Process-oriented perturbations of turbulence and shallow-convection applied to the AROME model

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Two perturbation methods are tested in a 1D-version of the AROME model to study their ability to produce ensemble spread in various idealized cases. The results are compared with the spread produced by SPPT (Stochastically Perturbed Parameterization Tendencies), which is the operational method currently used to perturb the model's physics in the regional ensemble prediction system AROME-EPS of Météo-France (Bouttier et al. 2012).
The motivations of this study are to investigate new ways of perturbing the model's physics, relying on stronger physical basis by focusing on given physical processes and their uncertainty.

Two processes are perturbed : turbulence and shallow-convection. For turbulence, the perturbation method of Kober and Craig (Kober and Craig 2016, Hirt et al. 2019) is used (hereafter referred to as KC16). It consists in an additive noise applied to temperature, humidity and wind tendencies produced by the turbulence parameterization scheme. The amplitude of the noise is controlled by the variables subgrid variances diagnosed by the turbulence scheme.
For shallow-convection, starting from Sakradzija et al. stochastic convection scheme (Sakrazija et al. 2015, 2016, Sakradzija and Klocke 2018), a stochastic closure of the mass-flux parameterization scheme of Pergaud et al. (2008) is implemented, based on coarse-graining of Large Eddy Simulations (LES).
Both perturbations are applied to obtain ensembles of single-column model (SCM) runs for several idealized cases. The new perturbations are referred to as PSP (Physically-based Stochastic Perturbations) following Kober and Craig's notation.
In order to compare PSP with SPPT, ensembles of SCM runs are also produced using SPPT, for the same cases. In order to make fair comparisons, SPPT is applied only to the sum of turbulence and shallow convection tendencies instead of the sum of all the physical tendencies.

Simulations of the following idealized cases have been used:

- **cumulus :**
  - ▹ ARMCu : : diurnal cycle with the development of a shallow cumulus cloud over a continental area (Southern Great Plains region, USA), (Brown et al. 2002)
  - ▹ SCMS : development of a shallow cumulus cloud in the trade wind region (Florida, USA), (Neggers et al. 2003)
  - ▹ BOMEX : trade wind shallow cumulus under steady-state conditions over ocean (east of Barbados), (Siebesma et al. 2003)
- **stratocumulus :**
  - ▹ FIRE : subtropical persistent marine stratocumulus (off the coast of California,USA), (Duynkerke et al. 2004)
- **radiation fog :**
  - ▹ LANFEX : development of a radiation fog over land (Cardington, UK), (Price et al. 2018)

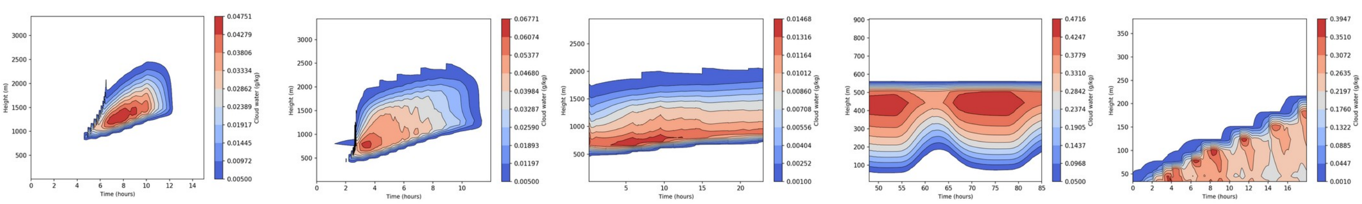

Figure 1. Evolution of cloud liquid water profiles in the 5 cases. From left to right : ARMCu, SCMS, BOMEX, FIRE, LANFEX. Note that the y-axis scale is not the same for all the graphs.

Summary of the results :

The impact of the perturbation method (either PSP or SPPT) on the cloud water content is found to vary greatly depending on the meteorological situation (figure 2).

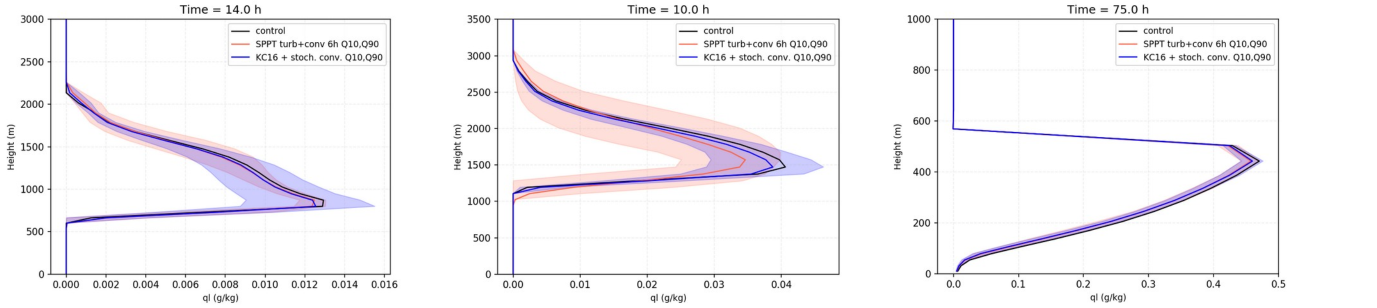

Figure 2. Specific mass of cloud liquid water (g/kg). From left to right : BOMEX, ARMCu, FIRE. The black line corresponds to the reference unperturbed AROME simulation. The orange line is the SPPT-ensemble mean, and the blue line is the PSP-ensemble mean. The shaded areas are the tenth to nineteenth percentile intervals.

PSP do not affect much the cloud top and base height, but have an impact on the liquid water content (q_L) inside the cloud, especially in the lower part of the cumulus clouds. SPPT on the contrary greatly affect the onset and development of the cloud, thus the impact of these perturbations is more visible in the ARMCu case where there is a strong diurnal cycle than in the BOMEX case which is under stead-state conditions. For the stratocumulus case, the spread is small compared to the liquid water content of the cloud for both SPPT and PSP-ensembles.

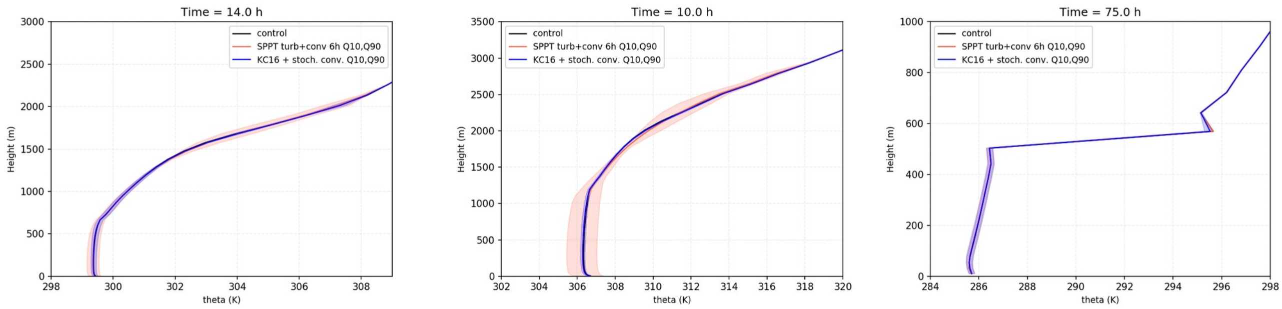

Figure 3. Same as figure 2 for potential temperature (K).

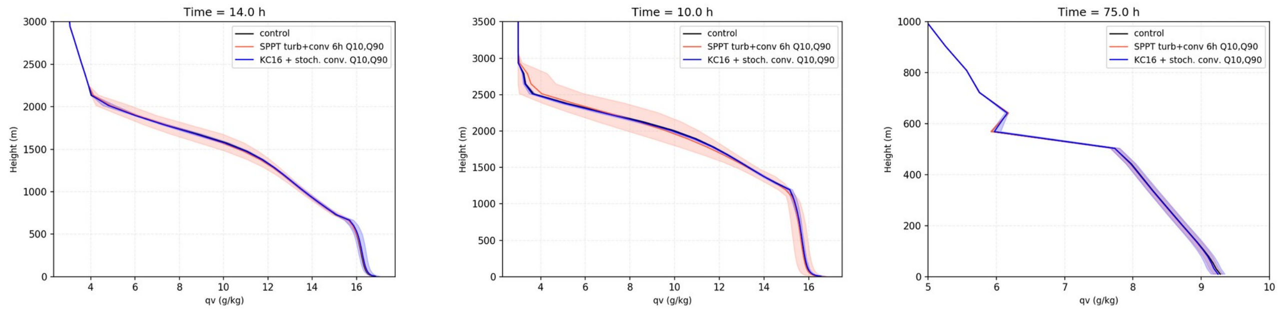

Figure 4. Same as figure 2 for specific humidity (g/kg).

In general, PSP produce lower temperature and humidity spread than SPPT, except in the stratocumulus case (figures 3 and 4). Several possible reasons have been identified :

1) KC16 perturbations added to temperature and humidity are quite low because the subgrid variance values are quite low in well-mixed layers, except for high values close to the surface.

2) The stochastic convection scheme has a limited impact on the environment temperature and humidity profiles, and rather affect the cloud water content through the mass-flux of the parameterized updraft and its thermodynamic characteristics.
3) The temporal correlation of the noise has a high impact on the accumulated perturbations. It is set to 6 hours for SPPT, whereas it is of 10 minutes for KC16 and 40 minutes for the stochastic convection.

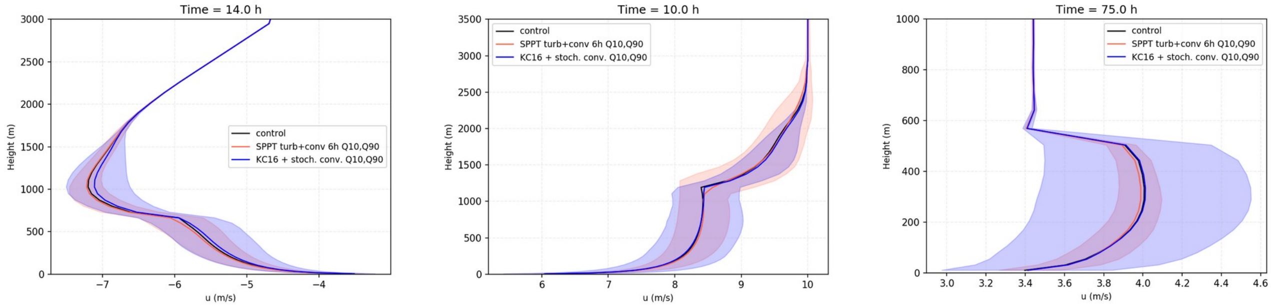

Figure 5. Same as figure 2 for zonal wind (m/s).

On the contrary, the wind spread in PSP ensembles is generally greater than in the SPPT ensemble (figure 5), for all the cases studied. This is linked to high KC16 perturbation values compared to the wind tendency values. These strong perturbations are due to the wind subgrid variances values which directly depend on the turbulent kinetic energy.

The results for the SCMS case are very similar to those of the ARMCu case, and are not shown here. The impact of PSP on the radiation fog case (LANFEX) is very limited, because the main physical processes governing this situation are radiation and microphysics processes. This motivates further research on perturbation methods targeting these processes.

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