Flow dependent stochastic Perturbations

Compare Singular Vector (SV) with Breeding (BV)

Baroclinic instabilities and deep convection

Lagged Forecast Perturbations

Michael Denhard & Arwed Ockel

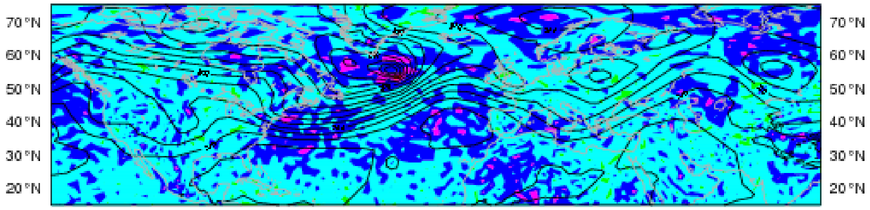
Initial ensemble perturbations - basic concepts

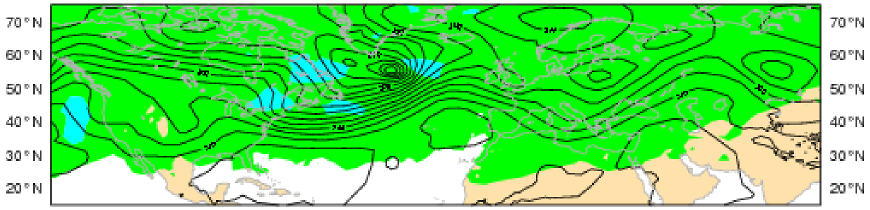
by Linus Magnusson 2012

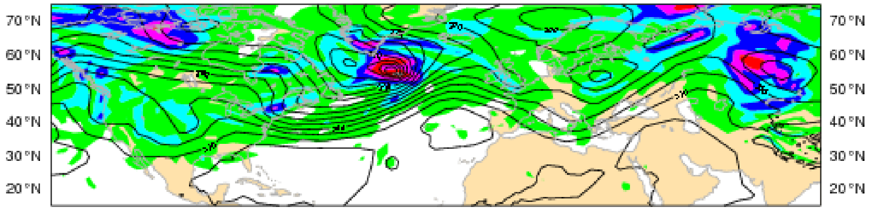
Evolution of ensemble spread

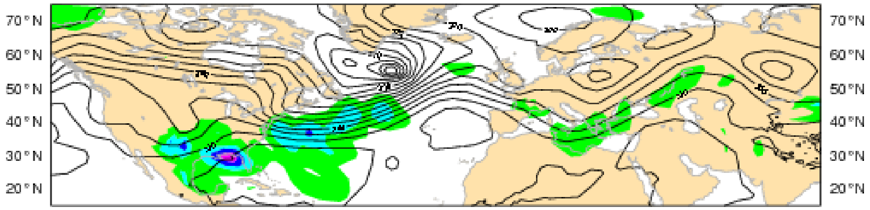
single case, total pert. energy 700 hPa

Initially


Random perturbations


Random Field perturbations


Breeding perturbations


Singular Vector perturbations

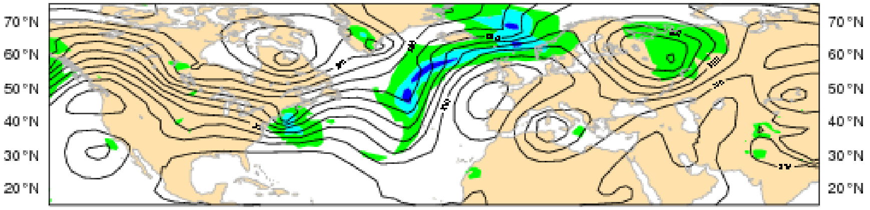
Maximum – red

Evolution of ensemble spread

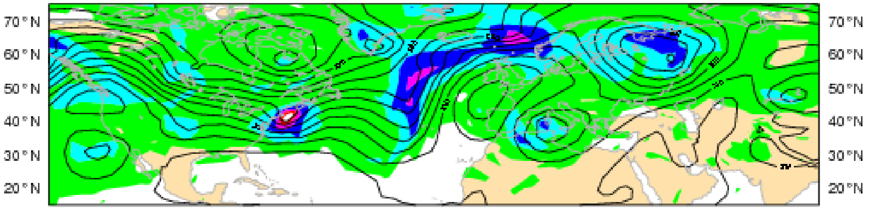
single case, total pert. energy 700 hPa

+48h

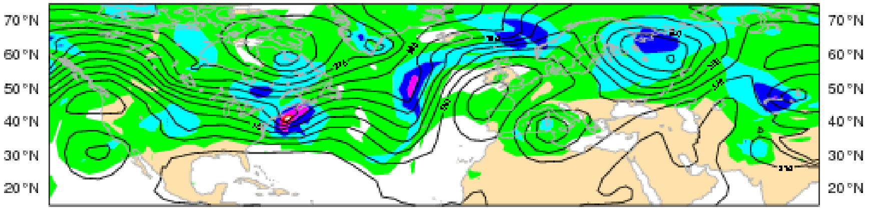
Random perturbations



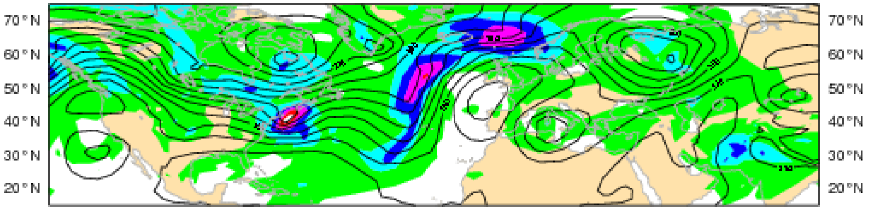
Random Field perturbations



Breeding perturbations



Singular Vector perturbations



Maximum – red, twice the scale as initially

Initial ensemble perturbations - basic concepts

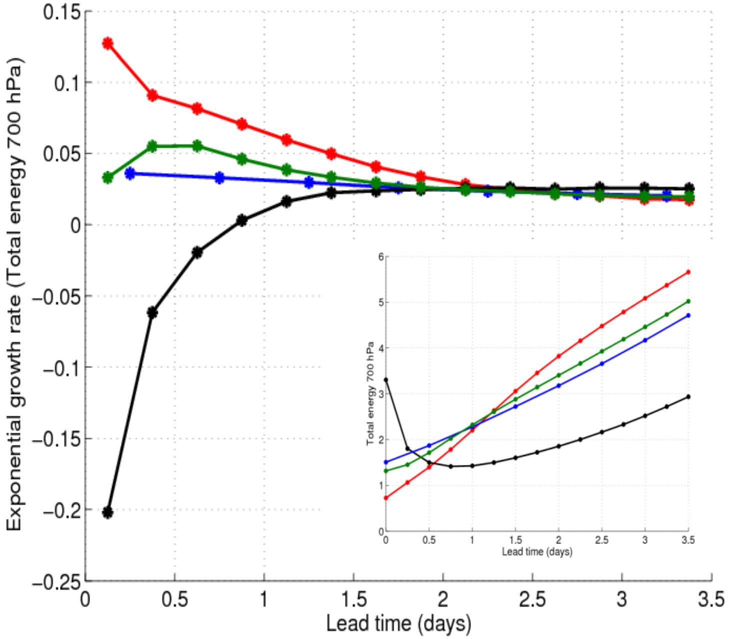
by Linus Magnusson 2012

Growth rate

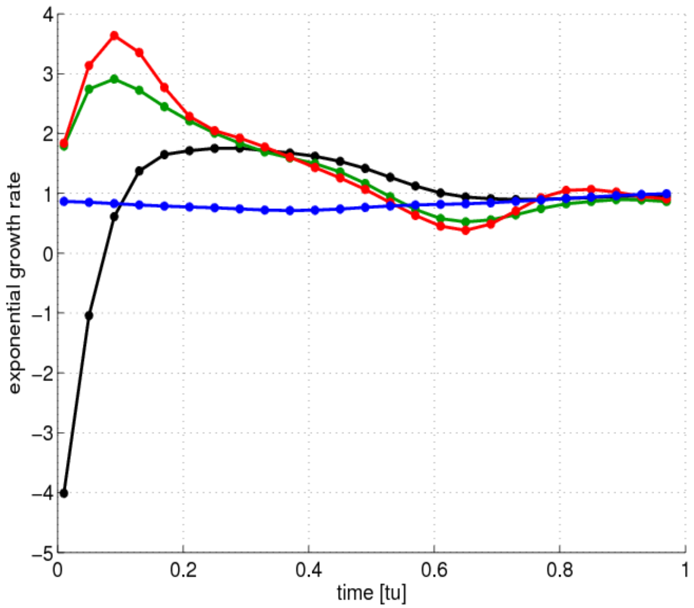
$$\lambda = \frac{1}{\Delta t}\ln\left(\frac{\|\Delta x(t+\Delta t)\|}{\|\Delta x(t)\|}\right)$$

$$\Delta x = x_p - x_{true}$$

NWP-model (ECMWF)



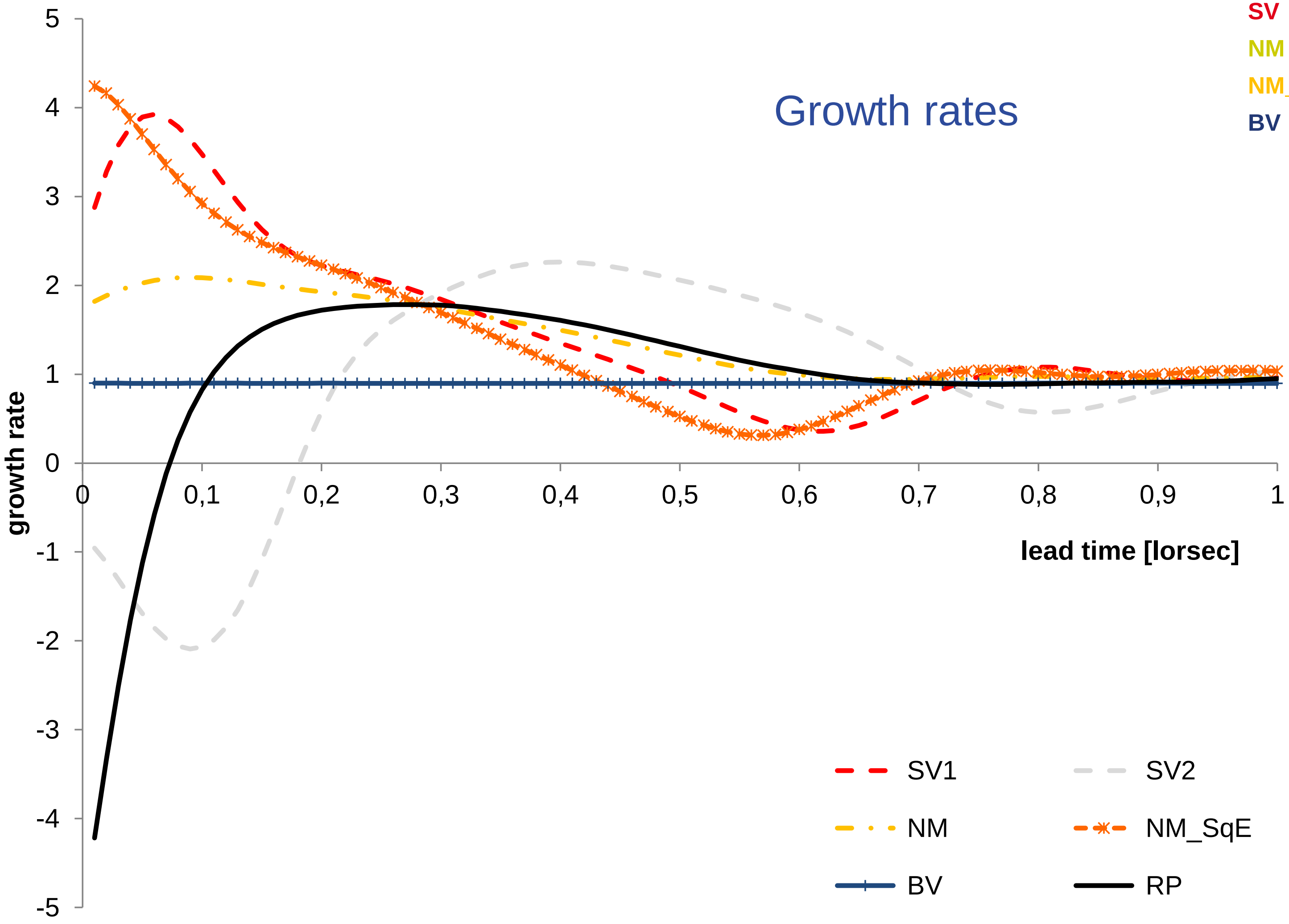
Lorenz-63



SV – red, BV – blue, Random Field Pert. – Green, Random Pert. - black

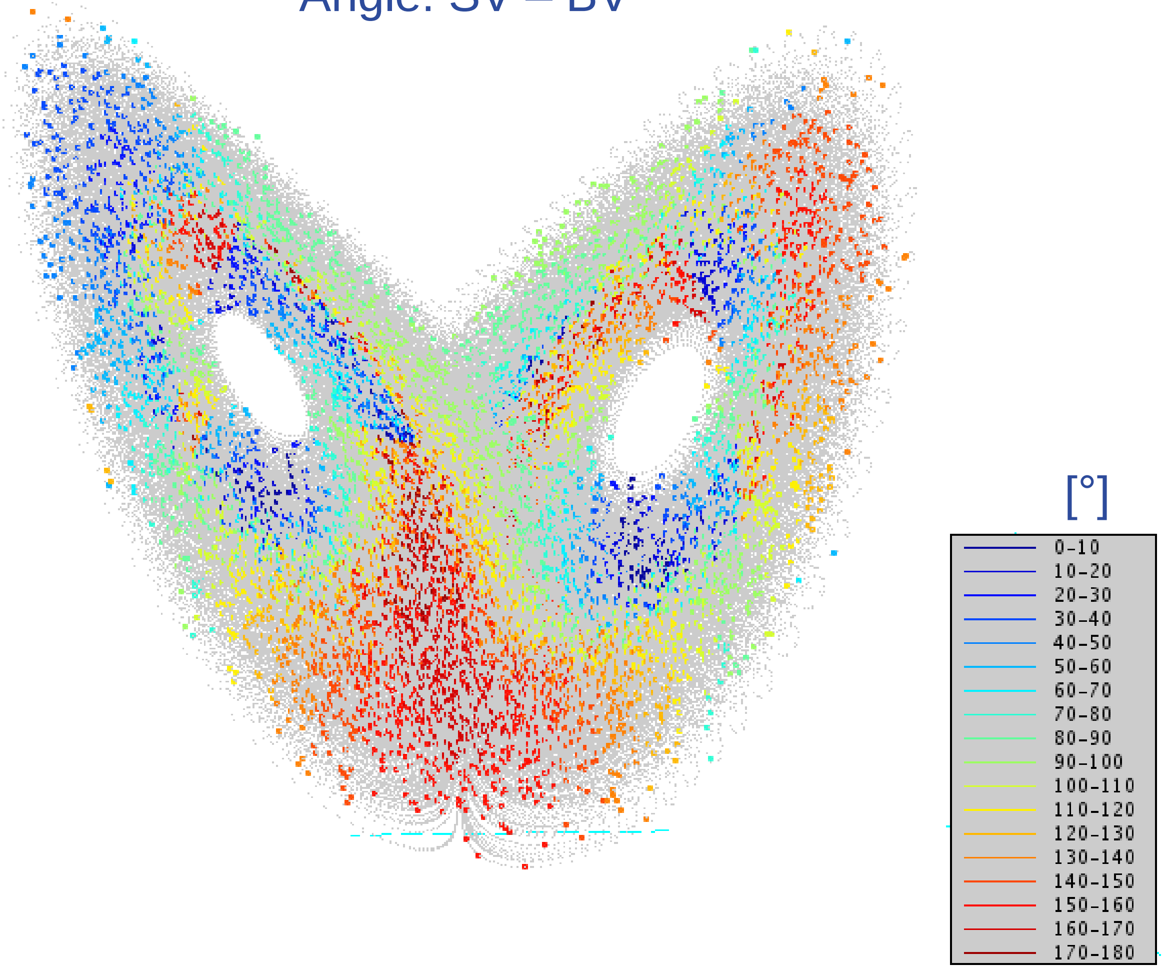
Initial Perturbations in the Lorenz63 model (Master Thesis Arwed Ockel)

RP - random perturbations
SV - Singular Vector
NM - Normal Mode
NM_SqE - SV, t(opt) = 0
BV - Breeding Vector

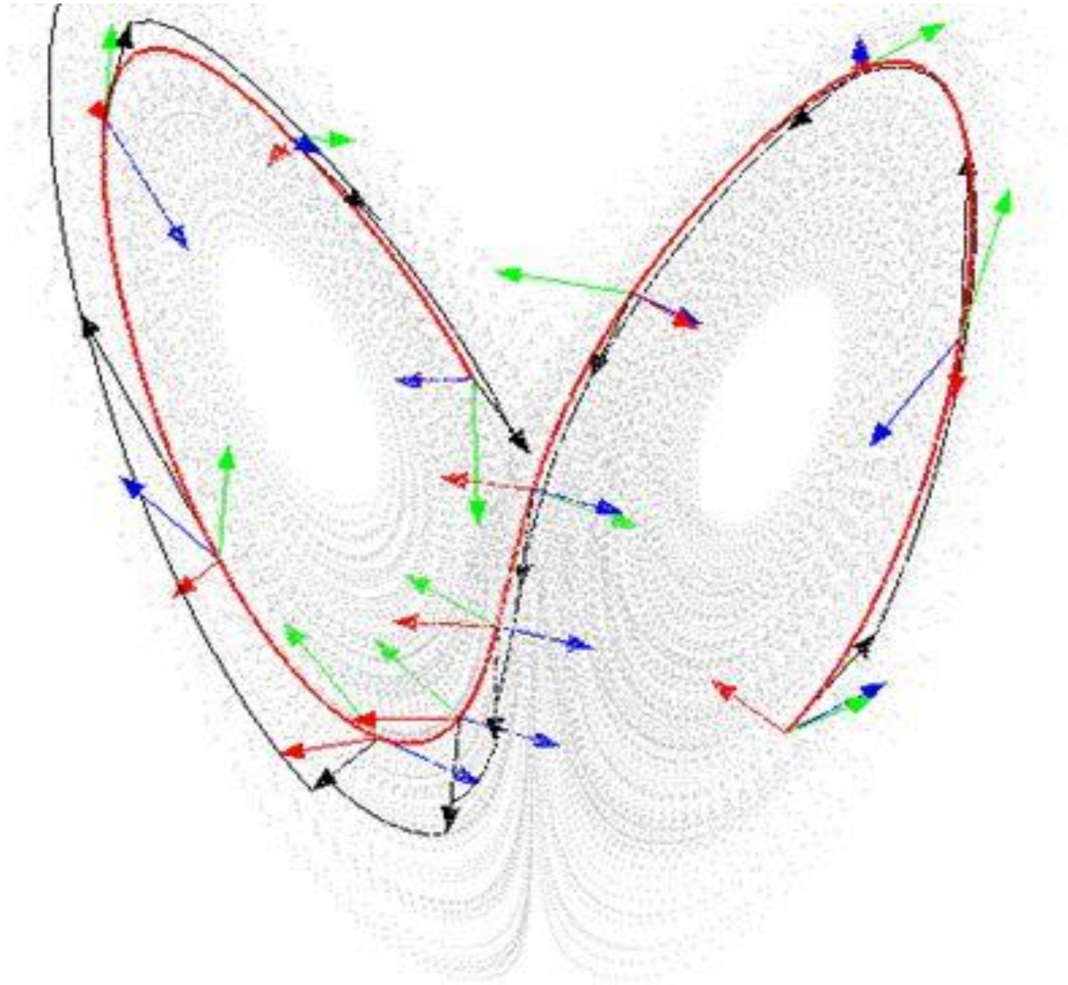


Initial Perturbations in the Lorenz63 model (Master Thesis Arwed Ockel)

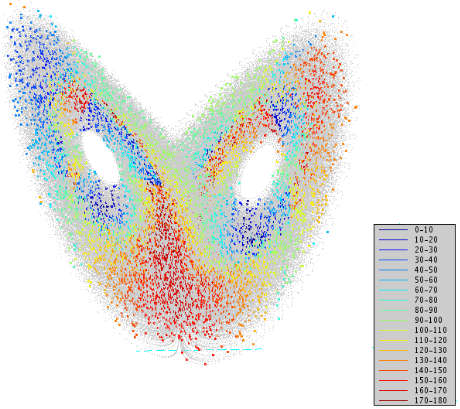
Angle: SV – BV



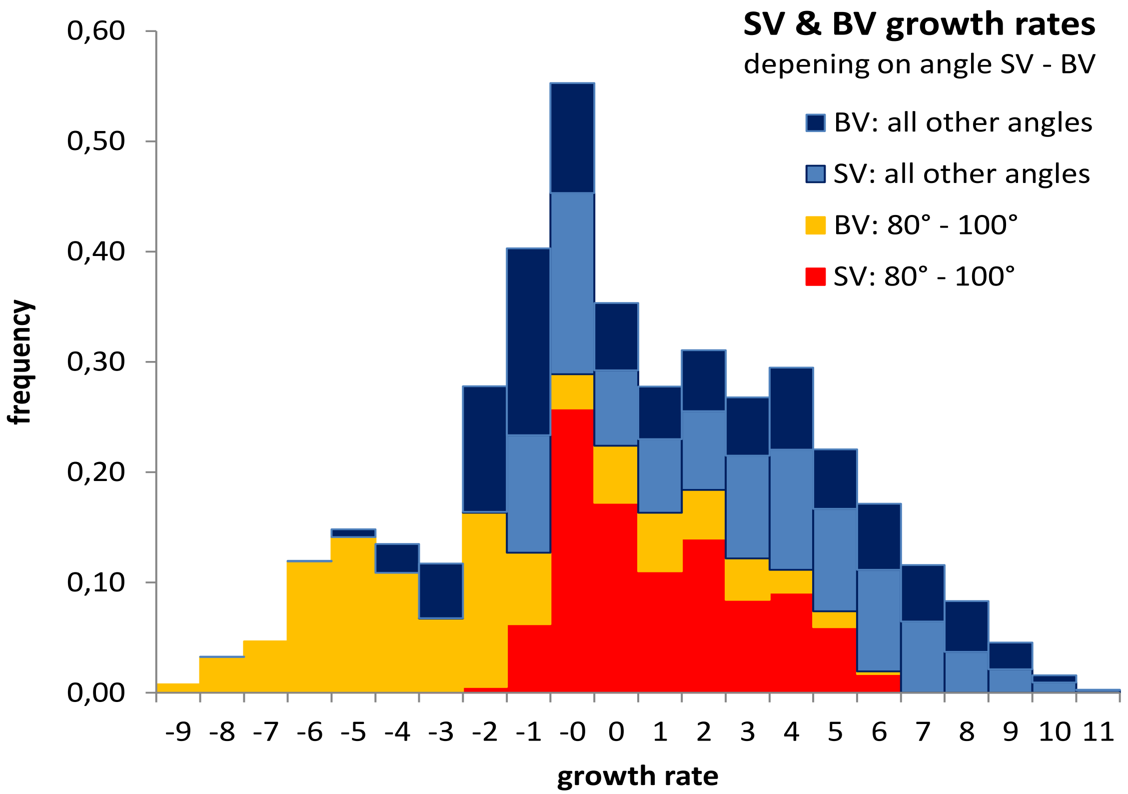
Initial Perturbations in the Lorenz63 model (Master Thesis Arwed Ockel)



- → Singular Vector
- → Normal Mode
- → NM_SqE
- → Breeding Vector

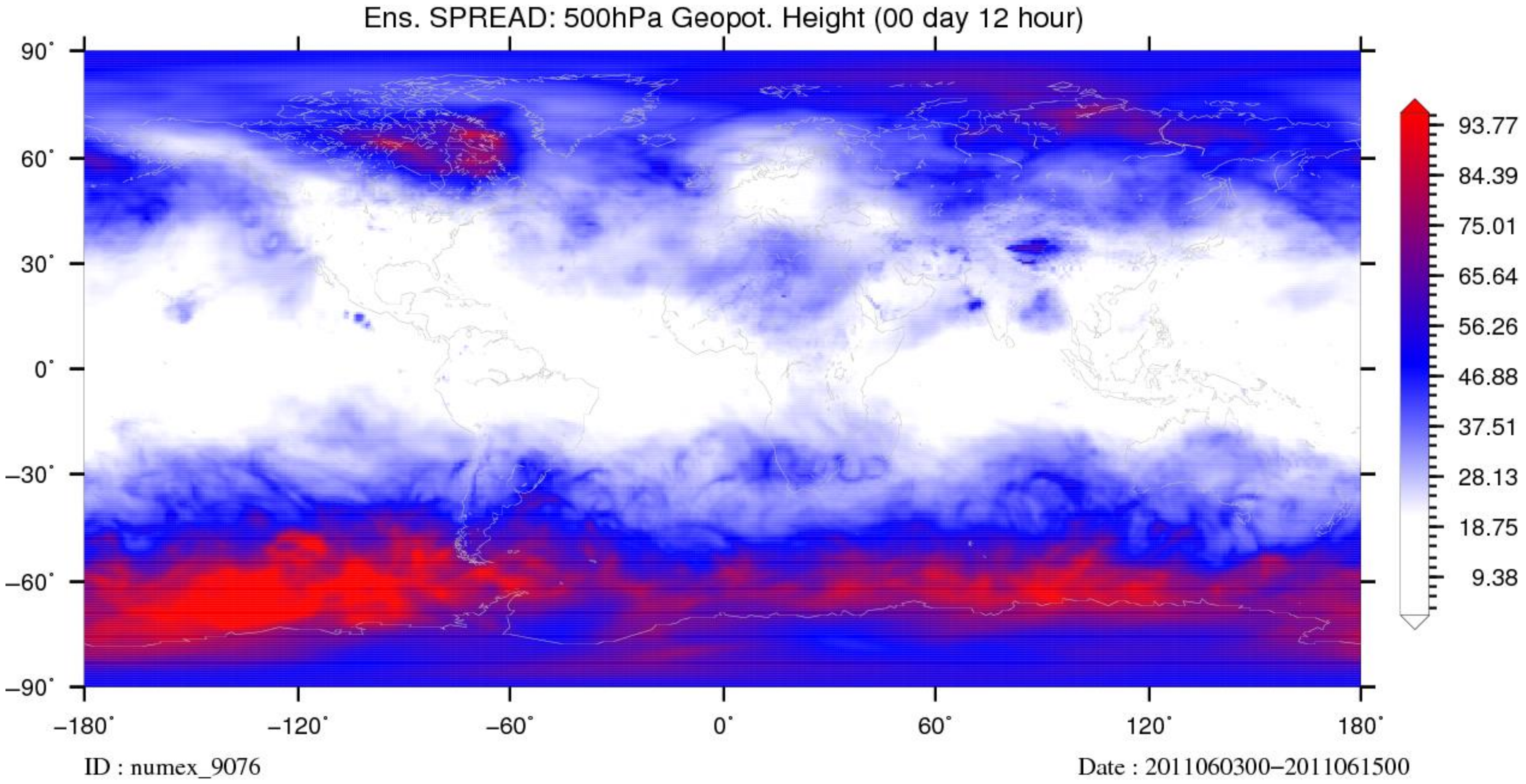


Initial Perturbations in the Lorenz63 model (Master Thesis Arwed Ockel)



- ➢ **SV perturbations predominantly avoid shrinking of errors in convergent flow**
  (**red** compared to **gold**)
- ➢ **Fastest growing modes occur in divergent flow and are well covered by Breeding**
  (**light** compared to **dark** blue)

GME Ensenble Kalman filter



Spread occurs in high northern & southern latitudes, where the flow is divergent and predictability is low.

Andreas Rhodin, Harald Anlauf, Jason Ambadan

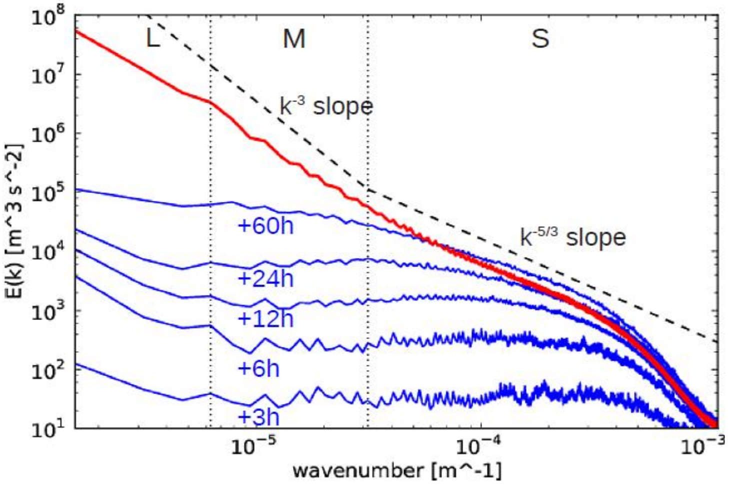
Ensemble Perturbations in NWP-models

Singular Vector (SV) Perturbations activate fast growing modes. **Which modes ?**

Baroclinic Instabilities

Tobias Selz, 2013

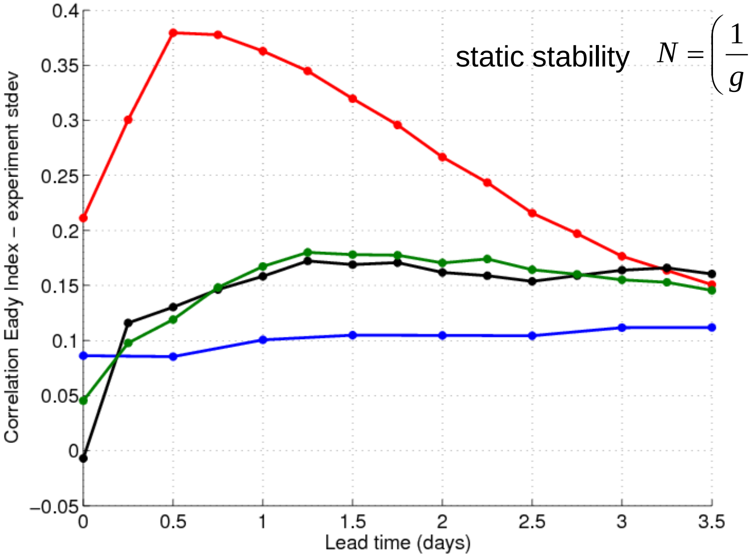
kinetic energy spectrum of control run (red)
kinetic energy spectra of **difference** wind (blue)



$$E = 0.3125 \frac{f}{N} \frac{dV}{dz}$$

V : horizontal wind

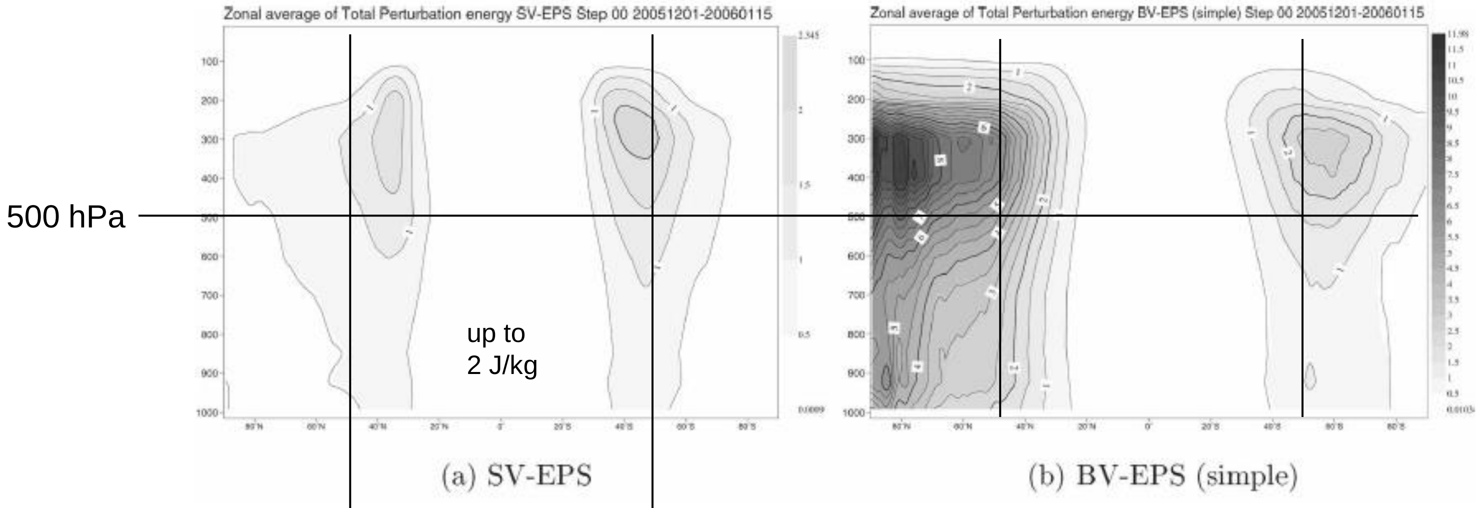
static stability $N = \left(\frac{1}{g} \frac{d \ln \theta}{dz} \right)$



- The change of the diff. KE slope at large scales after 24h indicates error growth driven by baroclinic instability

MAGNUSSON, L., NYCANDER, L., KÄLLÉN, E., 2008: Flow-dependent versus flow-independent initial perturbations for ensemble prediction, Tellus, 61A, 194-209

How do we force baroclinic instabilities ?



up to 12 J/kg

Magnusson, L., Leutbecher, M., Källen, E., 2008: Comparison between Singular Vectors and Breeding Vectors as Initial Perturbations for the ECMWF Ensemble Prediction System, Mon. Wea. Rev., 136, 4092-4104

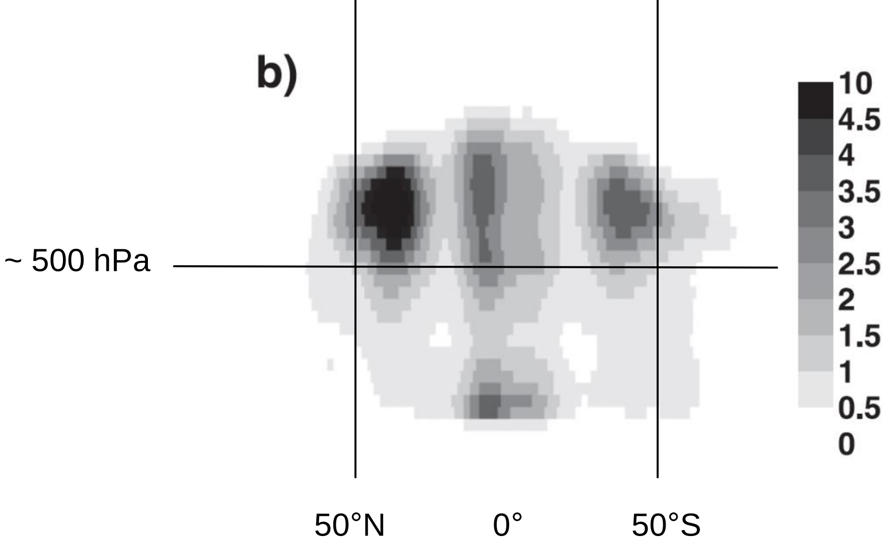


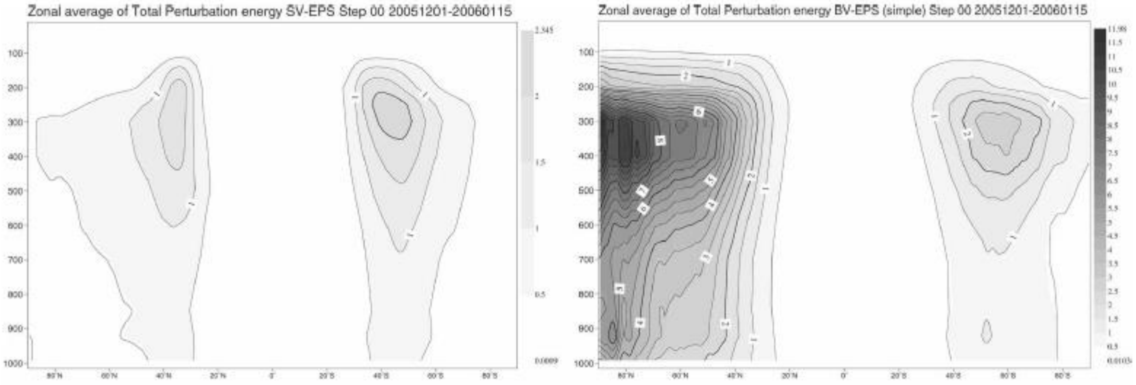
FIG. 4. **Zonally averaged annual-mean dissipation rate**
… contributions from (b) deep convection …

J. BERNER, G. J. SHUTTS, M. LEUTBECHER AND T. N. PALMER, 2009: A Spectral Stochastic Kinetic Energy Backscatter Scheme and Its Impact on Flow-Dependent Predictability in the ECMWF Ensemble Prediction System. J. ATMOS. SCI., 66, 603-626.

Initial ensemble perturbations - basic concepts

by Linus Magnusson 2012

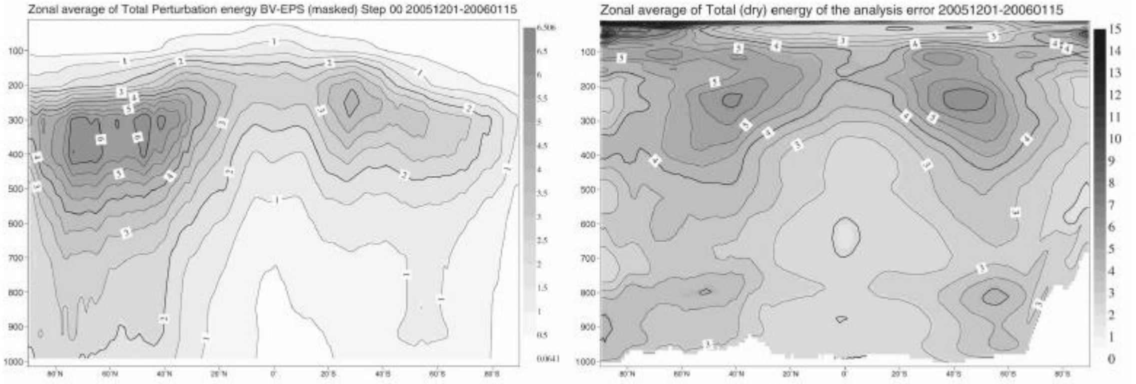
SV



(a) SV-EPS

(b) BV-EPS (simple)

BV



(c) BV-EPS (masked)

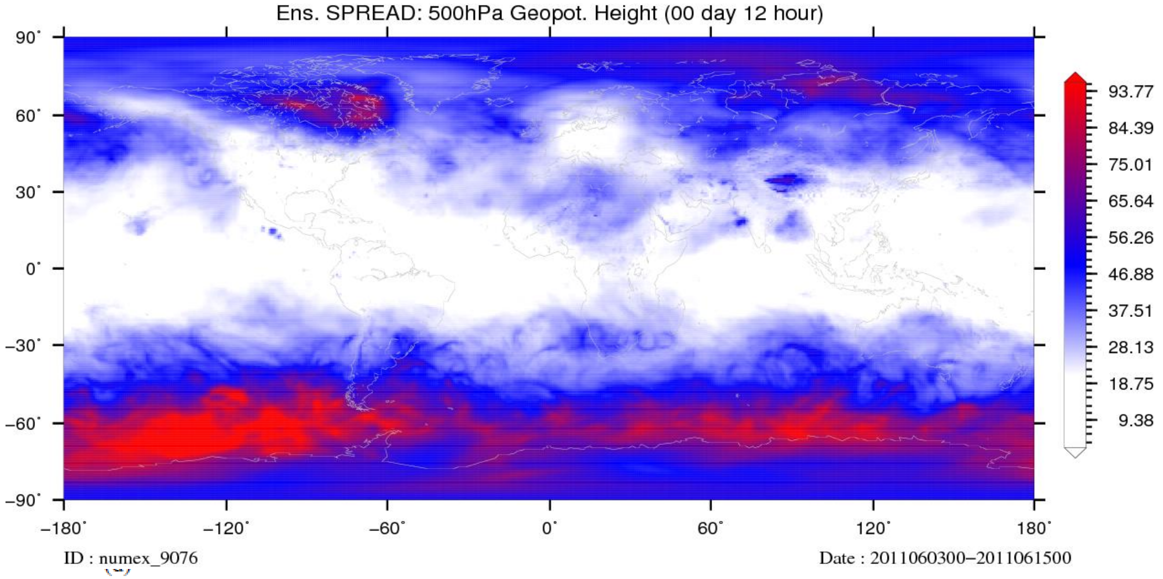
(d) Analysis error variance estimate provided

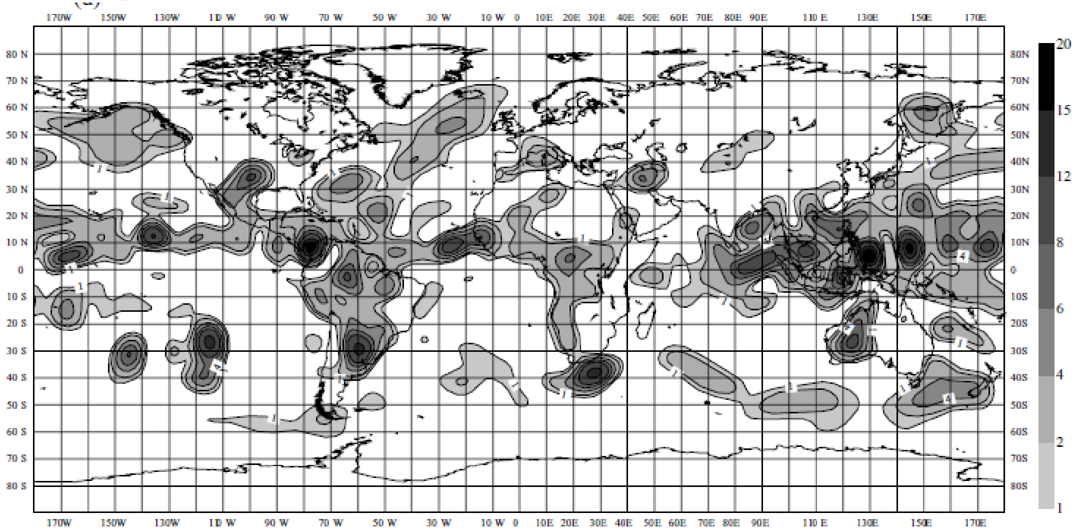
by 4D-Var

Fig. 2. The zonal average of initial perturbations and analysis error variance estimate in total energy. The mean over the period 1 Dec 2005–15 Jan 2006. The vertical axis is pressure (hPa) and the horizontal axis is latitude. The contour interval is 0.5 J kg^{-1}: (a) SV-EPS, BV-EPS (b) simple and (c) masked, and (d) error variance.

4-dVar
Analysis
error

How do we force baroclinic instabilities ?



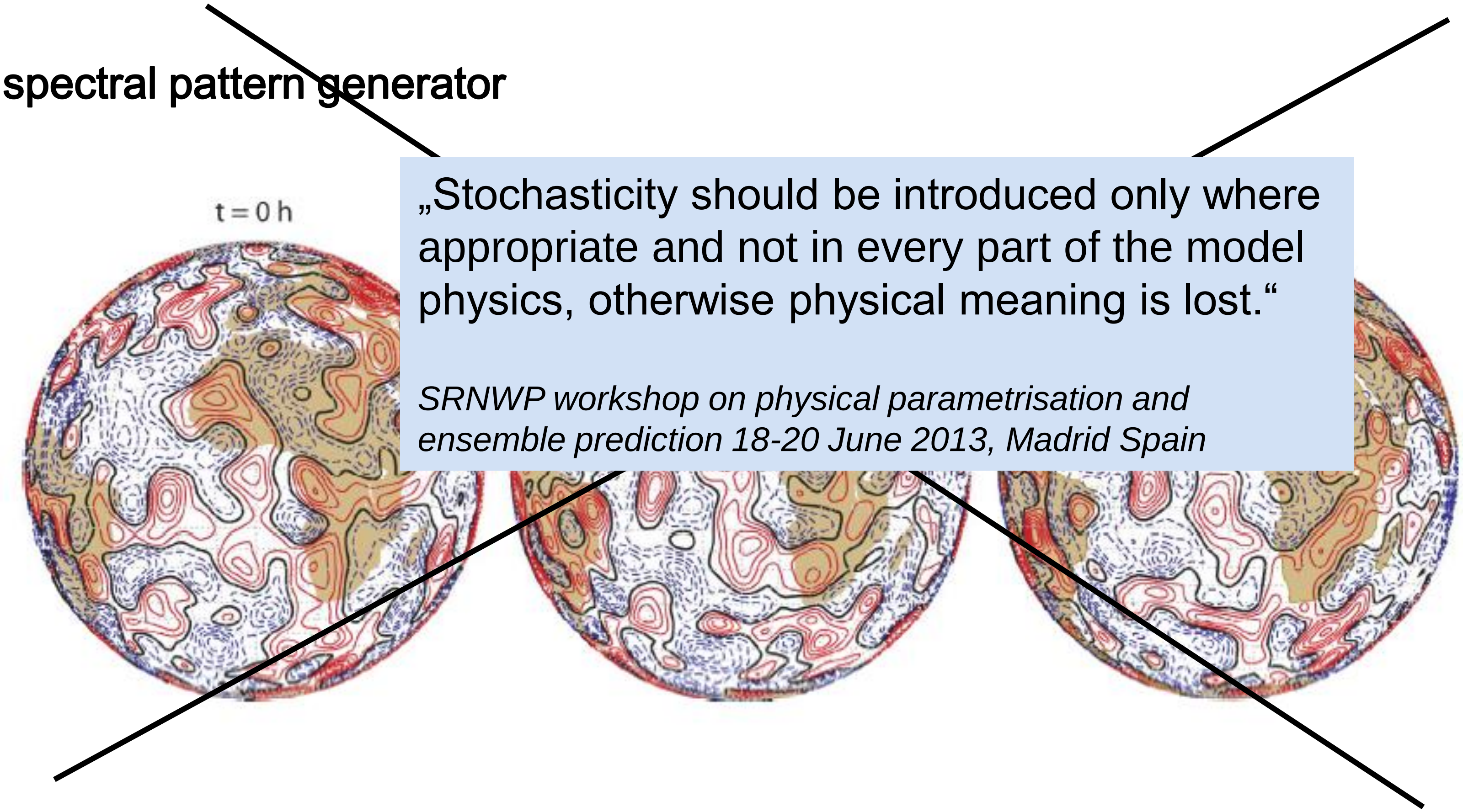


dissipation rate
from deep
convection

Shutts, 2005

Representing Model Error in Weather and Climate Prediction: Buizza (1999); Berner, Shutts, Leutbecher & Palmer (2009)

spectral pattern generator



„Stochasticity should be introduced only where appropriate and not in every part of the model physics, otherwise physical meaning is lost.“

SRNWP workshop on physical parametrisation and ensemble prediction 18-20 June 2013, Madrid Spain

Stochastic non-dynamical forcing pushes the model state away from its stable manifold !
→ perturbed model states lack dynamic consistency

Singular Vector Perturbations ECMWF Tech. Memo. 514, 2007

$$\mathbf{p} = \sum_{j=1}^{M} \alpha_j \cdot \mathbf{v}_j$$

$\mathbf{v}_j$ a set of leading singular vectors computed with the initial time metric $\mathbf{C}^{-1}$

α_j independent normally distributed random numbers with zero mean and unit variance

"**A Gaussian distribution** does not have **compact support** and occasionally the coefficients α can become so large that the resulting perturbations can **trigger numerical instabilities** in the integration."

- The standard deviation of the Gaussian for a set of singular vectors is set to

$$\sigma = \gamma / \overline{\kappa}$$

$\overline{\kappa}$ average analysis error variance norm for the set of singular vectors, scaled by the **analysis error standard deviation**

γ is determined empirically to yield adequate ensemble dispersion

- The sign of a singular vector is arbitrary → pairs of perturbations ($\mathbf{x}_+, \mathbf{x}_-$) by sampling the coefficients α for $\mathbf{x}_+$ and setting $\mathbf{x}_- = -\mathbf{x}_+$

ICON (initial + stochastic physics Perturbations)

$$\hat{\mathbf{F}}_{\Psi}(t) = \sum_{j=1}^{M} \alpha_j(t) \cdot \sqrt{\mathbf{D}_j(t)}$$

$\mathbf{D}_j$	a set of dissipation rates (e.g. deep convection, mountain wave drag, …)
$\alpha_j(t)$	backscatter ratio: random process which smoothly switches the forcing on and off

The perturbations can be added to the EnKF analysis ensemble

Shutts, 2005

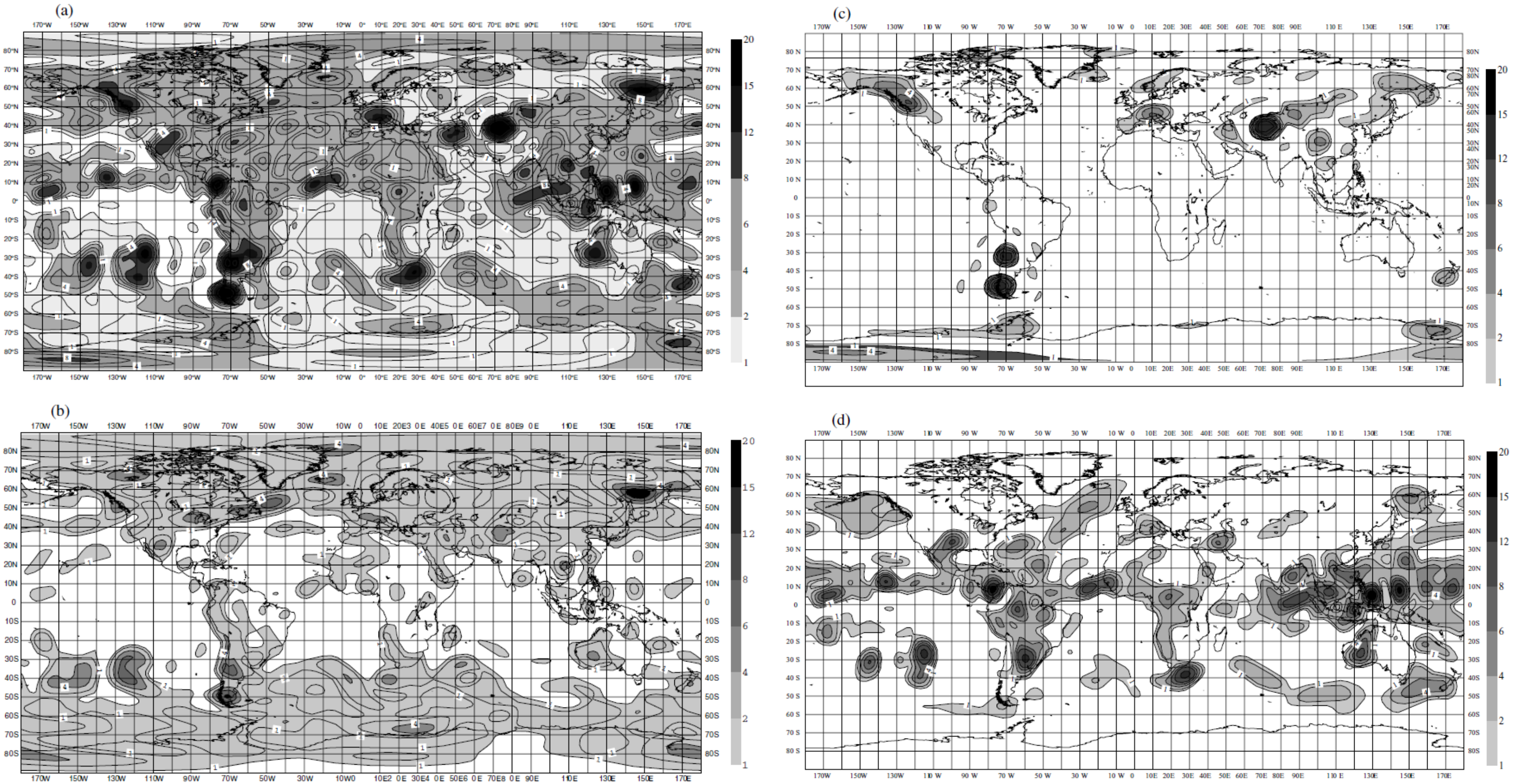
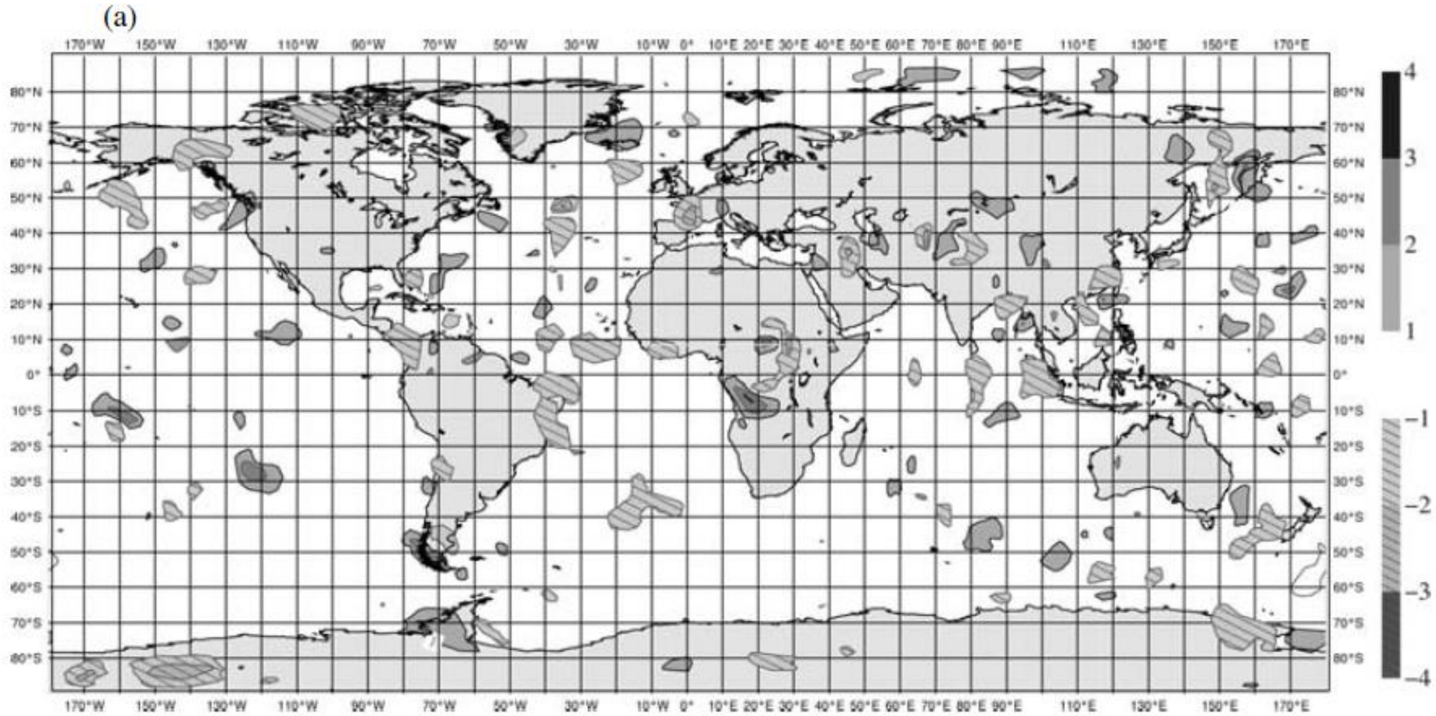
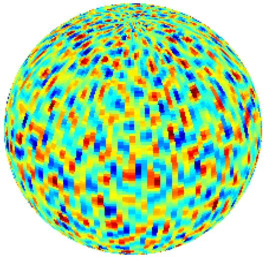


Figure 3. Smoothed total ‘dissipation rate’ (a) comprising contributions from (b) horizontal diffusion, (c) gravity-wave/mountain drag and (d) deep convection

Shutts, 2005

Figure 4. Stream-function forcing pattern (F_ψ) at (a) level 47 (~1.7 km). Units are m^2s^{-2}.

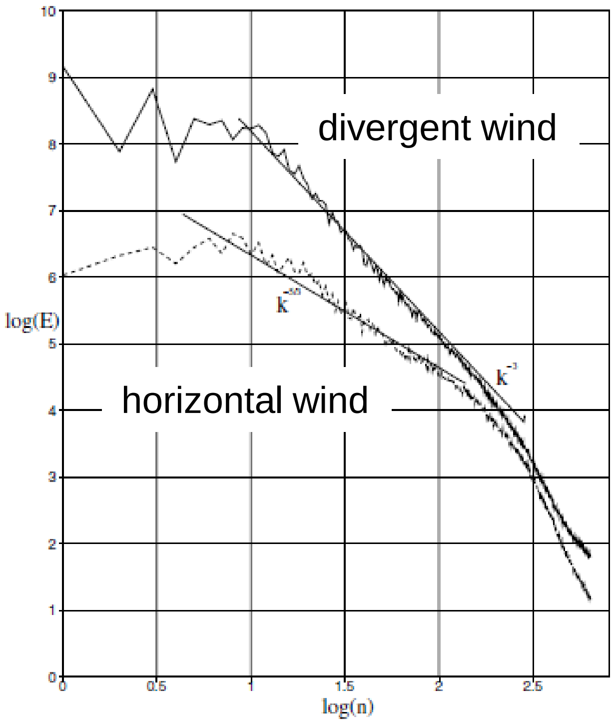


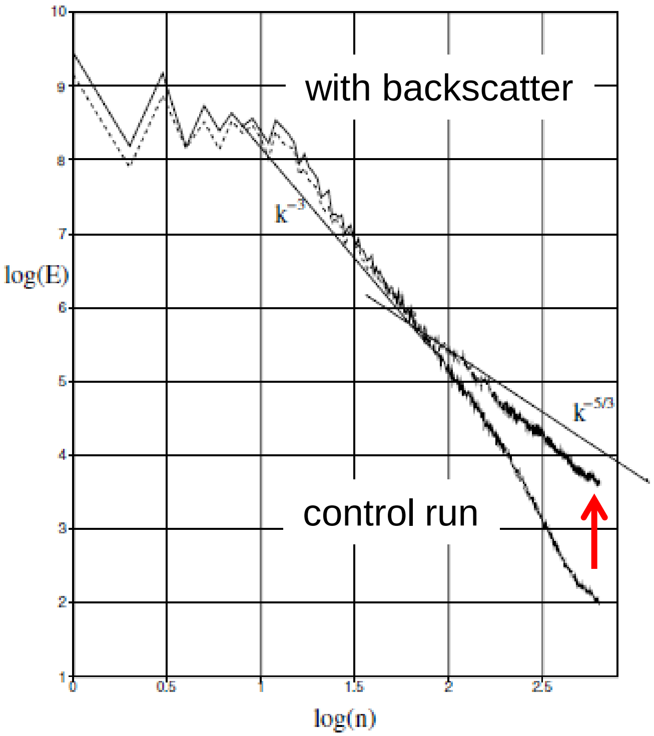


CELLULAR AUTOMATON

Shutts, 2005

Figures 6 & 7: Even “runs at T799 show no sign of the k−5/3 spectral slope (left). With the backscatter scheme there is substantially more energy at smaller scales (right), and it could be argued that we are compensating for a model deficiency by injecting energy at the smallest resolvable scales.”





What is the contribution of the cellular automaton spectral pattern generator ?

ICON Ensemble Project:

Backscatter the **dissipated energy pattern** from deep convection by chance with some auto-correlation in time ?

- initially & during the forecast.

Try the same with

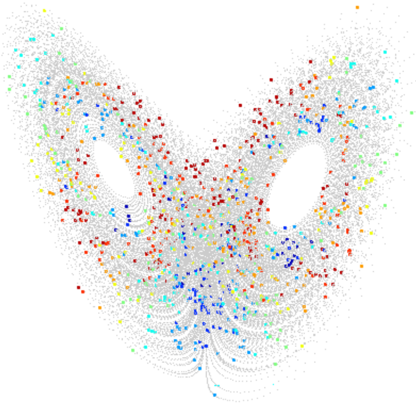
- gravity/mountain wave drag ?

- numerical dissipation rate ?

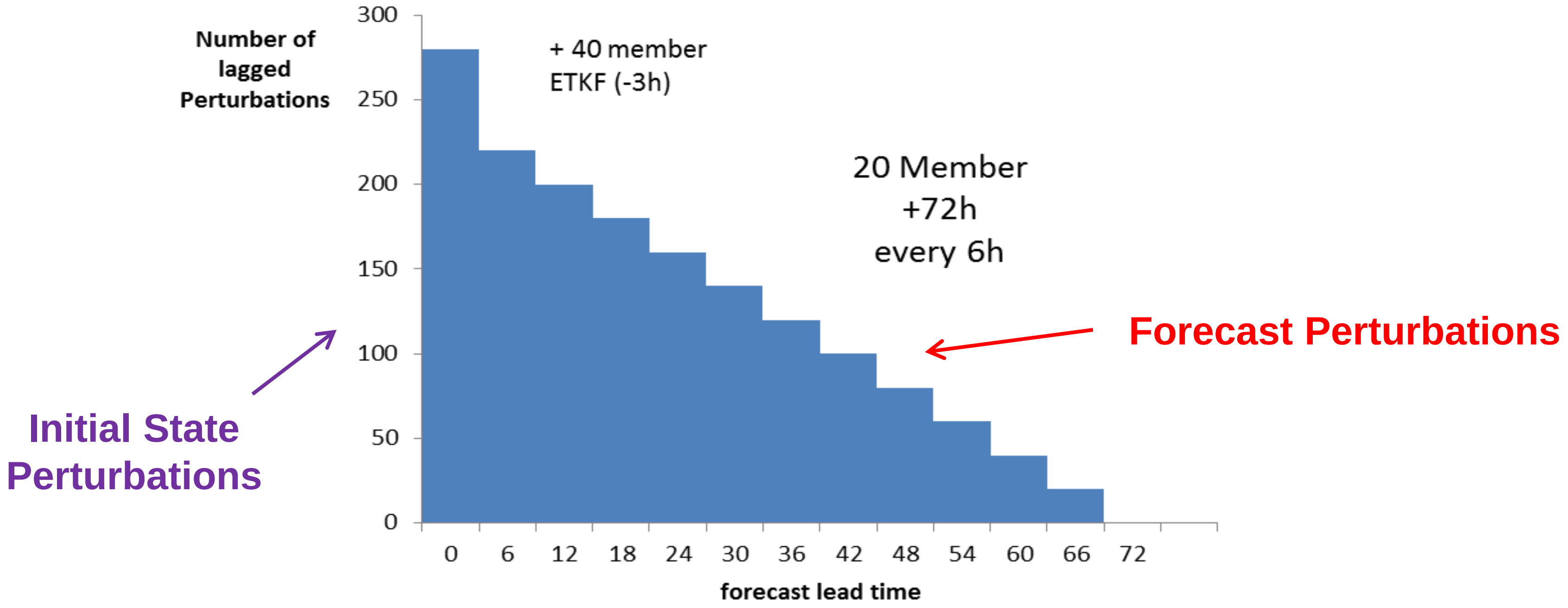
Lagged Forecast Perturbation Patterns („forecasters perspecitve“)

… to see, if we can find other dynamically relevant processes that relate to model error

The following slights are optional



Lagged Forecast Perturbations



Select or filter fastest growing perturbation patterns from lagged forecasts

dynamically consistent perturbations

Lorenz63
Lagged Forecast Perturbation Experiment

➔ Select the Perturbation with the largest instantaneous error growth rate

9 x lagged forecasts validating at initialisation time

+ 1 x inital random perturbation

---

10 possible perturbations

➔ The lag time is 0.1

➔ All forecasts are intialized by **random perturbations**

Lagged Forecast Perturbations