REQUEST FOR A SPECIAL PROJECT 2013–2015

MEMBER STATE: United Kingdom

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Project Title:

Representing uncertainty in weather and climate prediction

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SPGBTPUC**	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2012	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☐

Computer resources required for 2013-2015: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2015.)	**2013**	**2014**	**2015**
High Performance Computing Facility (units)	5,000,000	8,000,000	
Data storage capacity (total archive volume) (gigabytes)	6,000	10,000	

An electronic copy of this form ***must be sent*** *via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date): 11/04/2012

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

Principal Investigator: Tim Palmer

Project Title: Representing uncertainty in weather and climate prediction

Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (500,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

Special project application - Project description:
"Representing uncertainty in weather and climate prediction"

This project can be considered part of the "seamless prediction" programme, to bring into the climate arena, developments from NWP – here the development of stochastic parametrisations. It is expected that this work will feed back into NWP development.

The reasons to develop a stochastic (ie probabilistic earth system model) are primarily as follows. Firstly, by multiple realizations of the stochastic processes, "uncertainty" becomes an explicit prognostic variable. Secondly, through nonlinear rectification, stochastic parametrisations can in principle reduce (long-standing) model systematic error.

1. Process-Specific Stochastic Parameterisation

The key multiplicative noise parameterisation used in numerical weather prediction has been based on the output of the total parameterisation tendency in the thermodynamic and momentum equations. A key part of the current proposal is to develop process-specific stochastic parameterisations. The scope for development of stochastic parameterisations is almost endless, affecting all aspects of earth system modelling, from individual processes in the atmosphere, land surface, oceans, cryosphere, biosphere and so on. Here attention is given to three process-specific parameterisations: deep convection, the surface radiation flux and the soil parameterisation.

a) Convection

If one had to name a parameterisation to which weather and climate models are most sensitive, one would have little doubt that most climate modellers would name deep convection. To give an example, one of the most profound changes to the ECMWF model occurred with the replacement of the Tiedke convection with the Bechtold convection scheme (*Bechtold et al, 2008*). The revisions involved the introduction of a variable convective adjustment timescale, and a convective entrainment rate proportional to the environmental relative humidity.

As discussed in *Bechtold et al (2008),* this scheme helped reduce some of the long standing biases in the ECMWF model, notably in the large-scale extratropical flow, where a tendency of the model towards a positive bias in the northern annual mode pattern was evident. On the other hand, some aspects of the tropics were not improved, and there was a tendency in the new scheme for the monsoons to become too intense and for the trade winds to become excessively strong. When coupled to an ocean model, this led to a cold bias in eastern and central Pacific sea surface temperature.

Recently, *Berner and Palmer* (paper in prep) investigated the impact of stochastic backscatter on the climatology of the ECMWF model at T95 resolution. In the extratropics the response was in fact very similar to that of changing from the Tiedke to the Bechtold scheme – a reduction in the northern annular mode pattern bias. In the tropics the response was generally positive.

Palmer and Weisheimer (2011) have argued that the fact that the impact of two very different processes (introduction of stochastic backscatter and revision of deterministic convective parameterisation) are similar and project onto the climate system's dominant mode of variability (the northern annular mode) is not surprising, and could be considered a consequence of the fluctuation dissipation theorem.

These results indicate that in developing convective parameterisations, the deterministic and stochastic elements (convective backscatter can be considered an inherent part of the parameterisation of convection when considered from a stochastic standpoint) should be developed and tested together, i.e. in series and not in parallel. The situation described above is familiar in other areas of physics, such as quantum field theory, and solid state physics – the idea being that interactions of a system with inherent fluctuations in that system's environment, can, in effect, change the properties of that system. For example, the effective mass of the electron is determined in part by the bare mass as specified in the Lagrangian and in part by fluctuations of the quantum electromagnetic field in the electron's environment. It is this effective mass that is related to the observed mass. Similarly, when tuning parameters α to observations, the values of these parameters should be considered "effective values" modified by fluctuations in the convectively forced circulations.

As part of this proposal, it is therefore intended to return to the transition from the Tiedke to Bechtold schemes, and consider the development of a prototype "Stochastic Bechtold scheme" where not only will the link between entrainment and humidity be considered stochastically, but the corresponding forcing of convective available potential energy backscattered onto the resolved grid, will be considered "in series". The intention is to develop a scheme, which has all the benefits of the deterministic Bechtold scheme, with none of the negative "side effects" in the tropics.

b) Radiation

Earth's atmosphere radiates infrared energy in a number of infrared bands. Some of these, eg associated with well mixed gases such as carbon dioxide can be considered rather certain. Others, eg associated with water vapour and cloud condensates, can be considered uncertain because water vapour and cloud condensates are not well mixed. Indeed some would describe their distribution in space as fractal. This demonstrates that a stochastic multiplicative noise, even on a process-specific tendency like radiation, is not physically well justified. We therefore intend to study the development of stochastic longwave tendencies in which the specified radiatively active gas is considered explicitly.

Results using early versions of the ECMWF stochastic parameterisation code in numerical weather prediction and seasonal prediction have indicated that there is insufficient ensemble spread in near surface temperature, both over land and over the ocean (eg *Weisheimer et al,* paper in prep). The surface radiation flux is a key element of the earth system, driving ocean circulations and heating the land surface. A crucial element in determining these fluxes is the cloud fields. Currently, the radiative parameterisations are deterministic in the ECMWF model. It is proposed here to construct a stochastic parameterisation of radiation, based on a stochastic representation of cloud and humidity.

In the ECMWF model's radiation scheme, the effects of clouds are computed using the McIDA (Monte Carlo Independent Column Approximation) scheme (*Pincus et al, 2003, Morcrette et al., 2008*). McIDA partitions a model grid box, and computes radiative fluxes as an ensemble average from a specified distribution of humidity cloud properties, consistent with subgrid variability in these quantities. That is, although the McIDA-based parameterisation of radiative fluxes is itself deterministic, it is based on the concept of an underlying subgrid probability distribution of cloud and humidity. This makes McIDA an ideal scheme with which to develop stochastic radiative flux parameterisations. The following is therefore proposed: to estimate the cloud and humidity distribution based on a relatively coarse sub-grid partition and to estimate the radiative flux from a stochastic sampling of this distribution.

The first phase of this project will be to determine whether such a stochastic radiation scheme has an impact on near surface temperature scores for medium-range and seasonal forecasts. If, as expected, the answer is yes, then a proper assessment of cloud radiation interactions needs to be made, with reference to cloud/radiation observations, in order to make such a scheme scientifically robust.

c) Land Surface

Recent studies of the summer 2003 heat wave (*Weisheimer et al., 2011*) have shown how seasonal simulations of key climatic extreme events are sensitive to the representation of land surface processes in climate models. Indeed, from this case study, it would appear that the simulation of such extreme seasonal anomalies is more sensitive to uncertainties in land surface processes than oceanic processes.

It is proposed to develop a stochastic soil parameterisation scheme, in collaboration with scientists at ECMWF and King's College London. In the first phase of this project, we will test the multiplicative noise process developed for the ECMWF atmospheric model, i.e. where the overall tendencies from the ECMWF HTESSEL scheme will be multiplied by a stochastic pattern generator. The scheme will be tested in forecast and climate mode. In the second phase of the project, stochastic representations of key processes will be considered, embedded within the parameterisation scheme. For example, the soil hydrological module of HTESSEL ignores non-Darcian soil flow such as macropore flow and relies on values of hydraulic conductivity that are uncertain and have been estimated based on applying the Richards equation outside its scale of applicability. As in the case of atmospheric parameterisation, model parameters do not always refer to real measurable quantities.

2. Technical requirements

The estimate for the computer resources requirements is based on the costs of running the ECMWF seasonal forecasting system of the IFS CY36R4 coupled to NEMO ocean model, similar to the envisaged System 4. For the (low) horizontal resolution of T95 and 62 vertical levels in the atmosphere coupled to a 1 degree version of NEMO, a single integration over 1 month costs approximately 450 System Billing Units (SBU) on C1A or C1B and the total archive volume are approximately 220 MBytes. The corresponding numbers for the horizontal resolution T159 also with 62 vertical levels and coupled to a 1 degree NEMO version are approximately 700 SBU and 800MBytes, respectively.

Given that a typical seasonal forecast experiment would run for at least two start dates (one for the summer and one for the winter season), approximately 20 years of hindcasts over a length of 4 to 7 months with an ensemble of ~10 members, the total costs for one such experiment would be around 1,000,000 SBU for T95 and up to 2,000,000 SBU for 7 month long hindcasts in T159 with data storage requirements of 500,000 Mbytes and 2,300,000 Mbytes, respectively.

References

Pincus, R., Barker, H., and J.J. Morcrette, 2003: A fast, flexible, approximate technique for computing radiative transfer in inhomogeneous cloud fields. *J. Geophys. Res*., **108**, D13.

Bechtold, P., and co-authors, 2008: Advances in simulating atmospheric variability with the ECMWF model: From synoptic to decadal time-scales. *Quart. J. R. Meteorol Soc*., **134**, 1337-1351

Morcrette, J.-J., H. W. Barker, J. N. S. Cole, M. J. Iacono, and R. Pincus, 2008:, Impact of a new radiation package, McRad, in the ECMWF integrated forecasting system, *Mon. Weather Rev.,* **136**, 4773–4798, doi:10.1175/2008MWR2363.1

Palmer, T.N. and A. Weisheimer, 2011: Diagnosing the causes of bias in climate models – why is it so hard. *Geophys. and Astrophys. Fluid Dynamics,* **105**, 351-365, doi:10.1080/03091929.2010.547194.

Weisheimer, A., F. J. Doblas-Reyes, T. Jung, and T. N. Palmer (2011), On the predictability of the extreme summer 2003 over Europe, *Geophys. Res. Lett*., **38**, L05704, doi:10.1029/2010GL046455.