ANNUAL JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM (GDPFS) INCLUDING NUMERICAL WEATHER PREDICTION (NWP) RESEARCH ACTIVITIES FOR 2015

Introduction

Country – Poland;
Centre – Institute of Meteorology and Water Management – National Research Institute (Polish National Hydrological and Meteorological Service, IMGW-PIB)

1. Summary of highlights

The modeling suite at IMGW-PIB consists of the non-hydrostatic limited-area COSMO model (resolution – 7 km, mesh size - 415 x 445 gridpoints / 40 layers, 78 hour forecast; resolution – 2.8km, mesh size 380 x 405 gridpoints / 50 layers, 36 hour forecast, and the additional 2.8 resolution ensemble prediction system with 20 members) and of two models of ALADIN System developed by ALADIN consortium: ALARO (resolution 4km, 789x789 grid points / 60 layers, 66/60-hour forecast) and AROME (resolution 2km, 799x799 grid points / 60 layers and 30-hour forecast). Operational configuration of the system is shown in Fig. 1 below.

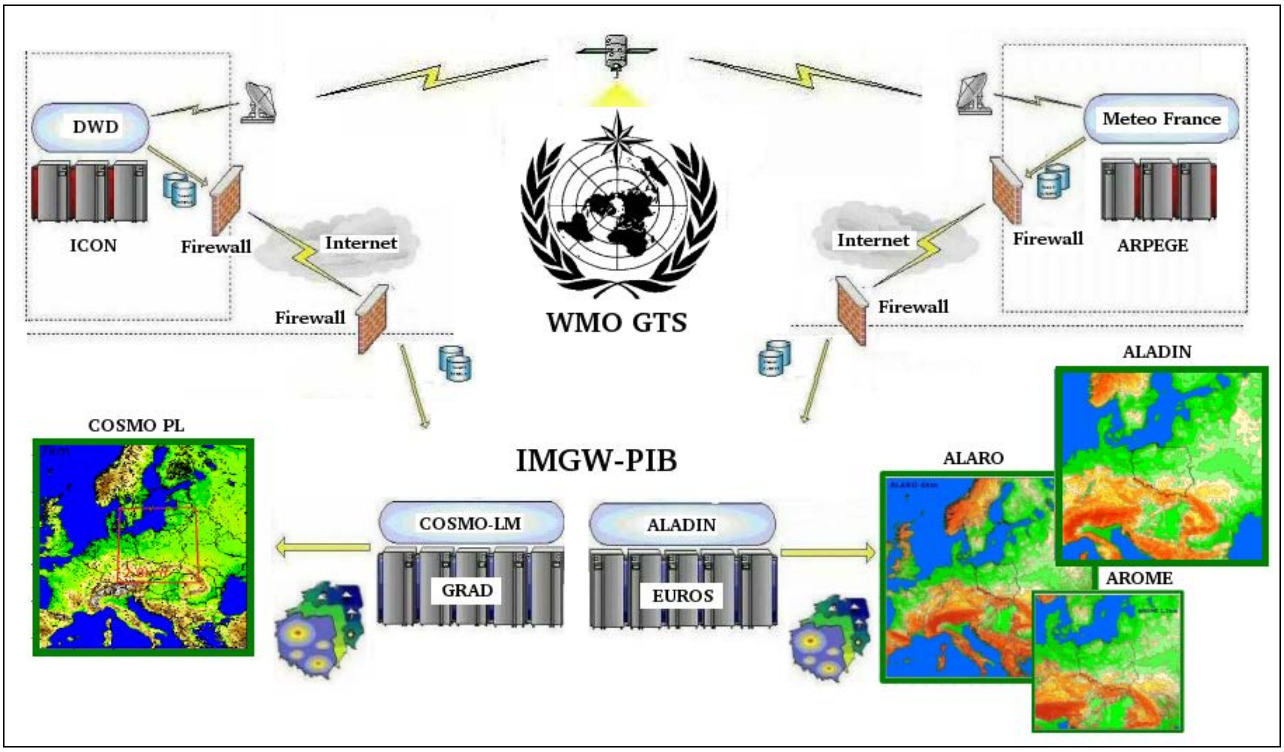

Fig. 1 Operational configuration of meteorological models at IMWM-NRI.

The IMGW-PIB works on two nowcasting systems: (i) system for nowcasting of main meteorological fields INCA-PL2 adapted from INCA model of ZAMG (Austrian NMS) which was implemented operationally in 2015; and (ii) system of precipitation estimation and nowcasting SEiNO which is under development and its first modules were implemented in 2015; the system will include two nowcasting models: SCENE and SNOF.

2. Equipment in use

The COSMO model is set for the operational use on the linux cluster “grad” – 4 casette C7000 system consisting of 145 HP BL460c Gen8 servers (139 computational nodes, 2700 cores) with 61 TF peak performance.
ALADIN System models are installed on linux cluster called “euros” – 97 computational HP BL460c Gen8 nodes: 2 x Intel Xeon E5-2690 @ 2.90GHz CPU and 128 GB RAM each. 1552-core cluster achieves approximately 30 teraFLOPS peak performance.
For nowcasting - Linux virtual machines (6 units) are used.

3. Data and Products from GTS in use

For NWP – boundary and initial conditions from global models of DWD (ICON) and Meteo-France (ARPEGE) together with observational data from GTS. For Forecast Offices - almost all observational data from the GTS are used (SYNOP, SHIP, TEMP, METAR, PILOT, AIREP, AMDAR, SATEM, SATOB, GRIB, BUFR).

4. Forecasting system

4.1 System run schedule and forecast ranges

The forecasting system schedule consists of multiple model(s) runs. Forecast runs with a data cut-off between 3 and 4h after the synoptic hours.

All COSMO models runs four times per day for the nominal 00, 06, 12 and 18 UTC hours, consist of 78h length forecasts at resolution of 7km, and 36 hour forecast at resolution 2.8km.

ALARO and AROME models runs are performed four times a day - for 00, 06, 12 and 18 UTC input data bases. ALARO suite forecast ranges are equal to 66 / 66 /66 / 60 hours respectively, while in case of AROME suite are equal to 30 hours for each run.

INCA-PL2 system in terms of precipitation rate and type has parameters: time step 10 min, maximum lead time 8 h, domain 800 km x 900 km (Poland), spatial resolution 1 km x 1 km. In terms of other meteorological fields: temperature at ground, 2 m, and dew point, wind chill, relative humidity, snow line, freezing level, icing, wind velocity and direction, the time step is 60 min.

The SEiNO system at present consists of the two following nowcasting models: SCENE and SNOF. The models are under development at IMGW-PIB. Parameters: time step 10 min, maximum lead time 2 h, domain 800 km x 900 km (Poland), spatial resolution 1 km x 1 km.

4.2 Medium range forecasting system (4-10 days)

Medium- and extended range forecasts up to now are prepared basing on external sources (mainly, available results of global models as GFS). They consist of decade (10-day) forecast prepared every ten days. In special situation it is required to prepare a long-term forecast (for one or three months). This is mainly done using available global models combined with climatological resources.

4.2.1 Data assimilation, objective analysis and initialization

4.2.1.1 In operation

n/a

4.2.1.2 Research performed in this field

n/a

4.2.2 Model

4.2.2.1 In operation

n/a

4.2.2.2 Research performed in this field

n/a

4.2.3 Operationally available Numerical Weather Prediction Products

n/a

4.2.4 Operational techniques for application of NWP products *(MOS, PPM, KF, Expert Systems, etc..)*

4.2.4.1 In operation

n/a

4.2.4.2 Research performed in this field

n/a

4.2.5 Ensemble Prediction System (EPS)

4.2.5.1 In operation

n/a

4.2.5.2 Research performed in this field

n/a

4.2.5.3 Operationally available EPS Products

a/a

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

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

Nudging technique applied in COSMO7km operational assimilation framework utilizing Sky/Globus system of Basler+Partner GmbH (responsible for acquisition and processing of the WMO/GTS observational data) and boundary conditions from ICON model (DWD).
Both models of ALADIN System are running in dynamical adaptation mode, so no data assimilation is applied.

4.3.1.2 Research performed in this field

Active participation in COSMO projects on remote-sensing data retrieval for assimilation purposes. Few test runs of an analysis cycle for data assimilation based on test data.

4.3.2 Model

4.3.2.1 In operation

a) COSMO

- 7km Domain: Central Europe, approx 2900 x 3200 km, initial data time: 00, 06, 12 and 18 UTC, forecast range: 78h, time step 20 sec;
- Nested 2.8km resolution model over approx 1060 x 1130 km domain centered over Poland area, initial data time: 00, 06, 12 and 18 UTC, forecast range: 36h, time step 55 sec;
- Nested COSMO-EPS system based on 20 members of COSMO 2.8km resolution models. Domain size approx 1060 x 1130 km centered over Poland area, initial data time: 00, 06, 12 and 18 UTC, forecast range: 36h;
- Prognostic variables: p, T, u, v, w, qv, qc, TKE, vertical co-ordinate: generalized terrain-following, horizontal- and vertical discretization: finite-difference, second order; time integration: two-time level Runge-Kutta high order scheme, diffusion: linear, fourth order;
- Horizontal grid: COSMO7km 415 x 445 (nested high resolution COSMO2.8km 380 x 405) gridpoints on a rotated latitude/longitude grid; Arakawa-C grid, orography: grid-scale average based on a 1-km data set;
- Parameterizations: surface fluxes based on local roughness length and stability, free atmosphere turbulent fluxes based on a level-2.5 scheme with prognostic TKE, full cloud radiation feedback based on predicted clouds, mass flux convection scheme, grid-scale precipitation scheme with parameterized cloud, microphysics, multi-layer soil model including simple vegetation and snow cover, new cloud-ice scheme (introduced in reference version of the model).

b) ALADIN

ALADIN System is a set of limited area models being developed in a frame of ALADIN Consortium. It comprises 3 models: ALADIN, ALARO and AROME. Two last of them are used at IMWM-SRI for operational purposes.

ALARO model suite:

- Non-hydrostatic primitive equations
- Semi-implicit, two-time level semi-Lagrangian advection scheme
- Hybrid vertical coordinates
- Davies-Kallberg coupling
- 3260 km x 3260 km domain
- 4.0 km resolution
- 4 runs a day - at 00, 06, 12 and 18 UTC, for 66, 66, 66, 60 hours respectively
- 789 x 789 grid points
- 60 vertical levels
- Coupling to ARPEGE model, every 3 hours
- AROME model suite:
- Non-hydrostatic primitive equations
- Semi-implicit, two-time level semi-Lagrangian advection scheme, physics based on MesoNH

- Hybrid vertical coordinates
- Davies-Kallberg coupling
- 1600 km x 1600 km domain
- 2.0 km of horizontal resolution
- 4 runs a day - at 00, 06, 12 and 18 UTC, for 30 hours each
- 799 x 799 grid points
- 60 vertical levels
- Coupling to ALARO model, every hour

4.3.2.2 Research performed in this field

Active participation in modeling consortia in both research and development fields.

4.3.3 Operationally available NWP products

- u- and v- component of wind and vertical velocity at model hybrid levels and at standard pressure levels and at 10m agl.,
- temperature at levels and at 2m agl.,
- specific humidity, specific cloud water content at levels
- pressure at levels
- snow temperature
- soil temperature at 0 and at 9cm down.
- water equivalent of accumulated snow depth
- soil moisture content at 0-10 and at 10-100 cm down
- water content of interception store
- surface precipitation amount, rain, grid scale and convective
- large scale and convective snow
- dew-point temperature at 2m agl.
- minimum and maximum temperature at 2m agl.
- maximum wind velocity at 10m agl.
- drag coefficient
- transfer coefficient (sensible heat)
- total, high, medium and low cloud cover,
- albedo
- net short-wave radiation (surface and top of atmosphere)
- net long-wave radiation (surface and top of atmosphere)
- downward photosynthetic active radiant flux density
- total precipitation
- surface roughness
- momentum flux, u and v component
- sensible and latent heat flux
- convection base and top index
- top of dry convection (above MSL)
- water run-off
- pressure reduced to MSL
- cloud cover, grid scale and convective at levels

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation

Short-range forecasts from Central Forecasting Office are based on direct model output (DMO) of both models.

4.3.4.2 Research performed in this field

Application of an Adaptive Regression (AR) technique to COSMO model results dedicated for hydrology, esp. temperature and precipitation corrections.
Application of robust D-MOS (Dynamical Model Output Statistics) technique to results of ALADIN model

4.3.5 Ensemble Prediction System

4.3.5.1 In operation

COSMO model runs time-lagged EPS with 20 members at 2.8km horizontal resolution. The system is run four times per day (00, 06, 12, and 18 UTC) providing 36 hour length forecasts. EPS apply perturbations of soil parameters (C_soil - urface area index of evaporating fraction) and surface temperature from initial conditions. The COSMO7km model provides the initial and boundary conditions for each of COSMO2.8km EPS members. In order to increase the spread of model parameters generated by forecasts, a concept of time-lagged IC/BCs was adopted in which the set of deterministic forecasts is subdivided into 5 -member groups starting at the consecutive time windows:

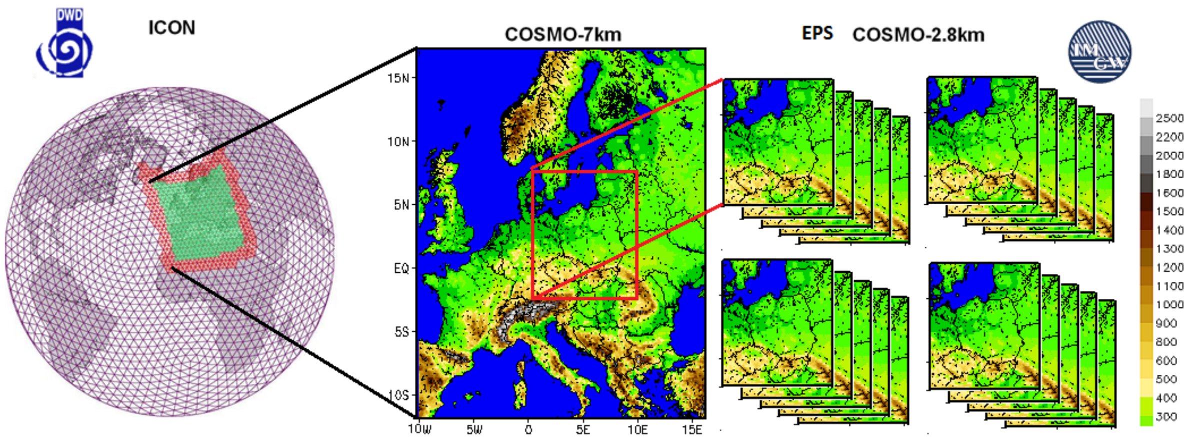

Fig. 2 Operational configuration of IMGW-PIB COSMO-EPS system.

4.3.5.2 Research performed in this field

Participation in SRMWP-EPSII and the internal COMSO-SPRED priority projects. The SPRED project subject is Studying Perturbations for the Representation of modeling uncertainties in Ensemble Development. The project is dealing also with the development of post-processing methods for the convection-permitting (CP) ensembles, especially focused on selected phenomena and intense events, and calibration.
Participation in ECMWF special project "Multiphysics and stochastic perturbations for high-resolution LAMEPS" performed by ALADIN / HIRLAM group.

4.3.5.3 Operationally available EPS Products

Meteorological fields presented in the graphical form in terms of ensemble mean, ensemble spread, probability of exceedance etc.

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

4.4.1 Nowcasting system

4.4.1.1 In operation

The INCA-PL2 and the following modules of SEiNO work operationally: (i) RainGRS module for generation of multi-source quantitative precipitation estimation (QPE), (ii) SCENE nowcasting model – in test mode.

(*Note: please also complete the CBS/PWS questionnaire on Nowcasting Systems and Services, 2014*).

4.4.1.2 Research performed in this field

The following nowcasting modules of SEiNO have been under development (research, programming, parameterization, or tests):

(i) SCENE – object-oriented precipitation nowcasting model developed especially for convective events, which includes the modules for: detection of convective precipitation based on information from weather radars, Meteosat, lightning detection system, and mesoscale NWP models and then determination of separate fields of movement vector for both stratiform precipitation and particular convection cells,

(ii) SNOF – precipitation nowcasting model based on the separation of meteorological objects of different spatial scale employing 2-D Fast Fourier Transformation, and then extrapolation of particular layers using autoregressive model AR(2); finally all the layers are aggregated into nowcasted field.

4.4.2 Models for Very Short-range Forecasting Systems

4.4.2.1 In operation

"[information on models in operational use, as appropriate related to 4.4]"

4.4.2.2 Research performed in this field

4.5 Specialized numerical predictions

MeteoFlight is a system which nowcasts meteorological hazards for air traffic expressed by weather hazard index (WHI) which incorporated weather radar reflectivity, Doppler measurements (wind speed, vertical and horizontal shears, turbulences), and data from lightning detection system. All the data are applied as sources for determination of current WHI. Then the WHI is nowcasted by the system up to 30 min to provide air traffic controllers with real-time information.

DMO is used for the production of any weather situation with the aid of LEADS (Leading Environmental Analysis and Display System) to produce single images or image sequences for Forecast Offices.

- Short-range forecasts of weather, wind, temperature, pressure and sensible temperature in pictorial form are automatically produced for online presentation on the Intranet and on the Internet.
- The state of road surfaces and – in general – on-road conditions are on-line predicted by a road weather forecast system using data based on model results and the energy balance model (SHAWrt) of the road surface, together with visibility and type of precipitation (FOGMOD_PL).
- Results from COSMO runs are available for National Atomic Agency in case of nuclear emergencies and/or accidents (RODOS system – Real Time On-line Decision and Support System).
- The possible influence of weather on human health ("bio-meteorology") is forecasted using COSMO results.
- Forecasts of QNH pressure are prepared for aviation purposes.
- Also, system for dispersion of pollutants is working in an operational way at IMWM, based on COSMO results processed for needs of dispersion modeling.
- Wave Watch III (sea waves model) has been tested and successfully implemented to operational suite. Input for WWIII is based on results from COSMO model.

4.5.1 Assimilation of specific data, analysis and initialization (where applicable)

4.5.1.1 In operation

n/a

4.5.1.2 Research performed in this field

n/a

4.5.2 Specific Models (as appropriate related to 4.5)

4.5.2.1 In operation

- SHAWrt – Simultaneous Heat and Water Transfer (road temperature) model
- FOGMOD_PL – visibility and type precipitation type model
- REMOTA – Regional Model for Atmospheric Transport of pollutants (esp. for volcanic dust transport modeling)
- QNH – calculations of QNH pressure for aviation.
- Wave Watch III – sea waves model.
- RADARSIM – simulations of radar (composite) pictures based on numerical forecasts

4.5.2.2 Research performed in this field

- Further development of SHAWrt/FOGMOD_PL based on Adaptive Regression Method; development of dispersion modeling in the frame of REMOTA modeling system;
- testing, adaptation and operational implementation of WaveWatchIII;
- testing, development and operational implementation of QNH;
- testing, development and operational implementation of RADARSIM.
- testing usefulness of snow model CROCUS fed with AROME forecasts for operational hydrological purposes.

4.5.3 Specific products operationally available

- road temperature and possibility of occurrence of “black ice”
- visibility, precipitation type
- depth of snow cover
- forecasts and diagnoses of common pollutants’ concentration and deposition patterns; forecast of concentration of volcanic dust in public flight routes
- QNH pressure for aviation

4.5.4 Operational techniques for application of specialized numerical prediction products *(MOS, PPM, KF, Expert Systems, etc..)* (as appropriate related to 4.5)

4.5.4.1 In operation

Adaptive Regression (AR) technique for SHAWrt/FOGMOD_PL.

4.5.4.2 Research performed in this field

n/a

4.5.5 Probabilistic predictions (where applicable)

4.5.5.1 In operation

n/a

4.5.5.2 Research performed in this field

n/a

4.5.5.3 Operationally available probabilistic prediction products

n/a

4.6 Extended range forecasts (ERF) (10 days to 30 days) (Models, Ensemble, Methodology)

4.6.1 In operation

n/a

4.6.2 Research performed in this field

n/a

4.6.3 Operationally available EPS products

n/a

4.7 Long range forecasts (30 days up to two years) (Models, Ensemble, Methodology)

4.7.1 In operation

n/a

4.7.2 Research performed in this field

n/a

4.7.3 Operationally available products

n/a

5. Verification of prognostic products

5.1 Annual verification summary

Verification of the model is an ongoing task in all COSMO centers. The main responsibility of the COSMO WG5 (Verification and Case studies)working group is to take care for the verification of operational model forecast, for the development of new verification methods and diagnostic tools as well as for case studies with COSMO model. Products are verified against both surface and upper air observations. Verification has become operational in 2004. List of verified products includes cloud cover, wind speed, temperature, dew point and ground pressure (for surface observations) and wind speed, temperature, pressure and relative humidity (for upper air soundings). Verification is currently done with implemented common (for COSMO consortium) verification packages VERSUS (VERification SuiteS).
Forecasts of ALADIN System models operationally exploited at IMWM-SRI are routinely verified. Software package HARP being applied for the task was developed within frame of ALADIN Consortium collaboration. Other software used for the verification was developed locally. Moreover IMWM-SRI takes part in ALADIN Verification Project which gives opportunity to compare forecast scores obtained in various ALADIN centers.

5.2 Research performed in this field

COSMO WG5 prepared long-term strategy for the Common Verification Software (CVS) which meets the „common needs“ requirements of the COSMO members. As defined by WG5, CVS should be supplemented by additional tools including local tools and existing external tools and, finally, that it should cover most verification needs identified by WG5 (diagnostics for operational datasets, conditional verification), addressing where possible the verification needs of all groups, utilizing additional tools when necessary while compromising between coverage of the needs and the cost / effort. Taking into consideration the various parameters special document “Recommendations: Strategy on Verification Tools” was prepared (based on answers to a questionnaire that was disseminated to all WG5 members and a dedicated meeting that took place in May 2015), in which possible scenarios for the future of Verification Tools were proposed.
A COSMO new priority Priority Project INSPECT devoted to spatial verification methods has been created to follow MesoVICT activities (http://www.ral.ucar.edu/projects/icp/) and to summarize the COSMO experience of applying spatial verification methods to high and very high resolution forecast systems (deterministic and EPS). The project started in April 2015; it is planned for two years. One of the scopes of INSPECT is to propose guidelines for application of new spatial methods based on the analysis of data gained during the project.
IMGW-PIB participate in collaboration within frame of ALADIN Consortium HARP verification project aimed on developing of flexible and powerful verification tool based on R package.
A STAT module of the SEiNO system for online calculation of reliability of particular models and lead times employing different quality criteria (continuous and based on contingency table) has been under development.

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

6.1 Development of the GDPFS

6.1.1 Major changes in the operational DPFS which are expected in the next year

6.1.2 Major changes in the operational DPFS which are envisaged within the next 4 years

6.2 Planned research Activities in NWP, Nowcasting, Long-range Forecasting and Specialized Numerical Predictions

6.2.1 Planned Research Activities in NWP

• active participation in COSMO research efforts (research projects of high priority, mainly on data assimilation, verification, ensemble prediction systems, model numerics and physical processes)
• active participation in ALADIN research efforts (as above)
• involvement in national/regional researches and studies

6.2.2 Planned Research Activities in Nowcasting

During next 4 years the SEiNO system will be completed, especially further major modules will be developed:
(i) MERGE – merging of three precipitation nowcasts from INCA-PL2, SCENE, and SNOF based on their reliability in previous time steps; then merging these combined nowcasts and mesoscale forecasts (from COSMO and AROME) by weighting with previous reliabilities of the fields,
(ii) PROB – generation of probabilistic nowcasts (in form of nowcast ensemble, set of percentiles or probability of exceedance),
(iii) STAT – determination of statistics of all particular models' reliability.

6.2.3 Planned Research Activities in Long-range Forecasting

n/a

6.2.4 Planned Research Activities in Specialized Numerical Predictions

Further research and development of all specialized products.

7. 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.

The COSMO modelling system supports three main applications, namely regional numerical weather prediction (NWP) including data assimilation, regional climate scenario calculations (CLM) and air quality (chemical weather) simulations (ART).

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.

IMGW-PIB is also a member of ALADIN Consortium which develops ALADIN NWP System. The System comprises 3 models – namely ALADIN, ALARO and AROME - which share dynamical core but have different physics parametrization packages.

7.1.1 In operation

Regional numerical weather prediction at IMGW-PIB is based on the COSMO and ALADIN System models. COSMO (see section 4.3.2a) covers vast part of Europe with 415x445 grid points at a grid spacing of 7 km and 40 layers, and the high resolution model COSMO-2.8km, covers Poland and its surroundings with a grid spacing of 2.8 km, grid 380 x 405 points/layer and 50 layers. The EPS system consist of 20 COSMO 2.8km members. ALARO operational suite domain covers most of territory of Europe with 4.0 km resolution, while AROME one covers territory of Central Europe with 2.0 km resolution.

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 COSMO priority projects in which INWM-NRI was recently participating includes:

PP CELO (COSMO-EULAG Operationalization) which aim is to get an operational version of COSMO model employing dynamical core with explicit conservative properties for very-high model resolutions,

PP INSPECT (Intercomparison of Spatial Verification Methods for COSMO Terrain), tests and evaluates new spatial verification methods, especially for convection-permitting EPS products, in close link with the international MesoVICT (Mesoscale Verification Inter-Comparison over Complex

PP VERSUS2 (VERification System Unified Survey 2) concludes the development of the common COSMO verification software VERSUS via implementation, in between, of the GRIB2, XML and extended EPS capabilities.

PP CDIC (Comparison of the dynamical cores of ICON and COSMO) tests the ICON dynamical core against the COSMO decision tree for dynamical cores within the COSMO strategy of harmonization with ICON.

PP SPRED (Studying Perturbations for the Representation of modeling uncertainties in Ensemble Development) is continuing the development of convection-permitting EPS methodology of former

PP COTEKINO (COsmo Towards Ensembles at the Km-scale IN Our countries) and focuses on improvement of spread/skill relation especially in the near-surface layer.

7.2 System run schedule and forecast ranges

See section 4.3.2a for COSMO arrangement and set-up(s).

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.

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.

Recently, the COSMO partners decided to renew the Agreement and its current version was signed on 19 June 2014.

Currently, the following national meteorological services are COSMO members:

Germany	DWD	Deutscher Wetterdienst
Switzerland	MCH	MeteoSchweiz
Italy	USAM	Ufficio Generale Spazio Aereo e Meteorologia
Greece	HNMS	Hellenic National Meteorological Service
Poland	IMGW-PIB	Institute of Meteorology and Water Management
Romania	NMA	National Meteorological Administration
Russia	RHM	Federal Service for Hydrometeorology and Environmental Monitoring

Israel Meteorological Service (IMS) has been accepted as an official Applicant to COSMO from the 1st September 2014.

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

Germany	AGeoBw	Amt für GeoInformationswesen der Bundeswehr
Italy	CIRA	Centro Italiano Ricerche Aerospaziali
Italy	ARPA-SIMC	ARPA Emilia Romagna Servizio Idro Meteo Clima

Italy	ARPA Piemonte	Agenzia Regionale per la Protezione Ambientale Piemonte

In 2015 COSMO has been used operationally under license agreement by the national meteorological services of the United Arab Emirates (NCMS), Brazil (IMET), Oman (DGMAN), Botswana (BMS) and Namibia (NMS), as well as by the regional meteorological service of Catalunya, by the Brazilian Navy (DHN) and by Saudi Arabia (CECCR). All services receive tailored lateral boundary data from DWD's global model ICON up to four times daily. Discussions on licenses are ongoing with Turkmenistan (Turkmen Gidromet) and Chile (DMC).
The annual licence fee for the operational usage of the COSMO model is not charged for developing countries. This allows e.g. Egypt, Indonesia, Kenya, Mozambique, Nigeria, Philippines, Rwanda, Tanzania and Vietnam to also use the COSMO model.

In late 1990 year Meteo-France has offered common development of LAM NWP model - it was ALADIN (Aire Limitée Adaptation dynamique Développment International) – to Bulgaria, Czech Republic, Hungary, Poland, Romania and Slovakia. Since that time many other countries joined the project. Currently, the following national meteorological services are ALADIN Consortium members:

Algeria	ONM	Office National de la Météorologie
Austria	ZAMG	Zentralanstalt für Meteorologie und Geodynamik
Belgium	IRM	Royal Meteorological Institute
Bulgaria	NIMH-BS	Bulgarian National Institute of Meteorology and Hydrology
Croatia	DHMZ	Meteorological and Hydrological Service of the Republic of Croatia
Czech Republic	CHMI	Czech Hydrometeorological Institute
France	METEO - FRANCE	Météo-France
Hungary	OMSZ	Hungarian Meteorological Service
Morocco	DMN	Direction de la Météorologie Nationale
Poland	IMGW-PIB	Institute of Meteorology and Water Management - State Research Institute
Portugal	IPMA	Instituto Português do Mar e da Atmosfera
Romania	NIMH	Administratia Nationala de Meteorologie
Slovakia	SHMU	Slovak Hydrometeorological Institute
Slovenia	meteo.si	Slovenian Environment Agency
Tunisia	INM	Institut National de la Météorologie de Tunisie
Turkey	TSMS	Turkish State Meteorological Service

In February 2016 "5th Memorandum of Understanding for ALADIN Consortium" was signed to establish next 5 years of international collaboration.

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.

7.4.2 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 (LETKF) technique in the frame of the KENDA priority project. A prototype 4-dimensional Local Ensemble Transform Kalman Filter (**4D-LETKF**) scheme has been developed for the COSMO model. A new Priority Project "KENDA-O" Km-scale ENsemble-based Data Assimilation for high-resolution Observations improve and extend the data assimilation system and use of observations in the framework of the KENDA-LETKF in view of better convective-scale deterministic and ensemble forecasts, particularly of quantities related to cloud and precipitation. A main focus is on the use remote sensing data and observations related to the boundary layer, humidity, cloud and precipitation, as well as the surface. This includes radar data, GNSS slant path delay, cloud information and water vapour from SEVIRI satellite radiances, ground-based remote sensing data related to the planetary boundary layer, Mode-S aircraft data, and screen-level observations. To make best use of these data may require algorithmic developments and extensions of the LETKF scheme, e.g. multi-scale multi-step approaches or specific modules to correct phase errors. High-resolution data dealt with in this project are often related to nonlinear processes and non-Gaussian errors, possibly with non-zero temporal correlations. Therefore, the question of the optimal analysis update frequency has to be studied carefully, and more exploratory research towards hybrid extensions of the EnKF, e.g. using particle filter approaches, should address issues such as non-Gaussianity or rank deficiency. Even though the focus of development clearly lies on the convective scale, the system will also be maintained and slightly extended for larger-scale applications. Here, one task addresses the use of polar-orbiting satellite radiances in clear sky or above clouds.

7.5 Operationally available Numerical Weather Prediction (NWP) Products

See section 4.3.3.

7.6 Verification of prognostic products

See section 5.

7.7 Plans for the future (next 4 years)

7.7.1 Major changes in operations

- All COSMO members operationally run a convection parameterising COSMO model version at around 7 km mesh-size and a convection permitting version (at 2.8 or 2.2 km mesh-size). Roshydromet additionally runs a version at 13 km mesh-size covering all Russia and its neighbourhood.
- DWD runs operationally since 2012 a convection permitting ensemble system at 2.8 km mesh-size. MeteoSwiss started the pre-operational evaluation phase of a system at 2.2 km. Convection permitting ensemble systems are further planned by ReMet (in collaboration with the regional services of Emilia-Romagna and Piemonte) and by IMGW-PIB.
- Ensemble data assimilation systems based on KENDA (Km-Scale Ensemble-Based Data Assimilation) are in the pre-operational evaluation phase at MeteoSwiss, DWD and ReMet (in substitution of CNMCA-LETKF). KENDA-O (Km-Scale Ensemble-Based Data Assimilation for High-Resolution Observations) follows COSMO PP KENDA intended to improve the data assimilation system and to extend the system for the use of new observation types including direct radar, satellite and aircraft data.
- MeteoSwiss additionally runs a convection permitting version at 1.1 km mesh-size in the pre-operational evaluation phase. This runs together with the ensemble system on a supercomputer with a high density of GPUs, what will be the worldwide first application of such a hybrid technology for operational weather forecasts.

7.7.2 Research performed in this field

A 5-year (www.cosmo-model.org/content/consortium/reports/sciencePlan_2015-2020.pdf) COSMO science plan summarizes the current strategy and defines the main goal of the joint development work within COSMO. The COSMO Science Plan for the period 2015-2020 was accepted by STC in March 2015 after careful evaluation by renowned European NWP experts. The main goal is the development of a modelling 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 this 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 tasks which will be complemented by the future projects. By the end of the planning period a migration of all COSMO applications to the regional (limited area) mode of the nonhydrostatic ICON Modelling Framework, jointly developed in recent years by DWD and Max-Planck-Institute for Meteorology, is foreseen. As a first step in this direction a common physics library shared by ICON and COSMO is being implemented.

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