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THORPEX Predictability and Dynamical Processes Working Group and WGNE Workshop
"Diagnosis of Model Errors"
ETH, Zurich - 7 to 9 July 2010

Report

Introduction

The first THORPEX Predictability and Dynamical Processes (PDP) and WGNE workshop entitled "Diagnosis of Model Errors" was held at ETH, Zurich, from 7 to 9 July 2010 (a list of participants may be found in Annex I below). The aim of the workshop, which was jointly sponsored by WWRP-THORPEX and WCRP, was to bring together dynamicists, model developers and experts on model error diagnosis to discuss diagnostic techniques that could be used and should be developed to understand the origin of forecast errors and, therefore, aid model improvement.

The workshop opened with a series of presentations discussing:

- The relevant dynamical and physical processes in polar regions, the mid-latitudes, subtropics and the tropics
- The challenges, opportunities and strategies for model development
- Overview of existing diagnostic techniques

The second part of the workshop was given over to discussions; topics included diagnostic techniques, available data sets, follow-on projects, recommendations to WWRP and WCRP as well as a timetable for future meetings and workshops.

Relevant dynamical and physical processes

Our understanding of the dynamical and physical processes that are relevant for forecasting depends on the time scale and region being considered. In Polar Regions, for example, short-range weather forecasts are mainly influenced by local boundary layer processes and micro-physics; on longer time scales, however, processes in remote regions (for example, mid-latitudes and tropics) become increasingly important. In general, it was found that there are a number of well-known forecast relevant processes such as condensation in warm conveyor belts of extra-tropical cyclones and deep convection in the tropics. However, it has been argued that we do not have a complete list of such processes and generally there is a lack of quantitative understanding of the relative importance of the different processes. In fact, this lack of knowledge is appreciated by the wider community as highlighted by the first results from the Community-wide Consultation on Model Evaluation and Improvement.

Challenges, opportunities and strategies for model development

Two different approaches are used as part of model development. The first approach is well-established and can be described as "bottom-up" in which new or improved physical parametrization schemes (or numerical formulations) are based on theory, observations or cloud resolving model studies. The second approach can be described as “top-down”; in this approach model problems are identified, for example through the use of metrics. In practice, the next step is to modify the model somehow and to “hope” that the problem will be alleviated.Finding methodologies that can identify model errors at the process level would greatly improve the benefits of the “top-down” approach. Understanding the origin of model problems through diagnostic studies would also help to prioritize model development.

Diagnostic techniques

A wide range of diagnostic techniques were presented at the workshop. A technique can be considered as being of diagnostic value if it helps to understand the origin of model problems at the process level. This is in contrast to other equally important but more descriptive techniques such as metrics or verification. One important aspect, highlighted by the workshop, is the fact that diagnostic techniques that can be used to understand the origin of model problems at the process level are potentially equally powerful in enhancing our understanding of the functioning of the atmosphere/climate system (for example in extra-tropical cyclones and mountain torques) and vice versa.

One of the most promising ways forward is to employ a seamless diagnostic approach, that is, by studying how errors evolve throughout the forecast. Focusing on the first few time steps (initial tendencies, analysis increment techniques) or short-range forecasts (Transpose-AMIP) allows one to localize the problem and to directly compare the model with observational data; studying how errors further develop after the first few time steps helps to pinpoint the origin of errors (for example tropical versus extra-tropical) that develop later on in the forecast (for example, Euro-Atlantic blocking). Interpreting results from the seamless diagnostic approach usually requires considerable insight into dynamical processes and their interaction with physical processes along with a deeper understanding how numerical models work. In order to fully exploit the potential of the seamless diagnostic approach it therefore seems necessary to improve collaboration between dynamicists and model developers in this area. From the results presented at the workshop it became clear that initial tendency techniques, which are nowadays routinely being used at ECMWF, JMA and the UK Met Office, have been very efficient in furthering our understanding of the impact of model changes and pointing towards regions/processes where models are erroneous. In its present form the initial tendency technique has been successfully applied in the tropics. For the extra-tropics, it was suggested applying the initial tendency technique also in a moving framework by following special features such as extra-tropical cyclones (see also “conditional sampling” below).

Diagnostic techniques that employ “conditional sampling” are now widely used both in the NWP and climate community. The basic idea is to consider forecast error separately for different conditions (for example suppressed versus active convection). Examples have been presented in which conditioning is based on “regime types” (for example regions with large-scale ascent or descent) or aspects for which parametrizations are directly sensitive such as stable or unstable boundary layers.

Carefully designed numerical experimentation can also be of large diagnostic value. One diagnostic technique, based on numerical experimentation, that has recently experienced some revival, is the so-called relaxation or nudging technique. In this technique, the development of forecast error is artificially suppressed in certain regions during the course of integration by relaxing the model towards analysis data. In this way possible remote origins (for example the tropics) of forecast error (for example in the extra-tropics) can be indentified. This can assist developers prioritize research efforts. Sensitivity experiments to investigate the influence of model formulation and resolution are potentially also very informative, especially when diagnosed carefully (for example, through the use of initial tendency techniques). The use of single column models and large eddy simulations in a bottom-up approach to parametrization development is also very promising.

Lagrangian techniques presented at the workshop include trajectory or tracer diagnostics. Studying PV (and Θ) and especially PV-*changes* along trajectories from analysis data enables the diagnosis of the role of diabatic processes in atmospheric flow features such as warm conveyor belts of extra-tropical cyclones. Using short-range forecasts allows estimation of the relative contribution to the total modification of PV (Θ) due to different atmospheric processes (for example radiation versus convection).

Traditionally, verification, while useful in overall model development, has contributed little to the understanding of model problems at the process level. However, verification techniques have recently been developed that are of diagnostic value–hence the expression *diagnostic verification*. Examples of the use of scale-dependent verification (for example planetary versus synoptic aspects) were presented at the workshop which helped ruling out contributions from certain processes such as numerical dissipation to forecast degradation found for a new model version.

Ensemble forecasts could be used to diagnose model error in a variety of ways. The analysis of ensemble forecasts could be used to diagnose model error in a variety of ways and their use may also help identify poorly modelled processes. Ensembles of forecasts from the same model but with differing uncertain parameter settings could be used to build covariance models between forecast errors and parameter errors. In principle, incorporation of these covariances into a data assimilation scheme would allow the data assimilation scheme to find parameter settings that improve forecasts. Work in this area is in its infancy and the issue of how to best design ensembles and ensemble data assimilation schemes for this purpose would benefit from focused research.

Clues to the origin of forecast error are also likely to be gained from a careful examination of the systematic differences between forecasts from differing prediction systems found in multi-model ensembles. While such comparisons have been performed from time to time in the past, the advent of the TIGGE archive system will greatly increase the ability of researchers to identify /conditioned /systematic model differences; e.g. given that the multi-model ensemble mean has a low pressure between 990 and 980 hPa what is the systematic difference between each of the models and the verifying observations?

There is a block of important issues that have not been addressed here but, due to their importance, should be discussed in a forthcoming workshop. Diagnosis of interactions between different components of the climate system, for example, merits special attention. Furthermore, there is a list of other powerful diagnostic tools not addressed in the workshop such as adjoint models and PV inversion techniques. Finally, it is crucial to discuss and further develop diagnostic techniques that could be used to diagnose model error specifically for high-impact weather events.

Datasets

Very valuable datasets have been provided through the YOTC project. As part of YOTC, high-resolution analysis and forecast data from different NWP centres have been made available (http://www.ucar.edu/yotc/data.html). For the ECMWF data set (1 May 2008 to 30 April 2010), it is also possible to download the tendencies from different physical processes which enable much more process-oriented research to be carried out.

As part of the ECMWF reanalysis activities, 10-day hindcast have been carried out on a daily basis. These cover the periods 1959-2001 (ERA-40) and 1989-today (ERA-Interim). These forecasts provide valuable data sources (using a constant model cycle) to study flowdependence of forecast error and to systematically identify source of particularly poor forecast (so-called forecast busts).

Recommendations and follow-on activities

The results presented in the workshop showed (i) state-of-the-art models still suffer from substantial errors and (ii) that diagnostic work has the potential to inform model developers about model problems at the process level and therefore provide information necessary to guide model development.

Despite substantial improvements in diagnostic techniques in recent years *it is crucial to further support research to advance diagnostic techniques* to the point where they become of direct use for model development. While considerable attention is devoted to thermodynamic aspects (for example EU project ENSEMBLES) future progress will hinge on a better understanding of physics-dynamics interactions–an area of research in which the PDP community has considerable expertise.

Model error diagnosis has been identified as one area where universities and research institution can make substantial contributions to the further development of models, thereby supporting the relatively small community of model developers.

It was highlighted that there is a lack of quantitative understanding how errors in the representation of different processes (for example latent heating in atmospheric “warm conveyor belts” versus convective contributions in cold air outbreaks) contribute to forecast failures. In order to be able to prioritize future model development it was recommended to carry out detailed research to obtain a better quantitative understanding of this issue.

It was decided to start joint projects to look more closely at two phenomena:

- Indian Summer Monsoon (ISM): The ISM is a large-scale phenomenon which is poorly handled by most models. The monsoon problem is an ideal test case to demonstrate that the use of different diagnostic techniques can provide information that leads to model improvements. It was appreciated that this project could profit from other activities within YOTC and the MJO/ ISM field experiment planned for 2011 (CINDY/DYNAMO, coordinated by University of Miami). *Next steps:* The project will start by building on the existing collaboration between ECMWF and the UK Met Office. Ongoing research will be discussed in a mailing list. For the future it is planned to invite other centres through WGNE. Progress will be reported in future meetings (for example PDP, WGNE and suitable conferences).

- Cyclonic systems (CS): What makes CS an attractive choice is that physics-dynamics interactions are crucial in CS and that CS are a major source of severe weather. Work is required to understand the influence of resolution and the relative importance of different processes for cyclone prediction. *Next steps*: Considerable work is in progress in refining existing diagnostic techniques to understand CS and how they are represented in models (for example ECMWF, University of Reading and ETH). It is proposed to compile the latest results and to kick-start the project by giving a joint presentation entitled *Diagnosis of Cyclonic Systems* at the Cyclone Workshop, which will be held at Monterey, USA, from March 27 - April 1 2011. This project has clear links to the activities planned in T-NAWDEX.

Both themes are ideal to link with the climate community and should be investigated both in NWP and climate models. Work on these topics will profit from Transpose AMIP activities. WGNE and PDP WG will be invited to specifically address these selected high priority issues. One potential outcome of these activities will be to better specify the essential observational needs (for example T-NAWDEX). Furthermore, it is crucial that both projects should consider developing a proposal that can be put forward to WGNE for advice and support through numerical experimentation.

The outcomes of the workshop and progress on the two special projects will be reported in upcoming meetings (for example the 26th session of WGNE in October 2010 and WWRP-JSC late winter 2011) and conferences (for example the Cyclone workshop 2011 in Asilomar and EGU 2011 in Vienna).

APPENDIX I: LIST OF PARTICIPANTS

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