# REQUEST FOR A SPECIAL PROJECT 2016–2018

**MEMBER STATE:** United Kingdom


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**Project Title:**

Improving Stochastic Parametrisation of Convection through the use of Data Assimilation

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

| **Computer resources required for 2016-2018:**<br>(The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2017.) | **2016** | **2017** | **2018** |
|---|---|---|---|
| High Performance Computing Facility | 750,000 | 2,000,000 | 4,000,000 |
| Data storage capacity (total archive volume) (gigabytes) | 1,200 | 3,000 | 6,000 |

*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):

7 August 2015

*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.

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# 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.*

## Introduction

Weather and climate forecasts are necessarily probabilistic in character. A key quality needed from a probabilistic forecast is that it is reliable. This refers to the consistency, when statistically averaged, of the forecast and measured probabilities of an event (Wilks, 2006). In order to produce a reliable probabilistic medium range forecast, it is important to represent potential errors in the forecast due to both initial condition uncertainty and model uncertainty.

Traditional deterministic convection schemes are modular, and represent the bulk average effect of unresolved sub-grid processes on the resolved scale flow. However, the underlying assumptions of modularity, scale-separation and convective quasi-equilibrium are rarely met - this is increasingly the case as the resolution of the atmospheric model increases. Deterministic parametrisation of convection provides no way of estimating the uncertainty in the forecast due to such deficiencies. An alternative approach is to use a stochastic convection parametrisation scheme. These schemes represent *one potential realisation* of the sub-grid process: they should be used in ensemble forecasts to represent the variability of unresolved convective processes (Palmer et al, 2009). Stochastic parametrisations have significantly improved the reliability of medium range and seasonal forecasts (Buizza et al, 1999; Palmer et al, 2009; Weisheimer et al, 2014).

There is increasing evidence that stochastic parametrisation is beneficial for the mean and variability of a climate model. Because the climate system is nonlinear, stochastic schemes can impact the simulated mean state (Williams, 2012; Weisheimer et al, 2014); this noise-induced drift can reduce model biases, improving the mean climate (Berner et al, 2008). Stochastic parametrisations can also improve the variability of the modelled climate, such as the Madden-Julian oscillation (MJO) (Weisheimer et al, 2014) and representation of weather regimes (Christensen et al, 2015; Dawson and Palmer, 2015).

Data assimilation (DA) has long been a vital tool for the development of parametrisation – following the work of Sardeshmukh and Klinker (1992). The development of ensembles of DA (EDA) systems allows this key diagnostic tool to be extended to aid the development of stochastic parametrisation. In this proposal, we propose to use the DA framework to improve stochastic physics schemes, with a specific focus on convection. The proposal builds on a new EDA diagnostic suite that has recently been developed at ECMWF (Rodwell et al, 2015). The error in the ensemble forecast mean is decomposed using consistency arguments into a random, bias and observational error component at short lead times (12hr) within the EDA cycle. This is a statistical decomposition that is used to test the averaged properties of many forecasts.

We propose to use the EDA diagnostic suite, which makes optimal use of observational data, to assess the realism of new possible stochastic representations of convection in the IFS; how closely does the stochastic scheme represent the uncertainty between the modelled and the true atmosphere.

Firstly, focusing on the location and spatial structure of the bias component will help isolate and identify systematic sources of error in the convection scheme, such as errors due to timing or dynamical adjustment. For example, theory indicates that deep convective clouds result in opposite signed vorticity anomalies in the mid to lower troposphere and at convective cloud top (Shutts, 1987): if convective momentum transfer is not properly represented in the model, error signatures such as this should be detectable using the DA system.

Secondly, comparing the random error component with the ensemble spread in convective regions will isolate and rigorously test the performance of the stochastic convection schemes. In fact, Rodwell et al (2015) use the EDA diagnostic suite to demonstrate the importance of using stochastic parametrisation schemes to represent error-growth rates in convective regions in the IFS.

Using the EDA diagnostic suite to identify shortcomings in convection parametrisation schemes will be the first step towards designing improved stochastic representations of convection. In the third year of the project, new stochastic schemes will be designed and tested in the same framework, evaluating the ability of such schemes to improve systematic biases and to reliably represent the uncertainty in convective clouds and in the dynamical forcing associated with such systems. In this way, the development of the EDA diagnostic, when coupled with complementary coarse-graining studies (Shutts and Palmer, 2007), will provide a comprehensive methodology to develop new stochastic parametrisation schemes.

## Scientific Objectives and Experimental Details

Our central objective is the development and assessment of new stochastic convection parametrisation schemes. We will achieve this through the development of a new methodology to evaluate ensemble forecasts. By studying systematic errors and reliability during the DA window, errors due to misrepresentation of convective processes are isolated: by focusing on convective areas at very short lead times, remote errors cannot infect the forecast.

By targeting convection, we will be able to significantly improve our understanding of stochastic convection parametrisations. Firstly, we will evaluate existing stochastic schemes at a range of model resolutions: the Stochastically Perturbed Parametrisation Tendencies (SPPT) scheme, which has recently been incorporated into MOGREPS; the Stochastic Kinetic Energy Backscatter scheme (SKEB); the Convective Backscatter scheme (Shutts 2015); the stochastic Eddy Diffusivity Mass Flux scheme (Suselj et al., 2014). SPPT and SKEB are widely used: evaluating these schemes using the DA suite will provide a benchmark. The convective backscatter scheme targets errors associated with representing deep convective mass flux, while the stochastic EDMF scheme represents uncertainty in convectively unstable boundary layers. By comparing holistic approaches (SPPT, SKEB) with process-based approaches (convective backscatter, EDMF) we keep an open mind as to which approach is best: holistic approaches allow precise model balances to be maintained, while process based approaches target specific sources of uncertainty.

Throughout, a key focus is using the DA diagnostic suite to identify systematic errors in existing convection parametrisations. In the third year, investigation into the next generation of stochastic schemes will begin to correct these deficiencies. Several individual processes could be targeted. Initiation of convection, due to cold pool dynamics and large-scale convergence, is poorly represented in models due to its dependency on sub-grid processes (Birch et al, 2014), but is crucial for capturing the timing and location of convection: a stochastic approach could represent the uncertainty in these triggers. There is also evidence that modelling entrainment as a stochastic process improves forecast reliability: Teixeira proposes a stochastic entrainment representation that will provide a starting point for focusing on this process. It is anticipated that our development of new stochastic schemes will also be informed by independent and complementary coarse-graining analysis carried out within our group at Oxford.

New stochastic schemes will be physically motivated and scale aware. Their performance will be evaluated in the DA framework before being tested in medium-range and seasonal ensemble forecasts at a range of resolutions. In particular, we will evaluate modelled variability, including mid-latitude weather regimes, the

MJO and monsoon intra-seasonal oscillations. The stochastic schemes must represent the important scale interactions between convection and the large-scale state to capture these modes of variability correctly, thus providing a rigorous final test for the new schemes.

## Technical Requirements

This project has been submitted to the NERC-MO funding call "Understanding & Representing Atmospheric Convection across Scales". Our initial Expression of Interest was selected for expansion into a full proposal, to be submitted in September 2015. If selected for funding, the project will begin in May 2016. We therefore require substantially less computer resources for 2016 than for subsequent years.

In the first year we will begin by porting Glenn Shutts's convective backscatter scheme into the latest cycle of the IFS and testing its performance. We will also test the performance of the 'independent SPPT' scheme (Arnold, 2013), in which an independent random pattern is used to perturb the tendencies from the different physical parametrisation schemes, before moving on to considering other stochastic parametrisations not currently in the IFS. At T255, ensemble forecast experiments cost approximately 500,000 SBU per 100 years. Budgeting for five, 30 start date, 30 ensemble member experiments out to a lead time of 10 days would therefore require 625,000 SBU

In the second and third years we will perform EDA experiments to rigorously evaluate the different stochastic approaches to convection parameterisation. We are also aware of the option to perform Ensemble Kalman Filter (EnKF) experiments, which can also be evaluated using the EDA diagnostics suite. We propose using both ensemble data assimilation techniques to test new stochastic parametrisation schemes within the EDA diagnostics suite framework.

Massimo Bonavita has provided us with the number of node hours required to perform an EDA or EnKF experiment at TL319:

> Numbers are as follows (IFS Cycle 41R2):
>
> EDA TL319 10 members: 270 node hours per day (27 node hours per member per day)
> EnKF TL319 50 members: 130 node hours per day (2.6 node hours per member per day)

Our experience with the IFS indicates that one SBU corresponds to 0.154 node hours

Mark Rodwell has advised that EDA experiments with as few as five members are able to detect significant improvements in reliability, but must be run over approximately 90 assimilation cycles, with an additional 25 cycles of 'spin up' to estimate and correct for the bias. At T319 this would cost (115 days * 5 members * 27 node hours per member per day) = 15,525 node hours, or 101,000 SBU. An EnKF experiment with an ensemble of 50 members could be run for the same cost.

We anticipate that we will carry out several EPS and data assimilation experiments to test the new stochastic convection schemes in the second and third year. We will only perform EDA and EnKF experiments on stochastic parametrisation schemes that we are happy perform well in EPS mode.

In the Second Year: 8 EPS experiments and 6 EDA/EnKF experiments = 1,606,000 SBU
In the Third Year: 16 EPS experiments and 14 EDA/EnKF experiments = 3,400,000 SBU

We scale these numbers up by 20% to allow for unforeseen problems and the uncertainty in these estimates giving 750,000 SBU in year one, 2,000,000 SBU in year two, and 4,000,000 SBU in year three.

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