Parameterized Processes and Atmospheric Variability

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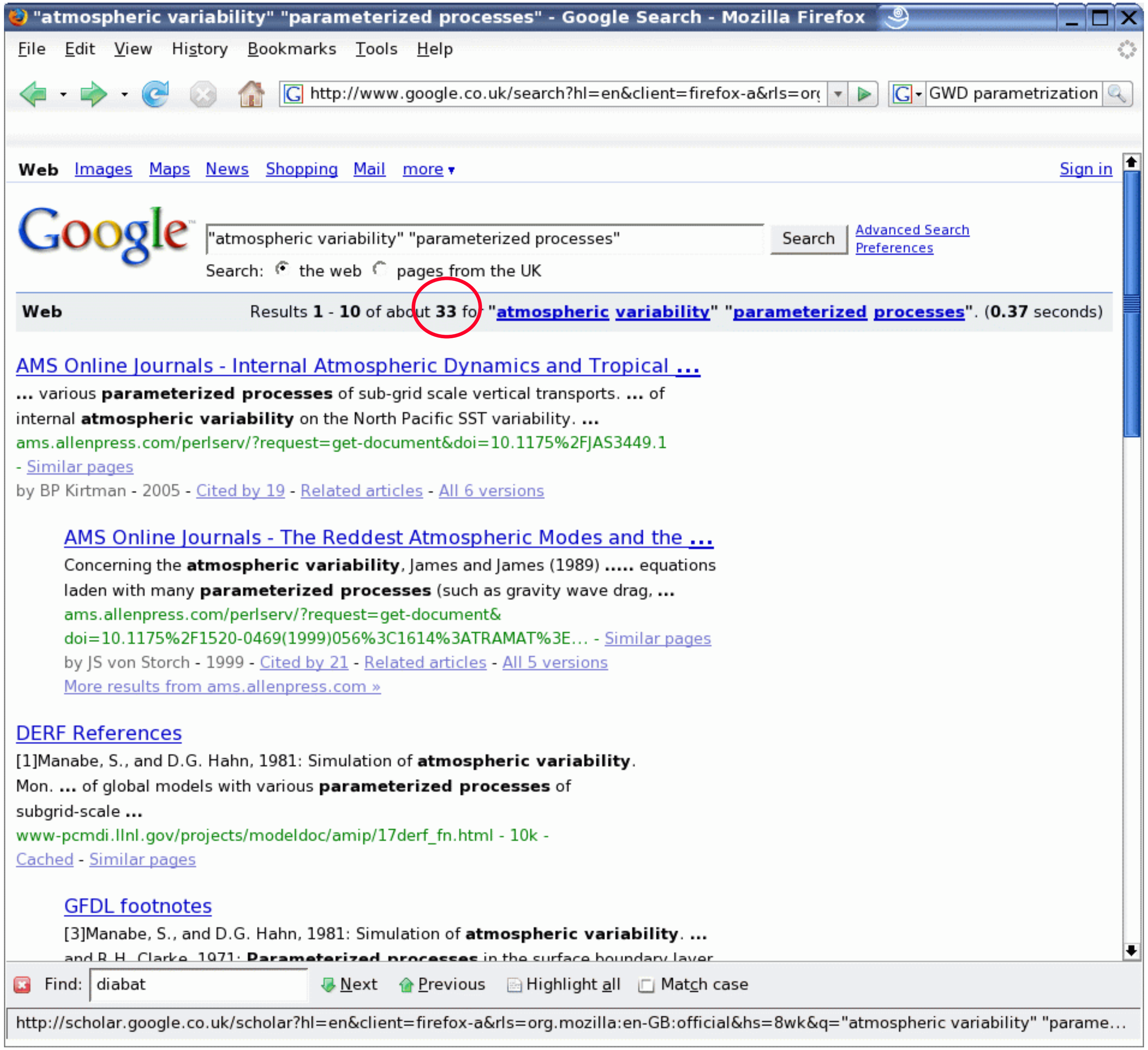
Thanks to: Peter Bechtold, Anton Beljaars, Tim Palmer, Mark
Rodwell, Soumia Serrar and Adrian Tompkins

Diagnostics

A Common Topic?



Conclusion #1

Not much is known about *parametrized processes and atmospheric variability.*

- A lot of data
  - atmospheric variability means long time series are required
  - many parameters (many processes)
  - model levels
- Not straightforward diagnostics
- Lack of observational data

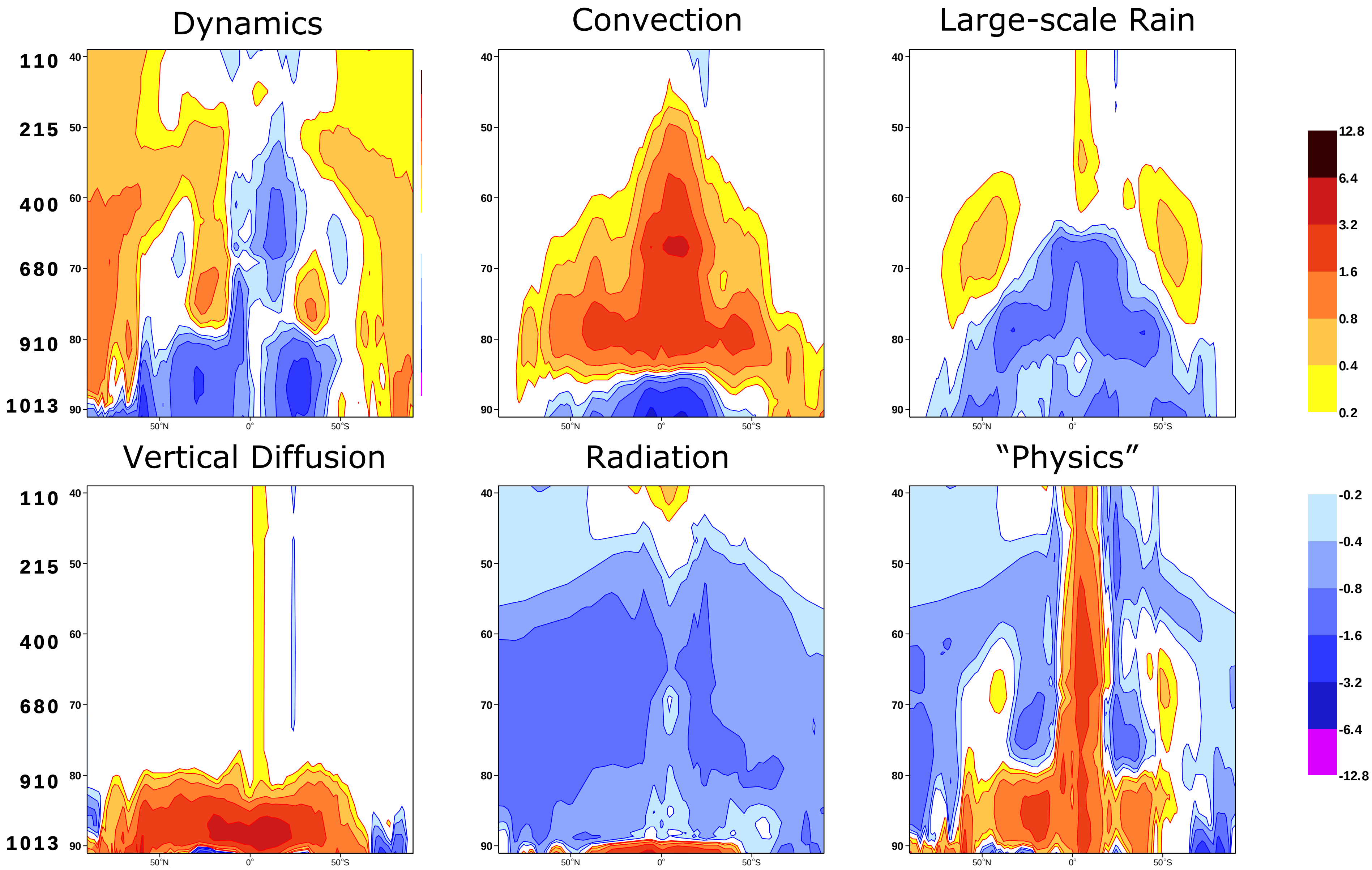
Diagnostics

Outline

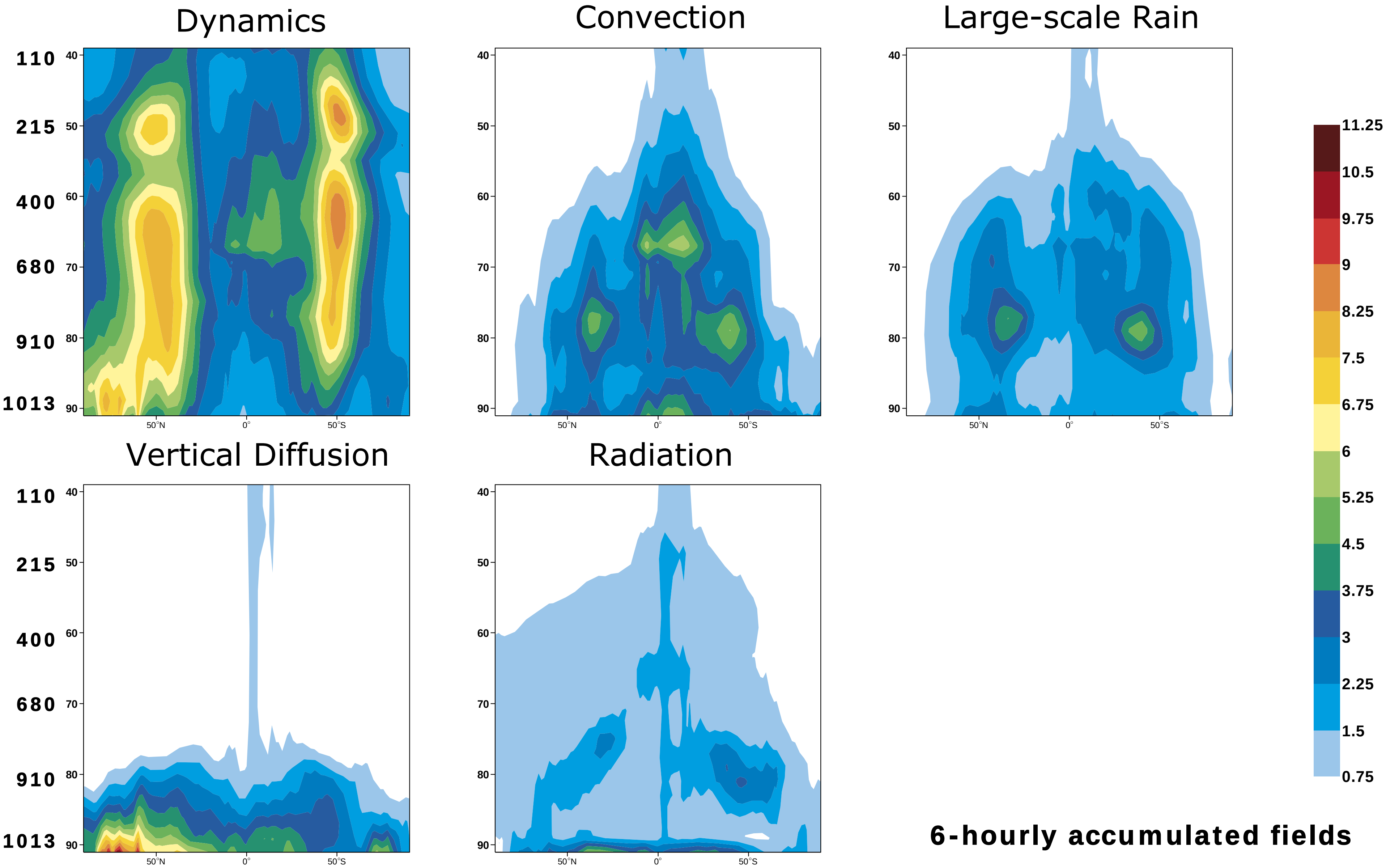
- Introduction: Parameterized processes in the ECMWF model
- Model assessment of atmospheric variability
  - How well do models simulate atmospheric variability?
  - How sensitive is simulated atmospheric variability to changes in physical parameterizations?
- What can we expect from future improvements?

Diagnostics

Mean T-Tendencies: 33R1 DJF 1999-2001

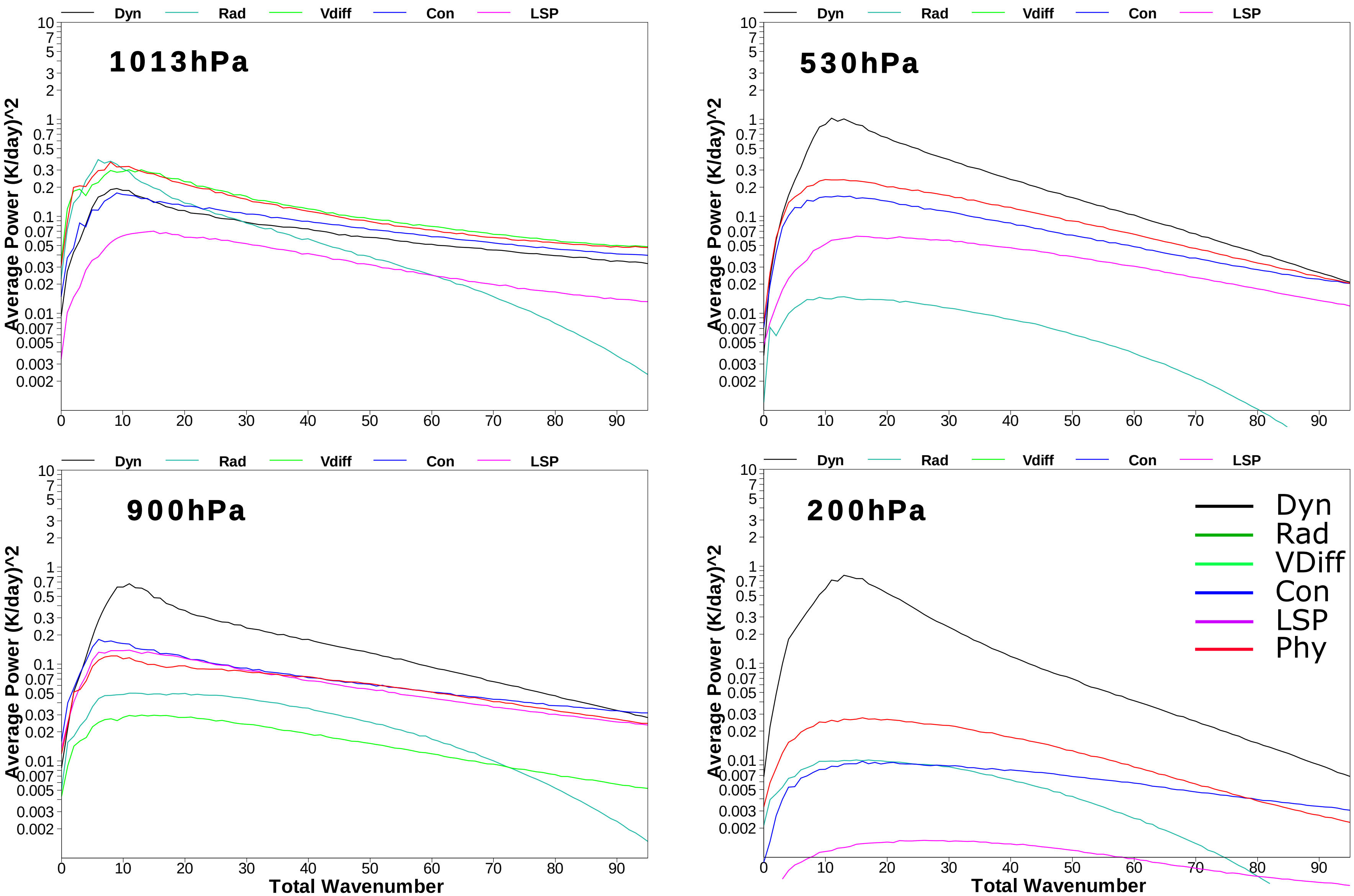


StdDev T-Tendency Anomalies: 33R1 DJF 1999-2001

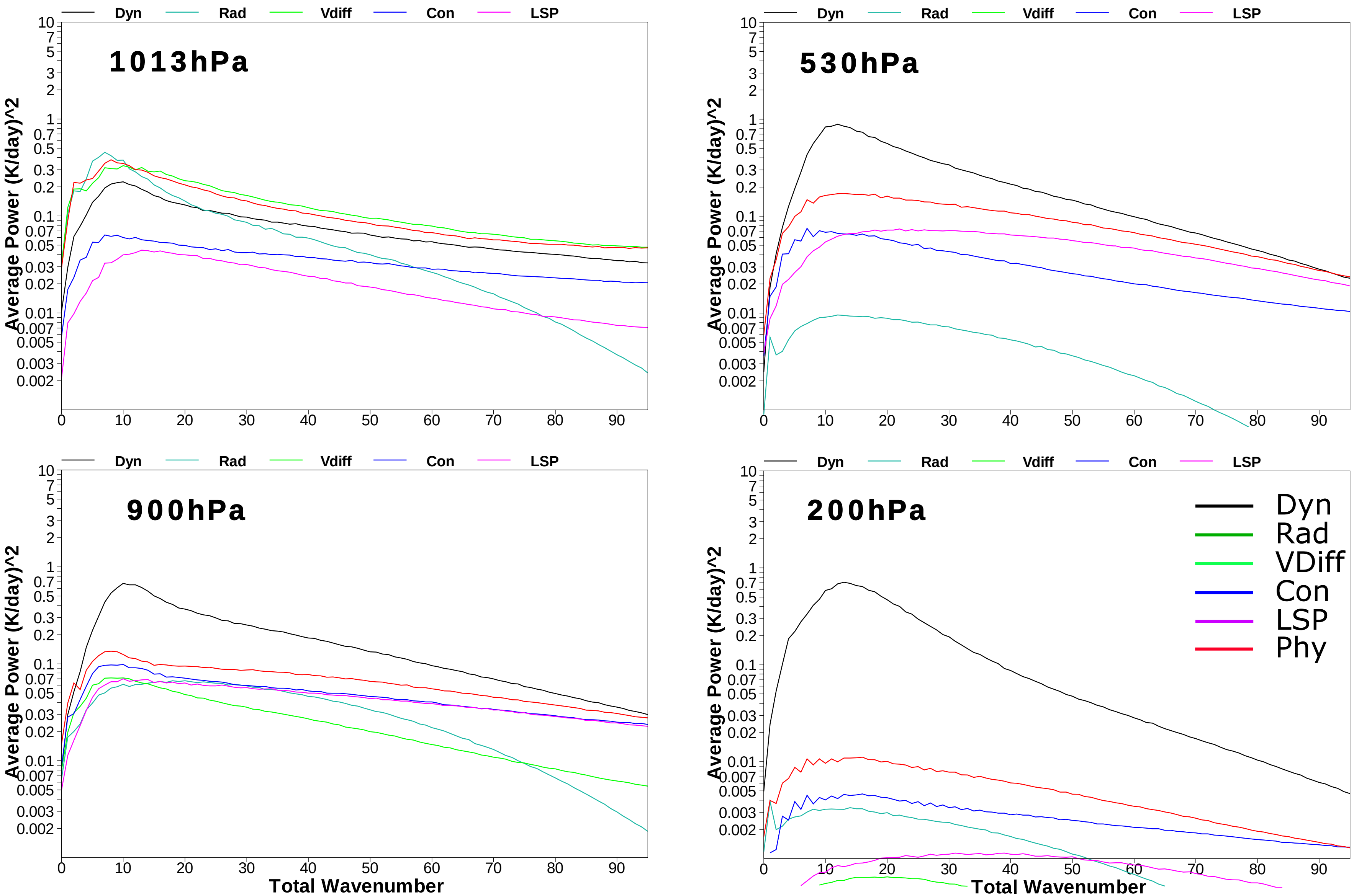


6-hourly accumulated fields

Spectra: T-Tendency Anomalies 33R1 DJF 1999-2001



Spectra: T-Tendency Anomalies 31R1 DJF 1999-2001



Conclusions #2

Diagnostics

- Parameterized process contribute significantly to tendency *variations*.
- Relative importance of parameterized processes to tendency *variations* increases towards the surface/tropics.
- Spectral characteristics:
  - Steep rise in power from planetary to synoptic scales
  - Relatively slow reduction from synoptic to smaller scales
  - Depend on model formulations (both level + shape)

Diagnostics

Outline

- ➢ Introduction: Parameterized processes in the ECMWF model
- ➢ Model assessment of atmospheric variability
  - How well do models simulate atmospheric variability?
  - How sensitive is simulated atmospheric variability to changes in physical parameterizations?
- ➢ What can we expect from future improvements?

Method

- Carry out climate runs for different cycles
- Look how model changes affect the model’s climate (mean state+variability)
- Usually more than one change: carry out more experiments to isolate the origin of a particular change.

Climate Run Diagnostics

➢ Model setup

- Model cycles: 29R2 (2005) - 33R1 (current)
- T_L159L91 (31R1 and higher) and T_L159L60 (older than 31R1)
- 13-months long integration for each year during 1962-2005 (1st November start)
- Diagnostics for DJF, MAM, JJA and SON

➢ Observational data sets

Recent Model Changes

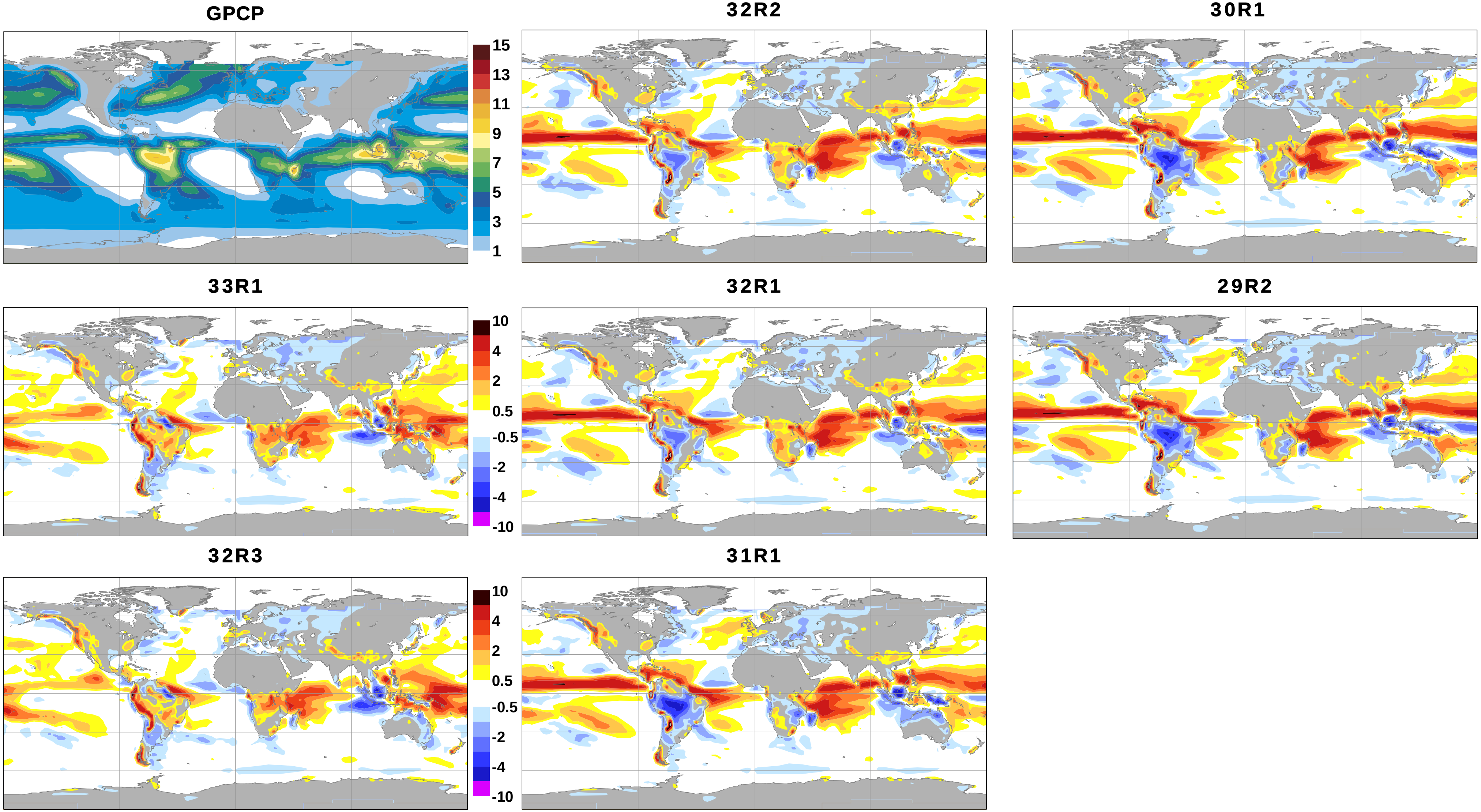
29R2	28 Jun 2005	Modifications to convection
30R1	1 Feb 2006	Increased resolution (L60 to L91)
31R1	12 Sep 2006	Revised cloud scheme (ice supersaturation + numerics); implicit computation of convective transports; introduction of orographic form drag scheme; revised GWD scheme
32R1	*not operational*	New short-wave radiation scheme; introduction of McICA cloud-radiation interaction; MODIS aerosol; revised GWD scheme; retuned ice particle size
32R2	5 Jun 2007	Minor changes to forecast model
32R3	6 Nov 2007	New formulation of convective entrainment and relaxation time scale; reduced vertical diffusion in the free atmosphere; modification to GWD scheme (top of the model); new soil hydrology scheme
33R1	3 Jun 2008	Slightly increased vertical diffusion; increased orographic form drag; retuned entrainment in convection scheme; bugfix scaling of freezing term in convection scheme; changes to the surface model

The ECMWF `Diagnostics Explorer’

IFS Component		Product(s)
Data assimilation	Observation space	**Observation usage** • Many data sources including satellite • Data count, first-guess departures (mean, RMS), bias corrections
	Model space	**Analysis increments** • Prognostic and other parameters • Mean, Standard Deviation, RMS • 21 pressure levels and zonal means
Weather forecast		**Forecast error** • Prognostic and other parameters • Mean, Standard Deviation, RMS • 21 pressure levels and zonal means
		Scale-dependent error and activity • Several parameters, levels and regions • All spatial scales and selected spatial scales
Model climate	AGCM & Coupled model	**Seasonal-means of error** • Several diagnostics including geopotential height, winds, velocity potential, Hadley and Walker circulations, ocean waves etc
		Seasonal-means of variability • Blocking • ENSO teleconnections • EOFs • Planetary and synoptic activity • Power spectra • Tropical waves (including MJO)

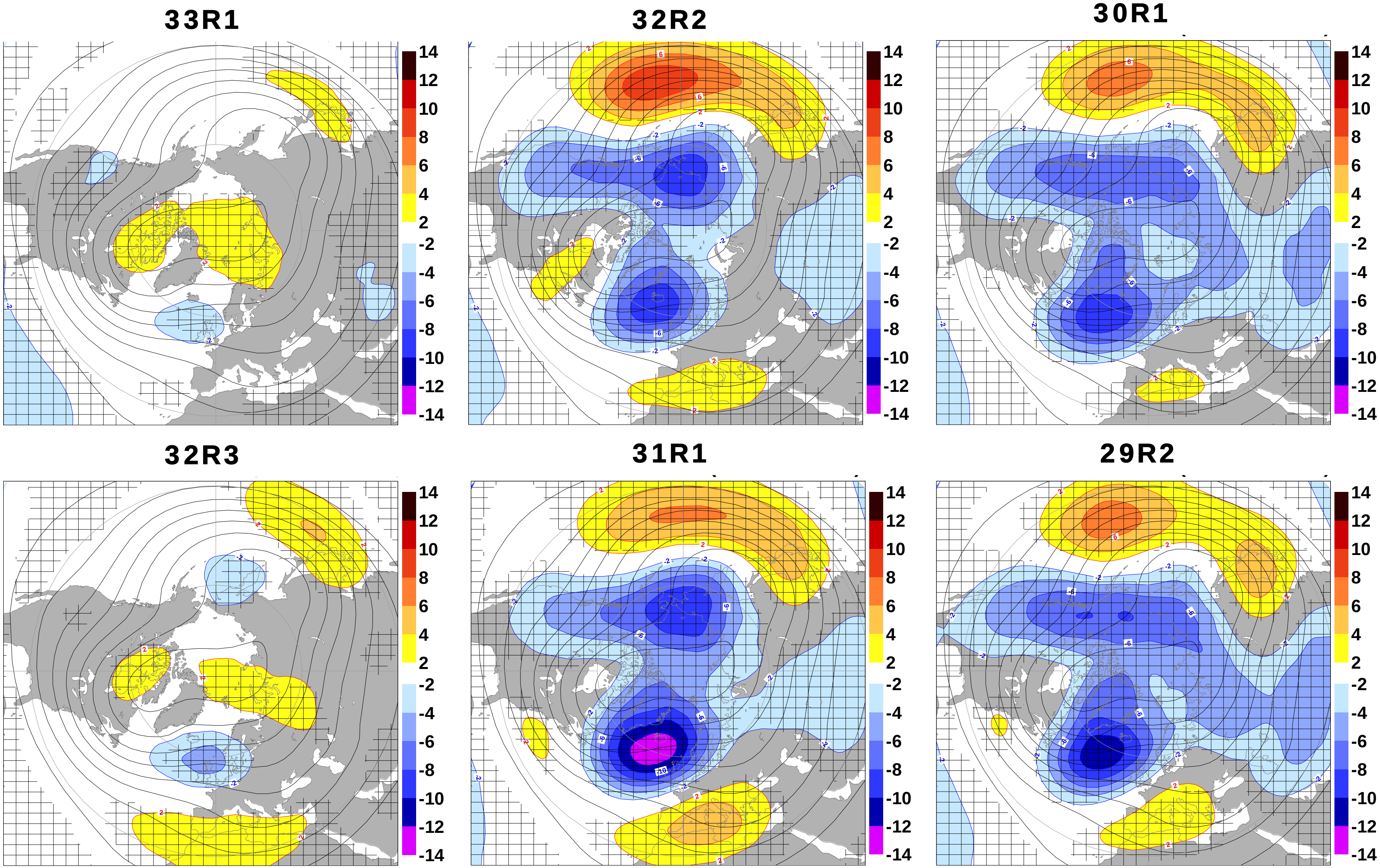
Table 1 Summary of the present diagnostics available on the ‘Diagnostics Explorer’ website.

Systematic Error: Precipitation (DJF)



Diagnostics

Systematic Error: Z500 (DJF)



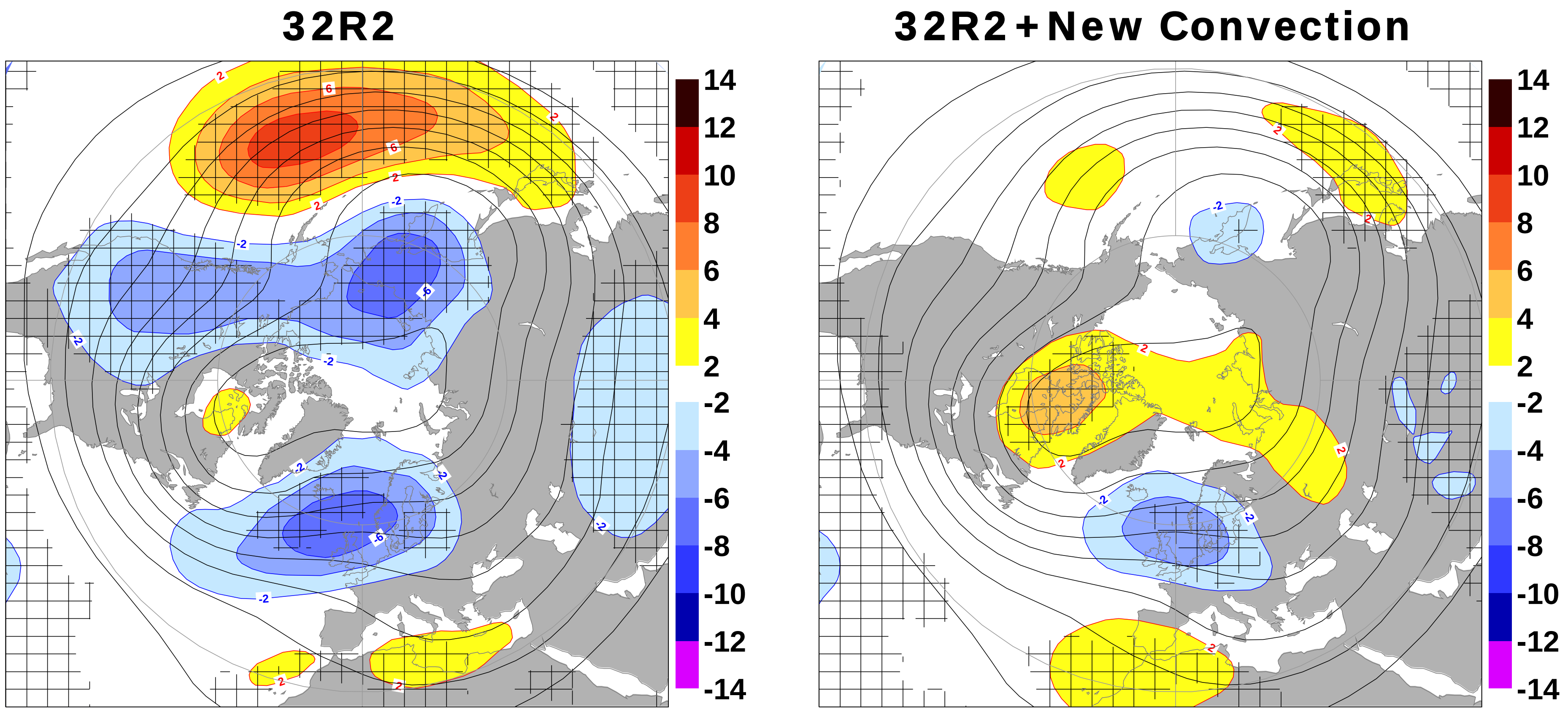
What led to the improvements in 32R3?

Further experimentation:

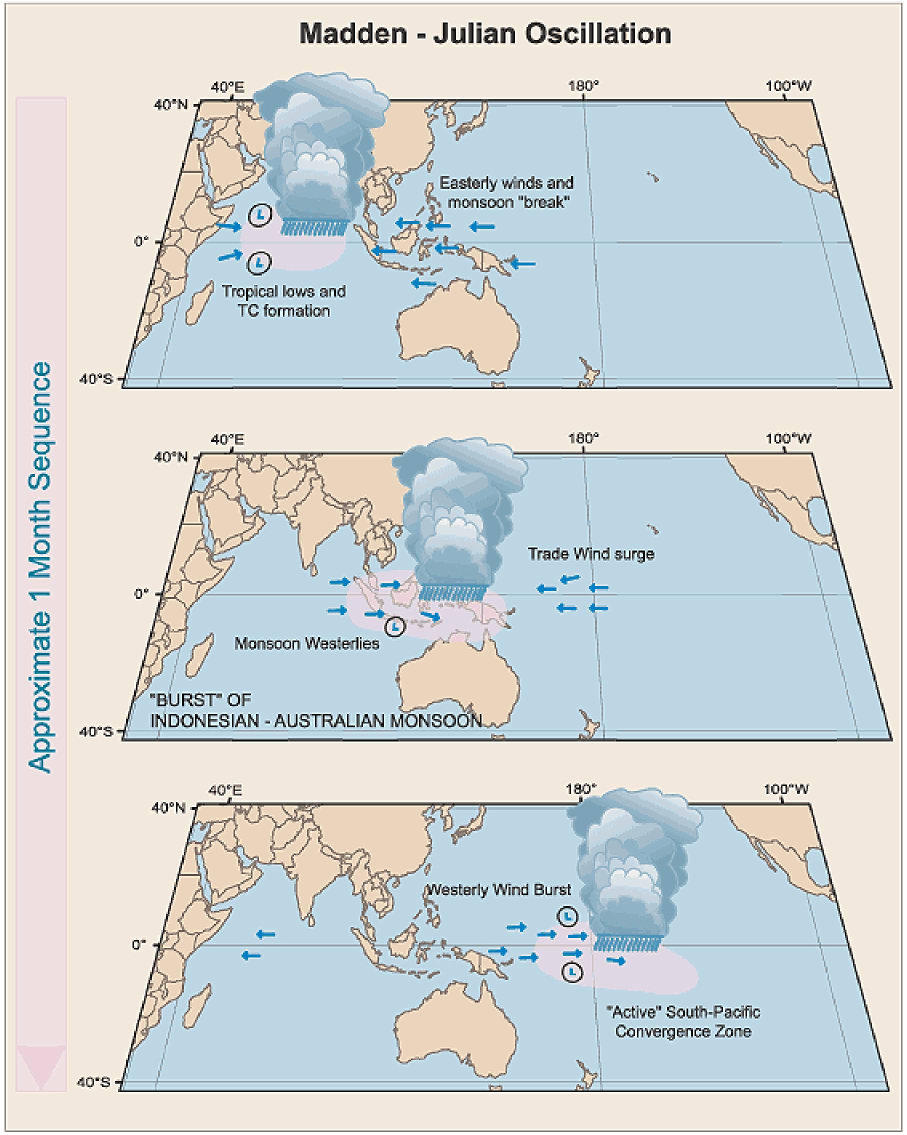
- Run the `old' model cycle with new convection scheme
    - Increased sensitivity to environmental moisture
    - Remove any imposed large-scale control of the convection through the ω field and the moisture convergence
- Run the `new' model cycle with old vertical diffusion.

Diagnostics

Systematic Error: Z500 (1990-2006 DJF)



Tropical Waves and MJO



Model symptoms:

- loss of amplitude
- propagation speed too fast
- no periodicity

Schematic: M Wheeler

Power Spectra: Various AR4 Models

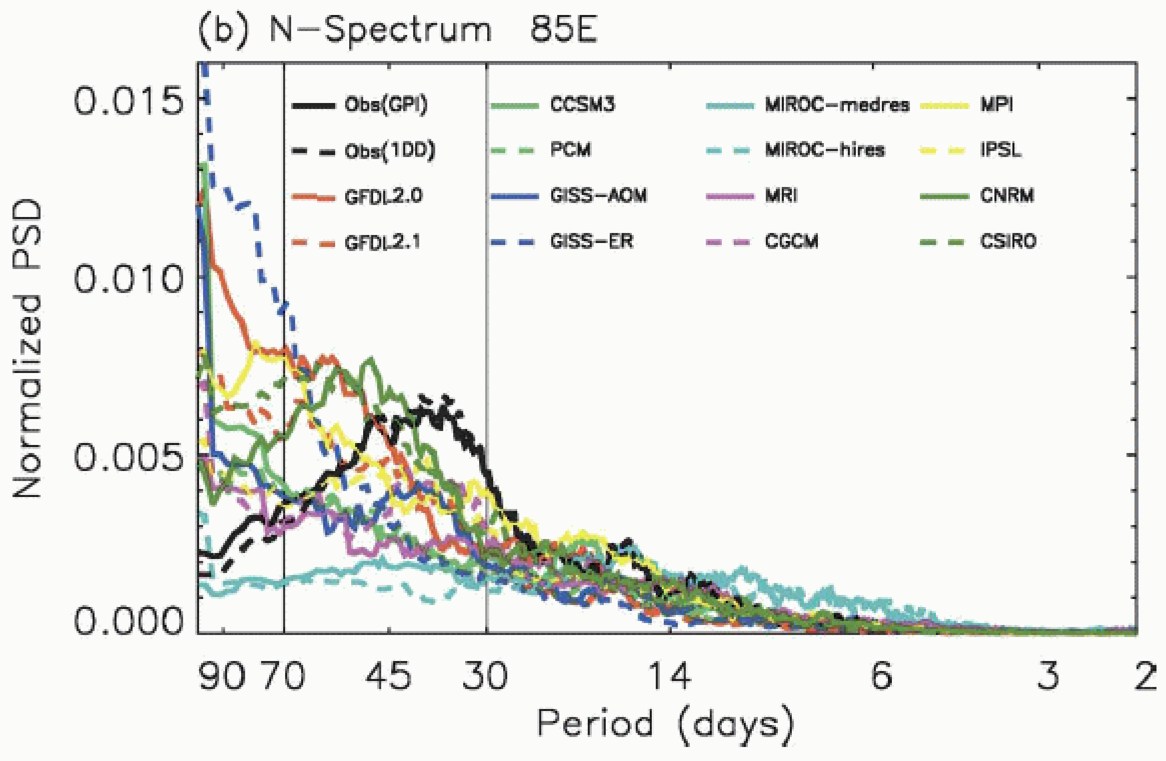
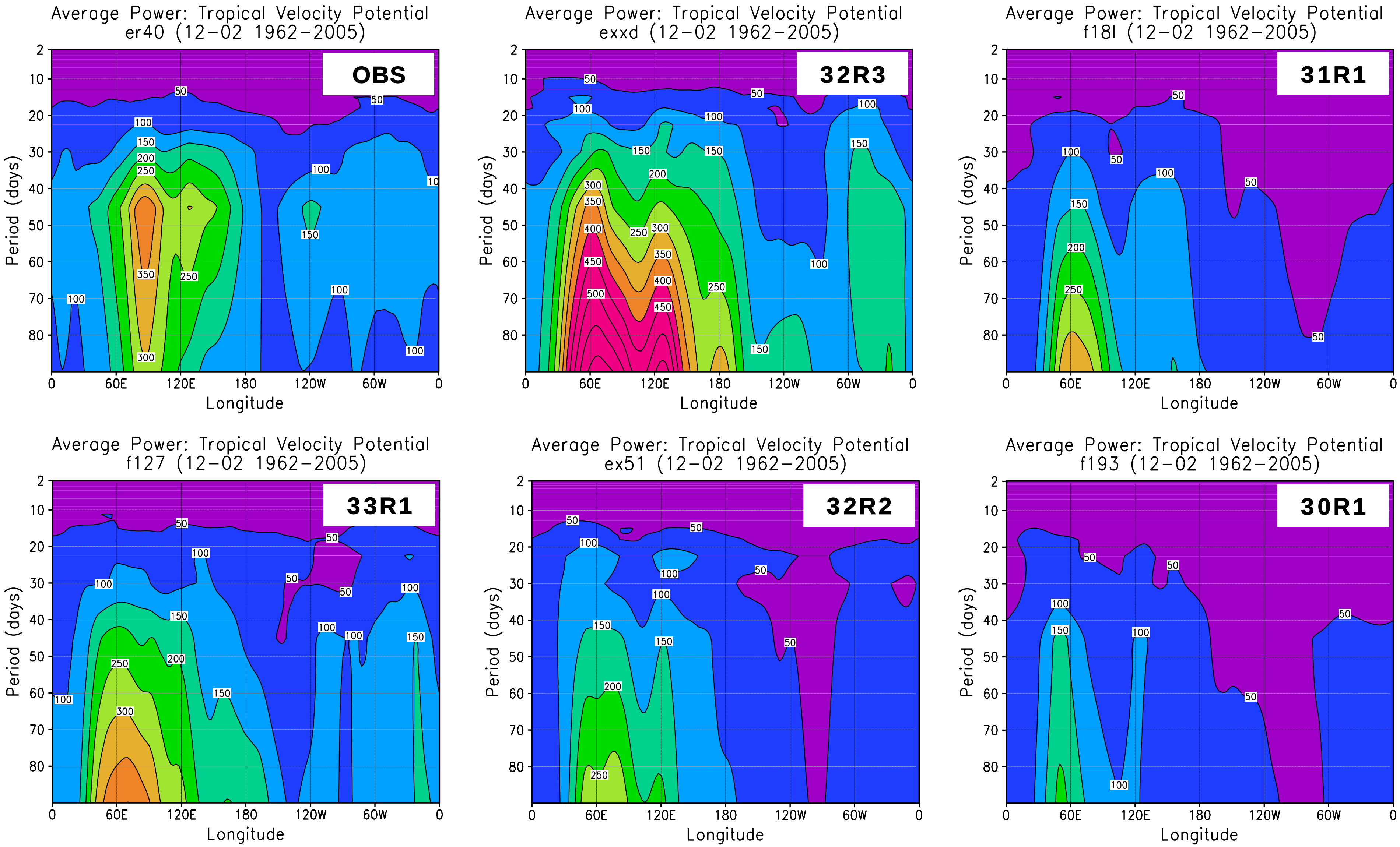


FIG. 12. Spectrum of the eastward wavenumber 1–6 component of equatorial precipitation (5°N–5°S) at 0°, 85°E for two observational datasets and 14 models: (a) raw and (b) normalized spectrum. Frequency spectral width 1/100 cpd.

Jin et al. 2006, JClim

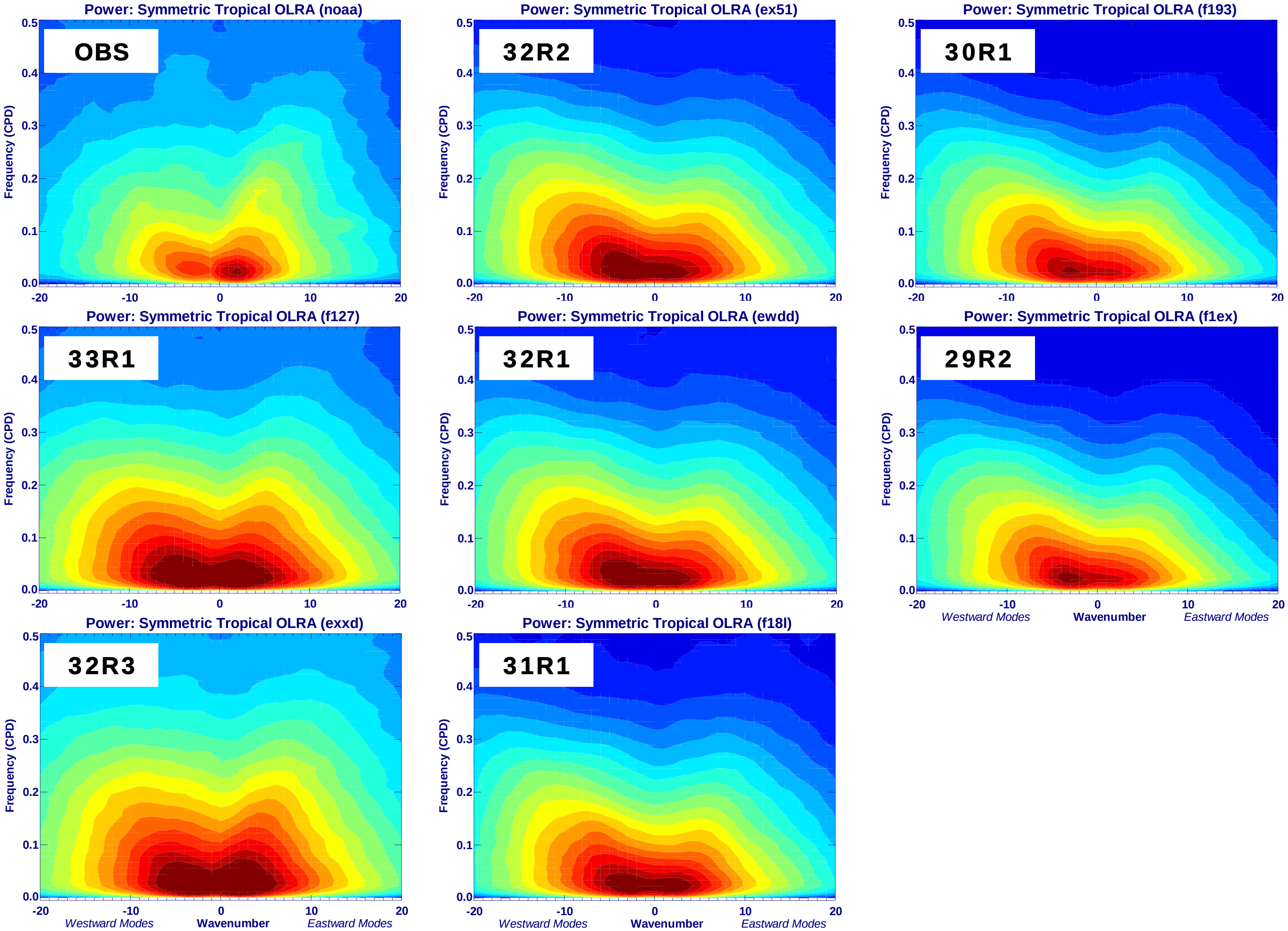
Diagnostics

Tropical X_{200} Spectra (DJF)

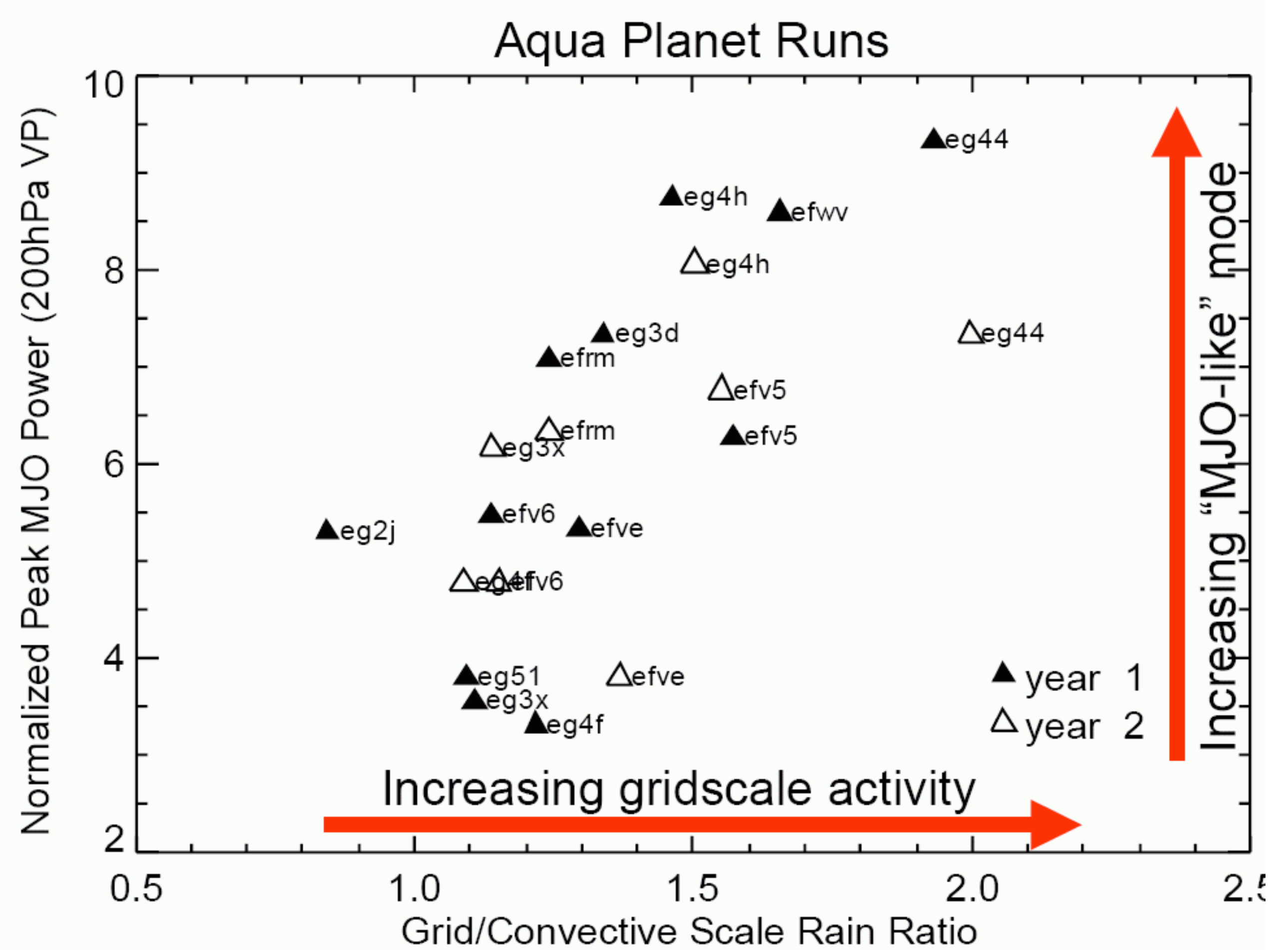


Diagnostics

Convectively Coupled Tropical Waves (DJF)



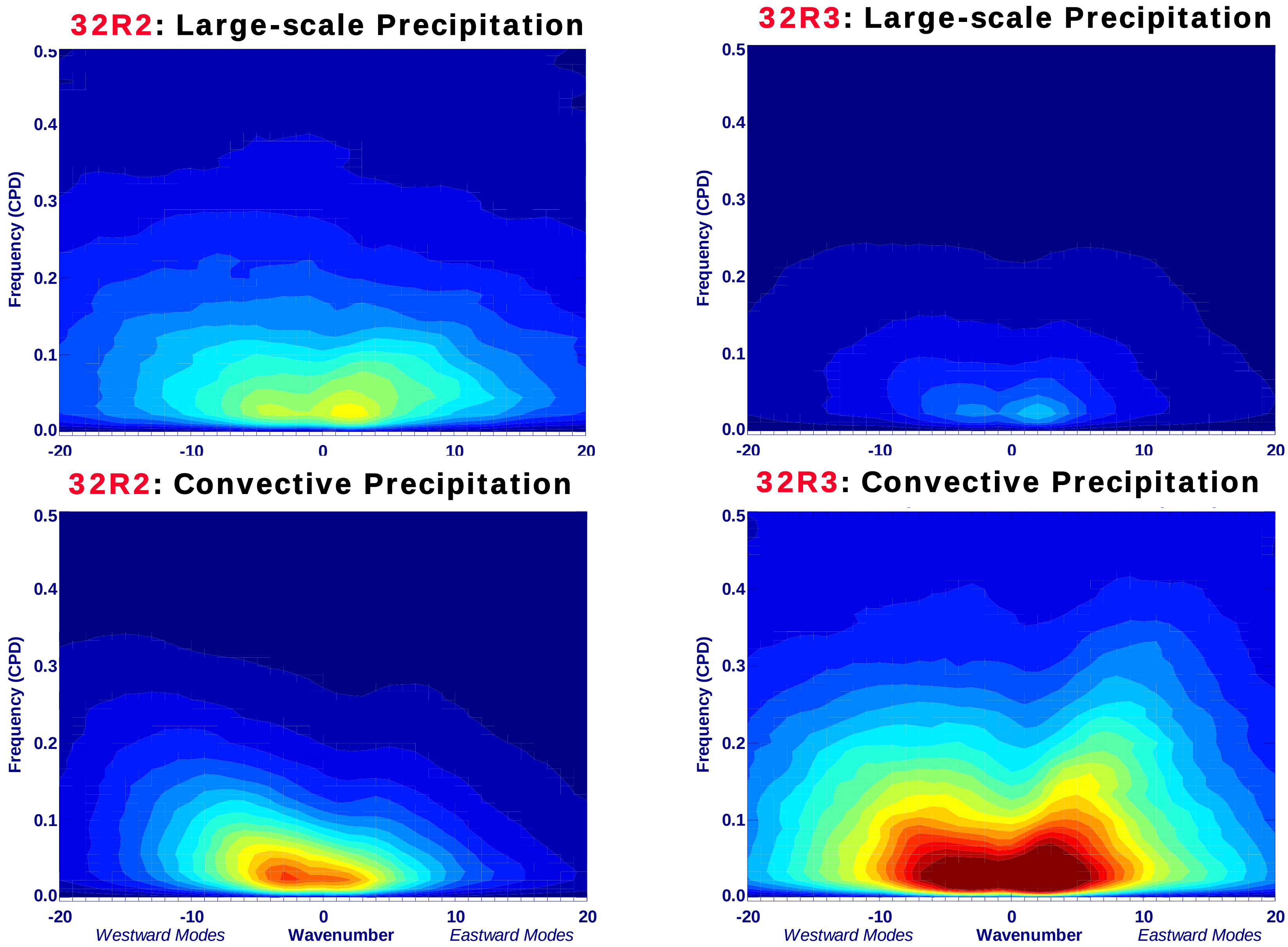
Large-scale vs. Convective Rain



- Influence of water-vapour convection feedback on MJO
- Eastward propagating Kelvin wave (20 day period) consequence of coupling between large-scale dynamics and grid-scale latent heating
- Convection scheme damps this mode
- See also Scinocca and McFarlane (2004)

Tompkins and Jung 2004

Convectively Coupled Tropical Waves (DJF)



Blocking Anticyclones

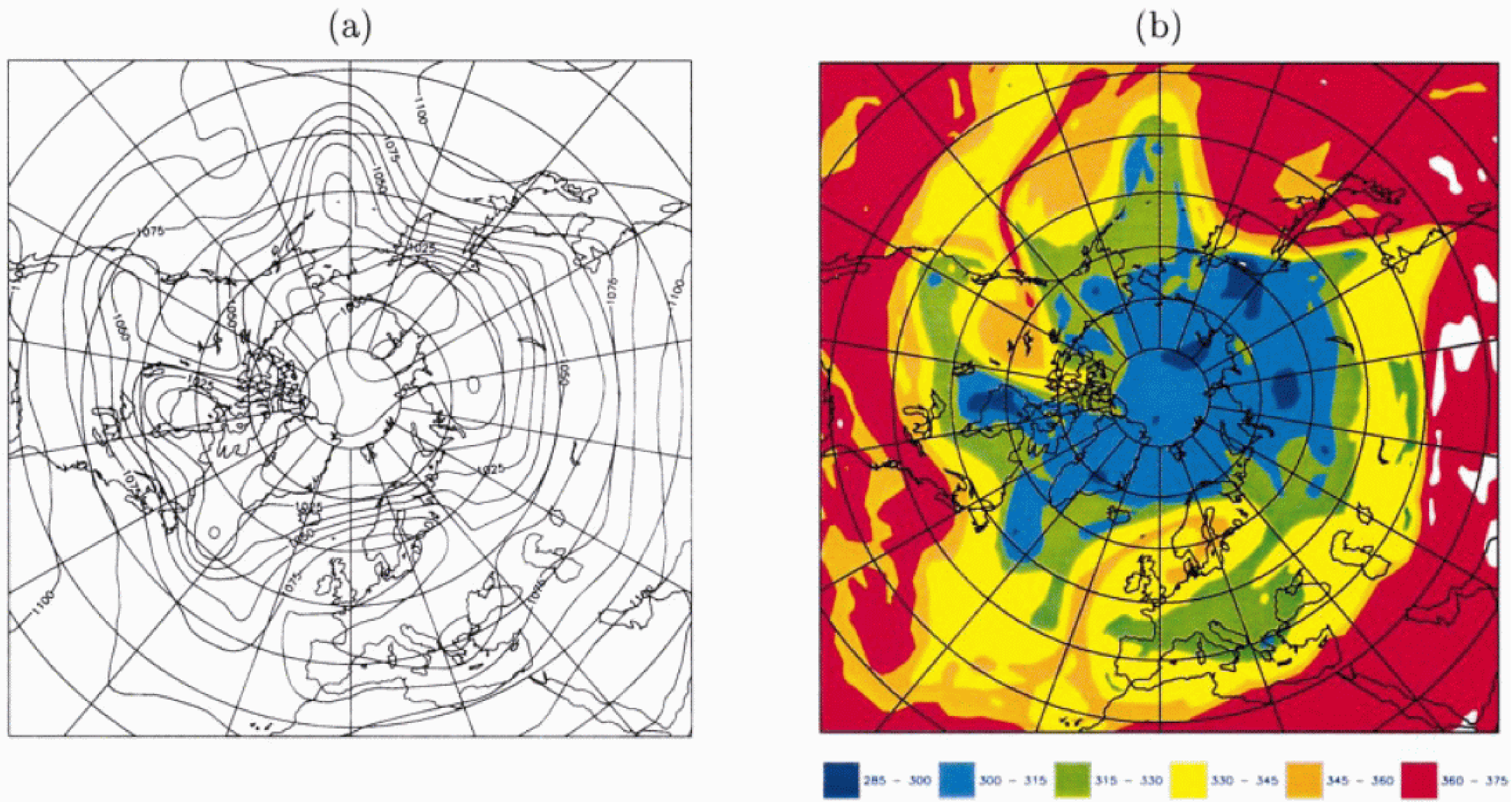


FIG. 1. Analyses of (a) 250-hPa geopotential height (dam) and (b) θ (K) on PV = 2 for 1200 UTC 21 Sep 1998.

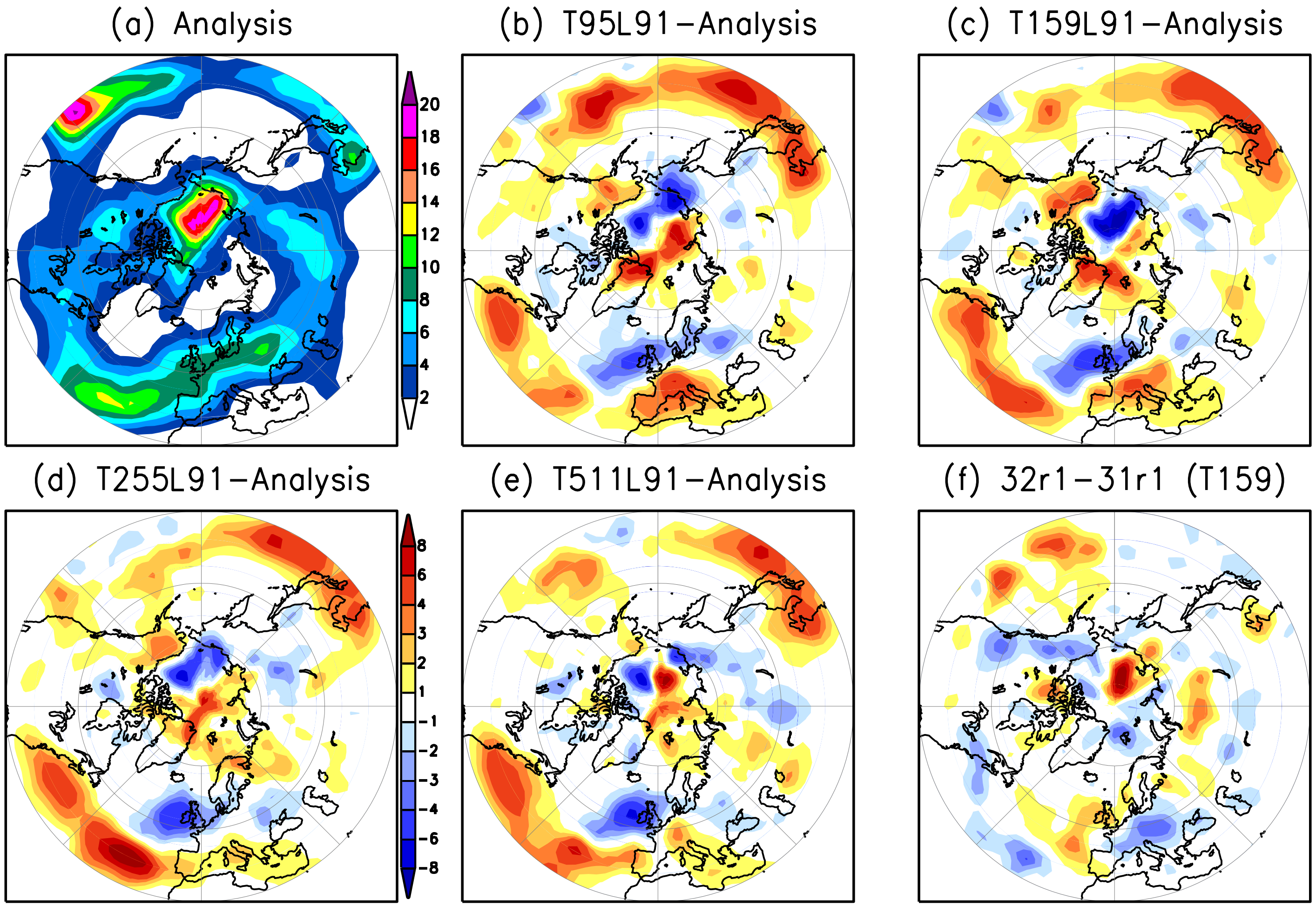
Pelly and Hoskins, 2003, JAS

Physical Processes and Euro-Atlantic Blocking

- "…the dominating effects of global orography (and of the Rocky Mountains in particular) in conditioning both onset and maintenance of the block are confirmed once more for this case." (Ji and Tibaldi, 1983)

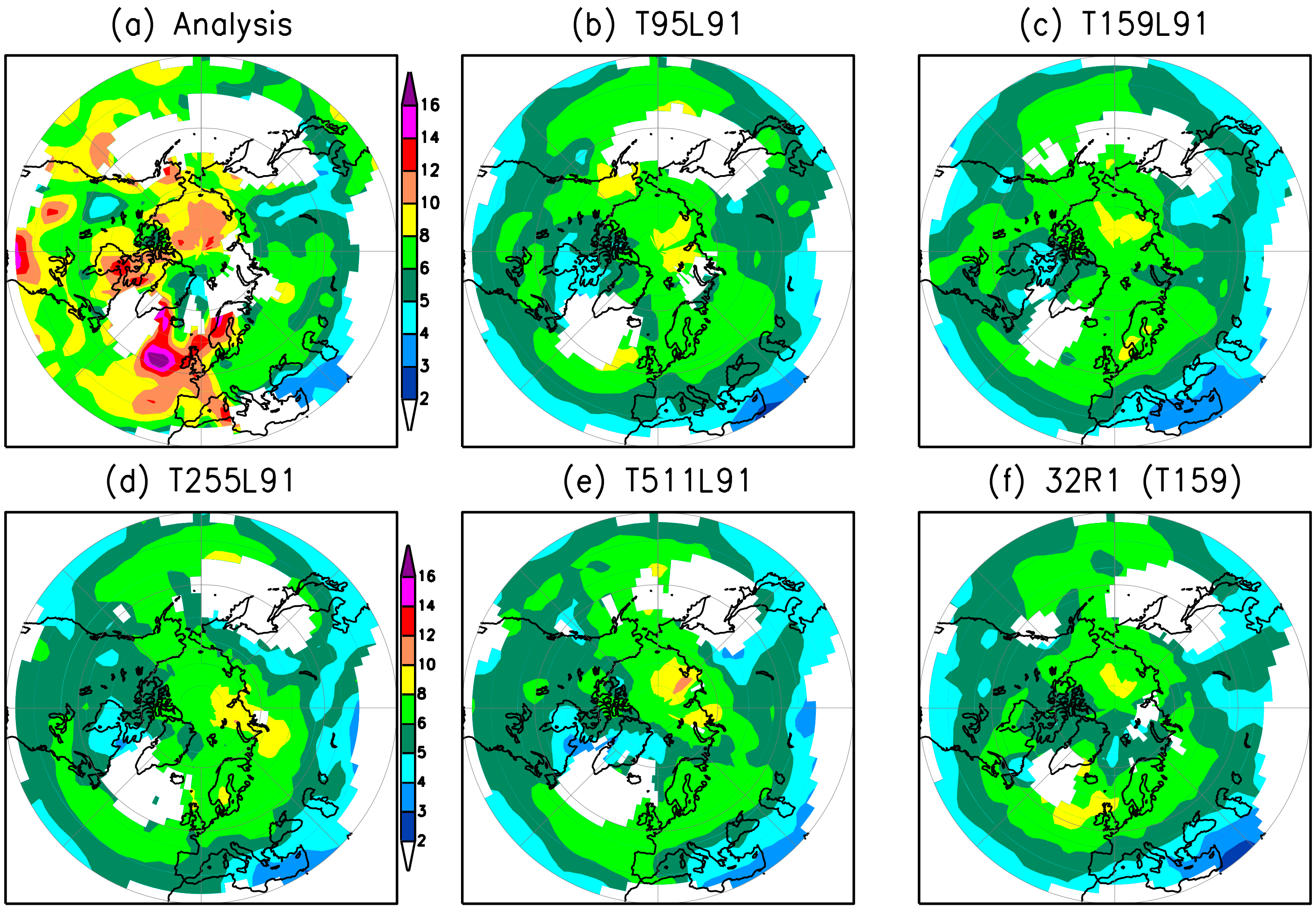
- "The percentage of 72h-backward trajectories (from the blocked region) that have undergone cross-isentropic transport of more than 5 K can amount to 80% … strongly diabatically modified air ($d\theta/dt > 20K$) reinforces the anticyclonic circulation with a percentage exceeding 20%." (Schwierz 2001)

Frequency of Anticyclones (DJFM)



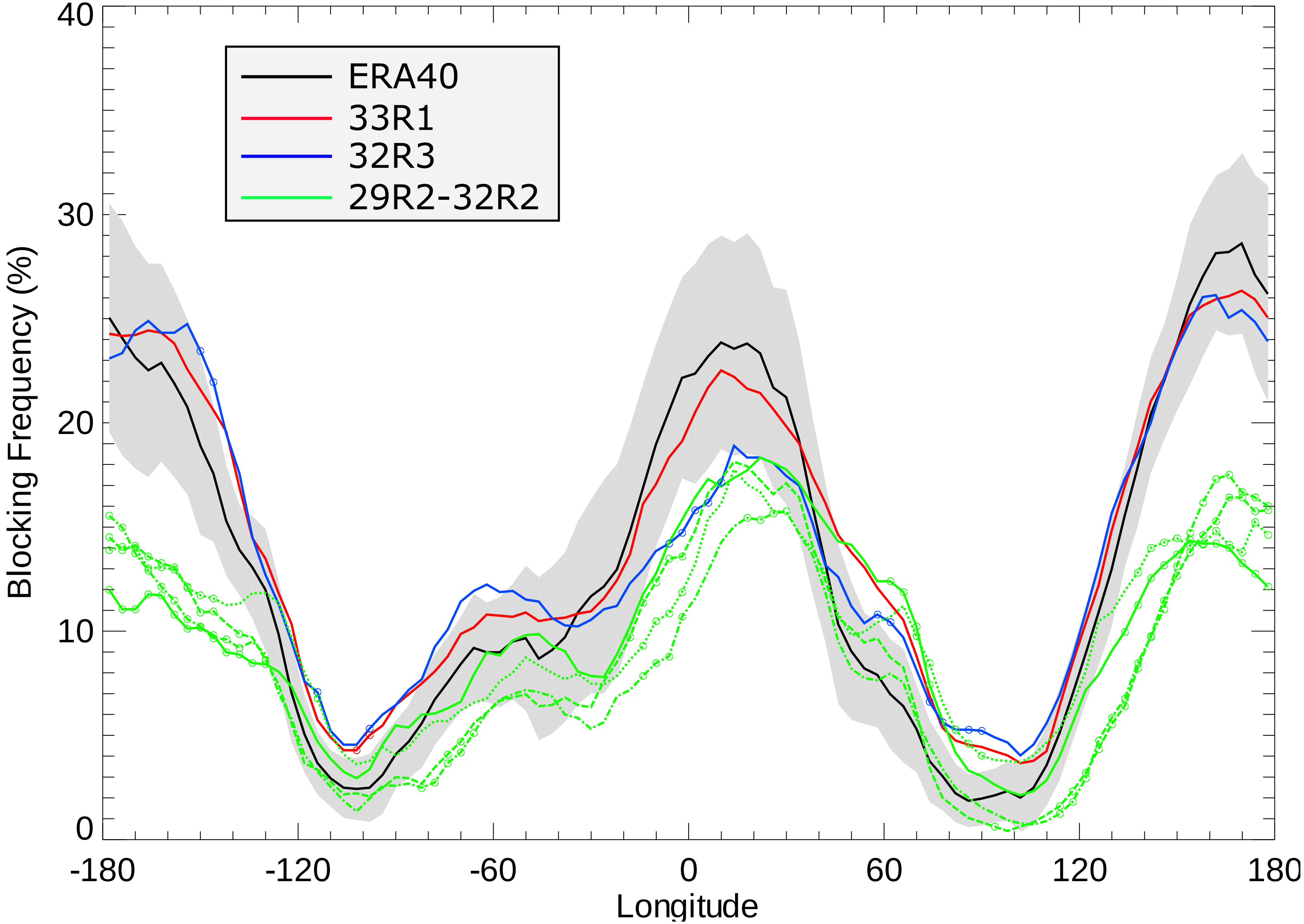
Long-lived anticyclones only (> 2 days)

Average Lifetime of Anticyclones (DJFM)

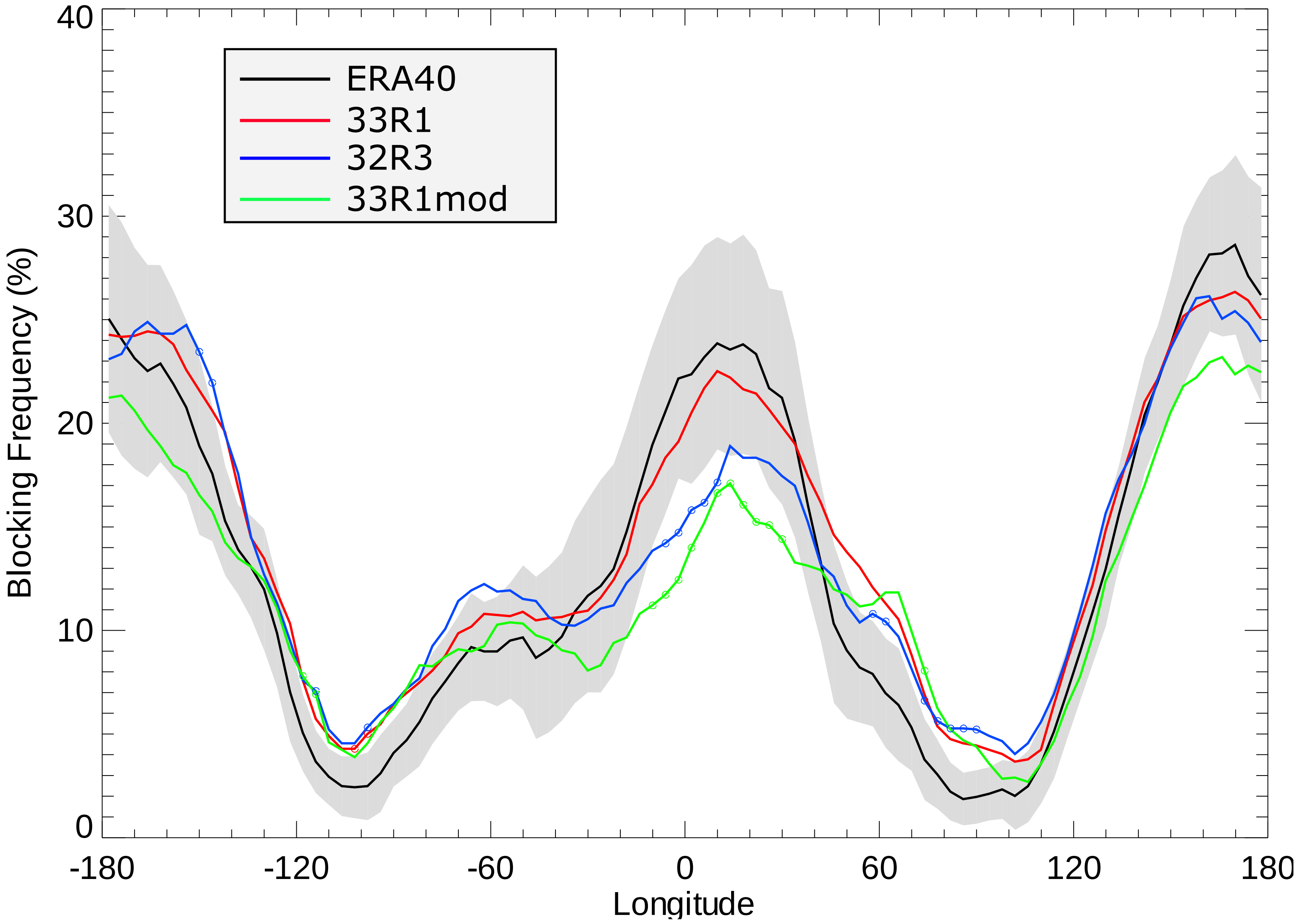


Long-lived anticyclones only (> 2 days)
Minimum number: 0.5 anticyclone/winter

Blocking Frequencies: DJFM 1990-2005



Blocking Frequencies: DJFM 1990-2005



Extratropical Cyclones/Warm Conveyor Belts

ECKHARDT ET AL.

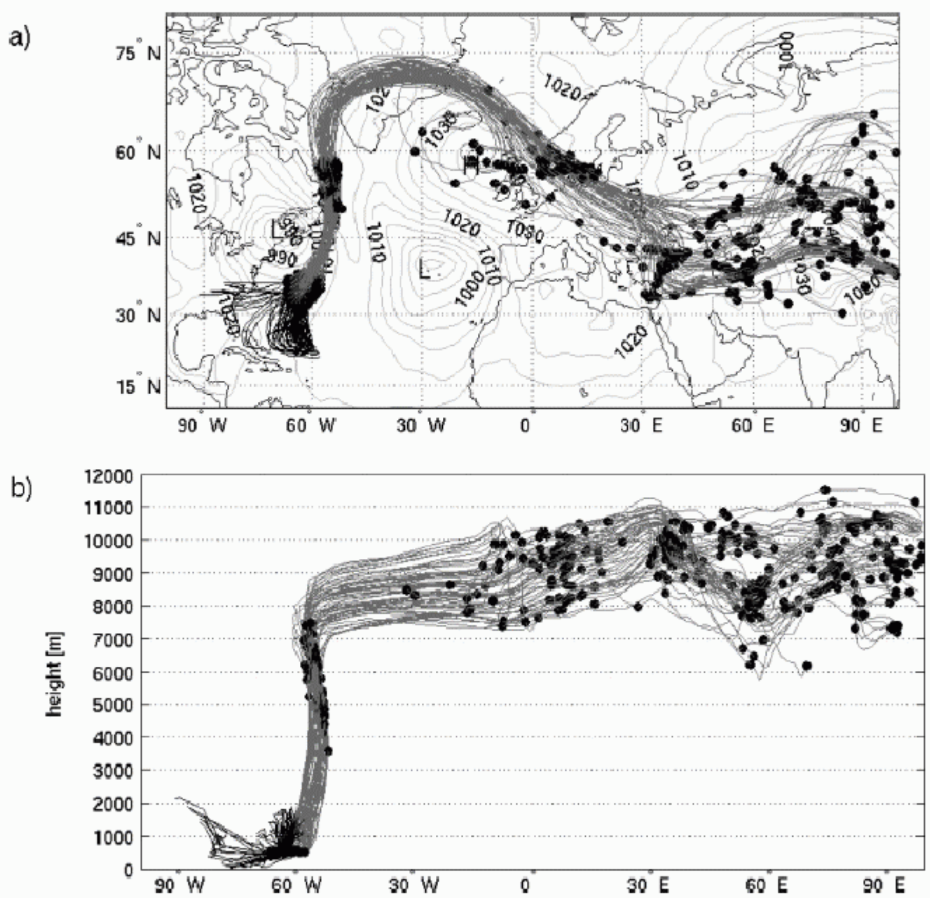
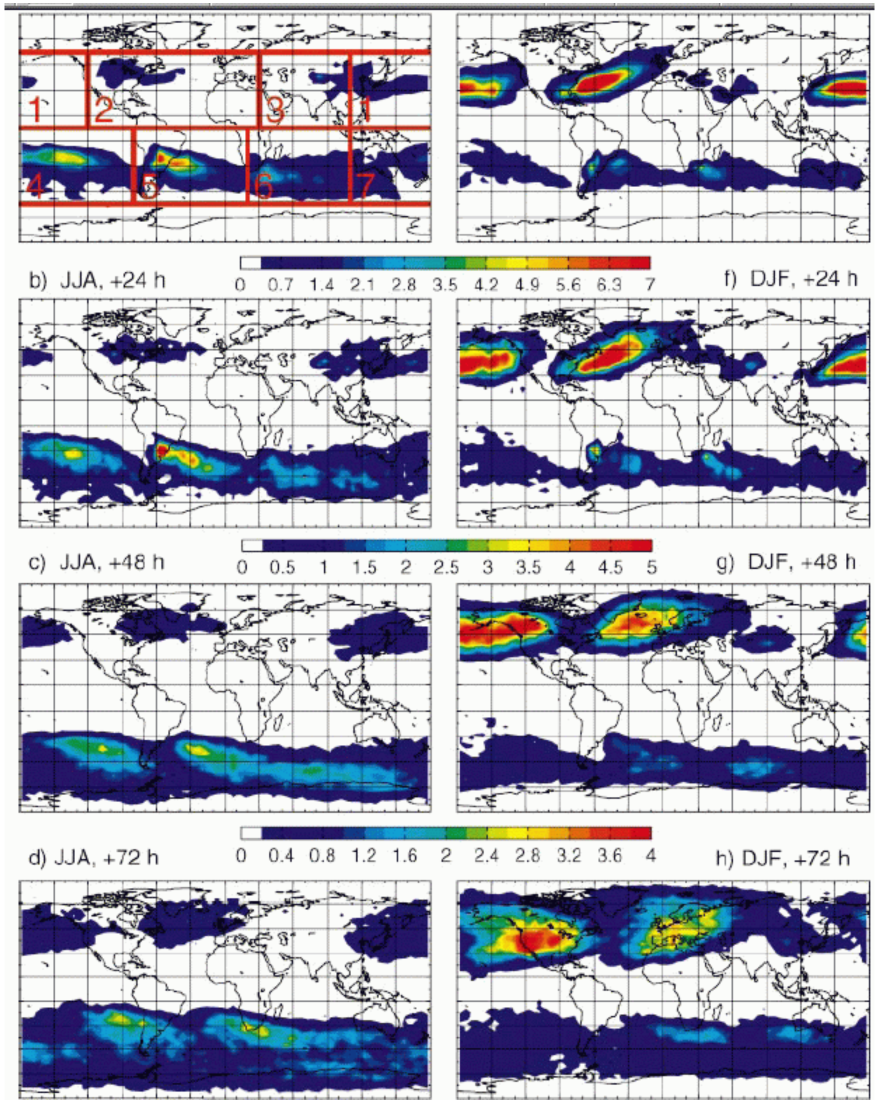


FIG. 2. Six-day trajectories starting 1200 UTC 23 Jan 1987, of which the first 2 days were identified as a WCB. (a) The forward trajectories (gray) and 3-day backward trajectories (black) from the starting locations of the forward trajectories. Positions along the forward trajectories are marked every 24 h. Sea level pressure (light gray) contour lines are drawn every 10 hPa for the trajectory starting time (1200 UTC 23 Jan 1987). For clarity, only those WCB trajectories associated with the cyclone over the eastern seaboard of North America are drawn. (b) Vertical projection of the trajectories shown in (a).



Eckhardt et al., 2004, JClim

Diagnostics

Extratropical Cyclones: The `Lothar' Example

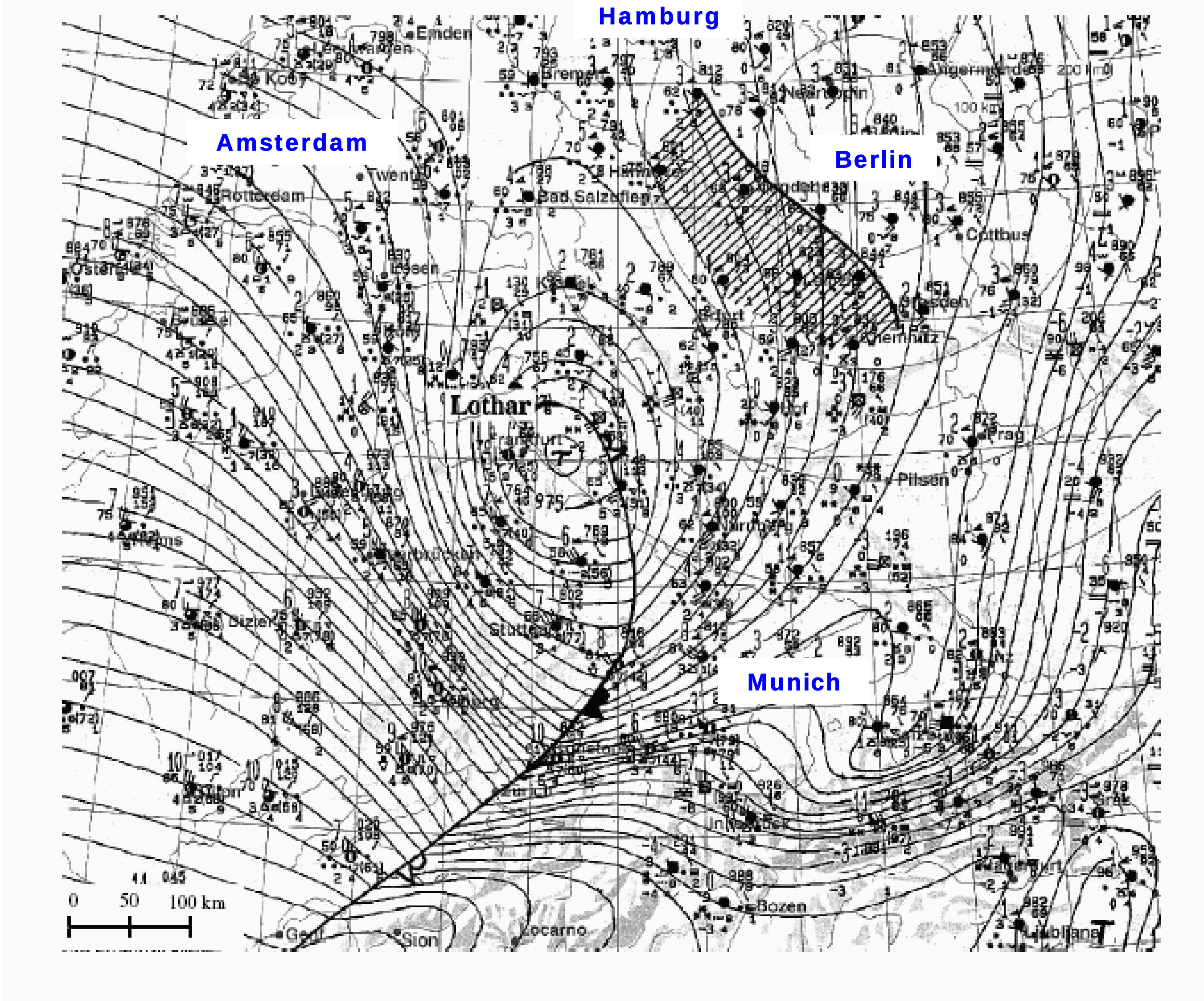


Figure 2. Berlin surface chart for central Europe for 12 UTC 26 December 1999 (isobar spacing 1 hPa).

Max. Wind speeds:

Lower areas: 150 km/h

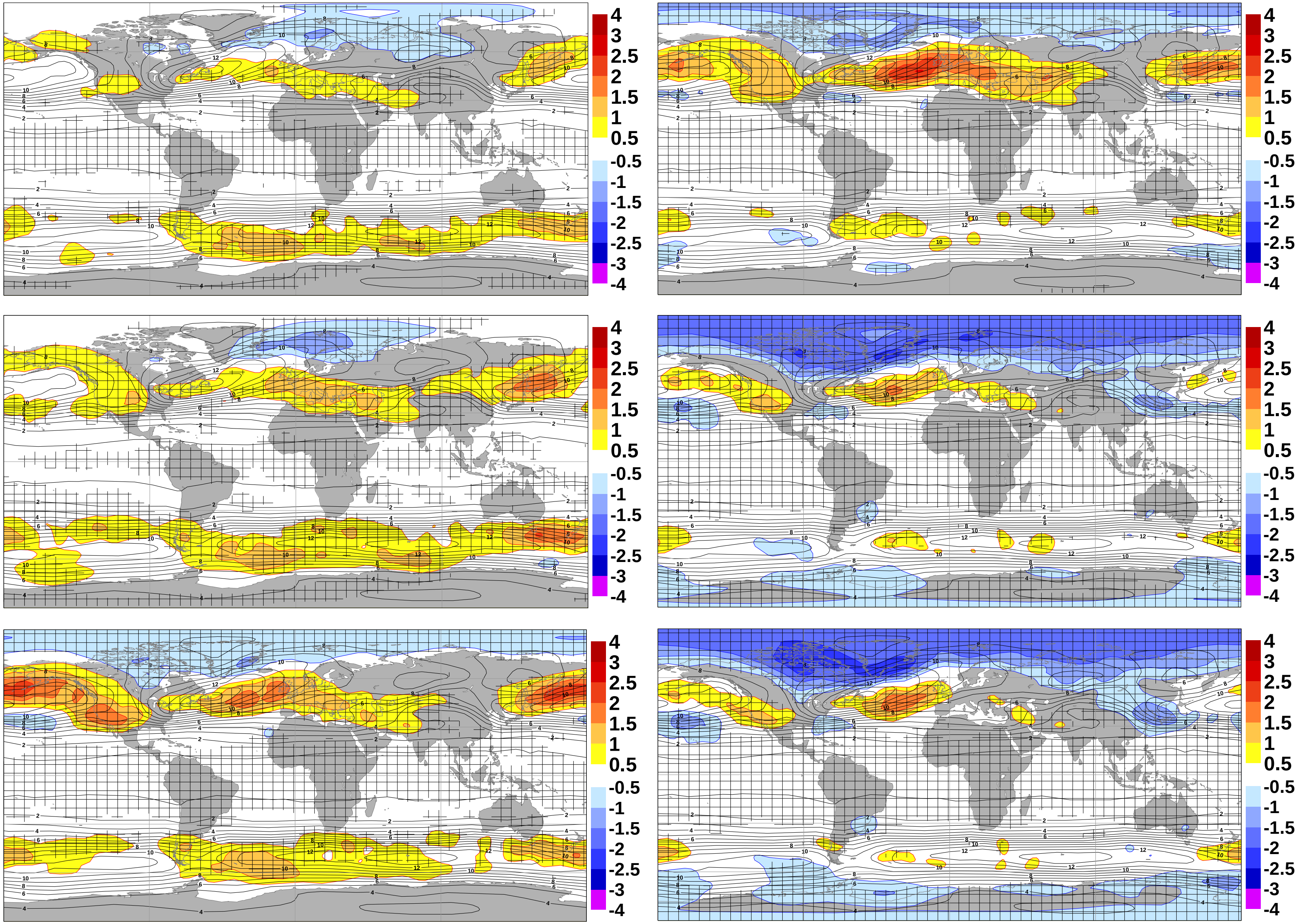
Higher areas:

250 km/h

Wernli et al, 1999, QJ

Diagnostics

Extratropical Cyclones/Warm Conveyor Belts



33R1

31R1

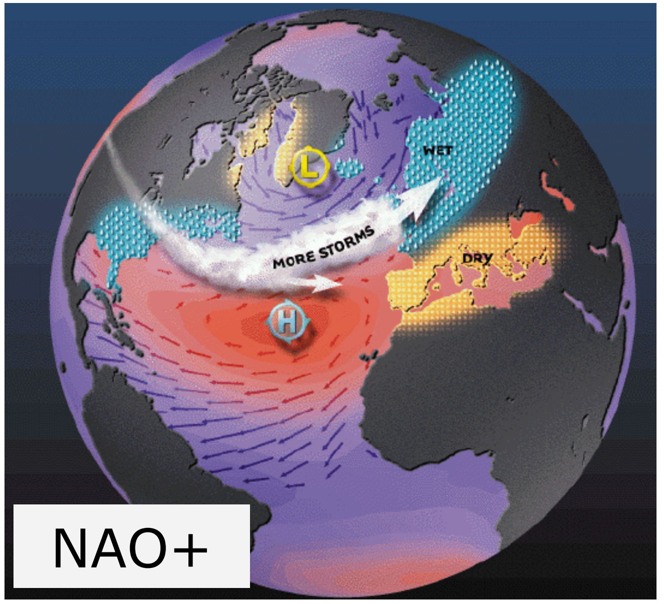
32R3

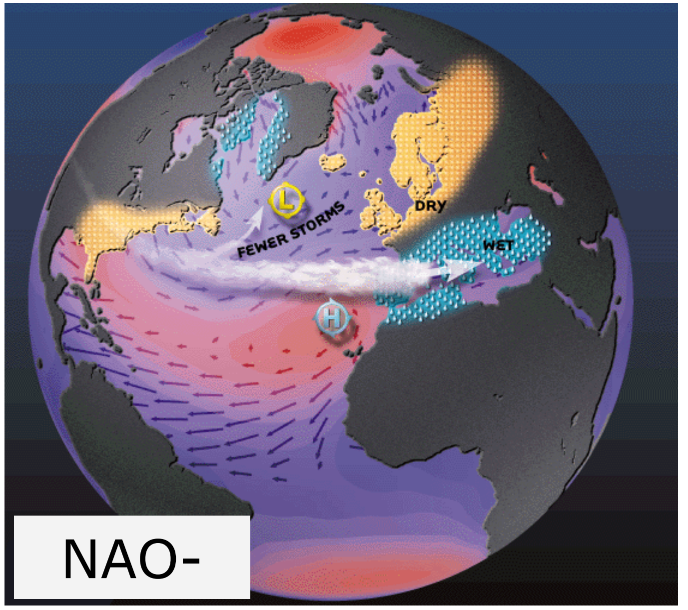
30R1

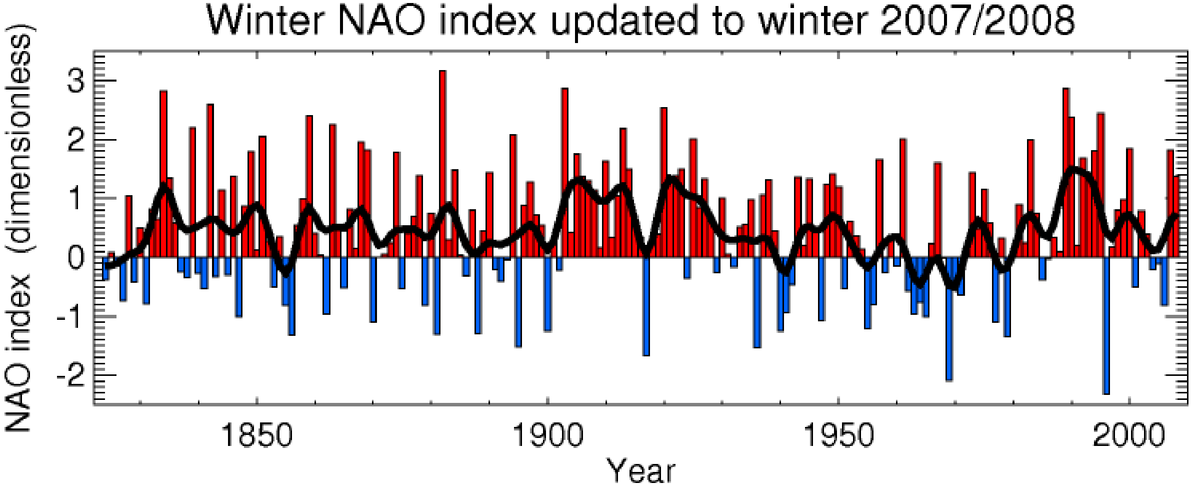
32R2

29R2

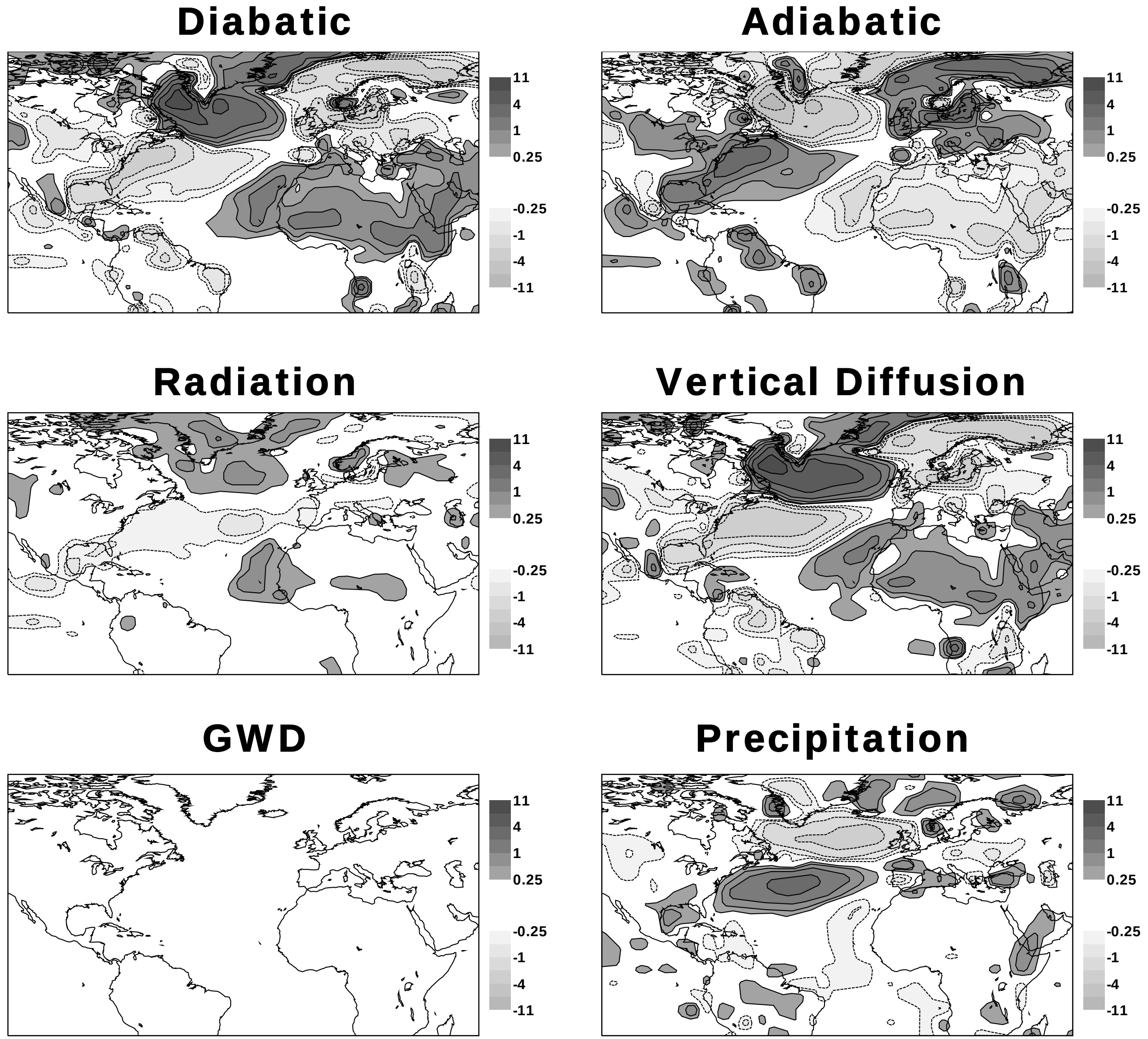
The North Atlantic Oscillation







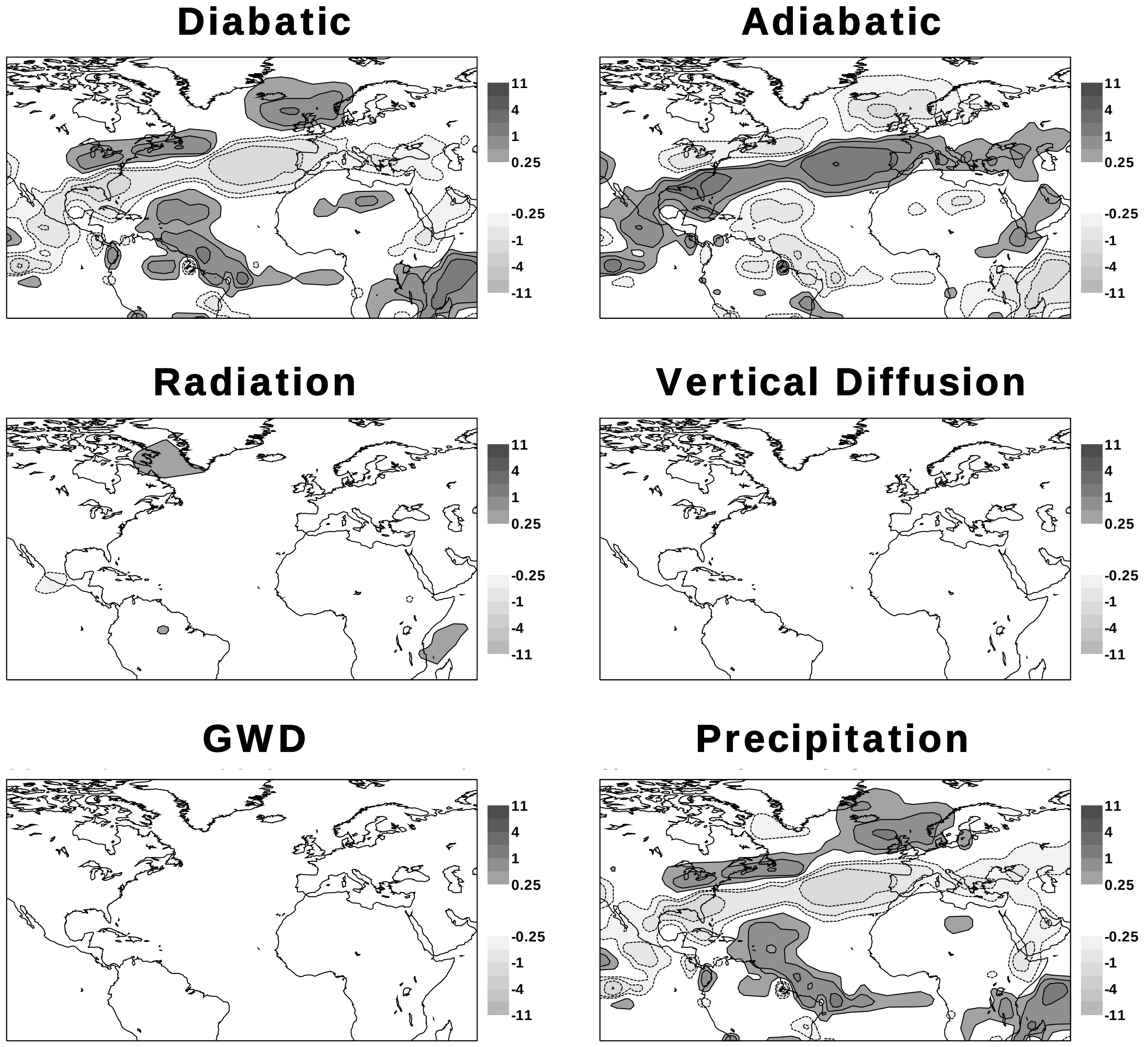
NAO-Related Diabatic T-Forcing: 850hPa



Greatbatch and Jung, 2007, JClim

Diagnostics

NAO-Related Diabatic T-Forcing: 500hPa

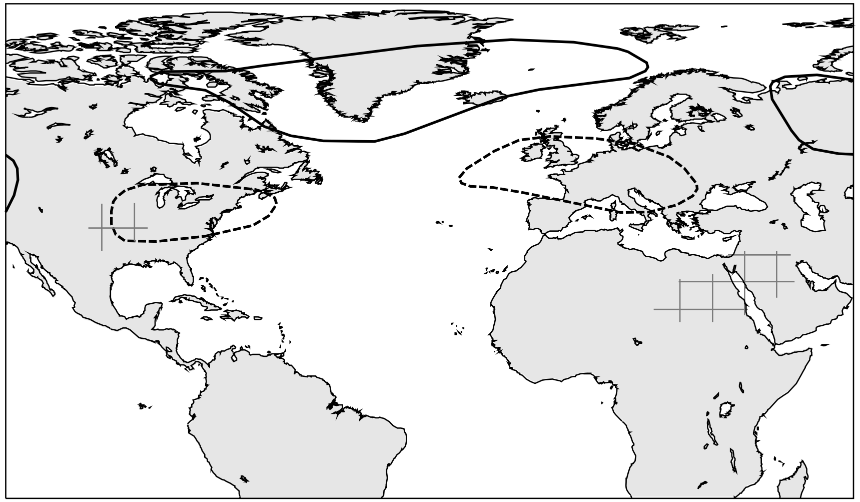


Greatbatch and Jung, 2007, JClim

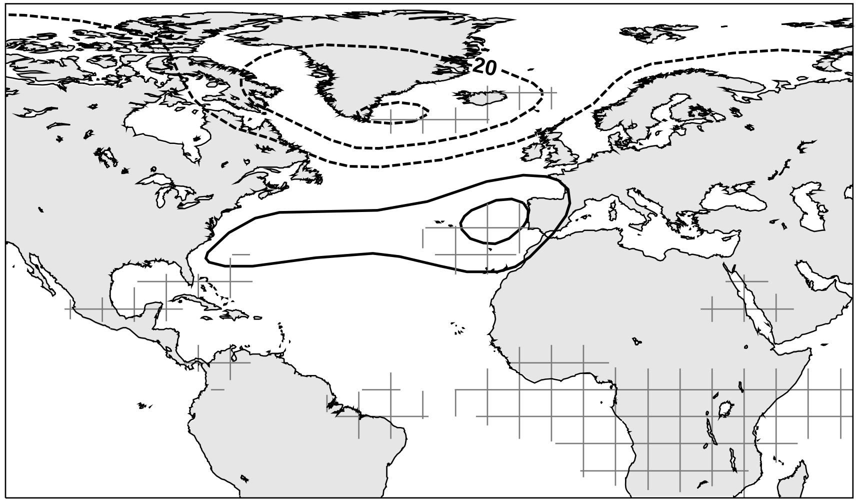
Diagnostics

Z500 Response: North Atlantic NAO-T-Forcing

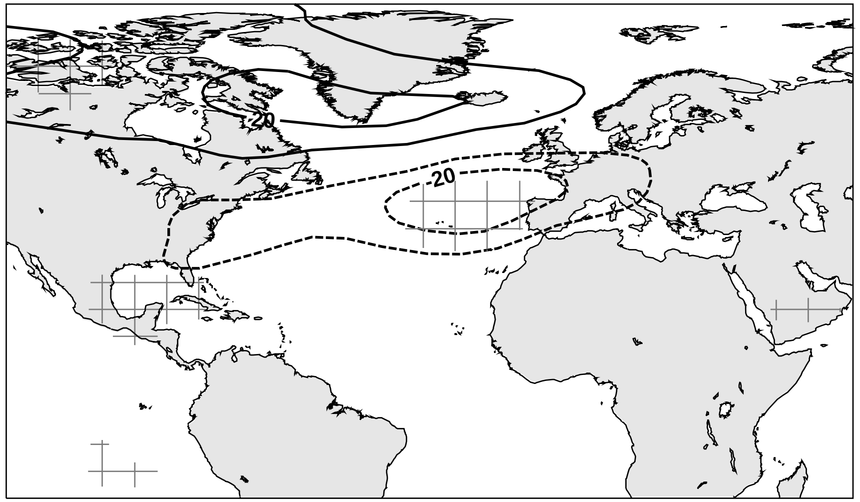
High NAO: DJFM 1962-1981



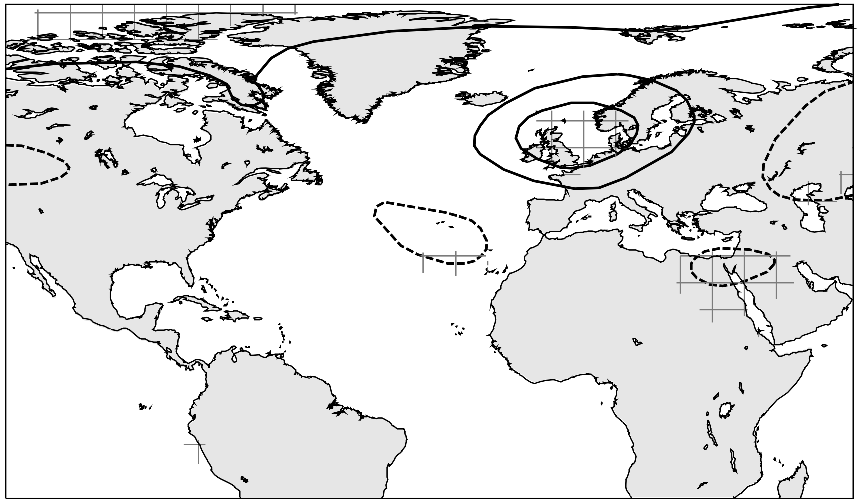
Low NAO: DJFM 1962-1981



High NAO: DJFM 1982-2001



Low NAO: DJFM 1982-2001



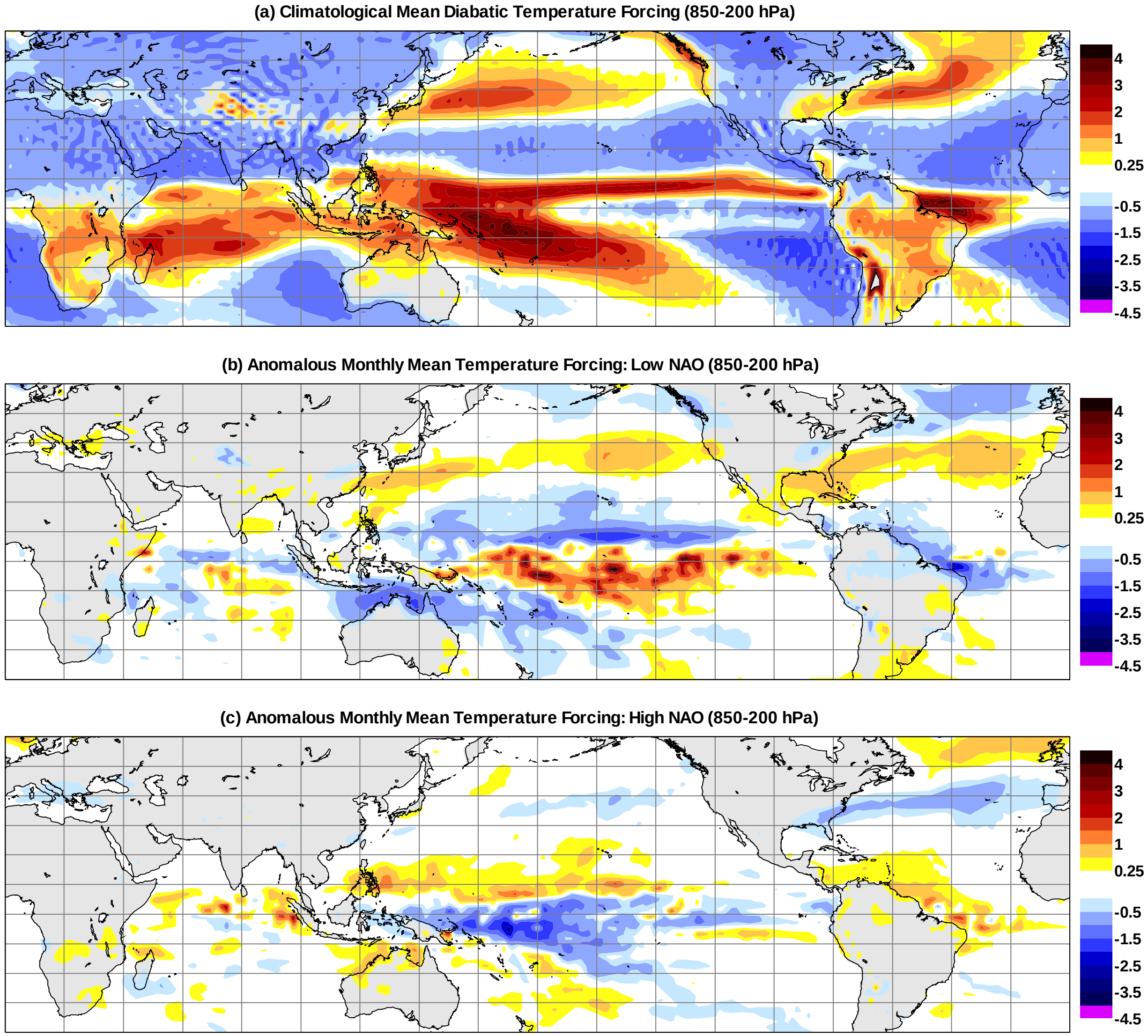
Diagnostics

Global NAO-Related Diabatic T-Forcing: 850-200hPa

Climatology

NAO-

NAO+

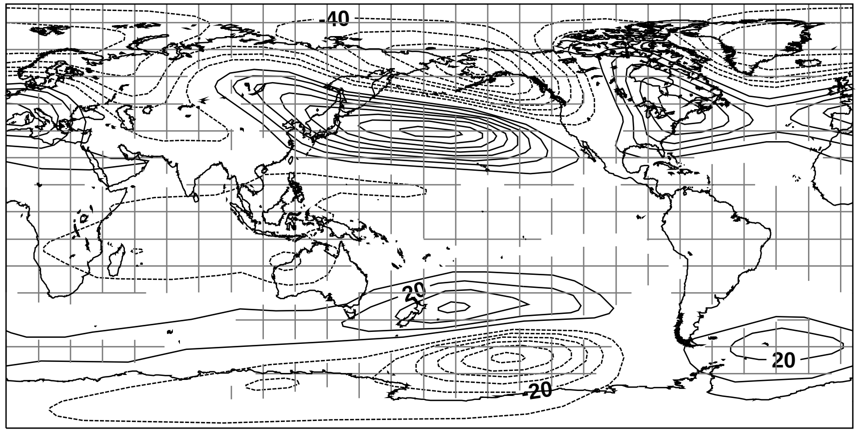


Greatbatch and Jung, 2007, JClim

Z500 Response: Tropical NAO-T-Forcing

Diagnostics

High NAO: DJFM 1962-1981



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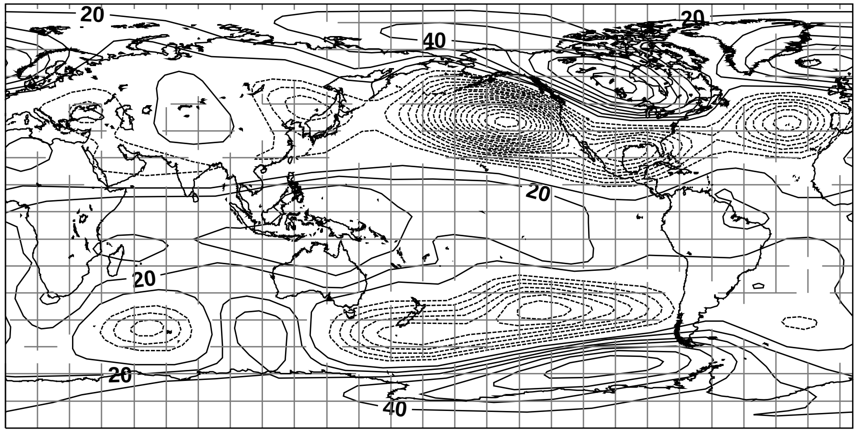

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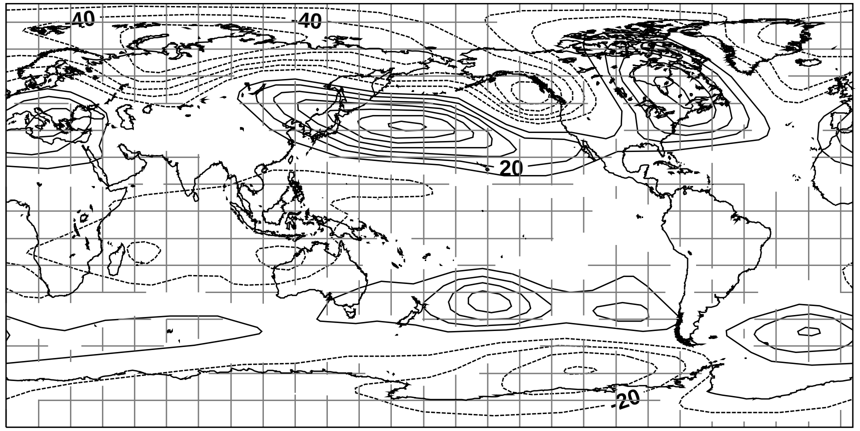
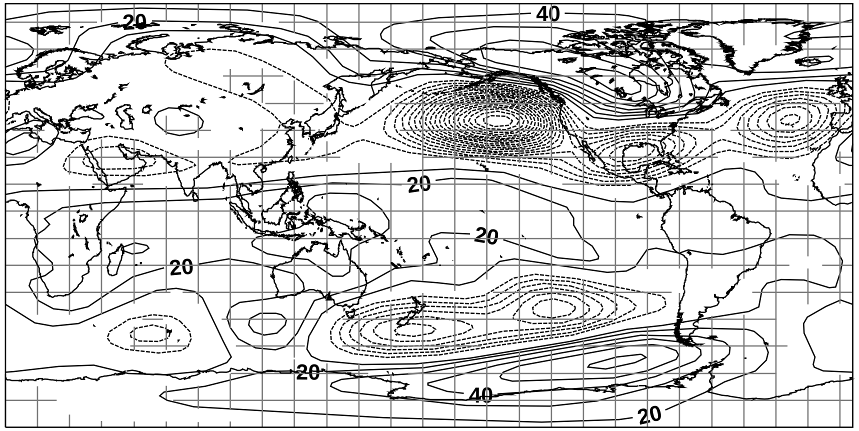
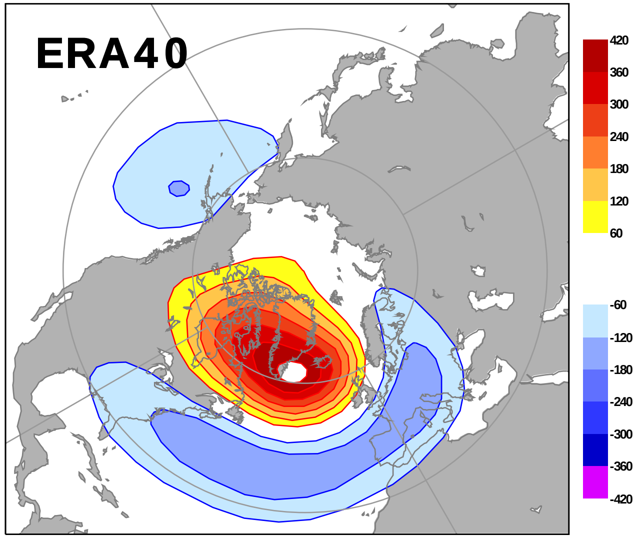


Low NAO: DJFM 1982-2001

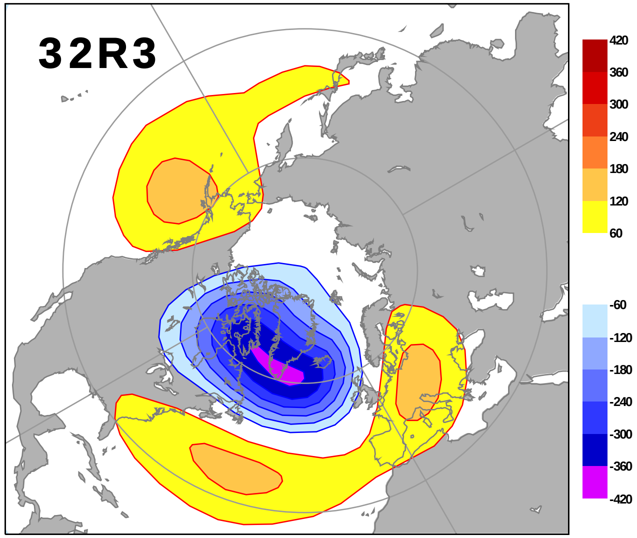


The NAO in the IFS

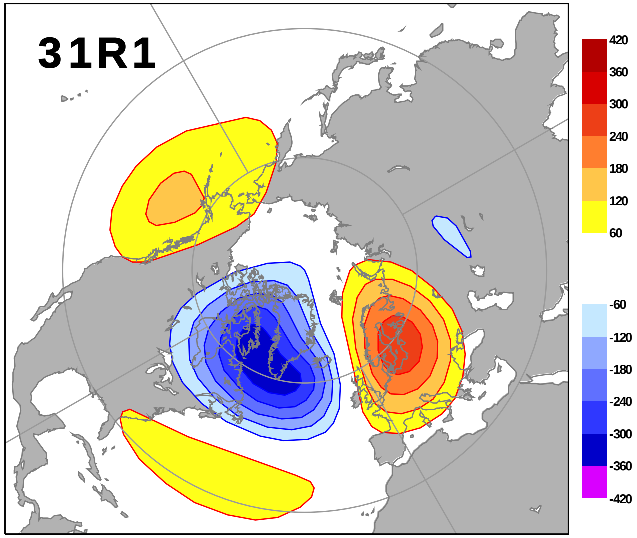
EOF1 25.6%: Z500 Anomalies er40 (NATL 12-2 1962-2005)



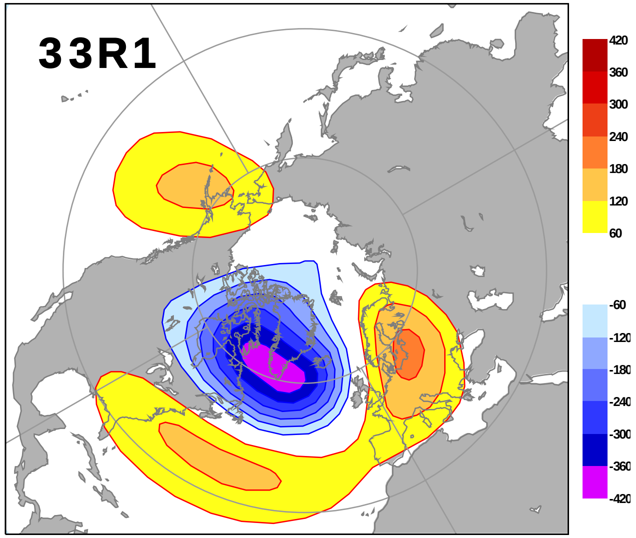
EOF1 23%: Z500 Anomalies exxd (NATL 12-2 1962-2005)



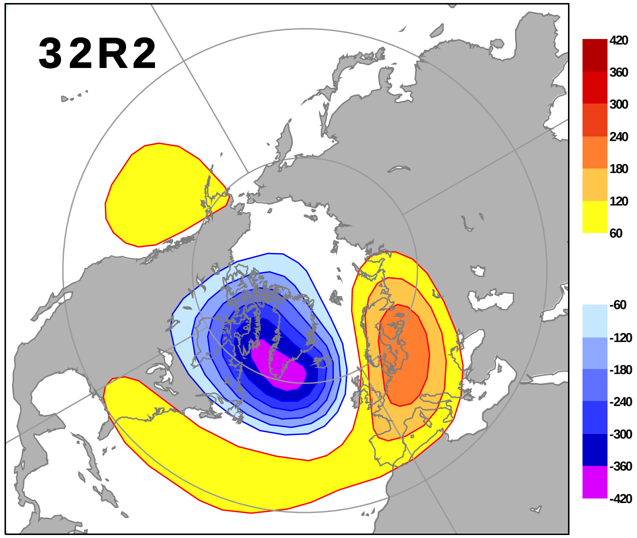
EOF1 23.5%: Z500 Anomalies f18l (NATL 12-2 1962-2005)



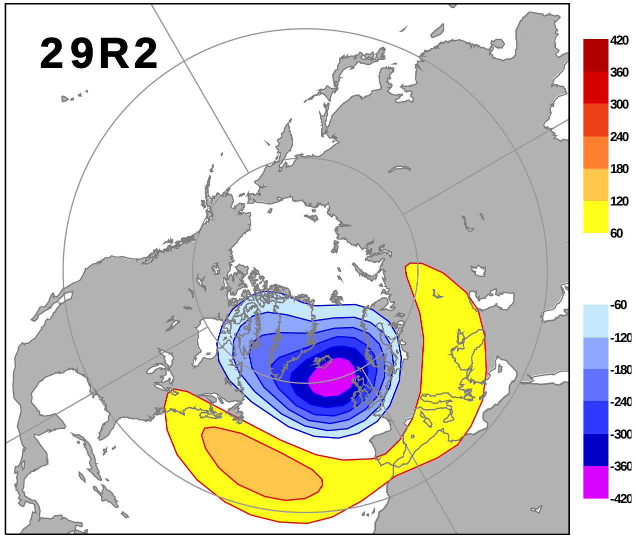
EOF1 23.4%: Z500 Anomalies f127 (NATL 12-2 1962-2005)



EOF1 25.4%: Z500 Anomalies ex51 (NATL 12-2 1962-2005)



EOF1 23.8%: Z500 Anomalies f1ex (NATL 12-2 1962-2005)



Conclusions #3

- Recent model changes have led to substantial improvements in the simulated climate of the model (mean+variability):
  - Northern Hemisphere blocking,
  - convectively coupled tropical waves,
  - Extratropical cyclones,
  - "teleconnection patterns" such as the NAO,…
- There are still outstanding issues in the ECMWF model:
  - Madden-Julian Oscillation,
  - near-surface easterly wind bias in the tropical Pacific,
  - QBO,…

Diagnostics

Outline

- Introduction: Parameterized processes in the ECMWF model
- Model assessment
  - How well do models simulate atmospheric variability?
  - How sensitive is simulated atmospheric variability to changes in physical parameterizations?
- What can we expect from future improvements?

Relaxation Formulation

Diagnostics

ECMWF model: $$\frac{\partial \mathbf{x}}{\partial t} = M(\mathbf{x})$$

ECMWF model with relaxation: $$\frac{\partial \mathbf{x}}{\partial t} = M(\mathbf{x}) - \lambda(\mathbf{x} - \mathbf{x}^{ref})$$

- Relaxations coefficient, λ, depends on longitude, latitude and height.
- Relaxation for u, v, T and $\ln p_s$ (same λ)
- $\mathbf{x}^{ref}$ is based on (interpolated) ERA-40 data.

Diagnostics

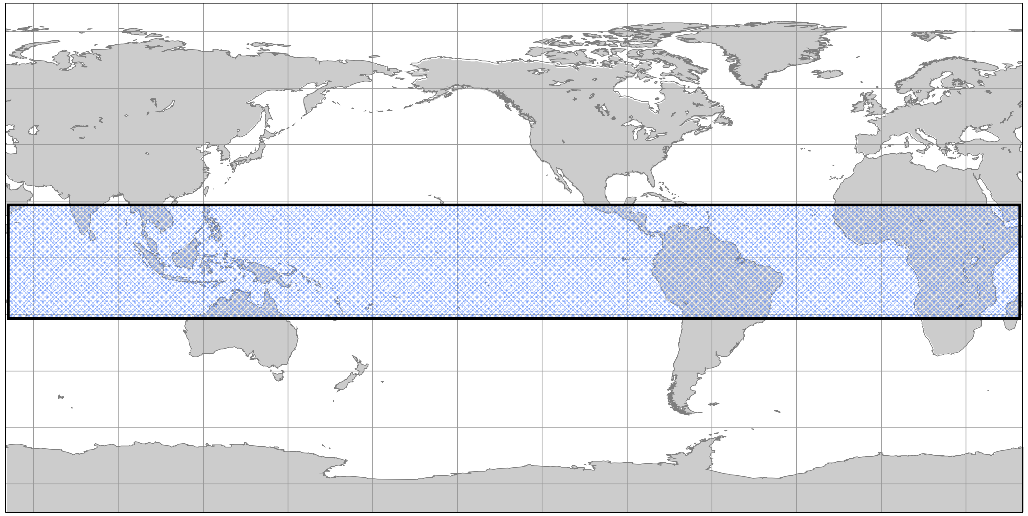
Experiments

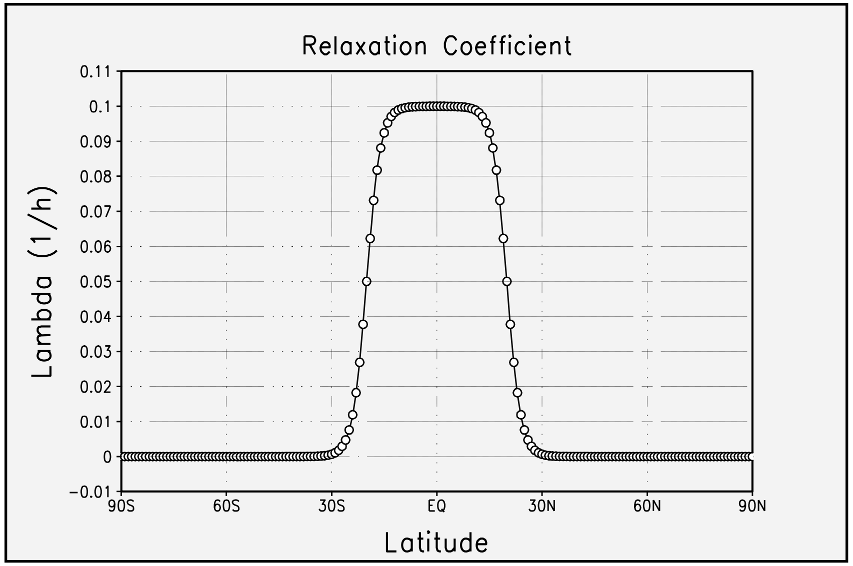
- Model version 32R1 (5/06–5/11 2007)
- T_L159 (125 km) with 60 vertical levels
- 88 30-day forecasts (15. Nov, Dec, Jan and Feb 1980/81-2000/01)
- Initial and boundary conditions as well as $\mathbf{x}^{ref}$: ERA-40 (T_L159L60)

- Control experiment
  - Persistent SST/sea ice

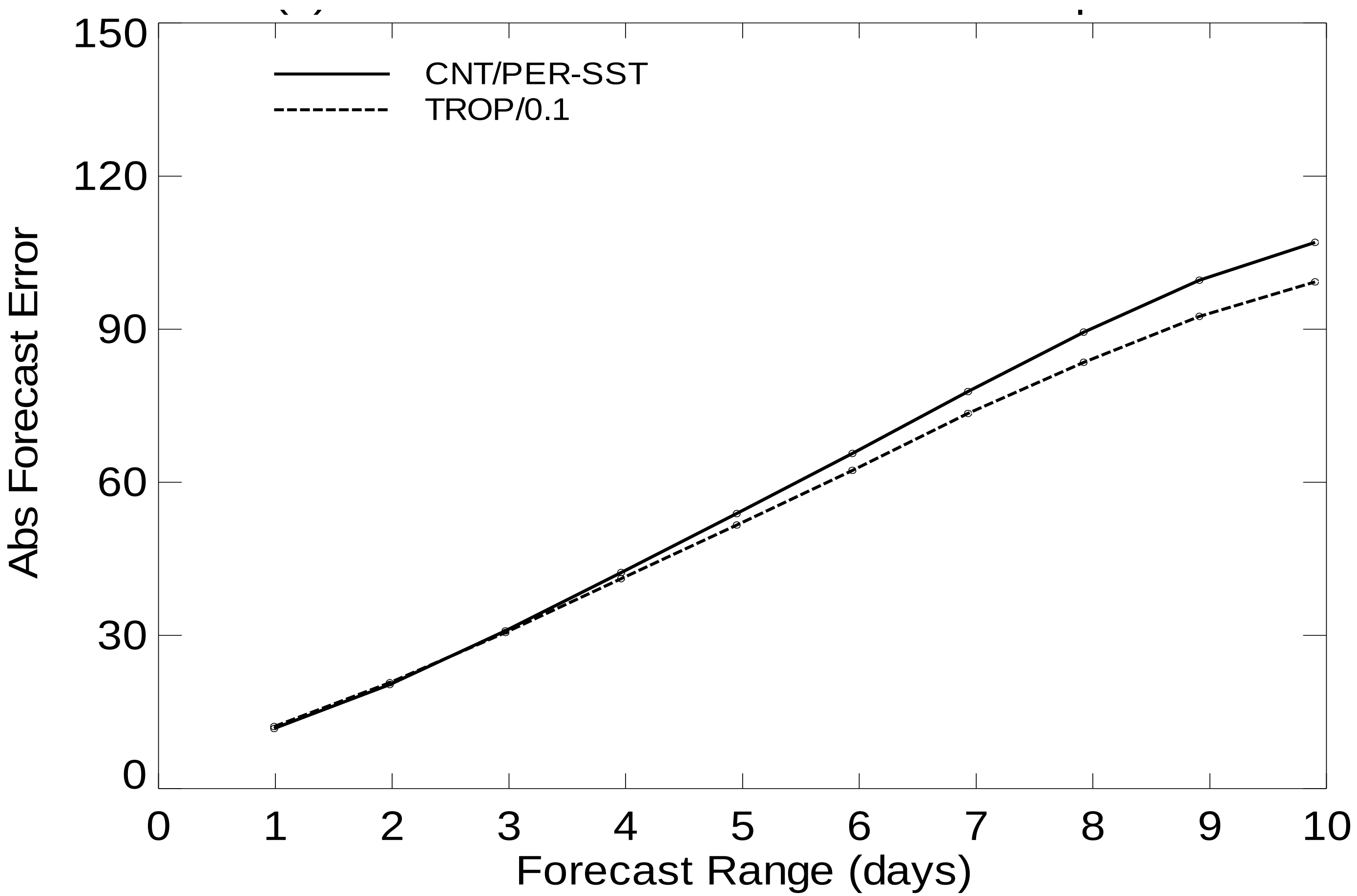
- Relaxations experiment
  - Persistent SST/sea ice
  - Relaxation in various regions (here tropics only)

Relaxation Region





Northern Hemisphere Z500 Forecast Error

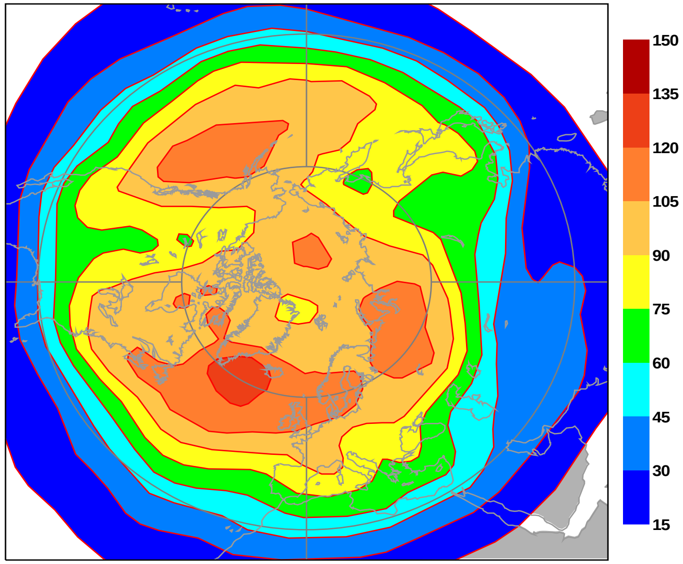


NH: 30^{o}-90^{o}N

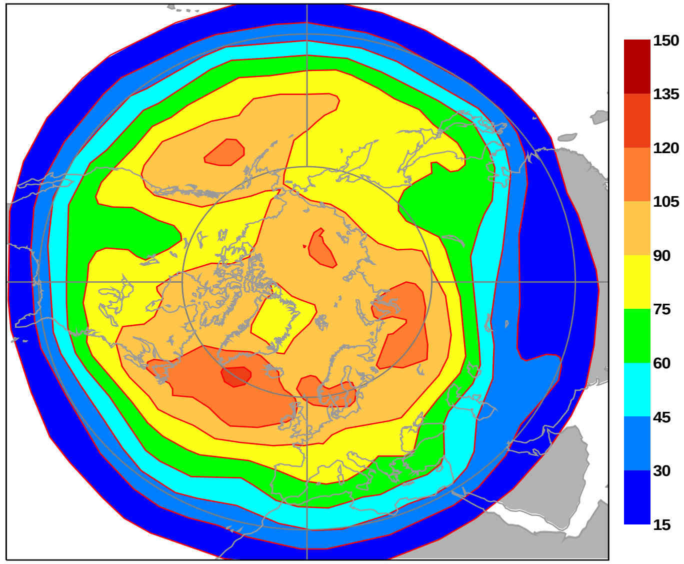
Diagnostics

Northern Hemisphere Z500 Forecast Error

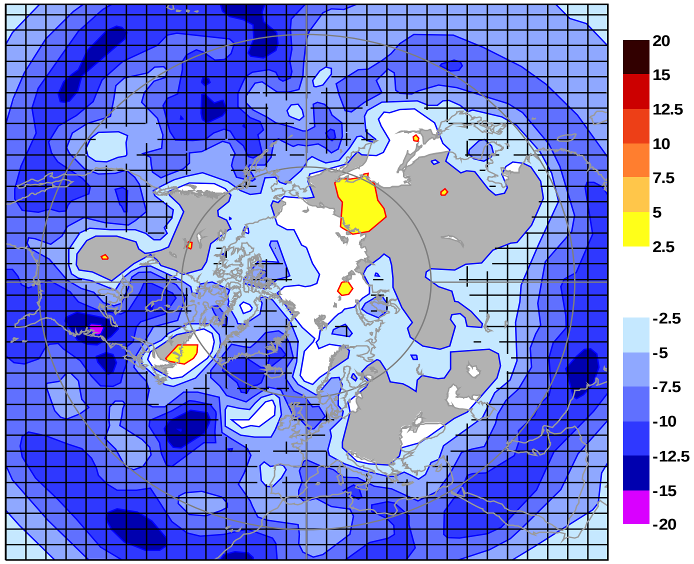
Control Integration



Tropical Relaxation



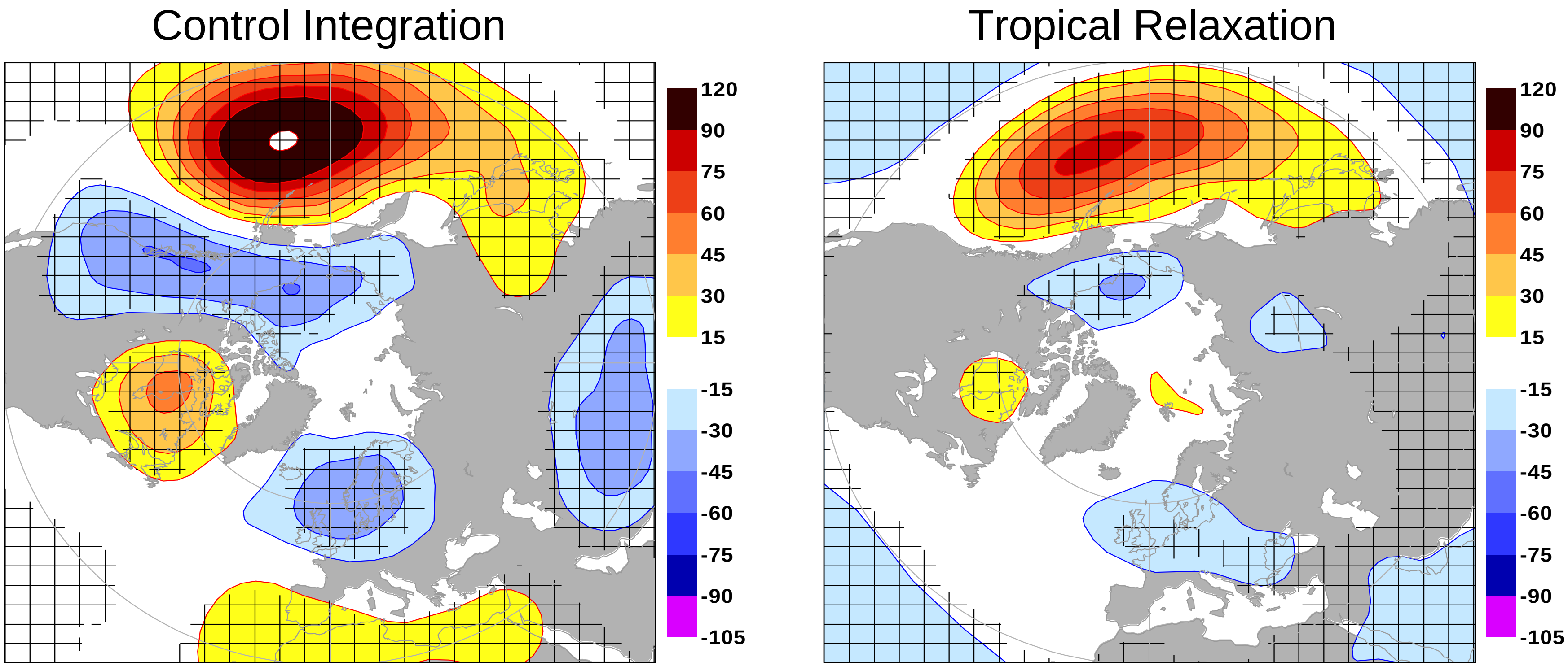
Relaxation-Control



Measure: mean absolute forecast error

Range: Medium-Range (D+5 to D+10)

Systematic Z500 Forecast (D+15 to D+30)



More on Relaxation Experiment

Summer issue of ECMWF Newsletter:

- Monthly forecasts
- Seasonal forecasts of the blocked European winter 2005/06

Conclusions #4

- Relaxation technique is a useful diagnostic tool
- Not a new technique, but better analyses makes it more powerful
- Improvements in the tropics will lead to better forecasts in the Northern Hemisphere extratropics
  - Improvements particularly in the far medium-range and extended-range.
  - Certain region will benefit more than others (good for Europe and the US)
- The relaxation technique can be used (to some degree) to locate the origin of systematic model error.
- Case studies for seasonal anomalies (“blocked” winter 2005/06)
- More details: Summer issue of ECMWF Newsletter

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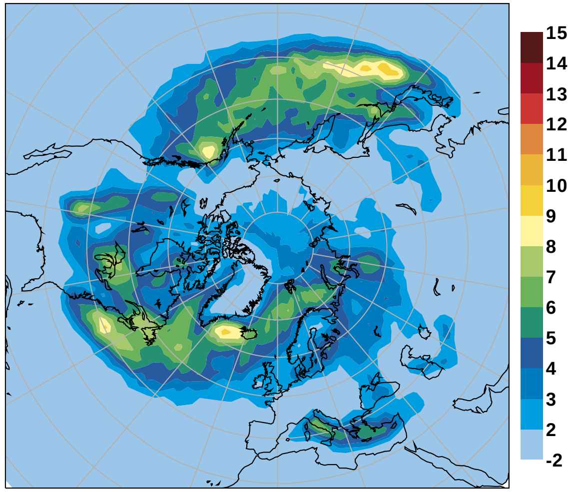
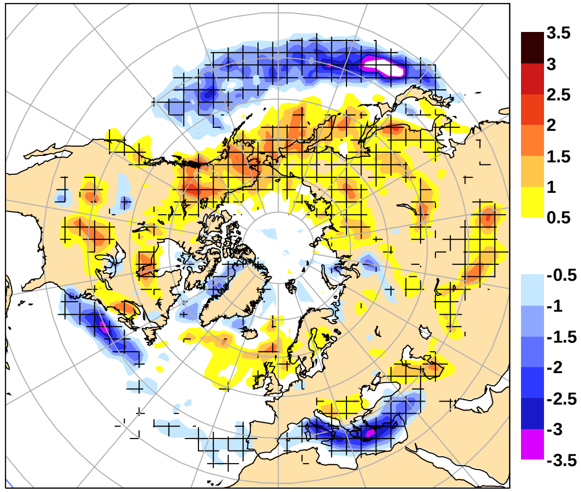
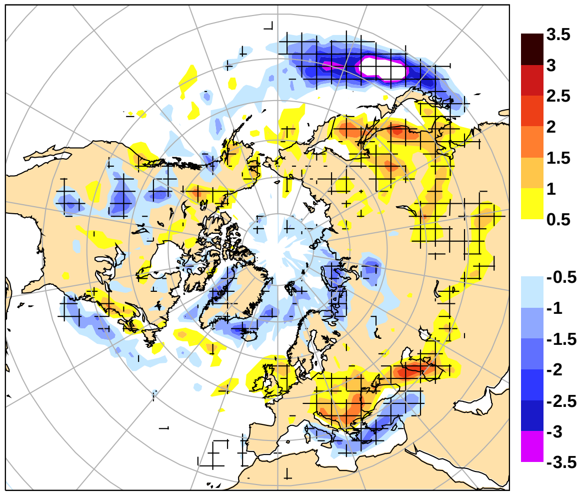
(a) Number of MSLP Minima (er40 DJFM 1962-2005)



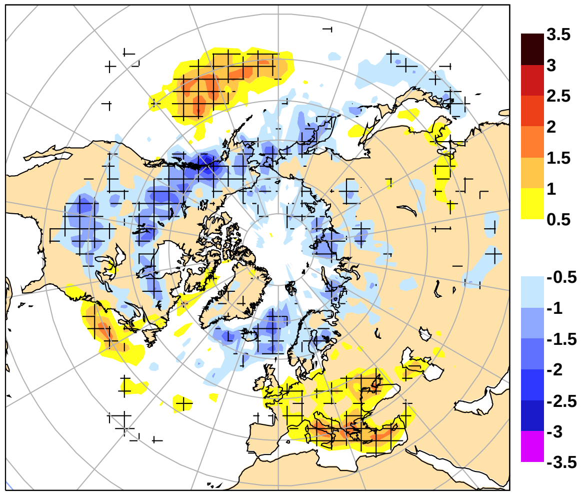
(b) Number of MSLP Minima (Cy32r2-er40 DJFM 1962-2005)



(c) Number of MSLP Minima (Cy32r3-er40 DJFM 1962-2005)

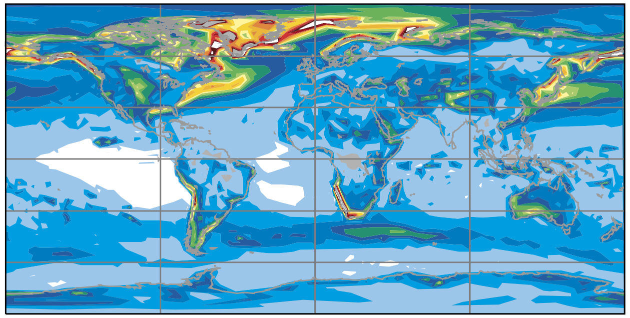


(d) Number of MSLP Minima (Cy32r3-Cy32r2 DJFM 1962-2005)

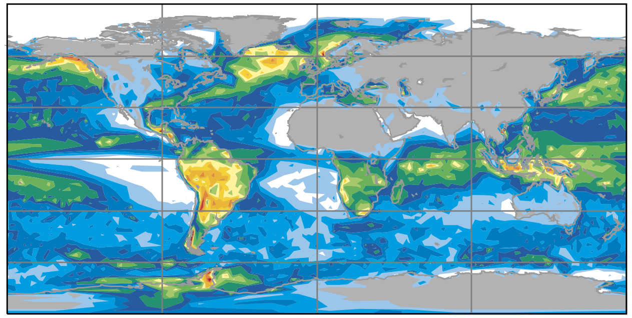


StdDev T-Tendencies @ 1013hPa: 33R1 DJF 1999-2001

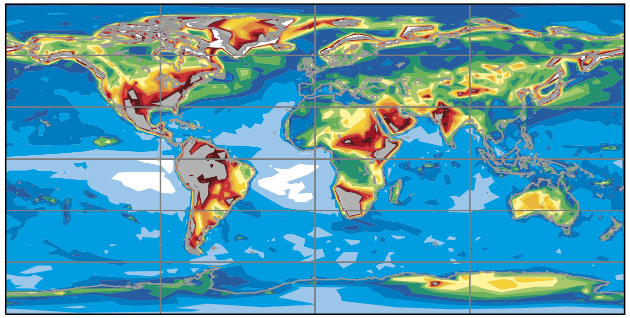
Dynamics



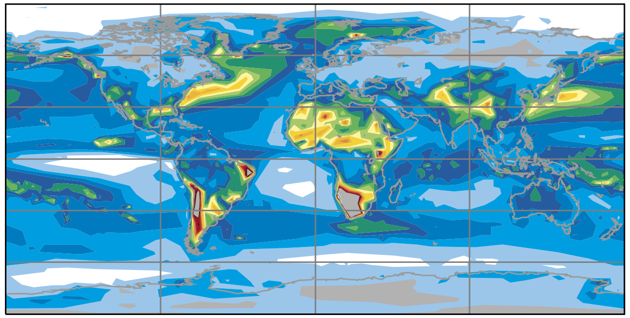
Convection

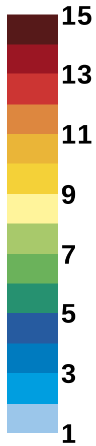


Vertical Diffusion

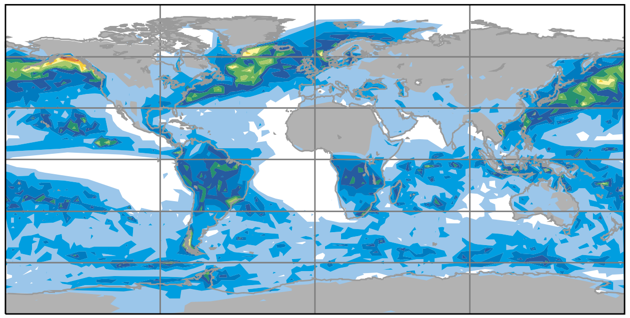


Radiation



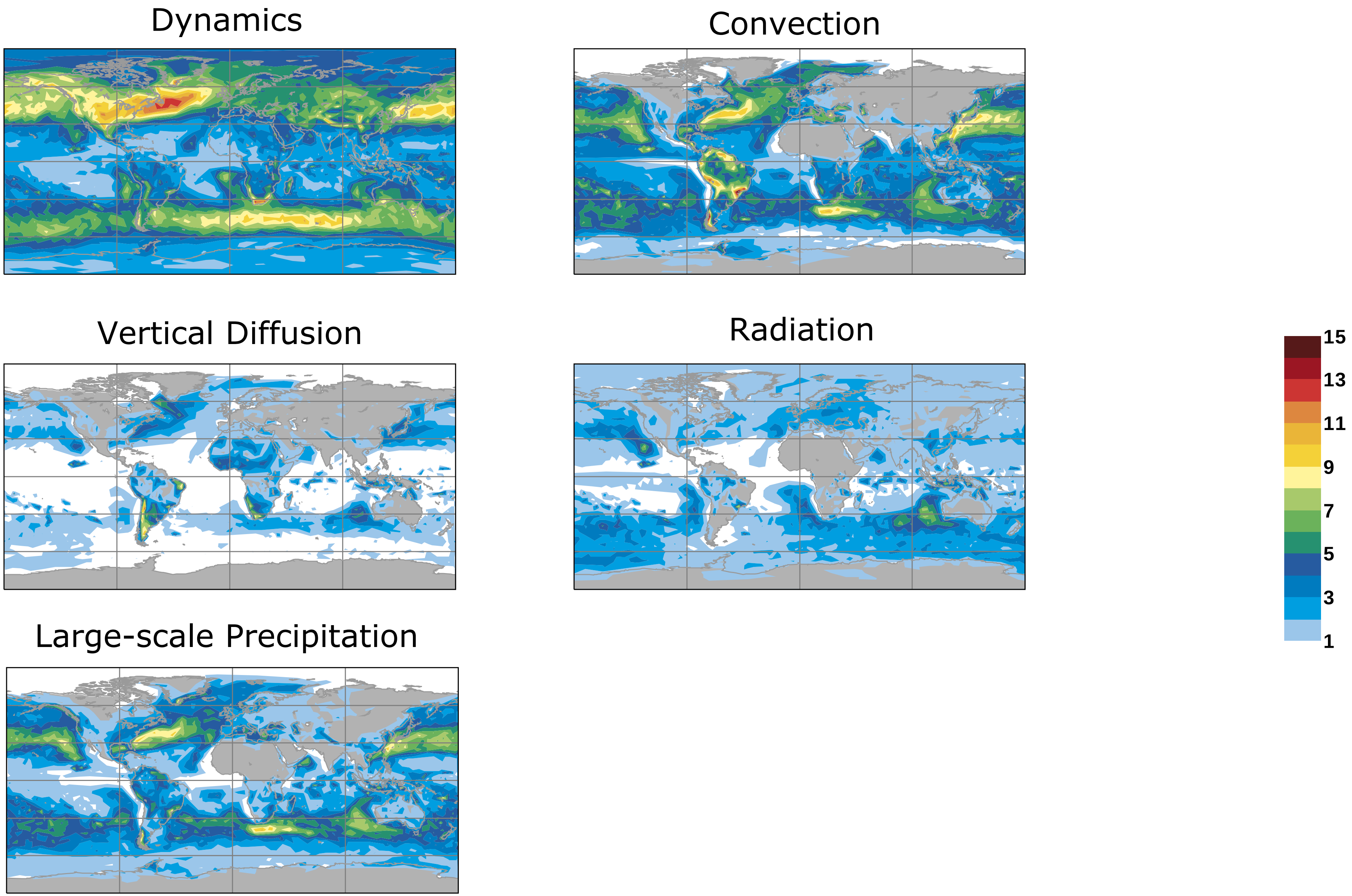


Large-scale Precipitation 1



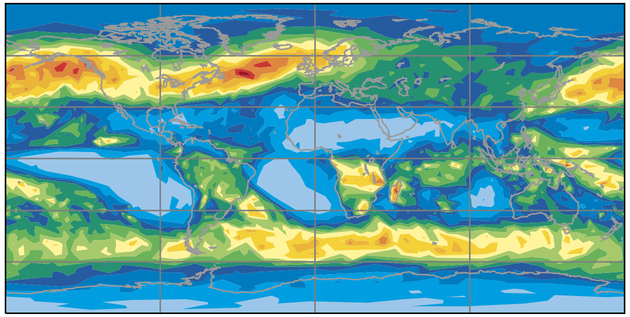
Diagnostics

StdDev T-Tendencies @ 900hPa: 33R1 DJF 1999-2001

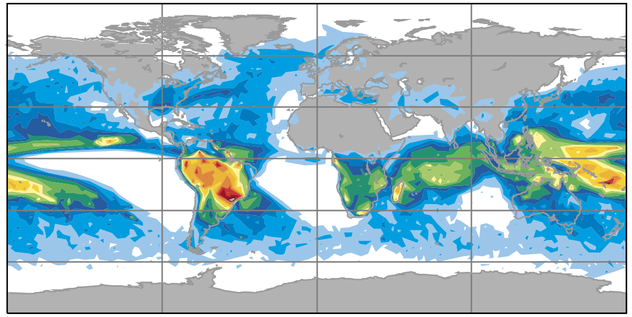


StdDev T-Tendencies @ 530hPa: 33R1 DJF 1999-2001

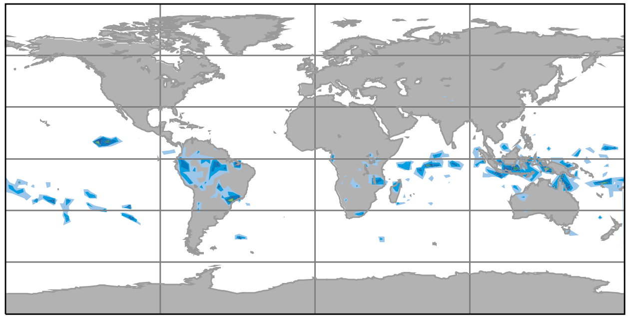
Dynamics



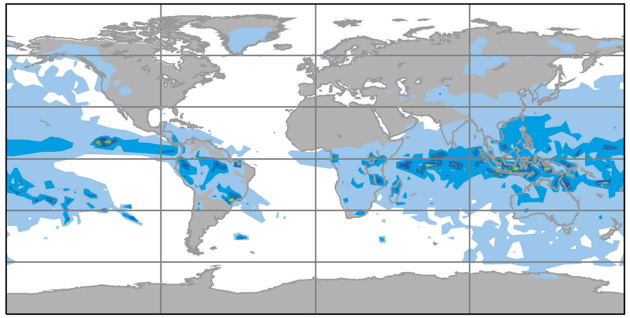
Convection



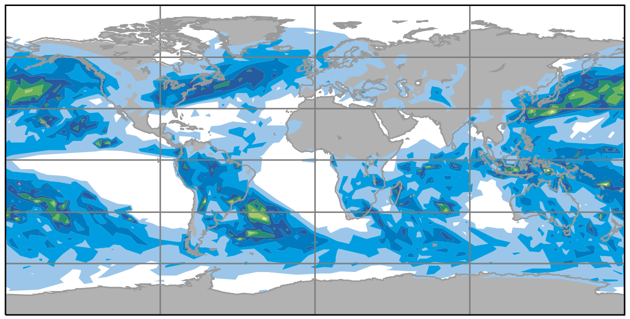
Vertical Diffusion

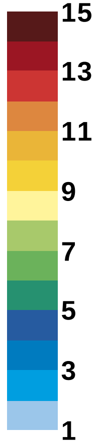


Radiation



Large-scale Precipitation

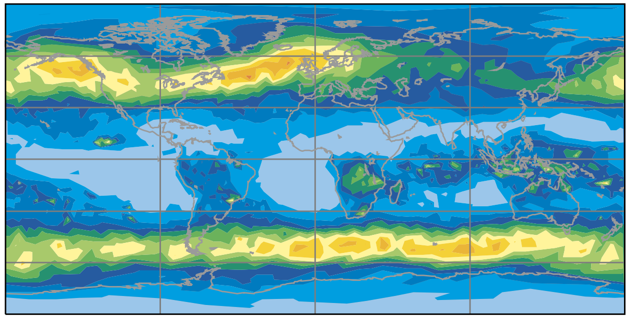




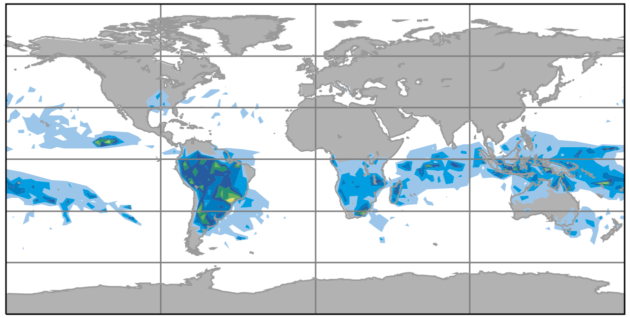
StdDev T-Tendencies @ 200hPa: 33R1 DJF 1999-2001

Diagnostics

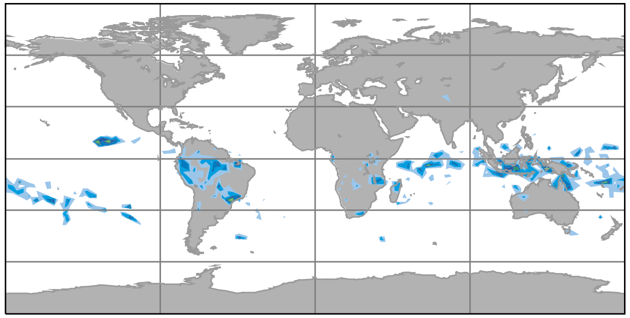
Dynamics



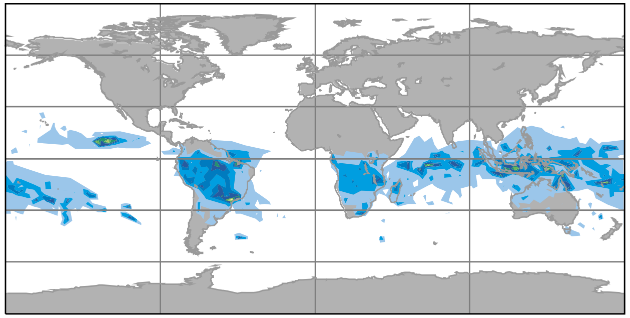
Convection



Vertical Diffusion



Radiation



Large-scale Precipitation