Program LEFE/ MANU	Project Title : IPSIPE Identification Physico-Statistique des Incertitudes en Prévision d'Ensemble	Years 2020-2022

PI: François Bouttier, francois.bouttier@meteo.fr
Participating Laboratory : Centre National de Recherches Météorologiques UMR3589

Context : meteorological predictions exhibit forecast uncertainties, which need to be quantified using ensemble predicition techniques. We have developed a scientific approach for improving the numerical modelling of uncertainties, to improve the value of weather forecasts.

Scientific objectives : a novel uncertainty modelling approach was explored, based on calibrated stochastic physical parametrizations. The main question was to clarify if known subgrid (or unresolved) physical processes had a significant impact on the skill of weather forecasts, with emphasis on kilometric-scale cloud and turbulent processes.

Main results :

Numerical experiments were performed with the operational AROME atmospheric model, using its 1D-column and 3D operational versions. A numerical representation of physical uncertainties was implemented as stochastic noise sources in the AROME parametrizations of subgrid turbulent mixing, subgrid convection, and radiation interaction with cloud microphysics. Stochasticity in turbulence was designed to represent the random impact of subgrid vortices in the boundary layer, using 1D turbulent mixing theory. Stochasticity in convection was designed as a probabilistic perturbation of the updraft equation, calibrated against high resolution LES (large eddy simulation) reference experiments with explicit convection (Figure 1). This allowed to represent the effect of a population of clouds in each active AROME model column. The impact of uncertain radiative processes was represented by perturbations to the equation of the radiative effect of cloud condensates. Some complementary experiments have studied the impact of perturbing AROME tuning parameters, such as the impact of aerosol concentration in radiative fog.

The importance of each stochastic process was measured using idealized test cases of characteristic weather regimes : daytime cumulus convection, stratocumulus layer over the ocean, nighttime radiative fog development, summer thunderstorms over Europe. It was also compared with other proposed approaches of uncertainty representation in numerical atmospheric models, such as SPPT (stochastic perturbations of physics tendencies) and SPP (stochastically perturbed parameters). Our physics-based representation was found to have a significant impact in the boundary layer, but it is only significant in some weather regimes and for some variables.

As a complement to stochastic physics, two other ensemble perturbation methods have been studied in terms of their ability to represent model uncertainties:

The SPPT approach was found to be effective in convective situations, particularly in the boundary layer (Figure 2), and we have found that its numerical behaviour can be stabilized by employing and improve "independent SPPT" (iSPPT) approach that decorrelates the ensemble perturbations between weakly coupled physical processes.

The SPP approach was found to be generally competitive and perhaps easier to implement than other schemes, particularly if it is extended to parameters whose impact was generally neglected in previous studies. In order to make SPP more effective, we have developed a new method to calibrate the associated noise generator in order to minimize the production of unphysical model biases by SPP in weather forecast models. This method works by inverting the mapping between the PDF (probability density function) of the noise generator in the ensemble prediction, and the PDF of the forecasted weather variables. The PDF inversion is learned in a bayesian way for the AROME-3D model using a large offline ensemble of AROME-1D predictions.

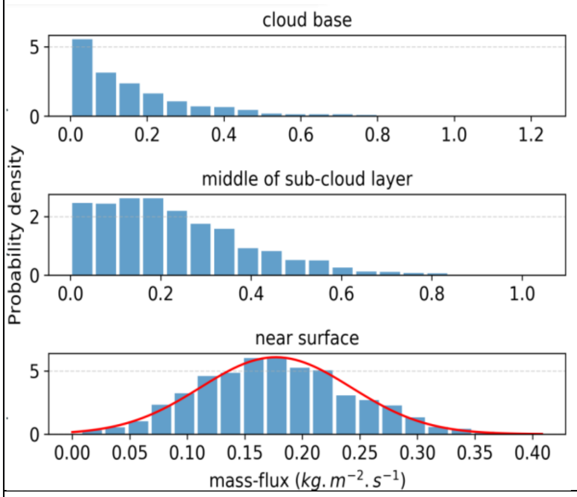	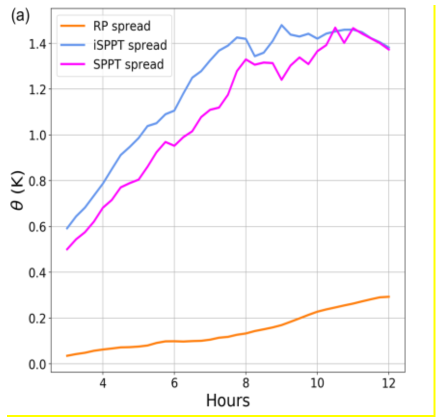

Figure 1 (gauche) : (tirée de la soutenance de thèse d'A. Fleury, 2022) distributions de probabilité du flux de masse convectif à trois niveaux verticaux, estimées à partir d'une simulation LES, pour injection dans la paramétrisation de convection stochastique AROME
Figure 2 (droite): (tirée de Bouttier et al 2022) comparaison entre les dispersions de prévisions d'ensemble de température potentielle dans la couche limite sur un cas de convection diurne, pour 3 schémas de perturbation de modèle (RP càd SPP, SPPT et iSPPT comme expliqué dans le texte).

Future of the project : these developments are being considered for implementation as perturbation schemes in operational weather ensemble prediction systems.

Number of publications, communications and theses:
3 articles (2 accepted, 1 submitted), 1 PhD thesis , 7 communications.

peer-reviewed publications :

Bouttier, F., A. Fleury, T. Bergot and S. Riette, 2022: A single-column comparison of model error representations for ensemble prediction. Bound. Layer Met., 183:167–197, *published online 24 Jan 2022*. https://doi.org/10.1007/s10546-021-00682-6 and https://hal.archives-ouvertes.fr/hal-03806323

Fleury, A., F. Bouttier and F. Couvreux, 2022: Process-oriented stochastic perturbations applied to the parameterization of turbulence and shallow-convection for ensemble prediction. *Quart. Jour. Roy. Met. Soc.*, **148** (743) 981-1000, *published online 1 Feb 2022*. https://doi.org/10.1002/qj.4242 and https://hal.archives-ouvertes.fr/hal-03558571

Fleury, A., F. Bouttier and T. Bergot, 2024: Calibration of parameter perturbations for ensemble prediction using an inverse problem. Submitted to *Mon. Wea. Rev.* on 12 Feb 2024.

thesis:

Axelle Fleury: université de Toulouse, "Approche physique des erreurs de modélisation en prévision d'ensemble atmosphérique" started Oct 2019, defended on 16 Dec 2022. https://hal.science/tel-03990894/

communications:

- Eumetnet SRNWP-EPS workshop, 2020
- ateliers de modélisation de l'atmosphère, 2021
- European Geophysical Union, 2021
- COSMO consortium workshop, 2021
- ACCORD-EPS working week, 2022
- ECMWF workshop on model uncertainty, 2022
  - ACCORD working week, 2023

Data availablility

The project data is available upon reasonable request to Météo-France.