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Physical processes in present and future large-scale models

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Summary

Introduction to parametrisation development – Anton Beljaars

Numerical weather prediction (NWP) has seen a quiet revolution over the years through a combination of improvements in model resolution, data assimilation techniques, usage of observations (e.g. from satellite) and model physics (Bauer et al. 2015). The relative contribution of each in the ECMWF system is difficult to quantify. Many improvements came as small incremental steps and often the full benefit of a particular development can only be seen later, after it has been optimized and interactions with other model components have been exploited. Another revolution is that in the early days of NWP, forecasters still made their own interpretation of weather, whereas current practice is to make use as much as possible of physics related model output, sometimes after application of bias correction. Examples of physics parameters are cloudiness, precipitation, precipitation type, screen level temperature / humidity, but also more exotic parameters like radiative and turbulent fluxes, convective stability indices, and boundary layer height. All these parameters have skill and are increasingly used in operational forecasting and research (e.g. Forbes et al. 2015; Seidel et al. 2014).

A parametrization scheme represents the tendencies due to a particular sub-grid process (e.g. clouds or turbulence) in the equations for large scale variables (e.g. wind, temperature and moisture). Such tendencies need to have realistic dependencies on large scale variables, e.g. clouds depend (although not exclusively) on relative humidity and turbulence depends on shear and stability. The challenge in parametrization is to develop schemes that represent these dependencies as realistically as possible. This is not necessarily the case yet; some dependencies may be poorly represented or may not even be known. It is sometimes thought that parametrization deficiencies lead to systematic errors, but errors are often flow dependent and result in apparent random errors. It is expected that in future more of the dependencies can be documented and included, leading to a reduction of flow dependent systematic errors. A few examples are illustrated.

The first example is the error structure of screen level temperature, which is influenced by many processes. It has systematic regional and seasonal patterns that are not well understood. It is speculated that errors are related to a combination of the effects of clouds, snow, land use parameters, and turbulent exchange. They all have substantial uncertainty and their own large scale error structure (Holtslag et al. 2014; Beljaars 2006).

The second example is about the introduction in the ECMWF model of a dependency of mass flux (and therefore convective precipitation) on environment moisture. This was a spinoff of the GEWEX Cloud System Studies (GCSS) project where Cloud Resolving Model (CRM) simulations were performed for a range of environment moisture settings. The study revealed a strong dependency, which did not exist in any of the parametrized schemes. After a major upgrade in the ECMWF model (Bechtold et al. 2008), the dependency on environment moisture reproduced the CRM simulations quite well, but more interestingly, it had a big impact on model characteristics: (i) model variability went up to a realistic level, (ii) large scale scores showed a modest improvement in spite of the increased activity, (iii) the initial perturbations in the ensemble system could be reduced by 30% because the internal variability of the model sustained a higher level of activity, (iv) the skill scores for the ensemble system were improved particularly for the 850 hPa temperatures, (v) tropical cyclone position errors were reduced by 15%, and (vi) MJO activity was improved shifting the useful MJO forecast range by 6 days.

The third example is about precipitation / evaporation feedback over land. The well-known study by Koster et al. (2004) has indicated a number of so-called hotspots over the globe where on the basis of model studies, predictability exists in the sub-seasonal time range due to memory of the soil moisture reservoir. This is mainly in semi-arid regions with a strong seasonal cycle of soil moisture and substantial control of soil moisture on evaporation. Also big differences between models were demonstrated, indicating that not all models may be optimal for seasonal prediction. Moisture budgets from ERA-I, indicate that in spring and summer, evaporation and precipitation are the dominant terms at mid latitudes. At the monthly time scale the atmospheric moisture convergence is slightly negative indicating that precipitation relies entirely on moisture that has evaporated from land. To get a feel of how precipitation over land responds to evaporation, classic sensitivity experiments were repeated (e.g. Rowntree and Bolton 1983; Beljaars et al. 1996). Integrations covering April to August were initialized globally at wilting point and at field capacity and the moisture budgets were considered at the monthly time scale. It turns out that at mid-latitudes, precipitation follows evaporation rather closely. Such sensitivity studies should be interpreted with caution as spring-time uniform wet and dry conditions are not very realistic, and the scale of interaction between land and atmosphere does play an important role (Taylor et al. 2007). However, there is a suggestion that a strong positive feedback exists in the ECMWF model between precipitation and evaporation (precipitation fills the soil moisture reservoir, which increases evaporation, which supplies moisture to precipitation). It also raises the question whether a model that links precipitation closely to evaporation can create anomalies e.g. drought? To ensure that a model faithfully represents nature, it will be necessary to investigate whether the two branches of the feedback are realistic namely (i) does precipitation respond realistically to evaporation, and (ii) does evaporation respond realistically to soil moisture and precipitation? These questions can only be answered by the analysis of observations or high resolution simulations of convection (see Dirmeyer in this seminar). Finally, a few examples were given of future new directions of parametrization development:

1. Use of satellite data, sensitive to hydrometeors in a NWP environment. The NWP environment is extremely attractive for model development because it allows separation of parametrization errors and errors in synoptic development. An example was shown of a 12-hour forecast with liquid water biases in frontal zones as seen from microwave satellite channels.
2. Parameter optimization using data assimilation techniques. There are different techniques for objective parameter optimization (Järvinen et al. 2012; Laine et al. 2012; Ollinaho et al. 2013) including 4DVAR with a control vector that includes model parameters. This will be particularly relevant for land surface related parameter fields that are poorly constrained (e.g. thermal coupling coefficients, soil properties and vegetation characteristics).
3. High resolution modelling over large areas is becoming feasible (e.g. Schalkwijk et al. 2015). It will allow the study of processes in support of parametrization development not only in the areas of convection and orography, but also for boundary layer processes (e.g. meso-scale shear may be the missing element in current turbulence schemes).

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