COSMO Priority Project PROPHECY (PRObabilistic Prediction at High-resolution with EnhanCed perturbation strategY): Project Plan

Version 9, 03.02.2022

Project leader:

Chiara Marsigli (DWD)

Project duration:

4 years: Sep 2020 – Aug 2024

Summary

A new Priority Project is proposed by WG7, the PROPHECY (PRObabilistic Prediction at High-resolution with EnhanCed perturbation strategY) PP. The main goal of the project is to coordinate the developments required to lead to a future generation of convection-permitting ensemble systems based on the ICON(-LAM) model. The main scientific focus is the development and testing of model perturbation methods. Beside this activity, also the methods for generating perturbed Initial and Boundary Conditions are addressed. The PP spans a period of 4 years, involving 7 COSMO members and requiring in total 10.76 FTEs.

Motivation

Status

Ensemble forecasting is a fundamental part of the forecasting system in the COSMO countries. In 2002 the Consortium started the operations of COSMO-LEPS, providing mesoscale ensemble forecasts over a COSMO domain. Beside a widespread use of the ECMWF IFS-ENS, now several COSMO partners run their own ensembles. At DWD, a global ensemble based on ICON run with 40 km mesh size is operational, accompanied by the European refinement ICON-EU-EPS at 20 km. At DWD, MCH, IMGW and COMET, km scale ensembles are operational over the national domain. COMET runs also a 7 km ensemble over a Mediterranean domain. Arpae has a pre-operational 2.2 km ensemble over Italy, and RHM is developing their ensemble perturbation strategy on the 2.2 km ensemble used for the Sochi Olympics. IMS is implementing an ensemble based on the COSMO model, driven by ECMWF IFS-ENS, at 2.5 km resolution.

Over the past years, the ensemble activities have strengthened and now the effort of the WG7 is mainly in the improvement of the model perturbation techniques to be used at the convection-permitting (CP) scale. Some of these techniques, which have been developed originally for the COSMO model or which were implemented in the model, are now being implemented, tested and further developed in the ICON model, run in the LAM mode and at km-scale resolution.

The purpose of the previous Priority Project APSU (which is going to end at the end of August 2020) was to ameliorate the CP ensembles, mainly by improving the perturbation strategy and by improving the post-processing. Considering the scope of the main task, that deals with the development and testing of model perturbation methods, the Project was unfortunately too short. In fact, this task addressed one of the fundamental problems of our ensemble systems, which is far from being solved for the CP scale. It was known that the strategies and methods object of the proposed research would have required longer time and deeper investigations, and could not be completed in the 2.5 year time frame provided. This "accepted" planning mismatch was due to the difficulty to make longer term plans in 2017-2018, because of the uncertainties about the transition from the COSMO to the ICON model in the different COSMO members.

Due to this organizational issue, the activities of the model perturbation task of APSU are not going to be completed by August 2020, when the PP APSU ends.

Some of the activities planned within the framework of APSU are still believed to be the most promising, and at the same time feasible. Therefore, their continuation is an important goal for the COSMO partners. On top, the investigation of the performances of these perturbation methods needs to be transferred to ICON-LAM, since now the transition to the new model is taking place and the COSMO partners are better able to plan their ensemble developments.

Beside these activities, new perturbation methods have emerged in the last years, which are worth testing in the COSMO ensembles. At the same time, some COSMO members are now developing their own CP ensembles, requiring the adaptation of the existing methods to their domain and ensemble characteristics.

This is the main reason why a new Priority Project is now proposed that is, focus on the developments needed to lead to a future generation of convection-permitting ensemble systems based on the ICON(-LAM) model.

In order to better define the context of the present project, the status of the migration to ICON in the different countries is here briefly summarised:

- MCH: now the project ModInterim (move to the ensembles COSMO-1E and COSMO-2E) is taking place. Then move to ICON ensemble in 2022-2023, once the model is ready to run on GPU.
- DWD: ICON-D2-EPS operational in Q1/2021.
- RHM: Implement an ICON-based ensemble at 2.2 km for the Moscow area.
- Arpae: Migration to ICON is planned at the moment only for the deterministic.
- COMET: move to ICON in ensemble mode only when the GPU capable code becomes available.
- IMGW: Migration to ICON is planned at the moment only for the deterministic runs.
- IMS: deterministic ICON-LAM over eastern Mediterranean driven by ICON global is running daily since mid. 2019. Additional deterministic ICON-LAM over central and south east Europe using IFS BCs is planned to run daily from early summer 2020. Currently ICON-LAM ensemble is planned to 2022.

Needs

The main needs in terms of ensemble forecasting development which have been identified by the members of WG7 are:

- Improve the description of the model uncertainty, in order to apply model perturbations which permit to have a better spread-skill relation in the ensembles, particularly for near surface weather parameters.
- Investigate and further develop the current approaches for initial and boundary condition perturbations, in order to improve relevant forecast aspects like the very short-range forecast (also in view of the focus on seamless forecasting systems), the forecast of severe weather, and the forecast of extremes.
- Perform or complete the transition to ICON-LAM also for the ensembles. This implies that the strategies used for providing model perturbations should be adapted and tested in the new model.

Actions proposed

On the basis of the status of ensemble forecasting in the COSMO countries and of the needs which have been identified, the following actions are proposed:

- **Action 1.1** Improve the existing methods used for model perturbation. For example, the SPPT method adopted at MCH could be improved by implementing the independent SPPT (iSPPT); the parameter perturbation method could be improved by adding new parameters or better refining their range of variability; the combination of the parameters should be tested. PP can be tested on new domains and the perturbations can be adapted to the domain characteristics. Part of this Action is to implement and test in ICON-LAM the methods already used in the COSMO model.
- **Action 1.2** Develop new methods for model perturbations, which takes into account the characteristics of the model error. In the APSU PP, new schemes were developed at DWD (EM-scheme) and at RHM (AMPT scheme), with promising results, but indicating that further research was needed. At present, these schemes need also to be implemented and tested in ICON-LAM (including the implementation of the SPG, on which AMPT is based, in ICON).
- **Action 1.3** Test new existing methods, which are suitable for model perturbations at the CP scale and move towards intrinsically stochastic physics schemes. Test the effect of the perturbations generated with the new stochastic shallow convection scheme under development at DWD. Also the implementation and test of SPP in ICON could be considered, if resources are available.
- **Action 2** Improve the Initial Conditions which are provided to the convection-permitting ensemble. Several ensembles use KENDA analyses as ICs, simply taking the first 20 analyses. A better usage of KENDA analyses as ICs can be explored, for example by selecting the 20 analysis with a clustering algorithm (tested at MCH) or by applying a different LETKF step to generate the KENDA analyses to be used for ensemble initialization. The clustering of KENDA ICs has not been planned in a Task, due to lack of resources. Design and improve perturbations for the initial conditions of the soil variables is also included here.
- **Action 3** Improve the Boundary Conditions which are provided to the convection-permitting ensembles. To this extent, it is interesting to evaluate the impact of using BCs from ICON-EPS, as it is done at DWD, also in other countries. A study about this issue has been performed at MCH as part of APSU. The BCs can be better used by applying a Cluster Analysis to the global

ensemble, leading to a more clever selection of the boundaries (like in COSMO-LEPS), different over different domains. Also the development of the lagged approach (adopted at IMGW) could be beneficial.

Deliverables

The deliverables of the Project are presented for each subtask. Summarising, the deliverables are: new configurations of the ensembles run by the COSMO Members, new perturbation methods, the adaptation of an existing method to a specific ensemble, the assessment of the impact of a specific perturbation in an ensemble.

Description of individual tasks

Task 0 Project Coordination

The PROPHECY PP includes and coordinates several activities aimed at the development of the ensemble systems of the COSMO Members. Seven COSMO Members are involved, with nine different ensembles. Therefore, a coordination Task is also activated, dealing with the organisation of virtual and physical meeting, writing of reports, frequent e-mail exchange. The final report will provide also a review of the status of the COSMO ensembles and of the perturbation methods applied.

A coordination with WG5 about the verification activities which are carried out in the project will also be maintained. For example, the usage of spatial verification methods will be encouraged where appropriate and the applicability of novel methodologies will be discussed in joint meetings organised with WG5 (e.g. sessions at the GM and during ICCARUS).

Coordination with WG1 will also be maintained for all the activities related to ICs derived from the KENDA system.

<u>Deliverable:</u> *Meetings, reports, Final Report.*

Participants: Chiara Marsigli (PL): 0.1 FTE/year; all: 0.1 FTE/year; duration: Sep 2020 – Aug 2024.

<u>FTEs for Task 0: 0.2/year (Sep 2020 - Aug 2024)</u>

Task 1 Model perturbation

Here the activities listed in Actions 1.1, 1.2 and 1.3 are performed.

Please note that a model perturbation method used in the COSMO Consortium is the Parameter Perturbation method (Marsigli et al., 2009; Gebhardt et al., 2011), which is abbreviated as PP (not to be mixed with Priority Project). A list of the names of the most common model perturbation methods is provided in Appendix 2.

Subtask 1.1 – Development of the parameter perturbation (IMGW).

The aim of this subtask is to test new perturbations to be added to the operational set-up of the TLE-MVE (Time-Lagged Ensemble - Model Varied Ensemble) ensemble.

First, research will be conducted to consider perturbations of various soil-related parameters, i.e. volume of voids, field capacity, permanent wilting point, air dryness point, hydraulic diffusivity and conductivity parameters, etc. Theoretical analysis of physical processes taking place in the soil suggests that perturbations of the above parameters should have a significant impact on heat and humidity fluxes from the earth's surface, which in turn should influence a forecast of the state of the atmospheric boundary layer. Based on numerical experiments, an attempt should be made to assess which of the above-mentioned parameters – when perturbed – has a significant impact on the forecast of meteorological fields important from the point of view of aviation meteorology, e.g. occurrence of fog, visibility range, wind gusts or CAT.

Then, perturbation of clouds and precipitation will be considered. It includes mainly all commonly used capture options – not just for droplets; auto conversion time, which is fixed in the model; various parametric schemes of cloud microphysical processes; roughness length perturbation; various schemes (algorithms) for the formation of fog.

In summary, soil-, boundary layer- and cloud-related parameters should be examined in two main directions:

- Test the perturbation of soil-related parameters, of parameters in the cloud and precipitation schemes in the PBL scheme.
- Particularly, evaluate the impact of different types of perturbation/perturbed parameters on the forecasts for aviation.

The experiments will be carried out for the domain covering Poland with adjacent areas, in a resolution of 2.8 km, for a period of at least one year, taking into account the division into hot and cold season.

<u>Deliverable:</u> Selection of new parameters to be introduced in the TLE-MVE ensemble.

Involved scientists: A. Mazur, G. Duniec, J. Linkowska (IMGW)

<u>FTEs for subtask 1.1: 0.7 (Sep 2020 - Aug 2024)</u>

Subtask 1.2 - Evaluation of the stochastic shallow convection scheme for the ensemble. (DWD)

At DWD, a stochastic shallow convection scheme (based on the Tiedtke-Bechtold/IFS scheme) is being implemented and tested in ICON (M. Ahlgrimm). Stochastic convection scheme is scale adaptive and produces perturbations to the convective tendencies that are consistent with the model state and the large-scale forcing, which can be used as model perturbations. This work follows the earlier works of Craig and Cohen, 2006; Plant and Craig, 2008; Sakradzija et al., 2015, 2016.

The stochastic shallow convection scheme is now implemented in ICON, and it has been tested in hindcast mode (model resolution 1.5 - 5 km), showing a good impact mainly in the PBL (T and Td at 2m, low cloud cover, radiation). Beside the continuation of the development and the related tests, the usage of this stochastic scheme should also be evaluated in ensemble forecasting.

The purpose of this task is to start the evaluation in ICON-D2-EPS. The work is organised in the following steps:

- Run selected case studies in an experimental framework, comparing different configurations, including runs:
  - with stochastic shallow convection only
  - with parameter perturbation only

  - with stochastic shallow convection + parameter perturbation
  - with perturbed physics + IC and BC perturbation
- Evaluate the contribution of the stochastic shallow convection to the ensemble spread and skill. All the usual scores will be computed. In addition, the new scores developed in the SINFONY project for the verification of the convection will also be applied.
- Discuss the results with the developer, possible feedbacks can require more testing, in case the scheme is further developed. The results will be discussed also with WG3a.
- If a promising configuration is found, run a longer experiment and evaluated the results with the indicated scores.

<u>Deliverable:</u> *Assessment of the impact of the new stochastic shallow convection scheme as model perturbation in ICON-D2-EPS.*

Involved scientists: C. Gebhardt, C. Marsigli (DWD)

<u>FTEs for subtask 1.2: 0.1 FTE/year (Sep 2020 – Aug 2023)</u>

Subtask 1.3 - Development of EM-scheme of a model for the model error. (DWD)

In the EM-scheme, the equations of the model tendencies are extended by a stochastic differential equation which describes the temporal and spatial correlations of model error tendencies forced by a Gaussian error. The parameters of this model for the model error are estimated on the basis of recent data of model errors. This estimation provides equations for the parameters using model tendencies as predictors.
The EM-scheme has been developed, implemented and tested at DWD within the framework of the COSMO model. First experiments with COSMO-D2-EPS showed that the method introduces additional spread but also biases in specific situations (e.g. wind bias in stable boundary layer). In general, the scores are mostly comparable to the operational COSMO-D2-EPS.
The method is currently implemented into the ICON model. The activity contributing to this PP is organised in the following steps:

- Further refinement of the method and tests in convection-permitting mode to improve scores, i.e. reduce bias problems.
- Further development of the method in ICON-D2: estimation of the ICON-D2 prediction error, determination of the parameters of the error model analogous to the procedure with COSMO-D2.
- Execution and evaluation of experiments with ICON-D2-EPS.

Since at RHM a similar method is under development (see Task 1.4), the already on-going exchange of results and subsequent discussion will be maintained. Virtual and physical meetings will be organised for this purpose.

Since further development of the EM scheme requires considerable effort of research character, the success of the method in terms of the performance scores is not guaranteed. If the experiments will show that the approach is not effective, it will be considered to adopt alternative perturbation methods. There is a risk that this task can be worked on with only restricted resources at DWD. Therefore, only a small amount of FTEs is assigned which is possibly subject to future adjustments.

<u>Deliverable:</u> *Assessment of the impact of the EM-scheme in ICON-D2-EPS.*

Involved scientists: C. Gebhardt (DWD)

<u>FTEs for subtask 1.3: 0.1 FTE/year (Sep 2020 – Aug 2023)</u>

Subtask 1.4 - Development of the AMPT scheme for stochastic representation of model error and its implementation in ICON-LAM (RHM).

The scheme named Additive Model-error perturbations scaled by Physical Tendencies (AMPT) has been developed based on an investigation of COSMO model errors. AMPT relies on the stochastic pattern generator (SPG, Tsyrulnikov and Gayfulin, 2017) as a source of spatio-temporal stochasticity. AMPT creates independent 4D model-fields (including cloud fields) perturbations. AMPT, like SPPT, does preserve spatial-mean values of the perturbed fields, but only in the probabilistic sense: the expectation of the spatial-mean values does not change due to AMPT. This guarantees that there is no drift in the spatial mean values due to AMPT.

AMPT was tested using COSMO-Ru2-EPS system over the Sochi region for winter-early spring period. Perturbations were introduced to temperature and wind. Two-month tests demonstrated an improvement in ensemble spread and CRPS for 2-m temperature as compared to SPPT. First results with 4D AMPT perturbations of soil temperature and soil moisture are promising. Benefits of AMPT perturbations of atmospheric humidity and cloud fields remain to be demonstrated.

The aim of this subtask is to transplant AMPT to ICON and re-tune it. This work will be accomplished in several steps:

1. Implementation of SPG into ICON-LAM
2. Implementation of AMPT into ICON-LAM (SPPT will be a special case of AMPT)
3. Tuning of AMPT parameters (both in the atmosphere and in the soil) in experiments with ICON-LAM
4. Testing AMPT in ICON-LAM-EPS for different seasons. Tests will be performed over the Moscow region.
5. Further development of AMPT for ICON-LAM-EPS:
    - Modification of AMPT for water related variables with the aim to ensure mass conservation for W_so and q_x in the mean sense.
    - Tentatively: development of a physical-space based version of SPG with the capability of generating perturbations with variable flow-dependent spatial and temporal length scales.

Originally the SPG was developed in the framework of the KENDA PP. Now the work for ICON-LAM has been moved to the ensemble project because the SPG is presently used only in the framework of model perturbations for the forecast ensemble.

Step 2. of the Task has the consequence that SPPT will be implemented in ICON-LAM. This activity will be coordinated with Task 1.6 and 1.7 (see below).

<u>Deliverable:</u> SPG implemented in ICON-LAM. AMPT implemented in ICON-LAM (with SPPT as a special case). Assessment of the impact of the AMPT scheme in ICON-LAM-EPS over the Moscow region.

Involved scientists: E.Astakhova, D.Gayfulin, M.Tsyrulnikov (RHM)

<u>FTEs for subtask 1.4: 1.25 FTE (Sep 2020 – Aug 2024)</u>

Subtask 1.5 - Introduce and test parameter perturbations at 2.2 km in ICON-based EPS for the Moscow region. (RHM)

A model-related uncertainty will be introduced to an ICON-based EPS using the Parameter Perturbation (PP) method.

- Experiments with PP in ICON-LAM-EPS will be performed for the Moscow region with an aim to select parameters to perturb and assess the resulting spread. No ICs&BCs perturbations will be introduced at the initial stage. Later, PP will be used in the Lagged-Average Forecast (LAF) ensemble (see Task 3.2) and in the ensemble with ICON-EPS ICs&BCs (when and if the data is available).
- The model-related spread and the probabilistic scores will be compared for experiments with PP and AMPT perturbations.

Deliverable: Assessment of the impact of the Parameter Perturbation method in ICON-LAM-EPS over Moscow region, in comparison with the AMPT perturbation method.

Involved scientists: E.Astakhova, D.Alferov, V.Egorova, D.Gayfulin, M.Tsyrulnikov (RHM)

FTE for subtask 1.5: 0.65 (Sep 2020 – Aug 2024)

Subtask 1.6 – Test of SPPT in ICON (COMET).

The SPPT scheme (Buizza et al., 1999), included in the AMPT scheme as special case (see subtask 1.4) will be tested in ICON as model perturbation (using the GPU version if available, otherwise using the CPU version).

An experimental ICON-IT EPS system will be run for a short period, initialized by the KENDA-ICON analyses on the Italian domain (about 2.2 km resolution). As a starting point, the SPPT mode will be tested and results will be compared with “no SPPT” run.

The proposed activity is subordinated to the results of the subtask 1.4, since steps 1. and 2. of the work of subtask 1.4 need to be completed before Task 1.6 can start.

Deliverable: Assessment of the impact of SPPT as model perturbation in ICON-IT EPS.

Involved scientists: M. Alemanno (COMET)

FTEs for subtask 1.6: 0.3 FTE (Jun 2021 - Aug 2022)

Subtask 1.7 – Implementation of SPPT in ICON, extension to iSPPT. (MCH)

The SPPT scheme which is now implemented in COSMO, and operational in COSMO-E (Klasa et al., 2018), will be implemented in ICON-LAM, to ensure to have an SPPT version in ICON-LAM which is at least as mature as the current one in COSMO. This will be done in coordination with subtask 1.4, with which synergies are expected. If the adaptation to ICON reveals that the scheme could be easily implemented as iSPPT (Christensen et al., 2017), this more general variant of the scheme will be preferred (currently only implemented in an old COSMO branch).

The porting of SPPT to GPU will be done afterwards, outside of this Priority Project.

Due to synergies this activity will be coordinated with subtask 1.4.

In the following years of the Project, other model perturbations techniques, which are developed in other tasks within this project, will be also tested by MCH in their ensembles, to be compared with SPPT, provided that resources will be available.

Deliverable: *Assessment of the impact of SPPT as model perturbation in the ICON-1E; extension of the implementation in ICON to iSPPT, if feasible.*

Involved scientists: S. Bellaire, A. Walser (MCH)

FTEs for subtask 1.7: 0.35 (Oct 2020 - Jul 2021)

Subtask 1.8 – Model Perturbation for ICON-2I-EPS (Arpae)

Once COSMO-2I-EPS is operational (with few additional modifications from the pre-operational version), Arpae plans to dedicate the next efforts to prepare the migration of COSMO-2I-EPS to the ICON-LAM model (i.e. ICON-2I-EPS). In this framework it is foreseen to introduce and test the Parameter Perturbation (PP) technique at 2.2km for ICON-2I-EPS.

Starting from the previous study performed by DWD for ICON-D2-EPS, sensitivity tests will be performed for the same parameters used at DWD, as well as for other parameters, with the aim to adapt the PP technique to the Italian domain. The work is organised as follows:

- Several experimental forecasts will be run at this first phase. Therefore, the test period will be quite short: no more than one week during summer and one week during winter.
- Sensitivity to the parameter variation of the near surface and upper air model variables will be analyzed.
- In the second phase, the parameter perturbation technique will be applied to the best suited set of parameter (those to which the model variables of interest are more sensitive) and its performance tested over a period of one summer month and one winter month. The focus for summer will be on the spread-skill relation in convection events.
- Similarly, once the SPPT will be available for the ICON-LAM model, it will be tested in the ICON-2I-EPS configuration by running a parallel suite over a period of one summer month and one winter month.
- Timetable:
    - Implementation and test PP in ICON-2I-EPS (June 2021 – June 2023, 0.3FTE)
    - Test SPPT in ICON-2I-EPS (Jan 2023 – Jan 2024, 0.2FTE)

Deliverable: *Selection of the parameters to be perturbed in ICON-D2-EPS. Assessment of the impact of SPPT in ICON-D2-EPS, compared with PP.*

Involved scientists: C. Marsigli, I. Cerenzia (Arpae)

FTEs for subtask 1.8: 0.5 (June 2021 – Jan 2024)

Subtask 1.9 - COSMO-LEPS: model perturbation in ICON-LAM at 7km over the full Mediterranean domain. (Arpae, HNMS)

In order to perform the migration of COSMO-LEPS to the ICON-LAM model (ICON-LEPS), Arpae plans to test model perturbations in the new suite:

- Introduce and test the parameter perturbation technique in ICON-LAM with 7km horizontal mesh size over the new extended domain (including the full Mediterranean Sea with Israel in the south-east corner).
- Once the SPPT is available for the ICON-LAM model, test it in the new "COSMO-LEPS" configuration (based on ICON-LAM) by running a parallel suite.

This phase will be preceded by a sensitivity test, aiming at identifying the ICON parameters most sensitive at 7km resolution over a Mediterranean domain. This test will be performed by HNMS.

- Timetable:
  - Selection of the ICON parameters for the sensitivity test (Dec 2020 – Feb 2021, 0.05 FTE)
  - Sensitivity test: implementation of a testing suite at ECMWF, using the Greek SBU, aimed at performing several deterministic runs of ICON-LAM over a domain including Greece, Italy and a part of the central-eastern Mediterranean Sea. Execution of the runs, objective verification (Jan 2021 – Sep 2021, 0.2 FTE)
  - Implementation and test PP in COSMO-LEPS upgraded (in case of approval to migrate to the ICON-LAM model over extended domain) (two phases: Oct 2020 – Jun 2021, 0. 05FTE, Jan 2022 – Jan 2024, 0.25 FTE)
  - Test SPPT in COSMO-LEPS upgraded (in case of approval to migrate to the ICON-LAM model over extended domain) (Jan 2023 – Jan 2024, 0.2 FTE)

The testing of the physics perturbation will not delay the implementation of the new suite, which can be done independently and starting with a simplified version (no SPPT, no PP).

<u>*Deliverable:*</u> *Introduction of model perturbations in the new ICON-based COSMO-LEPS.*

Involved scientists: I. Cerenzia (Arpae), E. Avgoustoglou (HNMS)

<u>FTEs for subtask 1.8: 0.5 + 0.25 (Oct 2020 – Jan 2024)</u>

Subtask 1.10 – Testing PP and SPPT over eastern Mediterranean. (IMS)

In order to reflect the model uncertainty, PP and SPPT will be tested for the new ensembles developed by IMS. Although these approaches were tested previously and applied in several COSMO ensemble systems, their application over the eastern Mediterranean in convection permitting resolution was not tested before.

During the first COSMO year of this Project, the work will be performed in COSMO-IL-EPS. This subtask will be performed after subtask 3.4, i.e. after the selection of optimal driving ECMWF IFS-ENS members. The proposed research is the following:

1. PP analysis:
   - During the 80 days (8 10-day long periods) chosen in subtask 3.4 (see below), COSMO-IL-EPS with 20 members will be executed for 78h once

per day at 00 UTC in 4 different configurations of PP. Cost: ~1600 SBU/d X 3.25d X 1per/d X 80d X 20mem X 4conf = 33.3M.
- Verification of 80 COSMO-IL-EPS runs will be performed, aimed at revealing:
  - COSMO-IL-EPS quality with respect to IFS-ENS
  - The answer whether PP is beneficial.

2. SPPT analysis:
   - During the same 80 days (see subtask 3.4), COSMO-IL-EPS with 20 members will be executed for 78h once per day at 00 UTC with the configuration of SPPT used at MCH. Cost: ~1600 SBU/d X 3.25d X 1per/d X 80d X 20mem = 8.3M.
   - Verification of 80 COSMO-IL-EPS runs will be performed, aimed at revealing:
     - COSMO-IL-EPS quality with respect to IFS-ENS
     - The answer whether SPPT is beneficial.
     - Comparison of SPPT and PP influences on spread and skill.

In the following two COSMO years of this PP, a similar research is planned for ICON ensemble over the eastern Mediterranean.

Deliverable: Introduction of model perturbations in COSMO-IL-EPS. Introduction of model perturbation in ICON-IL-EPS.

Involved scientists: A. Shtivelman, P. Khain, Y. Levi (IMS)

FTEs for subtask 1.10: 0.21 FTEs per COSMO year (Sep 2020 – Aug 2023)

Task 2 Initial Condition Perturbation

Here the activities listed in Action 2 are performed.

Subtask 2.1 – Generate alternative KENDA analyses to the initialise ensemble forecasting. (DWD)

ICON-D2-EPS uses as initial conditions the first 20 analyses produced by the KENDA (Schraff et al., 2016) data assimilation cycle. Although the analyses are optimised within the framework of the data assimilation process, they are not necessarily the best set of analyses describing the initial condition uncertainty for the purpose of ensemble forecasting, for example in terms of spread. The aim of this task is to evaluate the possibility of tailoring the analyses produced by KENDA for initialising the ensemble forecasting, without affecting the data assimilation process.

The work in the subtask is organised as follows:

- Perform an evaluation of the Initial Conditions in terms of spread and skill for several meteorological variables, in order to identify the weaknesses of the current ICs. A preliminary study showed that the ICs have too little spread in terms of wind (at 10m and upper air).
- In the computation of the spread/skill relation, care should be taken due to the presence of observation error and of conditional biases in the forecasts. For this reason, different approaches for the computation of the spread and skill will be used and compared:

- Compute the RMSE of the ensemble mean against model analyses instead of observation.
- Include the observation error in the computation of the RMSE of the ensemble mean against observations. For this purpose, estimate of the observation error can be derived from the Desroziers statistics.

This work will be carried out in collaboration with WG1 and WG5 (discussion of the methods, discussion of the results).

- Test, in an experimental framework (setting up a suitable test environment based on BACY) the application of a different LETKF step to generate the KENDA analyses. In particular, a gradual change of the covariance inflation, the relaxation to the prior, the horizontal and vertical localization, and other parameters of the scheme will be tested. In order to carry out this work, discussion with the data assimilation group is needed. It has to be underlined that the alternative KENDA analyses generated in this way will not be used in the next KENDA cycle, but only for ensemble initialisation, therefore data assimilation is not affected.
- Evaluate the impact of using of the newly generated analyses in an experimental ensemble set-up for ICON-D2-EPS. Compute spread/skill relation for near-surface and upper air variables.

<u>Deliverable:</u> Assessment of the impact of tailored Initial Conditions derived from KENDA in the ICON-D2-EPS ensemble.

Involved scientists: C. Marsigli (DWD)

<u>FTEs for subtask 2.1: 0.15 FTE/year (Sep 2020 – Aug 2024)</u>

Subtask 2.2 - Further assessment of the influence of various methods of perturbation of initial field of soil temperature. (IMGW)

Research at the IMGW is conducted on the impact of the perturbation of the initial values of the soil temperature field on the quality of the forecast. The perturbation method should be further tested, to identify the factors that have the most significant and the best impact on the final ensemble forecasts. This work will be conducted on the TLE-MVE ensemble, based on the COSMO model.

Two modifications of the perturbation method will be considered:

1. Dependence of the amplitude of the perturbation on the type of soil, continuing the work started in the APSU PP (the higher the porosity of the soil, the greater the amplitude of the perturbation). The perturbation will be applied to the temperature in the first few soil layers, in order to have a long-lasting effect in the forecast.
2. A random number generator is used for perturbation either in its basic form (supplied with the COSMO model code), or with additional consideration of breakdown into individual processors, as described in PP SPRED and APSU

In addition, it is assumed that the total change in temperature over the entire field is normalized to zero. This choice is based on the consideration that the overall impact of the perturbation should not shift the field to either side. The impact will be assessed using pre-defined indicators and forecasted fields, including near-surface and upper-level values of temperature, windspeed, air pressure etc.. Similar period, domain and resolution as in subtask 1.1 will be used.

<u>Deliverable:</u> Revision of the soil initial condition perturbation method in TLE-MVE.

Involved scientists: W. Interewicz, J. Linkowska, G. Duniec (IMGW)

<u>FTEs for subtask 2.2: 0.3/year (Mar 2022 - Feb 2024)</u>

Task 3 Lateral boundary Conditions

Here the activities listed in Action 3 are performed.

Subtask 3.1 - Compare ICON-1E with IFS-ENS vs. ICON-EPS BCs. (MCH)

First results with COSMO-1E have shown an increase in spread using ICON-EU-EPS BCs instead of IFS-ENS, which is beneficial for the short-range ensemble prediction system COSMO-1E. However, the error of the ensemble mean has found to be worse in general with ICON-EU-EPS BCs.

These investigations are planned to be repeated with ICON-1E (same setup as COSMO-1E but using ICON-LAM) and on longer periods in the framework of the OWARNA-2 project at MeteoSwiss.

<u>Deliverable:</u> Assessment of the impact of ICON-EPS BCs vs. IFS-ENS BCs for ICON-1E.

Involved scientists: A. Walser, NN (MCH)

<u>FTEs for subtask 3.1: 0.15 FTE (Jan 2022 – Jun 2022).</u>

Subtask 3.2 – Lagged approach (RHM)

A lagged approach (Lagged Average Forecast, LAF) has to be considered first for the ICON-LAM-EPS over the Moscow region, with a possible transition to ICON-EPS ICs&BCs at a later stage.

- Numerical experiments will be held with an ensemble formed of members using ICs&BCs resulting from deterministic forecasts with lead-times from 3 to 12 h. The possibility of weighting the members will be considered.
- If experiments are successful, the lagged approach will be further used to increase the ensemble size even after the ICON-EPS ICs&BCs are available.

It is reminded that additional uncertainty to this ensemble forecast system will be introduced by Parameter Perturbations (see Task 1.5).

<u>Deliverable:</u> Lagged approach implemented for providing ICs&BCs to ICON-LAM-EPS over the Moscow region.

Involved scientists: E.Astakhova, D.Alferov, V.Egorova (RHM)

<u>FTEs for subtask 3.2: 0.7 (Sep 2020 – Aug 2024)</u>

Subtask 3.3 – ICON-EU-EPS member selection. (DWD)

The aim of this subtask is to test and develop methods to select a subset of ICON-EU-EPS members (instead of members 1-20) as BC for ICON-D2-EPS, in order to provide better forecasts. Previous work performed at MCH provides useful guidance (Westerhuis, 2016). The work is organised as follows:

- Gather and evaluate literature on research and existing approaches in this context
- Implement and test existing approaches and benchmarks (e.g. clustering, random selection of members).
- Research on refinement of this methods and development of alternative approaches

<u>Deliverable:</u> *Assessment of the impact of member selection for providing BCs to ICON-D2-EPS.*

Involved scientists: C. Gebhardt (DWD)

<u>FTEs for subtask 3.3: 0.1 FTE/year (Jan 2021 – Aug 2024)</u>

Subtask 3.4 – Selection of a subgroup of ECMWF IFS-ENS members for BC. (IMS)

The selection of the optimal subgroup of members of IFS-ENS for driving a limited-area ensemble strongly influences ensemble spread and skill. Although this topic was investigated a few years ago by MeteoSwiss (Westerhuis, 2016), the eastern Mediterranean domain was not investigated previously, and the future increase in the number and resolution of IFS-ENS members keeps this topic important and relevant for next years.

The proposed research for the first COSMO year of the Project (2020-2021) is the following:

1. 8 10-day long periods will be chosen. During each period, COSMO-IL-EPS with 51 members will be run for 78h every 12h (at 00 and 12 UTC). Cost: ~1600 SBU/d X 3.25d X 2per/d X 80d X 51mem = 42.4M.
2. Verification of 160 COSMO-IL-EPS runs will be performed, aimed at revealing:
    - COSMO-IL-EPS preliminary quality with respect to IFS-ENS.
    - Identification of optimal 20 driving IFS-ENS members.
3. The Cluster Analysis (CA) will be used to optimally select the 20 members. The CA implemented for COSMO-LEPS (Molteni et al., 2001; Marsigli et al., 2001; Montani et al., 2003) will be used as a starting point, and adapted to the eastern Mediterranean region and to the specific application. For that purpose the CA will be deeply investigated and various IFS-ENS atmospheric fields will be considered in order to perform the synoptic classification and subsequent clustering, also in dependence of the season.
4. Expected results:
    - Selection method of 20 EC-ENS driving members.
    - Answer to the question whether additional spread is needed (from PP, SPPT, etc.).

In the following two COSMO years of this PP, a similar research is planned for the ICON ensemble over the eastern Mediterranean.

<u>Deliverable:</u> *Member selection of IFS-ENS to provide BCs to COSMO-IL-EPS and ICON-IL-EPS.*

Involved scientists: A. Shtivelman, I. Carmona, P. Khain, Y. Levi (IMS)

FTEs for subtask 3.4: 0.41 per COSMO year (Sep 2020 - Aug 2023)

Subtask 3.5 - Modification of lagged-approach scheme (IMGW)

At IMGW it is planned to research on the method of selecting a particular set of lagged ICs/BCs. In the current setup, the input data from previous launches of the model are used with equal importance, and every group has the same number of members.

Using the same set-up (in terms of period, domain and resolution) as in subtasks 1.1 and 2.2, it is planned to test whether a change in the weight assigned to a specific member in the EPS can significantly and positively affect the performance of the forecast. A "weight with memory" will be considered - the older runs would have smaller weights - or, the older runs would supply a smaller amount of members.

This task will be carried out for both the current operational setup and for different set-up with selected perturbation methods. For this purpose the results of subtasks 1.1 and 2.2 will be used, determining the most significant and the most promising perturbation methods in terms of forecasts' results. In order to perform this study, case studies will be also run, beside the operational suite.

Deliverable: Modification of the lagged-approach used for BCs.

Involved scientists: W. Interewicz, J. Linkowska (IMGW)

FTEs for subtask 3.5: 0.5 (Sep 2021 - Aug 2024)

Risks

Some tasks are affected by the risk of a reduction of human resources, either because they are based on non-permanent personnel, or because the research work can be delayed by operational needs. This risk may bring delays to the project, but not as serious as a cancelation of the activities, because these activities are part of the plans of the respective COSMO Members.

The tasks of the Project are mainly research tasks, therefore they are prone to redefinition, if the results of the research are not satisfying the expectations. In that case, the tasks may be modified, or stopped, and new research lines will be followed, activating new tasks. This behaviour was already observed in previous PPs and does not harm the general development of the ensemble systems. The main aim of the Project, which is the development of model perturbations and their test, as well as BC and IC perturbations, will not change, ensuring a development of the involved ensemble systems.

The Tasks are in general independent from each other, therefore a delay in one will not affect negatively the others. Only Subtasks 1.6 and 1.7 are dependent on part of subtask 1.4.

In the time frame of the project, the Consortium will continue and likely complete the transition to ICON-LAM. Therefore there may be delays due to the difficulties of the new model implementation and of the implementation of the model perturbation methods in the new model.

The RHM plans for task 3 related to usage of ICON-EPS ICs&BCs are prone to delays, modifications in the schedule or even cancellation if DWD has no possibility to provide the data in the future.

Participants

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DWD: C. Gebhardt, C. Marsigli
HNMS: E. Avgoustoglou
IMGW: G. Duniec, J. Linkowska, A. Mazur, W. Interewicz
IMS: A. Shtivelman, I. Carmona, P. Khain., Y. Levi
MCH: S. Bellaire, A. Walser, NN
RHM: E. Astakhova, D.Alferov, V.Egorova, D.Gayfulin, M.Tsyrulnikov

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Appendix 1: Task table

FTE-y 2020 (from Sep 2020 to Aug 2021): **3.12**
FTE-y 2021 (from Sep 2021 to Aug 2022): **3.02**
FTE-y 2022 (from Sep 2022 to Aug 2023): **3.07**
FTE-y 2023 (from Sep 2023 to Aug 2024): **1.80**

FTE-y total (from Sep 2020 to Aug 2024): **11.01**

Task	**Subtask**	**Contributing scientist(s)**	**FTE-y Total**	**FTE-y 2020**	**FTE-y 2021**	**FTE-y 2022**	**FTE-y 2023**	**Start**	**Deliverables**	**Date of delivery (*)**	**Preceding tasks**
0 total 0.8		C. Marsigli All	0.4 0.4	0.1 0.1	0.1 0.1	0.1 0.1	0.1 0.1	Sep 2020	Meetings, Reports	permanent	
1 total 5.48	1.1	A. Mazur, G. Duniec, J. Linkowska	0.7	0.2	0.2	0.2	0.1	Sep 2020	Results of new parameters in TLE-MVE, possible update of the operational ensemble	Aug 2024	
	1.2	C. Gebhardt, C. Marsigli	0.3	0.1	0.1	0.1		Sep 2020	Results of the impact of the scheme in ICON-D2-EPS	Aug 2023	
	1.3	C. Gebhardt	0.3	0.1	0.1	0.1		Sep 2020	Results of the impact of the scheme in ICON-D2-EPS	Aug 2023	
	1.4	D.Gayfulin, M.Tsyrulnikov	0.5	0.5				Sep 2020	SPG implemented to ICON-LAM AMPT implemented to ICON-LAM SPPT option introduced within AMPT	Aug 2021	
		E. Astakhova, D.Gayfulin, M.Tsyrulnikov	0.75		0.25	0.25	0.25	Sep 2021	Results of testing AMPT in ICON-LAM-EPS. Recommendations on AMPT parameters	Aug 2024	
	1.5	E.Astakhova, D.Alferov, V.Egorova, D.Gayfulin, M.Tsyrulnikov	0.65	0.2	0.15	0.15	0.15	Sep 2020	Results of numerical experiments on various physical parameter perturbations in ICON-LAM-EPS. Comparison PP vs AMPT vs SPPT	Aug 2024	
	1.6	M. Alemanno	0.3	0.1	0.2			Jun 2021	Results of the impact of SPPT in ICON-IT EPS	Aug 2022	**1.4**
	1.7	S. Bellaire, A. Walser	0.35	0.35				Oct 2020	SPPT implemented in ICON, possibly iSPPT implemented in ICON; results of the impact of the scheme in ICON-LAM	July 2021	**1.4**

	1.8	C. Marsigli, NN	0.5			0.3	0.2	Jan 2023	Definition of PP for ICON-2I-EPS; results of impact of PP and SPPT in ICON-2I-EPS	Aug 2024	
	1.9	I. Cerenzia, E. Augoustoglou	0.75	0.3	0.1	0.2	0.15	Oct 2020	Results of impact of PP and SPPT in COSMO-LEPS with ICON	Jan 2024	
	1.10	A. Shtivelman, P. Khain, Y. Levi	0.63	0.21	0.21	0.21		Sep 2020	Results of impact of PP and SPPT in COSMO-IL-EPS and in ICON-IL-EPS	Aug 2023	

Task	**Subtask**	**Contributing scientist(s)**	**FTE-y Total**	**FTE-y 2020**	**FTE-y 2021**	**FTE-y 2022**	**FTE-y 2023**	**Start**	**Deliverables**	**Date of delivery (*)**	**Preceding tasks**
2 **total 1.5**	2.1	C. Marsigli	0.6	0.15	0.15	0.15	0.15	Sep 2020	Results of ICs from modified LETKF in ICON-D2-EPS	Aug 2024	
	2.2	W. Interewicz, J. Linkowska, G. Duniec	0.9		0.3	0.3	0.3	March 2022	Results of impact of soil perturbation in TLE-MVE	February 2024	
3 **total 2.98**	3.1	A. Walser, NN	0.15		0.15			Jan 2022	Results of impact of ICON BC in ICON-1E	June 2022	
	3.2	E.Astakhova, D.Alferov, V.Egorova	0.4	0.2	0.2			Sep 2020	Implementation and verification of ICON-based lagged ensemble. Experiments with different weighting of members	Aug 2022	
		E.Astakhova, D.Alferov, V.Egorova	0.3			0.2	0.1	Sep 2022	Tests with ICON-EPS BCs&ICs	Aug 2024	
	3.3	C. Gebhardt	0.4	0.1	0.1	0.1	0.1	Jan 2021	Results of member selection for BC in ICON-D2-EPS	Aug 2024	
	3.4	A. Shtivelman, I. Carmona, P. Khain, Y. Levi	1.23	0.41	0.41	0.41		Sep 2020	Selection method of 20 EC-ENS driving members for COSMO-IL-EPS and for ICON-IL-EPS	Aug 2023	
	3.5	W. Interewicz, J. Linkowska	0.5		0.2	0.2	0.1	Sep 2021	Selection of weights for lagged approach	Aug 2024	

Appendix 2: Model perturbations.

The most widely used model perturbation methodologies are here listed and shortly described:

PP (Perturbed Parameters): each member has a different value of one or several parameters, fixed during the integration

RPP (Random Perturbed Parameters): each member has a different value of one or several parameters, fixed during the integration, but the value of the parameter is randomly chosen for each cycle and member

RP (Random Parameters): each member has a different value of one or several parameters, fixed in space during the integration but varying in time; the value of the parameter is randomly chosen for each cycle and member

SPPT (Stochastically Perturbed Parametrization Tendency): stochastically perturbed physical tendency, with spatial and temporal correlation

iSPPT (independent SPPT): as SPPT but the tendency from each parametrization scheme is perturbed using an independent stochastic pattern.

SPP (Stochastically Perturbed Parametrisations): physics parameters are stochastically perturbed with spatial and temporal correlation

PSP (Physically Based Stochastic Perturbations): Boundary Layer stochastic perturbations with amplitude based on information obtained from turbulence parameterization, with spatial and temporal correlation

Multi-physics: different members use different physics schemes, fixed

Multi-model: different members use different models, fixed

Stochastic parametrisation: a scheme for parametrising a physical process in the model which is intrinsically stochastic