REQUEST FOR A SPECIAL PROJECT 2024–2026

MEMBER STATE:	Germany, Greece, Italy
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Project Title:	**ICON NUMERICAL WEATHER PREDICTION METEOROLOGICAL 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.)	2024	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☒

Computer resources required for project year:		**2024**	**2025**	**2026**
High Performance Computing Facility	(SBU)	7.500.000	7.500.000	7.500.000
Accumulated data storage (total archive volume)[2]	(GB)	6000	6000	6000

Continue overleaf

[1] 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

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF and its Scientific Advisory Committee. The requests are evaluated based on their scientific and technical quality, and the justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests exceeding 5,000,000 SBU should be more detailed (3-5 pages).

Motivation

The **"ICON NUMERICAL WEATHER PREDICTION METEOROLOGICAL TEST SUITE**" Special Project aim is to employ the software environment built on the ECMWF platform during the SPITRASP projects (2013-2015, 2016-2017, 2018-2020, 2021-2023) in order to perform rigorous testing of new ICON model versions before the release of an official one. Previously, a similar testing platform was used for the evaluation of COSMO model versions 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 - Roshydromet is suspended temporarily from COSMO activities) and Israel (IMS), that aims to develop, improve and maintain a non-hydrostatic limited area modelling system to be used for both operational and research applications by its members.

Previous activities in the COSMO consortium were aimed towards a harmonization of development of the COSMO and ICON models. Following a gradual migration from COSMO to ICON-LAM, the latter is currently the official operational model for the members of the consortium. Following the release of the final version of the COSMO model (v6.0), maintenance of the model is now limited to the level needed for operational production, while development and testing of new features is restricted to ICON. Tests performed by the consortium members during the migration period have shown that ICON-LAM generally outperforms the COSMO-model in terms of both quality of results and computational efficiency.

Since the development of the COSMO Test Suite software environment starting with 2013, evaluations of new COSMO model versions performed with this platform were taken into account before operational implementation and official release of any model version. Some reduced testing and comparisons between the COSMO and ICON-LAM models were also tentatively performed in order to provide a first assessment of the benefits and requirements to include the ICON model in the NWP Test Suite framework. 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.

Activities performed during the Special Project will include the configuration of the ICON-LAM (ICOsahedral Nonhydrostatic general circulation model - Limited Area Mode) test suite and generation of objective verification statistics, for any test versions of the ICON model prior to the release as officially recommended version of operational use by COSMO members and support licensees.

Eleven COSMO and one ICON-LAM model versions have been installed and tested up to now. All versions have been evaluated in the framework of the SPITRASP special projects. More model versions of the ICON model are expected to be tested using this platform.

Scientific Plan

The initial platform to test only 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). This was followed by the **Testbed for the Evaluation of COSMO Model Versions** Special Project (2018-2020), during which the system was employed to continue the activities started in the previous two special projects. During this project, the platform was also extended to allow the evaluations of hindcast mode model runs and single precision versions of the model, in an effort to reduce computational costs. Finally, during the **COSMO and ICON Numerical Weather Prediction Test Suite** Special Project (2021-2023), the activities started in the previous three special projects were continued and extended to ensure the usage of a homogeneous verification platform for both the COSMO and ICON models. The purpose of this latest project was to provide a benchmark in order to evaluate new versions of the ICON-LAM model against exiting operational ones, prior to their official release. Part of the activities of this Special Project were also dedicated to the migration of the NWP Test Suite system from Cray HPC system in Reading to the new ATOS system in Bologna

The current NWP Test Suite platform available on ATOS provides standards against which the impacts of new developments in the ICON model can be evaluated. The main purpose in employing a controlled approach for objective, standardized testing and evaluation of the ICON model (and previously the COSMO model) is to ensure a fair comparison of corresponding model versions (operational against new), in order to assess the impact of new features introduced in the code.

Similar to previous activities carried on in the framework of the SPITRASP special projects, various versions of the ICON-LAM model (operational against new, prior to official release) will be integrated and evaluated for common domains. The integration areas will be selected so that most of the COSMO countries will be covered, ensuring that each COSMO member will have access to an objective and 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. Moreover, depending on specific test requirements, verifications will also be performed for different subdomains and station stratifications.

The set-up and configuration for the various versions of the ICON model will focus on minimising the effects of the initial and lateral boundary conditions and will also eliminate the data assimilation system. This approach enables the evaluation of the performance for each new model version through detailed testing, using a flexible and controlled environment, with an emphasis on newly introduced code developments. This will ensure the evaluation of new ICON model implementations prior to their official release.

The set-up and configuration for each set of full tests (model set-up, configuration, execution of runs, verification methods, statistical measures and production of statistical scores) will be tailored to the needs and requirements of the users and developers.

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

Phase I: Set-up of the ICON model

The first steps to be taken in setting up the test suite consist of activities concerning the installation of the ICON model, mainly **set-up of the NWP Meteorological Test Suite for the ICON model**

- availability of all the necessary external parameters files need for the integration of the ICON model (topography, lakes, land use, land-sea mask, etc.)
- availability of initial and lateral boundary conditions required by the simulations
- compilation of new versions of the **ICON TOOLS** interpolation software
- compilation of each **ICON** model version to be evaluated
- adaptation of various namelists employed by the ICON model
- availability of namelists necessary for the **ICON TOOLS** interpolation software

Phase II: Configuration and Execution of ICON-LAM Runs

Configuration of the ICON-LAM (Limited Area Mode) NWP Meteorological Test Suite will follow that employed in previous years for the COSMO Test Suite. If necessary, modification to the Test Suite set-up will be introduced during the project, with the aim to keep updated the configuration in terms of external, initial and boundary data and to follow the needs of COSMO members.

For the evaluation of new ICON-LAM model versions as soon as they are available, testing will be performed before official release.

In the current configuration of the ICON-LAM Test Suite, the ICON-LAM model runs at 2.5km horizontal resolution (scenario R2B10) and with 65 vertical levels. As in the case of the previous COSMO NWP Test Suite, simulations are carried out for two one-month periods (one in the winter and one in the summer). These periods can be updated during the project, depending on synoptic situations of interest. All simulations are performed in hindcast mode (forecast + 31days, with restart every 5 days).

The ICON-LAM model configurations are run in the current configuration on the domain presented in Figure 1 (W=-9.8, S=28.9, E=36.4, N=59.1), with the possibility to adapt the integration area to the needs of the model developers and verification experts during the project activities.

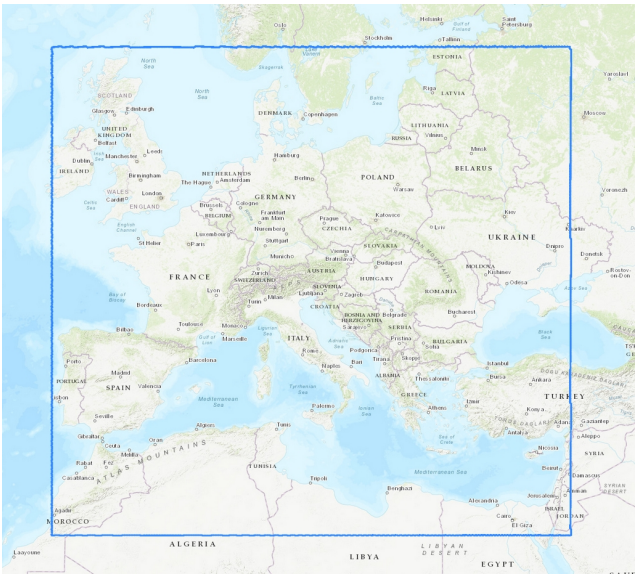

Figure 1. Integration domain for the ICON-LAM model at 2.5km horizontal resolution.

Initial conditions for the simulations for the atmospheric parameters and the sea surface temperature (SST) are at present obtained from the IFS model (using a 1-way direct nest). Three-hourly boundary conditions are provided by IFS, mixing analysis and forecasts. The soil state is initialized from the ICON-Global model, then the soil is left free to evolve following the model physics. Finally, the SST and sea ice fields are updated every 24 hours from the IFS analysis.

Model output in unstructured grib2 format is stored on the permanent storage of the ECMWF (ECFS). The model output includes the following variables:

type of level	N.er of fields	variables
model layer	585 (9*65)	U,V,T,P,QV,QC,QI,QR,QS
model level	132 (2*66)	W, TKE
surface	38	...
soil	35	T_SO, SMI, W_SO, W_SO_ICE, RUNOFF_S, RUNOFF_G
height above ground	8	T_2M, TD_2M, RELHUM_2M, U_10M, V_10M, VMAX_10M, TMAX_2M, TMIN_2M
isobaricLayer	3	CLCL, CLCM, CLCH
top	2	ASOB_T, ATHB_T
meanSea	1	PMSL

As previously mentioned, if necessary, modification to the Test Suite configuration can be introduced during the project, in order to maintain an updated configuration with regards to external, initial and boundary data, integration domains and simulation periods and any other settings depending on the needs of COSMO members.

A list of improvements has already been defined during the last General Meeting of Cosmo consortium. This includes:
- improving the initial condition of all experiments: the horizontal resolution will be increased, and a new analysis of soil water content will be introduced;
- using an improved topographic dataset;
- updating the reference model configuration, to take advantage of recent model developments and of the experience running the model in the last years;
- using a more recent reference year for simulations.

Moreover, the ecflow suite used to run the experiments will be completely revised and optimised.

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 FFV2 (previously Rfdbk) were previously implemented and running at ECMWF on the ecgate and cca platforms. These tools are currently implemented and under testing on the ATOS system. Overall, the MEC+FFV2 verification system ensures a fast and simple calculation of standard verification scores and offers the advantage of interactive and online production and visualization of results.

The 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 for several observation systems (e.g. SYNOP and radio sondes). They are produced by MEC and ingested in FFV2, that uses them to compute the verification scores. The production of Feedback files and verification

procedures are based on observations datasets available from the MARS database and converted from bufr to NetCDF format locally.

The production of feedback-files using MEC is performed on the **HPC machine** (which is also used for the model runs) and employs part of the available billing units. The FFV2 package and model output verification procedures are performed on the **ECS** interface.

The MEC+FFV2 verification system is used operationally at DWD and in all COSMO member countries for the current verification of both COSMO and ICON model chains. Currently, the use of this verification system for the evaluation of EPS model outputs is under implementation in all the COSMO member countries. Example verification results obtained with this system are available on the COSMO Consotrium official web-page.

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 basic quality control.

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, QV (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: feedback files, NetCDF feedback files including all forecasts valid at the time of observation.

The objective verification using the FFV2 package will be performed through grid-to-point comparisons that provide a correspondence between gridded surface and upper-air model data to point observations. Statistical scores will be computed for each period of interest, taking into account all observations available in the integration domain. However, results can be further on obtained for different station stratifications or subdomains, depending on developer and user requirements.

FFV2 characteristics and requirements:

- R interface for COSMO feedback files
- main purpose of is to load feedback file content with R
- additional functionalities useful for verification implemented as well
- namelist based verification scripts using FFV2 do the verification

Installation

- Sources: R language
- Dependencies: NetCDF library and R with additional R packages: sp, rgeos, parallel, data.table, SpecsVerification, matrixStats, RNetCDF, stringr, survival, grid, verification, reshape2, pcaPP
- 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

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

Phase IV: Additional steps and further actions

As previously mentioned, the design of the test suite offers a flexible and controlled environment for the evaluation of various model implementations and will allow to adapt system settings such as model set-up, experiment configuration, execution of runs and verification tasks depending on the requirements from the users and developers. Thus, 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:

- to run new versions of the ICON-LAM model,
- to update the ICON Test Suite set-up and create a new test benchmark,
- for the model verification activities.

The python, netcdf, eccodes and R utilities available on the ATOS platform are also necessary for this project.

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

Since not all Consortium members are ECMWF participating countries, special access rights should be provided to them for the duration of the project, with rights restricted to the activities connected to the project tasks described here.

Technical characteristics of the codes to be used

- **"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.
- **"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.
- **"MEC", The Model Equivalent Calculator,** can produce Feedback files for any model, which can then be used as input to produce verification statistics using FFV2. Some mandatory parameters from the model of interest must be available on all model levels: PS, T, U, V, P, QV, while others are optional, depending on the available observations and user needs (T2M, TD2M, PS, N, FF, DD, Gust, RR, etc). The software applies the observation operators from the data assimilation scheme to model forecasts and stores the results in verification files using the NetCDF Feedback file format. Observational data in NetCDF format (converted from BUFR) and model output in unstructured grib2 format are used for the

experiments. Verification files are generated separately for each observation type (SYNOP, TEMP, etc).

- **"FFV2",** 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 FFV2 based verification scripts is their flexibility, which means they can be modified and adjusted according to the needs of each user and (UNIX) system. The package contains a set of functions developed to exploit the information contained in feedback files, based on the functionality of the R data.table format. This ensures the possibility to handle huge data tables efficiently, using a concise syntax that allows to apply functions on sub-categories.

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 to present results from the testing of the new ICON-LAM configurations, taking into account the activities described above. A detailed description of all steps will be included in Technical Reports, from the compilation of a new model test version to the final production of the graphics for the statistical scores extracted, including detailed guidelines for the proper use and execution of NWP tests using ICON-LAM, before the official release of new model versions.