# JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2015

**Country: Germany Centre: NMC Offenbach**

## Summary of highlights

On 21st July 2015 a two-way nested refinement domain over Europe (called **ICON-EU** with a grid spacing of 6.5 km and 60 layers up to 23 km) was activated in the operational global non-hydrostatic icosahedral-triangular grid point model **ICON** (grid spacing 13 km, i.e. 2.949.120 grid points/layer, 90 layers up to 75 km).

On 20th January 2016 the 3D-Var data assimilation system for ICON was replaced by an En-Var (Ensemble Variational data assimilation system) and accompanied by an LETKF (Localised Ensemble Transform Kalman Filter). The LETKF ensemble data assimilation system provides initial conditions for a 40 member ICON ensemble at 40 km resolution (20 km over Europe). The En-Var uses the LETKF short range forecasts in order to derive a flow dependent background error covariance estimate which considerably improves the deterministic analysis.

A 40 member 40 km global EPS with 20 km nest over Europe is running pre-operationally, starting from the LETKF initial conditions.

Additionally, the operational **deterministic** modelling suite of DWD consists of two regional models, namely the non-hydrostatic regional model **COSMO-EU** (COSMO model Europe, grid spacing 7 km, 665x657 grid points/layer, 40 layers), and the convection-resolving model **COSMO-DE**, covering Germany and its surroundings with a grid spacing of 2.8 km, 421x461 grid points/layer and 50 layers. COSMO-EU will be switched off in Q4 2016 after the migration of all products to ICON-EU forecasts.

The regional **probabilistic** ensemble prediction system on the convective scale, called **COSMO-DE-EPS**, is based on COSMO-DE with a grid spacing of 2.8 km, 421x461 grid points/layer and 50 layers. Four global models, namely ICON (DWD), IFS (ECMWF), GFS (NOAA-NCEP) and GSM (JMA) provide lateral boundary conditions to intermediate 7-km COSMO models which in turn provide lateral boundary conditions to COSMO-DE-EPS. To sample the PDF and estimate forecast uncertainty, variations of the initial state and physical parameterizations are used to generate additional EPS members. The forecast range of COSMO-DE-EPS is 27 h (45 h for the 03 UTC forecast) with new forecasts every three hours.

The COSMO model (<http://cosmo-model.org/>) is used operationally at the national meteorological services of Germany, Greece, Italy, Poland, Romania, Russia and Switzerland, and at the regional meteorological service in Bologna (Italy). The military weather service of Germany operates a relocatable version of the COSMO model for worldwide applications. In 2014 the Meteorological Service of Israel (IMS) became applicant member of COSMO.

The LETKF for the COSMO model (KENDA, Kilometre-scale Ensemble Data Assimilation) runs operationally at the meteorological service of Switzerland and pre-operationally in Germany.

Six national meteorological services, namely Botswana Department of Meteorological Services, INMET (Brazil), DHN (Brazil), Namibia Meteorological Service, DGMAN (Oman) and NCMS (United Arab Emirates) as well as the Center of Excellence for Climate Change Research (King Abdulaziz University, Saudi Arabia) use the COSMO model in the framework of an operational licence agreement including an annual license fee.

National meteorological services in developing countries (e.g. Egypt, Indonesia, Kenya, Malawi, Mozambique, Nigeria, Philippines, Rwanda, Tanzania, Vietnam) use the COSMO model free of charge for official duty purposes.

For lateral boundary conditions, ICON data are sent via the internet to the COSMO model users up to four times per day. Each user receives only data from those ICON grid points (at the grid spacing of 13 km for all 90 model layers plus all 7 soil layers) which correspond to the regional COSMO model domain. Currently DWD is sending ICON data to more than 40 COSMO model users worldwide.

## 2. Equipment in use

**2.1 Main computers**

**2.1.1 Two Cray XC40 Clusters**

Each cluster:

Operating System CLE 5.2

796 nodes (364 x 2 CPUs Intel Xeon E5-2670v2 (10-core), 432 x 2 CPUs Intel Xeon E5-2680v3 (12-core)) with 17648 CPU cores

560.3 TFlops/s peak system performance

A total of 76.75 TiB physical memory (364 x 64 GiB and 432 x 128 GiB)

Cray Aries interconnect

Infiniband FDR and 10 GbE attached global disk space (Cray Sonexion and Panasas Active Stor), see 2.1.3

One Cray XC40 cluster is used to run the operational weather forecasts; the second one serves as research and development system.

**2.1.2 Two Cray/Megware Clusters**

Operating System SuSE Linux SLES 11

Cluster A:

1. nodes Megware MiriQuid

* 14 nodes with 2 CPUs Intel Xeon E5-2670v2 (10-core), 14 nodes with 2 CPUs Intel Xeon E5-2690v3 (12-core), entire system 616 cores
* 24 nodes with 128 GiB physical memory per node, 4 nodes with 512 GiB physical memory per node, entire system 5120 GiB physical memory

Cluster B:

22 nodes Megware MiriQuid

* 12 nodes with 2 CPUs Intel Xeon E5-2670v2 (10-core), 10 nodes with 2 CPUs Intel Xeon E5-2690v3 (12-core), entire system 480 cores
* 18 nodes with 128 GiB physical memory per node, 4 nodes with 512 GiB physical memory per node, entire system 4352 GiB physical memory

Infiniband FDR Interconnect for multinode applications

Network connectivity 10 Gbit Ethernet

Infiniband FDR and 10 GbE attached global disk space (Cray Sonexion and Panasas

Active Stor), see 2.1.3

Cluster B is used to run operational tasks (pre-/post-processing, special

product applications), cluster A research and development tasks.

**2.1.3 Global Disk Space (Cray Sonexion and Panasas Active Stor)**

Cray Sonexion (for work filesystems):

Hardware components: 4 x Cray Sonexion 1600

Total disk storage 3700 TiB

SAN connectivity: Infiniband FDR

2x 36 GB/s sustained aggregate performance

Software: Lustre 2.5

Panasas Active Stor 12 (for home filesystems):

Total disk storage 290 TiB

SAN connectivity: 10 Gb Ethernet

2x 3 GB/s sustained aggregate performance

Software: Panasas 5.5

Both global disk space (Cray Sonexion, Panasas) is accessible from systems in

2.1.1, 2.1.2.

**2.1.4 Two NEC/Oracle/NetApp data management clusters**

Oracle SUN Servers x2-4/x2-8 systems are used as data handling systems for

meteorological data.

Two redundancy clusters for operational tasks and research/development each with:

Operating System Oracle Linux Server 6.4

5 servers (2x Oracle SUN Server x2-4 ( 4x Intel Xeon E7-4870 (10-core)) as database

servers and 3x Oracle SUN Server x2-8 (8x Intel Xeon E7-8870 (10-core)) as data access servers)

A total of 320 CPU cores per cluster

4096 GiB physical memory per cluster

Network connectivity 10 Gbit Ethernet

NetApp storage systems (22x E5500 and 34x DE6000) providing 1382 TiB disk space

on the research/development cluster and 1656 TiB disk space on the operational tasks

cluster via Infiniband QDR

**2.1.5 IBM System x3650 Cluster**

Operating System RedHat RHEL5

9 IBM System x3650 M2 (2 quadcore processors, 2.8 GHz)

24 GiB of physical memory each

480 TiB of disk space for HPSS archives

30 Archives (currently 24 PB)

connected to 2 Oracle StorageTek SL 8500 Tape Libraries via Fibrechannel

This high-available cluster is used for HSM based archiving of meteorological data and forecasts.

**2.1.6 STK SL8500 Tape Library**

Attached are 60 Oracle STK FC-tape drives

20 x T10000B (1 TB, 120 MB/s)

40 x T10000C (5 TB, 240 MB/s)

**2.2 Networks**

The main computers are interconnected via Gigabit Ethernet (Etherchannel) and connected to the LAN via Fast Ethernet.

**2.3 Special systems**

**2.3.1 RTH Offenbach Telecommunication systems**

The Message Switching System (MSS) in Offenbach is acting as RTH on the MTN within the WMO GTS. It is called Weather Information System Offenbach (WISO) and based on a High-Availability-Cluster with two IBM x3650 M3 Servers running with Novell Linux SLES11 SP4 system software and Heartbeat/DRBD cluster software.

The MSS software is a commercial software package (MovingWeather by IBLsoft). Applications are communicating in real time via the GTS (RMDCN and leased lines), national and international PTT networks and the Internet with WMO-Partners and global customers like, EUMETSAT, ECMWF and DFS (Deutsche Flugsicherung = Air Navigation Services).

For the international and national dissemination via GISC-Offenbach the open source DWD software AFD is used (http://www.dwd.de/AFD/) for customers who not joined the RMDCN. The core high availability Linux cluster is running with scientific Linux and heartbeat. Standard protocols like ftp/sftp, http/https, smtp are in use.

**2.3.2 Other Data Receiving / Dissemination Systems**

**Windows 2008 R2 Server**

A Windows based Server System is used for receiving XRIT and LRIT data at Offenbach.

**LINUX Server**

2 Linux servers are used for the direct read out of L-Band and X-Band LEO Satellites.

LINUX servers are also used for receiving EUMETCast data (Ku-Band and C-Band)

There are four servers at DWD, Offenbach and 2 servers at Regional Office Leipzig.

Another LINUX server system is used for other satellite image processing applications.

The images and products are produced for several regions worldwide with different resolution from 250 m to 8 km. There are internal (NinJo, NWP) and external users (e.g. Internet). Five servers used for operational services and two servers for backup service.

**FTP**

HRPT, Aqua and Terra MODIS data (2 to 3 passes per day) DWD get from AGeoBW (Amt für Geoinformationswesen der Bundeswehr) Euskirchen as Backup.

**2.3.3 Graphical System**

The system *NinJo* (NinJo is an artificial name) has been operational since 2006. It is based on a JAVA-Software and allows for a variety of applications. As development of the software is very laborious and expensive the *NinJo* Project was realized in companionship with DWD, the Meteorological Service of Canada, MeteoSwiss, the Danish Meteorological Institute and the Geoinformation Service of the German Forces. The hardware consists of powerful servers combined with interactive *NinJo*-client workstations.

*NinJo* is an all-encompassing tool for anybody whose work involves the processing of meteorological information, from raw data right to the forecast.

For the user the main window is just the framework around the various fields of activity. Of course it is possible to divide up the displayed image over several screens. All products generated interactively on the screen can be generated in batch mode as well. Besides 2D-displays of data distributed over an extensive area also diagrams (e.g. tephigrams for radio soundings, meteograms or cross sections) can be produced.

Depending on the task to be accomplished it is possible to work with a variable number of data layers. There are layers for processing observational data such as measured data from observing stations, radar images etc. right through to final products such as weather maps, storm warnings etc. Data sources are constantly updated files in the relevant formats.

The *NinJo* workstation software comprises an

* modern meteorological workstation system with multi-window technology
* easily integrated geographical map displays
* meteograms, cross-sections, radiosoundings as skew-T-log-p or Stüve-diagrams
* a subsystem for monitoring of incoming data called *Automon*
* flexible client-server architecture
* high configurability via XML and immediate applicability without altering code

Tools for interactive and automatic product generation like surface analyses with isobars and fronts, surface prognostic charts and significant weather charts are in use.

A typical installation of the *NinJo* workstation on the forecasters desktop uses two screens. On a wide screen the weather situation can be presented in an animation.

## 3. Data and Products from GTS in use

At present nearly all observational data from the GTS are used. GRIB data from France, the UK, the US and the ECMWF are used. In addition most of the OPMET data are used.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No.** | **Obs Type** | **Used** | **Percent** | **Monitored** | **Comment** |
|  |  |  |  |  |  |
| 1 | TEMP | 59.804 | 2,6% | 244,135 | TEMP |
| 2 | PILOT | 13.026 | 0,6% | 46.554 | PILOT+Wind profiler |
| 3 | SYNOP | 146.797 | 6,4% | 302,493 | SYNOP LAND + SHIP |
| 4 | DRIBU | 9.250 | 0,4% | 9.735 | BUOYs |
| 5 | AIREP | 377.602 | 16,5% | 418.252 | AIREP+ACARS+AMDAR |
| 6 | SATOB | 181.134 | 7,9% | 197.818 | Satellite winds geostat.+polar |
| 7 | SCATT | 275.440 | 12,1% | 396.511 | Scatterometer ASCAT,OSCAT |
| 8 | RAD | 1.098.887 | 48,1% | 59.535.507 | Radiances (AMSU HIRS IASI) |
| 9 | GPSRO | 120.982 | 5,3% | 132.984 | GPS radio occultations |
|  |  |  |  |  |  |
|  | TOTAL | 2.282.922 | 100.0% | 61.283.993 |  |

Table 1: Typical number of observation data input per day in the global En-Var data assimilation; the data have been recorded on 2016-06-01 over 24 hours.

## 4. Forecasting system

### 4.1 System run schedule and forecast ranges

Preprocessing of GTS-data runs on a quasi-real-time basis about every 6 minutes on Sun Opteron clusters. Independent 4-dim. data assimilation suites are performed for all three NWP models, ICON (**ICO**sahedral **N**onhydrostaticModel, including the ICON-EU refinement domain over Europe), COSMO-EU and COSMO-DE. For ICON, analyses are derived for the eight analysis times 00, 03, 06, 09, 12, 15, 18 and 21 UTC based on an En-Var (PSAS) scheme. For COSMO-EU and COSMO-DE, a continuous data assimilation system based on the nudging approach provides analyses at hourly intervals.

**Deterministic system**

Forecast runs of ICON (including the ICON-EU refinement domain over Europe) and COSMO-EU with a data cut-off of 2h 14 min after the main synoptic hours 00, 06, 12 and 18 UTC consist of 78-h forecasts for COSMO-EU and 180-h forecasts (120-h for 06 and 18 UTC) of the ICON. ICON-EU forecast data are provided up to 120h four times per day. 27-h (45-h for 03 UTC) forecasts are performed for COSMO-DE eight times per day with a very short data cut-off of 30 minutes after 00, 03, 06, …, 18 and 21 UTC. Additionally, three ocean wave models (3rd generation WAM, see Section 4.5.2.1.2), the global GWAM, a European wave model (Mediterranean, North, Baltic and Adriatic Sea areas) EWAM and a coastal model (German Bight, Western and Southern Baltic) provide guidance about wind sea and swell based on 00 and 12 UTC wind forecasts of ICON and ICON-EU.

**Probabilistic system**

27-h (45-h for 03 UTC) forecasts are performed for COSMO-DE-EPS (Ensemble Prediction System) with 20 ensemble members eight times per day with a data cut-off of 60 minutes after 00, 03, 06, …, 18 and 21 UTC.

### 4.2 Medium range forecasting system (4-10 days)

#### 4.2.1 Data assimilation, objective analysis and initialization

4.2.1.1 In operation

As far as ICON (including the ICON-EU refinement domain over Europe up to 120h) is in use for medium range forecasting, the same procedures are applied as for short range forecasting described in item 4.3

4.2.1.2 Research performed in this field

*See 4.3.1.2*

#### 4.2.2 Model

* + - 1. In operation

Medium range forecasts at the DWD are mainly based on the ECMWF system (deterministic model and EPS). Additionally, ICON (see 4.3) forecasts up to 7.5 days augment the model guidance available.

4.2.2.2 Research performed in this field

**Non-hydrostatic global model ICON with local zooming option**

The further development of the non-hydrostatic global model ICON with local zooming option is jointly undertaken by DWD and the German Climate Research Centre MPI-M in Hamburg. The Karlsruhe Institute of Technology (KIT) contributes on-line coupled modules treating secondary aerosols, directly emitted components like soot, mineral dust, sea salt and biological material as pollen. Modules for the emissions of mineral dust, sea salt and pollen grains have also been developed by KIT. Processes as emissions, coagulation, condensation, dry deposition, and sedimentation are taken into account. A module to treat the washout in a consistent way has been developed.

(G. Zängl, F. Prill, D. Reinert, M. Köhler)

#### Operationally available Numerical Weather Prediction Products

ECMWF and ICON global forecasts are available up to day 7.5.

See Section 4.3.1.1 for ICON products.

#### 4.2.4 Operational techniques for application of NWP products

* + - 1. In operation

ECMWF-EPS-data and MOS (Model Output Statistics) applied to the ICON and ECMWF model are in use to produce medium-range forecasts up to day 7 (MOS: 10 days). Forecasts are provided for the public both in tabular form and in plain language. The forecasts in tabular form comprise the parameters daily maximum and minimum temperatures, relative sunshine duration, daily precipitation amount and probability, probability of snow, wind speed and direction, probability of thunderstorm, probability of fog. Medium-range forecasts in plain language are produced by forecasters in the Central Forecast Office in Offenbach. In addition to this the automatic text production is in use for worldwide forecasts, which are available by dialling a premium rate number on a fax machine, on a telephone answering device or on mobile telephones using short message system (SMS). The latter ones are produced however without forecasters’ intervention.

Progress was made in medium range forecasting concerning the risk assessment of extreme weather for the forecast interval 120 hours down to 36 hours by synoptic interpretation of model results in combination with the evaluation of the COSMO-LEPS (Limited Area Ensemble Prediction System) and EFI- (extreme forecast index) charts, provided by ECMWF. COSMO-LEPS is a dynamical downscaling of the ECMWF EPS, and was developed by the COSMO-Consortium (Members are Germany, Greece, Italy, Poland, Romania, Russia and Switzerland; see Section 7). The risk-assessment is made available as a bulletin called “5 day forecast of weather risks” and includes the probability of certain severe weather events like storm, heavy precipitation, severe thunderstorm situations, widespread snowfall or freezing precipitation, heat and cold waves. The bulletin is produced once a day in the late morning with actualisation according to new model results in the evening or night hours if necessary. It is available for the regional offices within DWD and for the public via the internet.

Agrometeorological forecasts cover a wide range of applications aiming at a reduction of the use of insecticides and fungicides or at an optimization of the water supply to plants. NWP results are combined with additional models which calculate the drying of leaves or the temperature and water balance in the ground.

4.2.4.2 Research performed in this field

Further refinement of physical modelling.

#### 4.2.5 Ensemble Prediction System (EPS)

See also section 4.3.5.2.

**4.2.5.1 In operation**

The EPS of ECMWF is in use for operational forecasting. A downscaling-system of the EPS with the name COSMO-LEPS (Limited Area Ensemble Prediction System) is in operation. COSMO-LEPS has been developed by the COSMO consortium (Consortium for Small Scale Modelling) under the leadership of ARPA-SIM, Bologna, see Section 7. From an ensemble of 16 forecasts for middle and southern Europe computed twice daily with a horizontal grid distance of 7 km, probability forecasts can be derived. The input data for COSMO-LEPS are provided by 16 representative members taken from the EPS of ECMWF.

**4.2.5.2 Research performed in this field**

10-day forecasts for Road Weather Information System (SWIS)

In order to meet various requests from users for medium-range forecast information in the Road Weather Information System of DWD, a new forecast product, based on the MOSMIX forecasts at DWD was introduced. These so-called trend forecasts for temperature and precipitation (liquid, solid, freezing) are given as probabilistic information, i.e. mean and standard deviation for temperature and probabilities for exceeding thresholds of precipitation amounts. The introduction of the new products was accompanied by a user workshop, in order to thoroughly explain the content, meaning and possible use of the products. During the winter season 2015/16 the forecasts were tested by the users, and the feedback is currently being evaluated by DWD.

Further research is done by ARPA-SIMC, Bologna, see Section 7!

#### 4.2.5.3 Operationally available EPS Products

Primarily ECMWF EPS products like EPS-Meteograms and a variety of parameters derived like maximum and minimum temperatures and probabilities of snow are available. The Extreme Forecast Index (EFI) is in use for early warning.

From COSMO-LEPS probability charts are available for middle and southern Europe which give information whether accumulated rain or snow, wind gusts, temperatures or CAPE values will exceed thresholds defined by warning requirements. The products are available up to 120 hours.

#### 4.3 Short-range forecasting system (0-72 hrs)

Operational short-range forecasting is based on the products available from the global non-hydrostatic model ICON (grid spacing of 13 km, 90 layers) and its two-way nested refinement ICON-EU (grid spacing 6.5 km, 60 layers) over Europe and its surroundings. The latter is currently running in parallel with the non-hydrostatic limited area model COSMO-EU (grid spacing of 7 km, 665x657 grid points/layer, 40 layers), covering the time period up to 78 hours from 00, 06, 12 and 18 UTC. COSMO-EU is nested in the ICON with an updating of the lateral boundary values at hourly intervals. COSMO-EU will be switched off in Q4 2016 after the migration of all products to ICON-EU forecasts.

For nowcasting and very short range forecasts (up to 27 hours / 45 hours from 03 UTC) the convection-permitting meso-gamma scale model COSMO-DE (grid spacing of 2.8 km, 421x461 grid points/layer and 50 layers) provides numerical guidance eight times per day with a very short data cut-off of 30 minutes. Lateral boundary conditions of COSMO-DE are derived from ICON-EU forecasts.

Ensemble forecasts on the convective scale are provided by COSMO-DE-EPS (see Section 4.3.5.1).

**4.3.1 Data assimilation, objective analysis and initialization**

4.3.1.1 In operation

**Global Model (ICON)**

1. **Global analysis of mass, wind field and humidity**

Analysis method Ensemble-variational assimilation in observation space.

Background error covariance matrix partly (30%)

derived from climatology (NMC-Method) and partly (70%) from the

flow-dependent 40-km (20 km over Europe) 40-member short-range EPS

forecasts based on a LETKF ensemble analysis.

Analysed variables p, T, u, v, relative humidity

Horizontal anal. grid Icosahedral-triangular grid of the ICON (average mesh size of 13 km)

Vertical resolution 90 height-based layers (SLEVE, see ICON)

Products a) on icosahedral-triangular grid of the ICON

(2.949.120 grid points/layer, 90 layers)

Variables: p, T, u, v, qv, qc, qi, qrain, qsnow

b) on a regular geographical grid, 1440 x 721 points (0.25° x 0.25°)

27 pressure levels 1000, 950, 850, 700, 500, ..., 3, 2, 1, 0.3, 0.1 hPa

Variables: pmsl, T, Φ, u, v, relative humidity

Assimilation scheme Intermittent data assimilation. Insertion of data every 3 hours. 3-h forecast used as first guess. All observations within a ± 1.5-h window used as synoptic. Cut-off time is 2 h 14 min for main forecast runs.

Initialization Incremental analysis update (*Bloom et al., 1996*; *Polavarapu et al., 2004*)

1. **Global analysis of surface parameters**

Analysis method Correction method

Analysed variables Sea surface temperature (SST), sea ice and snow cover

Horizontal anal. grid On icosahedral-triangular grid of the ICON (average mesh size of 13 km,

6.5 km over Europe)

Data used SST, sea ice: Synop-Ship, NCEP-SST analysis as background,

NCEP analysis of sea ice distribution.

Snow cover: Snow depth, present and past weather, precipitation amount,

temperature analysis. History taken into account.

NCEP analysis of snow cover.

Analysis method Optimal Interpolation using height correction

Analysed variables Temperature and relative humidity at 2 m

Horizontal anal. grid On icosahedral-triangular grid of the ICON (average mesh size of 13 km,

6.5 km over Europe)

Data used Model first guess T 2m, rh 2m and observations T 2m, Td 2m from reports of

synop stations, aircrafts, ships and bouys

Analysis method Variational method (*Hess, 2001*)

Analysed variables Soil moisture content

Horizontal anal. grid On icosahedral-triangular grid of the ICON (average mesh size of 13 km)

Data used Analyses of 2m temperature, forecast of 2m temperature, soil moisture,

surface fluxes relevant to surface energy balance from ICON

**Limited area model COSMO-EU**

1. **Limited-area analysis of atmospheric fields**

The data assimilation system for the COSMO-EU (EU = Europe) is based on the observation nudging technique (*Schraff, 1997)*. The variables nudged are the horizontal wind, temperature, and humidity at all model layers, and pressure at the lowest model level. The other model variables are indirectly adapted through the inclusion of the model dynamics and physics in the assimilation process during the nudging period. The lateral spreading of the observational information is horizontal, or optionally along model layers or isentropic surfaces. At present, the scheme uses operationally only conventional data of type TEMP, PILOT, SYNOP, BUOY, AMDAR and wind profiler. Additionally, precipitation rates derived from radar observations (5-min precipitation scans) are included via the latent heat nudging method (Stephan et al., 2008).

Analysis method Observation nudging technique and latent heat nudging

Directly analysed variables pressure at lowest model level, T, u, v, relative humidity

Horizontal anal. grid 665 x 657 points (0.0625° x 0.0625°) on a rotated latitude/longitude grid

Vertical resolution 40 hybrid layers

Products All analysis products are given on the 665 x 657 grid and available at

hourly intervals.

a) On the 40 layers

Variables: p, T, u, v, w, qv, qc, qi, qrain, qsnow, TKE

b) On 10 pressure levels (1000, 950, 850, 700, 500, ..., 200 hPa)

Variables: pmsl, Φ, T, u, v, ω, relative humidity

c) On 4 constant height levels (1000, 2000, 3000, 5000 m)

Variables: p, T, u, v, w, relative humidity

Assimilation scheme Continuous data assimilation in 3-h cycles.

Cut-off time is 2 h 14 min for COSMO-EU runs.

Initialization None

1. **Limited-area analysis of soil moisture**

Analysis method 2-dimensional (vertical and temporal) variational technique

Analysed variables Soil moisture content at 00 UTC

Horizontal anal. grid 665 x 657 points (0.0625° x 0.0625°) on a rotated latitude/longitude grid

Data used 2-m temperature analyses at 12 and 15 UTC

1. **Limited-area analysis of other surface parameters**

Analysis method Correction methods

Analysed variables Sea surface temperature (SST) and sea ice cover, snow cover,

temperature and relative humidity at 2 m

Horizontal anal. grid 665 x 657 points (0.0625° x 0.0625°) on a rotated latitude/longitude grid

Data used SST: Synop-Ship, US-data of ice border, sea ice cover analysis from BSH (German Maritime and Hydrographic Agency) for the Baltic Sea and satellite based remote sensing data (via NCEP-SST and ICON\_SST analyses).

Snow cover: Snow depth, present and past weather, precipitation amount,

2-m temperature analysis (plus model prediction).

**Convection-resolving model COSMO-DE**

1. **Limited-area analysis of atmospheric fields**

The data assimilation system for the COSMO-DE (DE = Deutschland) is based on the observation nudging technique (*Schraff, 1997)*. The variables nudged are the horizontal wind, temperature, and humidity at all model layers, and pressure at the lowest model level. The other model variables are indirectly adapted through the inclusion of the model dynamics and physics in the assimilation process during the nudging period. The lateral spreading of the observational information is horizontal, or optionally along model layers or isentropic surfaces. At present, the scheme uses operationally conventional data of type TEMP, PILOT, SYNOP, BUOY, AMDAR and wind profiler. Additionally, precipitation rates derived from radar observations (5-min precipitation scans) are included via the latent heat nudging method (*Stephan et al., 2008*).

Analysis method Observation nudging technique and latent heat nudging

Directly analysed variables pressure at lowest model level, T, u, v, relative humidity

Horizontal anal. grid 421x461 points (0.025° x 0.025°) on a rotated latitude/longitude grid

Vertical resolution 50 hybrid layers

Products All analysis products are given on the 421x461 grid and available at

hourly intervals.

a) On the 50 layers

Variables: p, T, u, v, w, qv, qc, qi, qrain, qsnow, qgraupel, TKE

b) On 10 pressure levels (1000, 950, 850, 700, 500, ..., 200 hPa)

Variables: pmsl, Φ, T, u, v, ω, relative humidity

c) On 4 constant height levels (1000, 2000, 3000, 5000 m)

Variables: p, T, u, v, w, relative humidity

Assimilation scheme Continuous data assimilation in 3-h cycles.

Cut-off time 30 min for COSMO-DE runs.

Initialization None

1. **Limited-area analysis of other surface parameters**

Analysis method Correction methods

Analysed variables Sea surface temperature (SST) and sea ice cover, snow cover,

temperature and relative humidity at 2 m

Horizontal anal. grid 421 x 461points (0.025° x 0.025°) on a rotated latitude/longitude grid

Data used SST: Synop-Ship, US-data of ice border, sea ice cover analysis from BSH (German Institute for shipping and hydrology) for the Baltic Sea and indirectly satellite data (via NCEP-SST and ICON\_SST analyses).

Snow cover: Snow depth, present and past weather, precipitation amount,

2-m temperature analysis (plus model prediction)

4.3.1.2 Research performed in this field

**Assimilation of satellite radiances in the global model ICON**

Work is in progress to assimilate more remote sensing data. Work is carried out on a variety of new instruments and satellites. It includes different infrared radiances (e.g. IASI = Infrared Atmospheric Sounding Interferometer) as well as humidity information of the microwave sensors, microwave sensors over land and under cloudy conditions. A new variational bias correction is under development.

(C. Köpken-Watts, O. Stiller, A. Walter, K. Raykova, S. Hollborn, R. Faulwetter, A. Fernandez del Rio)

**Assimilation of cloud-affected and cloudy radiances**

The assimilation of cloud related information from satellite radiances is an important topic of international research. We work on the reconstruction of cloud information within an atmospheric column based on a 1dvar-type approach, which is then integrated into our 3DVAR and VarEnKF/En-VAR (Variable Ensemble Kalman Filter) systems. In this framework, appropriate regularization methods which take care of the particular statistics of the data and states under consideration (e.g. non-Gaussian statistics) are under investigation.

(C. Köpken-Watts, O. Stiller, R. Faulwetter, A. Fernandez del Rio, R. Potthast)

**Ensemble Transform Kalman Filter assimilation for ICON and COSMO models**

The Ensemble Transform Kalman Filter (ETKF) Data Assimilation system is pre-operational for the regional convection-permitting COSMO-DE. The implementation is based on the Local Ensemble Transform Kalman Filter (LETKF) proposed by Hunt et al., 2007. For the global system the operational hybrid En-Var is developed further (see below). The global ensemble data assimilation and prediction system provides lateral boundary conditions for the COSMO-DE system. The COSMO LETKF itself provides initial perturbations to COSMO-DE-EPS. The quality of the basic EnKF (Ensemble Kalman Filtering) system for COSMO-DE has reached the break even with the current operational nudging system (Schraff et al. 2016), further improvements are on the way.

(C. Schraff, H. Reich, A. Rhodin, A. Fernandez, A. Cress, R. Potthast)

**Hybrid Variational and EnKF**

The hybrid VarEnKF method (called En-Var) for the global ICON model is further developed:

* 4D-En-Var: use the first guess and the background error correlations at the appropriate time.
* Scale selective assimilation: localise background error correlations in wavelet representation.
* Improve balance of the analysis state.

(A. Rhodin, H.Anlauf, A. Fernandez, R. Potthast)

**Adaptive Localization and Transformed Localization**

The Ensemble Kalman Filter employs localization to control spurious correlations and to enhance the number of degrees of freedom. Adaptive localization options in its dependence on the number of observations, the observation error and the degrees of freedom of the system have been investigated. In particular, a limiting theory for small localization radius has been formulated and tested for its practical relevance. Within a PhD project in collaboration with the University of Göttingen a transformed localization algorithm for radiance assimilation has been developed.

(H. Reich, C. Schraff, A. Nadeem, R. Potthast)

**GNSS ZTD and Slant Delay**

The assimilation of GNSS (Global Navigation Satellite System*)* slant delays and GNSS ZTD (Zenith Tropospheric Delay) is under development in cooperation with the Geo Research Center (GFZ) in Potsdam. We investigate the assimilation of ZTD into the global ICON model by the En-Var/LETKF. Also, an efficient operator for ZTD or STD (Slant Tropospheric Delay) has been implemented into COSMO-DE, experiments for STD assimilation are on the way.

(M. Bender, A. Rhodin, R. Potthast)

**RADAR forward operator**

A radar forward operator for the COSMO model has been developed in a research project with the Karlsruhe Institute of Technology (KIT), which calculates radial velocities and reflectivities as well as polarization information as is measured with the new radar network of DWD. The assimilation of radar volumetric data is investigated and tested in the EnKF framework in collaboration with the University of Bonn and DWD. Here, different update rates of the EnKF (5, 10, 15, 30, 60 min) for assimilating volume RADAR data have been investigated. Experiments with radial winds have been carried out in collaboration with LMU (Ludwig-Maximilian-Universität) Munich.

(E.Bauernschubert, T. Bick, M. Würsch, U. Blahak, K. Stephan, H. Reich, R. Potthast, C. Schraff)

**SEVIRI Cloud Products and Seviri Radiances**

Supported by a EUMETSAT Fellowship and Special Research Area we work on the assimilation of SEVIRI (Spinning Enhanced Visible and Infrared Imager) cloud products and SEVIRI radiances within the COSMO model based on the EnKF framework. In particular, cloud type and cloud top height information is fed into the assimilation scheme with the help of innovative discrepancy functions to enhance the sensitivity of measurements towards the model state increments. First assimilation experiments with SEVIRI radiances have been carried out by A. Perinanez in collaboration with Otkin (Wisconsin/Reading) and by Harnisch (LMU Munich).

1. Hutt, J. Otkin, C. Schraff, R. Faulwetter, R. Potthast)

**Particle Filters for Numerical Weather Prediction**

The use of particle filters is tested for large-scale numerical weather prediction. A framework for realizing different particle filters has been implemented into the VarEnKF/LETKF assimilation software of DWD, with a first resampling particle filter being available, first tests in a complete cycle for the global ICON EDA (Ensemble Data Assimilation) are currently carried out by Potthast and Rhodin. Within cooperation projects with ETH Zürich (S. Robert, H. Künsch) and University of Potsdam (S. Reich) different further particle filters are being implemented into our software currently, with tests targeted on the convective scale. Further cooperation projects on particle filters are under discussion with RIKEN (Rikagaku Kenkyūjo Kobe, Japan) and LMU Munich.

(R. Potthast, S. Robert, A. Walter, A. Rhodin, H. Reich, C. Schraff, S. Reich)

**Integrated Forecasting System (IVS)**

Within the new research project “Integriertes Vorhersagesystem (IVS)” the forecasting of small-scale high-impact weather phenomena (severe convection and heavy precipitation) over a lead time of 12 hours is investigated. It is planned to combine further develop products of nowcasting with forecast lead times of two hours and high update rate with the forecasting results of a short-range rapid update cycle (RUC) ensemble prediction system to achieve a seamless forecasting of the atmospheric state and weather phenomena from the current state of the atmosphere to short-range NWP.

The IVS System plans to employ an ensemble approach on all relevant spatial and temporal scales, in particular for nowcasting and the short-range forecasts of NWP. To explicitly resolve deep convective clouds, a grid spacing of 1 km is planned as well as an increase of the number of vertical model layers. The homogenization of model forecasts and nowcasting needs improvements in the use of temporal spatial high-resolution data such as RADAR and geostationary satellite data of conventional and hyperspectral sounders in the framework of ensemble data assimilation on the convective scale.

(U. Blahak, A. Seifert, E. Bauernschubert, R. Potthast, H. Anlauf, K. Stephan, and others)

**Assimilation of microwave radiances for soil moisture analysis**

The microwave emissivity model CMEM, used at ECMWF has been adopted to assimilate 1.4 GHz microwave brightness temperatures from SMOS and SMAP satellite. The code is adapted to run the forward model for ICON. Tests are underway to evaluate the simulated brightness temperature against SMOS observations. Work for the implementation into the soil moisture analysis scheme still has to be done to make use of these satellite observations.

(M. Lange, G. Paul)

**SST perturbations derived from multi product SST-L4 ensemble GMPE (GHRSST Multi-Product Ensemble)**

The multiproduct SST ensemble is used to generate perturbed initial conditions for sea surface temperature fields in the global ICON ensemble system. Tests are outlined to assess the impact of SST perturbations generated from random linear combinations of the multiproduct SST anomalies on the 40 ensemble members. Further tests are required to evaluate the impact against the unperturbed case and the present method which is based on stochastic perturbation patterns.

(M. Lange, A. Rhodin, G. Paul)

**4.3.2 Model**

**4.3.2.1 In operation**

**a) Schematic summary of the Global Model ICON**

Domain Global with two-way nested domain over Europe (ICON-EU)

Initial data time 00, 03, 06, 09, 12, 15, 18, 21 UTC

Forecast range global domain: 180 h (from 00 and 12 UTC), 120 h (from 06 and 18 UTC),

30 h (from 03, 09, 15, and 21 UTC):

European domain: 120 h (from 00, 06, 12 and 18 UTC), 30 h (from 03, 09, 15, and 21 UTC)

Prognostic variables ρ, Θv, vN, w, TKE, qv, qc, qi, qrain, qsnow

Vertical coordinate Height-based, SLEVE (*Leuenberger et al., 2010*), 90 layers with top at 75 km for global domain; 60 layers with top at ~23 km for European domain

Vertical discretization Finite-difference for momentum / finite volume for scalars; second order

Horizontal grid Icosahedral-triangular (*Sadourny et al., 1968*), average mesh size 13 km for global domain and 6.5 km for European domain; Arakawa-C grid

Horiz. discretization Finite-difference for momentum / finite volume for scalars; second order

Mass consistent transport of tracers (*Miura, 2007*)

Horizontal diffusion Linear, fourth order; nonlinear second order Smagorinsky

Orography Grid-scale average (slightly smoothed) based on a 1-km data set

Parameterizations Turbulent transfer based on prognostic TKE (*Raschendorfer 2001*)

Non-orographic gravity wave drag (*Orr, Bechtold et al., 2010*)

Sub-grid scale orographic effects (blocking and gravity wave drag) based

on *Lott and Miller, 1997*

Radiation scheme (RRTM, Mlawer et al., 1997; Barker et al., 2002) full cloud-

radiation feedback based on predicted clouds

Mass flux convection scheme after *Bechtold et al., 2008*

Kessler-type grid-scale precipitation scheme with parameterized cloud

Microphysics after *Doms and Schättler, 2004* and *Seifert, 2008*

7-layer soil model *(Heise and Schrodin, 2002; Schulz et al., 2016)* including simple vegetation and snow cover; prescribed climatological value for

temperature at about 14 m depth; for in-land lakes FLake (Mironov, 2008;

Mironov et al. 2010; http://lakemodel.net);

Tile approach with three dominant land-cover classes per grid point, separate treatment of snow-free and snow-covered parts

Over water: Fixed SST from SST analysis over open water; for ice-covered

ocean areas a sea ice model (*Mironov et al., 2012*) provides ice thickness

and temperature;

roughness length according to Charnock´s formula in ice-free areas

Analyses and forecasts (up to 180 h) data of ICON are sent up to four times per day (for 00, 06, 12 and 18 UTC) via the Internet to several other national meteorological services (Botswana, Brazil, Egypt, Georgia, Greece, Indonesia, Israel, Italy, Jordan, Kenya, Madagascar, Malawi, Malaysia, Mozambique, Nigeria, Oman, Pakistan, Philippines, Poland, Romania, Russia, Rwanda, Saudi Arabia, Serbia, South Africa, Switzerland, Tanzania, Turkmenistan, Ukraine, United Arab Emirates, Vietnam and Zimbabwe). These data serve as initial and lateral boundary data for regional modelling. For a detailed description of ICON, see *Zängl et al., 2015*.

**b) Schematic summary of the limited area model COSMO-EU**

Domain Europe

Initial data time 00, 06, 12, 18 UTC

Forecast range 78 h

Prognostic variables p, T, u, v, w, qv, qc, qi, qrain, qsnow, TKE

Vertical coordinate Generalized terrain-following, 40 layers

Vertical discretization Finite-difference, second order

Horizontal grid 665 x 657 points (0.0625° x 0.0625°) on a rotated latitude/longitude grid,

mesh size 7 km; Arakawa-C grid, see Fig. 1.

Horiz. discretization Finite-difference, third order upwind advection;

For the advection of moisture variables: *Bott (1989)* scheme with Strang-

splitting

Time integration Two-time-level, 3rd order Runge-Kutta, split explicit

(*Wicker and Skamarock, 2002*), Δt = 66 s.

Horizontal diffusion Implicit in advection operators. Explicit horizontal hyperdiffusion (4th order)

for the velocity components and Smagorinsky-type diffusion In the full

domain.

Orography Grid-scale average based on a 1-km data set. Topography has been filtered to remove grid-scale structures.

Parameterizations Surface fluxes based on a resistance model by vertical integration of a flux-gradient representation along a constant-flux transfer layer using a surface layer TKE equation (*Raschendorfer, 2001)*

Free-atmosphere turbulent fluxes based on a level-2.5 scheme with prognostic TKE (*Mellor and Yamada, 1974*) with contributions from non-turbulent processes *(Raschendorfer, 2001)*

Radiation scheme (two-stream with three solar and five longwave intervals)

after *Ritter and Geleyn (1992)*, full cloud-radiation feedback based on

predicted clouds

Mass flux convection scheme after *Tiedtke (1989)*

Kessler-type grid-scale precipitation scheme with parameterized cloud

Microphysics after Doms and Schättler, 2004 and Seifert, 2008

7-layer soil model *(Heise and Schrodin, 2002; Schulz et al., 2016)* including

simple vegetation and snow cover; prescribed climatological value for

temperature at about 14 m depth.

Over ocean: Fixed SST from SST analysis over open water; for ice-covered

ocean areas a sea ice model (Mironov et al., 2012) provides ice thickness

and temperature;

roughness length according to Charnock´s formula in ice-free areas.

Over inland lakes: Lake model FLake (Mironov, 2008; Mironov et al. 2010;

http://lakemodel.net).

COSMO-EU will be switched off in Q4 2016 after the migration of all products to ICON-EU forecasts.

**c)** **Schematic summary of the limited area model COSMO-DE**

Domain Germany and surroundings

Initial data time 00, 03, 06, 09, 12, 15, 18 and 21 UTC

Forecast range 27 h (45 h from 03 UTC)

Prognostic variables p, T, u, v, w, qv, qc, qi, qrain, qsnow, qgraupel, TKE

Vertical coordinate Generalized terrain-following, 50 layers

Vertical discretization Finite-difference, second order

Horizontal grid 421x461 points (0.025° x 0.025°) on a rotated latitude/longitude grid,

mesh size 2.8 km; Arakawa-C grid, see Fig. 1.

Horiz. discretization Finite-difference, fifth order upwind advection;

For the advection of moisture variables: *Bott (1989)* scheme with Strang-

splitting

Time integration Two-time-level, 3rd order Runge-Kutta, split explicit

(*Wicker and Skamarock, 2002*), Δt = 25 s.

Horizontal diffusion Implicit in advection operators. Explicit horizontal hyperdiffusion (4th order)

for the velocity components and Smagorinsky-type diffusion In the full

domain.

Orography Grid-scale average based on a 1-km data set. Topography has been filtered to remove grid-scale structures.

Parameterizations Surface fluxes based on a resistance model by vertical integration of a flux-gradient representation along a constant-flux transfer layer using a surface layer TKE equation (*Raschendorfer, 2001)*

Free-atmosphere turbulent fluxes based on a level-2.5 scheme with prognostic TKE (*Mellor and Yamada, 1974*) with contributions from non-turbulent processes *(Raschendorfer, 2001)*

Radiation scheme (two-stream with three solar and five longwave intervals)

after *Ritter and Geleyn (1992)*, full cloud-radiation feedback based on

predicted clouds

Mass flux convection scheme after *Tiedtke (*1989) for shallow convection

only. Deep convection is resolved explicitly by COSMO-DE.

Kessler-type grid-scale precipitation scheme with parameterized cloud

microphysics after Doms and Schättler, 2004 and Seifert, 2008

7-layer soil model *(Heise and Schrodin, 2002; Schulz et al., 2016)* including

simple vegetation and snow cover; prescribed climatological value for

temperature at about 14 m depth.

Over ocean: Fixed SST from SST analysis over open water; for ice-covered

ocean areas a sea ice model (Mironov et al., 2012) provides ice thickness

and temperature;

roughness length according to Charnock´s formula in ice-free areas.

Over inland lakes: Lake model FLake (Mironov, 2008; Mironov et al. 2010;

http://lakemodel.net).

4.3.2.2 Research performed in this field

**Revision of the soil heat capacity and conductivity in the land surface scheme TERRA**

The formulation of the soil heat capacity in the soil model TERRA was enhanced to account for the impact of organic mass in the soil on plant covered grid points. An improvement of the diurnal temperature amplitude in the model compared to measurements was observed. A further improvement of the simulated screen-level temperature in sand deserts is due to an adapted soil heat conductivity for dry sand.

(J. Helmert and G. Zängl)

**A new parameterisation of bare soil evaporation for the land surface scheme TERRA**

The bare soil evaporation simulated by the land surface scheme TERRA (Schulz et al., 2016) of the DWD global and regional atmospheric models is systematically overestimated under medium-wet to wet conditions. This creates a dry bias in the soil, a moist bias of near-surface humidity and a cold bias of near-surface temperature (at daytime). Furthermore, it leads to a reduced diurnal near-surface temperature range. Under medium-dry to dry conditions, the bare soil evaporation in TERRA is systematically underestimated.

In the standard model configuration of TERRA, the formulation of bare soil evaporation is based on the Biosphere-Atmosphere Transfer Scheme (BATS; Dickinson, 1984). In extensive tests with other formulations it turned out that a scheme based on a resistance formulation (for a review see Schulz et al., 1998) yields the best results. A new scheme was developed and implemented in TERRA. Experiments in offline mode, utilizing measurements of the DWD observatory Lindenberg (Falkenberg site), show substantial improvements with respect to moisture and temperature errors. Experiments in coupled mode, with ICON, show significant improvements as well.

(J.-P. Schulz and G. Vogel)

**Multi-layer snow model**

The multi-layer snow model differs mainly in two points from the current one-layer snow model. These are, 1) an arbitrary number of layers in snow instead of one bulk layer and 2) the possibility of water phase changes, existence of liquid water content, water percolation and refreezing within snowpack. The explicit vertical stratification (multi-layer structure) of various properties of snow (temperature, density etc.) allows a more correct representation of the temperature at the soil-snow and snow-atmosphere interface which is important for calculation of snow melting rate and surface turbulent fluxes. The accounting for liquid water and water phase changes within snowpack allows a more accurate calculation of the evolution of the snow properties, in particular, snow water-equivalent depth and snow density, which in turn determines snow heat conductivity.

An improved version of the model became available in the latest COSMO model version. In this version, some issues related to numerical stability are solved and some bugs are corrected.

(E. Machulskaya)

**Tile approach now operational!**

Tile approach is a means to account for surface heterogeneity within each model grid box. Within the framework of the tile approach, each model grid box is divided into a number of sub-grid elements characterised by different surface types. The surface types (e.g. forest, bare soil or water) and the fractional area of the sub-grid elements are specified by external-parameter fields. The fractional snow cover is considered separately for each element. Individual values of surface temperature and humidity and, importantly, individual vertical profiles of soil temperature and moisture are computed for each tile, where snow-covered and snow-free parts of each sub-grid element are treated as separate tiles. The algorithm takes particular care of the conservation of soil heat and moisture when the fractional snow cover changes with time. The grid-box mean fluxes of sensible and latent heat are determined by means of averaging of fluxes over different tiles weighted with the tile fractional areas. It should be emphasised that these weighted-mean fluxes differ from the fluxes computed on the basis of grid-box mean values of surface temperature and humidity.

The tile approach to compute surface fluxes was implemented into the COSMO model. Currently, there is no link between an external parameter database and the COSMO model code, so that only snow-covered/snow-free tiles and inland water tiles may be considered, because the information about the corresponding grid-box fractions of these surface types is available within the COSMO model itself. These two configurations of the tile approach were successfully tested through parallel experiments (see the GDPFS Report 2011). The results indicate that if snow is considered as a tile, the surface temperature of the snow-free tile can rise above freezing point independently of the surface temperature of the snow tile, which is physically plausible. Various case studies from the years 2011-2012 show that in the regions with fractional snow cover, the COSMO model without the tile approach keeps the surface temperature at freezing point, whereas with the tile approach the COSMO model is indeed able to reproduce the grid-box aggregated surface and air temperature several degrees higher than freezing point which is close to observations.

The tile approach is implemented into the global model ICON (operational at DWD since January 2015). As compared to COSMO, the tiled surface scheme implemented into ICON operates with the full set of land surface types. Inland water, open ocean water and see ice are also treated as tiles. The approach selects a prescribed number of dominating surface types for each grid box. In the case of partial snow cover, the snow-covered part and the snow-free part are treated as sepa-rate tiles (with separate soil temperature and moisture profiles) for a number of land surface types, e.g. bare soil or grass. However, for some other surface types, e.g. forest, no separate profiles are treated, although the surface temperature and humidity are computed as weighted means of tem-perature and moisture over snow-covered and snow-free parts.

(E. Machulskaya, D. Mironov, J. Helmert)

**Determination of required soil physical parameters for the COSMO land surface scheme TERRA using new basic soil data**

Numerical weather prediction (NWP) models need information about the soil state that is the lower boundary for atmospheric processes over land. Soil physical properties and soil moisture have an impact on the surface flux budget and therefore on the exchange of heat and moisture between land-surface and atmosphere**.**

#### Besides the influence of hydrological inputs, the observed high variability of soil moisture over space is partly due to soil properties and land surface characteristics (*Ashton, 2012*). The transport of moisture in the soil is controlled by soil hydraulic parameters. The NWP COSMO model uses these parameters for 6 aggregated soil types + information about glaciers, rocks, and sea water/ice, based on the FAO Digital Soil Map of the World (FAO-DSMW) in 5 arcminutes resolution.

#### Since 2008 the global Harmonized World Soil Database (HWSD) in 30 arc-second raster, provides over 16000 different soil mapping units that combines existing regional and national updates of soil information (*Nachtergaele, 2012*). With this comprehensive global data set it is possible to derive the soil types for the Soil-Vegetation-Atmosphere Transfer (SVAT) model TERRA of the NWP COSMO model as from the FAO-DSMW. However, the HWSD offers additionally a link between soil units and soil properties (e.g., fractions of sand, silt, clay, and organic carbon together with bulk density). By employing pedotransfer functions using these soil properties (e.g., *Wösten et al., 1999*) the required soil hydraulic parameters can be determined in TERRA from HWSD soil units together with a look-up table of soil properties *(Smiatek et al., 2015*).

Some benefit for the COSMO model can be derived from this approach. It preserves the high horizontal variability contained in the HWSD soils for the SVAT model and allows with a flexible look-up table of soil properties a quick adaptation for other soil data sets.

(J. Helmert, E.-M. Gerstner, G. Smiatek)

**Implementation of a vegetation canopy scheme in the land surface scheme TERRA**

The missing stratification of the vegetation in the land surface scheme TERRA was upgraded by the discrimination of the energy budget for the canopy and the vegetation floor. A prognostic equation for the canopy temperature was introduced, which accounts for the heat capacity of the vegetation. It is expected that the model improves the simulation of the diurnal cycle of the screen-level temperature and decreases the overestimation of the soil-temperature amplitude compared to measurements.

(J. Helmert, E. Machulskaya, M. Raschendorfer, G. Zängl)

#### 4.3.3 Operationally available NWP products

Short-range forecasts are based on direct model output (DMO) of the ICON, COSMO-EU, COSMO-DE and on MOSMIX and WarnMOS guidance based on ICON and ECMWF data.

#### 4.3.4 Operational techniques for application of NWP products

* + - 1. In operation

Forecasts are produced partly automatically, based on the data listed in 4.3. Forecasts in plain language and warnings for the public and for aviation are produced by meteorologists. Any kinds of fields, DMO, ensemble based data and MOS-data are available and used in combination with nowcasting techniques. Forecasts of significant weather (SWC) for Middle Europe are produced on the base of COSMO-EU and special techniques. NWP results are used for a variety of further applications. Some of these applications are briefly described below.

DMO is used for the production of any weather situation imaginable in 2-D or 3-D modules as still picture, dynamic graphics, or as a complete film. A graphics system developed for the visualization of meteorological data supports the interactive or automatic presentation of DMO in single images or image sequences.

Short range forecasts of weather and temperature in pictorial form are automatically produced for online presentation on the Internet using MOS-MIX forecasts of ICON and ECMWF (worldwide and national).

The state of road surfaces (road surface temperature and road surface condition) is predicted by a road weather forecast system (AutoSWIS –Automatisches Strassenzustands- und Wetter-Informations-System) using MOS MIX data based on ICON and ECMWF and an energy balance model of the road surface.

A 10 day regional forecast based on the 50 ensemble members of the ECMWF EPS data has been re-designed for SWIS. The forecast includes daily maximum/minimum temperatures as well as snow and precipitation probabilities. The regions are in accordance to the SWIS regions (7 lowland and 7 mountain regions). The grid points are interpolated to stations and then assigned to the regions. The upper and lower limits for the maximum and minimum temperatures are calculated from the mean values and the standard deviations. Precipitation and snow probabilities are also calculated by the mean values of the regions. In addition, a 15 day regional forecast for the DWD website (7 lowland regions) has been re-designed. The Forecast variables are daily maximum/minimum temperatures which are also based on ECMWF EPS data and calculated like the previous product.

The influence of weather on human health is forecasted using a bio-synoptical weather classification scheme and the predicted vorticity, temperature and humidity in the surfaces - 850- and 500 hPa. The thermal strain on a prototype human being is calculated by a physiologically relevant energy balance model which employs forecasted temperature, humidity, wind and short- and long-range irradiances derived from predicted cloudiness. Both weather classification and thermal strain data are calculated for all grid-points of the ICON-EU. Heat warnings are produced on the basis of GMOS-data. They base both on the thermal strain outdoors during daytime and the nocturnal thermal strain indoors. Latter is calculated using a thermal building simulation model. UV Index and resultant UV-warnings are forecasted within ICON / ICON-EU derived from the large scale UV Index forecasts. The large-scale UV Index is calculated depending on solar zenith angle and the column ozone forecast. Subsequently the large scale UV Index is adjusted by factors to variable aerosol amount and type, altitude, surface albedo of predicted snow cover and cloud optical thickness of predicted cloudiness of ICON / ICON-EU.

The aviation community needs forecasts of wind, temperature, air density and QNH for the planning and safe management of flights. These are provided as direct model output. Apart from the 2D QNH, the parameters are available in 3D for different height levels: for the lower atmosphere on geometric height levels, higher up on flight levels.

Two of DWD’s meteorological watch offices (MWOs) issue the low-level significant weather chart (LL-SWC) for the middle European area from the surface up to FL245. LL-SWCs are in use as general guidance for the aeronautical consulting business and in general aviation. They contain information on the expected significant weather, jet axes, visibility, clouds, turbulence, icing and cloud coverage. The aeronautical meteorological forecaster produce interactively the charts on meteorological work-stations based on COSMO-EU results combined with conventional synoptic methods.

For the planning of gliding flights in Germany and most parts of Middle Europe the software package TOPTHERM is used. TOPTHERM calculates the development of thermal lift for specific areas based on COSMO-DE. Aviation users can visualize the TOPTHERM results with the TOPTASK application available on DWD’s online briefing platform <http://www.flugwetter.de>.

Access to this platform requires registration with DWD. During the gliding season an advice for gliding pilots is prepared which may be received by the system PCMET. It presents charts of the lowest cloud base or the height of thermal activity, precipitation, wind direction and wind speed for several times during the day. It is based on COSMO-EU and COSMO-DE data.

Furthermore, the COSMO-EU model output provides the data base for the visualization software SkyView and the icing forecast algorithm ADWICE. SkyView visualizes forecasts of convection, cloudiness and wind at different levels on grid points in time steps of one hour up to 70h. Users can zoom into different areas in Europe. The flash application allows users to combine several parameters in the same map depiction. In this way, a common analysis of the requested parameters is possible.

The model ADWICE forecasts and diagnoses the atmospheric icing between surface and FL 360. In current operational use ADWICE provides hourly prognostic products up to 24h and 3 hourly forecasts up to 78h, updated four times a day. Furthermore there is a hourly updated

diagnostic product that provides the actual risk of aircraft icing using METAR, SYNOP, RADAR and Satellite information in addition to COSMO-EU model output data. At the moment results are visualised in NinJo (both, prognostic and diagnostic products) and in the Selfbriefing system pc\_met Internet (only prognostic products up to 48h).

An additional automated MOS system is used for the calculation of worldwide international and regional airport forecasts. The system is based on the IFS model (ECMWF), SYNOP and METAR observations. For Central European stations radar and lightning remote sensing observations as well as the advection of these quantities are included into the MOS equations. The forecasts are distributed hourly as guidance and in a TAF coded format (AutoTAF) up to +30h. Many of the forecasting elements are adapted for aviation purpose and give probabilistic information.

All aviation meteorological products are offered to a closer user group over the web site: <http://www.flugwetter.de>.

Agrometeorological forecasts cover a wide span of applications aiming at a reduction of the use of insecticides and fungicides or at an optimization of the water supply to plants. NWP results are combined with additional models which calculate the drying of leaves or the temperature and water balance in the ground. These forecasts are presented in <http://www.agrowetter.de>.

In the maritime department programs are run to extract globally direct model grid point information from the weather and sea state models for German research vessels and other ships or yachts. The data is distributed by automatic e-mail.

WarnMOS is a grid-based MOS-System for the territory of Germany. On a 1x1km² grid hourly updated probabilistic warning guidance for the next 24h and 75 h (four times a day) are calculated. Input data are the NWP models ICON and IFS (ECMWF), SYNOP data and remote sensing observations from precipitation radar and lightning. The forecasts are visualised in NinJo and serve as input data for AutoWARN. In addition the forecasts are used in the DWD mobile app “WarnWetter”

4.3.4.2 Research performed in this field

**Project OOG/OMG**

A system “Objective Optimization“ (OOG) has been developed which serves to continuously generate a single consensus forecast from different site specific forecast guidances, nowcasting products, and recent observations (Rohn and Heizenreder, 2007). The system is fully integrated within the meteorological workstation NinJo of DWD. The system has been extended in order to additionally integrate results of the meso-gamma scale model COSMO-DE.

The system has been extended to allow for manual modification of site specific forecast guidances by using DWD’s meteorological workstation NinJo. A new process for merging these modified model outputs with latest OOG forecasts (which contain current observations) has been developed to provide one optimized and latest forecast guidance “approved by the forecaster” (OMG).

**Project AutoWARN**

The semi-automatic operational warning decision support system AutoWARN has been developed at the German Weather Service (DWD) as part of its overall strategy of further automation and centralization of the weather warning service. One aim is to help forecasters to deal with increasing amounts of NWP and observational/Nowcasting data. (Reichert, 2009; 2011; 2013; Reichert et al., 2015).

In a first step, available NWP model and ensemble forecasts (COSMO-DE-EPS, ECMWF-EPS, ICON) are combined into a single warning forecast product (ModelMIX). This is done using an Ensemble Model Output Statistics (Ensemble-WarnMOS) approach based on logistic regression on a probabilistic basis. Various DWD Nowcasting systems (Cell Detection and Tracking KONRAD, CellMOS, Radar-based precipitation analysis and forecast RADVOR, Vertically Integrated Liquid Water VIL derived from 3D-Radar data, Mesocyclone Detection) as well as observations and model output (COSMO-DE) are combined using a fuzzy logic approach to obtain a robust Nowcasting Warning Product (NowCastMIX), updated every 5 minutes. In a second step, both products, ModelMIX and NowCastMIX, with a spatial grid-resolution of 1 km, are used by AutoWARN in order to generate automated warning proposals that can be quality-controlled and modified manually by forecasters or that just serve as a basis for issuing individual manual warnings by forecasters. The result is a final warning status used to produce the full range of individual textual and graphical warning products for customers in a fully automatic mode. These products include internet and mobile app visualizations for about 300 German districts with a high update frequency. An even higher spatial resolution for up to around 11,000 German municipalities becomes operational in 2016.

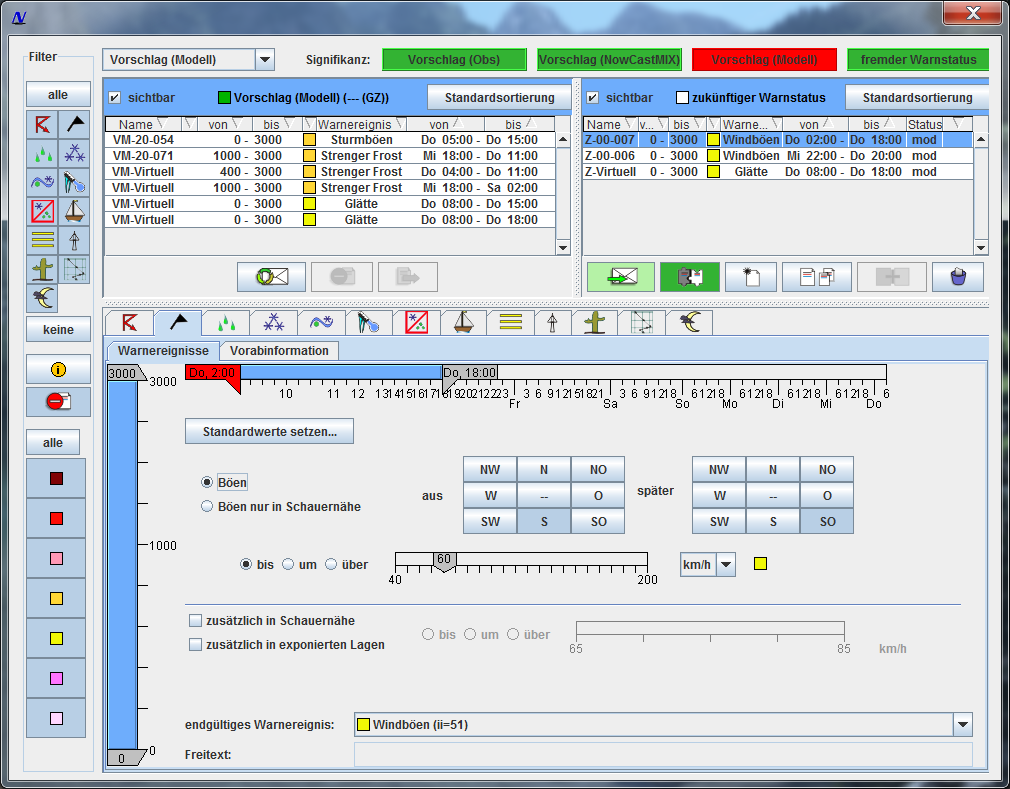
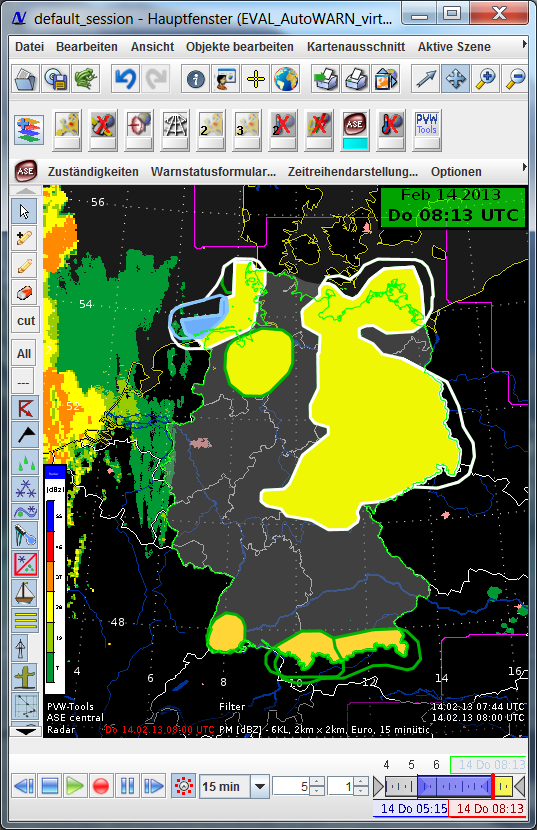


Figure 1: Graphical User Interface for AutoWARN within NinJo

A new version AutoWARN 2.1 became operational in autumn 2015 including enhanced warning proposals based on a full version of ModelMIX (including ensemble forecasts from COSMO-DE-EPS and ECMWF-EPS) and an extended range of customer-specific warning products (with different levels of spatio-temporal warning details). Current work focuses on ergonomic software improvements and a better treatment of moving warning events (weather object-based approach).

**Project EnsembleMOS**

As MOS Systems for ICON and ECMWF are operational, a system to statistically optimize and calibrate ensemble data is currently in development. The new EnsembleMOS system is enhanced for the special requirements and application of ensemble models such as COSMO-DE-EPS and EZMWF-EPS (later ICON-EPS as well). Based on the WarnMOS setup with a new logistic regression approach it is prepared to provide statistically optimized and calibrated probabilistic forecasts as input for AutoWARN (see above).

**Project ADWICE**

The postprocessing system ADWICE forecasts and diagnoses the atmospheric aircraft icing between surface and FL 360.The microphysics scheme of COSMO-EU/ICON has been modified in 2015 to improve the prediction of supercooled liquid water (SLW). Aim of this work was to extent the usage of SLW prediction within the ADWICE framework to improve aircraft icing prognosis. SLW was strongly underpredicted by the COSMO-EU/ICON model und therefore ADWICE did not rely on the model SLW prediction but uses its own parameterisation (parcel model). Results show, that there is a slight improvement of icing forecasts using the modified SLW. However, the parcel method still needs to be used in combination with SLW model output.

Furthermore, a global setup of ADWICE forecasts with ICON numerical model data has been tested and is expected to get operational in October 2016.

Current work focuses on development of forecasts for aircraft icing risk in addition to icing intensity level and scenario.

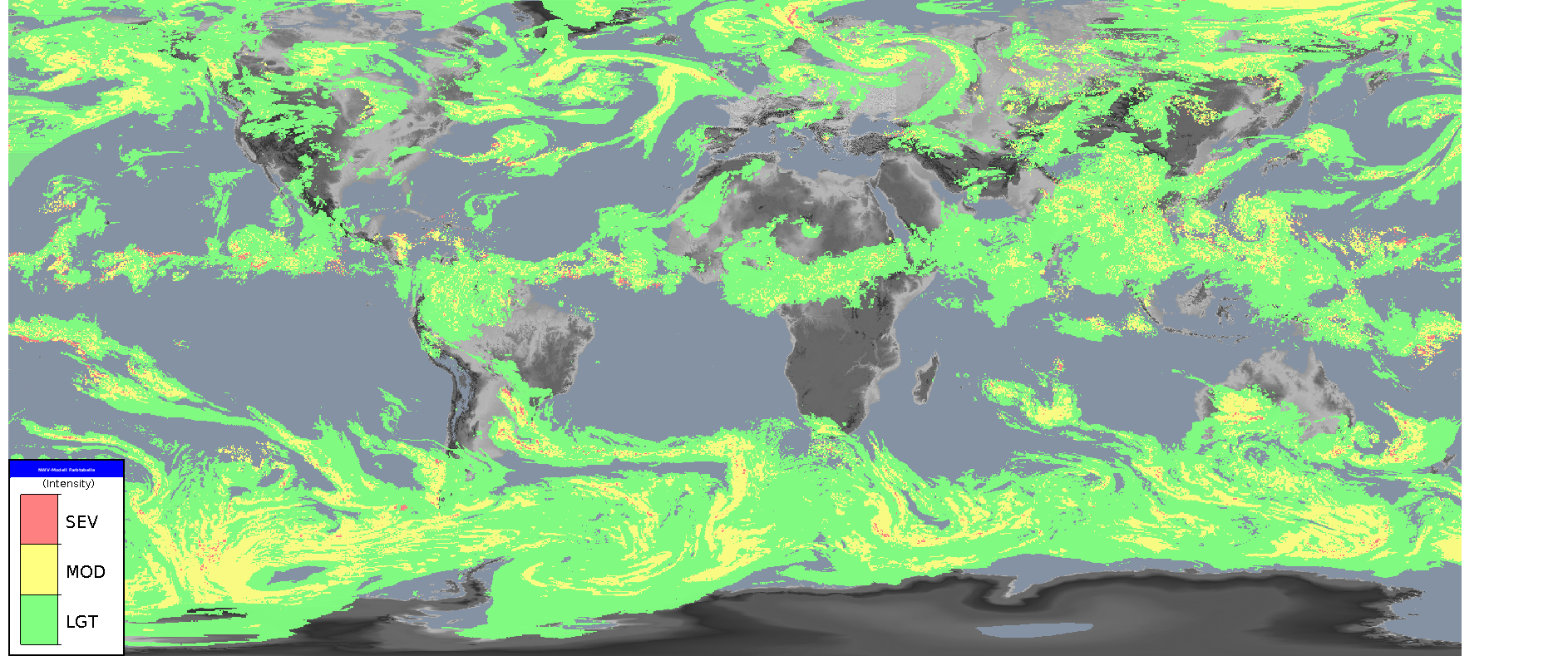


Figure 2: Example for a global icing intensity level forecast (maximum in column) with ADWICE on ICON: Light (green), Moderate (yellow) and Severe (red) icing.

**Project Turbulence Forecast for aviation**

The prediction of turbulence is an exercise for aviation forecast at DWD. A prognostic turbulent kinetic energy (TKE) scheme is considered in our regional model COSMO-EU. The Eddy Dissipation Rate (EDR) has the capability to assimilate the sources and depressions of the TKE equation. The EDR is to be linked up with the TKE over the Kolmogorov equation.

It is a principal question, whether the numerical prediction model will be able to reflect the relevant sources for aircraft turbulence. In a further step additional production terms were introduced into our prognostic TKE scheme related to the generation of turbulence by the action of shear of wind, subgrid scale orographic blocking and gravity wave breaking and subgrid scale convection. Measurements of EDR over the US are used together with EDP ( “parameter”, because third root of EDR) from COSMO nested over the US domain. A satisfactory statistics (verification EDP vs. EDR-measurement) justified the start of the operational introduction of the EDP.

The EDP forecasts the turbulence between FL100 and FL490 currently and provides hourly prognostic products up to 24h, updated twice a day (00,12 UTC). Results are visualised in NinJo (used by MWO’s e.g. for SIGMET) and over Web Map Service.

However, we suffer from special problems related to EDR measurements based on power spectra of vertical velocity of the airplane and model deficits. We are going to introduce further improvements. All enhancements are to be realized with the new global model ICON.

**Project Integrated Terminal Weather System (ITWS) / Low Level Wind Shear Alert System (LLWAS)**

At DWD is running a project to develop an Integrated Terminal Weather System (ITWS) for the hubs Frankfurt and Munich. In the first step analysis and NowCast of convective weather events with the System NowCastMix/ITWS will be considered. The NowCastMix/ITWS-System will be improved by implementation of a cell-cyclus module. Furthermore, the NowCastMix/ITWS-System for convective weather will be extended in a third-party funded project (LuFo WeAC – Weather for ATM and CDM) to winter weather situations. In an EC funded project within FP7 the benefit of using a high resolution airport model as NowCast Tool will be investigated (COSMO-MUC).

Further, a Low Level Wind Shear Alert System based on remote sensing measurement sensoric (combination of X-Band Radar and LIDAR) will be implemented at the airports of Frankfurt and Munich.

**SESAR WP11.2 Meteorological Information Services and SESAR Demonstration Activities**

DWD participates within an EUMETNET EIG consortium in both SESAR (Single European Sky Air Traffic Management Research Programme) projects in SESAR WP11.2 and SESAR Demonstration activities. The goal of SESAR is to support the realisation of a homogenous European Sky.

The aim of the first project is to develop harmonised, consistent aviation meteorology fields / parameter for the local and en-route situations. Issues are convective weather situations (analysis, nowcasting and ensemble-based methods), icing, turbulence, winter weather and capacity studies. Beside DWD Météo France, UK Met Office, FMI, SMHI, Met Norway and KNMI join the project as EUMETNET member. Consolidated products have been developed and verified and will be made available for validation campaigns.

In the second project current national meteorological products have been validated during fight trials in the first half of 2014. DWD is engaged with ADWICE and COSMO-EU turbulence. Météo France and UK Met Office join the project with convective weather products as well as high level wind and temperature fields as well as convective weather products. Those three national weather services are considered as one project member (labelled as EUMETNET consortium). The project has ended September 2014 with a satisfying response by the users.

**Project TAF-Guidance / AutoTAF by the Met Alliance**

The MOS AutoTAF system described above (4.3.4.1) has been redesigned for the use at the DWD and as a common AutoTAF forecasting system within the Met Alliance. The driving model GME has been replaced by the IFS (ECMWF) deterministic model due to an agreement within the Met Alliance and due to verification results. One aim of the project is to set up and operate a verification system based on agreed verification method.

**Projects EWeLiNE and ORKA**

In the research projects EWeLiNE (2012-2016 = Erstellung innovativer Wetter- und Leistungspro gnosemodelle für die Netzintegration wetterabhängiger Energieträger) and ORKA (2012-2015 = Optimierung von Ensembleprognosen regenerativer Einspeisung für den Kürzestfristbereich am Anwendungsbeispiel der Netzsicherheitsrechnungen ), the overarching objective is to improve the power forecasts of the power production from renewable energies. Both projects focus on forecasts for wind energy and photovoltaic (PV) since these energy sources are highly weather dependent and as such fluctuating in time. A very high potential for improving the power forecasts lays in the improvement of the quality of the underlying weather forecasts. In both projects, the collaboration with external partners in research and industry plays a major role.

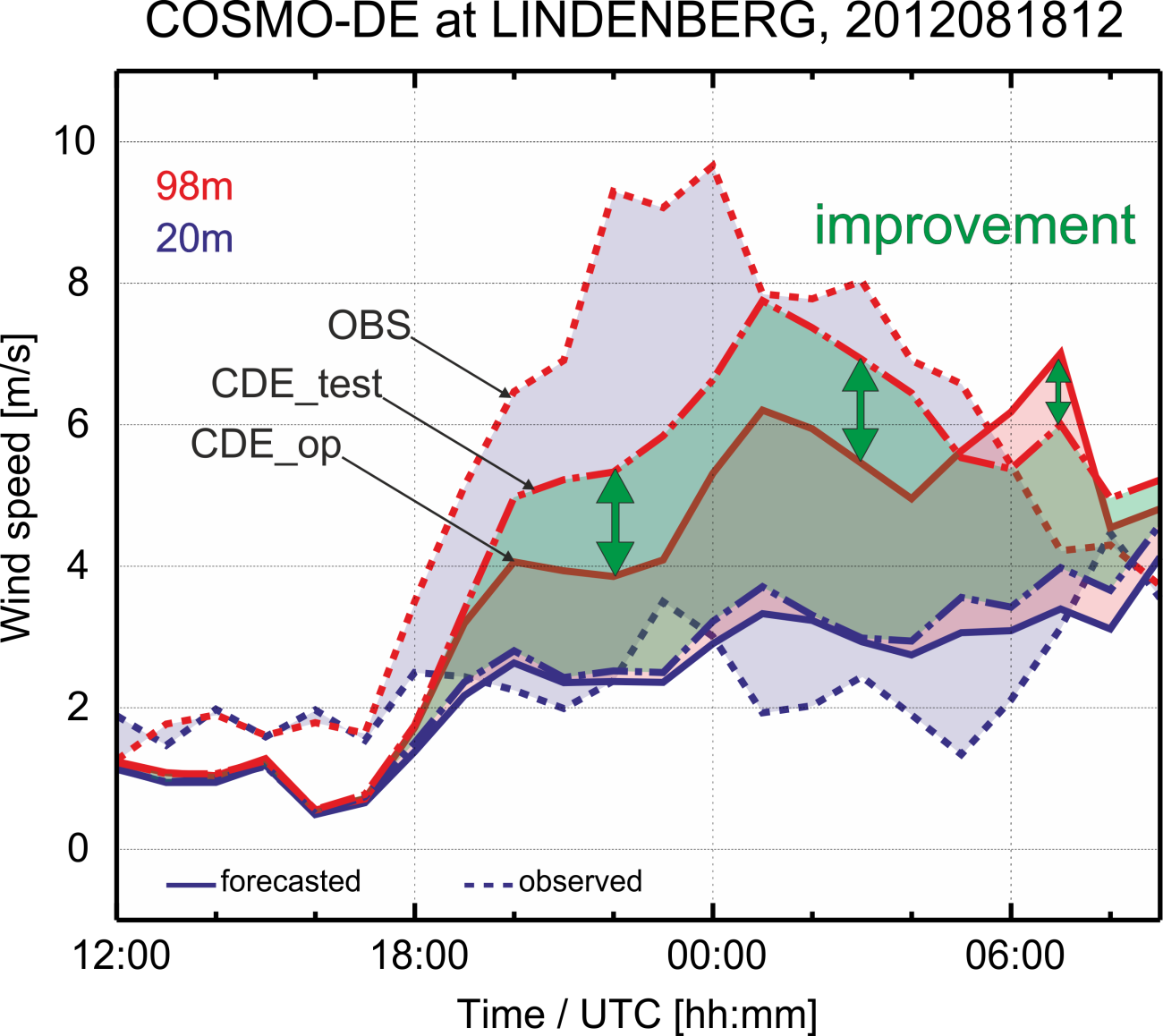
In EWeLiNE, the main focus lies on achieving better forecasts for the current and following day. DWD is aiming at improving the deterministic and probabilistic weather forecasts and developing new user optimized products. COSMO-DE and COSMO-DE-EPS are the main focus of the work. The research aspects include optimized treatment of the parameterized processes, assimilation of newly available observations from wind or PV power plants and satellites, optimized ensemble generation and post-processing methods, and thereby in particular potential enhancements of MOS on the DMO. The verification of the forecasts is extended from traditional parameters (e.g., temperature, precipitation, and surface wind speed) to e.g., global radiation and wind speed at different altitudes. The verification of renewable energy relevant parameters has been carried out for the deterministic and the probabilistic forecasts to identify error characteristics of the forecasts compared to measurements (e.g., surface based pyranometer measurements, satellite retrieved data and wind towers). Figure 2 illustrates the bias of COSMO-DE-EPS wind speed forecasts at approximately 100 m for the winter 2012/2013 and summer 2013 (3-month averages). In winter, the bias of the wind speed is the highest. During the other time of the year - especially in the summer- wind speeds in hub height exhibit strong daily cycles, which causes difficulties for the forecast. A reduced bias is achieved by applying bias correction based on bivariate Ensemble Model Output Statistics (EMOS) (for wind forecasts) for the winter season. In parallel, ongoing work deals with optimizations of the turbulence- and transfer scheme of COSMO-DE in order to allow for more stable conditions during night and by artificially increasing vertical mixing after sunrise and thereby reducing the error of the daily cycle.

Figure 1.
Figure 1.


Figure3:

Bias of the 20 members of COSMO-DE-EPS, 3 UTC run, wind speed forecast at 90-110 m. Left: 3-month average for the winter 2012/2013, right: 3-month average for summer 2013.

Furthermore, ongoing work deals with improved ensemble generation. The first step considers the coupling of COSMO-DE-EPS to the LETKF scheme that is being developed within the KENDA (km-scale Ensemble Data Assimilation) project. In this way, COSMO-DE-EPS gains an ensemble of initial conditions directly from the data assimilation. Experimental results show increased spread and reduced forecast error for the first approx. 10 hours of the forecast when combining the operational BCEPS (Boundary Condition Ensemble Prediction System) system with initial conditions from KENDA. As already mentioned above, statistical post-processing methods of COSMO-DE-EPS for wind at e.g., 100m height and global radiation are being tested. The methods that are being considered involve quantile regression (for wind and solar radiation) and bivariate Ensemble Model Output Statistics (EMOS) (for wind forecasts). Based on user requirements, the focus is put on generation of calibrated scenarios. E.g., a variation of the ensemble copula coupling (ECC) technique called kinetic-ECC is being tested, where a temporal component is added to the usual ECC. Moreover, the MOS of DMO has been extended to renewable energy relevant parameters and the temporal resolution was increase from 3 h to 1 h. During the whole project, the requirements of the users, i.e. the Transmission System Operators (TSO), will be integrated into the research activities to obtain user optimized products. An effort is especially put on the development of probabilistic products and the integration of these into the systems of the users. The products will be tested in live-mode during a demonstration phase at the end of the project.



***Fig.3)*** *Cabauw, 18. August. 2012; Observed (blue) and fore-casted (red) wind speed profiles for lead times +18 up to +21 hours, corresponding to 06:00 UTC up to 09:00 UTC. Note the persistence of a decoupled layer in the forecasted profiles after sunrise (04:30 UTC). Similar profiles can be found for Lindenberg and Risø for the same date.*

***Fig.4)*** *Lindenberg, 18. August. 2012; Observed (dotted) and operationally forecasted (solid) wind speed in 20 and 98 m. Note that the LLJ is too weak and too long-living in the model. A test run (dash dotted lines; momentum flux at the ground was slightly reduced, stability during night as well as mixing after sunrise were increased) shows better results. (namelist settings: tur\_len=150, a\_stab=1, pat\_len=200, rlammom= 0.5, tk[h,m]min= 0.001, if sobs .gt. 5 tk[h,m]min=1.5)*

#### 

Figure 4:

Optimized solar radiation ensemble forecasts based on COSMO-DE-EPS. Reference (operational setup) in black, and experimental setup with optimized model physics perturbations in orange. Left: CRPS, right: Spread and rmse of solar radiation at the surface. The optimized physic perturbations lead to a slight improved CRPS at noon, and an increased ensemble spread. The effect on the rmse of the ensemble mean remains neutral.

The focus of the project ORKA lies on improving probabilistic forecasts on the forecast range of 0-8 h, in particular by optimizing the generation of ensembles and by improving the representation of parameterized physical processes of the COSMO-DE-EPS. For improving the ensemble spread within the first few hours of the forecast, the vertical filter of the initial condition perturbations has been modified. Furthermore, the physics perturbations are being extended. Figure 3 illustrates experiments with respect to optimized solar irradiance ensemble forecasts. In the experiment, physics perturbations with respect to cloud water and cloud ice in the radiation scheme, and the thickness of shallow convection clouds have been combined with the operational setup. The effect on wind speed at hub height (not shown) was neutral, and the effect on solar radiation was positive, e.g. in terms of reduced CRPS (Conditional Ranked Probability Score) and improved ensemble spread.

#### 4.3.5 Ensemble Prediction System (EPS)

4.3.5.1 In operation

**Operational systems based on models with parameterized convection**

EPS products from the ECMWF and COSMO-LEPS as described in 4.2.5.3 are in use also for short range forecasting as far as applicable. In addition to this, SRNWP-PEPS (Poor Man’s Ensemble Prediction System) is in use since 2006.

**SRNWP-PEPS** (“Poor man’s” Ensemble Prediction System of the Short Range Numerical Weather Prediction Program) is running in operational mode. The SRNWP-PEPS combines most of the operational LAM 8Limited Area Modelling) forecasts of the European weather services. The products are generated on a grid with a horizontal resolution of approximately 7km (see figure 4).

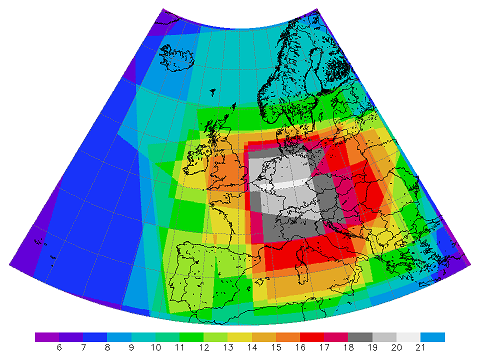


Figure 5: Domain and maximum ensemble size of the SRNWP-PEPS.

In Europe there are four different main operational limited area models (LAM) developed by different consortia. These four models are all representatives of today's state of the art in the Short-Range Numerical Weather Prediction field and are used by more than 20 national weather services to produce their operational forecasts (EUMETNET SRNWP = Short Range Numerical Weather Prediction Programme). The weather services run their models on different domains with different grid resolutions using different model parameterizations, data assimilation techniques and different computers producing a huge variety of different forecasts. Bringing together these deterministic forecasts, the **SRNWP-PEPS** provides an estimate of forecast uncertainty. Of course, this estimate is biased, e.g. due to model clustering in consortia, and some sources of uncertainty are still missing. However, ensemble post-processing would be able to generate calibrated probability forecasts from the **PEPS**. The main purpose is the improvement of European severe weather warning systems.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Meteorological**  **Service** | **Regional Model** | **Coupling Model** | **Resolution (km)** | **Forecast Period (h)** | **Time interval (h)** | **Main Runs (UTC)** |
| **Belgium** | ALADIN-BE | ARPEGE | 15 | +60 | 1 | 0, 6, 12, 18 |
| **France** | ALADIN | ARPEGE | 11 | +48 | 3 | 0, 12 |
| **Austria** | ALARO5 | ECMWF | 4.8 | +72 | 1 | 0, 6, 12, 18 |
| **Croatia** | ALADIN | ARPEGE | 9 | +72 | 1 | 0, 12 |
| **Czech. Repub.** | ALADIN-LACE | ARPEGE | 11 | +48 | 1 | 0, 6, 12, 18 |
| **Hungary** | ALADIN-LACE | ARPEGE | 11 | +48 | 1 | 0, 6, 12, 18 |
| **Slovakia** | ALADIN-LACE | ARPEGE | 11 | +48 | 3 | 0, 12 |
| **Slovenia** | ALADIN-LACE | ARPEGE | 9.4 | +48 | 3 | 0, 12 |
| **Denmark** | HIRLAM | ECMWF | 16 | +60 | 1 | 0, 6, 12, 18 |
| **Finland** | HIRLAM | ECMWF | 16 | +54 | 1 | 0, 6, 12, 18 |
| **Spain** | HIRLAM | ECMWF | 18 | +48 | 1 | 0, 6, 12, 18 |
| **Netherlands** | HIRLAM | ECMWF | 22 | +48 | 1 | 0, 6, 12, 18 |
| **Ireland** | HIRLAM | ECMWF | 11 | +54 | 3 | 0, 6, 12, 18 |
| **Norway I** | HIRLAM | ECMWF | 8 | +48 | 1 | 0, 12 |
| **Norway II** | HIRLAM | ECMWF | 12 | +48 | 1 | 0, 12 |
| **Sweden** | HIRLAM | ECMWF | 11 | +48 | 3 | 0, 6, 12, 18 |
| **Germany** | COSMO-EU | ICON | 7 | +78 | 1 | 0, 6, 12, 18 |
| **Switzerland** | COSMO-7 | ECMWF | 7 | +72 | 1 | 0, 12 |
| **Poland** | COSMO | ICON | 14 | +72 | 3 | 0, 12 |
| **Italy** | EuroLM | EuroHRM | 7 | +48 | 1 | 0, 12 |
| **United Kingdom** | UM-EU | UM-Global | 11 | +48 | 1 | 0, 6, 12, 18 |

Table 2: Models contributing to SRNWP-PEPS

**Very short range convection-permitting COSMO-DE-EPS**

COSMO-DE-EPS is a very short range ensemble prediction system based on the convection-permitting model COSMO-DE. The model COSMO-DE has a horizontal grid-spacing of 2.8 km, produces forecasts with a lead time of 0-27 hours, covers the area of Germany and has been in operational mode at DWD since April 2007 (section 4.3.2).

The aim of COSMO-DE-EPS is the quantification of forecast uncertainties on the convective scale where the predictability is limited to very short forecast ranges. An estimate of uncertainties provides an added value compared to a single deterministic forecast, because it allows for an interpretation of the forecast in probabilistic terms. Such probabilistic information is essential in decision-making processes and risk management.

With the aim to quantify forecast uncertainties, variations are introduced to COSMO-DE model physics, initial conditions, and lateral boundary conditions (*Peralta et al., 2012, Gebhardt et al., 2011*). Variations of model physics are realized by non-stochastic perturbations of parameters in the parameterization schemes. Initial conditions and lateral boundary conditions are varied by nesting the COSMO-DE ensemble members into a boundary-condition EPS (BC-EPS). The BC-EPS consists of different COSMO 7 km simulations which are nested into forecasts from different global models (ICON of DWD, IFS of ECMWF, GFS of NOAA/NCEP and GSM of JMA). Perturbations of the initial soil moisture fields have been included in the operational COSMO-DE-EPS since January 2014. They are derived from differences between COSMO-EU und COSMO-DE soil moisture analyses in layers down to a depth of 1m below surface.

Since December 2010, the ensemble prediction system COSMO-DE-EPS has been running in pre-operational mode. Operational production with 20 members started on 22 May 2012. The current version comprises 20 ensemble members, with a horizontal grid-spacing of 2.8 km. COSMO-DE-EPS is started 8 times a day (00 UTC, 03 UTC, …), and each ensemble run has a lead time of 27 hours (45 hours for 03 UTC). Probabilistic products (e.g. exceedance probabilities and quantiles) are calculated for parameters and thresholds relevant for the warnings issued by the DWD forecasters.

* + - 1. **Research performed in this field**

Verification results for COSMO-DE-EPS indicate that the perturbations have a beneficial effect on probabilistic precipitation forecasts when compared to deterministic forecasts. This benefit is most effective for convective summer precipitation. However, the ensemble forecasts are underdispersive and overconfident.

.

Regarding the representation of forecast uncertainty, research is in progress to use initial conditions from members of the COSMO-DE ensemble data assimilation and lateral boundary data from ICON-EPS. Furthermore, additional physics perturbations have been tested in order to increase the ensemble spread in lower level wind-speed, cloudiness and screen level temperature.. Further research is done to include stochastics aspects in the representation of model error.

Plans for **ICON short range EPS**

The ICON short range EPS will have 40 members with a global horizontal resolution of approximately 40 km (20 km over Europe) and forecast lead times up to 72h. It is planned to start the operational service in Q4 2017. The initial ensemble perturbations will be based on the Ensemble Data Assimilation system (VarEnKF = Variational Ensemble Kalman Filter) developed at DWD (see section 4.3.1). Forecasts from the VarEnKF analysis ensemble are still under-dispersive and research is performed on setting perturbations in dynamical systems. The first option for adding fast growing perturbations to the analysis ensemble is to use lagged forecasts to identify and filter unstable modes. In addition, we work on alternatives to the Singular Vectors (SV) approach which provides the fastest growing modes but requires forward and backward integration of the linearized model. An alternative can be the “Limited Memory Broyden” method (LMB). It uses the full nonlinear model to approximate the fastest growing modes in an iterative procedure. We have implemented and further improved the LMB algorithm in low dimensional Lorenz systems. We are now able to very well approximate the Singular Vector perturbation in these low dimensional dynamical systems. It is ongoing work to adopt the algorithm to high dimensional NWP models.

To simulate model error, a stochastic physics package is provided by our physical aspects section based on a linear stochastic modelling approach using stochastic mode reduction. Since we have good results in the COSMO model we will also implement and test the linear stochastic modelling approach in the ICON-EPS.

(M. Denhard)

#### Operationally available EPS Products

Similar to COSMO-LEPS (see 4.2.5.3), also SRNWP-PEPS and COSMO-DE-EPS provide probability charts for Europe which give information whether accumulated rain or snow, wind gusts, temperatures or CAPE values will exceed thresholds defined by warning requirements. Products based on SRNWP-PEPS are available up to 42 hours and those based on COSMO-DE-EPS up to 27 hours Exceeding probabilities, quantiles, ensemble mean, spread, min, max are calculated for total precipitation, total snowfall, 10m wind gusts, 2m temperature, cloud cover, CAPE, and simulated radar reflectivities. For precipitation, also “upscaled” probabilities are provided. They refer to predefined regions which are substantially larger than the model grid (*Ben Bouallègue and Theis, 2014*).

The products of COSMO-DE-EPS are visualized within the visualization tool NinJo. The NinJo system has been complemented by an “ensemble layer”. This layer is also used to visualize other ensemble systems such as COSMO-LEPS, PEPS and ECMWF EPS.

**4.4 Nowcasting and Very Short-range Forecasting Systems (0-6 hrs)**

**4.4.1 Nowcasting system**

* + - 1. In operation

Nowcasting activities make use of a number of remote-sensing systems, focussing on radar-based precipitation monitoring and nowcasts (RADOLAN, RadVOR), real-time lightning detection (LINET, nowcast GmbH) and the NowCastMIX pre-processing tool for automatic warning generation, in combination with the high-resolution numerical weather prediction model, COSMO-DE.

An important component of the radar-focussed precipitation nowcasting is KONRAD (Konvektion in Radarprodukten), developed originally at the DWD observatory at Hohenpeissenberg, Bavaria, performing reflectivity-based cell identification and tracking. It is a very robust system which has been used consistently for some 15 years now. Further storm cell tracking is provided by the MOS-based system CellMOS, developed a few years after KONRAD. This utilises statistical relationships between observed thunderstorm data and various input datasets, including radar, lightning and NWP model data, to provide probabilistic estimates of cell tracks and their severe weather attributes, such as wind gusts, precipitation amount, hail and frequency of lightning.

Ultimately all of the above data sources are also pre-processed together in the nowcasting tool, NowCastMIX, which computes, on a 5-minute rapid updating cycle, an integrated, optimised set of automatic warnings for the next hour for thunderstorms, torrential rain, snowfall and freezing rain. NowCastMIX provides this warning data for the DWD’s forecast advisory centre, via the AuoWARN process, for civil aviation advisory centres and even direct to the public via the DWD’s WarnWetter App.

* + - 1. Research performed in this field

Project AutoWARN with NowCastMIX

The automated warning process in AutoWARN utilizes outputs from various nowcasting methods and observations, combined with NWP model data, to generate a forecast-time dependent automatic warning status. This is permanently manually controlled and modified by the forecaster before text and graphical warning products are generated. In order to provide a generic optimal solution for nowcast warnings in AutoWARN all nowcast input data is pre-processed together in a single grid-based system: the NowCastMIX. This provides an ongoing real-time synthesis of the various nowcasting and forecast model system inputs to provide a single, consolidated set of most-probable short-term forecasts, focussing on thunderstorm and heavy rain events, as well as on the winter events, snow and freezing rain.

NowCastMIX combines data intelligently from various radar-based sources with lightning strike data and NWP model output. The speed and direction of storm cells is assessed and used to forecast regions at imminent risk of storm developments. The potential severity of the storms is estimated by deploying a fuzzy logic system to assess the relative risk of each of the attributes involved: hail, severe guts and torrential rain.

4.4.2 Models for Very Short-range Forecasting Systems

* + - 1. In operation

**Schematic summary of the convection-resolving model COSMO-DE**

Domain Germany and surrounding

Initial data time 00, 03, 06, 09, 12, 15, 18, 21 UTC

Forecast range 27 h (45 h from 03 UTC)

Prognostic variables p, T, u, v, w, qv, qc, qi, qrain, qsnow, qgraupel, TKE

Vertical coordinate Generalized terrain-following, 50 layers

Vertical discretization Finite-difference, second order

Horizontal grid 421 x 461 points (0.025° x 0.025°) on a rotated latitude/longitude grid,

mesh size 2.8 km; Arakawa-C grid

Horiz. discretization Finite-difference, fifth order upwind advection

For the advection of moisture variables: *Bott (1989)* scheme with Strang-

splitting

Time integration Two-time-level, 3rd order Runge-Kutta, split explicit

(*Wicker and Skamarock, 2002*), Δt = 25 s

Horizontal diffusion Implicit in advection operators. Explicit horizontal hyperdiffusion (4th order) in

the boundary zones and in the full model domain for the velocity components. Smagorinsky-type diffusion in the full domain

Orography Grid-scale average based on a 1-km data set. Topography has been filtered to remove grid-scale structures

Parameterizations Surface fluxes based on a resistance model by vertical integration of a flux-gradient representation along a constant-flux transfer layer using a surface layer TKE equation (*Raschendorfer, 2001*)

Free-atmosphere turbulent fluxes based on a level-2.5 scheme with prognostic TKE (*Mellor and Yamada, 1974*) with contributions from non turbulent processes *(Raschendorfer, 2001)*

Radiation scheme (two-stream with three solar and five longwave intervals)

after *Ritter and Geleyn (1992)*, full cloud-radiation feedback based on

predicted clouds

Mass flux convection scheme after *Tiedtke (1989*) only for shallow convection

Kessler-type grid-scale precipitation scheme with parameterized class-6

cloud microphysics

7-layer soil model *(Heise and Schrodin, 2002; Schulz et al., 2016)* including

simple vegetation and snow cover; prescribed climatological value for

temperature at about 14 m depth

Over sea/ocean water: Fixed SST from SST analysis.

Over inland water bodies: the lake parameterization scheme Flake (<http://lakemodel.net>) is used to predict the water surface temperature; for frozen lakes the ice surface temperature and the ice thickness are predicted. The Charnock formula for the water aerodynamic roughness is used over sea/ocean and inland water bodies.

* + - 1. Research performed in this field

**Influence of diabatic processes on the pressure and temperature equation**

In the COSMO model, the continuity equation is transformed to a pressure equation via the equation of state. At the moment, the contributions Qh to the pressure tendency due to diabatic heating (phase changes, turbulent/convective transports, divergence of radiation fluxes) and the contributions Qm due to mass transfer (internal exchange to/from hydrometeors by phase changes, external diffusion over the grid box boundaries changing system composition) are neglected in the pressure equation, which also affects the temperature equation via its pressure term. Effectively, this leads to a temperature equation which does not contain Qm and which employs cp as the relevant heat capacity.

Consistent to that, it is assumed that the "saturation adjustment" (an "infinitely fast" phase change process with corresponding temperature change towards vapor/liquid equilibrium) happens at constant pressure, which leads to the usual formulation of the adjustment equations. Note that one has to specify such an additional constraint otherwise the adjustment problem would not have a unique solution.

As a consequence, mass is not conserved during diabatic change processes. For example, during microphysical phase changes, there is locally a spurious mass loss during condensation / sublimation and a mass gain during evaporation / sublimation, equal in relative terms for all gaseous species including water vapour. Because normally there is more condensation than evaporation (thanks to precipitation) we expect a net mass loss in the model, and loss of water vapour might decrease subsequent precipitation.

In a new model version, the terms Qh and Qm due to diabatic processes (except turbulent dissipation and one thermodynamical cross-effect term) are included in the pressure equation. Correspondingly this influences the temperature equation in a way that now simply cv replaces the former cp as relevant heat capacity and a new contribution due to the Qm term appears on the right hand side. For the saturation adjustment, this means that we now have to assume locally constant density during this process and that the relevant heat capacity is now cv instead of cp. Experiments have been conducted to investigate the influence of including the Qh and Qm terms on the precipitation forecast. The results suggest that there is a slight increase in total precipitation (1-3 %) and an insignificant shift in fine structure of precipitation patterns. Also we observe a slight enhancement of local precipitation maxima, which has a positive influence on our “fuzzy” precipitation verification scores. Also, there is a (weak) positive influence on geopotential and surface pressure. All other quantities and scores seem to behave neutral.

(U. Blahak, A. Seifert)

**Extension of the COSMO-DE setup**

It is planned for Q2 2018 to enhance the COSMO-DE setup in three respects. Firstly, the horizontal grid spacing will be reduced from 2.8 km to 2.2 km (0.02°). Secondly, the number of vertical levels will be increased from 50 to 65 levels. The additional levels will mainly contribute to increase the resolution of the boundary layer. The main purpose is a better initiation of convection. Thirdly, the domain will be slightly extended mainly in the western direction. In particular, the assimilation of additional radar data by latent heat nudging in this area can improve the forecast quality. Additionally, the domain extension to the south will include the whole Alpine region without cutting through its high mountains.

(M. Baldauf, B. Ritter)

**Development of a TKE-Scalar Variance turbulence-shallow convection scheme for the COSMO model**

The TKE-Scalar Variance (TKESV) turbulence-shallow convection scheme for NWP models has been developed within the framework of the COSMO priority project UTCS (Unified Turbulence shallow Convection Scheme). The TKESV scheme carries prognostic equations for the turbulence kinetic energy (TKE) and for the scalar variances (variances of total water specific humidity and of the liquid water potential temperature and their covariance). These prognostic second-moment equations include the turbulent diffusion terms (divergence of velocity-velocity and velocity-scalar triple correlations) that are parameterised though the down-gradient approximation. Recall that the current COSMO-model turbulence scheme (referred to as the TKE scheme) computes the scalar variances from the diagnostic relations that are obtained from the respective second-moment equations by neglecting the turbulent diffusion and the time-rate-of-change terms. One more essential difference between the new and the current schemes is in the computation of scalar fluxes. The current scheme is based on the down-gradient approximation whereas the new scheme accounts for non-gradient terms (among other things, this allows for up-gradient scalar transfer). The non-gradient corrections to scalar fluxes stem from the buoyancy terms in the scalar-flux budget equations; those terms are parameterised with regard for the turbulence anisotropy. The formulation for the turbulence length (time) scale used within the TKESV scheme accounts for the effect of static stability (current operational COSMO model uses a Blackadar-type turbulence length scale formulation independent of static stability).

The TKESV scheme was successfully tested through single-column numerical experiments. The TKESV scheme outperforms the TKE scheme in dry convective PBL (Planetary Boundary Layer). The PBL is better mixed with respect to potential temperature. An up-gradient heat transfer that is known to occur in the upper part of the dry convectively-mixed layer is well reproduced. For cloudy PBLs, the application of the TKESV scheme leads to a better prediction of the scalar variances and TKE and to slight improvements with respect to the vertical buoyancy flux and to the mean temperature and humidity. Both schemes tend to overestimate fractional cloud cover in the cumulus-topped PBL. This error is attributed primarily to the shortcoming of quasi-Gaussian sub-grid scale (SGS) statistical cloud parameterization scheme used by both TKESV and TKE schemes to determine fractional cloudiness and the buoyancy production of TKE.

The TKESV scheme is implemented into the COSMO model and tested through a series of parallel experiments with the COSMO-EU and COSMO-DE configurations including the entire COSMO-model data assimilation cycle. Verification of results from parallel experiments indicate improvements as to some scores, e.g. two-metre temperature and humidity and fractional cloud cover. A detailed scientific documentation of the TKESV scheme is in preparation. Modifications associated with the TKESV scheme will soon be included into the official COSMO-model code (for details, see the Model Development Plan at the COSMO web site). The work is underway to implement the TKESV scheme into the global NWP model ICON.

(D. Mironov and E. Machulskaya)

**Plans to achieve a consistent description of SGS processes by scale separation**

On the way towards a scale separated set of SGS (sub-grid scale) parameterizations, we already have introduced additional scale interaction source terms in our prognostic TKE equations related to separated non-turbulent horizontal shear modes and to wake modes generated by SSO (subgrid-scale orography). Finally, we introduced a first version of a similar scale interaction term from our convection parameterisation closely related to the buoyant production of SGS kinetic energy by the convection process. Recently we also introduced TKE-advection as well as horizontal diffusion by means of the separated horizontal shear eddies.

While the TKE-production by SSO is switched on in our operational version, the other two terms need to be verified in the next future. However, they are used as diagnostic source terms in order to derive an improved EDR (eddy dissipation rate) forecast for aviation purposes.

Besides operational testing, we are going to use EDR-measurements by aircrafts in order to estimate the value of undetermined parameters in the formulations of those additional TKE source terms.

We are further planning to reformulate our current version of a scale interaction term caused by non-turbulent thermals related to surface inhomogeneity using input parameters of the present SSO scheme. After substituting a before constant length-scale parameter of that scheme by the standard deviation of SSO height had already improved the model scores, we now want to adapt the parameterization to be more specific to nocturnal density flows along SSO slopes. Further we want to test now the contribution of TKE-advection and of TKE-production by separated vertical shear modes, as well as the impact of mixing by the additional non turbulent modes themselves (starting with horizontal diffusion by the separated shear eddies).

Finally it is aimed to reformulate in particular the current convection scheme in order to account for the counterpart of the scale interaction term in the convection scale budgets and to come along with a consistent overall description of SGS cloud processes. These last aims however belong to a longer time scale.

(M. Raschendorfer)

**Plans to consolidate our surface-to atmosphere transfer and to account for inhomogeneity of surface roughness and tall effective roughness layers**

We started implementing some reformulations of the transfer scheme allowing for a stronger influence of the resulting transfer coefficients on thermal surface layer stratification. We aim to continue this work and hope to remove some of our systematic errors related to the diurnal cycle of near surface variables. After single column component tests have shown that some numerical limits (as minimal diffusion coefficients) together with a so far supressed adaption of our assumed vertical profile functions of surface layer diffusion coefficients are due to a rather low sensitivity on stratification, we now are testing the adapted interpolation function and try to substitute the constant minimal diffusion coefficients by proper statistical and physical parameterizations.

On a longer perspective, this task also includes the introduction of the vertically resolved roughness layer already mentioned in earlier plans, based on the concept of a spectral separation of equivalent topography described by an associated surface area index and a roughness height. By this procedure the large scale part of topographic land use structures are represented by additional source terms in all budget equations on the model levels being within the roughness layer, which is a generalization of the SSO approach. This includes a description of the roughness layer built by the change of land use within a grid box surface, being important for the aggregation of roughness parameters available for a couple of surface tiles within a grid box. We formally implemented these related extensions into the running test version of our turbulence scheme. However the description of the external input parameters is an issue for future investigation.

(M. Raschendorfer)

**Adoption of the turbulence- and transfer-scheme for use in the ICON model**

In order to run our COSMO turbulence scheme in ICON, we implemented a couple of modifications related to numerical stability and efficiency, modularity of the source code, as well as improvements in the way how to achieve positive definiteness of TKE and the stability functions.

Further we reformulated the code for implicit vertical diffusion in order to call a single subroutine for arbitrary tracers with a flexible setting of boundary conditions and of options related to the degree of implicitness and the treatment of vertical fluxes given not in a flux-gradient representation.

All these changes have been introduced to the ICON model and are running there as the default configuration. Further, some statistical parameterizations have been introduced, in order to substitute so far constant parameters (as the minimal diffusion coefficients) by some empirical functions of the model state. After this version has been merged with some further development of the COSMO version, a common turbulence package for both models, COSMO and ICON has been developed. As a next step we are going to find optimal parameter settings of this updated scheme for its use in COSMO.

(M. Raschendorfer)

### 4.5 Specialized numerical predictions

#### 4.5.1 Assimilation of specific data, analysis and initialization

4.5.1.1 In operation

None

4.5.1.2 Research performed in this field

None

**4.5.2 Specific Models**

4.5.2.1 In operation

**4.5.2.1.1 Trajectory Models**

Trajectory model:

Forecast variables r (λ, ϕ, p or z, t)

Data supply u, v, w, ps from NWP forecasts (or analyses)

Numerical scheme 1st order Euler-Cauchy with iteration (2nd order accuracy)

Interpolation 1st order in time, 2nd (ICON) or3rd (COSMO-EU) order in space

1. Daily routine (ca. 1500 trajectories)

Trajectories based on COSMO-EU forecasts:

Domain Domain of COSMO-EU

Resolution 0.0625° (as COSMO-EU)

Initial data time 00, 12 UTC

Trajectory type Forward trajectories for about 110 European nuclear and 4 chemical installations, backward trajectories for scientific investigations

Forecast range 72-h trajectories, optional start/arrival levels

Trajectories based on ICON forecasts:

Domain Global

Resolution 13 km

Initial data time 00, 12 UTC

Trajectory type 168-h forward trajectories for ca. 120 European nuclear sites and 8 German regional forecast centres, backward trajectories for 37 German radioactivity measuring sites and 8 forecast centres using consecutive +6h to +18h forecast segments

168-h backward trajectories for all GAW stations and to the German meteorological observatories.

72-h backward trajectories for 5 African cities in the framework of the METEOSAT-MDD program, disseminated daily via satellite from Exeter

168-h backward trajectories for the German polar stations Neumayer (Antarctica) and Koldewey (Spitzbergen) and the research ships Polarstern and Meteor, disseminated daily

Mainly backward trajectories for various scientific investigations

Forecast range 168-h forward and backward trajectories, optional start/arrival levels

b) Operational emergency trajectory system, trajectory system for scientific investigations:

Models COSMO-EU or ICON trajectory models

Domain COSMO-EU or global

Data supply u, v, w, ps from COSMO-EU or ICON forecasts or analyses,

from current data base or archives

Trajectory type Forward and backward trajectories for a choice of offered or freely eligible stations at optional heights and times in the current period of 7 to 14 days

Forecast range 72-h (COSMO-EU) or 168-h (ICON)

Mode Interactive menu to be executed by forecasters

* + - * 1. **Ocean wave models**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **GWAM** | **EWAM** | **CWAM** |
| **Domain** | **Global** | **European Seas**  south of 66°N,  east of 10.5°W | **Coastal Seas**  south of ~53°N,  ~6°E – 15°E |
| **Grid** | reduced lat/lon | regular lat/lon | |
| **Resolution** | 0.25° x 0.25° | 0.05° x 0.10 | 30‘‘ x 50‘‘ (~900m) |
| **Numerical scheme** | Shallow water, 3rd generation WAM | | |
| **Wind data supply**  (u,v at 10 m) | ICON | ICON-EU refinement domain | |
| **Assimilation**  (over last 12 hours) | Altimeter wave- hights  Analysed wind fields | Predicted wind fields | |
| **Initial data time** | 00 and 12 UTC | | |
| **Forecast range** | 174 h | 78 h | 48h |
| **Model output** | 18 integrated spectral parameters (e.g. significant wave height, peak period and direction of wind sea and swell), as well as wave spectra at selected positions | | |
| **Verification** | Available on request | | |

CWAM is running pre-operationally in a coupled mode with an ocean circulation model provided by the Federal Maritime and Hydrographic Agency of Germany (BSH).

**4.5.2.1.3 Lagrangian particle dispersion model**

As a part of the German radioactive emergency system a Lagrangian Particle Dispersion Model (LPDM) is in use at DWD. The LPDM calculates trajectories for a multitude of particles emitted from a point source using the grid‑scale winds and turbulence parameters of the NWP-model and a time scale based Markov‑chain formulation for the dispersion process. Concentrations are determined by counting the number and mass of particles in a freely eligible grid. Dry deposition parameterisation follows a deposition velocity concept and wet deposition is evaluated using isotope-specific scavenging coefficients. Radioactive decay, a vertical mixing scheme for deep convection processes and optionally particle-size depending sedimentation coefficients is included too. Additionally, an assimilation scheme for measured concentration data can be activated. Starting from these observed fields or from selected receptor points the LPDM can be run also in a backward mode to determine unknown source positions. The LPDM was successfully validated using data of the ANATEX (Asia North Atlantic Tracer Experiment) and ETEX (European TracerExperiment) tracer experiments. In the ATMES-II report of the 1st ETEX release the model took the first rank of the 49 participating models. During the follow-up project RTMOD an evaluation of an accidental Cs-137 release (Algeciras, May 1998) was performed. The transport and dispersion of the cloud and the calculated dose rates were found to be in good agreement with the measurements. In the ENSEMBLE-ETEX reanalysis (2003) the ranking of the model was again excellent.

The LPDM can be run on basis of the DWD's operational weather forecast models (ICON, COSMO-EU/COSMO-DE). In case of emergency the model output will be transmitted to the national 'Integrated Measurement and Information System' (IMIS) using slightly modified WMO codes. The calculations are also part of the European real-time decision system RODOS (Real-Time Online Decision Support System) in Germany. In this context data transfer and coupling with the operational RODOS system is tested several times a year. The model consistently assimilates the provided local scale source information, and calculates the transport and dispersion of selected (currently 9) standard nuclides simultaneously. The LPDM simulations can be also driven by COSMO-DE data. In this context snow pellets are included as a separate precipitation form in the wet deposition procedure. On request the model is operationally running in a backward mode to participate in the multi-model backtracking ensemble of the CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organization).

The LPDM code is optimised for MPP/Vector computers (e.g. IBM P5 575, NEC SX9, CRAY-XC 30). For this purpose the code is supplemented by MPI-based parallelisation features. The model is also implemented at Meteo Swiss based on the Swiss COSMO-version.

In the context of the Fukushima-Daiichi catastrophe the model was extensively utilized. During the release phase of the accident (March/April 2011) DWD provided dispersion forecasts for the public mainly based on global NWP(GME)-data. Additionally, the COSMO-LPDM (7 km grid spacing) was run in a quasi-operational mode for the relevant region covering Japan and its surroundings.

The global version of the LPDM is now based on ICON (operational since January 2015). As a member of the WMO multi-model backtracking ensemble of the CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organization) the LPDM was run for about 20 CTBTO-requests in backward mode. Since March 2015 these calculations are also based on the ICON model. Additionally, in the context of a National Data Centre Preparedness Exercise (NPE15) supporting backtracking calculation were performed (Oct./Nov.).Routinely, the operational model system was applied in several emergency tests at national (IMIS/RODOS) and international level (IAEA-WMO exercises).

(H. Glaab, A. Klein)

* + - 1. **Research performed in this field**

**4.5.2.2.1 COSMO-ART**

The COSMO-ART system, where ART stands for ‘Aerosols and Reactive Trace gases’, is an extension of the operational COSMO model. The complete set of ART modules developed at the Institute for Meteorology and Climate Research at the Karlsruhe Institute of Technology (KIT) is online coupled in a tightly integrated way to the COSMO model. I.e. the same routines for transport and diffusion of the gas phase and aerosol tracers are used as for the prognostic moisture quantities in NWP. The possible applications of COSMO-ART range from simple tracer dispersion problems to complete aerosol-radiation and aerosol-cloud interaction studies including the formation of secondary aerosol particles from the gas phase.

At DWD the model system is mainly employed for the dispersion modelling of volcanic ash and mineral dust.

In case of a volcanic eruption with relevance for the German air space COSMO-ART is run on an enlarged domain, the model results are made available on the NinJo workstations of and used by the aviation forecasters as a secondary source of information. To parameterise the emission of volcanic ash an empirical relation between observed plume height and mass eruption rate is used. To get to quantitative results for the mass concentration of volcanic ash in the atmosphere, aircraft measurements of the particle size distribution and number concentration are used. At the University of Hohenheim a LIDAR forward operator is developed. This operator will ease the comparison of model results and observations of the ceilometer network of DWD and is a prerequisite for the data assimilation of such measurements.

Different institutions use COSMO-ART to run forecasts of mineral dust. For example the United Arabian Emirates have set up daily model runs in their operational cycle.

The strong Saharan dust event beginning of April 2014 is currently investigated in a joint effort of DWD and KIT. Runs including the aerosol-radiation interaction of the simulated dust showed a significant reduction of the short-wave radiation at the surface. This for example had a big impact on the power produced by solar energy. Further studies will also include the aerosol-cloud interaction parts.

(J. Förstner, H. Glaab)

An additional application of COSMO-ART is the pollen forecast. The pollen module was initially developed by the IMK of KIT. Further development has been performed by KIT and MeteoSwiss and recently also by DWD. Up to now four pollen taxa are implemented: Alder, birch, grasses and Ambrosia. The pollen forecasts of these taxa are running operationally for the COSMO-7 domain at MeteoSwiss. The model output is provided to DWD. In July 2016, the COSMO-ART pollen forecast is published on the DWD webpage.

(C. Endler)

**4.5.2.2.2 ICON-ART**

Following the explanation of COSMO-ART in the previous section the ICON-ART system is the likewise extension of ICON. ICON-ART is currently under development at the IMK of KIT and the DWD, aiming at the complete functionality mentioned above. New developments for the ART modules will actually first be implemented with ICON before to be taken over also for COSMO. At DWD the model will be employed for dispersion modelling of volcanic ash, mineral dust and radionuclides.

The modules for volcanic ash, radionuclides, sea salt and mineral dust are nearly completely implemented. The ART modules have been restructured at KIT to streamline further expansions and developments using the object oriented capabilities of FORTRAN 2003. For example it is planned to introduce the treatment of volcanic ash also in the 2-moment cloud-microphysics framework, i.e. to use prognostic equations for the 0th and 3rd moment and different modes to represent the particle size distribution.

The (internally mixed) aerosol modes for the interaction with the gas phase chemistry will be implemented. For a flexible configuration of the gas phase chemistry the Kinetic Pre-processor KPP will be used. Aerosol-radiation and aerosol-cloud feedback processes will be implemented, where the later is realized in combination with the 2-moment cloud-microphysics scheme which is now also available in ICON.

(J. Förstner, H. Glaab)

#### 4.5.3 Specific products operationally available

The forward and backward trajectories are an important tool for emergency response activities. In addition to these forecasts for concentration and deposition of radionuclides are produced using a Lagrangian Particle Dispersion Model.

Based on the ocean wave models charts are produced for swell and significant wave height, frequency and direction.

Forecasts of the optimal (shortest and/or safest) route of ships are evaluated using the results of the global ocean wave model and of NWP in the ship routing modelling system of the DWD. The system calculates isochrones taking into account the impact of wave and wind on different types of ships.

A special application of the NWP result is a hydrological model-system called SNOW 4. It estimates and forecasts snow-cover development. The model calculates and forecasts grid-point values of the snow water equivalent and melt water release every six hours. The snow cover development is computed with the help of physically-based model components which describe accumulation (build-up, increase), metamorphosis (conversion, change) and ablation (decrease, melting).

The model input data are

- hourly averages of air temperature, water vapour pressure and wind velocity for the last 30 h

- solar surface radiation/sunshine duration/cloud cover and precipitation totals of the last

30h

- daily amounts of snow cover depth and three times a week water equivalent of snow cover

- output data of the COSMO-EU model

- radar data of hourly precipitation depth

- satellite data of snow coverage

The model output contains

* daily values of gridded snow depth observations (reference point 06.00 UTC)
* analyzed values of snow cover development (30 h backward, 1-h-intervals):
* snow depth (in cm)
* water equivalent (in mm)
* specific water equivalent (in mm/cm)
* forecast values of snow cover development (forecast interval 72 hours, forecasting for 1-h-intervals):
* snow depth (in cm)
* water equivalent (in mm)
* precipitation supply, defined as the sum of snowmelt release and rain (in mm)
* in addition forecast values of snow temperature and ice content can be derived

The results are provided grid-oriented and with a coverage for Germany and the surrounding basins of rivers flowing through Germany.

The UV index for all effective atmospheric conditions is operationally forecasted for up to 3 days with a global coverage and a high resolution European coverage. The UV Index on a global scale is forecasted in post-processing to DWD’s global model ICON. The forecast is based on column ozone forecasts that are provided by the Royal Dutch Meteorological Institute KNMI (as part of the Copernicus Atmosphere Monitoring Service) in an hourly resolution and interpolated to the ICON grid.

First a large-scale UV Index is calculated depending on solar zenith angle and the column ozone forecast. Subsequently the large scale UV Index is adjusted by factors to variable aerosol amount and type, altitude, surface albedo of predicted snow cover and cloud optical thickness. The calculations include aerosol optical depth forecasts of the ECMWF provided as part of the Copernicus Atmosphere Monitoring Service.

The large-scale UV-Index forecasts are suited to interpolation to the grids of national higher resolution models (HRM). They can then be adjusted to the HRM topography and HRM forecasts of snow cover and cloudiness. The DWD UV Index forecast on a high resolution European scale is done in post-processing to ICON\_EU that provides the detailed forecasts for the above mentioned adjustments of the large scale UV Index. Additionally site specific forecasts are available and are presented WHO-conform in the web.

All forecasts are supplied to the interested WMO member states of the Regional Association VI (Europe) by the RSMC Offenbach via its server [ftp-outgoing.dwd.de](file:///\\ofnfa138\p17230\Synoptik\WMO\Zumeldungen_2015\ftp-outgoing.dwd.de). For more information see <http://www.uv-index.de>.

The department agrometeorology of DWD provides agrometeorological warnings on the basis of NWP:

- forest fire danger prognoses

- grassland fire index

- warnings for heat stress in poultry

- forecast of potato late blight

and other indices of plant pests and plant diseases. These are part of the advisory system AMBER (Agrarmeteorologisches Beratungsprogramm).

### 4.6 Extended range forecasts (ERF) *(10 days to 30 days)*

#### 4.6.1 Models

4.6.1.1 In operation

None

4.6.1.2 Research performed in this field

None

#### 4.6.2 Operationally available NWP model and EPS ERF products

Use of ECMWF Var-EPS products.

### 4.7 Long range forecasts (LRF) *(30 days up to two years)*

4.7.1 In operation

Planned within 2016

4.7.2 Research performed in this field

Based on research at University of Hamburg and Max-Planck-Institute for Meteorology and in cooperation with both institutions DWD is setting up an operational system for seasonal forecasts at ECMWF. The coupled climate model MPI-ESM (Max-Planck-Institute-Earth System Model) is prepared for this purpose. The model components are the atmospheric model ECHAM, the ocean model MPIOM with sea ice parameterisations, the land and vegetation model JSBACH and a runoff model to close the hydrological cycle. The current resolution of the ECHAM model is 1.9°x1.9° while the ocean has around 1.5 ° grid widths. More details on the model description can be found in Stevens et al (2013) and Jungclaus et al. (2013).

The operational set up is as follows: the model needs to produce reforecasts of the last 30 years for each start date (i.e. month) and forecasts which are then assessed on the basis of the reforecast statistics.

The initial conditions are produced in an assimilation run in which ECMWF-reanalyses data for atmosphere and ocean and sea-ice data from NSIDC are nudged for the reforecasts. ECMWF-IFS analyses are nudged in the forecast mode.

An ensemble is set up by using the method of breeding in the ocean (Baehr and Piontek, 2013) and the perturbation of a physical parameter in the atmosphere. First results have been discussed and published in Baehr et al. (2014) and Domeisen et al. (2015).

The system is now implemented into the workflow management at ECMWF and produces forecasts since May 2015. Within summer 2016 an application will be submitted to join the EUROSIP project at ECMWF. The application to the WMO center of LRF will be submitted as well. The fully operational service is planned to start within 2016.

**Reference:**

Baehr J, K Fröhlich, M Botzet, DIV Domeisen, L Kornblueh, D Notz, R Piontek, H Pohlmann, S Tietsche, WA Müller, 2014: The prediction of surface temperature in the new seasonal prediction system based on the MPI-ESM coupled climate model. *J. Climate*, 1-13, 2014.

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Domeisen DIV, AH Butler, K Fröhlich, M Bittner, WA Müller, J Baehr, 2015: Seasonal predictability over Europe arising from El Niῆo and stratospheric variability in the MPI-ESM seasonal prediction system. *J. Climate*, **28**, 256-271, 2015.

Jungclaus J, N Fischer, H Haak, K Lohmann, J Marotzke, D Matei, U Mikolajewicz, D Notz, J von Storch, 2013: Characteristics of the ocean simulations in MPIOM, the ocean component of the MPI-Earth System Model. *Journal of Advances in Modeling Earth Systems,* 422-446, DOI 10.1002/jame.20023

Stevens B, M Giorgetta, M Esch, T Mauritsen, T Crueger, S Rast, M Salzmann, H Schmidt, J Bader, K Block, R Brokopf, I Fast, S Kinne, L Kornblueh, U Lohmann, R Pincus, T Reichler, E Roeckner, 2013: The atmospheric component of the MPI-M Earth System Model: ECHAM6. *Journal of Advances in Modeling Earth Systems,* **5**, 146-172, DOI 10.1002/jame.20015

#### 4.7.3 Operationally available EPS LRF products

Use of ECMWF Var-EPS products.

## 5. Verification of prognostic products

5.1.1.

Verification results of prognostic products are shown in the tables 3a - f.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
| **24.h** | 11 | 10 | 10 | 9 | 9 | 8 | 8 | 7 | 7 | 8 | 9 | 9 | 8.8 |
| **48.h** | 20 | 19 | 18 | 17 | 16 | 14 | 14 | 13 | 14 | 15 | 16 | 18 | 16.1 |
| **72.h** | 31 | 30 | 28 | 28 | 26 | 22 | 21 | 20 | 22 | 25 | 24 | 28 | 25.4 |
| **96.h** | 44 | 43 | 40 | 40 | 37 | 32 | 30 | 29 | 33 | 38 | 35 | 39 | 36.7 |
| **120.h** | 59 | 58 | 53 | 54 | 49 | 43 | 39 | 40 | 44 | 54 | 48 | 53 | 49.5 |
| **144.h** | 74 | 72 | 66 | 69 | 62 | 55 | 49 | 51 | 55 | 69 | 62 | 66 | 62.5 |
| **168.h** | 86 | 86 | 79 | 81 | 75 | 65 | 58 | 59 | 68 | 85 | 74 | 78 | 74.5 |

Table 3 a: **Verification of the DWD Global-Model, RMS error (m), geopotential height 500 hPa.**

**Area: Northern hemisphere, 00 UTC, 2015**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
| **24.h** | 10 | 9 | 10 | 10 | 12 | 12 | 13 | 13 | 12 | 10 | 10 | 9 | 11,0 |
| **48.h** | 19 | 16 | 20 | 19 | 23 | 24 | 24 | 24 | 22 | 19 | 18 | 16 | 20,3 |
| **72.h** | 31 | 26 | 32 | 32 | 36 | 39 | 38 | 38 | 34 | 29 | 27 | 26 | 32,2 |
| **96.h** | 44 | 38 | 47 | 46 | 52 | 55 | 54 | 54 | 48 | 42 | 40 | 38 | 46,4 |
| **120.h** | 57 | 51 | 60 | 61 | 67 | 71 | 70 | 71 | 65 | 57 | 56 | 49 | 61,3 |
| **144.h** | 70 | 63 | 74 | 77 | 83 | 86 | 86 | 90 | 84 | 72 | 70 | 62 | 76,4 |
| **168.h** | 82 | 73 | 84 | 89 | 100 | 102 | 101 | 105 | 99 | 85 | 82 | 73 | 89,7 |

Table 3 b: **Verification of the DWD Global-Model, RMS error (m), geopotential height 500 hPa.**

**Area: Southern hemisphere, 00 UTC, 2015**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
| **24.h** | 1,5 | 1,3 | 1,3 | 1,2 | 1,1 | 0,9 | 0,9 | 0,9 | 0,9 | 1,0 | 1,1 | 1,2 | 1,11 |
| **48.h** | 2,3 | 2,1 | 2,1 | 2,0 | 1,7 | 1,5 | 1,5 | 1,5 | 1,5 | 1,7 | 1,8 | 2,0 | 1,80 |
| **72.h** | 3,3 | 3,1 | 3,0 | 2,8 | 2,5 | 2,1 | 2,0 | 2,1 | 2,3 | 2,6 | 2,5 | 3,1 | 2,61 |
| **96.h** | 4,6 | 4,3 | 4,1 | 3,9 | 3,4 | 2,9 | 2,7 | 2,8 | 3,2 | 3,9 | 3,6 | 4,2 | 3,62 |
| **120.h** | 6,0 | 5,7 | 5,4 | 5,2 | 4,4 | 3,7 | 3,5 | 3,7 | 4,2 | 5,3 | 4,9 | 5,5 | 4,78 |
| **144.h** | 7,3 | 6,9 | 6,6 | 6,5 | 5,4 | 4,6 | 4,3 | 4,7 | 5,1 | 6,7 | 6,3 | 6,8 | 5,92 |
| **168.h** | 8,3 | 8,0 | 7,9 | 7,4 | 6,3 | 5,4 | 5,0 | 5,4 | 6,1 | 7,9 | 7,6 | 8,0 | 6,94 |

Table 3c: **Verification of the DWD Global-Model, RMS error (hPa), mean sea level pressure.**

**Area: Northern hemisphere, 00 UTC, 2015**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
| **24.h** | 1,1 | 1,0 | 1,2 | 1,3 | 1,5 | 1,4 | 1,5 | 1,5 | 1,3 | 1,2 | 1,1 | 1,0 | 1,24 |
| **48.h** | 2,0 | 1,7 | 2,1 | 2,2 | 2,5 | 2,5 | 2,6 | 2,5 | 2,3 | 2,0 | 1,8 | 1,6 | 2,14 |
| **72.h** | 3,0 | 2,5 | 3,1 | 3,4 | 3,7 | 3,9 | 3,9 | 3,8 | 3,6 | 3,0 | 2,7 | 2,6 | 3,26 |
| **96.h** | 4,2 | 3,5 | 4,4 | 4,8 | 5,2 | 5,5 | 5,4 | 5,4 | 5,0 | 4,3 | 3,9 | 3,7 | 4,61 |
| **120.h** | 5,4 | 4,7 | 5,6 | 6,2 | 6,7 | 7,0 | 6,9 | 7,0 | 6,5 | 5,7 | 5,4 | 4,7 | 5,97 |
| **144.h** | 6,4 | 5,7 | 6,8 | 7,6 | 8,0 | 8,6 | 8,3 | 8,6 | 8,1 | 7,1 | 6,7 | 5,7 | 7,29 |
| **168.h** | 7,4 | 6,4 | 7,6 | 8,5 | 9,5 | 9,9 | 9,6 | 9,8 | 9,4 | 8,3 | 7,6 | 6,7 | 8,39 |

Table 3d: **Verification of the DWD Global-Model, RMS error (hPa), mean sea level pressure.**

**Area: Southern hemisphere, 00 UTC, 2015**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
| **24.h** | 11 | 12 | 11 | 11 | 9 | 8 | 8 | 8 | 8 | 9 | 9 | 10 | 9,7 |
| **48.h** | 22 | 25 | 21 | 22 | 18 | 16 | 15 | 14 | 16 | 17 | 18 | 20 | 18,7 |
| **72.h** | 36 | 40 | 34 | 36 | 30 | 27 | 23 | 23 | 27 | 31 | 29 | 34 | 30,7 |

Table 3e: **Verification of the DWD Global-Model, RMS error (m), geopotential height 500 hPa.**

**Area: Europa-Atlantic, 00 UTC, 2015**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
| **24.h** | 1,4 | 1,5 | 1,4 | 1,3 | 1,0 | 0,9 | 0,9 | 0,9 | 1,0 | 1,0 | 1,1 | 1,3 | 1,1 |
| **48.h** | 2,5 | 2,6 | 2,3 | 2,2 | 1,8 | 1,6 | 1,5 | 1,4 | 1,7 | 1,8 | 2,0 | 2,3 | 2,0 |
| **72.h** | 3,7 | 4,0 | 3,4 | 3,4 | 2,7 | 2,5 | 2,2 | 2,1 | 2,6 | 3,1 | 2,9 | 3,7 | 3,0 |

Table 3f: **Verification of the DWD Global-Model, RMS error (hPa), mean sea level pressure.**

**Area: Europa-Atlantic, 00 UTC, 2015**

5.1.2.

Verification results of the Global‑Model ICON, for the region where forecasts are submitted

via facsimile, 2015.

**PART VI VERIFICATION**

**Surface pressure (hPa)**

|  |  |  |
| --- | --- | --- |
| **Time** | RMS | An. Cor. |
| **T+24** | 1,1 | 0,992 |
| **T+48** | 2,0 | 0,977 |
| **T+72** | 3,0 | 0,945 |

**Geopotential 500 hPa (gpm)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Time** | |  |  | | --- | --- | | RMS | An. Cor. | | |  |  | | --- | --- | | An. Cor. | An. Cor. | |
| **T+24** | 9,7 | 0,996 |
| **T+48** | 18,7 | 0,986 |
| **T+72** | 30,7 | 0,963 |

**Temperature 850 hPa (K)**

|  |  |  |
| --- | --- | --- |
| **Time** | RMS | An. Cor. |
| **T+24** | 0,9 | 0,982 |
| **T+48** | 1,3 | 0,955 |
| **T+72** | 1,8 | 0,914 |

**Temperature 500 hPa (K)**

|  |  |  |
| --- | --- | --- |
| **Time** | RMS | An. Cor. |
| **T+24** | 0,7 | 0,985 |
| **T+48** | 1,2 | 0,959 |
| **T+72** | 1,7 | 0,913 |

**Relative Humidity 500 hPa (%)**

|  |  |  |
| --- | --- | --- |
| **Time** | RMS | An. Cor. |
| **T+24** | 11,4 | 0,883 |
| **T+48** | 17,7 | 0,720 |
| **T+72** | 21,9 | 0,568 |

**Vector**  **Wind 850 hPa (m/s)**

|  |  |  |
| --- | --- | --- |
| **Time** | RMSE | Bias |
| **T+24** | 2,5 | 0,049 |
| **T+48** | 3,9 | 0,090 |
| **T+72** | 5,4 | 0,107 |

**Vector**  **Wind 250 hPa (m/s)**

|  |  |  |
| --- | --- | --- |
| **Time** | RMSE | Bias |
| **T+24** | 4,3 | 0,085 |
| **T+48** | 6,8 | 0,130 |
| **T+72** | 9,8 | 0,172 |

Table 4: **Verification results of the Global‑Model, for the region where forecasts are submitted**

**via facsimile, 2015**

5.2 Research performed in this field

A Global Skill Score called “COSI” (Collection Of Small Instances) to judge the long term trend of the models’ performance was introduced by the COSMO group in 2007. The Score combines scores for different forecast parameters like 2-m-temperature, 10-m-winds and 6-hour precipitation. Further investigation goes on in order to make the score more significant.

## 6. Plans for the future *(next 4 years)*

### 6.1 Development of the GDPFS

**6.1.1**

None

**6.1.2**

None

### 6.2 Planned research Activities in NWP, Nowcasting and Long-range Forecasting

**6.2.1** **Planned Research Activities in NWP**

The model domain of the convection-permitting regional model COSMO-DE (and its ensemble system COSMO-DE-EPS) will be extended to the west, north and south, the grid spacing reduced from 2.8 km to about 2.2 km, and the number of layers increased from 50 to 65.

Moreover, ensemble based data assimilation schemes will be introduced for the global model ICON and the regional model COSMO-DE.

**6.2.2** **Planned Research Activities in Nowcasting**

**Project RADOLAN**

A quantitative precipitation nowcasting method based on extrapolated real-time precipitation radar data, with hourly calibration against rain gauge measurements (RADOLAN: Radar-Online-Adjustment), has become operational at DWD. This Radar-Online-Forecasting (RADVOR) extrapolates the quantitative precipitation radar products in 15 minute time steps for up to two hours into the future. The basis of this method is the combination of two different extrapolation modules – one only for strong convective fields, the second especially for stratiform precipitation fields. Ongoing research is being undertaken to apply a module to use the COSMO-DE NWP wind field for tracking the radar data. This may allow one to extend the radar based quantitative precipitation forecast range until up to four hours into the future.

**Project AutoWARN**

Project Optimization of NowCastMIX within AutoWARN

In order to provide a generic optimal solution for nowcast warnings in AutoWARN all nowcast input data is pre-processed together in a single grid-based system: the NowCastMIX. This runs at the DWD to provide a single optimal set of gridded warning fields every 5 minutes. The goal of NowCastMIX is thus to provide and optimize an ongoing real-time synthesis of the various nowcasting and forecast model system inputs to provide a single, consolidated set of most-probable short-term forecasts.

A spatial clustering technique has been introduced in NowCastMIX to reduce noise and short-term temporal variations in the warning outputs, providing an optimal balance between forecast accuracy and practical usability. NowCastMIX has run over six summer convective seasons, yielding a comprehensive, high resolution dataset of thunderstorm analyses and corresponding warnings. This provides a valuable research resource for developing methods to improve quality. A verification of NowCastMIX forecasts against its own analyses has helped to refine the cell motion vector algorithm for generating optimal downstream warnings, leading to a measureable improvement in overall quality. This has been achieved by verifying how the different input systems available for estimating cell trajectories can be optimally weighted, relative to each other, to yield the best overall results.

The fuzzy logic rules for estimating the strength and attributes of thunderstorms in NowCastMIX have been retuned further, taking many case studies from the previous five years into account, as well as utilising comprehensive statistical distributions of input data values and resulting thunderstorm categorisations. These new rules have a significantly enhanced capability for dealing with extreme events in particular.

Winter nowcasting has been introduced into NowCastMIX via the provision of warnings for snowfall in three different severity levels and for freezing rain events. These are based on a combination of current radar data with high-resolution numerical weather prediction model data (COSMO-DE), yielding information about temperature profiles, surface conditions and the current snow limit and/or freezing level.

**6.2.3** **Planned Research Activities in Long-range Forecasting**

None

1. **Consortium**

**7.1 System and/or Model**

The *COSMO Model* (<http://cosmo-model.org/content/model/general/default.htm>) 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 model, and postprocessing utilities are required to run the model in NWP mode, climate mode or for case studies.

7.1.1 In operation

Regional numerical weather prediction at Deutscher Wetterdienst is based on the COSMO Model. COSMO-EU (see sections 4.3.1 and 4.3.2) covers Europe with 665x657 grid points/layer at a grid spacing of 7 km and 40 layers, and the convection-resolving model COSMO-DE, covers Germany and its surroundings with a grid spacing of 2.8 km, 421x461 grid points/layer and 50 layers. Based on COSMO-DE, a probabilistic ensemble prediction system on the convective scale, called COSMO-DE-EPS, became operational with 20 EPS members on 22 May 2012. It is based on COSMO-DE with a grid spacing of 2.8 km, 421x461 grid points/layer and 50 layers. See also section 7.3 for COSMO members.

On behalf of COSMO, [ARPA-SIMC](http://www.arpa.emr.it/sim) operates the regional ensemble prediction system **COSMO-LEPS** (<http://www.cosmo-model.org/content/tasks/operational/leps/default.htm>) at the European Centre for Medium Range Weather Forecasts (ECMWF) in the “Framework for Member-State time-critical applications”. COSMO-LEPS is the Limited Area Ensemble Prediction System developed within the COSMO consortium in order to improve the short-to-medium range forecast of extreme and localized weather events. It is made up of 16 integrations of the COSMO model, which is nested in selected members of ECMWF EPS.

COSMO-LEPS covers Central and Southern Europe with 511x415 grid points/layer at a grid spacing of 7 km and 40 layers. The system runs twice a day, starting at 00 and 12UTC with a forecast range of 132 hours.

7.1.2 Research performed in this field

The joint research and development is mainly undertaken in the eight working groups (<http://cosmo-model.org/content/consortium/structure.htm>) and a number of priority projects and priority tasks. The current priority projects are: “Km-Scale Ensemble-Based Data Assimilation for High-Resolution Observations” (KENDAO), see section 7.4.1, “COSMO-EULAG Operationalization” (CELO) which aims at an operational version of COSMO model employing compressible dynamical core with explicit conservative properties for very-high model resolutions, “Comparison of the Dynamical Cores of ICON and COSMO” (CDIC) tests the new ICON dynamical core for regional applications and paves the way to its implementation into the COSMO consortium model, “Testing and Tuning of Revised Cloud Radiation Coupling” (T2(RC)2) tests and optimizes representation of radiation interactions with cloud and aerosol, “Calibration of COSMO Model” (CALMO) which aims at development of automatic, multivariate and based on objective methods calibration of parameterizations of physical processes for the model, “Verification System Unified Survey 2” (VERSUS2) developing an operational verification package for deterministic and ensemble forecasting, “Intercomparison of Spatial Verification Methods for COSMO Terrain” (INSPECT) aims at evaluation of spatial verification schemes for convection-permitting deterministic and ensemble products, “Performance On Massively Parallel Architectures” (POMPA) for preparation of the COSMO model code for future high performance computing systems and novel architectures including GPU systems, “Studying Perturbations for the Representation of Modelling Uncertainties in Ensemble Development” (SPRED) for development of convection-permitting ensembles and especially methodologies for near-surface model perturbations. The priority task “Consolidation of Surface to Atmosphere Transfer” (ConSAT) continues with improvements of the turbulence scheme and atmosphere-surface interactions, while the priority task “TERRA Stand Alone” (TSA) will provide an updated, stand-alone version of COSMO surface model. Environmental prediction aspects of the model involving chemistry, aerosol effects and transport (COSMO ART) are developed in close cooperation with the Karlsruhe Institute for Technology (KIT) in Germany.

**7.2 System run schedule and forecast ranges**

See section 4.3.2 for COSMO-EU and 4.4.2 for COSMO-DE and COSMO-DE-EPS and for other COSMO members.

**7.3 List of countries participating in the Consortium**

COSMO stands for **CO**nsortium for **S**mall-scale **MO**delling. The general goal of COSMO is to develop, improve and maintain a non-hydrostatic limited-area atmospheric model, the COSMO model, which is used both for operational and for research applications by the members of the consortium.

The consortium was formed in **October 1998** at the regular annual DWD (Germany) and MeteoSwiss (Switzerland) meeting.

A Memorandum of Understanding (MoU) on the scientific collaboration in the field of non-hydrostatic modeling was signed by the Directors of DWD (Germany), MeteoSwiss (Switzerland), USAM (Italy, then named UGM) and HNMS (Greece) in March/April 1999. The MoU has been replaced by an official COSMO Agreement, which was signed by the Directors of these four national meteorological services on 3 October 2001. Recently a new COSMO [Agreement](http://cosmo-model.org/content/consortium/agreement.htm) aiming at future challenges in high resolution regional numerical weather prediction as well as climate and environmental applications was accepted by the Directors of the COSMO members and was signed on 7 August 2014.

In 2002, the national weather service of Poland (IMGW) joined the Consortium in effect from 4 July. The National Institute of Meteorology and Hydrology (NMA) of Romania and the Federal Service for Hydrometeorology and Environmental Monitoring of the Russian Federation joined the Consortium in effect from 21 September 2009.

Currently, the following national meteorological services are COSMO members:

|  |  |  |
| --- | --- | --- |
| Germany | [DWD](http://www.dwd.de/) | Deutscher Wetterdienst |
| Switzerland | [MCH](http://www.sma.ch/) | MeteoSchweiz |
| Italy | [ReMet](http://www.aeronautica.difesa.it/Pagine/default.aspx) | Aeronautica Militare-Reparto per la Meteorologia |
| Greece | [HNMS](http://www.hnms.gr/) | Hellenic National Meteorological Service |
| Poland | [IMGW](http://www.imgw.pl/) | Institute of Meteorology and Water Management |
| Romania | [NMA](http://www.inmh.ro/) | National Meteorological Administration |
| Russia | [RHM](http://wmc.meteoinfo.ru/about) | Federal Service for Hydrometeorology and Environmental  Monitoring |

These regional and military services within the member states are also participating:

|  |  |  |
| --- | --- | --- |
| Germany | [AGeoBw](http://www.streitkraefteunterstuetzungskommando.bundeswehr.de/) | Amt für GeoInformationswesen der Bundeswehr |
| Italy | [CIRA](http://www.cira.it/) | Centro Italiano Ricerche Aerospaziali |
| Italy | [ARPAE-SIMC](http://www.arpa.emr.it/sim) | ARPAE Emilia Romagna |
| Italy | [ARPA Piemonte](http://www.arpa.piemonte.it/) | Agenzia Regionale per la Protezione Ambientale  Piemonte |

The Meteorological Service of Israel ([IMS](http://www.ims.gov.il/IMSENG/All_Tahazit/homepage.htm)) became officially applicant member of COSMO in September 2014.

Six national meteorological services, namely Botswana Department of Meteorological Services, INMET (Brazil), DHN (Brazil), Namibia Meteorological Service, DGMAN (Oman) and NCMS (United Arab Emirates) use the COSMO model in the framework of an operational licence agreement including a license fee.

National meteorological services in developing countries (e.g. Egypt, Indonesia, Kenya, Mozambique, Nigeria, Philippines, Rwanda, Tanzania, Vietnam) can use the COSMO model free of charge.

**7.4 Data assimilation, objective analysis and initialization**

7.4.1 In operation

The data assimilation system for the COSMO model is based on the observation nudging technique. The variables nudged are the horizontal wind, temperature, and humidity at all model layers, and pressure at the lowest model level. The other model variables are adapted indirectly through the inclusion of the model dynamics and physics in the assimilation process during the relaxation. At present, radiosonde, aircraft, wind profiler, surface synoptic, ship, and buoy data are used operationally. For model configurations at the convection-permitting scale, radar-derived precipitation rates are included additionally via the latent heat nudging method. If nudging is used for data assimilation, an extra initialization is not required. Separate two-dimensional analysis schemes based on the successive correction technique are deployed for the depth of the snow cover and the sea surface temperature, and a variational scheme for the soil moisture.

Gradually, the default data assimilation system based on nudging technique is being replaced with Local Ensemble Transform Kalman Filter (see section 7.4.2).

As for COSMO-LEPS, the following initialization is performed: the upper-level initial conditions of the individual members are interpolated from the ECMWF EPS elements providing the boundaries. On the other hand, the initialization at the lower boundary is performed by taking the surface fields of COSMO-EU, including soil temperature and humidity, and blending them with those provided by ECMWF.

* + 1. Research performed in this field

The focus of research efforts lies on the development of a novel data assimilation scheme based on the Local Ensemble Transform Kalman Filter technique in the frame of the KENDAO priority project. Its main purpose is to deliver perturbed initial conditions for convection-permitting ensemble prediction systems as well as initial conditions for such deterministic systems. For more information, see

<http://www.cosmo-model.org/content/tasks/priorityProjects/kendaO/default.htm>.

Following encouraging test results, including comparison with nudging, the project aims at operationalization and further development of the LETKF assimilation system. The current research includes, in between,:

- use of remote sensing data and observations related to the boundary layer, humidity, cloud and precipitation, and surface

- algorithmic developments and extensions of the system, including multi-scale multi-step approaches

- exploratory research towards hybrid extensions of the system.

After pre-operational testing, the system was already implemented for operational use in MeteoSwiss in 2016 and its operational implementation at DWD is expected in late 2016 / early 2017. .

**7.5 Operationally available Numerical Weather Prediction (NWP) Products**

See section 4.3.3.

As for COSMO-LEPS, the available operational products include the following:

* “deterministic products”: different weather scenarios (one per member) for the model variables, at several forecast ranges
* “probabilistic products”: probability of exceedance of user-defined thresholds for the different model variables, at several forecast ranges
* “pointwise products”: meteograms over station points in terms of the main model variables.

**7.6 Verification of prognostic products**

See section 5 in reports of COSMO members.

**7.7 Plans for the future (next 4 years)**

7.7.1 Major changes in operations

See section 6.1 in reports of COSMO members

7.7.2 Research performed in this field

The 6-year science plan covering the period 2015 – 2020

* **(**<http://cosmo-model.org/content/consortium/reports/sciencePlan_2015-2020.pdf>**)** summarizes the current strategy and defines the main goal of the joint development work within COSMO. The main goal is the development of a model system for short to very short range forecasts with a convective-scale resolution to be used for operational forecasting of mesoscale weather, especially high impact weather. The research-oriented strategic elements to achieve the goal are: an ensemble prediction system, an ensemble-based data assimilation system and a verification and validation tool for the convective scale, extension of the environmental prediction capabilities of the model, use of massively parallel computer platforms. The actions for achieving the goal are undertaken within the current priority projects and task (see section 7.1.2), most of which were already defined based on the recent version of the Science Plan.

Moreover, until 2020 a gradual transition of the COSMO model system to the regional mode of the ICON modelling framework is planned.

The science plan has been accepted by the COSMO Steering Committee in March 2015. In 2016-2017, a review of the COSMO scientific strategy is planned with the aim to prepare plans of new priority projects for the period 2018-2020.

7.7.2 Research performed in this field

The 6-year science plan covering the period 2015 – 2020

**(**<http://cosmo-model.org/content/consortium/reports/sciencePlan_2015-2020.pdf>**)** summarizes the current strategy and defines the main goal of the joint development work within COSMO. The main goal is the development of a model system for short to very short range forecasts with a convective-scale resolution to be used for operational forecasting of mesoscale weather, especially high impact weather. The research-oriented strategic elements to achieve the goal are: an ensemble prediction system, an ensemble-based data assimilation system and a verification and validation tool for the convective scale, extension of the environmental prediction capabilities of the model, use of massively parallel computer platforms. The actions for achieving the goal are undertaken within the current priority projects and task (see section 7.1.2) which will be complemented by the future projects.

In the near future, the planned research activities will include new priority projects on:

* further development and operationalization of the 4D LETKF data assimilation system
* testing the ICON dynamical core
* further development of cloud-radiation coupling
* development and implementation of spatial verification methods

Moreover, until 2020 a gradual transition of the COSMO model system to the regional mode of the ICON modelling framework is planned.

The science plan has been accepted by the COSMO Steering Committee in March 2015.

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