# Model Imperfections

**Tim Palmer**

**ECMWF**

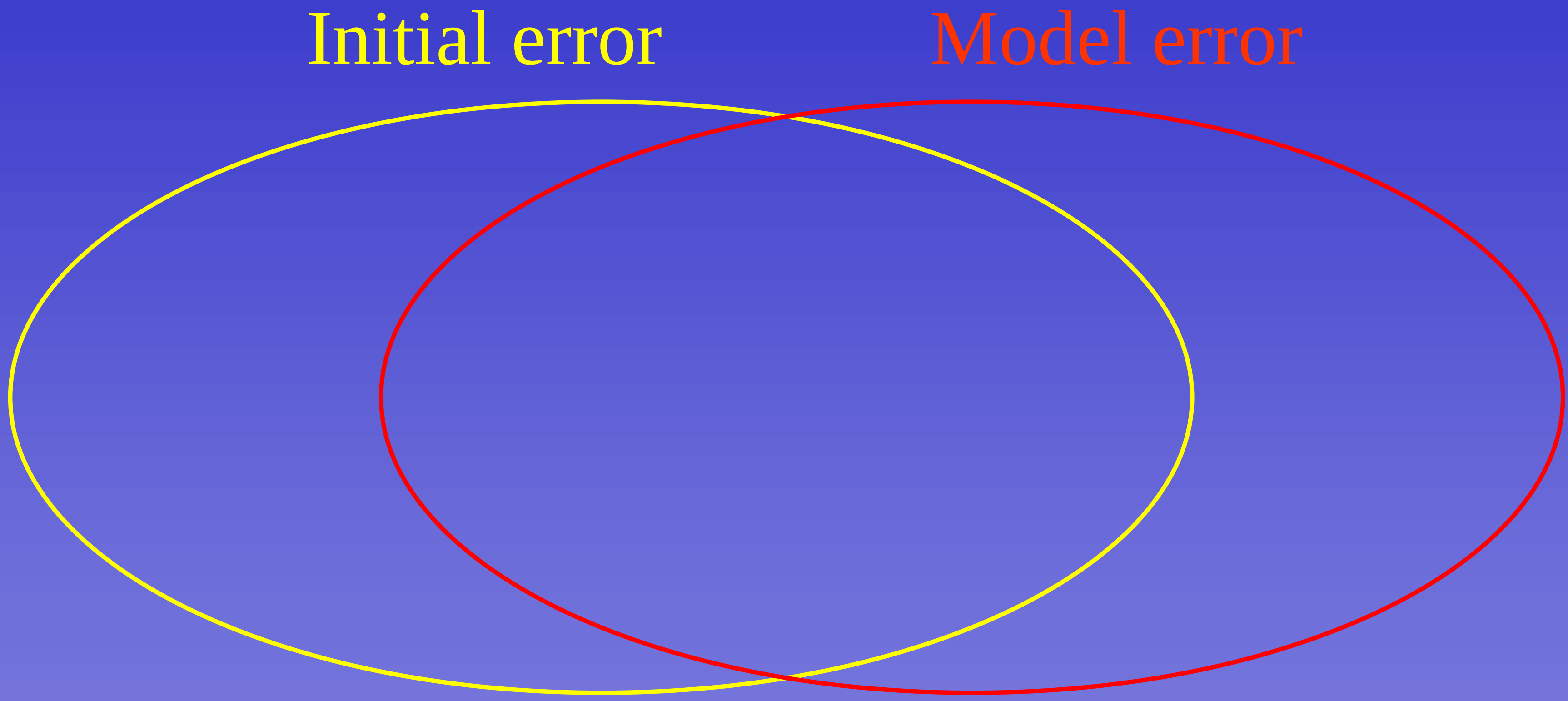
With acknowledgement for contributions with no imperfections to:

Judith Berner, Roberto Buizza, Paco Doblas-Reyes, Renate Hagedorn, Thomas Jung, Glenn Shutts

Imperfect forecasts are due to:

- Initial imperfections
- Model imperfections

But…




These are not disjoint sets!

- Initial condition – a value of the forecast model's state vector obtained by assimilating observations (typically point or pixel-scale) into the model.

- Observations which are influenced by scales of motion that are not well represented by the model's equations of motion (up to several grid lengths) can't be assimilated accurately.

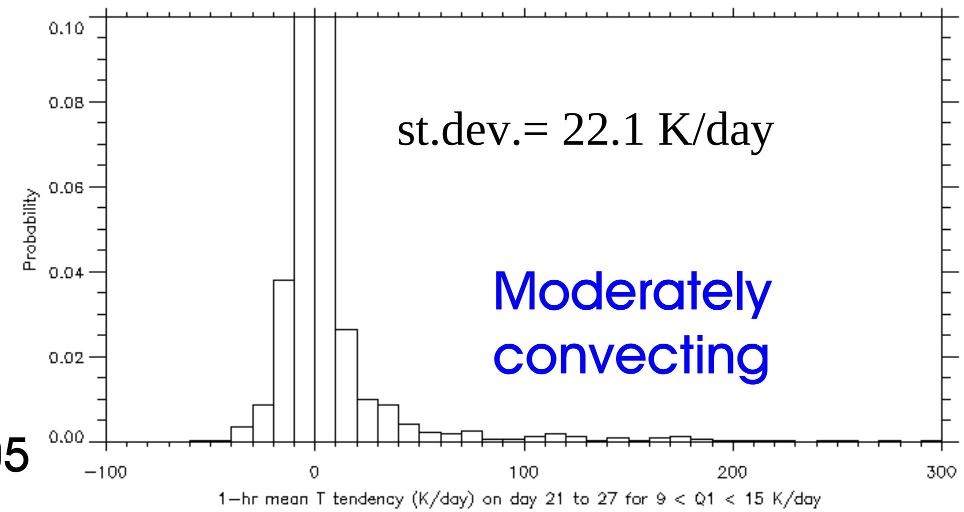
- Such model-induced initial error doesn't partition well into $J_b$ and $J_o$.

- Singular vectors may sample some of this model-induced initial uncertainty.

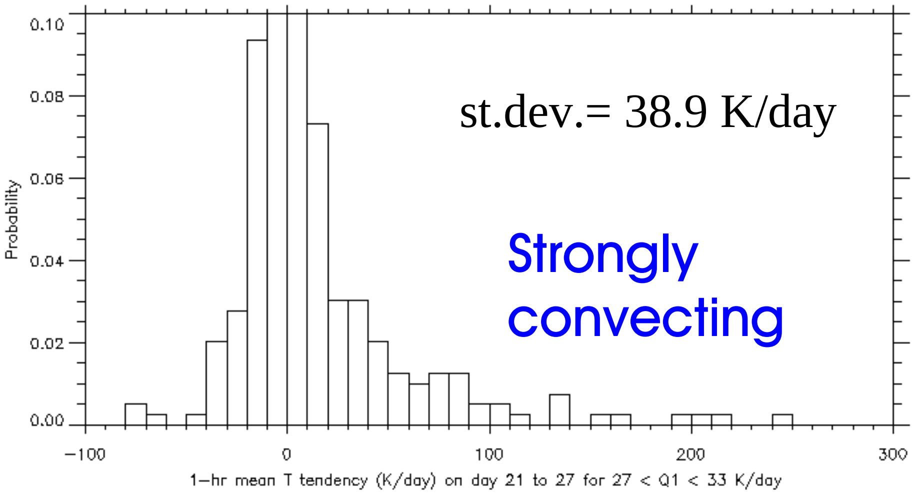
# Quantifying Model Uncertainty by T63 coarse-grain budget analysis in Cloud Resolving Model

Shutts and Palmer 2004; Palmer et al, 2005

9 < Q1 < 15 K/day




27 < Q1 < 33 K/day




pdfs from T tendency sub-samples selected according to their Q1 range .

tendency data drawn from 7 fields (each with 8192 x 128 points) at z=5 km and 24 hours apart

# Spread-Skill for Three Operational Ensemble Forecast Systems

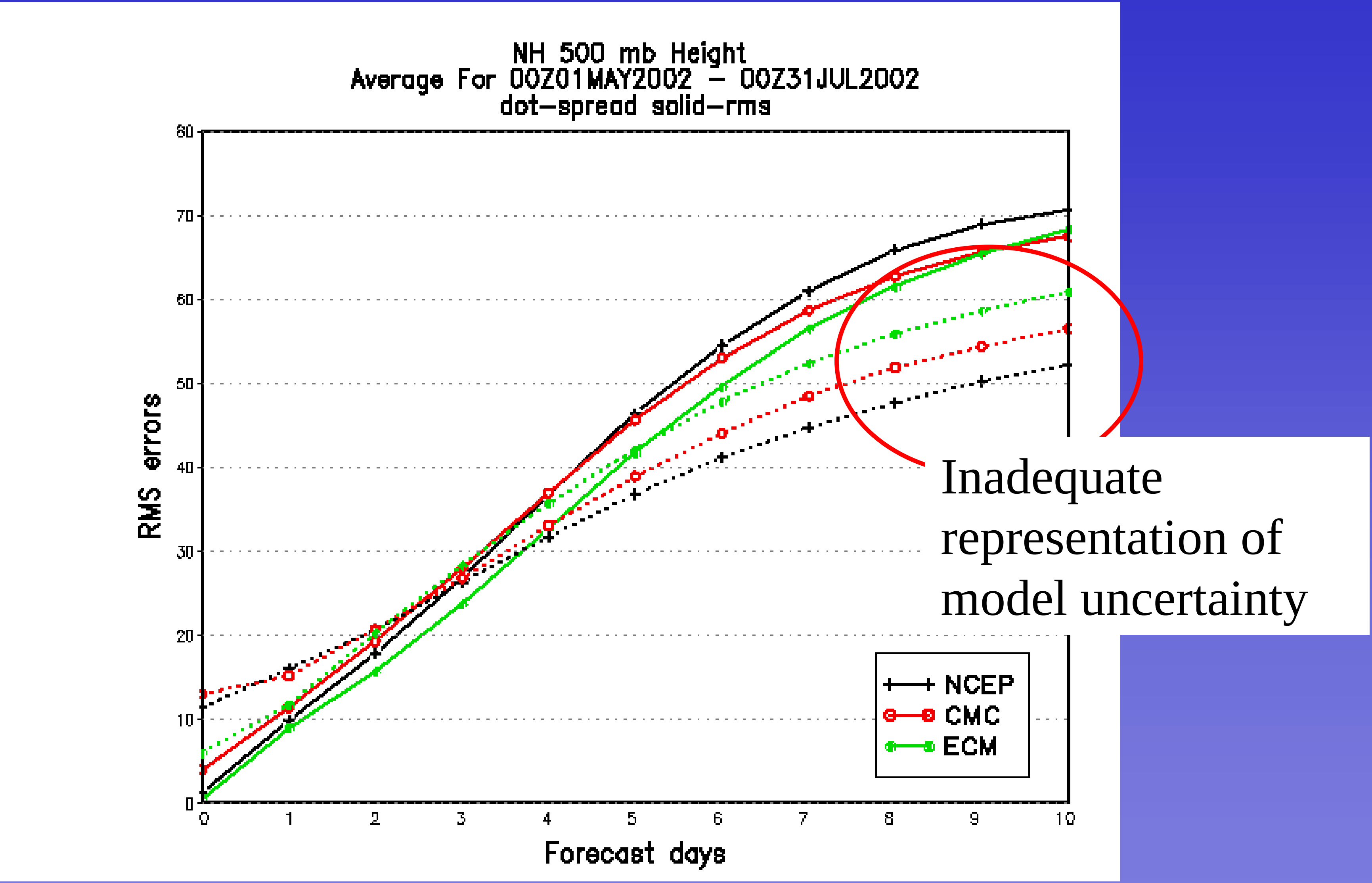
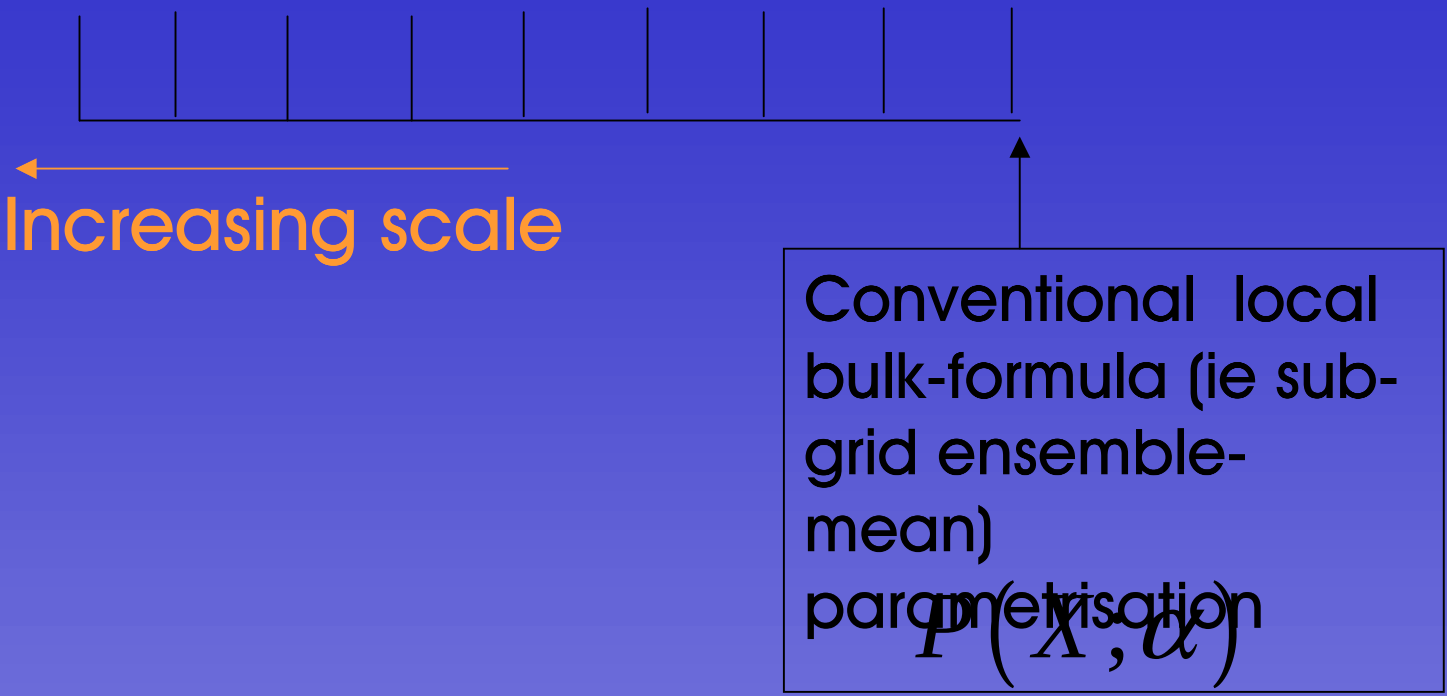



*Figure 6. May-June-July 2002 average RMS error of the ensemble-mean (solid lines) and ensemble standard deviation (dotted lines) of the EC-EPS (green lines), the MSC-EPS (red lines) and the NCEP-EPS (black lines). Values refer to the 500 hPa geopotential height over the northern hemisphere latitudinal band 20º-80ºN.*

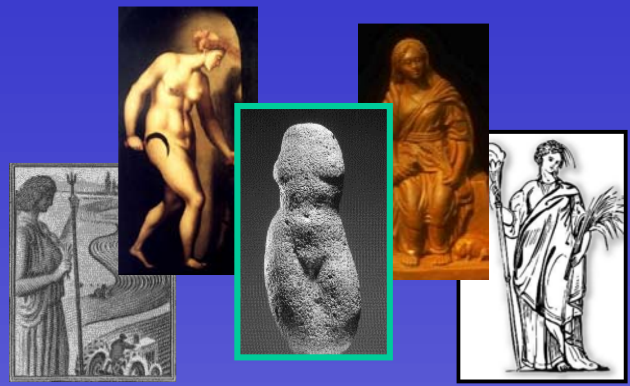
## Standard Paradigm for Comprehensive Earth-System Model




Representing model uncertainty *within* this general framework:

- Sample over different GCMs (eg DEMETER, CMIP)
- Sample over different parametrisations *P* (eg Houtekamer, 1996)
- Sample over different parameters α (eg Murphy et al, 2004; Stainforth et al 2005)

# Δημητηρ



## Development of a European Multi-Model Ensemble System for Seasonal to Interannual Prediction

# DEMETER Multi-model ensemble system

- 7 global coupled ocean-atmosphere climate models

| Partner | Atmosphere | Ocean |
|---|---|---|
| ECMWF | IFS | HOPE |
| LODYC | IFS | OPA 8.3 |
| CNRM | ARPEGE | OPA 8.1 |
| CERFACS | ARPEGE | OPA 8.3 |
| INGV | ECHAM-4 | OPA 8.2 |
| MPI | ECHAM-5 | MPI-OM1 |
| UKMO | HadCM3 | HadCM3 |

9 member ensembles

ERA-40 initial conditions

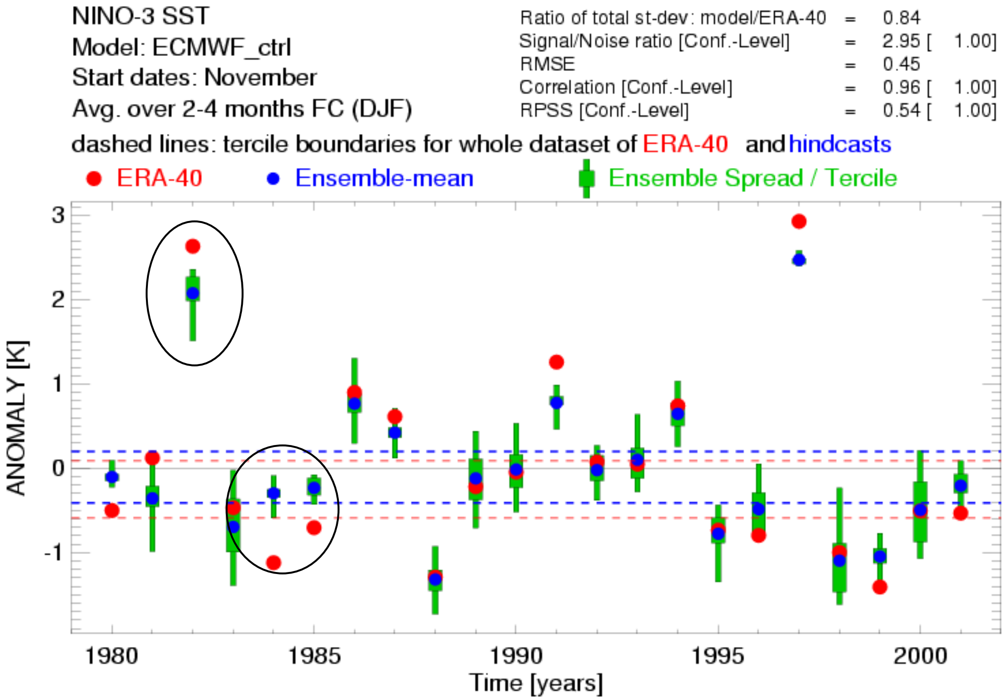
SST and wind perturbations

4 start dates per year

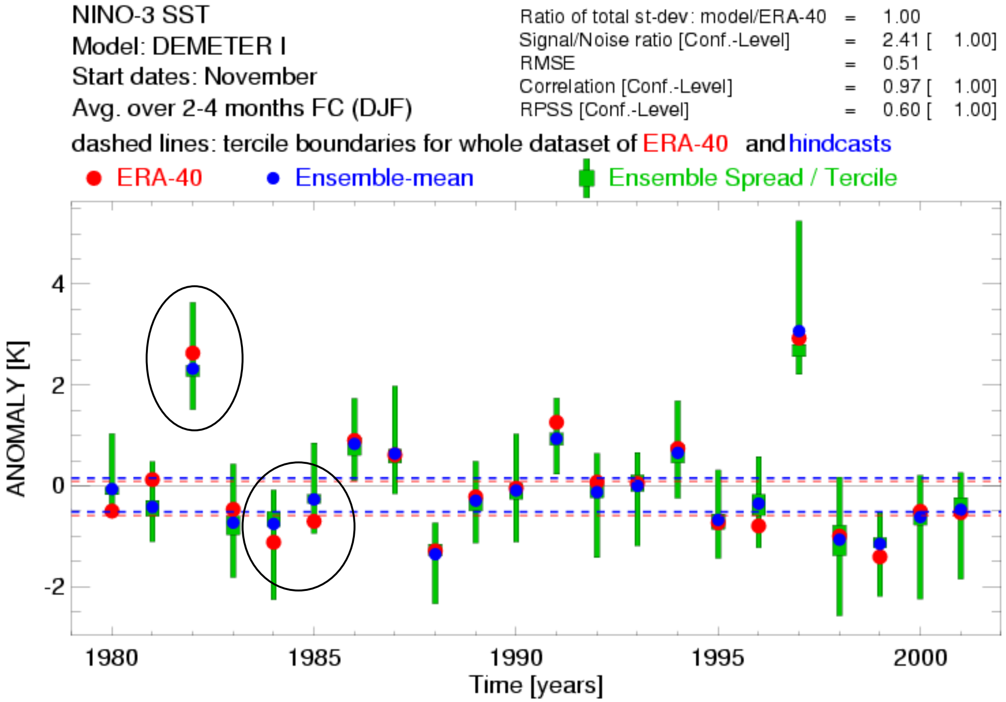
6 months hindcasts

- Hindcast production for: 1980-2001 (1958-2001)

ECMWF

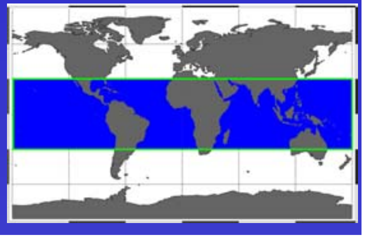


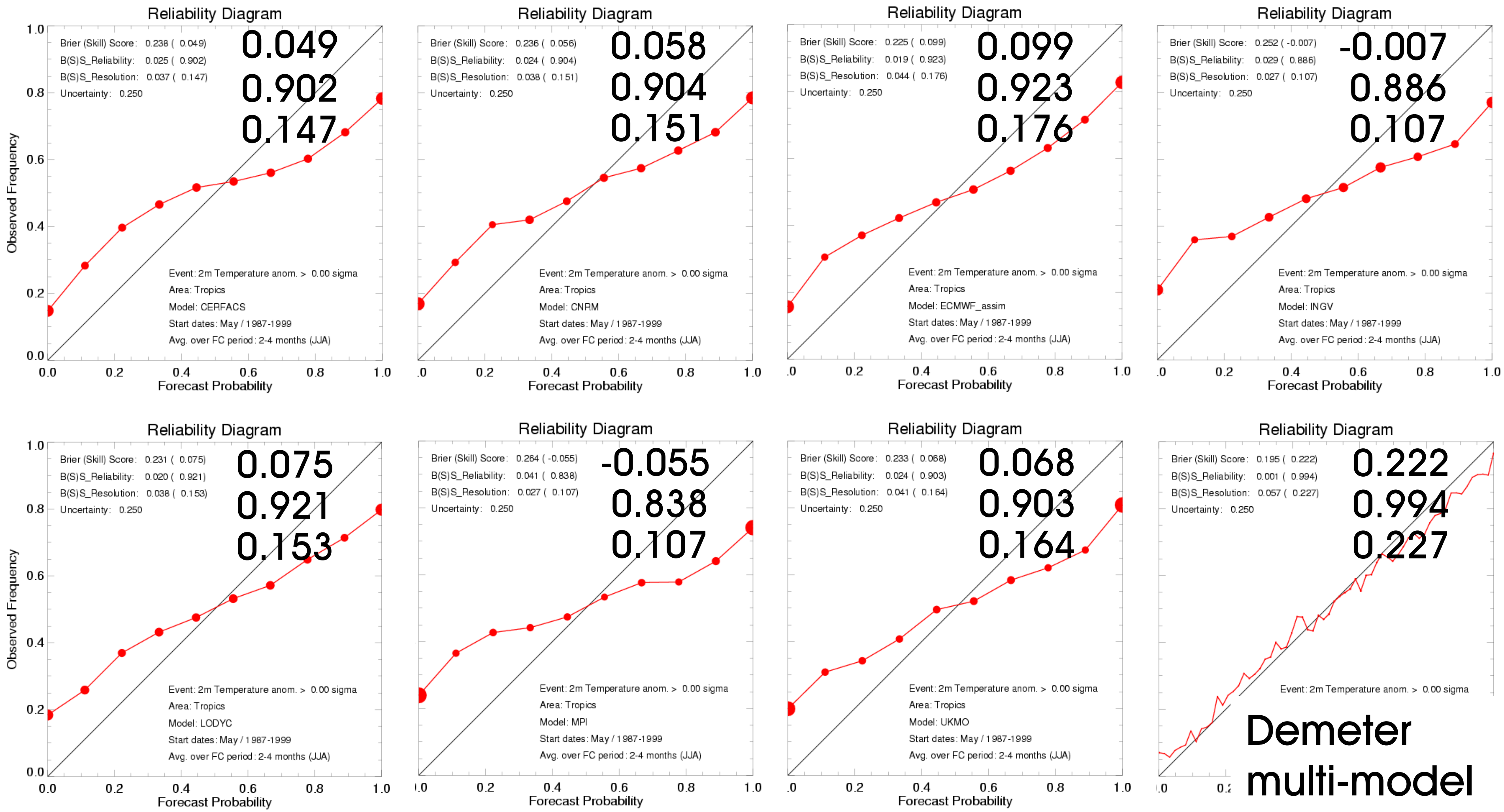

DEMETER




Palmer et al, 2004; Hagedorn et al 2005

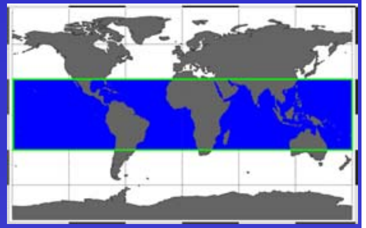
# Reliability: 2m-Temp.>0

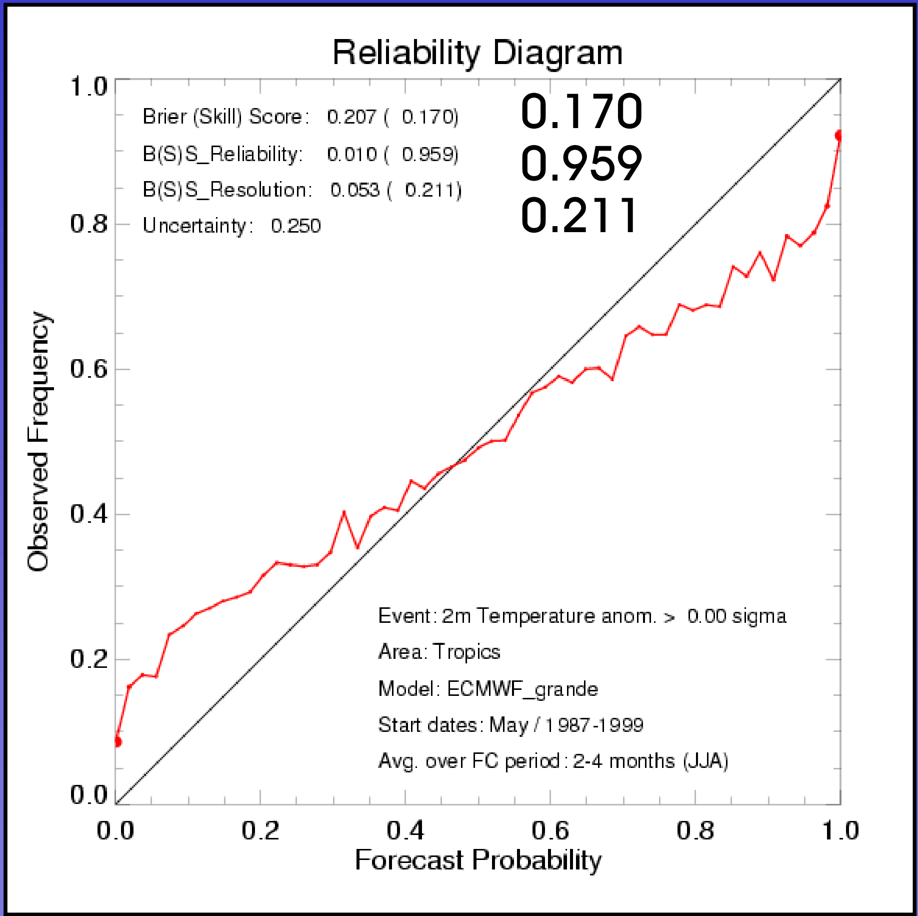




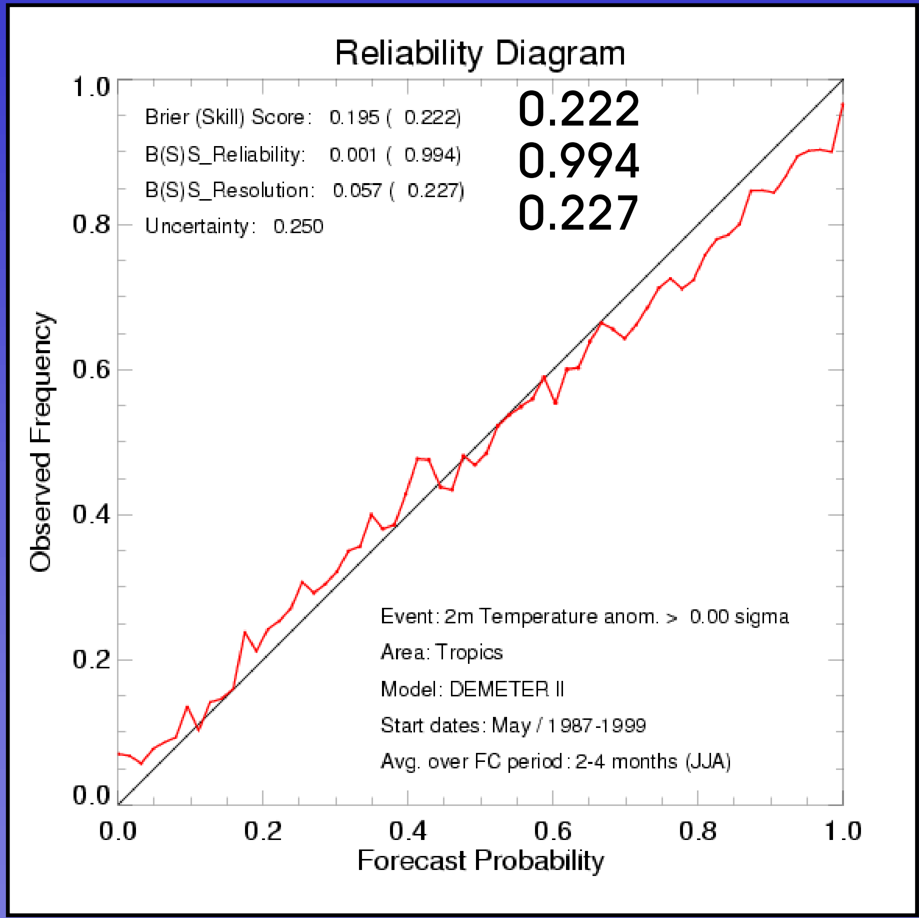

Palmer et al, 2004 BAMS; Hagedorn et al 2005 Tellus.

# Reliability: 2m-Temp.>0



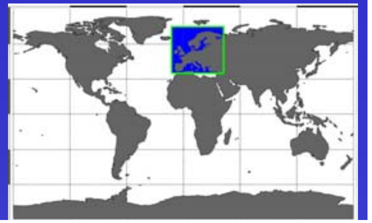


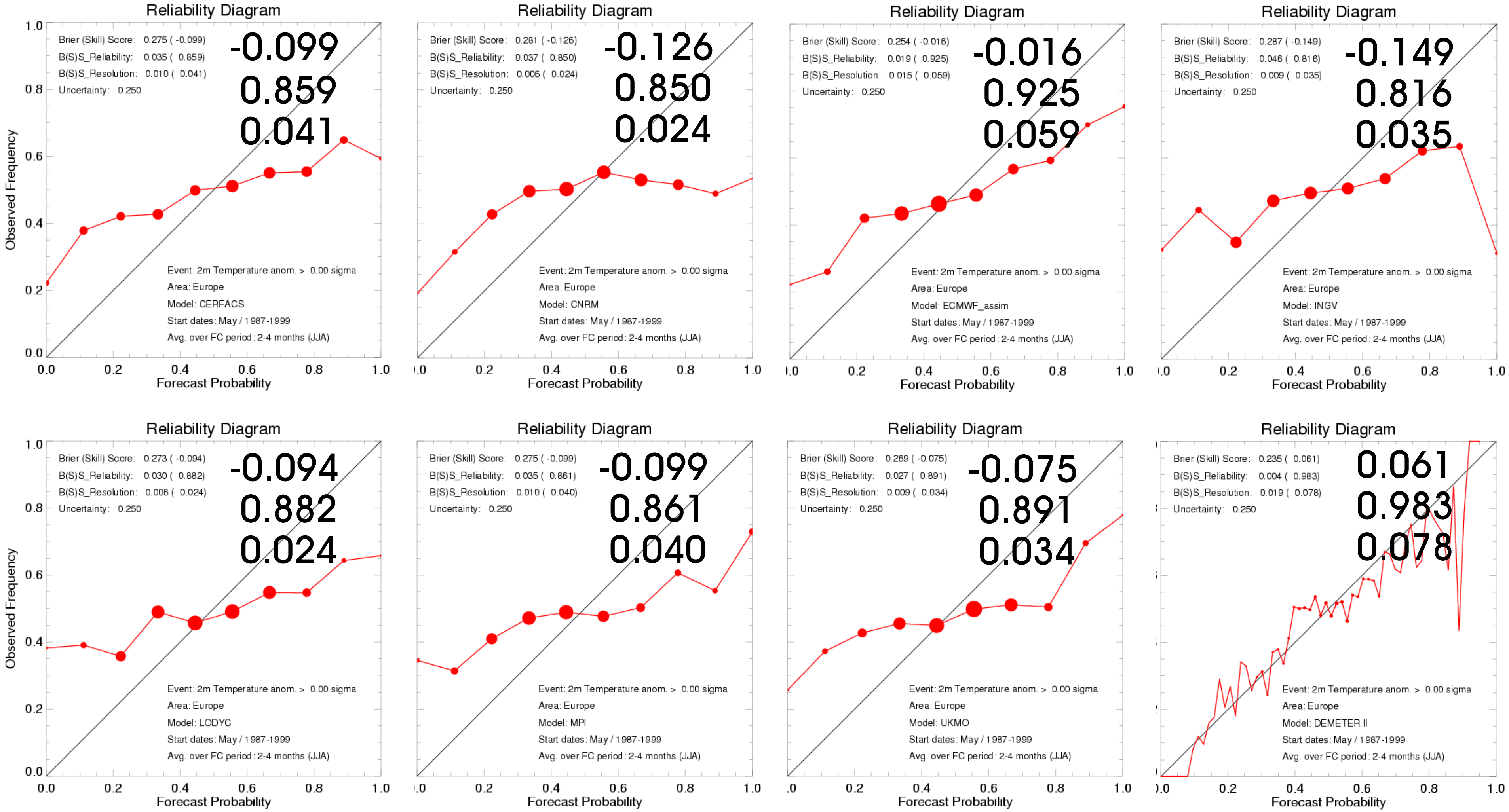

single-model (54 members)



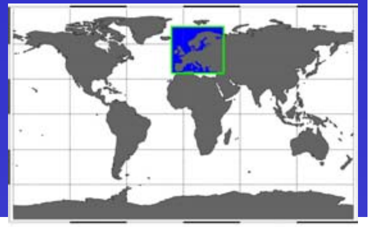

multi-model

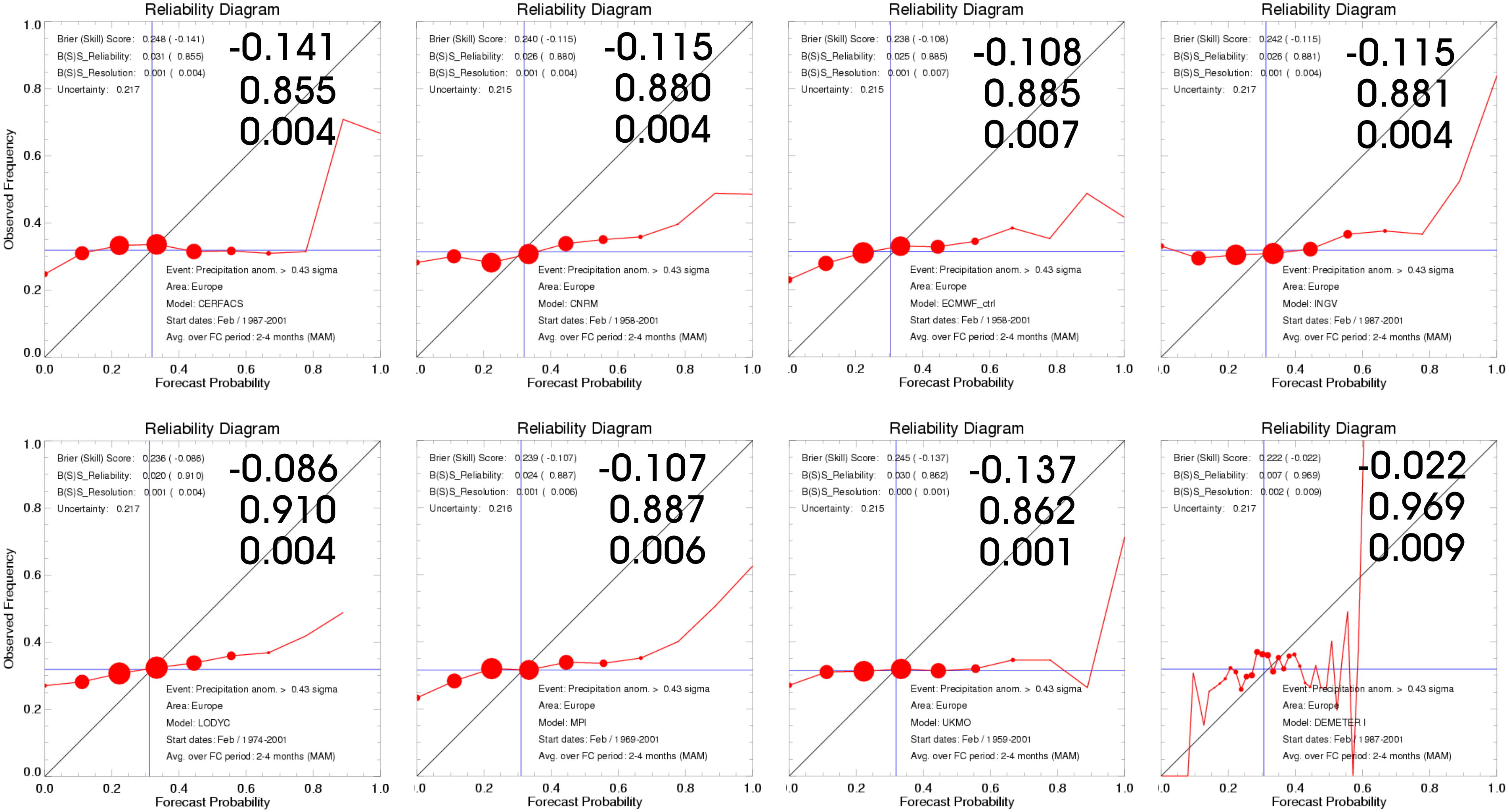
# Reliability: 2m-Temp.>0



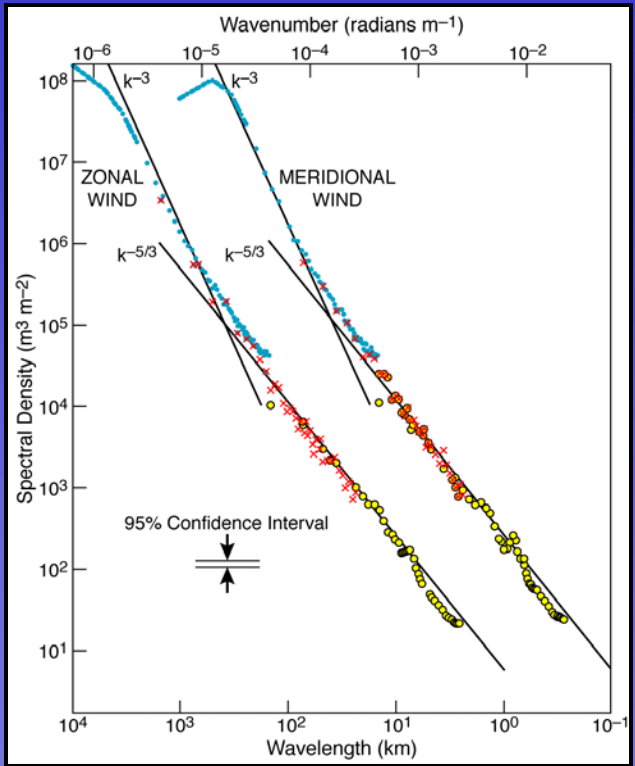


# Reliability: Precip>0.43σ

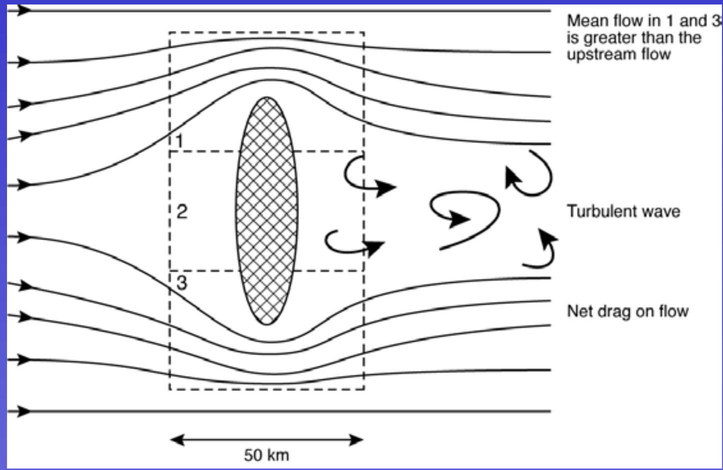


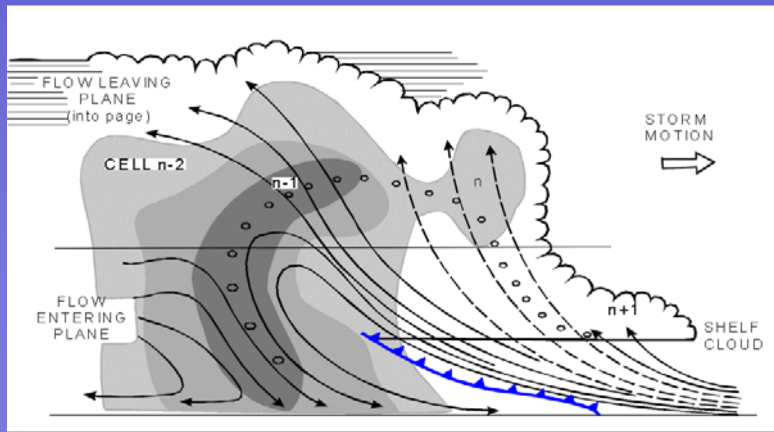


# Are there inherent shortcomings to the multi-model representation of uncertainty? Yes!

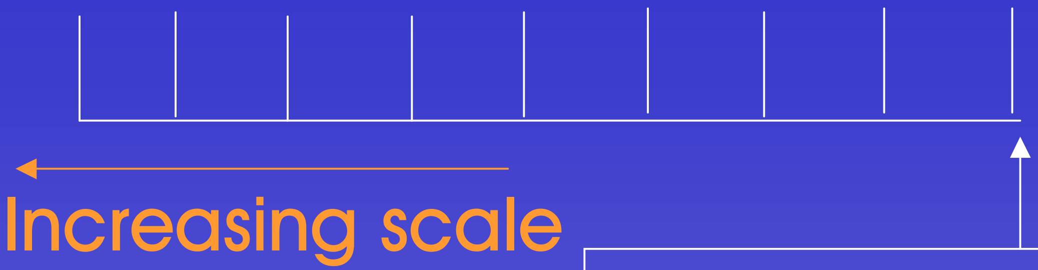



Nastrom and Gage, 1985



# Stochastic Paradigm for Comprehensive Earth-System Model




**Stochastic parametrisation**

$$P(X;\alpha,e)$$

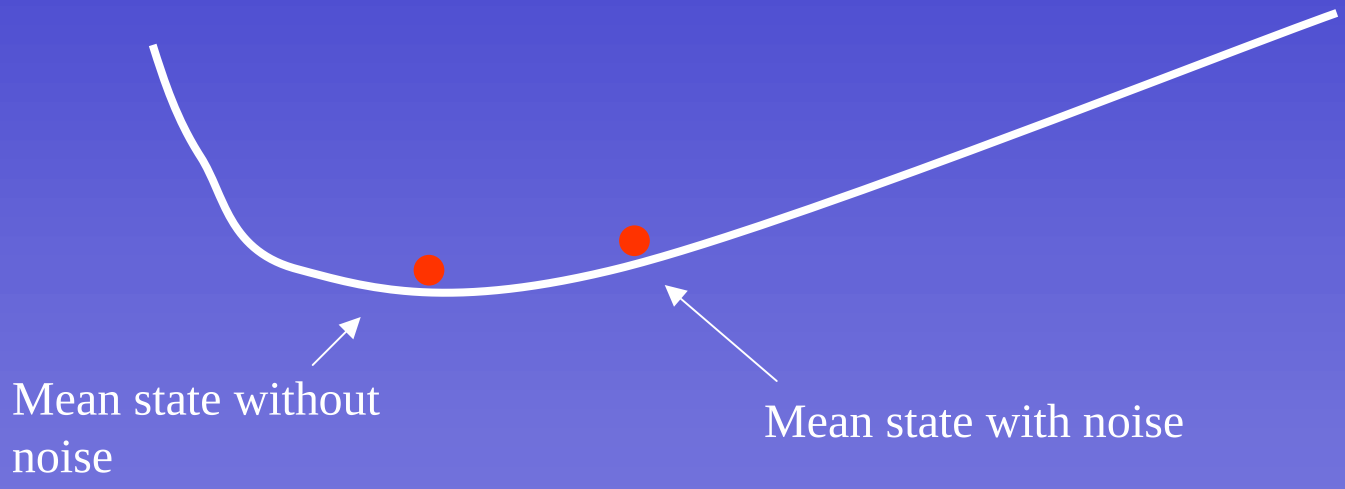
$e$ is spatio-temporally correlated stochastic noise, sampling some prescribed sub-grid PDF (eg based on a CRM).

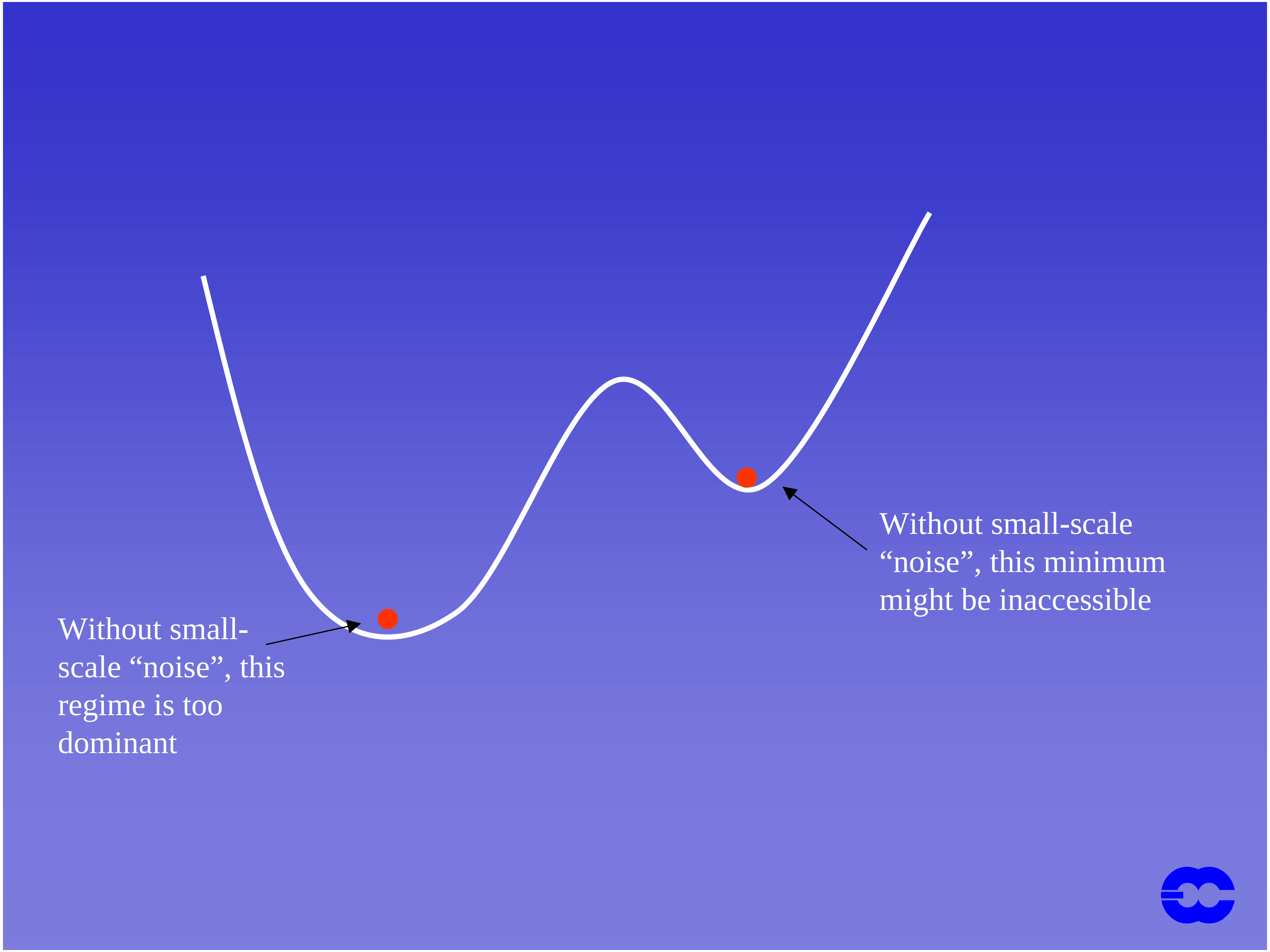
Fundamental **conceptual difference** from standard paradigm: at each timestep, stochastic parametrisation generates a specific realisation, and not the mean of some putative ensemble of sub-grid circulations.

## Possible benefits of stochastic parametrisation:

- More complete representation of model uncertainty
- Reduction in model systematic error (noise-induced drift)
- More accurate estimate of internal climate variability (cf detection/attribution studies)

# Could stochastically sampling the probability distribution of the sub-grid tendency, rather than always sampling the mode of the distribution, make a difference?




Without small-scale "noise", this minimum might be inaccessible
Without small-scale "noise", this regime is too dominant

# ECMWF Stochastic Physics Scheme

$$\dot{X} = D + P + e$$

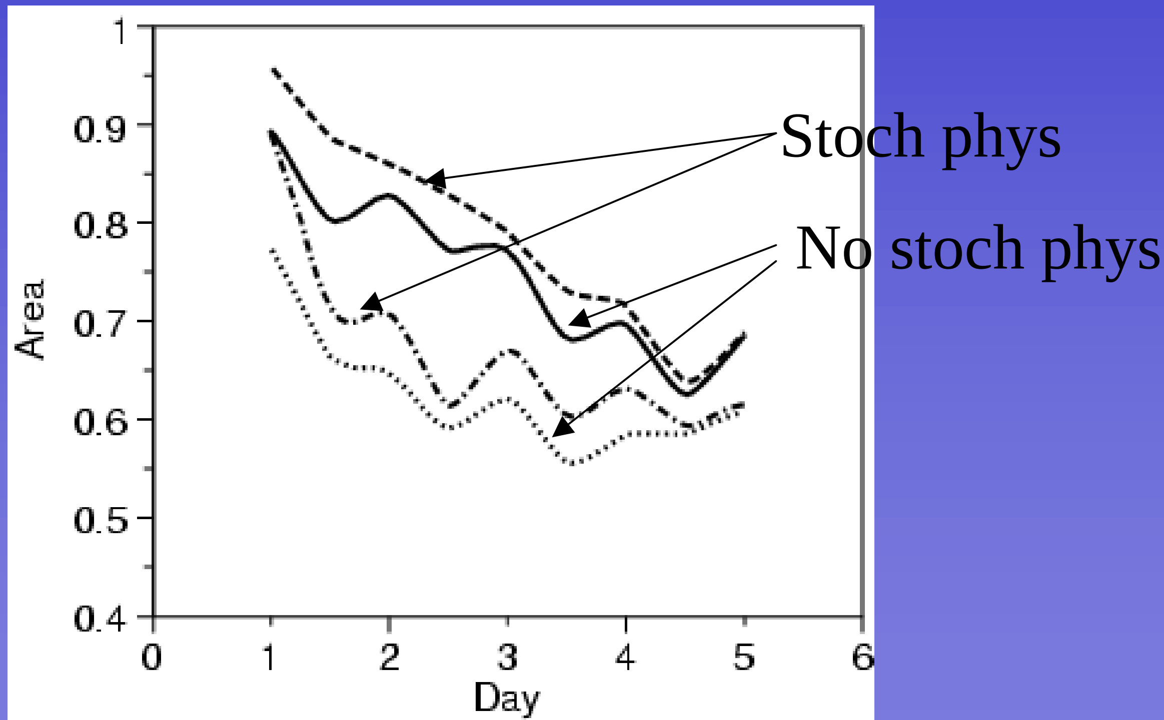
$$e = \varepsilon P$$

Buizza, Miller and Palmer, 1999; Palmer 2001

- ε is a stochastic variable, drawn from a uniform distribution in [-0.5, 0.5], constant over time intervals of 6hrs and over 10x10 lat/long boxes
- Multiplicative form of noise consistent with coarse-grained budget analysis from cloud-resolved model.

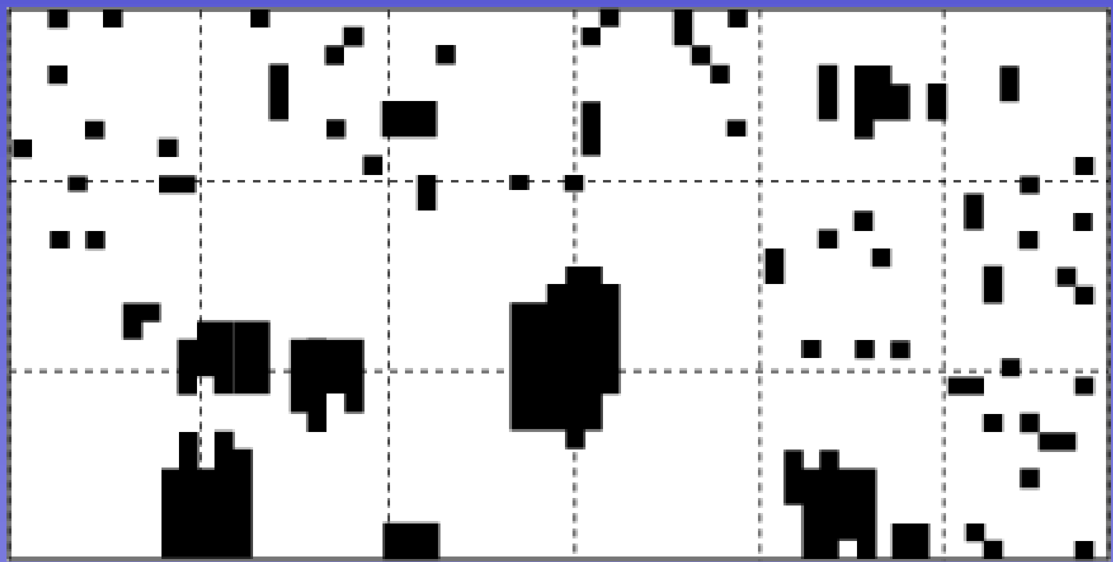
# Stochastic Physics has a positive impact on medium-range EPS skill

Area under ROC curve. E: precip>40mm/day.
Winter- top curves. Summer – bottom curves



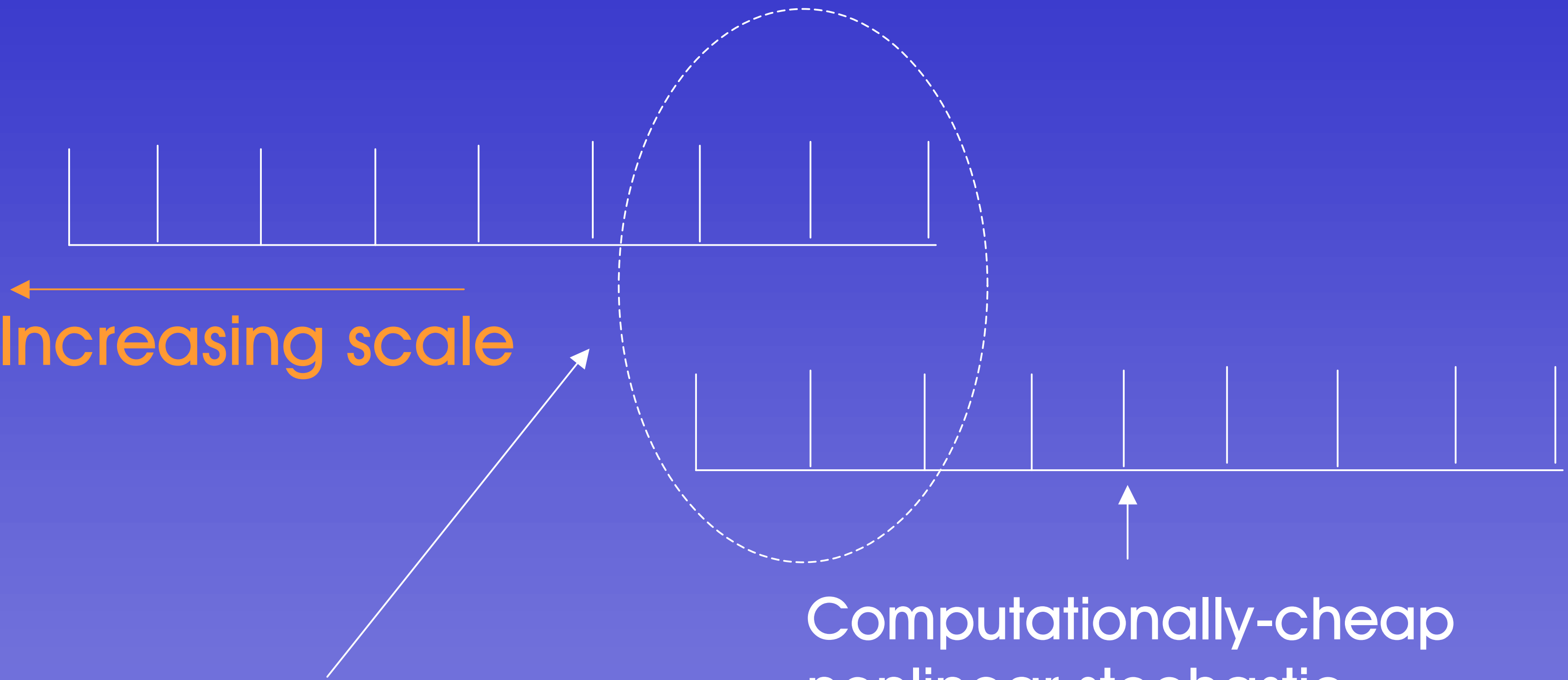

Buizza et al, 1999

Instead of “pure” stochastic forcing, consider a stochastic-dynamic representation of subgridscale – eg cellular automaton (Wolfram 2002) – can represent both chaotic (stochastic) and coherent (eg soliton, wave-like) processes.



Palmer (2001)

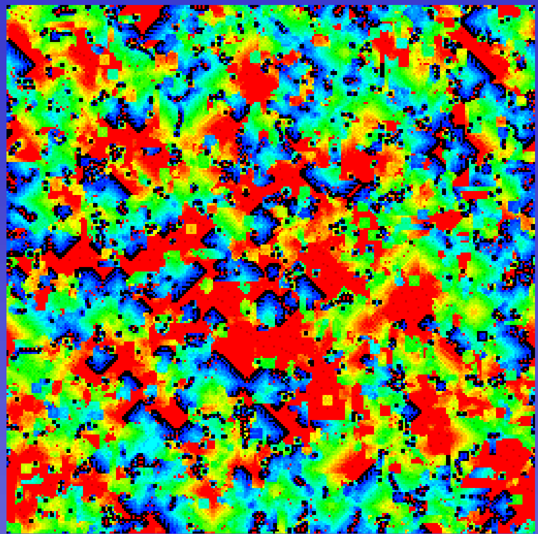
# A stochastic-dynamic paradigm for Earth-System Models




Coupled over a range of scales

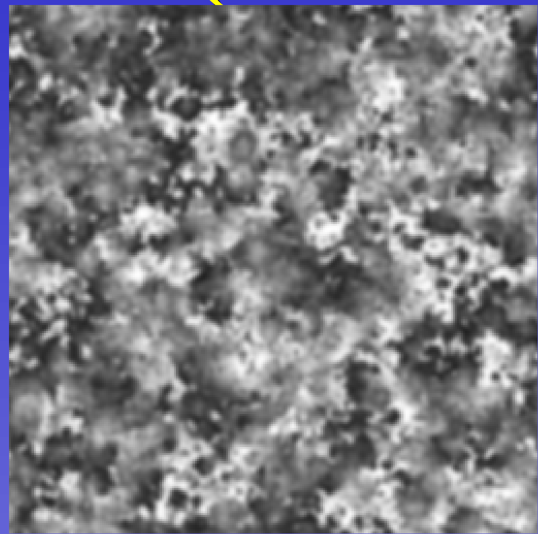
Computationally-cheap nonlinear stochastic-dynamic model, providing specific realisations of sub-grid motions rather than ensemble-mean sub-grid effects

# Cellular Automaton Stochastic Backscatter Scheme (CASBS)



smooth

scale



Cellular Automaton state

streamfunction forcing shape $\Psi$ function

$$\frac{\partial \psi}{\partial t} = \alpha \cdot \Psi(x, y) \cdot \sqrt{\mathrm{D}}$$

D = sub-grid energy dissipation due to numerical diffusion, mountain drag and convection

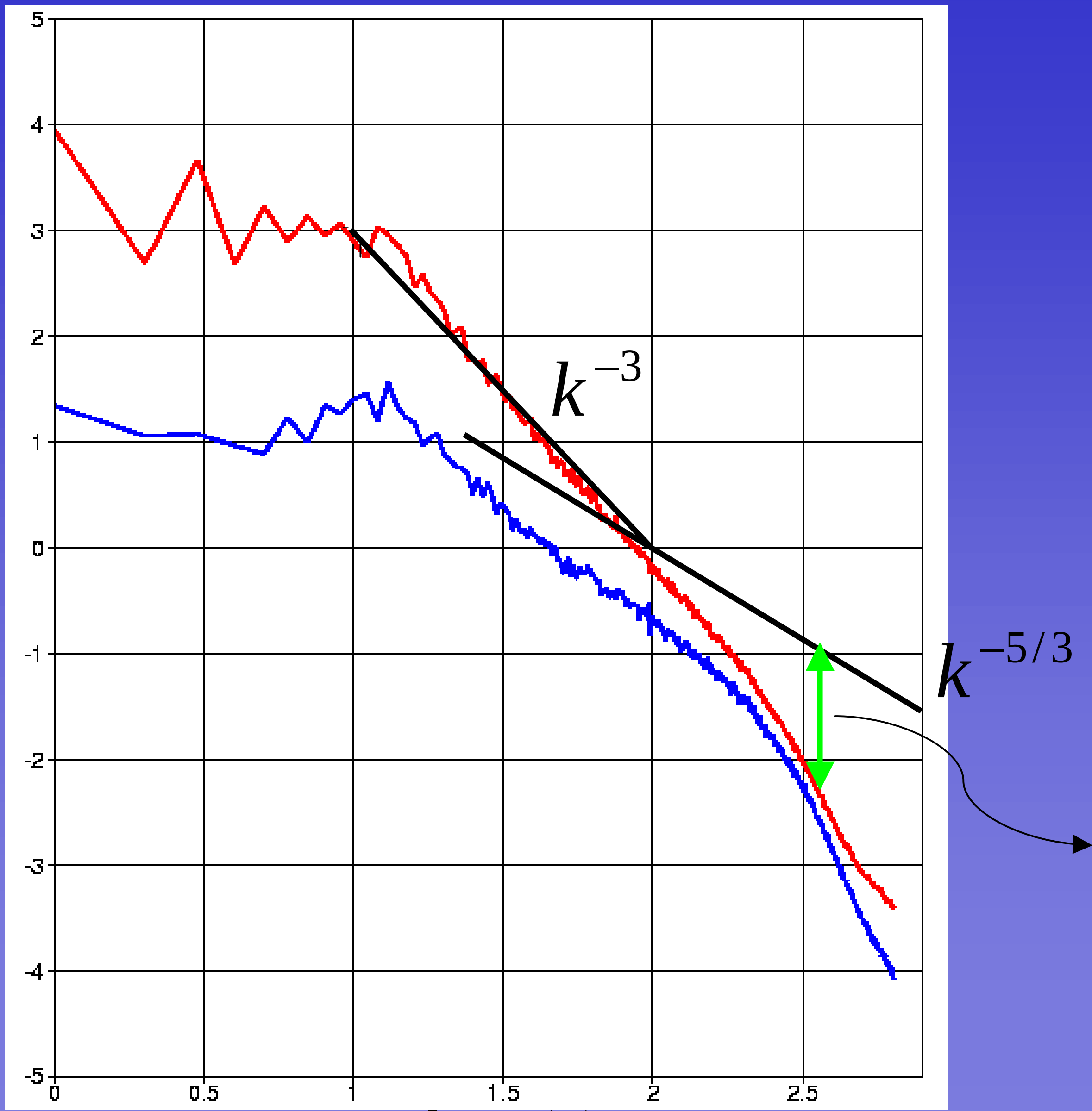
$\alpha$ = dimensional parameter

G.Shutts, ECMWF Tech Memo

# Energy spectrum in 5-day T799 run

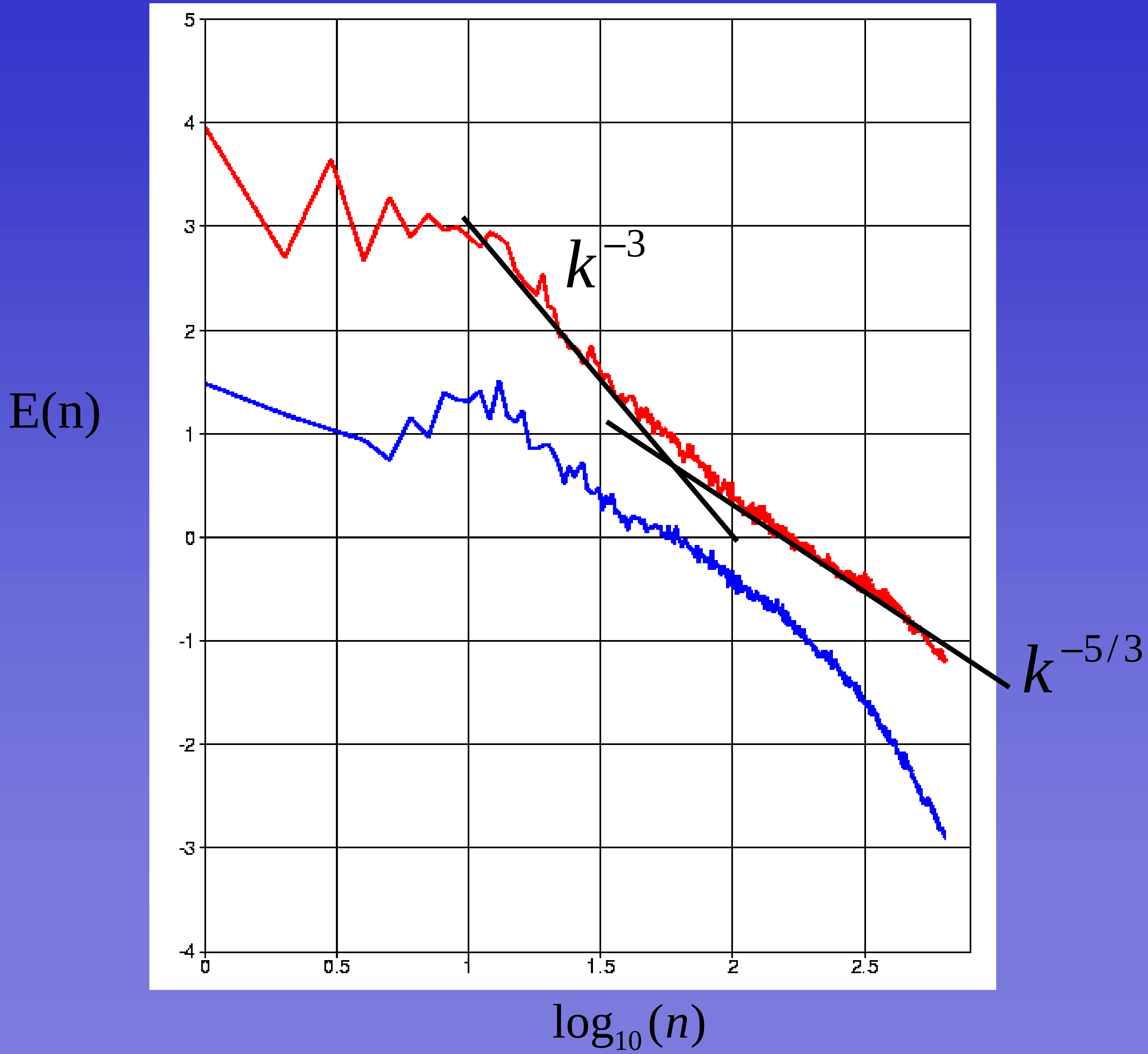
E(n)

**n = spherical harmonic order**




$\log_{10}(n)$

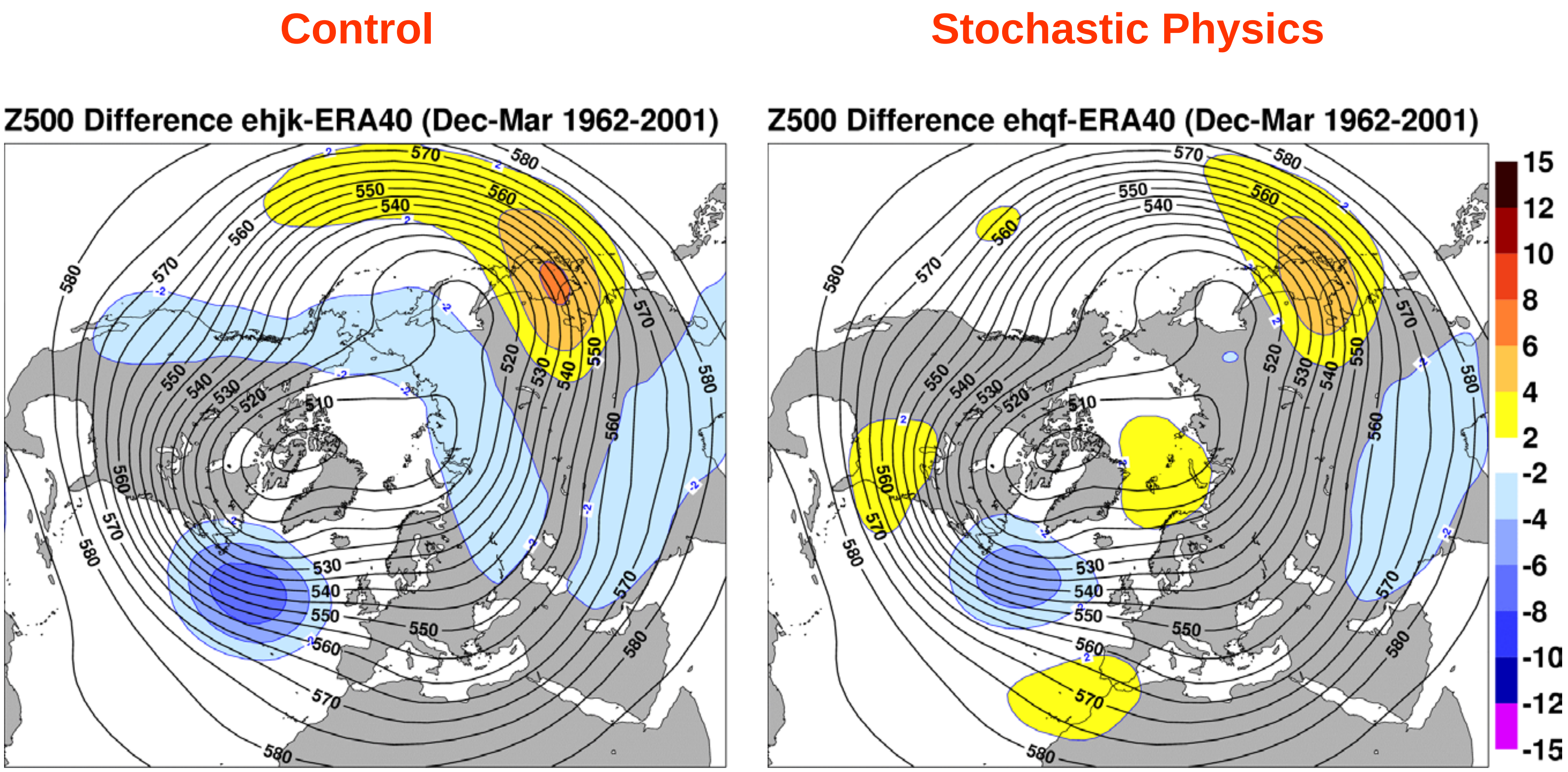
# Energy spectrum in 5-day T799 run with CASBS



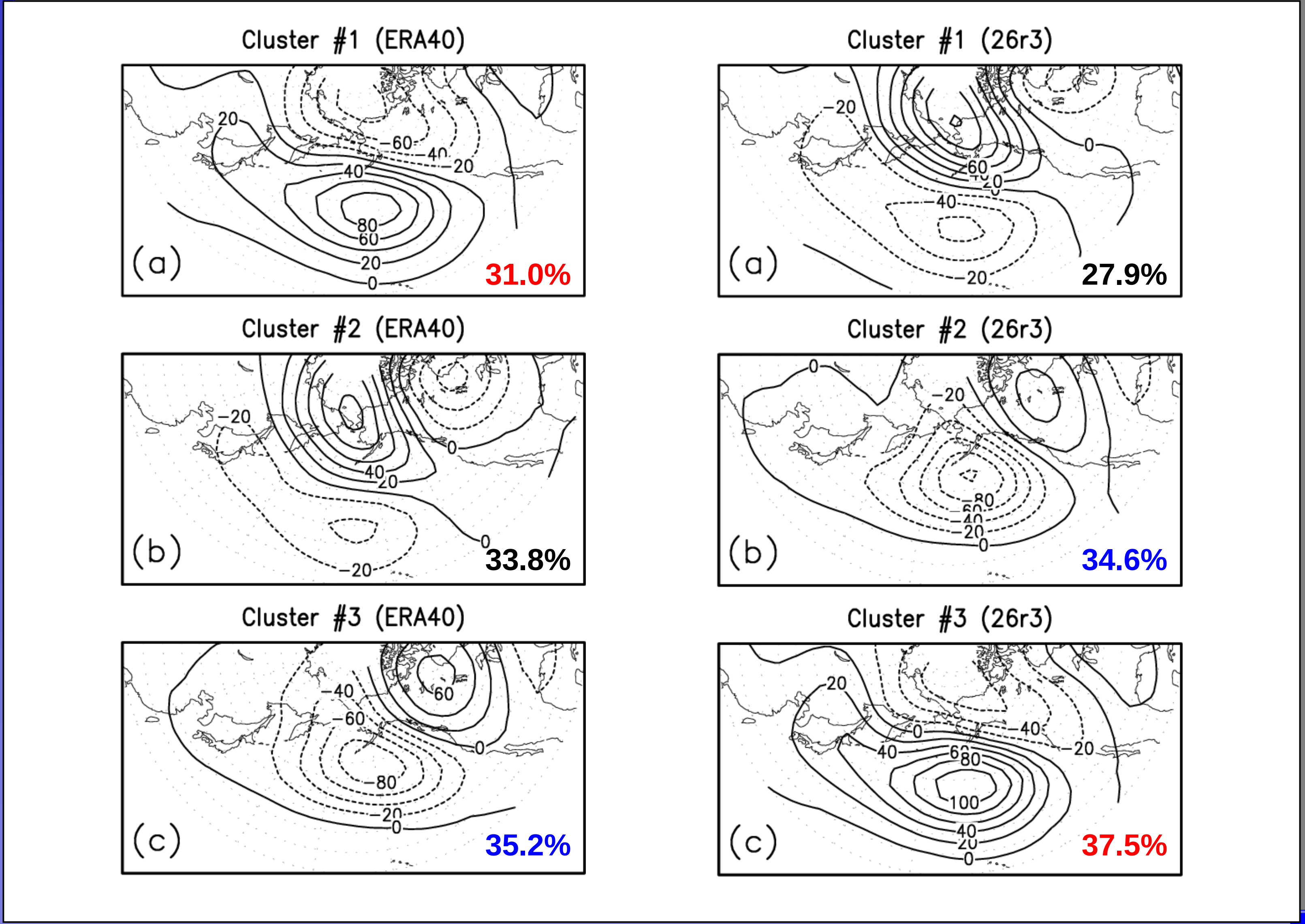
# Model Integrations

- 6 month runs from 1 October 1962-2001
- Cy26r3 TL95L60 atmosphere only (with and without CASBS)
- Analysis on DJFM

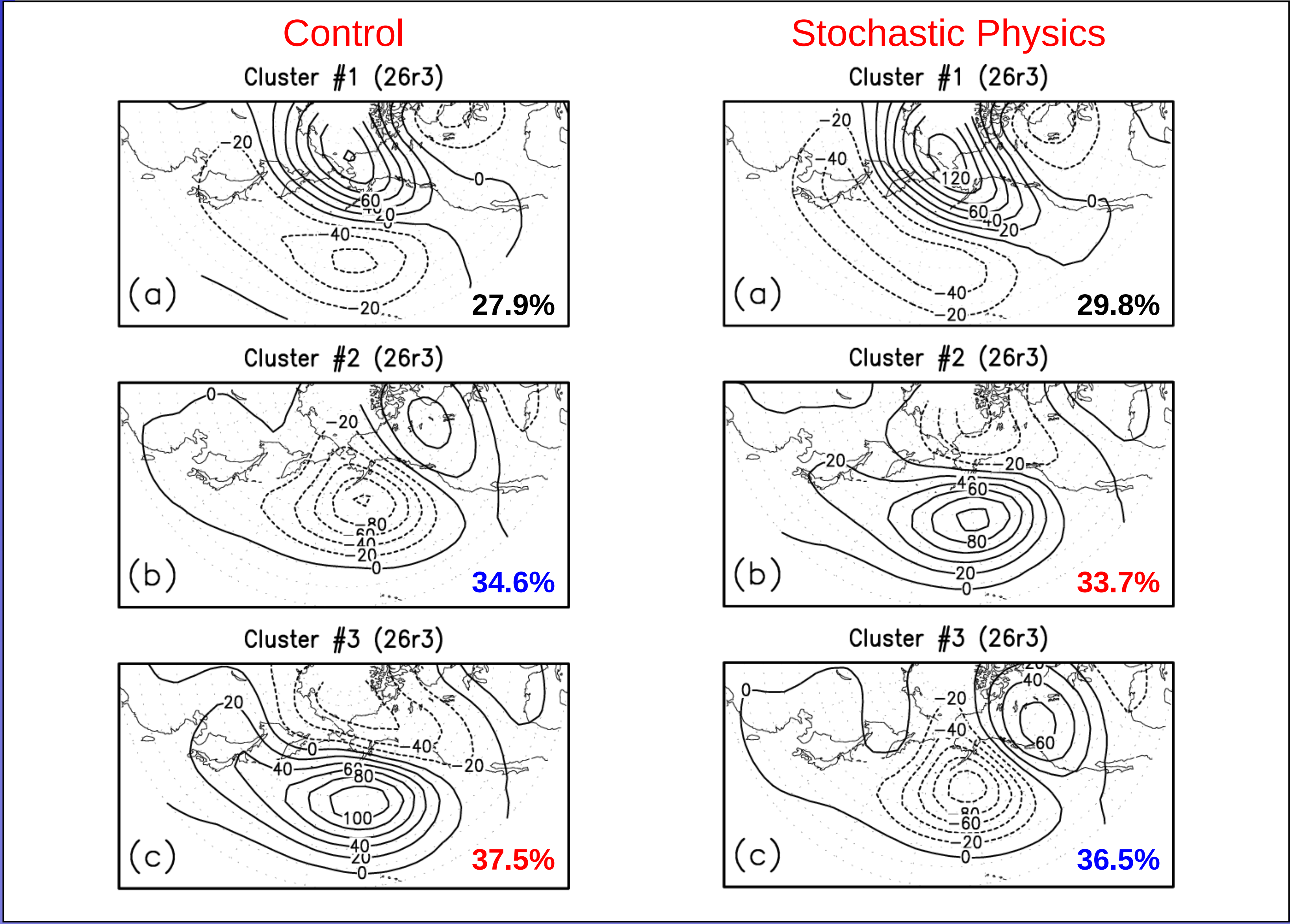
# Systematic Z500 Error



# Weather Regimes: ERA-40 vs control



# Weather Regimes: Impact of Stochastic Physics



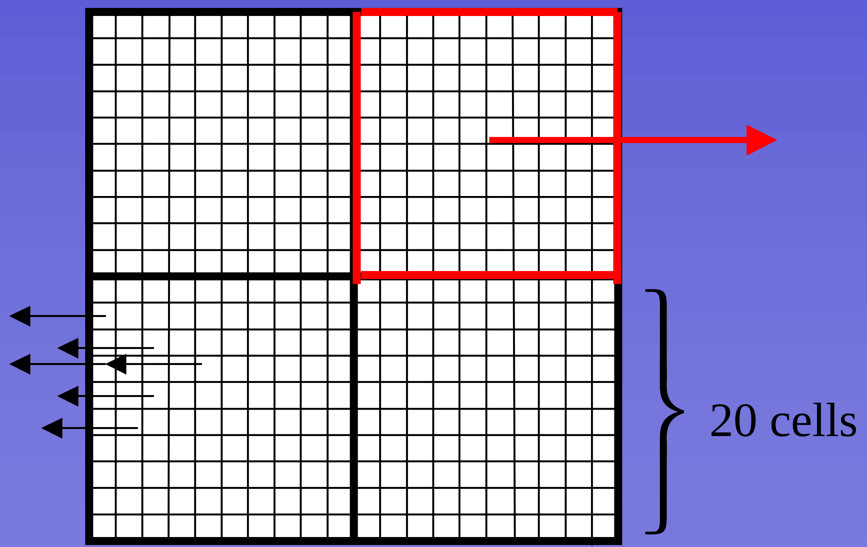
Develop the CA rules to incorporate meteorology. For example

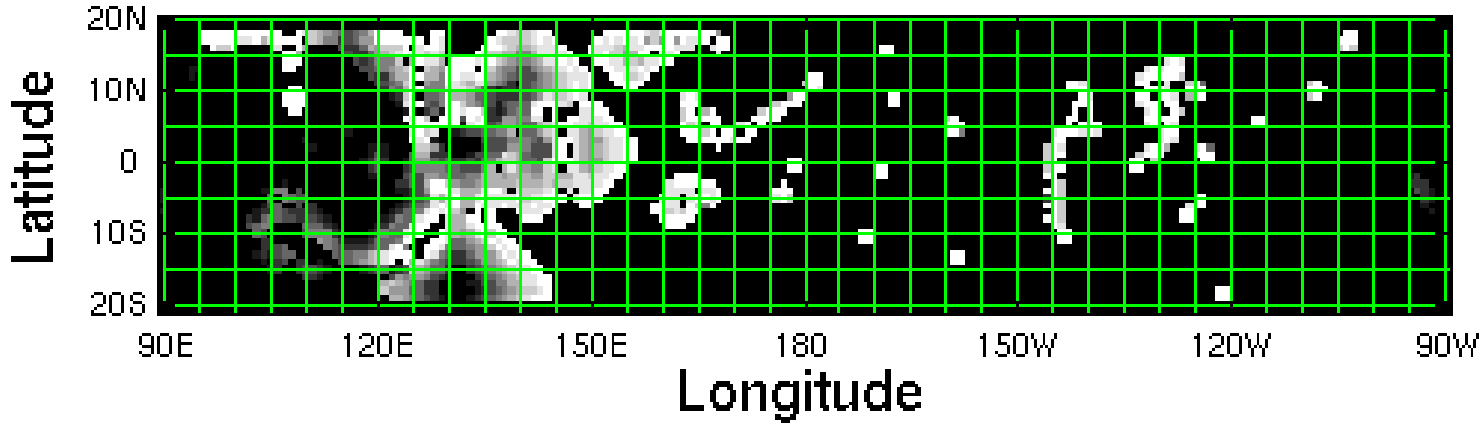
- Agglomerations (organised convection) have larger probability of continued life
- Advection of individual on-cells by trade wind (through grid-box boundaries)
- Eastward propagation of “probability waves” coupled to on-state cells (cf moist Kelvin-wave dynamics; MJO)

# Multiscale-CA

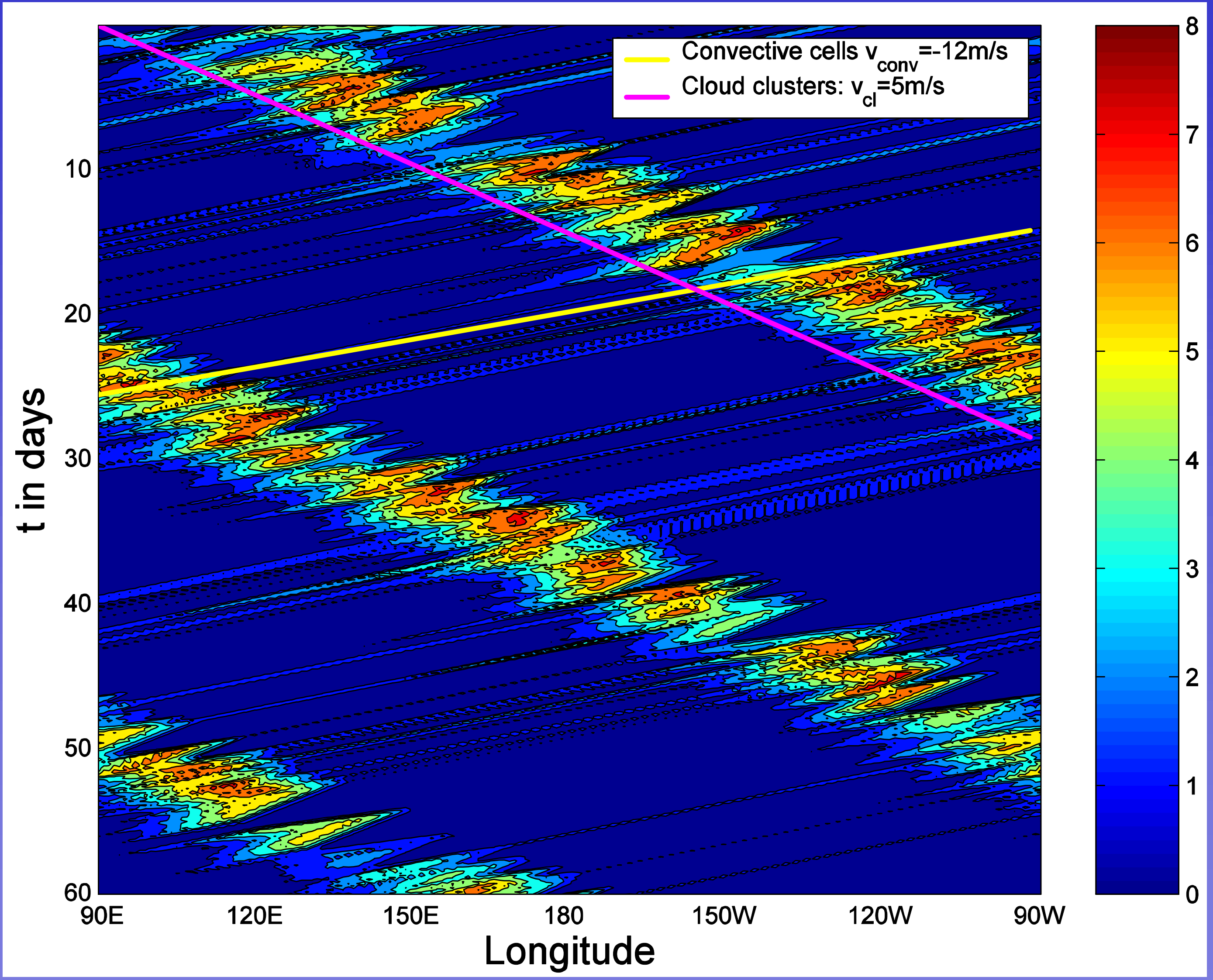
- Small-scale cells evolve according to rules and propagate/advect to the west
- Intermediate-scale cells can be on/off and propagate to the east
- Fertile cells in small-scale CA can only be born if intermediate-scale cell is ‘on’

Sketch




20N
10N
0
10S
20S
Latitude
90E
120E
150E
180
150W
120W
90W
Longitude

# Hovmöller diagram



# ENSEMBLES

**(EU-FP6 Integrated Project, Successor of DEMETER)**

Inter-compare performance of:

- Multi-model;
- Perturbed parameter;
- Stochastic-dynamic parametrisation;

in coordinated seasonal and decadal timescale integrations.

ENSEMBLES will provide substantial input into the new WCRP COPES (Coordinated Observation and Prediction of the Earth System) initiative.

# CONCLUSIONS and FUTURE DIRECTIONS

- Representing model uncertainty is still at a primitive stage. Much important work could be done, eg by analysis of coarse-grained budgets from cloud-resolving models.

- A study intercomparing different representations of model uncertainty:

    - Multi-model ensembles

    - Multi-parameter ensembles

    - Stochastic parametrisation

could/should be undertaken for 15-day forecast timescales under TIGGE auspices ("THORPEX meets COPES").