Performance of the ECMWF Model in Polar Regions

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(ECMWF Annual Seminar on Polar Meteorology)

Thanks to: Martin Leutbecher + colleagues from RD

Outline

- Analysis
- Predictability issues
- Specific Phenomena
- Systematic Error

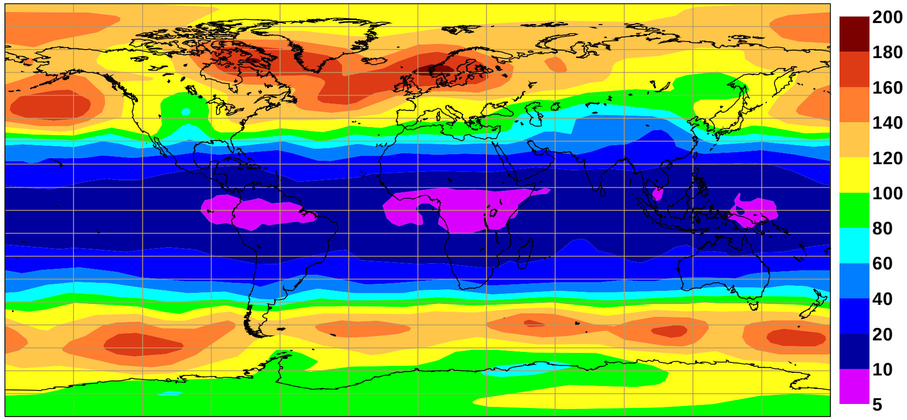
Focus

- **Region**
  - Primarily Northern Hemisphere
- **Season**
  - Boreal winter (DJF and DJFM)
- **Atmospheric circulation**

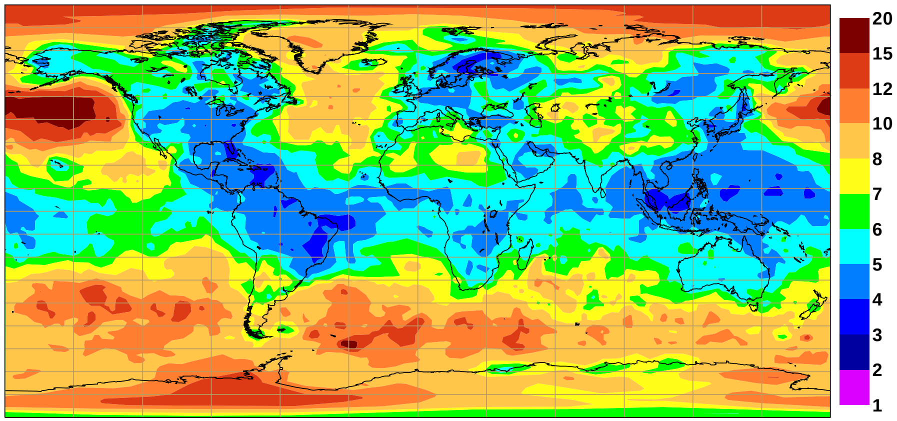
ERA-40 vs Operational Analysis

Total Z500 Variability

(a) Standard Deviation: Total Z500 Variability (ERA40, 2000-01)

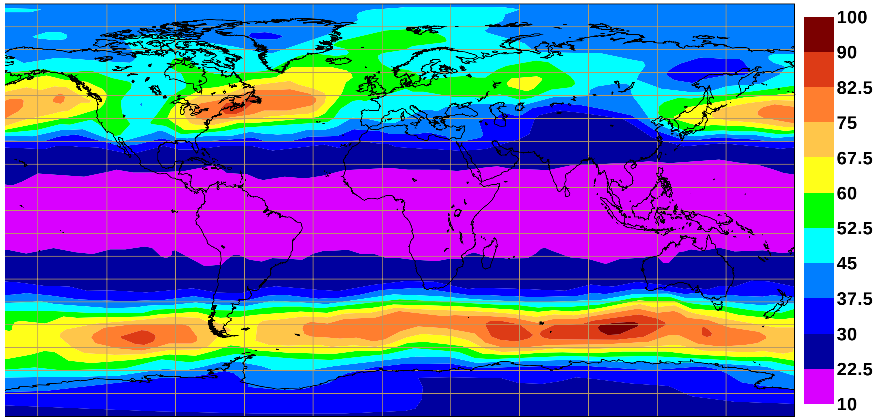


(b) Standard Deviation: Difference OD-ERA40 (2000-01)

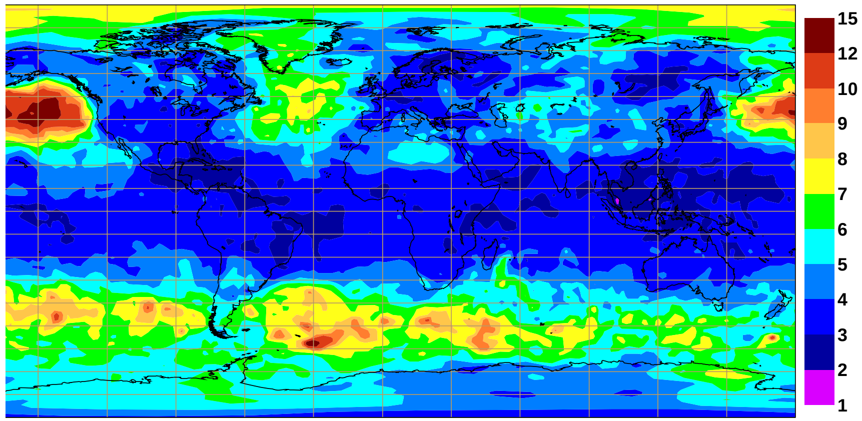


Synoptic Z500 Variability

(a) Standard Deviation: Synoptic Z500 Variability (OD DJF 2000-01)

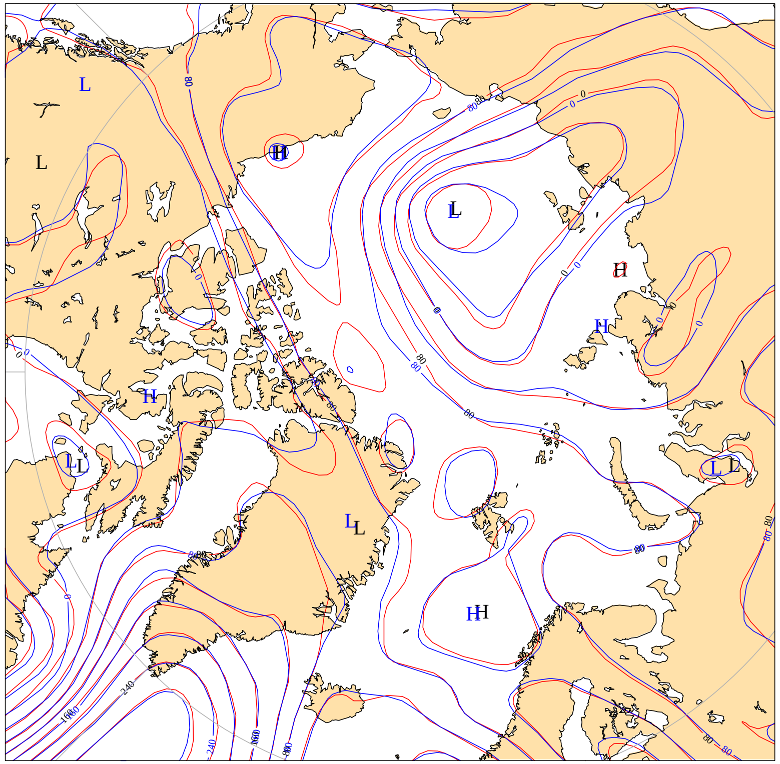


(b) Standard Deviation: Difference OD-E4 (Synoptic, DJF 2000-01)

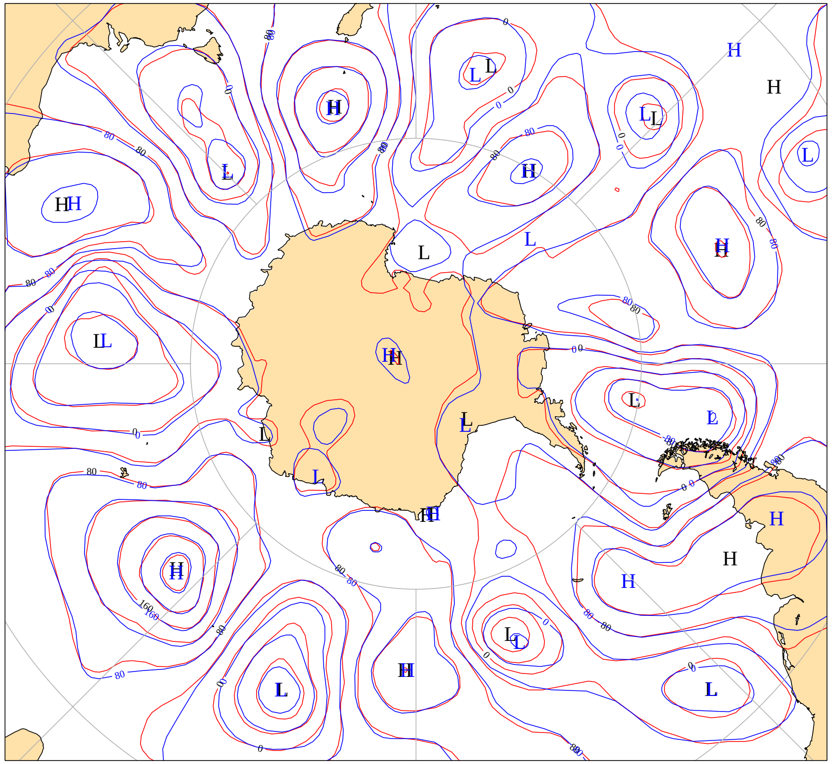


Synoptic-Scale Z500 Snapshots

3 December 2000 12UTC



7 December 2000 12UTC

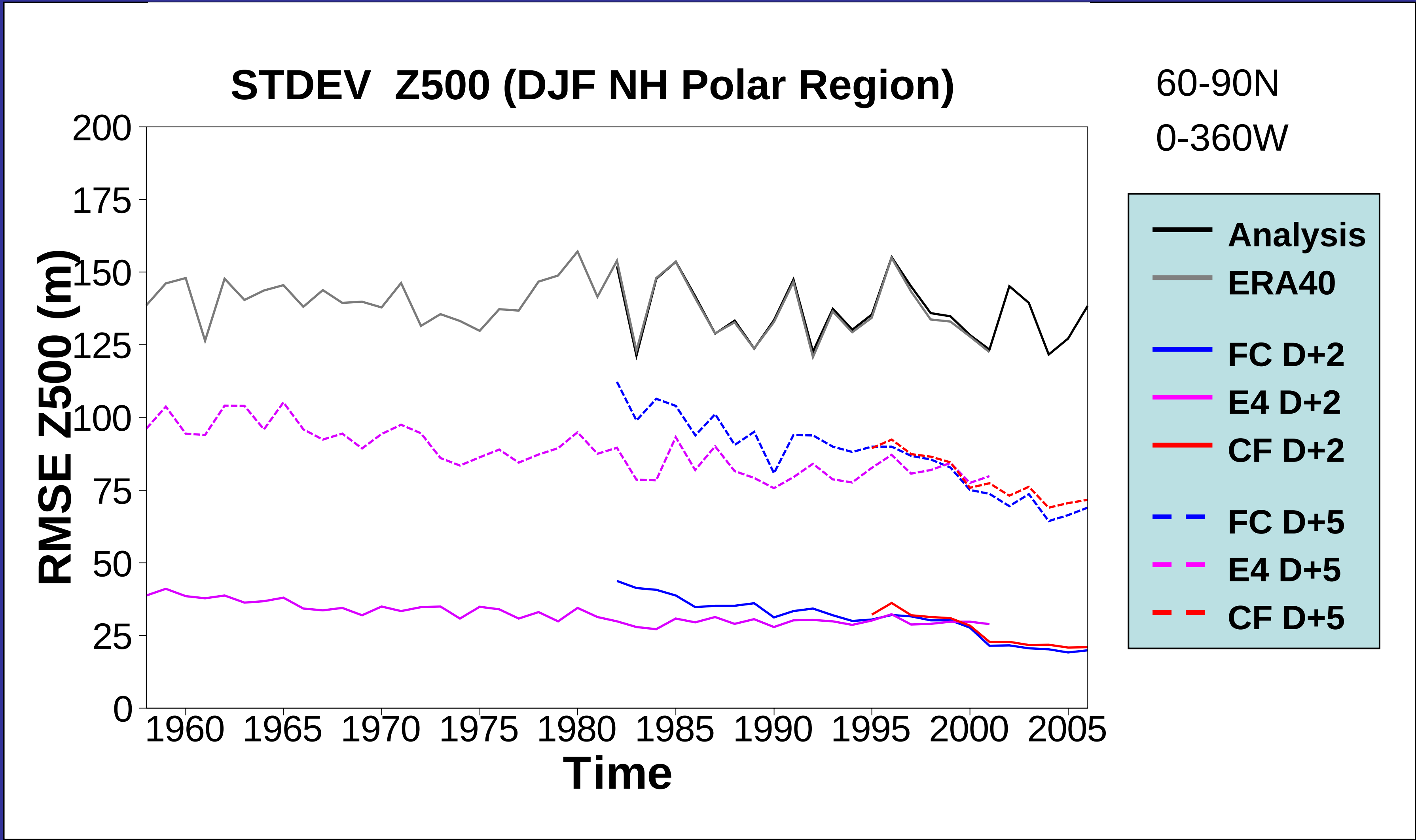


2-8 day bandpass-filtered data

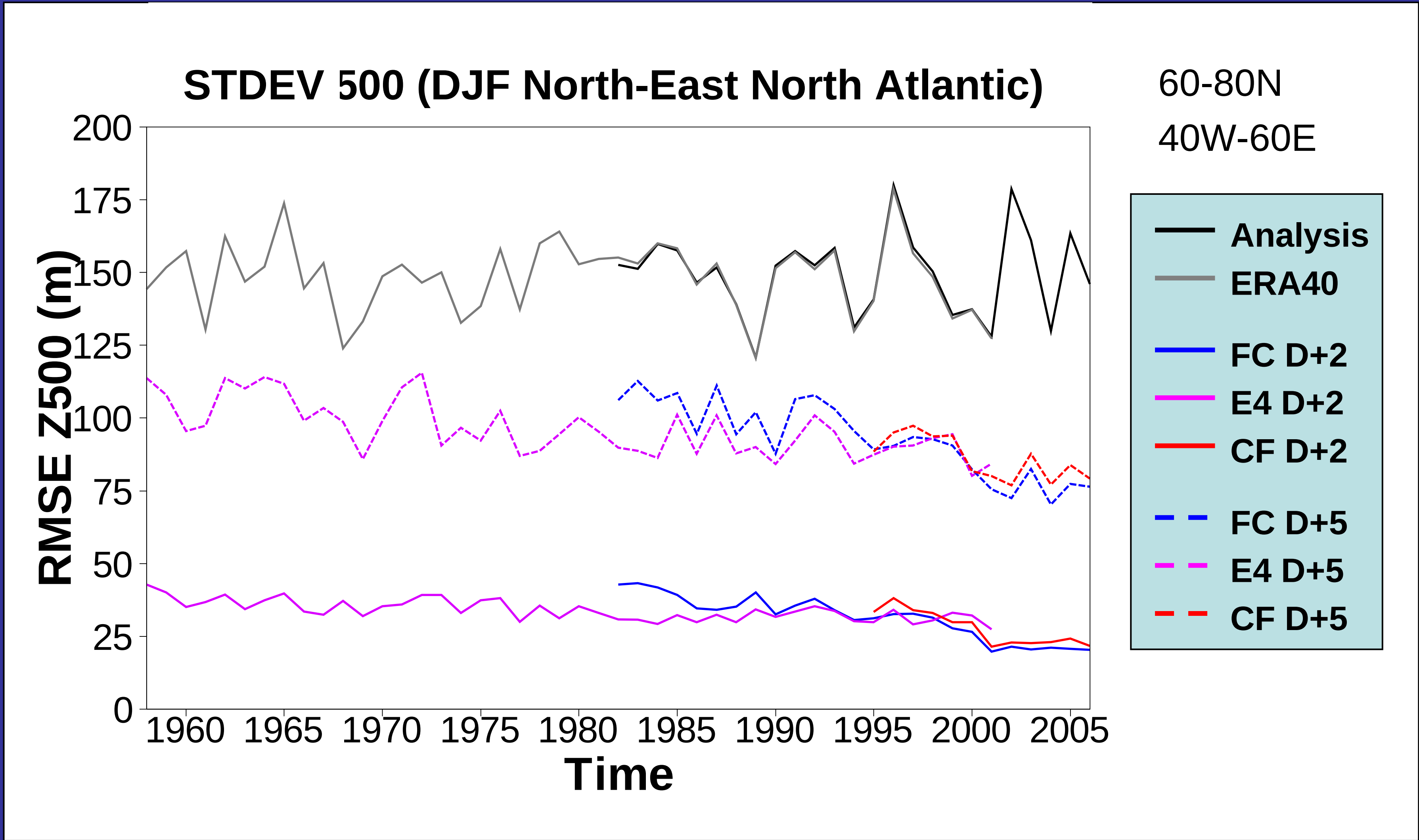
Conclusions

- Analyzed circulation seems good enough for the purposes of this study
- This is true for synoptic and planetary scales
- Clearly improvement in recent years

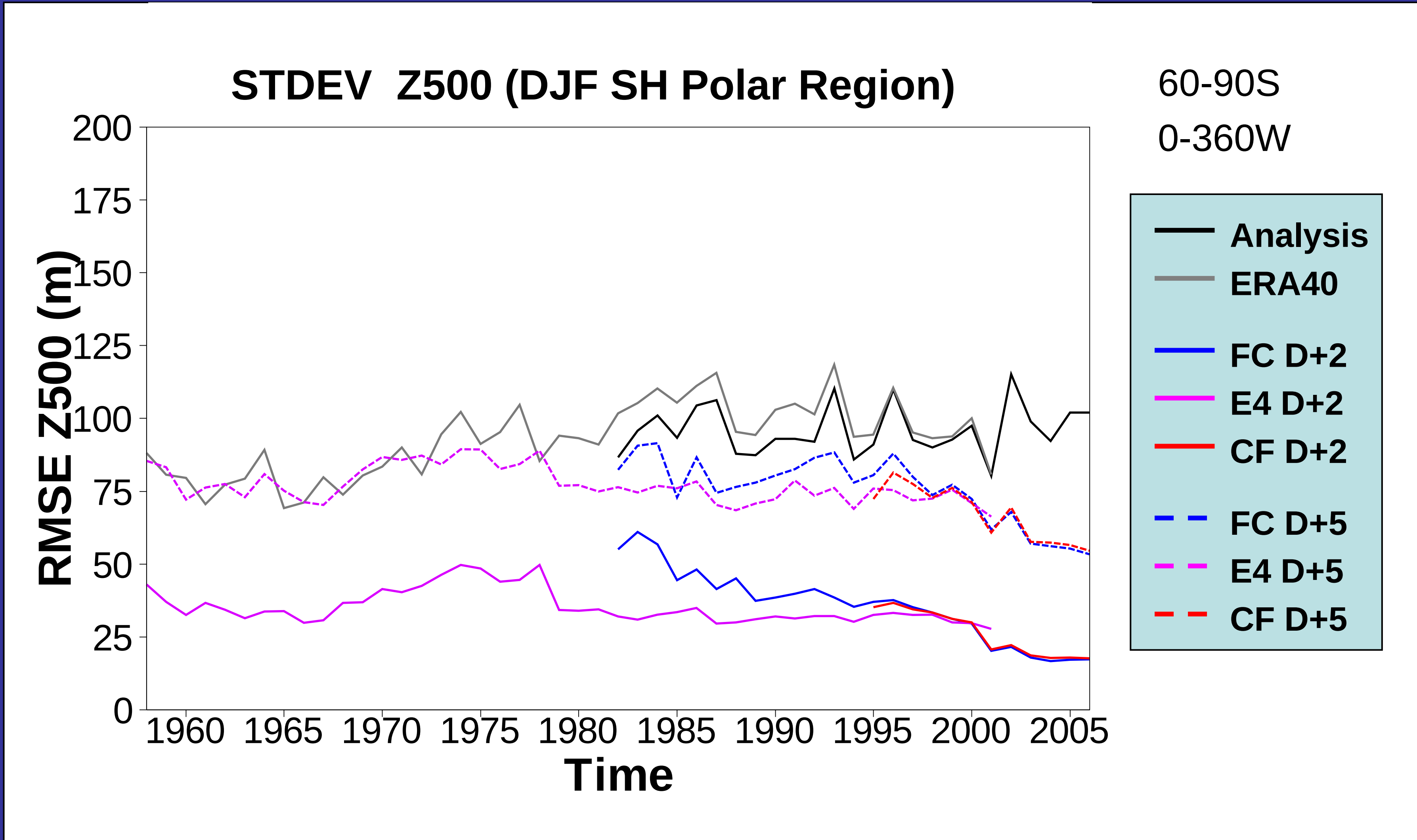
Temporal Evolution of Deterministic Forecast Error



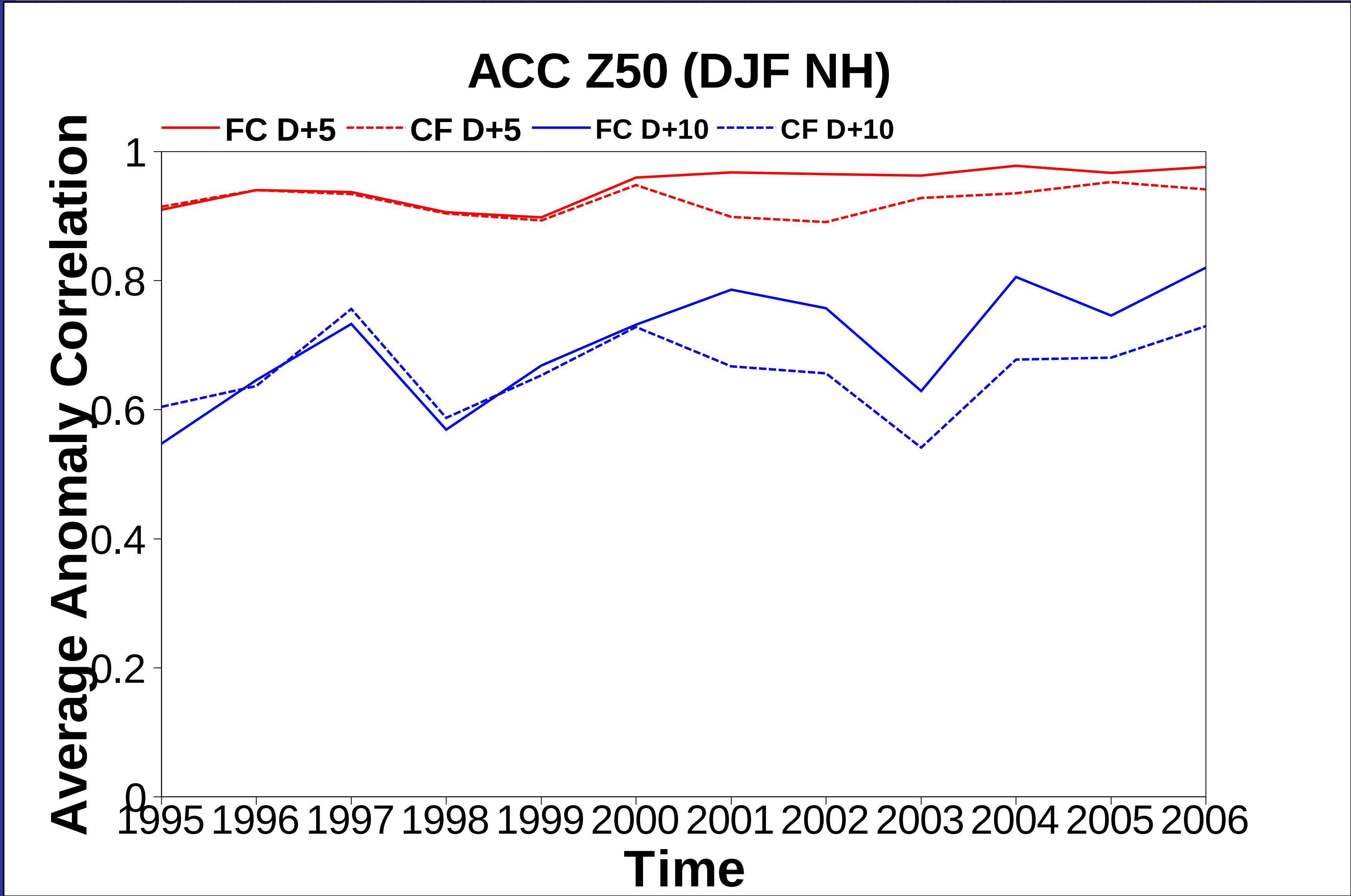
Temporal Evolution of Deterministic Forecast Error



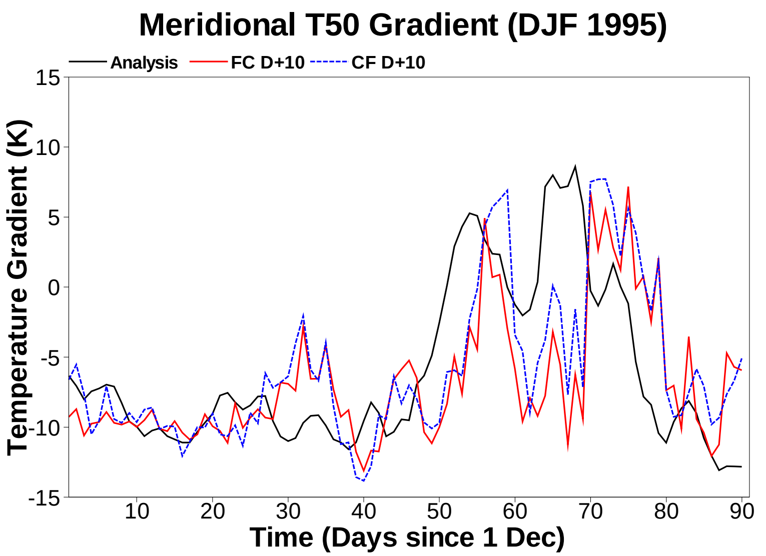
Temporal Evolution of Deterministic Forecast Error

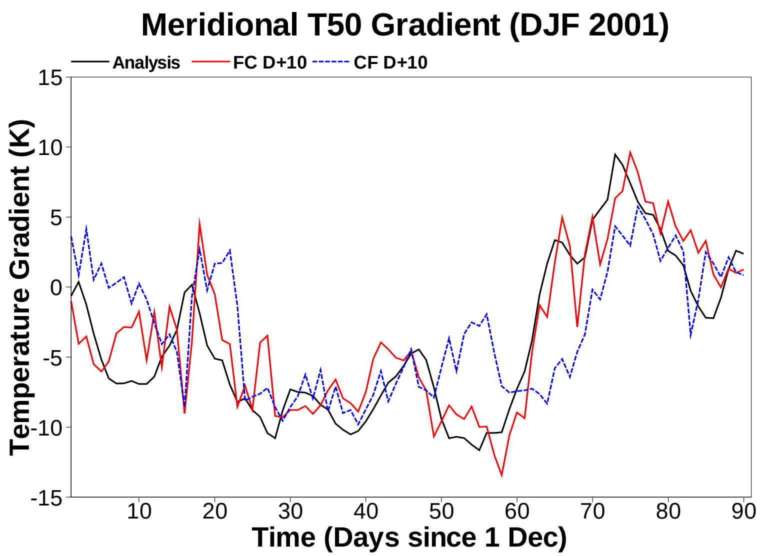


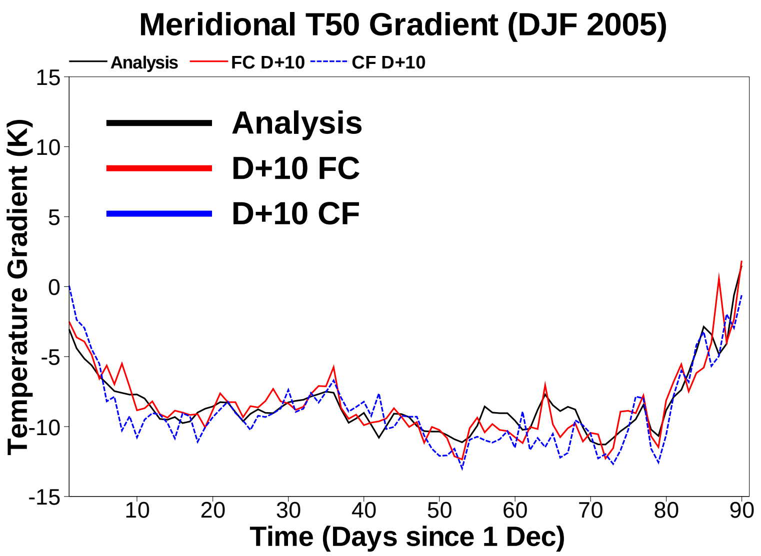
ACC Z50 DJF NH: 1995-2006

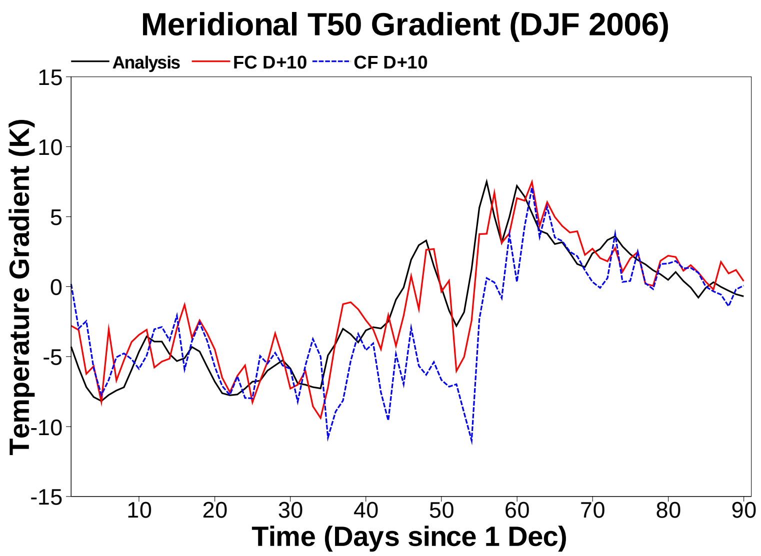


Time Series of the Meridional Temperature Gradient

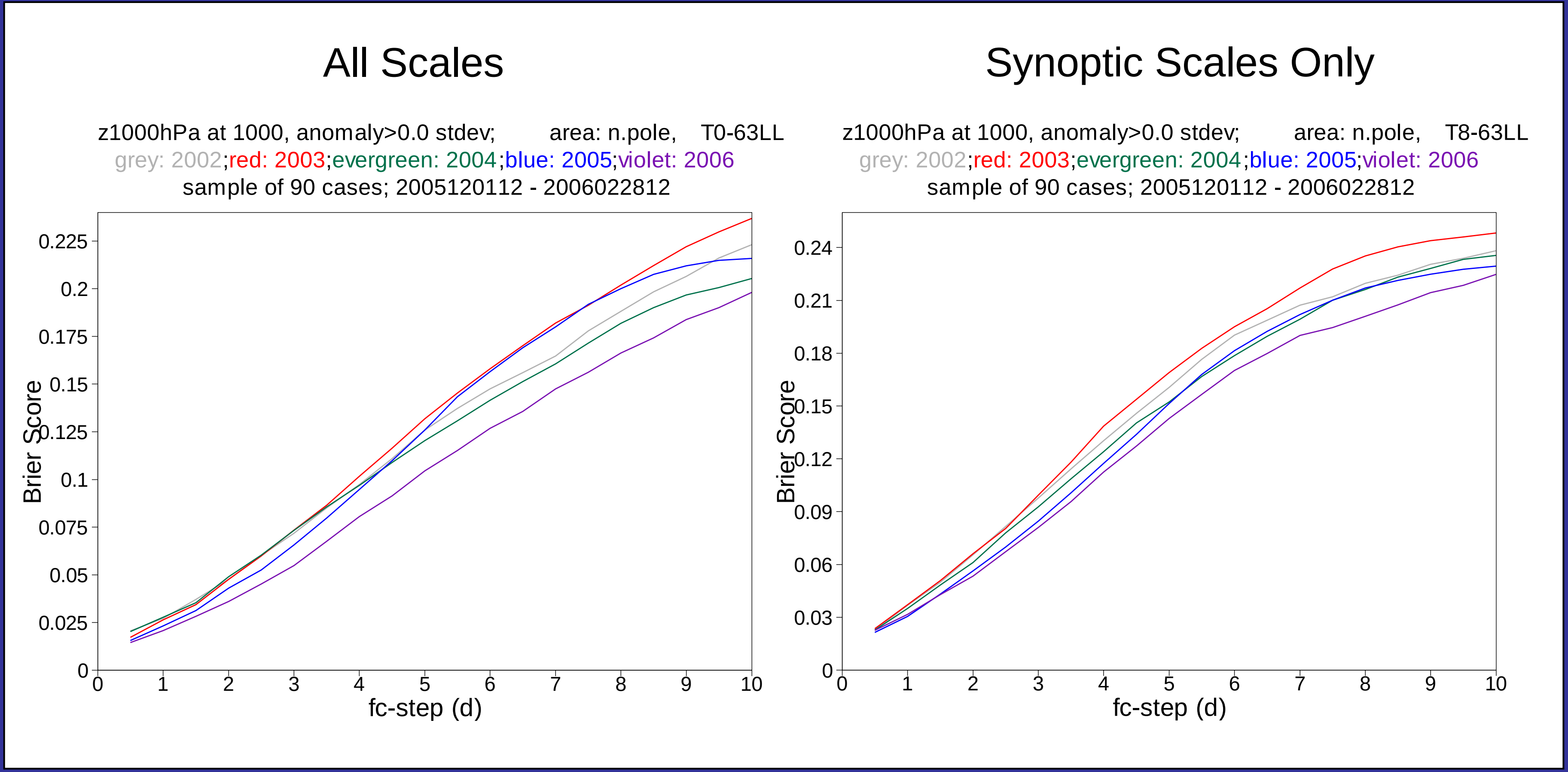








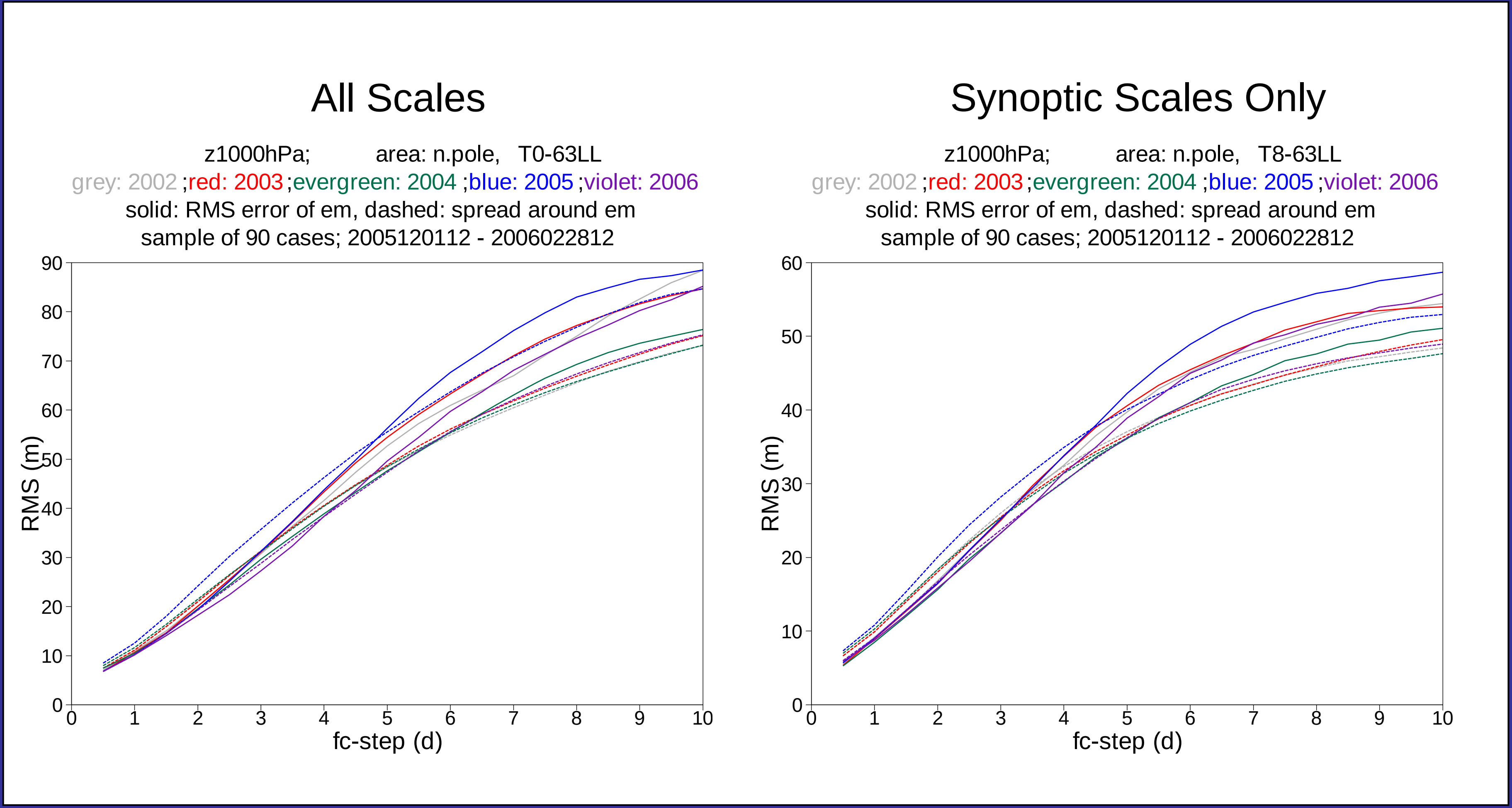
Probabilistic Skill: NH Polar Cap



Polar Cap=north of 65N

Courtesy of Martin Leutbecher

EPS Skill vs. Spread: NH Polar Cap



Solid lines: RMSE of EM

Dashed lines: Ensemble spread

Courtesy of Martin Leutbecher

Sensitivity of Forecast Error to Initial Conditions

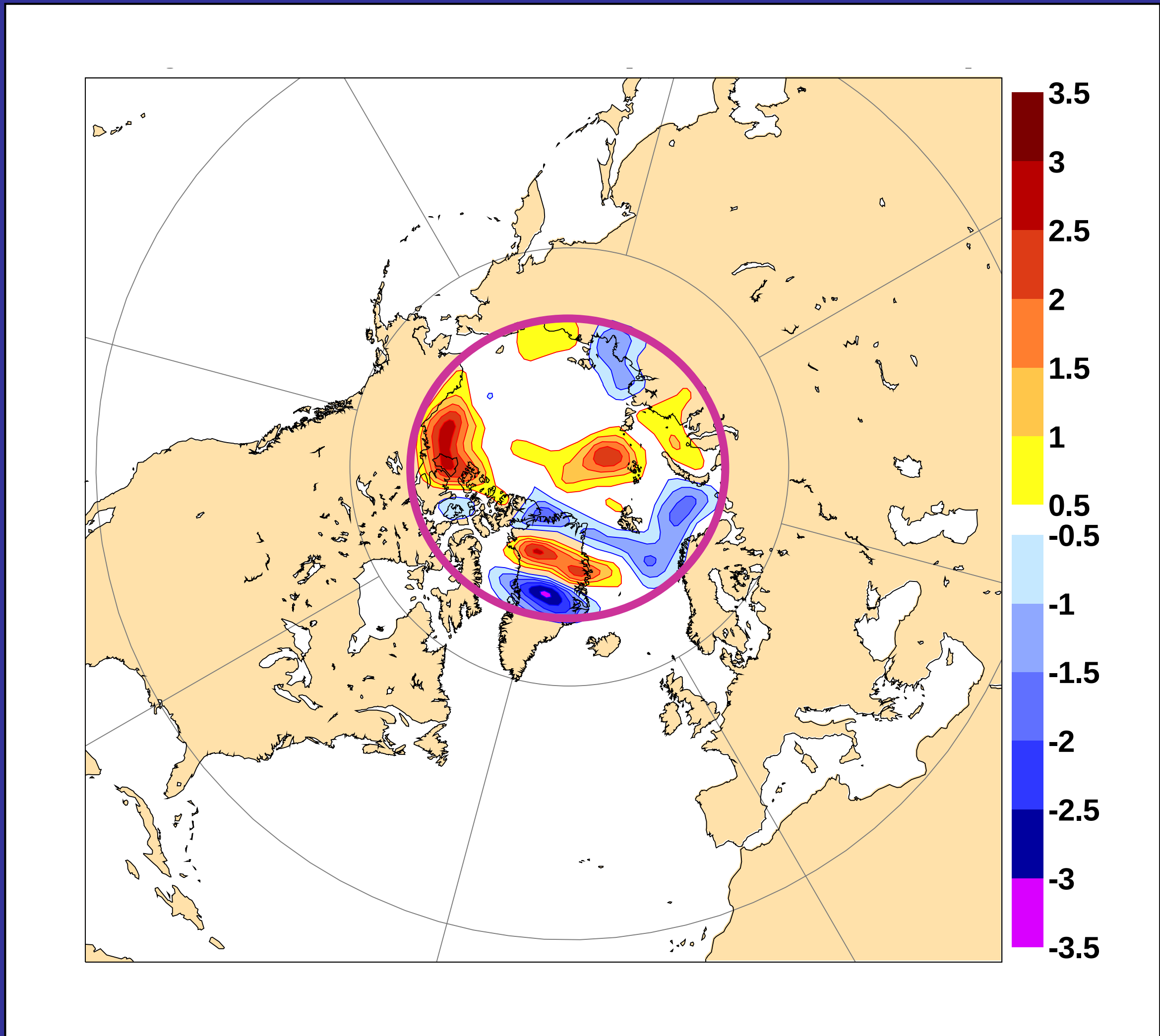
Q: How do perturbations to the initial conditions look like that have a large impact on forecast error north of 70N?

$$\nabla_0 J$$

$$\delta J = \left\langle \nabla_0 J, \delta \mathbf{x}_0 \right\rangle$$

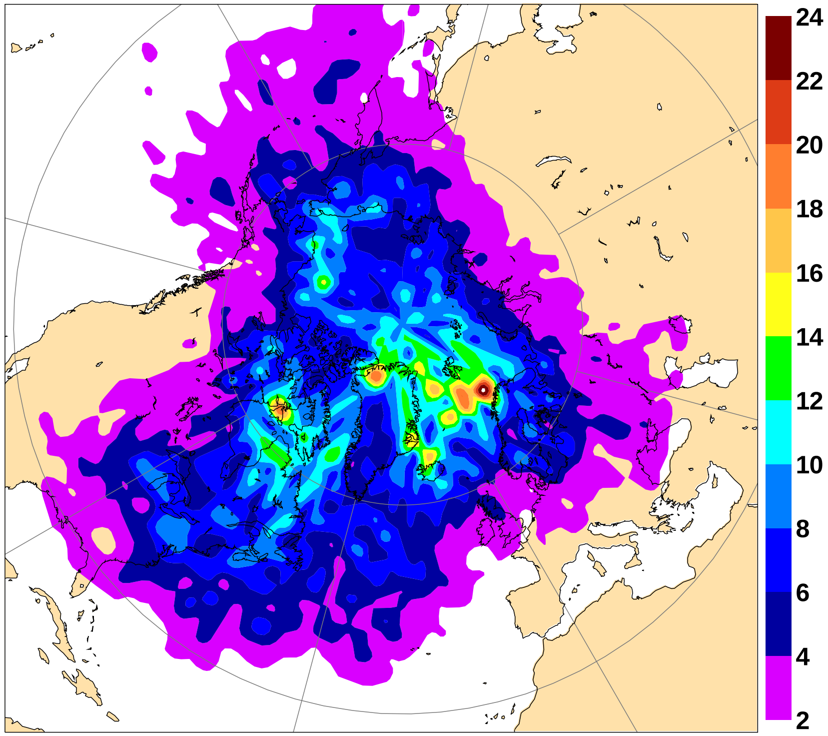
- **T159L60 TL/AD**
- **linearized physical processes**
- **Target: north of 70N**
- **48 hour forecast error**

D+2 Forecast Error in Polar Regions: Temperature at about 500 hPa (20041129)

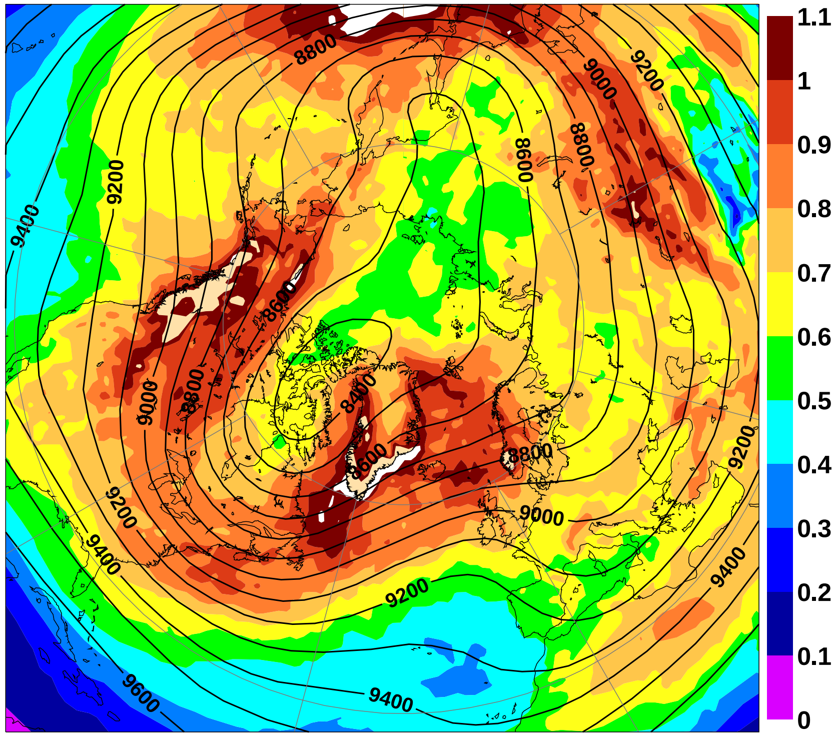


Forecast Sensitivity (DJFM 2004/05) to Initial Perturbations

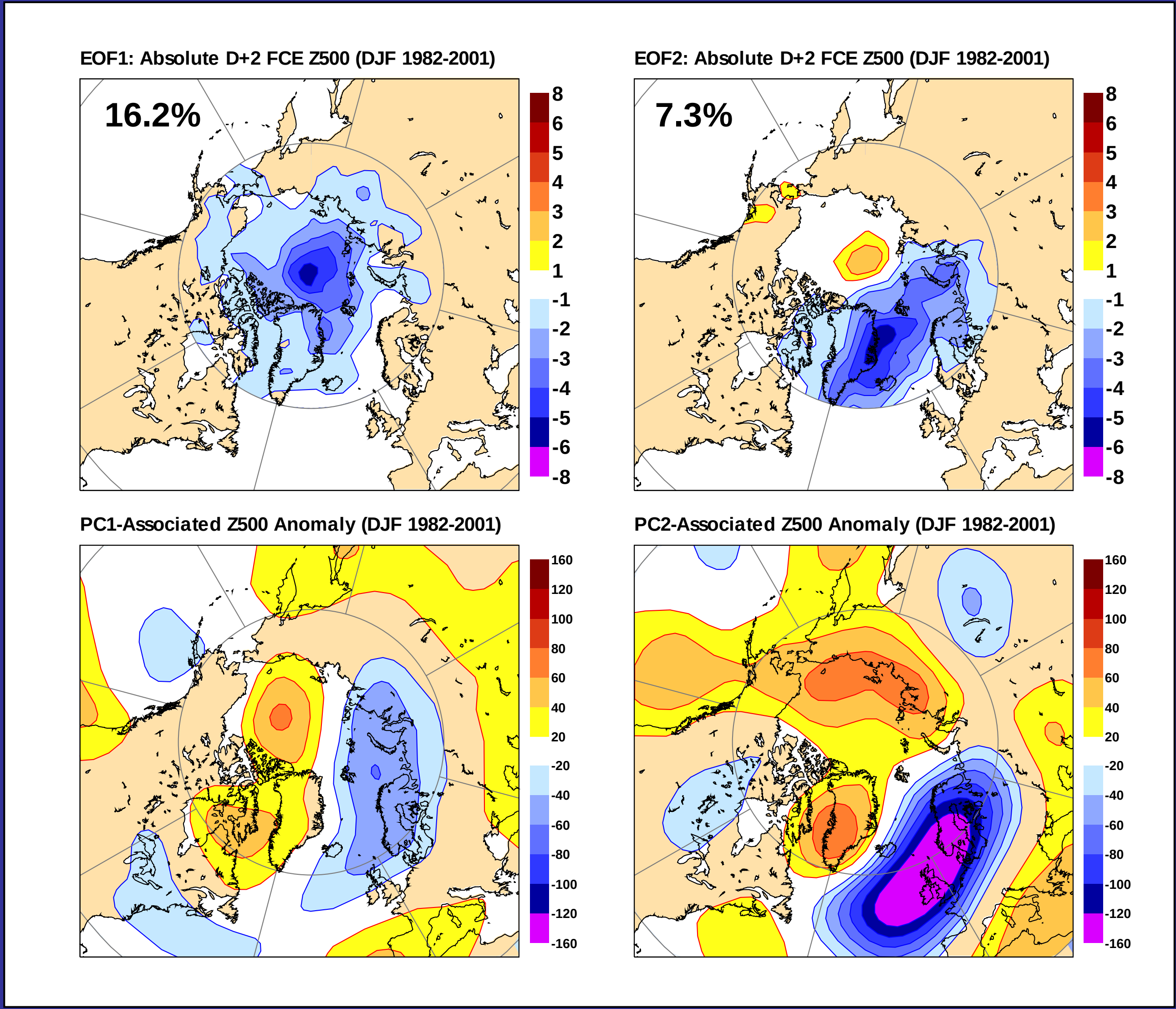
Mean Absolute Value: T-Sensitivity at about 500hPa



Eady Index, Z500

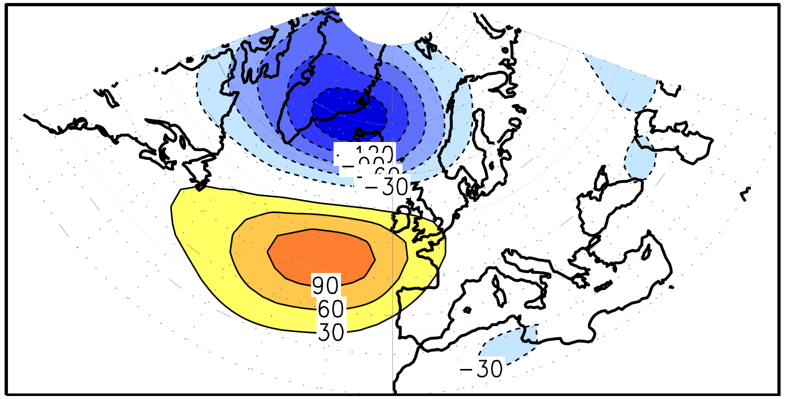


Flow-Dependent Deterministic Forecast Error (D+2, DJF, 1982-2001)

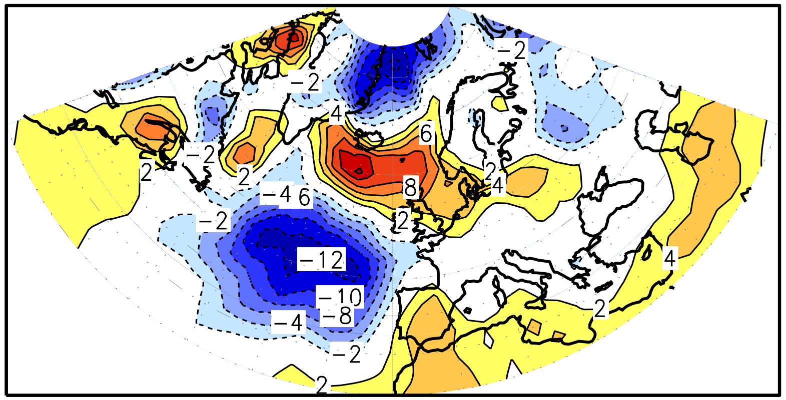


Flow-Dependent Deterministic Forecast Error

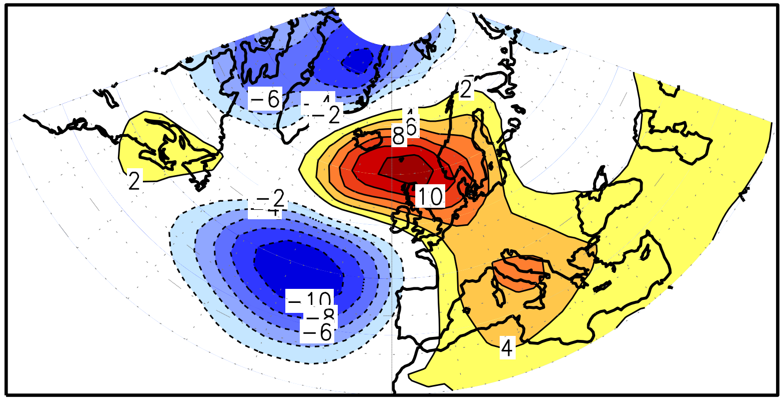
Composite Z500 (01/96–12/02)
Analysis vs NAOI



Composite Z500 (01/96–12/02)
D+5 Forecast Error vs NAOI



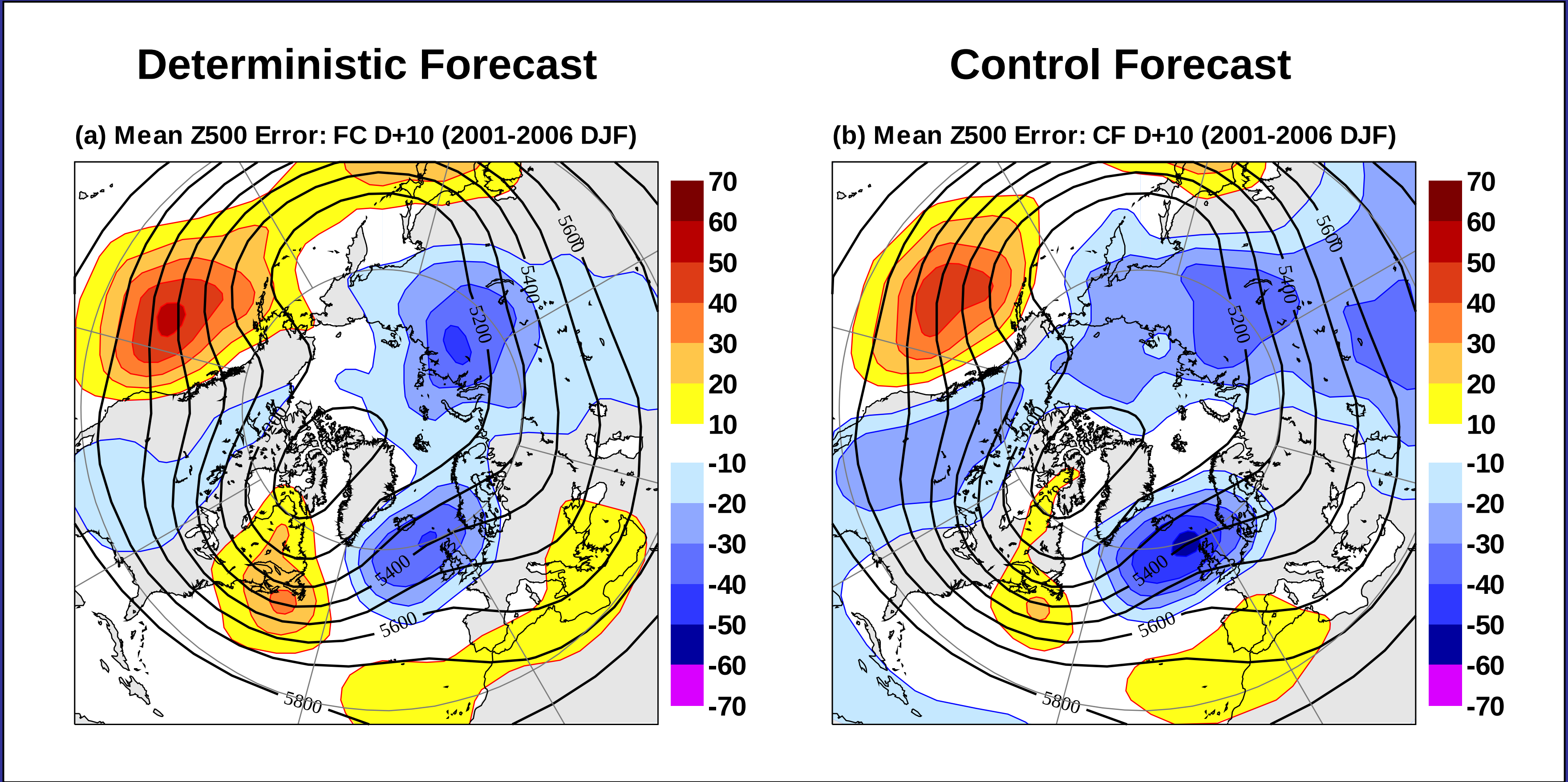
Composite Z500 (01/96–12/02)
D+5 EPS Spread vs NAOI



Conclusions

- Substantial improvements in the predictive skill in polar regions
  - Troposphere and stratosphere
  - Deterministic and probabilistic
  - Resolutions seems to be a key-element
- Mid-latitude North Atlantic has an impact on high-latitude forecast skill (flow-dependent)
- Deterministic forecast error is flow-dependent
- EPS captures flow-dependence in the mid-latitudes (also polar regions?)

Mean Z500 Errors at D+10 (DJF)



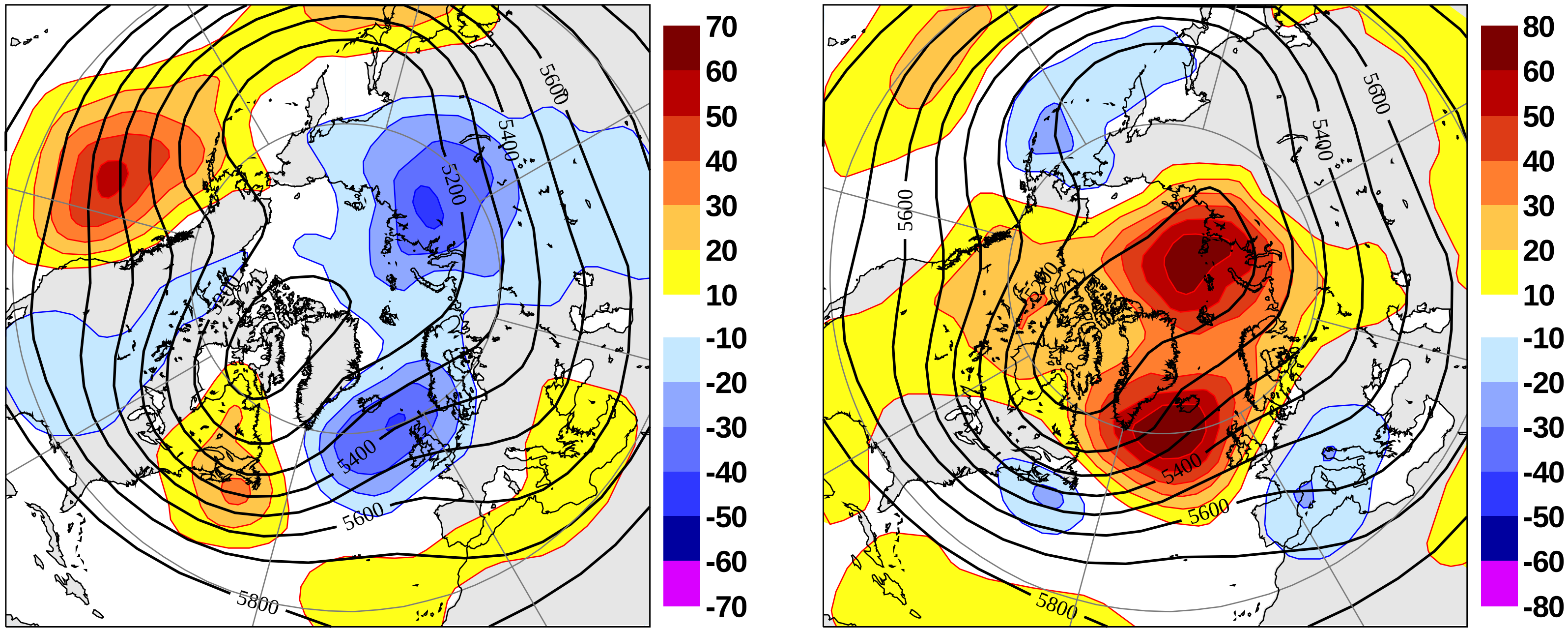
Spurious Systematic Z500 Error?

Mean D+10 Forecast Error

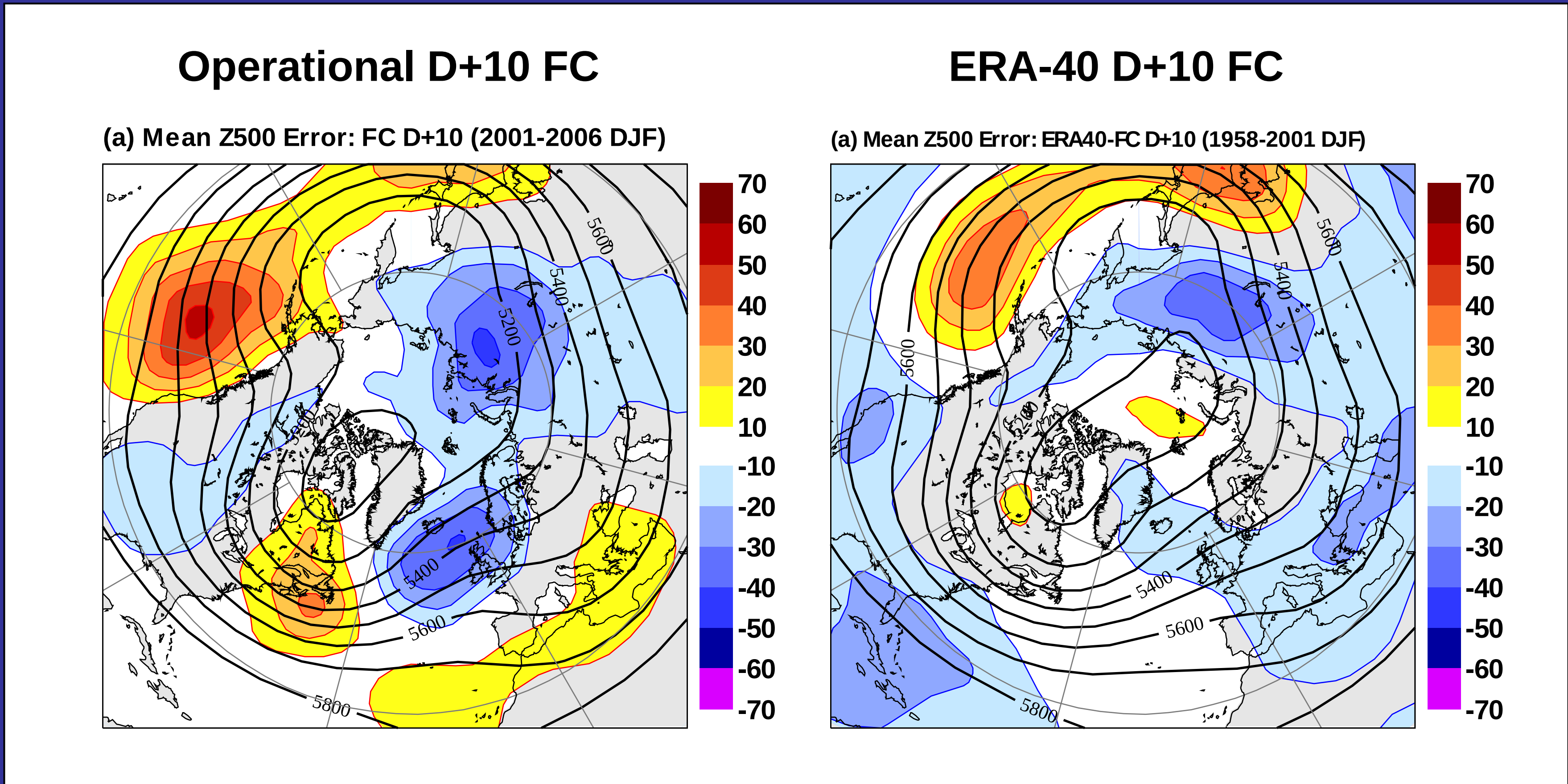
(DJF 2001-06)

Observed Anomaly

(DJF 2001-06)



Spurious Systematic Z500 Error?



Jung, QJ, 2005

Conclusions

- Systematic errors of the circulation are difficult to detect at high-latitudes (large decadal-scale variations)
- Loss of predictability might be misinterpreted as biases
- Long time series are necessary (reforecasts)
- ERA-40 reforecast (D+10) show rather little systematic error in polar region (NH)
- However, in some region systematic errors continue to grow beyond D+10…

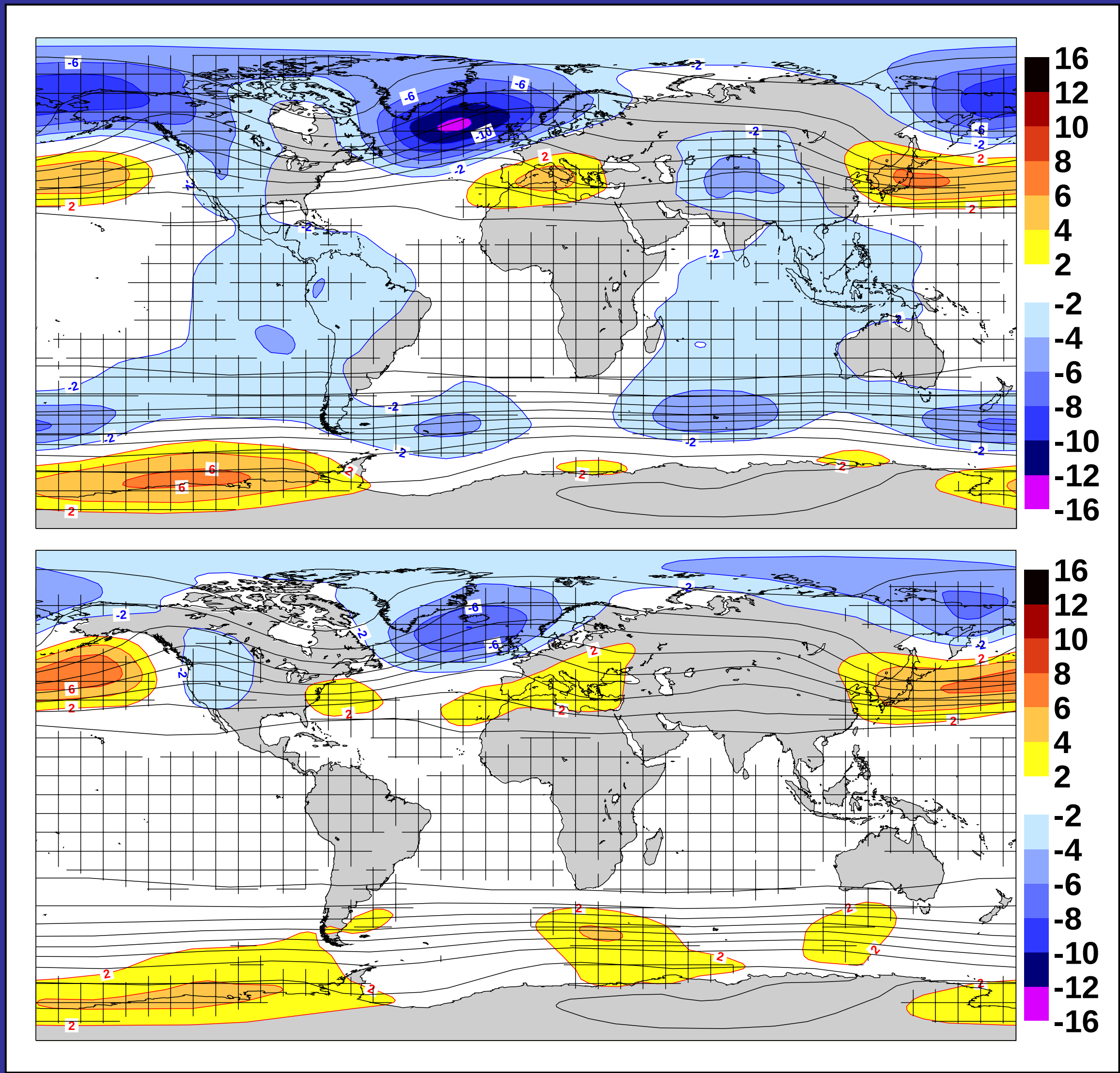
Seasonal Integrations

- **Atmospheric model only (different model cycles and resolutions)**
- **Lower boundary conditions: Observed SSTs (uncoupled)**
- **Initial conditions: ERA-40 and/or OD analysis**
- **One run for each of a large number of winters (e.g., 1990-2005)**

Mean Z500 Error and Horizontal Resolution (DJFM 1990-2005)

T_L95L91-OBS

T_L511L91-OBS



Extratropical Cyclones: Questions

- How well do we simulate observed characteristics of high-latitude cyclones?
- How sensitive are the results to horizontal resolution?

Extratropical Cyclones: Experiments

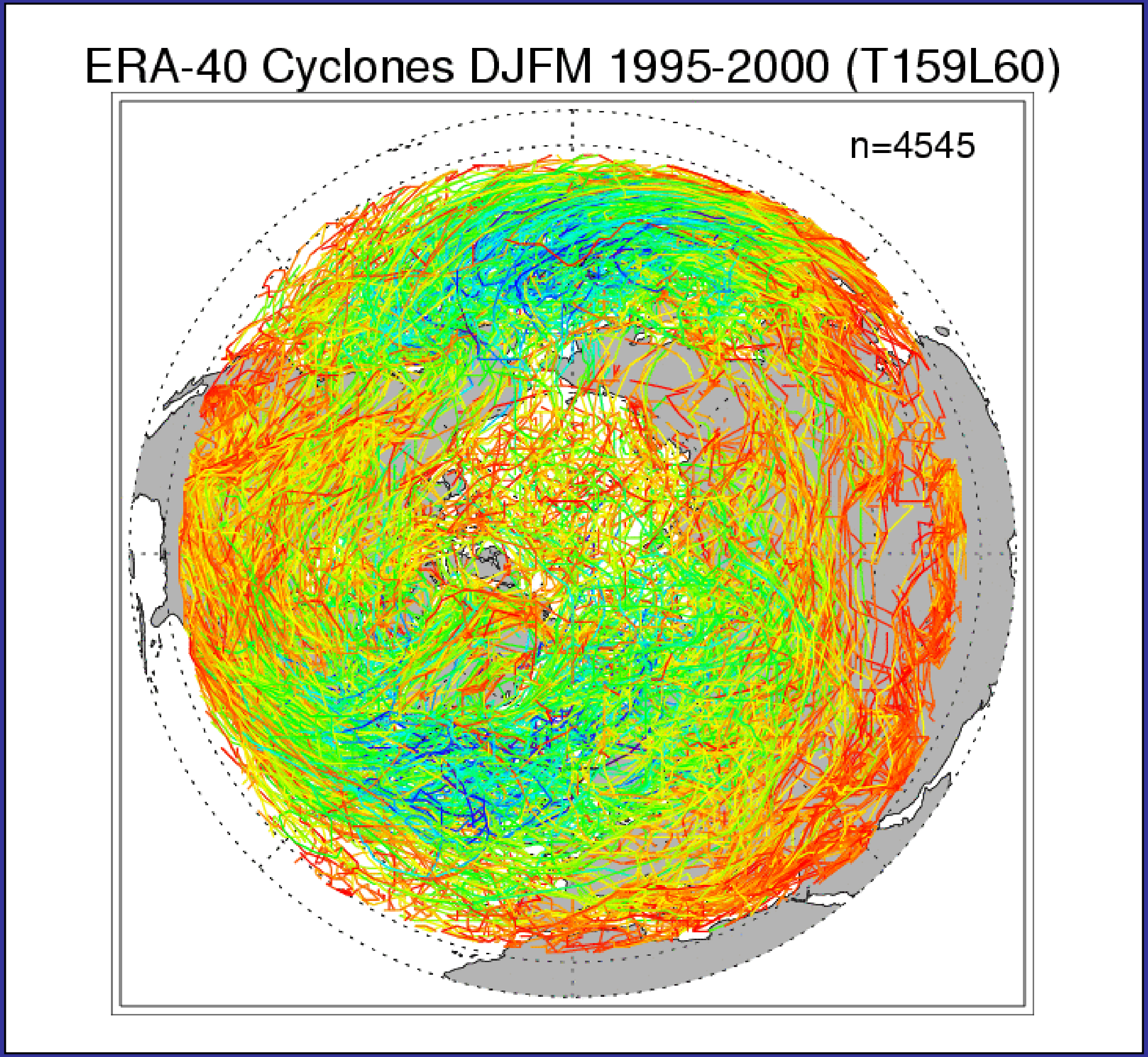
- **Three data sets:**
  - **ERA-40/Operational analyses for verification**
  - **T_L95L91 run (31R1)**
  - *T_L159L91 run (31R1)*
  - *T_L255L91 run (31R1)*
  - **T_L511L91 run (31R1)**
- **DJFM 1990-2005 (forecasts start 1st November)**
- **6-hourly MSLP interpolated to a common 2.5x2.5 deg grid**

Description up to T255 in Jung et al. (2006), to appear in QJ

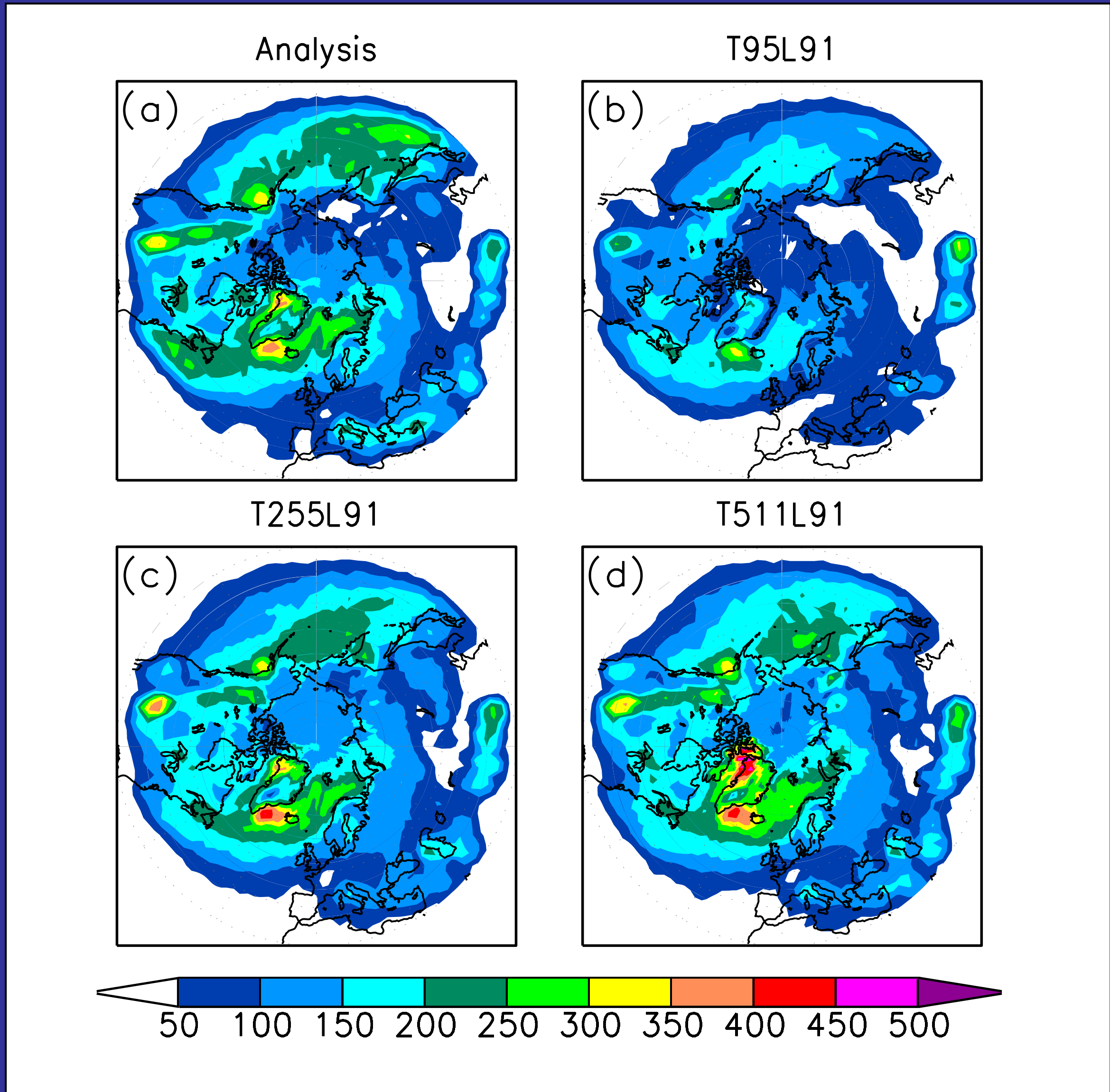
Tracking Software

- **Strategy: Searching for and tracking local minima in MSLP fields**
- **High temporal resolution required (6-hourly data)**
- **Data have been interpolated to 1-hourly data for tracking**
- **The accuracy of the software is very high (verified against manually tracked systems)!**
- **The software has been developed by Sergey Gulev and co-workers**

Extratropical Cyclone Tracks and Pressure

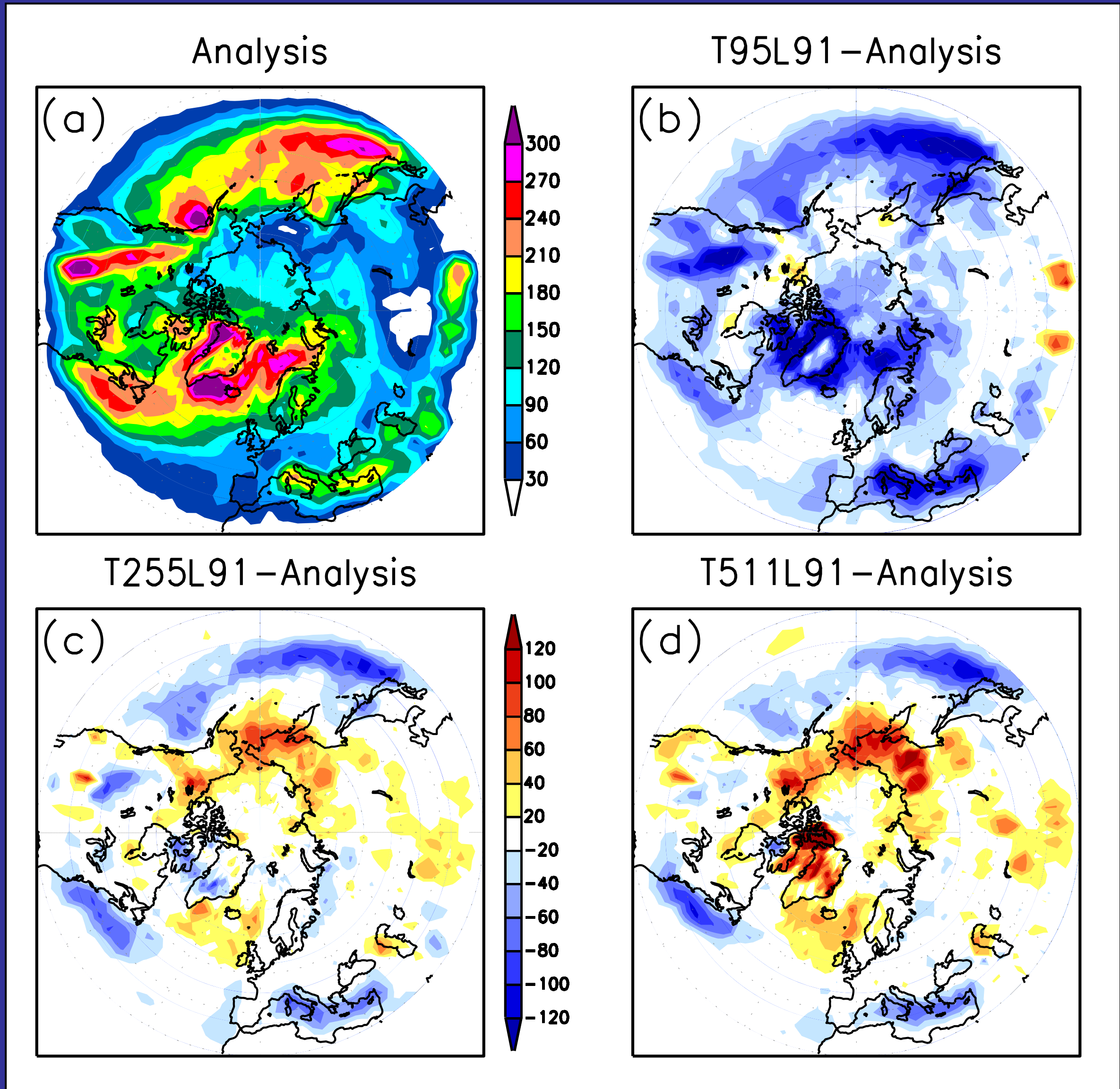


Number of Extratropical Cyclones (1990-2005)

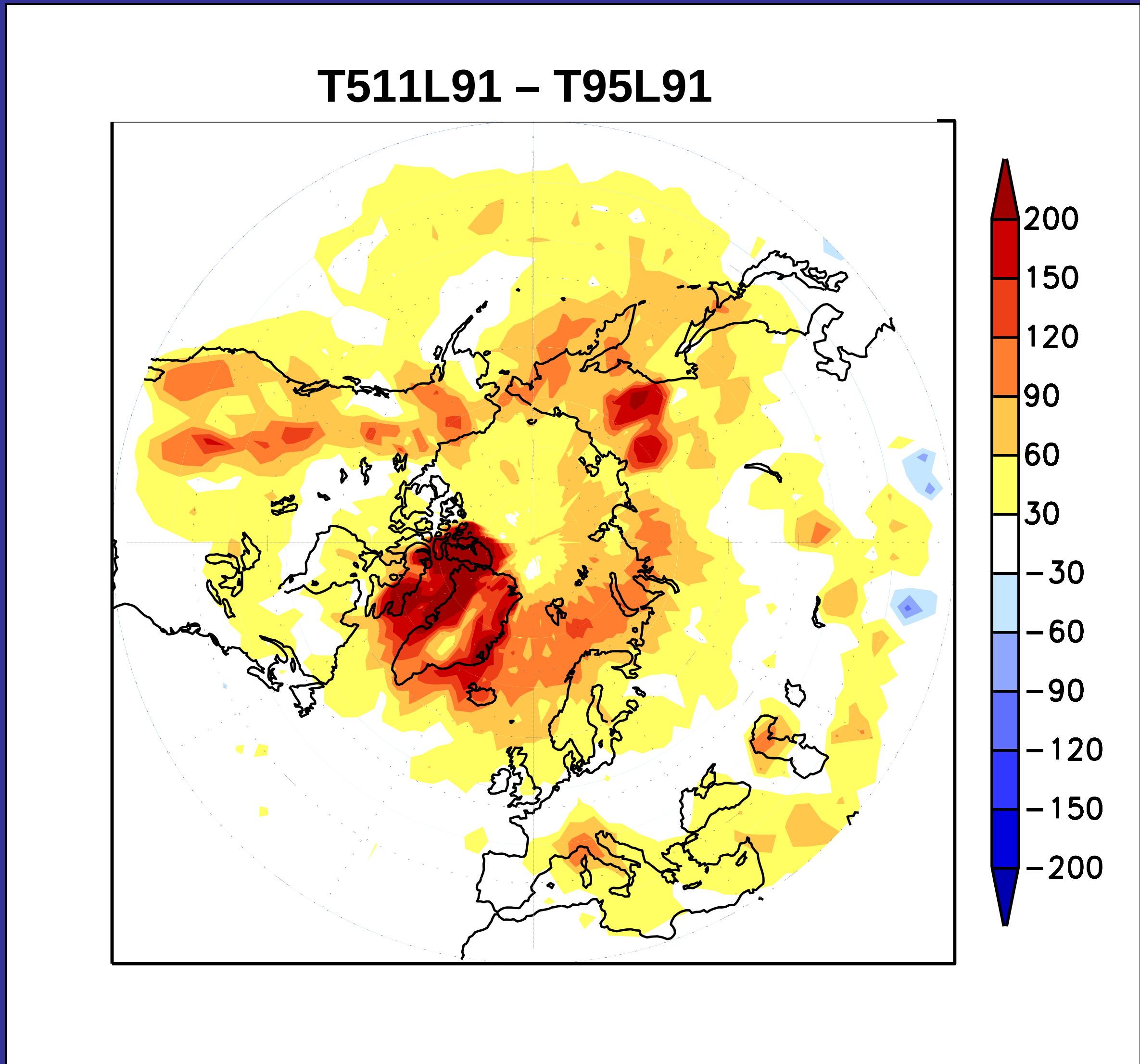


> 2 days

Number of Extratropical Cyclones (1990-2005)

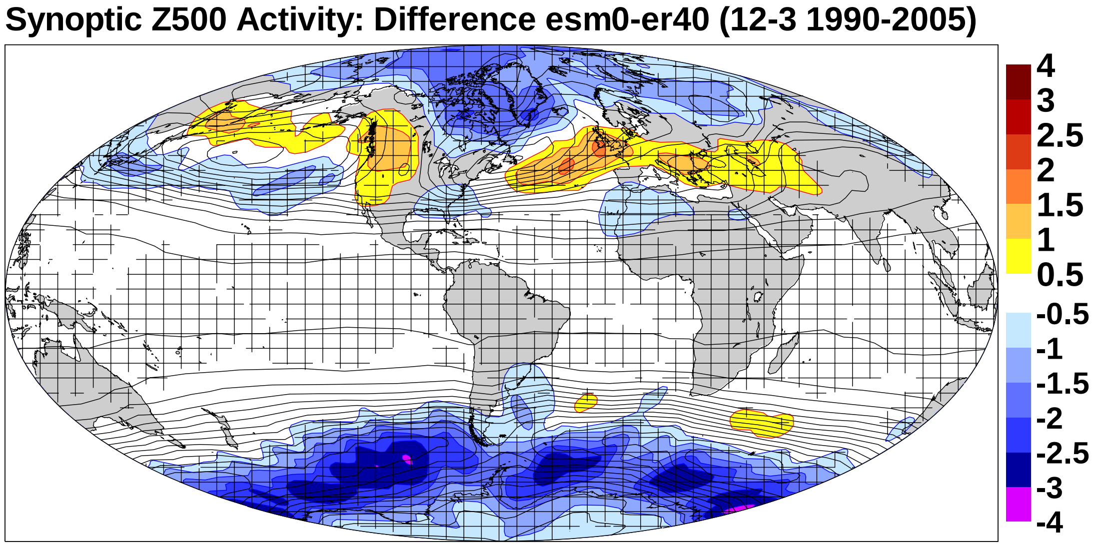


Influence of Horizontal Resolution on the Number of Extratropical Cyclones (1990-2005)

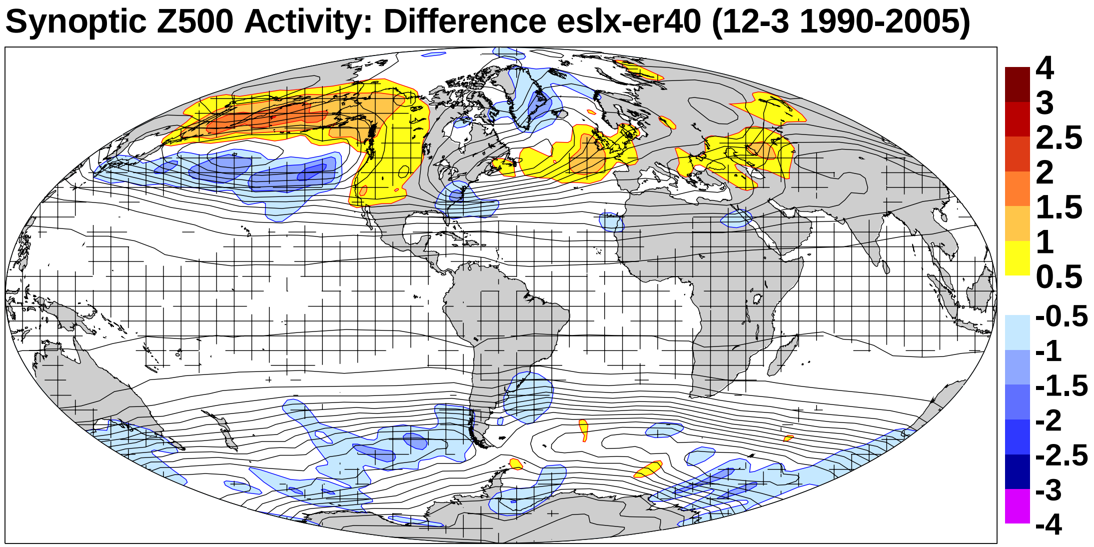


Synoptic Activity and Horizontal Resolution (DJFM 1990-2005)

T_L95L91
-ERA40

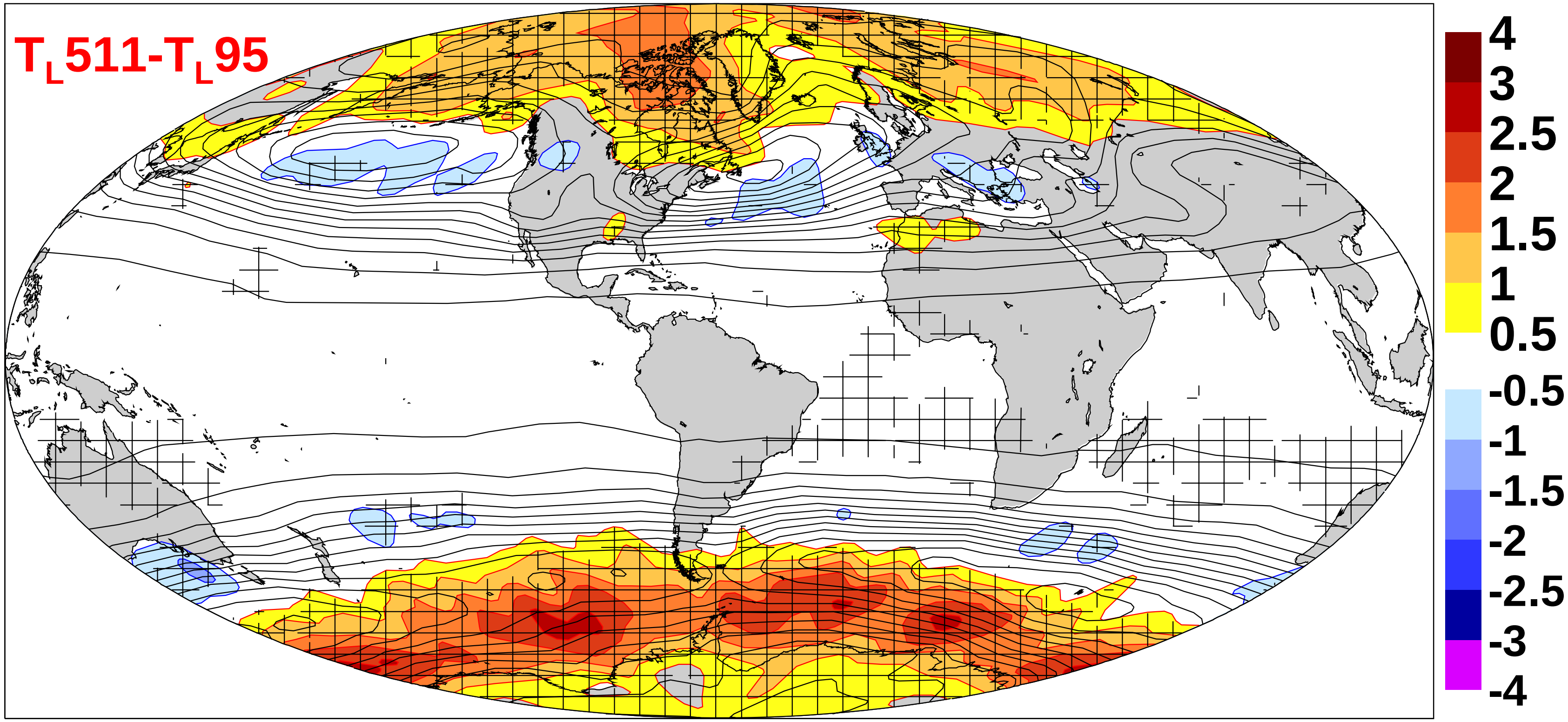


T_L511L91
-ERA40

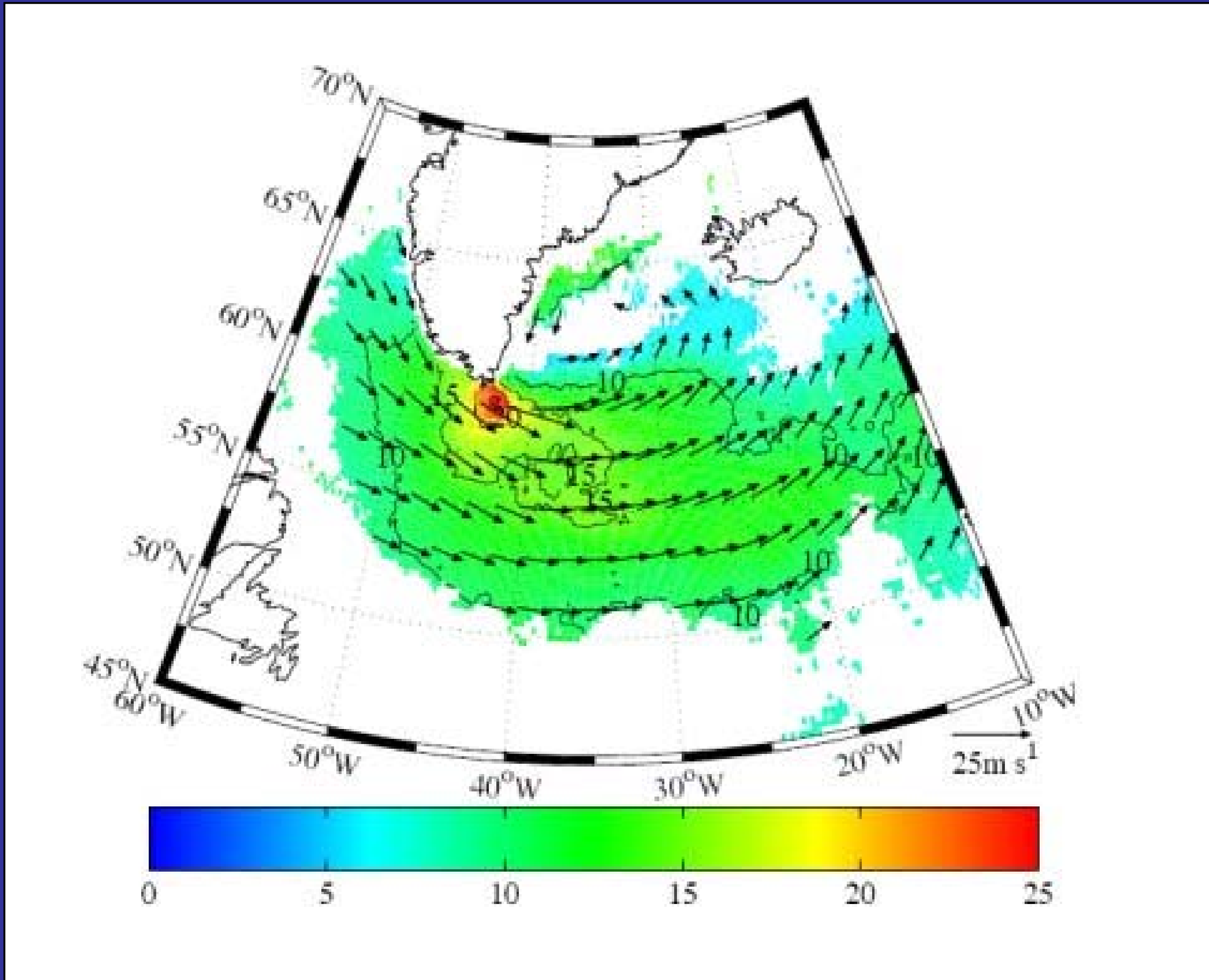


Synoptic Activity and Horizontal Resolution (1990-2005)

Synoptic Z500 Activity: Difference eslx-esm0 (12-3 1990-2005)

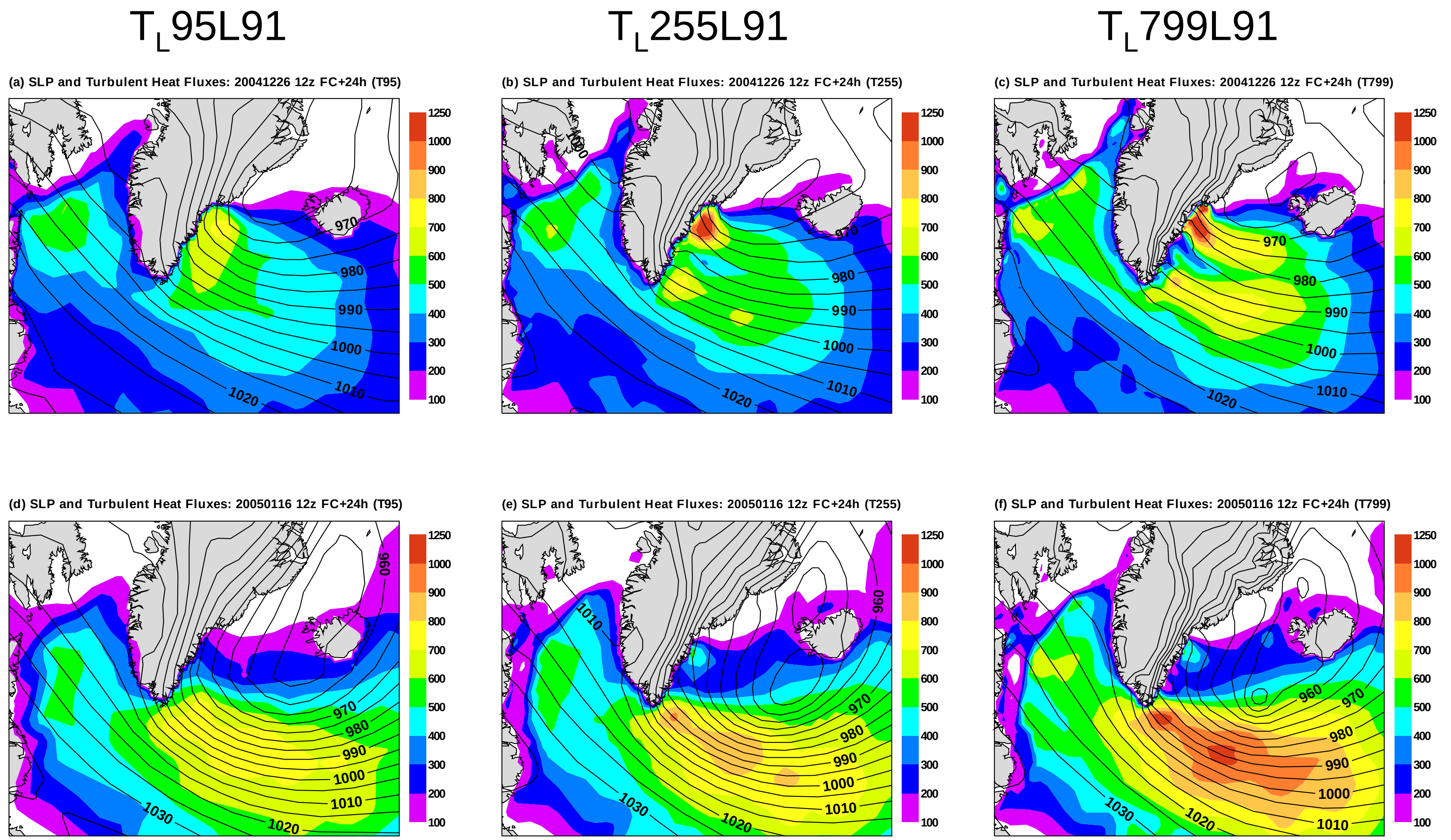


The Greenland Tip Jet Events



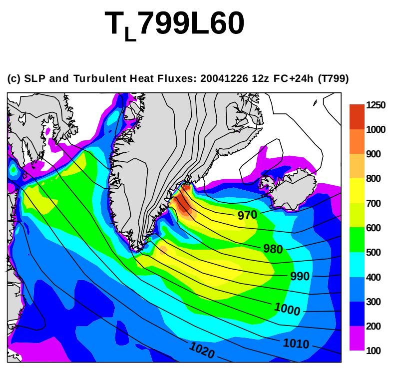
Moore and Renfew (2005)

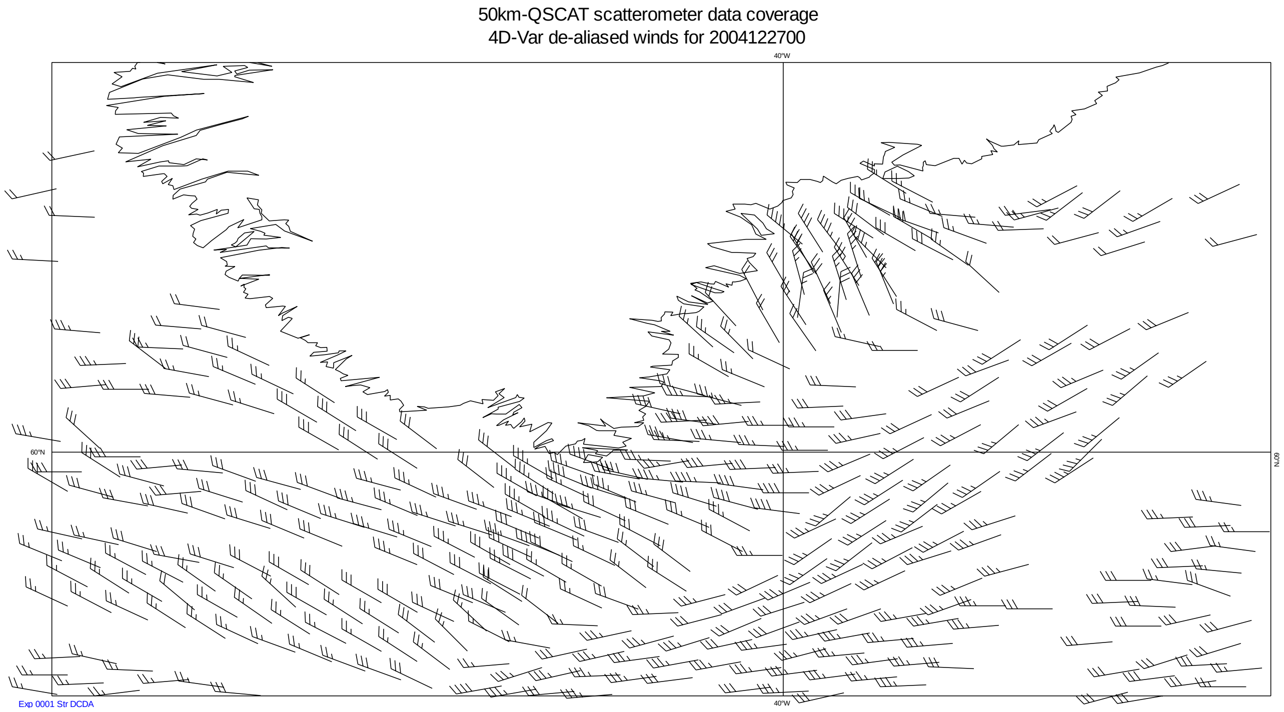
Greenland Tip Jet Events: D+1 Forecasts at Various Resolutions



Jung and Rhines, JAS, submitted

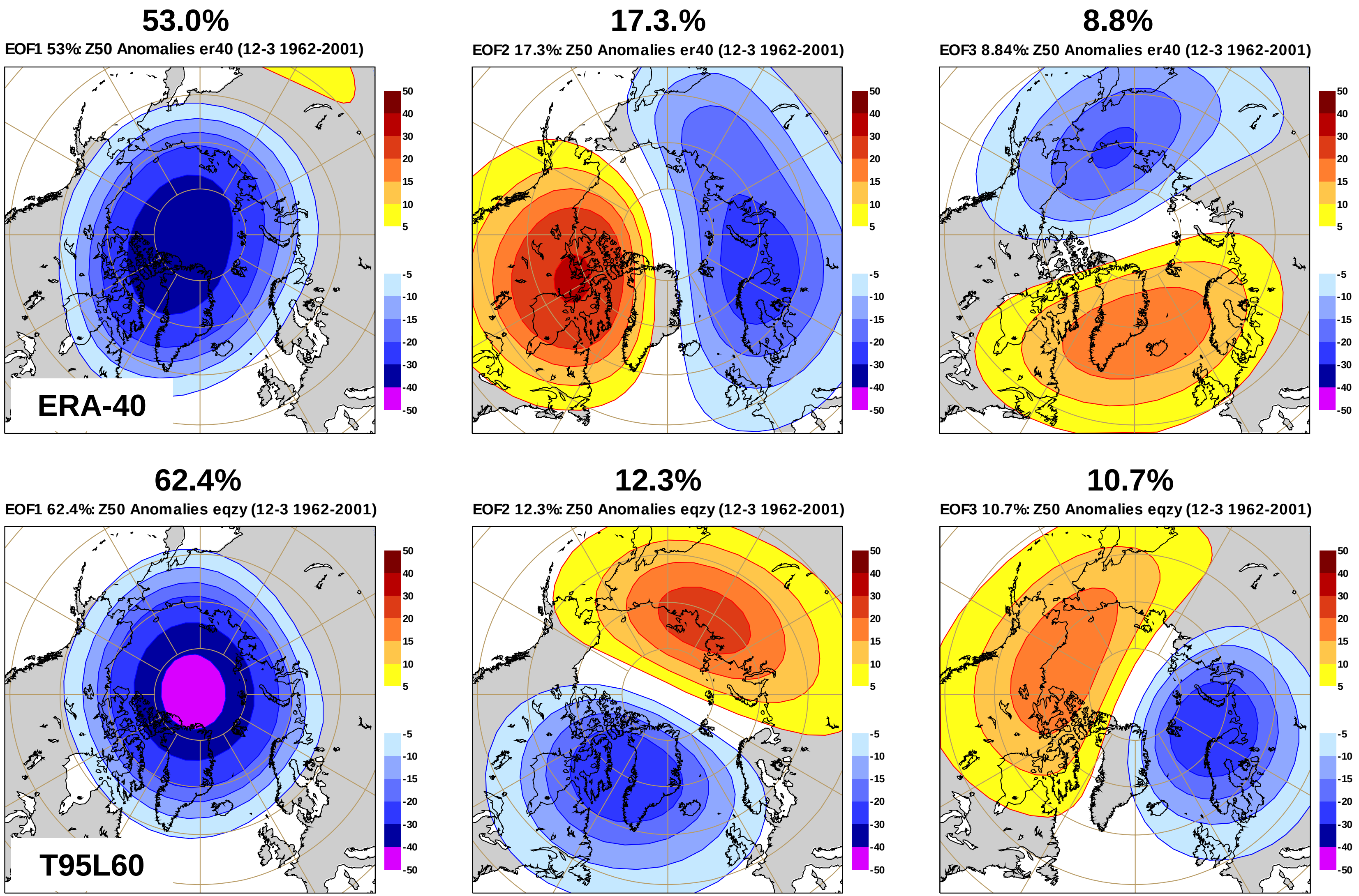
Greenland Tip Jet Events: QuikSCAT Winds



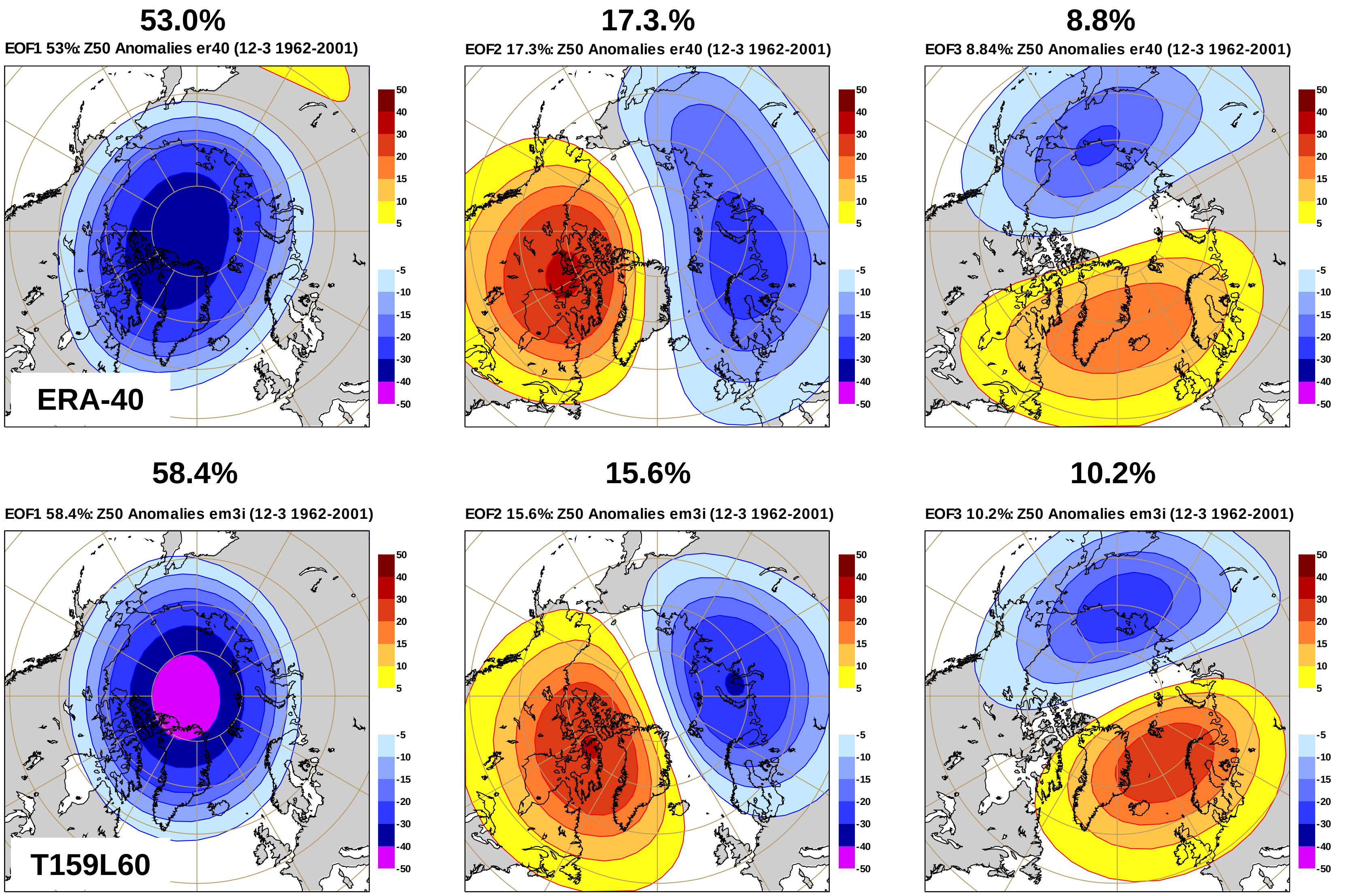


Courtesy of Hans Hersbach

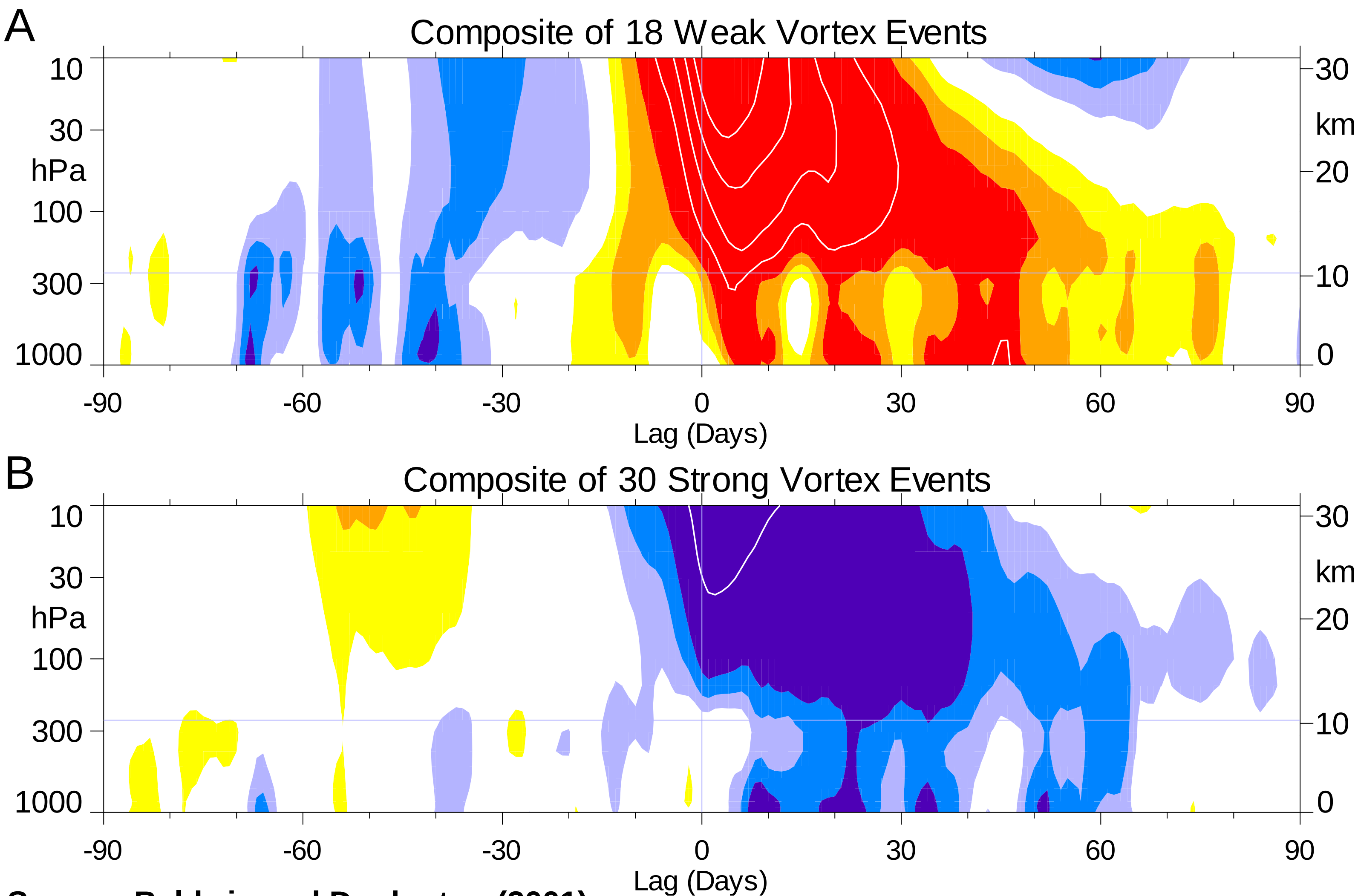
Leading EOFs: Z50 Anomalies



Leading EOFs: Z50 Anomalies



The Stratosphere-Troposphere Link



Source: Baldwin and Dunkerton (2001)

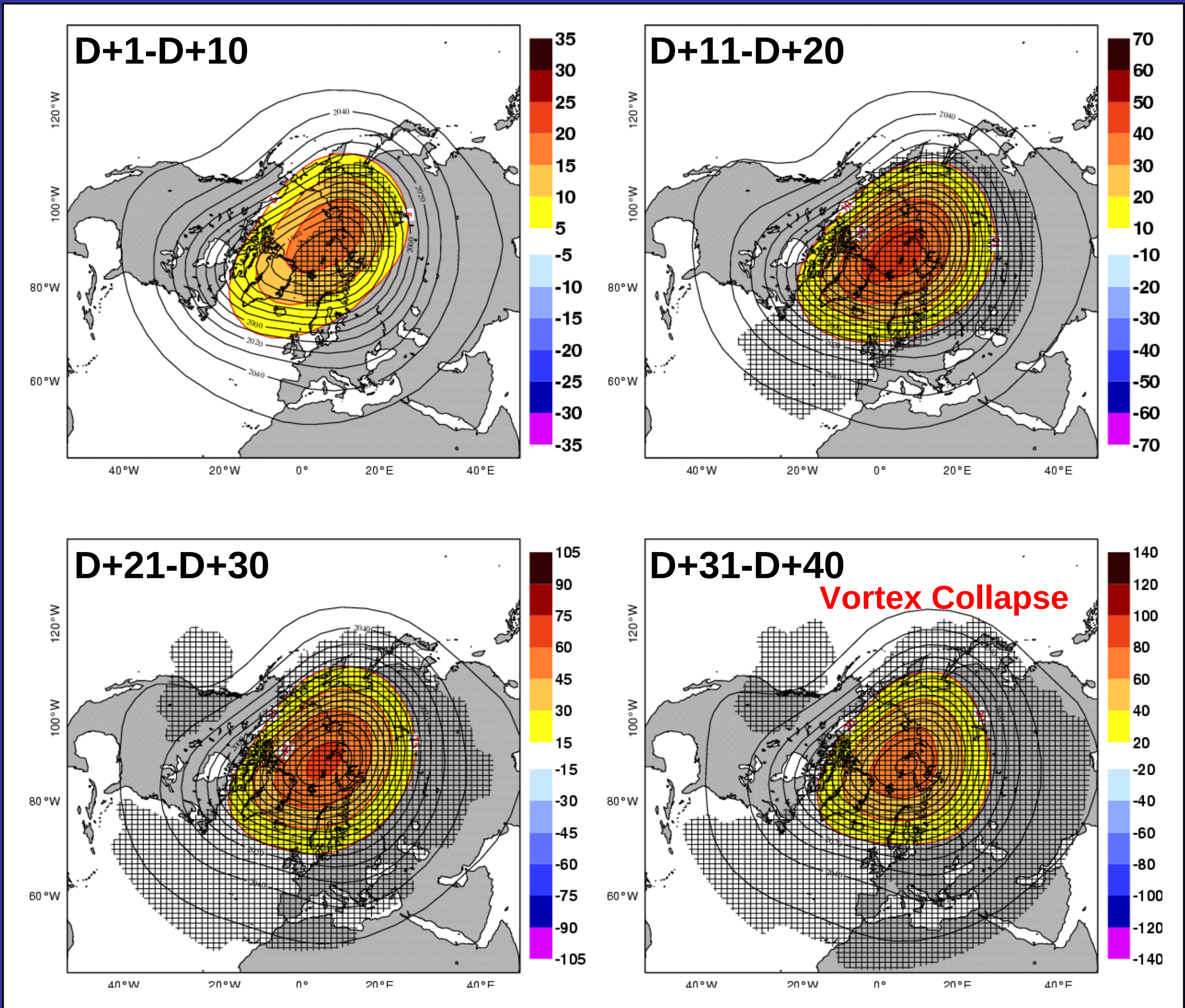
Methodology

$$\dot{\mathbf{x}} = \mathbf{IFS}(\mathbf{x}_0) \pm \mathbf{F}$$

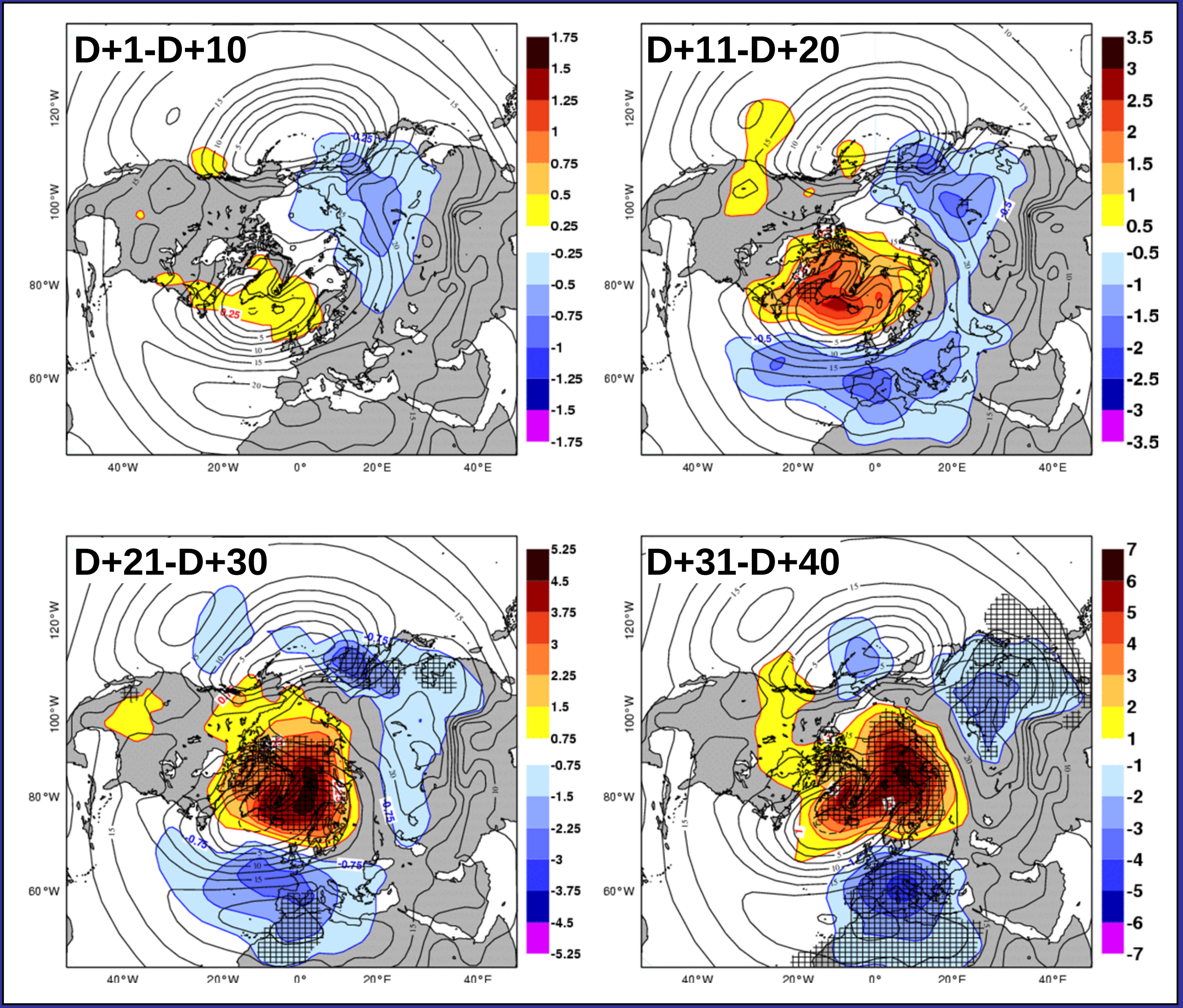
- **F is the composite optimal forcing of the polar vortex (adjoint, 18 cases)**
- **F is applied in the stratosphere only (>150 hPa)**
- **3 40-day forecasts for every winter (1982-2001)**
- **Control & Control ± F**
- **T_L95L60 (cycle 28r1)**

Jung and Barkmeijer, MWR, 2006

Stratospheric Response (50hPa)



Z1000 Response (Weak-CNTL)

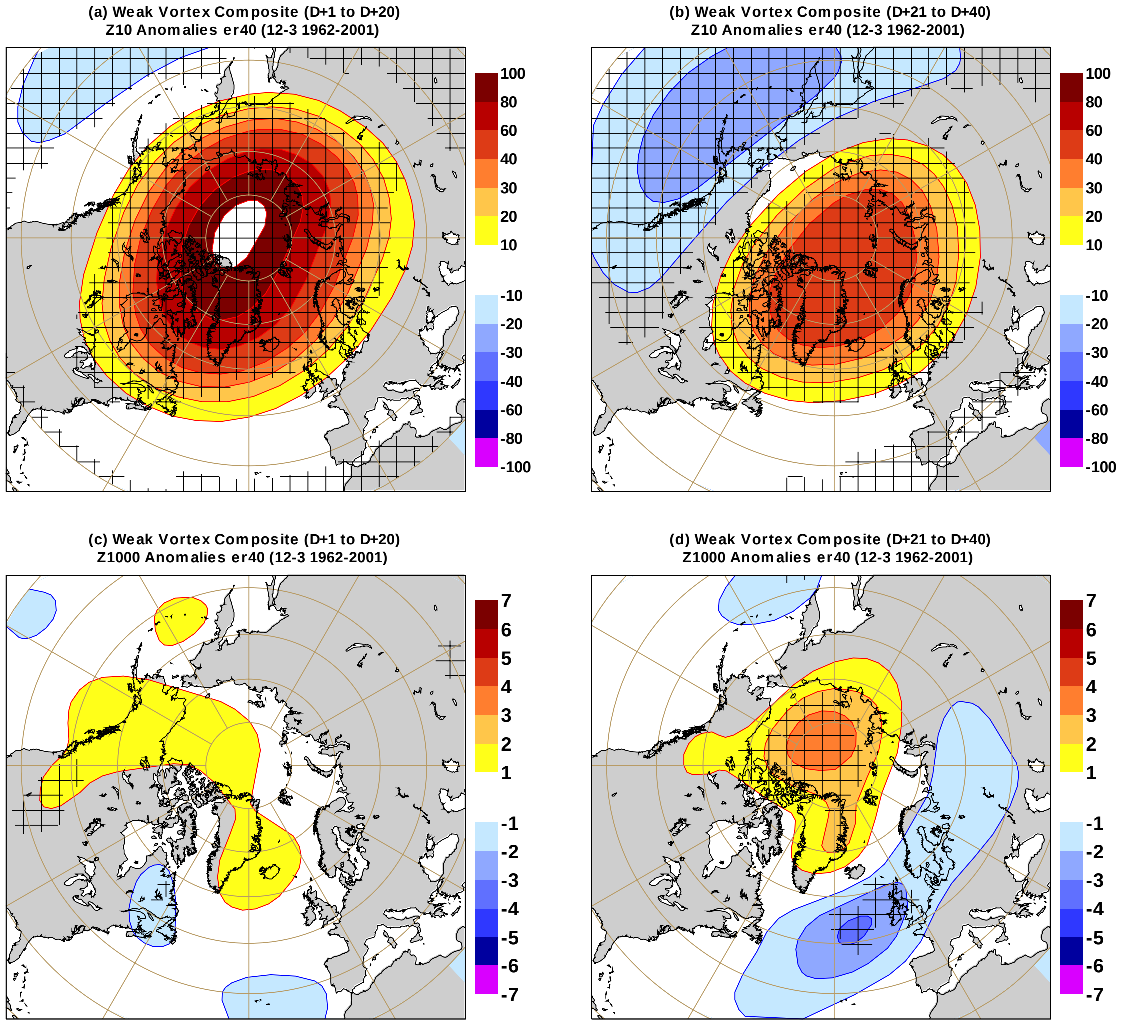


Strong Vortex Composites (ERA-40)

D+1 to D+20 | D+21 to D+40

10 hPa

1000 hPa



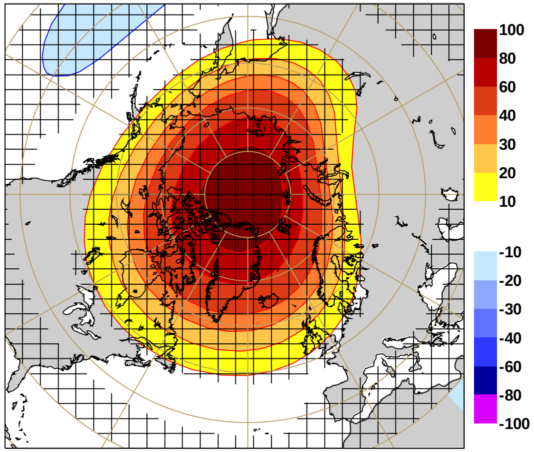
Strong Vortex Composites (T_L95L91)

D+1 to D+20

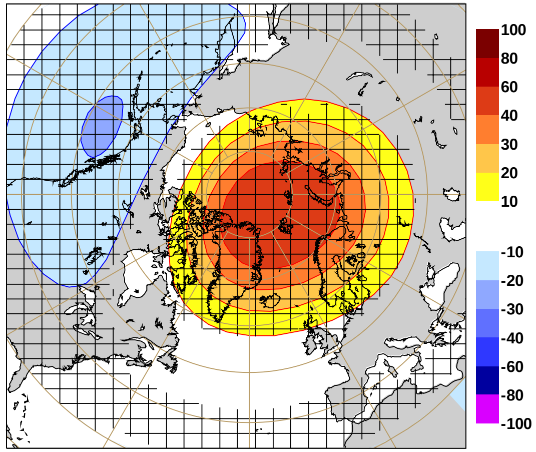
D+21 to D+40

10 hPa

(a) Weak Vortex Composite (D+1 to D+20)
Z10 Anomalies eqz8 (12-3 1962-2001)

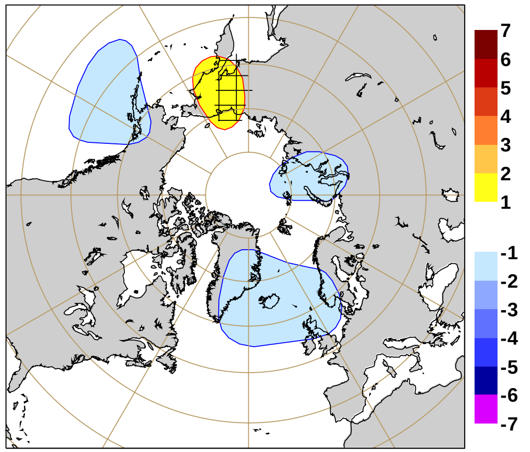


(b) Weak Vortex Composite (D+21 to D+40)
Z10 Anomalies eqz8 (12-3 1962-2001)

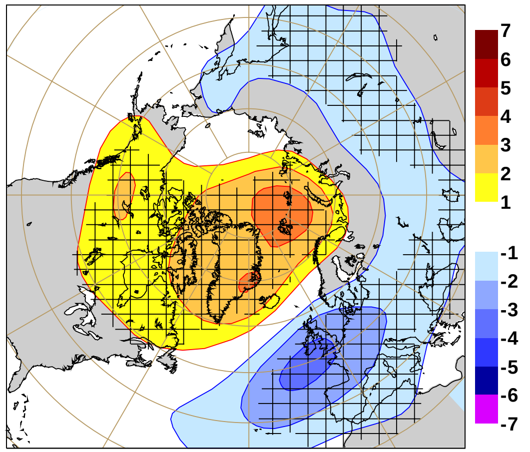


1000 hPa

(c) Weak Vortex Composite (D+1 to D+20)
Z1000 Anomalies eqz8 (12-3 1962-2001)



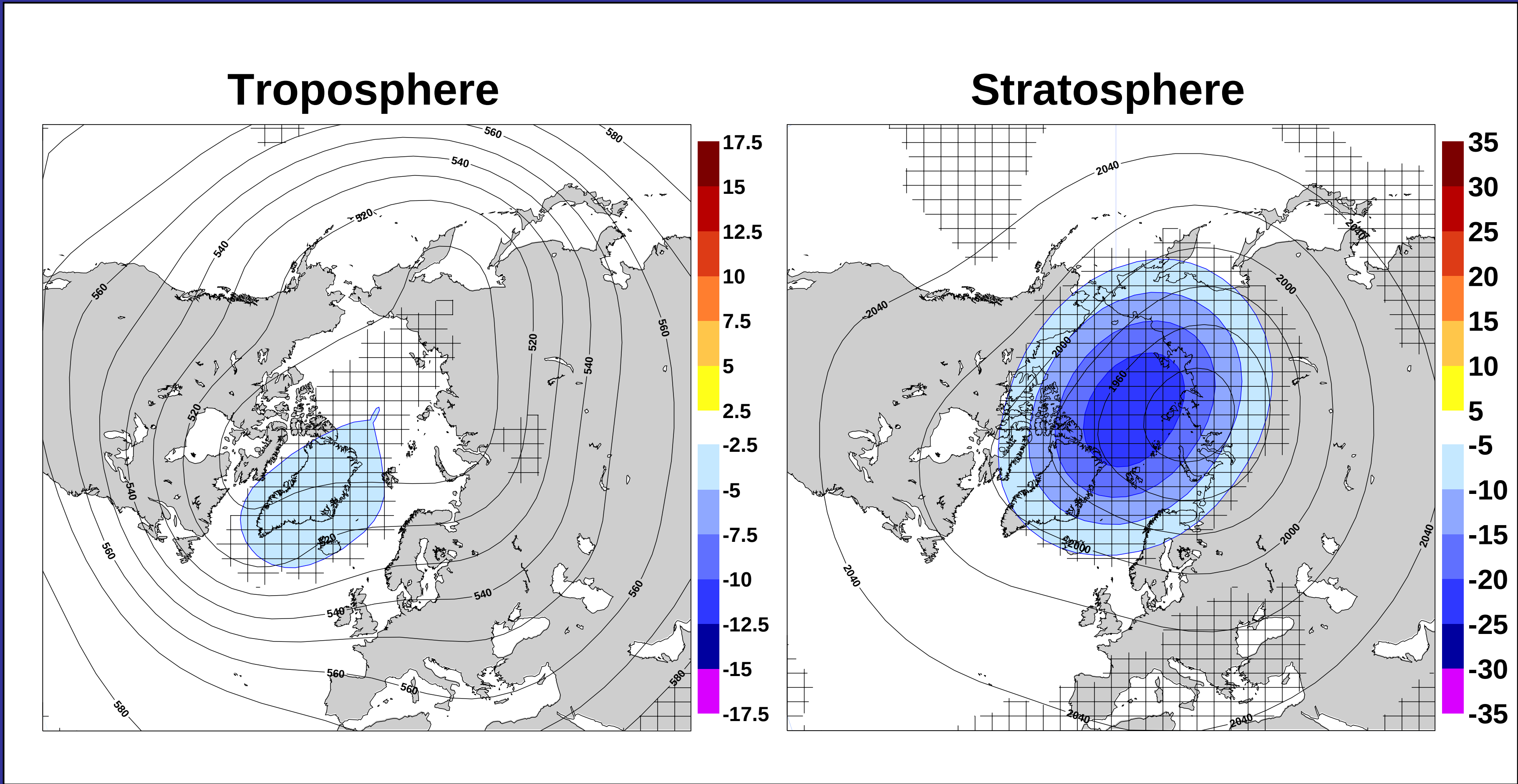
(d) Weak Vortex Composite (D+21 to D+40)
Z1000 Anomalies eqz8 (12-3 1962-2001)



Sensitivity to Vertical Resolution

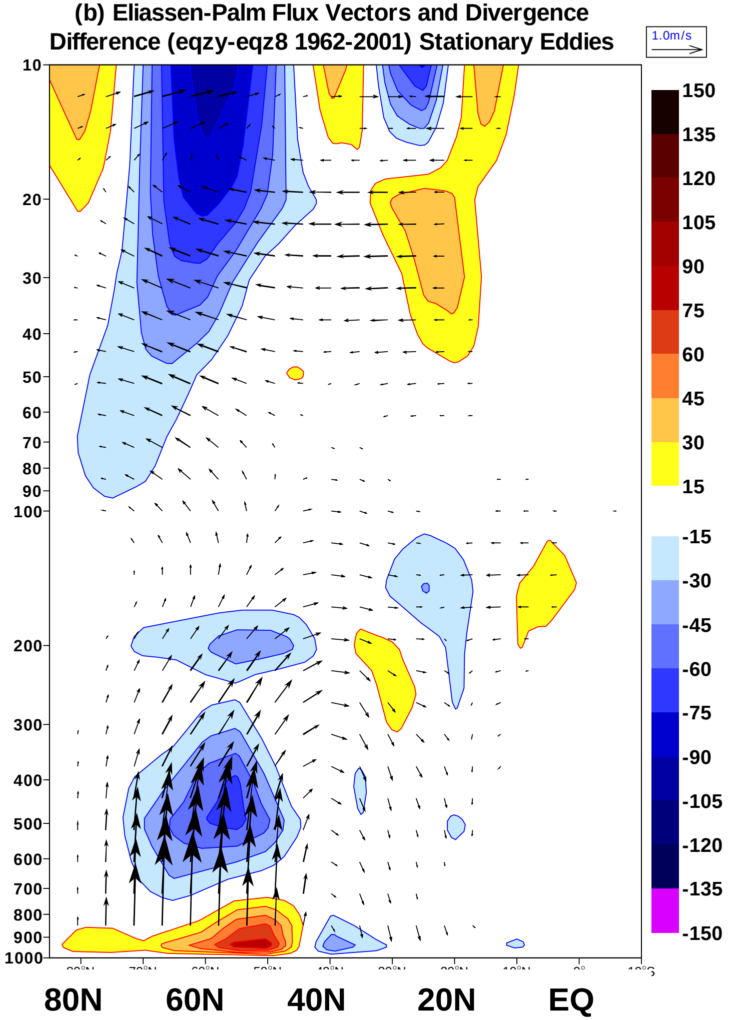
- Two different resolutions (L62 and L91)
- Same resolution up to 150hPa.
- L91:
  - About 45 levels in the stratosphere
  - Highest level at 0.01 hPa
- L62:
  - About 15 levels in the stratosphere
  - Highest level at 5 hPa
- All runs at T_L95
- DJFM 1962-2001 (starts on 1st October)

Influence of Vertical Resolution (L62-L91)

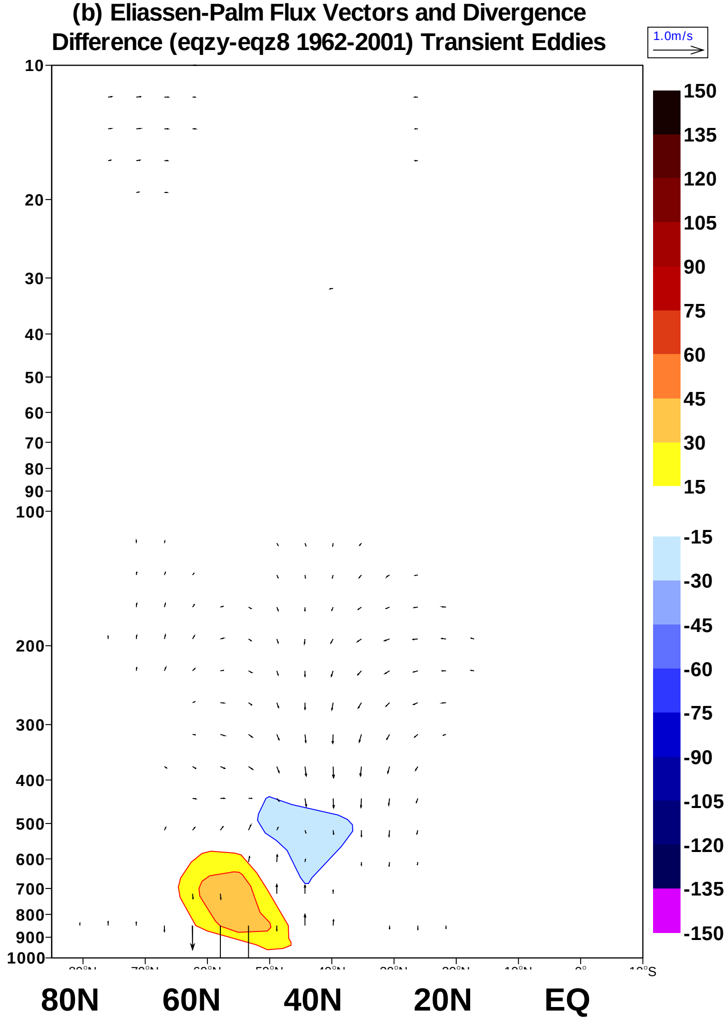


Influence of Vertical Resolution (L62-L91)

Stationary Waves



Transient Waves



Conclusions

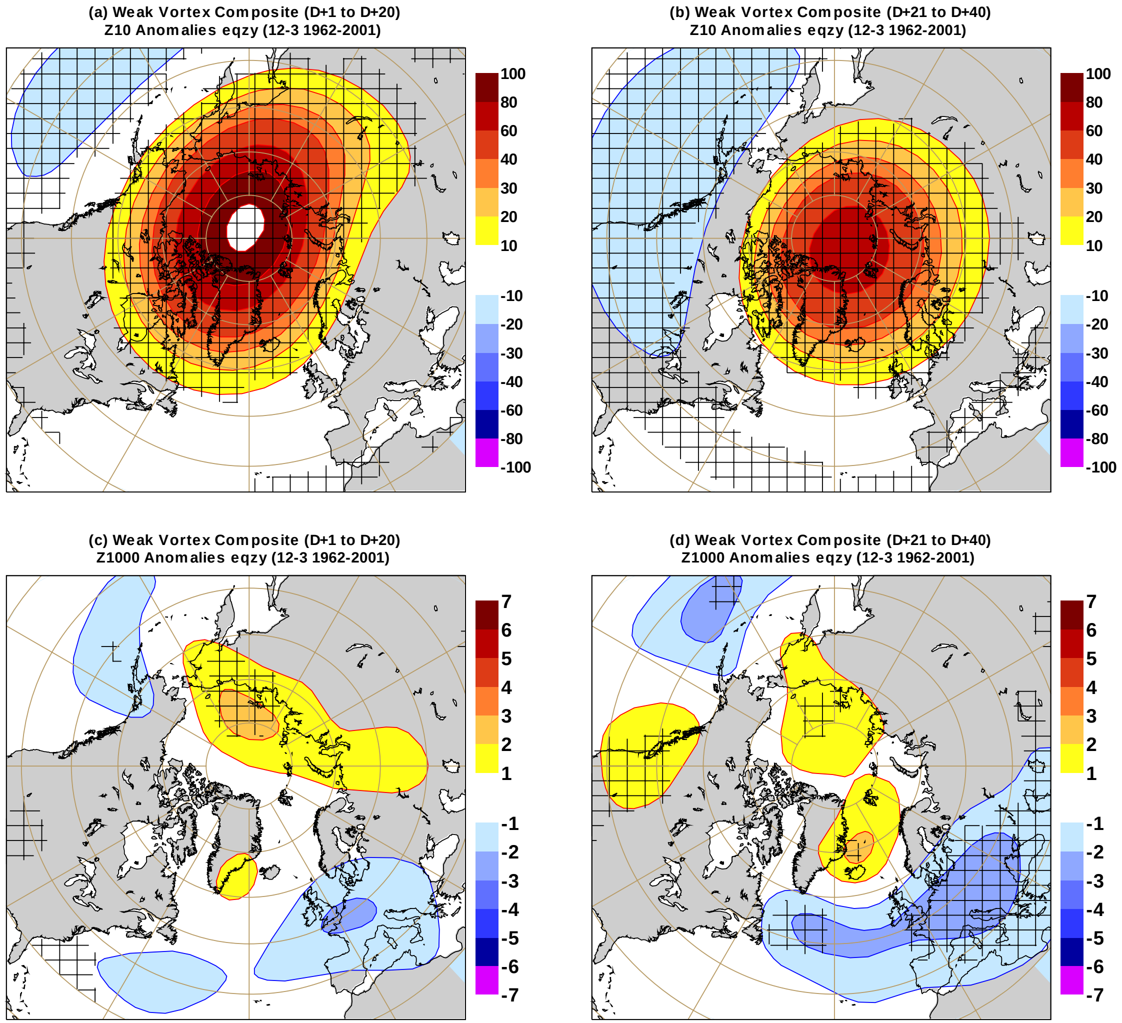
- Substantial improvements of the model climate at very high resolution (e.g, westerly wind bias).
- This is particularly true for synoptic-scale systems in high-latitudes.
- More realistic simulation of the stratospheric eigenstructure.
- Vertical resolution primarily influences stationary waves.
- “Downward propagation” is captured by the ECMWF model (even at T_L95L62).

Strong Vortex Composites (T_L95L62)

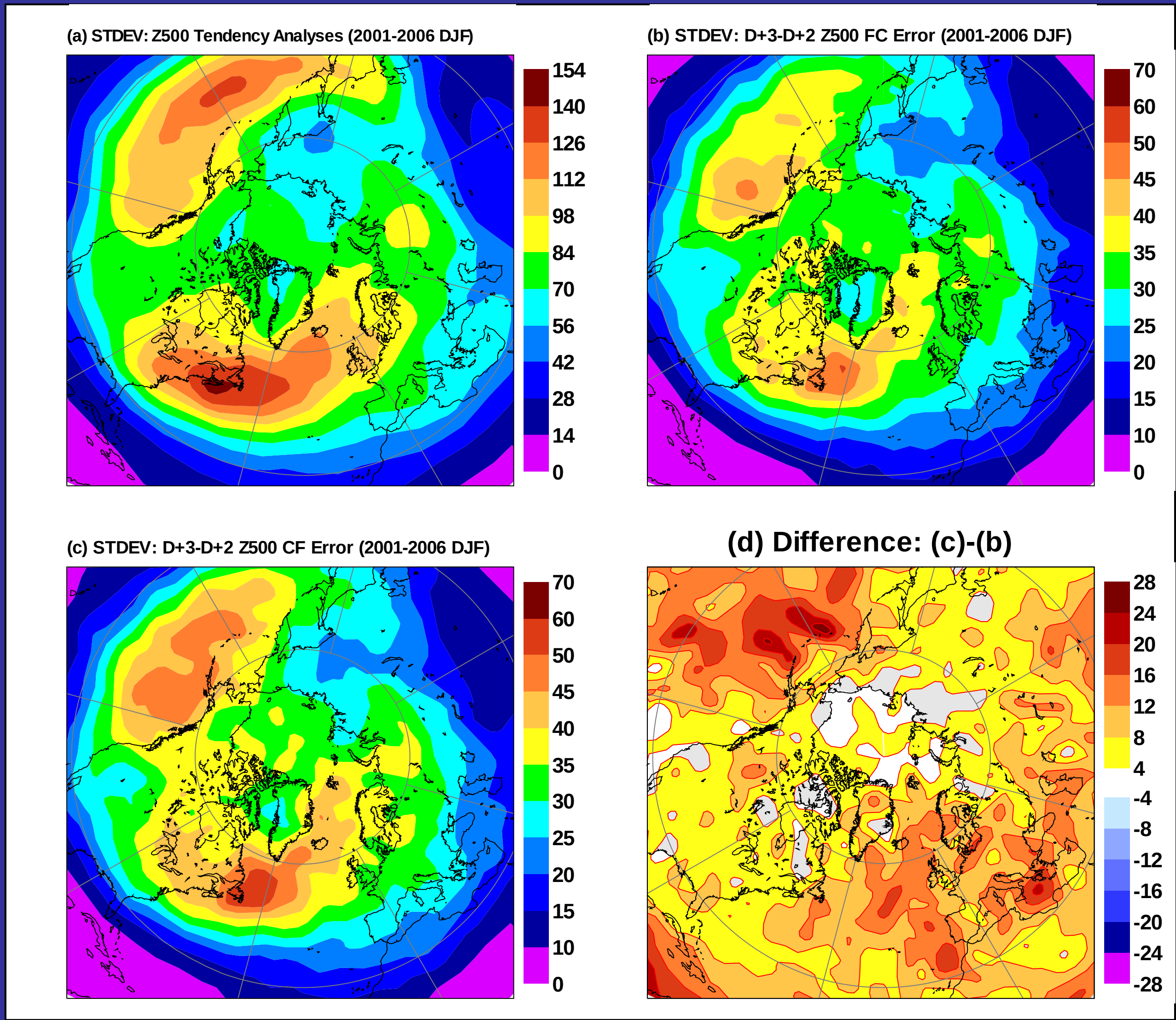
D+1 to D+20 | D+21 to D+40

10 hPa

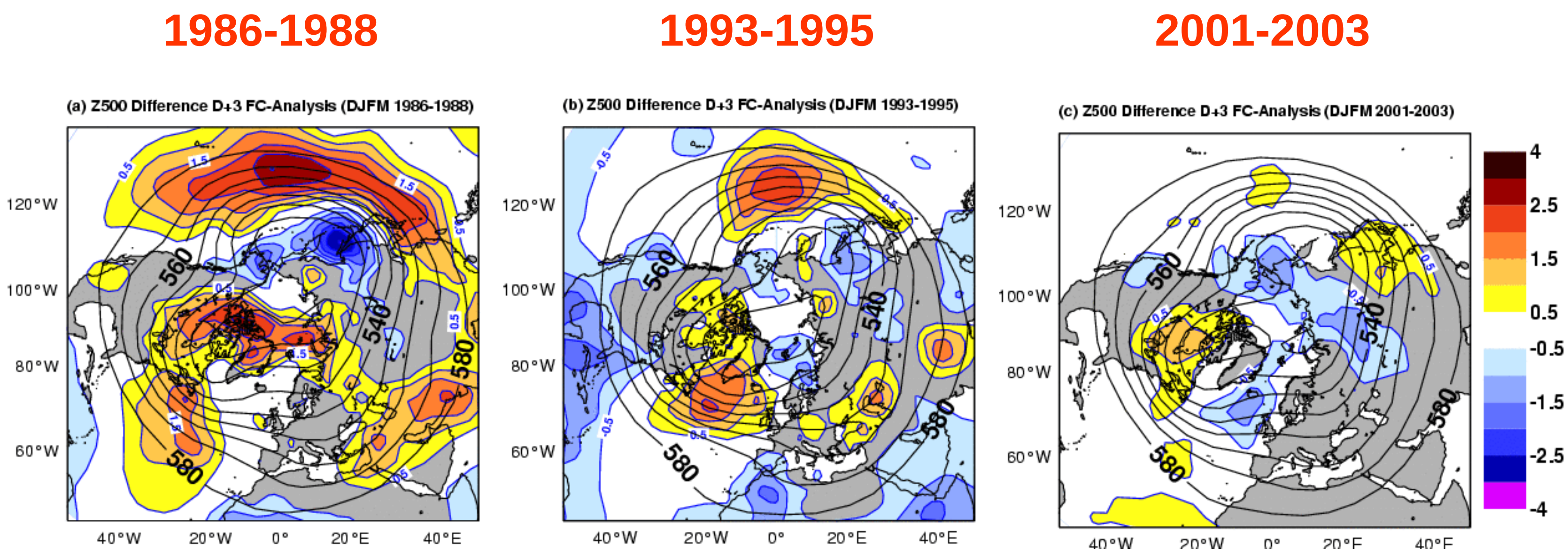
1000 hPa



STD of Forecast Error: D+2.5 Z500 Tendency (2-8 days)

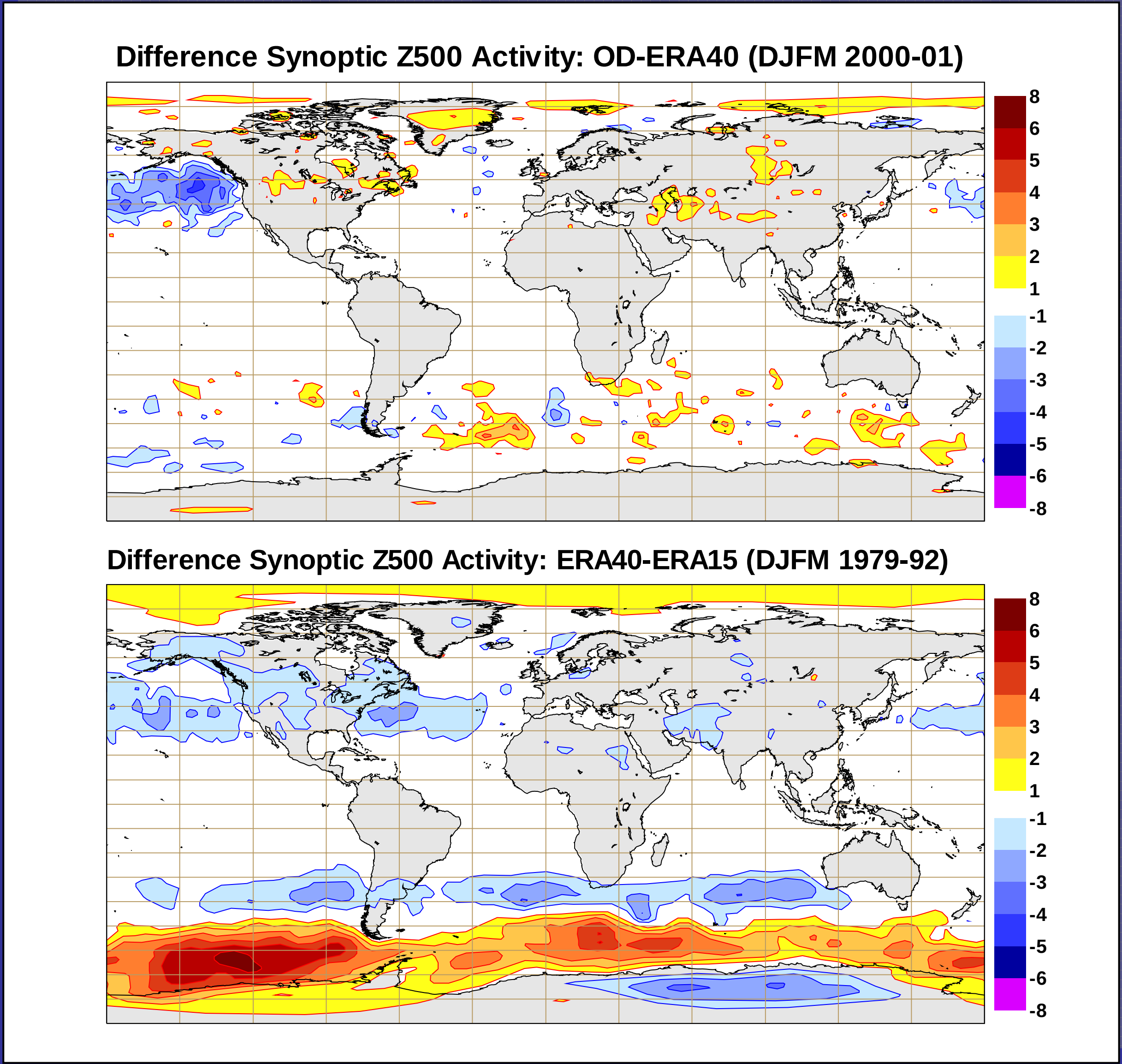


Evolution of D+3 Systematic Z500 Errors

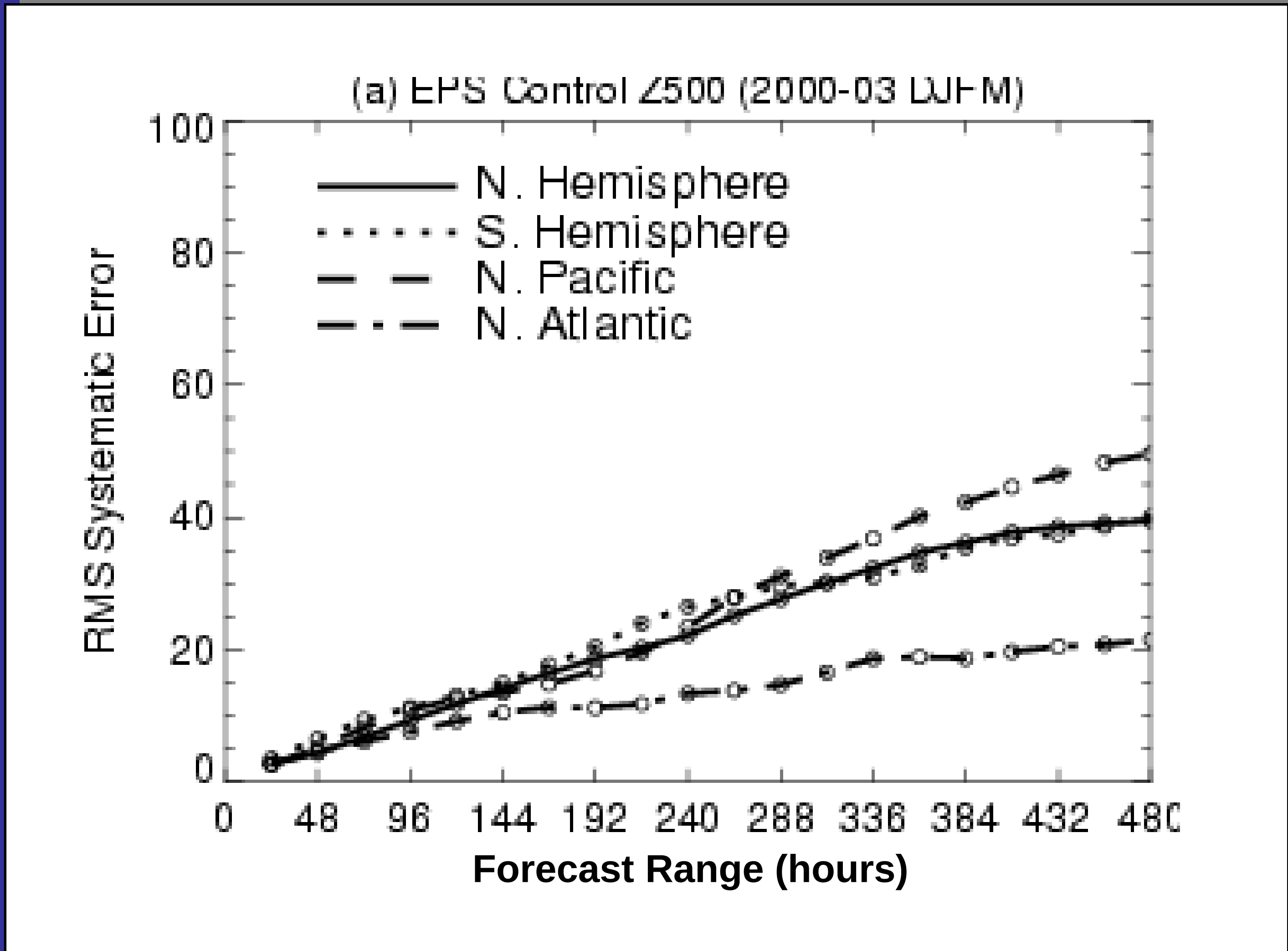


Jung, QJ, 2005

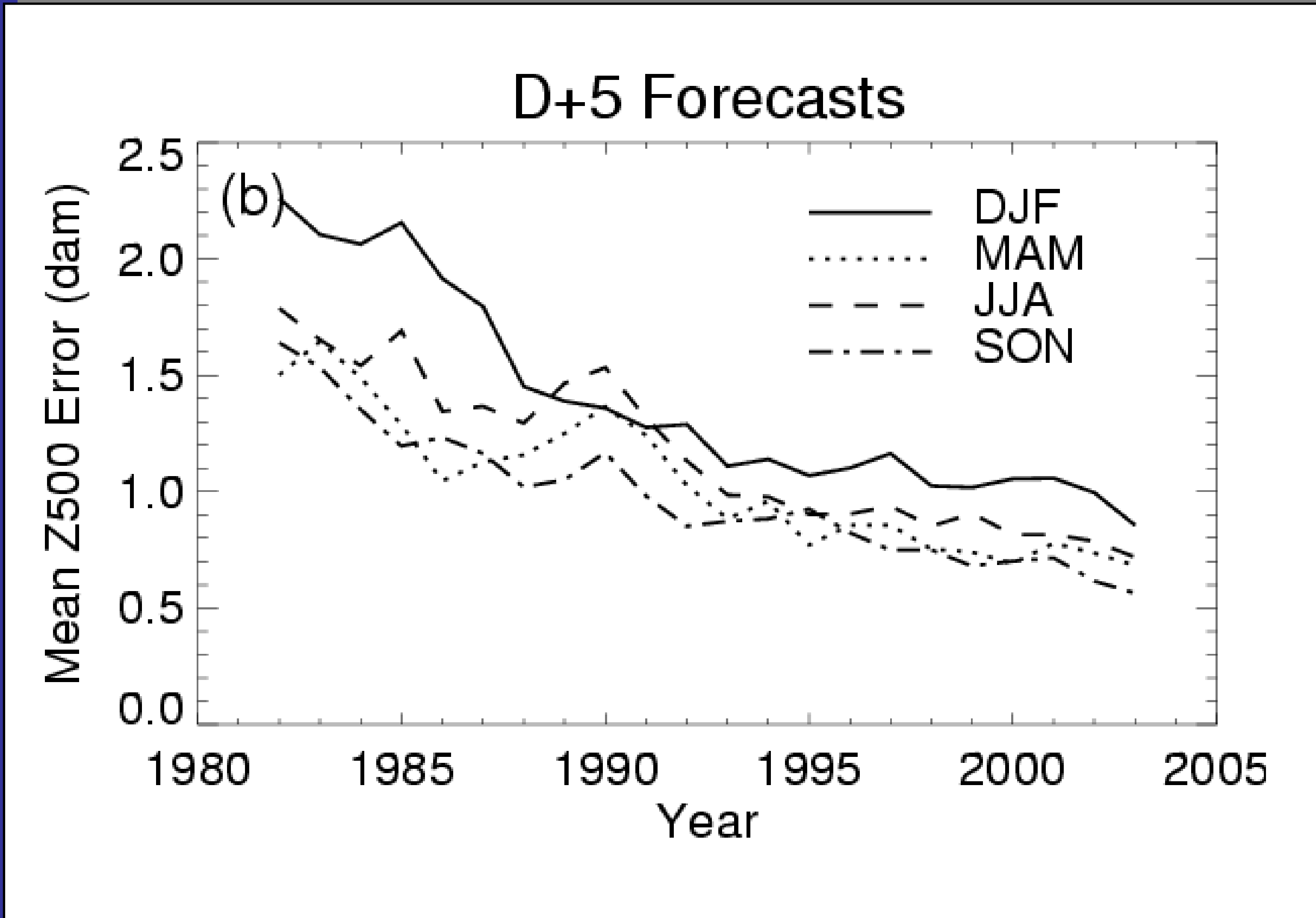
Synoptic Z500 Activity in Different Analyses



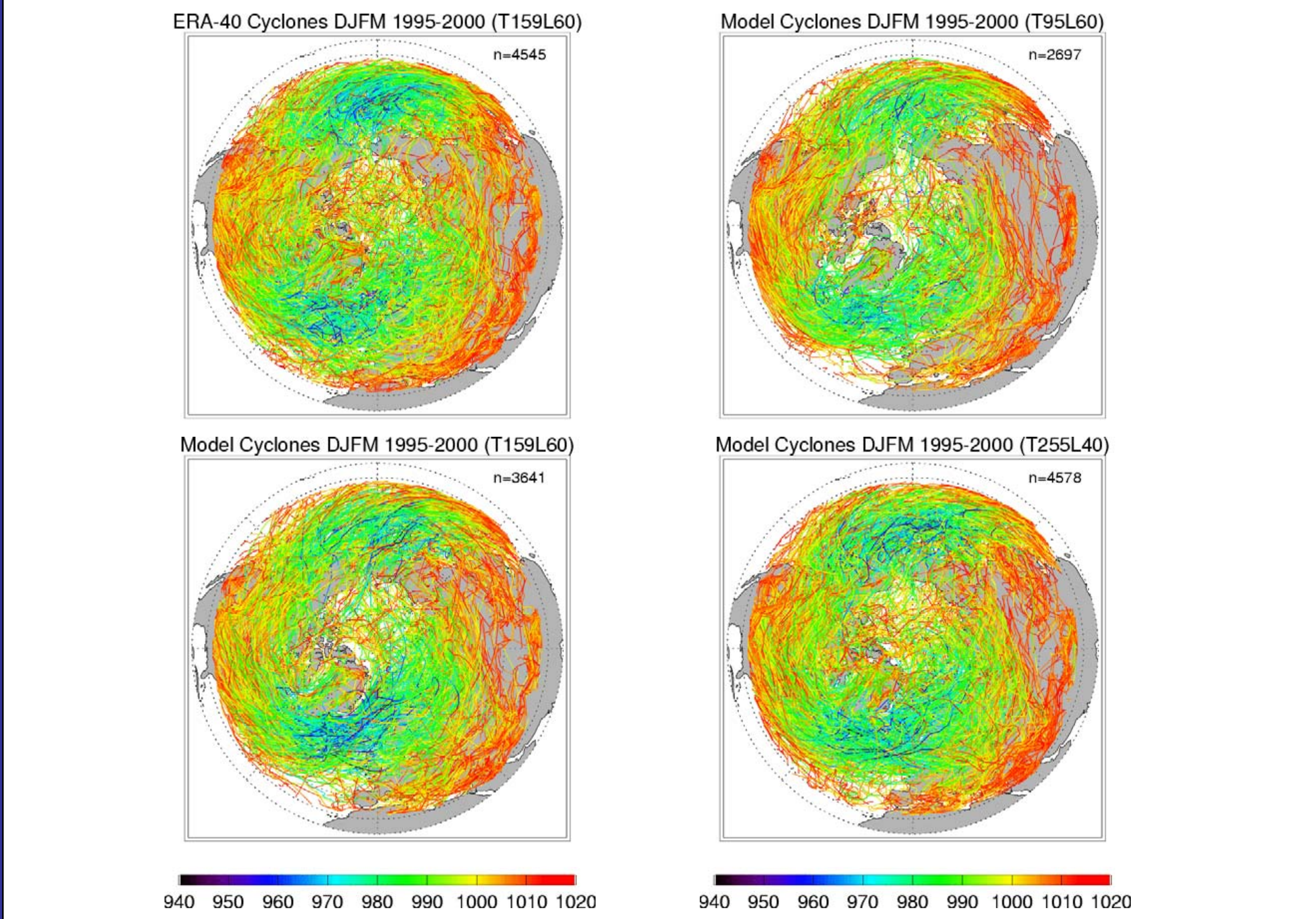
Systematic Error Growth: EPSC Z500 (DJFM 2000-03)



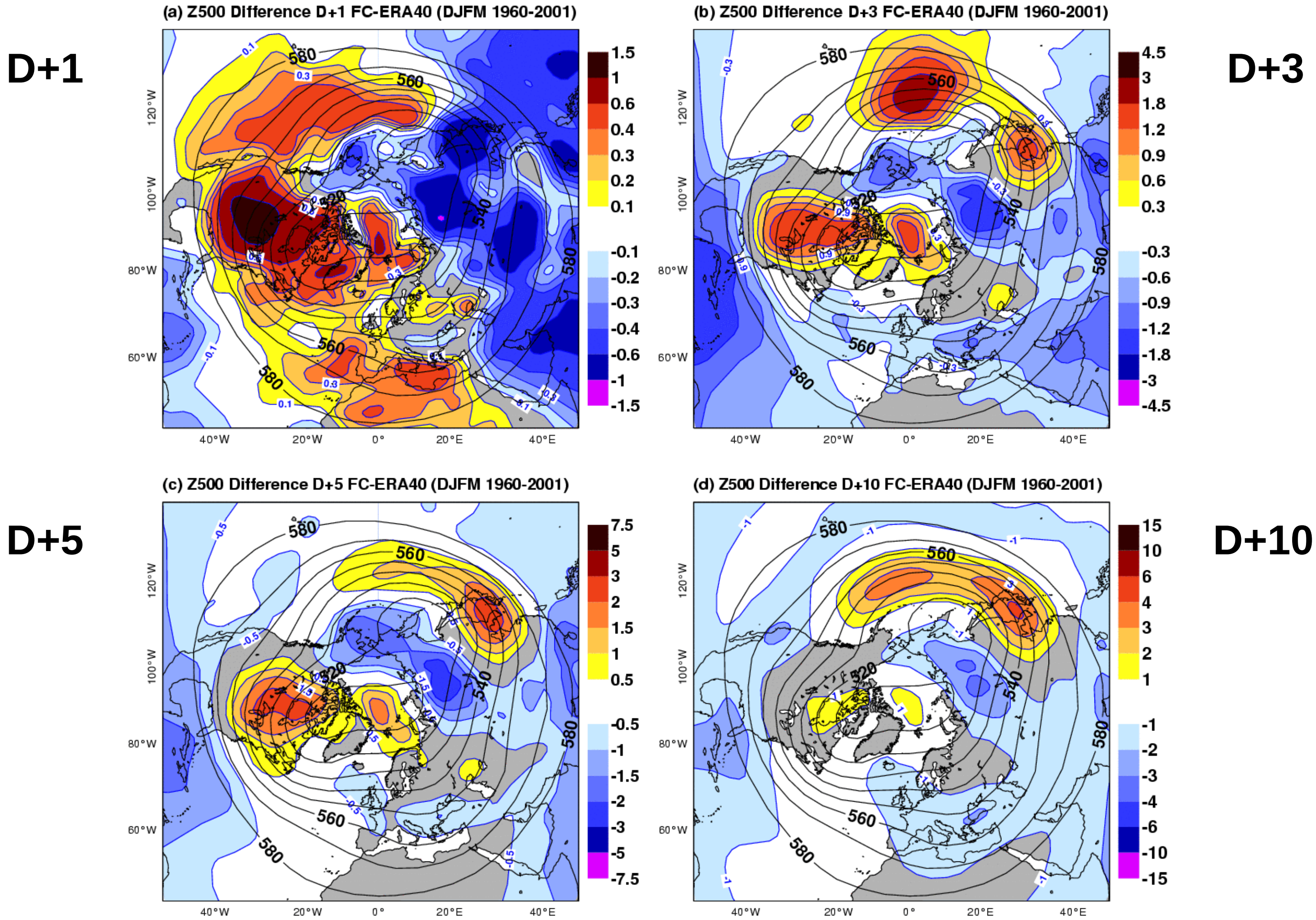
Reduction of Systematic Errors (1981-2003)



Extratropical Cyclone Tracks (1995-2001)

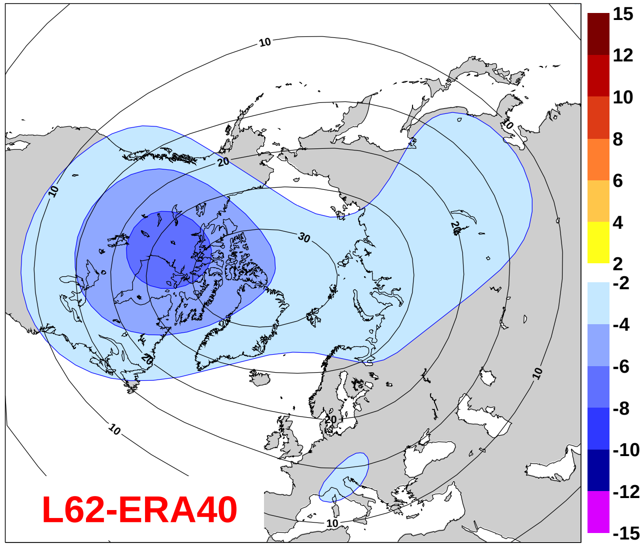


Systematic Z500 Error Growth: Medium-Range (DJFM 1960-2001)

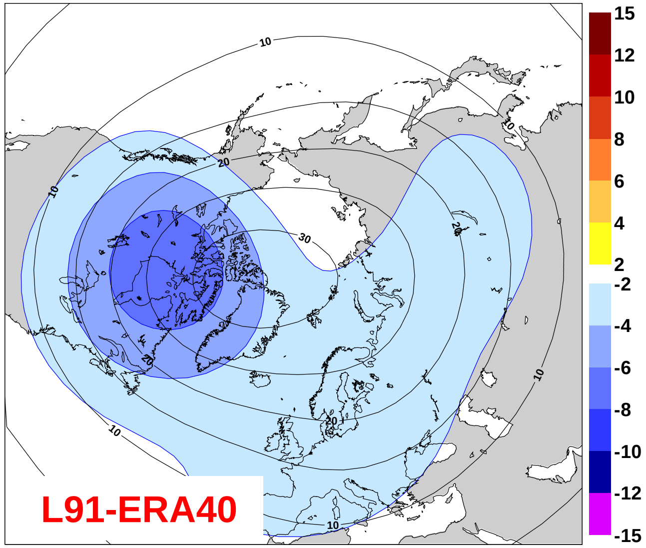


Planetary-Scale Z50 Variability (k=1-5)

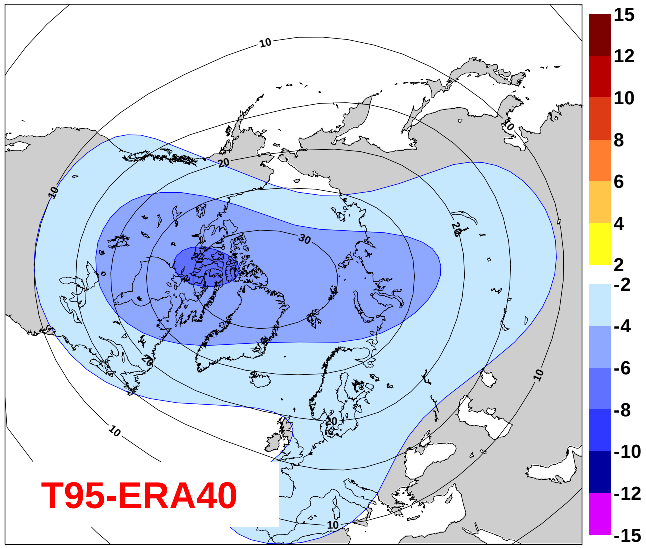
Standard Deviation: Planetary-Scale Z50 Variability
(k=1-5 er40 and eqzy-er40 12-3 1962-2001)



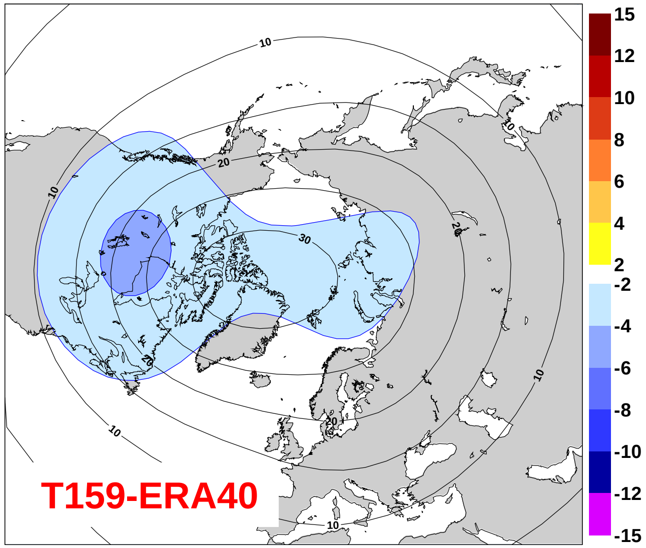
Standard Deviation: Planetary-Scale Z50 Variability
(k=1-5 er40 and eqz8-er40 12-3 1962-2001)



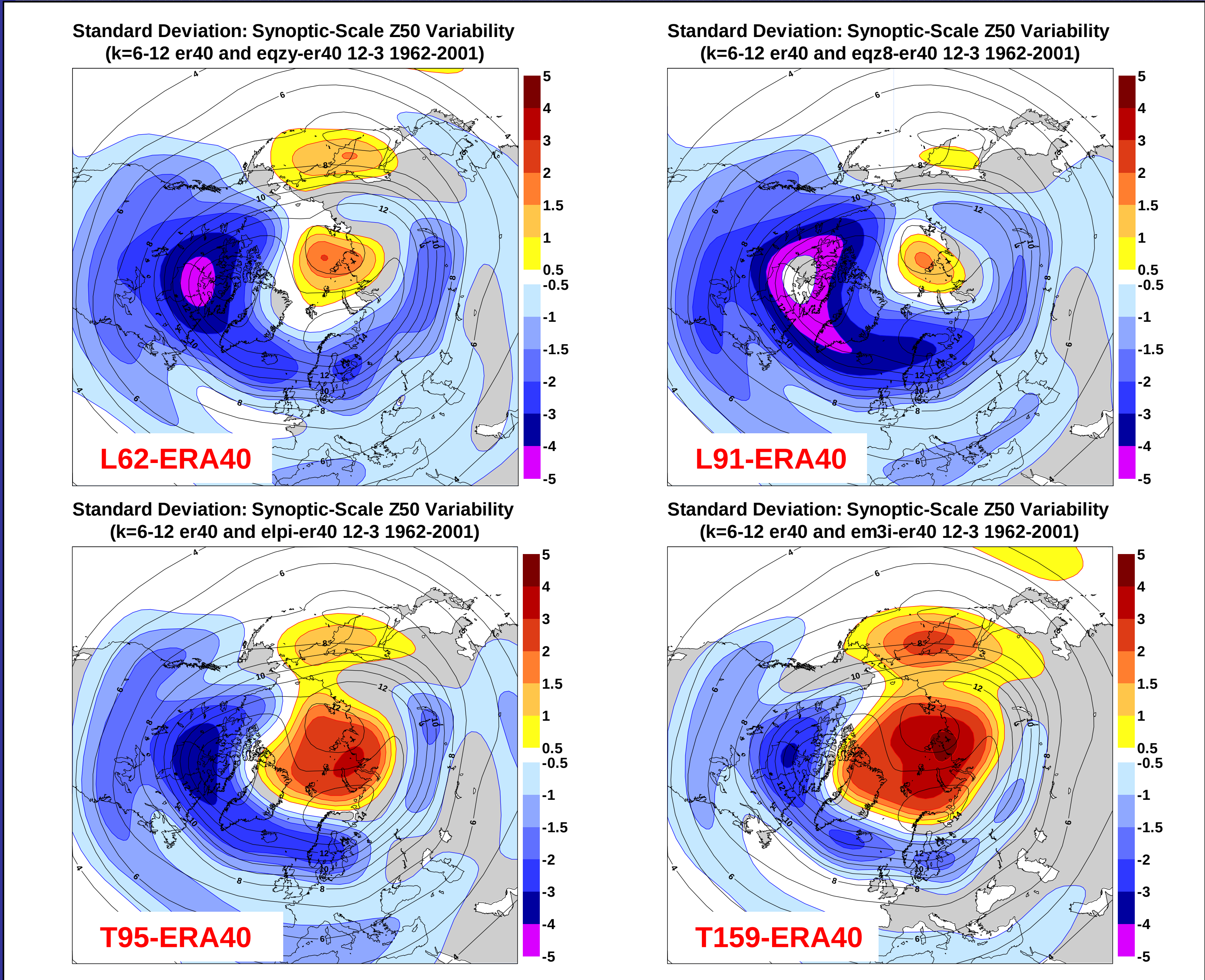
Standard Deviation: Planetary-Scale Z50 Variability
(k=1-5 er40 and elpi-er40 12-3 1962-2001)



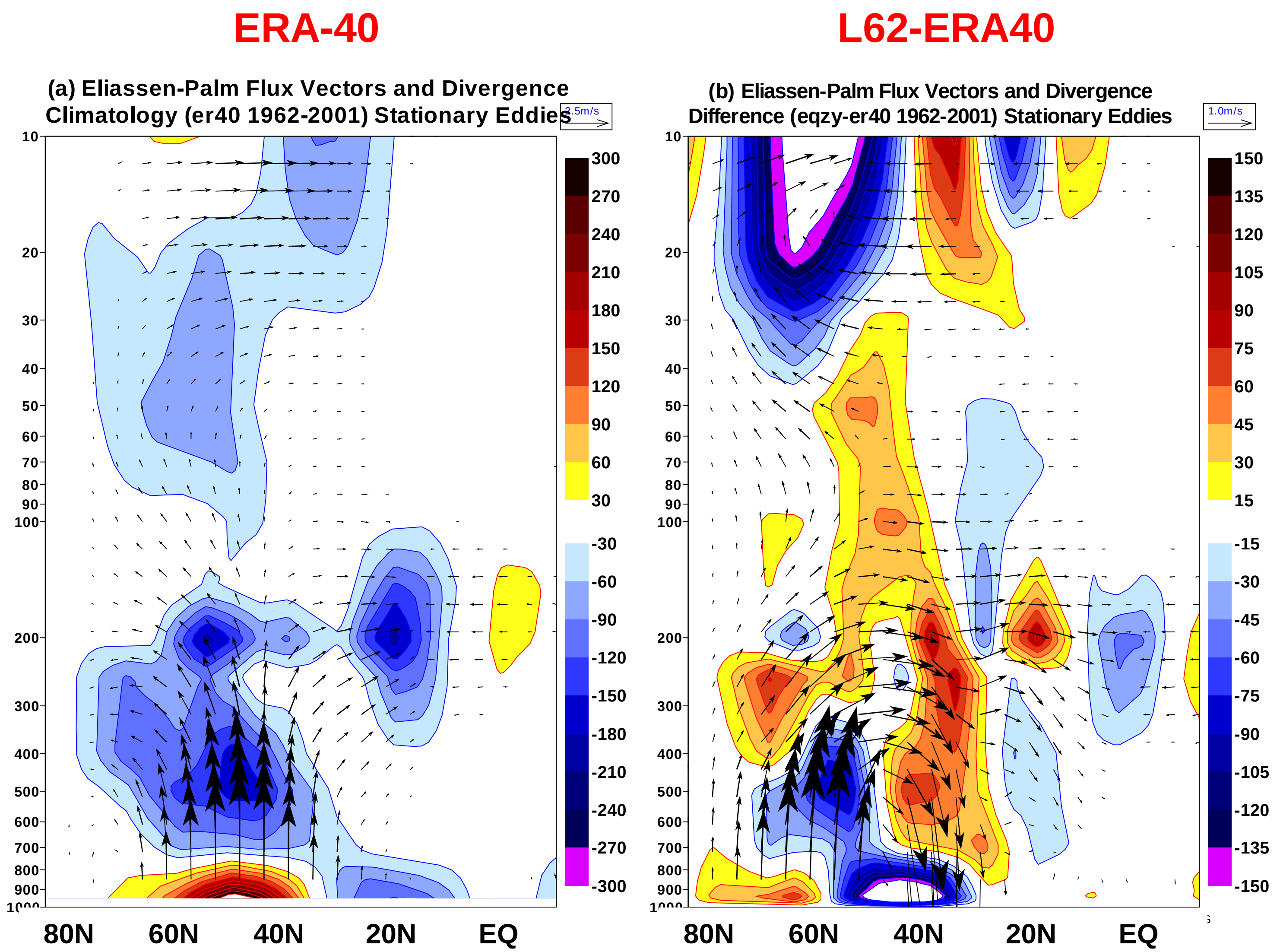
Standard Deviation: Planetary-Scale Z50 Variability
(k=1-5 er40 and em3i-er40 12-3 1962-2001)



Synoptic-Scale Z50 Variability

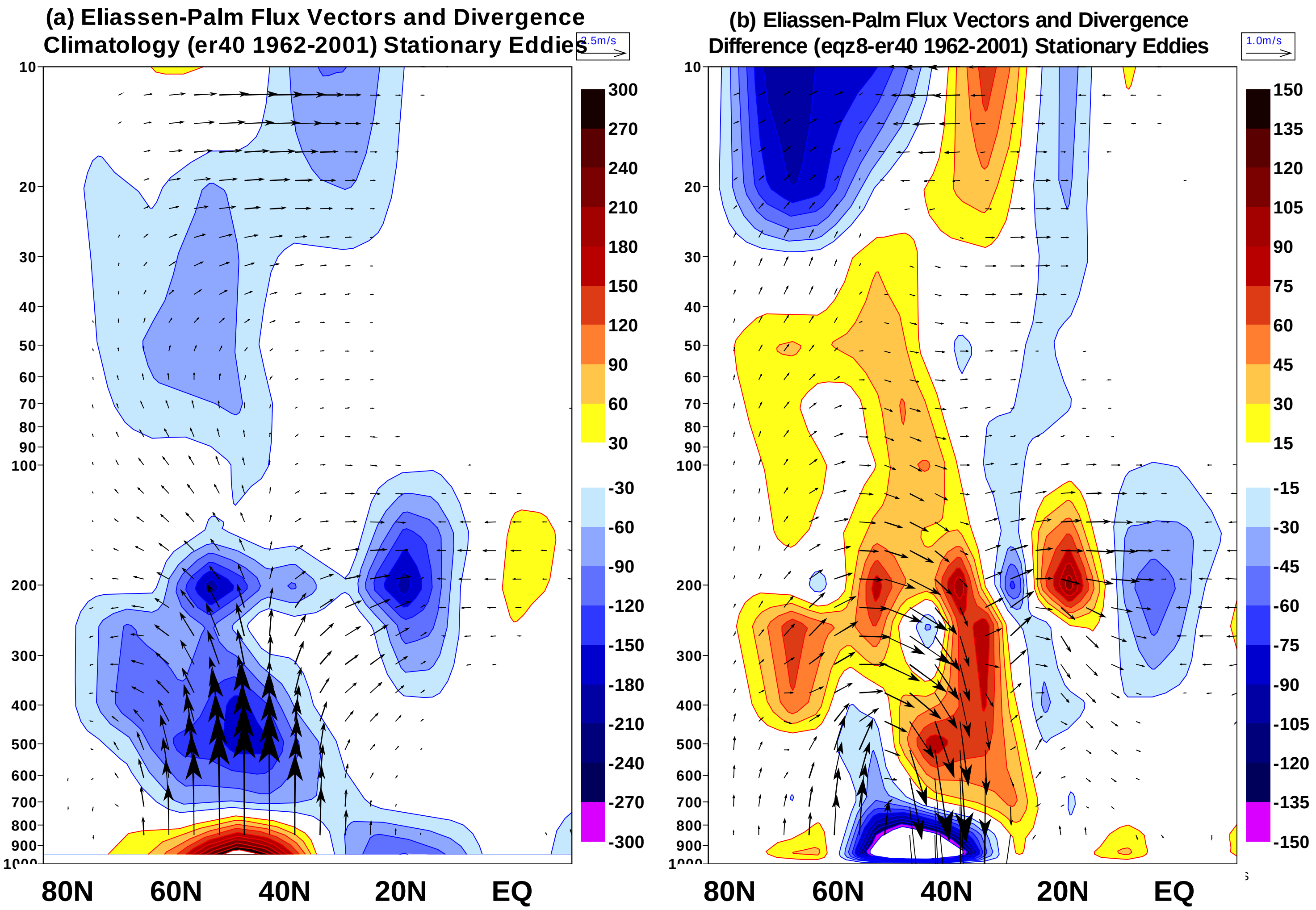


EP-Flux Vectors and Divergence: Stationary Eddies

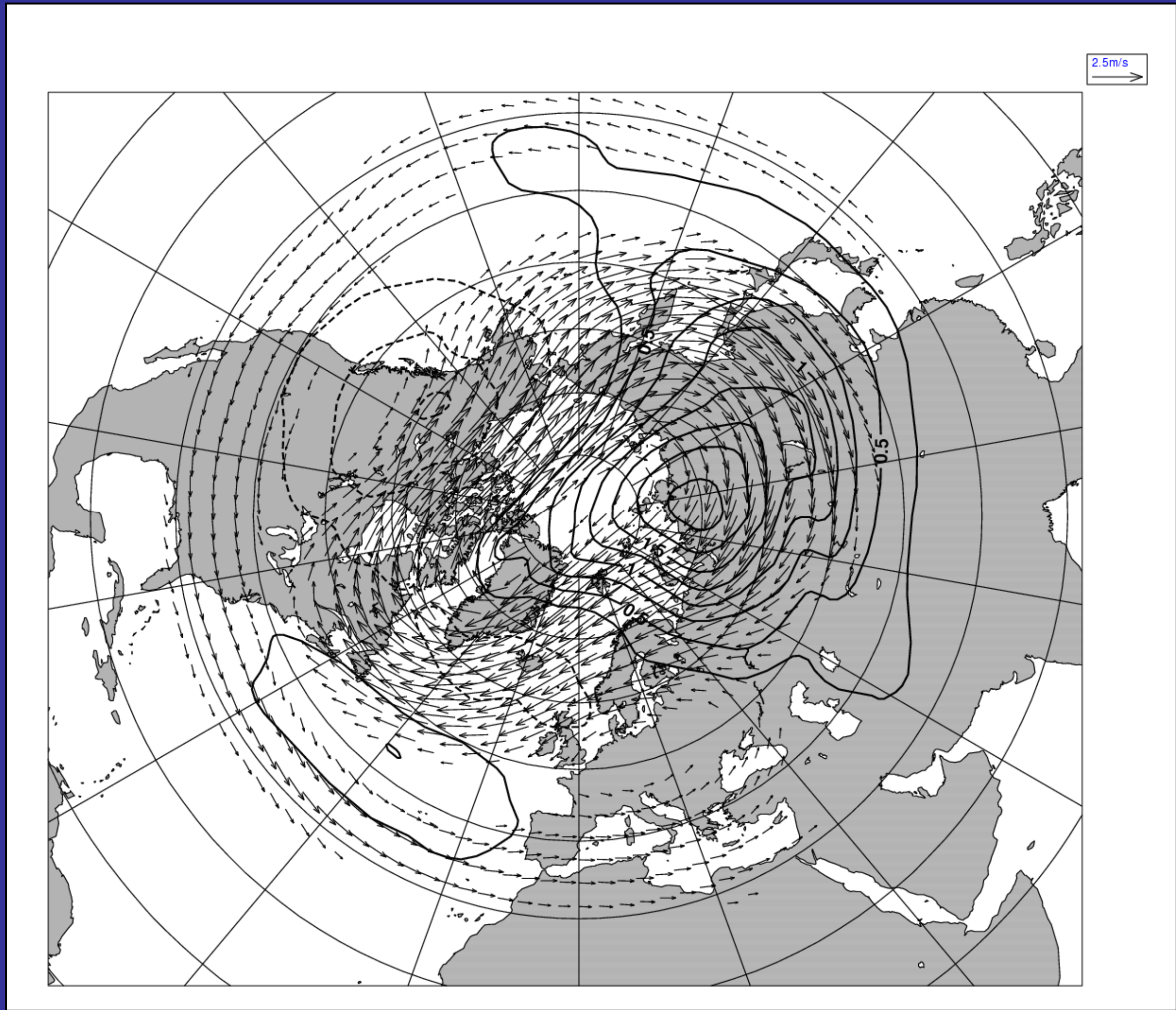


EP-Flux Vectors and Divergence: Stationary Eddies

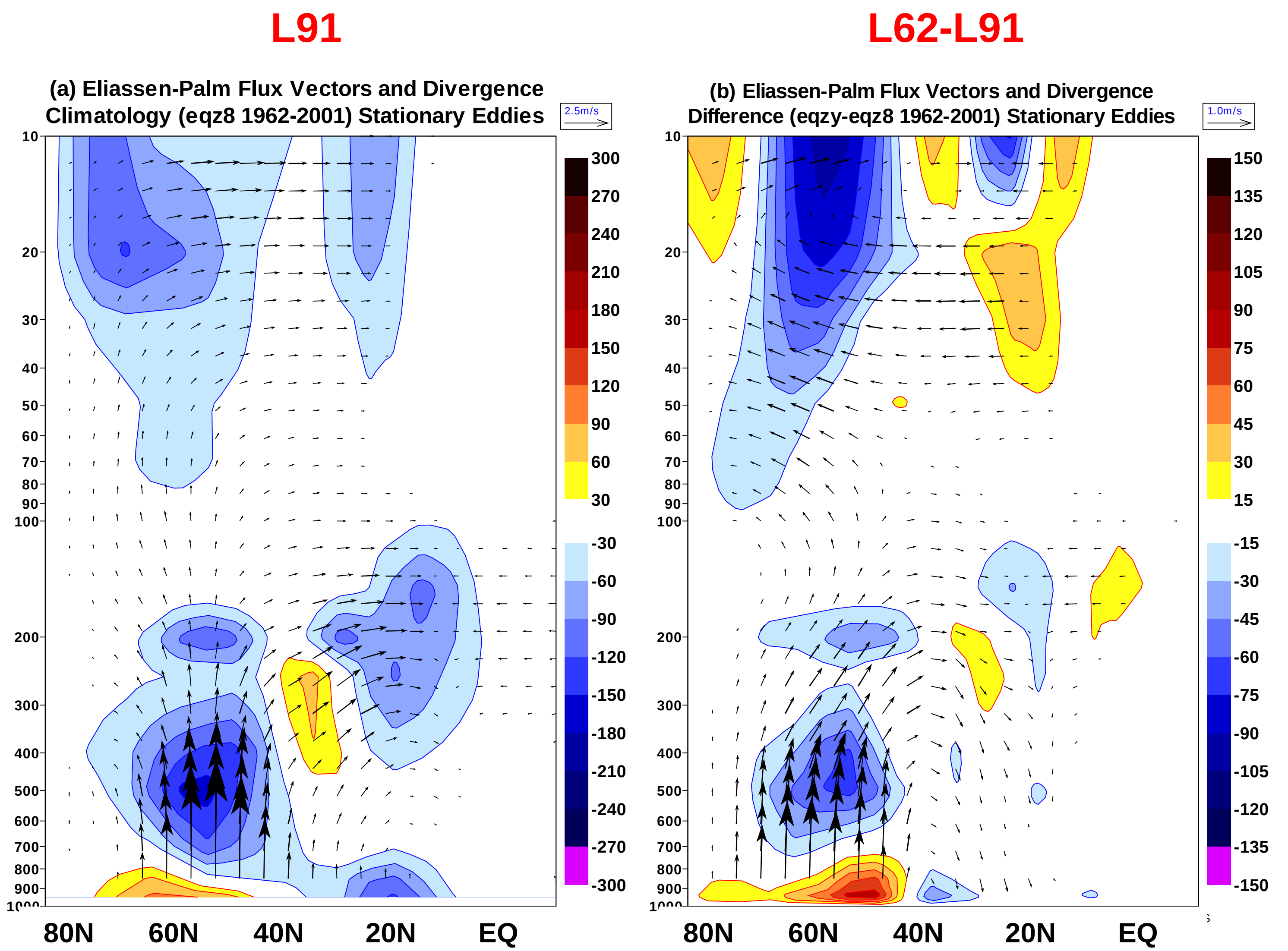
ERA-40 **L91-ERA40**



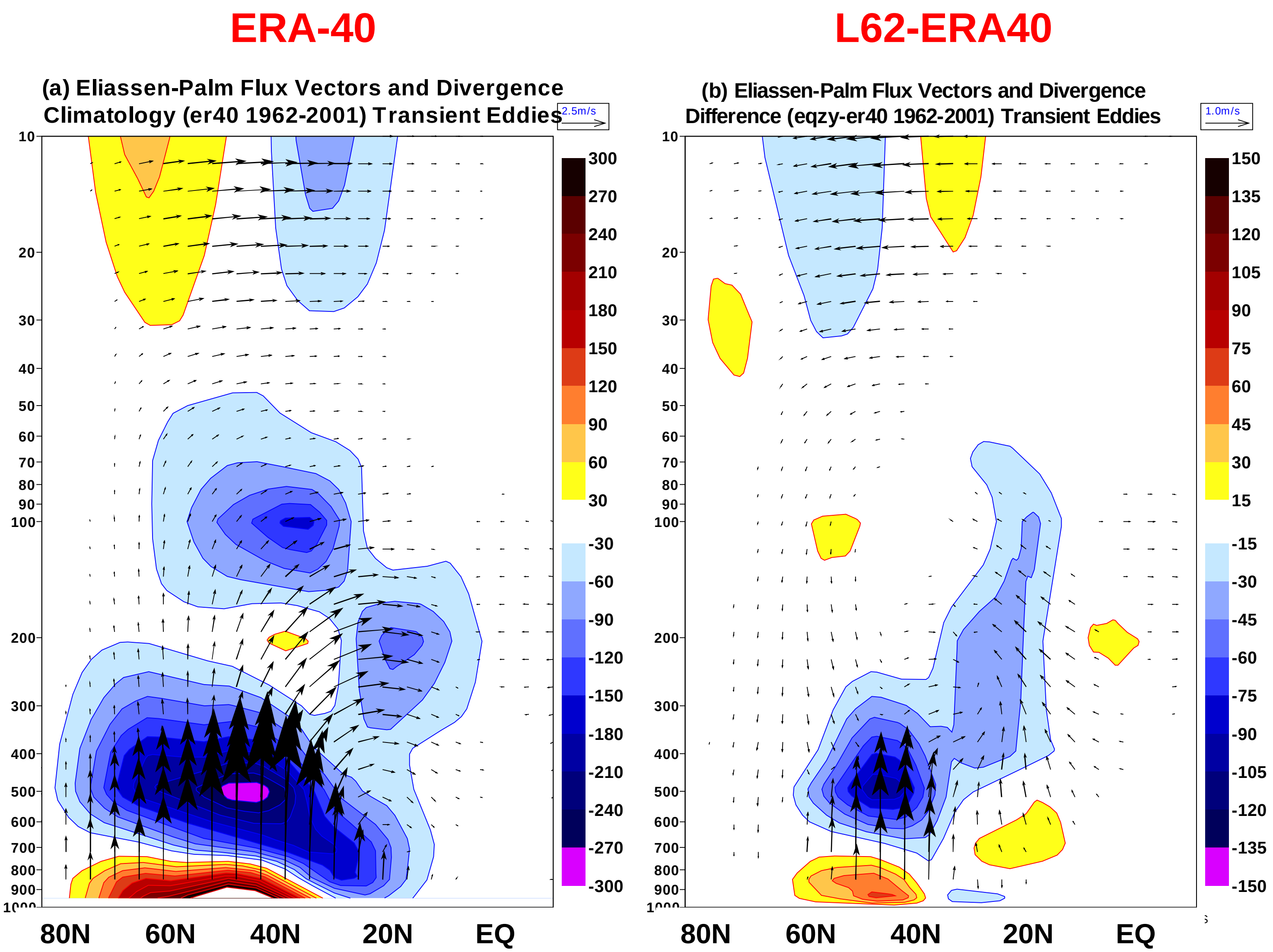
Optimal Stratospheric Forcing (50hPa)



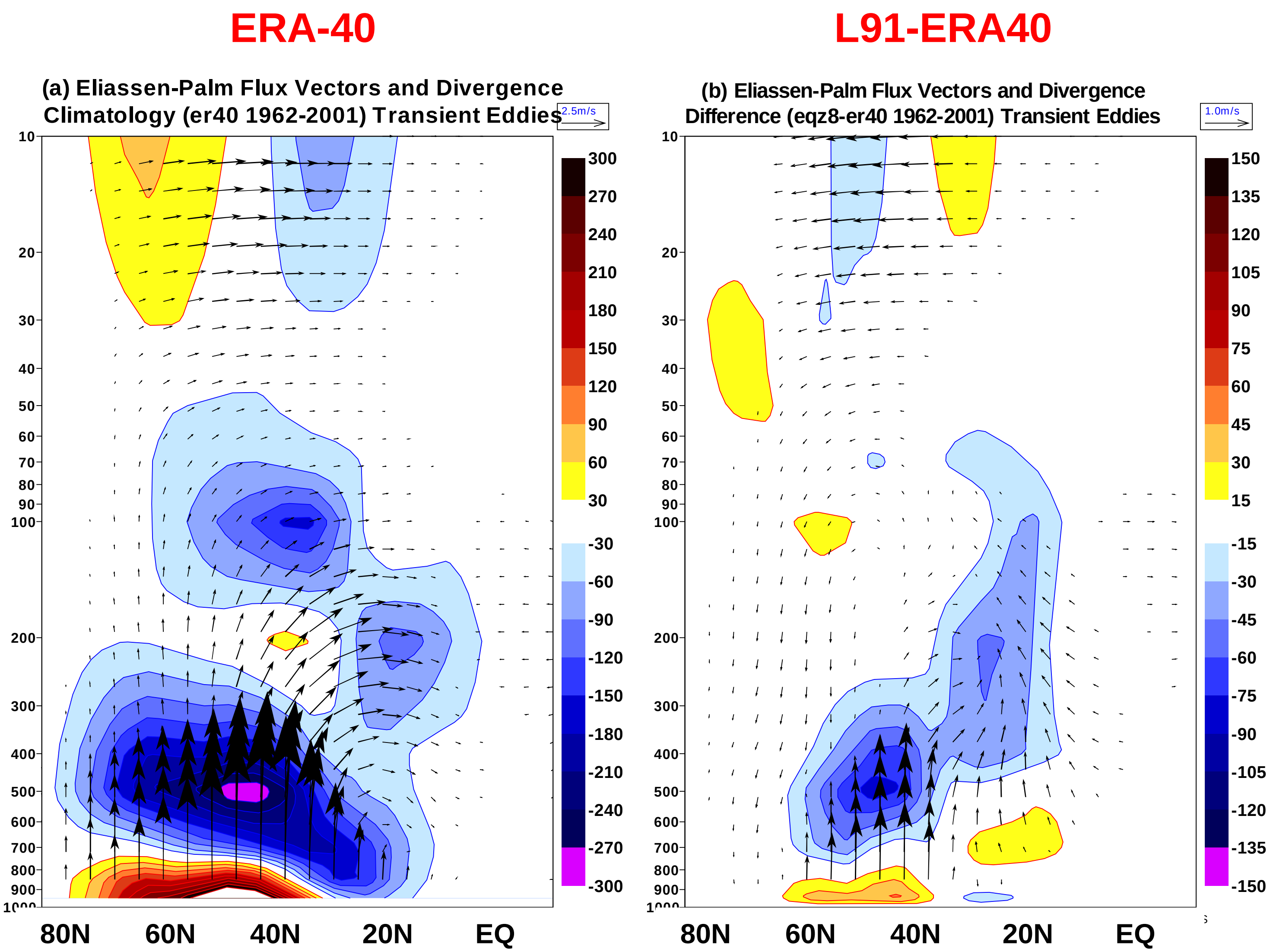
EP-Flux Vectors and Divergence: Stationary Eddies



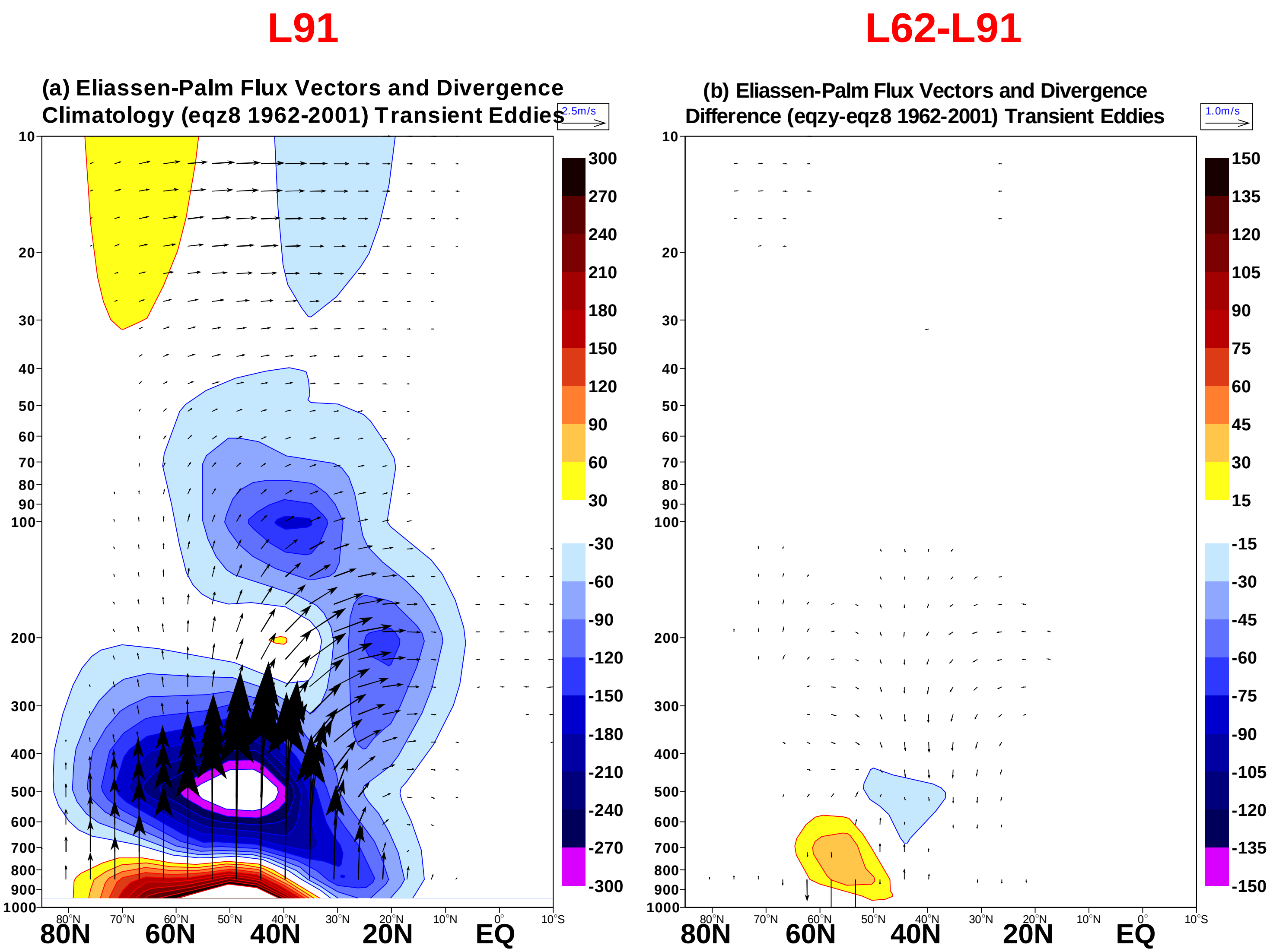
EP-Flux Vectors and Divergence: Transient Eddies



EP-Flux Vectors and Divergence: Transient Eddies



EP-Flux Vectors and Divergence: Transient Eddies



Synoptic Z500 Activity D+21-D+30