Stochastic Workshop

2-3 March 2021

Minutes of the discussion

The purpose of this workshop was to present and discuss recent works on intrinsically stochastic parametrisations in the NWP models.
The Workshop has been organised in the framework of the COSMO Consortium to promote activities aimed at making our model "more intrinsically stochastic", also for the usage in an ensemble approach. The European modelling Consortia were invited, since similar activities are taking place all around Europe and where discussed at EWGLAM. The on-going activities and the plans of the different groups have been presented, and the methodologies and the open issues have been discussed. George Craig (LMU) and Judith Berner (NCAR) have been invited to give introductory talks.

Agenda:

Chairperson: Chiara Marsigli

- Chiara Marsigli (DWD): Opening, purpose of the meeting
- George Craig (LMU): Introductory talk about intrinsically stochastic parametrisations
- Mirjam Hirt (LMU): Stochastic Parameterization of Processes Leading to Convective Initiation in Kilometer-Scale Models

Chairperson: Alan Hally

- Axelle Fleury and Francois Bouttier (Météo-France): Stochastic physics experiments in the AROME model
- Michael Whitall (Met Office): Plans for a stochastic version of the comorph convection scheme

Chairperson: Alfons Callado

- Judith Berner (NCAR): Stochastic microphysics at convection resolving scales
- Martin Leutbecher (ECMWF): Stochastic representation of model uncertainties at ECMWF

Chairperson: Christian Keil

- Mirijana Sakradzija (MPI): Local impact of stochastic shallow convection on clouds and precipitation in the tropical Atlantic
- Maike Ahlgrimm (DWD): An update about the stochastic shallow convection scheme in ICON at DWD

Chairperson: Inger-Lise Frogner

- Sophia Schäfer (DWD): Uncertainties, stochastic and deterministic components in radiation modelling
- Mikhail Tsyrulnikov and Dmitriy Gayfulin (RHM): Attempts to objectively identify a stochastic model for model errors
- Martin Sprengel and Christoph Gebhardt (DWD): Characterization of the model error in ICON-D2-EPS using a flow-dependent partial SDE

Chairperson: Chiara Marsigli

- Moritz Pickl (KIT): A process-oriented perspective on stochastic physics, with a focus of SPPT on warm conveyor belts in the IFS
- Anne McCabe (Met Office), Marco Arpagaus (MeteoSwiss): Presentation of the open issues

Minutes:

The minutes summarise the discussion taking place during the workshop.

From the talk of G. Craig:
There are two types of model errors:

- systematic errors -> need multi-parameter or multi-model (dealing with unknown processes)
- random variability -> need stochastic variability (dealing with unresolved processes)

It can happen that having the spread-error relation right does not solve all the problems, because it does not tell the full story (e.g. bias, signal/noise ratio paradox, variability should be compared to the climatological one).
Tuning spread and skill works in the medium-range but can be that it does not work at the convective scale.
-> Instead of looking for a "stochastizator", look for what is uncertain in parametrisations
The model should be intrinsically stochastic, because at each scale there is a gray zone.
Proposed issues for the discussion:

- interaction with climatological variance (convection like S2S?)
- interaction with numerical artifacts (gray zone)

From the talk of J. Berner:
Why is the Perturbed Parameter (PP) method more often adopted in convection-permitting ensembles than in the synoptic scale systems? Does this depend on the space and time scale of the Perturbed Parameters?
How to find the scale of the perturbation?
Diagnostics: it is proposed a joint probability density function of the distributions of the spread in pairs of different variables (e.g. 2m T and SWR). Behaviour of the error growth is shown from the spectra.

G. Craig: The uncertainties and the predictability at the convective scale are not independent form the synoptic situation. Is the difference between CP scale and synoptic scale the same as the difference between synoptic scale and S2S scale?
G. Craig mentions a result by C. Snyder, showing that a little perturbation in the mean flow is enough to destroy the small scale information, leading to error saturation; therefore it is not important what exactly is perturbed at the synoptic scale, with respect to the small scale. On the other hand, when perturbations are applied at the S2S scales, the synoptic scale error saturates fast. Therefore it has always to be specified "large scale" or "small scale" with respect to what, and for which saturation time.

J. Berner: PP works at the CP scale because it introduces small scale perturbations, while at the synoptic scale perturbations at larger scale are needed (e.g. SPPT)?
Is there a model error characteristics at the CP scale (different error growth regime), due to which PP is sufficient?

D. Mironov: PP works because the parameters are in reality functions, which we simplify to parameters. They are processes we do not fully understand, while stochastic physics are processes we partly understand and we try to include their uncertainty in a coherent way.
M. Raschendorfer: the evolution of the grid scale parameters should be expressed as function of other variables/parameters, but this is usually not possible, therefore we need a stochastic approach.

About SPP and SPPT:

- SPP still not able to beat SPPT at ECMWF
- SPP very effective in HIRLAM HarmonEPS (2.5 km), SPPT not satisfactory (IL Frogner)
- SPPT very effective in COSMO at MeteoSwiss (due to strong forcing?) (M. Arpagaus)
- advantage of SPPT: to perturb all the parametrisations in one go

In the work presented by A. Fleury, physically based stochastic perturbations were added within the turbulence scheme and shallow convection scheme. These perturbations gave comparable dispersion to SPPT when SPPT was only applied to the schemes concerned.

M. Whitall presented a scheme which is a “rethink on how we do stochastic convection”. The scheme gave improved representation of sporadic small showers for UKV simulations.

A. Seifert: stochastic microphysics could be a relevant contribution moving to the cloud scale

M. Tsyrulnikov proposes the use of the distinction between epistemic uncertainty (use of the ensemble to represent our ignorance) and aleatoric uncertainty
J. Berner: even if the errors are small scale and random, in the model they soon interact with the large scale flow. How long do local small scale error stay small?

From a comment by I.-L. Frogner and M. Sprengel: stochastic schemes and model for model error schemes can be complementary, since the stochastic schemes describes the uncertainty related to a particular process, which the model for model error schemes could represent the bulk uncertainty. It could be beneficial to apply both SPP and stochastic physics, together.
C. Gebhardt: in addition, stochastic schemes remove part of the systematic uncertainty and this could help the bulk schemes in removing the rest

Strong forcing and weak forcing situations: it is important to always distinguish between strong forcing and weak forcing situations, the response of the small-scale perturbations is always much smaller in strong forcing situation. M. Hirt reports that their PBL perturbations mainly effective in weak forcing situations.
Has PP a different effect under weak and strong forcing conditions? (likely yes, since it is the case for all perturbations). Should the parameters be perturbed in different ways according to the weather conditions?
C. Marsigli observed in strong forcing cases that PP influence the position of the precipitation structure, more than SPPT

A. McCabe: under which conditions do we experience cancellation of perturbations?
M. Raschendorfer: the parametrisations have different roles, convection and turbulence can act in opposite ways, so that the perturbations cancel. M. Koehler: partly responsible could also be the saturation of the error growth. (and: how to diagnose the error growth saturation?)

G. Craig: due to the tuning present in the models, differences in the behaviour are expected testing a scheme in a single-column model and in the 3d model.

F. Bouttier: do we have enough observations to evaluate which method works and for which scale/weather type?

G. Craig: how much of the stochasticity should be in the model? How much of what is made with a model for the more error can be made instead in a post-processing, considered that some methods can be quite expensive?

The final discussion was introduced by A. McCabe and M. Arpagaus, who presented a list of open issues they collected during the two days:

1. <u>Systematic Errors vs Random Variability</u>
Systematic errors can be present at all scales (related to epistemic uncertainty); random variability is primarily associated to unresolved sub-grid scale processes (aleatoric uncertainty)

- Do we agree that intrinsically stochastic parameterisation schemes should primarily model random variability?
- How should we treat epistemic uncertainty? Can we (given we lack the knowledge)?

- Is there a consensus that we are all ‘more comfortable’ with physically based schemes (e.g. perturbed parameter and stochastic parametrizations as opposed to SPPT)?
- We have had talks on perturbed parameter schemes, stochastic parametrizations and modelling model error. Each are motivated to address different kinds of errors. Do they end up doing similar jobs in an ensemble? How do we expect them to interact? Do we think our future research should concentrate on one in particular, or all?

2. Error Growth & Decorrelation Timescales

- Is error growth in mesoscale models fundamentally different than in global models?
- And if so, can that explain why small-scale models seem to be happy with SPP only, whereas in coarse models, one needs stronger perturbations (and larger decorrelation length) as provided by e.g. SPPT? (However, M. Leutbecher showed that SPP can be as effective as SPPT)
- What is the interaction between random variability and larger scale deterministic / climatological variability (e.g. synoptic systems)? Can we relate the difficulties of error growth at the convective scale to other ‘grey zones’ at different spatial scales?
- Are there simple experiments we could do to help improve our understanding of error growth at the convective scale?
- Why do some perturbations need surprisingly large scales to be effective?
- What are the optimal length scales for spatial patterns at the convective scale?
- How does error growth change for strongly and weakly forced regimes?

3. Where should we focus future work?

- Machine Learning
- Stochastic parametrizations of convection and radiation. Are there particular processes that we need to represent stochastically? E.g. initiation of convection, organization of convection, problems with the frequency of light vs heavy precip. events, cloud cover?
- Model error
- Perturb the dynamics?

4. How are we evaluating the ensemble? Are the stochastic approaches better than a post-processed ensemble?

- Not explicitly talked about but important to all of us

J. Berner: in the work by H. Christensen (Constraining stochastic parametrisation schemes using high-resolution simulations; rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.3717; 2019) high-resolution data are coarse-grained to find the spatial scale for the SPPT and iSPPT perturbations. The method has been proposed in the framework of a project launched by PDEF and WGNE of WMO aiming at validate the high-resolution models. A dataset (based on ICON at 3km resolution) will be distributed to the partners, in order to have the same dynamics. Single Column Models will be used in the different set-up, after a coarse graining of the data at 22 km. Output will be the pdf of the subgrid-scale variables.
J. Berner also reports their plan to test the usage of data assimilation increments to estimate the scale of the errors.

M. Arpagaus: the stochastic schemes address the smaller scale uncertainty, by describing subgrid scale processes, while the schemes representing a bulk effect address larger scale uncertainty. Both need to induce an upscale of the perturbations, otherwise they die out.

F. Bouttier expresses the conceptual gap between the stochastic schemes, where the stocasticity is based on physical knowledge, and the model error manifesting in the forecast error, which instead contains several processes we ignore.

M. Leutbecher highlights the problem that the model error and of the initial condition error usually overlap in our estimates

A. Hally describes their experience at Met Eireann (E. Gleeson) about the use of Machine Learning to derive Roughness Length: the classification algorithm provides a RL estimate, but the estimate of the uncertainty associate is still not satisfactory. There was also a comment that Machine Learning for the moment seems to be confined to trying to improve physics parameterisations, DA and post-processing, whereas its use for getting a handle on model uncertainties is as of yet not that developed.

F. Bouttier underlines that for a robust estimate of the relation between spread and error we need to mix different weather regimes, therefore it is not possible to see where and how we benefit from the different types of perturbations. A. McCabe reaffirms the importance of a stratification of the sample on the basis of the weather regime, including the difference between weak and strong forcing conditions. F. Bouttier suggests to try Machine Learning techniques applied to clustering for the regime identification for such a purpose. G. Craig adds that the discrimination between weak and strong forcing is also dependent on the region considered.

M. Leutbecher proposes to formulate a concise definition of “intrinsically stochastic parametrisation”, independent from the history of the scheme, but focussing on its properties. What are the characterising properties of what we call “intrinsically stochastic”?

- A. McCabe: a scheme which tries to represent something known the be intrinsically stochastic
- M. Tsyrulnikov: a scheme where we try to model the uncertainty at its origin. In a complex multi-scale system, even a very simple original uncertainty develops, in the forecast, into a hugely complex uncertainty pattern. Therefore, it is better to try to tackle the uncertainty at its origin, where there is a chance it can be easily modelled.
- G. Craig: also SPPT can be considered an intrinsically stochastic parametrisation, but we do not know a parametrisation of what! On the other hand, the Mellow-Yamada scheme can be considered a stochastic paremetrisation, since it provides a prediction of the variance. When we introduce stochasticity in the model, do we introduce it in the process where we think it belongs or do we introduce it in a process different from the one of which we are trying to estimate the uncertainty? [C. Marsigli: similar to the old singular vector debate: do we perturb the initial conditions where we know that have errors or where the perturbations grow best?]
- M. Whitall: in the intrinsically stochastic parametrisations the uncertainty is an uncertainty of the subgrid process and it is introduced at the subgrid scale, while in the other methods it is an uncertainty in the scheme itself and it is introduced “somehwehere” in the model or in the scheme.
- D. Mironov: it should be distinguished between applying the stochasticity as a “trick” or as a mean to restore based on principles what we miss in the truncations.
- C. Marsigli: the definition of what is a stochastic scheme is also a matter of scale, since what is a subgrid process depends on the scale to which the model is applied

M. Leutbecher concludes by remarking that the aleatoric uncertainty is associated with the many subgrid-scale states associated to the same grid-scale state. However, since we do not have a perfect paramterisation even for the mean state, we are still addressing the epistemic uncertainty. Likely the latter will be reduced as long as the former is developed. Anyway, it is not possible yet to develop the two components independently from each other.

M. Tsyrulnikov: ideally, any module in the observations-assimilation-modelling chain (a physical parameterization scheme or a numerical scheme etc.) should not produce just one deterministic output. It should inform the modules "down the road" about the uncertainty of its output. Then, the estimate of the uncertainty will build up in the system gradually and naturally, leading to justified rather than tuned ensembles.

A good final remark to close the Workshop, is therefore this recommendation:
“Always provide, together with a statement, both in the science and the life, an estimation of its uncertainty”.