The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1968-9

Conference on Teleconnections in the Atmosphere and Oceans

17 - 20 November 2008

Relevance of neutral singular vectors for representing seasonal-mean teleconnections.

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The University of Tokyo, General Research Building
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Chiba 277-8568
JAPAN

Relevance of neutral singular vectors for representing seasonal-mean teleconnections

Our works on the neutral mode:

- ✓ Kimoto et al. (2001, GRL)
- ✓ Watanabe et al. (2002, JC)
- ✓ Watanabe and Jin (2004, JC)
- ✓ Jin et al. (2006a,b, JAS)
- ✓ Pan et al. (2006, JAS)

Masahiro Watanabe
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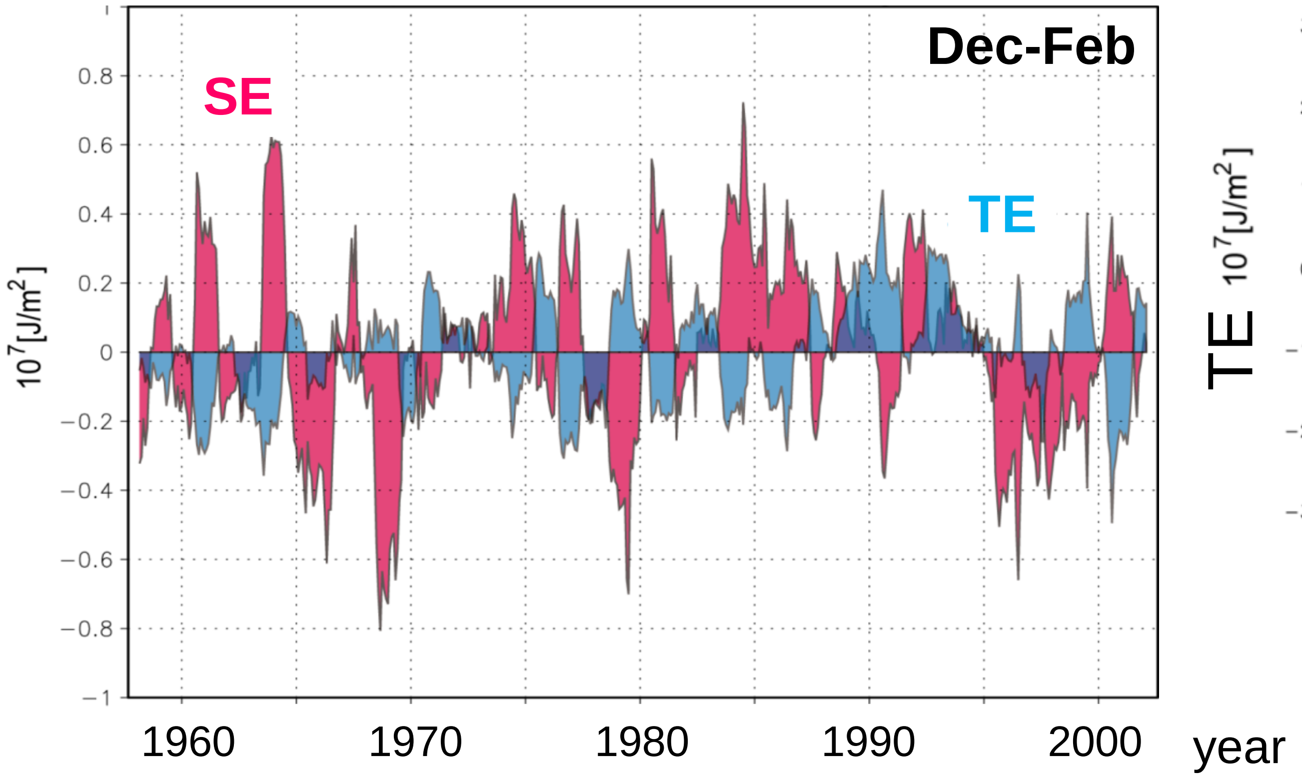
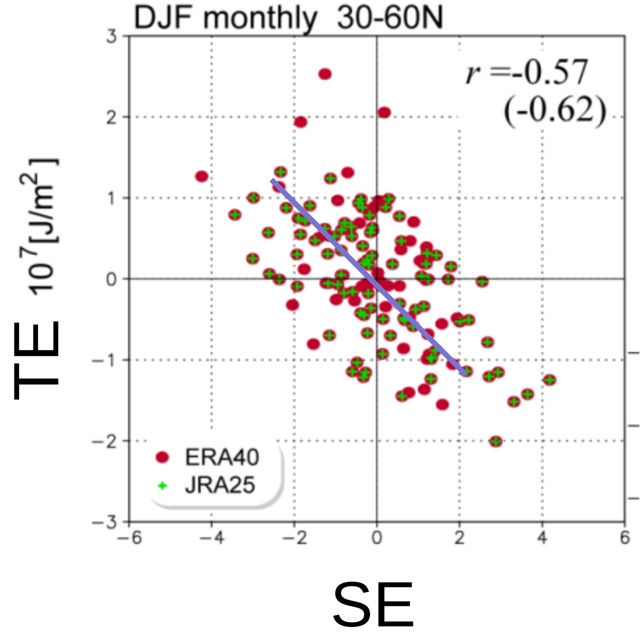
Variability in the meridional heat transport

Vertically integrated transport of the dry static energy,13mo rm, 30-60N avg.





Northward transports of the dry energy due to synoptic and stationary eddies tend to compensate with each other. Why?

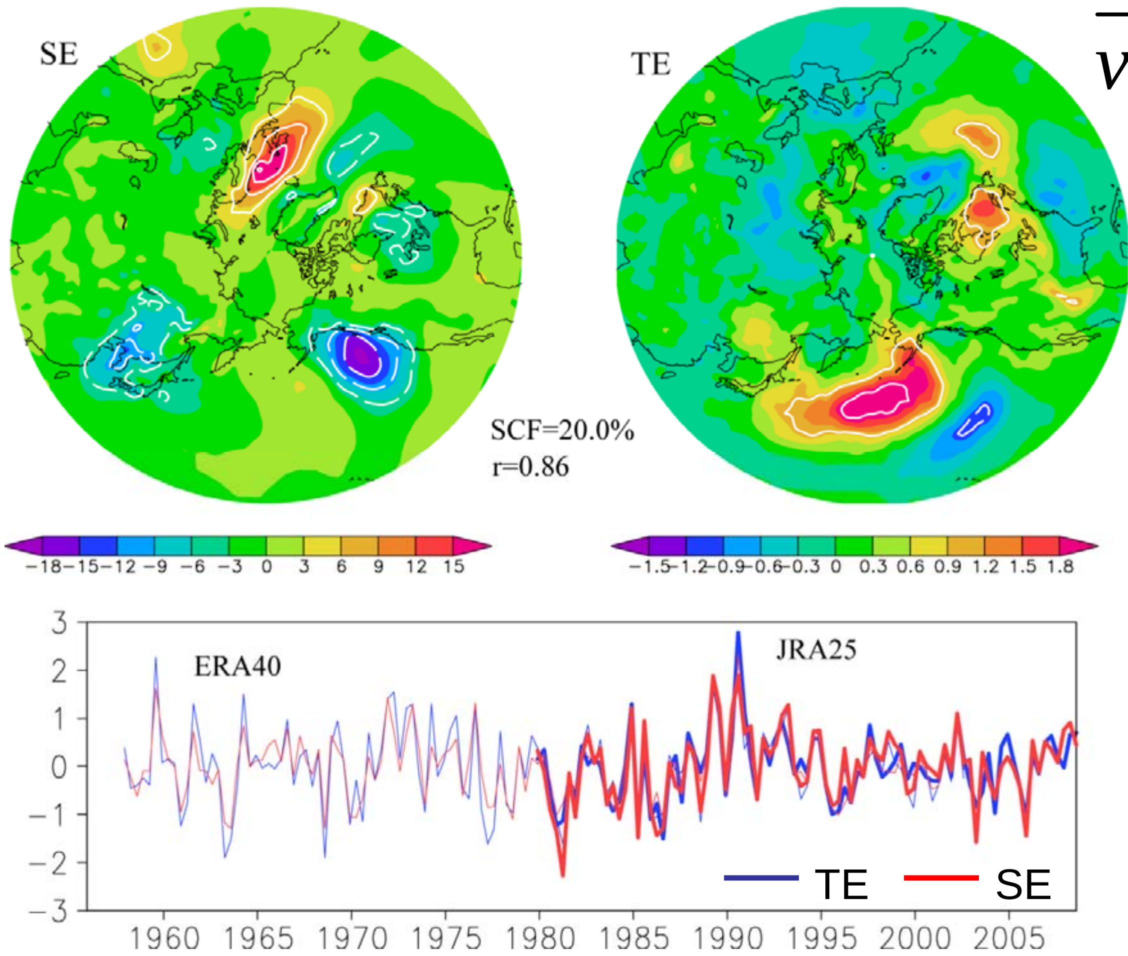
- **Inconsistent with an intuitive SE-TE relationship**
- **A thermal adjustment that minimizes the variability in TOTAL heat transport ?**

Mode of compensating heat transports

Thermal Seesaw between Transient and Stationary eddies (TS2)

SVD1 (hetero.regression) for 850hPa meridional heat fluxes

$\overline{v}^{*}\overline{T}^{*}$ $\qquad$ $\overline{v'T'}$



Inverse relationship prevailing over the N. Pacific
(cf. Nakamura et al. 2002)

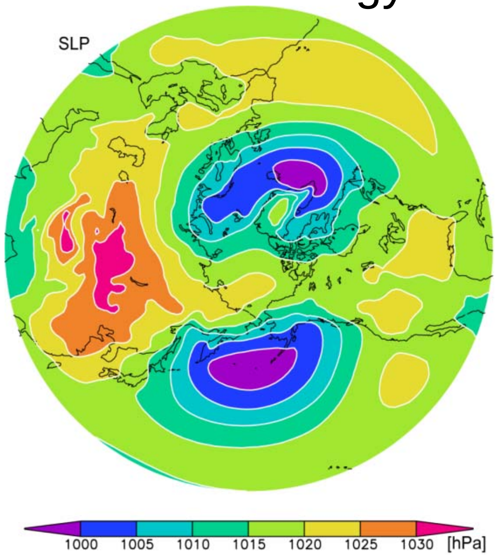
$\overline{A}$ Monthly mean

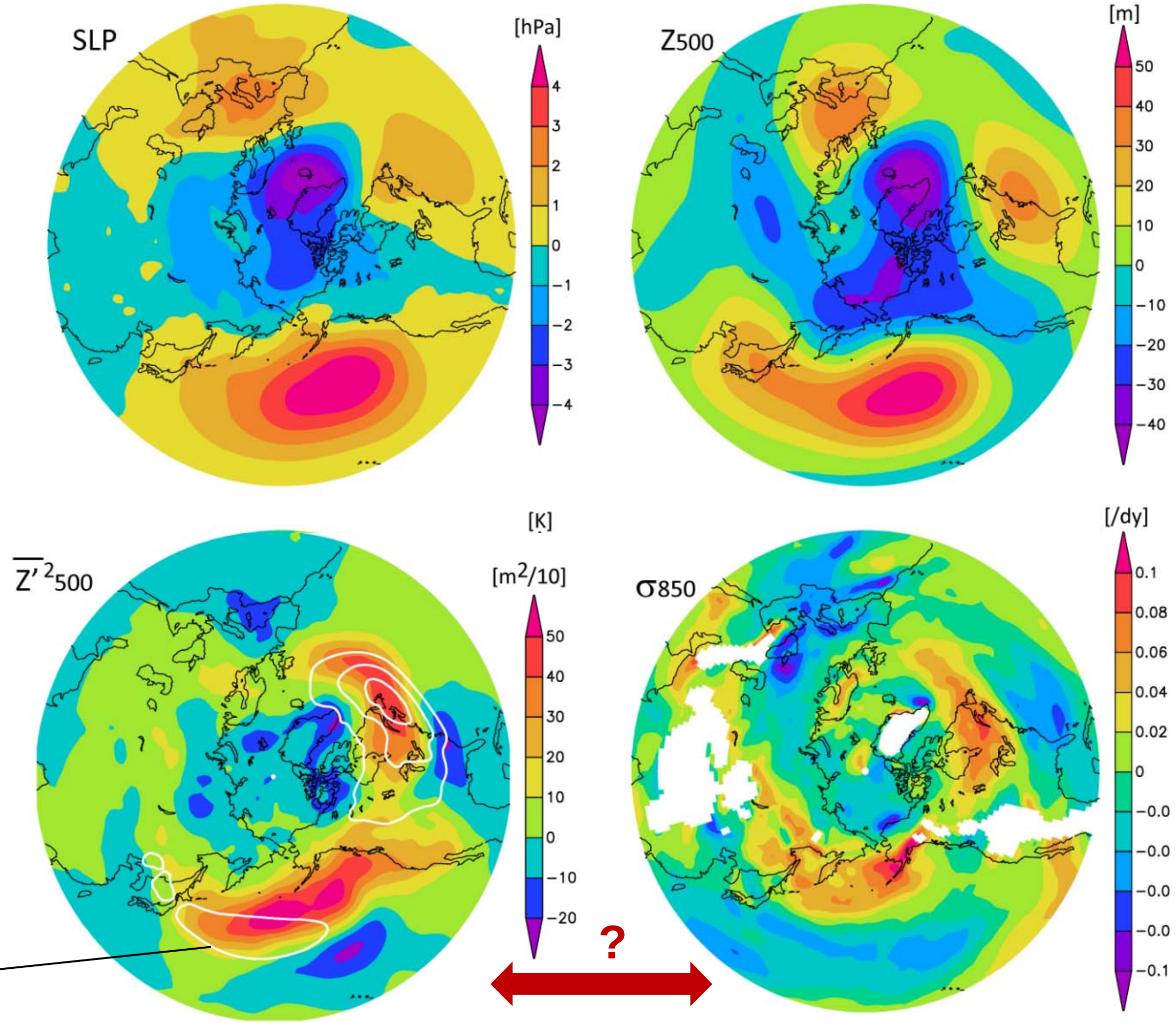
A^{*} Stationary eddies

A' Transients (2-8d)

Monthly mean anomalies associated with TS2

SLP climatology





Weakened Aleutian Low
Intensified Icelandic Low

TS2 vs AO indices: *r*=+0.66

Northward shifted and intensified storm track

Mean position

Mechanisms ?

☐ LBM3.0 (Watanabe and Kimoto 2000, 2001; Watanabe and Jin 2002,2003)

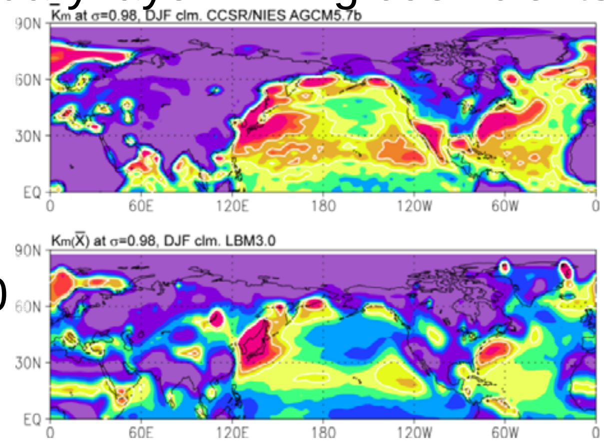
- T42L20 Linearized global spectral model
- JRA winter (DJF) basic state
- Linearized physical processes
  - ✓ ~~convective / stratiform precipitation~~
  - ✓ surface fluxes
  - ✓ turbulent mixing
  - ✓ land surface heat balance

*** In this study, the dry version is used**

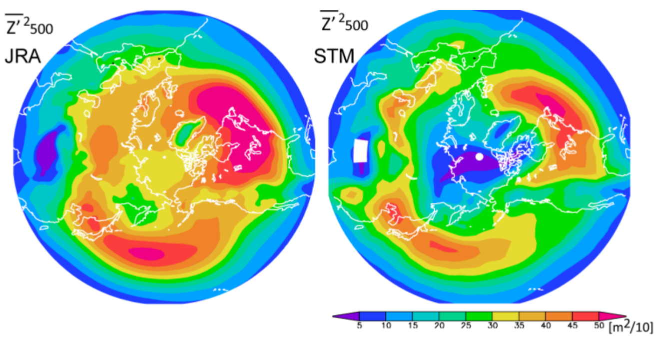
Boundary layer mixing coefficients

AGCM

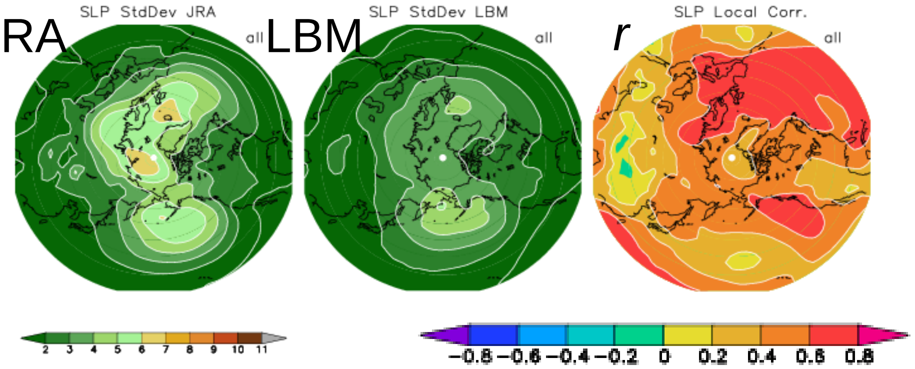
LBM3.0



- Steady forced linear response
- Storm track model (Zhang and Held 1999)



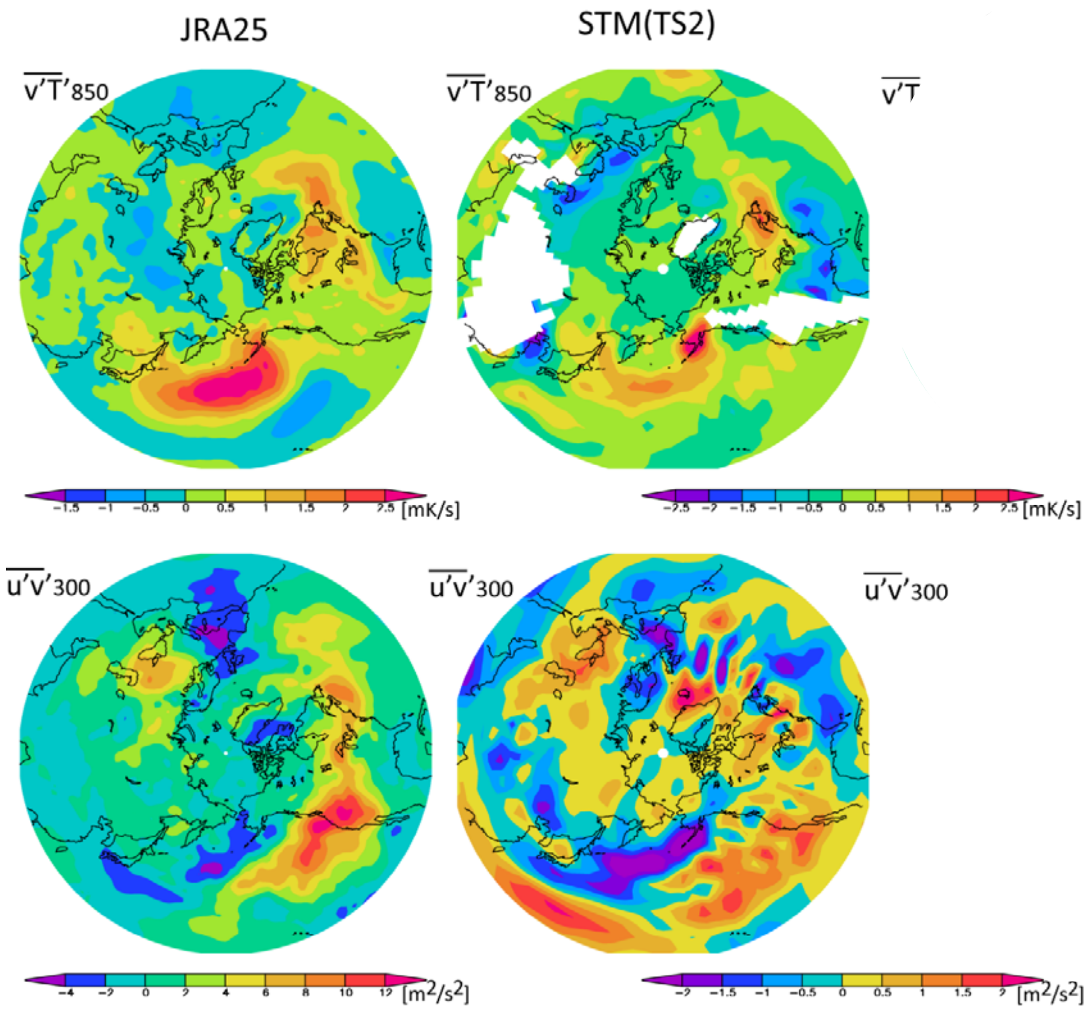
Reproduction of SLP variability 1979-2008



Causes of the storm track change

$\overline{v'T'}_{850}$

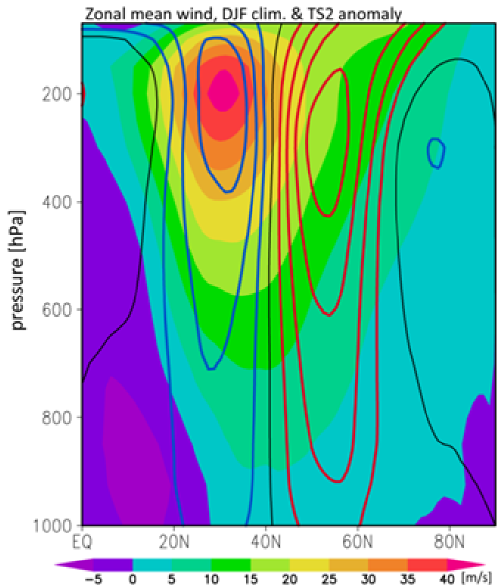
$\overline{u'v'}_{300}$



Barotrpic change > Baroclinicity change !!

Causes of the storm track change

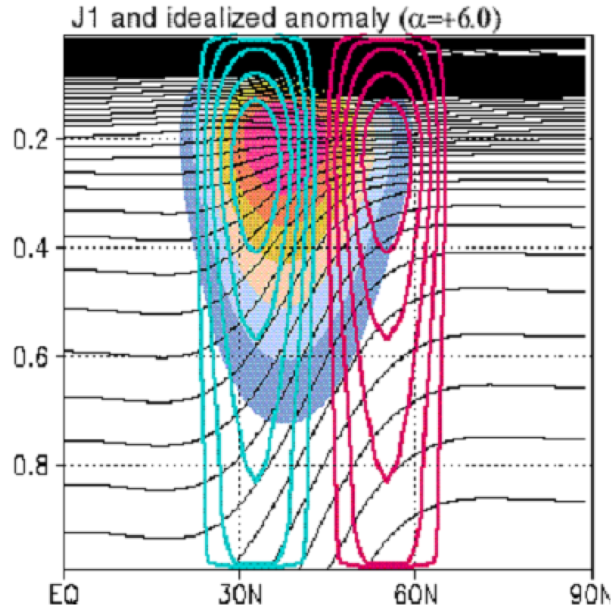
Why $\overline{v'T'}$ is strengthened by changes in barotropic component?

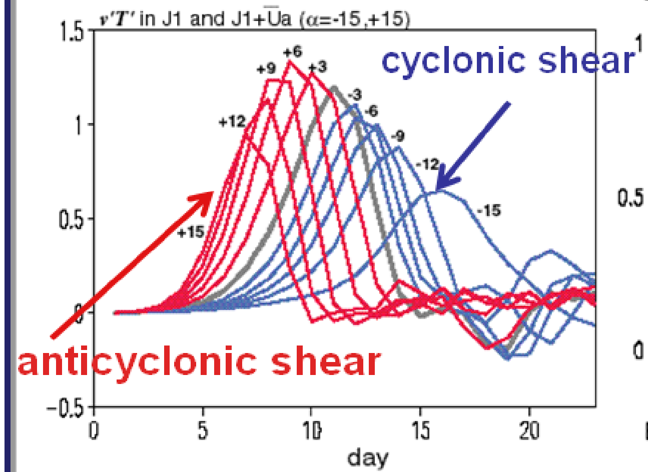


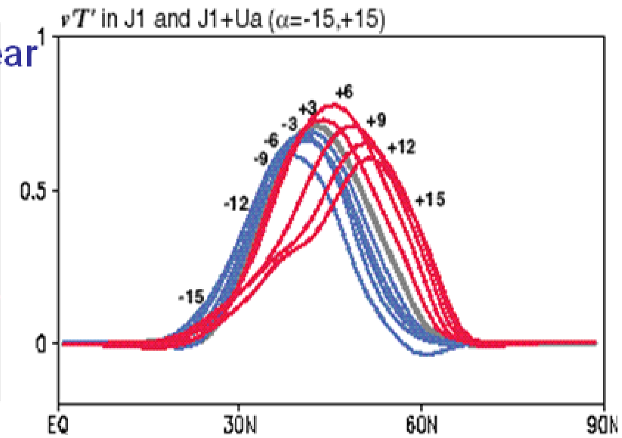
$\overline{v'T'}$ strengthens due to increasing of the LC1-type cyclogenesis !

Baroclinic lifecycle exp.
(T63L20 nonlinear dynamical core)

[v'T'] change due to anticyclonic U shear
- intensified
- shifted northward

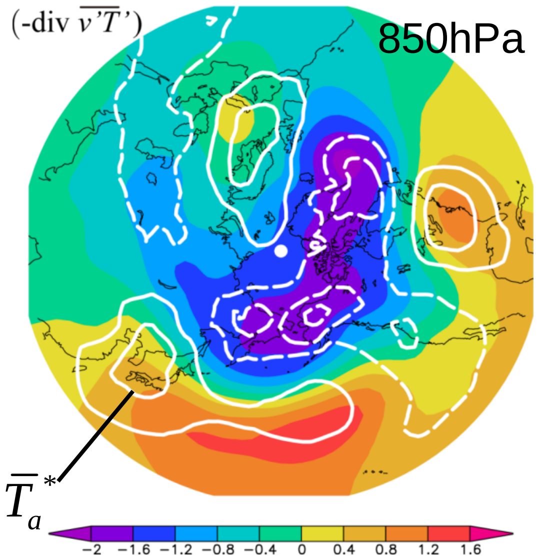






Downgradient approximation of TE heat fluxes

$$\Delta^{-1}(-\nabla\bullet\overline{v'T'})_a$$



Baroclinicity (e.g., Lindzen and Farrell 1980, Hoskins and Valdes 1990)

$$\overline{v'T'} \propto \sigma_{BI} = -0.31\frac{g}{\overline{T}N}\frac{\partial\overline{T}}{\partial y}$$

Diffusive role of transient eddy heat fluxes (Ting and Lau 1993)

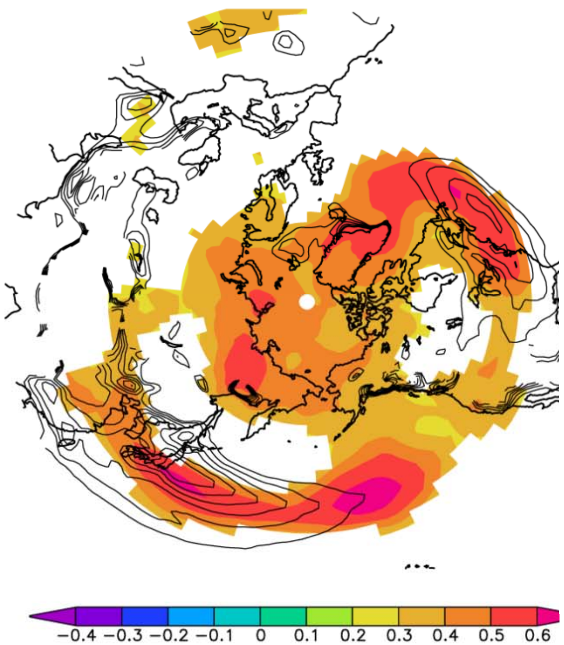
$$-\nabla\bullet(\overline{v'T'})_a \approx \kappa_e \nabla^2 \overline{T}_a$$

Linear steady balance

$$\mathbf{LX}_a = \mathbf{Q}_a + \mathbf{F}_\varsigma + \mathbf{F}_T$$

$$(\mathbf{L}+\mathbf{D}_T)\mathbf{X}_a = \mathbf{Q}_a + \mathbf{F}_\varsigma$$

$r(\overline{T}a, \Delta^{-1}(\text{-div v'T'})a)$



Transient eddy vorticity forcing

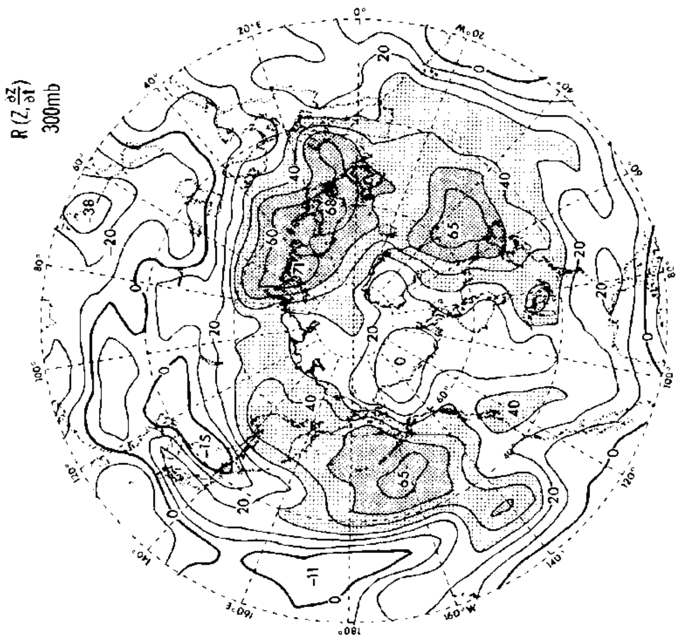


FIG. 13. Distribution of temporal correlation coefficients (in percent) between monthly averaged 300 mb height and the local 300 mb height tendency associated with vorticity transports by bandpass eddies. Contour interval is 10%. Regions with correlation values exceeding 30% and 50% are depicted by light and dense stippling, respectively.

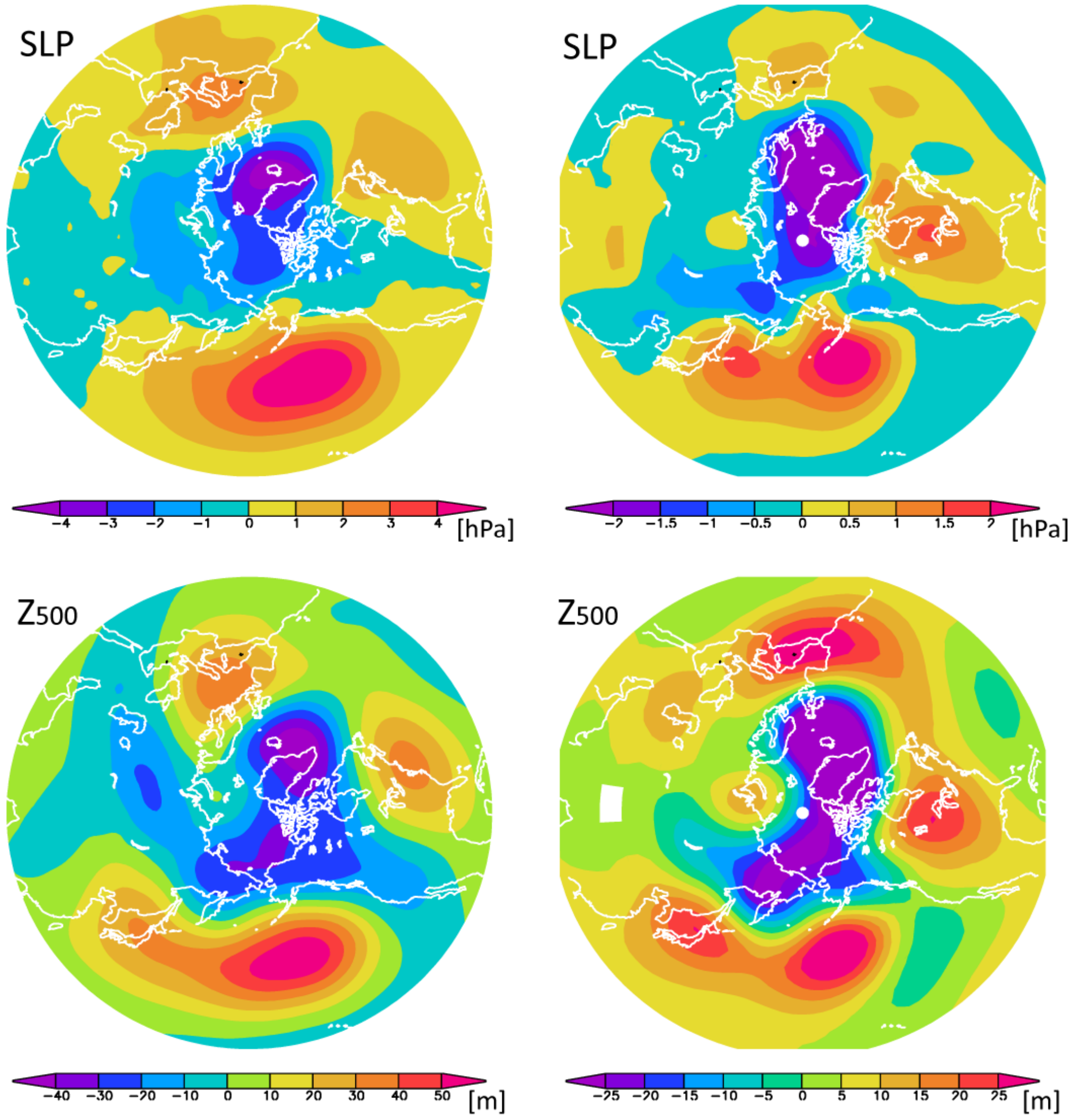
Lau (1988)

Causes of the SE change

	JRA	LBM
	Reg. SVD1, JRA25	Steady linear response

SLP

Z500



Linear balance:

$$(\mathbf{L}+\mathbf{D}_T)\mathbf{X}_a = \mathbf{Q}_a + \mathbf{F}_\varsigma$$

Xa: monthly anom.

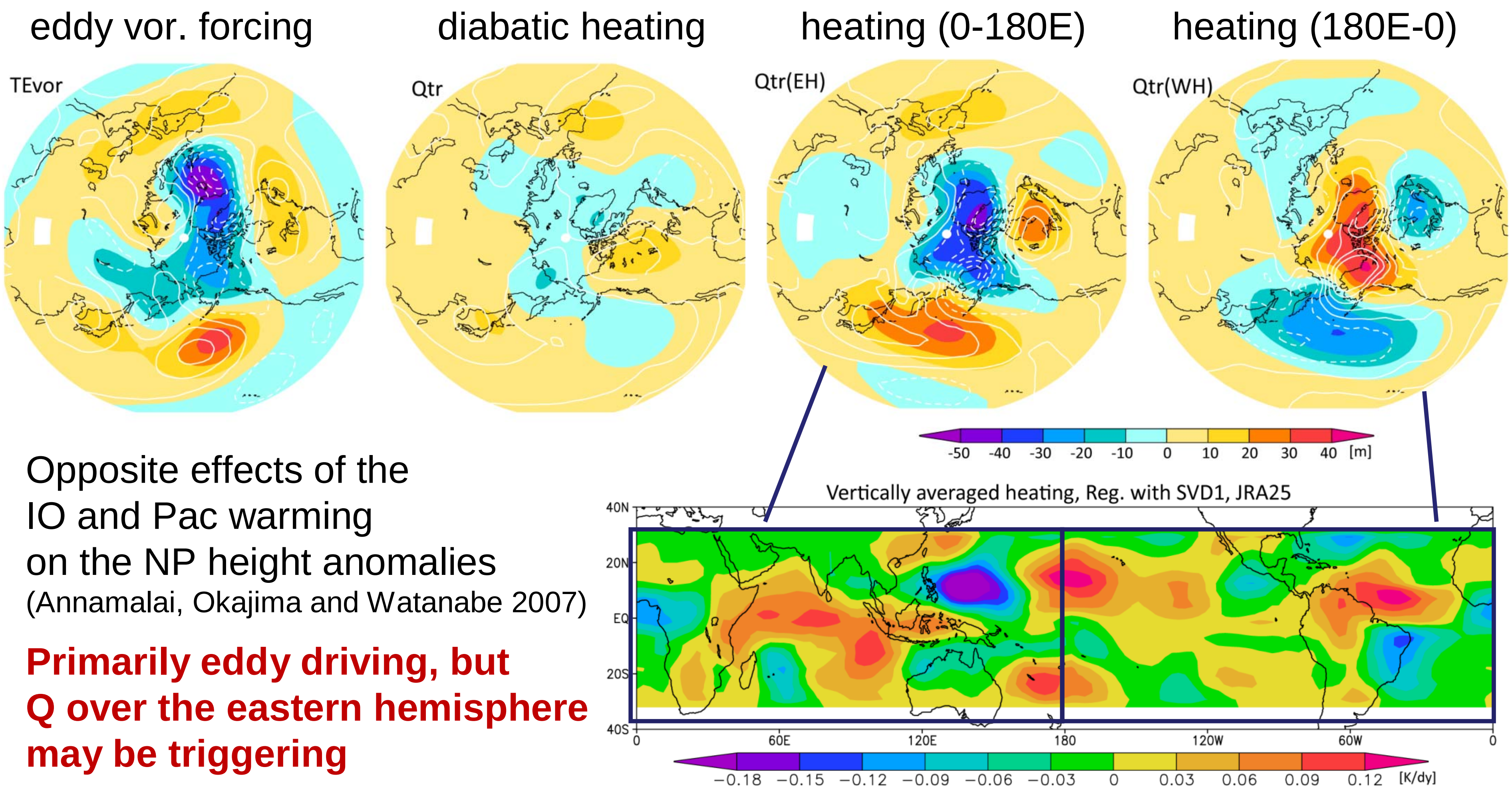
Qa: heating anom.

F_ζ: eddy vor. forcing.

D_T: eddy thermal. diff.

Tropical diabatic heating

Z_{500} LBM response to:

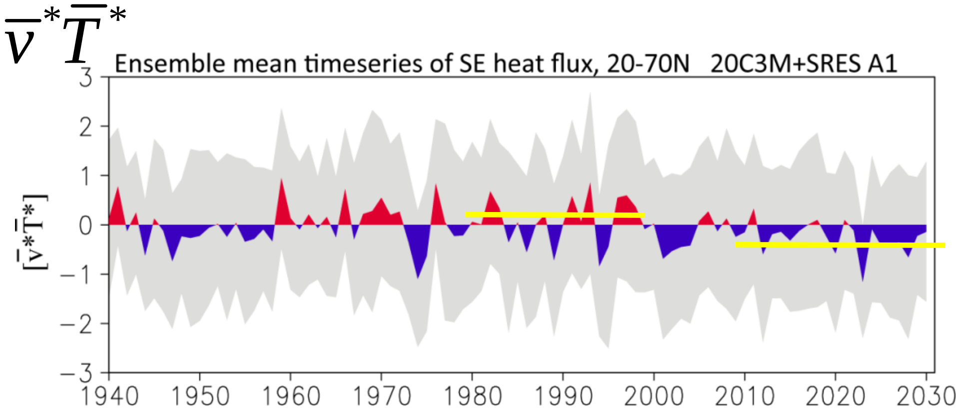


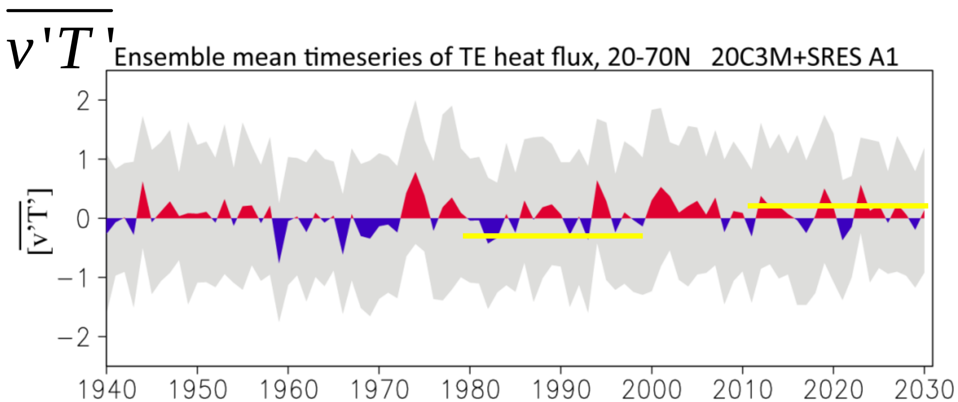
Opposite effects of the
IO and Pac warming
on the NP height anomalies
(Annamalai, Okajima and Watanabe 2007)

**Primarily eddy driving, but
Q over the eastern hemisphere
may be triggering**

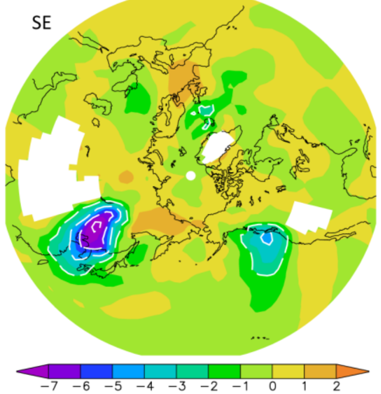
Future projection

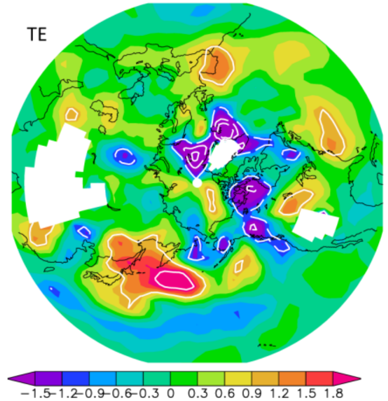
MIROC-mid 10 member ensemble

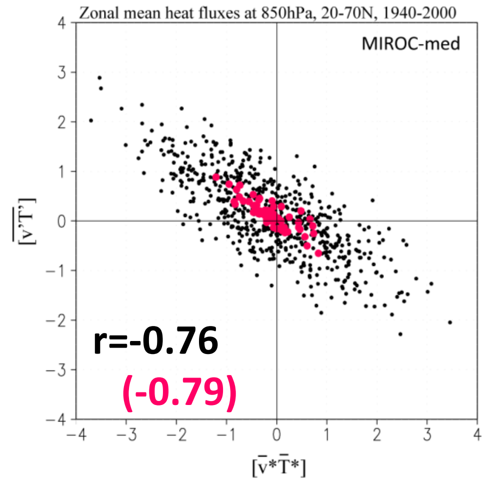




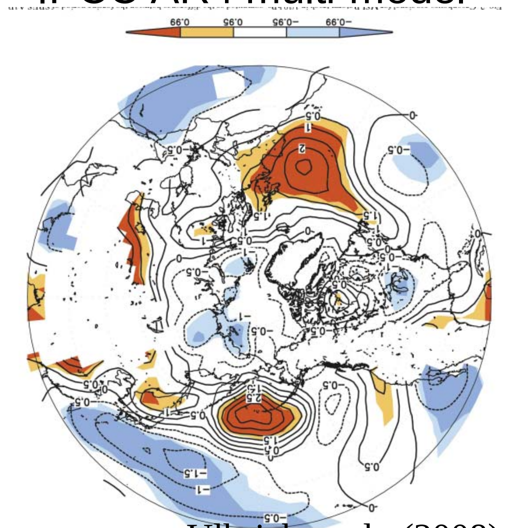
(2011-2030) minus
(1981-2000) mean







Chg in cyclone intensity
IPCC AR4 multi-model



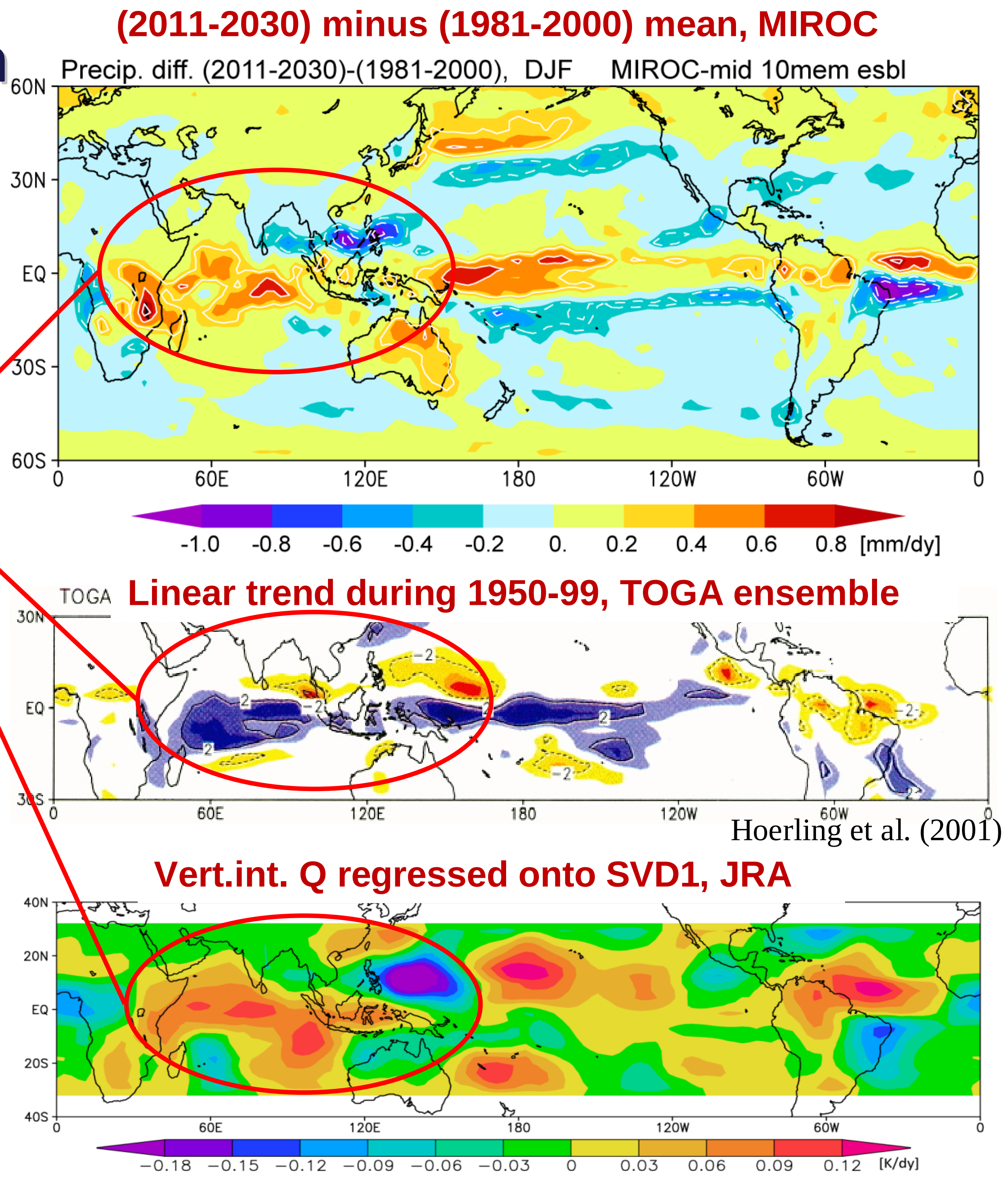
Ulbrich et al. (2008)

Long-term change in the tropical heating

A common feature of the precipitation (diabatic heating) anomalies:

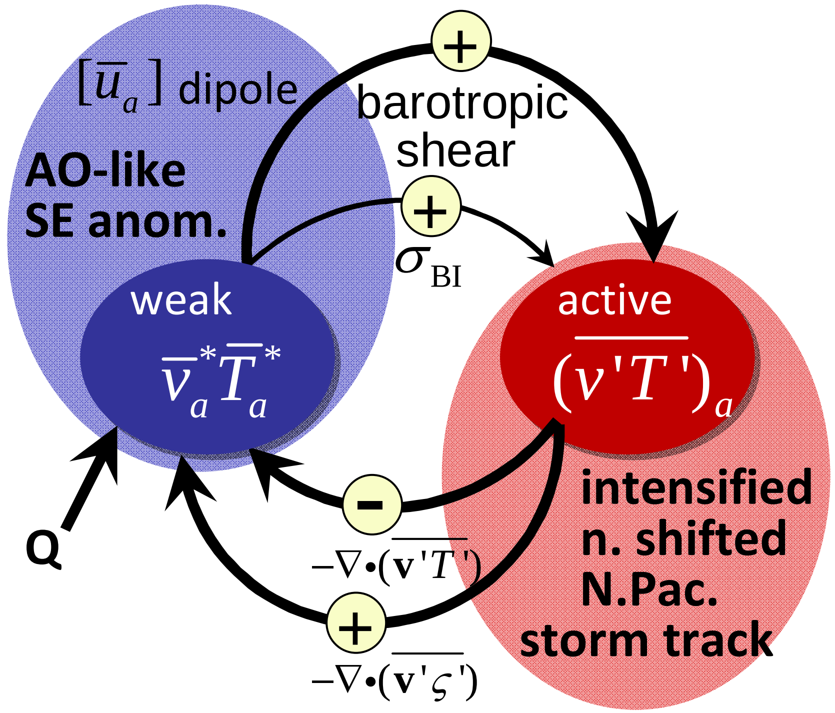
heating (increasing precip.) over the eq. western Indian Ocean

cooling (decreasing precip.) over the off-eq. western Pacific



Summary

- Compensating atm. meridional heat transports between stationary eddies (SE) and transients (TE)
- Cause of the TE change: changes in σ_{BI} and the barotropic shear
- A thermal adjustment? NO!
- TS2 cannot be amplified by the thermal coupling, but does dominate
- Cause of the SE change: TE vorticity forcing and Q over the eastern hemisphere



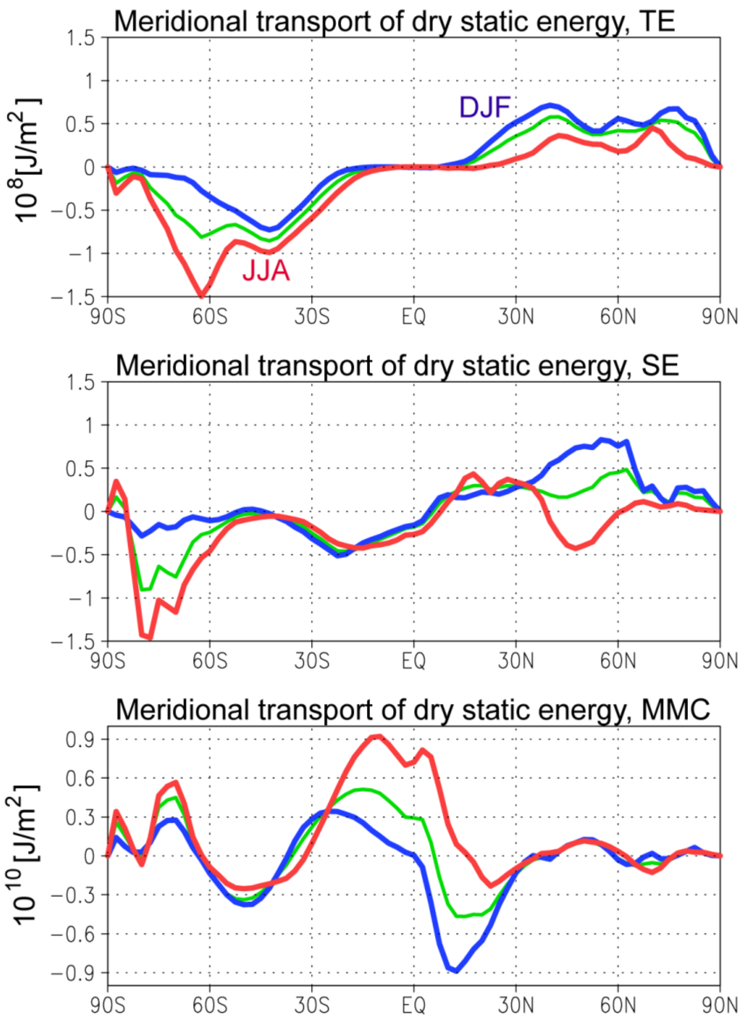
Implication

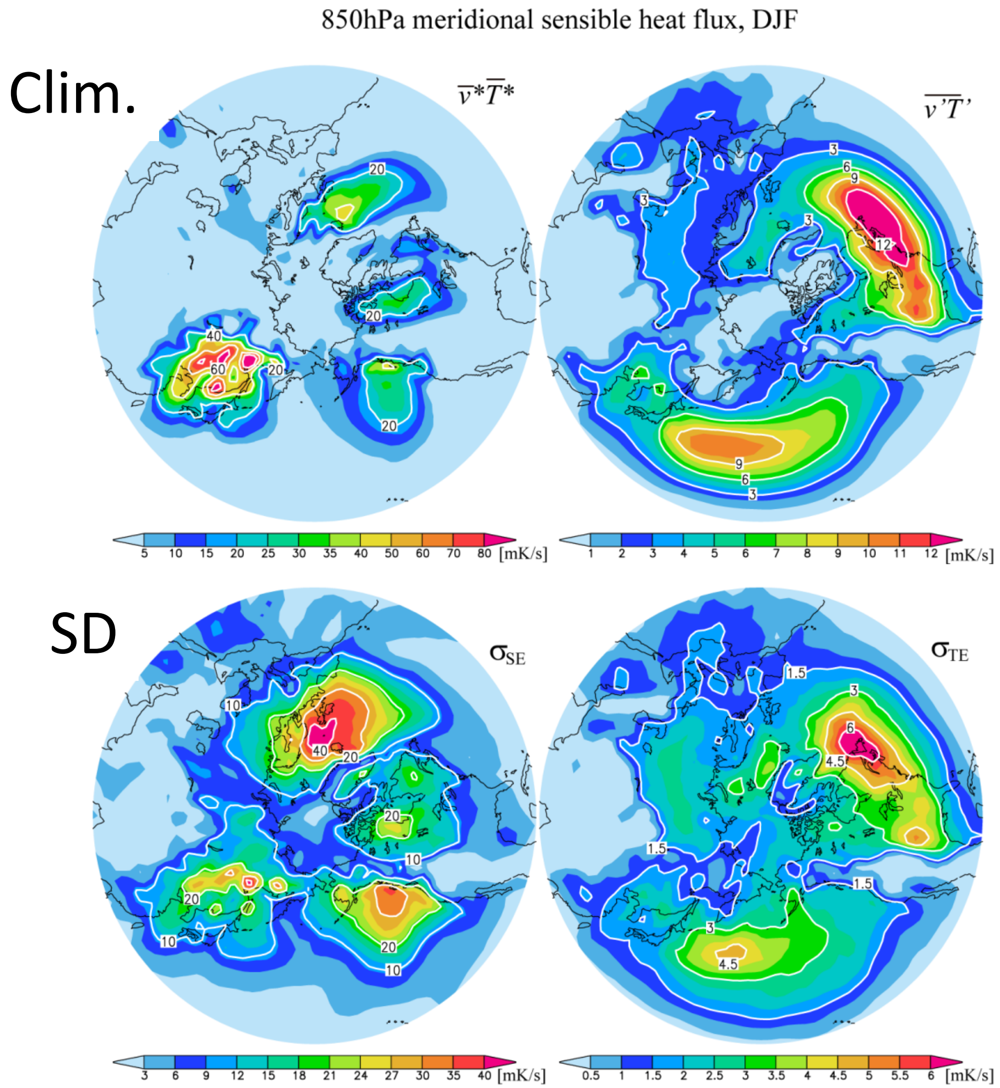
- Future change in the stationary eddies and transients
  reflects the trend in the simulated TS2

- Change in the horizontal shear (but not the upper-level baroclinicity) may be of importance for the future trend of the NH storm tracks reported by many studies (e.g., Hall et al. 1994; Geng and Sugi 2003; Yin 2005; Lambert and Fyfe 2006; Ulbrich et al. 2008).

Backup

Meridional heat transport in the atmosphere

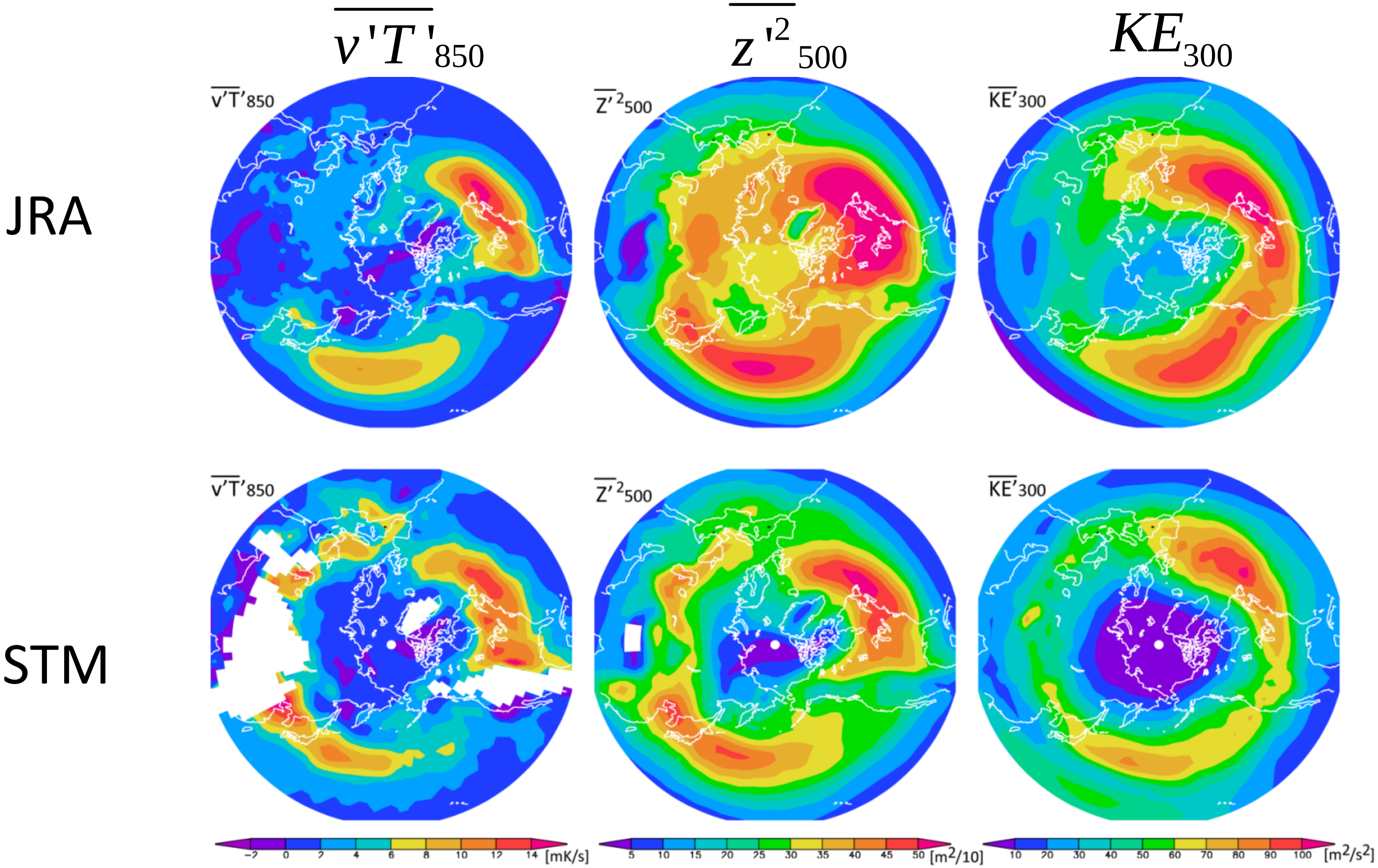




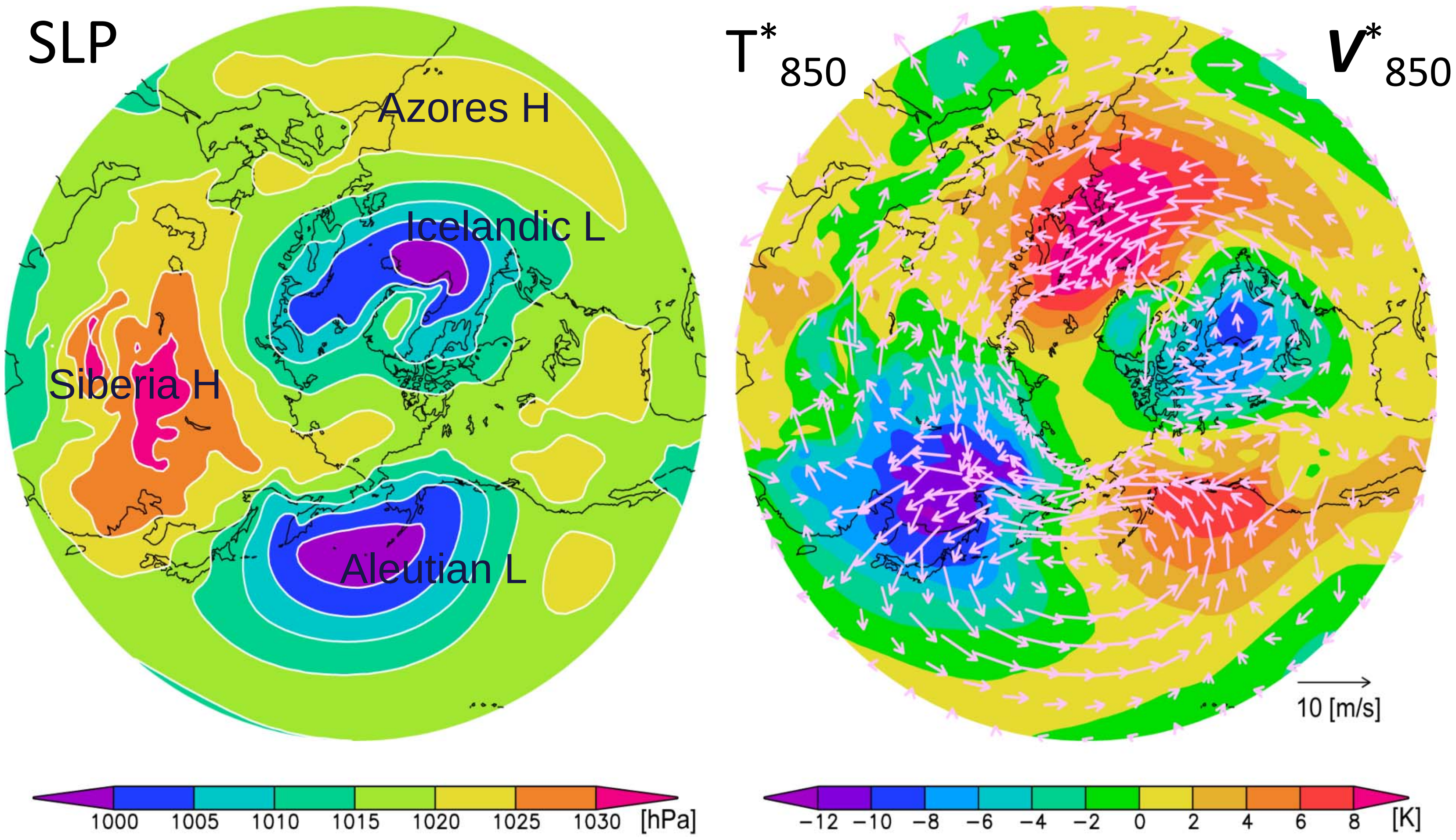
Causes of the storm track change

Storm track model (STM)

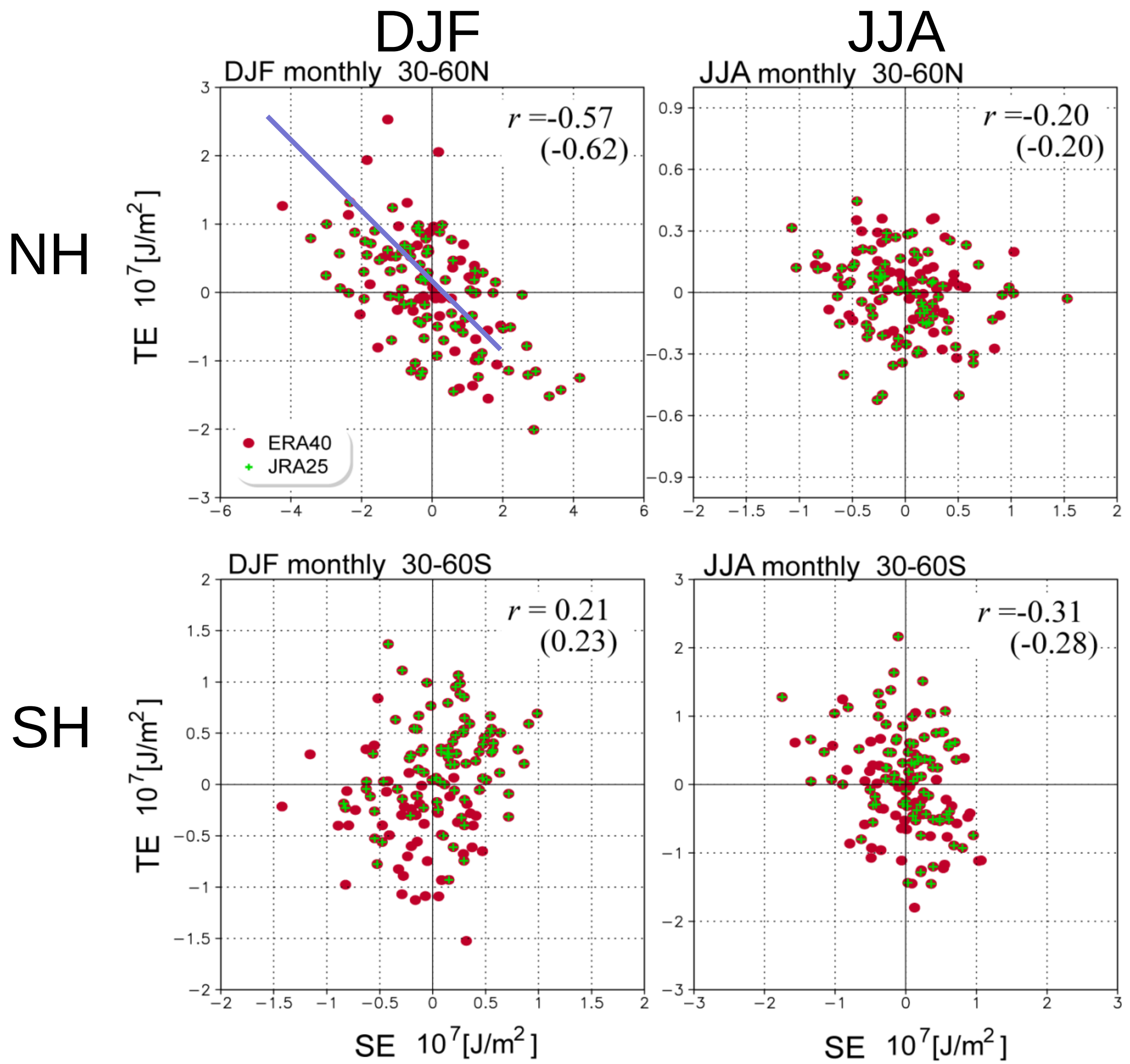
- Stochastically-forced linear baroclinic system (T42L20)
- Simple time integration (Zhang and Held 1999)



Winter climatological state



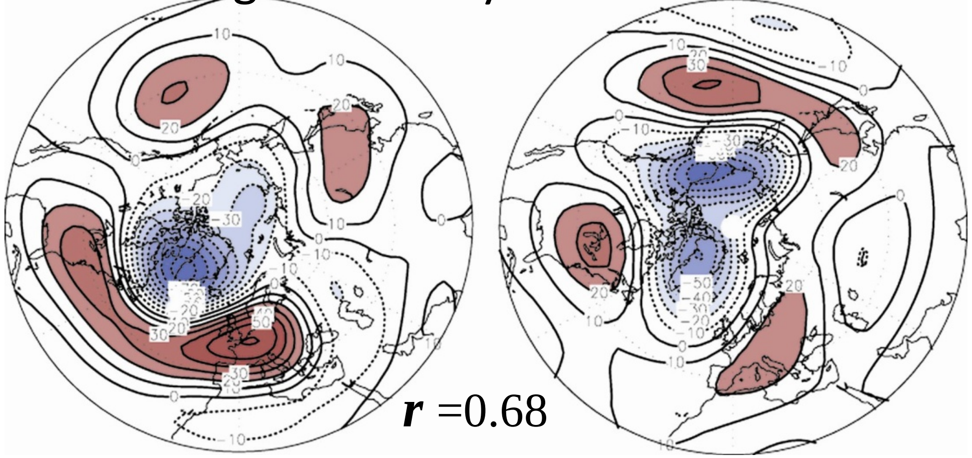
Zonal mean heat transport: SE vs TE



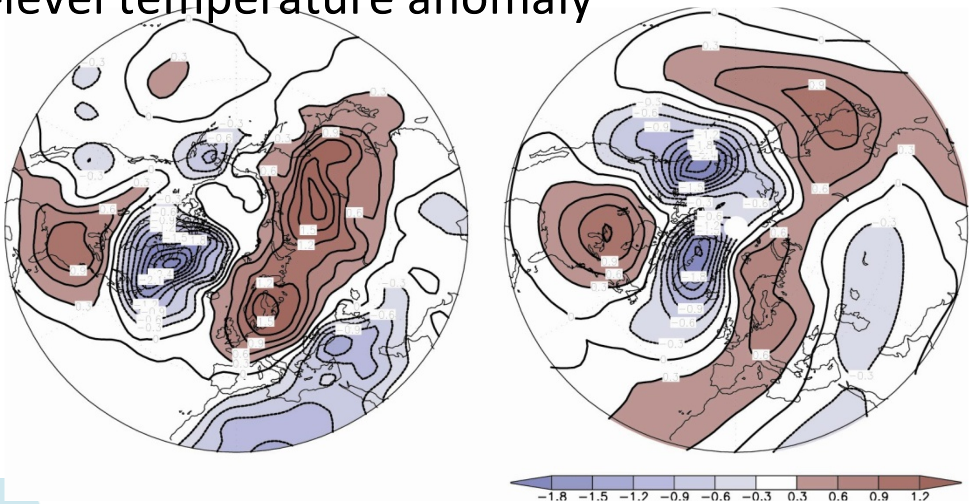
Neutral mode

Obs. AO
upper-level height anomaly

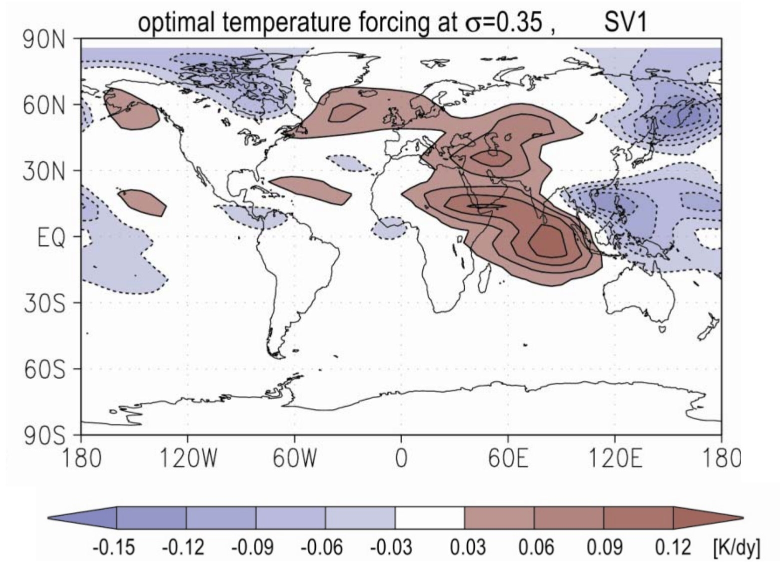
Neutral mode
(v-vector)



low-level temperature anomaly



Optimal thermal forcing
(u-vector)



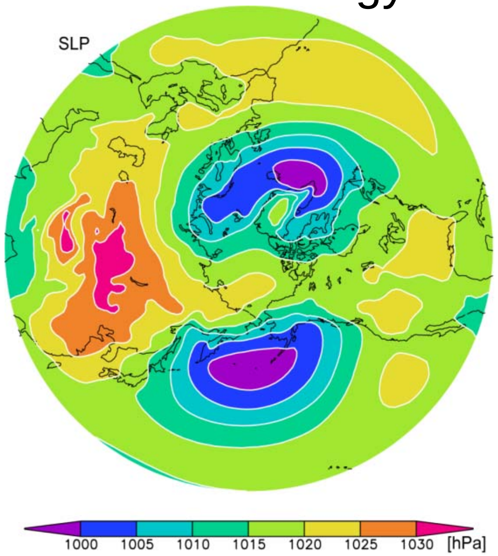
Watanabe and Jin (2004, JC)

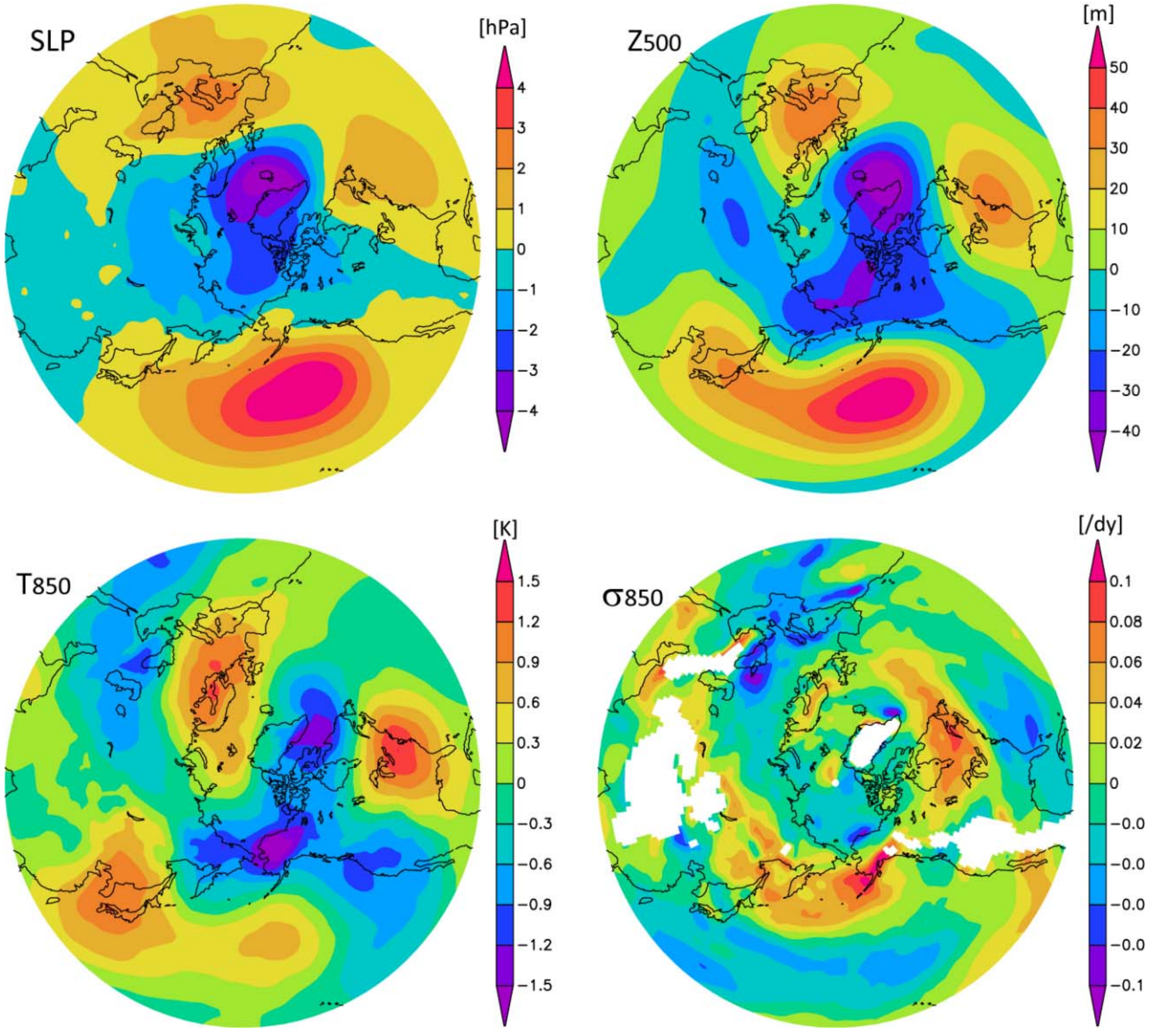
Zero-sum rule ?

NLBM

Monthly mean anomalies associated with the TS2

SLP climatology





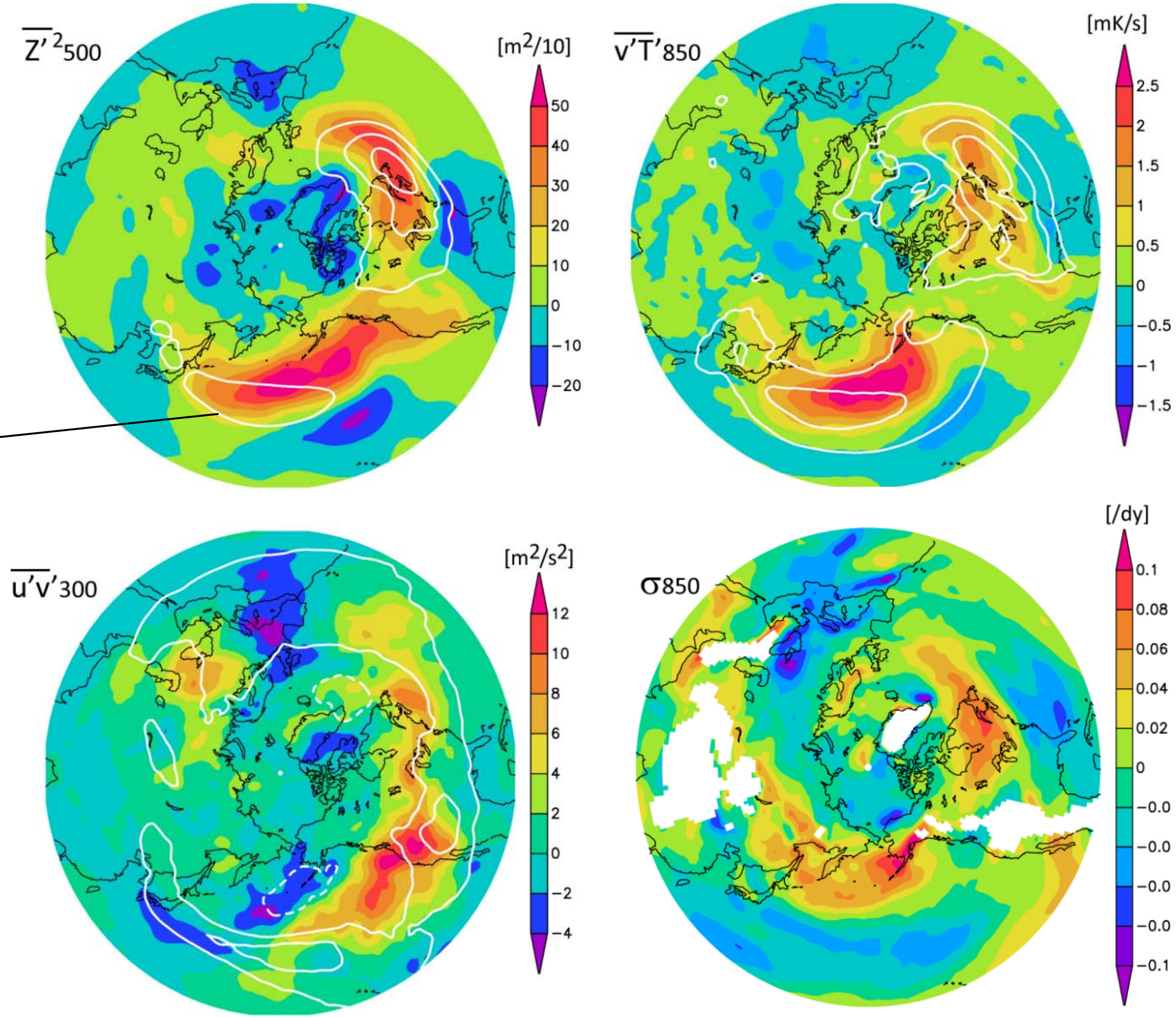
Weakened Aleutian Low
Intensified Icelandic Low

TS2 index vs AO index:
***r* =+0.66**

Monthly mean storm track anomalies associated with the TS2

Northward shifted and intensified storm track

Mean position



Anomaly pattern of $\overline{v'T'}$ may partly be consistent with the change in low-level baroclinicity

要チェック

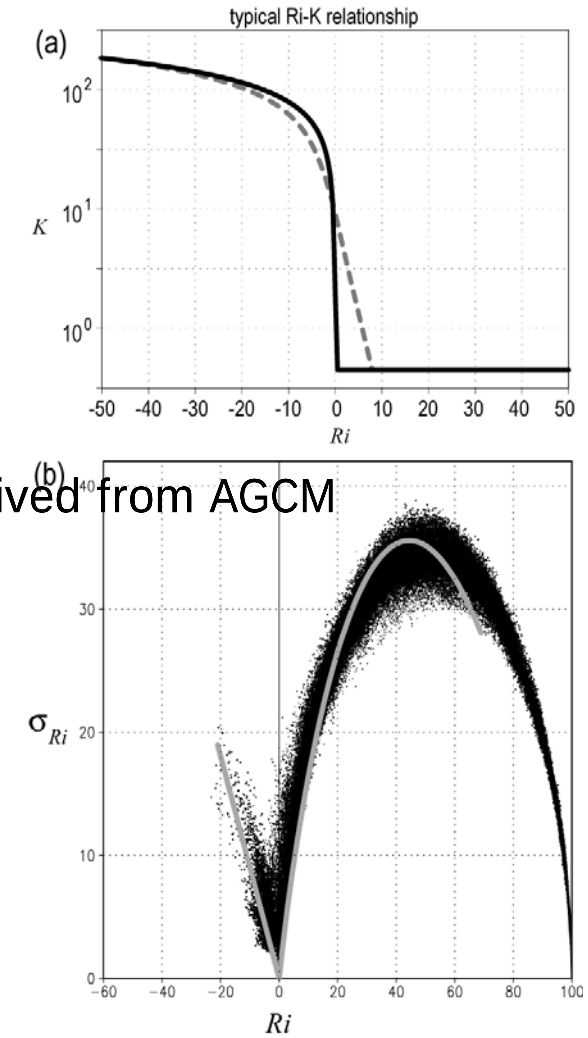
Lambert and Fyfe (2006)
マルチモデルでの低気圧数と強さの将来変化

Implication:　低気圧活動の将来変化の解釈
将来、強い低気圧が増えるのは、上層傾圧
度の増加によるのではなく、順圧シアに
よって低気圧のライフサイクルが変化する
（LC2型が減り、LC1型が増える）から？

LC1が増えると、EKEは逆に減るはず
Akahori and Yoden
しかし、TS2+時にv'T'増加とともにEKEも増大、合わない？

Mizuta et al. 2008 (Tech. Repo. MPI)

Development of the mLBM3.0 package



Derived from AGCM

Turbulent mixing of momentum, heat and moisture

$$F'_j = \bar{K}_j \frac{\partial X'_j}{\partial \sigma} \quad , \quad K_j = f_j(R_i)$$

where the mixing coef. is a highly nonlinear function of the Ri number

$$R_i = \left(g\theta_s^{-1}\partial\theta / \partial z\right) / \left(\partial^2 u / \partial z^2 + \partial^2 v / \partial z^2\right)$$

We can approximate $\overline{R_i(X)} \simeq R_i(\bar{X})$,
but $\overline{K(R_i)} \neq K(\overline{R_i})$!

Using a relationship between the time-mean and the variance of Ri, we assume its PDF G(Ri) and then obtain the basic-state mixing coef. as

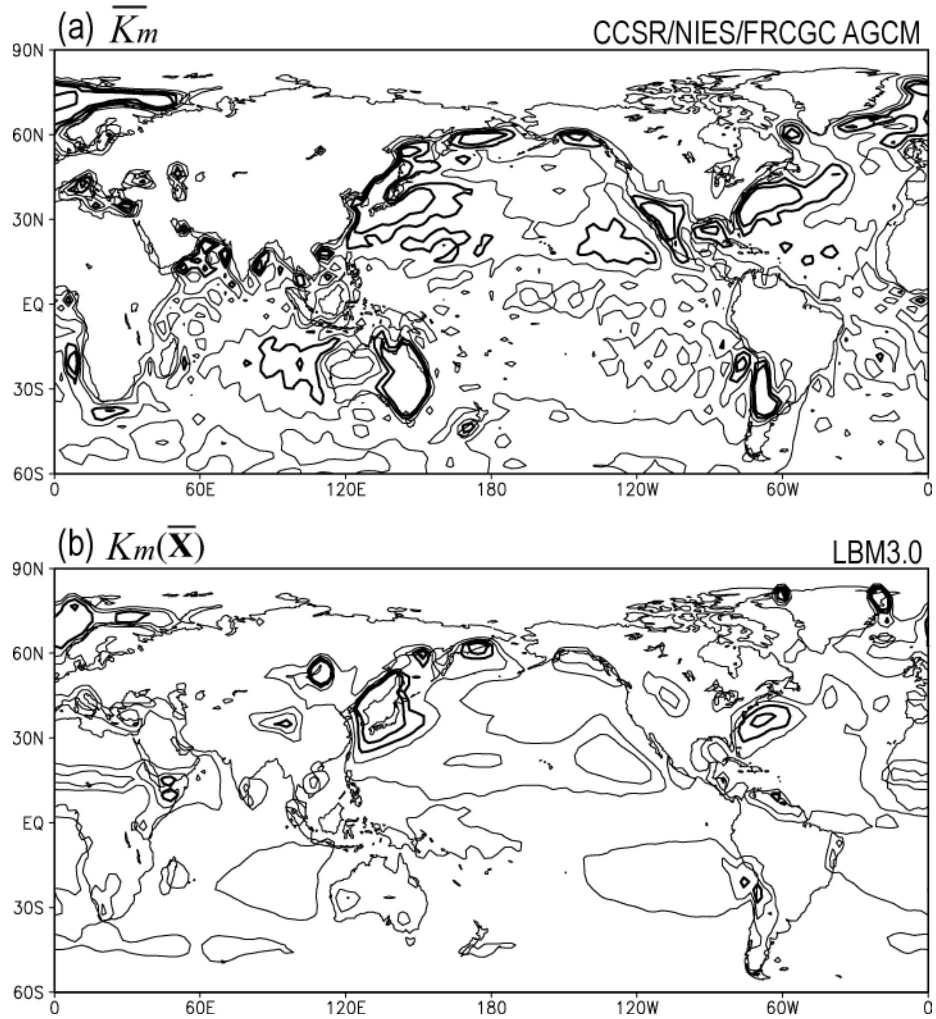
$$\bar{K}_j = \frac{\int_{R_i^-}^{R_i^+} f(R_i) G^*(R_i) dR_i}{\int_{R_i^-}^{R_i^+} G^*(R_i) dR_i}$$

Development of the mLBM3.0 package

Boundary layer mixing coefficients

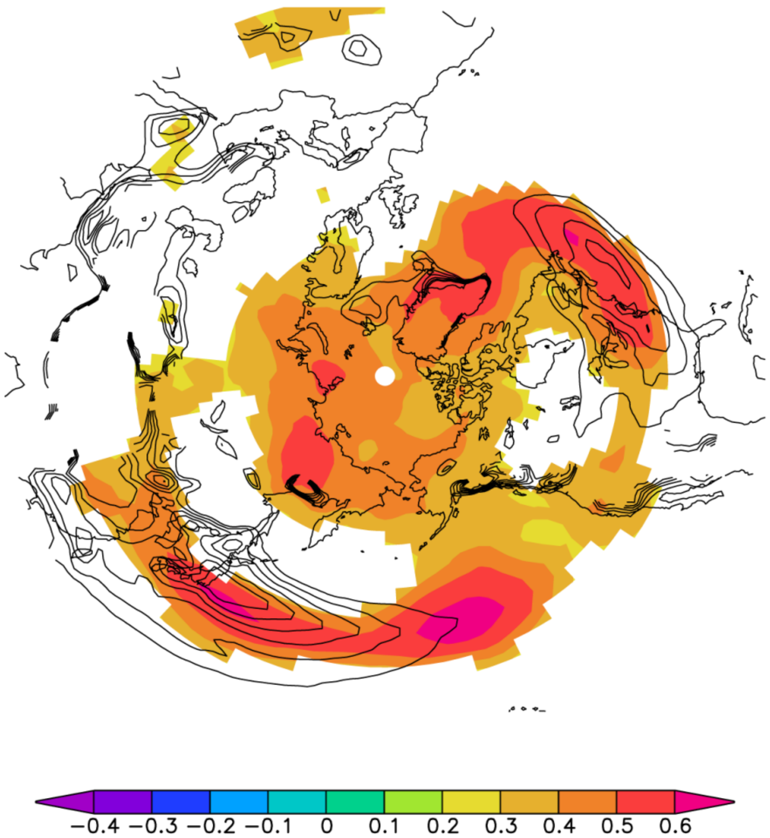
AGCM DJF clim.

mLBM3.0
(with AGCM DJF clim.
 as a basic state)

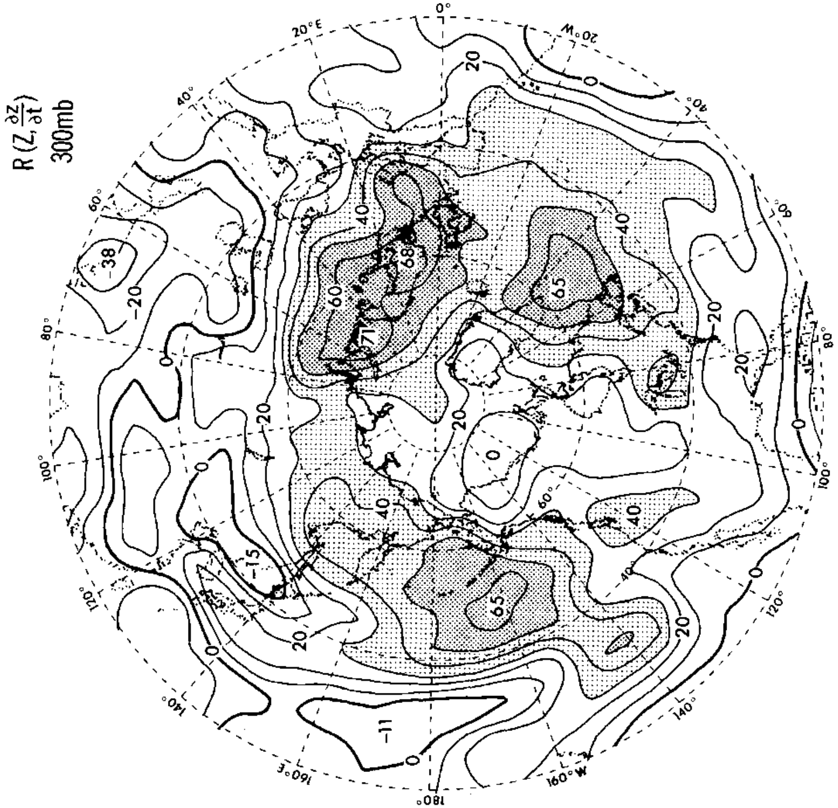


Down-gradient approximation of TE heat fluxes

$r(\overline{T}a, \Delta^{-1}(-\text{div } v'T')a)$



Transient eddy vorticity forcing



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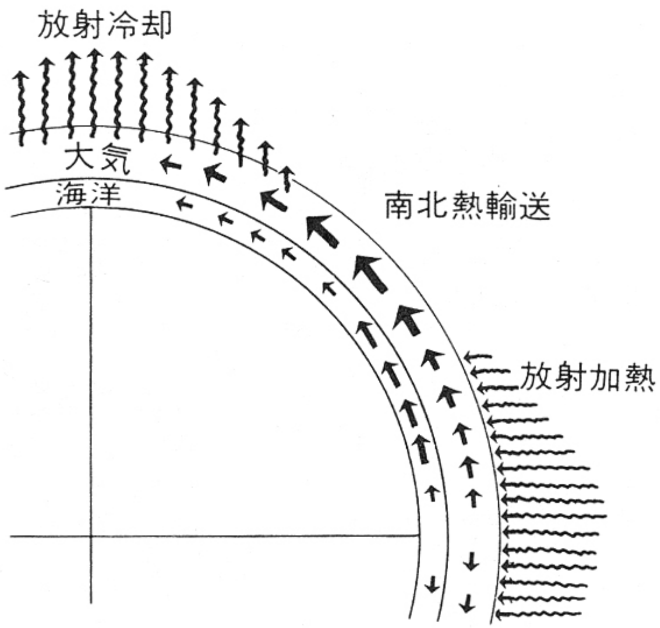
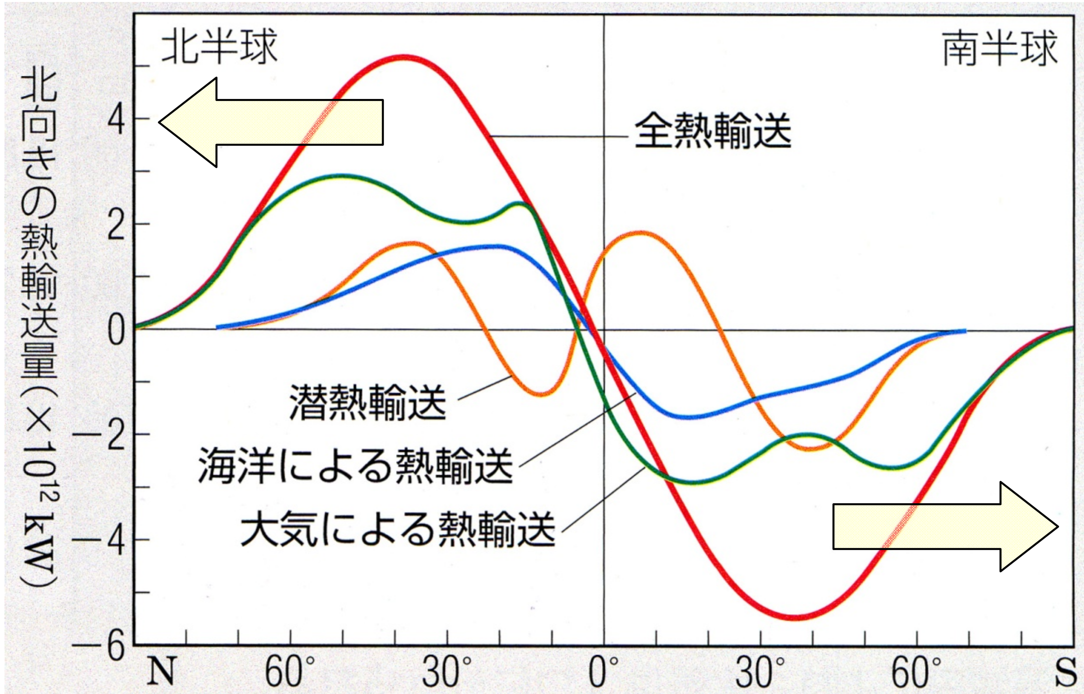
Lau (1988)

Introduction

Meridional heat transport: a fundamental process for the climate system



浅井ら(1993)



Data and model

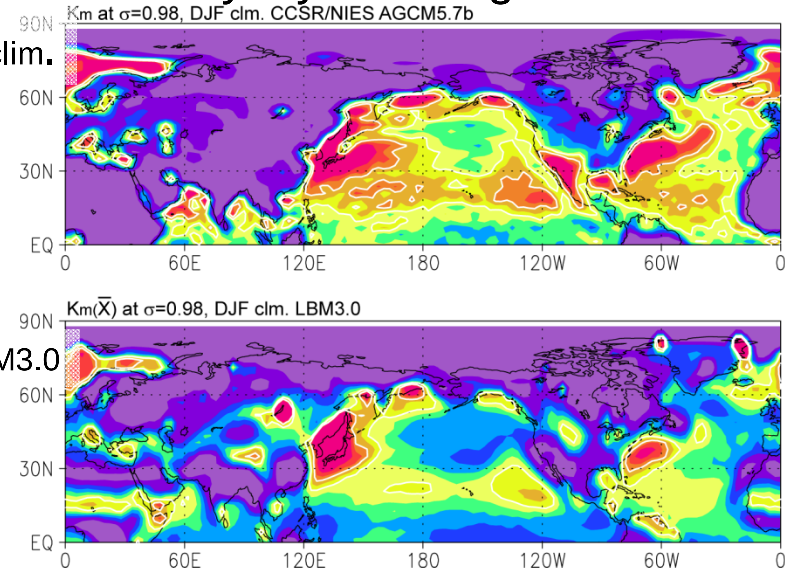
- **ERA40** (Uppala et al. 2005)
  - Sep1957-Aug2002
  - 2.5x2.5deg
- **JRA25** (Oonogi et al. 2007)
  - Jan1979-Sep2008
  - 1.25x1.25deg
- **LBM3.0** (Watanabe and Kimoto 2000, 2001; Watanabe and Jin 2002,2003)
  - Linearized global spectral model (T42L20)
  - JRA winter (DJF) basic state
  - Linearized physical processes
    - ✓ ~~cumulus convection~~
    - ✓ ~~stratiform precipitation~~
    - ✓ surface fluxes
    - ✓ turbulent mixing
    - ✓ land surface heat balance

*** In this study, the dry version is used**

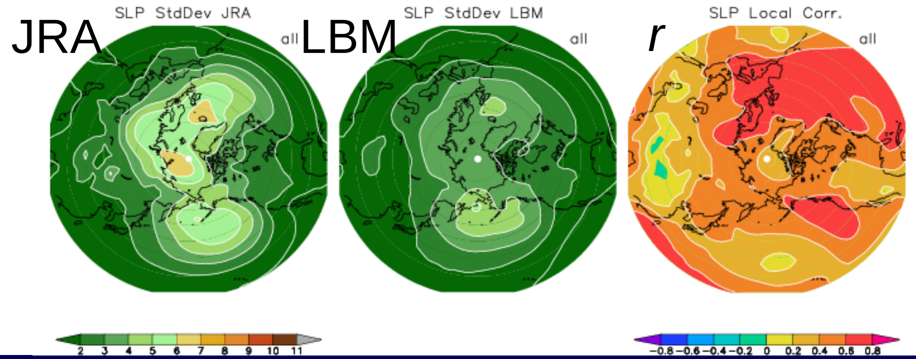
Boundary layer mixing coefficients

AGCM DJF clim.

LBM3.0

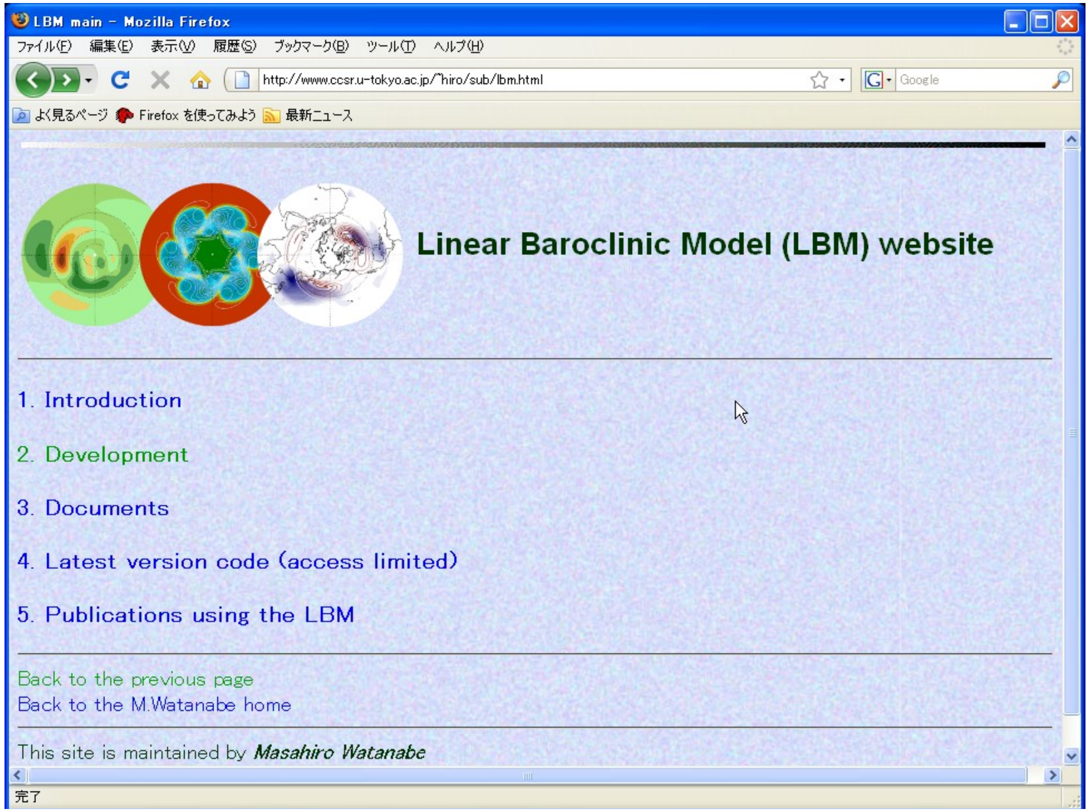


Reproduction of SLP variability 1979-2008

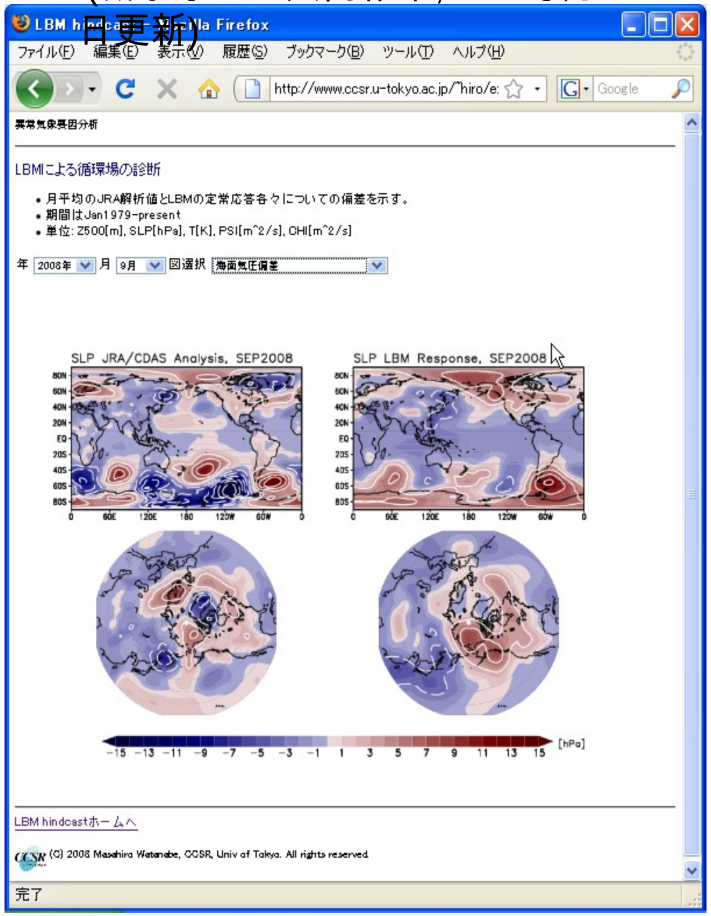


Using the LBM

LBM website (http://www.ccsr.u-tokyo.ac.jp/~hiro/sub/lbm.html)



異常気象要因分析
(気象庁との共同作業, web毎月3日更新)

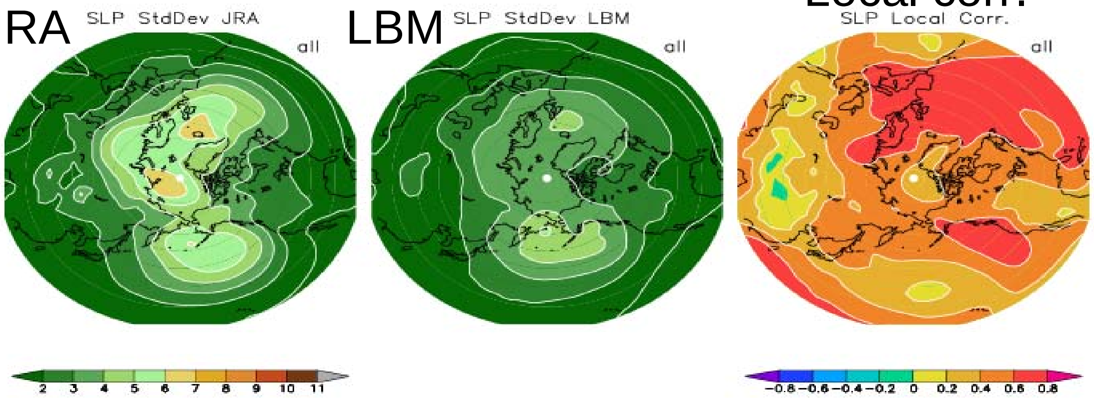


Reproduction of SLP variability 1979-2008

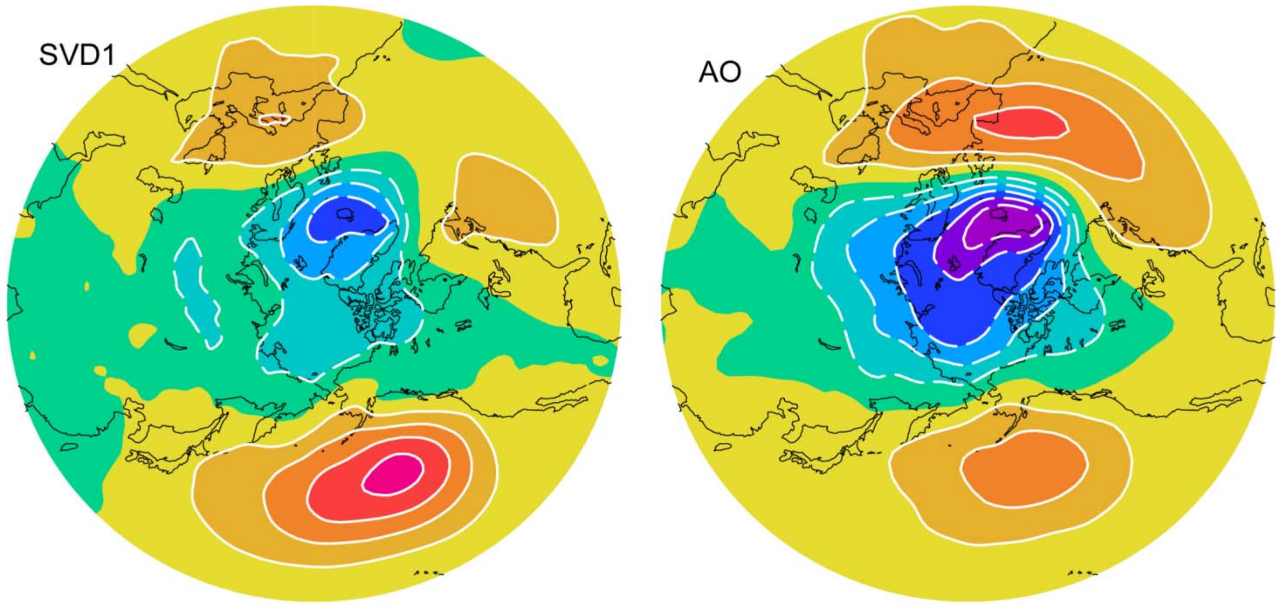
Local corr.

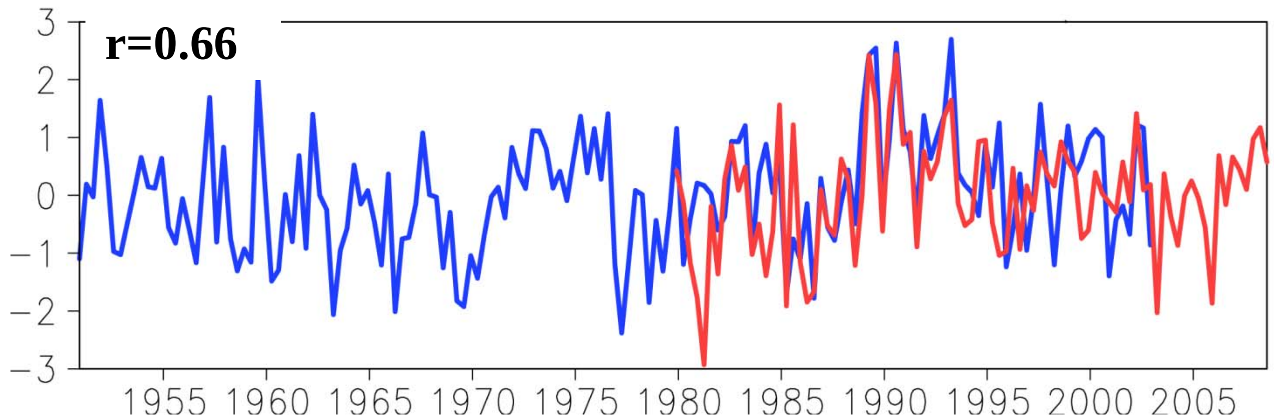
JRA

LBM

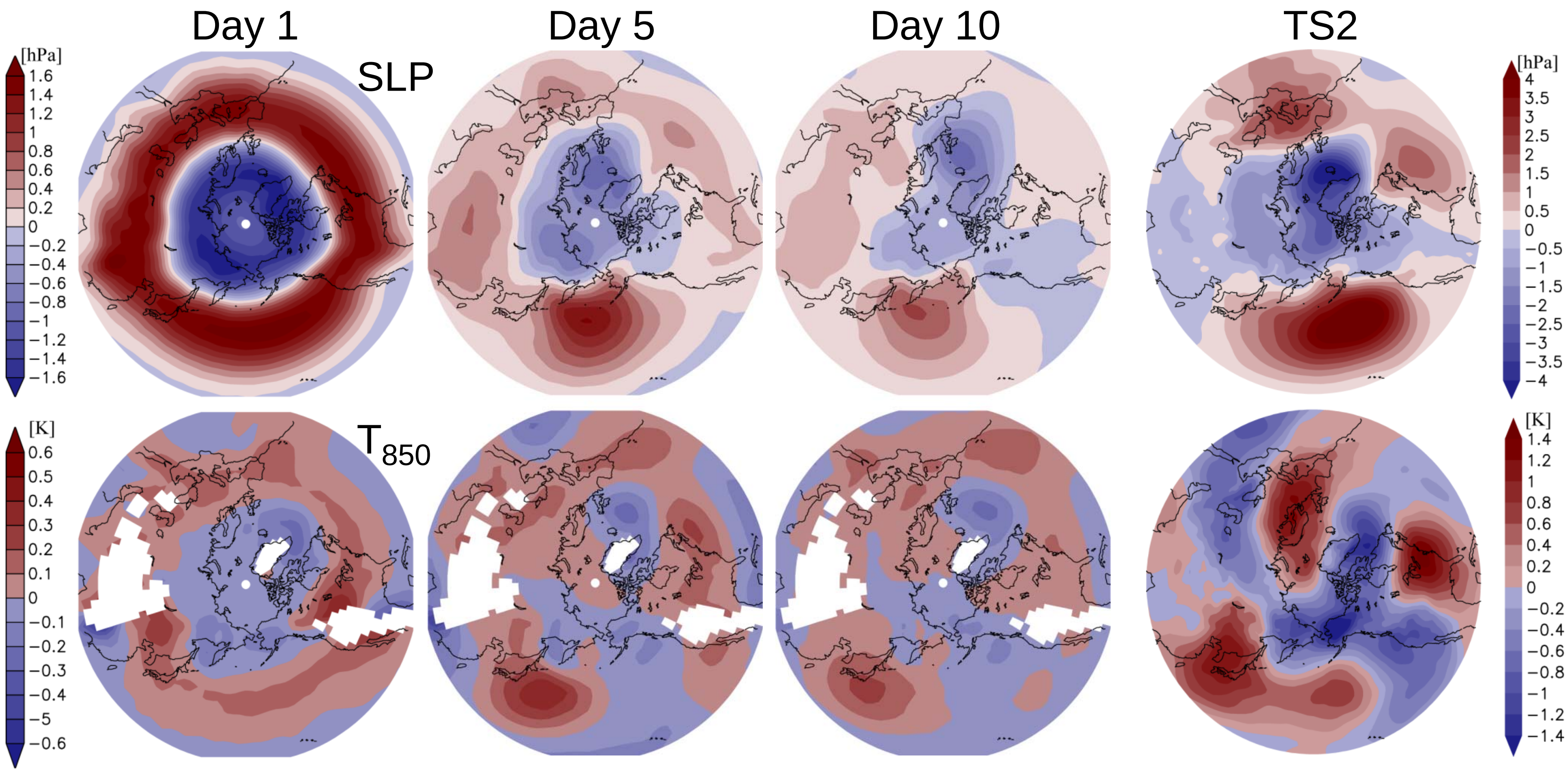


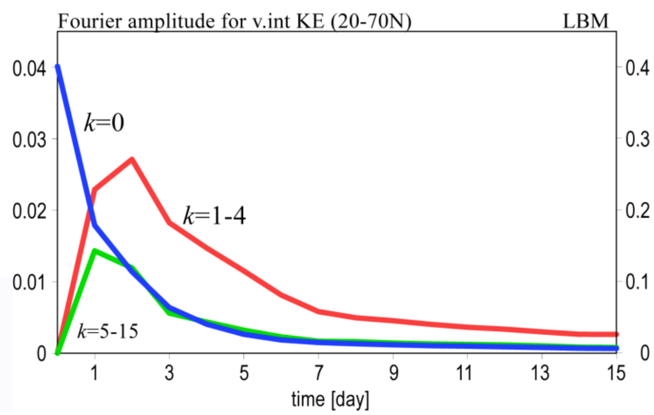
TS2 and AO


SVD1
AO


r=0.66
3
2
1
0
−1
−2
−3
1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005

Time evolution from initial barotropic anomaly





Summary

- Interannual variability of the atm. meridional heat transports tends to be compensated between the stationary eddy (SE) anomalies and transients (TE) (called TS2)
- The TS2 is found only in the NH winter, accompanied by the AO-like dominant variability
- Cause of the TE change: baroclinicity and barotropic shear
- Cause of the SE change: Q over the eastern hemisphere and the transient eddy vorticity forcing
- TE and SE changes are interacting, but the thermal coupling cannot amplify them (need momentum process!)