Maintaining Realistic Uncertainty in Model and Forecast

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LONG-TERM GOALS

My long term goal is to better understand ensemble forecasting in general and the dynamics of initial uncertainty given only imperfect models when predicting any physical system. Of particular interest to me are methods which aim to evaluate predictions of high dimensional systems like the atmosphere, methods to best combine different models, and determination of aims which are both achievable by the forecaster and useful for the user.

OBJECTIVES

I wish to establish exactly how uncertainty in the initial condition and imperfections in the model limit the prediction of nonlinear dynamical systems (NDS) like the atmosphere and ocean. Of particular interest is the evaluation and interpretation of ensemble forecasts, now routinely made at the European Centre for Medium-Range Weather Forecasting (ECMWF) and the National Center for Environmental Prediction (NCEP). Particular questions include (i) how to best distribute computational resources between using larger ensembles versus higher resolution models, (ii) when to select a best model versus when to use an ensemble over models, (iii) how to evaluate current ensemble formation schemes and (iv) whether the answers to these questions change when regional forecasts are of interest. While the focus is on geophysical fluid dynamics, the insights gained are applicable across a wide range of forecasting and control systems, including mechanical and industrial processes and general questions of data analysis and assimilation..

APPROACH

My initial approach is to develop tests of internal consistency and then apply them in the context of simple numerical and laboratory systems where more reliable statistics can be gathered than in the operational systems. These initial applications often suggest improvements in technique and understanding which ease application to operational models, where my approach has already uncovered several fundamental inconsistencies, both in model formulation and evaluation.

WORK COMPLETED

A general overview of ensemble forecasting and the limitation of current ensemble formation schemes, focusing on the perfect model scenario, was completed (Smith, Ziehmann and Fraedrich, 1999).

Review of the goals of ensemble forecasting in the face of real world limitations was begun, and alternative (achievable) targets were identified to replace ideal (but unphysical) targets.

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Tests we developed were used to evaluate the duration of the linear regime in operational weather forecasts, this is a crucial parameter in determining the consistency of ensemble formation techniques.

A new variety of shadowing trajectory was defined, and used to show the limitations model error puts on data assimilation techniques.

General conclusions of Lorenz and Emanuel (1988) on the relative merits of different schemes for making adaptive observations (selecting which additional observations to take among a wide range of potential observations), were reviewed and modified, and then extended to the imperfect model case. Methods to test the relevance of our conclusions in an operational setting were developed (Hansen and Smith, 1999).

A new cost function was derived showing the limitations of the common one step least squared error criteria; at present applications are limited to low dimensional systems, but both deterministic and stochastic models are considered (McSharry and Smith, 1999).

Using models suggested by Lorenz (1996), a scheme has been developed to provide a test bed for exploring the improvement of the parameterisation of sub-gridscale processes, and for better understanding the model sensitivity to parameters.

Quantification of the relative benefits of ensemble size versus model accuracy have been derived in the special case of Gaussian uncertainties; the smallest ensemble size likely to capture "truth" within the bounding box of the ensemble, has been computed as a function of the model bias and the standard deviation of the perturbations used to form the ensemble.

We have begun a study of improvements to radial basis function models based on the cylindrical basis functions of Judd (1998), applications to simple systems show promising ensemble forecasts; application to the rotating fluid annulus experiment shall begin shortly.

Alternative methods for constructing ensembles have been explored and evaluated using our new minimum spanning tree test; the major insight gained here is that ensemble forecasting almost certainly fails to give accurate probability density forecasts unless both perfect model and perfect ensemble are in hand. Thus, rather than attempt to improve ensemble formation, we have concentrated on alternative targets for ensemble forecasting, leading us to the bounding box and new varieties of shadowing trajectories.

RESULTS

Initial studies on the duration of the linear regime in operational weather forecasting models revealed that the regime is much shorter than commonly assumed, implying that some operational ensemble formation schemes are not internally consistent.

It is almost certainly the case that accurate PDF forecasts of the weather cannot be obtained; attempting bounding box forecasts is shown to be promising. The size of ensemble required to form a good bounding box is shown to remain relatively small, even in high dimensional systems, as long as the model error (bias) is small; and to increase rapidly in even moderate dimensional systems as the bias increases.

Minimal Spanning Trees (MST) have been used to generalise the Talagrand diagram to higher dimensions, thereby allowing more robust assessment of ensemble forecasts.

IMPACT/APPLICATIONS

Initial studies suggest that the commonly held goals of ensemble forecasting are almost certainly unachievable. By changing the questions asked, we hope to allow greater use of the forecasts for the user.

Future work should allow definitive answers on distribution of computational resources between improved model accuracy and ensemble size.

TRANSITIONS

ECMWF is considering shortening the optimisation time in its operational ensemble forecasts.

RELATED PROJECTS

1- Understanding Model Error. A graduate studentship sponsored by ECMWF; David Orrell is studying the implications model error holds for ensemble forecasting and methods to search for shadowing orbits in operational weather models.

2 - Boiling Dynamics. Prof David Kenning (Oxford, engineering) is using the modelling techniques we have developed to study the dynamics of boiling.

3 - Roll resonance and intercept. Toru Hirose (1999) has completed a Masters Thesis based on an application of our work on data assimilation and quantifying uncertainty, the aim of the project was to consider the likelihood of roll resonance in a cylinder falling through the atmosphere and thereby confounding simple intercept strategies.

4 - Rogue thermocouple detection. Liam Clarke (1999) has completed a Masters Thesis applying our approach to the identification of intermittently unreliable sensors in a long data stream containing roughly 100 sensors. The industrial application was for monitoring thermocouples in the heat-exchangers of a nuclear power plant. British Energy (formally Nuclear Electric) has funded a D Phil studentship which Liam Clarke has taken up in my group.

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