An outlook on the developments in the field of Predictability and Ensemble Methods (WG7) in the COSMO Consortium

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The development, maintenance and verification of ensemble forecasting systems is an activity highly dependent on the activities of the other Working Groups of COSMO. The development of the model and of the data assimilation clearly influences not only the performance of the systems but also the possibilities to further develop the ensembles and implement new perturbation methods. Furthermore, there is a continuous exchange of methods and ideas with the verification and post-processing groups. Though they are part of the standard forecasting systems, ensembles have an additional complexity, due to their probabilistic nature, which requires specific verification and post-processing methods. In the last years, due to the transition of the COSMO Consortium to the ICON-LAM model, also the issue of the transition of the ensemble systems have entered the WG7 activities.

The activities of WG7 in the COSMO Consortium currently focus on the development of the convection-permitting ensemble systems run by the COSMO partners. These ensembles are operational at DWD, MCH, IMGW, COMET, IMS and Arpae, and under development at RHM.

The design and implementation of methods for generating the ensemble forecasting systems is performed through: studies of the atmospheric predictability at the relevant time and spatial scales, identification of the sources of modelling uncertainties which are most affecting the forecast, generation (or choice) of perturbation methods suitable for the representation of these uncertainties, implementation of the methods in the modelling framework and their tuning, extensive testing and verification. This process requires normally few to some years to be completed, depending on the specific method.

Our ensembles proved to have skill in the forecast of the weather at high-resolution, both statistically over evaluation periods and on severe weather cases of interest for the forecasters and/or for the users. However, they also show some unsatisfactory performances, measured by the objective verification or reported by the forecasters:

- Missing or underestimation of relevant events (intensity errors, localisation errors, timing errors)
- Insufficient reliability of the forecast for weather parameters like precipitation and wind (mismatch between probability of an event and its observed frequency)
- Lack of spread for near-surface weather parameters, statistically over a long period, which may cause the missing of an intense event

In order to improve the ensembles, beside the need of improving the model and that data assimilation, which is addressed by other WGs, it is needed to improve the perturbation methods. The perturbations applied to a LAM ensemble are: Initial Condition (IC) perturbation, Boundary Condition (BC) perturbation, model perturbation. The most promising developments for the next five years are those which can lead our ensembles to an effective representation of the km-scale uncertainty, both in the initial conditions and in the model, and of the error sources relevant for the processes generating high-impact weather. These developments are outlined here.

Initial Conditions.

The KENDA system used for Data Assimilation provides a set of perturbed analyses to be used as Initial Conditions for the convection-permitting ensembles. Currently, KENDA-derived ICs are used at DWD. MCH, COMET, Arpae and IMS. In this respect, the main activity of WG7 in terms of Initial Condition perturbation is to keep a close link with WG1: WG1 develops

KENDA and WG7 assesses the performance of KENDA-derived ICs in the forecast ensembles. This collaboration will continue in the next years. Beside this, it has emerged the need of tailoring the KENDA analyses for the purposes of ensemble forecasting, without affecting the KENDA cycle itself and therefore the quality of the assimilation. In order to do this, a simple way is to select, out of the KENDA analyses, a subset which perform best for ensemble initialisation, following the work of Westerhuis (2016). Another planned research work is the generation, as part of the KENDA cycle, of an alternative set of analyses, where the LETKF step is optimised (in terms of inflation, localisation, scheme parameters) to maximise the skill of the forecasting ensemble. There alternative analyses are to be employed only as ensemble ICs and not in the next KENDA cycle.,. These activities are planned for the next 2-3 years. As a more general and long term plan (5-10 years), it is needed to establish a closer link with the data assimilation, exploring approaches of best member selection in the data assimilation ensemble and the usage of particle filters data assimilation methods.

Boundary Conditions.

For a LAM ensemble, perturbed Boundary Conditions are a crucial ingredient. When possible, BCs from a global (or coarser resolution) ensemble should be used. To this extent, the availability of BCs from ECMWF-ENS or from ICON-EPS is very important for the development and the performances of the convection-permitting ensembles in COSMO. In order to optimise the choice of the BCs from a coarser resolution ensemble, for COSMO-LEPS was developed a selection based on a Cluster Analysis (Molteni et al., 2001; Marsigli et al., 2001). In this approach, it is performed a clustering of the members of the driving ensemble (IFS-ENS) in terms of the atmospheric fields describing the weather at the larger scale, identifying the main future weather scenarios. This enables to select as boundary conditions for the higher-resolution ensemble only the subset members which maximise the diversity in terms of scenarios. This approach has been widely used in several countries and it seems to be a promising method also for the convection-permitting scale. Adaptation is required when implementing the method on a different geographical area, with its specific weather, since the Clustering is performed on the weather patterns. Studies in this direction are planned in several COSMO Members (DWD, MCH, IMS) for the next future (2-4 years).

Model perturbation.

The uncertainties affecting the model are many and their effect is often not known. In some cases it is known that some approximations are introducing an “error”, for example by setting a global parameter, considering that likely the value is dependent on the weather situation or on other physical processes. In other cases, it is known that a parametrisation for a certain physical process would be needed, but it is computationally too expensive for the operational run, or it is still not known how to formulate that effect in the model. Despite being widely used, the modelling at the convection-permitting scale is still affected by many uncertainties and the problem of the grey zone for the convection is far from being solved.

In order to represent these sources of uncertainty in the ensemble forecast system, several methods have been developed (for a list of the acronyms used here, see the Appendix). In the Consortium two methods are used operationally: Perturbed Parameters (PP) and SPPT (Stochastically Perturbed Parametrization Tendency, Buizza et al., 1999). In the first method, a set of model parameters is perturbed in the different ensemble members, selecting the new values from a given range. Though the method is quite simple and it does not produce generally a high amount of spread, it permits to improve the performance of the ensemble in specific weather situation. In addition, being the perturbations usually not very large, it does not lead to model crashes. In the next 2-3 years, part of the work will focus on the migration of this method to ICON-LAM, where the parameters to be perturbed and their range of variation need to be defined, aiming at including a wide range of physical processes. This work will be carried on in collaboration with the model physics groups. The dependency of the perturbations on the weather situation requires that the Parameter Perturbation set-up is redefined when the model resolution is changed or the ensemble is implemented on a different geographical area. In this work we expect beneficial synergies with the CALMO project, since CALMO provides information on the internal variability of the parameters used in the calibration (definition of tunable parameters, assessment of the sensitivity of the model with respect to each of these parameters, definition of parameter optimum and of reasonable range to perturb the parameter).

The SPPT method is producing more spread than PP, but the set-up of the method requires some care in order to avoid model crashes. In order to address this point, in the next year it will be implemented and tested in ICON-LAM a variant of it, iSPPT (Christensen et al., 2017), where the perturbations are applied independently to the different physics schemes. SPPT needs also to be tuned on the specific geographical area. SPPT tuning includes the horizontal and vertical scale of the perturbation patterns and their amplitude, and it will include also the set-up of different values of these parameters for the different physics schemes which are perturbed. MCH and RHM are working on the implementation of this method in ICON, which will be followed in the next 3 years by tests in different ensembles (MCH, COMET, ICON-LEPS).

An investment on the development of new and original model perturbation methods has also been done in the last few years, and it will continue in the future.

The AMPT method (Additive Model-error perturbations scaled by Physical Tendencies) has been developed by RHM. 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 perturbations. This method is being tested in the research ensemble at RHM, for perturbation of both the atmospheric and soil variables, with promising results. It will be implemented in ICON-LAM, permitting the continuation and the extension of the testing and a full development of the method in the next 3 years. This includes also the implementation of the Stochastic Pattern Generator.

The SMME method (Stochastic Model of the Model Error, previously called EM-scheme) has been developed at DWD. SMME aims at modeling the model error by integrating a stochastic partial differential equation at different heights levels for u, v, and T. The solution of the SPDE has spatial and temporal correlations corresponding to the model error in the training data set. These solutions of the SPDE are added to the tendencies in the slow physics scheme. The scheme has been implemented in COSMO and it is being migrated to ICON in the next year. It is planned to continue the work and test this method for the perturbation of the model, possibly in addition to the simpler PP method.

The availability of the SPG in ICON would permit to implement in ICON the SPP perturbation method, in analogy with the work performed in the HIRLAM Consortium. SPP can be regarded as an evolution of the PP method, where the parameters are perturbed on the basis of spatial patterns specific for each model physics scheme. The adoption of such a method would require some cooperation with the physics groups, in order to implement the perturbation in each physics scheme. At the moment, there are no plans about this method in the Consortium, but it should be kept into consideration, particularly when resources will be freed from other tasks.

The most promising approach to model perturbation is regarded to be, already for some years, the usage of intrinsically stochastic parametrisations, which strive to represent the model uncertainties directly at their source, in the formulation of the physics schemes. The topic has been recently discussed in a dedicated Stochastic Workshop, organised by the COSMO Consortium, with the participation of a wide European community (see http://www.cosmo-model.org/content/tasks/workGroups/wg7/default.htm). The early work of Plant and Craig (2008) showed that a deep convection scheme where the representation of the physical process is stochastic, producing a different value of the contribution of the convection to the model variables at each call under the same conditions, offers a better representation of the convection parametrisation itself, also in deterministic sense. This approach offers a way of representing the uncertainties intrinsic in the parametrisation of that process which is consistent with the formulation of the scheme itself and which can be easily used in the ensemble forecasting. In COSMO the deep convection is no longer parametrised, therefore the specific scheme has never been adopted, but the idea can be followed and adopted in other physics scheme, leading to a model which represents intrinsically its own uncertainty. Currently, a stochastic shallow convection scheme (Sakradzija et al., 2015, 2016) is being implemented in ICON at DWD, with the purpose of improving the model. The test of this scheme in ensemble generation with ICON-LAM will be performed in the Consortium in the framework of the PROPHECY PP. Another method based on this approach is the Physically Based Stochastic Perturbations (PSP), developed by the University of Munich (Kober and Craig, 2016; Hirt et al., 2019), which is also being implemented in ICON and which will be tested in ensemble mode at DWD. These tests will take place within the next 2-3 year. If results are promising, this should lead the Consortium to consider to invest in the development of physics schemes with elements of stochasticity, which is only possible in a close collaboration between physics groups and the ensemble group.

Another important component of the model affected by uncertainty are the physiographic fields. Ideally, these fields should be provided together with an estimate of their uncertainty and it should be developed a method to include it in an ensemble forecast formulation, starting from the simple method of using different realisations of the physiographic fields in the different members. This is not an easy task, due to the difficulty of elaborating good physiographic data at high-resolution for the models. It is possible however to foresee some investment in this direction in the future (considering a 5 year horizon), where the application of artificial intelligence algorithms will likely play a major role (e.g. Bessardon and Gleeson, 2021).

Evaluation of the developments and verification.

Despite being widely used for operational forecasting for many years, ensemble systems should still be “handled with care”. On the one hand, the interpretation of the ensemble output and the generation of probabilistic products are still an open issue, due to the intrinsic difficulty of the probabilistic approach. On the other hand, ensemble verification is still a separate branch of the forecast verification practice, due to the different characteristics of the ensemble verification scores. This generates often difficulties in the communication between the ensemble community and the rest of the NWP community, which can be exemplified by the different reception of the concept of “spread”. This quantity, crucial for the ensemble forecasting, difficult to evaluate for non-Gaussian variables, has a well-defined meaning only in a statistical sense, generating confusion when it is used as a generic word for “members´ diversity”. In fact, an ensemble forecast can be objectively evaluated only in a statistical sense, while it does not make sense to judge it for a single weather event. Having this problem emerged in many years of ensemble collaboration within COSMO, it is important to invest even more in the future in improving the methods for ensemble evaluation and verification, reinforcing the collaboration with WG4 and WG5. In particular, the assessment of the spread/skill relationship, on which ensemble development in largely based, will require more attention, including in the practice the most recent developments available in the literature (e.g. Ben Bouallegue et al., 2020 and references therein). For this longer-term activity, taking place in the next 5 years, it is planned to collaborate also with WG1, where the evaluation of the spread/skill relationship for the data assimilation ensemble plays also a central role.

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Appendix: Model perturbations.

The mentioned 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
- 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
- Stochastic parametrisation: a scheme for parametrising a physical process in the model which is intrinsically stochastic
- PSP (Physically Based Stochastic Perturbations): Boundary Layer stochastic perturbations with amplitude based on information obtained from turbulence parameterization, with spatial and temporal correlation.
- SSC (Stochastic Shallow Convection): stochastic version of the shallow convection scheme.
- AMPT: Additive Model-error perturbations scaled by Physical Tendency
- SMME: Stochastic Model of the Model Error