Initial ensemble perturbations
-
basic concepts

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Acknowledgements: Erland Källén, Martin Leutbecher, …, …

ECMWF

Introduction

Perturbed forecast = **Optimal analysis** + **Perturbation**

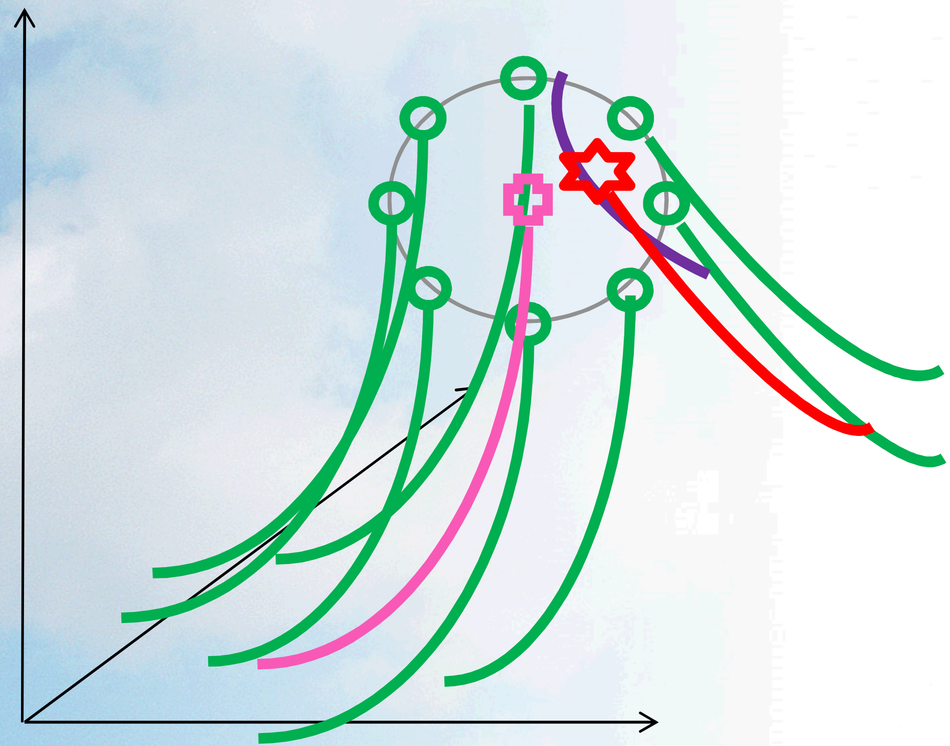
Perturbations added to a subset or all model variables

"How to construct the initial perturbations?"

"Why does not pure random numbers work?"

ECMWF

Introduction



Starring list

Analysis – best estimate

Uncertainty estimate

Bifurcation line

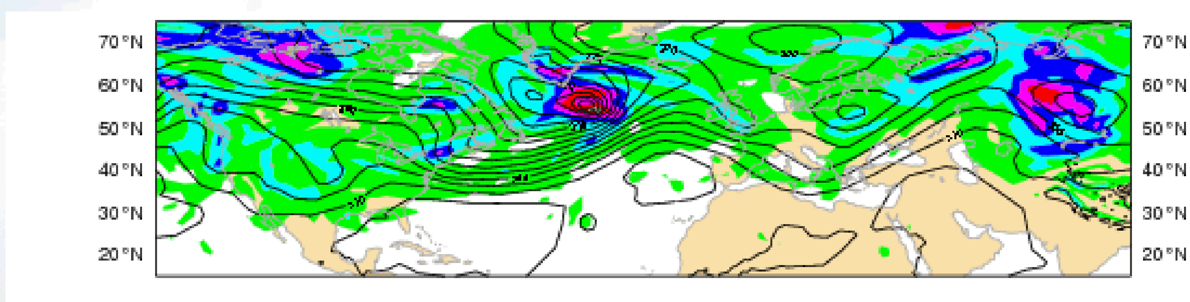
Perturbed members

Truth (unknown)

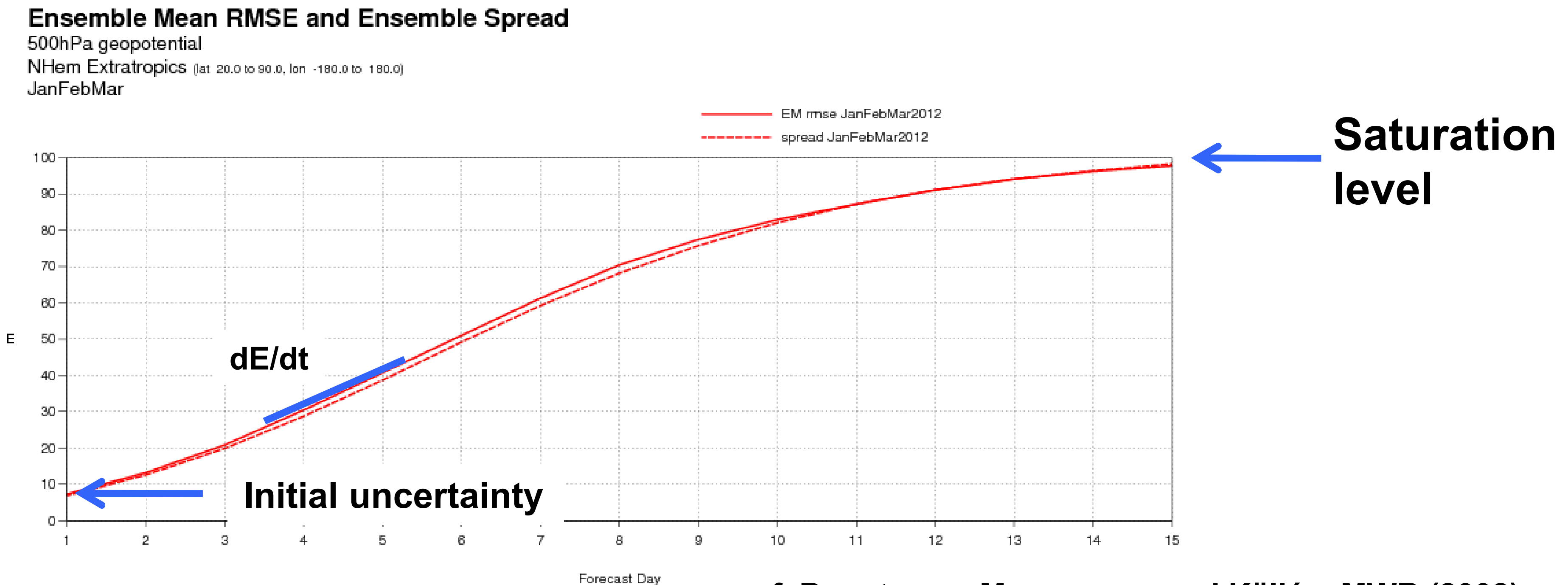
"If we knew the truth, we have started the forecast for it."

Desirable properties of initial perturbations

- Sampling analysis uncertainty
  - Mean amplitude
  - Geographical distribution
  - Spatial scale
  - ”Error of the day”
- Sustainable growth
- High quality of probabilistic forecast



Ensemble mean RMSE and ensemble spread



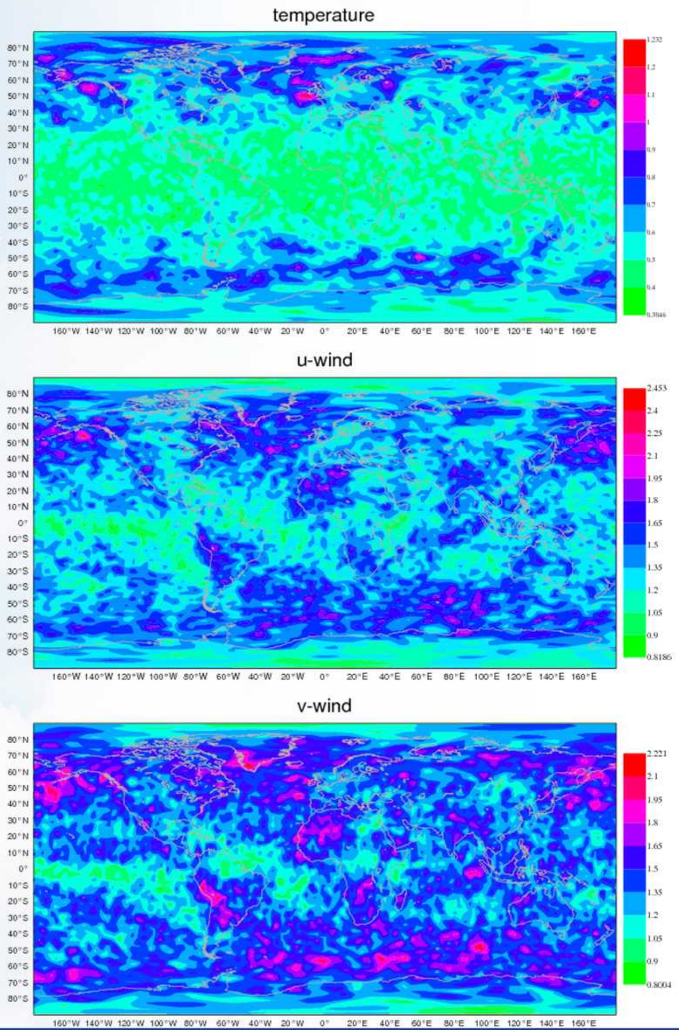
cf. Bengtsson, Magnusson and Källén, MWR (2008)

Optimally: Ensemble mean RMSE = ensemble spread

Random Perturbations (why does it not work?)

Analysis error estimate

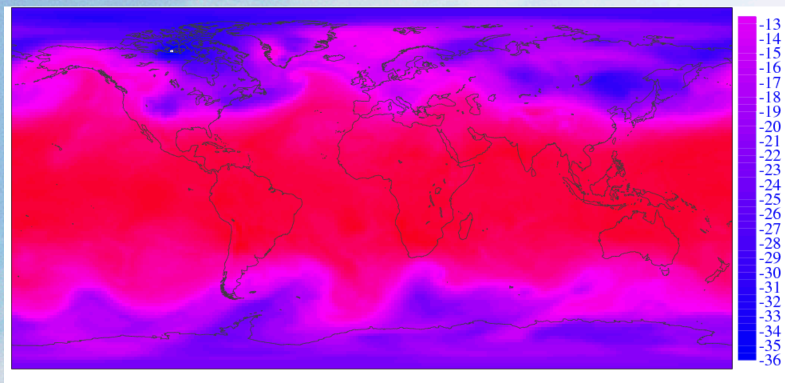
Random grid-point number (-1 to 1) x



x global tuning factor

Random Field (RF) perturbation (for benchmarking)

Analysis Random date 1



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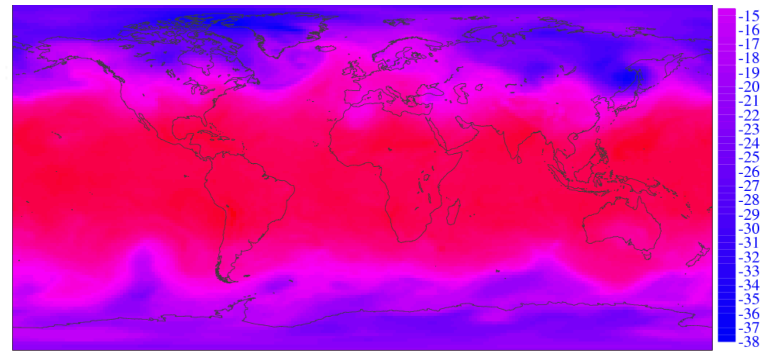
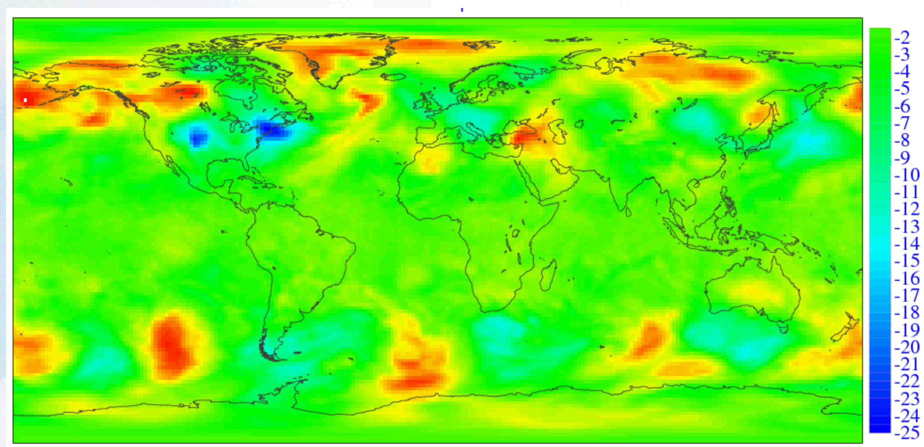
Analysis Random date 2



x normalizing factor =

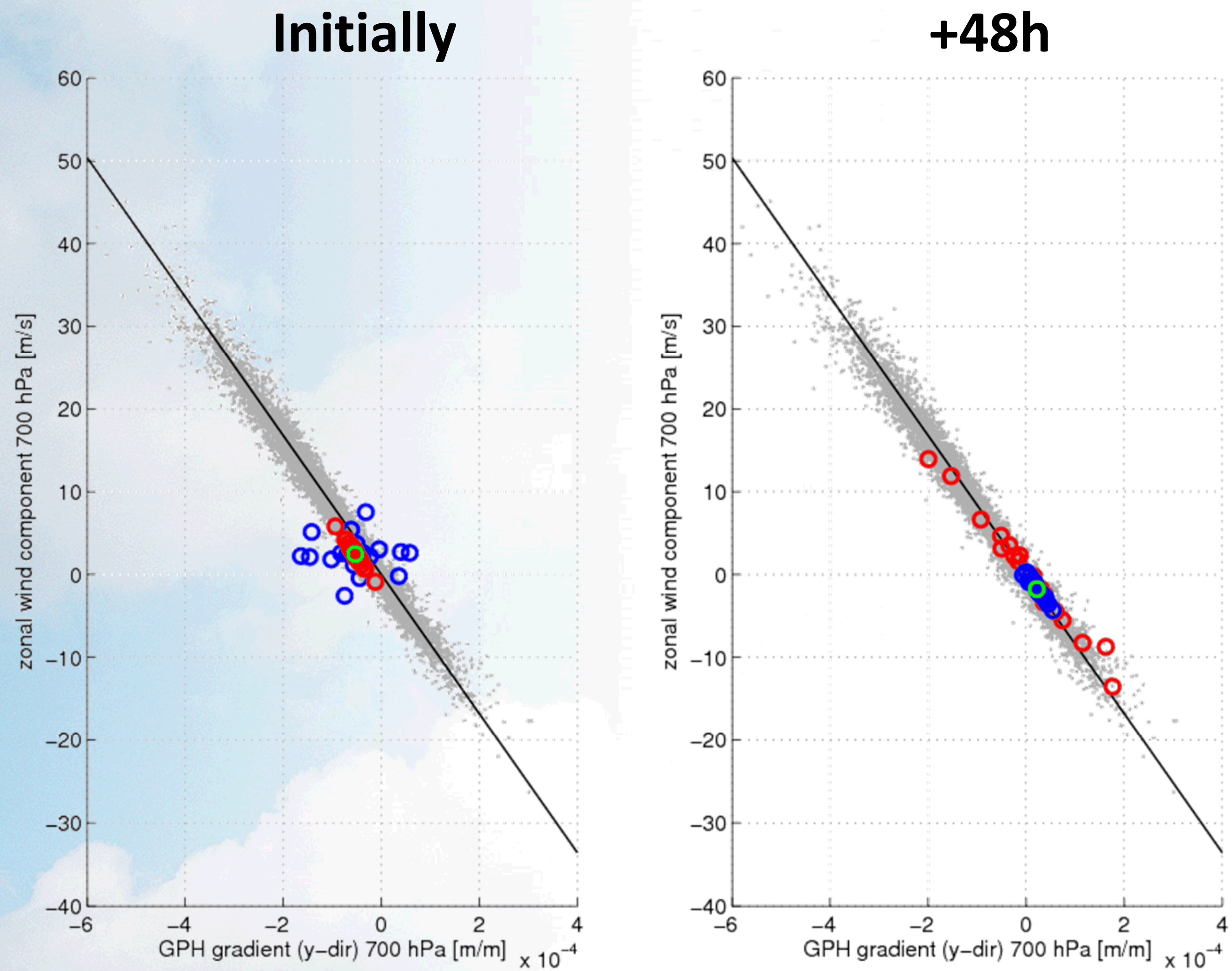
Random Field Perturbation



Not flow-dependent, but linear balances maintained

cf. Magnusson, Nycander and Källén, Tellus A (2009)

Geostrophic balance and perturbations



Blue – random pert., Red – random field, climatology - grey

ECMWF

Singular vectors

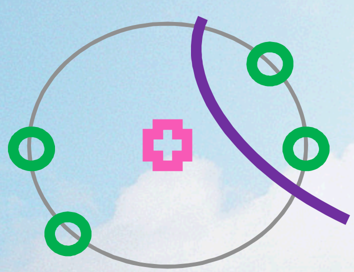
$$\alpha = \frac{\langle \Delta\vec{x}(t), \Delta\vec{x}(t) \rangle}{\langle \Delta\vec{x}(0), \Delta\vec{x}(0) \rangle}$$

Optimize perturbation growth for a time interval

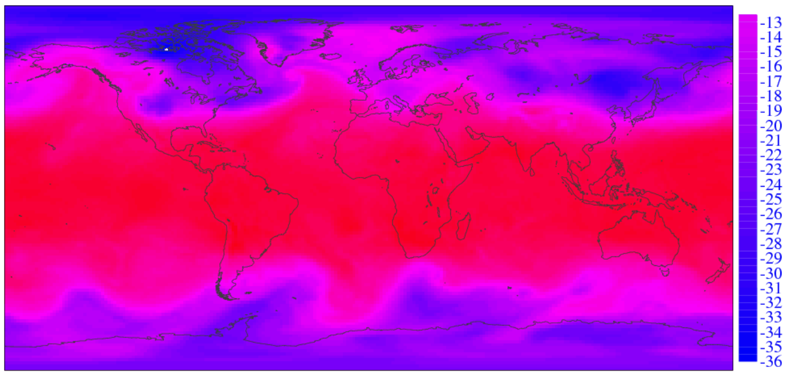
Norm dependent!

M tangent linear operator. $\Delta x(t)=M(t,x_0)\Delta x(0)$

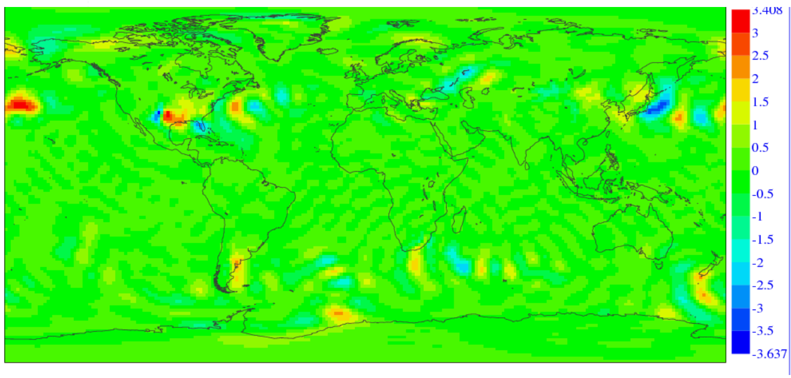
(Will be further explained by Simon Lang)



Atmospheric state

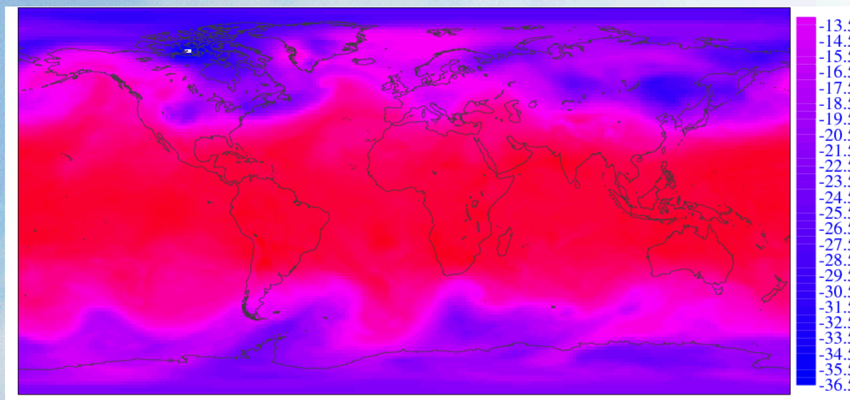


Singular vector perturbation



Breeding perturbations

Perturbed Forecast +06h



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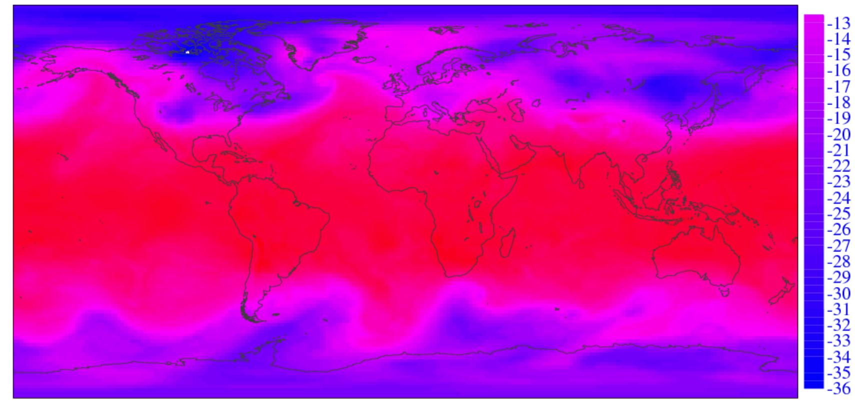
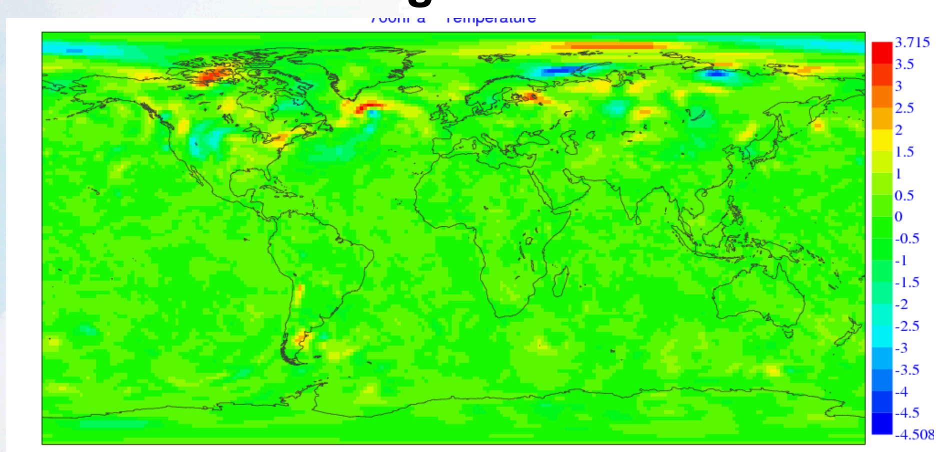
Unperturbed Forecast +06h



Breeding vector

x normalizing factor =



Ensemble transform perturbations (further development of BV)

(Wei et al., Tellus A, 2008)

$$X^{\mathrm{f}} = [x_1^{\mathrm{f}}, x_2^{\mathrm{f}}, \ldots, x_m^{\mathrm{f}}, \ldots, x_k^{\mathrm{f}}]$$

(x=pf-em), compare with BV

$$X^{\mathrm{a}} = [x_1^{\mathrm{a}}, x_2^{\mathrm{a}}, \ldots, x_m^{\mathrm{a}}, \ldots, x_k^{\mathrm{a}}]$$

$$X^{\mathrm{a}} = X^{\mathrm{f}} C \Gamma^{-1/2}$$

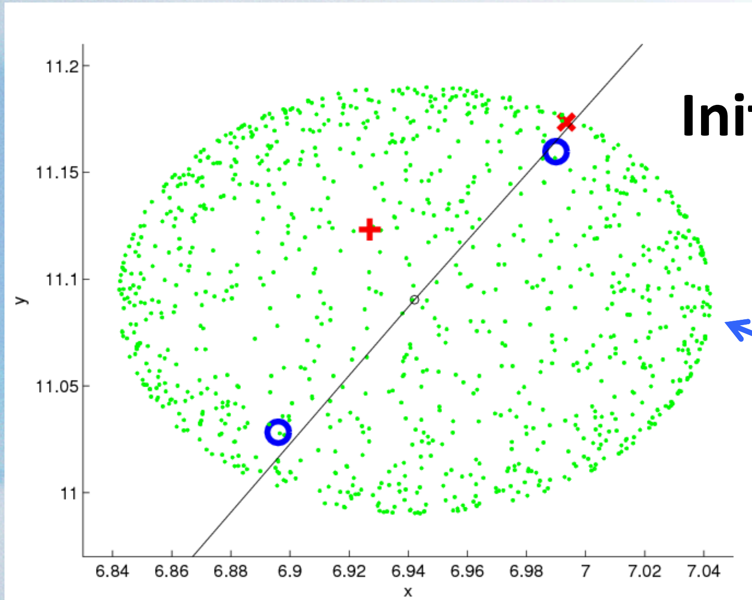
Make the perturbations orthogonal

C and Γ from eigenvalue problem: $\dfrac{{X^{\mathrm{f}}}^T {P_{op}^{\mathrm{a}}}^{-1} X^{\mathrm{f}}}{n}$

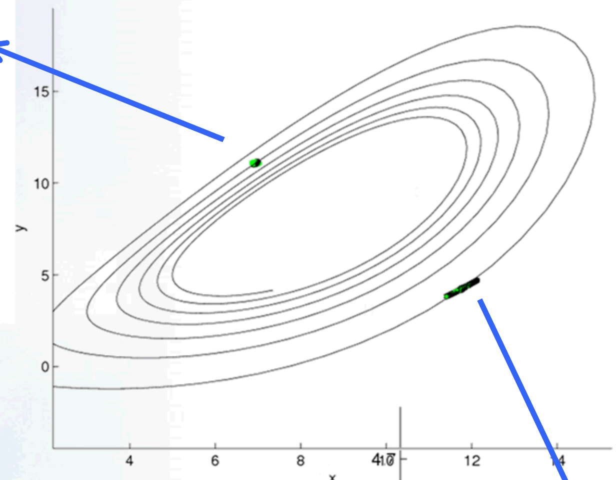
Error norm

- Simplex transformation
- Regional re-scaling
- ETKF perturbations similar idea (Wang and Bishop, JAS, 2003)

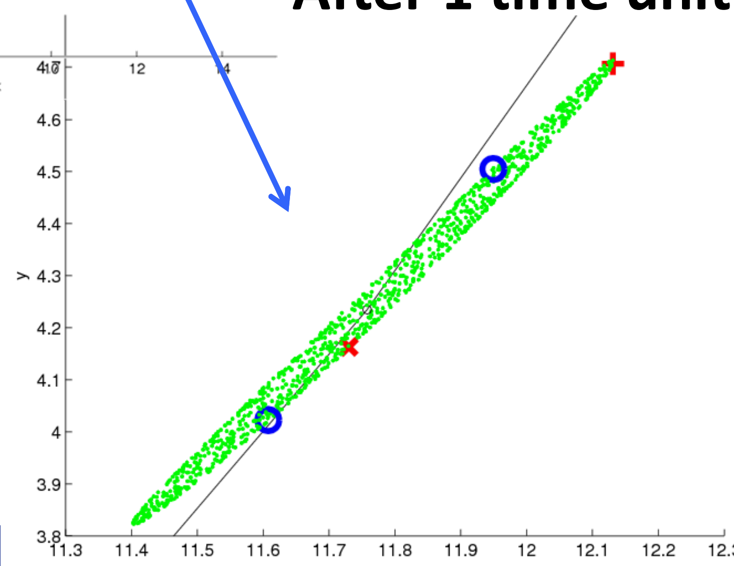
Perturbation methods Lorenz-63



Initial point



After 1 time unit

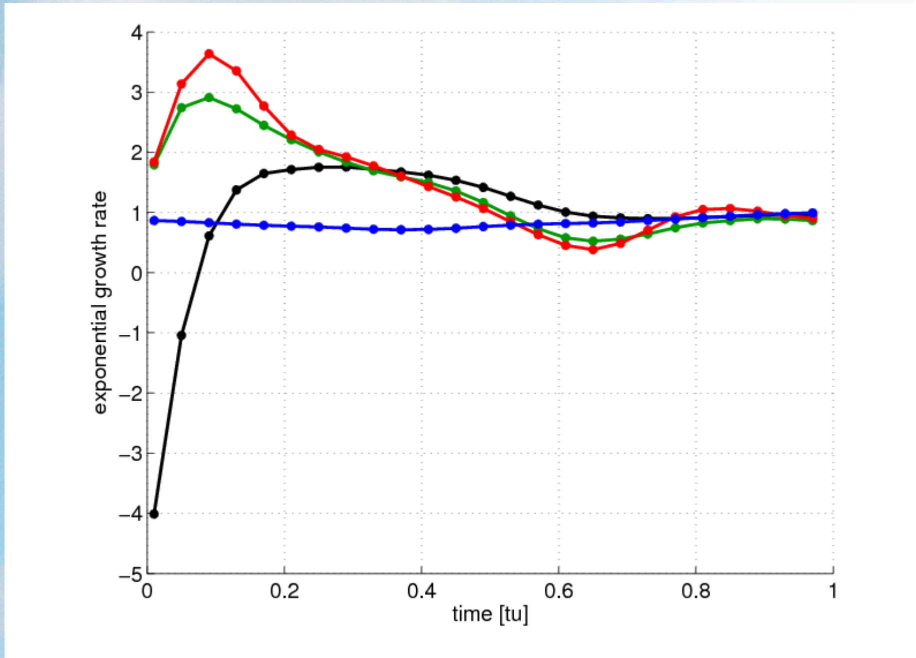


- Random pert.
- ✚ 1st SV
- ✖ 2nd SV
- ○ BV

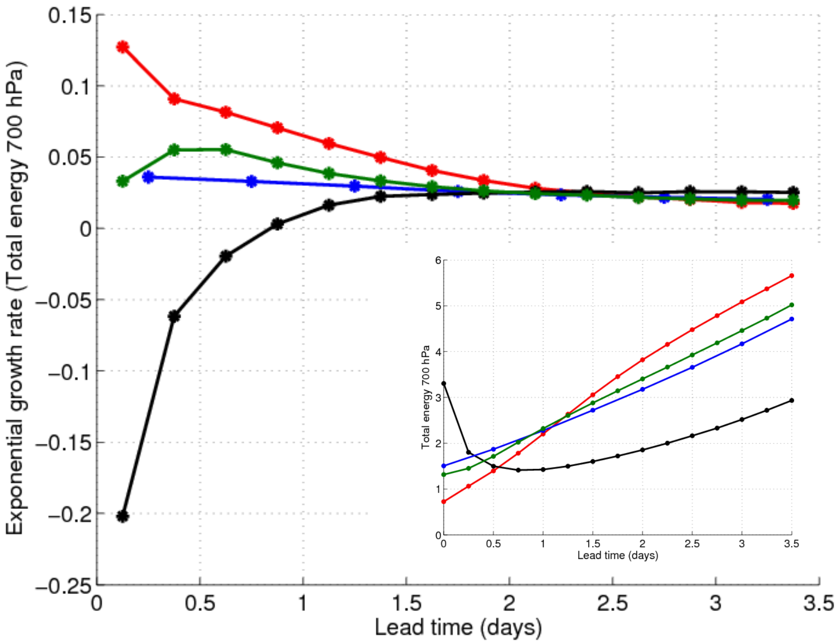
Exponential perturbation growth

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

Lorenz-63



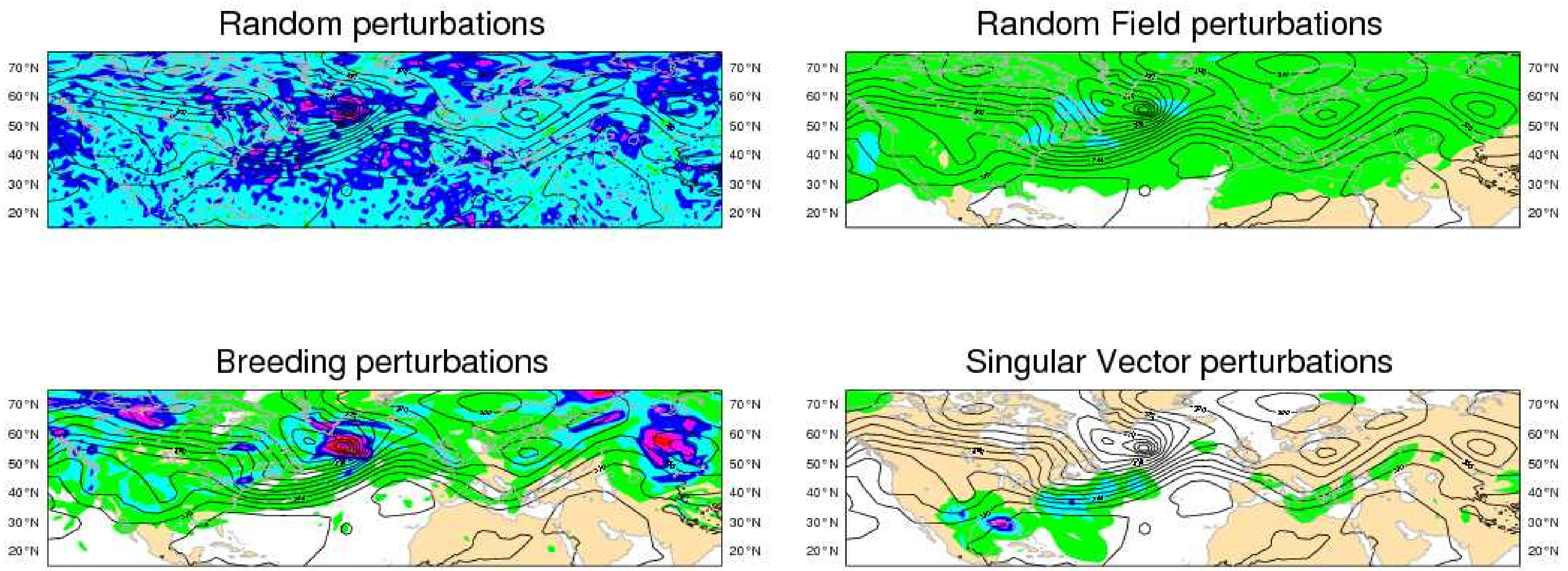
NWP-model (ECMWF)



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

Evolution of ensemble spread
(one case, total pert. energy 700 hPa)

Initially

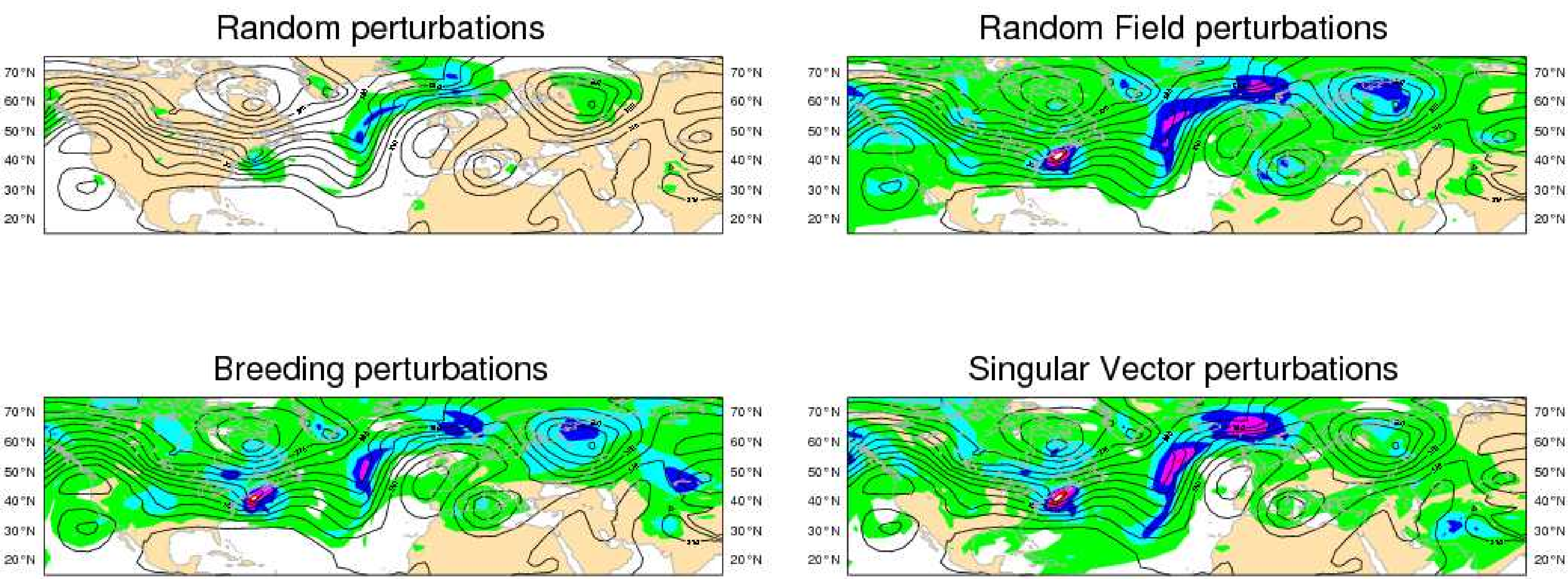


Maximum – red

ECMWF

Evolution of ensemble spread (one case, total pert. energy 700 hPa)

+48h

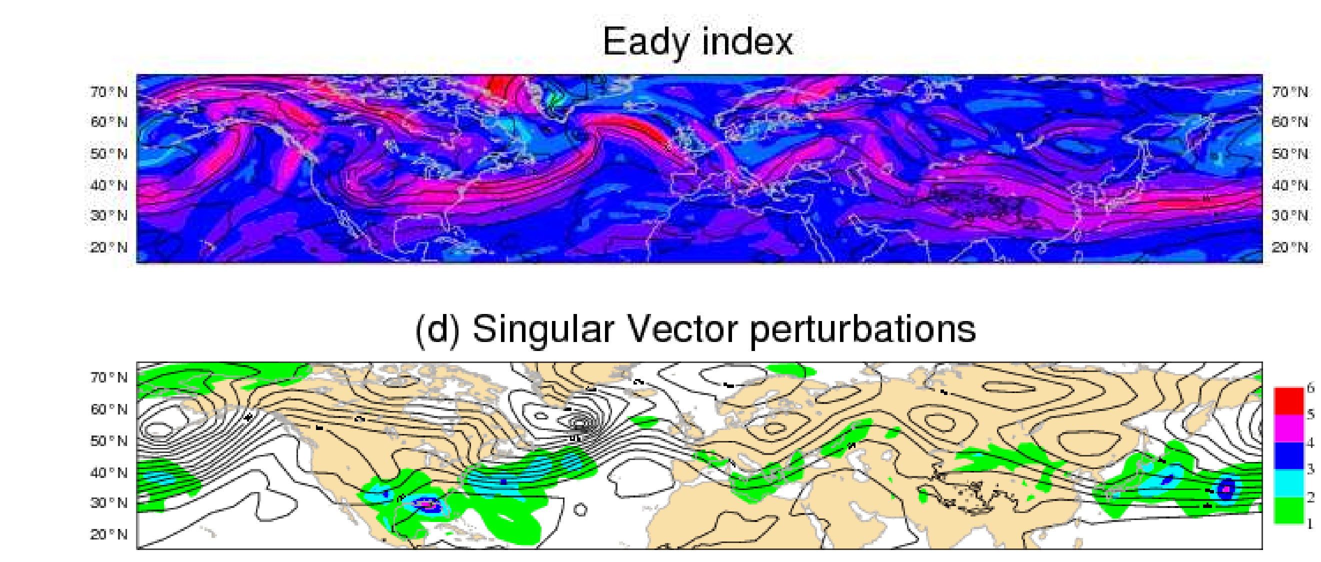


Maximum – red, Scale 48: twice the scale for +00h

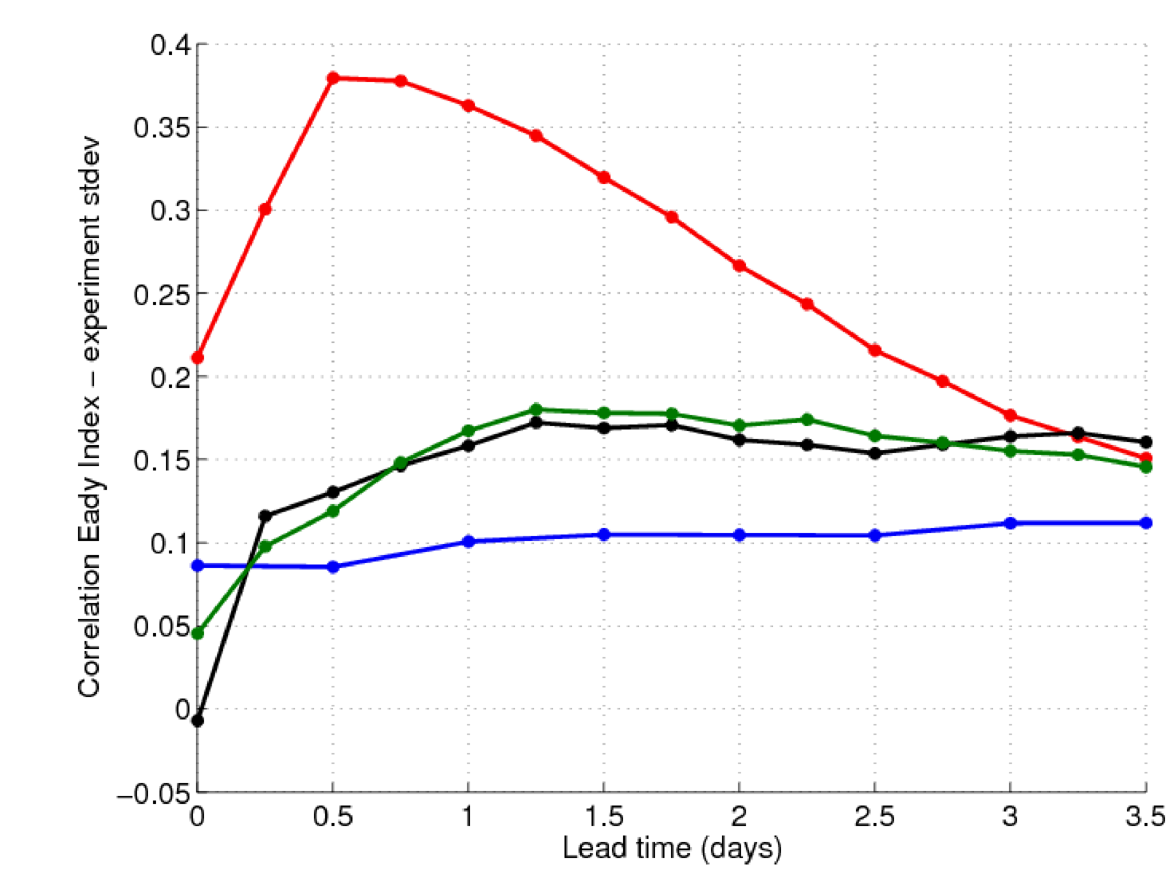
ECMWF

Connections between perturbations and baroclinic zones

$$E = 0.3125 \frac{f}{N} \frac{dV}{dz}$$ *Fastest growth rate of normal modes*



Correlation Eady index – Ens. Stdev z500



SV - Red
ET - Blue
RF – Green
RP - Black

(20N-70N)

Mean initial perturbation distribution

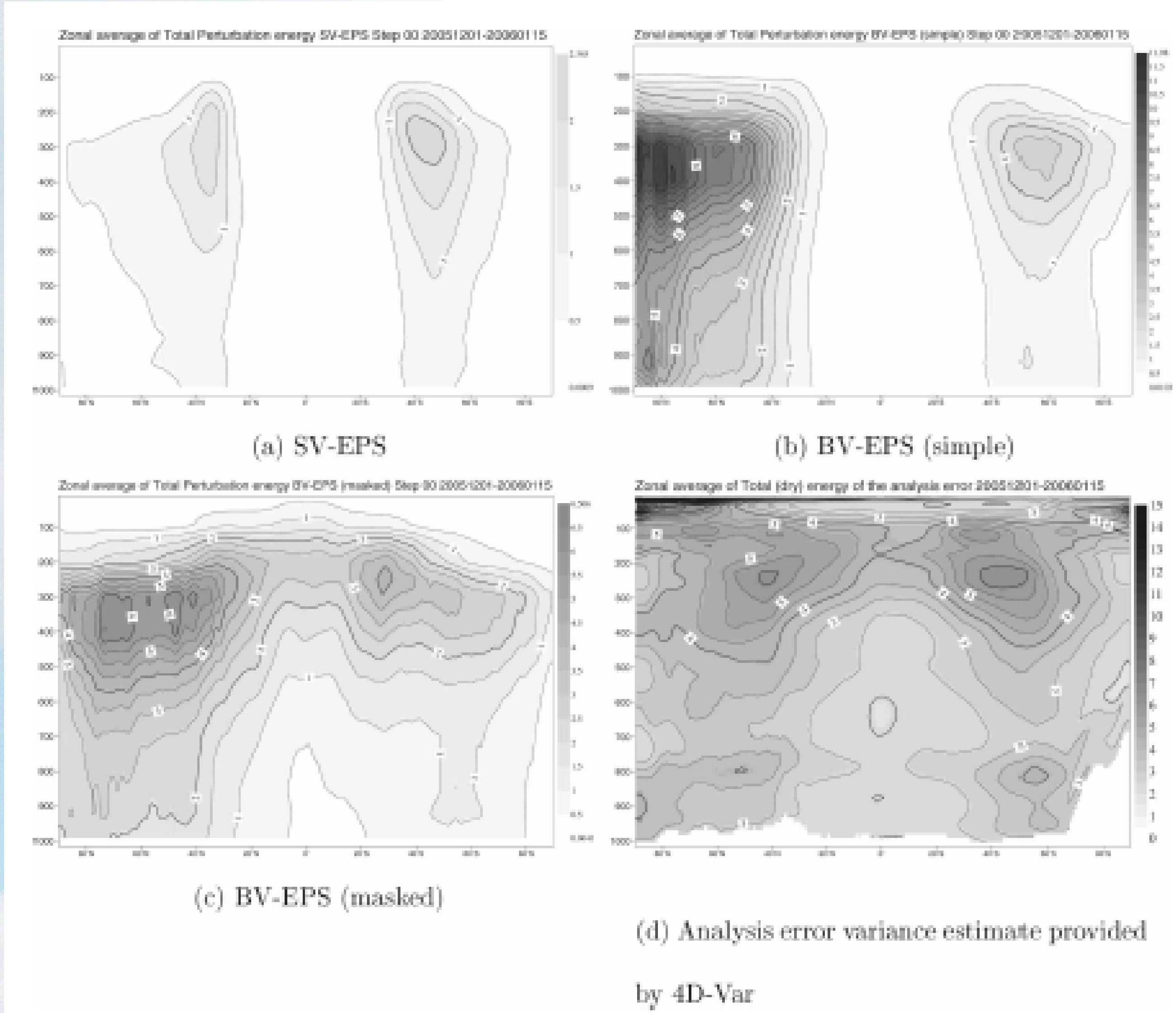


Figure 2. Magnusson, Leutbecher and Källén. 2008 (MWR)

Mean perturbation distribution after 48 hours

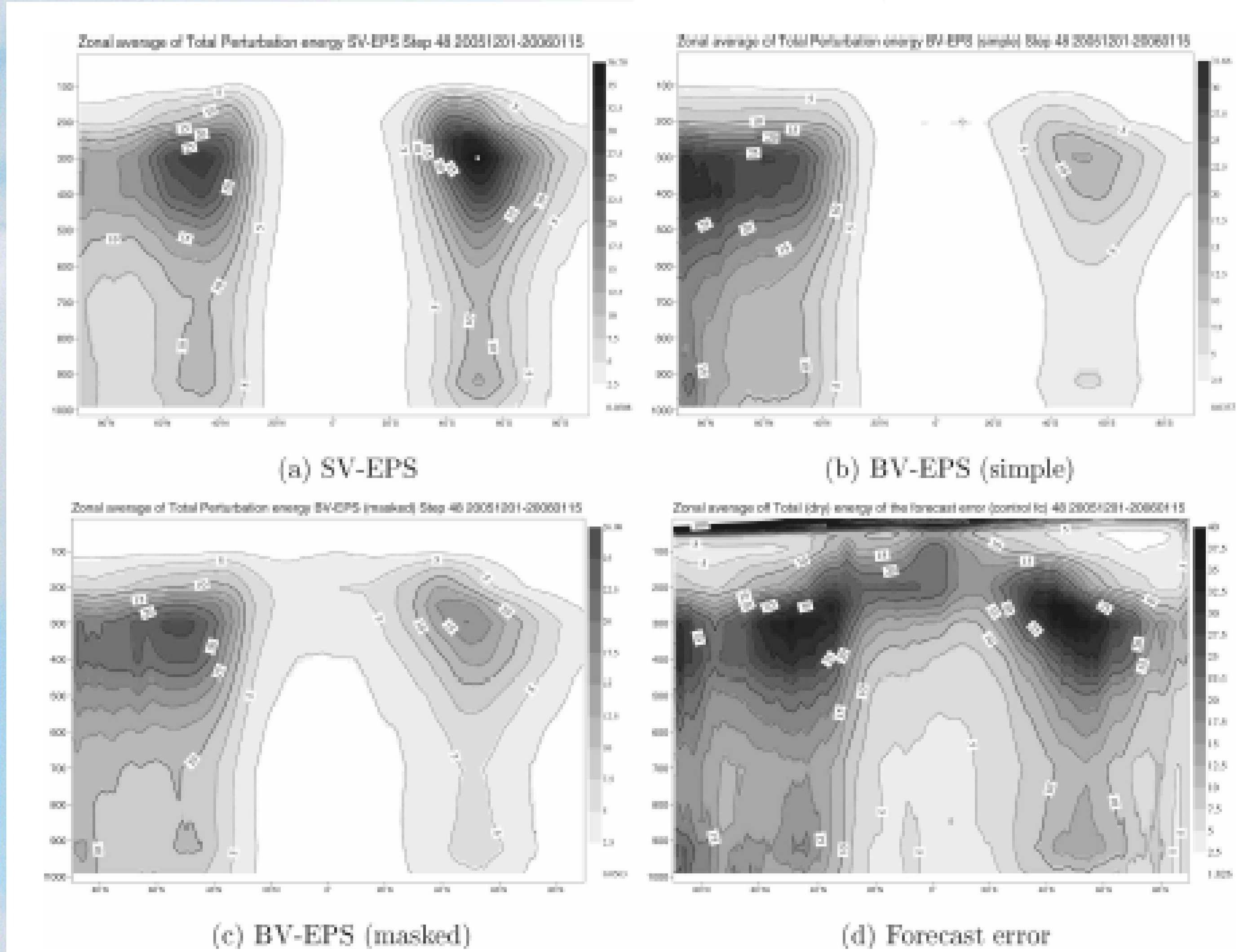
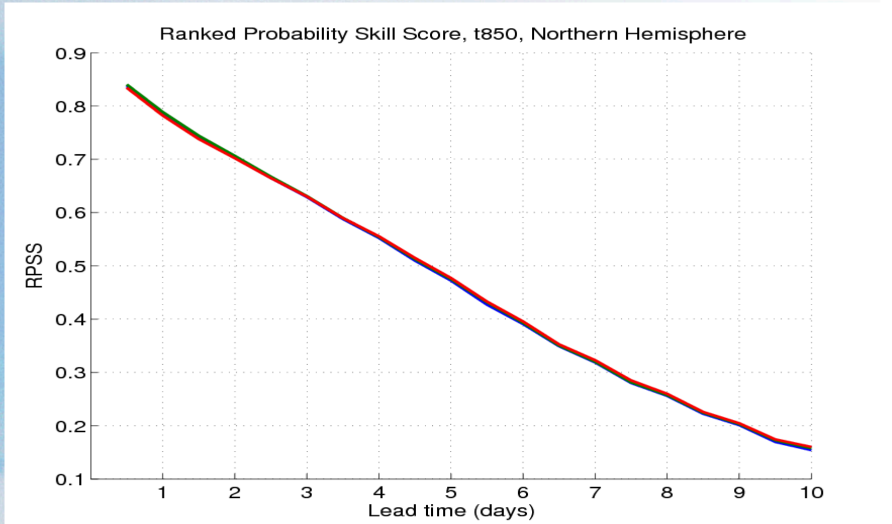


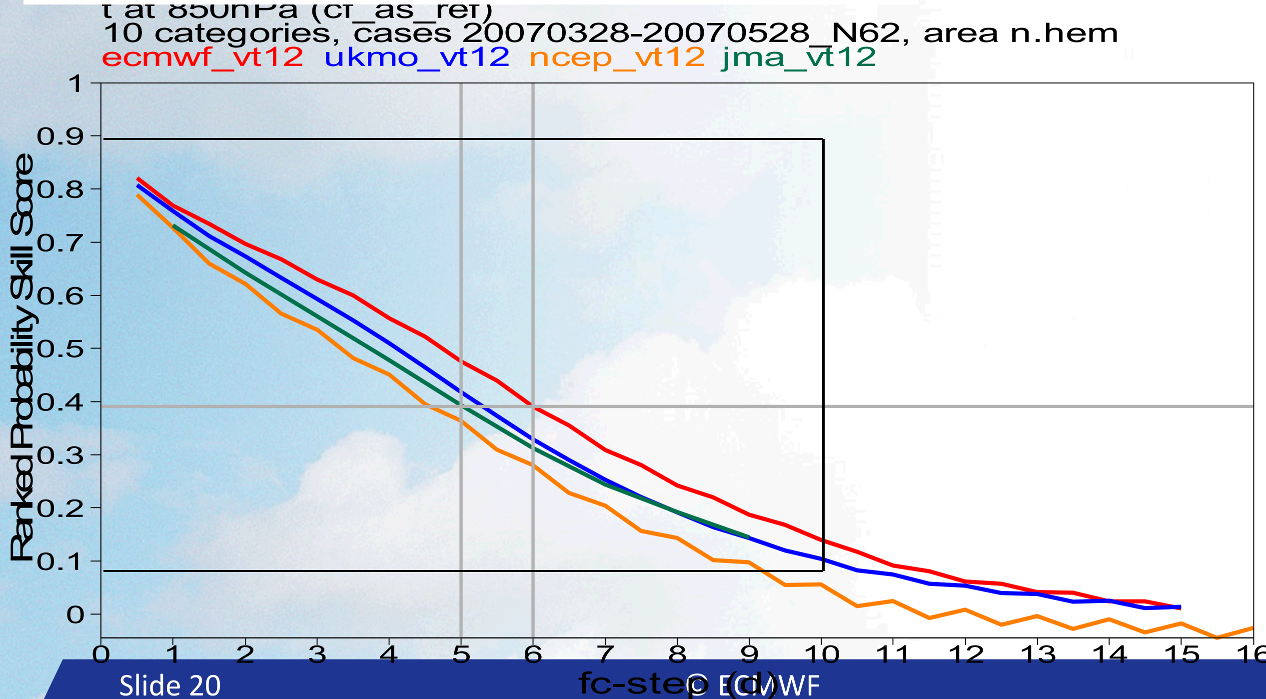
Figure 3. Magnusson, Leutbecher and Källén. 2008 (MWR)

Ranked Probability skill score - t850



Different initial perturbations (N.Hem)

SV - Red
ET - Blue
RF – Green



Different Centres (from Park et al.(2008), Courtesy R. Buizza)

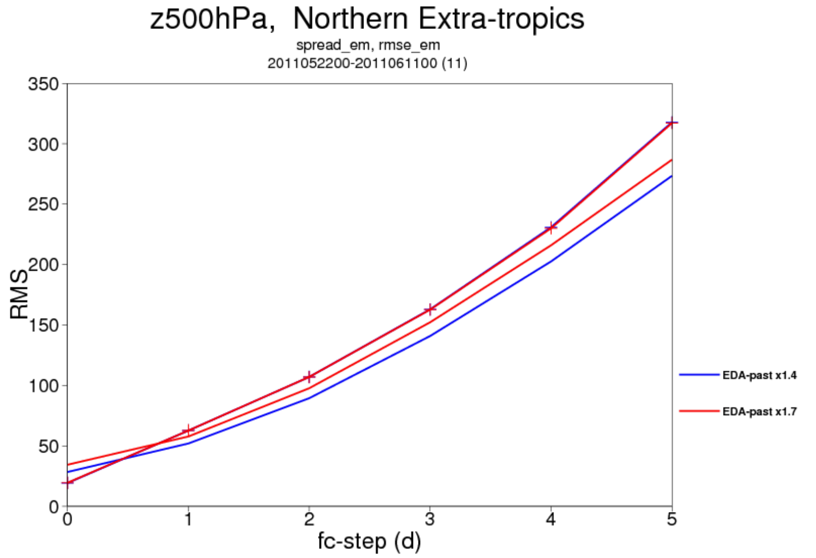
Other things to consider - Perturbation symmetry

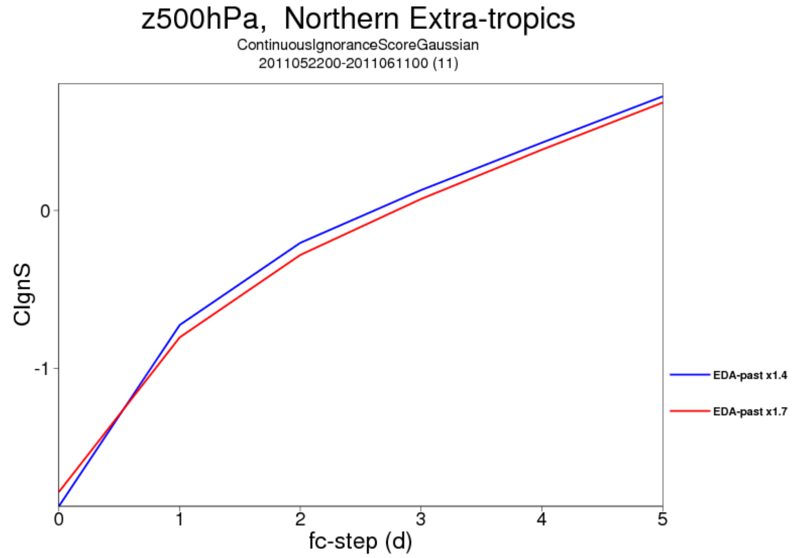
- +/- symmetry -> rank N/2
- Simplex transformation -> rank N-1

- No clear advantage for simplex transformation in our metrics

Other things to consider - Importance of initial amplitude scaling

Two models with different tuning of the initial amplitude

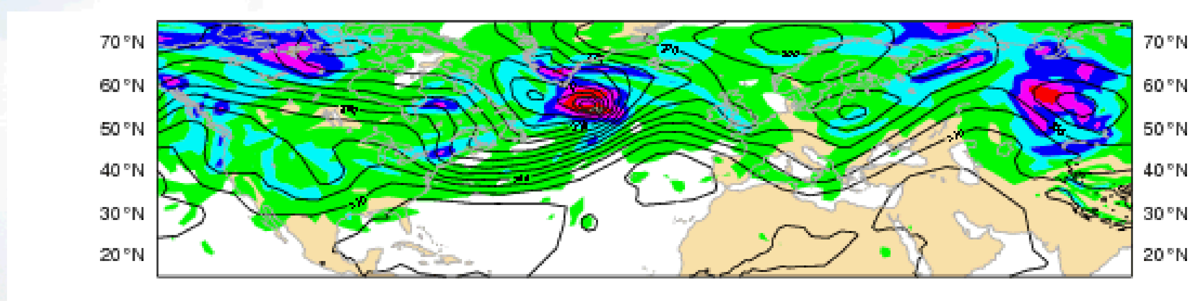




Perturbation growth is highly model dependent!

Desirable properties for initial perturbations

	SV	BV and ET	RF	Random
<u>Sampling analysis uncertainty</u>				
Mean amplitude		v	v	
Geographical			v	V
Spatial scale	v	V	v	
Growth	v (too fast?)	V	v	
An Error of the day	V	v		
<u>Fc Error of the day</u>	V	V	V	V
<u>Fc Quality</u>	V	V	V	



Ensemble assimilation and prediction