REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: Germany, Greece, Italy

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Project Title:

COSMO and ICON Numerical Weather Prediction Test Suite

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SPITRASP**	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2021	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☒

Computer resources required for 2021-2023: (To make changes to an existing project please submit an amended version of the original form.)		**2021**	**2022**	**2023**
High Performance Computing Facility	(SBU)	5.000.000	5.000.000	5.000.000
Accumulated data storage (total archive volume)[2]	(GB)	2000	4000	6000

Continue overleaf

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The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

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Extended abstract

Introduction

The **"COSMO and ICON Numerical Weather Prediction Test Suite**" Special Project aims is to employ the software environment built on the ECMWF platform during the SPITRASP projects (2013-2015, 2016-2017, 2018-2020) in order to perform rigorous testing of new COSMO model versions before the release of an official one. Also, during the activities of this project, the existing testing platform will be extended and adapted to the ICON model. Procedures will include the configuration of the ICON-LAM test suite and generation of objective verification statistics, for any test versions of the COSMO and ICON models prior to their official release.

COSMO (Consortium for Small-scale Modelling) is an European group for numerical weather prediction with participating meteorological services from Germany (DWD), Greece (HNMS), Italy (USAM), Switzerland (MeteoSwiss), Poland (IMGW), Romania (NMA), Russia (RHM) and Israel (IMS), with the goal of developing, improving and maintaining a non-hydrostatic limited area modelling system to be used for both operational and research applications by the members of COSMO.

Present activities in the COSMO consortium are aimed towards a harmonization of development of the COSMO and ICON (ICOsahedral Nonhydrostatic) models, with gradual migration from COSMO to ICON-LAM (ICON - Limited Area Mode) as the future operational model. Further development of the COSMO model will be reduced to the level needed for operational production, with development and testing of new features restricted mainly to ICON. First tests performed by the consortium members suggest that ICON-LAM outperforms the COSMO-model in terms of both quality of results and computational efficiency.

Since the development of the COSMO Test Suite software environment, the evaluation of new COSMO model versions performed with this platform has been taken into account before operational implementation (release of any official version). Controlled testing using the NWP Test Suite as a benchmark has proven useful in assessing not only the general model performance, but also the impact of new developments introduced for the representation of various numerical or physical processes. Results obtained with these verification procedures also offer valuable support in advising to upgrade the model test version to a new official release.

Nine model versions have been installed and tested up to now. These versions have been evaluated in the framework of the SPITRASP special projects. More model versions of both COSMO and ICON are expected to be tested using this platform.

Scientific Plan

The initial platform to test versions of the COSMO model (7 km horizontal resolution) within a well-defined framework prior to their release was developed in the framework of the **NWP Meteorological Test Suite ECMWF** Special Project (2013-2015). In continuation of this project, during the **COSMO NWP Meteorological Test Suite** Special Project (2016-2017), the platform was updated in order to perform tests and evaluate higher resolution (convection permitting) COSMO model (2.8 horizontal resolution). Finally, in the framework of the **Testbed for the Evaluation of COSMO Model Versions** Special Project (2018-2020), the system was employed to continue the activities started in the previous two special projects. Also during this latest period, the platform was extended to allow the evaluations of hindcast mode model runs and single precision versions of the model, in an effort to reduce computational costs.

The **COSMO and ICON Numerical Weather Prediction Test Suite Special Project** intended to continue the activities started in the previous three special projects will ensure the usage of a homogeneous verification platform for both the COSMO and ICON models. This is meant as a benchmark in order to evaluate new versions of the model against exiting operational ones, prior to their official release. This platform also provides standards against which the impacts of new developments in the model should be evaluated.

The aim of using this type of controlled approach for standardized testing and verification for the COSMO and ICON models is to ease the comparison of corresponding model versions (operational against new), in an effort to assess the impact of new features introduced in the code.

Similar to previous activities carried on in the framework of the SPITRASP special project, both the 7km and the 2.8km COSMO and ICON models will be integrated and evaluated for common domains or, depending on specific test requirements, also on different subdomains. The integration areas will be extended so that most of the COSMO countries will be covered. This will enable each COSMO member to have access to a standardised evaluation for its own domain, via local storage of the data on the ECFS system and availability of verification results on the COSMO web site.

The set-up and configuration of the COSMO and ICON models will focus on minimising initial and lateral boundary conditions effect, while also eliminating the data assimilation system. Through this approach, performance of each new model version can be thoroughly tested, with an emphasis on newly introduced code developments.

The design of the current test suite employed for these tasks is meant to offer a flexible yet controlled environment for the evaluation of new model implementations prior to their official release. As a consequence, the set-up and configuration for each set of full tests (model set-up, configuration, execution of runs, verification methods and statistical measures) is to be adapted to the requirements of the users: developers, area experts and verification experts, operational users and so on.

As a general rule, new versions of the model will be considered “valid” and will be accepted for official release and operational implementation if the different sets of verification results show either a positive impact compared to the previous model version over the common domain, or at least a neutral one.

Phase I: Set-up of the COSMO and ICON models

The first steps to be taken in setting up the test suite consist of activities concerning the installation of the COSMO and ICON models, mainly:

1. Set-up of the NWP Test Suite for the COSMO model

- availability of all the necessary external parameters files for both model resolutions (topography, lakes, land use, land-sea mask and so on)
- adaptation of various namelists needed for both model resolutions
- implementation of the interpolation program INT2LM (newest version available)
- implementation of new COSMO versions to be tested

2. Set-up of the NWP Test Suite for the ICON model

- all the necessary external parameters files need to be available for the ICON model (topography, lakes, land use, land-sea mask, etc.)
- adaptation of various namelists employed by the ICON model
- compilation of new versions of the **ICON TOOLS** interpolation software
- each ICON version to be evaluated will be compiled

Phase II: Configuration and Execution of Runs

1. Configuration and Execution of COSMO Runs

With regards to the COSMO model, the testing environment will be employed for new versions prior to their official release, both for the 7km (double precision and single precision) and the 2.8km (double precision) horizontal resolutions, in hindcast mode. The model set-up and configuration will follow the operational characteristics in most meteorological services, with the minimization of impact from features such as initial and lateral boundary conditions and data assimilation and with an emphasis on new model developments.

For the hindcast mode and for both model resolutions, the tests will be performed for runs initialized by the 00UTC data. Initial conditions will be provided by ECMWF HRES analysis, whereas lateral boundary conditions will be introduced with a 3 hourly frequency and will include the ECMWF HRES analyses (at hours 00, 06, 12 and 18UTC) and short cut off analyses (at hours 03, 09, 15 and 21UTC). Soil will be initialized from ICON-EU for both model resolutions.

Testing and evaluation procedures will be concentrated on two extended retrospective periods, covering a broad range of weather regimes (null, weak, strong events over the domain of interest), one month during the winter season (December 2017) and one during the summer (July 2017).

Due to the flexibility of the testing environment and necessity to adapt to user requirements, simulation periods (as well as model configuration) can vary, depending on the new developments that are to be evaluated.

2. Target configuration of ICON-LAM and Execution of ICON-LAM runs

Configuration of the ICON-LAM test suite will follow that employed in previous years for the COSMO Test Suite. This will entail a duplication of the COSMO NWP Test Suite in the Ecflow format.

For the evaluation of new ICON-LAM model versions (limited area mode) as soon as they are available, testing will be performed again at two horizontal resolutions: 7km and 2.8km. Simulations are to be carried out for two one-month periods (one in the winter and one in the summer), July and December 2017 and will be performed in hindcast mode (fc +31days, using restart every 5 days).

The COSMO and ICON-LAM models at the two horizontal resolutions will be run on the domains presented in Figure 1, respectively, with the possibility to adapt the integration area to the needs of the model developers and verification experts.

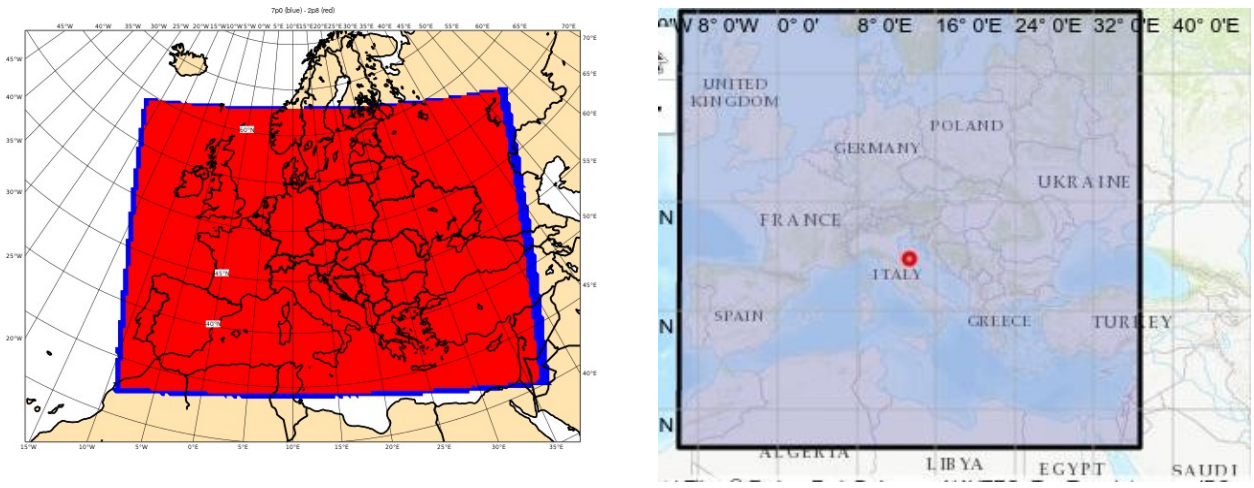

Figure 1. Integration domain for the COSMO model, 7km (blue) and 2.8km (red) resolutions (left) and ICON model (right).

Initial and lateral boundary conditions will be used from ECMWF HRES analysis and forecast (at 3, 9, 15, 21UTC, with 3 hours forecast-range), while the soil information will be intialized from ICON-EU, then free soil (both at 7km and 2.8km).

The integration domain for ICON-LAM@2.8km will be nested ICON-LAM@7km. Model output in grib2 will be stored in ecfs.

Phase III: Model Output Verification

The Model Equivalent Calculator (MEC) software for the production of Feedback Files, and verification scripts based on the R package Rfdbk have been previously implemented and are already running at ECMWF. These tools are currently used operationally at DWD for the operational verification of both COSMO and ICON model chains. The MEC+Rfdbk system is currently also under implementation in all the COSMO member countries. The most important advantages of this verification system are the shortfall of data pre-processing. This means all data are in one place, with observation and forecast correctly assigned to each other, while quality control is done by data assimilation. The procedure ensures a fast and simple calculation of standard verification scores and the interactive and online production of results.

The MEC-Rfdbk verification system is based on the use of Feedback files, that hold information on observations and their usage in the data assimilation system and are available for each observation system used. They are produced by the Model Equivalent Calculator (MEC) within the data assimilation system or as stand-alone and contain information regarding the observations (including meta-data) and corresponding model analysis, first-guess and past forecast, in NetCDF format. Another advantage of using Feedback files is that have a relatively small size (e.g. 4.8Mb SYNOP for COSMO-7km run for the NWP Test Suite domain) and are produced as one file for each valid-time, model and observation system.

Observations datasets are retrieved from the MARS database and converted from bufr to NetCDF format locally.

Verification activities (computation of scores) will be performed using **Rfdbk,** an R-based code of functions developed explicitly to exploit the information contained in feedback files. The package allows: to load FF content (partially, parallel), to calculate basic verification scores (deterministic & EPS) and to perform some convenience functions like data adjustment, re-labeling, binning etc. and produce verification results.

For this part, the verification will be performed with grid-to-point comparisons in order to compare gridded surface and upper-air model data to point observations. Statistical scores will be computed for each period of interest and each domain, but results can also be obtained for different station stratifications or subdomains, depending on user requirements.

The results obtained with this verification procedure will offer insight over the implementation of new model features, enabling the COSMO community to decide if new model versions can be accepted for official release and operational implementation.

The production of feedback-files using MEC is performed on the same machine used for the model runs and employs part of the available billing units, while the Rfdbk package and model output verification procedure is performed on ecgate.

Phase IV: Additional steps and further actions

After the model set-up, experiment configuration, execution of runs and verification tasks are performed. As previously mentioned, the design of the test suite should offer a flexible and controlled environment for the evaluation of various model implementations. In consequence, verification methods and statistical measures employed for model evaluations may be extended to perform additional verification activities, depending on user requirements.

Use of ECMWF computer resources, software and data infrastructure

The computer resources will be used in order to run both the COSMO and ICON models, as well as for the model verification activities.

The netcdf, eccodes and R utilities (already available on ecgate and cca) are necessary for this project.

Data storage resources will be used in order to locally store the model output obtained from the numerical experiments in the ECFS system.

Because not all consortium members are ECMWF participating countries, special access rights should be provided to them for the duration of this project, with rights restricted to the activities connected with the project tasks as described above.

Technical characteristics of the codes to be used

- "**INT2LM**", the program used to perform the interpolation from coarse grid model data to COSMO initial or lateral boundary conditions. Simulations will be initialized by the 00UTC data, with initial and lateral boundary conditions provided by ECMWF IFS files, whereas soil will be initialized from ICON-EU for both COSMO model resolutions.
- "**COSMO**", the code performing the actual numerical weather prediction with the non-hydrostatic limited-area atmospheric prediction model COSMO. This code has been designed for both operational forecasts and various scientific applications on the meso-beta (from 5 to 50km) and meso-gamma (from 500m to 5km) scale. The COSMO model is based on the primitive thermo-hydrodynamical equations describing compressible flow in a moist atmosphere. 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 parameterisation schemes.
- **"ICON TOOLS",** a set of command-line tools for remapping, extracting and querying ICON data files, based on a common library and written in Fortran 90/95 and Fortran 2003. ICON TOOLS provide a number of utilities for the pre- and post-processing of ICON model runs. All of these tools can run in parallel on multi-core systems (OpenMP) and some offer an MPI-parallel execution mode in addition.
- **"ICON",** the code performing the actual numerical weather prediction with the non-hydrostatic atmospheric prediction model ICON (limited area mode). This model was designed targeting a unified modelling system for NWP and climate modelling. The main achievements of ICON are exact local mass conservation, mass-consistent tracer transport, a flexible grid nesting capability and the use of non-hydrostatic equations on global domains. The dynamical core is formulated on an icosahedral-triangular Arakawa C grid. To achieve competitive computational efficiency, time splitting is applied between the dynamical core on the one hand and tracer advection, physics parametrizations and horizontal diffusion on the other hand. The current activities in the COSMO consortium are aimed towards a harmonization of development of the COSMO and ICON models, with gradual migration from COSMO to ICON-LAM as the future operational model.
- **"MEC", The Model Equivalent Calculator** 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). Original observational data (CDFIN, i.e. BUFR format converted to NetCDF) are used for the current experiments, with verification files generated separately for each observation type (TEMP, PILOT, SYNOP, etc). A common set of observations (e.g. bufr data retrieved from ECMWFs mars archive) converted in NetCDF format will be used as input in MEC along with the model output.
- **"Rfdbk",** is an R-based code of useful functions developed to exploit the information contained in feedback files. The package allows: to load FF content (partially, parallel), to

calculate basic verification scores (deterministic & EPS) and to perform some convenience functions like data adjustment, re-labeling, binning etc. 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. Base on Rfdbk, R scripts to quickly and reliably produce verification results have been developed. These can be modified and adjusted according to the needs of the users.

Deliverables:

The detailed guidelines for the proper use and execution of each NWP test using this platform prepared during previous special projects related to this activity will be revised, considering both models and resolutions (7km and 2.8km) and all the additional activities described above. A detailed description of all steps will be included, from the compilation of a new COSMO model test version to the final production of the graphics for the statistical scores extracted.

The Test Suite procedure will also be adapted and applied to the ICON numerical weather prediction model (limited area mode). This will include detailed guidelines for the proper use and execution of NWP tests using ICON, before the official release of new model versions.