First and second derivatives for future use in AROME physics

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1) Motivations - Introduction.

The AROME[7] numerical weather forecast model is a limited area model (LAM), whose code organization is based on the assumption that the best cost/benefit is gained from only treating the vertical sub-grid scale physical processes. Thus, the physical parameterizations do not have any information from neighboring columns. This organization allows a highly optimal distribution of the operations on the supercomputer. However, in recent years more and more parameterizations have appeared which require the use of horizontal gradients. They appear in particular with turbulence over complex terrain (cf. Goger et al.(2018)[3]), in deep convective clouds (cf. Verrelle et al.(2017)[8]) or at high resolution where the assumption of horizontal homogeneity may not be valid (cf. Honnert and Masson (2014)[4]). AROME would then lose the possible benefit of such parameterizations. The idea of this work is to recover the horizontal gradients calculated in the semi-Lagrangian dynamical scheme and to make them available for use in the physical parameterizations.

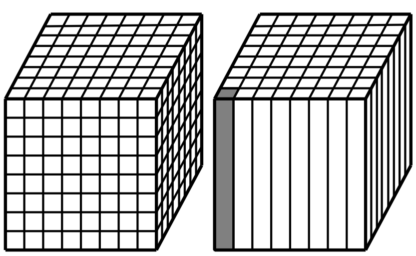

Figure 1: On the left, LAM 3D dynamical core. On the right, the purely vertical information transport in the model sub-grid parameterizations.

2) Computation

Geographic information does not exist in the physical part of the model. It does exist in the dynamic part, however, it is distributed on different processors according to Figure 2. The semi-Lagrangian advection scheme needs this information which circulates from one processor to another via a semi-Lagrangian halo (see Fig. 2 and IFS technical report[2] for more details). In the current work, the mechanism of the semi-Lagrangian halo has been used in order to compute horizontal gradients of all parameters (cf. Fig. 2). Only direct neighbors are need, thus the halo is one grid space wide. The structure of the halo is defined as in the fullposs software[9]. However, the halo is used when the water mixing ratios (grid point parameters) are declared and computed, in order to be able to compute mixing ratio horizontal gradients as needed in Verrelle et al.(2017)[8]. Then, the horizontal gradients are transported from one routine to the next by the AROME physical interface.

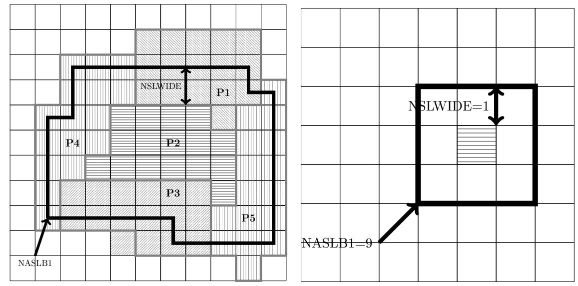

Figure 2: On the left, schematic representation of the semi-Lagrangian halo inspired from IFS technical report[2]. On the right, use of this semi-Lagrangian halo for computation of horizontal gradients. P1 to P5 represent groups of grid cells distributed on different processors. NSLWIDE is the width of the halo for P2 and NASLB1 is the total number of points.

3) First Results

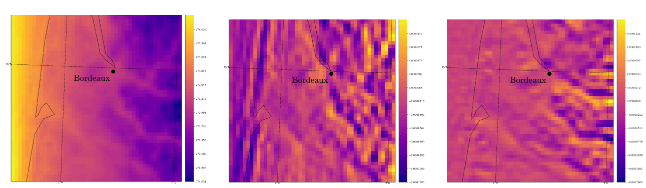

Figure 3: Temperature (T), $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ at the first level of the domain (April, 21st 2020)

The first tests have been made in a AROME toy model of 15 levels over the South-West of France, with 1, 2 and 4 processors. One can see the domain around the city of Bordeaux in Fig. 3, 4 and 5. All the parameters presented hereafter are computed in the dynamical core of the model and extracted in the AROME physical parameterization part. One can see that zonal and meridional horizontal gradients of potential temperature (Fig. 3) and water vapor mixing ratio (Fig. 5) are consistent, as well as the first and second order gradients of meridional wind (Fig. 4).

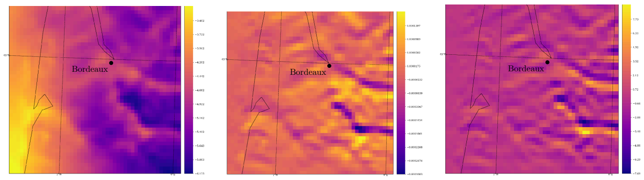

Figure 4: Idem Fig. 3 for the meridional wind (v), $\frac{\partial v}{\partial y}$ and $\frac{\partial^2 v}{\partial y^2}$

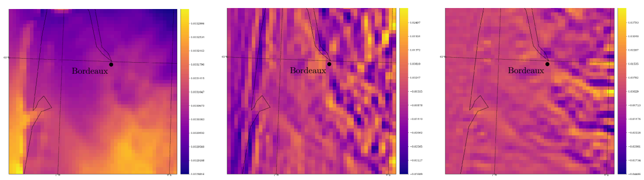

Figure 5: Idem Fig. 3 for water vapor mixing ratio (r_v), $\frac{\partial r_v}{\partial x}$ and $\frac{\partial r_v}{\partial y}$

Secondly, AROME cycle cy48 has been tested at 500 m and a time step of 15 s in a domain over the Alps (see Fig. 6) which is a difficult area of the France domain due to high mountains and steep slopes. It appears that the code modification is robust.

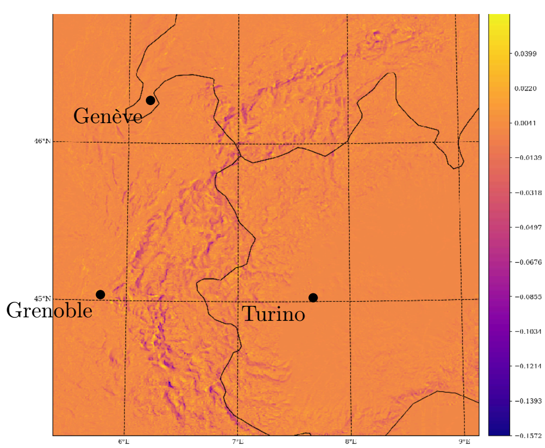

Figure 6: Wind divergence at around 40 m high (level 88).

4) Conclusions and Perspectives.

Over complex terrain at kilometre scales, the full three-dimensional effects have been found to be important in the shear production term for TKE (cf. Goger et al.(2018)[3]). Goger et al.(2018)[3] therefore proposes an extension of the 1D prognostic TKE equation used in the COSMO (COnsortium for Small-Scale Modeling) model turbulence scheme because that scheme otherwise underestimates the TKE. The 1D form considers only the contributions to shear production from vertical gradients of horizontal winds, but Goger et al.(2018)[3] supplement this with a further contribution of TKE containing horizontal gradients of the velocity. With the proposed changes, this is not very easily implementable. Otherwise, Verrelle et al.(2017)[8] propose to increase the mixing into the cumulus deep clouds by adding turbulence terms from Moeng et al.(2010)[6], which are horizontal gradients of the total mixing ratio and the potential temperature. Such gradients are not computed yet in the current version of the code. Finally, a complete transformation of the 1D turbulence scheme of AROME (cf. Cuxart et al.(2000)[1]) into a 3D scheme as in Meso-NH[5] would demand the computation of the horizontal divergence of the turbulence flux inside the physical parameterizations, which is not possible with this version of the code.

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