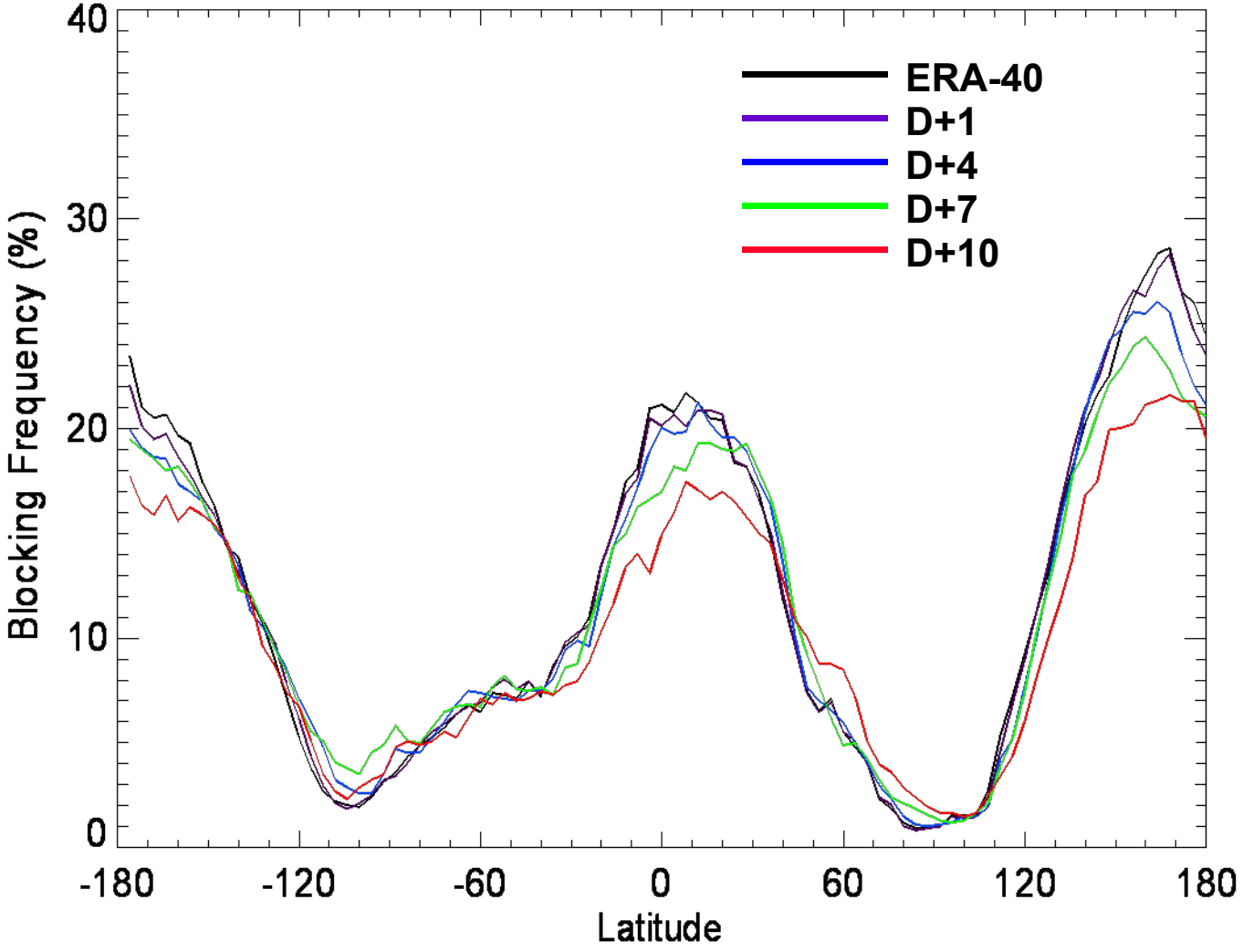
Diagnosing Remote Origins of Forecast Error Using Relaxation Experiments

Thomas Jung

ECMWF

Acknowledgements: Tim Palmer, Mark Rodwell, Martin Miller and Soumia Serrar

Blocking Frequency Errors (31R2)



DJF 1990-2001

ECMWF

Outline

- Different applications of the relaxation technique
- Medium-range and monthly predictability
- Seasonal mean circulation anomalies
  - Origin of the anomalously cold European winter of 2005/06

The Ultimate Goal

ECMWF 10 Year Strategy (2006-2015)

"The principal goal of ECMWF in the coming ten years will be to maintain the current, rapid rate of improvement of its global, medium-range weather forecasting products, with particular effort on early warnings of severe weather...

Complementary goals are:
...
To improve the quality and scope of monthly and seasonal-to-interannual forecasts
..."

Crucial Questions

- Where should we invest our resources in forecasting system development?
- How much emphasis should we put, for example, on the tropics compared to the extratropics?
- Here we use the relaxation technique to address these questions.

Strategy

- Choose a region (e.g. tropics)
- During the forecast suppress the development of forecast error in this region artificially.
- See what the impact is elsewhere (e.g. Europe)

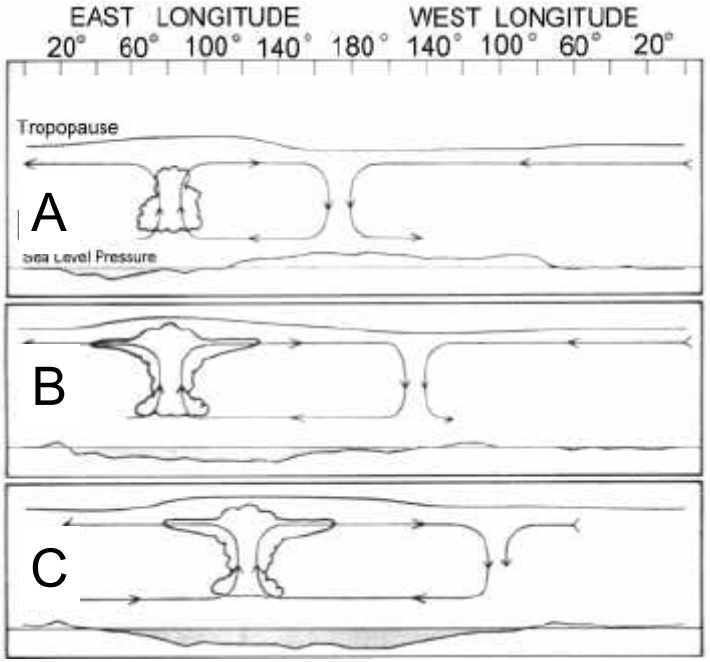
$$\frac{\partial \mathbf{x}}{\partial t} = G(\mathbf{x}) - \lambda(\mathbf{x} - \mathbf{x}^{ref})$$

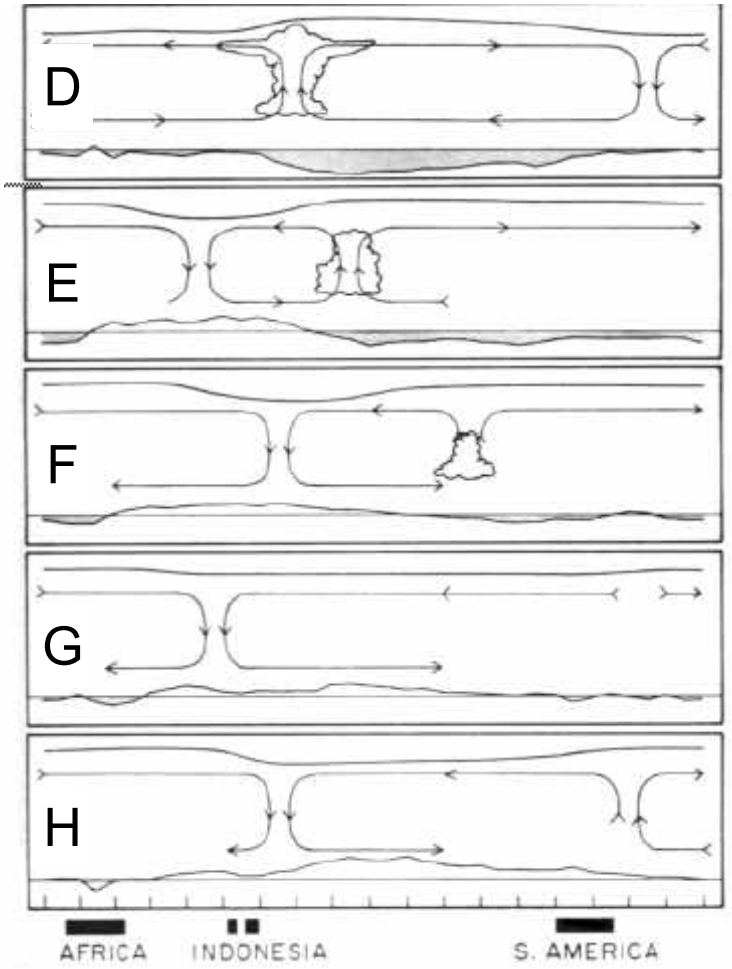
- Not a new approach (e.g., work in the late 1980s at ECMWF)
- More powerful computers
- Much more realistic analyses
- Other applications

Criteria for Forecast-Relevant Regions

- Criteria for possible forecast-relevant regions:
  - Should have influences on our region of interest.
  - Should potentially possess predictability.
  - Should be relatively poorly represented by state-of-the art models (→ room for improvement)
- Remote regions considered here:
  - Tropics, stratosphere and North Pacific

The Madden-Julian Oscillation

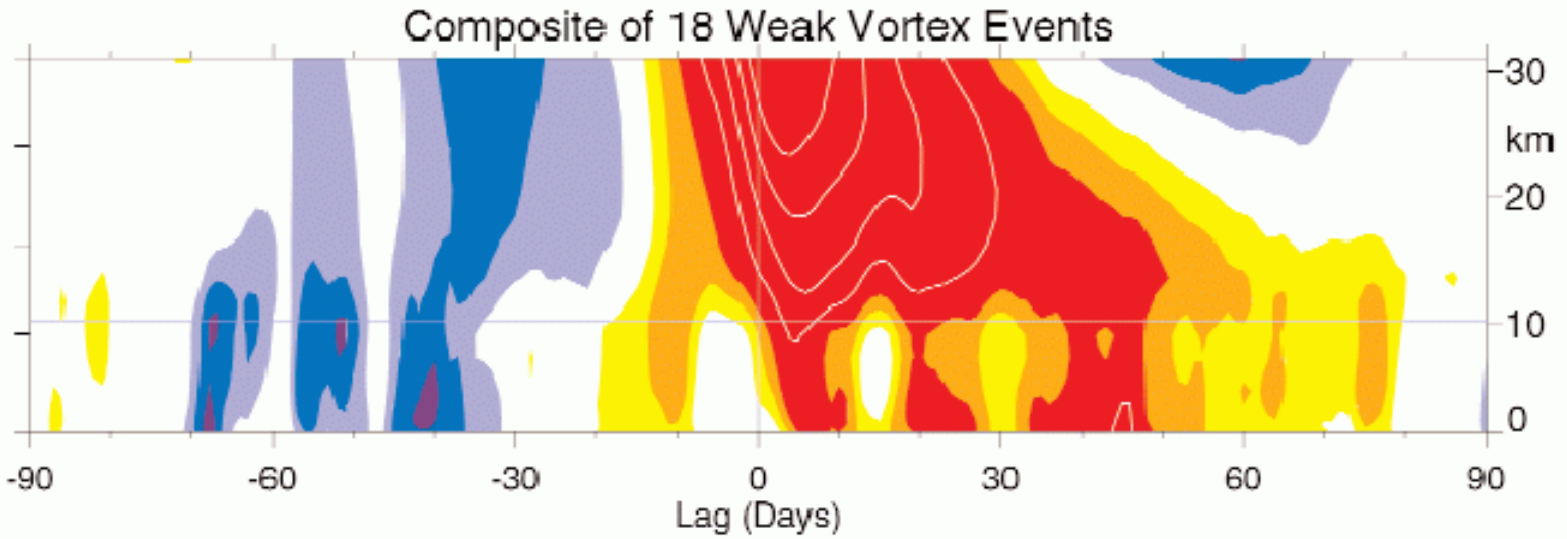




- **Low-frequency, quasi-periodic**
- **Teleconnections**
- **Key-aspects poorly represented by models**

From Madden and Julian (1994)

The Stratosphere-Troposphere Link



Weather from above. A weakening stratospheric vortex (red) can alter circulation down to the surface, bringing storms and cold weather farther south than usual.

- **Low-frequency**
- **Some models do have problems.**

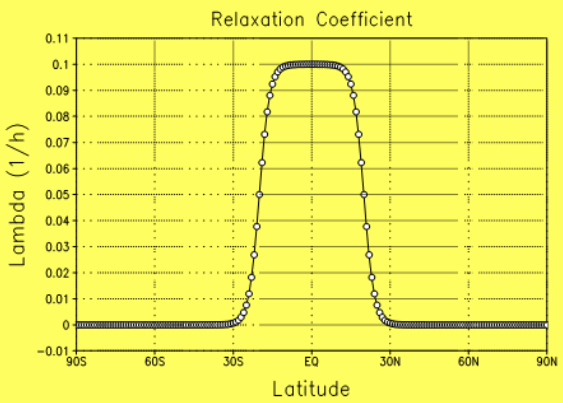
Baldwin and Dunkerton (2001)

Relaxation Formulation: Details

- No relaxation (control integration)
- Relaxation regions
  - Tropics
  - Northern Hemisphere stratosphere
  - North Pacific
- Relaxation in grid point space
  - T, u, v (and $\ln p_s$)

$$\frac{\partial \mathbf{x}}{\partial t} = G(\mathbf{x}) - \lambda(\mathbf{x} - \mathbf{x}^{ref})$$

Localization



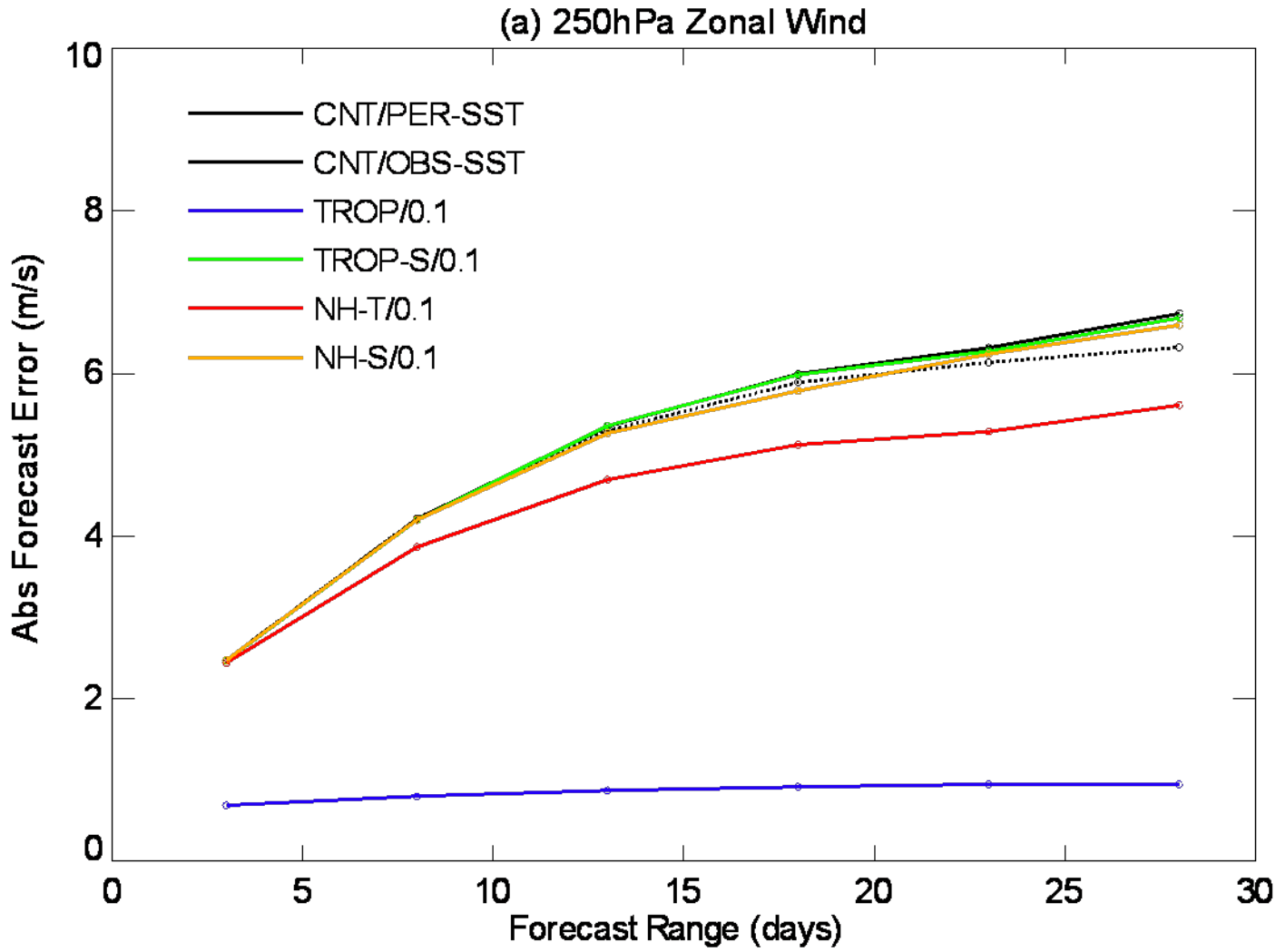
Experimental Setup

- Model cycle 32R1 (5/06–5/11 2007)
- T_L159 (125 km) with 60 levels in the vertical
- 88 30-day forecasts (15th of Nov, Dec, Jan and Feb 1980/81-2000/01)
- Initial/boundary conditions: ERA-40 (T_L159L60)

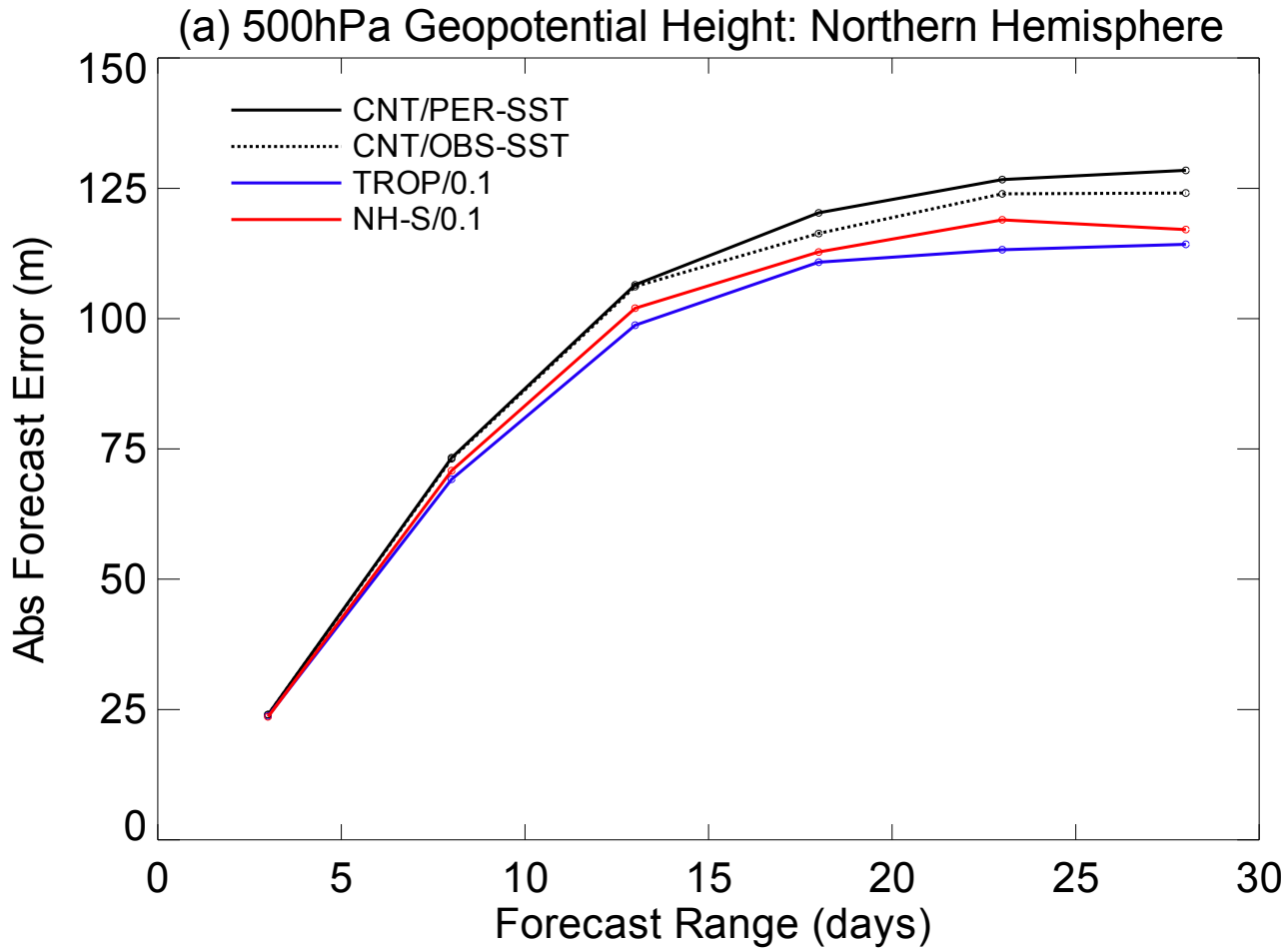
- Control experiments
  - persisted SST/sea ice
  - observed SST/sea ice

- Relaxation experiments
  - persisted SST/sea ice
  - various relaxation regions (here tropics/stratosphere)

Tropical Forecast Error: U @ 250 hPa

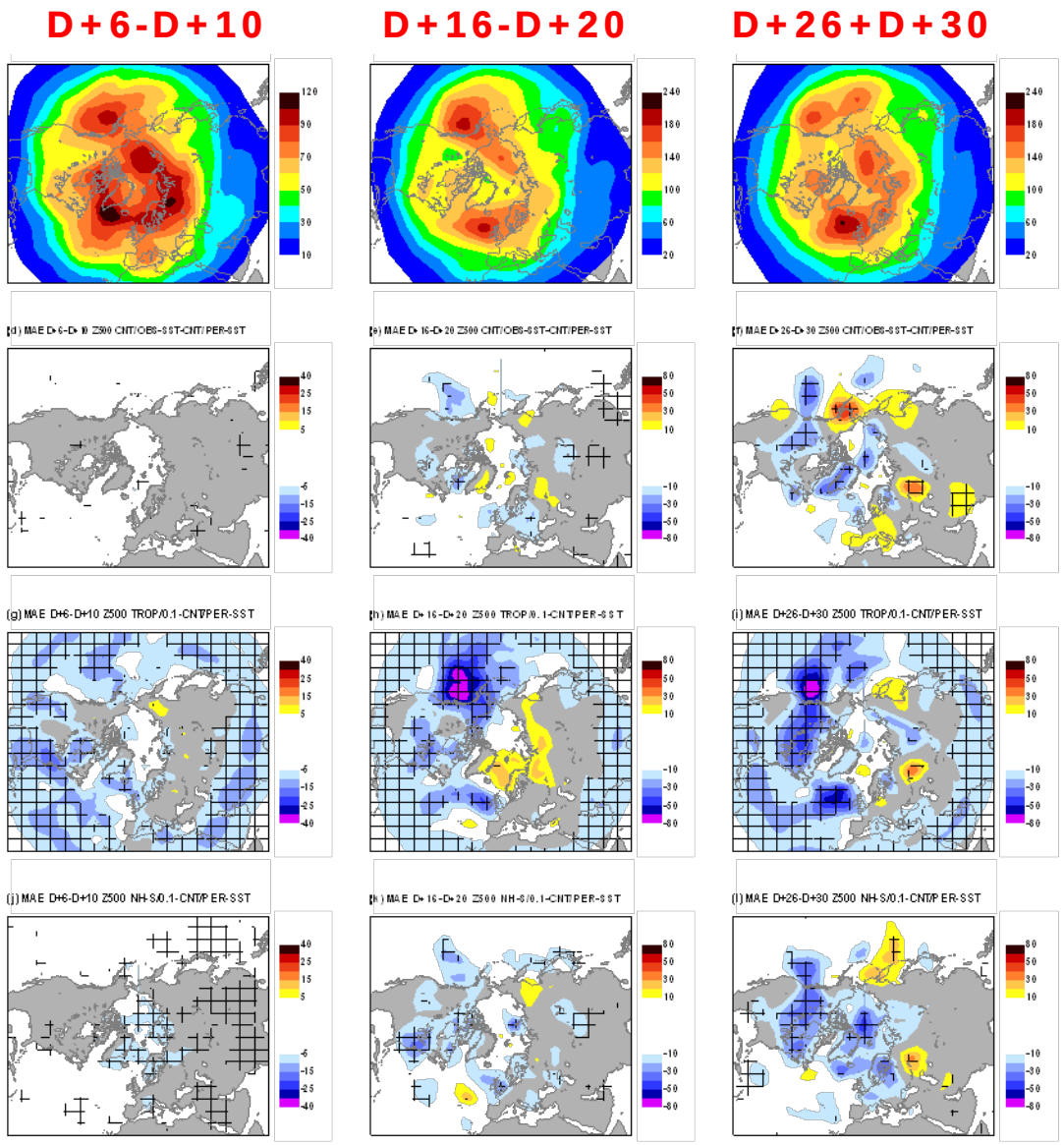


Northern Hemisphere Z500 Forecast Error

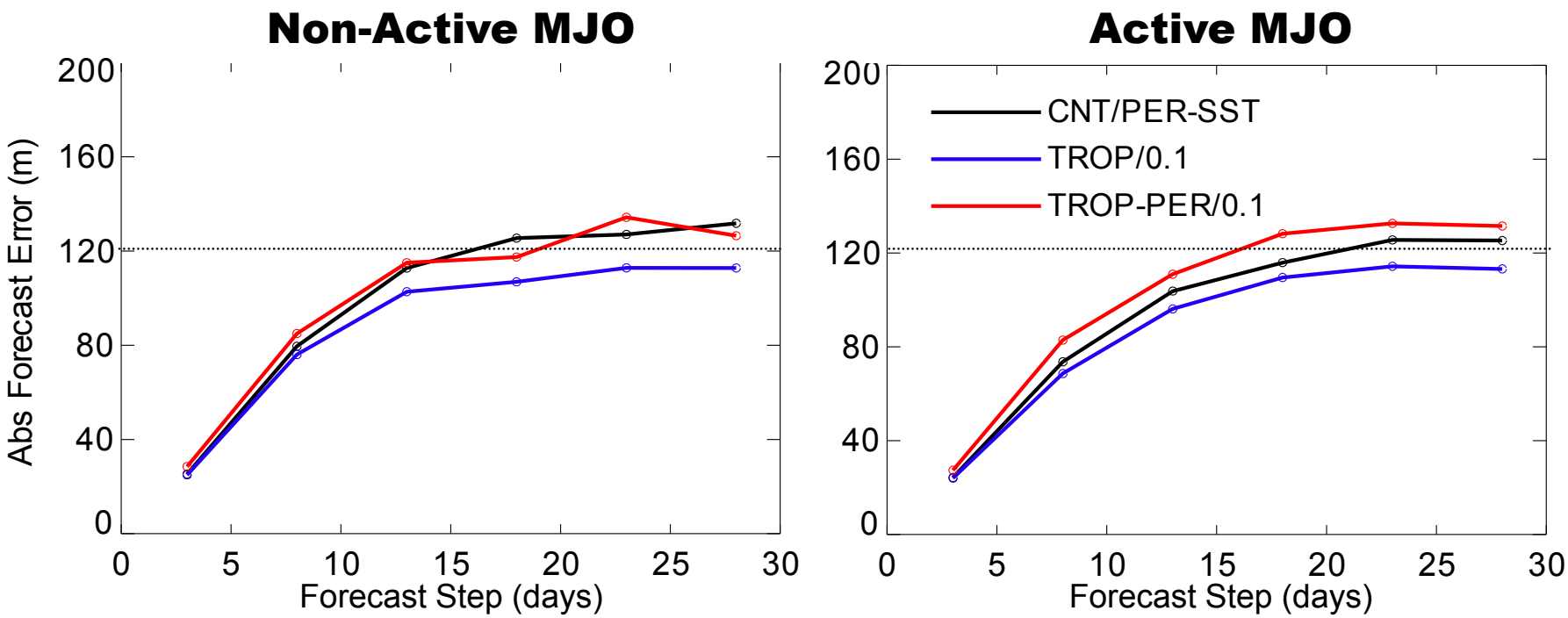


North of 40°N

Impact of Relaxation



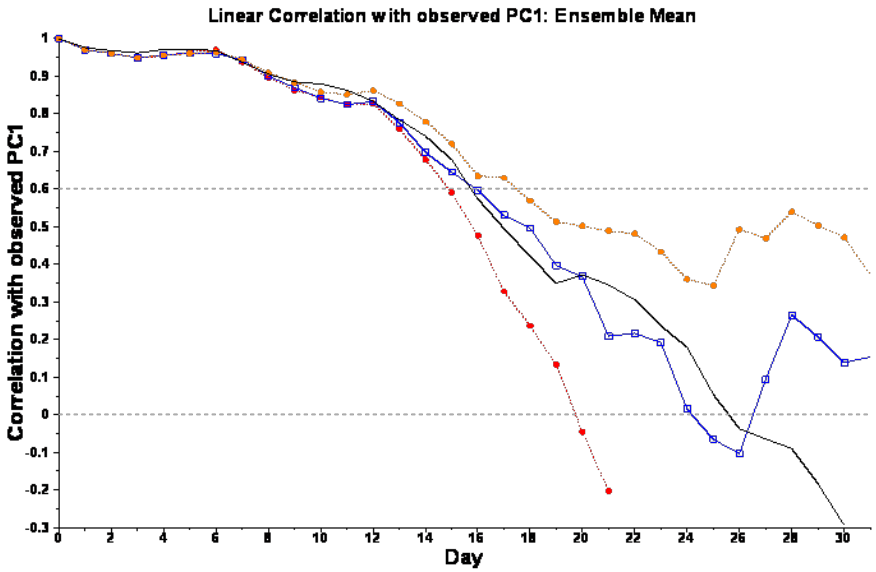
Role of the MJO



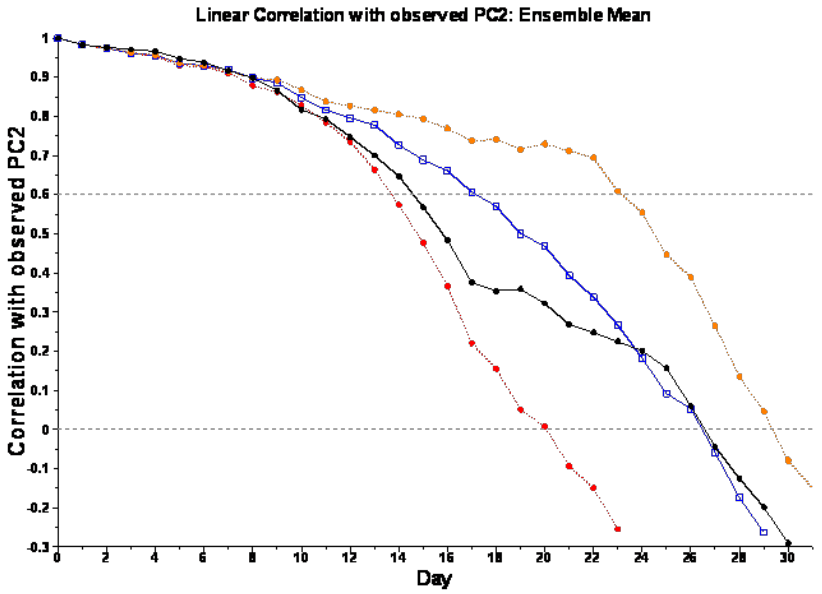
Northern Hemisphere Z500

Dynamical Predictability of the MJO

PC1



PC2



Persisted SSTs

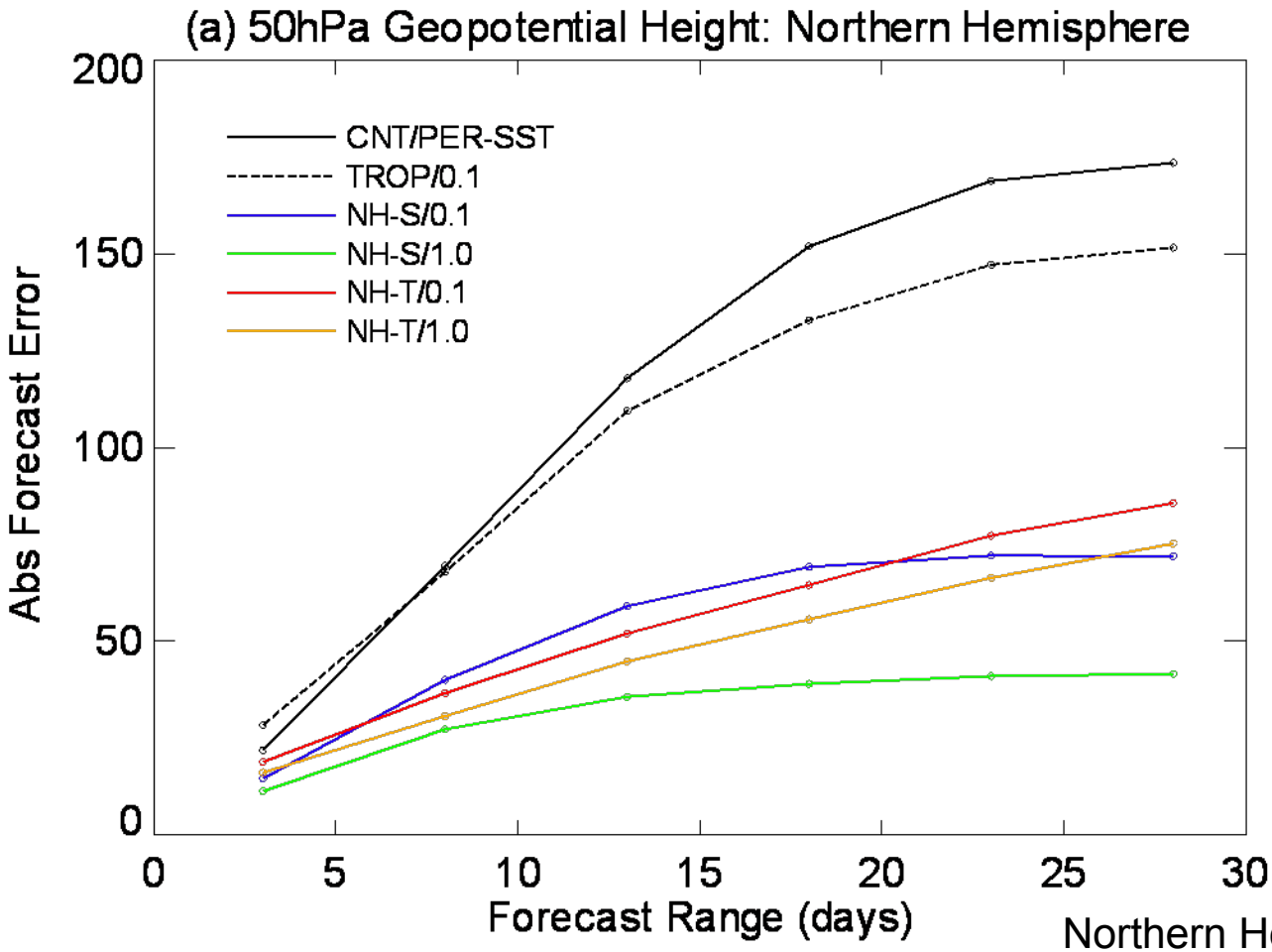
Coupled after day 10

Coupled

Ocean ML

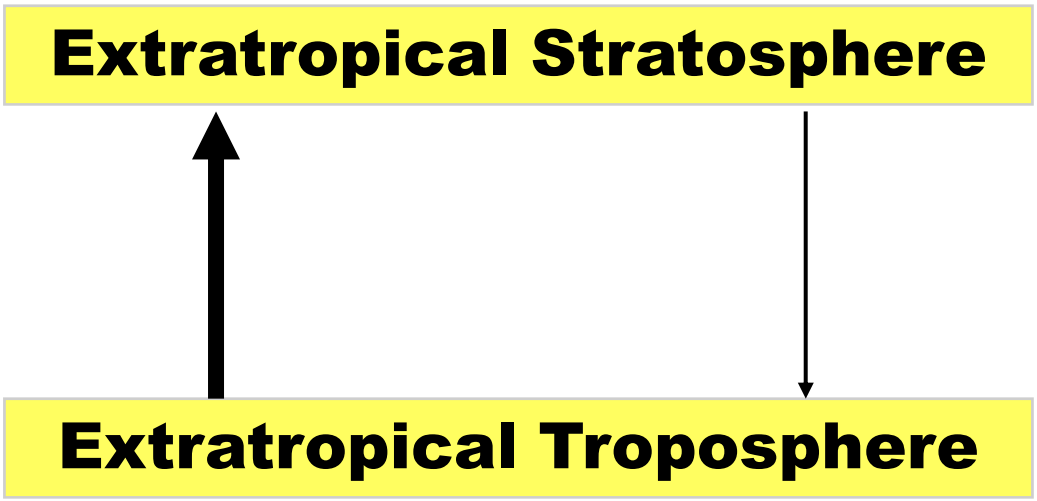
Vitart et al., 2007

Stratospheric Forecast Error



Northern Hemisphere Z50

How to Interpret These Results

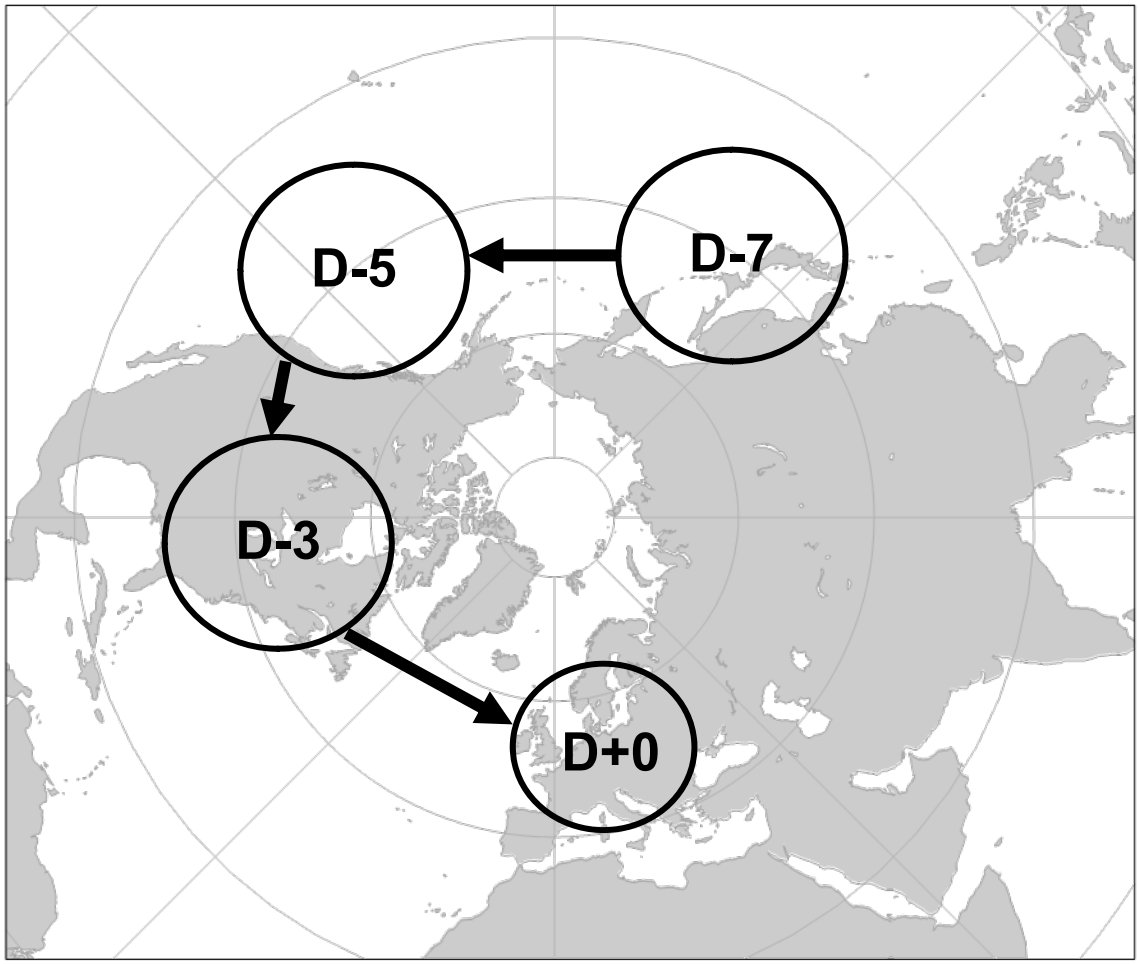


Different Techniques!

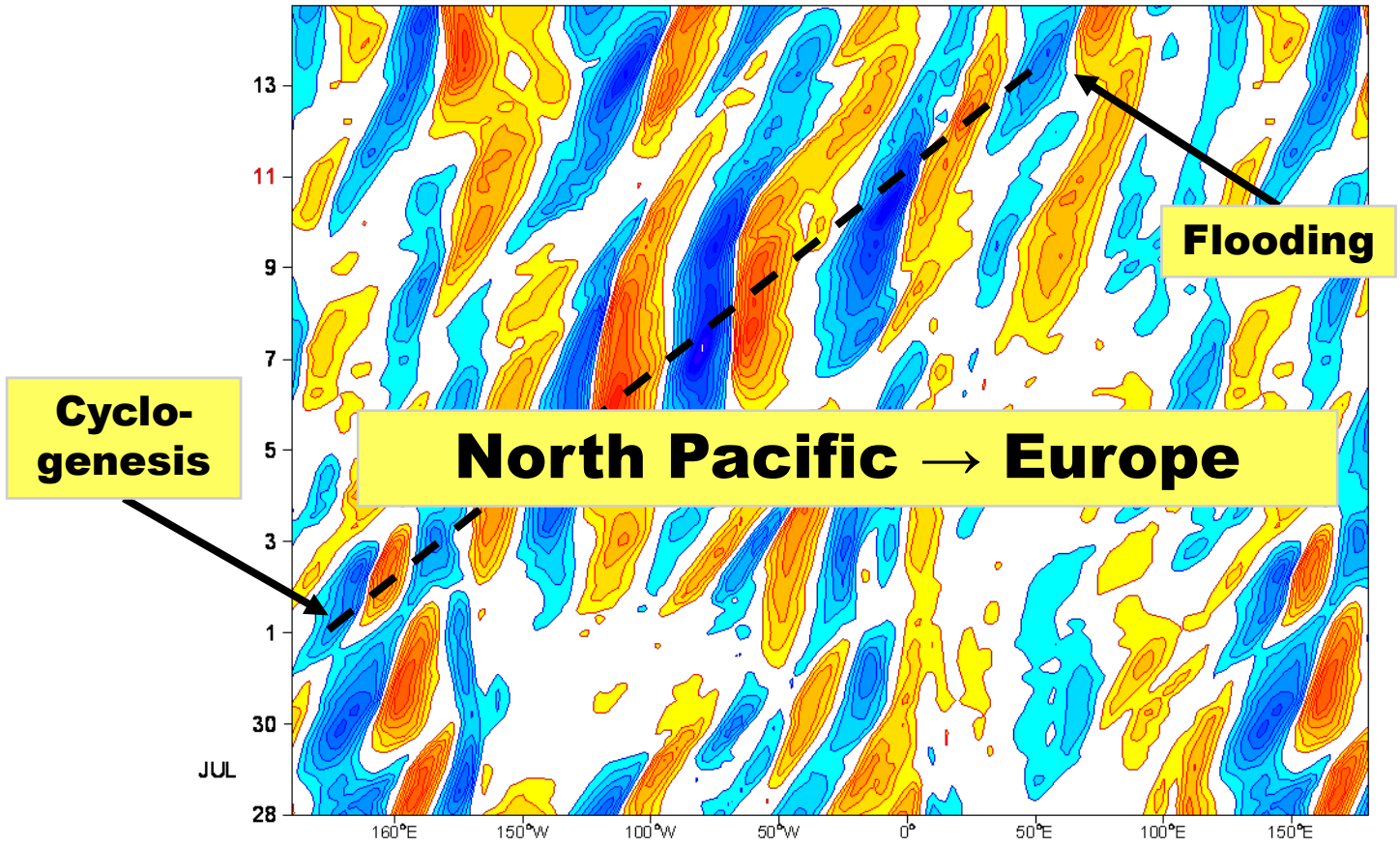
Summary I

- Better tropical forecasts lead to reduced forecast errors in the extratropics.
- Particularly, North Pacific, North America and Europe.
- These improvements are not due to the MJO.
- What do we improve in the tropics that leads to better extratropical forecasts?
- Stratospheric relaxation experiments show downward impact.
- However, these experiments are difficult to interpret in terms of predictability.

Origin of European Forecast Error: ECMWF User's Guide



Rossby Wave Trains



$V_{40\text{-}60N}$

From THOPREX Science Plan

Downstream Impact of Analysis Degradation

Day 1

Day 2

Day 5

Day 7

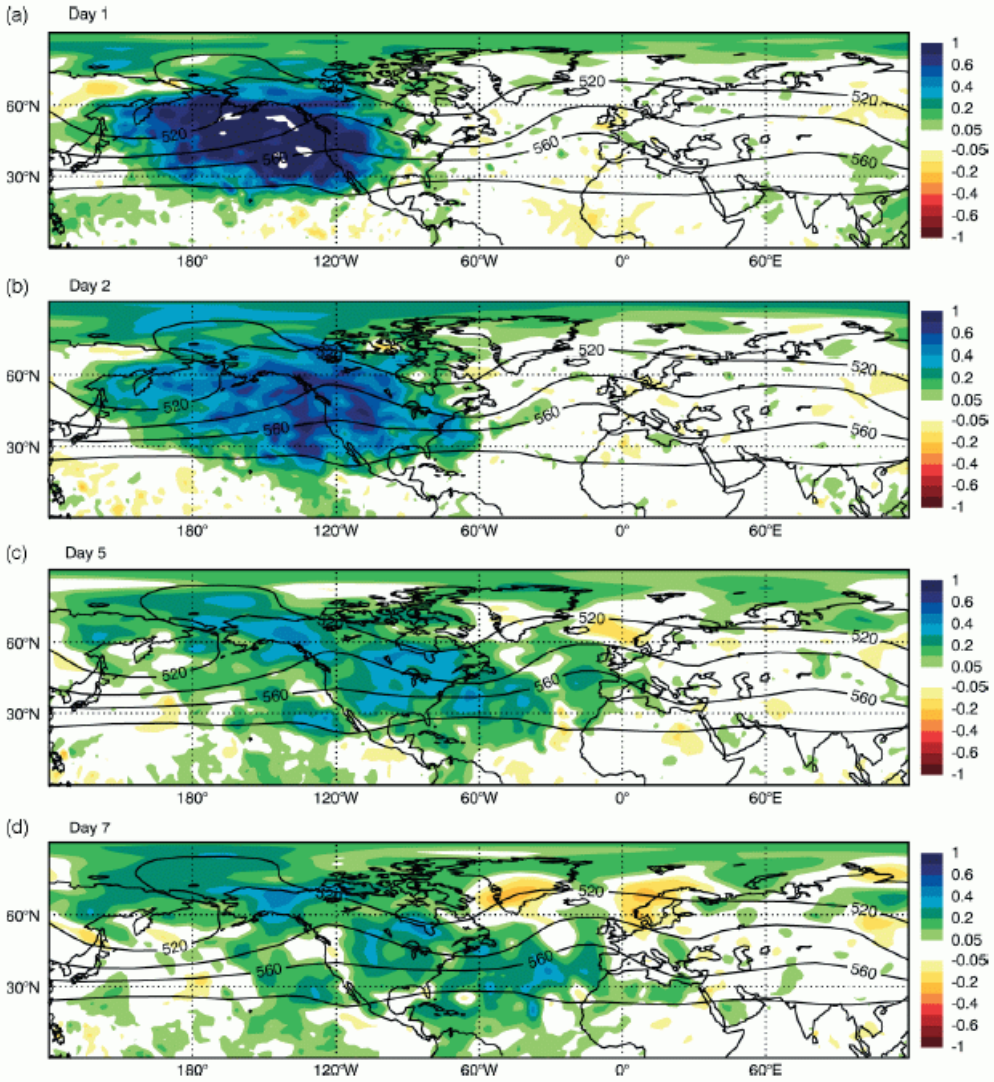


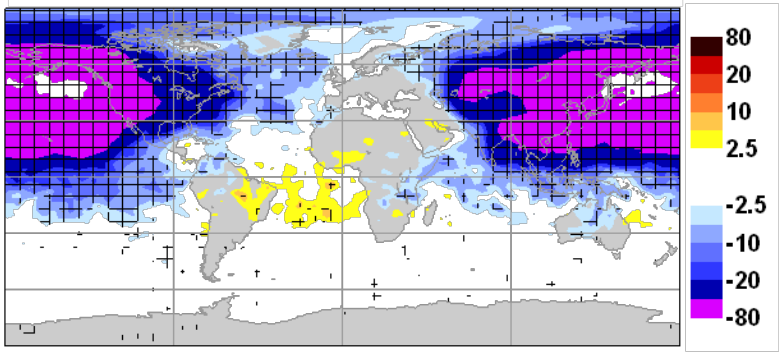
Figure 3. Winter Pacific: Normalized *rmse* differences between SEAIN forecast and SEAOUT. Blue-purple show the negative impact and yellow-black positive impact of SEAOUT. Panels (a)–(d) show forecasts errors for days 1, 2, 5 and 7.

Kelly et al. 2007

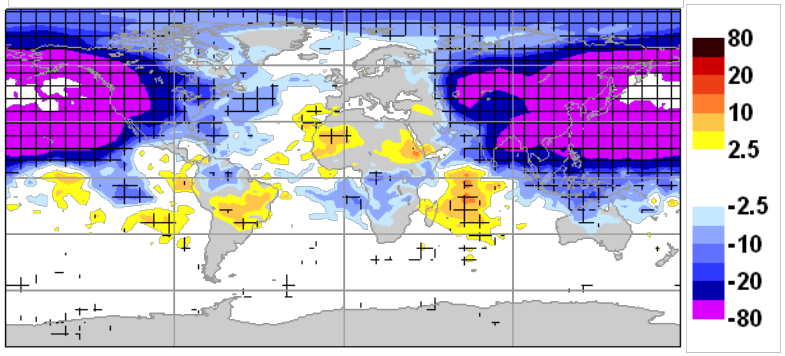
ECMWF

Z500 Forecast Error: D+1 to D+5

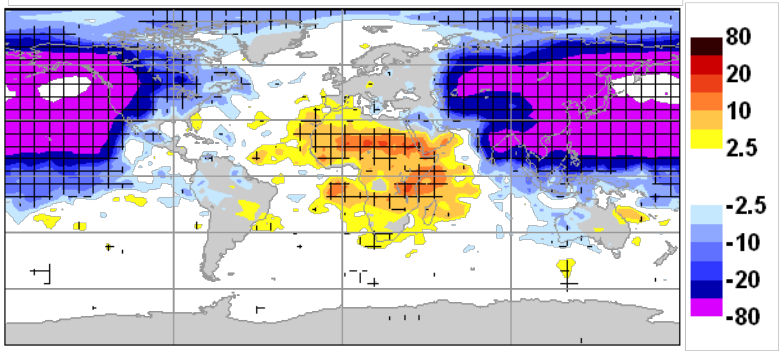
(a) MAE D+1-D+5 Z500 DJF



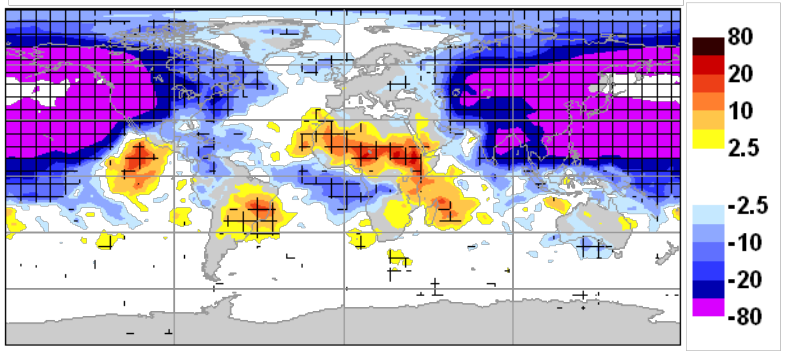
(b) MAE D+1-D+5 Z500 MAM



(c) MAE D+1-D+5 Z500 JJA



(d) MAE D+1-D+5 Z500 SON

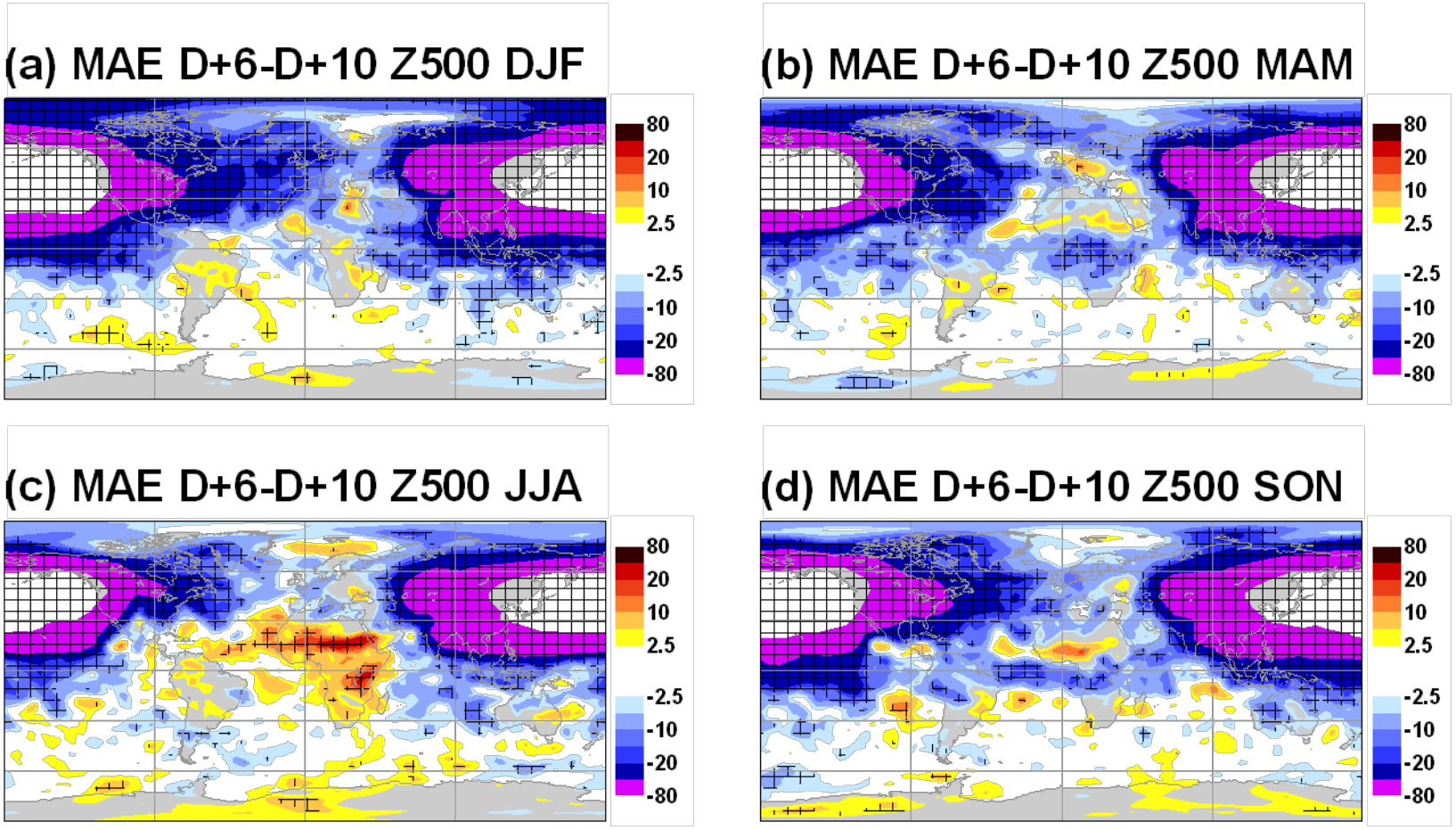


In %!

North Pacific relaxation: 90°E-140°W, 10°-60°N

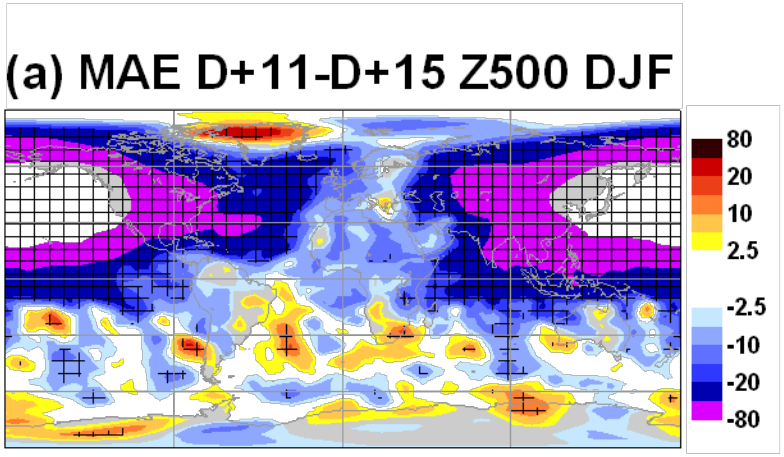
ECMWF

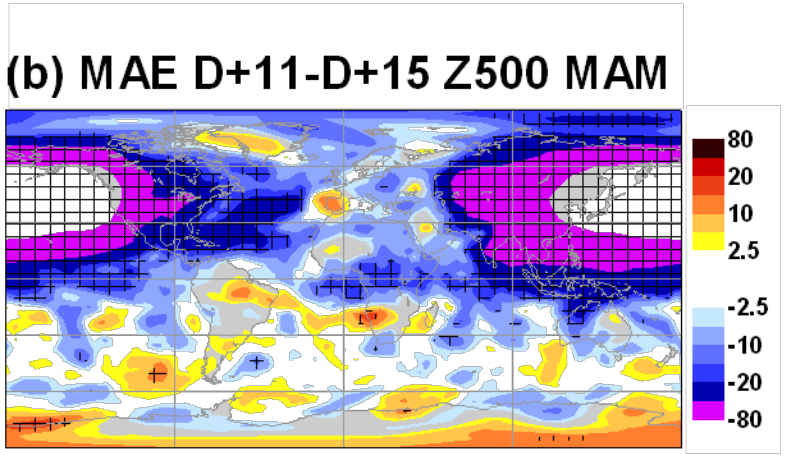
Z500 Forecast Error: D+6 to D+10

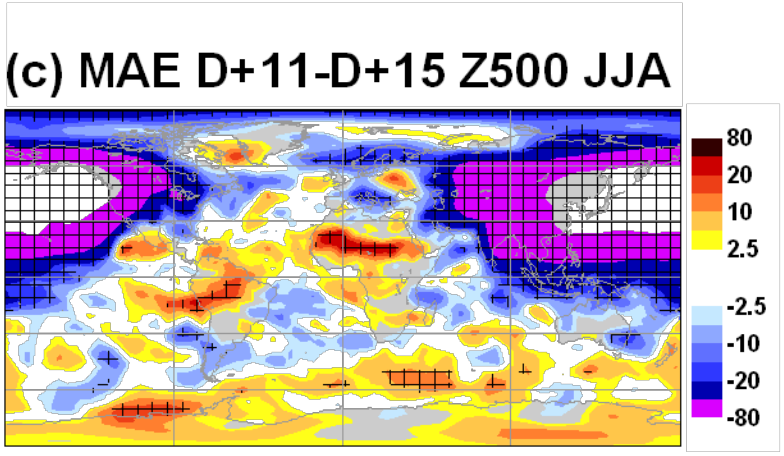


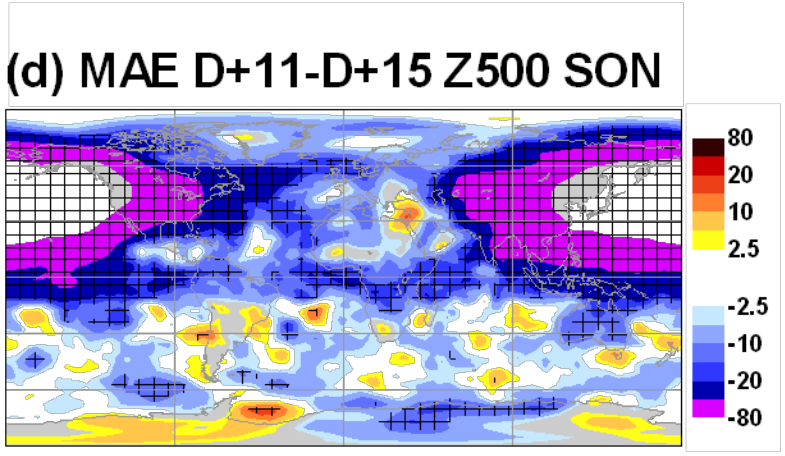
North Pacific relaxation: 90°E-140°W, 10°-60°N

Z500 Forecast Error: D+11 to D+15



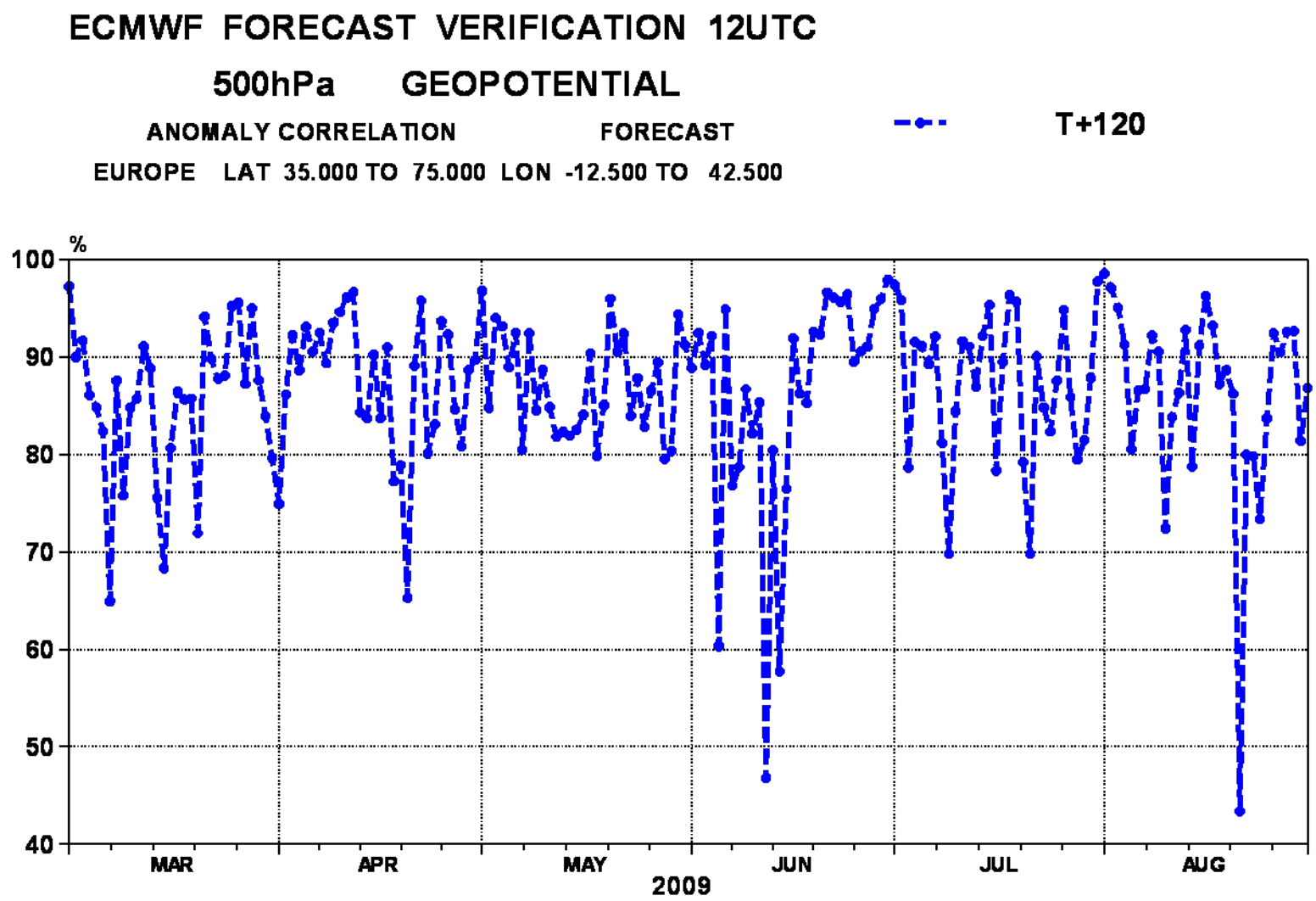






North Pacific relaxation: 90°E-140°W, 10°-60°N

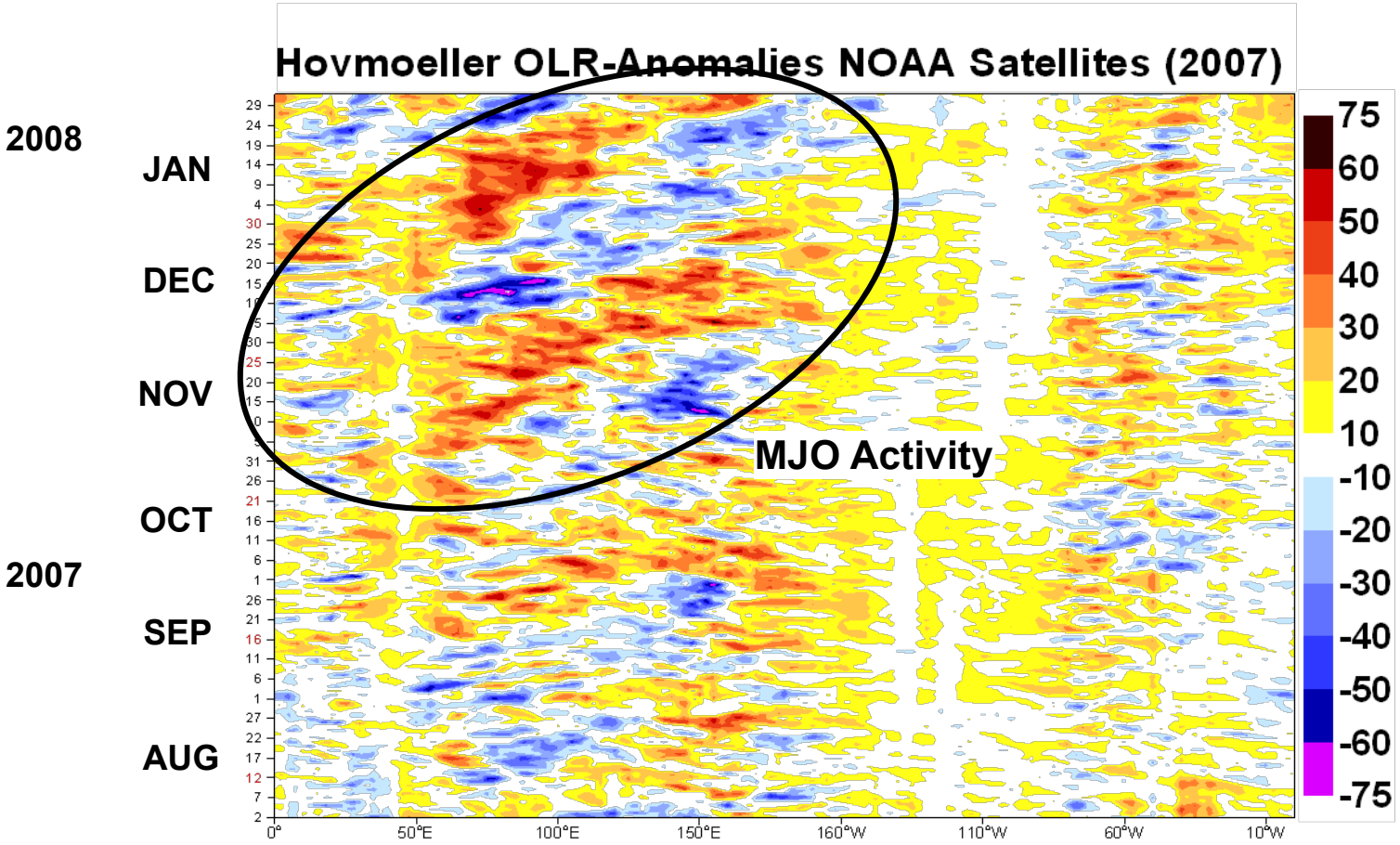
Time Series: D+5 ACC Z500 Europe



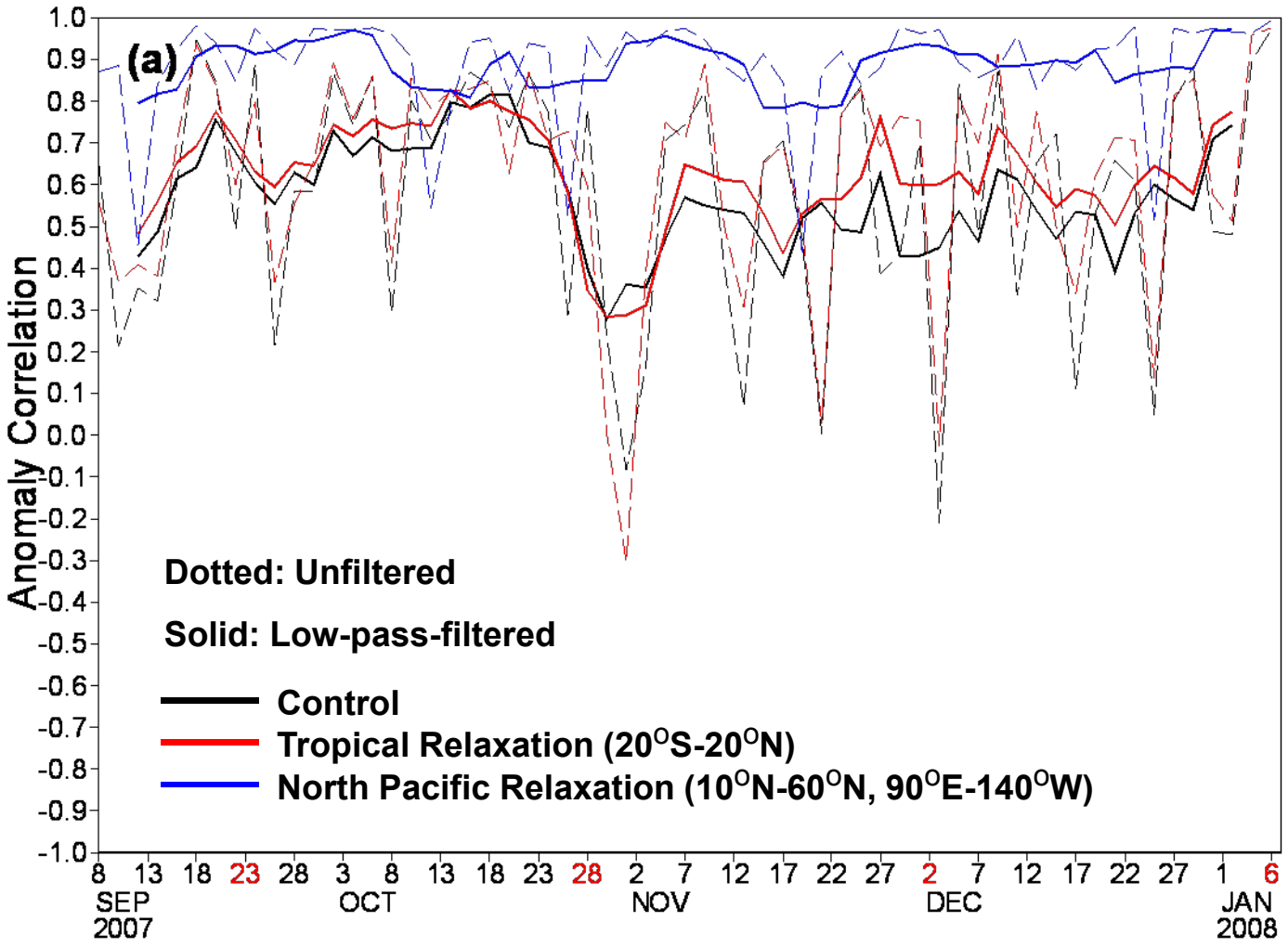
Tropical Origin of Extratropical Forecast Busts?

- There have been suggestions that some forecast busts over North America can be traced back to tropical error.
- Conjecture is that errors in representing the MJO are involved (→ THORPEX).
- Here we test this hypothesis:
  - T_L255L60
  - Relaxation towards ERA-Interim
    - Tropics (20°S-20°N)
    - North Pacific (10°N-60°N, 90°E-140°W)
  - 15-day forecasts every other day 1st Sep to 31st Dec 2007
    - Period of strong MJO-type variability in November and December.

Tropical OLR Anomalies



ACC: D+7 Z500 Forecast for North America

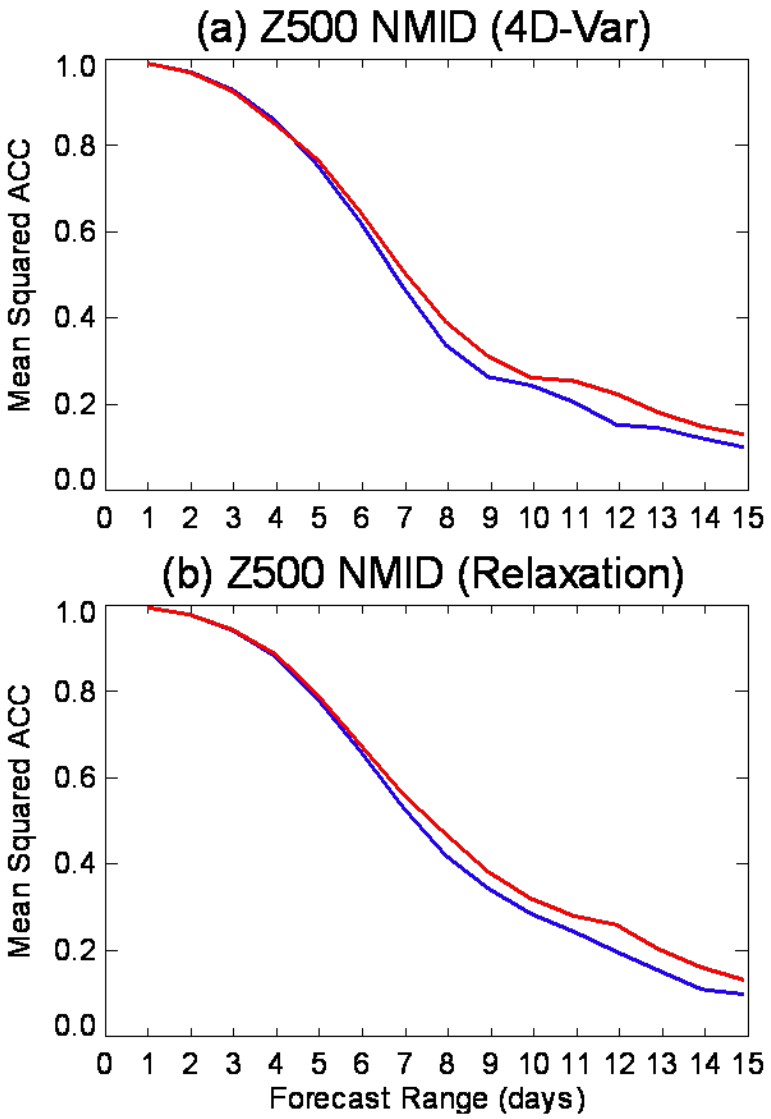


Testing the Relaxation Approach

- Relaxation or nudging is a form of data assimilation.
- Imbalances occur close to the relaxation boundaries (spurious vorticity and divergence).
- Why not use the ECMWF 4D-Var system and assimilate data in the tropics only?

- Set of `normal' 15-day forecasts.
- Set of 15-day tropical relaxation experiments
- set of 15-day 4D-Var experiments with assimilation of tropical observations only.

4D-VAR versus Relaxation

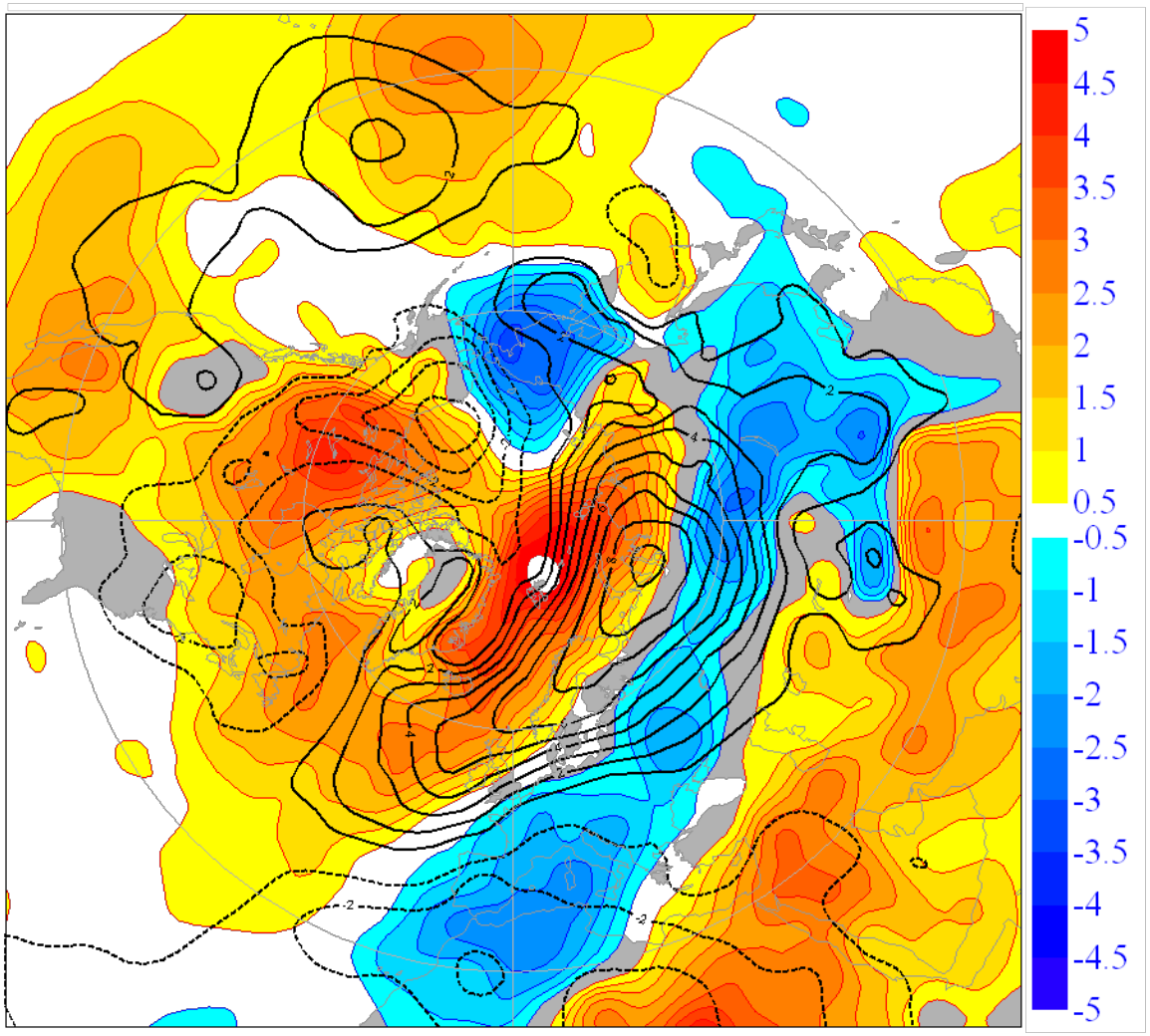


- NMID=40°-60°N
- 22 cases
- 3 January to 7 March 2009
- YOTC/Winter T-PARC
- MJO event captured
- 4D-Var two orders of magnitude more expensive!

Summary II

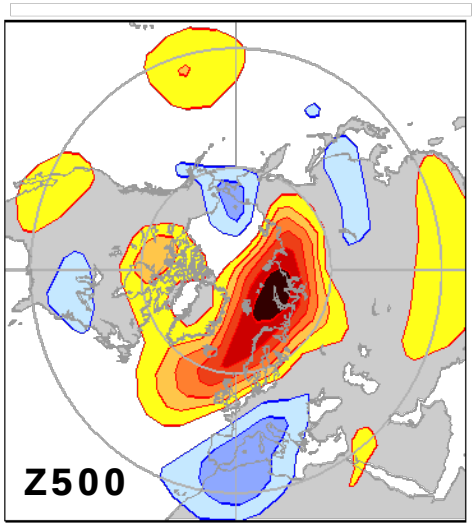
- Reduced forecast error in the North Pacific has little influence on predictability over Europe.
- What is going on:
  - Weak connection (test flow-dependent aspects)?
  - Model problems?
- Tropics are not source of forecast busts over North America (Europe)
  - Extratropical dynamics are crucial.
- 4D-Var experiments with assimilation of tropical observations only yields similar results!

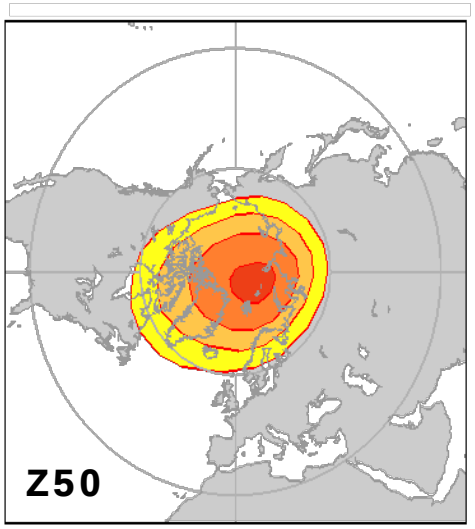
The Cold European Winter of 2005/06

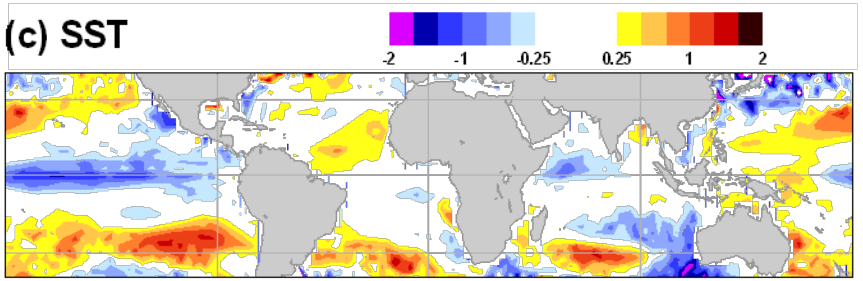


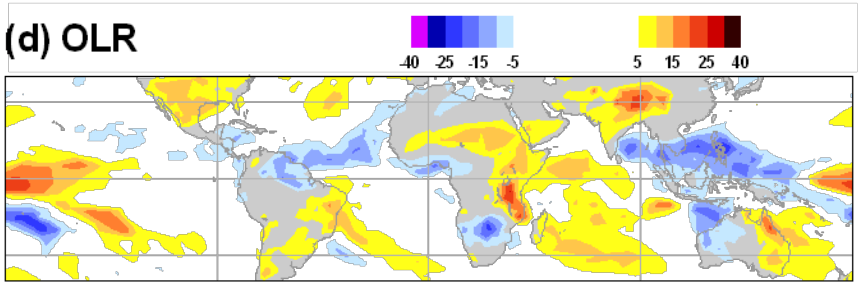
- Much studied
- North Atlantic SST anomalies
- SSW in January 06

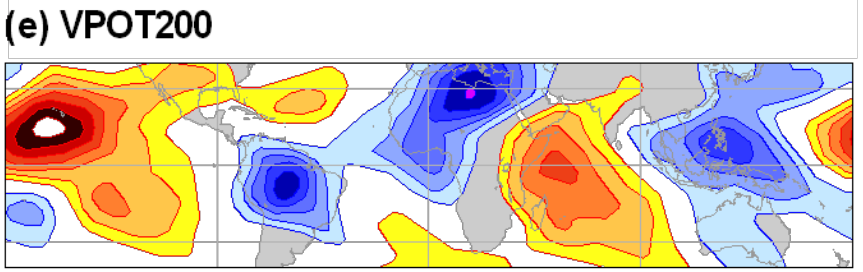
The Cold European Winter 2005/06

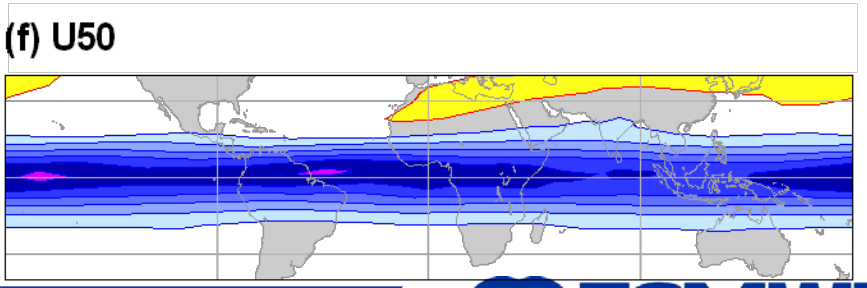












Seasonal Forecast Experiments: Setup

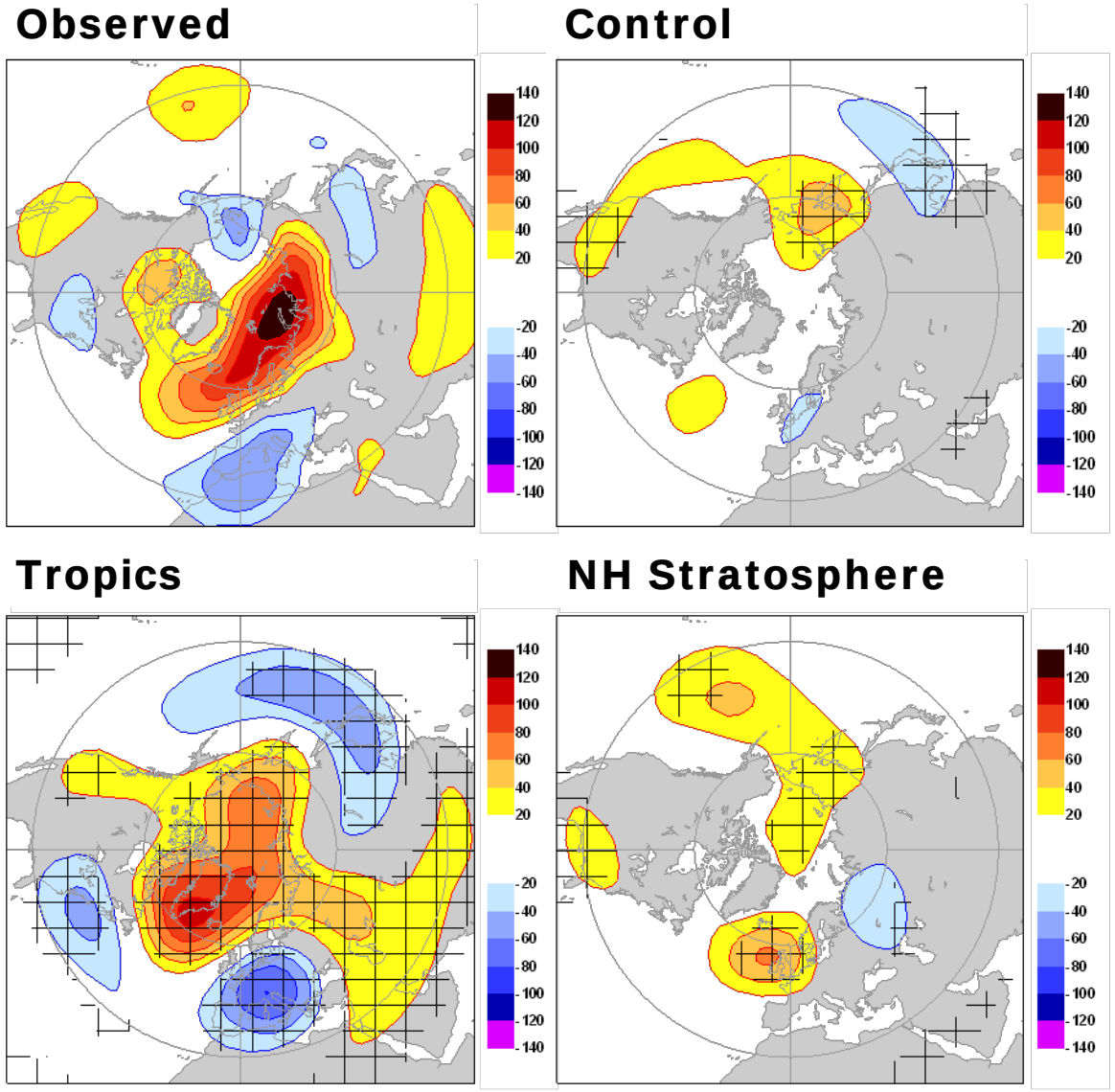
- Model cycle 32R1 (5/06–5/11 2007)
- T_L95 (210 km) with 60 levels in the vertical
- Initial/boundary conditions: Operational analysis (T_L95L60)
- Ensembles: 17 members (2005111612/to/2005112012/by/6hrs)
- Diagnostic period: 1st December 2005 to 28th February 2006
- Observed SST/sea ice

- Calibration runs (16th November 12UTC, 1990-2006) with and without relaxation

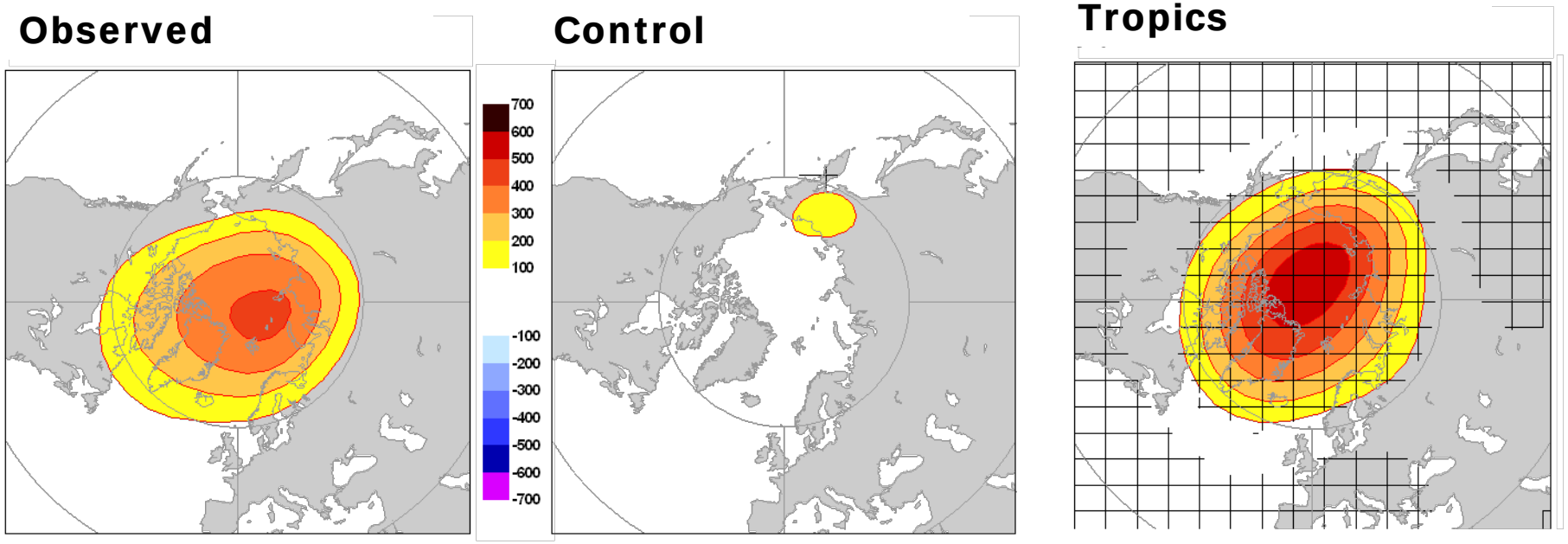
- Control ensemble

- Relaxation ensembles (various regions)

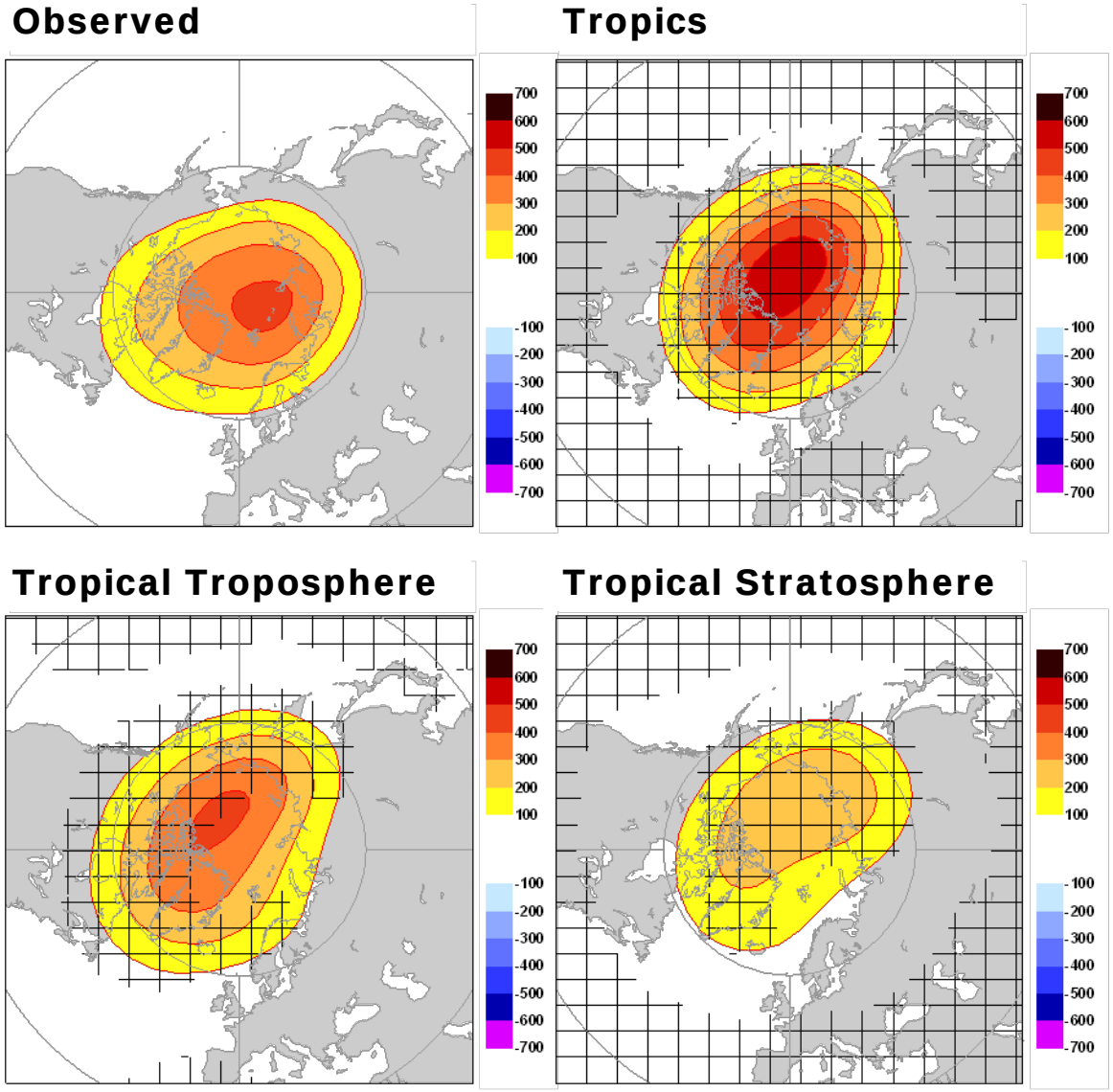
Z500 Anomalies: DJF 2005/06



Z50 Anomalies: DJF 2005/06



Z50 Anomalies

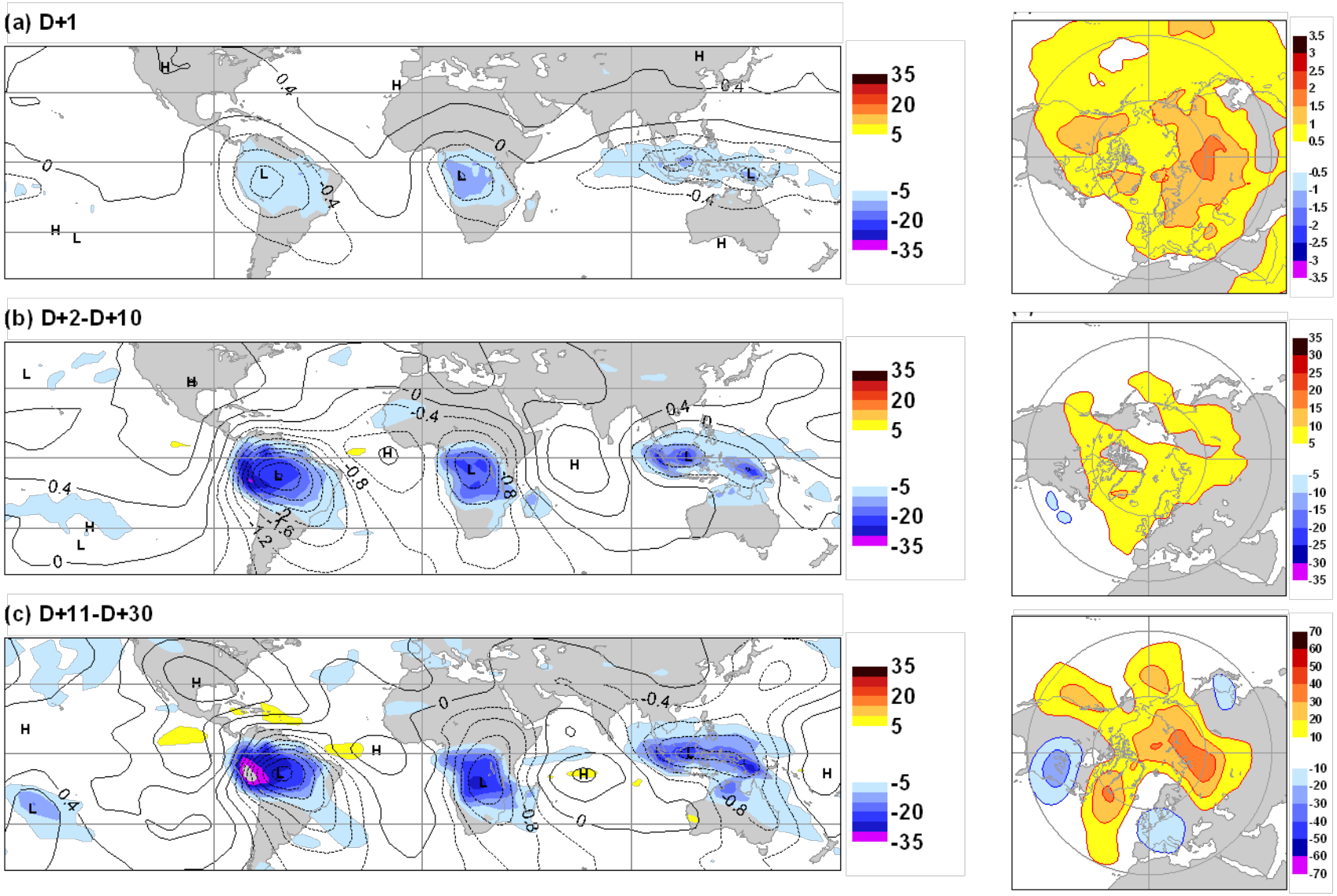


Summary III

- Extratropical circulation anomalies in winter 2005/06 had their origin in the tropics:
  - Troposphere (South America and tropical Atlantic)
  - Stratosphere (negative phase of the QBO)
- Stratosphere might have added some memory, but the SSW was triggered from the tropics.
- Application to other seasonal mean circulation anomalies in progress.
- Relaxation technique is a powerful diagnostics approach!

Thank you!

Impact of Radiation Scheme Changes



ECMWF

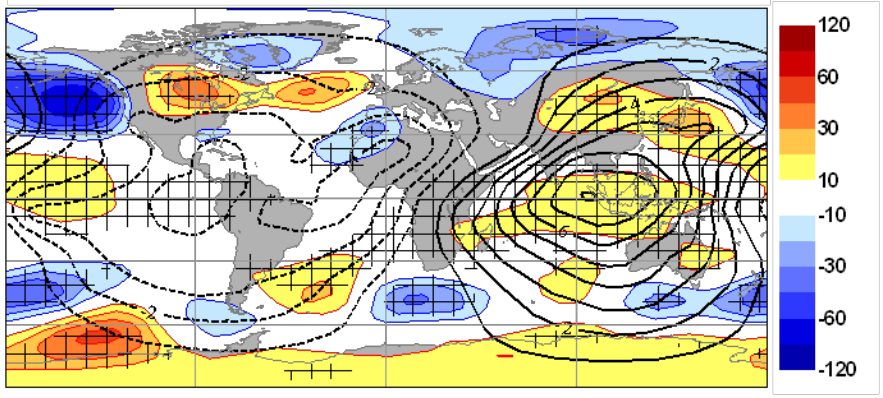
The Ultimate Goal

THORPEX Mission

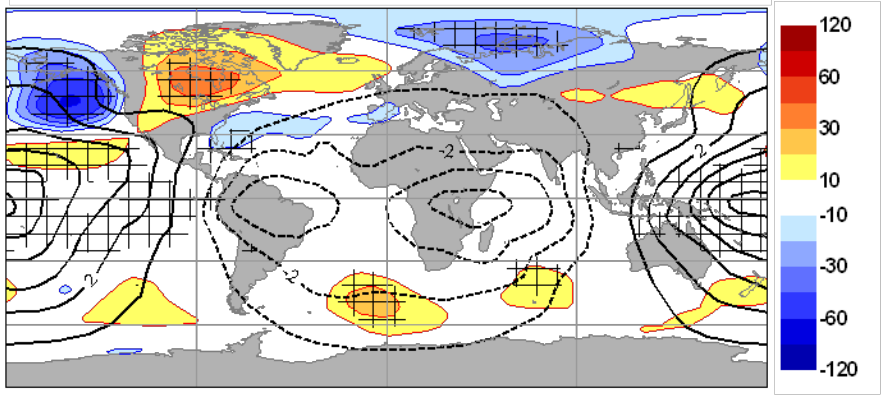
THORPEX is a 10-year international research and development programme to accelerate improvements in the accuracy of one-day to two-week high impact weather forecasts for the benefit of society, the economy and the environment.

Tropics: (1) Remote Influences

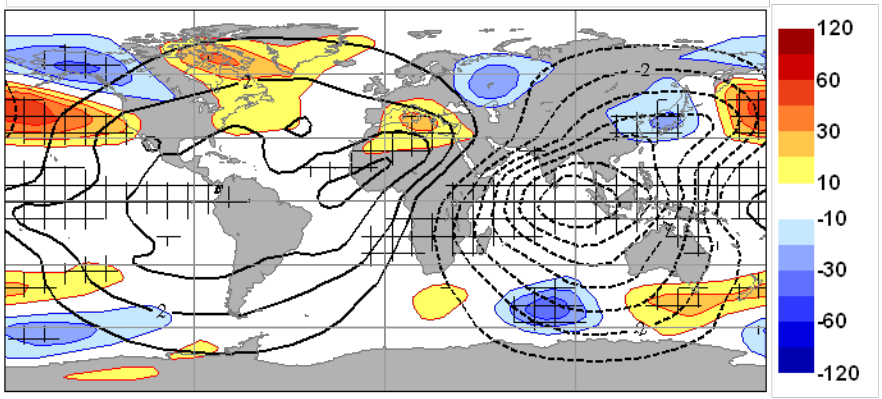
Strong PC1 (Velocity Potential, Z500, 35R3, 12-2 1963-2006)



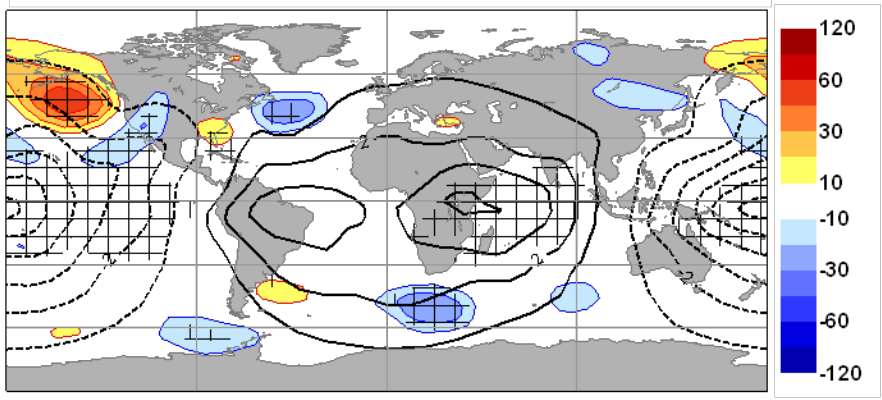
Strong PC2 (Velocity Potential, Z500, 35R3, 12-2 1963-2006)



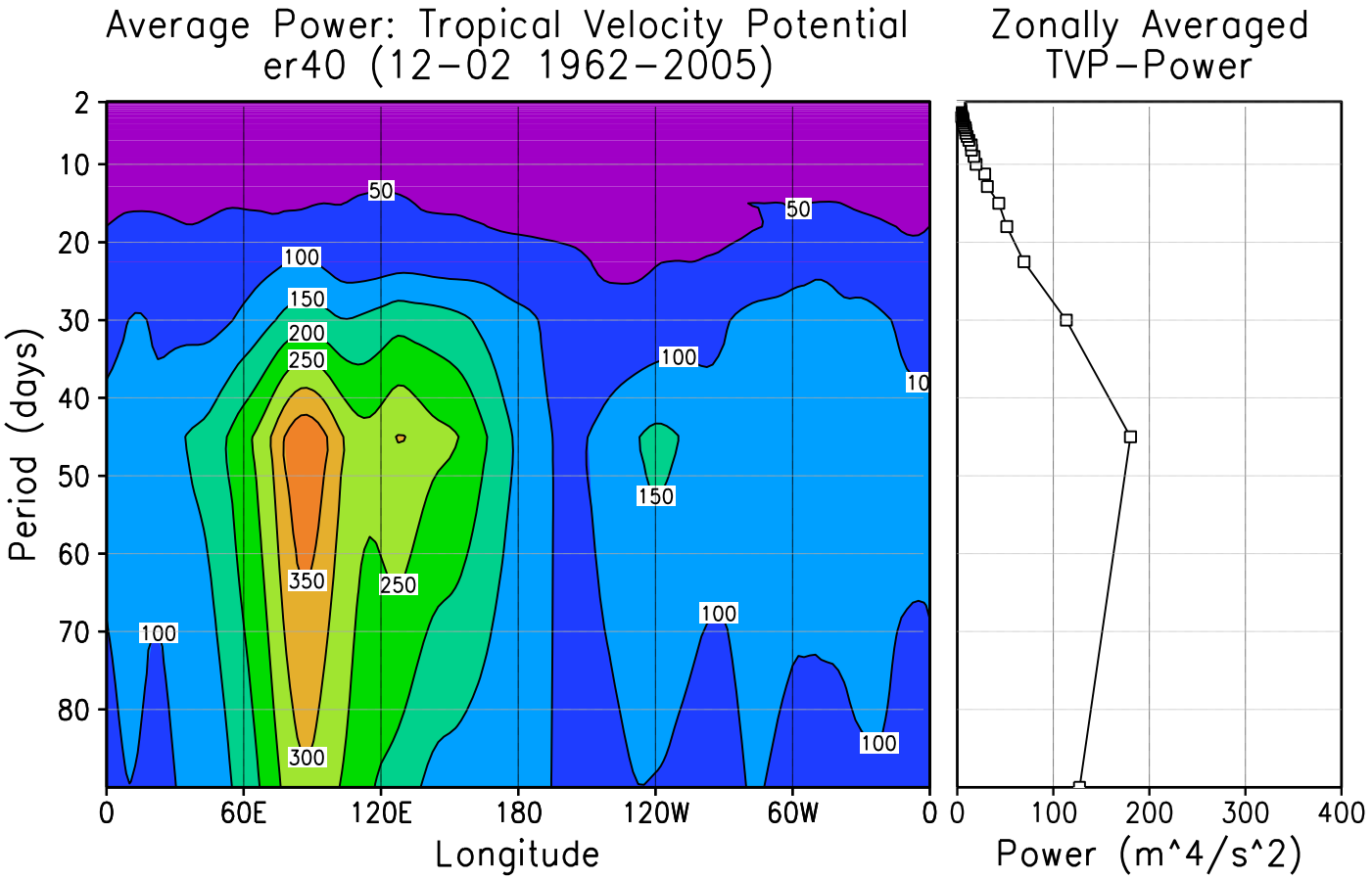
Weak PC1 (Velocity Potential, Z500, 35R3, 12-2 1963-2006)



Weak PC2 (Velocity Potential, Z500, 35R3, 12-2 1963-2006)



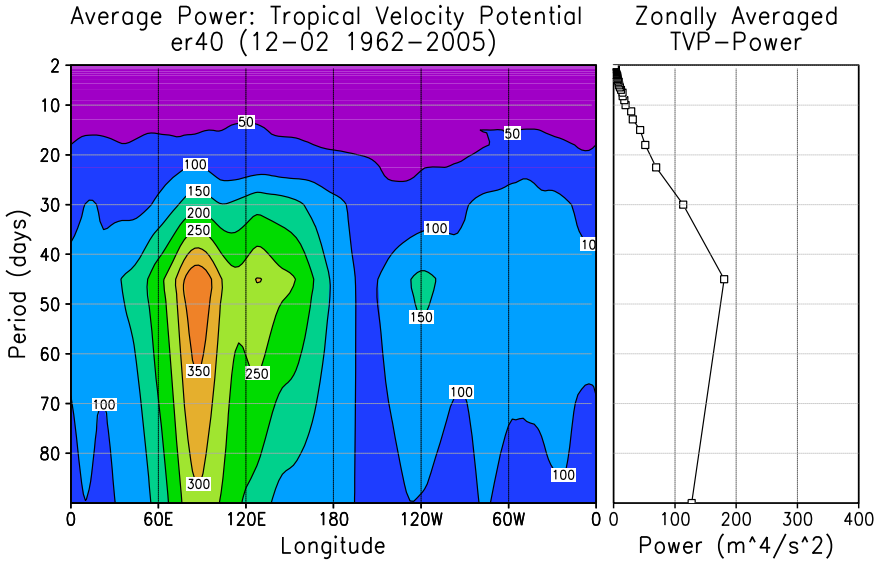
Tropics: (2) Potential Source of Predictability



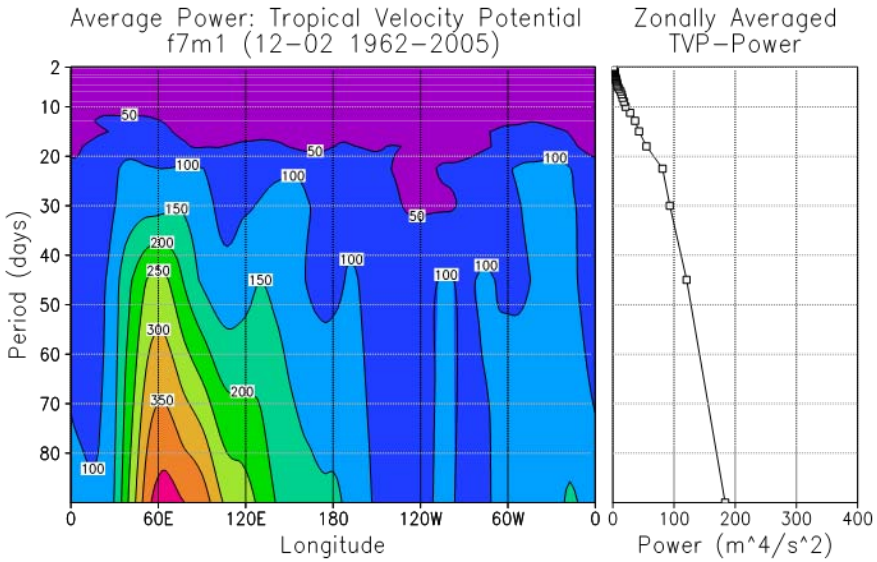
- **Low-frequency phenomenon**
- **Quasi-periodicity**

Tropics: (3) Poorly Represented in Models

Reanalysis

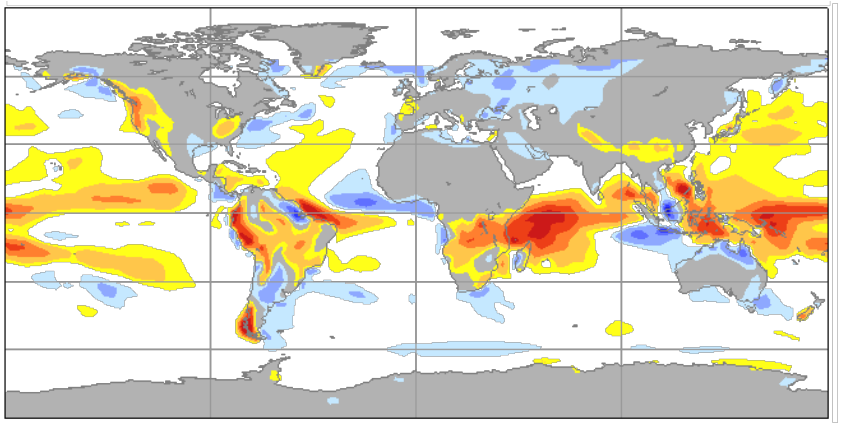


ECMWF Model

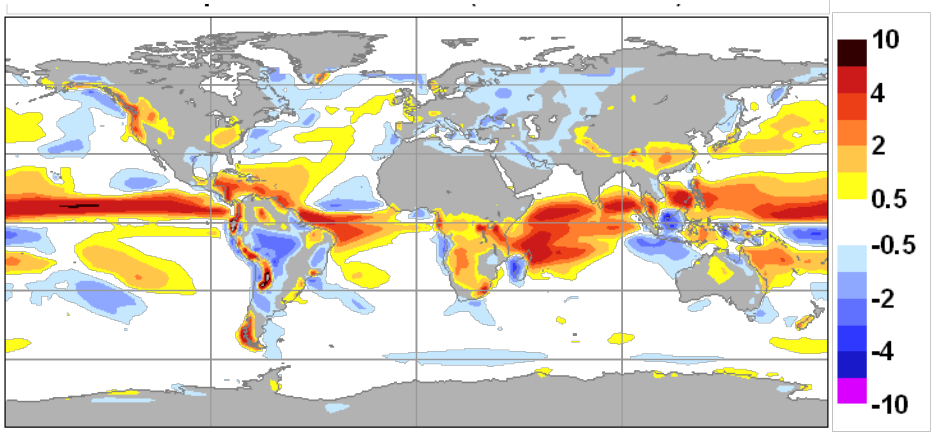


Systematic Precipitation Errors

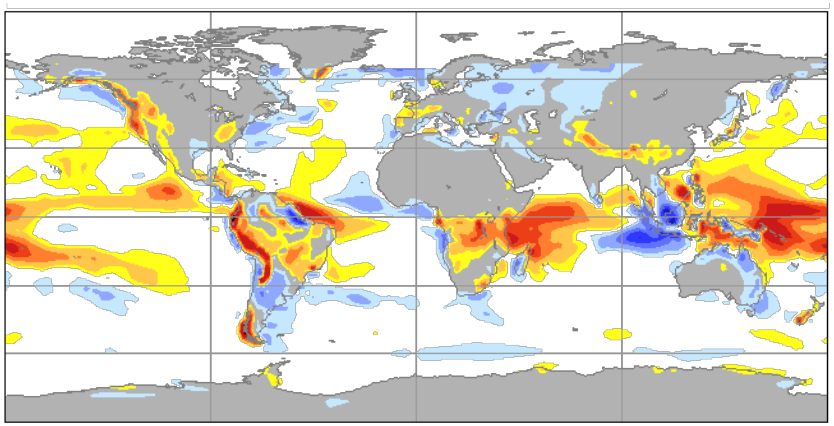
ECMWF 35R3 (yesterday)



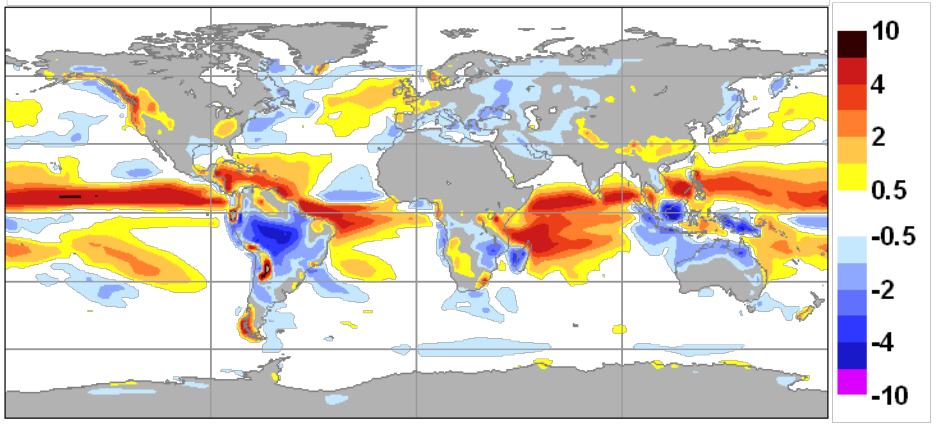
ECMWF 32R1 (Jun 2007)



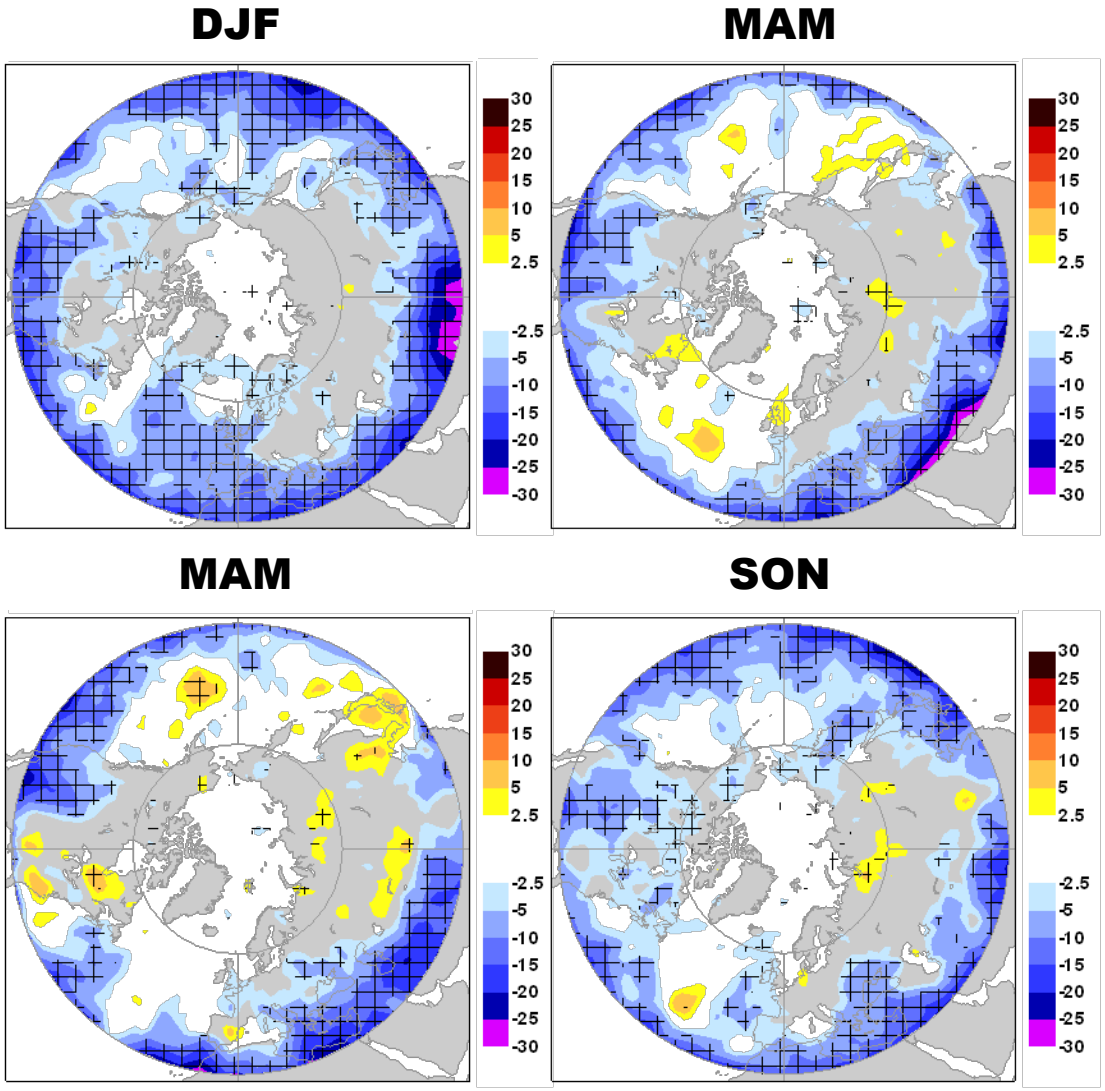
ECMWF 32R3 (Nov 2007)



ECMWF 31R1 (Sep 2006)

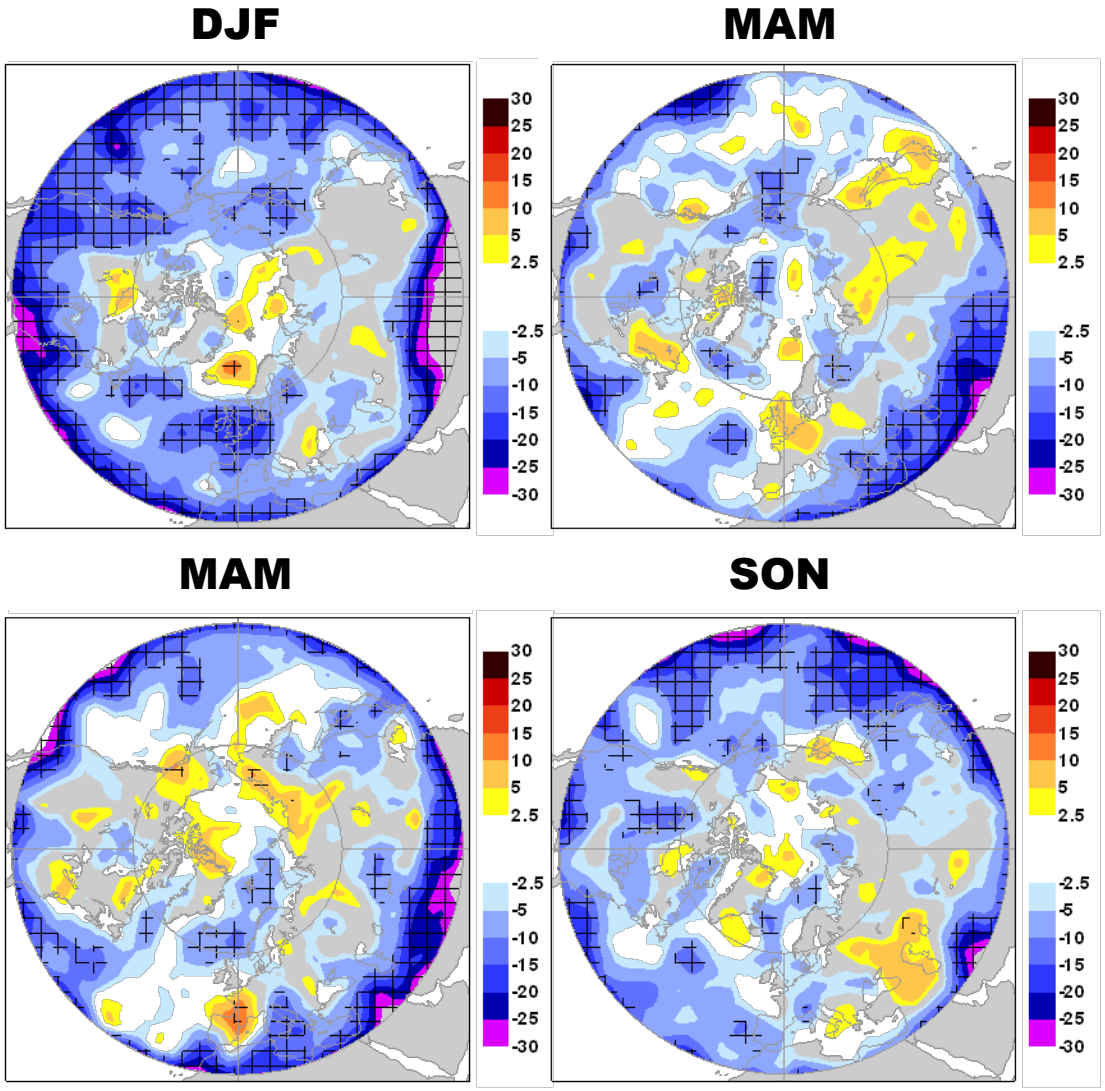


Tropical Relaxation: D+1 to D+5



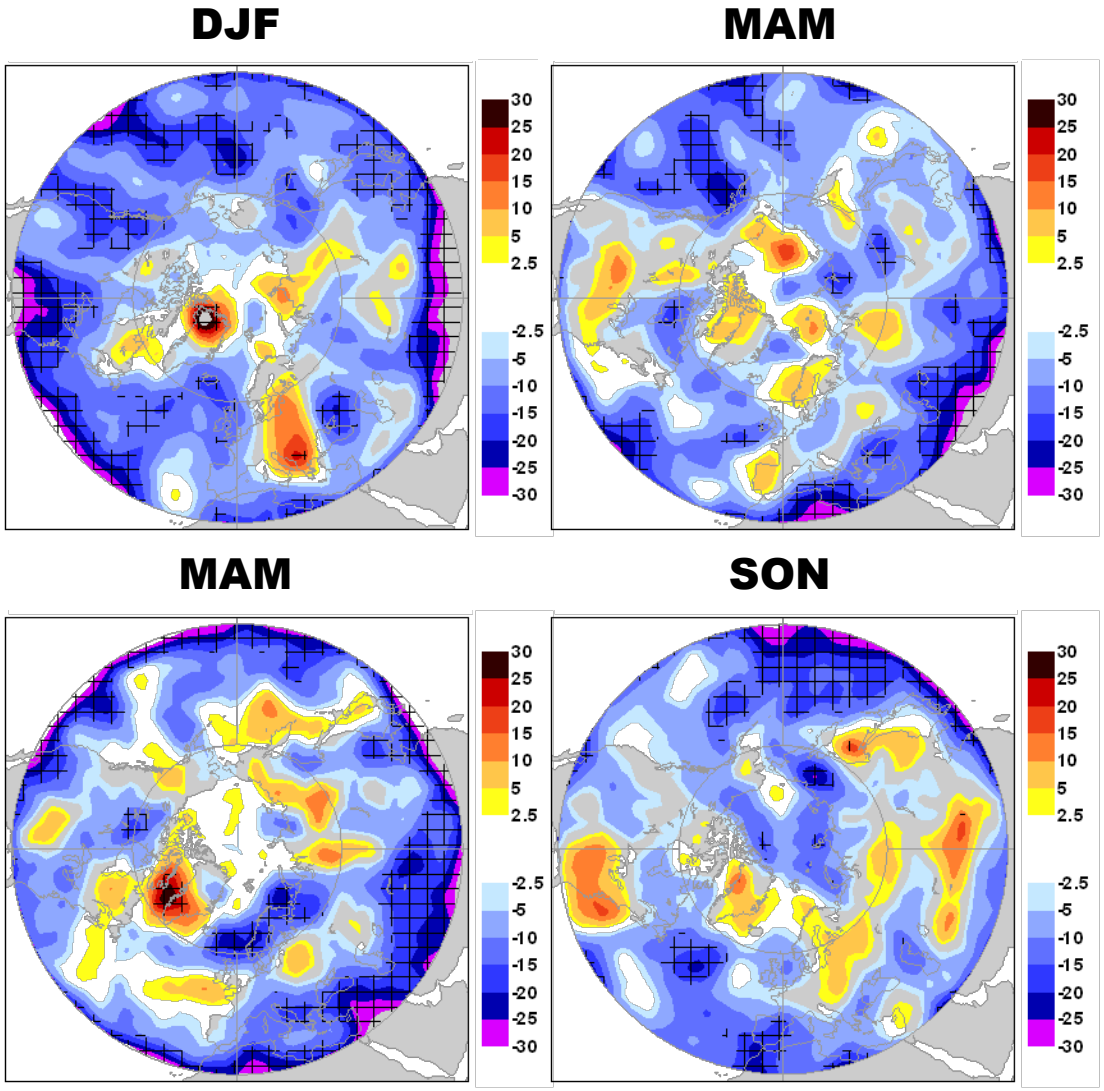
- **mean absolute error**
- **differences in percent**

Tropical Relaxation: D+6 to D+10



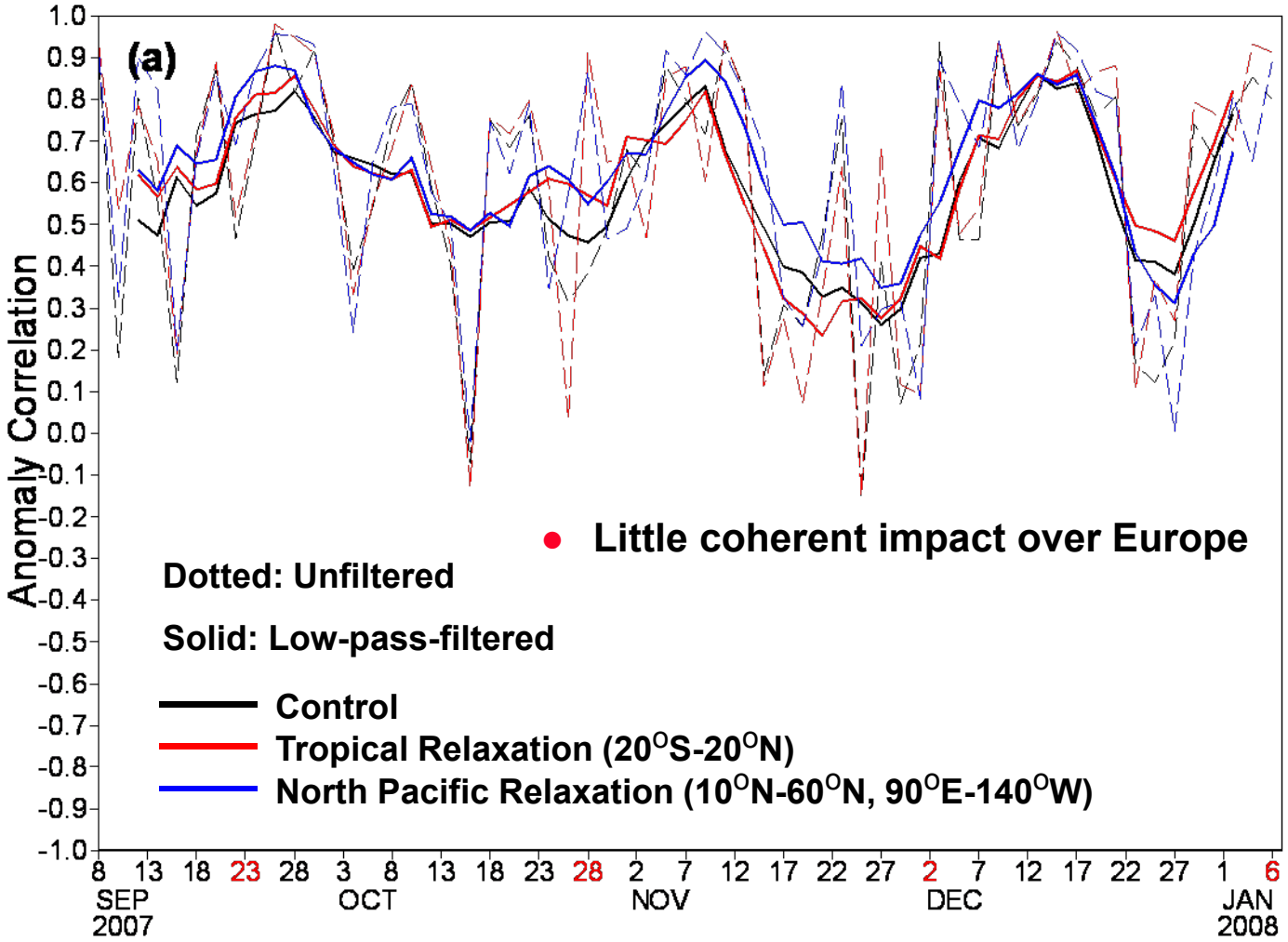
- **mean absolute error**
- **differences in percent**

Tropical Relaxation: D+11 to D+15

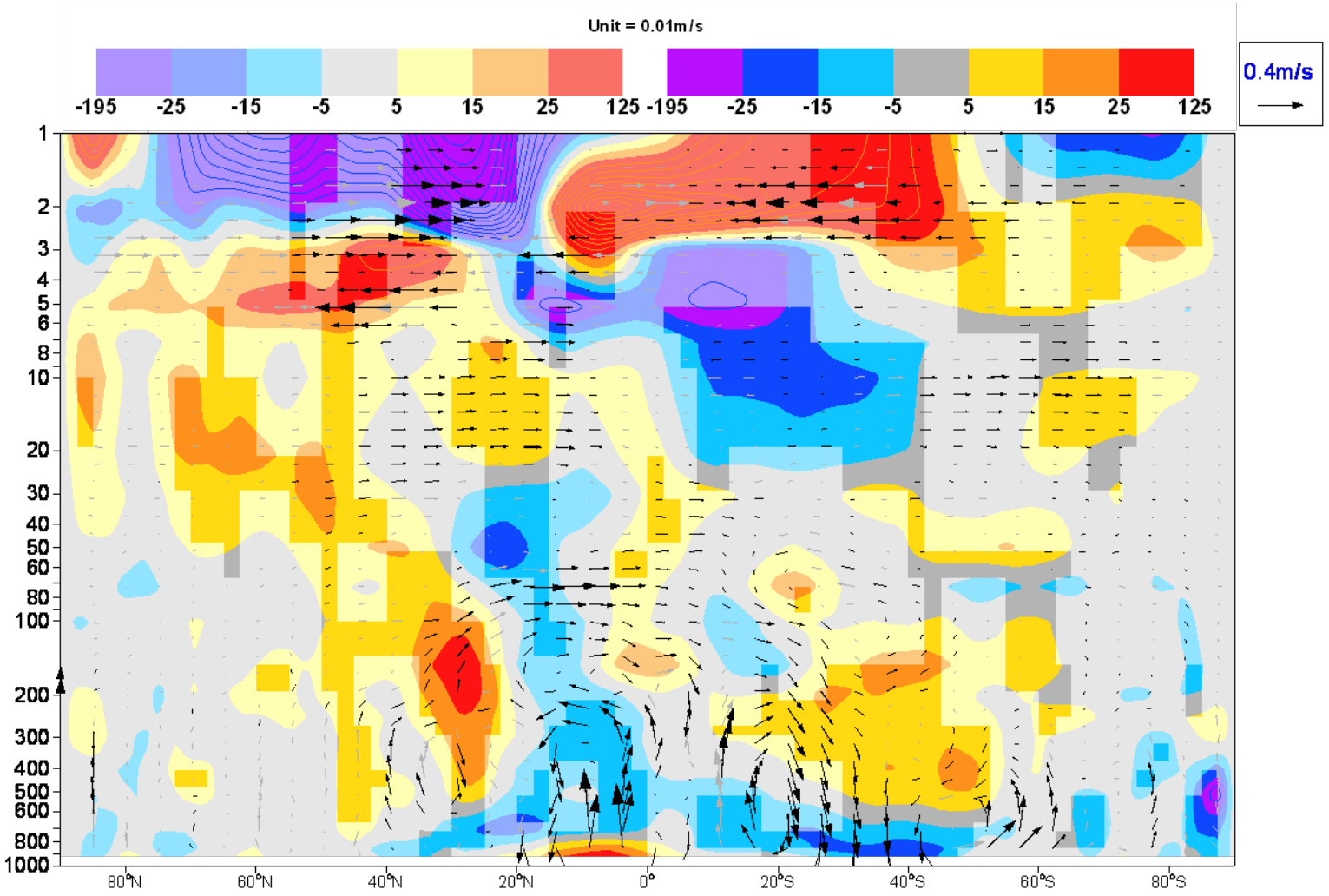


- **mean absolute error**
- **differences in percent**

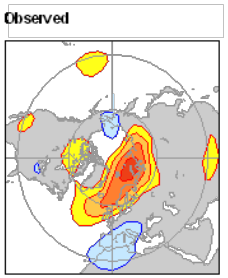
ACC: D+7 Z500 Forecast for Europe

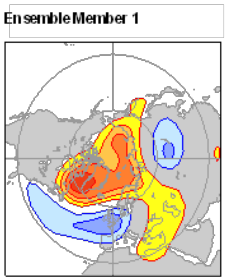


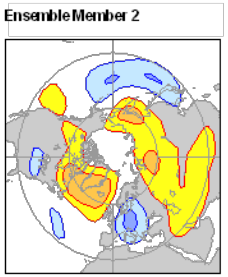
Zonal Average Mean T Analysis Increments

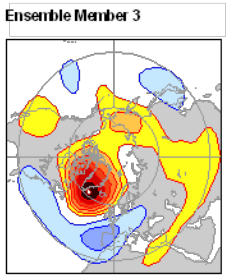


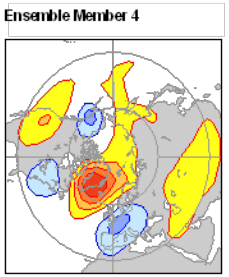
Z500 Anomalies: DJF 2005/06

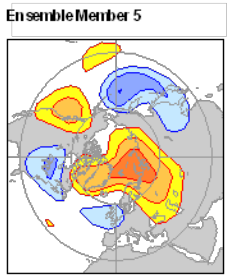




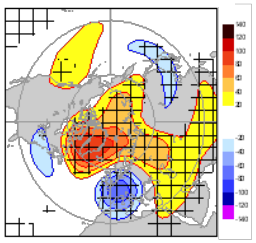


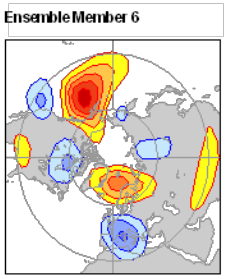


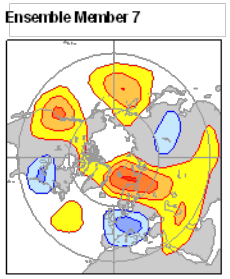


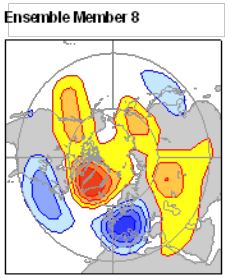


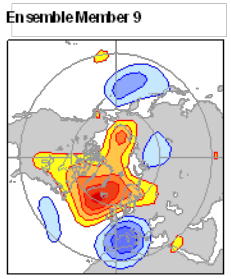
Ensemble Mean

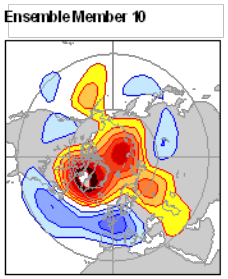


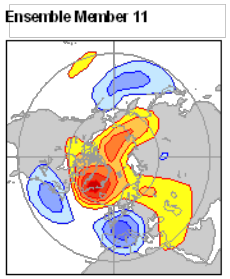


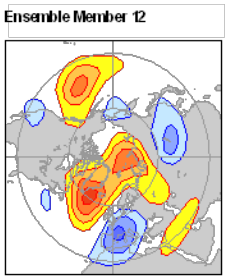


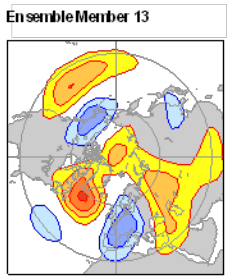


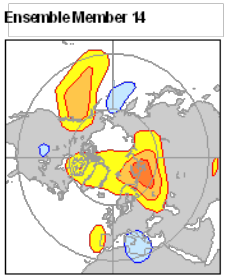


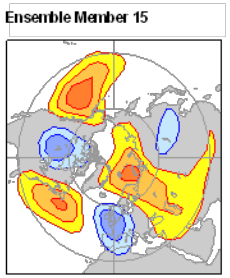


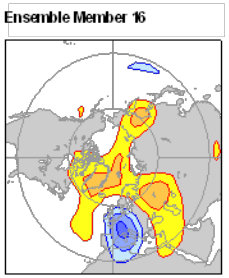


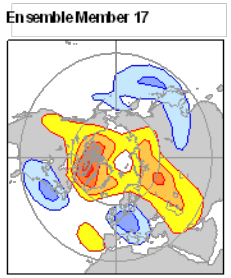






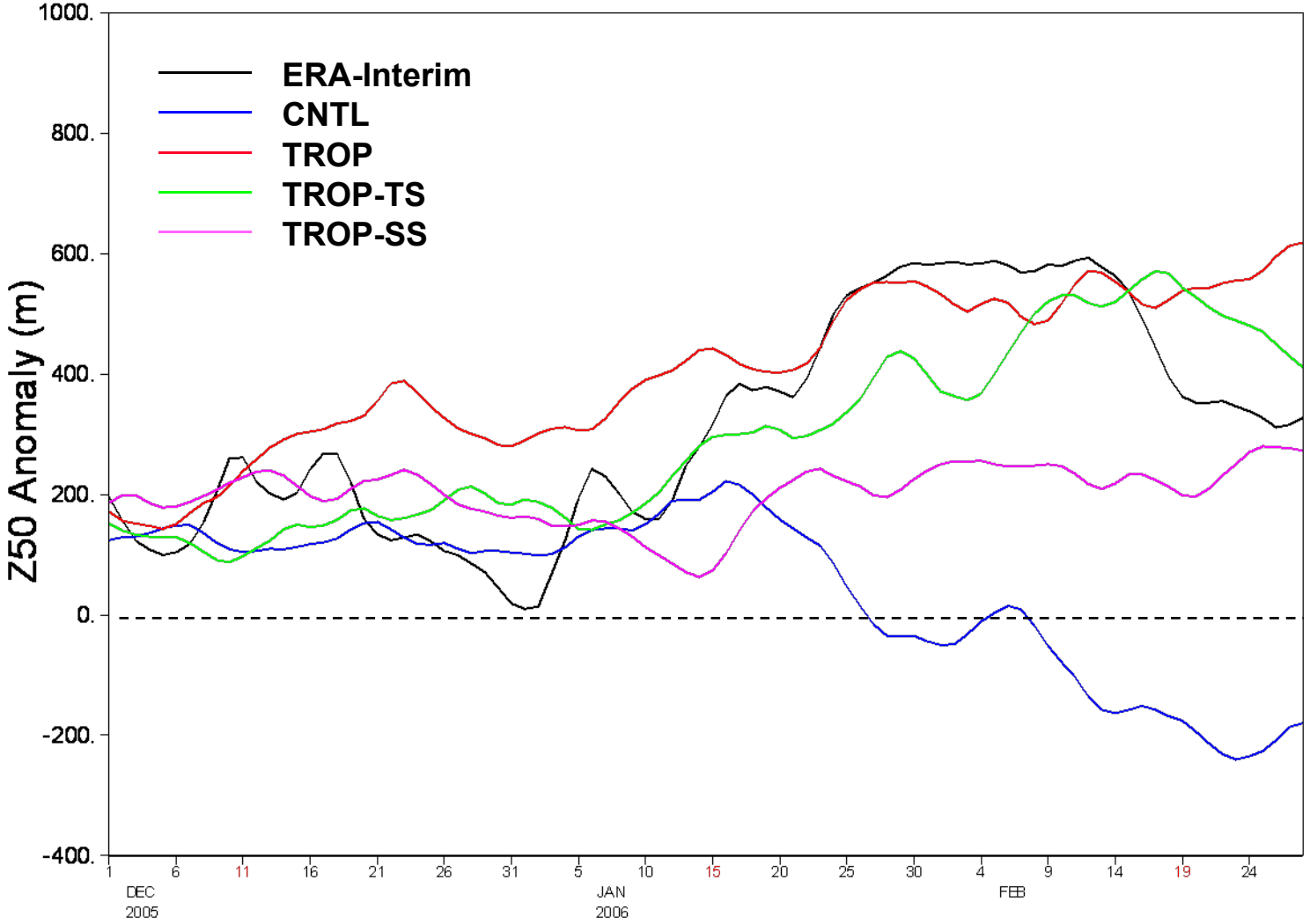




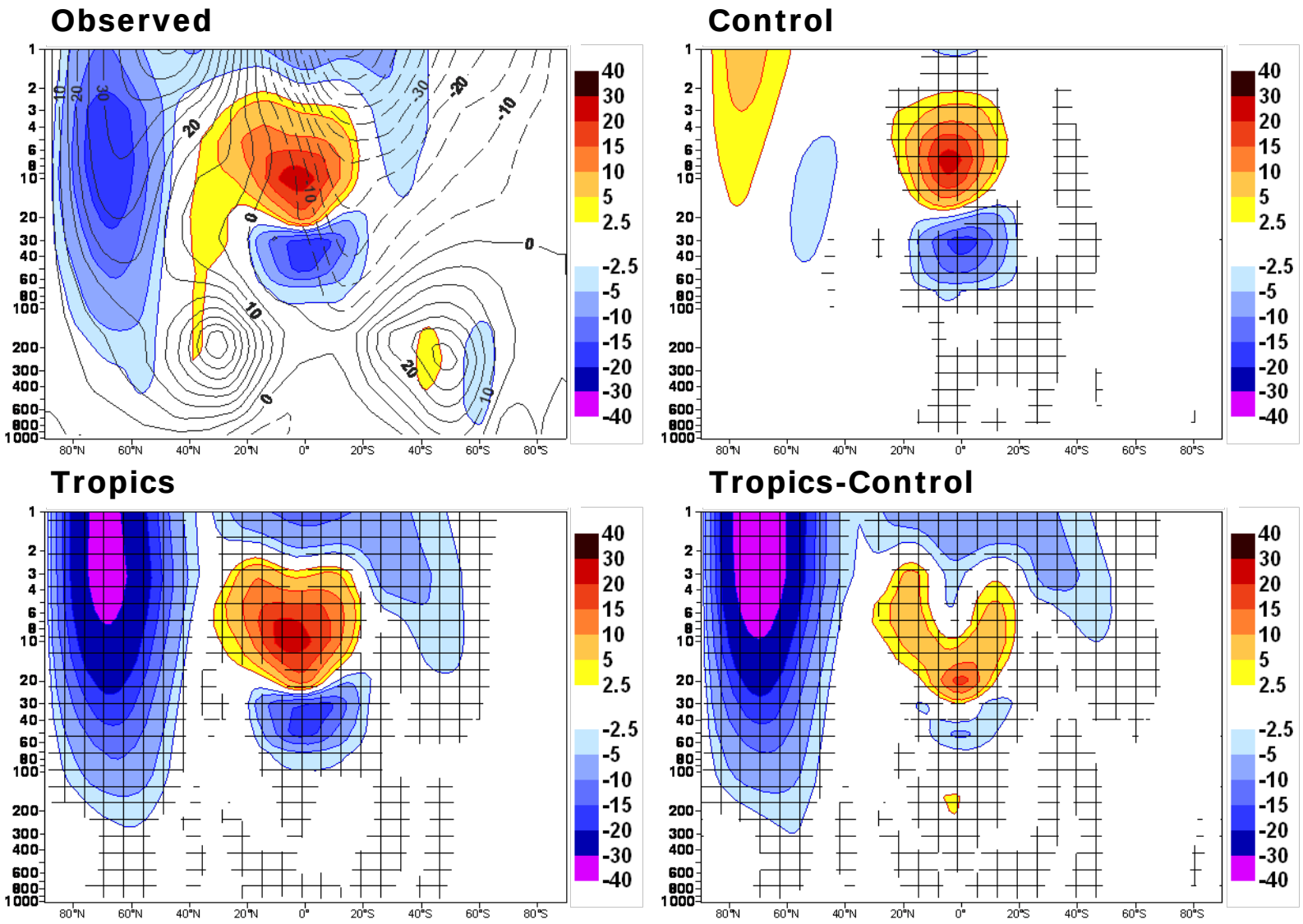


ECMWF

Ensemble Mean Anomaly: Polar Z50

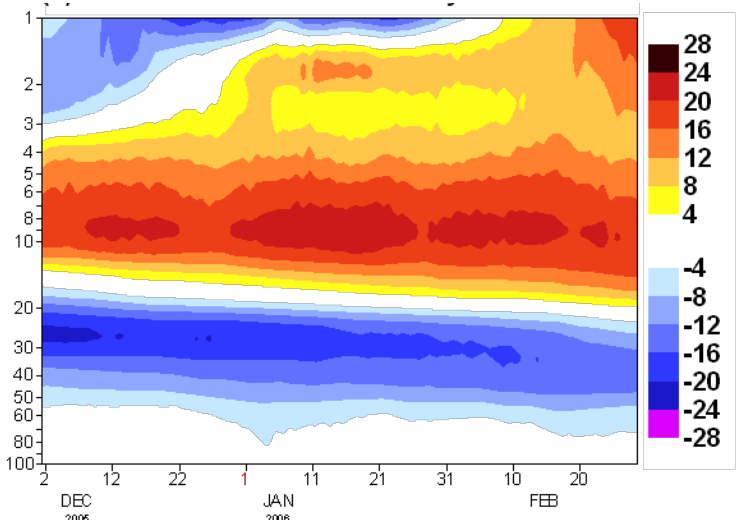


Quasi-Biennial Oscillation

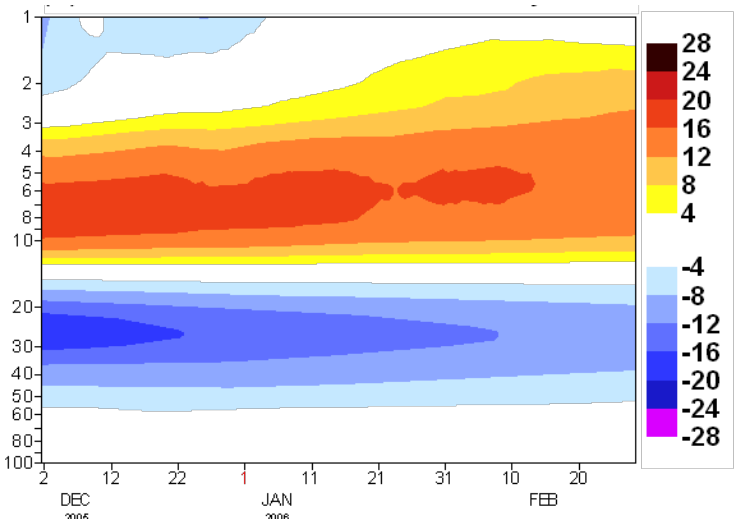


Quasi-Biennial Oscillation

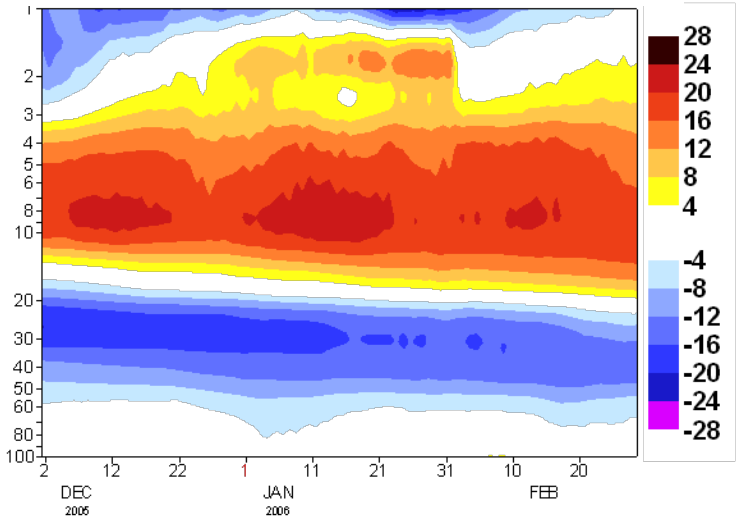
Observed



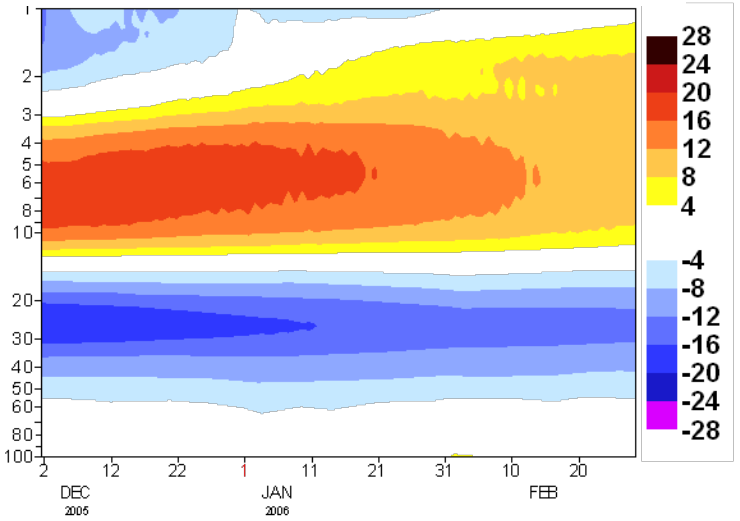
Control



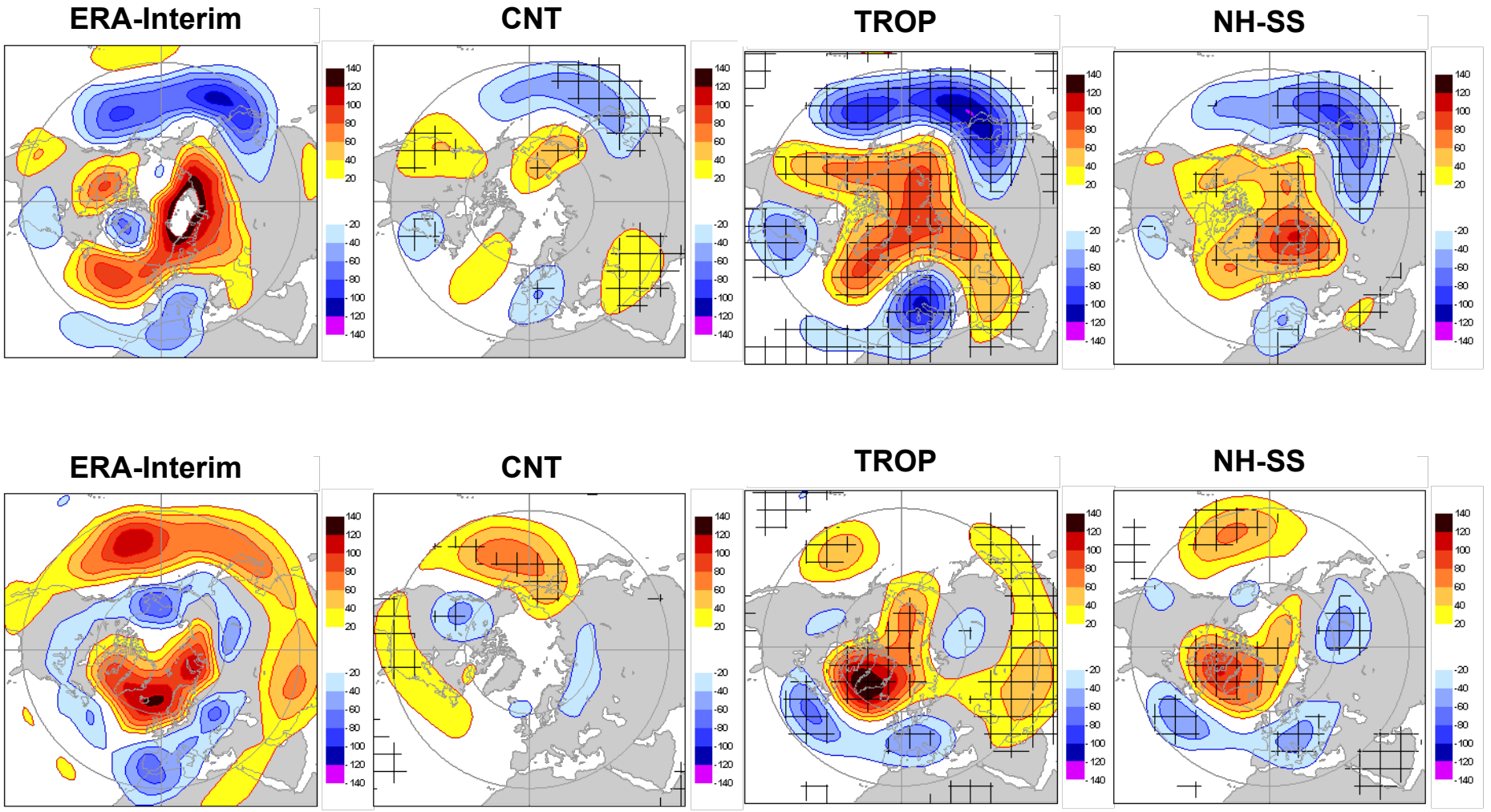
Tropics



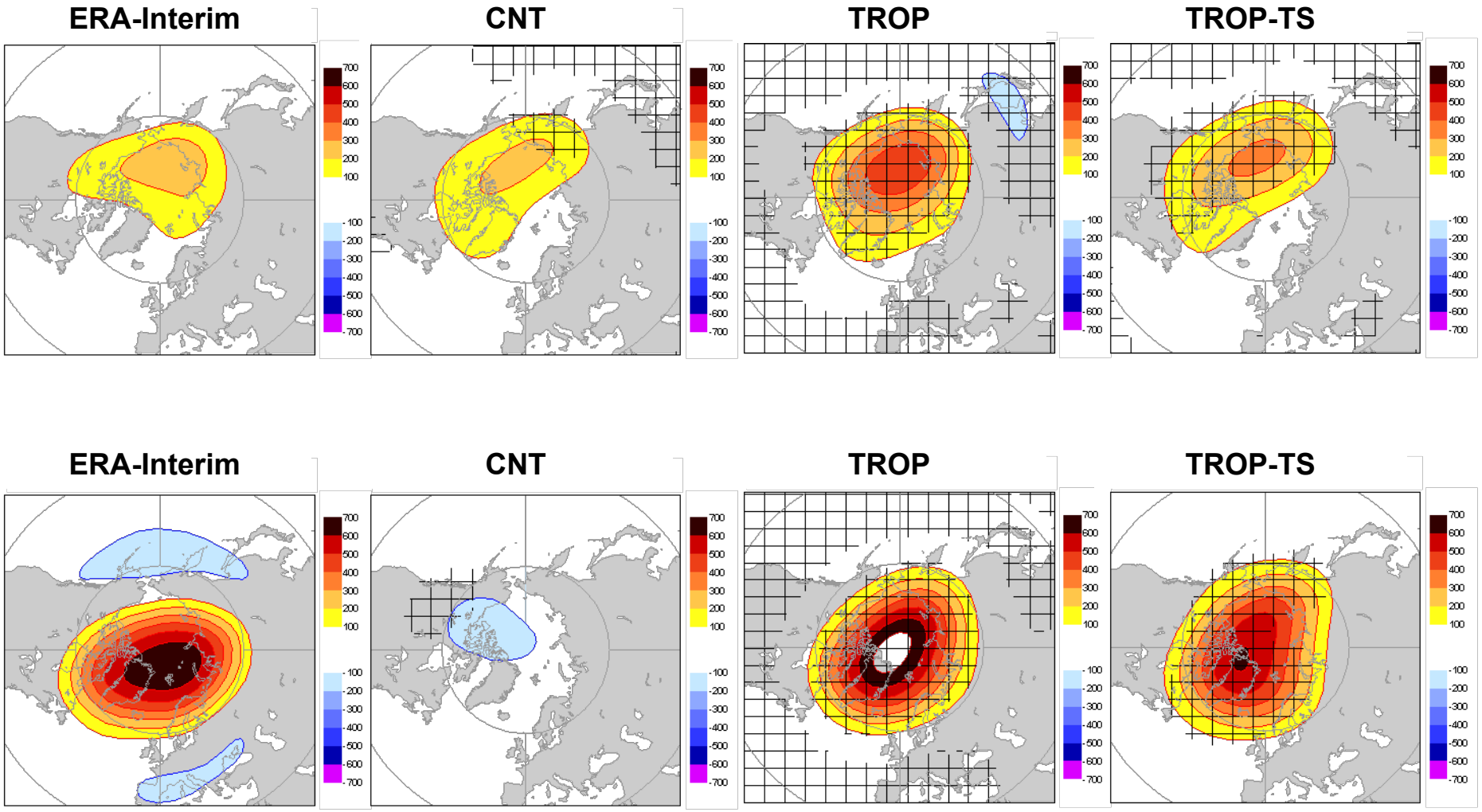
Tropical Troposphere



Z500 Anomalies: Early vs. Late Winter

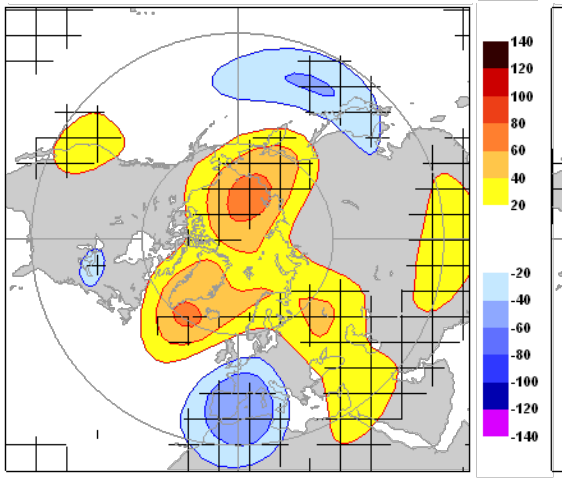


Z50 Anomalies: Early vs. Late Winter

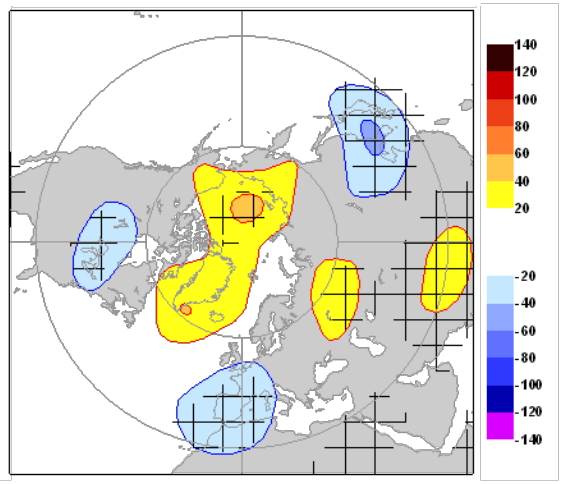


Which Tropical Region is Important?

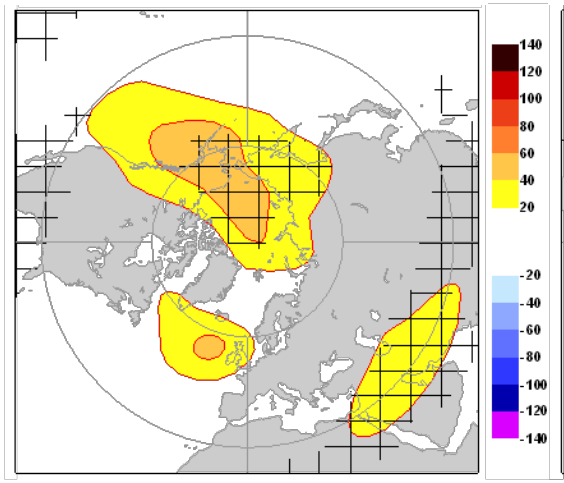
TROP-TS



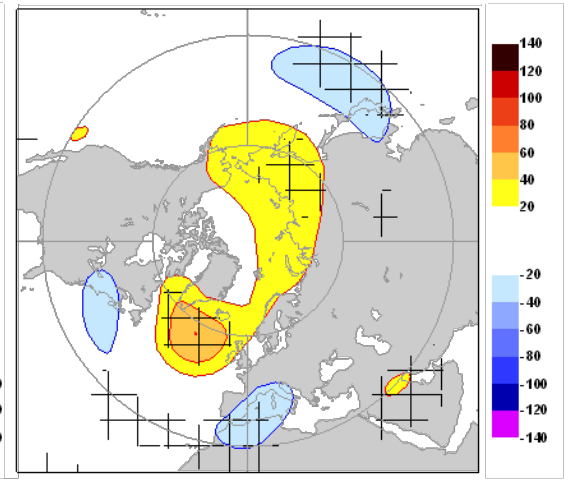
TROP-TS: 0-90E



TROP-TS: 150E-120W



TROP-TS: 90E-0



Mechanisms: RWS Diagnostics