On the Contrasting Storm Track-Jet Relationship between the Pacific and Atlantic Storm tracks:

Energetics in the Sub-seasonal evolution/ inter-decadal variability

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Overview

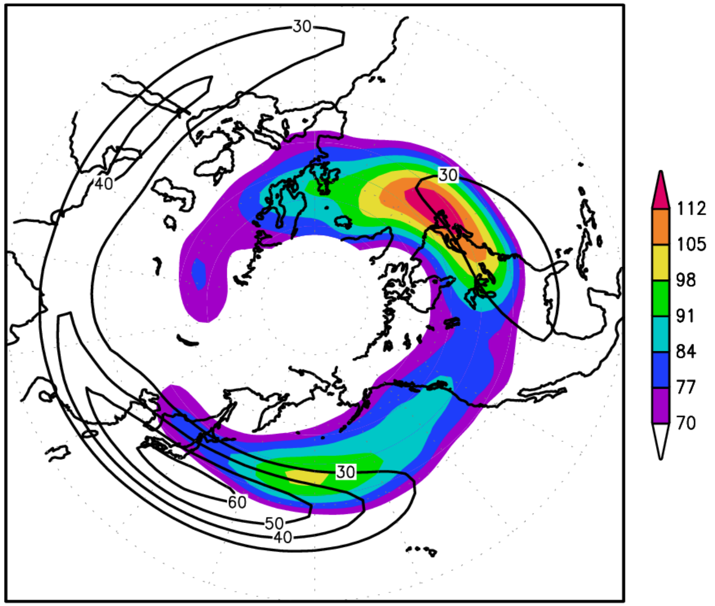
- **Statistics of storm track activity are highly important for seasonal anomaly.**
- **The storm tracks play an important role in vertical and horizontal exchange of heat, water vapor, and momentum [e.g. Yin, 2005 (*GRL*); Bengtsson *et al.*, 2006 (*JC*)].**
- **Regions where transient synoptic eddies tend to be strongest are defined as the "*Storm tracks*" [e.g. Blackmon, 1976 (*JAS*); Lau, 1988 (*JAS*); Chang *et al.*, 2002 (*JC*)].**
- **Two storm tracks manifest over the North Pacific (Pacific storm track, PST) North Atlantic (Atlantic storm track, AST).**

• **Shading : *Storm track***

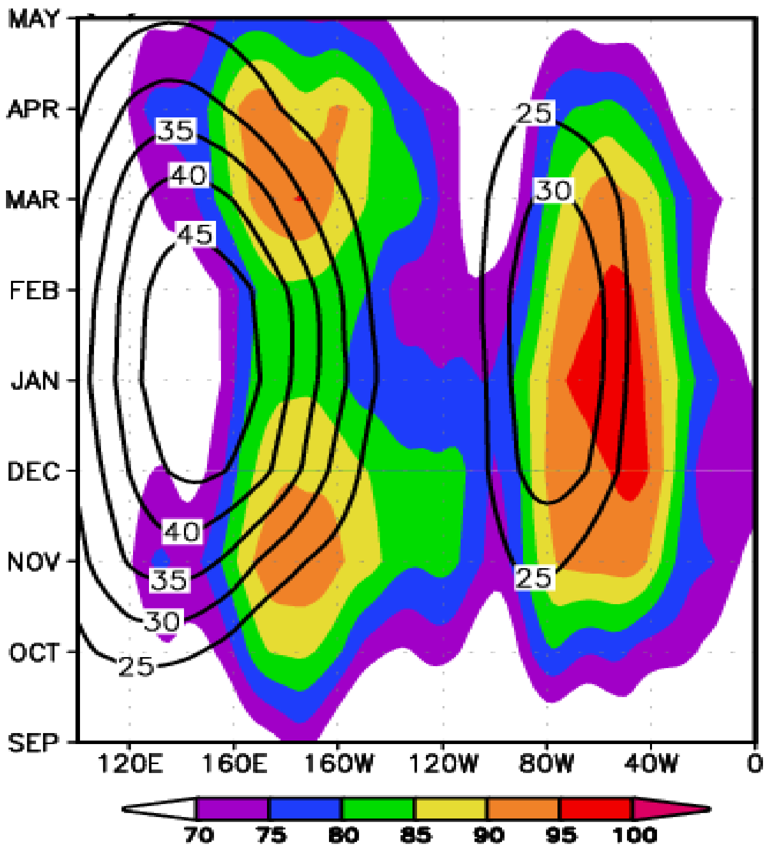
- Winter averaged root-mean-square (RMS) of the 2-7 day band-pass filtered 300hPa geopotential height

• **Contour : DJF U300**

Storm track & Jet



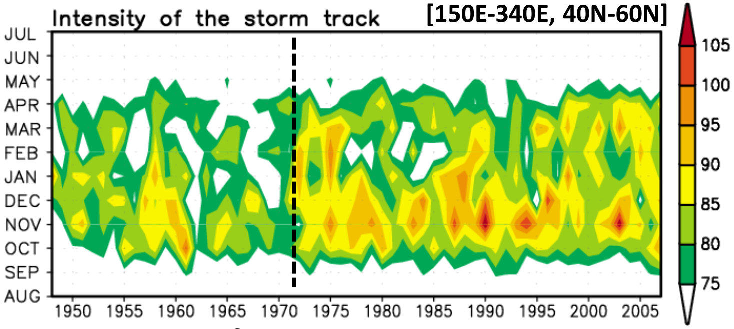
Part I:
[“Midwinter suppression in the PST” by Nakamura, 1992 (JAS)]



- **Storm tracks VS jets**
- **Baroclinic instability** in the storm track regions is largest during midwinter when the upper-tropospheric jets are strongest.
  Based upon linear theories, the storm track activity should be directly correlated with the level of baroclinicity.

Part II

- ***Interdecadal variability*** of the two storm tracks
  - Intensification of the storm tracks since the early 1970s [e.g. Chang and Fu, 2002 (*JC*); Nakamura *et al*., 2002 (*JC*); Harnik and Chang, 2003 (*JC*)]

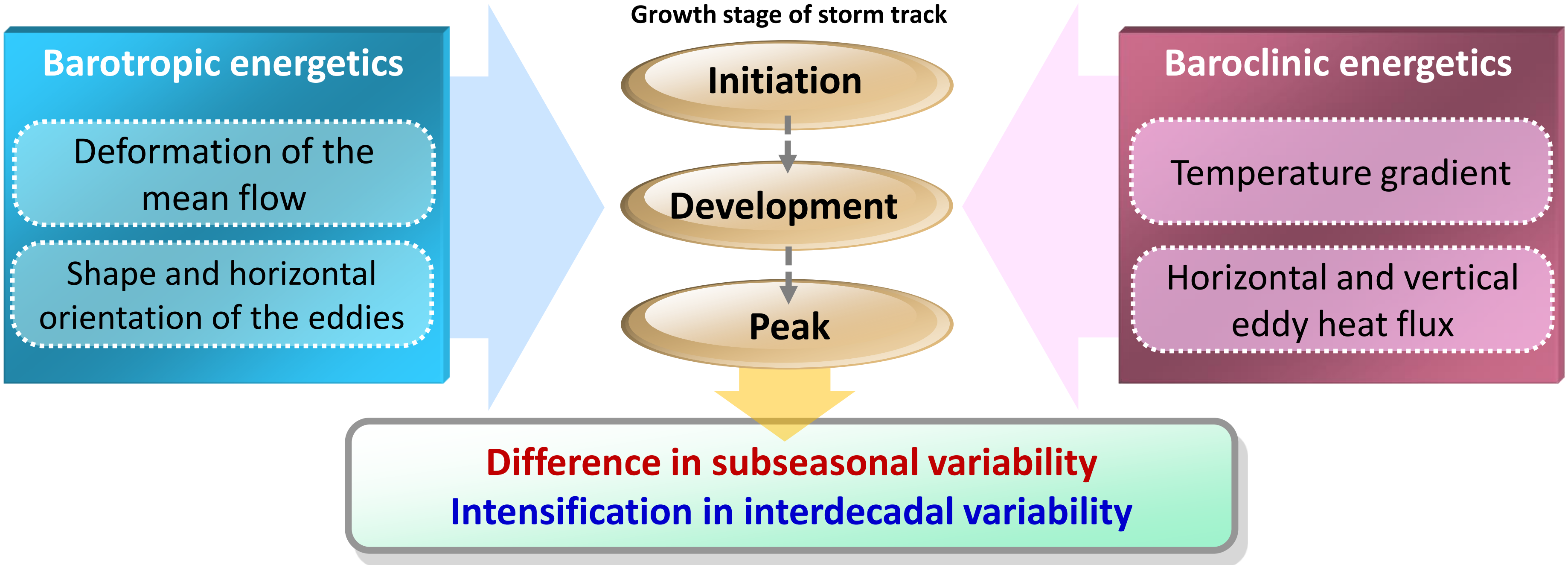


- **Interannual variability of the storm tracks**
  - Response to ENSO (Equatorward in El Niño years, poleward shift in La Niña years) [Eichler and Higgins, 2006 (*JC*)]
  - Relationship with teleconnection patterns (Intensification of AST in positive AO) [Nie *et al*., 2008 (*ASL*); Rivière and Orlanski, 2007 (*JAS*)]
  - Even if storm track variations linearly dependent on ENSO-like variability and the AO are removed, substantial interdecadal variations still remain [Chang and Fu, 2002 (*JC*)].

- The implications of the interdecadal shift of the storm tracks and the ***reason of this variability are questions***.

Essence

Q1 Why do the two storm tracks show different subseasonal variability?



- How the energetics contribute to each growth stage of the storm tracks?
- Which dynamical process and associated factors induce the subseasonal difference between two storm tracks?

Q2 What factors and dynamics can intensify the strength of storm tracks in the Northern Hemisphere?

Decomposition

- Decomposition of barotropic diagnostics
  - Barotropic dynamics depends on the ***deformation of the mean flow*** (D-vector) and ***horizontal structure of transient eddies*** (E-vector) [Black and Dole, 2000 (*JC*)].
  - Barotropic energy conversion (**BTEC**) can be expressed by the inner product of the D-vector and E-vector [Cai *et al*., 2007 (*Tellus*)].

$$BTEC = \frac{p_0}{g}\left\{\underbrace{\frac{1}{2}(\overline{v'^2} - \overline{u'^2})(\frac{\partial\bar{u}}{\partial x} - \frac{\partial\bar{v}}{\partial y})}_{\text{Related to the stretching deformation}} + \underbrace{(-\overline{u'v'})(\frac{\partial\bar{v}}{\partial x} + \frac{\partial\bar{u}}{\partial y})}_{\text{Related to the shearing deformation}}\right\}$$

Decomposition : Related to the stretching deformation; Related to the shearing deformation

- Decomposition of baroclinic diagnostics
  - Baroclinic energy conversions (**BCEC I**) between mean and eddy available potential energy can be inferred by examining interaction between ***horizontal eddy heat flux*** and ***temperature gradient*** [Dole and Black, 1990 (*MWR*); Cai *et al*., 2007 (*Tellus*)].

$$C_1 = (\frac{p_0}{p})^{C_V/C_P}\frac{R}{g} \qquad C_2 = C_1(\frac{p_0}{p})^{R/C_P}/(-\frac{d\Theta}{dp})$$

$$BCEC\ \text{I} = -C_2\left(\underbrace{\overline{u'T'}\frac{\partial\bar{T}}{\partial x}}_{\text{Zonal component}} + \underbrace{\overline{v'T'}\frac{\partial\bar{T}}{\partial y}}_{\text{Meridional component}}\right)$$

Decomposition : Zonal component; Meridional component

  - Energy conversion (**BCEC II**) between potential and kinetic energy of eddies can be expressed by ***upward eddy heat flux*** [(Dole and Black, 1990 (*MWR*); Cai *et al*., 2007 (*Tellus*)].

$$BCEC\ \text{II} = -C_1(\overline{\omega'T'})$$

Effects of efficiency and moisture inside baroclinic energetics

- **Efficiency of baroclinic energy conversion**
  - To exhibit the three-dimensional structure of the upward eddy heat flux associated with the storm tracks
  - The maps of regression coefficients for different levels show the structure and evolution of baroclinic wave [Lim and Wallace, 1991 (*JAS*); Chang, 1993 (*JAS*)].

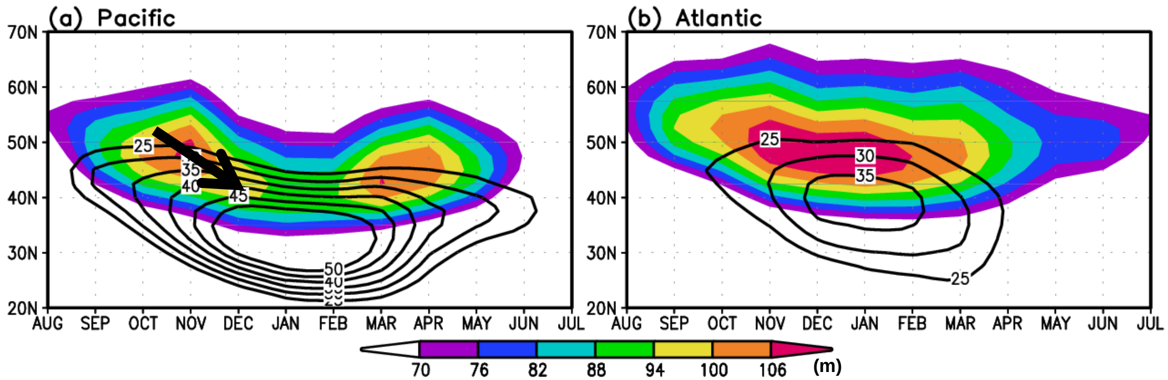
$$b(i) = \frac{1}{N}\sum_t y_t(i)x'_t$$

- **Moisture effect on the storm track development**
  - To compare the moisture effect on the different subseasonal variability of two storm tracks
  - The northeastward moving Kuroshio Current in the western North Pacific and Gulf Stream over the Atlantic can transport heat and moisture into the storm tracks.

$$MSE = C_pT + gz + Lq$$

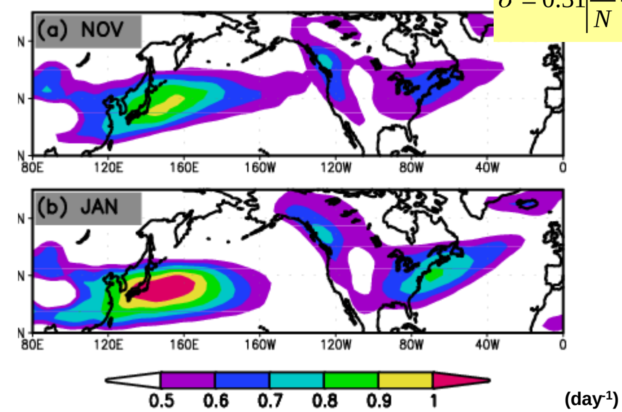
Latitudinal and longitudinal variation of the storm tracks

Lat-time

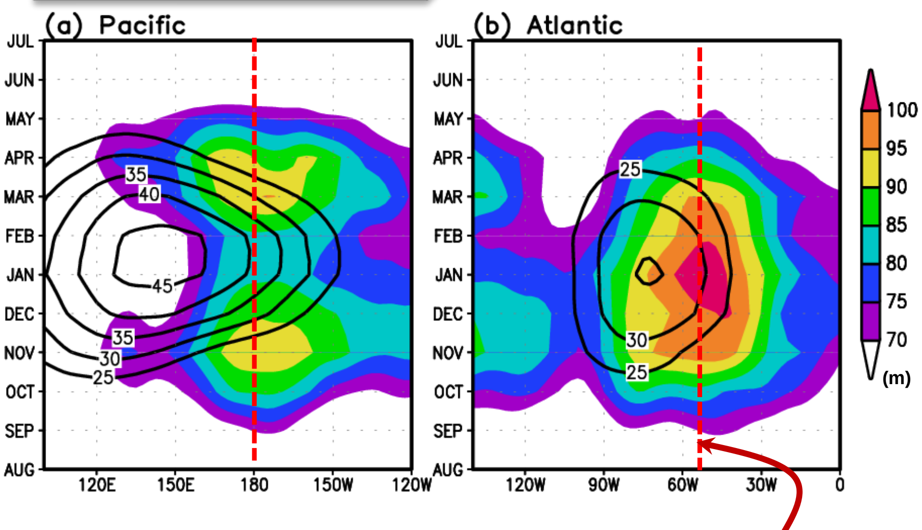


Baroclinicity (Eady growth rate)

$$\sigma = 0.31\left|\frac{f}{N}\frac{\partial U}{\partial z}\right|$$



Lon-time



Contour : U300
Shading : Storm track (300hPa)

Storm track axis (STAXS)

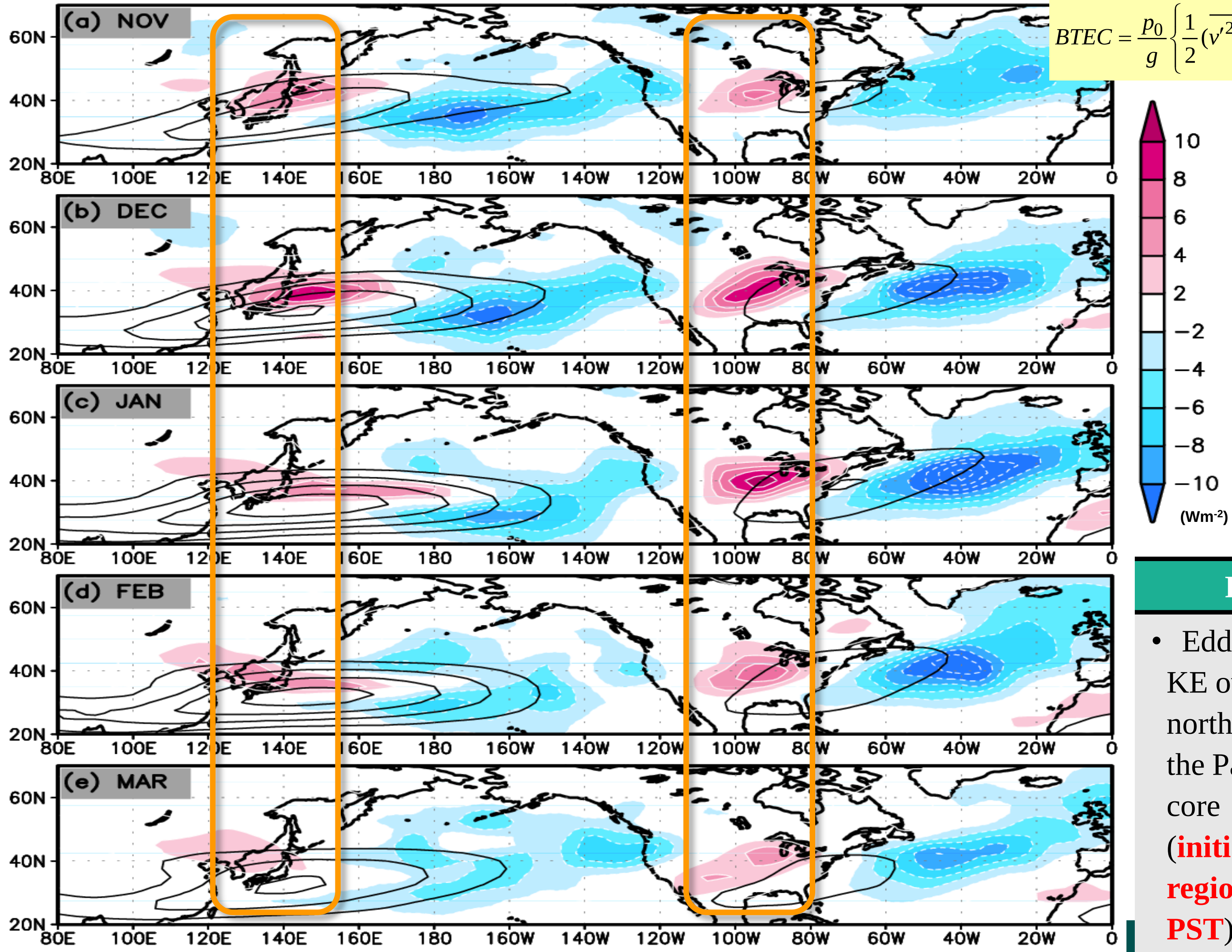
PST	AST
• The PST gets shifted southward and weakened. • Longitudinal location of maximum variability does not change.	• The AST tends to persist in locating around [50°N, 60°W] and get intensified.

		Pacific	Atlantic
Longitudinal mean	Storm track	160°-200°E	70°-30°W
	Jet stream	130°-170°E	90°-50°W
Latitudinal mean	Storm track	35°-55°N	37.5°-57.5°N
	Jet stream	20°-40°N	30°-50°N

Effects of interaction between the mean flow and transient eddies: Barotropic energy conversion

300hPa

$$BTEC = \frac{p_0}{g}\left\{\frac{1}{2}(\overline{v'^2}-\overline{u'^2})(\frac{\partial \bar{u}}{\partial x}-\frac{\partial \bar{v}}{\partial y})+(-\overline{u'v'})(\frac{\partial \bar{v}}{\partial x}+\frac{\partial \bar{u}}{\partial y})\right\}$$



U300 (30,40,50,60ms^{-1})

PST	AST
• Eddies obtain KE over the north side of the Pacific jet core (**initiation region of PST**).	• Eddies gain KE at the Atlantic jet entrance region (**initiation region of AST**).

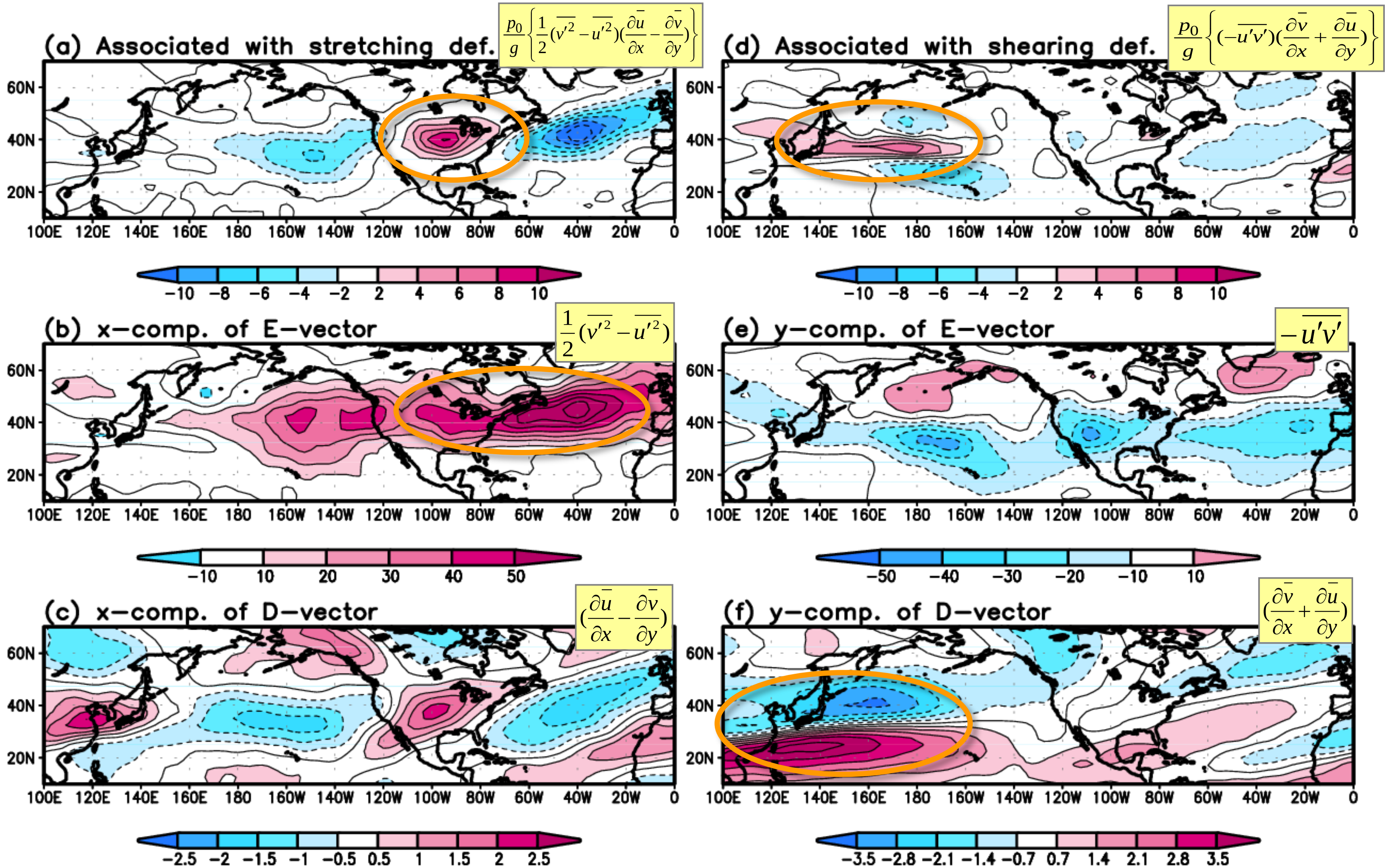
Effects of deformation of the mean flow and horizontal structure of eddies

- ***Which factors are more important to determine the initiation of the storm tracks?***

→ **In order to separate the roles of deformation of the mean flow and horizontal structure of eddies on barotropic energetics**

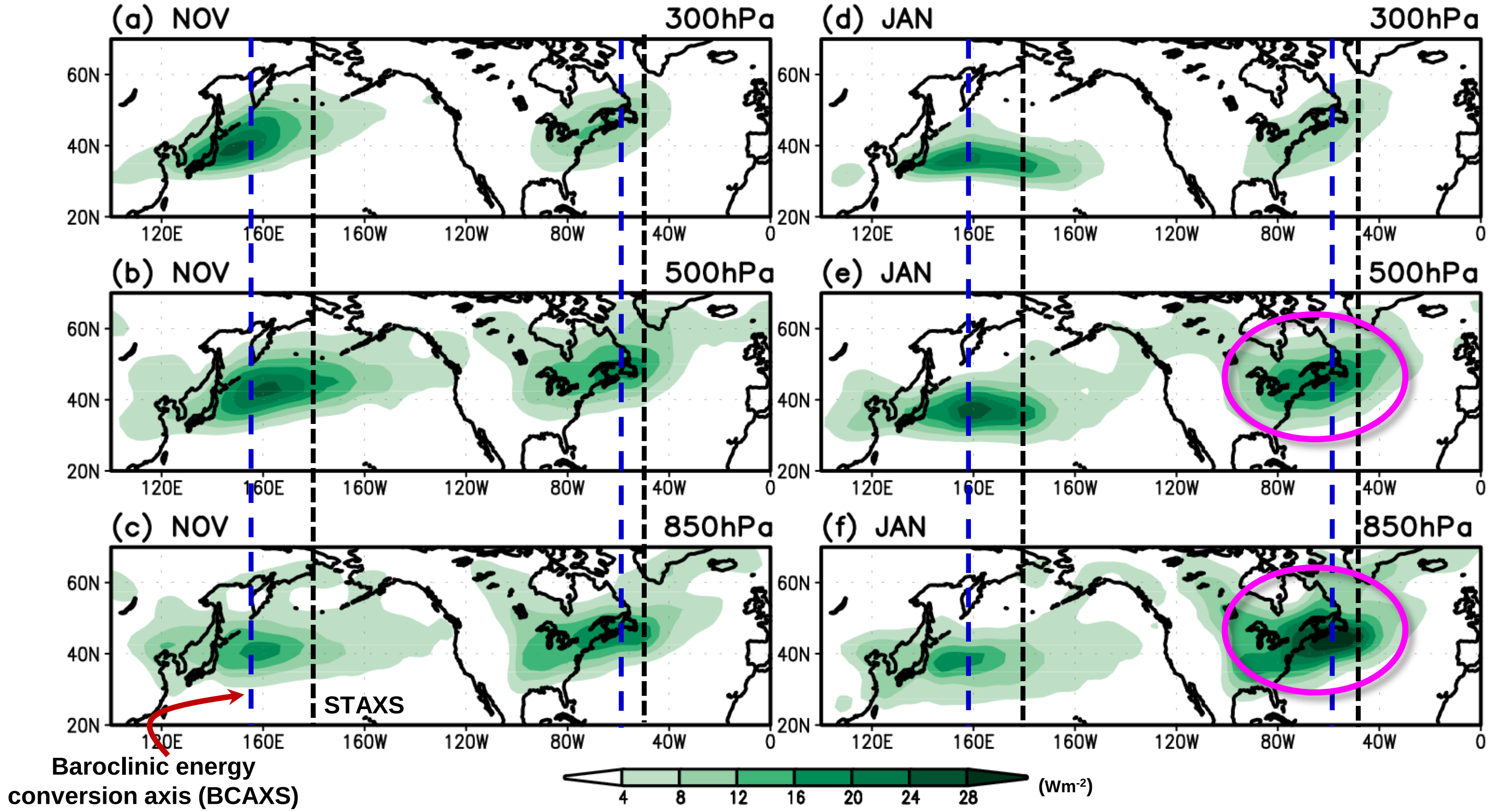
► **Decomposition of barotropic energy conversion**

Effects of deformation of the mean flow and horizontal structure of eddies



Effects of horizontal eddy heat flux and thermal gradient: Baroclinic energy conversion I

$$BCEC\,\mathrm{I} = -C_2\left(\overline{u'T'}\frac{\partial \overline{T}}{\partial x} + \overline{v'T'}\frac{\partial \overline{T}}{\partial y}\right)$$



<table>
<tr><th>PST</th><th>AST</th></tr>
<tr><td colspan="2">• The maximum potential of energy conversion rate occurs at upstream of the two storm track cores, implying that this energy conversion plays a role as an energy source of the developing storm tracks.</td></tr>
<tr><td>• The distance between the cores of storm track and energy conversion is much larger.</td><td>• Potential energy conversion rate increases during midwinter, particularly at the mid and low-levels.</td></tr>
</table>

Contribution of horizontal eddy heat flux and thermal gradient to baroclinic energy conversion I

- ***Which factors induce the increase in baroclinic energy conversion and enhancement of the AST in midwinter?***

→ **In order to separate the effects of horizontal eddy heat flux and thermal gradient in zonal and meridional direction on baroclinic energetics**

► **Decomposition of baroclinic energy conversion**

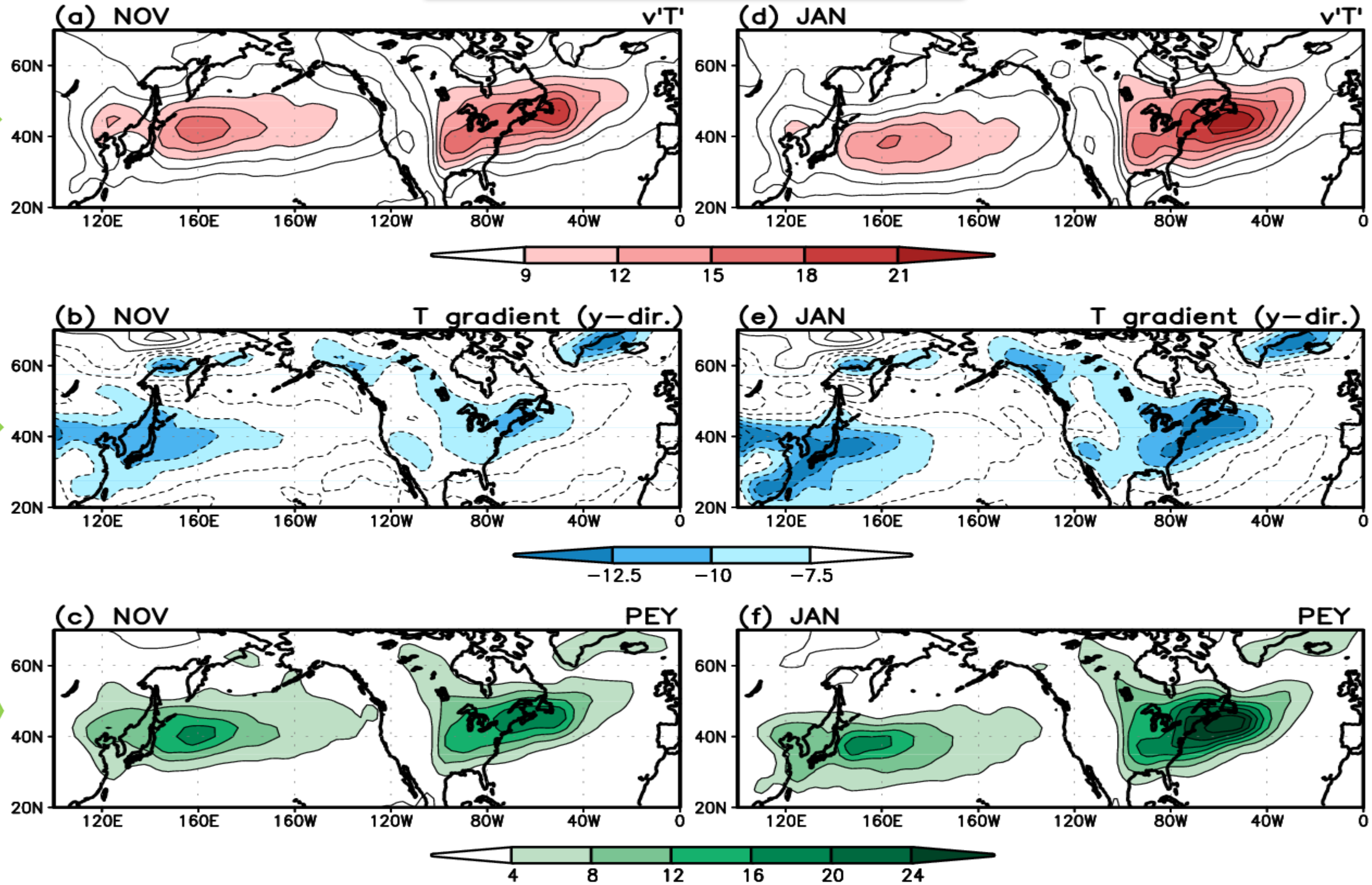
Contribution of horizontal eddy heat flux and thermal gradient to baroclinic energy conversion I

Meridional component

$\overline{vT'}$

$\frac{\partial \overline{T}}{\partial y}$

$-C_2\left(\overline{v'T'}\frac{\partial \overline{T}}{\partial y}\right)$

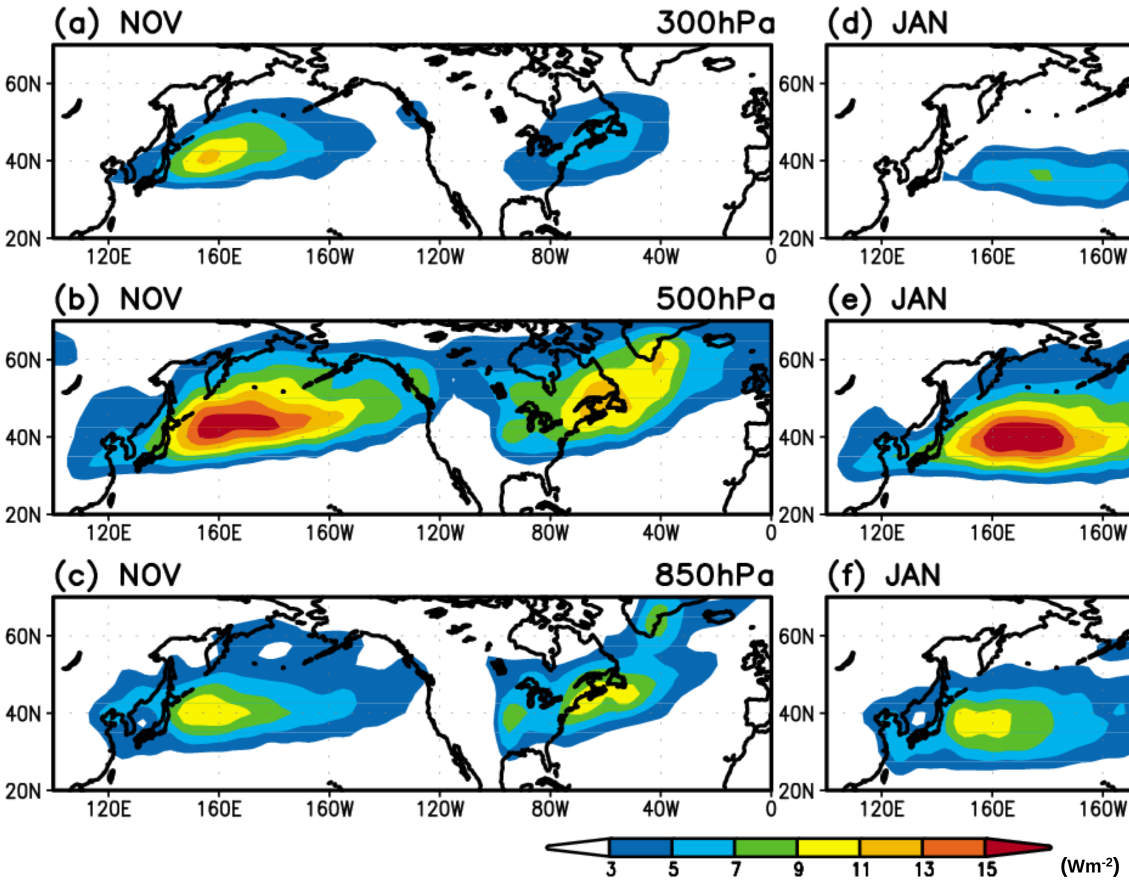


PST	AST
• Discrepancy of core regions for meridional eddy heat flux and meridional thermal gradient	• Coincidence of core regions for meridional eddy heat flux and for meridional temperature gradient

Effects of upward eddy heat flux

: Baroclinic energy conversion II

$$BCEC\ \mathbf{II} = -C_1(\overline{\omega' T'})$$



PST	AST
• The maximum energy conversion rate occurs at **upstream of the two storm track cores** (**energy source of the developing storm tracks**).	
• Remarkable decrease of energy conversion is seen in the Pacific at 300hPa.	• **Increases at 500hPa and 850hPa** may be related to the **intensifying of AST during midwinter**.

Efficiency of baroclinic energy conversion II

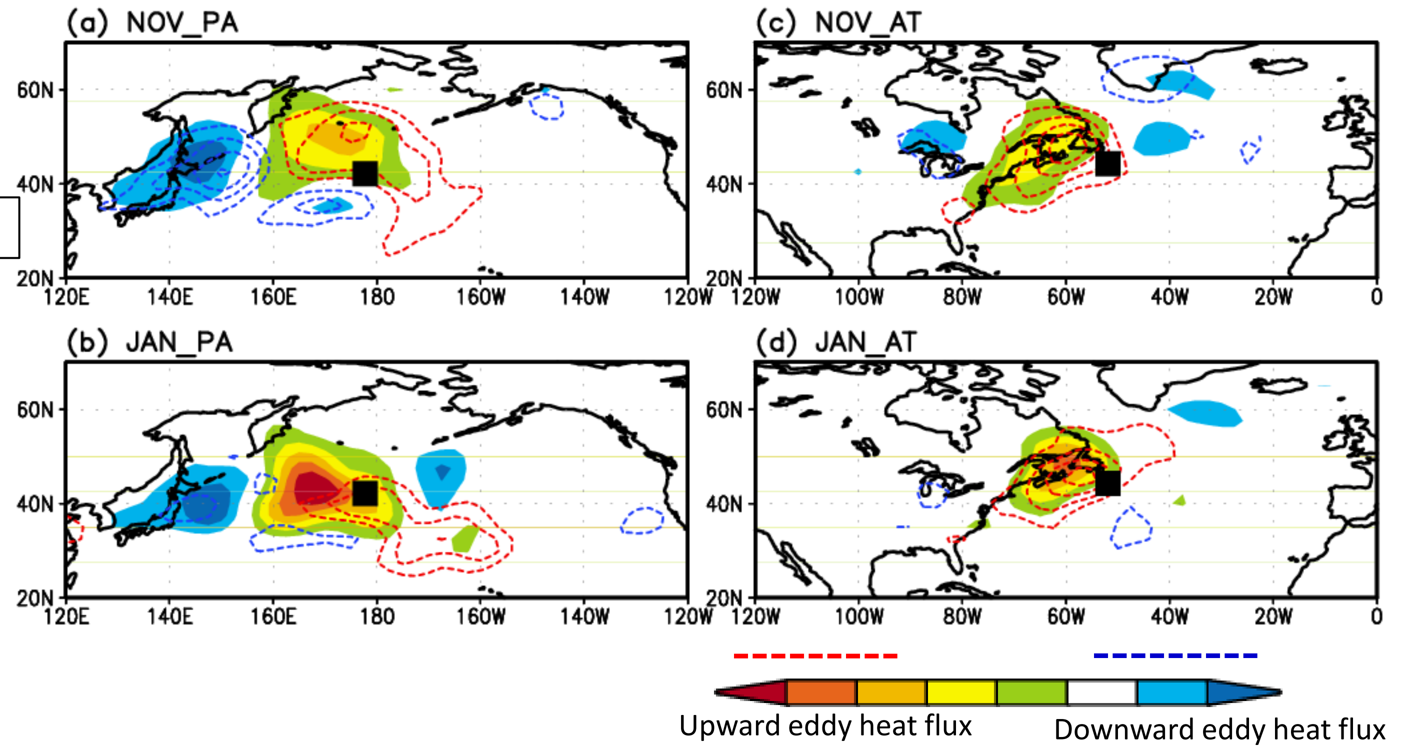
: Base point - Maximum region of the storm track activity

$$b(i) = \frac{1}{N}\sum_t y_t(i)x'_t$$

500hPa ω´T´
300hPa ω´T´

300hPa h´

Dashed : 300hPa ω´T´
Shading : 500hPa ω´T´

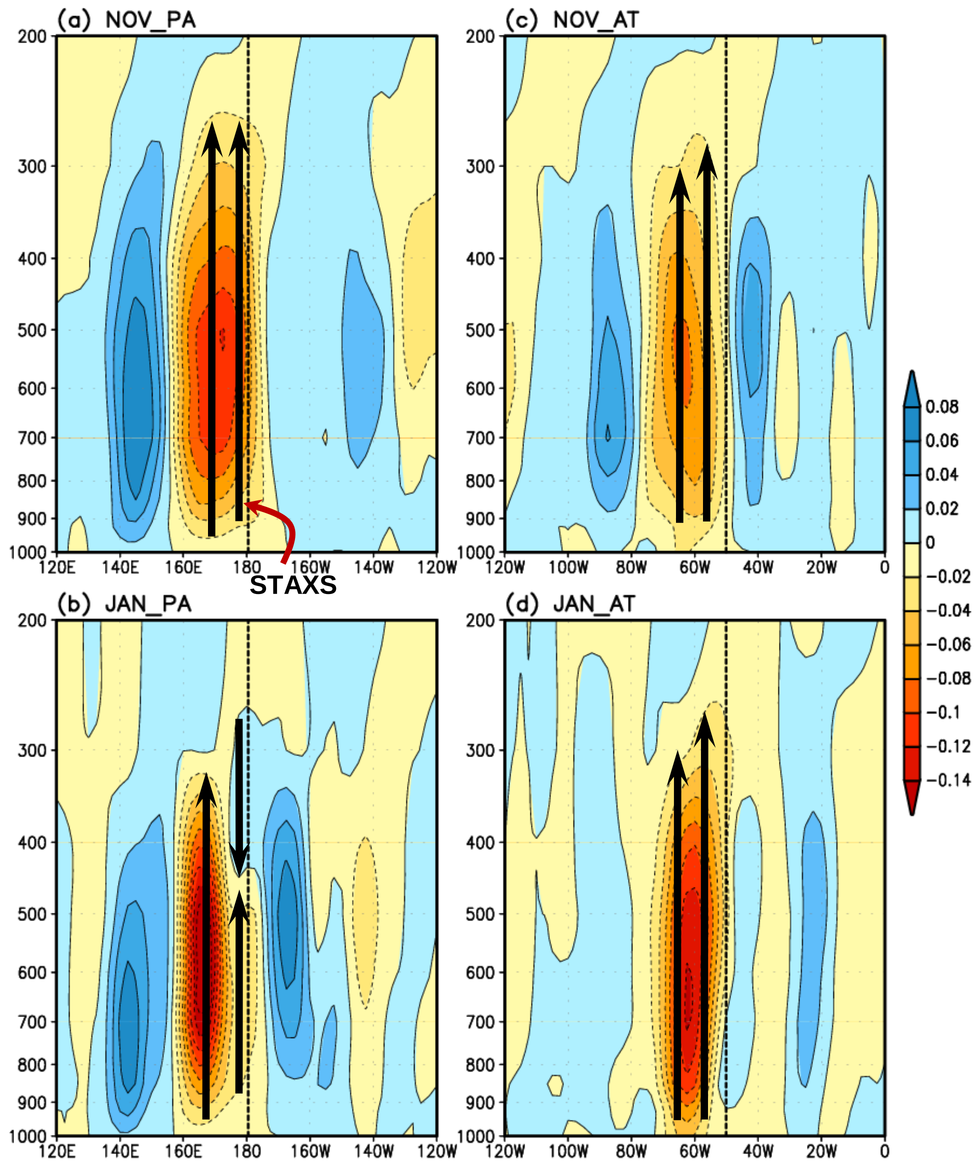


PST	AST
• BP : 175ºE-180, 40º-45ºN	• BP : 55º-50ºW, 42.5º-47.5ºN
• In January, upward eddy heat flux region at 300hPa shifted in downstream of 500hPa upward eddy heat flux maximum region or over the descending motion region (**Less efficient energy conversion in midwinter**).	• Upward eddy heat flux maximum region at 500hPa corresponds to that at 300hPa in both November and January (**More efficient energy conversion**).

Efficiency of baroclinic energy conversion II

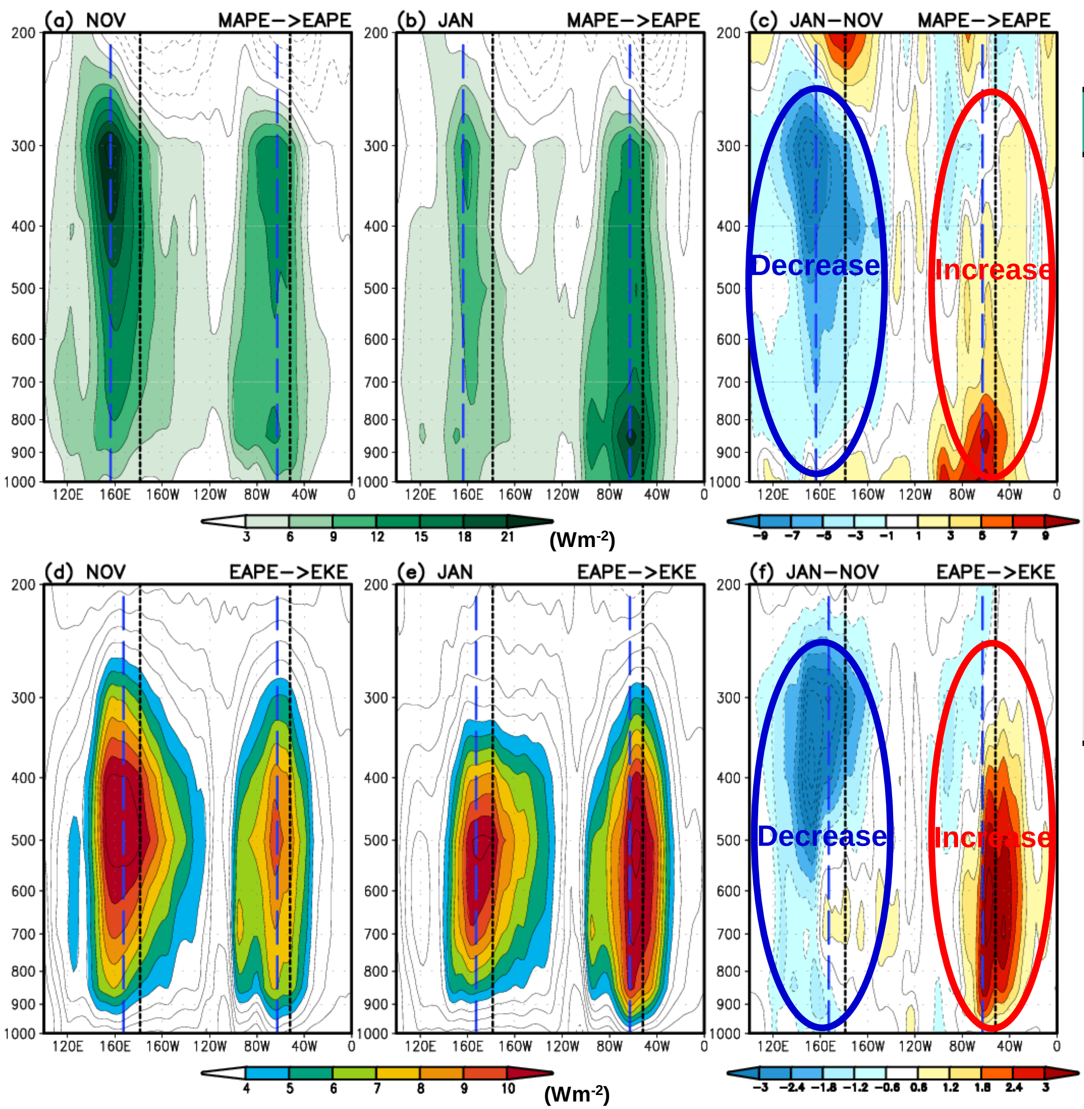
: Vertical structure of upward eddy heat flux

PST	AST
• BP : 175ºE, 42.5ºN	• BP : 55ºW, 45ºN
• **In January, upward eddy heat flux is invaded by downward eddy heat flux** along axis of the maximum storm track activity.	• The vertical characteristics of upward eddy heat flux in November are similar to January and **upward eddy heat flux increases at the upstream of the AST** in January compared to November.



Difference between January and November

: Vertical structure of baroclinic energy conversion



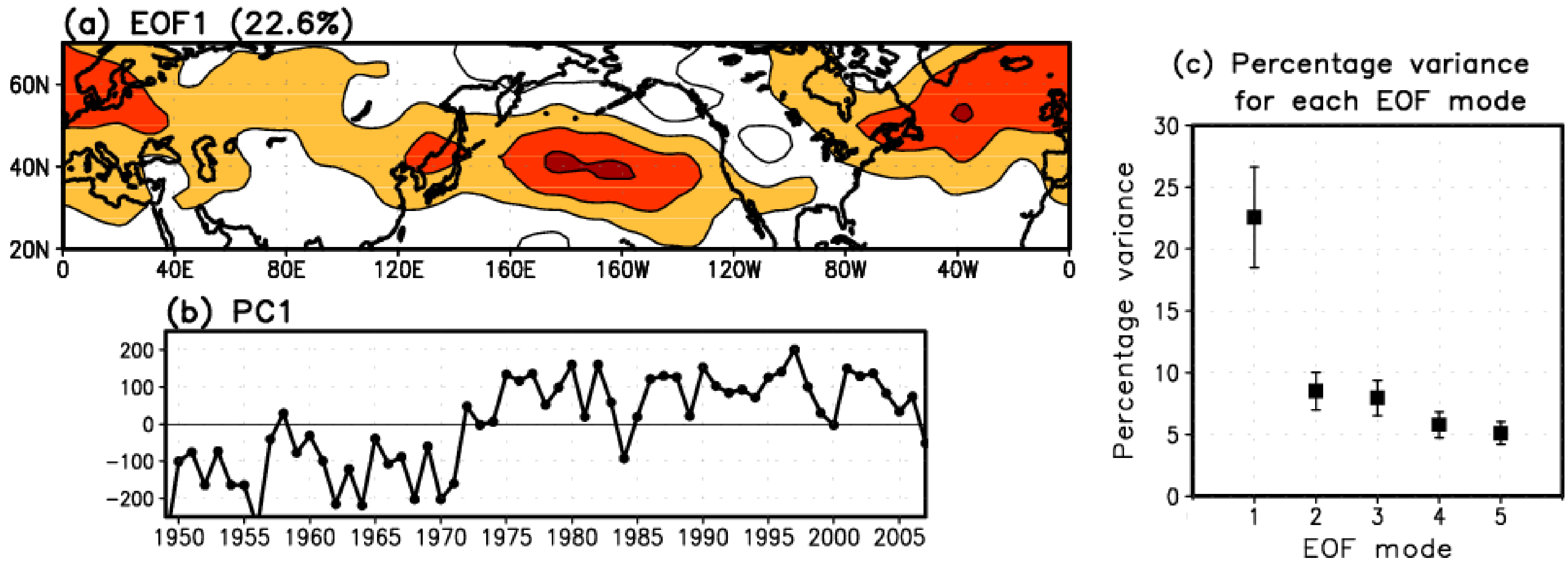
PST	AST
• Potential energy conversion shows the **maximum at the upper level**. • Baroclinic energy conversion **decreases**, particularly at **upstream of the PST**, implying **weak energy source for developing baroclinic wave**.	• Potential energy conversion is **large at the low-level**. • Baroclinic energy conversion **increases along the core of AST as well as in its upstream**.

Energetics
37.5°-57.5°N

Summary I: Subseasonal variability

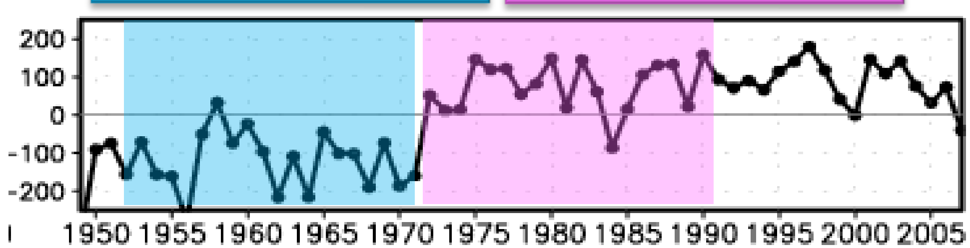
	PST	AST
• <u>Barotropic energetics</u> "***Initiation of the storm track***"	• ***North edge of the jet cores*** • Round shaped eddies • ***Shearing deformation effect*** > Stretching deformation effect	• ***Jet entrance*** • Meridionally elongated eddies • Shearing deformation effect < ***Stretching deformation effect***
• <u>Baroclinic energetics</u> "***Different subseasonal variability of storm track***"	• ***Upstream of storm track → Energy source for development of the storm track***	
	• ***<u>Discrepancy of core regions</u> for meridional eddy heat flux and thermal gradient*** • ***<u>low efficiency</u> in baroclinic energy conversion in midwinter***	• ***<u>Coincidence of core regions</u> for meridional eddy heat flux and for temperature gradient*** • ***<u>high efficiency</u> in baroclinic energy conversion in midwinter***
• <u>Moisture effect</u> "***Extra source of development of storm tacks***"	• ***Small moist static energy*** along baroclinic energy conversion axis • Great ***decrease of moist static energy*** in midwinter	• Relatively large moist static energy in midwinter • Latent heat release in the AST region in midwinter

Principal mode of interannual variability for the storm tracks*: EOF analysis (NCEP-NCAR Reanalysis I)*



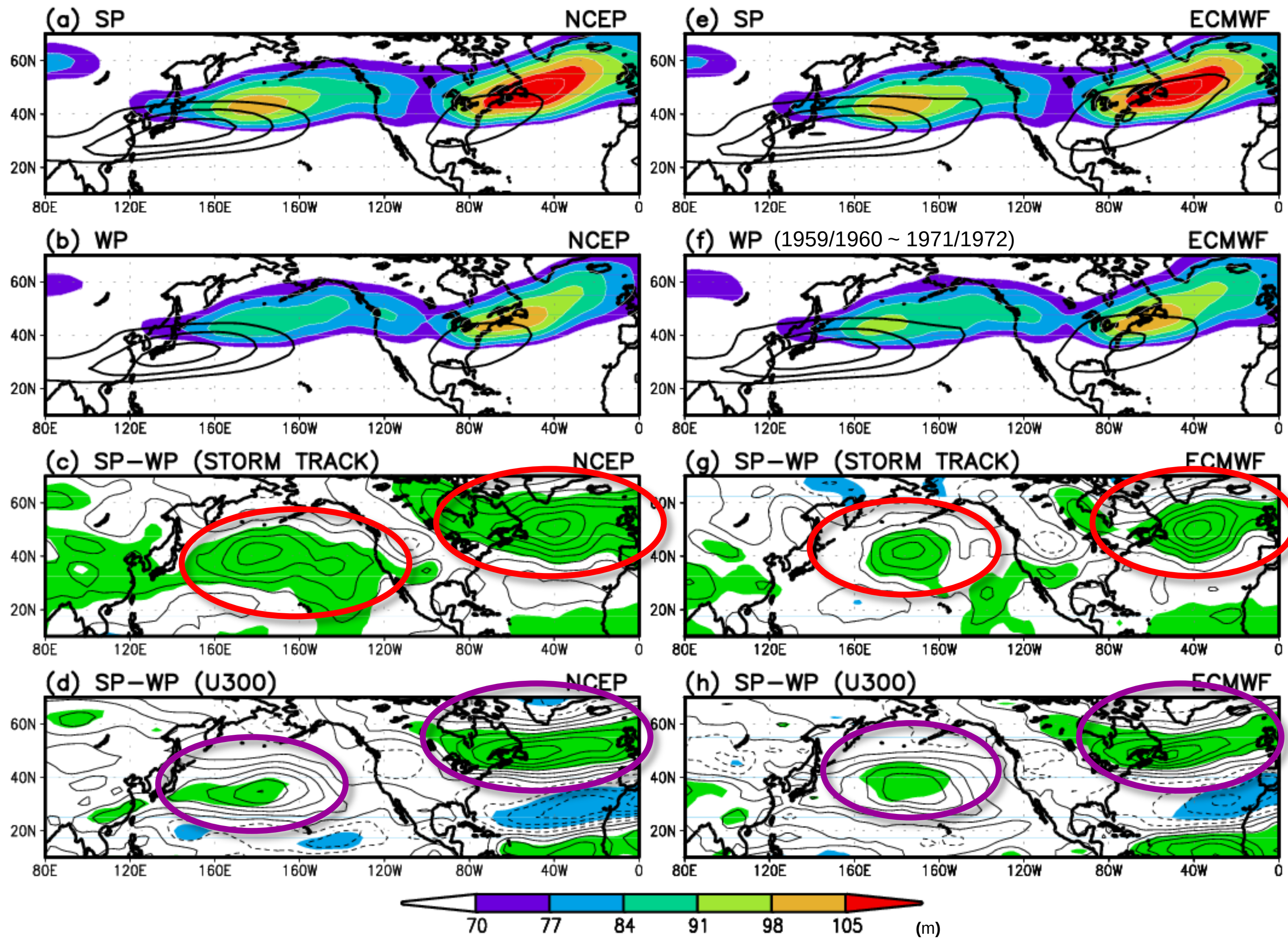
Weak period (WP, 1952-1971)

Strong period (SP, 1972-1991)



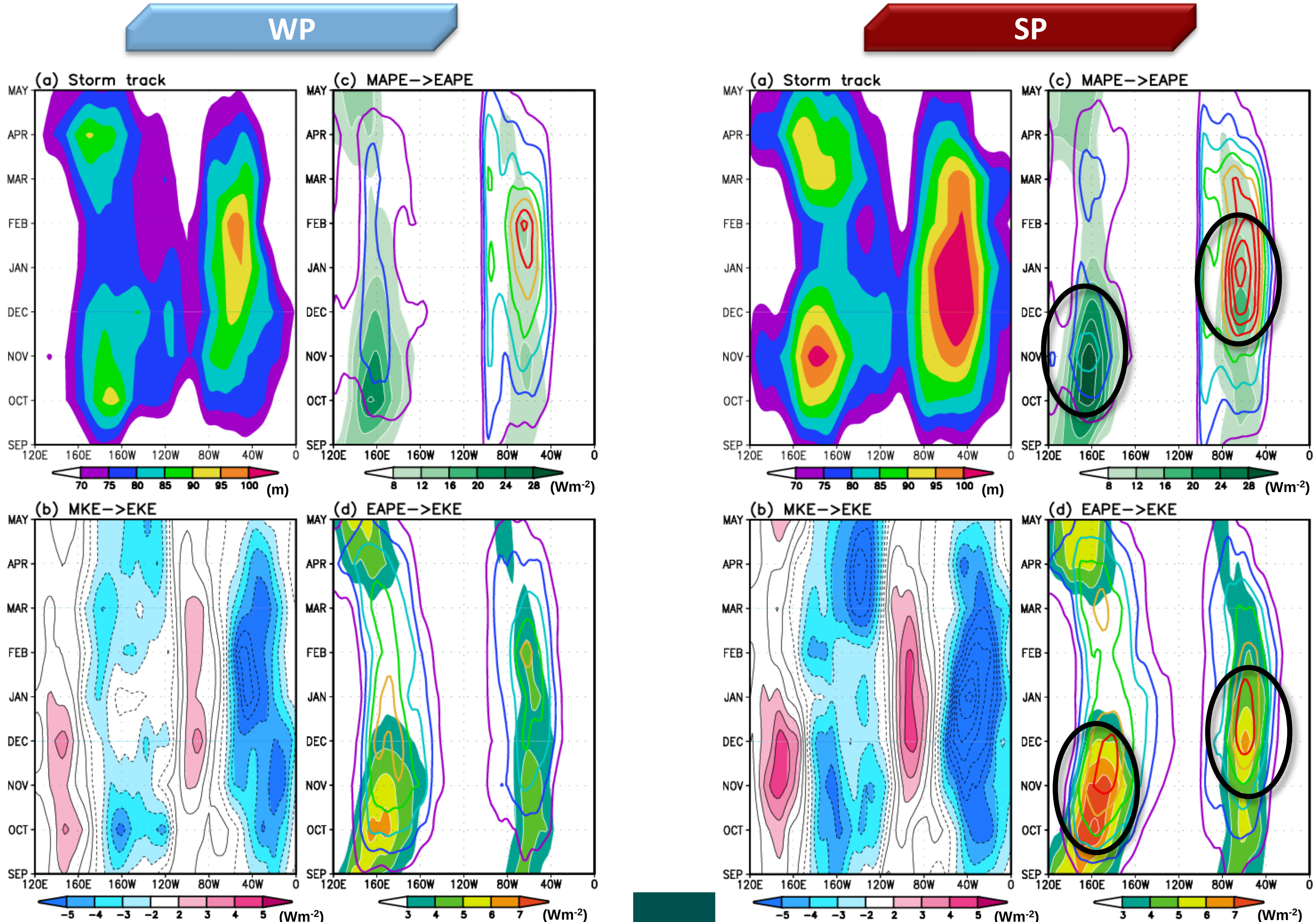
Change in the storm track intensity (NDJFM)

: Comparison between SP and WP (300hPa)



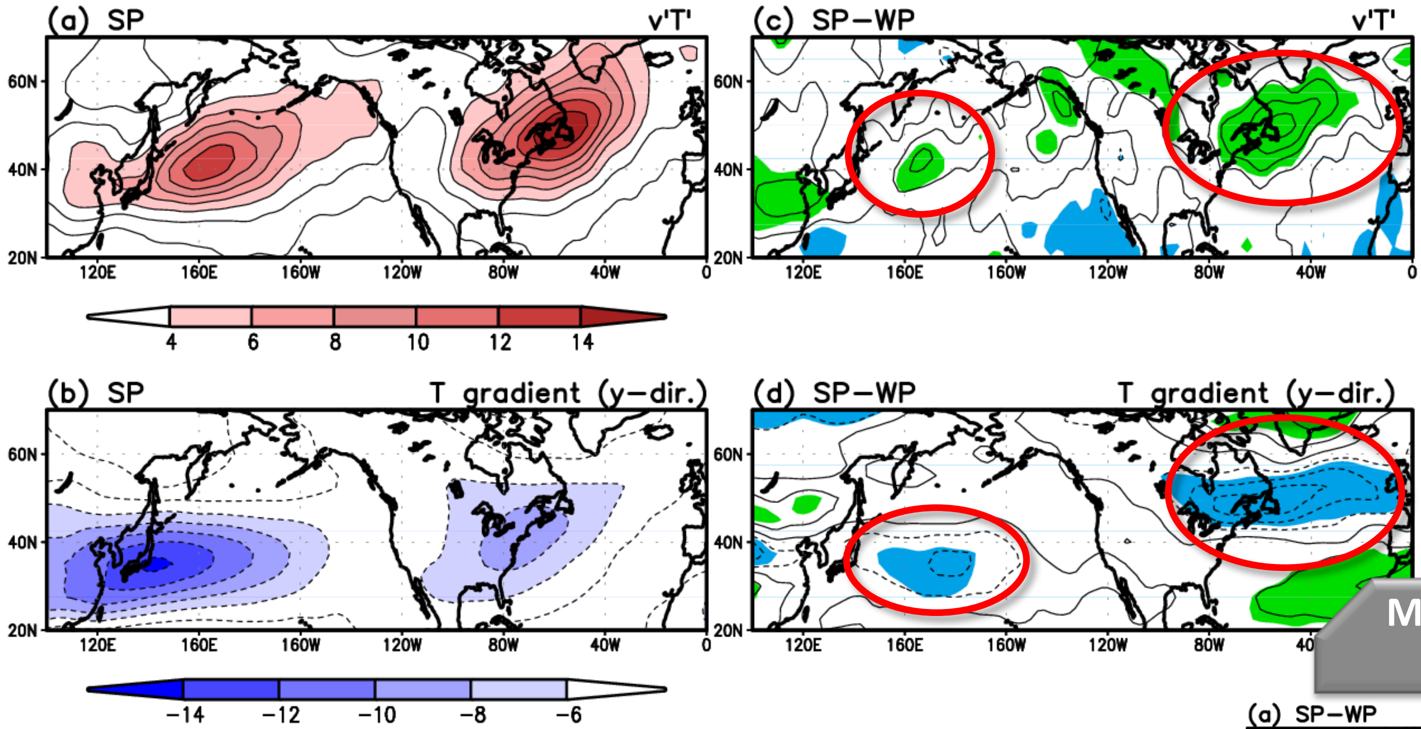
- In the Pacific and Atlantic, **both the storm tracks and jet significantly increased from WP to SP**.

Subseasonal variability of the storm tracks and their associated energetics

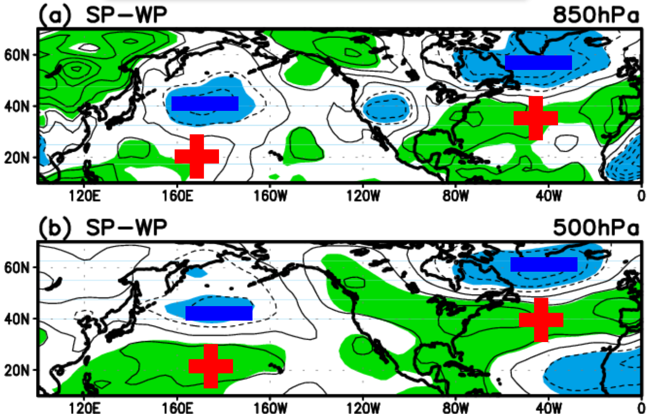


Change in horizontal eddy heat flux and thermal gradient: Decomposition (NDJFM)

Meridional component (500hPa)



Mean temperature difference



- Both **meridional eddy heat flux and meridional temperature gradient** are closely related to the increase of baroclinic energy conversion and **strengthening trend of the storm tracks**.

- The **coincidence of change region for eddy heat flux and temperature gradient in meridional direction in SP** can amplify the baroclinic energy conversion and storm track intensity.

Summary II: Interdecadal variability

	PST & AST
• <u>*Barotropic energetics*</u> "***Initiation of the storm track***"	• Insignificant change of initiation region
• <u>*Baroclinic energetics*</u> "***Intensification of the storm tracks***"	• ***Significant increase of meridonal temperature gradient and poleward eddy heat flux*** over the storm track regions
• <u>*Moisture effect*</u> "***Extra source of development of storm tacks***"	• ***Increase of latent heat flux*** in the storm track regions

conclusions

Source of Initiation

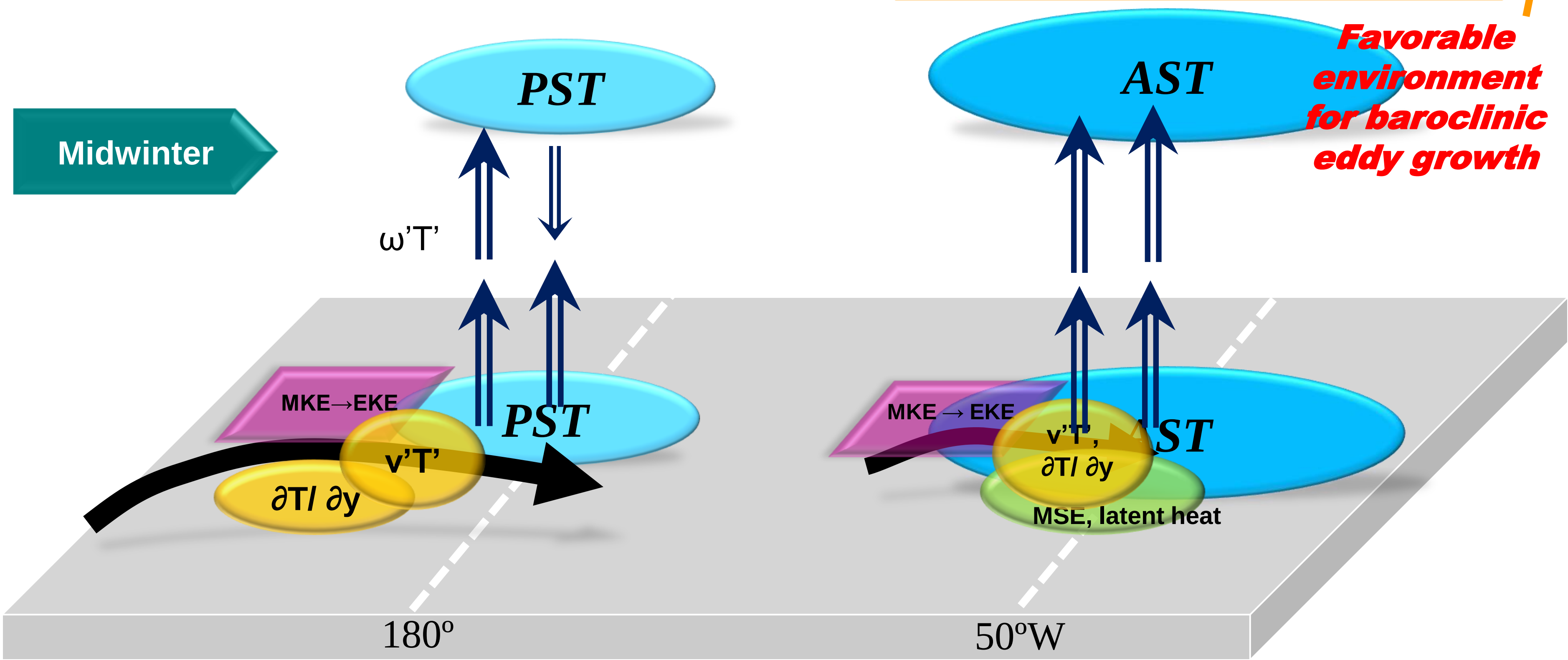
Source of Enhancement or Suppression

Barotropic energy conversion (Shearing deformation)

Discrepancy **of core region for poleward eddy heat flux, meridional temperature gradient, and upward eddy heat flux**

Barotropic energy conversion (Stretching deformation)

Coincidence **of core region for poleward eddy heat flux, meridional thermal gradient and upward eddy heat flux + Moisture effect**



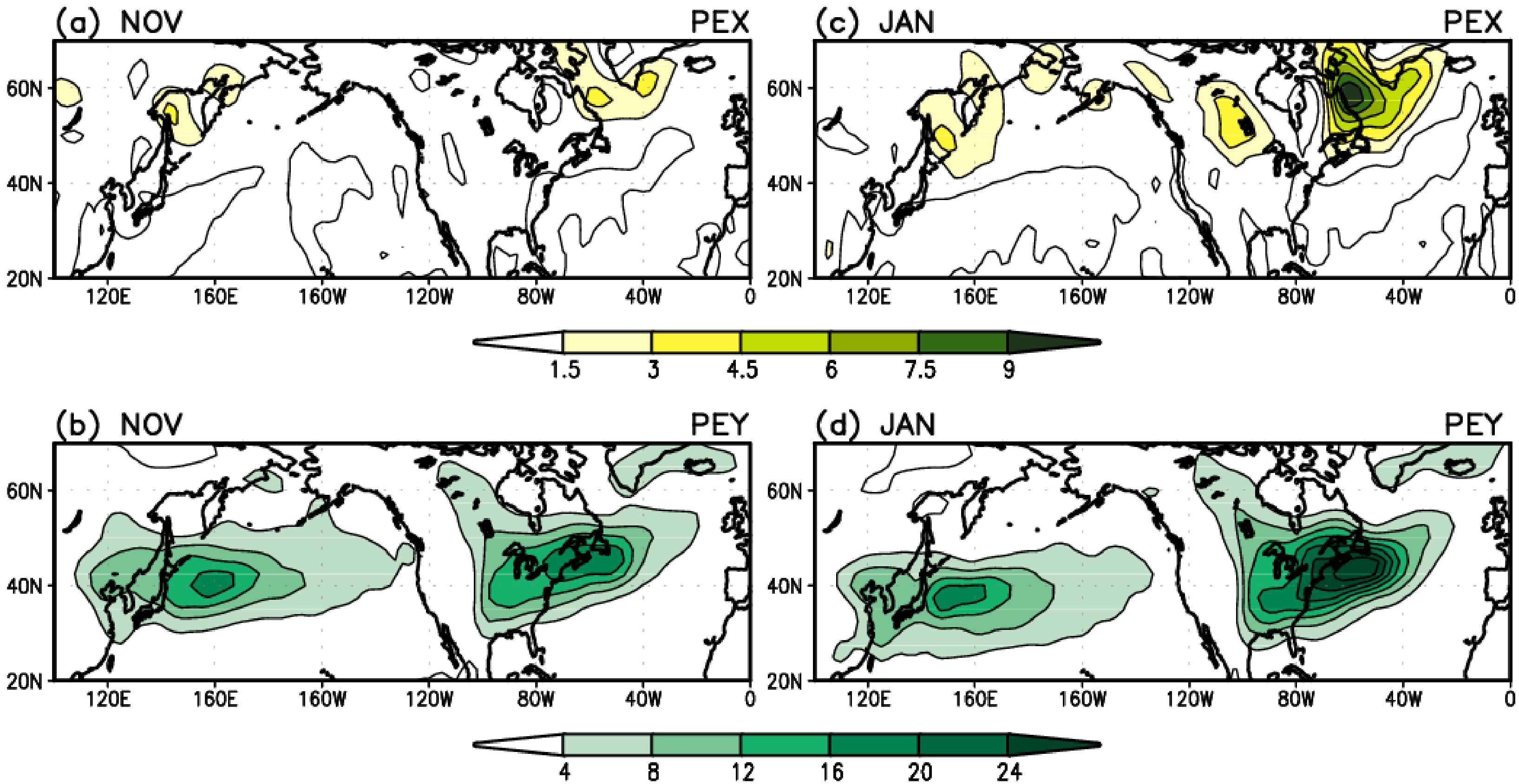
THANK YOU!

- **Possible causes for the midwinter suppression on PST**
  - Speed of westerly jets (Positive correlation with the westerly jet speed only to ~45ms^{-1}) [Nakamura, 1992 (*JAS*); Nakamura and Sampe, 2002 (*GRL*)]
  - Polar front jet over the Atlantic and strong subtropical jet over the Pacific [Lee and Kim, 2003 (*JAS*)]
  - Upstream seeding (Strong eddy damping over an upstream) [Zurita-Gotor and Chang, 2005 (*JAS*); Robinson and Black, 2006 (*MWR*)]
  - Enhanced barotropic damping in the Pacific [Deng and Mak, 2006 (*JAS*)]
  - Diabatic effects [Chang, 2001 (*JAS*)]

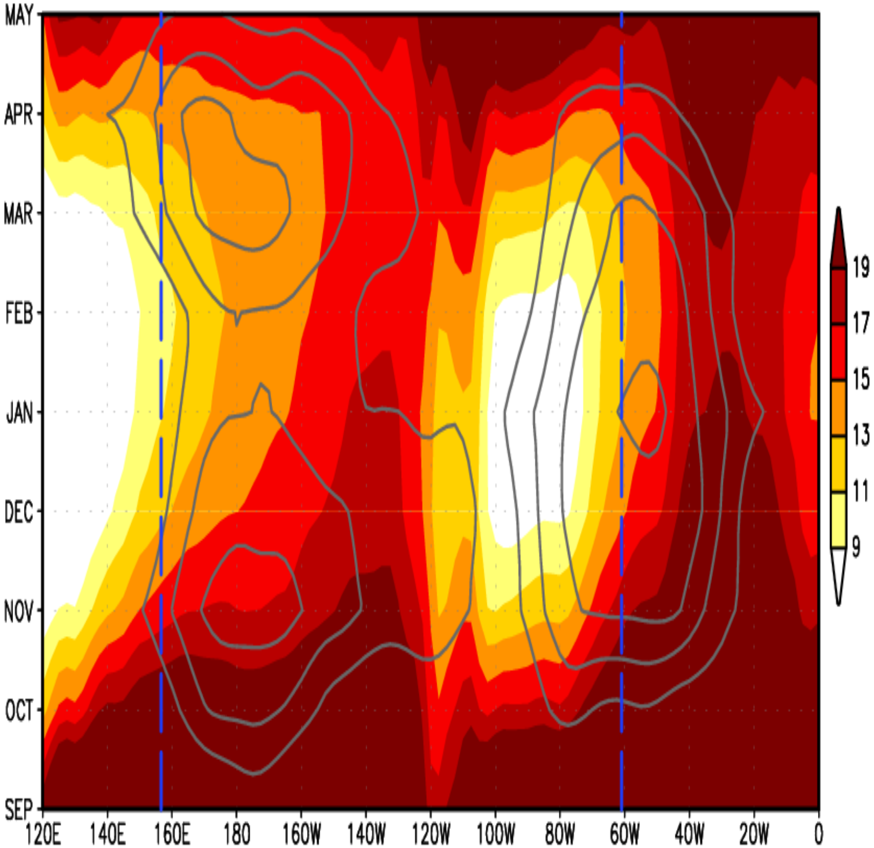
Contribution of horizontal eddy heat flux and thermal gradient to baroclinic energy conversion I

$-C_2\left(\overline{u'T'}\frac{\partial\overline{T}}{\partial x}\right)$

$-C_2\left(\overline{v'T'}\frac{\partial\overline{T}}{\partial y}\right)$



Moisture effects: MSE-DSE



Vertical structure of moist static energy & meridional eddy moisture flux