SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2023
Project Title:	COSMO and ICON Numerical Weather Prediction Test Suite
Computer Project Account:	SPITRASP
Principal Investigator(s):	Amalia Iriza-Burca (NMA,Romania) [1] Ines Cerenzia (Arpae-SIMC, Italy) [2] Enrico Minguzzi (Arpae-SIMC, Italy)[2]
Affiliation:	National Meteorological Administration (NMA) [1] Regional Agency for Prevention, Environment and Energy of Emilia-Romagna – Hydro-Meteo-Climate Service (Arpae-SIMC) [2]
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Umberto Modigliani and his staff, Andrea Montani
Start date of the project:	2021
Expected end date:	2023

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	5 000 000	460714.14 (~10%)	5 000 000	3.247.445 (~65%)
Data storage capacity	(Gbytes)	4 000	11 000	6 000	27 000

Summary of project objectives (10 lines max)

The COSMO and ICON Numerical Weather Prediction Test Suite Special Project continues the activities started in the previous three special projects will ensure the usage of a homogeneous verification platform for both the COSMO Sand 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. 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. The set-up and configuration of the models will focus on minimising initial and lateral boundary conditions effect, 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.

Summary of problems encountered (10 lines max)

No problems encountered.

Summary of plans for the continuation of the project (10 lines max)

The detailed guidelines for the proper use and execution of each NWP test using the Cray platform prepared during previous special projects related to this activity will be revised considering the ICON model and corresponding model configurations, as well as implementation on the new Atos machine. A detailed description of all steps will be included, from the compilation of a new ICON model test version to the final production of the graphics for the statistical scores extracted. Activities (including use of resources) will also include evaluating new official versions of the ICON model prior to their release as well as maintenance of the Test Suite. The current SP is planned to be continued through a new one: "ICON NUMERICAL WEATHER PREDICTION METEOROLOGICAL TEST SUITE" (2024-2026), currently under submission.

List of publications/reports from the project with complete references

I. Cerenzia, E. Minguzzi – *"NWP ICON Test Suite"*, WG6 – NWP Test Suite Meeting, videoconference, 20 January 2023
M. Milelli and colleagues - "*WG6 News about our activities*", The 24th COSMO General Meeting, Athens, Greece, 12 - 16 September 2022
F. Gofa - "*Overview of activities*", The 24th COSMO General Meeting, Athens, Greece, 12 - 16 September 2022
I. Cerenzia, E. Minguzzi – *"NWP ICON Test Suite"*, The 24th COSMO General Meeting, Athens, Greece, 12 - 16 September 2022

Summary of results

In the context for the switch off of the Cray HPC in Reading, the NWP meteorological test suite was migrated to the new Atos system (aa) in Bologna. As versions v5.08 and v6.0 of the COSMO model (presented in previous reports) are the last for this model, the COSMO test suite will no longer be needed. As a result, only the ICON test suite was ported and adapted to the new ECMWF systems in Bologna.

As a consequence, project activities were concentrated on implementing and testing the ICON test suite previously running on the Cray HPCs (cca and ccb) to the new system. These activities include:

- implementation of the ICON Test Suite to the Atos system (model configuration and integration, processing of model output for production of feedback files)
- implementation of the MEC system for production of feedback files

- implementation of the FFV2 (previously Rfdbk) package dedicated to the calculation of statistical scores.

These migration activities started in 2022 and tests for the new processing chain implemented on Atos are on-going, in order to be able to evaluate any new official version of the ICON model by the end of this year. Activities (including use of resources) will also include evaluating new official versions of the ICON model, most likely during the second part of the year.

A definitive time line for the release of a new ICON model version is not yet available, but it is anticipated that a new request will come within 2023.

Phase I: Set-up of the ICON model

The first steps in porting and setting up the test suite on the Atos HPC machine consisted of activities concerning the installation of the ICON model, mainly **set-up of the NWP Meteorological Test Suite for the ICON model** on the new platform, including:

- 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 the **ICON TOOLS** interpolation software
- compilation of the **ICON** model version to be used for testing purposes (in this case, v2.6.5 and v2.6.5.1, previously implemented on the Cray HPC)
- 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

The **previous test suite configuration**, run on the **Cray HPC (Reading)** consisted of continuous runs (hindcast with 5-daily restarts) for two one-month periods: July + December 2017. The ICON-LAM model was run at two horizontal resolutions:

- Coarse (6.6 km / configuration R3B8; dtime = 60s): using initial conditions for the atmosphere from IFS, soil from ICON-GLOBAL and 3-hourly boundary conditions from IFS (analysis and forecast); the integration domain covered the Mediterranean sea and most Europe: W = -10.9, S = 28.3, E = 37.5, N = 59.7 (with approx. 310k cells);
- Fine (2.5 km / configuration R2B10; dtime = 24s): set up as 1-way nest in the coarse resolution run, using SST and Sea Ice daily updated from IFS analysis; the integration domain covered the Mediterranean sea and most Europe: W = -9.8, S = 28.9, E = 36.4, N = 59.1 (with approx. 2 000 000 cells)

For this configuration, one test was performed on the Cray HPC, using ICON version 2.6.1 compared to COSMO version v5.08. The model at both horizontal resolutions was run in two configurations: once with 65 vertical levels – for control, and once with 50 vertical levels (6.6km resolution) and 40 vertical levels (2.5km horizontal resolution) for comparison against the COSMO test suite.

For the **new test suite configuration**, implemented on the **Atos HPC (Bologna)**, the coarse run (6.6 km) and the runs with a reduced number of vertical levels were no longer performed. The current runs were performed on the finer grid (2.5 km / configuration R2B10; dtime = 24s). 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.

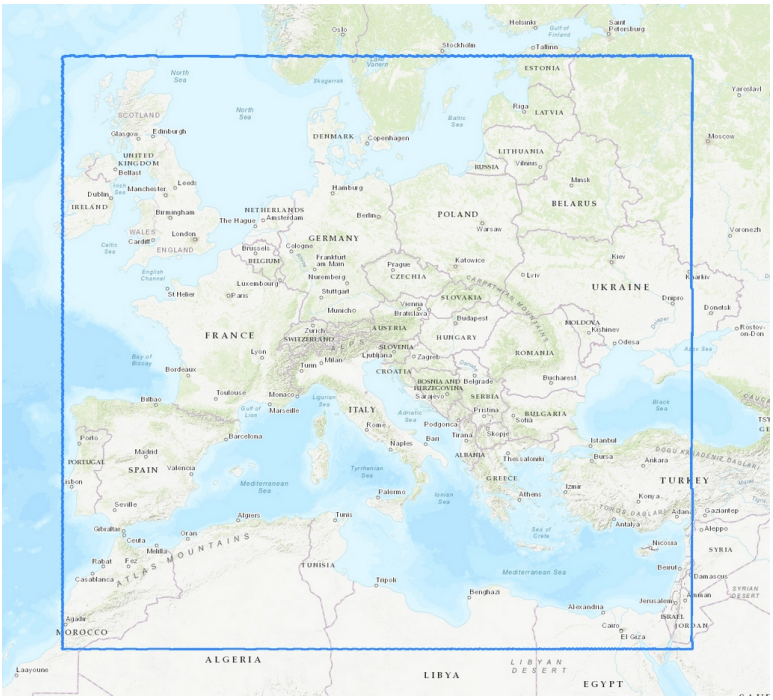

Figure 1. Integration domain for the ICON-LAM model at 2.5km horizontal resolution.

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

Type of level	Number of fields	variables
Mean sea level	1	PMSL
Surface	38	……..
Soil	35	T_SO, SMI, W_SO, W_SO_ICE, RUNOFF_S, RUNOFF_G
Height above ground	8	T2M, TD_2M, RELHUM_2M, U_10M, V_10M. VMAX_10M, TMAX_2M, TMIN_2M
Top	2	ASOB_T, ATHB_T
IsobaricLayer	3	CLCL, CLCM, CLCH
Model layer	585 (9*65)	U,V,T,P,QV,QC,QI,QR,QS
Model level	132 (2*66)	W, TKE

Apart from this, a file containing information regarding constant model parameters is also produced. This file include the following parameters:

Type of level	Number of fields	variables
Surface	9	HSURF, lsm, DEPTH_LK, fldfrc, LAI, vegetation, ROOTDP, SOILTYP, sdsgso
GeneralVertical	66	HHL

For the **benchmark test on Atos**, the following **compiler options** were employed in the implementation of the ICON-LAM model:

```
MODULES='prgenv/intel intel/2021.4.0 intel-mpi/2021.4.0 hdf5/1.10.6 netcdf4/4.7.4 intel-mkl/19.0.5 Ecmwf-toolbox/2021.12.0.0'
BLAS_LAPACK_LDFLAGS='-lmkl_gf_lp64 -lmkl_sequential -lmkl_core'
CC='mpiicc' FC='mpiifort'
CFLAGS='-gdwarf-4 -O3 -qno-opt-dynamic-align -ftz -march=native -fp-model=precise'
ICON_FCFLAGS='-O2 -assume realloc_lhs -ftz -fp-model=precise'
EXTRA_CONFIG='--enable-grib2 --enable-mixed-precision --enable-openmp --enable-dace --enable-ecrad --disable-jsbach --disable-ocean –enable-emvorado'
ICON_ECRAD_FCFLAGS="-D__ECRAD_LITTLE_ENDIAN"
```

The model simulations were submitted/run using the following **resource configuration**:

```
#SBATCH --qos=tp
#SBATCH --ntasks=576
#SBATCH --cpus-per-task=1
#SBATCH --hint=nomultithread
#SBATCH --contiguous
#SBATCH --mem-bind=local
#SBATCH --export=STHOST=ws2
```

The following experiments were either performed or are expected to be run on Atos :

ICON-LAM version	**Simulation period**	**Set-up on Atos**	**Status**
2.6.1	July 2017, December 2017	direct nesting in IFS (configuration R2B10)	finished
2.6.5.1	July 2017, December 2017	direct nesting in IFS (configuration R2B10)	finished
2.6.5.1	July 2021, December 2021	direct nesting in IFS (configuration R2B10); new simulation period; new topography (Merit); updated namelists (radiation scheme ECRAD); new soil initial conditions (ICON-EU); slightly smaller domain; revision of ecflow suite	expected
2.6.6	July 2021, December 2021	Same as previous.	expected

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 procedure includes the conversion of observations from bufr to netcdf format (using *bufr2netcdf*), pre-processing of model output in grib format for ingestion in MEC,

processing model output and corresponding observations to obtain feedback files (MEC), execution of verification procedures (FFV2) and transfer and visualization of results on the COSMO shiny server.

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. 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 **Atos 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 conversion of observations from bufr to netcdf format (using *bufr2netcdf*) can also be performed on the **ECS** interface. The current operational bufr2netcdf version used on the Atos machine is **2.13 (precompiled using gcc).**

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.

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

The current operational **MEC version** used on the Atos machine is V2_14, compiled using the gcc/11.2.0 environment module.

In order to run the MEC processing chain, the following steps were implemented on the new Atos machine:

- pre-processing of model output files stored on ECFS: model output files stored as grib2 files containing 24 time steps each are split into either hourly or three hourly files (depending on user needs); for each time step, two types of such files are produced:
  - files containing parameters on model layer, model level, isobaric level and parameters on fixed levels (height above ground), such as temperature, wind components, mean sea level pressure, cloud cover and so on.
  - files containing accumulated parameters: precipitation, 10 meter wind gust, maximum and minimum 2 meter temperature.
- preparation (creation and linking) of input files required by MEC: constant files produced by the model, model grid file description, forecast files, observations
- set -up of MEC namelist file and run scripts
- production of feedback-files using MEC

For the **benchmark test on Atos**, the following **environment** is employed to run MEC for ICON-LAM:

```
MODULES='prgenv/gnu R/4.0.4 ecaccess/4.0.2 gcc/12.2.0 hdf5/1.12.2 netcdf4/4.9.1 ecmwf-toolbox/2023.04.1.0 openblas/0.3.21 hpcx-openmpi/2.9.0'
```

The MEC tests were submitted/run using the following **resource configuration**:

```
#SBATCH --qos=np
#SBATCH --nodes=8
#SBATCH --ntasks-per-node=64
#SBATCH --cpus-per-task=4
#SBATCH --threads-per-core=2
#SBATCH --hint=multithread
#SBATCH --contiguous
#SBATCH --mem-bind=local
#SBATCH --mem=16384
```

The costs for producing a month of feedback files for one model configurations (including pre-processing of model output files) is around 200 000BUs.

The objective verification using the FFV2 package is 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 ICON 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 verification was performed with grid-to-point comparisons in order to compare gridded surface and upper-air model data to point observations. The selected NWP suite stations are situated in an area covering -25/24/65/65 (W/S/E/N) and are around 3200. Due to the specifications of the verification system for hindcast runs (single run), +24 hours lead time is shifted to 0.

The verification modules for testing the COSMO and ICON models include *surface continuous parameters, precipitation verification (6h and 12h)* and *upper air verification (TEMP based)*, as follows:

- 2m temperature (T2M), 2m dew point (TD2m), 10 meter wind speed (FF), total cloud cover (N), surface pressure (PS): mean error (ME), root mean square error (RMSE), mean absolute

error (MAE), standard deviation (SD), R^2, TCC (tendency correlation), LEN (number of observations used), OMEAN and FMEAN (observed and forecast mean), etc.;

- precipitation for selected thresholds (greater than 0.2, 0.4, 0.6, 0.8, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 25, 30): probability of detection (POD), false alarm rate (FAR), equitable threat score (ETS), frequency bias (FBI), Performance diagrams, etc.
- upper air temperature (T), relative humidity (RH) and wind speed (FF) for selected pressure levels (250., 500., 700., 850., 925., 1000.): BIAS, MAE, RMSE, SD, etc.

Verification activities are currently on-going for the following experiments:

ICON-LAM version	Simulation period	MEC processing	Score production
2.6.1	July 2017	on-going	expected
2.6.1	December 2017	on-going	
2.6.5.1	July 2017	expected	
2.6.5.1	December 2017	expected	

Phase IV: Additional steps

Activities (including use of resources) to test a new official version of the ICON-LAM model prior to its release which is anticipated in the second part of the year.
Maintenance of the Test Suite.
Revision of 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 according to present results from the testing of the new ICON-LAM configurations, taking into account the activities described above.

Detailed descriptions 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.

The current SP “COSMO and ICON Numerical Weather Prediction Test Suite” will end in 2023 and is planned to be continued through a new SP “ICON NUMERICAL WEATHER PREDICTION METEOROLOGICAL TEST SUITE” (2024-2026) which is currently under submission. Activities performed during the new Special Project will be dedicated 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