Working Group 1: Future developments in deterministic and stochastic parametrizations

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Our group considered the desirability of including representations of uncertainty in the development of parameterizations. (By 'uncertainty' here we mean the deviation of sub-grid scale fluxes or tendencies in any given model grid box from truth.) We unanimously agreed that the ECWMF should attempt to provide a more physical basis for uncertainty estimates than the very effective but ad hoc methods being used at present. Our discussions identified several issues that will arise.

1) How can physical representations of uncertainty be developed in the context of existing techniques (SPPT, SKEB, etc.)?

Currently, the most successful technique for representing model uncertainty in ECMWF ensemble system is SPPT. This technique is the baseline, in the sense that improvements going forward will be judged relative the efficacy of SPPT.

There remains considerable scope for improvement in SPPT including calibration and a more individual, process-based variant. In particular, coarse-graining studies with IFS forecasts should make it possible to assign more credible levels of uncertainty to each of the parameterisation schemes. SPPT modifies the total parameterisation tendency and is based on a pattern generator. A natural evolution is to perturb different parametrization scheme differently, and possibly even with different patterns.

Beyond this however, the Centre should directly target the physical parameterisation schemes with respect to their inherent uncertainties. There is general agreement that deep convection, especially in the tropics, would make a good first target. There may also be opportunities to treat the uncertainty in gravity wave drag associated with unresolved orography, especially because this process is known to be very sensitive to wind profiles.

SPPT is based on pattern generators and these could also be used to modulate key parameters associated with parameterizations. Observations or process models such as CRMs can be used calibrate the spatial, temporal and structural nature of perturbations to refine the pattern generator in SPPT. It should be possible to improve on the ad hoc correlation scales associated with the three patterns in SPPT (and likewise for modulating parameters).

Recent coarse-graining studies using the IFS have been applied at the process level and have clarified the relationship between the magnitude of the uncertainty in the parameterization tendency and the mean tendency. There is growing evidence that the variance is proportional to the mean tendency. This conflicts with the underlying assumption in SPPT but is consistent with an underlying Poisson process. There also appears to be an additive component in that uncertainty exists even at zero mean tendency. Further investigation is required and EPS simulations carried out to explore the possibility that increased probabilistic skill results from using a more appropriate probability distribution function.

There was some discussion about the desirability of achieving a shallower slope in the model's energy spectrum. This could be realised through new techniques such as the vorticity confinement algorithm or other numerical methods that give non-local upscale energy transport. This may lead to improved parameterisation responses at the near grid scale.

An issue that arises when physical process uncertainty is treated individually concerns its effect within the sequential call structure of parametrization code. For instance, radiation uncertainty generally derives from cloud uncertainty and one would want to have that causality respected in the subroutine calling sequence. There was also some concern expressed about physical inconsistency in SPPT, such as the lack of surface energy flux perturbations when SPPT perturbs parametrization tendencies in the column above.

Lastly, the cultural gap between physical parametrization development and EPS development was noted as a problem, particularly for the EPS community. Traditionally, parametrization development has had deterministic NWP as its context and this can lead to problems (e.g. reduced model stability) when stochastic perturbations are generated out of the parametrization tendencies.

Recommendations

- ECMWF should test new formulations that address physical parameterisation uncertainty. For instance, the cellular automation pattern generator should be tested to perturb parameterizations.
- Tropical convection appears to be the best candidate for initial efforts, both because it has been the subject of several studies (including talks by Jakob, Majda, and Plant at this workshop) and because it impacts many other aspects of the model.
- The broader research community should be encouraged to invest effort in establishing a firm physical basis for stochastic perturbations. The most likely place to put this is directly into the physical parametrization scheme.

2) In what circumstances and for which processes do stochastic perturbations project onto the large-scale flow?

Both existing stochastic methods presently used at ECMWF to represent model uncertainty impose one or more large-scale patterns to the perturbations. This is because many algorithms that introduce noise at the grid scale do not affect forecast evolution in a significant way. But is at least one counter example in which methods operating at the grid scale do indeed change the large-scale flow. In order to be able to invest wisely in stochastic methods for representing model uncertainty we need to delineate under what circumstances and at what spatial and temporal scales do stochastic perturbations impact the large-scale dynamics.

At this stage it is unclear to what extent spatial and temporal coherence play a role in this process. In addition, it is also not clear how these effects depend on the specifics of the parameterizations, the spatial and temporal resolution, and the large-scale numerics.

It seems impossible to assess these dependencies without a concerted research effort using different methodologies and large-scale models. This effort should take place in the context of international coordinating groups such as the Working Group on Numerical Experimentation (WGNE), in order not only to entrain the overall modelling community, but also to ensure that the results of such a study are as generic and applicable as possible.

Recommendations:

- Initiate a community study, possibly within the auspices of an international group such as WGNE, to investigate this issue by testing different yet simple (to implement) stochastic perturbation methodologies (including different spatial and temporal correlations) in the context of simplified GCM simulations.

3) Implementation issues in the development of stochastic physical parameterizations

There are three existing techniques for introducing uncertainty at the model level: running multiple models, running multiple physical parameterizations within a given model, and varying parameters within a given model. The path we endorse here – developing parameterization with explicitly random elements to represent the uncertain response to a given forcing – has been less well-explored to date. Within this context, one can introduce stochastic behaviour into schemes in several ways: by varying the inputs, by perturbing parameters and assumptions within the scheme, or by introducing randomness into the scheme's response to a given forcing (e.g. through transition probabilities or finite sample sizes). Since the goal is to provide a strong physical basis for uncertainty estimates, it seems likely that each method is most appropriate for a different category of uncertainty.

Where process knowledge is high - radiation is one example – it is most sensible to perturb the inputs. That might mean sampling or integrating over a distribution, depending on the relative scales of the relevant variability and the grid size. This is a way to reflect "external" uncertainty and/or variability when the process depends strongly on the inputs.

Where process knowledge is uncertain one can perturb parameters and/or assumptions within the scheme. This approach could be used to represent uncertainty in ice habit distributions, for example.

Uncertainty and errors also arise when assumptions used to build the parameterization break down. This is so far most obvious in the treatment of deep convection: it's clear that grid sizes are now far too small to encompass a large number of deep convective elements. This can be treated by averaging the process outcome over a finite (and presumably scale-dependent) number of samples.

Some kinds of uncertainty are more ambiguous. Convection, for example, can be very sensitive to initial conditions at both the small and the large scale. It is not clear to what extent the construction of the initial ensemble samples the large-scale variability, but it's presumably important not to count this uncertainty twice. Similarly, it's important not to double-count uncertainties by adding stochastic elements and then inflating tendencies after the fact.

Enumerating various sources of uncertainty and finding appropriate ways to represent each is expected to be a significant task.

Recommendations:

- ECMWF should invest in the development of stochastic parameterizations where the physical basis for uncertainty is made explicit. We support a substantial investment, i.e. by hiring a scientist to work on the problem full time, as we expect this area to attract increasing attention in the coming years.

- ECMWF should explicitly include uncertainty treatments (likely stochastic treatments) in the development of future parameterizations for both the ensemble prediction system and the deterministic model. The latter provides a good test of the physical plausibility of the error treatment.

4) How do we make the link with fine scale models and observations?

There is a strong community working on the development of traditional parameterization, in particular in the area of clouds and convection, which is organized in programs such as GCSS. This community employs observations and high-resolution process models (CRMs, LESs) in the evaluation and development of parameterizations. We encourage the developers of stochastic parameterizations to engage in the existing activities by, for example, participating in the existing intercomparison studies. This will both enable the confrontation of new ideas in stochastic parameterization with observations and process models and help integrating what are currently somewhat separate communities.

A more comprehensive evaluation of stochastic parameterizations will require new approaches to the analysis of both observations and process model output. Observational and modelling studies presented in this workshop allowed for the quantification of the degree of stochastic behaviour of the convective response (i.e. precipitation) in relation to the large scale forcing (i.e. moisture convergence). To facilitate such studies will require the collection and storage of full 3D output at high temporal frequency of process models as well as a more comprehensive analysis of existing and future observations.

Intercomparison studies for traditional parameterizations focus on their capability of representing the mean effects of sub-grid scale processes on the large scale. For stochastic parameterization, it is necessary to evaluate whether the variability of these effects is represented realistically and to what extend these perturbations lead to realistic variability on the larger resolved scales (e.g. realistic ensemble spread). This will require the application of innovative evaluation techniques and will likely necessitate dedicated intercomparison effort for stochastic parameterizations at both the process and full model application level.

Recommendations:

- We encourage the developers of stochastic parameterization to engage in existing (intercomparison) activities wherever possible.
- The broader community should consider designing and making available dedicated CRM and observational data sets that support the development and evaluation of stochastic based parametrization (in particular clouds and convection).

We support a dedicated stochastic parametrization intercomparison project.

5) How do we represent "structural" errors in physical parametrization

A part of the uncertainty (or model error) that is not readily addressed by current methods relates to error in regions that are not targeted by the perturbed tendency, random parameters or stochastic backscatter approaches. For instance, convection parametrization may completely fail to trigger convection in some places and therefore this uncertainty will be completely missed by SPPT and random parameters which generate perturbations from the parametrization tendencies. Another structural error that might exist in convection parametrization concerns the vertical profile of convective heating which is known to play a critical role in forcing equatorially-trapped waves.

Varying parameters such as the entrainment rate might help to achieve this uncertainty in the profile of diabatic heating but SPPT would not directly address this issue.

The fact that physical parametrization is column-based also imposes structural error. An example of this is orographic gravity wave drag parametrization that assumes wave packets remain in the same grid column whereas there have been many studies recently that show that wave activity (and associated momentum fluxes) can be carried long distances from their mountain source.

Lastly, there remains the possibility of model error that is not presently recognized or understood.

Recommendation

- Address potential 'unknown random error' by including some additive background forcing noise to EPS perturbed forecasts (e.g. an isotropic, global vorticity forcing function)