Diagnostics and Model Error An Introduction

Tim Palmer
ECMWF

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with the National Pandemic Flu Service

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If you have flu-like symptoms and are concerned that you may have swine flu **Click here**

Antiviral medicine advice:
Please note NHS Direct cannot issue antiviral medicines. They can only be obtained by the National Pandemic Flu Service or from your GP

- Common health questions
- Health encyclopaedia (A-Z)
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- Overwhelming support for the NHS
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- What is the National Pandemic Flu Service?

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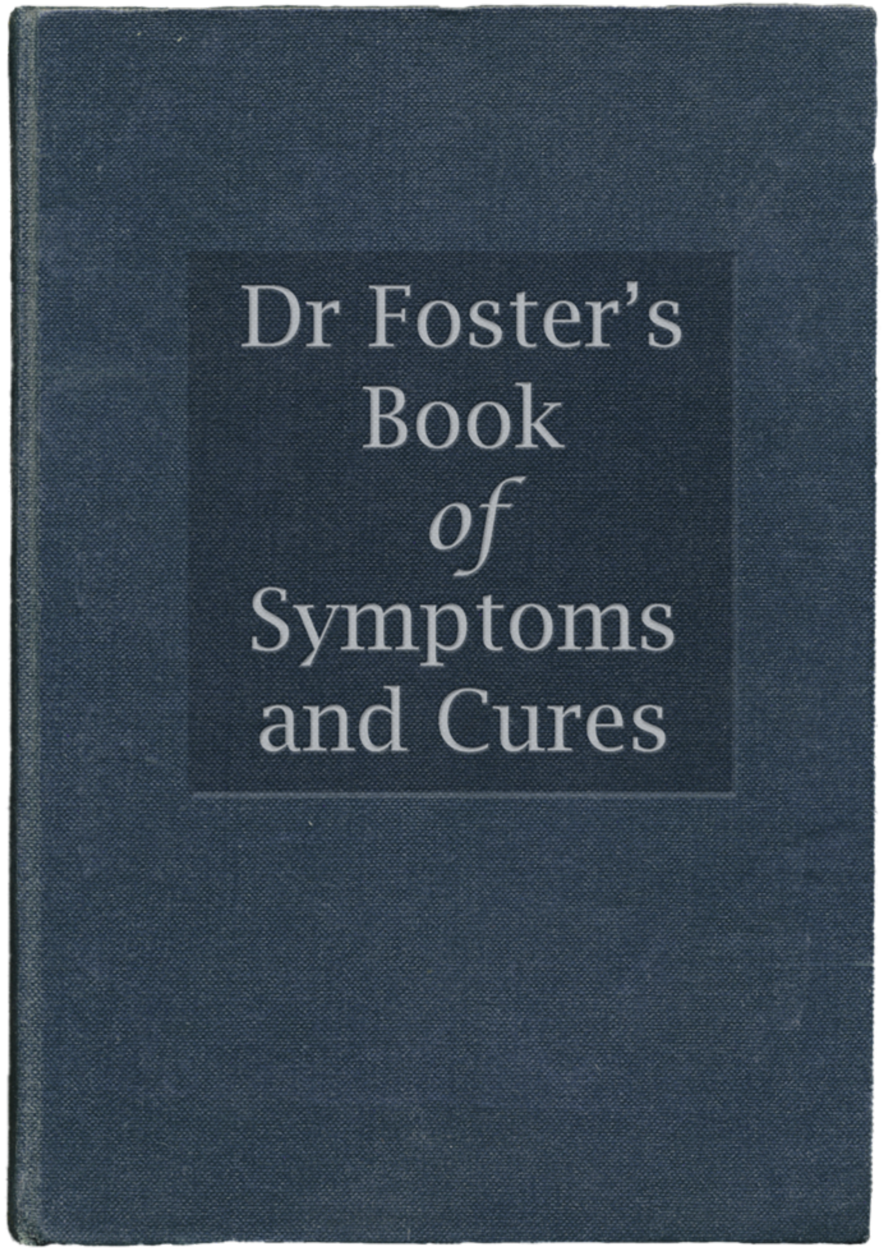
@Liz_Azyan @failedmuso Liz, Rob, thanks for the RT. 10 minutes ago

@gioias You're welcome. 17 minutes ago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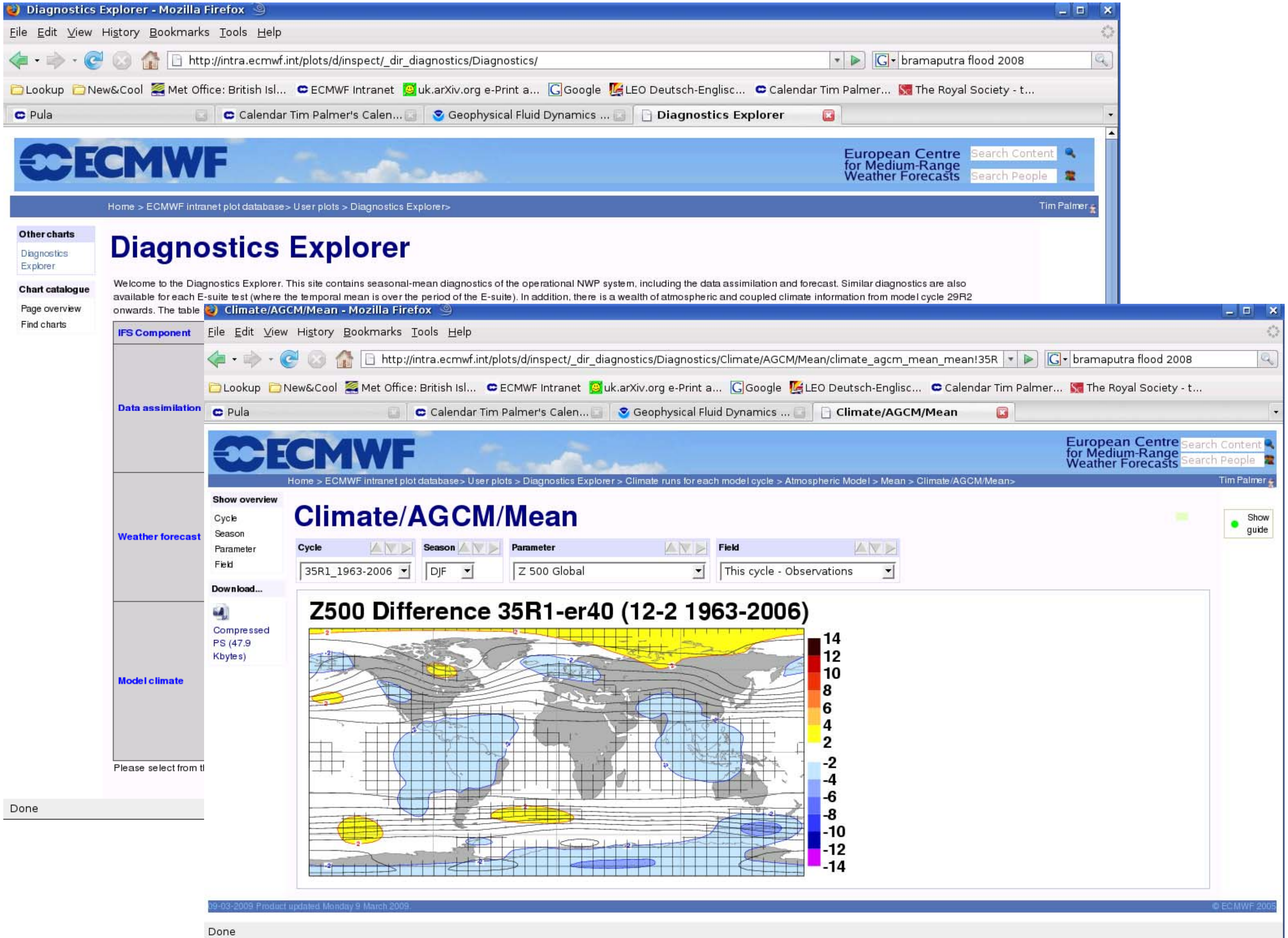

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Diagnostics Explorer
Welcome to the Diagnostics Explorer. This site contains seasonal-mean diagnostics of the operational NWP system, including the data assimilation and forecast. Similar diagnostics are also available for each E-suite test (where the temporal mean is over the period of the E-suite). In addition, there is a wealth of atmospheric and coupled climate information from model cycle 29R2 onwards. The table
IFS Component
Data assimilation
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Z500 Difference 35R1-er40 (12-2 1963-2006)
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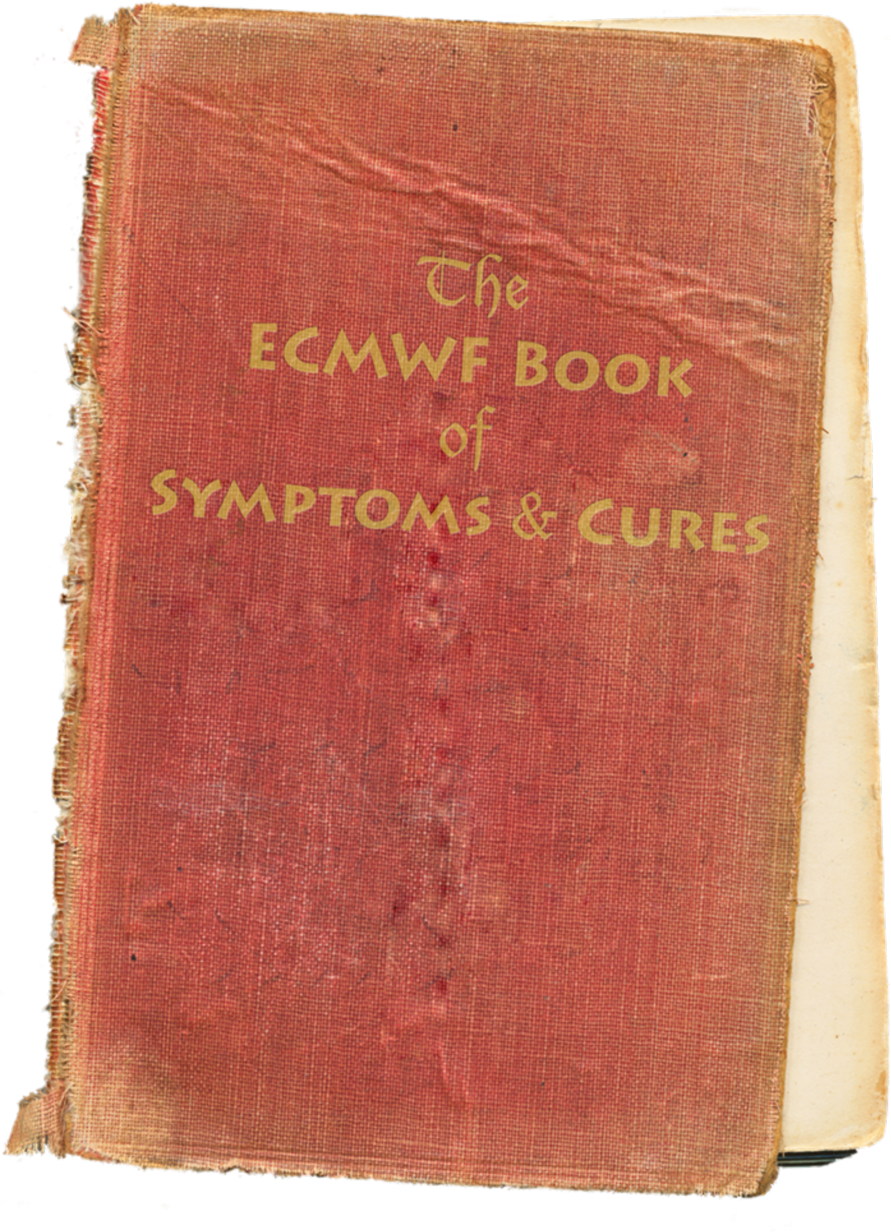

The
ECMWF BOOK
of
SYMPTOMS & CURES

If thy model's climatology hath:

Fever and high temperature in upper parts

Severe chills in lower parts

Bouts of excessive windiness in middle parts

Too much wetness over the warm pool with very dry patches elsewhere

Then:

Increase diffusion coefficient
by ten percent

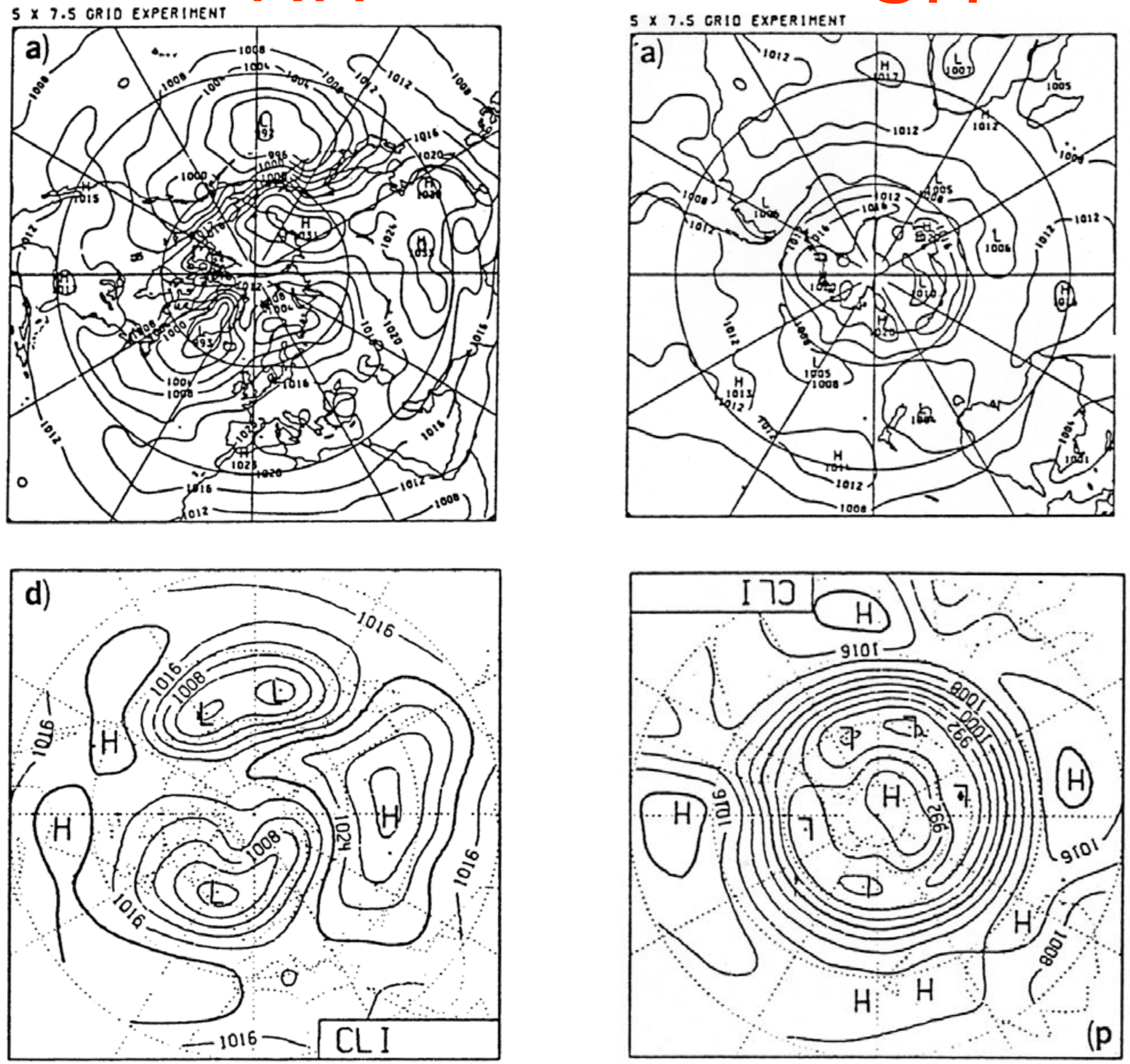
and

Decrease convective entrainment
parameter by five percent

DJF surface pressure climatology of 5°x7.5° grid point model

NH

SH



model

obs

If thy model's climatology hath:

Weak winds in Southern parts

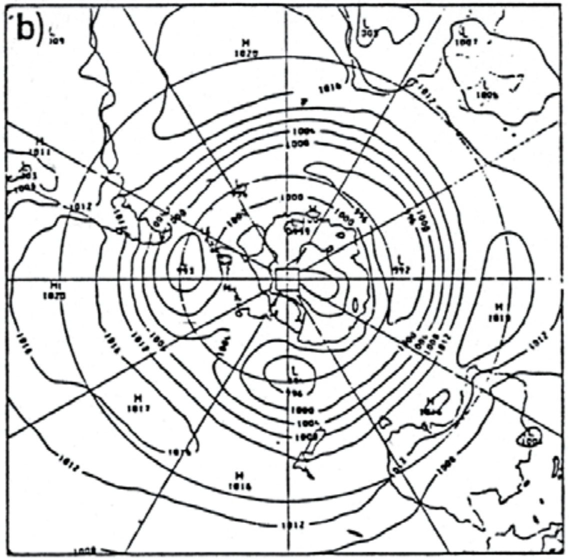
Realistic winds in Northern parts

Then:

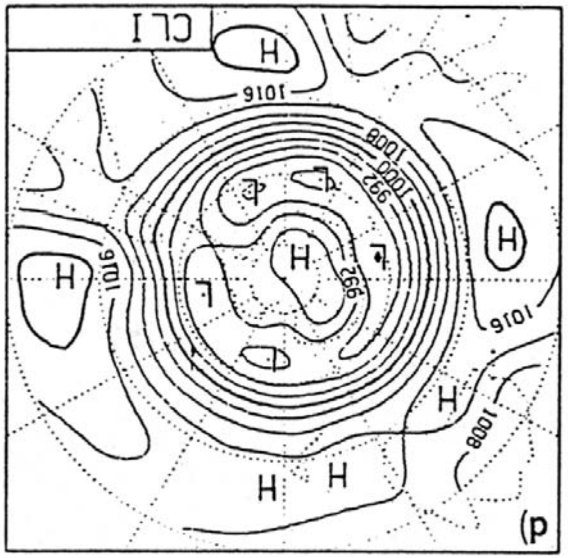
Reduce surface drag coefficient over the ocean

SH

2.5°x3.75° grid point model



model



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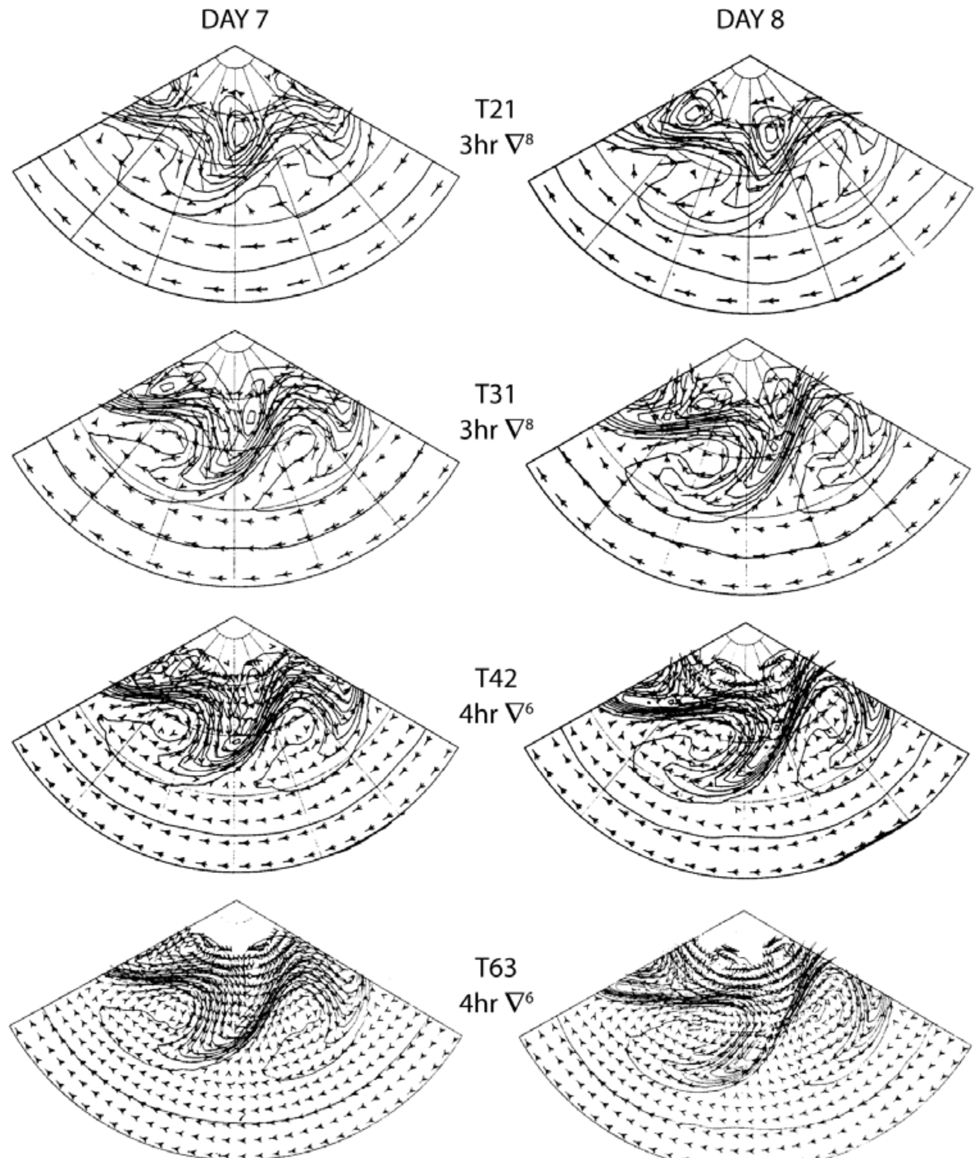
BAROCLINIC LIFECYCLE

(Hoskins & Simmons 1978)

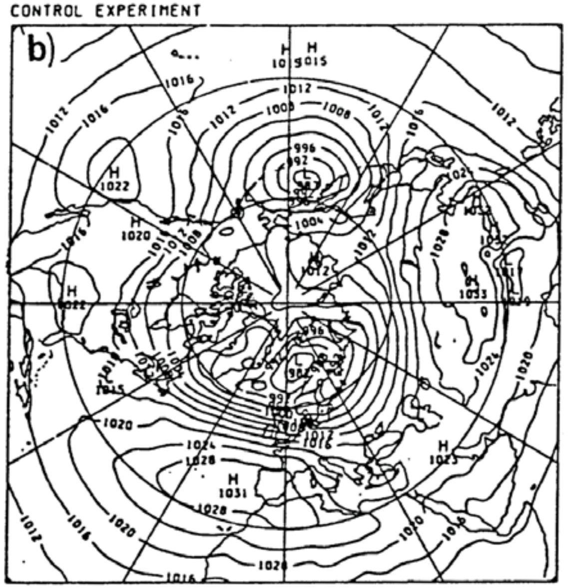
Potential vorticity and relative flow at $\theta = 350K$



MB Nov. 1989

NH

2.5°x3.75°
grid point
model



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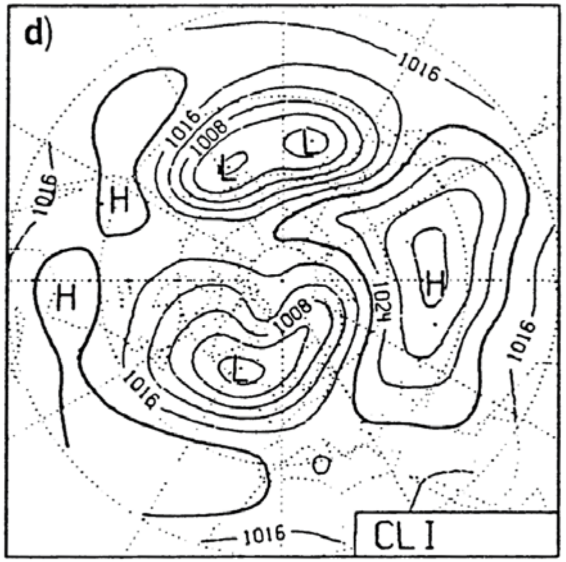


obs

If thy model's climatology hath:

Weak winds in Southern parts

Realistic winds in Northern parts

Then:

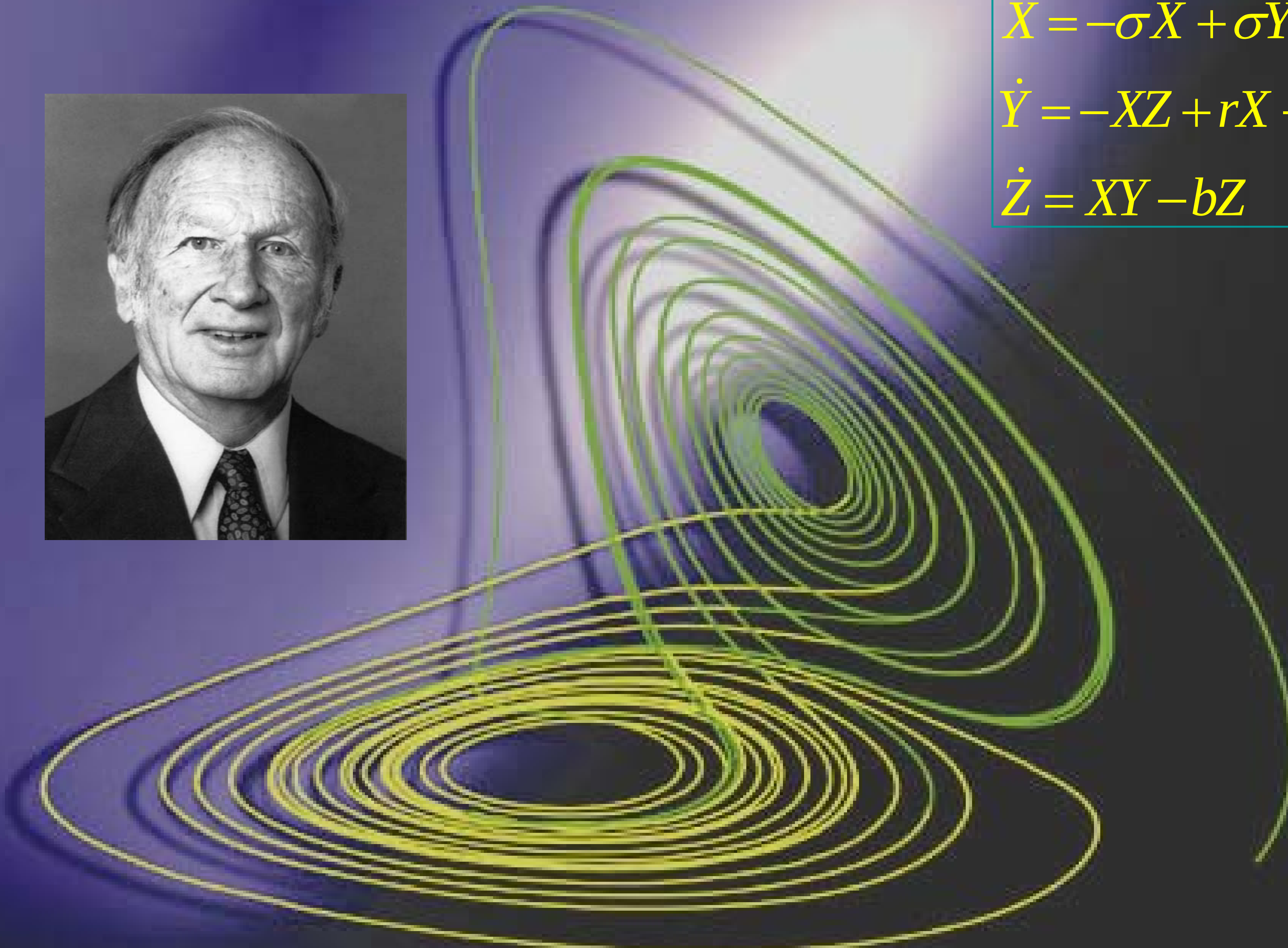
Reduce surface drag coefficient over the ocean

Model Diagnosis

What "looks good" (eg NH flow in 5°x7.5° model) might actually "be bad"!

(Here because of compensating errors between two **completely** different physical processes: poorly resolved baroclinic waves, and missing orographic drag.)

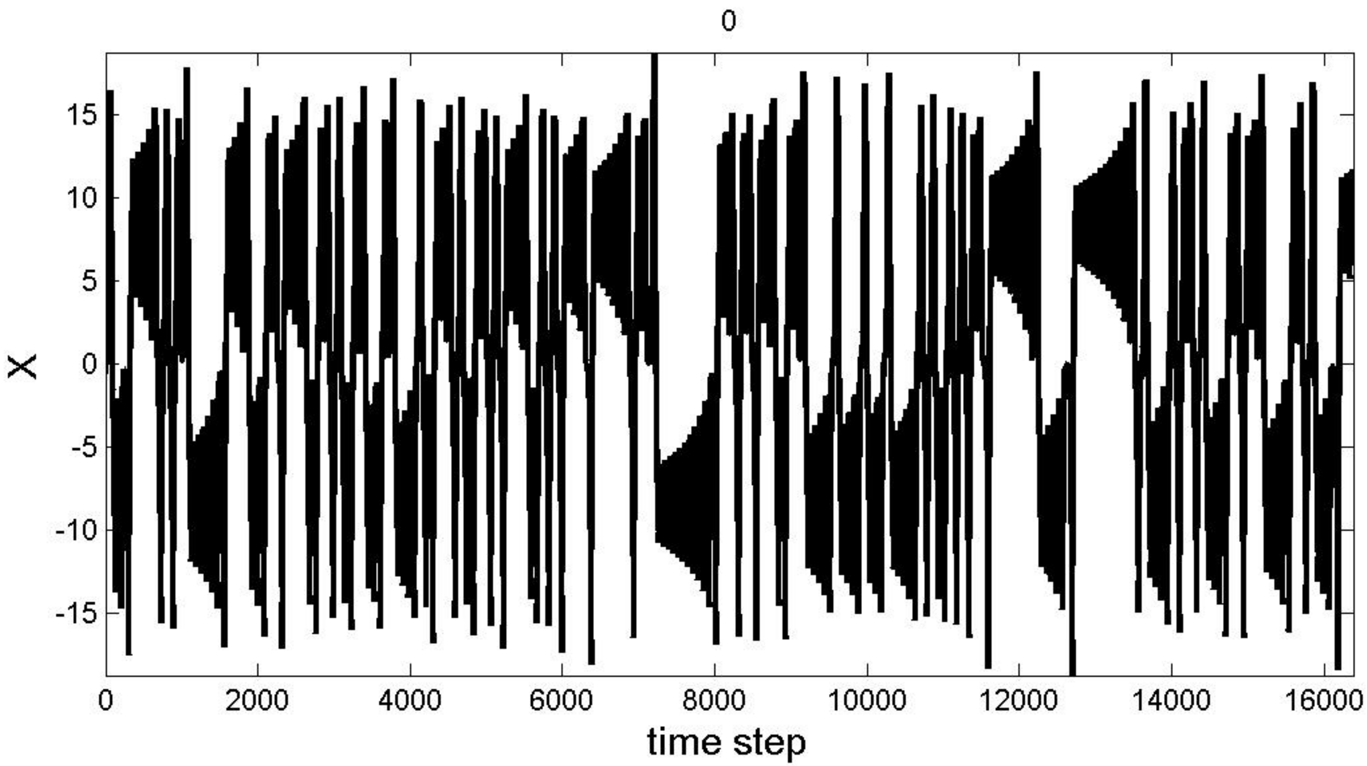
What is the fundamental origin of this "looks good …is bad" difficulty?



$$\dot{X} = -\sigma X + \sigma Y$$

$$\dot{Y} = -XZ + rX - Y$$

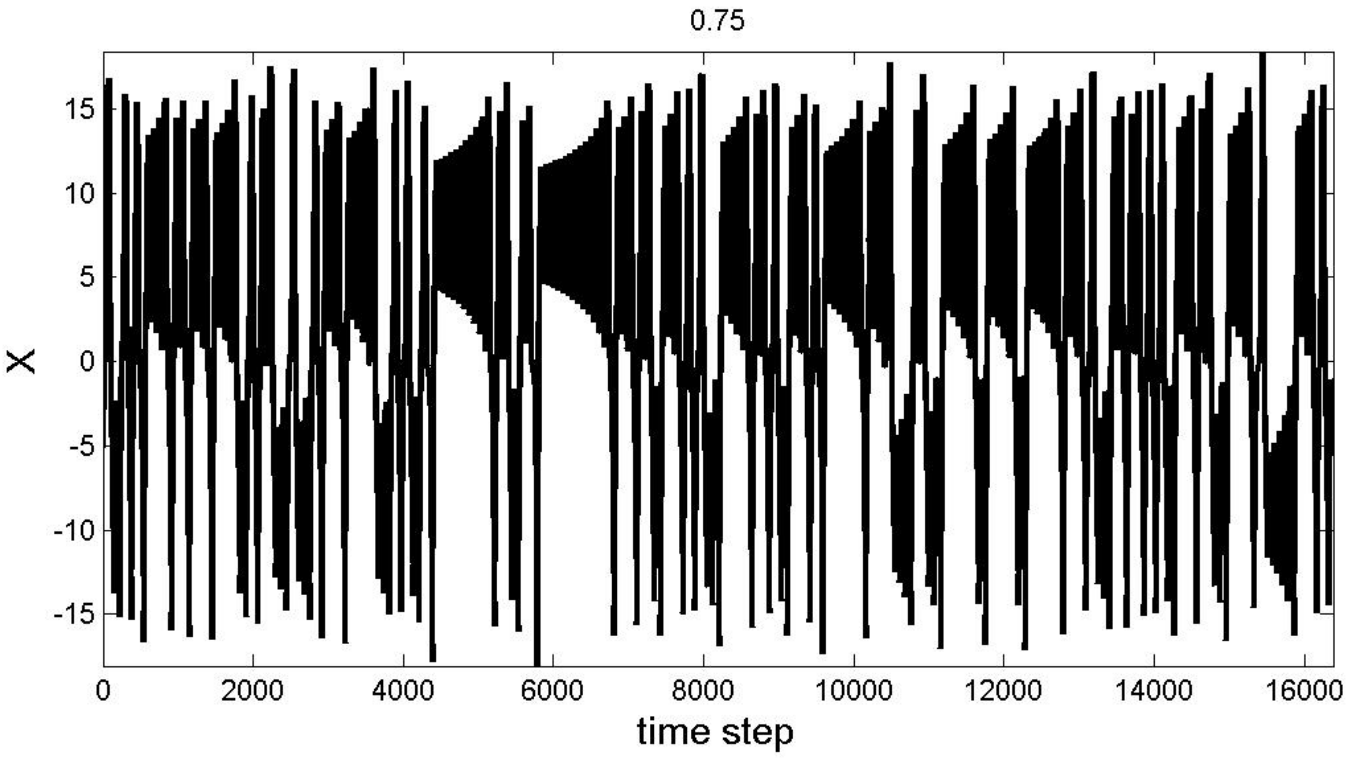
$$\dot{Z} = XY - bZ$$



$$\dot{X} = -\sigma X + \sigma Y$$

$$\dot{Y} = -XZ + rX - Y$$

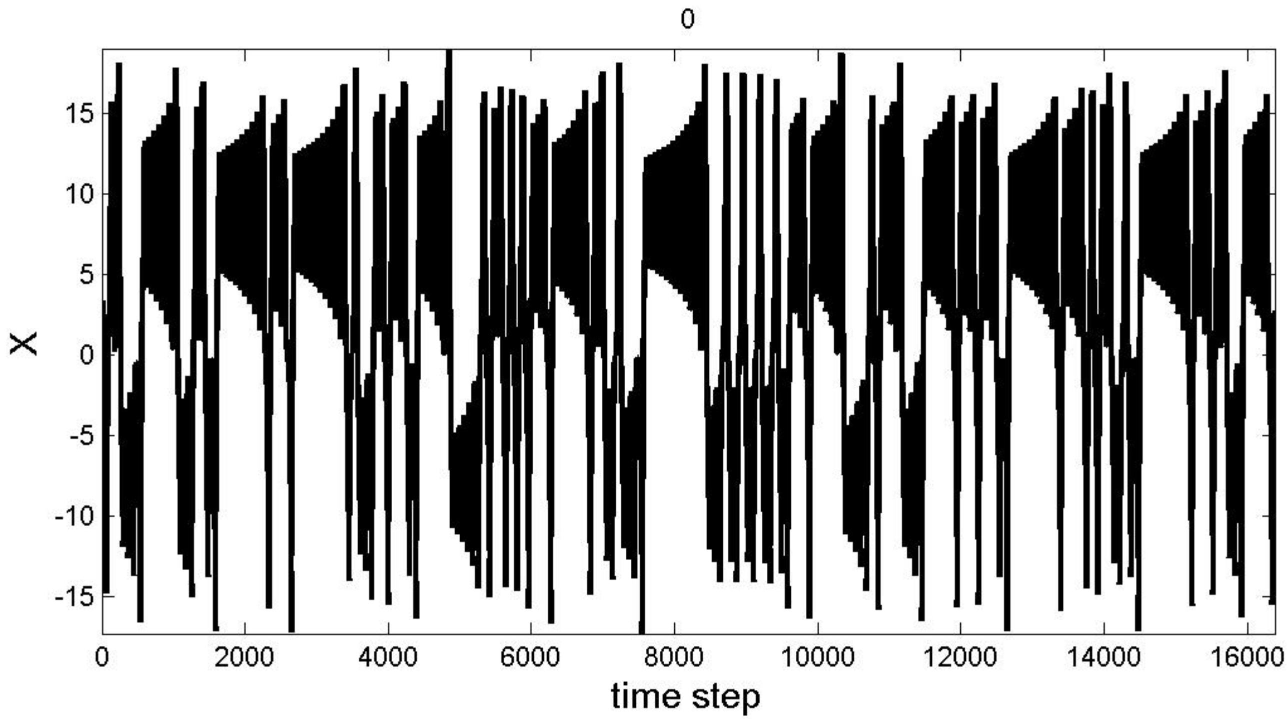
$$\dot{Z} = XY - bZ$$



$$\dot{X} = -\sigma X + \sigma Y + f\cos\theta$$

$$\dot{Y} = -XZ + rX - Y + f\sin\theta$$

$$\dot{Z} = XY - bZ$$

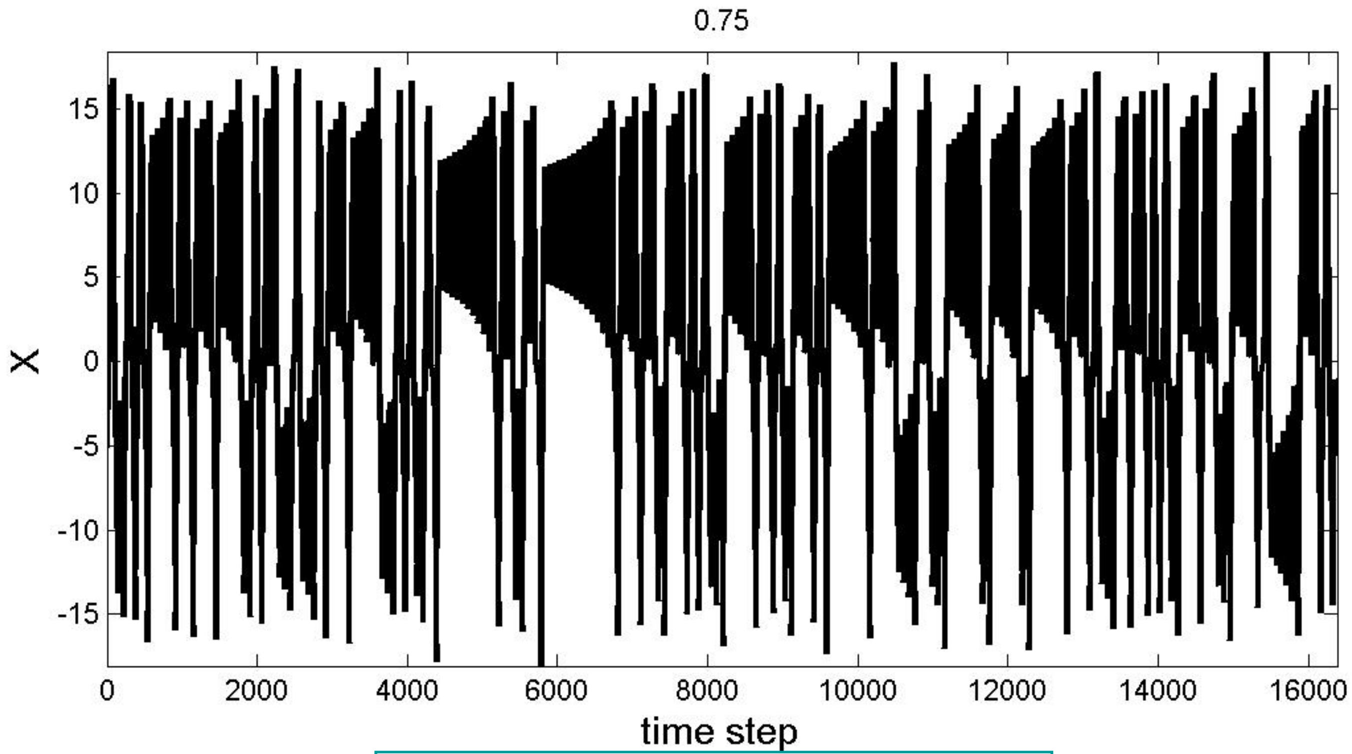


$$\dot{X} = -\sigma X + \sigma Y + f$$

$$\dot{Y} = -XZ + rX - Y$$

$$\dot{Z} = XY - bZ$$

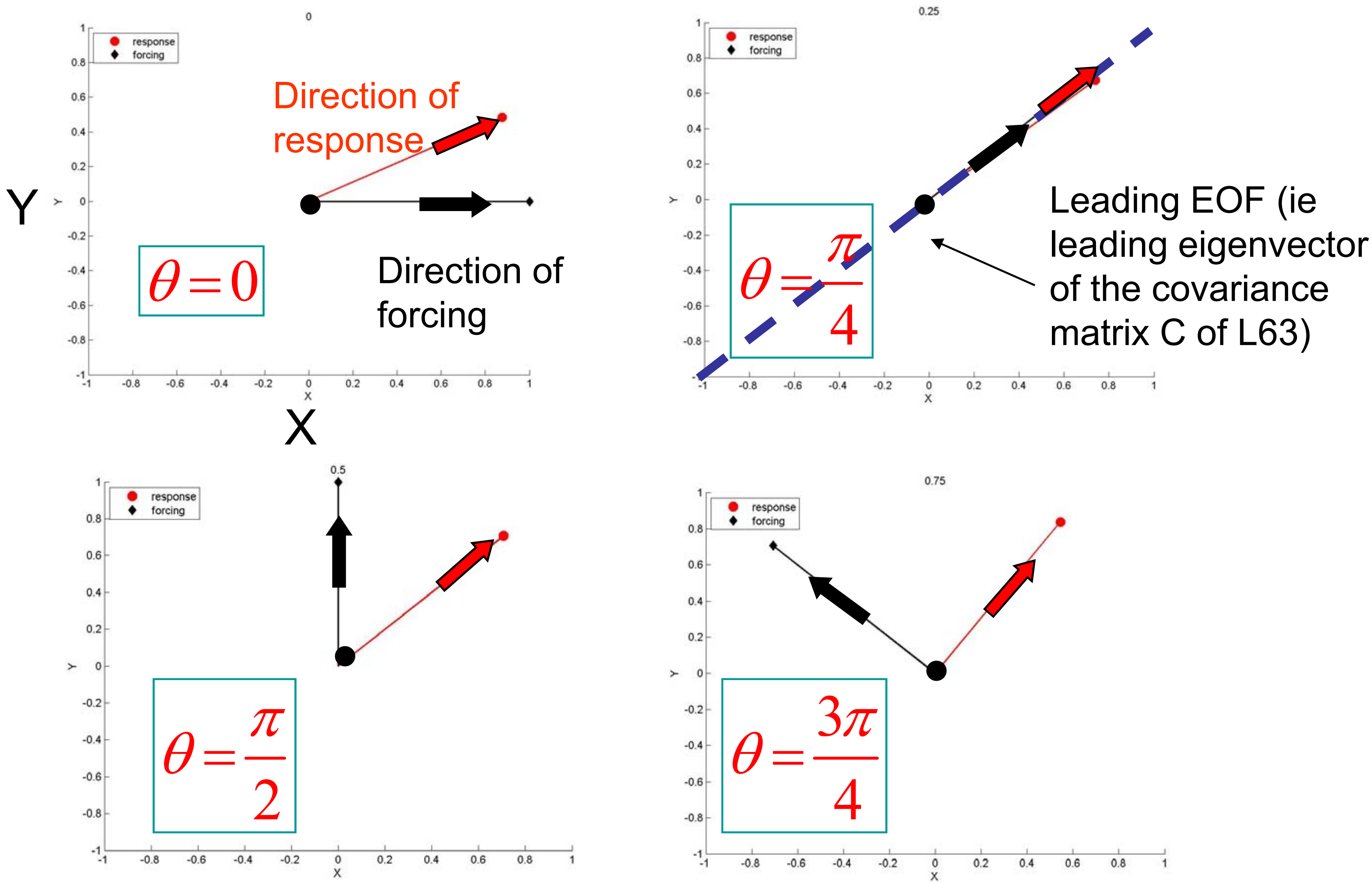
Looks Good………Is Bad!



$$\dot{X} = -\sigma X + \sigma Y - \frac{f}{\sqrt{2}}$$

$$\dot{Y} = -XZ + rX - Y + \frac{f}{\sqrt{2}}$$

$$\dot{Z} = XY - bZ$$

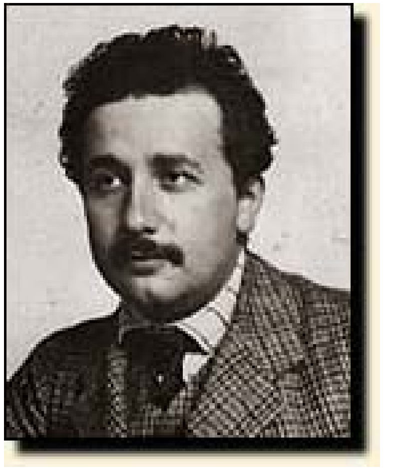


0
0.25
0.5
0.75
response
forcing
Direction of response
Direction of forcing
Y
X
$\theta = 0$
$\theta = \frac{\pi}{4}$
$\theta = \frac{\pi}{2}$
$\theta = \frac{3\pi}{4}$
Leading EOF (ie leading eigenvector of the covariance matrix C of L63)

1. Climatological response to external forcing seems to be linked to system's dominant internal modes of variability. (Cf high res, low res model biases – the Northern and Southern Annular Modes - NAM, SAM - are the dominant modes of surface variability.)

2. Quite different forcings can produce similar responses (cf underrepresentation of baroclinic eddies compensated by underrepresentation of orographic drag.

Why?



1905 - Annus Mirabilis

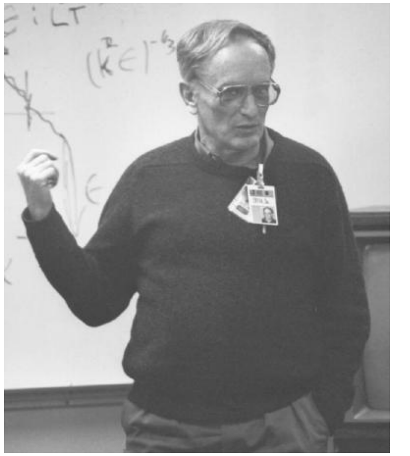
- Special Theory of Relativity
- Quantum explanation of the photoelectric effect
- Brownian Motion

..the same random forces which cause the erratic motion of a particle in Brownian motion would also cause drag if the particle were pulled through the fluid.

Fluctuation Dissipation Theorem

A very general result of statistical thermodynamics which quantifies the relation between the fluctuations of a system in thermal equilibrium and the response of the system to applied perturbations

First applied to the climate system by Chuck Leith



$$\dot{X} = F[X]$$

$$\dot{X}' = F[X'] + \delta f$$

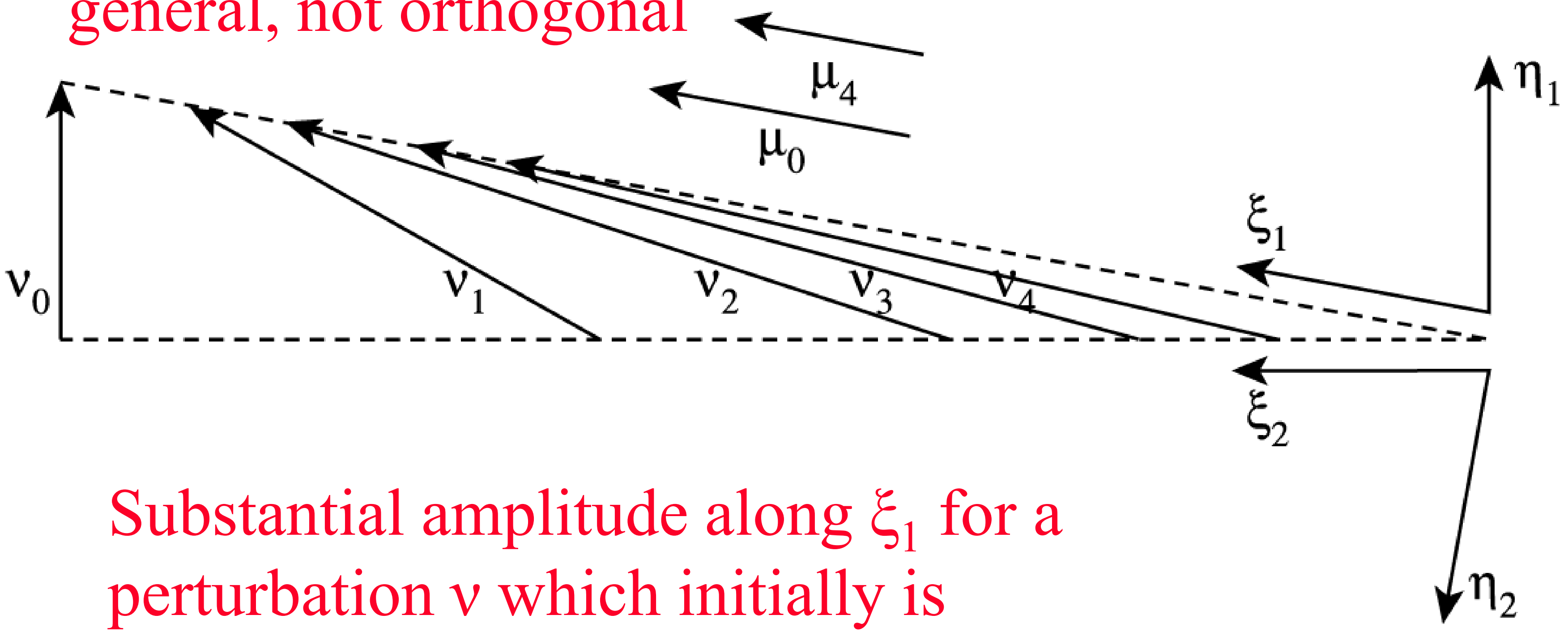
$$\delta X = X' - X \quad \Rightarrow \quad \delta \bar{X} = \mathrm{L}\delta f$$

By the Fluctuation-Dissipation theorem (Leith, 1975)

$$\mathrm{L} \approx \int_0^\infty C(\tau) C^{-1}(0)\, d\tau$$

C is lag-τ covariance matrix of X

Because of the advective nonlinearity in the equations of motion, the eigenmodes of a system linearised about a stationary basic state, are, in general, not orthogonal



Substantial amplitude along ξ_1 for a perturbation ν which initially is almost orthogonal to ξ_1 (this adjustment can occur on timescales of days)

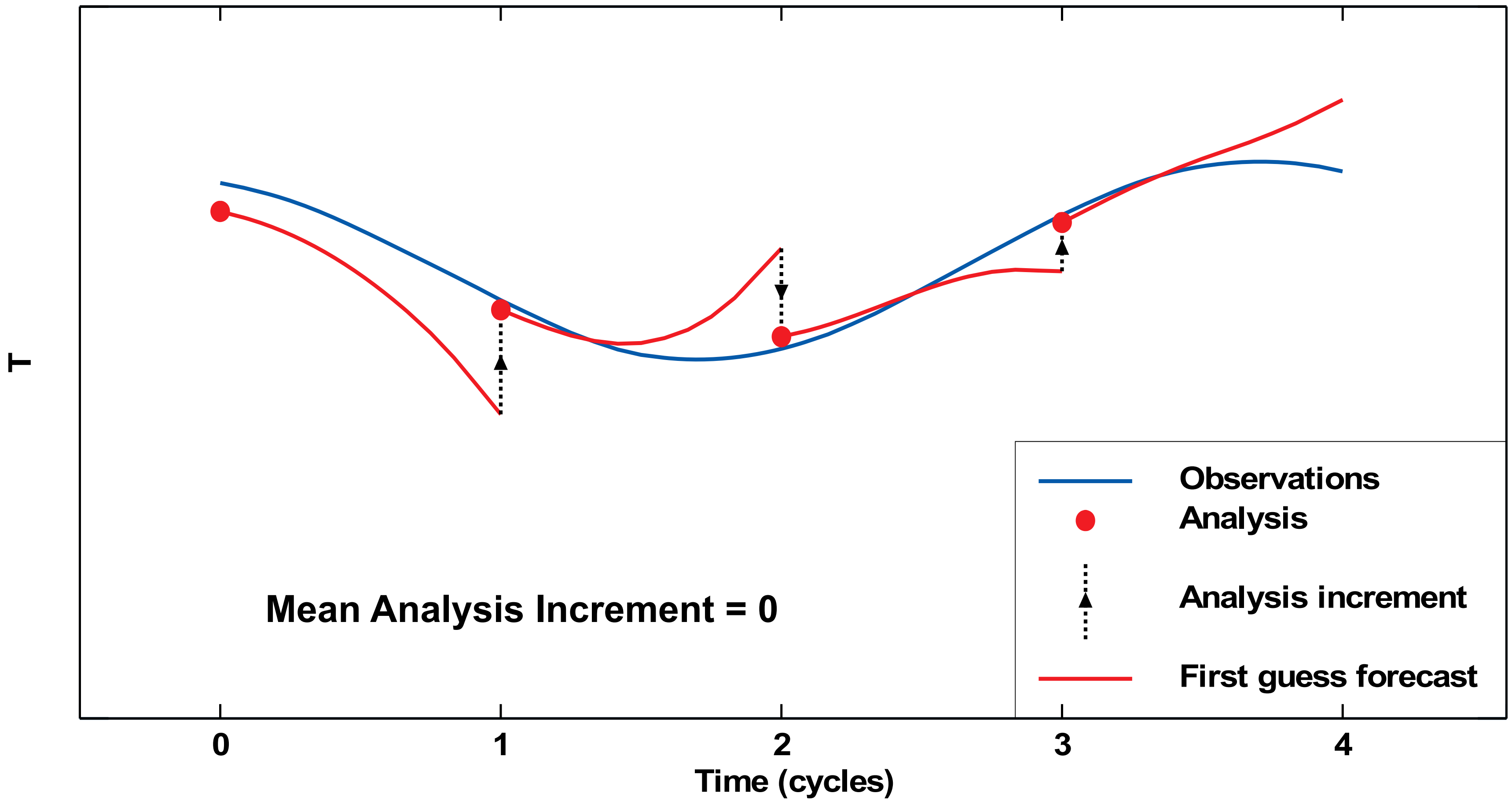
Model diagnosis is difficult because the long-term response of the system to some forcing is linked to the system's dominant internal modes of variability. Different forcings can have similar responses.

Both issues are a consequence of the nonlinearity of the equations of motion of climate.

What to do?

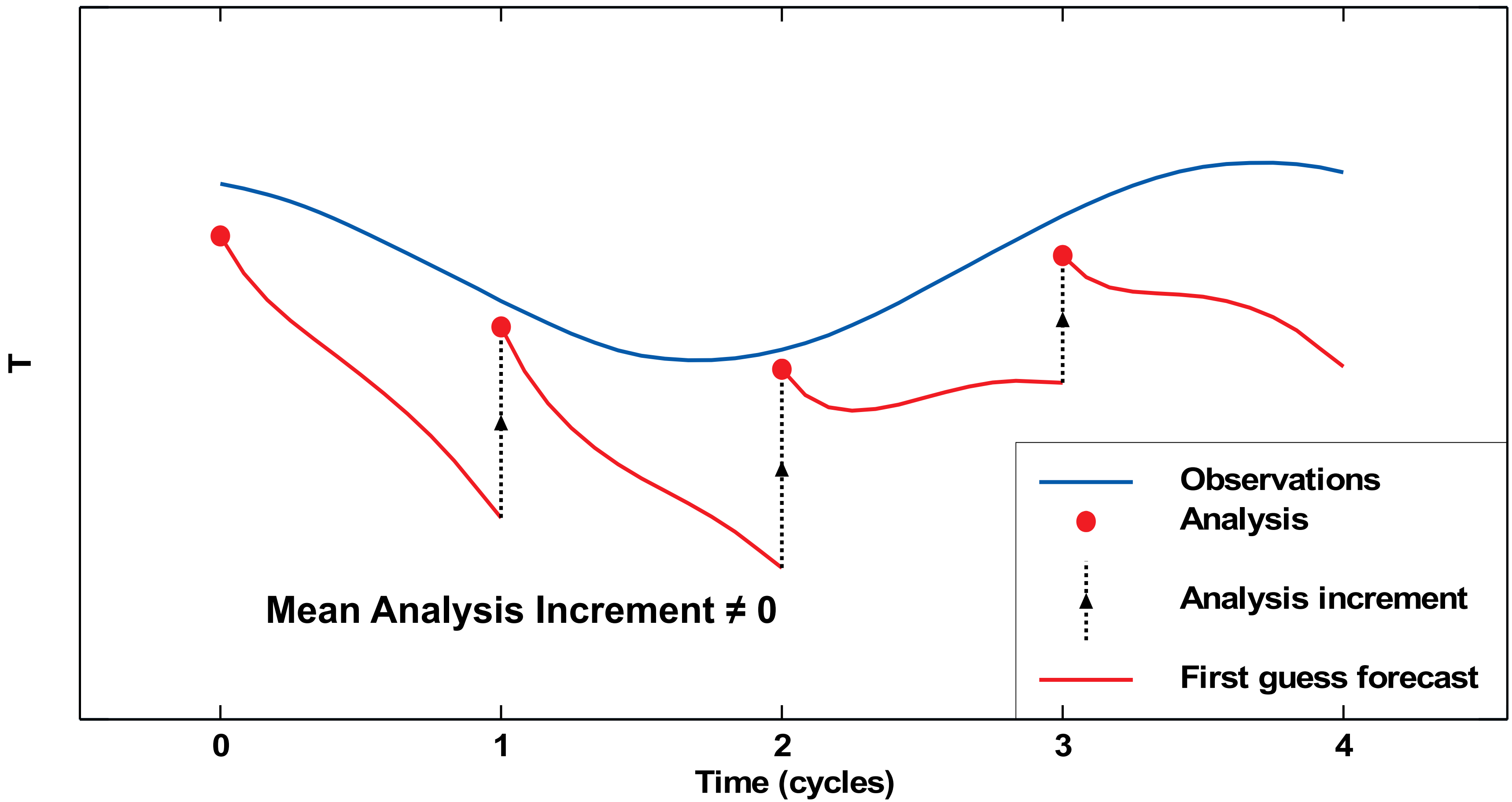
Don't focus diagnostics exclusively on the long-term response. Look at the short-term transient response too….eg within the data assimilation system itself

Data Assimilation Cycle: Perfect Model



Observations are not assumed to be perfect, but they should be sufficiently unbiased

Data Assimilation Cycle: Imperfect Model



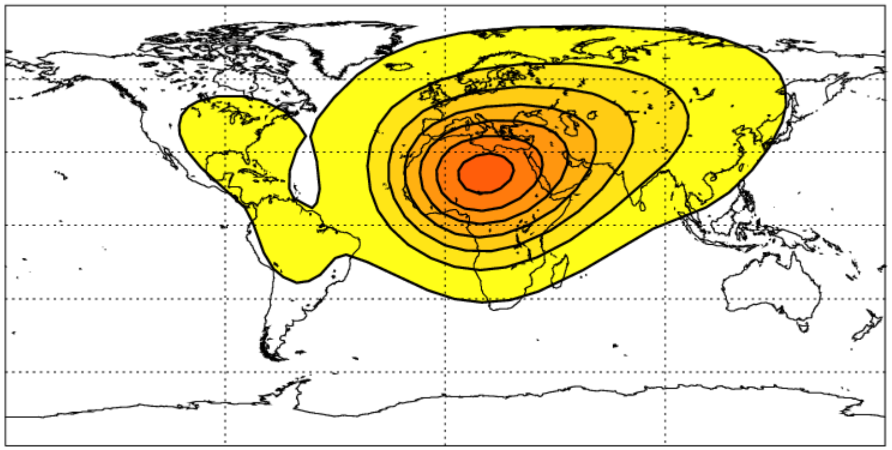
−Mean Analysis Increment = Mean Net Tendency
= Convective + Radiative + … + Dynamical Tendency

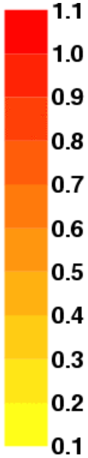
Can assess individual processes when acting on states close to the truth

(Klinker and Sardeshmukh 1992)

Old and New Aerosol Optical Depth

OLD (NO ANNUAL CYCLE)

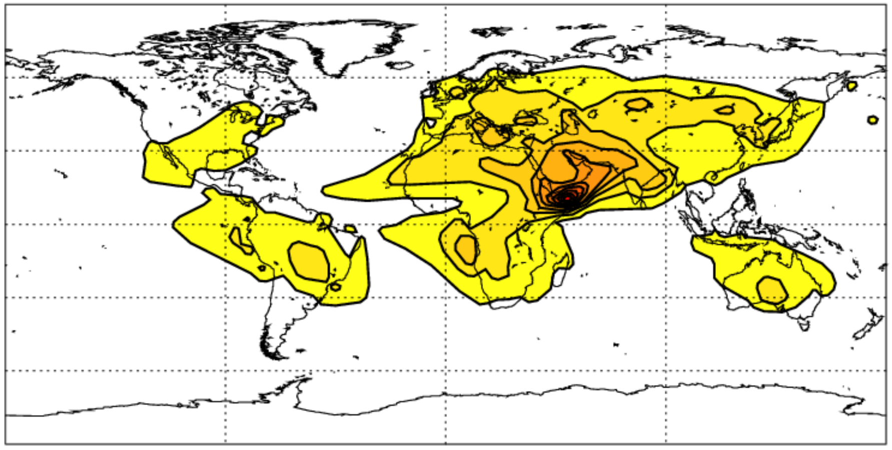




OPTICAL DEPTH d AT 550nm

ATTENUATION FACTOR = e^{-d}

NEW (JULY)



- **LARGE SAHARAN SOIL-DUST CHANGE**
  - **SCATTERS & ABSORBS**
  - **SINGLE SCATTERING ALBEDO ≈ 0.9**
- **CHANGE COMPARIABLE TO**
  - **UNCERTAINTY IN PRESENT LOADING**
  - **CHANGES IN LOADING DUE TO CLIMATE CHANGE**

Old: C26R1 (Tanre et al. 1984), New: C26R3 (Tegen et al. 1997).

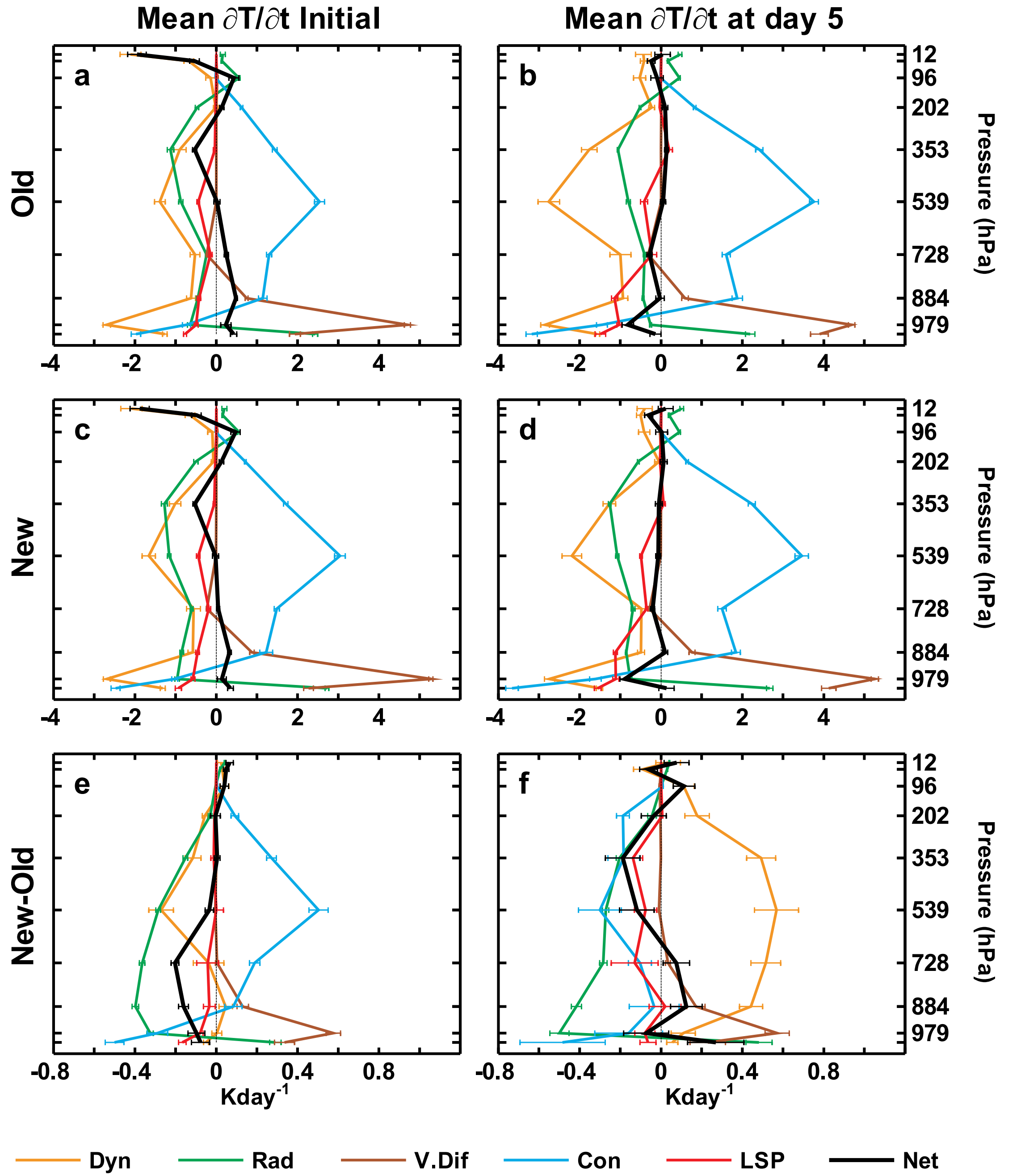
Initial Tendencies

<u>Old Aerosol</u>

Initial net warming of lower troposphere (a) → Positive feedback by D+5 (b) with increased convection and large-scale dynamical moisture convergence

<u>New Aerosol</u>

Initial radiative forcing change (e) → More initial convection but reduced initial net warming (c) and thus smaller feedback with dynamics (d)



North Africa = [5°N-15°N, 20°W-40°E]. Mean of 31 days X 4 forecasts per day X 12 timesteps per forecast. 70% confidence intervals are based on daily means. CONTROL model = 29R1,T159,L60,1800S.

Can a 6hr weather forecast tell us about global warming 100 years from now?

(Rodwell and Palmer, 1986)


http://www.newscientist.com - Soaring global warming 'can't be r

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NewScientist.com

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Soaring global warming 'can't be ruled out'

Click to Print

19:03 26 January 2005
NewScientist.com news service
Jenny Hogan

The Earth may be much more sensitive to global warming than previously thought, according to the first results from a massive distributed-computing project.

The project tested thousands of climate models and found that some produced a world that warmed by a huge 11.5°C when atmospheric carbon dioxide concentrations reached the levels expected to be seen later this century.

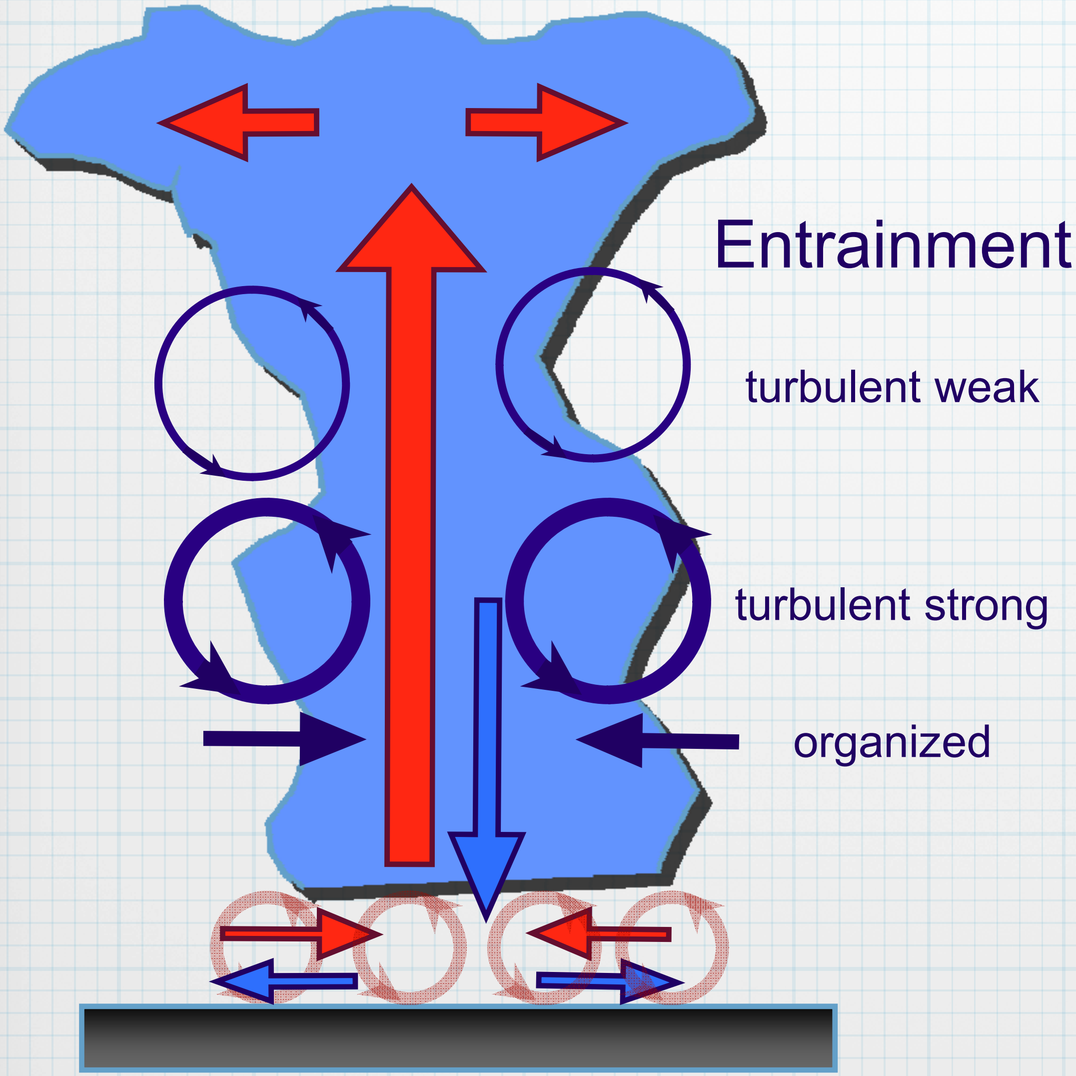
This extreme result is surprising because it lies far outside the 1.4°C to 4.5°C range predicted by the Intergovernmental Panel on Climate Change (IPCC) for the same CO_2-level increase - a doubling of CO_2 concentration from pre-industrial times. But it is possible the IPCC range was wrong because its estimate is based on just a handful of different computer models.

Enlarge image

The climate modelling software divides the Earth's surface into boxes hundreds of kilometres square (image: Climateprediction.net)

"There are no obvious problems with the high temperature models, Stainforth says…. The uncertainty at the upper end has exploded, says team-member Myles Allen."

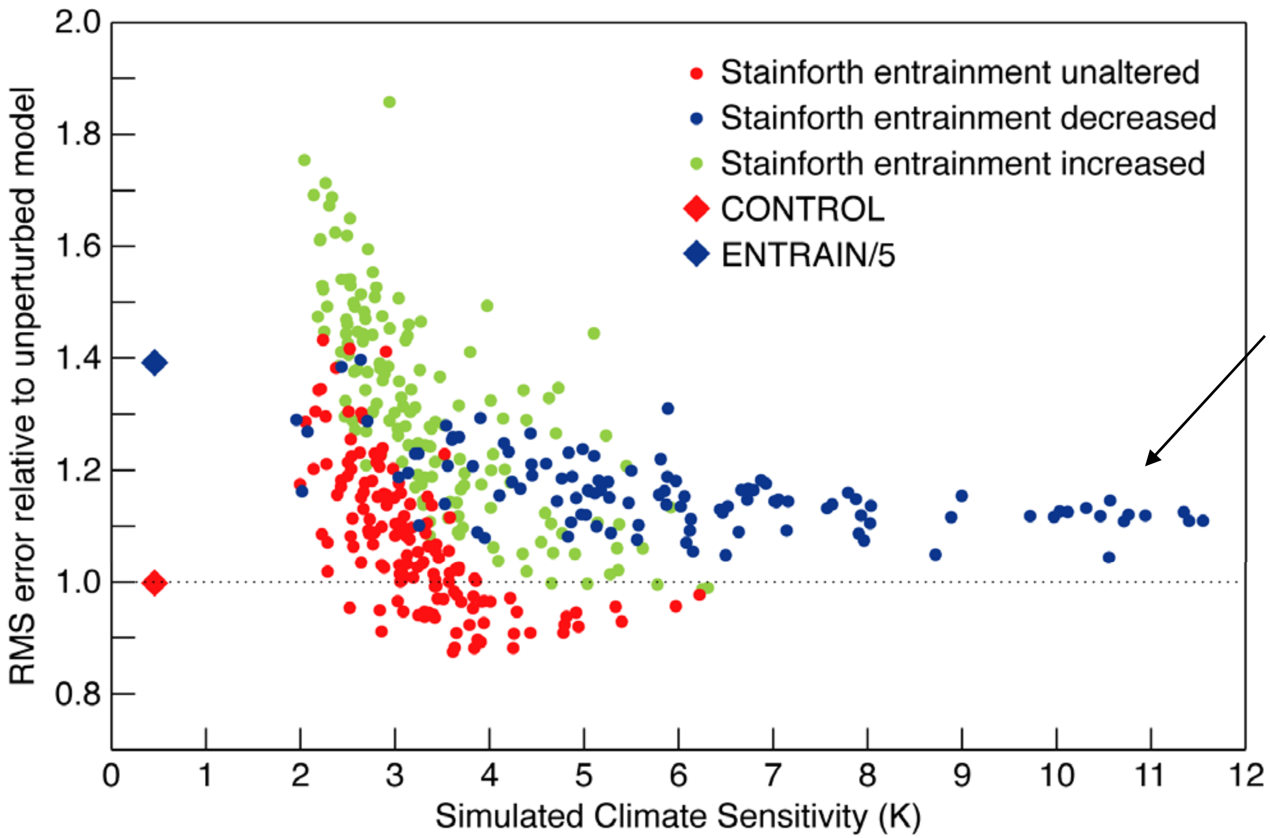
One key parameter in a convection parametrisation is the entrainment-rate parameter



Entrainment

- mixes environmental air into convective clouds
- is caused by turbulence and/or organized inflow
- thereby reduces the difference of cloud to environment, which is the fuel the cloud thrives on
- strength of its effect depends on entrainment rate (model parameter) and difference in properties of cloud and environment
- high entrainment rate and/or very dry environment -> shallow clouds
- low entrainment rate and/or very moist environment -> deep clouds

Climate: Error vs Sensitivity



Highest climate sensitivity for low entrainment models

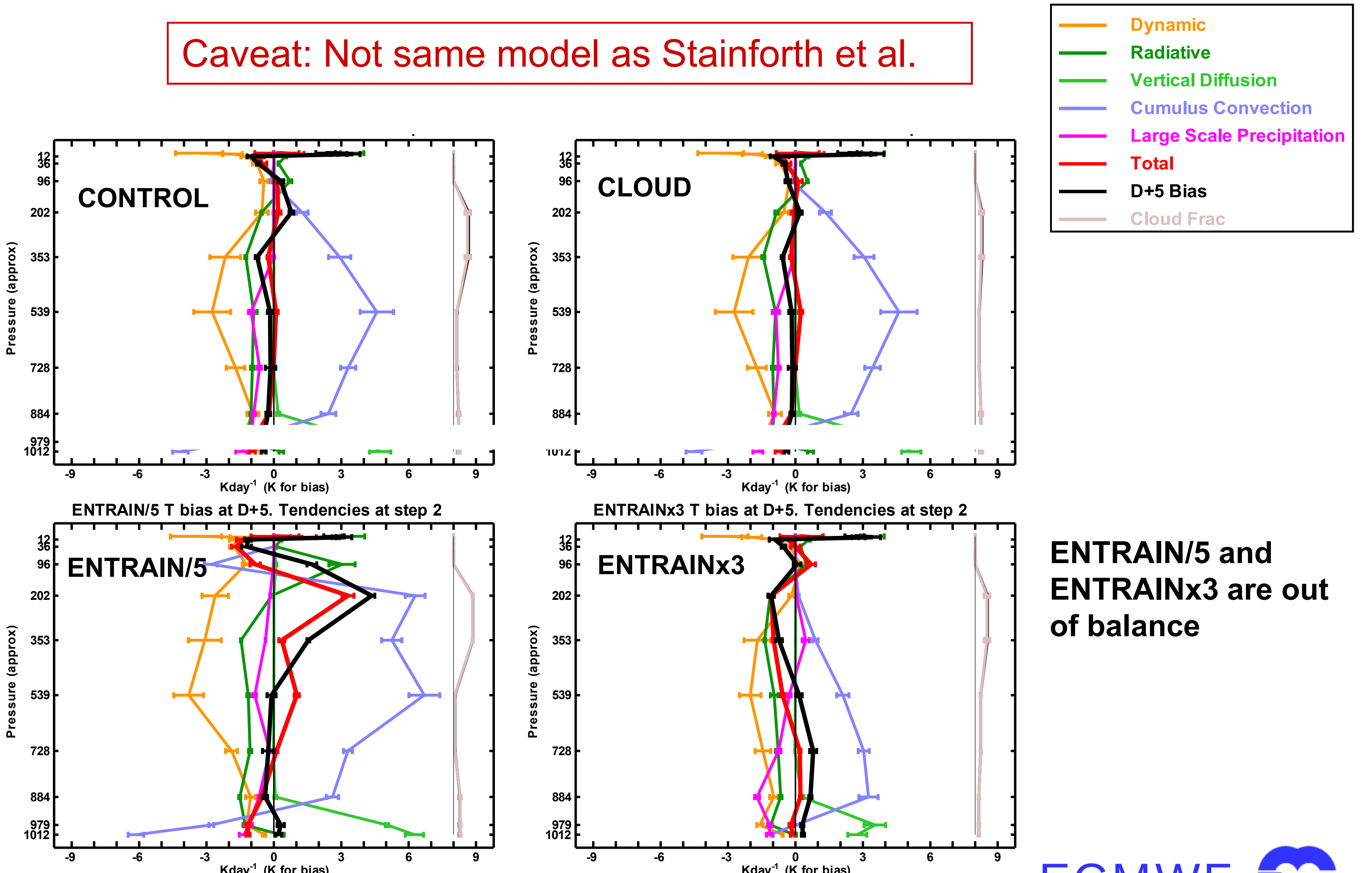
fast physics!

Circles: AGCM + Mixed-Layer model results from Stainforth et al. (2005) show combined RMSE of 8 year mean, annual mean T_{2m}, SLP, precipitation and ocean-atmosphere sensible+latent heat fluxes (equally weighted and normalised by the control).

Diamonds: AGCM results from Rodwell & Palmer (2006) show RMSE from 39 year mean, annual mean T_{850}, SLP and precipitation (equally weighted and normalised by the control).

January 2005 Initial T Tendencies

Caveat: Not same model as Stainforth et al.



ENTRAIN/5 and ENTRAINx3 are out of balance

ECMWF

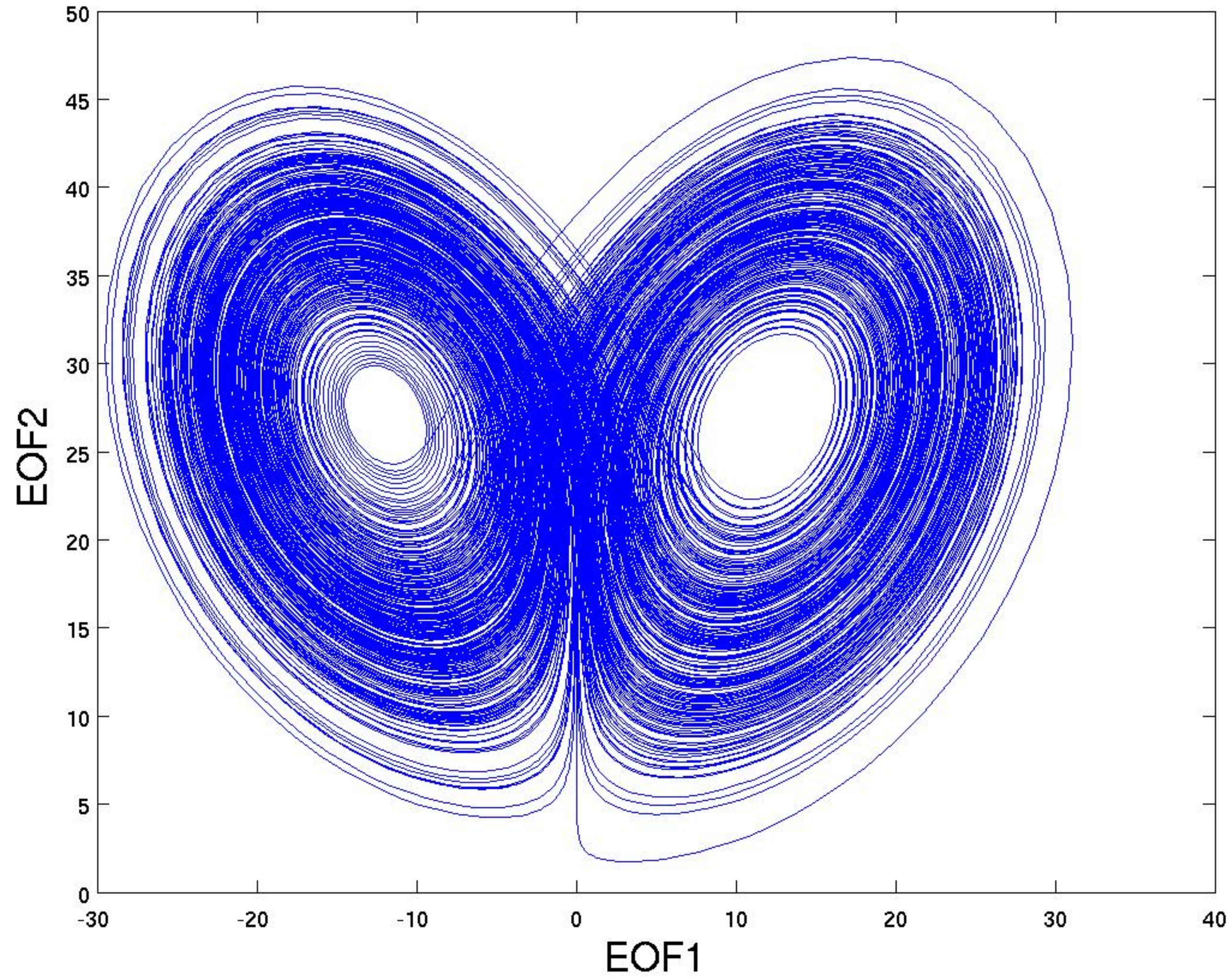
So that’s it. Just perform the weather/climate model diagnostics on the first 6 hours of a forecast and all problems can be easily diagnosed and cured.

Umm…actually not that simple!

Eg 2) Lorenz(1963) in an EOF basis

$$\dot{a}_1 = 2.3a_1 - 6.2a_3 - 0.49a_1a_2 - 0.57a_2a_3$$
$$\dot{a}_2 = -62 - 2.7a_2 + 0.49a_1^2 - 0.49a_3^2 + 0.14a_1a_3$$
$$\dot{a}_3 = -0.63a_1 - 13a_3 + 0.43a_1a_2 + 0.49a_2a_3$$

Selten (1995)



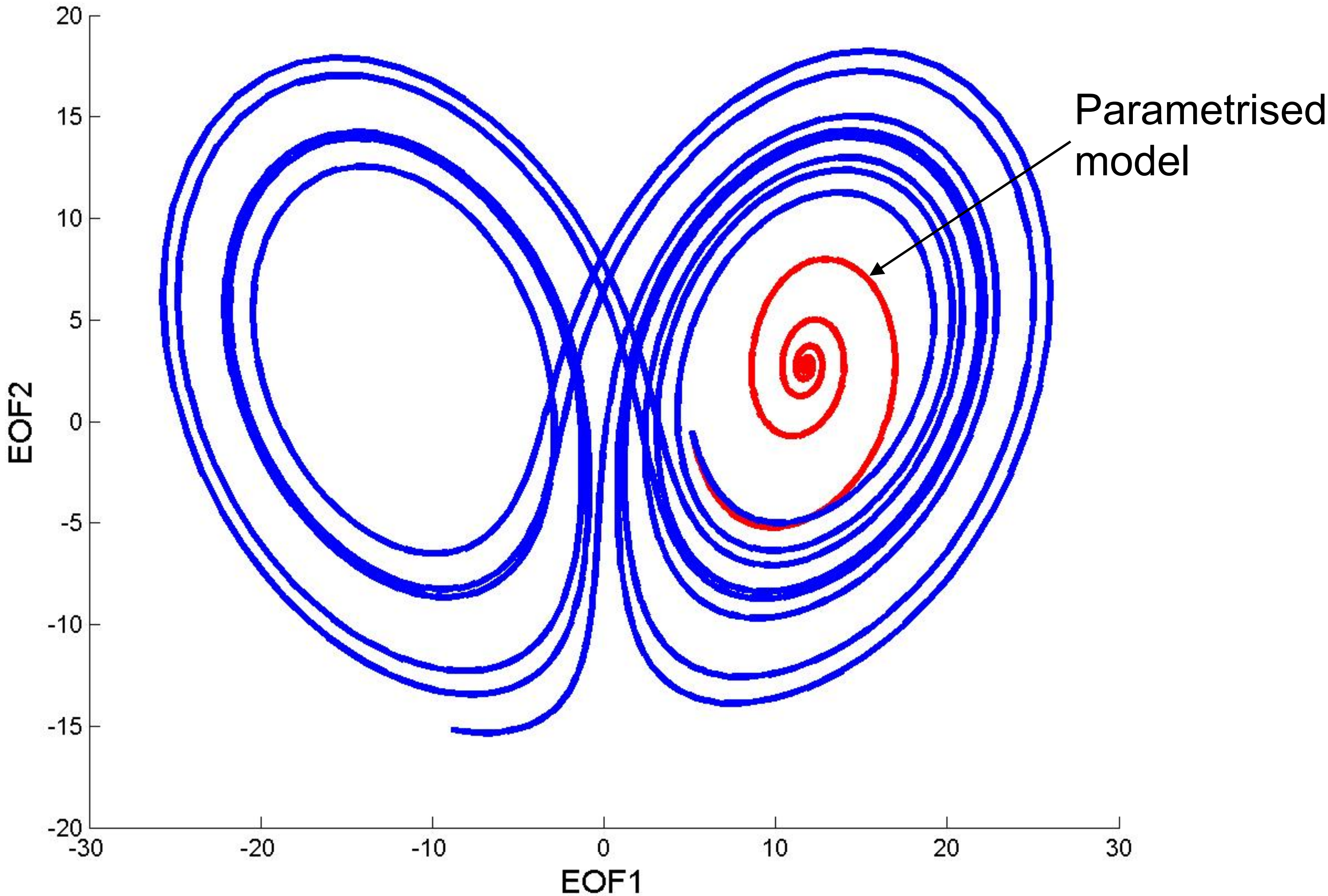
3rd EOF only explains 4% of variance.
Parametrise it?

Lorenz(1963) in a truncated EOF basis with parametrisation of a_3

$$\dot{a}_1 = 2.3a_1 - 6.2a_3 - 0.49a_1a_2 - 0.57a_2a_3$$

$$\dot{a}_2 = -62 - 2.7a_2 + 0.49a_1^2 - 0.49a_3^2 + 0.14a_1a_3$$

$$a_3 = P(a_1, a_2; \alpha, \beta \ldots)$$



$$P\left(a_1, a_2; \alpha, \beta..\right) = \alpha a_1 + \beta a_2$$

Parametrised model is good as a short-range forecast model of L63, but exhibits major climatic errors.

Make parametrisation more complicated – eg quadratic, cubic…transcendental function of PCs?

Won't help. By Poincaré-Bendixon theorem, the parametrised model cannot exhibit chaotic variability for any deterministic ("bulk formula") parametrisation

What about making the parametrisation stochastic?

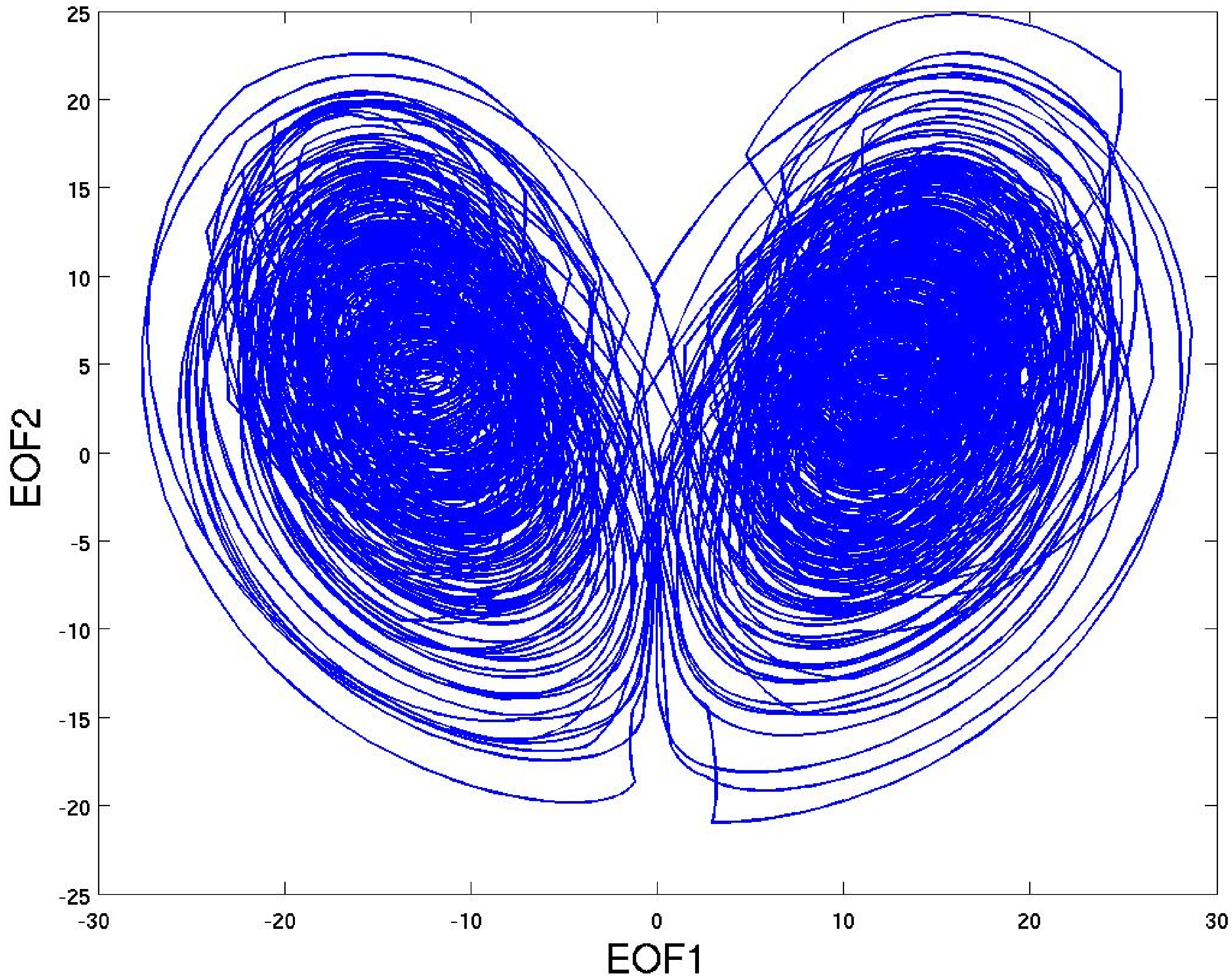
Stochastic-Lorenz(1963) in a truncated EOF basis

$$\dot{a}_1 = 2.3a_1 - 6.2a_3 - 0.49a_1a_2 - 0.57a_2a_3$$

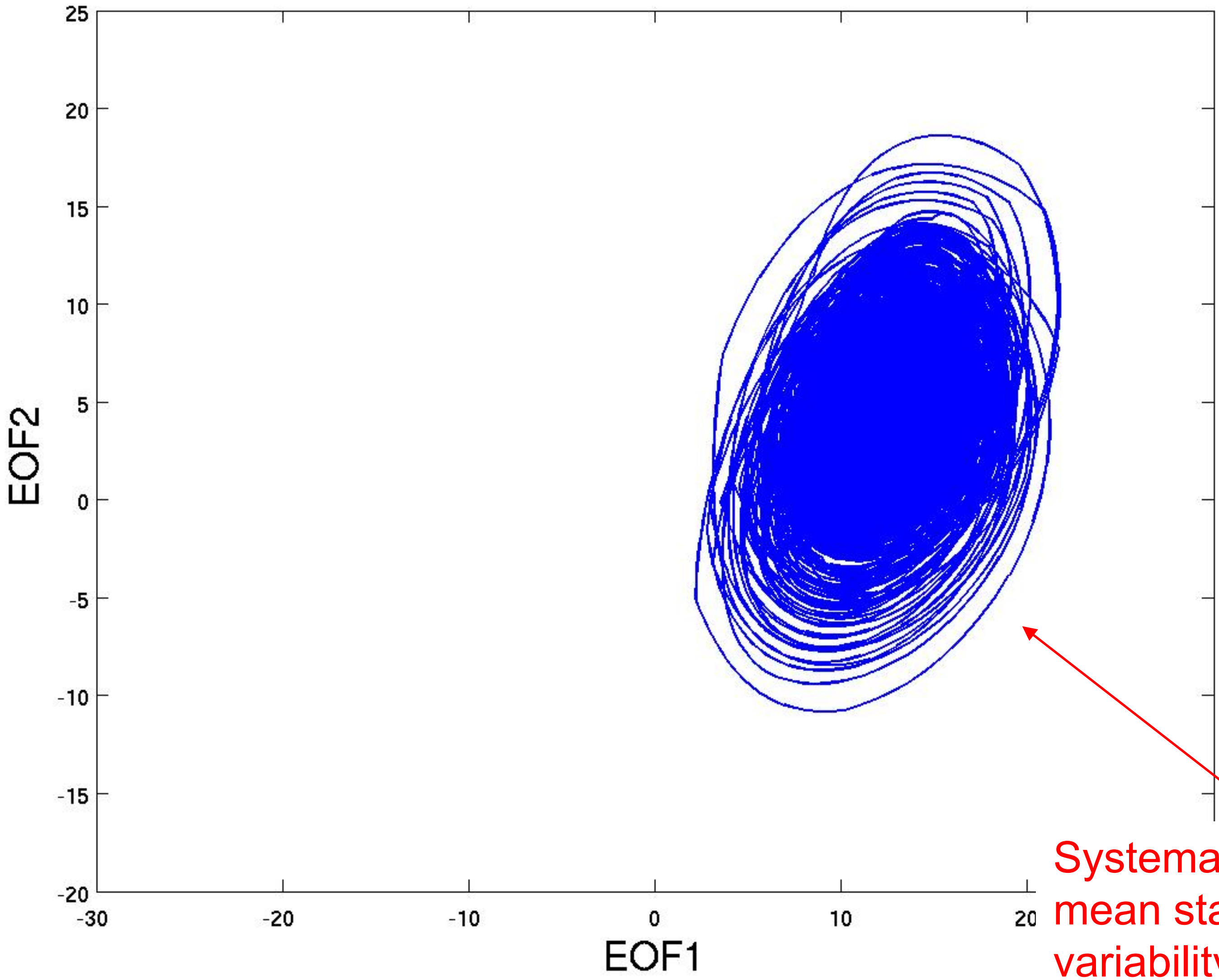
$$\dot{a}_2 = -62 - 2.7a_2 + 0.49a_1^2 - 0.49a_3^2 + 0.14a_1a_3$$

$$a_3 = \beta$$

Stochastic noise



Stochastic Truncated L63



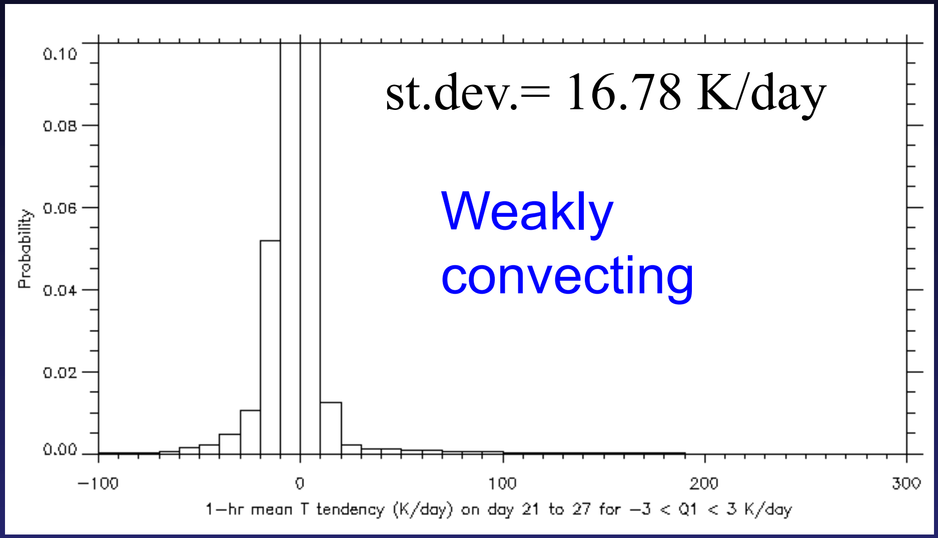
Systematic bias in mean state and variability cf L63

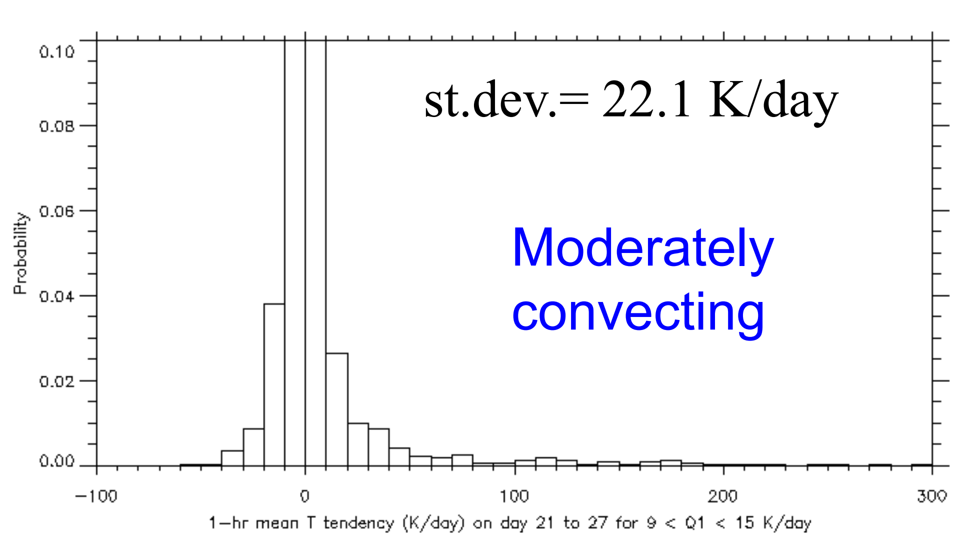
Too weak/ Too white Noise

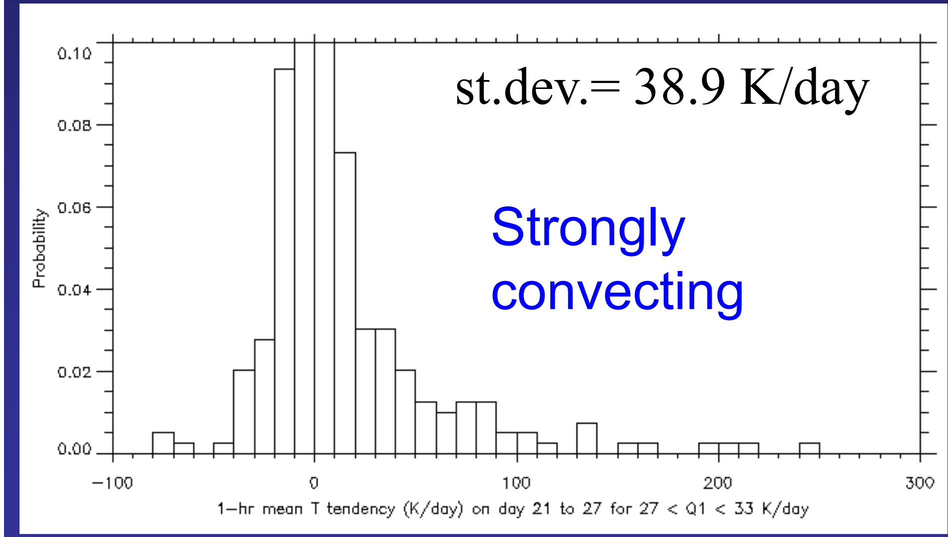
Is there a component of model error in contemporary NWP/climate models, associated with the fact that their parametrisations are deterministic rather than stochastic?

- Calculate exact PDF of sub-grid temperature tendencies in a coarse-grained (~**50km**) grid box based on output from a cloud-resolving (~**1km**) model treated as “truth”.
- PDFs are constrained such that parametrised tendencies based on coarse-grain input fields lie within boxes of width **6K/day**.

Shutts and Palmer, J.Clim, 1987







Width of pdf ∝ parametrised tendency

Stochastic Parametrisations in use at ECMWF

- Stochastic Tendency Perturbations (Buizza et al, QJ, 1999)

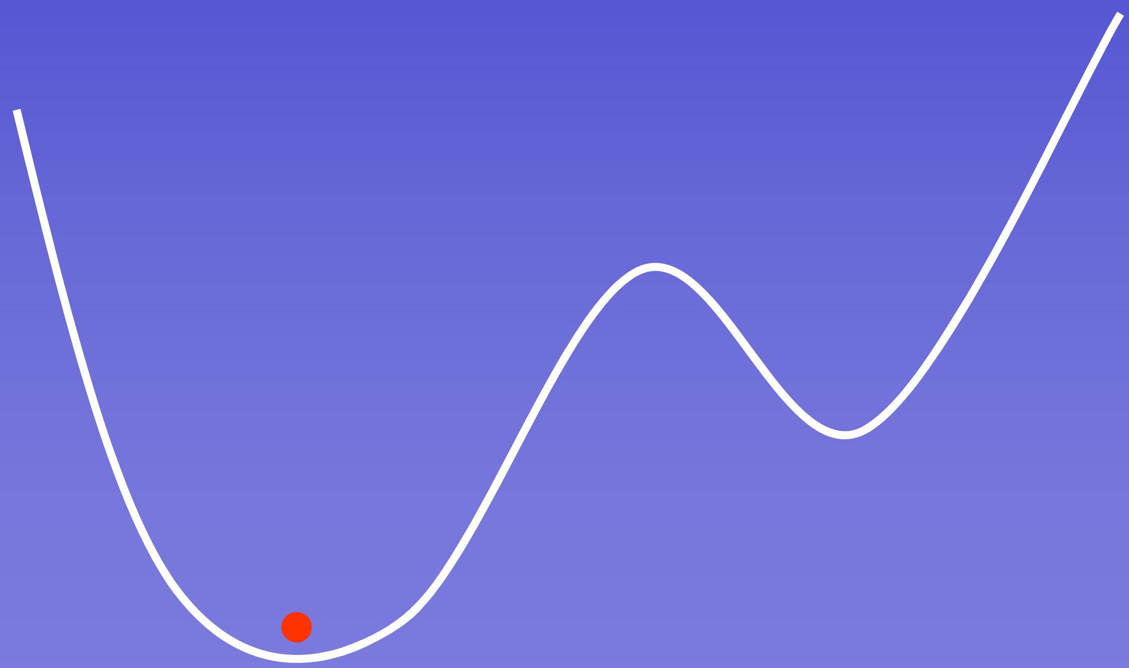
Stochastic process

$$\dot{X} = D(X) + \sigma P(X)$$

- Spectral Stochastic Backscatter (cf Leith, 1990;Berner et al JAS, March 2009)

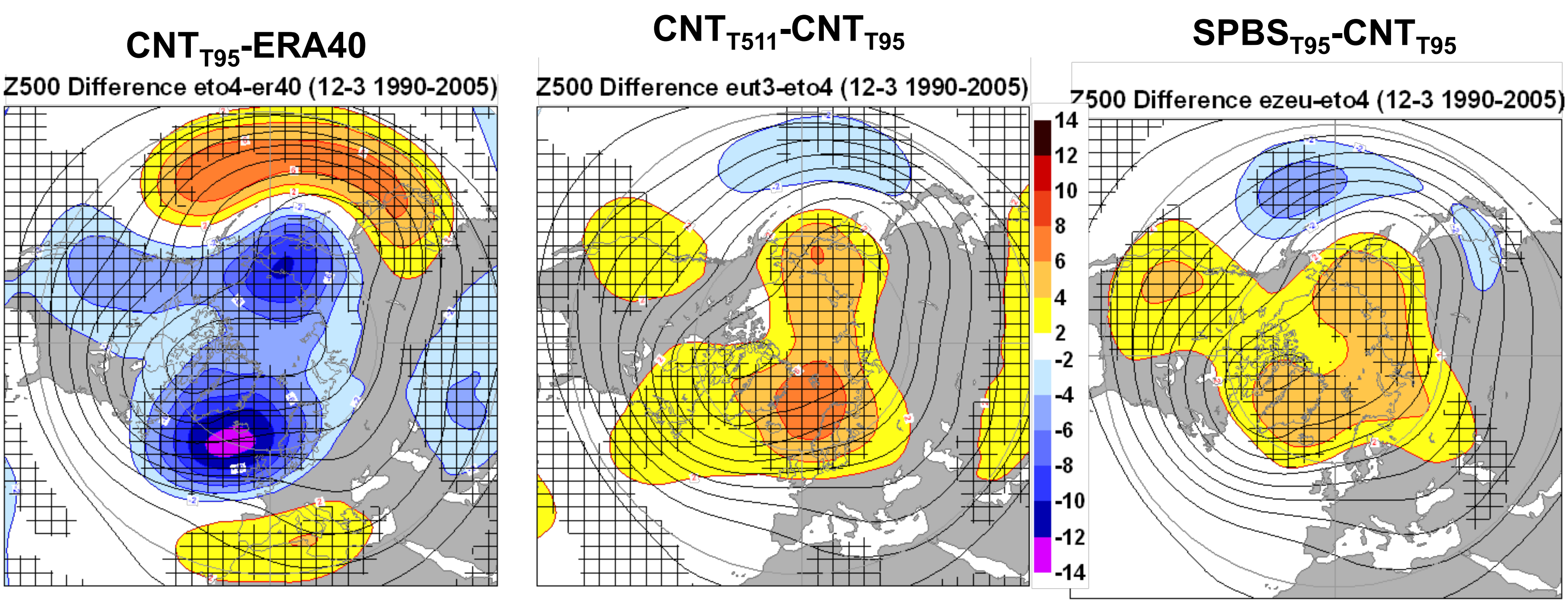
Schematic illustration of potential impact of stochastic parametrisation on systematic error

Eg ball bearing in potential well.



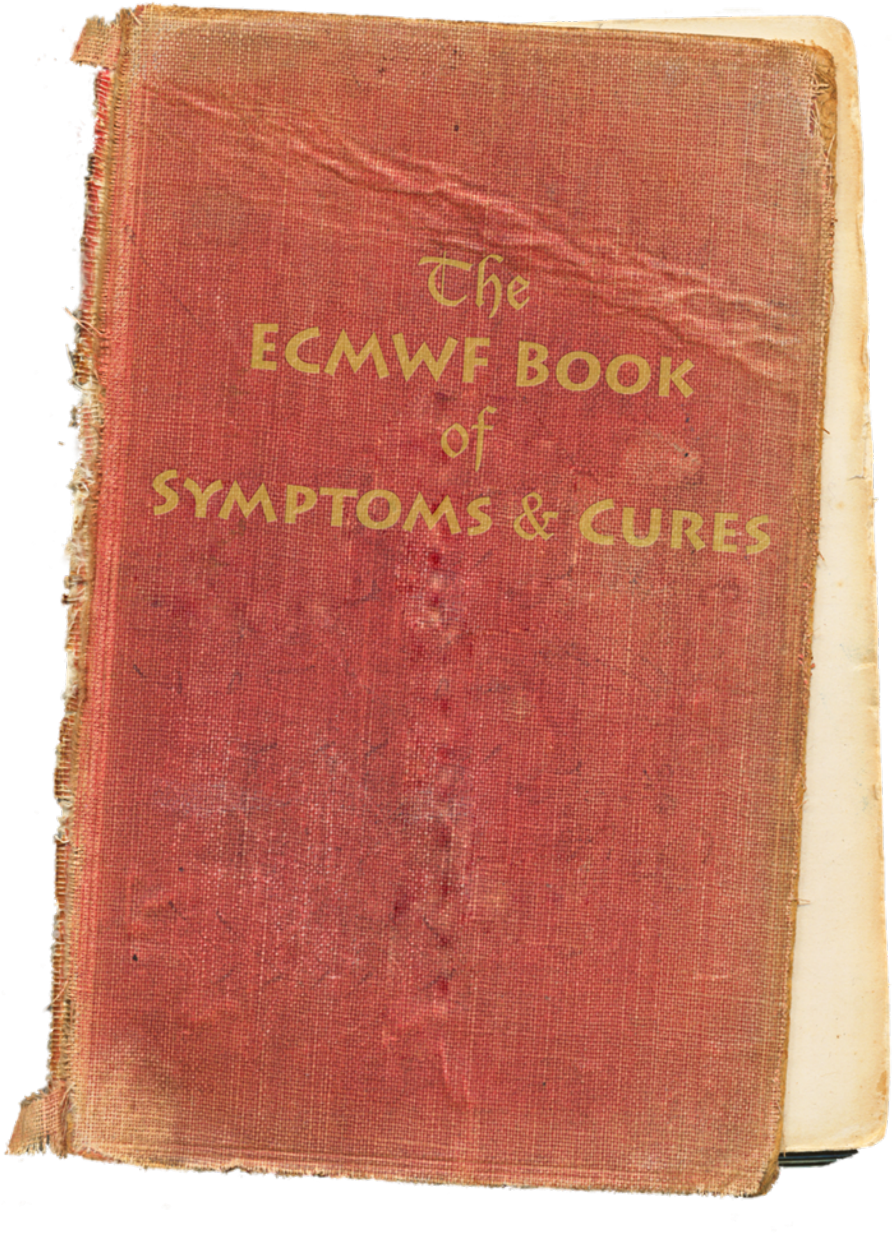
Stochastic Physics versus Resolution

- Experiments with model cycle 31R1
- Experiments with Berner et al (JAS 2009) stochastic backscatter scheme
- Winters (Dec-Mar) of the period 1990-2005



Conclusions

- Advective nonlinearity of climate makes the problem of diagnosing model error a challenging one. Response to imposed forcing is tied to internal modes. Different forcings can exhibit similar responses.
- One way forward is to focus on short-range tendencies – this technique could potentially powerful in helping to reduce the long standing problem of reducing uncertainty in climate sensitivity
- However, there is a second class of model error arising from the use of deterministic parametrisations.
- Stochastic parametrisation is a tool to both represent and reduce model error.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