Predictability, Dynamics and Ensemble Forecasting (PDEF)Working group

Presentation to WGNE

Craig H. Bishop
Naval Research Laboratory, Monterey, USA
Richard Swinbank
Met Office, Exeter, UK

Outline

- Intro to PDEF
- Stochastic physics challenge
- Conclusions

Introduction to WWRP PDEF WG

- A merger of THORPEX TIGGE (The International Grand Global Ensemble) and PDP (Predictability and Dynamical Processes) working groups
- First meeting to be held May 21-22, Karlsruhe, directly following Karlsruhe conference.

Terms of reference for PDEF

- To advance the science of dynamical meteorology and predictability research, and their application to ensemble forecasting
- To encourage scientific investigations to improve ensemble predictions by better accounting for analysis, model and forecast uncertainties
- To promote research on the evaluation of ensembles
- To foster collaboration between the academic community and operational centres
- To promote the development of ensemble applications and the transition into operations
- To support WWRP projects and field experiments, including Forecast Demonstration Projects and Research and Development Projects (HIW PPP S2S).
- To promote the use of TIGGE, TIGGE-LAM and other ensemble datasets
- To facilitate and encourage training in the science of predictability, dynamics and ensemble forecasting
- To provide scientific direction for the development of the TIGGE and TIGGE-LAM archives

Initial foci

- Stochastic representation of the effect of sub-grid-scale uncertainty in numerical models
- Construction of ensemble initial conditions
- Interactions of diabatic processes with meso/synoptic scale dynamics
- Assessment of multi-model ensembles and calibration techniques
- Coupled modelling & assimilation

Membership

- **Co-chairs**
- Craig Bishop - NRL, USA
- Richard Swinbank – Met Office, UK
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- **Members**
- Oscar Alves – CAWCR, Australia
- Judith Berner - NCAR, US
- Masayuki Kyouda – JMA, Japan
- John Methven – U Reading, UK
- Zhiyong Meng – U Peking, China
- Mark Rodwell - ECMWF, UK
- Olivia Rompainnen-Martius – U Bern, Switzerland
- Susanne Theis - DWD, Germany
- Munehiko Yamaguchi – JMA/MRI, Japan
- Yuejian Zhu – NCEP, USA
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- Ex officio
- TIGGE panel chair: Manuel Fuentes, ECMWF, Int

Need for Stochastic modeling

1. Numerical models only have a finite number of variables. At best, they can represent some sort of averaged or filtered version of reality.
2. Imagine a near infinite number of Earth replicates. Choose one of them. Find its corresponding model-specific filtered/averaged state by appropriately averaging/smoothing its atmospheric-oceanic-land-surface-topographical state. Find the subset of replicate Earths having exactly the same filtered state. The time evolution of each of these filtered states will differ because of the sub-grid scale differences, and be inherently stochastic because of the hidden nature of the sub-grid scale differences.

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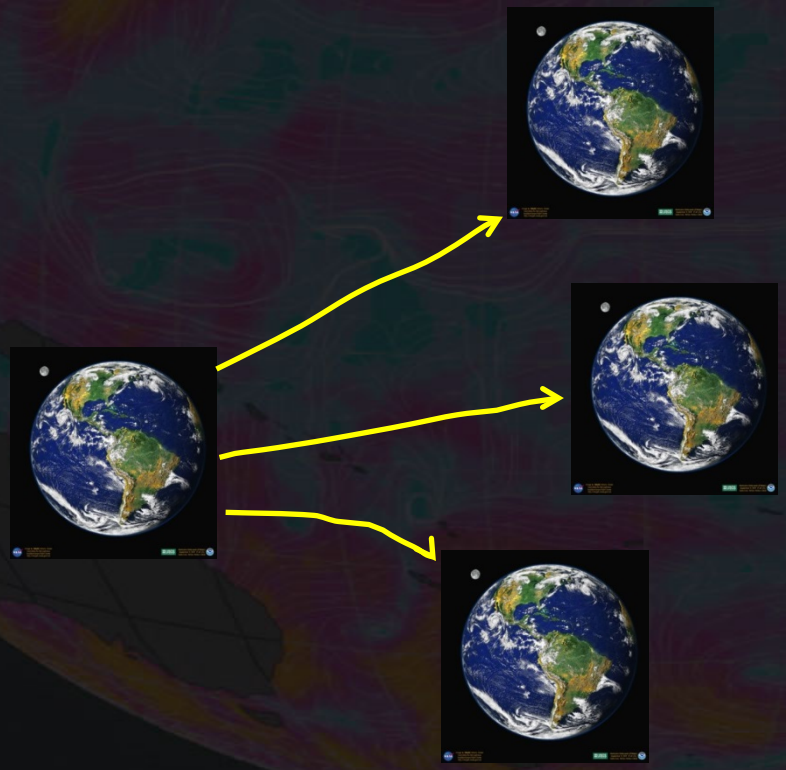

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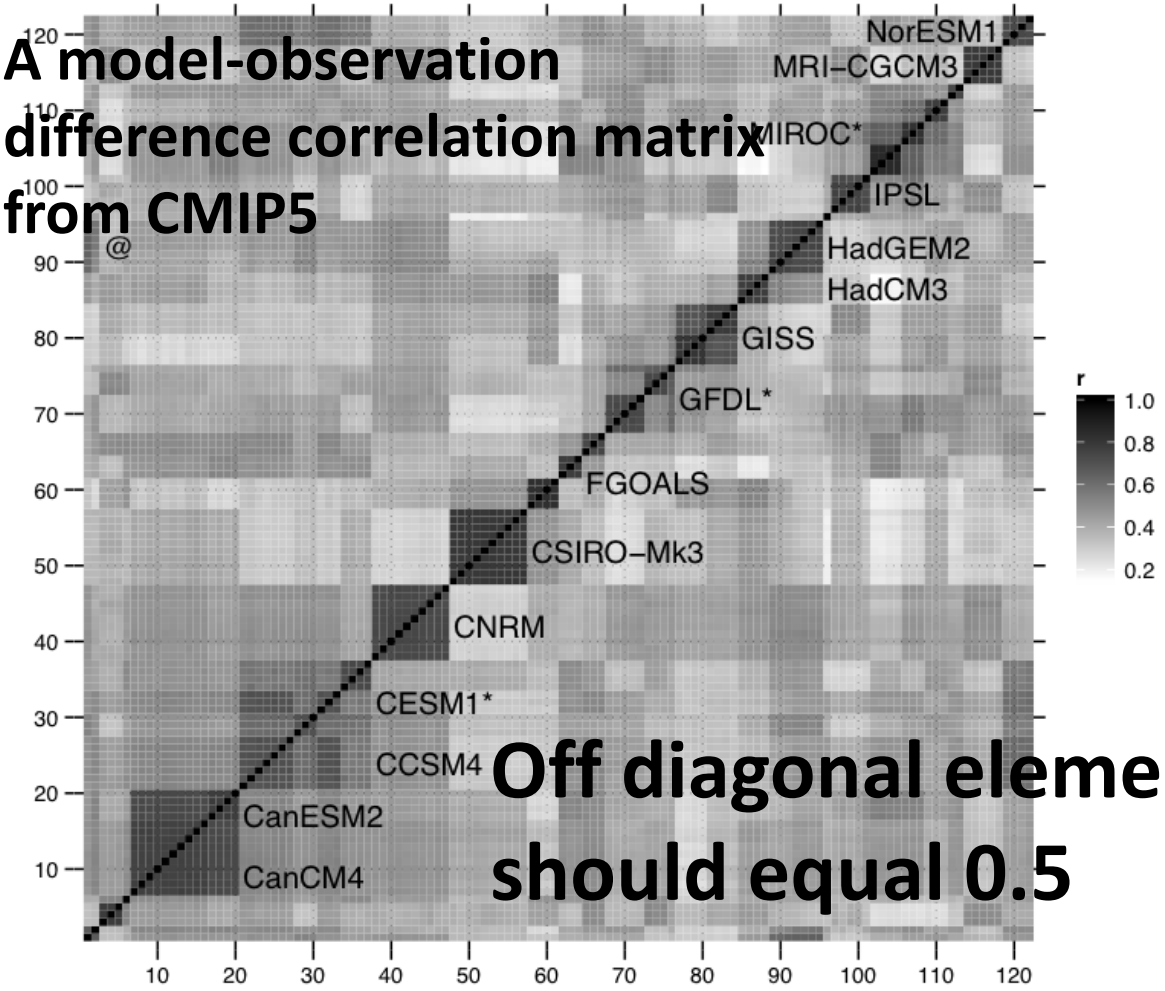
3. **The most useful *ensemble* of stochastic models would be statistically indistinguishable from the evolution of its replicate Earth counterpart. Agreed?**
4. **A possible ideal "deterministic" model would perfectly predict the evolution of ensemble mean of the Earth replicates – it would minimize mean square errors from observations. Is there interest in producing such models?**

Without stochastic models …

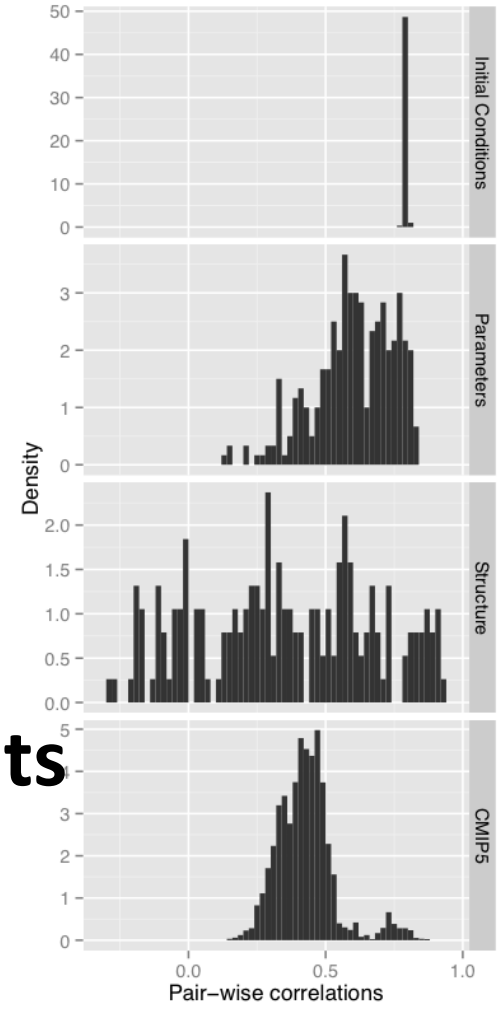
1. Ensemble variance will not be able to keep pace with error variance as the forecast proceeds.
2. The spatial covariance of the ensemble members will be incorrect.
3. The correlation of differences between climate models and verifying observations will be unrealistically large.
4. The distribution of observations will be distinguishable from the distribution of ensemble members.
5. **Problematically, the 4 aforementioned problems can be superficially ameliorated through the repeated addition of appropriately structured noise - without any consideration of sub-grid scale processes.**

$$\mathbf{A} = \left\langle \left(\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} - \begin{bmatrix} x_{\text{our Earth}} \\ x_{\text{our Earth}} \\ x_{\text{our Earth}} \end{bmatrix} \right) \left(\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} - \begin{bmatrix} x_{\text{our Earth}} \\ x_{\text{our Earth}} \\ x_{\text{our Earth}} \end{bmatrix} \right)^T \right\rangle = \begin{pmatrix} 2\overline{\sigma^2} & \overline{\sigma^2} & \overline{\sigma^2} \\ \overline{\sigma^2} & 2\overline{\sigma^2} & \overline{\sigma^2} \\ \overline{\sigma^2} & \overline{\sigma^2} & 2\overline{\sigma^2} \end{pmatrix}$$

A model-observation difference correlation matrix from CMIP5



Off diagonal elements should equal 0.5



Haughton et al, in review, *Climate Dynamics.*

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Need for definition of sub-grid scale

- How to filter high resolution reality to obtain the filtered state that the model's numerical scheme is designed to evolve?
- A clear answer
  - would provide a rigorous starting point for parameterizing sub-grid scale effects.
  - would also help state estimators (DA) better define "observation error of representation".

More Questions

- **How can one unambiguously distinguish between the “grid-scale” and the “sub-grid-scale” for a numerical model?**
- **What is the filter that one needs to apply to reality to find the sequence of states that the model was designed to represent?**
- **Model diffusion must influence this filter, but how?**

Is the ideal model non-diffusive?

- $\cos(mx)\cos(nx)=\cos[(m+n)x]+\cos[(m-n)x)]$
- Non-linearity causes each scale to be influenced by all other scales. Each scale can only be influenced by the scales/waves resolved by the model.
- Relative magnitude of the time-stepping errors incurred by this failure to represent the full range of scale interactions are likely larger for short wavelength waves than longer wavelength waves.
- Isn't it better to damp erroneous tendencies than keep them?
- Shouldn't this need to damp erroneous tendencies determine the filtering function that should be applied to reality to obtain (a) the best state to initialize the model with, and (b) the best sequence of states with which to compare the model's prediction of the sequence of states?
- **Should the ideal NWP scheme be diffusive?**

Ways forward

- **More "Grey-Zone" type experiments!**
- Comparison of spectra from very high resolution model climates and lower resolution models to determine filter required to go from high-res to low-res.
- New approaches to discrete solutions to the Navier-Stokes equations in which the space-time filtering decisions are made explicit and *a priori.*
- Comments welcome!

Grey zone project

Proposal (from WGNE 2010 meeting)

• Project driven by a few expensive experiments **(controls)** on a large domain at a ultra-high resolution (Δx=100~500m) (~2000x2000x200 grid points).

•Coarse grain the output and diagnostics (fluxes etc) at resolutions of 0.5, 1, 2, 4, 8, 16, 32 km. **(a posteriori coarse graining: COARSE)**

•Repeat CONTROLS with 0.5km 1km, 2km, 4km, 8km, etc without convective parametrizations etc **(a priori coarse graining: NOPARAMS)**

•Run (coarse-grain) resolutions say 0.5, 1km, 2km, 4km and 8km with convection parametrizations **(a priori coarse graining: PARAMS)**

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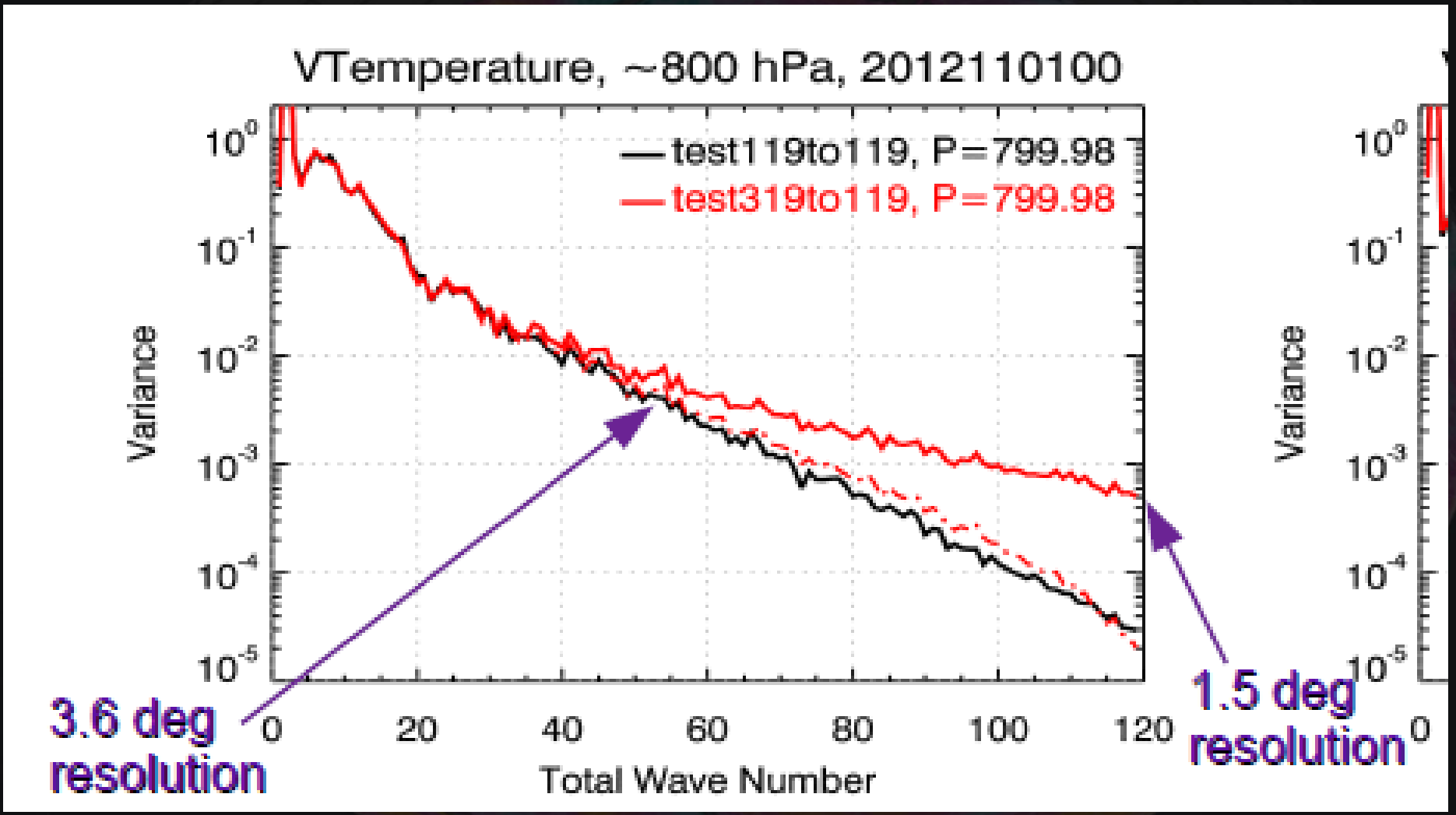

(Thanks to Karl Hoppel, NRL, DC)

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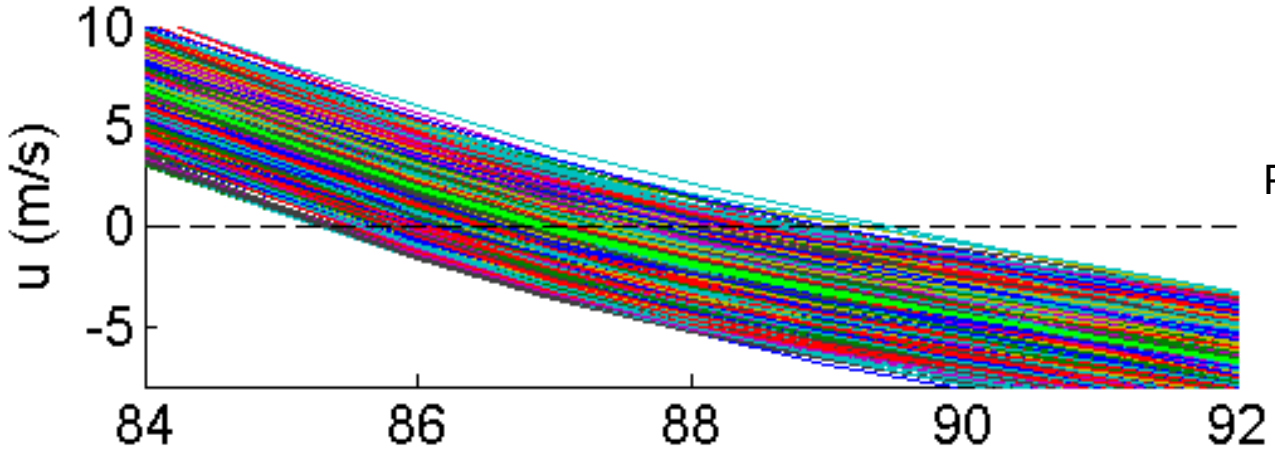
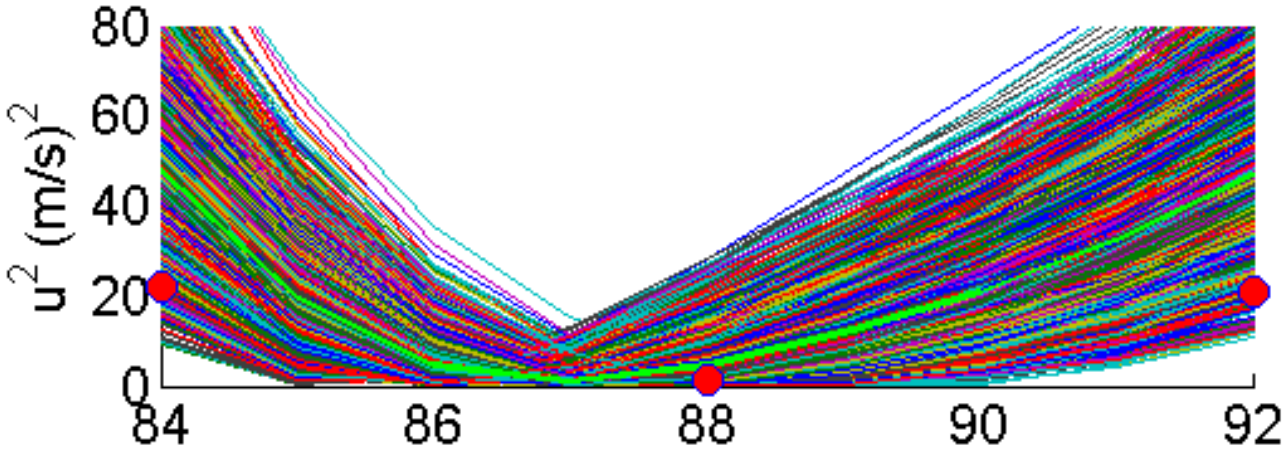
- New approaches to discrete solutions to the Navier-Stokes equations in which the space-time filtering decisions are made explicit and *a priori.*
- ***WGNE input likely very helpful for solving stochastics parameterization problems.***
- Comments welcome!

Consider this prior



Prior ensemble of zonal wind

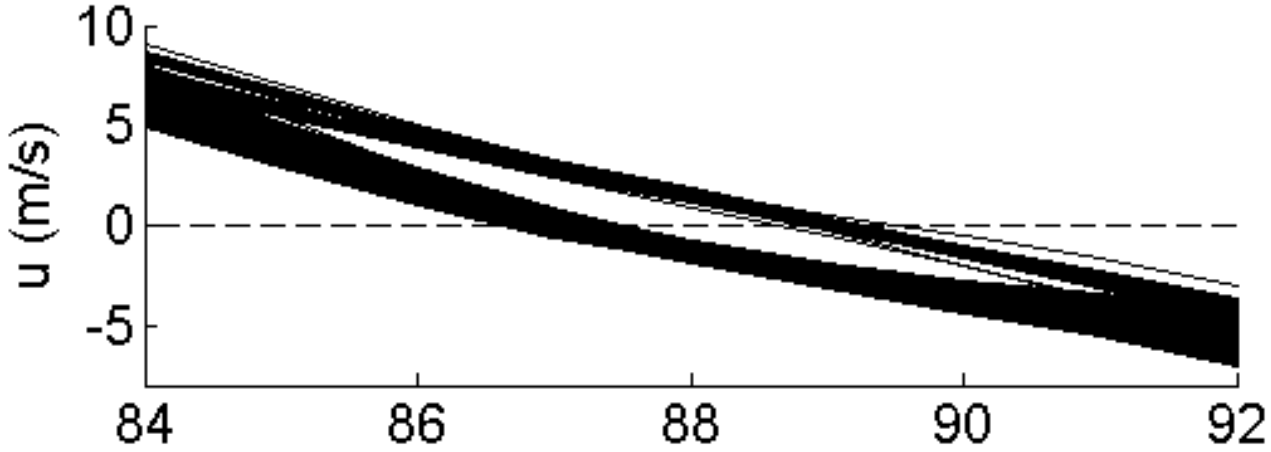


Prior ensemble of zonal wind squared

$y = 22.2\ m^2 s^{-2}$ $y = 1.27\ m^2 s^{-2}$ $y = 21.2\ m^2 s^{-2}$

Red dots are observations of the square of the zonal wind

Shouldn't the posterior look like this?



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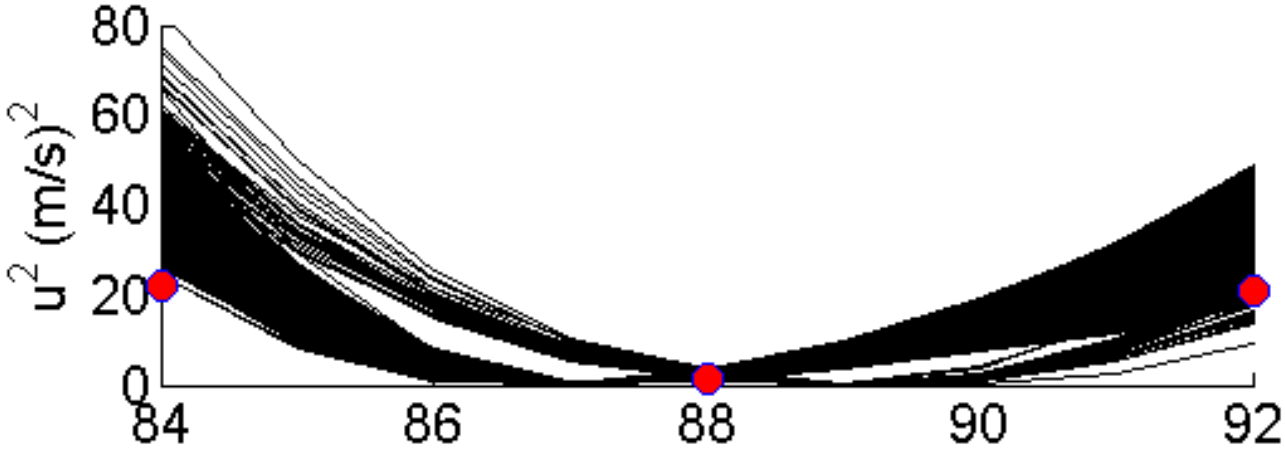

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