# Summary of Results from the COSMO Priority Project CARMA: Common Area with Rfdbk/MEC Application

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## 1 Introduction and Short Overview of the MEC-Rfdbk System

Before the start of PP CARMA (Common Area with Rfdbk/MEC Application), Common Plot (CP) verification Activities were carried out using the VERSUS verification software environment. In recent years, partly due to technical limitations of VERSUS and lack of further development, the possibility of utilizing multiple verification modules that would not necessarily be linked to one software package was considered (e.g. VAST software for spatial methods). However, it is essential to maintain a common tool for the CP Activities, in order to ensure the adoption of the same verification practices and allow the long-term monitoring of the derived results (Gofa et. al, 2015; Gofa, 2016).

The MEC-Rfdbk system replaced the VERSUS software environment 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 the production of the CP verification, with spatial verification performed with other available COSMO tools (VAST, etc.). A centralized transfer and visualization of CP statistics on COSMO web server also facilitates the easier analysis of the outcome of CP activities and was also one of the main deliverables of the project. Although MEC-Rfdbk is also suitable for EPS verification, this type of application was not included in the CARMA project, due to the fact that EPS verification is not part of CP activity.

The Model Equivalent Calculator (MEC; Potthast, 2016) software for the production of Feedback Files (FF) (`http://cosmo-model.org/content/model/documentation/core/\\cosmoFeedbackFileDefinition.pdf`), and verification scripts based on the R libraries Rfdbk (Fundel, 2021), are tools that were developed and are in operational use at DWD for the verification of both COSMO and ICON model chains. The three main components of the MEC-Rfdk verification system (figure 1) are:

- MEC: used to produce FF based on model output and observations in netcdf format; results stored also in NetCDF format (FF);
- Rfdbk: used to compute statistical scores using the FF produced by MEC; results stored in Rdata format;
- Shiny web-server: used to visualize the results (COSMO web server).

The FF are produced by the Model Equivalent Calculator (MEC; Potthast, 2019) within the data assimilation system or as stand-alone. For the purpose of this project and the first test of the system, FF were produced using a common set of observations retrieved in bufr format from the ECMWF MARS archive. These observations were converted to NetCDF format with the bufr2netcdf software (Patruno and Cesari, 2011) and used as input in MEC. Further on, these feedback-files are used by the Rfdbk (Fundel, 2021) package to calculate the verification scores. Finally, the verification scores in Rdata format are visualized on the dedicated COSMO web page, using the R Shiny Server (Wang et al., 2020). This centralized, online and interactive visualization of the results on the COSMO web-site using the R Shiny Server is meant to enable a easy and interactive evaluation of the results.
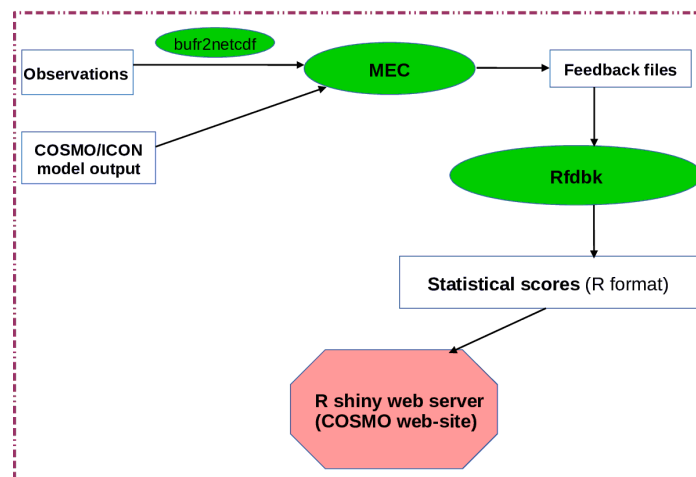
Figure 1: Schematic representation of the MEC-Rfdbk system.

## 2 Overview of System Implementation

The main outcome of the project was the implementation of the new CVS in most COSMO countries, with the system already in use for various operational implementations of both COSMO and ICON (depending on model data availability), as can be seen from tables 1 and 2.

|  | IMPLEMENTATION | | PRODUCTION | | Visualization (optional) |
|---|---|---|---|---|---|
|  | DACE/MEC | Rfdbk | FF | SCORES | |
| **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** | yes | yes | yes | yes | yes |
| **RHM** | yes | yes | on going | | |
| **IMS** | yes | yes | yes | yes | yes |
| **ArpaE** | yes | on going | yes | on going | |

Table 1: Status of implementations for the MEC-Rfdbk system in each center.

* denotes that the system was installed and in use before the start of the project.

|  | NMA | HNMS | DWD | MCH | CoMET | IMGW | RHM | IMS | ArpaE |
|---|---|---|---|---|---|---|---|---|---|
| **COSMO** | x | - | x | x | x | x | - | - | x |
| **ICON** | x | x | x | x | - | - | x | x | - |

Table 2: Overview of models verified by each center using the MEC-Rfdbk software.

First applications based on MEC-Rfdbk for CP activities started in the 2020 spring season (MAM 2020), while the number of model scores computed with the new CVS has gradually increased until present (14 models expected for JJA2021). 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 (e.g production of FF from the IFS model). These activities are included in the COSMO-SPRT (Support) Common Plot activities for 2021-2022. 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 (e.g. upper air verification, 6h precipitation in all time intervals, conditional verification and update of the system with new versions of the software).

For detailed description of the MEC-Rfdbk system and results obtained during the project, we refer to the documentation presented in Section 4.

## 3 Timeline of Results

For the various results obtained during the CARMA project and exemplified in the sections bellow, the following models were employed:

- ICON GLOBAL, ICON-EU, ICON-D2, COSMO-D2 (DWD)
- COSMOPL7 / COSMO-PL, ICONPL, COSMO-CE-PL, COSMOP2k8 (IMGW-PIB)
- COSMO_ME, ICON_IT2, COSMO_IT2 (COMET)
- ICONGR (HNMS)
- ICON_IMS / ICON_IL2p5 (IMS)
- COSMO-1E, COSMO-2E (MCH)
- COSMO-RO_2p8, ICON-RO_2p8, 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 ($thresholds \geq 1, \geq 4$ and $\geq 7$) and 10-meter wind gust ($thresholds :\geq 12.5, \geq 15, \geq 20 m/s$).

Scores for continuous parameters include the mean error (ME) and root mean squared error (RMSE), mean absolute error (MAE), standard deviation (SD) and the correlation coefficient (R2) (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) and frequency bias (FBI). Other scores based on the number of hits, misses, false alarms and correct negatives respectively are also available. For all scores, the number of observations used in computations (LEN) is also available as well as the observation mean (OMEAN) and the forecast mean (OMEAN).

For the purpose of the project and future Common Plot Activities, scores are computed either for national domains or for the two domains used in the Common Area Verification Activities (see figure 2).

The two areas were initially 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. Starting with the JJA2021 season, common area stratification is defined by polygons instead of station lists.
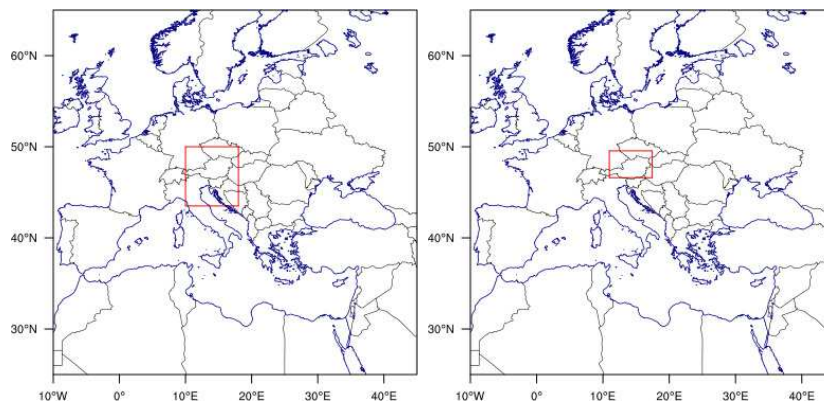
Figure 2: Common Areas: CA1 (left) and CA2 (right) used for the verification.

The verification results exemplified 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 for the project 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 Gofa et. al (2021).

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 are detailed in Iriza-Burca, 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 of interest for Common Plot Activities.

Following the first seasonal verification results obtained for MAM2020, 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). This report offered the first published verification results regarding the transition for the COSMO national meteorological services to the ICON model.

For this report, verification results for the SON2020 season were obtained either entirely using the MEC-Rfdbk system (e.g. COSMO-RO_2p8 vs. ICON-RO_2p8) or originally with the VERSUS verification software and then translated to Rdata in order to visualize them using Rfdbk/Shiny server (COSMO-CE-PL vs. ICON-PL and Common Area Verification Results).

Starting with the 2021 winter season **(DJF2021)**, the first complete results obtained with MEC-Rfdbk, were included in the Seasonal Common Verification Results. For the DJF2021 season, FF were produced for 3 models on CA1 (ICON-EU, COSMOPL7, COSMO_ME; figure 3) and 8 models on CA2 (ICON-D2, ICON_IL2p5, ICONGR, ICONPL, COSMO-1E, COSMO-2E, COSMO-D2, COSMOP2k8).

Scores for national domains were also computed for some of the models. Additionally, results from ICON-RO_2p8 and COSMO-RO_2p8 were provided for the corresponding national domain. Due to differences in availability of model data, some model verification results were either computed separately for each model and merged using R scripts developed by HNMS or computed with the VERSUS verification software and translated to Rdata in order to be visualized along with the rest of the models.
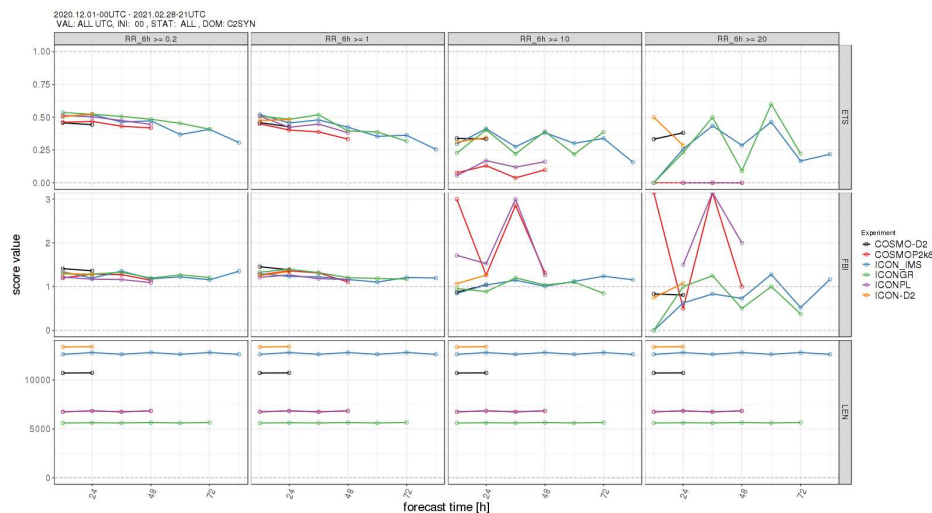


**Figure 3:** DJF2021 - Categorical scores for RR_6h (CA2): ETS (top), FBI (middle) and number of observations (bottom) values for CA2; thresholds (left to right): $\geq 0.2mm/6h$, $\geq 1mm/6h$, $\geq 10mm/6h$ and $\geq 20mm/6h$. COSMO-D2 (black), COSMOPk28 (red), ICON_IMS/ICON_IL2p5 (blue), ICONGR (green), ICONPL (purple) and ICON-D2 (orange)

The number of models included in the verification activities increased for the **MAM2021** season. For this period, FF were produced from 4 models for CA1 (ICON-GLOBAL, ICON-EU, COSMO_ME, COSMOPL7) and 9 models for CA2 (ICON-D2, ICON_IL2p5, ICONPL, ICONGR, ICON_IT2, COSMO-CE-PL, COSMO-1E, COSMO-2E, COSMO_IT2), again with additional results for national domains (including ICON-RO_2p8, COSMO-RO_2p8).

As can be seen by the number of observations used for the computation of statistical scores for continuous variables (figure 4), the differences in availability of model data was reduced compared to the previous season, with results from more models computed simultaneously and directly with MEC-Rfdbk, instead of being computed with the VERSUS verification software and translated to Rdata for visualization.

Compared to the previous seasons, starting with **JJA2021**, a polygon description will be employed 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.

For the JJA2021 season, FF are expected to be produced from 4 models for CA1 (ICON-GLOBAL, ICON-EU, COSMO_ME, COSMOPL7) and 9 models for CA2 (ICON-D2, ICONGR, ICON_IL2p5, ICON_IT2, ICONPL, COSMO_IT2, COSMO-CE-PL, COSMO-1E, COSMO-2E). For national domain verification, 12 models are expected to be included (from CA1 and CA2, additionally ICON-RO_2p8, COSMO-RO_2p8). Also starting with this season, upper air verification based on TEMP observations will be included in the Common Plot Activities, after tests for individual domains/models during PP CARMA.
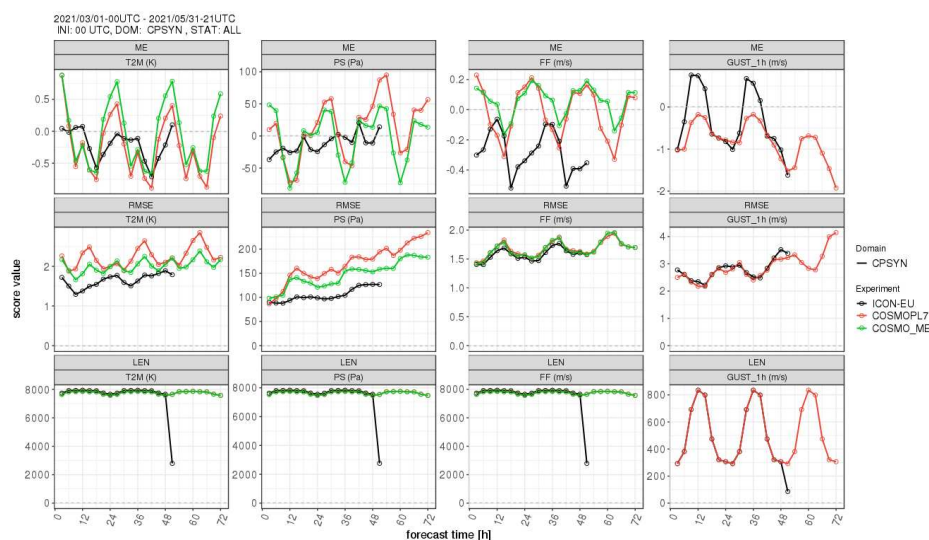
Figure 4: MAM2021 - ME (top), RMSE (middle) and number of observations (bottom) values for CA1; left to right: T2M, PS, FF and GUST (1h). ICON-EU (black) (black), COSMO-PL7 (red) and COSMO_ME (green)

## 4 Conclusions and Available Documentation

Following the finalization of the CARMA project, it can be concluded that 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 are 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 the trend 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.

**How to install**
`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@DWD.docx (also on COSMO Repository) `http://www.cosmo-model.org/shiny/users/fdbk/RfdbkVeriDoku.html`

**About feedback files**

Ffverificationsuite@DWD.docx (also on COSMO Repository) `http://www.cosmo-model.org/shiny/users/fdbk/RfdbkVeriDoku.html`

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

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