Representing Model Uncertainty: A Case Study in Seamless Prediction

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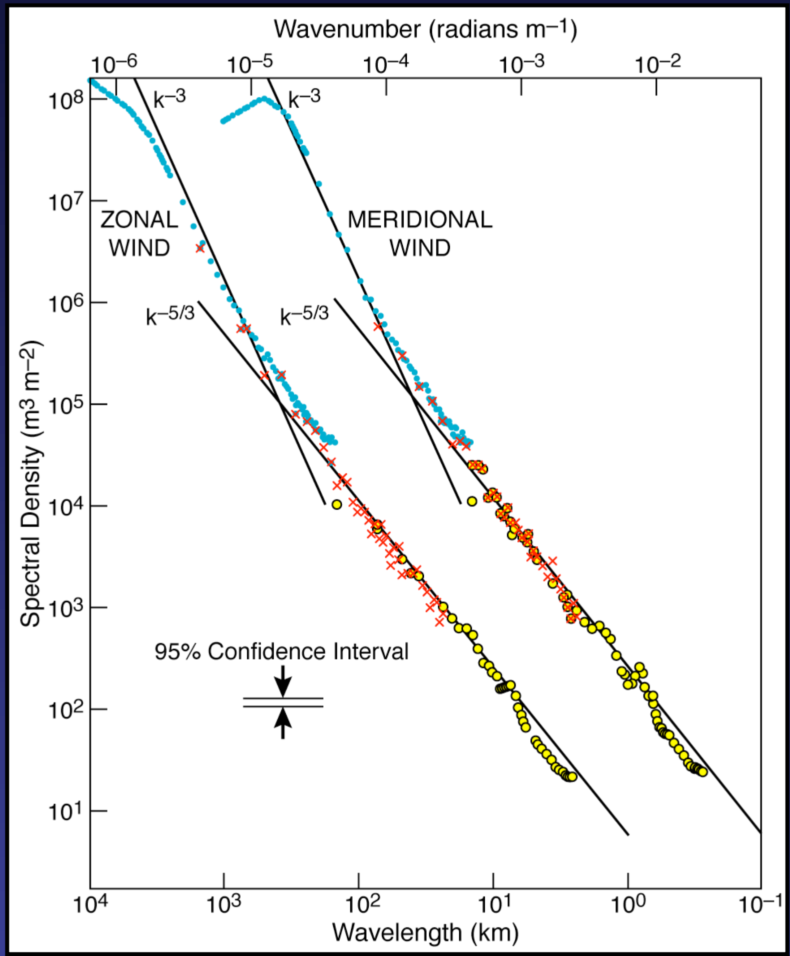
Why is it so difficult to simulate climate accurately?

What, fundamentally, is the source of model error?

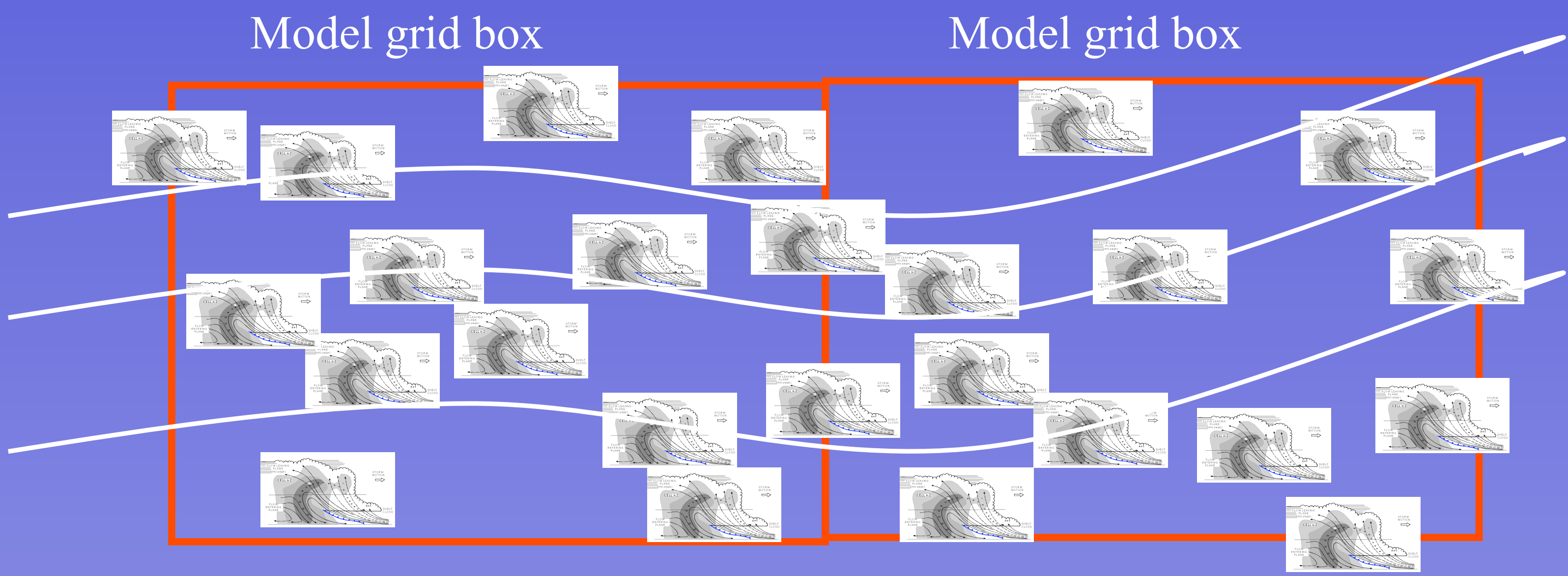
How can we represent reliably the impact of model error in climate forecasts?

A (shallow) power law for atmospheric energy wavenumber spectra

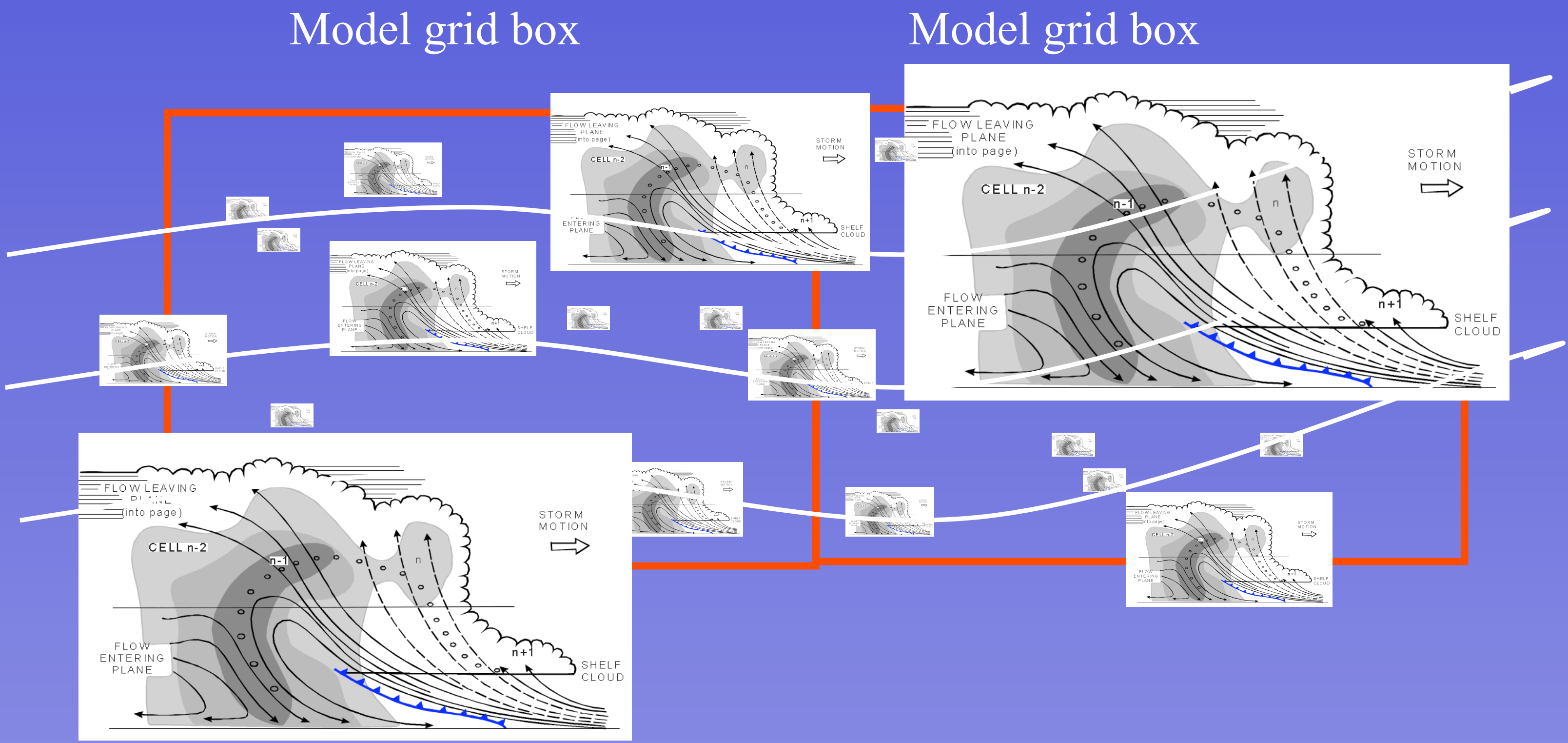


No scale separation between resolved and unresolved scales in weather and climate models

Deterministic parametrisation assumes some scale separation between the resolved flow and the unresolved parametrised scales (eg Arakawa and Schubert, 1974) eg



Power-law structure indicates that reality is more like….



Power law structure is consistent with scaling symmetries for Navier Stokes…

Let $\mathbf{v}$, p be a solution to the incompressible Navier Stokes equations.

Then, for any $\tau \in \mathrm{R}^{+}$,

$$\mathbf{v}_{\tau}(x,t) = \tau^{-1/2}\mathbf{v}\left(\frac{x}{\tau^{1/2}}, \frac{t}{\tau}\right)$$

$$p_{\tau}(x,t) = \tau^{-1}p\left(\frac{x}{\tau^{1/2}}, \frac{t}{\tau}\right)$$

is also a solution pair

What, fundamentally, is the source of model error?

Violation of power law/ scaling symmetries by the conventional deterministic truncation/parametrisation ansatz is fundamentally the source of model errror and uncertainty.

How can we represent reliably the impact of model error in climate forecasts?

The Multi-Model Ensemble

- A pragmatic approach to the representation of model uncertainty

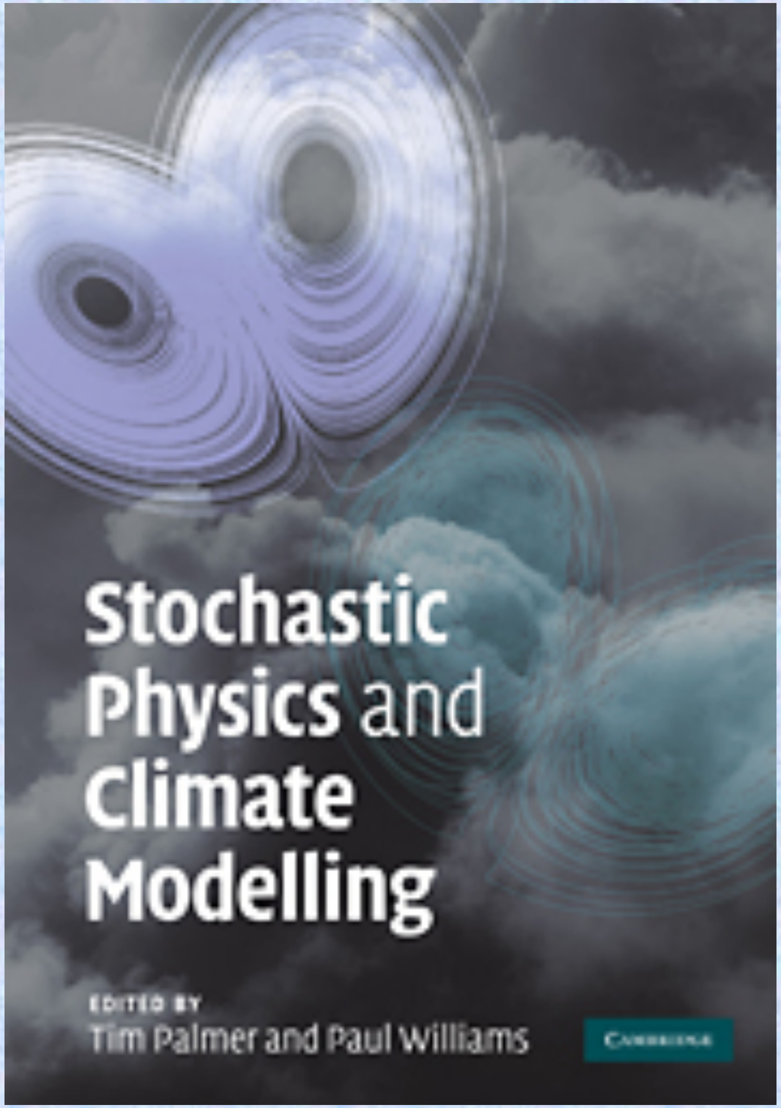
- Insensitive to systemic errors related to the violation of power-law, scaling symmetries of the underlying partial differential equations, by all members of the MME. The models are structurally too “similar”.

On the Effective Number of Climate Models

Pennell and Reichler. J.Clim. 2011

"The strong similarities in model error structures found in our study indicate a considerable lack of model diversity. It is reasonable to suspect that such model similarities translate into a limited range of climate change projections."


TECHNICAL MEMORANDUM
598
Stochastic Parametrization and Model Uncertainty
Palmer, T.N., R. Buizza, F. Doblas-Reyes, T. Jung, M. Leutbecher, G.J. Shutts, M. Steinheimer, A. Weisheimer
Research Department
October 8, 2009
This paper has not been published and should be regarded as an Internal Report from ECMWF.
Permission to quote from it should be obtained from the ECMWF.
European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen terme


Stochastic Physics and Climate Modelling
EDITED BY
Tim Palmer and Paul Williams

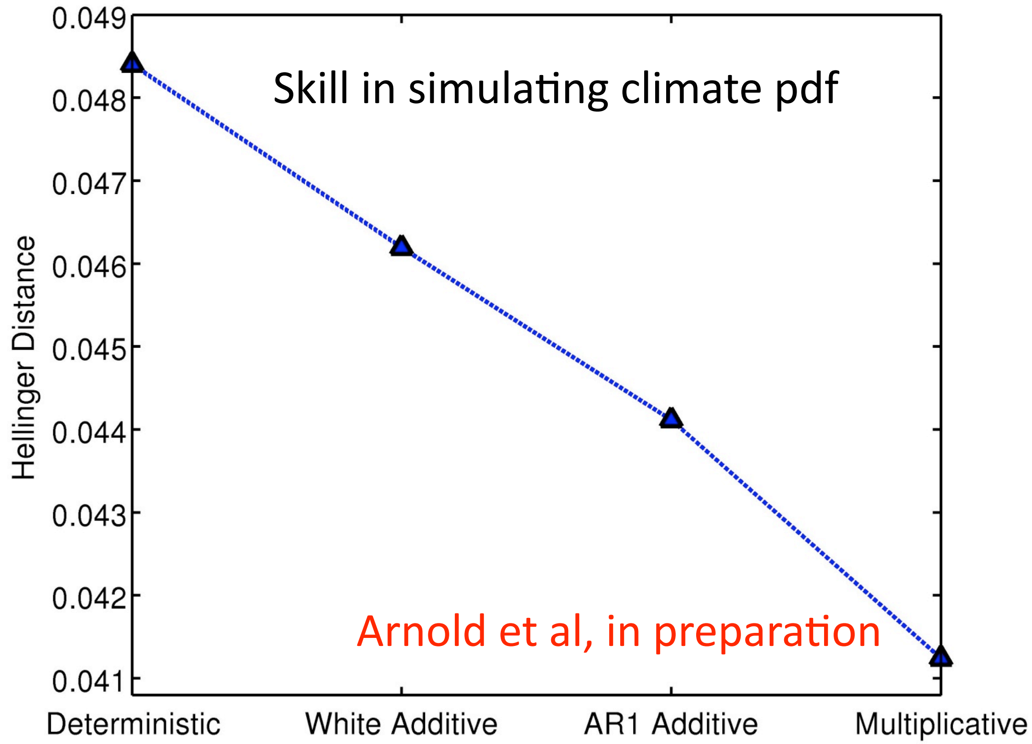
Experiments with the Lorenz '96 System (ii)

$$\frac{dX_k}{dt} = -X_{k-1}\left(X_{k-2} - X_{k+1}\right) - X_k + F - \frac{hc}{b}\sum_{j=J(k-1)+k}^{kJ} Y_j$$

$$\frac{dY_j}{dt} = -cbY_{j+1}\left(Y_{j+2} - Y_{j-1}\right) - cY_j + \frac{hc}{b}X_{\mathrm{int}[(j-1)/J+1]}$$

Assume Y unresolved

Approximate sub-grid tendency by U



Deterministic: $U = U_{det}$

Additive: $U = U_{det} + e_{w,r}$

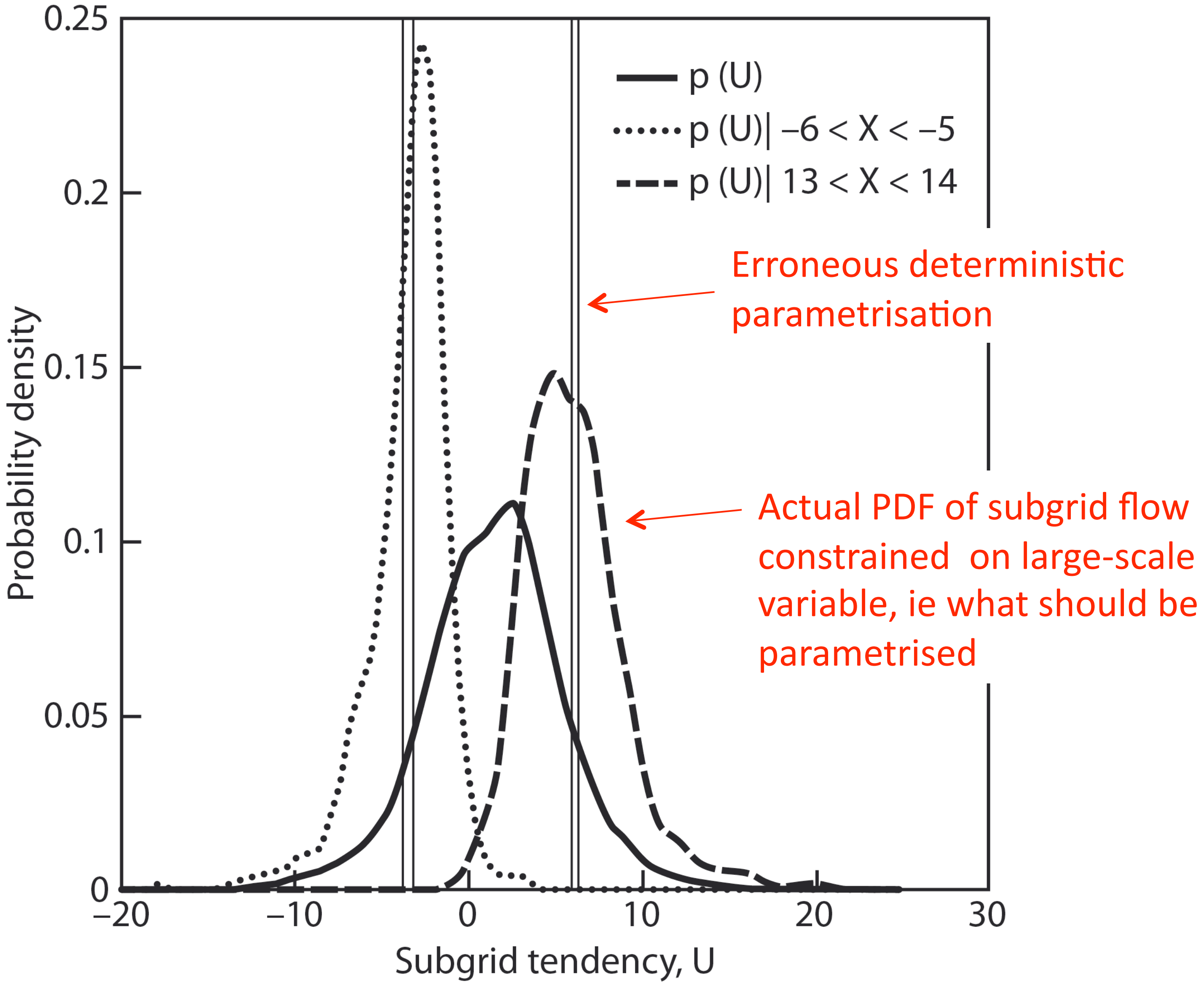
Multiplicative: $U = (1+e_r)\, U_{det}$

Where:

U_{det} = cubic polynomial in X

$e_{w,r}$ = white / red noise

Fit parameters from full model



Pdfs from Lorenz 96

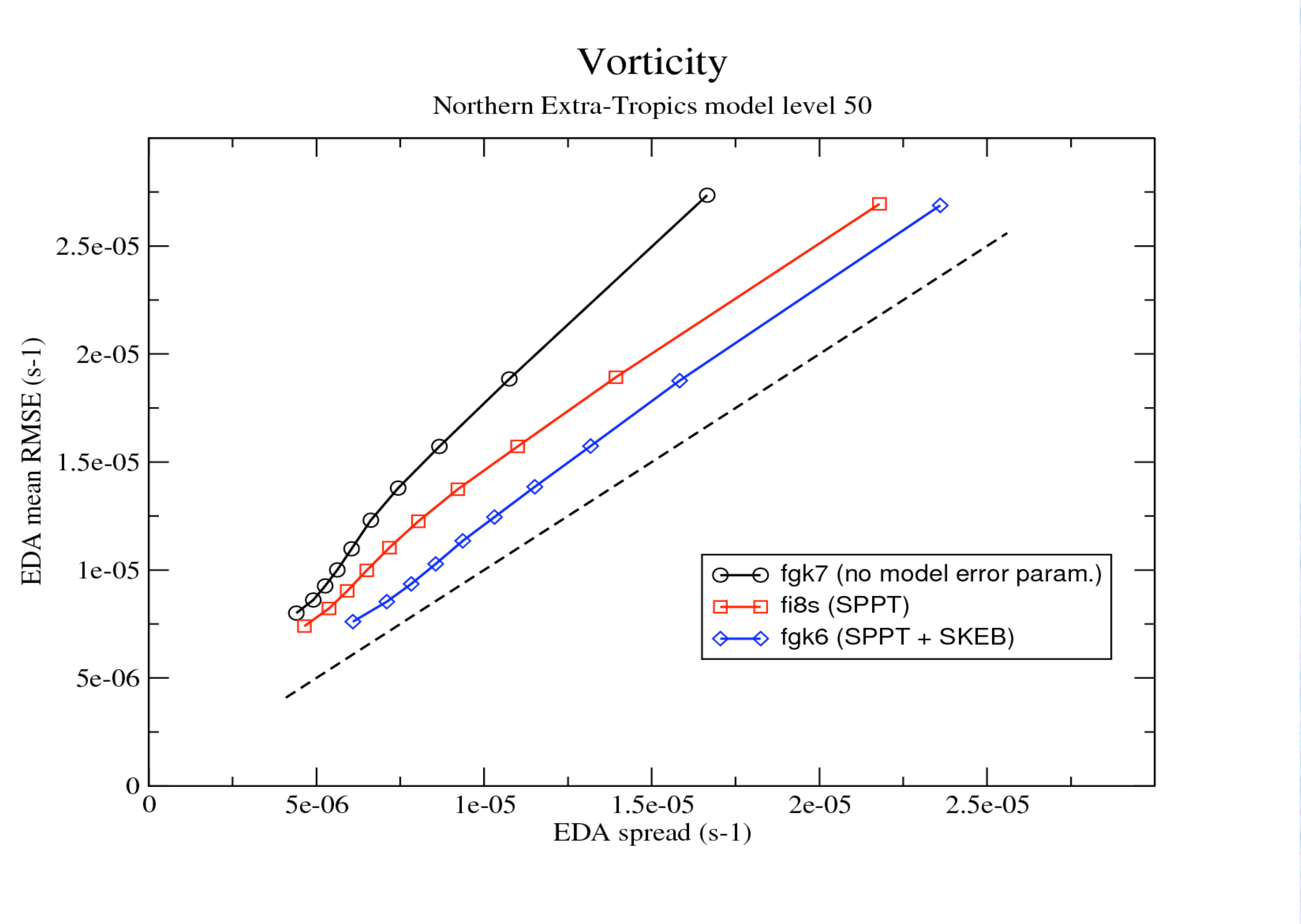
Brier Skill Score: ENSEMBLES MME vs ECMWF stochastic physics ensemble (SPE)

lead time: 1 month

	T2m				precip			
	May		Nov		May		Nov	
	cold	warm	cold	warm	dry	wet	dry	wet
MME	0.178	**0.195**	0.141	0.159	0.085	0.079	0.080	0.099
SPE	**0.194**	0.192	**0.149**	**0.172**	**0.104**	**0.118**	**0.095**	**0.114**
CTRL	0.147	0.148	0.126	0.148	0.044	0.061	0.058	0.075

Hindcast period: 1991-2005
SP version 1055m007

Weisheimer et al GRL (2011) – See poster



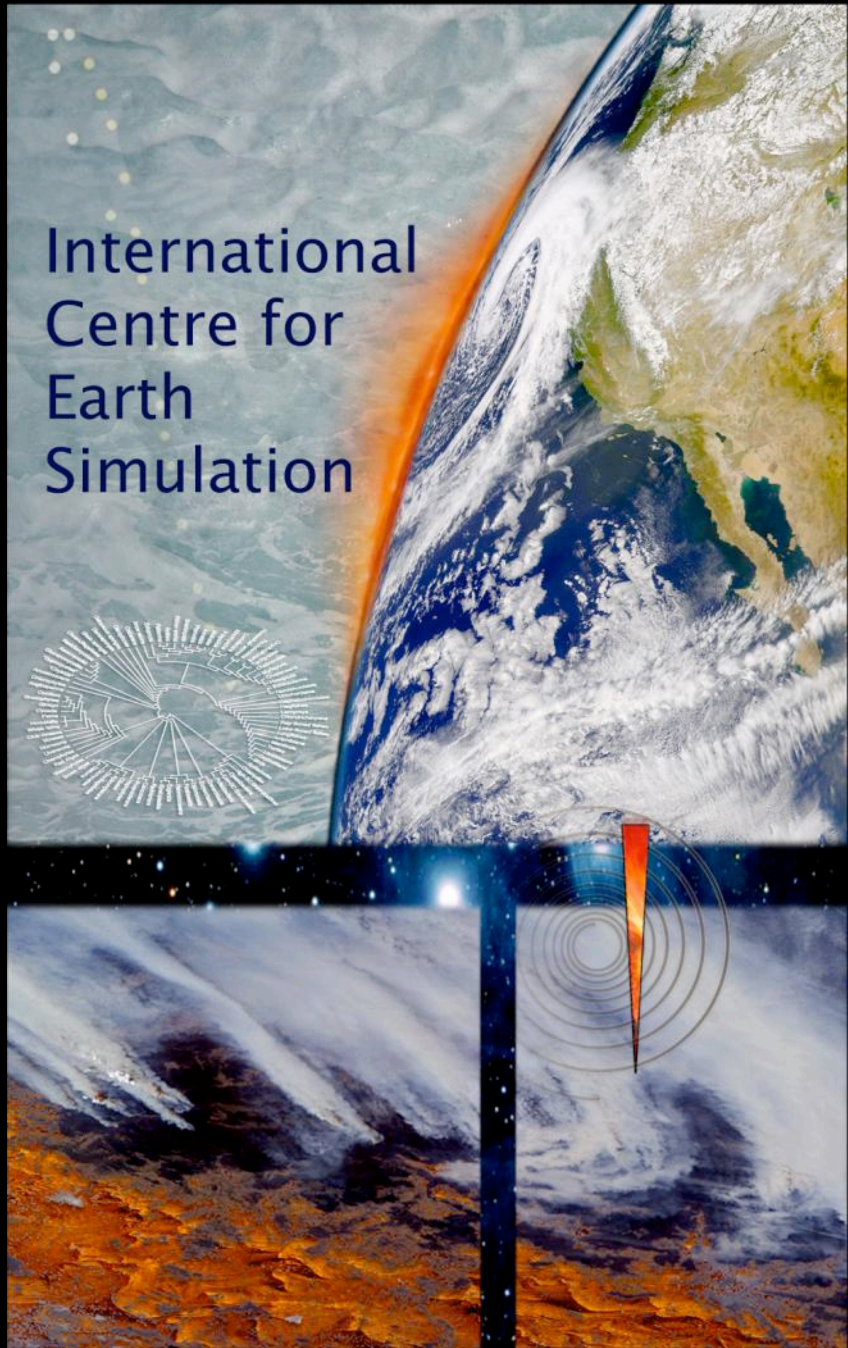
Performance of stochastic parametrisation in data assimilation mode. M. Bonavita, personal communication.

Stochastic Parametrisation

- Potentially a more rigorous approach to the representation of model uncertainty than MMEs - more consistent with underlying scaling symmetries, power laws etc.
- Can outperform multi-model ensembles on monthly/seasonal timescales

- Limited results to date
- Needs to be further developed at the process level and extended to other components of the earth-system (oceans, land surface etc)

Community-wide approach towards a Probabilistic Earth-System Model – enabling human and computing resources to benefit from economies of scale?


International
Centre for
Earth
Simulation

Network on Stochastic Parameterization and Modelling

- Initiated at a recent Isaac Newton Institute programme on mathematics and climate
- Moderated by Judith Berner (NCAR) and Tim Palmer, (Univ. of Oxford, ECMWF)
- URL has info on how to subscribe and post messages and get help from the site administrator
- Every member can post to list
- **Sign up at http://mailman.ucar.edu/mailman/listinfo/stoch**

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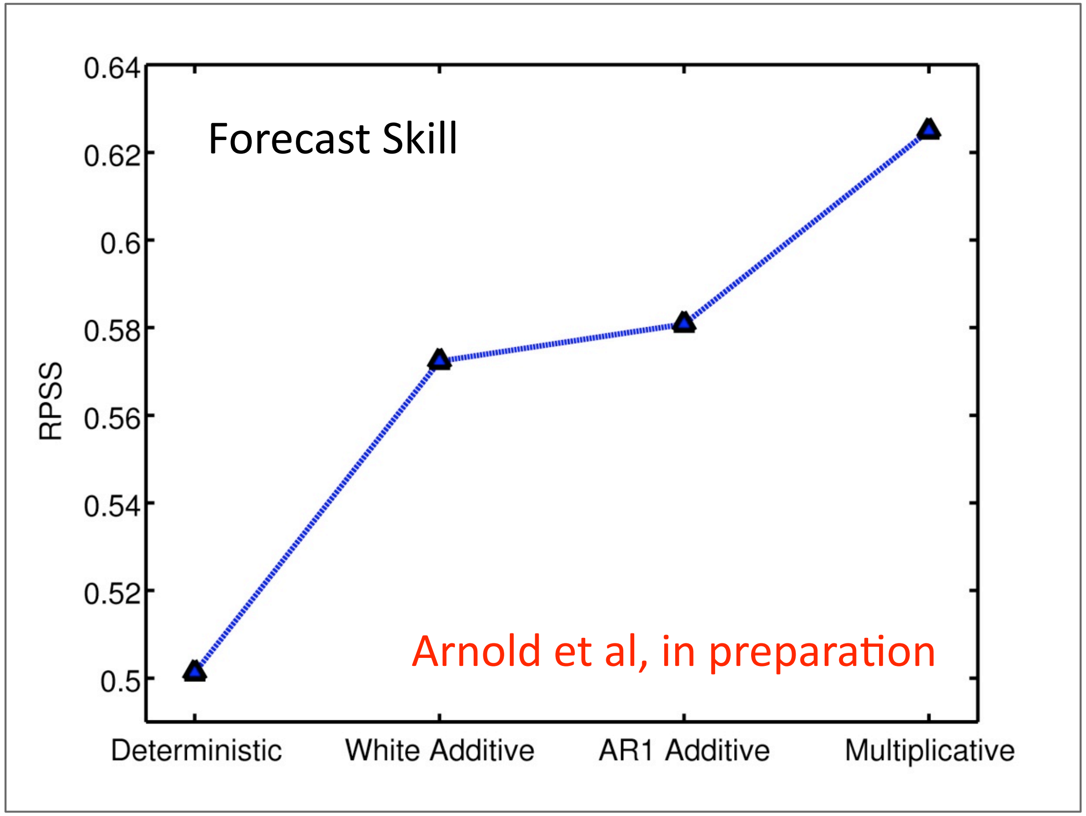

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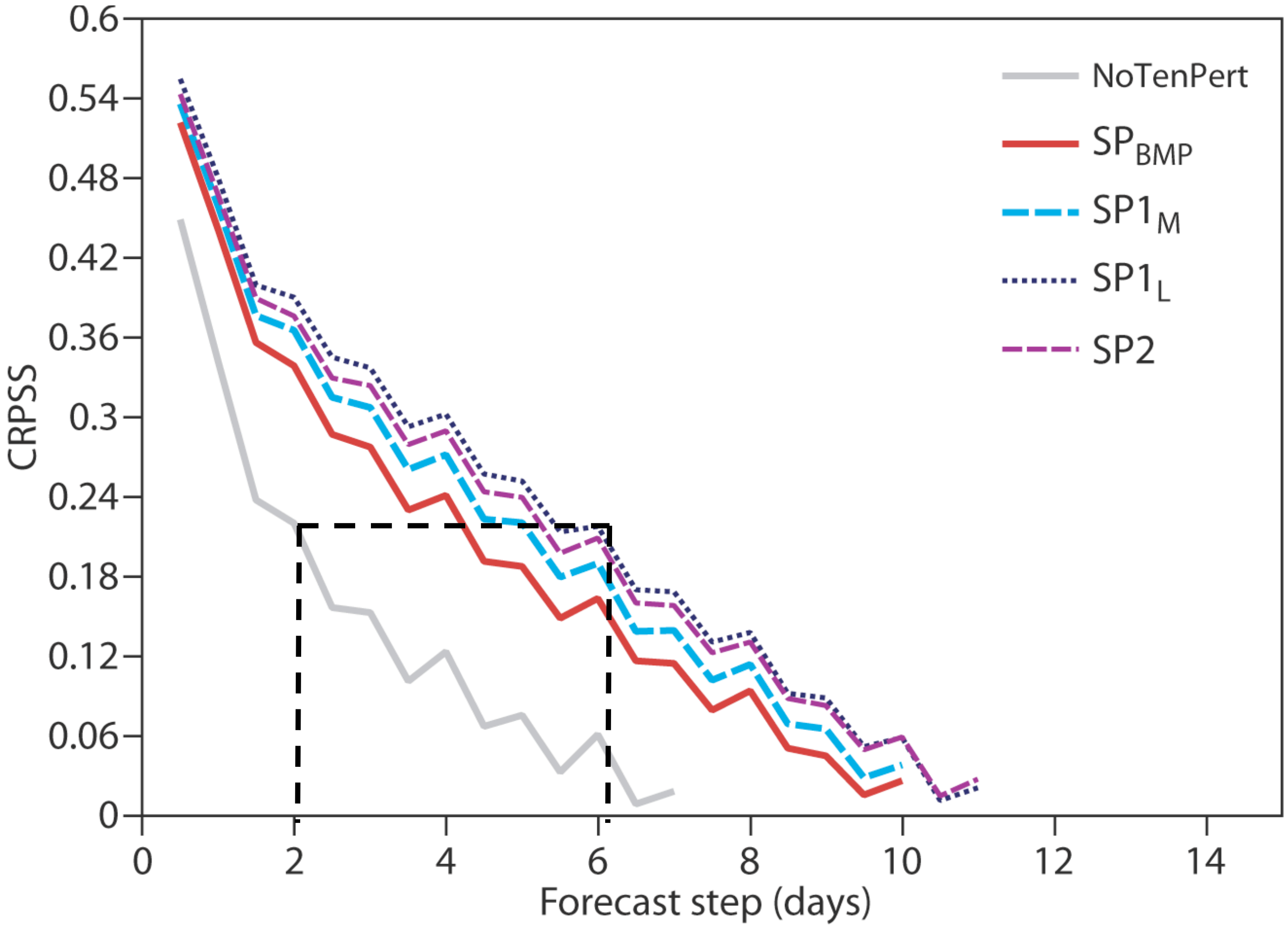
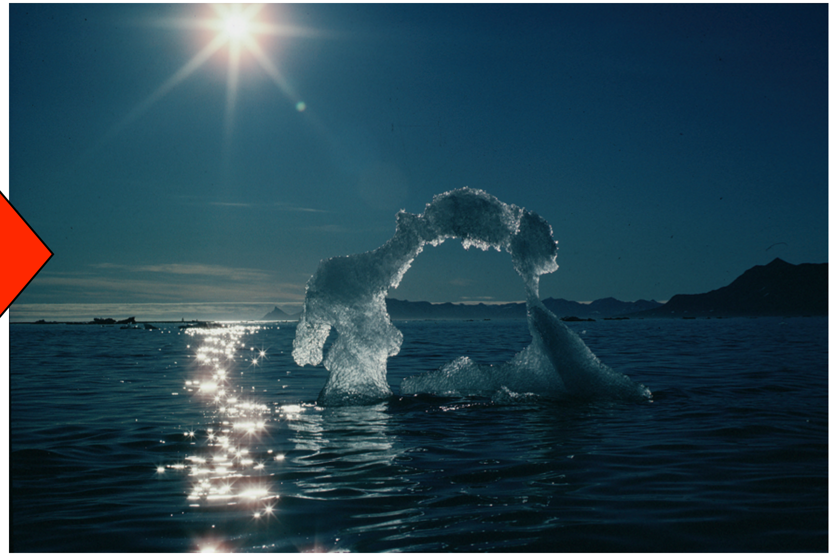
October 8, 2009

Medium-Range Predictions of 850hPa Temperature (Tropics)



Bringing the insights and constraints of NWP to the climate-change timescale.



Using data assimilation to constrain climate sensitivity

Rodwell, M.J. and T.N.Palmer, 2007: Using numerical weather prediction to assess climate models. Q.J.R. Meteorol.Soc., 133, 129-146.

Using SI prediction as a test of reliability of multi-model precip climate change probability

Palmer, T.N., F.J. Doblas-Reyes, M. Rodwell and A.Weisheimer, 2008: Bulletin Am Met Soc