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The COSMO Priority Project CARMA: Common Area with Rfdbk/MEC Application Final Report

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1 Introduction

In 2006, the STC approved the development of a common, unified verification 'library' through the VERSUS project, which was followed by the PP-VERSUS2 in 2009. The objective of this strategic decision was to develop a common COSMO verification software package that would enable the production of homogeneous and comparable statistical results. In recent years, partly due to technical limitations of VERSUS and the ceasing of further development, the WG5 members considered the possibility of utilizing multiple verification modules that would not necessarily be linked to one software package (e.g. VAST software for spatial methods). For the CP activity, it is essential to maintain a software as a common tool for their production as this will ensure the adoption of the same verification practices that will allow for the easier long-term monitoring of the derived results.

Before the start of PP CARMA, Common Plot verification activities were carried out using the VERSUS verification software environment. Because of the technical limitations of VERSUS and lack of further development, it has been decided within the consortium that this should be replaced with the MEC-Rfdbk software. The MEC-Rfdbk system uses small files for fast calculation of verification scores, while the results can be browsed interactively online. The verification is based on the use of feedback files (FF), that hold information on observations (including meta-data) and their usage in data assimilation, as well as the corresponding model analysis, first-guess and past forecasts, in NetCDF format. These files are relatively small, being produced for each valid time / observation type and can be used for various verification tasks.

The Model Equivalent Calculator (MEC) software for the production of Feedback Files, and verification scripts based on the R package Rfdbk, are tools that were developed and are in operational use at DWD for the verification of both COSMO and ICON model chains.

1.1 Goal of PP

The goal of the CARMA Priority Project (2018-2021) was to replace the existing VERSUS verification software environment with the MEC-Rfdbk software developed by DWD, as a Common Verification Software (CVS), in order to perform part of the verification activities in the consortium. The main use of the new CVS is be the production of the Common Plot (CP) verification while spatial verification should rather be performed with other available tools (VAST, etc.) in each service. MEC-Rfdbk is also suitable for EPS verification, but this type of application was not be included in the current project as EPS verification is not part of CP activity, but can be considered in a next phase. The CVS that is based on MEC-Rfdbk is chosen with the intention of being a useful user-friendly tool for the entire COSMO community. It addresses the need to perform traditional point verification both for the surface and the upper air using conventional methods, which arise from operational and research activities. Moreover, a centralized transfer and visualization of CP statistics on COSMO web server will facilitate the easier analysis of the outcome of this activity and is one of the main goals of this project.

The most striking advantages of the new verification system adopted for CP preparation activity, are the shortfall of data pre-processing (all data in one place, observation and forecast correctly assigned to each other, quality control done by data assimilation, small files), the fast and simple calculation of standard verification scores and the interactive visualisation and online production of results.

PP CARMA was also linked with the following COSMO tasks:

- Support Activities – NWP Test Suite: the MEC-Rfdbk system is currently installed and used on the ECMWF platform for the evaluation of new model versions before they are officially released.
- PP C2I Task 3 for the evaluation and comparison of COSMO and ICON-LAM forecasts: the MEC+Rfdbk system was used to produce verification results included in the ICON Report "Verification of ICON in Limited Area Mode at COSMO National Meteorological Services" (Rieger et al., 2021) published as part of the Priority Project
- Support Activities – Common Plot verification (SPRT).

1.2 Brief Description of System Design

The MEC-Rfdbk verification system is based on the use of feedback files (FF) that hold information on observations and their usage in the data assimilation (DA) system. FF and are available for each observation system used in DA and contain information regarding the observations (including meta-data) and corresponding model analysis, first-guess and past forecast (also ensemble) in the NetCDF format. These files have a relatively small size (e.g. 4.8Mb SYNOP for COSMO-7km run for the NWP Test Suite domain covering the entire Europe) and are produced as one file for each valid-time (time window), model and observation system. A detailed description of FF can be found here (http://cosmo-model.org/content/model/documentation/core/default.htm).

The FF are produced by the Model Equivalent Calculator (MEC; Potthast, 2019) within the data assimilation system or as stand-alone. Information from FF can be used for verification tasks (e.g. name, location, level, weight in DA, ensemble spread, Talagrand index and so on). Further on, these files are used by the Rfdbk (Fundel, 2021) package to perform some convenience functions like data adjustment, re-labelling, binning etc. and then calculate the verification scores. Finally, the verification scores in Rdata format are visualized on the dedicated COSMO web page, using the R shiny server (Chang et al., 2020).

A schematic diagram of the system is presented in Fig. 1, followed by short descriptions of the main system components. **For more detailed presentations of the MEC-Rfdbk system and its components, including information regarding installation and use, please check the dedicated documents referenced in Section 6.**

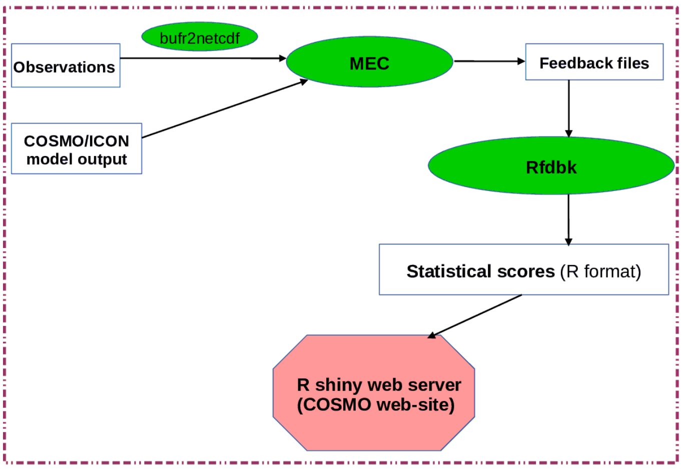

Figure 1: Schematic representation of the MEC-Rfdbk system.

1.2.1 The Model Equivalent Calculator (MEC)

MEC applies the observation operators from the data assimilation scheme (Nudging, 3Dvar, Ensemble Kalman Filter) to model forecasts (COSMO, ICON) and stores the results in verification files (NetCDF feedback file format). The software can use as input observations, model runs (deterministic or ensemble), analysis runs or even another MEC run, depending on the user needs and can be applied to interpolate between two or more time periods. Observation operators are either those implemented in the DWD global data assimilation code (3dvar/EnVar/LETKF) or those implemented in the COSMO model, as used in the nudging and the KENDA/LETKF data assimilation scheme. Alternatively, the fof-files (feedback file format as well) written by COSMO (in the nudging mode or in the first guess run for KENDA) may be taken as input for MEC. A further option is to use the original observational data (CDFIN, i.e. BUFR format converted to NetCDF). In these cases verification files will be generated separately for each observation type (TEMP, PILOT, SYNOP, etc).

For this project (as well as for the permanent Common Plot Activity), this second approach was adopted by using a common set of observations retrieved in bufr format from the MARS archive. These observations are converted in NetCDF format with the bufr2netcdf software (Patruno and Cesari, 2011) and used as input in MEC. The results of MEC are stored in the NetCDF feedback file format.

The advantages of using the MEC software as part of the verification system for CP activities are related to data pre-processing (all data in one place) and ensuring observation and forecasts are correctly assigned to each other, with quality control done by data assimilation.

MEC characteristics and requirements:

- produces feedback files
- namelist based

Installation

- Sources: Fortran 2003/2008 and C (Makefile for gfortran provided)
- Dependencies: NetCDF, CGRIBEX (MPI Hamburg), GRIP-API (ECMWF), (MPI recommended), Fortran compiler, C compiler
- Sufficient memory to hold one model state (1 ensemble state)

IO specifications

- model in Grib2 format – COSMO or ICON-LAM
- parameters - PS, T, U, V, P, Q (mandatory, all model levels); T2M, TD2M, CLC, CLCT, CLCL, CLCM, CLCH, CLC, H_SNOW, TOT_PREC, VMAX_10, TMIN_2M, TMAX_2M
- observations (CDFIN: BUFR converted by bufrx2netcdf to NetCDF)
- output: ver-files, NetCDF feedback files including past forecasts

MEC can produce feedback-files for any model, which can then be used as input to produce verification statistics using Rfdbk. Some mandatory parameters from the model of interest must be available on all model levels: PS, T, U, V, P, Q, while others are optional, depending on the available observations and user needs (T2M, TD2M, PS, N, FF, DD, Gust, RR, etc).

The production of IFS FF using the Common Plot set of observations (cdfin files) is at the moment on-going, due to some limitations of the MEC software that need further investigation. This activity is included in the COSMO-SPRT Common Plot one for 2021-2022.

1.2.2 The Rfdbk package

This is an R interface that aims to exploit the information contained in the feedback files and can be used to perform feedback file-based verification. Rfdbk uses as input the feedback files obtained from MEC (one file for each validity date and observation type) and outputs score files (again, for each validity date and observation type). Rfdbk exploits the functionality of the R data.table format and can therefore handle huge data tables efficiently with a concise syntax that allows to apply functions on sub-categories. Rfdbk itself is not a verification package but an assortment of R functions (libraries). Based on Rfdbk libraries, R scripts exist to quickly and reliably produce verification results. These scripts can be modified and adjusted according to the needs of each particular system that will be linked to.

Rfdbk characteristics and requirements:

- R interface for COSMO feedback files
- main purpose is to load feedback file content with R
- additional functionalities useful for verification implemented as well
- namelist based verification scripts using Rfdbk do the verification

Installation

- Sources: R language
- Dependencies: NetCDF library and R with additional R packages: RNetCDF, data.table, parallel, strings, survival, grid, verification, reshape2, pcaPPIO specifications
- input - feedback files obtained previously with MEC - one file for each validity date and observation type
- output - score files for each validity date and observation type

Verification can be done for various types of observations (SYNOP, radiosondes, radio occultation, aircraft, wind profiler and so on). Continuous scores are computed for various types of observations, while categorical scores are also available for SYNOP observations. Verification can be performed for deterministic runs (forecast or hindcast) or ensemble, for any model (COSMO, ICON, IFS, etc.), while cross model verification (e.g. COSMO vs. ICON vs. IFS) is also possible. The package allows the handling of large data tables that facilitate the loading of feedback file content, data adjustment, binning, calculation of basic verification scores and so on. Rfdbk -based scripts can be used for:

- domain average verification (function of forecast lead-time for a user defined verification period), including domain stratification,
- time series (function of valid time in the verification period or as a function of the forecast lead-time)
- station based verification (function of observation station).
- aggregation on sub-domains, height bins, levels or periods

Rfdbk is a user-friendly package that can be employed in R-based scripts in order to perform point verification for either surface or upper air parameters using various types of observations and model runs. The advantage of using Rfdbk based verification scripts is their flexibility, which means they can be modified and adjusted according to the needs of each user and (UNIX) system.

1.2.3 R Shiny web server

On top, an interactive (R based) tool for the online visualization of verification results has been developed and will be also adopted in this project. This is based on the R Shiny web server that is currently setup on the COSMO web-site for the NWP Test suite needs. Through this capability it is possible to have on demand interactive plot web browser application, plot and arrange scores, summary score charts and browse data, with separate web-based apps for each observation and verification type.

This centralized, online and interactive visualization of the results on the COSMO web-site using the R Shiny server is meant to enable an easier evaluation of the results.

1.3 Overview of System Implementation

PP CARMA has obtained the successful results. The main outcome was the implementation of the new CVS in most countries of the COSMO consortium, with the system already in use for various operational implementations of both COSMO and ICON, as can be seen from tables 1 and 2.

	IMPLEMENTATION		PRODUCTION		Visualization
	DACE/MEC	Rfdbk	FF	SCORES	(optional)
NMA	yes	yes	yes	yes	yes
HNMS	yes	yes	yes	yes	-
DWD	*(yes)	*(yes)	*(yes)	*(yes)	*(yes)
MCH	*(yes)	*(yes)	on-going	on-going	
COMET	yes	yes	yes	yes	
IMGW-PIB	yes	yes	yes	yes	yes
RHM	yes	yes	on-going		
IMS	yes	yes	yes	yes	yes
ArpaE-SIMC	yes	on-going			

Table 1: Status of implementations for the MEC+Rfdbk system in each centre. *denotes that the system was installed and in use before the start of the project.

	NMA	HNMS	DWD	IMGW-PIB	COMET	MCH	RHM	IMS	ArpaE-SIMC
COSMO	x	-	x	x	x	x	-	-	x
ICON	x	x	x	x	x	-	x	x	-

Table 2: Overview of models verified by each centre using the MEC+Rfdbk software.

First results using the MEC+Rfdbk output for some CP activities started in the 2020 spring season (MAM 2020). The number of model scores computed with the new CVS has gradually increased until present (15 models expected for JJA2021), as will be shown in Section 3, dedicated to presenting the PP results.

2 Description of Tasks

2.1 Task 1: First Level Support Implementation and Training

Goal: The first level support implementation and training of the Project Support Team (PST) were included. In turn, the PST ensured and supported the implementation of the system for all the other partners.

2.1.1 Subtasks

1.1 Documentation review (MEC-Rfdbk), analysis of resources required. Preparation of a document for verification task specifications (common areas, models, parameters, statistical indices, representation) included in CP activity.

1.2 Documentation preparation (MEC-Rfdbk) with all the necessary installation and use notes for the PST training.

1.3 Preparation of a complete example set of data (one season, one model) to be used during the training and testing period. Model output as a test bed, including parameters that are part of CP requirements prepared. Adaptation of observations in NetCDF format (with bufr2netcdf COSMO software).

1.4 Training provided by DWD experts for first level support to the PST. During this training, a “clean” installation of MEC, Rfdbk and Shiny routines for visualization of results will be performed on a test machine. A complete cycle of model evaluation for a test case (outcome of Task 1.3) over CP area will be performed (observation preparation, run of MEC for Feedback files preparation, run of Rfdbk for extraction of statistical indices for both continuous and dichotomic parameters, visualization of results with Shiny).

1.5 Implementation of the MEC-Rfdbk system at NMA and HNMS (PST), in order to set up the MEC+Rfdbk system in all participating countries (with support from DWD experts where necessary).

1.6 Adaptation of scripts to produce the necessary statistical information for the production of the CP requirements, on a seasonal basis. Preparation and testing of scripts for semi-automatic use of the system.

1.7 Setup of web interface with the use of Shiny R routines on COSMO server to host CP activity outputs once the system becomes operational.

2.1.2 Deliverables and Preliminary Results

- Written instructions for installation and use of MEC-Rfdbk system.
- Installation of the MEC-Rfdbk system at NMA and HMNS (PST) and first tests of the implementation.
- Scripts for semi-automatic use of the system, available to project participants through common WG5 repository.
- Dataset (forecast/observation) to be used for test period of MEC-Rfdbk system.
- Completion of test period experiment and production of statistics (PST).
- Web interface to host Common Area plots for all countries.

The observations necessary for CP activity are prepared and disseminated to the participants operationally, on a daily basis.

Together with the daily observations, three sets of scripts are available for:

- production of FF with MEC from various model specifications (COSMO, ICON-LAM native or regular grid), on different platforms (local machine, ECMWF)
- production of scores using Rfdbk
- templates for plotting the results using the shiny server

The web interface to host Common Area plots for all countries is available on the COSMO web-site: http://www.cosmo-model.org/shiny/apps/carma/.

2.2 Task 2: Second Level Implementation and support+

Goal: Implementation of the MEC-Rfdbk system by all the member countries in the consortium, with support from PST (DWD support provided only when necessary and always through the PST).

2.2.1 Subtasks

2.1 Remote training PST for users from each centre. Dissemination of instructions, mailing list creation for problems solving, videoconferences, etc.

2.2 Implementation of MEC-Rfdbk system in each participating centre with support of PST

2.2.2 Deliverables and Preliminary Results

MEC-Rfdbk system installed by all project participants with support from PST. An overview of implementation status for each system component was shown in tables 1 and 2 (Section 1.3).

2.3 Task 3: Cross-validation of implementation

Goal: Testing of the verification system implementation and training through practical use.

Requirements from the participating scientists with regards to their verification needs led to the necessity of shifting the initially main task of the project from COSMO to ICON, in the view of the COSMO to ICON migration. As a consequence, two additional sub-tasks were included after the start of the project. The first additional sub-task was directly related to the COSMO to ICON migration and the need to test the new verification system for ICON-LAM implementations, rather than continue to invest much effort in adapting it for COSMO needs. Apart from this, an optional sub-task was also proposed, which was not foreseen at the beginning of the project. With the shiny server (COSMO web) used for both CP activities and the NWP Test Suite verification platform and due to the interest of the participants to use the MEC+Rfdbk system for verification requirements additional to CP activities, set-up of individual shiny servers was advised, in order to avoid loading the COSMO shiny server unnecessarily.

2.3.1 Subtasks

3.1 Performance of a test with all the necessary output for the CP reports. This task included development/adaptation of automatic procedures (scripts adaptation to local DBs) for seasonal CP activities based on the MEC-Rfdbk system by all services. Preparation of MEC output files for seasonal CP.

3.2 Transfer to statistical output to COSMO web server and visualization of results through installation of Shiny server (capability developed in Task 1.6) for comparison purposes.

3.3 Optional comparison of test output with VERSUS system or any other "home" verification system.

3.4 Set-up and testing of MEC+Rfdbk capabilities for ICON-LAM
Set-up of system and performance of a test with all the necessary output of ICON-LAM for the CP reports. This task was added due to the requirements of the participants, in view of the new ICON implementations. Some centres were unable to verify COSMO because of MEC model data requirements and lack of storage resources (e.g. not all required model data are archived). This additional sub-task also took into consideration the migration from COSMO to ICON.

3.5 (optional) Set-up of individual shiny server for visualization
At the start of the project, the shiny server on the COSMO web-site was used for visualization of results from Rfdbk (CP verification as well as NWP test suite). However, this can only be a solution for the CP activities, since verification activities of the users from the MEC+Rfdbk system vary and also include other type of individual verification. For future use (optimal) of the MEC+Rfdbk system, the set-up of individual shiny servers for each interested centre was suggested, to facilitate the visualization of the verification results. Similar to the implementation of the MEC+Rfdbk system, the shiny server was first set-up for the PST team who would, in turn help the other participants set-up their own systems.

2.3.2 Deliverables and Preliminary Results

- Evaluation of MEC-Rfdbk system for CP production based on an example dataset. Comparison with results from other verification software.

- Implementation of CP seasonal output with the MEC-Rfdbk system.

2.4 Task 4 Elaboration of guidelines for CARMA (MEC-Rfdbk) system use

Goal Preparation of documentation on the use of the MEC-Rfdbk system (including CP activities specifications).

2.4.1 Deliverables and Preliminary Results

Guidelines on the implementation, use and application of the MEC-Rfdbk system for CP production. ***An overview of the PP documentation (including Guidelines) is available in Section 6.***

2.5 Overview of Issues and Remaining Discussion Points

Remaining Discussion Points
Following the finalization of the project, a few remaining issues are at the moment still on-going, due to some limitations either of the software or specific problems of some users. These activities are included in the COSMO-SPRT Common Plot activities for 2021-2022 and refer to:

- IFS based FF
- installation and user support
- inclusion of all models in the new verification system

As Common Plot activities are a continuous and evolving task, some features of the current requirements might differ to the ones envisioned at the beginning of the project. As a consequence, follow up activities will also aim to incorporate the new requirements included in this year guidelines of the CP activity, such as:

- upper air verification
- 6h precipitation in all time intervals
- conditional verification
- update of the system with new versions of Rfdbk and distribution of new MEC versions for FF production

3 Timeline of Activities and Results

For the various results presented in the sections bellow, the following models were employed:

ICON GLOBAL (DWD)
ICON-EU (DWD)
COSMOPL7 / COSMO-PL(IMGW-PIB)
COSMO_ME (COMET)

ICON-D2 (DWD)
ICON_IT2 (COMET)
ICONGR (HNMS)
ICON_IMS / ICON-IL2p5 (IMS)
ICONPL (IMGW-PIB)
COSMO-CE-PL (IMGW-PIB)
COSMO_IT2 (COMET)
COSMO-1E (MCH)
COSMO-2E (MCH)
COSMO-RO_2p8 (NMA)
ICON-RO_2p8 (NMA)
COSMO-D2 (DWD)
COSMOP2k8 (IMGW-PIB)
COSMO-RO (NMA)

Standard Verification (seasonal) is generally performed for the following continuous parameters: 2-meter temperature – T2M (deg K), 2-meter dew point temperature - TD2M (deg K), surface pressure - PS (Pa), total cloud cover - N (octa), 10-meter wind speed - FF (m/s), wind direction - DD (deg) and wind gust - Gust (1 hour, m/s). Categorical scores are also computed, for the following parameters: 6 hour accumulated precipitation - RR_6h (thresholds: 0.2, 1, 5, 10, 15, 20 mm/6h), total cloud cover (thresholds >= 1, >= 4 and >= 7) and 10-meter wind gust (thresholds: >= 12.5, >= 15, >= 20 m/s).

Scores for continuous parameters include the mean error (ME) and root mean squared error (RMSE), mean absolute error (MAE), standard deviation (SD) and so on (only ME and RMSE will be discussed in the following examples). Dichotomic scores include the probability of detection (POD), false alarm rate (FAR), equitable threat score (ETS), frequency bias (FBI). Other scores based on the number of hits, misses, false alarms and correct negatives respectively are also available, but will not be shown. For all scores, the number of observations used in computations (LEN) is also available.

For the purpose of the project and future Common Plot Activities, scores were performed either for national domains or for the two domains used in the Common Area Verification Activities (see Figs. 2, 3 and Table 3).

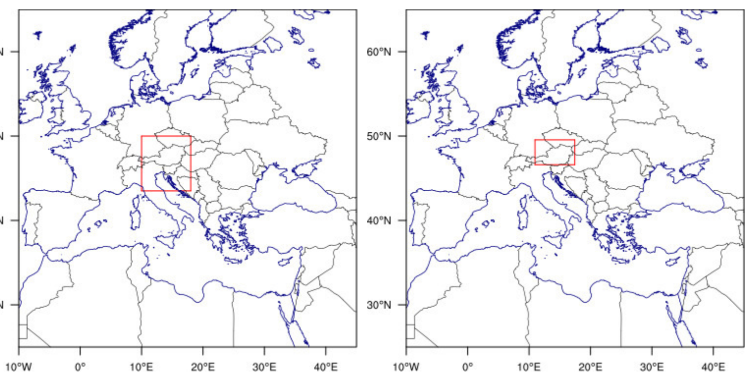

Figure 2: Common Areas: CA1 (left) and CA2 (right) used for the verification.

The two common areas for which the scores are computed include parts of Northern Italy, Austria, Slovenia, Croatia, Germany, Bosnia and Herzegovina, Hungary, Slovakia, and the Czech Republic. For Common Area 1, 96 stations were selected, with altitudes between 0m and 753 meters. Although slightly more restricted geographically, Common Area 2 included a larger number of stations than CA1. The stations in CA2 also cover a greater range of altitudes compared to CA1 (maximum altitude 3114m in CA2 compared to 753m in CA1). Table 3 offers an overview of station distribution for the two areas. The two areas were defined according to the list of stations previously used in verification activities with VERSUS. The results are computed taking into account all stations of interest. However, results are also available stratified by station altitude.

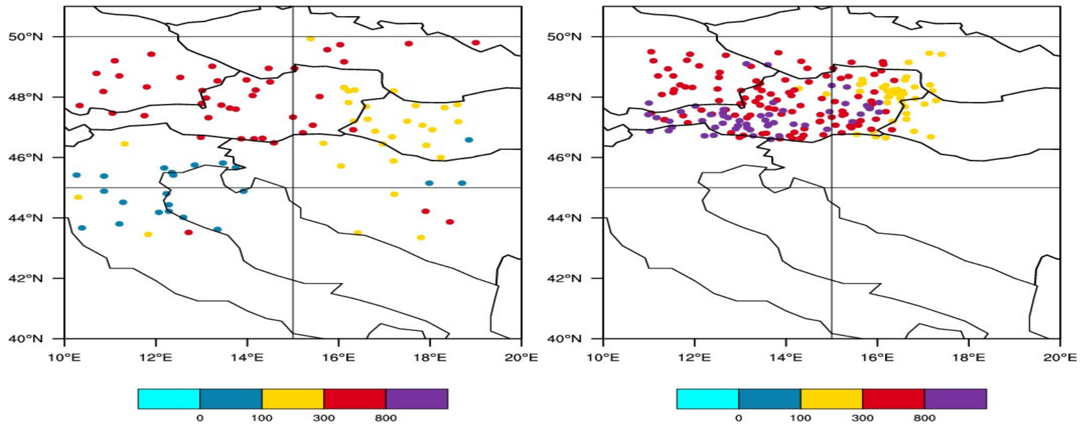

Figure 3: Location and altitude of synoptic stations in CA1 (left) and CA2 (right) used for the verification.

Common Area	**Number of stations**					**Altitude**	
	Total	$alt < 100m$	$100m < alt < 300m$	$300m < alt < 800m$	$alt > 800m$	Min	Max
CA1	96	23	30	43	0	0m	753 m
CA2	205	2	41	107	55	0m	3114m

Table 3: Overview of stations distribution for the 2 Common Areas, depending on altitude.

The verification results presented in the following sections are a sample of the derived statistics that were gradually obtained following the implementation of the MEC+Rfdbk system in more participating institutes. Complete sets of statistical scores obtained with the MEC-Rfdbk verification system for the models considered here are either available on the COSMO shiny server (http://www.cosmo-model.org/shiny/apps/carma/) or detailed in various papers referenced hereafter, including the Common plot annual reports available on the COSMO web site (http://cosmo-model.org/content/tasks/verification.priv/default.htm). For a detailed description of the Common Area Verification Activities, we refer to the document by

The following type of graphs produced with the MEC-Rfdbk system are exemplified below:

- Categorical scores for Gust (Fig. 4), RR_6h (figure 6) and N (figure 8);
- Scores for continuous parameters (Figs. 5 and 7);
- Scores for upper air parameters (figure 9);
- Comparison between two models showing reduction in ME and RMSE (Fig. 5).

3.1 MAM 2020: First Results

The first results of a cross model verification (with the MEC-Rfdbk software) for the Common Plot activities were performed for the 2020 spring season (MAM 2020) and detailed in Iriza-Burcă, Linkowska, and Fundel (2020). For these results, a set of three COSMO model runs were considered: COSMO-D2 (DWD), COSMO-PL (IMGW) and COSMO-RO (NMA). Only COSMO 00 UTC model runs were evaluated, with forecast step every 3 hours. The integration domains for COSMO-D2 and COSMO-PL were the operational ones (also included in the official Common Plots activities), while the COSMO-RO integration domain differed from the operational set-up of the model employed in NMA (in order to cover the Common Areas). The scores were computed for the two common areas presented before. Selective results obtained with the MEC+Rfdbk system for CA1 are presented below.

Categorical scores for 10-meter wind gust (1 hour) computed for CA1 (exemplified in Fig. 4) show a generally higher probability of detection for the 12.5m/s threshold than for the 15m/s one. For the first threshold, highest POD values are obtained during the day, with lower values starting with +21 hours anticipation, especially for COSMO-D2. A high false alarm rate from all three models can be seen for the 15m/s threshold, especially from COSMO-RO for CA1 in the second part of the considered forecast interval. For this threshold, a slightly better behaviour is exhibited by COSMO-RO for the first hours of forecast, while for the 12.5m/s threshold, the behaviour of the three models is similar for both areas. For both areas, the behaviour of the model (mainly for the 12.5 m/s threshold) is more similar between COSMO-D2 and COSMO-RO. For a detailed analysis of all the results for MAM 2020, we refer to the paper by Iriza-Burcă, Linkowska, and Fundel (2020).

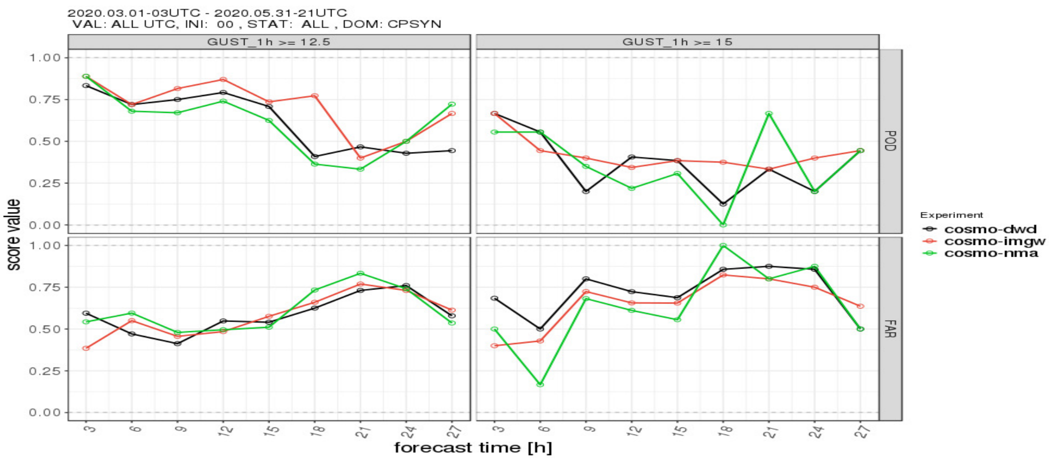

Figure 4: MAM2020 - Categorical scores for Gust (CA1); POD (top) and FAR (bottom): threshold >= 12.5 (left) and >= 15 (right). COSMO-D2 (black), COSMO-PL (red) and COSMO-RO (green).

3.2 SON2020: Verification of ICON in Limited Area Mode at COSMO National Meteorological Services

Some verification results using the MEC+Rfdbk system were included in the ICON Report "Verification of ICON in Limited Area Mode at COSMO National Meteorological Services (Rieger et al., 2021) published as part of the Priority Project 'Transition of COSMO to ICON' (PP C2I). The aim of the project was to ensure a smooth transition for the COSMO national meteorological services to the ICON model and the report offered the first published verification results on this subject. For this report, verification results were obtained either entirely using the MEC+Rfdbk system (e.g. COSMO-RO_2p8 vs. ICON-RO_2p8) or with the VERSUS verification software and translated to Rdata in order to visualize them using Rfdbk/Shiny server (COSMO-CE-PL vs. ICON-PL and Common Area Verification Results).

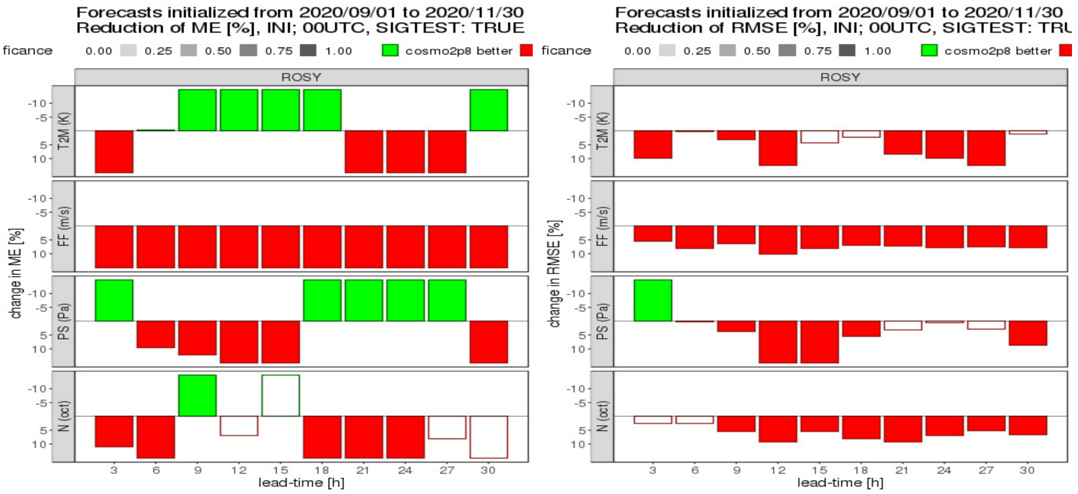

Figure 5: SON2020 - Comparison between ICON-RO-2.8km and COSMO-RO-2.8km: changes in ME (left) and RMSE (right) for all Romanian synop stations; top to bottom: T2M (K), FF (m/s), PS (Pa), N (octa); green - COSMO-RO-2.8km better, red - ICON-RO-2.8km better.

Comparison between ICON-RO-2.8km and COSMO-RO-2.8km **showing reduction in ME and RMSE** is exemplified in Fig. 5. The results obtained with MEC+Rfdbk suggested a good performance of the ICON-LAM model integrated for Romanian territory for the season of interest (up to 78 hours), with a small systematic increase in errors for the later forecast times (+60 hours) for T2M, FF, PS and N (Fig. 5). The comparison between COSMO-RO-2.8km and ICON-RO-2.8km showed a better performance from ICON for most continuous parameters, for the first 30 hours of forecast, visible especially from the reduction in the amplitude of errors.

3.3 DJF2021: First Common Activity Applications

Starting with the 2021 winter season (2021), the first results obtained with MEC+Rfdbk were included in the Common Verification Results (Fig. 6). For the DJF2021 season, FF were produced from the following models:

CA1: ICON-EU, COSMOPL7, COSMO_ME
CA2: ICON-D2, ICON_IMS / ICON-IL2p5, ICONGR, ICONPL, COSMO-1E, COSMO-2E, COSMO-D2, COSMOP2k8
National domains: ICON-RO_2p8, COSMO-RO_2p8

Selective Results for CA2 are shown in Fig. 6 (categorical scores RR_6h). ETS (Equitable Threat Score) and FBI (Frequency Bias) computed for 4 thresholds ($>= 0.2mm/6h$, $>= 1mm/6h$, $>= 10mm/6h\ and\ >= 20mm/6h$). Results suggest a better performance of the models for the lower thresholds ($>= 0.2\ mm/6h$, $>= 1mm/6h$), with a general tendency to over-forecast. For the higher thresholds, this tendency is mostly shown by COSMOP2k8 and ICONPL.

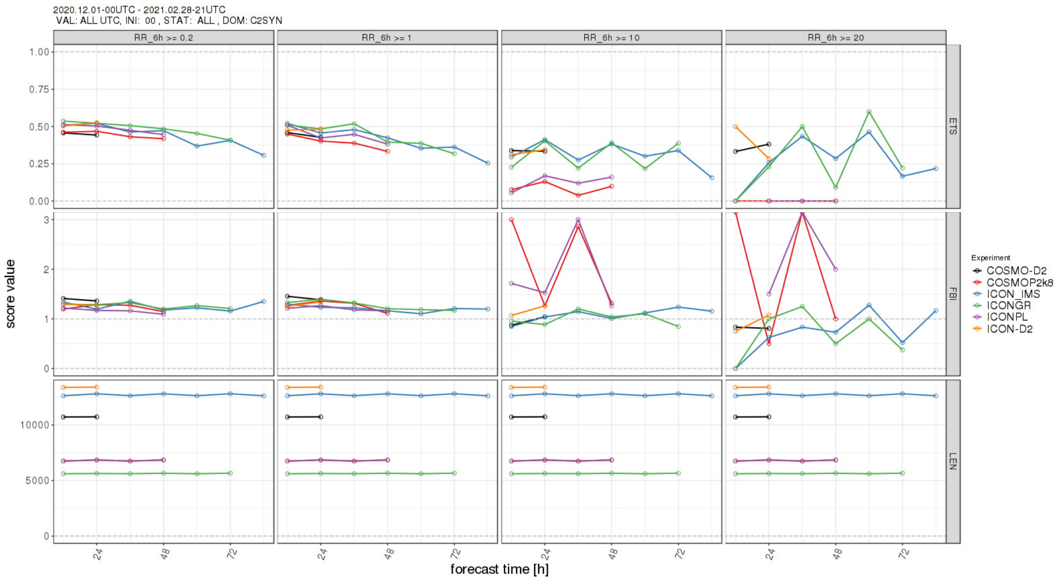

Figure 6: DJF2021 - Categorical scores for RR_6h (CA2): ETS (top), FBI (middle) and number of observations (bottom) values for CA2; thresholds (left to right): $>= 0.2mm/6h$, $>= 1mm/6h$, $>= 10mm/6h$ *and* $>= 20mm/6h$. COSMO-D2 (black), COSMOPk28 (red), ICON_IMS / ICON-IL2p5 (blue), ICONGR (green), ICONPL (purple) and ICON-D2 (orange).

3.4 MAM2021: Extended Common Area Activities

For the MAM2021 season, FF were produced from the following models:

CA1: ICON-GLOBAL, ICON-EU, COSMO_ME, COSMOPL7
CA2: ICON-D2, ICON_IMS / ICON-IL2p5, ICONPL, ICONGR, ICON_IT2, COSMO-CE-PL, COSMO-1E, COSMO-2E, COSMO_IT2
National domains: ICON-RO_2p8, COSMO-RO_2p8

Selective Results for CA1 are presented in Fig. 7, exemplifying scores computed for continuous parameters. For this season and area, in general, lowest ME values are obtained from ICON-EU, that also displays the smaller amplitude of errors for all parameters. The difference in number of observations is given by the fact that ICON-EU is only integrated for a period of 48 hours.

Selective Results for National Domains can be seen in Fig. 8. **Categorical scores for cloud cover** are computed for 3 thresholds (in octa): $N >= 1$, $>= 4$ *and* $>= 7$), taking into account all Italian stations (**national domain**). These results show a similar behaviour of all three evaluated models (COSMO_ME, COSMO_IT2 and ICON_IT2), especially for the first two thresholds, with high POD and a relatively small FAR. Slightly larger values of FAR can be seen for the highest threshold.

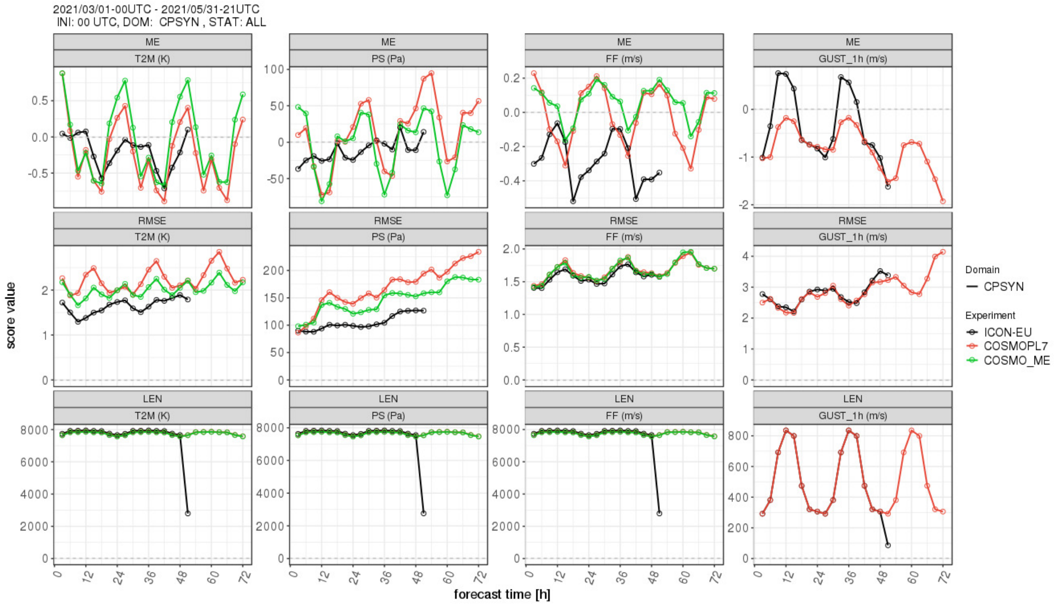

Figure 7: MAM2021 - ME (top), RMSE (middle) and number of observations (bottom) values for CA1; left to right: T2M, PS, FF and GUST (1h). ICON-EU (black) (black), COSMO-PL7 (red) and COSMO_ME (green).

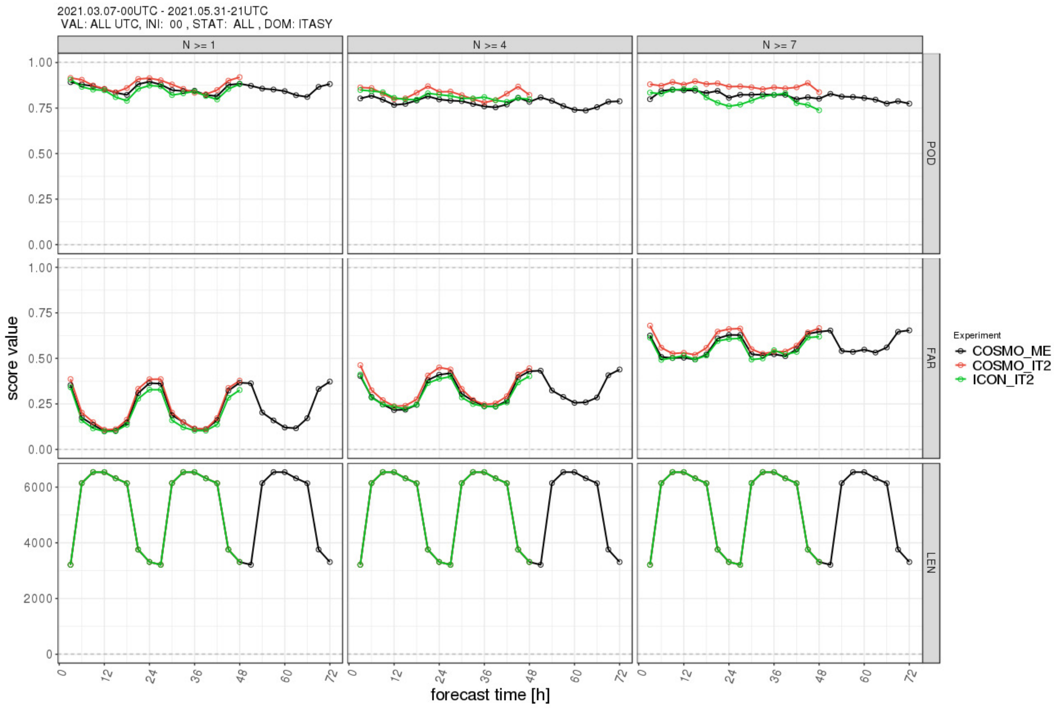

Figure 8: MAM2021 - Categorical scores for Cloud Cover: POD (top) and FAR (bottom) values from: COSMO_ME (black), COSMO_IT2 (red) and ICON_IT2 (green) for Italy national domain (all Italian stations); thresholds (left to right): >= 1, >= 4 *and* >= 7 (octa).

3.5 JJA2021: Ongoing Activities

Compared to the previous season, starting with JJA 2021, it was decided to employ a polygon description for the verification area instead of the previously used station lists. Also starting with the JJA2021 season, TEMP verification scores obtained with the MEC+Rfdbk verification system will be gradually included in the Common Plot activities. An example of the derived statistics obtained for upper air parameters is presented in Fig. 9.

For the JJA2021 season, FF are expected to be produced from the following models:

CA1: ICON-GLOBAL, ICON-EU, COSMO_ME, COSMOPL7
CA2: ICON-D2, ICONGR, ICON_IMS / ICON-IL2p5, ICON_IT2, ICONPL, COSMO_IT2, COSMO-CE-PL, COSMO-1E, COSMO-2E
National domains: All as CA1 and CA2, ICON-RO_2p8, COSMO-RO_2p8

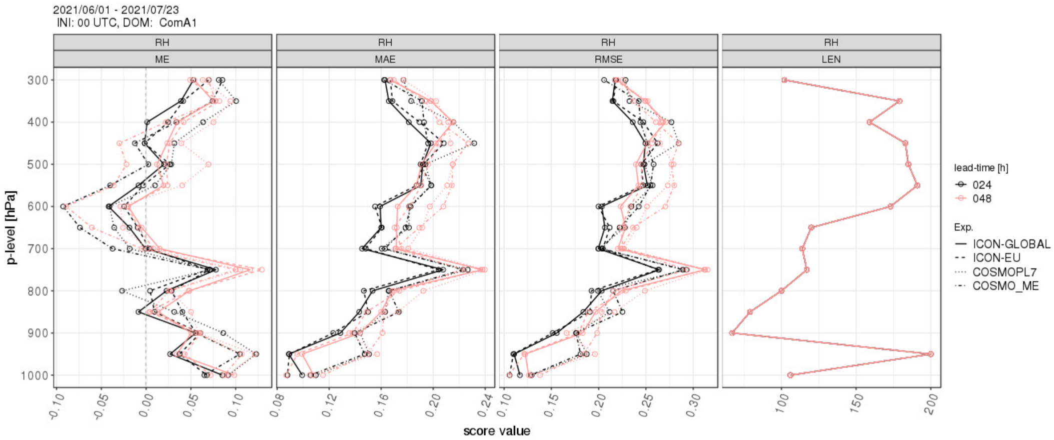

Figure 9: JJA2021 – Upper air relative humidity: ME, MAE, RMSE and LEN (left to right), values from: ICON-GLOBAL (continuous line), ICON-EU (dashed line), COSMOPL7 (dotted line) and COSMO_ME (dotted and dashed line), for +24 h (black) and 48 h (pink) lead time; scores computed for CA1.

4 Conclusions and Outlook

Following the finalization of the project, the MEC-Rfdbk system is implemented and runs operationally in IMGW-PIB, IMS, NMA, HNMS and COMET for various configurations of the ICON and COSMO models. As previously mentioned, the system was already in use before the start of the project in MCH (surface verification only) and DWD.

The following type of graphs can be produced with the MEC-Rfdbk system for Common Plot Activities:

- Categorical scores for Gust, RR_6h and N;
- Scores for continuous parameters;
- Scores for upper air parameters;
- Comparison between two models showing reduction in different scores.

All the remaining open issues that concern MEC-Rfdbk adaptation in some services and implementation of new features, will be performed through WG5 SPRT Common Plot activity.

Detailed documentation and templates for the use of the MEC-Rfdbk system are available for usage both for CP and national verification activities.

For more detailed presentations of the MEC-Rfdbk system and its components, including information regarding installation and use, documentation is available in the COSMO repository (PP CARMA Branch): http://cosmo-model.org/view/repository/wg5/PP-CARMA .

5 Meetings

- 20th COSMO General Meeting, Saint Petersburg (Russia), 3-7 September 2018
- ICCARUS 2019 (ICON/COSMO/CLM/ART USER SEMINAR), Offenbach, Germany, 18 – 22 March 2019
- COSMO-CARMA TRAINING for PST, Offenbach, Germany, 9 – 11 April 2019
- 21st COSMO General Meeting, Rome (Italy), 9-13 September 2019
- ICCARUS 2020 (ICON/COSMO/CLM/ART User Seminar), 2 – 6 March 2020 / PP CARMA web-meeting, 1st April 2020 (Minutes)
- 22nd COSMO General Meeting, 1-11 September 2020, teleconferences
- ICON/COSMO/CLM/ART User Seminar (ICCARUS) 2021, virtual seminar 8 – 19 March 2021 (Minutes)
- PP CARMA virtual discussion (PL and WG5c, 1st July 2021 (Minutes)
- 23rd COSMO General Meeting, 14-17 September 2021, teleconference

6 Documentation

The documentation for the installation and use of the MEC+Rfdbk verification system is available in the COSMO repository (PP CARMA Branch):
http://cosmo-model.org/view/repository/wg5/PP-CARMA

How to install (COSMO repository)
http://cosmo-model.org/repository/wg5/PP-CARMA/Task1/Install_notes_CARMA_v1.5.pdf

How to use (example based on NWP Test Suite @ECMWF; COSMO Repository)
NWPTest-Suite_Doc4CARMA.docx

About RFDBK
Ffverificationsuite[at]DWD.docx (COSMO Repository)
http://www.cosmo-model.org/shiny/users/fdbk/RfdbkVeriDoku.html

About feedback files
cosmoFeedbackFileDefinition.pdf
http://cosmo-model.org/content/model/documentation/core/default.htm

General Guidelines (COSMO repository)
http://cosmo-model.org/repository/wg5/PP-CARMA/Task1/CARMA_guidelines.pdf

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List of COSMO Newsletters and Technical Reports

(available for download from the COSMO Website: www.cosmo-model.org)

COSMO Newsletters

No. 1: February 2001.

No. 2: February 2002.

No. 3: February 2003.

No. 4: February 2004.

No. 5: April 2005.

No. 6: July 2006.

No. 7: April 2008; Proceedings from the 8th COSMO General Meeting in Bucharest, 2006.

No. 8: September 2008; Proceedings from the 9th COSMO General Meeting in Athens, 2007.

No. 9: December 2008.

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No. 11: April 2011.

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No. 16: July 2016.

No. 17: July 2017.

No. 18: November 2018.

No. 19: October 2019.

No. 20: December 2020.

COSMO Technical Reports

No. 1: Dmitrii Mironov and Matthias Raschendorfer (2001):
Evaluation of Empirical Parameters of the New LM Surface-Layer Parameterization Scheme. Results from Numerical Experiments Including the Soil Moisture Analysis.

No. 2: Reinhold Schrodin and Erdmann Heise (2001):
The Multi-Layer Version of the DWD Soil Model TERRA_LM.

No. 3: Günther Doms (2001):
A Scheme for Monotonic Numerical Diffusion in the LM.

No. 4: Hans-Joachim Herzog, Ursula Schubert, Gerd Vogel, Adelheid Fiedler and Roswitha Kirchner (2002):
LLM — the High-Resolving Nonhydrostatic Simulation Model in the DWD-Project LITFASS.
Part I: Modelling Technique and Simulation Method.

No. 5: Jean-Marie Bettems (2002):
EUCOS Impact Study Using the Limited-Area Non-Hydrostatic NWP Model in Operational Use at MeteoSwiss.

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Description of some convective indices implemented in the COSMO model.

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No. 28: Ulrich Blahak (2016):
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No. 43: H. Muskatel, U. Blahak, P. Khain, A. Shtivelman, M. Raschendorfer, M. Kohler, D. Rieger, O. Fuhrer, X. Lapillonne, G. Rivin, N. Chubarova, M. Shatunova, A. Poliukhov, A. Kirsanov, T. Andreadis, S. Gruber (2021):
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The COSMO Priority Project APSU: Final Report
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_45

COSMO Technical Reports

Issues of the COSMO Technical Reports series are published by the *COnsortium for Small-scale MOdelling* at non-regular intervals. COSMO is a European group for numerical weather prediction with participating meteorological services from Germany (DWD, AWGeophys), Greece (HNMS), Italy (USAM, ARPA-SIMC, ARPA Piemonte), Switzerland (MeteoSwiss), Poland (IMGW), Romania (NMA) and Russia (RHM). The general goal is to develop, improve and maintain a non-hydrostatic limited area modelling system to be used for both operational and research applications by the members of COSMO. This system is initially based on the COSMO-Model (previously known as LM) of DWD with its corresponding data assimilation system.

The Technical Reports are intended

- for scientific contributions and a documentation of research activities,
- to present and discuss results obtained from the model system,
- to present and discuss verification results and interpretation methods,
- for a documentation of technical changes to the model system,
- to give an overview of new components of the model system.

The purpose of these reports is to communicate results, changes and progress related to the LM model system relatively fast within the COSMO consortium, and also to inform other NWP groups on our current research activities. In this way the discussion on a specific topic can be stimulated at an early stage. In order to publish a report very soon after the completion of the manuscript, we have decided to omit a thorough reviewing procedure and only a rough check is done by the editors and a third reviewer. We apologize for typographical and other errors or inconsistencies which may still be present.

At present, the Technical Reports are available for download from the COSMO web site (www.cosmo-model.org). If required, the member meteorological centres can produce hard-copies by their own for distribution within their service. All members of the consortium will be informed about new issues by email.

For any comments and questions, please contact the editor:

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