmstats` which can read and write extended `YUVERIF` files. Here, the extended format of `YUVERIF` is described which can contain the increments from one or several runs.

Similarly to the regular report body, the number of entries (increments) per model run depends on the basic type of reports. Moreover, the number of runs, for which the increments of an observation level are written to the same line, also depends on that type. Both the number of entries and the number of runs on the same line are given in the following list:

increment body length

basic type of report	# entries	# runs per line
complete synoptic surface-level report	14	1
short surface-level report	9	2
very short surface-level report	5	3
upper-air single-level report	4	4
multi-level report (each obs. level)	5	3
ground-based GPS report	1	12

For multi-level reports, this means that the five increments from the first run followed by twice five increments from the next two runs are written to one line for the first observation level. Analogously, the increments from these three runs are then written for the other observation levels line by line. Finally, an extra line is added for multi-level reports only with the three surface pressure increments (in [Pa]) from the three runs, before the process is repeated for the next (one, two, or) three runs, and so on. The following list declares the complete set of 14 increment entries:

report body extension on increments

1.	zonal wind component	(for GPS reports: IWV [1/100 mm])	[1/100 m/s]
2.	meridional wind component		[1/100 m/s]
3.	temperature		[1/100 K]
4.	relative humidity		[1/10 %]
5.	pressure (surface-level reports) | geopotential (upper-air)		[Pa] | [m2/s2]
6.	total cloud cover	(full model value instead of increment)	[octas]
7.	low cloud cover	(full model value instead of increment)	[octas]
8.	(horizontal) visibility	(full model value instead of increment)	[10 m]
9.	precipitation amount	(full model value instead of increment)	[1/10 mm]
10.	minimum temperature (at 2 m during past 12 hrs)		[1/10 K]
11.	maximum temperature (at 2 m during past 12 hrs)		[1/10 K]
12.	minimum ground temperature (at 5 cm during past 12 hrs)		[1/10 K]
13.	max. wind speed of gusts (time range as in regular body)		[m/s]
14.	global radiation, sum over 1 hour		[10 kJ/m2]

6.1.8   `YUPRINT` — **Nudging: Other Aspects**

`YUPRINT` provides a large variety of information. Much of it has been used mainly at the stage of developing and testing new pieces of code. Instead of inflating this documentation by explaining all types of statements in detail, only the most important ones are described here, including those which are most likely to be of some value for monitoring the model run. A small part of the information written to `YUPRINT` is also written to the standard output or to file `YUCAUTN`. These parts are described in the respective sections 6.1.9 and 6.1.5. Much of the information is 'local', i.e. it relates only to a certain sub-domain which accommodates the grid point with coordinates given by the `NAMELIST` variables 'ionl','jonl' and which coincides with the area processed by one node on an MPP (massively parallel platform, i.e. with distributed memory) computing environment. Also, most types of information are given only at the first timestep, or once per hour.

After some self-explanatory header information about the run, some details about the processing of aircraft data and cloud observations, the numbers of single-level reports 'NSGOB', of multi-level reports 'NMLOB', and of GPS reports 'NGPOB' currently stored on each subdomain (related to nodes 'CART_ID') are provided (Figure 6.14). 'NTOTSGO', 'NTOTMLO', and 'NTOTGPO' denote the number of reports which have been read at previous timesteps. 'GLOBAL NUMBER' relates to the number of reports on the total model domain.

The lines (starting with) 'airep' provide the following information for an aircraft report: number of active reports, internal report index, passive report flag, end of nudging period in [timesteps], timestep in [h], station identity, observation time, beginning and end of individual nudging time window relative to observation time in [h], time in [h] for which analysis increments are to be computed currently, end of period for which these analysis increments are valid, temperature observation error in [K], temperature nudging coefficient for aircrafts in [s^{-1}], observation level pressure in [Pa]. Time is always specified relative to the initial model time except where indicated differently.

```
 NUMBER OF SINGLE- AND MULTI-LEVEL AND GPS DATA TO BE PRINTED:
 NODE:        CART_ID  | NTOTSGO | NTOTSG | NTOTMLO | NTOTML | NTOTGPO |  NTOTGP
              0           0        128        0        38        0        152
              1           0        864        0       163        0       3023
...
             14           0         78        0         6        0         11
 MAX. LOCAL NUMBER:      0        5810        0       430        0       4046
 LOCAL ARRAY SIZE :              8360                557               11704
 GLOBAL NUMBER    :      0       14748        0      1150        0       15611
.........
airep    0   13   0  630 0.011  EU3080     -0.5   0.5   1.5   0.0 0.03 0.8 0.0006  72990.
.........
mladm:  45 multi-level reports
mladm    1    0    1  141   55  02591    -999.00   2.67  0.00  3.00  3.00  0.00  0.12  0.00  0.12
...
mladm   45    0  128  135   87  EU7654   -999.00   0.33  0.00  1.50  1.50  0.00  0.80  0.00  0.80
sgadm:  429 surface-level and 354 upper-air single-level reports
sgadm    1  843    0  217  119  22892      0.00-999.00  0.50  0.00  0.00  0.94  0.00  0.94  0.00
...
sgadm  429    0 1750   19  101  LF4B     -999.00   1.17  0.00  1.50  1.17  0.00  0.24  0.00  0.24
sgadm  430   13    0  131   84  EU3080    -0.47-999.00  0.50  0.00  0.00  0.01  0.00  0.01  0.00
...
sgadm  783    0  785  171   70  EU0301   -999.00   1.52  0.00  1.50  1.50  0.00  0.01  0.00  0.01
gpadm:  181 GPS reports
gpadm    1    1  701   91   22  BUDP-BKG_  -0.50   0.50  1.00  1.00  1.00  0.47  0.53  0.00  0.69
...
gpadm  181    0 1327  114   13  VEST-NGAA-999.00   1.08  0.00  1.50  1.50  0.00  0.30  0.00  0.30
.........
ps   -QC: 60195      11 Obs/Mod/Thresh  853.60  849.22  4.30, Time Obs/Mod   0.0   0.0
uv   -QC: 08495       0 Obs/Mod/Thr 24.7  -5.2 -16.0  -4.3 27.9, Time O/M  2.4  0.0, P   10.
IWV-sc-QC: 60571      0 Obs/Mod/Thr   5.56  10.79 5.13, T O/M  1.8  0.0, bias|w  0.0 0.0
V-mult-QC: 08019     137                          , Time Obs/Mod   0.0   0.0, P  916.- 368.
```

Figure 6.14: Example file `YUPRINT`, first part related to observation statistics and quality control.

The lines 'mladm', 'sgadm', and 'gpadm' provide the local number of currently active multi-level, single-level, resp. GPS reports or stations and list the following items of them: station indices for 2 reports (i.e. 1 report in the past and 1 report in the future), grid point coordinates, station identity, 2 observation times in [h] (i.e. for the 2 reports; '-999' denotes missing report), lengths of the decreasing part, selected increasing part, and minimum possible increasing part of the temporal weight function, the 2 temporal weights according to the temporal function selected, the 2 temporal weights assuming that temporal linear interpolation cannot be applied.

A statement containing '-QC:' is made whenever the quality status of an observation changes due to the threshold quality control (QC), i.e. when an observation does not pass the QC for the first time, or when it is accepted after it has failed the QC in the past.

After some information e.g. on extrapolating surface pressure and on processing of aircraft data and multi-level data, YUPRINT provides the following self-explanatory lists (Figure 6.15): surface-level observations interpolated to the lowest model level, multi-level observation increments from TEMP, PILOT, or AIRCRAFT reports or (in a different format) as derived from GPS-ZTD reports.

The lines 'ps_spread' (Figure 6.16) relate to the spreading of pressure observation increments at the lowest model level. They consist of the station identity, the local part of the nudging weights (i.e. temporal and quality weight) of the 2 reports from the station, the total weight at grid point (ionl2, jonl2) from all the reports processed previously (including the present report), the 2 observation increments (in [Pa]), the total sum of weighted increments at that grid point, the distance (in [km]) of the station to that point, the indication whether that point is within the area of influence, and the orography-dependent correction of the lateral weights at that point. The line 'ps-ana.incr.' provides the local coordinates of point (ionl2, jonl2) and the final surface pressure analysis increment at that point.

```
Interpolation of surface-level observations to the lowest model level ke
=====================================================================
(upper-air single-level reports are also listed here)
(station height differences with the flag "s" are scaled as for the extrapolation of pressure)
          | obs: observed values / ke: obs. interpolated to level ke / inc: obs. increments at ke |
Sta.   | height  | surf. pressure |    10m - horizontal wind   | 2m-temperature | 2m-rel humid.|t
 id    | diff. * | obs / ke / inc | 10m-obs /  at ke  /   inc  | obs / ke / inc | obs/ ke /inc |
EU1312      0.  227.3************* 28.2 13.7********** -3.2 -4.1 221.4******  2.4********** 0.00
10946    s 53.  937.6  931.4  0.4  1.9 -0.7  3.2 -1.8  0.0  0.0 273.9 272.6  0.0 0.89 0.94-0.07
.....
Vertical profiles of observation increments from TEMP, PILOT, AIRCRAFT
=====================================================================
station 06610    , (255,271), 56 levels ; mbotlv, mtoplv    6    2    8    4    1   12
  u-incr  v-incr   T-incr   Qd-incr RH-incr pressure height pot. T. 06610
***************    1.578  -0.00099  -0.219  95800.   535. 278.36
***************    1.553*****************  95659.   547. 278.36
***************    1.455*****************  95113.   593. 278.41
***************    1.324*****************  94394.   654. 278.69
***************    1.156*****************  93483.   732. 279.08
***************    1.009  -0.00075  -0.180  92700.   799. 279.32
   1.055  -0.039   0.916  -0.00074  -0.178  92500.   817. 279.39
   1.027  -0.045   0.955*****************  92367.   828. 279.43
...
station ZIMM-BKG_, (260,271), 24 levels ; mbotlv, mtoplv    0    0    5    0    0   11
        quality weight   Qd-incr RH-incr pressure height pot. T. ZIMM-BKG_
        0.48531          -0.00050  -0.128  90514.   990. 279.89
        0.57270          -0.00048  -0.127  89441.  1085. 280.17
.....
Integrated water vapour IWV values from processing of ground-based GPS
=====================================================================
timestep:    0
    obs #  satu-  obs IWV:   adjusted:    IWV     model w.  satu- extra-
   time it- rated repor- re-     ice,   from  model cloud rated polat.
STA hr erat. lev    ted trieved  bias qv-obs   IWV   ice  model quot  p-int p-rep
ZIMM- 0.5  1   0 *******  5.72   5.72  5.72   6.24  6.24 10.61  0.6  914.6*******
```

Figure 6.15: Example file YUPRINT, second part related to observations and observation increments.

```
ps_spread 63112      , weights 0.97 0.03  0.58, (wght.) incr  -52.83   -2.9   -5.9, dist  171. T 0.9
ps_spread 63101      , weights 0.97 0.03  0.91, (wght.) incr  -47.35   12.6  -10.8, dist  163. T 0.9
...
End of ps_ana_i: weight sqr   3.55, net weight 0.000409, ana incr -0.3988  1.0000
ps-ana.incr.   18 126        -0.399
.........
mul-kl: 01400       3, p,z: obs/v-cut:     0.  8253.  -400.  9165.100000.  -400. -1597. 10474.: no k
air-kl: EU1337     1 23720., height at obs/cutoff: 10949.  7722. 14176., k-range 13  6
thresh RH k 40 40 285 385 10142       34.,mx omy:k+1,k: 1.000 0.735,RH incr 0.045-0.092
...
airmy: EU3080     131  84 1,omyk1/2 0.011 0.000 vCS-fac 1.000 0.935 dz  2571. omym 0.716381
...
sfc-kl: 06610       2 94994., height at obs/cutoff:  563.9 -400.0, k-range 41
sfc-kl: 06610       3 94994., height at obs/cutoff:  563.9  572.4, k-range 41
sfc-cor 06610       4 35 167 103  140.,spr-par: ob,cutof   564.*******,at k   564.  480  402
omyk: 06610     4 3 0.972 0.028 1.000 0.972 0.028  269.27 T 0.00   563.9   563.9 1.0
.........
zuwi,om?u: 06610 -0.0419 0.7773 0.1840
ztwi,om?t: 06610 -0.0086 0.9657 0.3401
zqwi,om?q: 06610 -0.00344256 0.5075 0.1302
.........
mul-infl(km) 277. EU4591     352 477, z: obs,v-cut:  2082.  3508.  1391.  4567., k-range: 34 20
air-infl(km) 492. SAS903     234 517 20647., zu/vwi,omyu   0.025  -0.042  0.7700
sfc-infl(km) 140. 06610        167 103 94994., zqwi,omyq,2 0.198833  6.1970  3.8493
...
thresh uv k 31 31 260 452 01427        24.,mx omy:k+1,k: 0.642 0.490,uv incr   1.9   0.1
thrair T  k 27 31 27 358 478 EU7654     1721.,max omy: 0.792,T  incr   0.0  -1.9
air-cor EU1337     1 13 167 103  408.,spr-par: ob,cutof 10949.  7722. 14176.,at k  7368.  640   43
thrair uv k 13 13  6 167 103 EU1337     10949.  7368.,max omy: 0.240,uv incr   1.0  -2.1
```

Figure 6.16: Example file YUPRINT, third part related to spreading of observation increments.

The lines 'sfc-kl' , 'sfc-cor' , 'sfc-infl' , and 'omyk:' for surfac-level data resp. 'mul-kl' , 'air-kl' , 'ras-cor' , 'air-cor' , 'mul-infl' and 'air-infl' for upper-air data provide a variety of information on the spreading of observation increments (Figure 6.16). The lines 'thresh' and 'thrair' also relate to the spreading of surface-level resp. upper-air single-level data and consist of the observation type ('uv' for wind, 'T' for temperature, 'RH' for humidity), the current vertical model level, the lowest (for upper-air data only) and uppermost model level influenced by the observation, the grid point coordinates of the station, the station identity, the height at the observation point, the value of the spreading parameter (usually height) at the current model level, the maximum spatial weight at any grid point on the previous (for surface-level data only) and current model level within the local sub-domain, and the 2 observation increments. The entry 'vCS-fac' in the lines 'airmy' denote the reduction factor of the scale of the vertical weight function below and above a single-level aircraft observation. The lines 'zuwi' (or 'ztwi' , 'zqwi') provide the station identity, the sum of weighted zonal wind (resp. temperature or humidity) increments, the sum of weights, and the sum of squared weights from the previously processed and the present observations at the lowest but fifth model level at grid point (ionl, jonl).

The same applies to lines 'omu' (see Figure 6.17, resp. 'omt' , 'omq') and lines 'ntstep= .... ztwi' (without squared weights) except that the sum is over all observations. The lines 'nudge_horiz_wind' or 'Tqnudge' deliver the local coordinates of grid point (ionl2, jonl2), the model level, and the analysis increments of the wind components resp. of temperature, of specific humidity from nudging temperature data, and of humidity from nudging humidity data at that point. The lines 'itera q11' indicate the iteration in solving the Poisson equation to derive geostophic surface pressure increments from wind increments based on 10-m wind data. From these pressure increments, geostrophic wind field can be derived again, from which the maximum relative change in [0.1 %] in the iteration and the maximum magnitude of the wind increments are also given for the subdomain with point (ionl2, jonl2). Furthermore, 'zdfi_max' and 'max(psaigeo_1)' provide the largest positive and negative geopotential resp. pressure increment on that subdomain. The arrays of lines 'nudging, ' list the analysis increments as a result of different processes as indicated, at the given six pres-

```
ntstep=   0, k=35, T / qv / qc : 276.84 0.004943 0.000000  18 126, ztwi / omyt:   0.00 0.00000
Tqnudge: T,q-ana.incr.   18 126  35   0.0008  0.000000  0.000000
omu: weight/ sqr/ weighted incr 35   0.0000   0.0000   0.0000   0.0000
omu: weight      / weighted incr 35   0.0001153          1.3699  -0.4132
.........
geostroph_ps_corr: uv-ana.incr.   18 126   0.0000   0.0000
itera q11 umax =   1    120.014440    0.164226
itera q11 umax =   2     64.963402    0.164223
...
itera q11 umax =  50     2.570915    0.175688
 zdfi_max =   8  0.2562859401204606  -2.629577730880562E-002
 max(psaigeo_1):   8  0.2927315768875584  -3.061252112578843E-002
 max(psaigeo_2):   8  0.2634584191988025  -2.755126901320959E-002
.........
nudge_horiz_wind: uv-ana.incr.   18 126  35   0.0138  -0.0056
    0  34 651   3: max. unreduced geost. incr. on total domain, v-gr.pt:    2.75
    0  34 185 106: max. unreduced geost. incr. on inner domain, u-gr.pt:    0.59
    0  34 224 134 0.83: reduced geost. incr. at i/jonl:  -0.001  -0.002
.........
nudging, pressure                      3767. 23293. 55121. 85067.100053. 101361.
nudging, p-incr, no T-change         -0.005 -0.031 -0.072 -0.112 -0.131  -0.133
nudging, p-incr, T-corr, no T-nudge   0.007  0.042  0.080 -0.030 -0.124  -0.133
nudging, p-incr, T-nudge, no evapo.  -1.694 -7.566 -1.024 -0.020 -0.113  -0.133
nudging, p-incr, T-nudge complete    -0.025 -0.112 -0.030 -0.085 -0.128  -0.133
nudging, T-incr, T-corr, no T-nudge   0.000  0.000  0.001  0.002  0.002   0.002
nudging, T-incr, T-nudge, no evapo.   0.023  0.006 -0.166  0.002  0.002   0.002
nudging, T-incr, T-nudge complete     0.000  0.000 -0.002  0.001  0.001   0.001
nudging, q-incr, RH-nudge, no evapo.  0.000  0.000  1.327  0.000  0.000   6.580
nudging, q-incr, T+RH-nudge complete  0.000  0.000  0.019  0.000  0.000   0.206
nudging, u-incr, geostrophic          0.000  0.000  0.000 -0.002 -0.001   0.000
nudging, v-incr, geostrophic          0.000  0.000  0.000  0.000  0.000   0.000
```

Figure 6.17: Example file `YUPRINT`, forth part related to weighted increments and balancing.

sure levels at grid point (`ionl, jonl`). Mostly self-explantory information on the geostrophic wind correction is given by the lines containing '`geost. incr.`' (not shown).

Last but perhaps most essentially, nearly self-explanatory lists of the coordinates of the grid points, at which the maximum absolute values for the analysis increments occur on each model level, are provided together with the values of the increments themselves (Figure 6.18). This is done at each timestep that new analysis increments are computed, and it allows to monitor which variables at which levels are explicitly influenced by the nudging.

```
Analysis increments at timestep   12
max. (ABS of) analysis increments of mass field
(prior to condensation / evaporation except for pressure increments)
le- T-corr global T-incr  global qv-incr due gl.  qv-incr  global RH-incr global  p-incr  global
vel   [K]   coord.   [K]  coord. to T-incr coord.  [g/kg]  coord.    [%]  coord.   [Pa]   coord.
 1  0.000   0  0   0.04 634  91  0.0000   0  0   0.0000   0  0   0.00   0  0   0.689 635   92
 2  0.000   0  0   0.08 640  87  0.0000   0  0   0.0000   0  0   0.00   0  0   0.740 273  189
...
 9  0.000   0  0  -0.04 326 582  0.0000   0  0   0.0000   0  0   0.00   0  0   1.600 268  196
10  0.000   0  0   0.05 325 185  0.0000   0  0   0.0001 113 320   0.11 113 320   1.743 533  518
...
38 -0.067 195 648  0.07 114  40  0.0000   0  0  -0.0326 300 225  -0.62 300 226  13.929 195 648
39 -0.067 195 648  0.07 114  40  0.0000   0  0  -0.0329 300 225  -0.62 301 225  14.097 195 648
40 -0.067 195 648  0.07 114  40  0.0000   0  0   0.1434 520  84  -1.47 649 645  14.215 195 648
...
max. (ABS of) increments of horizontal wind field components in [m/s]
(ana incr: analysis increments
 net incr: net observation increments
 geo corr: geostrophic wind correction)
le- u-ana  global  v-ana  global  u-net  global  v-net  global  u-geo  global  v-geo  global
vel incr   coord.  incr   coord.  incr   coord.  incr   coord.  corr   coord.  corr   coord.
 1  0.06 258 343   0.05 599 131  -13.3 540  82    7.1 483 345   0.00   0  0   0.00   0  0
 2  0.09 280 248   0.10  60 594  -11.2 540  82   -9.0  42 319   0.00   0  0   0.00   0  0
...
13  0.11 292 111   0.15 105 508    8.3 292 111   -9.0 337  64   0.00   0  0   0.00   0  0
14  0.16 113  40  -0.14 114  40    9.4 175  25    9.4  55  16   0.00 193 109   0.00 649  26
...
33  0.17 420  64  -0.22  23 249   -9.6 641 218   10.1 621 200  -0.13  16 238  -0.22  23 249
...
39  0.20 410  55   0.23 344 648   -9.1 642 220    7.3 255  88  -0.01  16 238  -0.02  23 249
40  0.20 410  55   0.23 344 648   -9.2 642 220    7.4 258  84   0.00  16 238  -0.01  23 249
```

Figure 6.18: Example file `YUPRINT`, fifth part related to analysis increments.

6.1.9   Standard Output — Basic Monitoring of Nudging

As already mentioned e.g. in Section 6.1.5, warning messages containing the label 'CAUTION' are also issued to the standard output, if the values of the NAMELIST variables 'maxmlo', 'maxuso', 'maxsgo', or 'maxgpo' are not large enough to hold in memory and process all observations. In such a case, the program will not crash or stop (see Section 6.1.5). In the standard output, such a message is written for each individual multi-level observation report, which cannot be used due to insufficient array size. Furthermore, summary messages indicate how many reports of which type had to be discarded for that reason.

Figure 6.19 lists the types of regular messages that are also written to the standard output by the nudging. The first line specifies the length of regular time boxes (in [h]) in which analysis increments are computed once and then used to update the model variables at all timesteps within the time box (this length corresponds to 'NAMELIST' variable 'tconbox' (in [s])). 'AI-box' denotes the time box interval (in [h]), and 'mean' the middle of the interval, i.e. 'mean' declares the time (in [h]) for which the temporal weights used to compute the analysis increments are exactly valid. 'next: AI' denotes the time (in [h]) at which new analysis increments are to be computed for the next time, and 'obs process' the next time at which new observations must be read again from the AOF. If the observations are read from NetCDF observation input files, the 'obs process' entry does not have any meaning and is simply equal to zero.

Next, the path name of the BLACKLIST/WHITELIST file is given. This is followed by a list of NetCDF observation input files which do not exist due to missing data, but which would be read if they existed. Then for each of the existing NetCDF observation input files, the number of reports are indicated and the time interval from which all reports have to be read currently. This last type of lines is written again whenever new observations are read, which is typically once every hour.

```
!! Analysis Increments ("AI") held constant during time boxes of ca 0.067 hours
   hour: AI-box: [0.000,0.056], mean: 0.028, next: AI: 0.07, obs process.: 0.00

 open and read BLACKLIST / WHITELIST from ./blklsttmp
 NOTE: NO FILE ./cdfin_tempdrop (.nc)
 NOTE: NO FILE ./cdfin_amdar_ml (.nc)
 NOTE: NO FILE ./cdfin_amdar_vp (.nc)
 NOTE: NO FILE ./cdfin_acars_uk (.nc)
 NOTE: NO FILE ./cdfin_acars_us (.nc)
 NOTE: NO FILE ./cdfin_synop_mob (.nc)
 NOTE: NO FILE ./cdfin_metar (.nc)
 NOTE: NO FILE ./cdfin_satob (.nc)
 processing   415 reports from  -58 -  241 [min] from file cdfin_temp
 processing    14 reports from  -58 -  241 [min] from file cdfin_tempship
 processing     7 reports from  -58 -  241 [min] from file cdfin_pilot
 processing     5 reports from  -58 -  241 [min] from file cdfin_pilot_p
 processing  2829 reports from  -28 -  151 [min] from file cdfin_amdar
 processing  3709 reports from  -28 -  151 [min] from file cdfin_acars
 processing   118 reports from  -28 -   91 [min] from file cdfin_wprof
 processing    20 reports from  -28 -   91 [min] from file cdfin_rass
 processing   556 reports from  -28 -   91 [min] from file cdfin_radar_vad
 processing  8662 reports from  -58 -  151 [min] from file cdfin_synop
 processing   335 reports from  -58 -  151 [min] from file cdfin_ship
 processing   246 reports from  -58 -  151 [min] from file cdfin_buoy
 processing 16369 reports from  -58 -  151 [min] from file cdfin_gps_zenith
 processing   705 reports from  -58 -  151 [min] from file cdfin_ascat
 processing     0 reports from  -58 -  151 [min] from file cdfin_qscat
```

Figure 6.19: First part of example messages on nudging written to standard output.

Next (see Figure 6.20), the path name of the NetCDF feedobs (or feedback) file is given. At timestep zero and after each time box defined by 'tconbox', the number of reports and number of individual observations that are currently written to the feedobs file are also indicated, as well as the numbers of reports and obserations already having been written at previous timesteps.

It follows a line with 'NUMBER OF (SINGLE OR PAIRS OF) REPORTS WITH OBS INCREMENTS'. This provides the total number of increment reports (resp. stations in case of temporal linear interpolation of observations), which have been used to compute the observation increments (for the purpose of nudging or of writing a NetCDF feedobs or VOF file) at the timestep given at the beginning of the line. In the subsequent lines, it is specified how many of these increment reports are multi-level, upper-air single-level, surface-level, surface pressure, and scatterometer increment reports. The multi-level reports are further distinguished between radiosonde TEMP, PILOT balloon, wind profiler, radar VAD wind, aircraft, RASS temperature, and GPS humidity (from ZTD resp. IWV observations) increment reports. (An additional entry is added for preparing the use of retrievals from satellite radiance data; this number is always zero here.) This whole block of lines is also written at 'tconbox' intervals and is quite helpful for monitoring the assimilation.

```
Creation of NetCDF feedobs file fof_*
OPENED: /e/uwork/fe12sra/test/09022409/lme/sx9/zlm4m/zwtyp/fof_20090224090000.nc
      feedobs file: # newrep  4734, oldrep      0, newobs  38392, oldobs       0
    STEP    0: NUMBER OF (SINGLE OR PAIRS OF) REPORTS WITH OBS INCREMENTS:  8744
             1259 multi-level: 106 TEMP,  2 PILOT,  16 WINDPROF,  20 RADAR-VAD
                              225 AIRCRAFT, 1 RASS,  889 GPS,    0 RETRIEVALS
             1999 sing-lev aircraft, 2878 in-situ surface, 2444 surf. pressure
              164 scatterometer


Temperature correction for (surface) pressure nudging: top at 400hPa in layer 14
================================================================================
                              (*): relative to the surface pressure increment
height T-corr pressure  z-z    dp level |height T-corr pressure  z-z    dp level
       K/hPa full hydro correl (*)      |       K/hPa full hydro correl (*)
 7746. -0.000 374. 374. 0.000  0.000 14 | 9030. -0.000 312. 312. 0.000  0.000 14
 7110. -0.016 410. 410. 0.001  0.001 15 | 8587.  0.000 332. 332. 0.000  0.000 15
 6506. -0.069 446. 446. 0.013  0.008 16 | 8157.  0.000 354. 354. 0.000  0.000 16
 5933. -0.121 482. 482. 0.038  0.022 17 | 7742.  0.000 375. 375. 0.000  0.000 17
 5391. -0.172 519. 519. 0.076  0.045 18 | 7344. -0.010 397. 397. 0.000  0.000 18
 4878. -0.220 555. 556. 0.122  0.076 19 | 6962. -0.129 419. 419. 0.007  0.007 19
 4395. -0.267 592. 592. 0.177  0.115 20 | 6598. -0.272 441. 441. 0.033  0.025 20
 3941. -0.310 628. 628. 0.237  0.161 21 | 6252. -0.408 462. 462. 0.073  0.055 21
 3516. -0.351 663. 663. 0.301  0.214 22 | 5924. -0.538 483. 483. 0.127  0.097 22
 3119. -0.386 697. 697. 0.366  0.272 23 | 5616. -0.659 504. 504. 0.190  0.149 23
 2749. -0.419 730. 730. 0.433  0.334 24 | 5327. -0.767 524. 524. 0.259  0.209 24
 2408. -0.448 762. 762. 0.501  0.399 25 | 5058. -0.867 543. 543. 0.335  0.276 25
 2093. -0.473 792. 792. 0.568  0.465 26 | 4809. -0.951 561. 561. 0.411  0.348 26
 1806. -0.492 820. 820. 0.631  0.530 27 | 4580. -1.021 578. 578. 0.487  0.423 27
 1544. -0.507 847. 847. 0.690  0.594 28 | 4371. -1.077 594. 594. 0.560  0.498 28
 1308. -0.518 871. 871. 0.745  0.656 29 | 4181. -1.120 609. 609. 0.631  0.571 29
 1097. -0.525 893. 893. 0.795  0.713 30 | 4011. -1.150 622. 622. 0.694  0.641 30
  911. -0.529 913. 913. 0.839  0.766 31 | 3860. -1.169 635. 634. 0.753  0.706 31
  748. -0.530 931. 931. 0.878  0.813 32 | 3728. -1.182 645. 645. 0.805  0.765 32
  608. -0.528 946. 946. 0.911  0.855 33 | 3614. -1.187 655. 655. 0.850  0.818 33
  489. -0.526 959. 959. 0.938  0.891 34 | 3517. -1.188 663. 663. 0.890  0.863 34
  391. -0.522 970. 970. 0.958  0.922 35 | 3437. -1.185 670. 670. 0.921  0.902 35
  311. -0.517 979. 979. 0.973  0.947 36 | 3372. -1.181 675. 675. 0.948  0.933 36
  249. -0.512 986. 987. 0.984  0.966 37 | 3321. -1.176 680. 680. 0.967  0.958 37
  202. -0.508 992. 992. 0.991  0.981 38 | 3283. -1.171 683. 683. 0.982  0.976 38
  168. -0.504 996. 996. 0.996  0.992 39 | 3255. -1.167 685. 685. 0.993  0.990 39
  144. -0.502 999. 999. 1.000  1.000 40 | 3235. -1.164 687. 687. 1.000  1.000 40
```

Figure 6.20: Second part of example messages on nudging written to standard output.

Next, two examples for the temperature correction balancing the surface pressure nudging are given, one for a grid point with surface pressure close to 1000 hPa , and one for an elevated grid point. The information provided at each model level consists of the height (in [m]), the temperature correction (in [K/hPa]), the full pressure and the hydrostatic pressure (in [hPa]), the quotient between the (hypothetic) height increment at upper levels and at the surface, the quotient between the resulting upper-air pressure increment and surface pressure increment, and the model level index.

The lines containing 'dt,dt2,dtdeh' describe that at timestep 0, the length of the timestep is halved outside the nudging, but set to the original length temporarily within the nudging. Before that, the size of the coarse grid used to speed up the Poisson solver is indicated.

Messages are also written whenever two-dimensional surface analysis based on Synop observations are written to Grib files. 't2m' relates to 2-m temperature, 'r2m' to 2-m relative humidity, 'fff' to 10-m wind speed, and 'prc' to precipitation.

The lines with 'maybe not written to YUVERIF' indicate reports, that are flagged not to have been written to the VOF or NetCDF feedobs files at the time when they are deleted internally for the reason of being too old to be used any more. Most often, this relates to multi-level aircraft reports which may have been created only after the observation time. This can happen, when new observations with the same aircraft identifier (station ID) are read. Then, all multi-level reports are deleted first, and multi-level reports are derived again based on all the single-level reports from the same aircraft, even if some of those reports are older than the current model time. Normally, the aircraft observations missing on the feedobs file(s) should already have been written as a single-level report report or as part of another multi-level report. Lines of the type considered can also relate to other observation types. Typically, this occurs for redundant reports from stations which issue very frequent reports of observation types where temporal linear interpolation is applied between active reports.

The lines starting with 'nudge:' render the last timestep of the model run, the index of (the lowest, middle, or top) model level, and temperature and specific humidity ('Tq') resp. pressure and zonal wind ('pu') at grid point (ionl, jonl) in unformatted form. This often allows to diagnose tiny differences between runs done with slightly different model versions

```
  coarse grid size for Poisson solver =   63  63
      STEP 0: dt,dt2,dtdeh: within the nudging   40.  80. 0.0111
      STEP 0: dt,dt2,dtdeh: outside the nudging  20.  40. 0.0056
   Surface analysis GRIB output file <lansfc> opened
 t2m- GRIB field written on file
 r2m- GRIB field written on file
 fff- GRIB field written on file
 fff- GRIB field written on file
...
  NOTE: m-l report EU5185    , 2.05 [hrs], 99892. [Pa] maybe not written to YUVERIF
  NOTE: GPS report ZIM2-LPTR , 2.53 [hrs],******* [Pa] maybe not written to YUVERIF
  NOTE: m-l report EU3421    , 1.95 [hrs], 65764. [Pa] maybe not written to YUVERIF
...
 nudge: Tq   270  40  276.9854634975543   4.096394061700189E-003
 nudge: pu   270  40  1775.909540306221  -2.396582502917388
 nudge: Tq   270  20  256.6670491482951   1.044913113842654E-003
 nudge: pu   270  20  -96.66768992558980  19.39489036339958
 nudge: Tq   270  1  211.5194561088256   3.947515866446530E-006
 nudge: pu   270  1  766.6450024472723  -1.518195750920522
```

Figure 6.21: Third part of example messages on nudging written to standard output.

or configurations and helps to identify the existence of errors which lead to violations of bit-identical reproducibility. Note that once such a difference or error is present at a grid point to which observations are assigned, then the nudging process will usually spread it very quickly to the whole model domain including point (`ionl,jonl`).

It is further mentioned, again, that 'CAUTION' messages related to insufficient array sizes are also written to the standard output (see also Section 6.1.5). This includes messages on individual multi-level reports, on multi-level aircraft reports (e.g. 'CAUTION for maxmlo: nexceair 0 11'), as well as summary messages.

Finally, there are messages (Figure 6.22), which are not written by the nudging itself, but which are related to the set-up of the data assimilation as a whole. It lists the originating process for a number of 2-dimensional grib fields which are used as part of the initial condition of the model integration. Time range indicator 13 means that the corresponding field has been produced by an COSMO-Model assimilation integration, whereas a value of 0 indicates that the field originates from a snow analysis (for 'T_SNOW' , 'W_SNOW', and 'W_I'), a sea surface temperature analysis, or another external data collection and interpolation process. Additional element number 20 for 'W_SO' implies finally that the initial soil moisture fields are produced by the variational soil moisture analysis instead of the nudging-based COSMO-Model assimilation run.

```
 Note: analysis field LAI       with time range indicator  0   is used
 Note: analysis field VIO3      with time range indicator  0   is used
 Note: analysis field HMO3      with time range indicator  0   is used
 Note: analysis field PLCOV     with time range indicator  0   is used
 Note: analysis field ROOTDP    with time range indicator  0   is used
 Note: analysis field LAI       with time range indicator  13  is discarded
 Note: analysis field ROOTDP    with time range indicator  13  is discarded
 Note: analysis field PLCOV     with time range indicator  13  is discarded
 Note: analysis field HMO3      with time range indicator  13  is discarded
 Note: analysis field VIO3      with time range indicator  13  is discarded
 Note: analysis field RHO_SNOW  with time range indicator  13  is discarded
 Note: analysis field T_ICE     with time range indicator  13  is discarded
 Note: analysis field H_ICE     with time range indicator  13  is discarded
 Note: analysis field H_ICE     with time range indicator  0   is used
 Note: analysis field T_ICE     with time range indicator  0   is used
 Note: analysis field RHO_SNOW  with time range indicator  0   is used
 Note: analysis field W_SNOW    with time range indicator  0   is used
 Note: analysis field T_SNOW    with time range indicator  0   is used
 Note: analysis field W_I       with time range indicator  0   is used
 Note: analysis field T_SNOW    with time range indicator  13  is discarded
 Note: analysis field W_SNOW    with time range indicator  13  is discarded
 Note: analysis field W_I       with time range indicator  13  is discarded
 Note: analysis field T_SO      with time range indicator  13  is discarded
 Note: analysis field T_SO      with time range indicator  13  is used
 Note: analysis field T_SO      with time range indicator  13  is used
 Note: analysis field T_SO      with time range indicator  13  is used
 Note: analysis field T_SO      with time range indicator  13  is used
 Note: analysis field T_SO      with time range indicator  13  is used
 Note: analysis field T_SO      with time range indicator  13  is used
 Note: analysis field T_SO      with time range indicator  13  is used
 Note: analysis field T_SO      with time range indicator  13  is used
 Note: analysis field T_SO      with time range indicator  0   is used
 Note: analysis field W_SO         with add. element number   20   is used
 ...
 Note: analysis field W_SO         with add. element number   20   is used
 Note: analysis field W_SO         with add. element number   0   is discarded
 ...
 Note: analysis field W_SO         with add. element number   0   is discarded
```

Figure 6.22: Example messages on the originating processes for 2-dimensional grib fields which are part of the initial condition.

6.1.10   `YUSURF` — 2-D Surface Analyses

`YUSURF` relates to the determination of two-dimensional analyses which are based mainly on observations and can be used for verification purposes and as input for separate analysis schemes such as the variational soil moisture analysis. There are four types of analyses, namely the 2-m temperature analysis, the 2-m relative humidity analysis, the 10-m wind speed analysis, and the precipitation analysis. While the latter is based purely on observations, the first three include the corresponding fields of the model run as first guess fields. The basic functions and parameters of the successive correction schemes are first outlined in `YUSURF` (Figure 6.23).

Then, some basic information is provided for the analysis at grid point (`ionl`,`jonl`) for each analysis variable, analysis date, and correction scan (Figure 6.24). The squared distance 'zdistm' (in [km^2]) to that point, the distance scaled by the scan radius ('zrormx'), and the horizontal weight 'wwa' are written up for each observation influencing that point.

```
                                  SURFACE (ANY 2-D) ANALYSIS RUN
                                  ------------------------------
    -2M TEMPERATURE ANALYSIS
    -2M RELATIVE HUMIDITY ANALYSIS
    -PRECIPITATION ANALYSIS
    -10M WIND SPEED ANALYSIS

 ANALYSIS DATE: MON 16.04.2012  06 UTC

 Total precipitation amount in the last 12. hours
 ------------------------------------------------
 Precipitation analysis parameters:
 Weights function:   W   = H(R) * V(H)
 where            :   H(R)= (RMAX**2-R**2)/(RMAX**2+R**2)
                      V(H)= 0.5*(COS(H/HMAX*PI)+0.5
                      HMAX= MAX(MOD_ORO ,    400.) m
 Analysis function:  A = SUM(W*D)/SUM(W)

 Number of scans:     3
 Scan 1, radius:   40000. m
 Scan 2, radius:   70000. m
 Scan 3, radius:  110000. m
 No smoothing

 2m temperature analysis sucessive correction parameters:
 --------------------------------------------------------
 Weights function:   W   = H(R) * V(H)
 where            :   H(R)= (RMAX**2-R**2)/(RMAX**2+R**2)
                      V(H)= (HMAX**2-H**2)/(HMAX**2+H**2)
                      HMAX= MAX(MOD_ORO/2.7 ,    300.) m
 Increment function: I = SUM(W*D)/SUM(W)

 Number of scans:     3
 Scan 1, radius:  200000. m
 Scan 2, radius:  100000. m
 Scan 3, radius:   50000. m

 2m Rel. Humid. Analysis Sucessive Correction parameters:
 ........................................................................................
 10m wind speed analysis sucessive correction parameters:
 --------------------------------------------------------
 Weights function:   W   = H(R) * V(H)
 where            :   H(R)= (RMAX**2-R**2)/(RMAX**2+R**2)
                      V(H)= (HMAX**2-H**2)/(HMAX**2+H**2)
                      HMAX= MAX(MOD_ORO/3.0 ,    300.) m
 Increment function: I = SUM(W*D)/SUM(W)

 Number of scans:     3
 Scan 1, radius:  200000. m
 Scan 2, radius:  100000. m
 Scan 3, radius:   50000. m
```

Figure 6.23: Example file `YUSURF`, first part on description of methods.

After a description of the grid point itself, station identity, latitude, longitude, height, observation increment, and total weight of the increment at the grid point are also provided for these observations. For precipitation observations assigned to the grid point itself, this is complemented by the vertical distance 'zvdis' and vertical weight 'zwi' in the lines starting with 'zmodor'. Finally, the resulting analysis increment of the scan and some statistics on the analysis are provided.

```
 Total number of surface observations extracted from ODR:  nobtot= 1049
 zdistm=189364. zrormx=0.947 wwa=0.055
...
 zdistm=192541. zrormx=0.963 wwa=0.038

 Diagnostic 2M TEMPERATURE analysis   scan 1
  grid point  ix=167  iy=103  lat= 47.54  lon=   8.74  height= 462.
 Observations influencing this grid point:

 stat_id     lat      lon   height  increment  weight
 06771      45.84     8.93   352.    -1.21     0.08
 06770      46.00     8.96   301.     0.02     0.16
...
 10733      49.30     8.91   240.    -0.33     0.02
 Resulting t2m analysis increment:  -0.15
 ..................................................................
 Diagnostic 2M TEMPERATURE analysis   scan 2
 ..................................................................
 Resulting t2m analysis increment:  -0.25
 ..................................................................
 Diagnostic 2M TEMPERATURE analysis   scan 3
 ..................................................................
 Resulting t2m analysis increment:  -0.04

 *** STATISTICS ON ANALYSIS OF 2M TEMPERATURE; UNIT=DEGREES
      SUM OF CHANGES      =  60422.7556
      NO. OF ANAL. POINTS =     194081
      AVERAGRE CHANGE     =      0.3113
      STANDARD DEVIATION  =      0.8121
      MAX. CHANGE         =      3.9370
      MAX. POSITIVE CHANGE =     3.9370
      AT MODEL LAT./LON.  =     -3.3500       0.4500
      MAX. NEGATIVE CHANGE =    -1.9850
      AT MODEL LAT./LON.  =     -4.7750       3.8250
 ...........................................................................
 Diagnostic 2M REL. HUMIDI analysis   scan 3
 ...........................................................................
 Diagnostic 10M WIND SPEED analysis   scan 3
 ...........................................................................
 zdistm= 14959. zrormx=0.374 wwa=0.623
 zdistm= 26371. zrormx=0.659 wwa=0.217
 .........
 zmodor= 462. rpaght= 540. zvdis=  78. zvdmax= 462. zwi=0.931 wwa=0.511
 zmodor= 462. rpaght= 445. zvdis= -17. zvdmax= 462. zwi=0.997 wwa=0.210

 Diagnostic PRECIPITATION  analysis   scan 1
  grid point  ix=167  iy=103  lat= 47.54  lon=   8.74  height= 462.
 Observations influencing this grid point:

 stat_id     lat      lon   height  increment  weight
 06679      47.48     8.90   540.    11.00     0.51
...
 Q942       47.77     8.82   445.     2.00     0.21
 Resulting prc analysis increment:   7.61

 *** STATISTICS ON ANALYSIS OF PRECIPITATION AMOUNT; UNIT=mm
      SUM OF CHANGES      = 497251.8071
      NO. OF ANAL. POINTS =     194081
      AVERAGRE CHANGE     =      2.5621
      STANDARD DEVIATION  =      8.7602
      MAX. CHANGE         =    137.0000
      MAX. POSITIVE CHANGE =   137.0000
      AT MODEL LAT./LON.  =      5.3250      -0.7250
      MAX. NEGATIVE CHANGE =     0.0000
      AT MODEL LAT./LON.  =     -5.0000      -2.8000
```

Figure 6.24: Example file YUSURF, second part on current analyses.

6.2   NetCDF Feedobs File

For data assimilation or verification purposes, a special NetCDF '*feedobs*' file (sometimes also (mis)called '*feedback*' file) can be written. This file contains the observations themselves from a specifiable period within the model integration period (see `Namelist` parameter '`hversta`', etc.). Moreover, it also accommodates estimated observation errors and other pieces of information which depend on the model state of the COSMO run itself. This includes the quality control flags, bias corretions, as well as the simulated observations derived from the model state exactly at the respective observation times.

The purpose of the feedobs file is to serve as input for a Local Ensemble Transform Kalman Filter (LETKF) analysis, or for a utility, which computes the simulated observations from various model runs and writes them into an extended NetCDF *feedback* file. This feedback file then contains all the input information required for grid point verification. Its format (and in principle its contents) are identical to that of the feedobs file, except that such feedback files can contain the simulated observations from more than just one model run. The format is described in a separate documentation '`Feedback File Definition`' which can also be found on the COSMO web site (www.cosmo-model.org).

The file name of the feedobs file has the following form:

> '`fof_`' // `yyyymmddhhttss` // '`.nc`'

with : `yyyy`: year , `mm`: month , `dd`: day , `hh`: hour , `tt`: minute , `ss`: second .
(`yyyy` means 'year' in 4 digits, while the other quantities are expressed in 2 digits each.)
The date and time refers to '`verification_ref_date`' and '`verification_ref_time`' as described in the '`Feedback File Definition`. As the file name starts with '`fof`', the feedobs file is also sometimes called '*fof*' file.

Considering the purpose of the NetCDF feedobs file, it should contain all the observations that are potentially used for grid-point verification. This means that it contains many more observation types than actively used in data assimilation, i.e. e.g. in a LETKF analysis. However, it does not include all types of 'exotic' observations present e.g. in an original surface synoptic report, and it also fails to contain all the header and complementary information (e.g. on the instrumentation) from the originial observation reports. Thus, the feedobs file cannot be considered a complete surrogate or extension of the original BUFR observation files resp. NetCDF observation input files.

6.2.1   Operator Specific Feedobs Files

In addition to the above mentioned standard feedobs file several operator specific feedobs files may exist. Observation operators which are not part of the nudging assimilation system, e.g. the radar operator or the STD operator, use their own feedobs files. These files can be used for verification purposes or by the LETKF.

The file name used by the STD operator is defined in a similar way as the standard feedobs file name but with an additional substring `gnssgb` for *GNSS ground based* observations:

> '`fof_gnssgb_`' // `yyyymmddhhttss` // '`.nc`'

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