Summary of the working group discussion on the representation of convection in high resolution numerical models

Dmitrii Mironov and Colin Jones

Excellent discussions of convection and turbulence parameterisation issues took place during the workshop. Among other things, an attempt was made to identify (i) at which resolution (horizontal grid size) of a numerical model of atmospheric circulation (NWP model, climate model) can convection parameterisation (scheme) be switched off entirely, (ii) at which resolution a parameterisation of deep precipitating convection is no longer needed but a parameterisation of shallow non-precipitating convection should be kept, (iii) what are the key quantities that ensure consistency between convection scheme and other physical parameterisation schemes of an atmospheric model, (iv) which avenues of investigations (development strategies) are most fruitful.

There is an opinion nowadays that convection scheme can simply be switched off if a horizontal grid size of an atmospheric model is less than about 4 km. Such hope seems to be illusory. Even with a horizontal grid size of about 1 km, a convection parameterisation will be required. Although convective motions in most of the troposphere are going to be explicitly resolved, triggering of convection, the process that predominantly occurs through the boundary layer, remains at sub-grid scales and should therefore be parameterised. The question is whether a separate convection scheme should be kept, or the work performed by a convection scheme can be delegated to an extended turbulence scheme capable of describing non-local boundary-layer convection in a rational way. Most currently used turbulence schemes are unable to describe boundary-layer convection realistically.

Three resolution ranges are identified. With a horizontal grid size of order 2 km or less, no parameterisation of deep precipitating convection is required. However, a parameterisation of shallow non-precipitating convection, either as a separate scheme or as part of a non-local turbulence scheme, is required. With a grid size of order 10 km or greater, deep precipitating convection should be parameterised in one way or the other. The grid-size range from about 2 km to about 10 km is a “grey zone” where a deep convection parameterisation is still required but should be less active than it is in most currently used atmospheric models. It should be mentioned that the above grid-size thresholds are not grounded theoretically. They are based on practical experience of numerical model users and should be treated as rough tentative estimates.

As part of a very complex, strongly non-linear numerical modelling system, a convection parameterisation is intimately coupled with all other system components. Achieving harmony between a convection scheme and other parts of the system physics and numerics is a challenge. The first priority task is to make a convection scheme consistent with (i) a grid-scale microphysics scheme and (ii) a sub-grid scale cloud scheme. In most NWP and climate models, convective and grid-scale microphysical processes, e.g. generation of precipitation, are described differently. A grid-scale scheme usually incorporates more of the essential physics. A more consistent treatment is required. As to parameterisation of the sub-grid scale cloudiness, there is consensus of opinion that a statistical sub-grid scale cloud scheme is the most promising alternative. The statistical cloud scheme has the great potential but is sensitive to the input. The key quantities are the sub-grid scalar variances (variance of temperature and of humidity with respect to their grid-box means) that enter the formulations of the cloud fraction and of the cloud water content within a grid box. As both “convection” and “turbulence” contribute to the sub-grid scalar variances, a coherent convection-turbulence formulation is required.

Three avenues of inquiry (development strategies) have been outlined that are loosely referred to as short term, medium term, and long term strategies.

(1) Short term.
Traditional mass-flux convection schemes are kept.

Doing it this way, one should put up with numerous shortcomings of the current mass-flux convection schemes. Although the overall performance of the current schemes within NWP and climate models with comparatively low resolution is not entirely unsatisfactory, many assumptions that stand behind them are too restrictive. These are, first of all, the assumptions that (a) convection is quasi-stationary (no time-rate-of-change terms in the mass-flux equations), and that (b) in a triple decomposition of a quantity in question (vertical velocity, temperature, humidity) into the contributions from updraughts, from downdraughts, and from the so-called environment, a mean over the environment is equal to a mean over the entire grid box. The former assumption deprives a convection scheme of memory. As a result, a scheme responds to external forcing practically instantaneously, leading to a premature initiation of convection and an erroneous diurnal cycle. It is common knowledge that none of the existing convection schemes is able to realistically reproduce diurnal cycle of precipitation. The latter assumption actually means that the area covered by convective updraughts and downdraughts is small as compared to the size of grid-box. This assumption is valid, to a good approximation, for the horizontal grid-size of order 200-300 km. It can probably be tolerated if the grid size is of order 50 km. It is no longer acceptable for the grid size of order 10 km or less, where it leads to a far too active convection, the result of double counting of a considerable range of energy-containing scales of motion.

A way towards improvement of the model performance in the framework of the short term strategy basically lies with tuning/revising some formulations in the existing mass-flux schemes. It should be realised, however, that considerable progress along this line is not very likely. Some improvement can be achieved through tuning/revising (i) convective trigger function, (ii) formulation of entrainment and detrainment, and (iii) the way convective precipitation is generated and evaporated. An attempt should be made to suppress generation of convective precipitation in favour of grid-sale precipitation, e.g. by making the cloud condensate produced by a convection scheme available to a grid-scale microphysics scheme for potential precipitation.

It is recommended to keep away from the “grey zone”. That is, the existing convection schemes should be applied in the numerical models whose grid size is greater than about 10 km. With a smaller grid size, a parameterisation rule should be introduced to slow down deep convection. That parameterisation rule can use a number of criteria to recognise deep convection, such as (i) CAPE, (ii) the mass flux intensity as computed by the convection scheme, and (iii) condesate production and precipitation generation in the convection scheme.

(2) Medium term.
Convection schemes based on the mass-flux approach are kept but should be further developed to eliminate their most notable drawbacks.

Doing it this way, one should introduce memory to the mass-flux equation and relax (or get rid of) the assumption that the mean over the environment is equal to the gird-box mean. One way of doing it is to introduce an equation for the fractional area of convective updraughts and an equation for the vertical velocity in the updraught. Both equations should include the time-rate-of-change term. We recall that the current mass-flux convection schemes carry a steady-state equation for the updraught mass flux, which is, by definition, the product of the mean density, the area fraction covered by convective undraughts, and the difference between the updraught vertical velocity and the grid-box mean vertical velocity (a similar equation is carried for the downdraught mass flux). The scheme solves for the mass flux as function of height. However, by virtue of the above assumption (b), there is no way to separately determine the updraught area fraction and the updraught vertical velocity.

The above two additional evolution equations require boundary conditions at the cloud base. One way to specify the updraught fractional area and the updraught vertical velocity at the cloud base is to relate them to the properties of the boundary-layer turbulence through the Deardorff-type convective scaling. Account must be taken of the skewed nature of convective turbulence. An extended mass-flux scheme will require an advanced formulation for the rate of turbulent entrainment and detrainment. Recall that in the current mass-flux scheme the rate of turbulent entrainment and detrainment is either set to a constant value independent of height or is determined through a buoyancy sorting procedure. An advanced formulation should account, in a physically plausible way, for the dependence of entrainment/detrainment rate on height and on the buoyancy difference between the updraught and the environment. Other formulations (parameterisation rules) that will require modification in the advanced mass flux-scheme include formulations of convective precipitation and of convective downdrafts. Suppressing convective precipitation in favour of grid-sale precipitation, e.g. by making the cloud condensate produced by a convection scheme available to a grid-scale microphysics scheme for potential precipitation, should be tried out. A better parameterisation of convective downdraughts is an unresolved problem that calls for further research. An improved representation of microphysics and precipitation generation in convection schemes may require an iterative procedure to compute the updraught buoyancy and the microphysical quantities.

An extended mass-flux scheme is expected to offer a reasonably accurate solution for the “grey zone”, but this remains to be seen. The work towards an extended mass-flux scheme has been initiated (see the presentation by Luc Gerard).

(3) Long term.
A separate convection scheme is no longer used. A unified convection-turbulence scheme based on the second-order closure ideas is developed. The scheme accounts for non-local features of convective mixing and treats all sub-grid scale mixing processes in a unified framework.

Doing it this way, part of the work performed presently by the convection scheme is delegated to the turbulence scheme. This requires developing a turbulence scheme that includes extended formulations for the third-order moments largely responsible for non-local transport properties of convective motions. Furthermore, the incorporation of transport equations for variances of scalar quantities, such as temperature and specific humidity, is essential if not indispensable. The mass-flux approach is used as a guidance to develop advanced non-local formulations for the quantities in question, however a unified scheme is formulated in terms of statistical moments of turbulence. This approach has a number of advantages.

First, a unified scheme is more transparent and more controllable. It does not require splitting of sub-grid motions into a quasi-organised part (convection) and a random, quasi-homogeneous, quasi-isotropic part (turbulence). It therefore avoids a number of conceptual difficulties inherent in the mass-flux approach. Next, a unified scheme is “rescalable”, that is, an increased resolution can be accounted for in a physically plausible way through formulations of dissipation and return-to-isotropy length (time) scales. In mass-flux convection schemes, this dependence is hidden in various closure formulations, first of all, in the formulations of entrainment and detrainment. Those closure formulations are difficult to reformulate/adjust as the resolution is increased. Then, communication between a unified scheme and a sub-grid scale cloud scheme is facilitated. The quality of the input information for statistical sub-grid cloud scheme is to be improved. At present, neither the convection scheme nor the turbulence scheme provides necessary input information for the sub-grid cloud scheme. A description of scalar variances is far less satisfactory than is required. It is going to be considerably improved through the use of transport equations for the sub-grid scalar variances. Finally, in view of ever increasing computer power and an increasing horizontal resolution of NWP and climate modelling systems, an extended turbulence scheme has a higher life expectancy than a convection scheme and is, therefore, more worth an effort.

Gryanik and Hartmann (2002) have developed a closure model that satisfies most of the above requirements. Its salient feature is a skewness-dependent formulation for the third-order and fourth-order moments that are largely responsible for non-local mixing (see e.g. Abdella and McFarlane 1997, Zilitinkevich et al. 1999, Mironov et al 1999, Abdella and McFarlane 1999, and Abdella and Petersen 2000). The closure model is developed for the dry convective boundary layer. Its further development to incorporate moisture and, possibly, other hydrometeors, and its testing to see if convection over a wide range of scales (from a few tens of metres to about 50 km) can be described realistically is not trivial. This seems to be manageable, however.

A unified second-order closure scheme is no doubt the most promising alternative to treat shallow convection. It is likely to be a better alternative for deep convection too. Treatment of precipitation processes within the second-order modelling framework seems to be more difficult than within the mass-flux framework. This is not an issue for high-resolution models where only shallow convection should be parameterised. It is, however, an issue for coarse-resolution models where a parameterisation for deep precipitating convection is required.

References:

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