Ways to address the issue of compensating errors in physical parameterizations

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June 2001

Compensating errors ?

What do we call compensating errors ? Let us look at an example on the temperature equation, as it appears in most of the deterministic models :

$$\frac{\partial T}{\partial t} = -\left(\vec{u} \cdot \overrightarrow{\mathrm{grad}}\right) T + \frac{RT}{c_p} \frac{\omega}{p} + T_{rad} + T_{prec} + T_{vd} + ...$$

The temperature tendency is given by the sum of several terms like here radiation, precipitations, vertical diffusion, etc... It is thus possible to make a good temperature prediction while overestimating absorption due to solar radiation for example, and simultaneously underestimating the latent heat release from precipitation processes : it is a compensating error.

Now, where modelers make changes in their prediction systems in physics, dynamics or data assimilation systems, the first think they do is to control that biases remain low, and if not they proceed to "tunings" which are very often done on the physical parameterizations.

There is here a big risk then to correct an existing bias while modifying the wrong parameterization, increasing in that way a compensating error.

Today, most of the global prediction models have quite low biases, but they came to that point with their own approach, depending on the problems they had to solve, on the urgency of these problems, and operating the modifications on the subjects for which people working at that time in the service had skills to.

But what is the magnitude of these compensating errors today ? An idea to estimate it is to compare predictions from different models, using diagnostics coming from the individual physical processes.

This what we did in 1997 with Pedro Viterbo from ECMWF : inside the frame of the Arpege-Ifs collaboration the French model Arpege and the european model

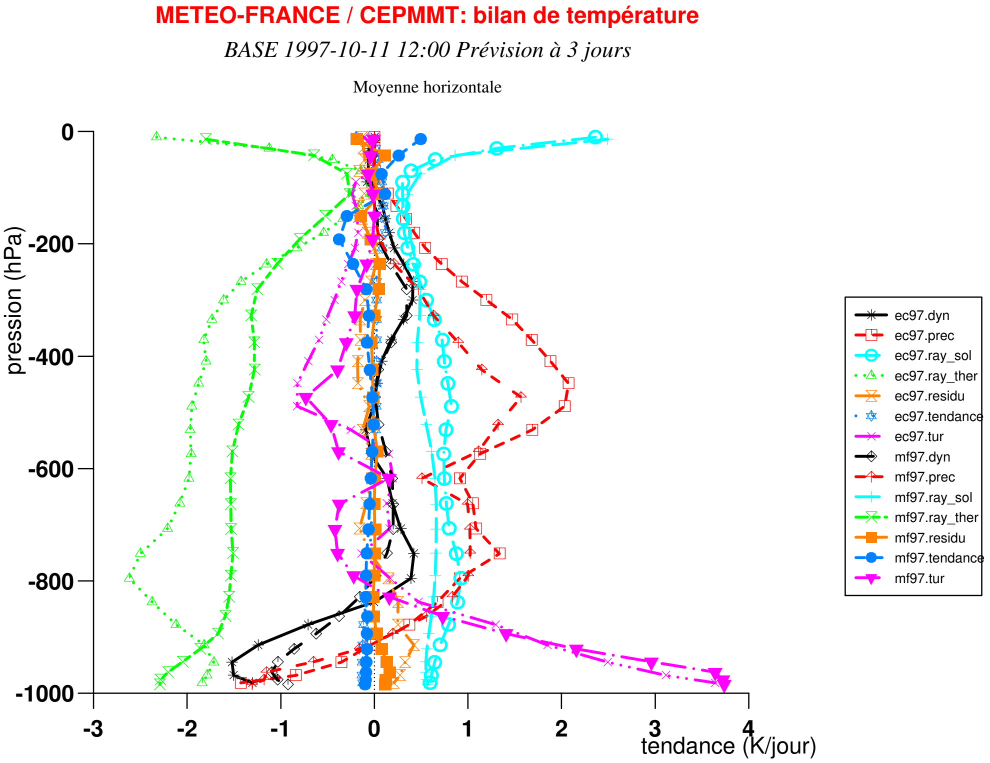

FIG. 1 – Temperature budget ECMWF / MÉTÉO-FRANCE. "ec97" : ECMWF model (IFS) ; "mf97" : MÉTÉO-FRANCE model (ARPEGE) ; "dyn" : dynamics ; "prec" : precipitations ; "ray_sol" : solar radiation ; "ray_ther" : infra-red radiation ; "tur" : vertical turbulent diffusion ; "tendance" : total tendency ; "residu" : terms not available to grid-point diagnostics : horizontal diffusion, semi-implicit, etc...

IFS share the same tool to get prognostic variables budget, simplifying in that way a comparison concerning many individual terms !... What we did is to run a 3 days prediction, one with the IFS the other with the ARPEGE, both in operational configuration. The complete budget of temperature in global horizontal mean[1] is on figure 1.

What do we learn from this graphic ? First, that important compensating errors exist !... For example heating due to solar radiation absorption is 30% bigger in the ECMWF model than in MÉTÉO-FRANCE, and this is true at many levels !... Let us recall that this result is significant since it is a global mean in a 3 days prediction. If one looks at the heating due to precipitations the difference is even bigger : the ECMWF model latent heat release is twice the MÉTÉO-FRANCE one around 300 hPa !... For infra-red cooling to space, the difference is about $1\,K/day$ around 800 hPa !... Neither Pedro Viterbo nor me were expecting so strong differences between the two models at that space and time scale !...

[1] One uses the global horizontal mean in order to "pack" the information, allowing to put all results on the same graphic.

These errors are compensating ones as one can see on the graphic : the total tendency difference between the two models is quite small [2]. Around 400 hPa for example, the ECMWF model precipitation heating is much stronger than the MÉTÉO-FRANCE one, and this is compensated but more infra-red cooling and vertical diffusion.

But even if these errors are compensating ones, every time there is a difference on a given physical term, one of the models at least is wrong !... Let us take two examples :

1. Knowing for example that the ECMWF model tends to overestimate precipitation fluxes[3], one can guess that the difference between ECMWF and MÉTÉO-FRANCE on precipitations between 200 and 400 hPa is probably an ECMWF bias.
2. If one looks at infra-red radiation, knowing from other sources (temperature biases in the PBL during clear winter nights) that our radiation scheme tends to underestimate the greenhouse effect from the upper atmosphere on the PBL, one can guess that the difference between ECMWF and MÉTÉO-FRANCE on this radiative cooling is probably a MÉTÉO-FRANCE bias.

But the aim here is not to enter into the details about the tracks to solve the existing biases from the above budget, but simply to show that significant compensating errors in the physics exist in present NWP models. Let us now briefly propose some ways to address this issue of compensating errors.

Isolating processes / scales

In **model intercomparisons** all variables and fluxes are available in an "easy to compare" form. Every difference between two models indicates then an error in at least one model, at this time and space scale. But few model intercomparisons address the reasons explaining the existing differences. A new approach for model intercomparisons is to compare large scale models using bulk approaches or parameterizations to finer mesh models dealing with the same process in an explicit way : for example intercomparisons between NWP (Numerical Weather Prediction) models or GCM (Global Climate Models) versus CRM (Cloud Resolving Models).

The **model to satellite approach** : satellite data allow to address finer time and space scales than ground based observed data or radiosond data do. It is also a good tool to make validations over areas lacking for conventional observations. Figure 2 has for example been used to compare model humidity over Indian Ocean to water vapour imagery.

Single Column Modelling is an efficient tool to isolate problems from the physical parameterizations : firstly physics is isolated from the dynamics, which is observed and forced. Secondly observational datasets deal with meteorological archetypes (clear sky, stratocumulus regions, convective, etc...) and this reduces the number

[2] see the two dark blue curves on the graphic

[3] the global surface precipitation rate from ECMWF is 3.5 mm/day, but climatologies indicate a value about 2.7 mm/day.

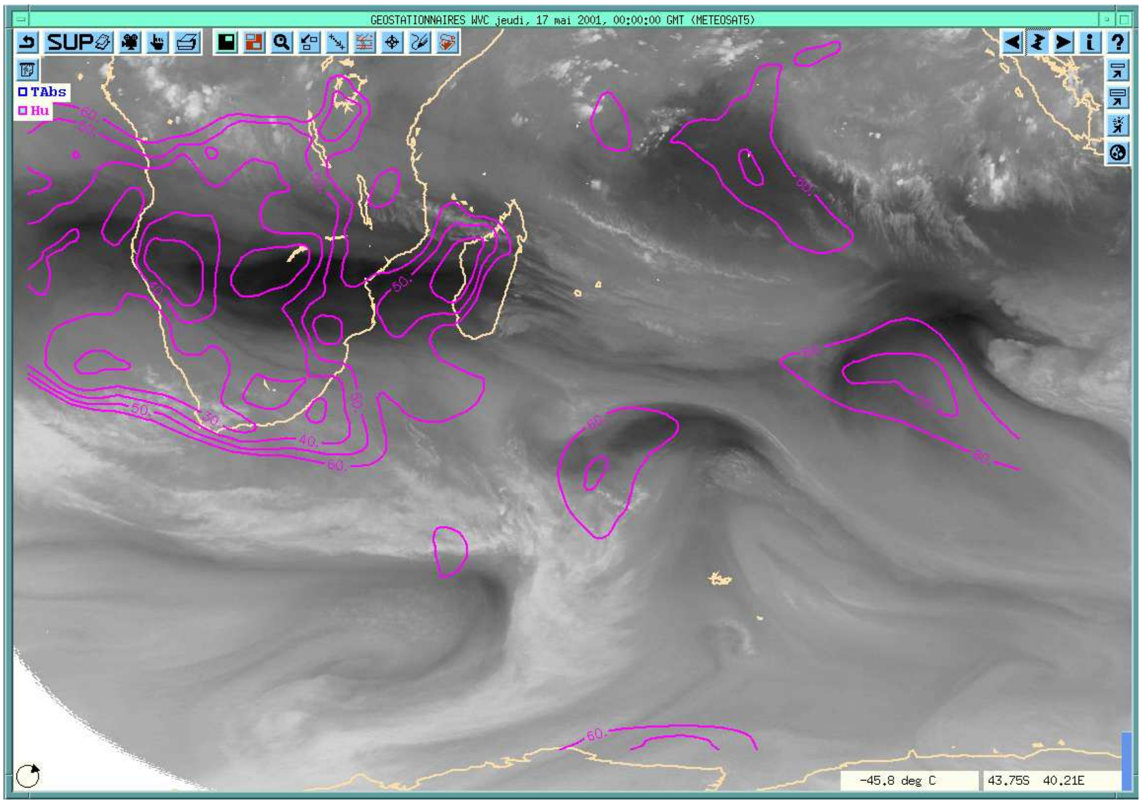

FIG. 2 – ARPEGE relative humidity compared to METEOSAT 5 water vapour imagery.

of significant processes involved. Finally observed fluxes are available, and fluxes address in a more direct way parameterizations than state variables do.

Magnitude and even sense of many feedbacks in the atmosphere strongly depend on the time and space scale involved. This is also the case in models : magnitude and even sense of the feedbacks depend on the resolution, and finer meshs allow new feedbacks to appear. But fine mesh results interpolated at the coarser mesh should lead to close results to those of the coarse mesh model run. So **changing the model resolution** is a way to validate the feedbacks inside the physics or between physics and dynamics. The figure 3 shows the different frames in which the ARPEGE-ALADIN can be used.

Finally studying model predictions under **slowly varying forcings, focusing on when bifurcations occur**, is regarding for the physics. For example the beginning of showers in the diurnal cycle in the tropics, or the transition between stratocumulus, cumulus and cumulonimbus for a path going from marine anticylonic regions to trade winds and then into the ITCZ.

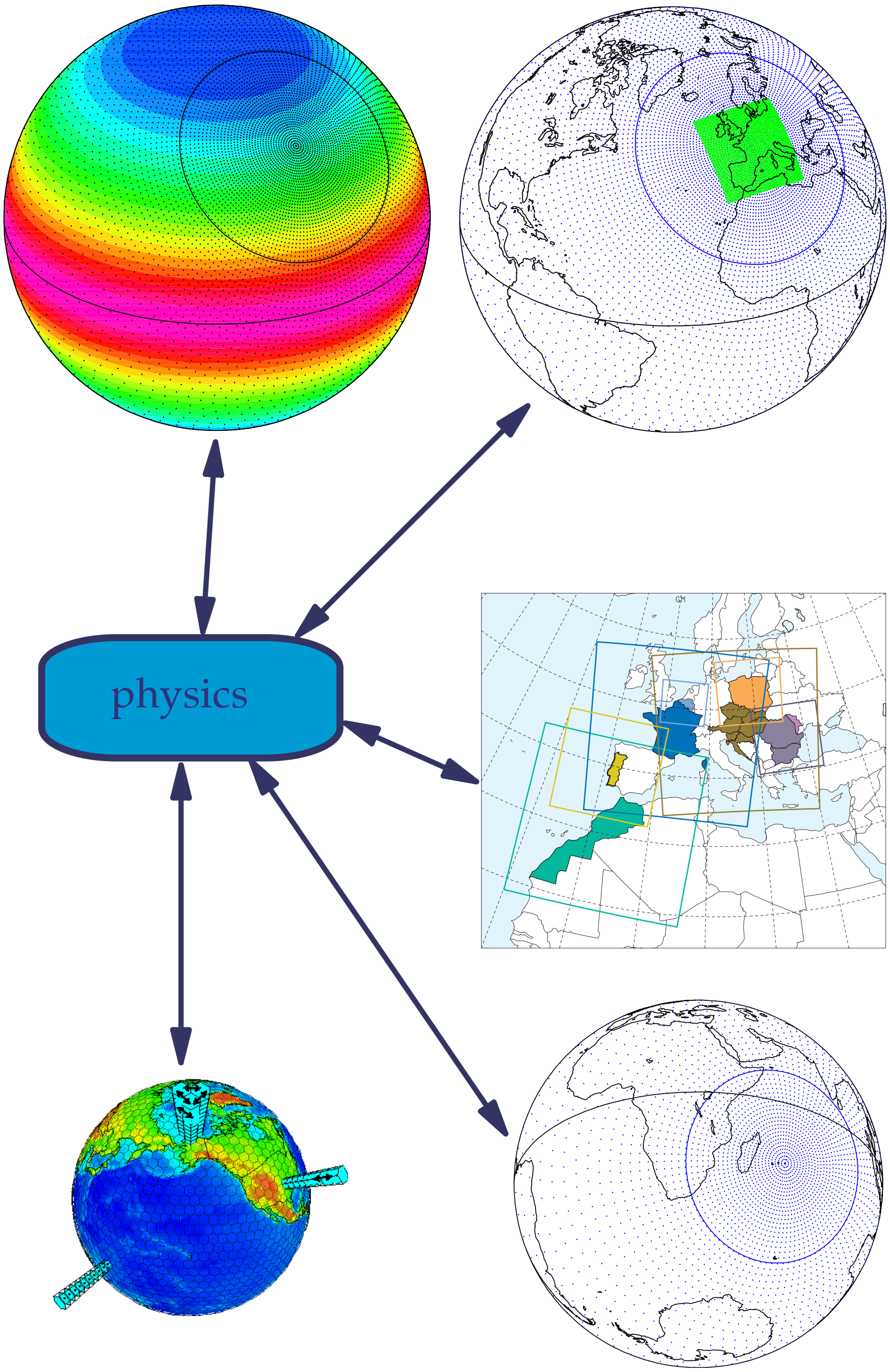

FIG. 3 – The ARPEGE-ALADIN physics can be used in many different geometries and at different resolutions : aquaplanet mode, stretched global grid, Limited Area Models, Single Column Modelling, etc...