REQUEST FOR AN EMI R&D PROJECT 2027–2029

Country/Organisation: ……

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Project Title: TESTBED FOR THE EVALUATION OF ICON MODEL VERSIONS

To make changes to an existing project please submit an amended version of the original form

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.)	2027	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☒

Computer resources required for project year:		**2027**	**2028**	**2029**
High Performance Computing Facility	[SBU]	5.000.000	5.000.000	5.000.000
Graphics Processing Unit Cluster-A	[GBU]			
Graphics Processing Unit Cluster-B	[GBU]			
Accumulated data storage (total archive volume)[2]	[GB]	30000	30000	30000

[1] The Principal Investigator will act as contact person for this EMI R&D 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.
[3] The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

EWC resources required for project year:		**2027**	**2028**	**2029**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

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Extended abstract

All EMI R&D 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 EMI R&D 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 EMI R&D 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 main objective of the **"TESTBED FOR THE EVALUATION OF ICON MODEL VERSIONS"** Special Project is to employ the software environment built on the ECMWF platform during previous SPITRASP projects (2013-2015, 2016-2017, 2018-2020, 2021-2023, 2024-2026) for the purpose of rigorous testing of new ICON-LAM (ICOsahedral Nonhydrostatic general circulation model - Limited Area Mode) model versions before their official release. A similar testing platform was used in the past for the evaluation of COSMO model versions prior to official releases.

Since the development of the COSMO (Consortium for Small-scale Modeling) Test Suite software environment in 2013, evaluations of new COSMO model versions performed with this platform were considered before operational implementation and official release of any model version. Following the implementation of a corresponding Test Suite for the ICON-LAM model, reduced testing and comparisons between the two 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. During the past years, 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 - Germany (DWD), Greece (HNMS), Italy (USAM), Switzerland (MeteoSwiss), Poland (IMGW), Romania (NMA), Israel (IMS) and Russia (RHM - Roshydromet is suspended temporarily from COSMO activities). Accordingly, project activities have been completely migrated towards testing of the ICON model in LAM mode.

Starting with 2013, the controlled testing of the COSMO and later on ICON-LAM versions using the NWP Test Suite framework as a benchmark has been employed to assess not only the general model performance over common areas, but also the impact of new developments introduced for the representation of various numerical or physical processes.

Activities performed during the new Special Project will continue the benchmark testing and evaluation of new ICON-LAM model versions. This includes the configuration of the ICON-LAM 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.

Thirteen COSMO and ICON-LAM versions have been installed, tested and evaluated up to present in the framework of the SPITRASP special projects. More model versions of the ICON-LAM 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 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. The platform was also extended to allow the evaluations of hindcast mode model runs and single precision versions of the model, to reduce computational costs. During the **COSMO and ICON Numerical Weather Prediction Test Suite** Special Project (2021-2023), the activities started in the previous special projects were continued and extended to ensure the usage of a homogeneous verification platform for both the COSMO and ICON models. Part of the activities of this Special Project were also dedicated to the migration of the framework from the Cray HPC system in Reading to the ATOS system in Bologna. Finally, the **ICON Numerical Weather Prediction Meteorological Test Suite** Special Project (2024-2026) was carried out on ATOS and provided standards against which the impacts of new developments in the ICON model were evaluated, continuing the activities of testing new versions of the ICON model in LAM mode against existing operational ones, prior to their official recommendation.

The main purpose of the new **EMI R&D project** is to continue providing a framework for rigorous testing of the ICON model and ensure a fair comparison of corresponding model versions (operational against new), while assessing the impact of new features introduced in the code.

Future versions of ICON-LAM model will be integrated and evaluated for common domains prior to official recommendation, by comparison with meteorological observations and operational implementations. The target is to use model versions in the test suite, which are officially released as open source code (https://www.icon-model.org/).

The integration domain will be selected so that most of the COSMO countries are covered, to provide an objective and standardised evaluation for the domains of each COSMO member. For this purpose, the Project will employ local storage of the data on the ECFS system and availability of verification results on the COSMO web site. Verification will also be performed for different sub-domains and station stratifications, depending on specific test requirements and evaluation results.

As in previous SPITRASP projects, set-up and configuration for the tested versions of the model will be built to reduce effects from the initial and lateral boundary conditions. Moreover, model configurations will not employ the data assimilation system. This will ensure the evaluation of the performance from each new model version with an emphasis on newly introduced code developments.

As ICON-LAM is currently the official operational model for the members of the COSMO consortium and various licensees, 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 adapted to the needs and requirements of the users and developers.

New versions of the model will be considered “valid” and will be recommended for official use and operational implementation in COSMO and for licensees 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 a neutral one.

Phase I: Set-up of ICON-LAM

Activities for the **set-up of the NWP Meteorological Test Suite for the ICON-LAM model** include:

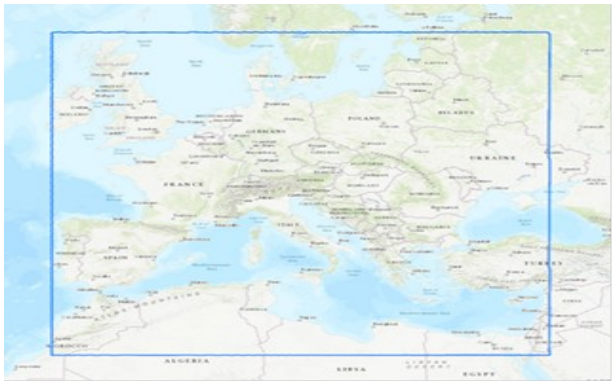
- collection of all the necessary external parameter files needed for the integration of the ICON model (topography, lakes, land use, land-sea mask, etc.)
- extraction and pre-processing of initial and lateral boundary conditions required by the simulations
- compilation of new versions of the **ICON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

Phase II: Configuration and Execution of ICON-LAM Runs

Configuration of the current Meteorological Test Suite will follow the framework employed in previous years, with modification to the set-up introduced during the project, where necessary. The aim of this activity is to ensure an updated configuration in terms of external input, initial and boundary data and follow the needs of COSMO members.

In the current configuration of the ICON-LAM Test Suite, the model runs at 2.5km horizontal resolution (scenario R2B10), employing 65 vertical levels. Simulations are carried out for two one-month periods (one in the winter and one in the summer). The periods may be updated during the project, depending on synoptic situations of interest and availability of required data.

To reduce computational costs and data storage requirements, all simulations will be performed in hindcast mode, as a continuous forecast for 31days, with restart every 5 days. Initial conditions for the simulations of the atmospheric parameters and the sea surface temperature are provided by the IFS model (with a 1-way direct nest). Hourly boundary conditions are also provided by IFS (mixed analysis and forecast), while soil state is initialized from the ICON-EU model and then freely evolves following the model physics. Finally, the SST and sea ice fields are updated every 24 hours from the IFS analysis. The “Top Boundary Nudging” option is activated for newer configurations, to ensure that synoptic scale circulation over Europe will follow more closely the ECMWF analysis. Climatological concentrations of trace gases will also take into account changes in atmosphere composition in the last decades, with small effects on the description of radiative exchanges. At present, ICON-LAM is run on the domain presented in the figure below, with the possibility to adapt the integration area to the needs of the model developers and verification experts during the project activities.



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

Modification to the Test Suite configuration can be introduced during the project, 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. Moreover, the ecflow suite used to run the experiments will be periodically revised and optimised.

Model output on the icosahedral grid in grib2 format is stored on the permanent storage of the ECMWF (ECFS) and 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

Phase III: Model Output Verification

The MEC+FFV2 verification system is used operationally by DWD and the COSMO consortium for the current verification of both COSMO and ICON model chains. Currently, the use of this verification system for the evaluation of deterministic model runs is operational in all active COSMO countries, while implementations for EPS model outputs have been tested and are expected to become operational in the future. Example verification results obtained with this system are available on the COSMO Consortium official web page.

The Model Equivalent Calculator (MEC) software to produce Feedback Files, and verification scripts based on the R package FFV2 (previously Rfdbk) were previously implemented and running at ECMWF 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 produced by MEC and ingested in FFV2, that uses them to compute the verification scores. The feedback files hold information on observations and their usage in the data assimilation system and are available for several observation systems (e.g. SYNOP and radio sondes). The advantages of using the MEC software as part of the verification system 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. The production of Feedback files and verification procedures are based on observations datasets extracted from the MARS database (local conversion from bufr to NetCDF).

Production of feedback-files using MEC is performed on the **HPC machine** (as are the model runs), using part of the available billing units, while the FFV2 package and model output verification procedures are performed on the **ECS i**nterface. This procedure was configured taking into account the computational costs required by the MEC system, whereas the FFV2 verification package needs a very limited amount of resources.

MEC characteristics:

- produces feedback files
- namelist based
- 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)
- input - model in Grib2 format – COSMO or ICON-LAM
- input - observations (CDFIN: BUFR converted by bufrx2netcdf to NetCDF)
- output – feedback files containing observation and model information.

FFV2 characteristics:

- R interface for Feedback Files
- namelist based verification scripts
- 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.

Similar to the implementation of new model versions and modifications to the set-up and configuration depending on user and developer requirements, the MEC+FFV2 components of the system will also be updated with new versions of the software (when available), to ensure an objective evaluation of the model performances.
The standardized verification 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, considering 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.

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.
The first of these extensions will be to use radar composites to perform high resolution areal verification of the precipitation field, at least over parts of the domain. At a later stage, it may be possible to introduce additional verifications focused on specific, high impact meteorological situations, such as extreme precipitation, heat/cold waves, etc.

Use of ECMWF computer resources, software and data infrastructure

- **Computer resources** will be used to run new versions of the ICON model in LAM mode, update the ICON Test Suite set-up and create a new test benchmark, and for model verification activities.
  The python, netcdf, eccodes and R utilities available on the ATOS platform are also necessary for this project.
- **Data storage resources** will be used to store the model output obtained from the ICON numerical experiments in the ECFS system.
  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/ICON-LAM"**, the code performing the actual numerical weather prediction with the nonhydrostatic 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.
- **"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 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 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 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 officially recommended and accepted operational implementation.

Verification results obtained with this system will be available on the COSMO Consortium official web page, along with the corresponding Technical reports. 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, considering the activities described above. A detailed description of all steps will be included in the 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.