Summary and recommendations from Working Group 2: Model uncertainty representations in global and longer lead time ensembles

Co-chairs: *Lisa Bengtsson (NOAA) and Hannah Christensen (Uni Oxford)*

Rapporteur: *Christopher Roberts (ECMWF)*

Participants: *Richard Forbes (ECMWF), Bing Fu (NOAA), Edward Groot (JGU Mainz), Simon Lang (ECMWF), Eun-Heu Lee (KIAPS), Ashu Mamgain (NCMRWF), Mark Muetzelfeldt (Uni Reading), Ron McTaggart-Cowan (ECCC), Pirkka Ollinaho (FMI), Philip Pegion (NOAA), Abhijit Sarkar (NCMRWF), Tobias Selz (LMU Munich), Leo Separovic (ECCC), Warren Tennant (UKMO)*

The aim of Working Group 2 (WG2) was to identify the key issues and recommend priorities for future research directions for ECMWF and the wider research community on model uncertainty (MU) representation in global and longer lead time ensembles. This summary provides a brief record of some of the main points discussed by the Working Group and the recommendations.

Currently, most operational centers utilize stochastic physics for model uncertainty representation, with the Stochastically Perturbed Physics Tendency (SPPT) and Stochastic Kinetic Energy Backscatter Scheme (SKEBS) being the most commonly used. The consensus in our working group discussion was that these schemes have served the operational centers well for decades, in particular for medium-range weather forecasts and seasonal prediction. However, some known shortcomings of the SPPT and SKEBS approaches were discussed, which can be summarized as:

- SPPT does not conserve moisture and energy without additional fixers or correcting factors.
- While appealingly simple on paper, SPPT requires additional infrastructure to make sure it behaves (e.g., negative humidity checks, tapering of boundary layer, can introduce spurious oscillations on 2*delta-t time scale due to activating and deactivating convection).
- From a physics development perspective SPPT is difficult to justify as it throws away the effort that has gone into conservation etc.
- SPPT can have cases where unphysical states exist, and forecasters complain.
- SPPT has too few tunable parameters to rebalance the system effectively when ported to a new model/cycle.
- Performance of SKEBS is resolution-dependent, and it becomes more expensive at higher resolutions where it has less impact. The dissipation estimate requires active tuning for each resolution. Otherwise, there is the counterintuitive behavior that with higher resolution, the scheme is more active.
- SKEBS (and SPPT) can have vastly different results in different models, understanding why this happens is desirable.

Thus, WG2 recommends that alternative approaches should be explored. Global modeling centers have already made great strides in addressing some of the above challenges by perturbing parameters or processes inside the physics parameterizations, using the Stochastically Perturbed Parameterizations (SPP) approach, or including stochastic parameterizations in the physics schemes themselves (e.g. stochastic cumulus closure formulation, sampling cloud number/intensity from prescribed PDF or cellular automata etc.).

While recent efforts using SPP and stochastic parameterization schemes within the sub-grid physics seem promising, the working group recognizes that there are distinct sources of model uncertainty, with different physical or numerical origins that may need to be addressed in different ways. These include, but are not limited to, sampling uncertainty, structural errors, physical processes which have been excluded, parameter uncertainty, inherent process uncertainty, incomplete calculation of the process and dynamics (including advection, numerics (truncation) and diffusion). **For this purpose, WG2 recommends gaining a better understanding how different types of uncertainty should be represented, and how they work together with other (stochastic) schemes.**

For instance, inherently stochastic physics schemes, by definition, have a good theoretical underpinning, but do not necessarily lead to enhanced spread. These schemes still have value because they address the very real uncertainty arising from the range of possible subgrid-scale states associated with a given resolved-scale flow. On the other hand, parameter perturbations address the fact that we do not have a full understanding of physical processes or how to represent them in the model. They are effective at increasing spread, but we have a more limited theoretical understanding of how such schemes work in practice. For example, parameter perturbations can suffer from the same issue as SPPT - while in SPPT the model compensates at a later timestep to minimize the impact of the perturbation at an earlier timestep, in SPP physics schemes called later within the physics timestep can react to compensate perturbations made within earlier schemes.

Both inherently stochastic physics schemes and model uncertainty representations could be applied in the same ensemble with the clear understanding that they address different sources of uncertainty. **To combine schemes in this way, WG2 recommends to utilize perfect model frameworks and observations to inform us about the part of uncertainty that needs to come from the stochastic sampling, vs parameter perturbations, vs multiplicative scaling of tendencies (if required).** Methods include coarse-graining activities, the recently proposed MuMIP project (which combines coarse graining with coordinated short, low resolution runs from different forecasting models to measure model error statistics), and use of dense-station field campaigns. There is also general interest in the relative performance of the various model uncertainty schemes at different modeling centers. Such comparisons would be beneficial in understanding the utility or effectiveness of each scheme.

In a similar notion, WG2 recomends that more work should be done to understand the scales of error. In current uncertainty representation development, the hypothesis is that errors come from smaller scales and that models are failing to propagate these errors upscale, which is the underlying reason why large scale patterns are used for noise correlations. The question is if the upscale propagation is too slow in the models? Or is it missing entirely? Furthermore, will the upscale propagation be systematically different as we move to convection permitting scales in the global systems, since convective organization in the tropics interacts with convectively coupled equatorial waves, which act as a Rossby wave source. Related, models run on convective “permitting” resolutions can better capture the k-5/3 slope of the kinetic energy spectra, and it is interesting to understand if a better representation of the slope of the spectra in this mesoscale range, in global modeling systems, can lead to an enhanced upscale propagation of model error.

To further our understanding of how different types of uncertainty should be represented, and which scales are needed for appropriate model uncertainty growth, **WG2 recommends that collaboration between operational centers and academia should be enhanced,** and that the WMO - WGNE/PDEF/GASS could be the right forum to facilitate such collaboration. A report from this WG will be presented at WGNE-36 in an effort to promote these connections. In addition, **WG2 recommends that operational centers (ECMWF and others) should consider putting out targeted calls for input from academia, perhaps associated with special project compute time, to guide research in the wider community.** The working group also recognizes that enhanced collaboration between the ensemble and the physics parameterization developers is desirable and having model uncertainty representation within the sub-grid physics parameterizations provides an opportunity for such collaboration.