The representation of convection in the ECMWF forecast systems: progress, problems, and prospects

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Introduction

This presentation will review recent progress and activities at ECMWF in the area of convective parametrization, will identify and discuss some specific problems and issues, and will discuss some areas of new and/or promising research in the representation of convective processes. The talk will consider convection in the context of both forecasting and data assimilation, and also aspects of the ECMWF model 'climate' as revealed by ensembles of seasonal timescale forecasts both coupled and uncoupled.

Operationally ECMWF runs global models and data assimilation at a wide-range of horizontal resolutions (and timesteps) from ~200 kms down to ~40 kms with testing at ~25 kms ongoing. This puts great demands on the efficacy, robustness and economy of the model physics not least the convection scheme.

Recent improvements to the operational convection scheme

From operational monitoring it had become evident that in some situations (mainly in summer) unrealistically high precipitation was produced by the model over land, and particularly over the USA. In these cases model precipitation was dominated by large scale condensation accompanied by strong ascent (~1 m/s) over a small number of grid points. When this occurs during the first guess computation, it is harmful to data assimilation as the resolved ascending motion creates large divergent flows in the upper troposphere, which do not fit the observations.

Further diagnosis revealed that the convection scheme failed to be sufficiently active in night time situations. This was traced back to the lack of convection activation when the lower levels are stable. In the current convection scheme, activation of deep convection is only possible from the lowest model level, otherwise the so-called 'midlevel' convection should take over, but midlevel convection is rather weak with the current closure. When the parametrized convection is not strong enough, the resolved motion results in overly strong precipitation events.

To alleviate these problems, the convection activation algorithm has been redesigned. Prior to the changes, the scheme made a decision on the occurrence of cumulus convection and its type: shallow, deep or mid-level, and cloud base values were specified. The scheme switched on if an undiluted parcel exceeds a negative buoyancy of 0.5 K at cloud base. The undiluted parcel ascent was also used for the type decision according to an estimate of cloud depth. Furthermore only the lowest level was tested in this manner.

The new formulation starts with an entraining plume from the lowest model level to test for shallow or deep convection depending on cloud depth, with deep convection requiring a minimum cloud depth of 200 hPa. For shallow convection the parcel is initialised with thermodynamic excess properties and a vertical velocity according to surface layer similarity. Then, mixed layer parcels (averaged over 30 hPa) are lifted with an entraining plume model (constant entrainment) from any level up to 300 hPa above the surface to test for deep convection thus enabling deep convection to occur when the lower layers are stable. The discrete cloud base is now set to the closest model level instead of the level below cloud base. Convective activity has also been increased by decreasing the water loading in the updraught. Furthermore, precipitation efficiency in the updraughts has been increased by 50% leading to less detrainment of condensate to the stratiform clouds. The entrainment rate was also increased.

The modifications to the convection scheme result in a systematic increase of the convective precipitation at the expense of large-scale precipitation . Because of the increased activity of the convection scheme, the atmosphere is better stabilized and the number of cases with extreme precipitation is substantially reduced. This is particularly noticeable in the first guess divergence and the 200 hPa height increments over N-America at 12 UTC. The then operational system showed many night-time events with strong vertical motion (up to 1 m/s), strong precipitation and excessive divergent flow in the upper troposphere. The resulting wind field was not supported by the observations, resulting in rejection of data and non-optimal performance of the data assimilation system. The new cycle reduces the extreme events by stabilizing the atmosphere through more active parametrized convection . The improved analysis over N-America is reflected in smaller wind errors over N-America in the 24 hour range and a downstream effect of improved medium-range forecasts over the Atlantic and Europe. These changes contributed largely to a much improved spring/early summer forecast performance this year.

Diurnal cycle

The diurnal cycle of convection over land has been studied in collaboration with Meteo-France in the context of the EU-funded EUROCS project (EUROpean Cloud Systems). Different versions of the convection scheme have been evaluated i) in Single Column Model simulations of an idealized continental convective case against Cloud Resolving Model data, and ii) in T159 (125 km) 40-day global integrations covering February 1999, against analysis, surface precipitation data, TRMM precipitation data and radiosonde data.

The conclusions from this study are that the model is not yet able to reproduce the observed daily maximum rainfall occurring at 15 LST over tropical South America and Africa, but typically produces maximum rainfall at 12 LST and also some early morning precipitation. However, with the latest model changes described above, the forecast mean thermodynamic structure shows only very small biases with respect to analysis and radiosondes. The sensitivity of the model to shallow convection has also been investigated (different shallow convective closures and entrainment/detrainment rates), but no significant impacts on the diurnal cycle were found.

A critical issue remains as to whether these deficiencies in the diurnal cycle are responsible for the systematic under-prediction of precipitation over S America and Africa that has been a long-standing error in the model climate.

Shallow convection

Shallow convection, or cumulus, in the traditional and more precise definition (as opposed to cumulonimbus!), is by far the most ubiquitous of convective cloud types, and observed over the global oceans about half of the time. In the Tropics it occurs over the oceans virtually throughout the year, and also over land in both the Tropics and extra-tropics (in the warmer seasons) where it substantially modulates the diurnal cycle of surface fluxes etc. Particularly in the Trades it is responsible for maintaining the vertical structure of temperature and moisture by cooling and moistening the upper part of the PBL, thus counterbalancing the warming and drying due to subsidence. It thus dominates the cloud cover and strongly influences the surface fluxes, including the momentum fluxes, and hence plays a critical role in determining the coupling of the atmosphere and ocean. Likewise, in the extratropics shallow convection is the dominant cloud type over the oceans in winter as cold, dry continental air flows out over relatively warm oceans. The shallow convection communicates the very large surface fluxes to the lower troposphere and hence to the baroclinic processes.

A few examples will be shown to emphasise the importance of shallow convection both on the climate and more suprisingly perhaps on the medium-range forecast performance. This will also serve to redress the balance somewhat since deep convection inevitably dominates forecasting issues (justifiably), and many tropical circulation and climate discussions (unjustifiably!).

Moist Advection-Diffusion PBL Parametrization

Stratocumulus cloud cover prediction still provides a challenge for many GCMs and NWP models including the current ECMWF model. Encouraging results will be shown from the development of a moist advection-diffusion PBL parametrization which has a unified treatment of both mass-flux and K-diffusion terms within a moist PBL. The mass-flux term represents the strongest updraughts and counter-gradient fluxes, while the conventional K-diffusion represents the small-scale turbulent motion and down-gradient fluxes. This advection-diffusion parametrization also lays the groundwork for a future PBL/shallow convection unification.

Forecasting severe convection in the medium range

An example will be shown of the application of the ECMWF model in forecasting a severe convective event

Tropical issues

The sensitivity of the mean tropical circulation and related fluxes will be discussed in the context of recent model changes, and a study of the characteristics of the MJO in the monthly forecast system (coupled T159L40) will be reviewed.

Linear and adjoint physics

A new simplified convection scheme and its linear and adjoint versions have been developed and are already used in the 1DVAR algorithms for the research developments in assimilation of rain rates and brightness temperatures in rainy areas. They will also be tested in singular vector computations and in the 4DVAR system.

Furthermore once the tangent-linear and adjoint versions of physical parametrization schemes are developed, they can be used for purposes other than just data assimilation. The model's adjoint is a powerful tool which enables the estimation of a given output quantity to all the input variables of a parametrization scheme. Compared with the standard approaches for evaluation of physical parametrization schemes (sensitivity of all the outputs to a given input quantity), the adjoint is a complementary approach for sensitivity studies.

Assimilation of rainfall information

Assimilation of rain and cloud information derived from satellite observations has been recognized to have high potential in improving the quality of the forecast of tropical and mid-latitude cloud systems. In particular, data from the Microwave Imagers (SSM/I and TMI) has been proven suitable for assimilation into global NWPs. An example will be shown of the assimilation of rain information in the case of super-typhoon MITAG (Philippines, 5 March 2002). The importance of the partitioning of convective and large-scale precipitation (a poorly defined concept in itself) is an issue in this work.

Stochastic physics

A variety of different formulations of stochastic physics have been developed and tested, most of which use a cellular automaton (CA) algorithm to evolve quasi-random patterns to parametrize near-gridscale forcing. These schemes have been implemented in:

1. A cloud-resolving model (the Met Office Large Eddy Model (LEM)) configured to have equatorial beta-plane geometry and spanning a large sector of the tropics, and is run at NWP resolutions with convective parametrization and compared with equivalent runs using 5 km resolution without convective parametrization.
2. The ECMWF IFS running (i) 10-day forecasts, (ii) seasonal T95 forecasts and (iii) T95 aquaplanet integrations, all with and without CA-based stochastic physics.

For the most part, the physical context of these attempts at stochastic forcing has been the parametrization of deep convection. Considerations of convective cloud scale and model resolution imply that parametrization of this process should be statistical in nature. Under fixed tropospheric cooling and prescribed, idealized SST the LEM model evolves domain-scale, low frequency variability as the convection organizes into squall lines and cloud super-clusters (after about 30 days). Running the model at coarse resolution (~ 80 km grid) with convective parametrization fails to reproduce the growth of this large-scale variability. Inclusion of stochastic forcing (so far) has resulted in only marginal improvements.

Future work

The presentation will end with some remarks on ongoing work, thoughts on longer term developments and a link to the workshop’s closing discussion session.