THE CONVECTIVE PARAMETERIZATION PROBLEM

Breadth and Depth

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The workshop summarized in this article is the seventh in a series with the purpose of discussing the fundamental theoretical issues of convective parameterization. The workshop also constitutes the last meeting under funding for European Cooperation in Science and Technology (COST) Action ES0905. With the aim of synthesizing the whole convective parameterization problem, workshop participants examined a wide range of issues, from the mathematical basis to end users' needs.

CONCEPTS FOR CONVECTIVE PARAMETERIZATIONS IN LARGE-SCALE MODELS VII: OPERATIONS AND FUNDAMENTALS

WHAT:	Forty-three scientists from 13 European countries, Israel, and the United States met to synthesize the breadth of convective parameterization issues.
WHEN:	18–20 March 2014
WHERE:	Toulouse, France

END USERS AND OBSERVATIONS. Numerical weather forecasts, in which convective parameterization is an indispensable component, are performed with the end users' needs in mind. For example, at the German weather service (Deutscher Wetterdienst, DWD), there are four major operational requirements of the associated user groups: 1) wind and turbulence forecasting for aviation support; 2) solar and wind prediction for renewable energy; 3) precipitation warnings, especially for extreme events; and 4) nowcasting for local service departments.

However, better satisfaction of the end users does not necessarily ensure the overall quality of the forecasts. Recall that the evolution of the synoptic weather system is primarily dictated by the pressure field under the quasigeostrophic principle. Thus, a good forecast of, say, surface pressure is key to ensuring the overall quality of a numerical weather forecast system. Whether it rains or whether the wind blows, though of practical importance, is less easy to forecast, and such a failure should not be considered fatal from the point of view of forecast–model quality. To make forecasts of user needs truly reliable, a reliable prediction of surface pressure must first be ensured. Though tuning may easily improve the forecast skill of those secondary variables, it is often accomplished with deteriorations in other aspects of the forecasts, especially the climatological state of the model. The model improvements must be performed in totality, rather than by trying to satisfy the end users in a short-sighted manner.

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Similarly, though we should listen to end users, their needs also should not dictate the overall priorities in developing and improving a numerical weather forecast system. These decisions should be made based on physical principles that dictate the evolution of the weather system.

The quantity of satellite observational data currently available is enormous, and the extensive possibilities for model verification that these datasets provide should not be underestimated. Possibilities for extensive studies of cloud and precipitation field structures over the globe down to the convective scale are hardly overemphasized. Satellite information is especially valuable for verifying various subgrid-scale parameterizations, particularly for cloud fractions.

However, these datasets pose a similar problem for end users. Satellite technology mainly consists of observing a state of the atmosphere from space by measuring electromagnetic radiation emitted by the atmosphere at various wavelengths. Some satellites also use active electromagnetic radiation emitted from instruments such as radar and laser. Those measurements are primarily aimed at thermodynamic as well as chemical states (including water concentrations) of the atmosphere as well as the optical properties of clouds. This information is again rather secondary with respect to the primary concerns related to convective parameterization, namely the strength of convection measured by convective mass flux, which may be observationally estimated as the updraft velocity of convection multiplied by a fractional area occupied by convection over a domain of concern. Thus, we should be cautious about developing an overreliance on satellite technology.

DEVELOPMENTS AND VERIFICATIONS. Incorporation of cloud microphysics into convective parameterization is of particular importance for many reasons. For example, to evaluate convective aerosol feedback at global scales, an implementation of this process into convective parameterization is indispensable. For these purposes, efforts are under way for implementing more realistic cloud processes into convective parameterizations. Unfortunately, some assumptions are required in order to introduce cloud processes into convective parameterization in a general manner. Verification of this implementation can be performed for satellite data with some success. However, these validities are hard to judge because of the assumptions introduced in order to make an implementation possible. These assumptions mainly have to do with the evaluation of the convective vertical velocity, which is difficult to perform in a straightforward manner, especially as a result of the presence of nonhydrostatic pressure.

Verification of forecasts requires extra effort. Convective events are often so localized both in space and time that conventional error measures, for instance those based on root-mean-square (RMS) error, may not be so useful. For example, predicted convective intensity may be right but with an incorrect position in space and time. A conventional error measure would not positively evaluate a correctly predicted intensity at all. However, such a forecast should not be considered a total failure but, rather, be seen to have some value. A qualitatively different measure must be introduced in order to better quantify this aspect of forecast error.

Many methodologies have already been proposed for this purpose with varying success, but they come with the major difficulty of having to identify the physical causes of their inherent forecast errors. This points to a basic limitation of any purely statistically based measures. Being introduced without consideration of the physical processes involved, they do not reveal any physical processes in any direct manner by design. Efforts are required to develop, for example, a precipitation forecast verification method by fully taking into account the nature of microphysical processes that control precipitation. Wavelet decomposition may provide such physically based verification methods.

NUMERICAL ALGORITHMS AND STATISTICAL PHYSICS. Convection forecasts may be fundamentally considered numerical issues. Once a physically based model is established, including all the parameterizations, it must be implemented in a certain numerical manner. This final step cannot be treated lightly. These details critically influence model performance. In particular, numerical algorithms introduce various filters (spatial and temporal) both explicitly and implicitly. The consistency of these numerical filters and subgrid-scale parameterization is, unfortunately, rarely considered. To make numerical implementation of the model physics easy, a time-splitting approach is often taken, in which a temporal tendency for each physical process is added to a model variable in a sequential manner. Both the consistency and stability of this approach must carefully be evaluated. The definition of “subgrid scale” is a more subtle issue, because the model mesh size is a misleading measure for this definition. An effective resolution of a model is known to be 4–10 times larger than model mesh size. We may further introduce the concept of a believable scale, below which model performance cannot be trusted, although such a subscale may still be considered "resolved" with respect to the effective resolution.

Furthermore, the subgrid-scale convective processes represent their own complexities. Proper understanding from a point of view of the statistical physics may first be required. In recent years, it has gradually become clear that atmospheric convection may be considered at self-organized criticality, in analogy with thermodynamic criticality but self-organizing into this state. There are pieces of evidence supporting this notion: for example, statistics of the episodic precipitation events, which behave in a similar manner to avalanches in cellular-automaton models, and satellite-based precipitation estimates that identify a critical point as a function of column-integrated water with a power-law pattern of behavior beyond the critical point, which is representative of any critical phenomena. Physical mechanisms for such behavior are still to be identified, possibly with extensive use of cloud-resolving models. Implications for convective parameterization are also to be fully assessed.

A NEED FOR MORE PRACTICAL APPROACHES? The goal of the present COST Action has been to establish a theoretical fundamental basis for the convective parameterization problem. In particular, the efforts have promoted two complementary parameterization developments: 1) the Module Multiscale Microphysics and Transport (3MT; Gerard et al. 2009), as a mass-flux-based convective parameterization for the high-resolution limit, and 2) the turbulent kinetic energy–scalar variance mixing scheme (TKESV; Machulskaya and Mironov 2013), as a generalization of a turbulence scheme including both convection and cloud processes.

Though these efforts have had some success, we may question this premise on the basis of the difficulties encountered and the slowness of the progress. We may even argue that much faster progress can be made by more direct sensitivity studies that compare the model performance with observations.

By the same token, numerical modeling of convective processes can help parameterization development in a more direct manner. For example, if we can identify a key variable (e.g., precipitation rate) that controls the characteristics of convection, an appropriate formula required for a convective parameterization can be derived by simply running large-eddy simulations. Such a diagnosis enables, for example, an extension of a parameterization originally developed for shallow to deep convection.

These practical approaches even pose a serious question concerning the need for theoretical self-consistencies in developing convective parameterizations. Many operational parameterizations must live with many inconsistencies for practical reasons. Correcting all these inconsistencies (most likely minor and harmless) may not be operational priorities at all for improving forecast performance. However, to what extent can these practical approaches substitute more fundamental research? This remained an unanswered question during the workshop.

A HOLISTIC VIEW. This workshop covered a wide range of implications for convective parameterization in atmospheric modeling from various perspectives: end users' needs, observational verifications, and numerical implementations, as well as fundamental statistical physics.

In this respect, efforts over the years under leadership of the Global Atmospheric System Studies (GASS) Panel [formerly known as the Global Energy and Water Cycle Exchanges Project (GEWEX) Cloud System Study (GCSS)] cannot be underestimated. This World Meteorological Organization (WMO) initiative tries to put all the model understandings and observational knowledge together to obtain a holistic view of the atmospheric processes. Extensive model comparison projects organized under GASS are designed to reveal basic physical processes. The present COST Action ES0905 has complemented these efforts by investigating deeply into theoretical issues.

However, the present workshop has revealed that going deep is not enough. We need to find the means for applying those theoretical insights into a wide range of issues that convective parameterization researchers face. Unfortunately, the perspectives arising from various different interests and needs hardly fit into a simple, single theoretical framework. Though this should not undermine the need to dig into more fundamental theoretical investigations, needs should also be recognized to maintain a breadth of all the perspectives involving weather forecast problems.

Unfortunately, developing such a holistic view by integrating all the different perspectives is by itself hard work. Efforts under GASS should be critically reexamined to identify a better approach. We may even question whether model comparison is the best means for achieving this goal. The present COST Action network has provided a unique opportunity for establishing dialogue between a wide range of communities, and we hope that such efforts continue beyond this Action network.

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