



第五章:

大气环流中的纬向环流系统

5.1 Storm Tracks

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Outline



- Observed features
 - from two basic approaches
 - seasonal variation
 - inter-annual, decadal variations
- Storm track dynamics
 - Baroclinic eddy life cycle
 - Transient eddy energy budget
- Summary and discussion



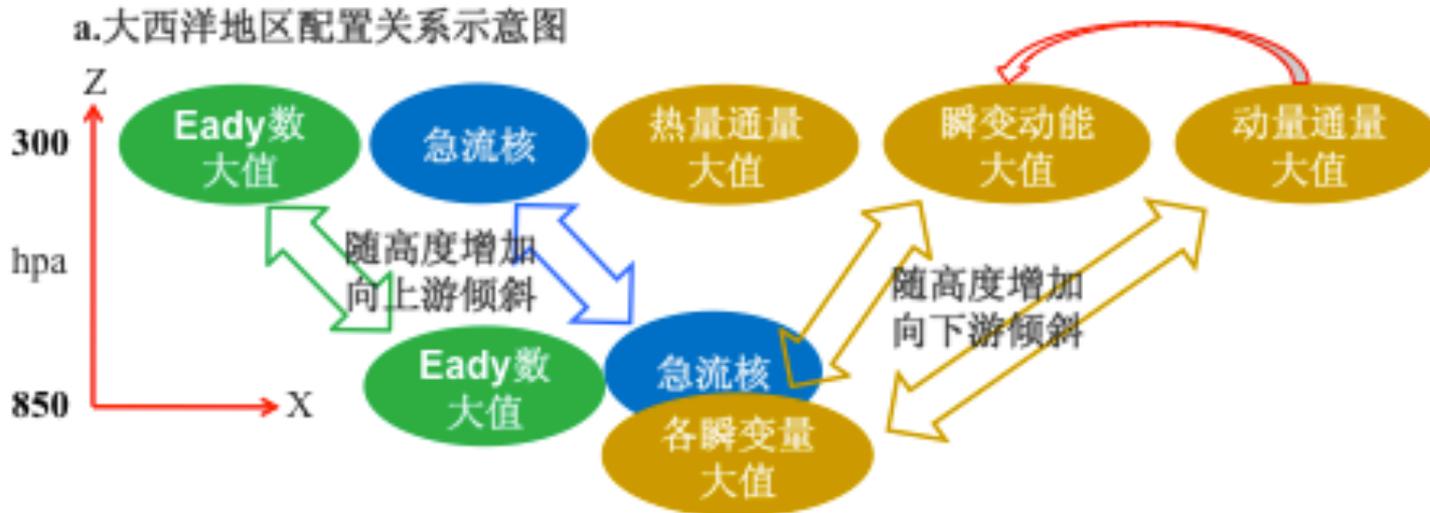
Observed features



- Two basic approaches to diagnosing storm tracks:
 - The traditional one: **track the position** of individual weather systems, produce statistics for their distributions, e.g. track densities, storm life span...
 - The **bandpass filtering** approach (in synoptic time scales): estimate the statistics **at a set grid points** in analyzed fields, which can provide a 3-d picture of storm tracks.



Observed features



b. 太平洋地区

- (1) 交换上图中300hpa瞬变动能大值和动量通量大值位置;
- (2) 水平方向两两之间距离增大。



Observed features

- Seasonal variation

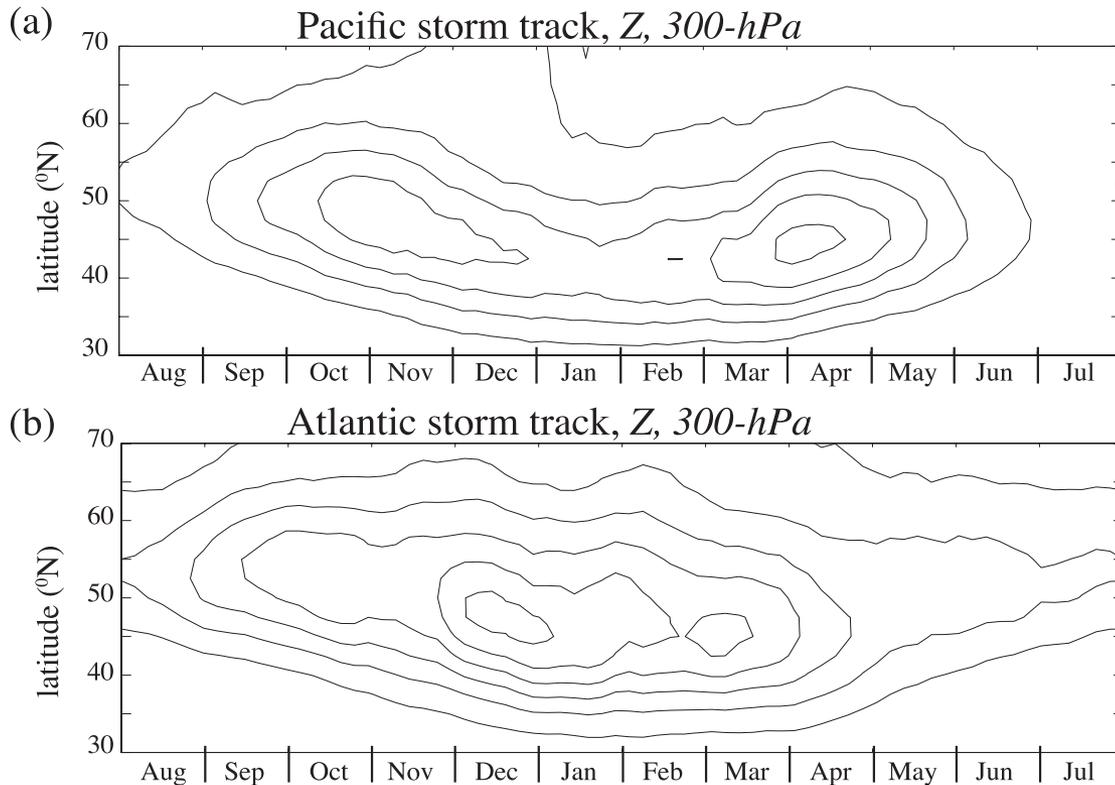


FIG. 1. Midwinter suppression of the Pacific storm track, shown as the variance in geopotential height at 300 hPa: (a) Pacific domain (20°–70°N, 140°E–180°) and (b) Atlantic domain (20°–70°N, 30°–70°W). The contour interval is 1500 m² starting at 2000 m². This is an update of Fig. 2 in Nakamura (1992) for the ERA-40 dataset between 1958 and 2001. The data are 2–6 day bandpass filtered using a fourth-order Butterworth filter to obtain daily climatologies. Results are smoothed with a 31-day running mean filter and plotted every five days. Large tick marks on the abscissa correspond to the first day of each month.

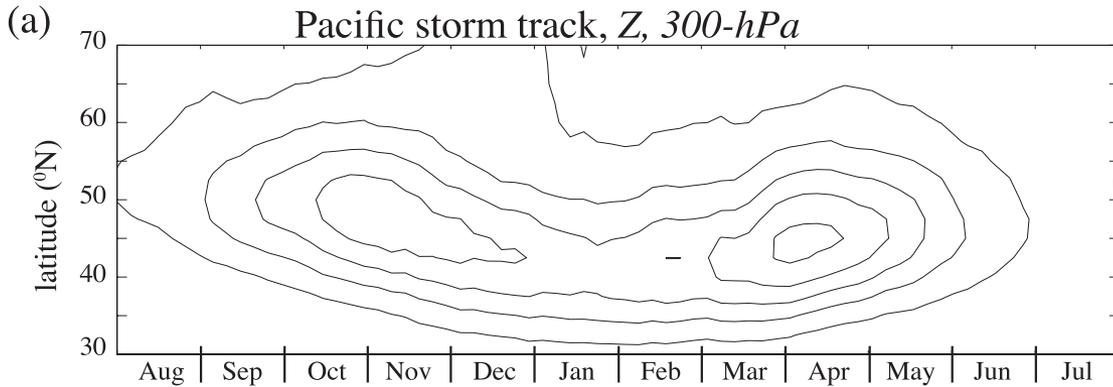
Most intense in the transition seasons, MAM and SON, weaker in DJF (**mid-winter minimum**), whose variation is not consistent with the mean flow baroclinicity.

Strongest in DJF and least pronounced in JJA, with the actual position varies little



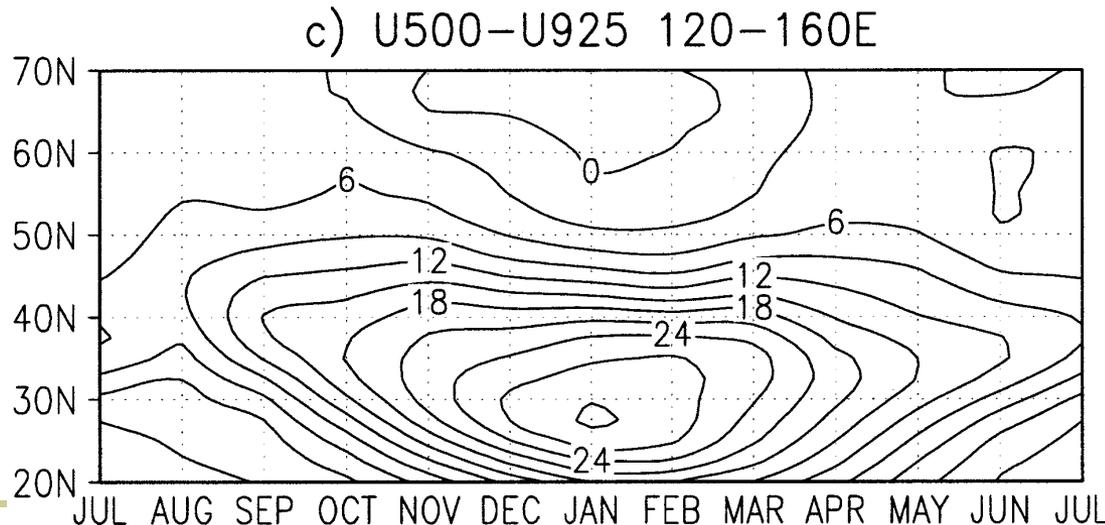
Observed features

- Seasonal variation



Most intense in the transition seasons, MAM and SON, weaker in DJF (**mid-winter minimum**), whose variation is not consistent with the mean flow baroclinicity.

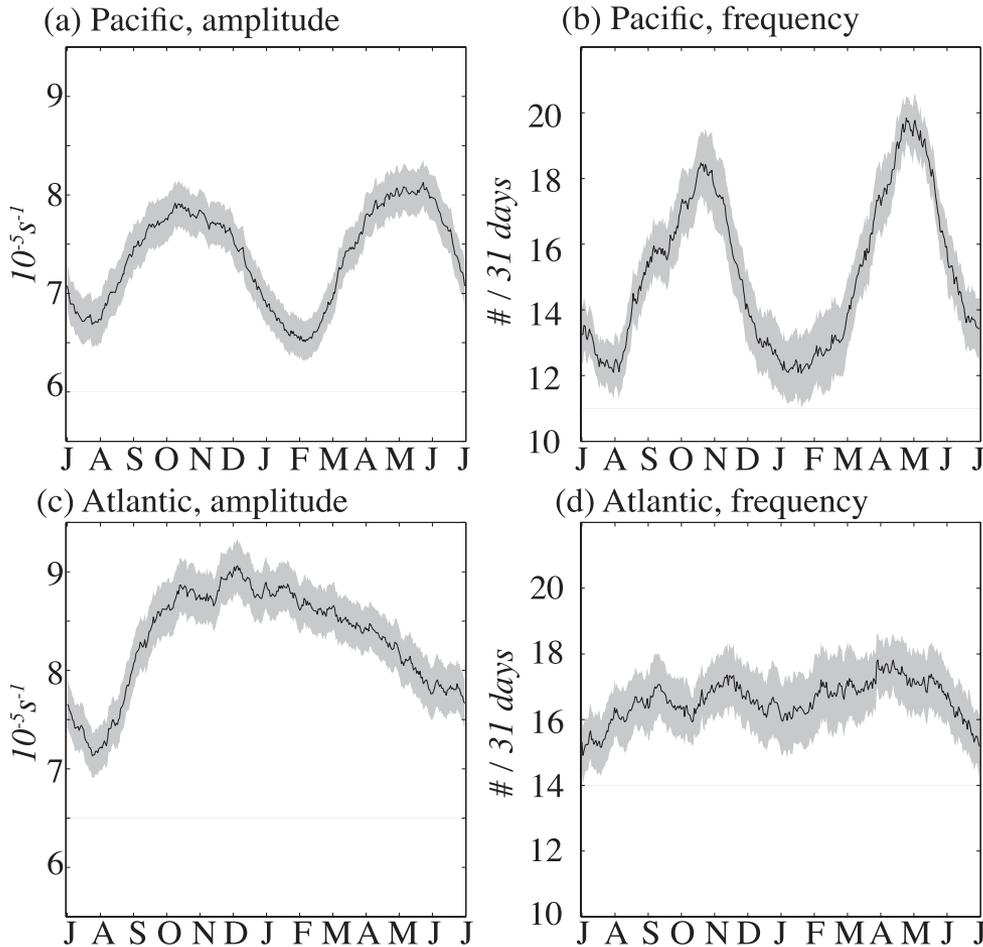
Mean flow baroclinic zone moves equatorward and becomes strongest in winter.





Observed features

- Seasonal variation



Different seasonalities between the Pacific and Atlantic storm tracks.

from Penny et al, JC, 2010

FIG. A1. As in Fig. 3 but for relative vorticity at 300 hPa. Units in (a) and (c) are 10^{-5} s^{-1} .

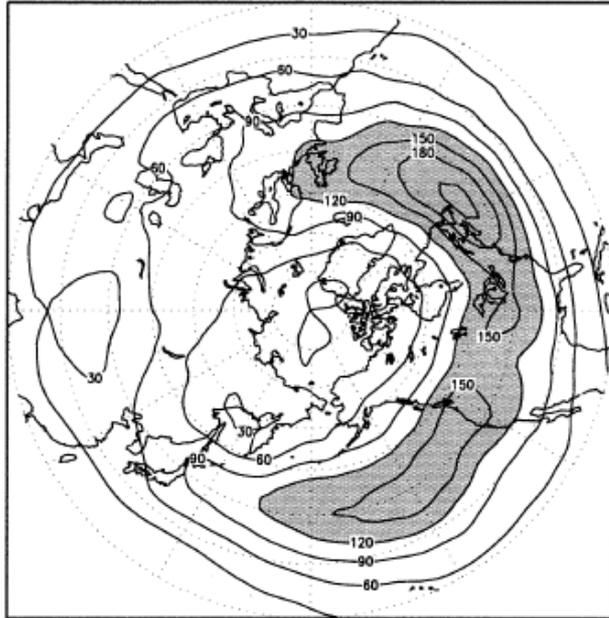


Observed features

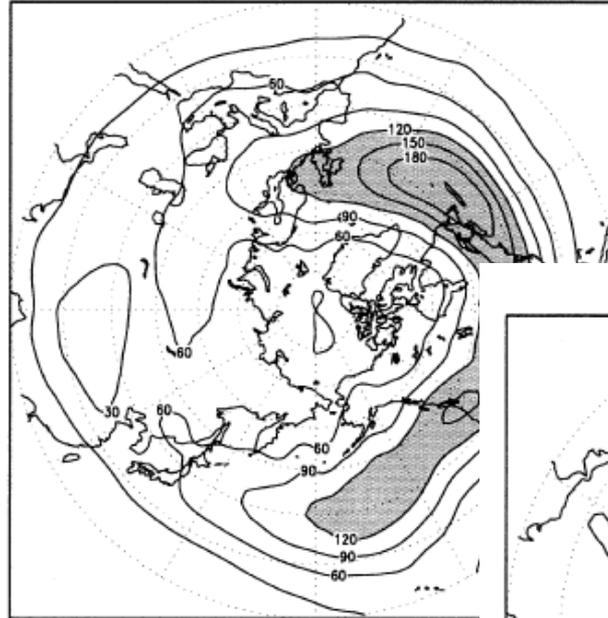
- Inter-annual variation



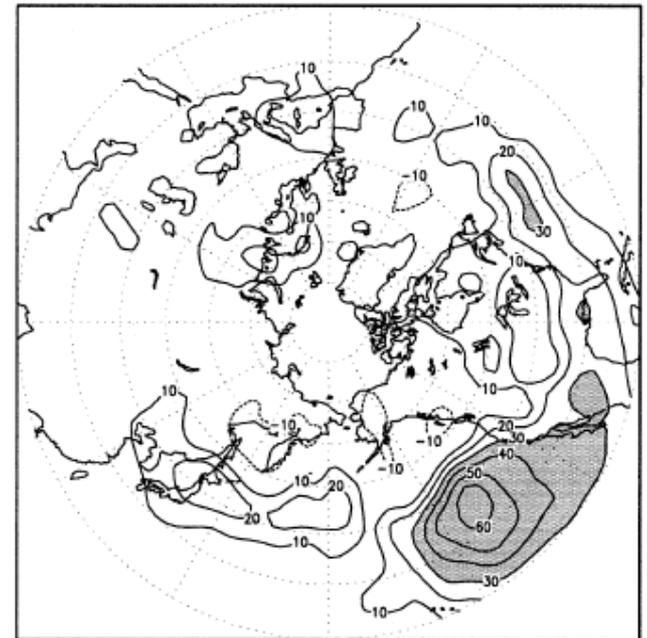
a) DJF El Nino years



a) DJF La Nina years



c) Difference



The Pacific storm track shifts equatorward and downstream during El Niño years, which is considered in response to the local enhancement of the Hadley Cell.

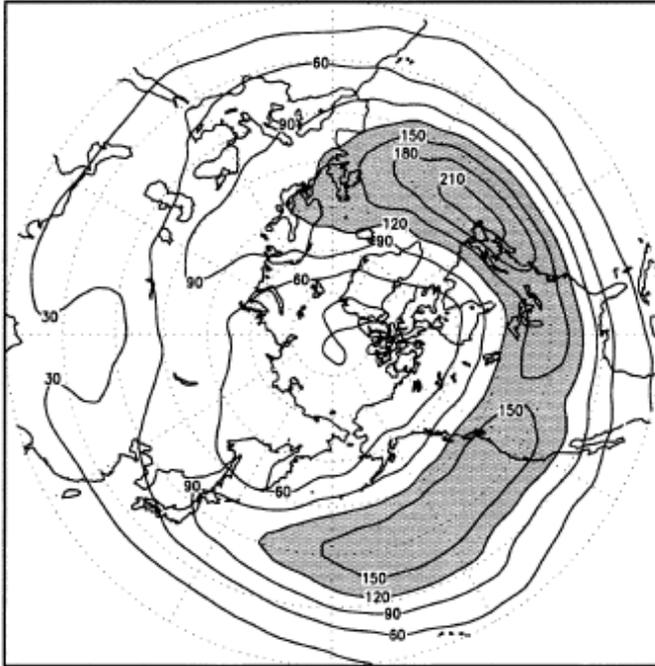


Observed features

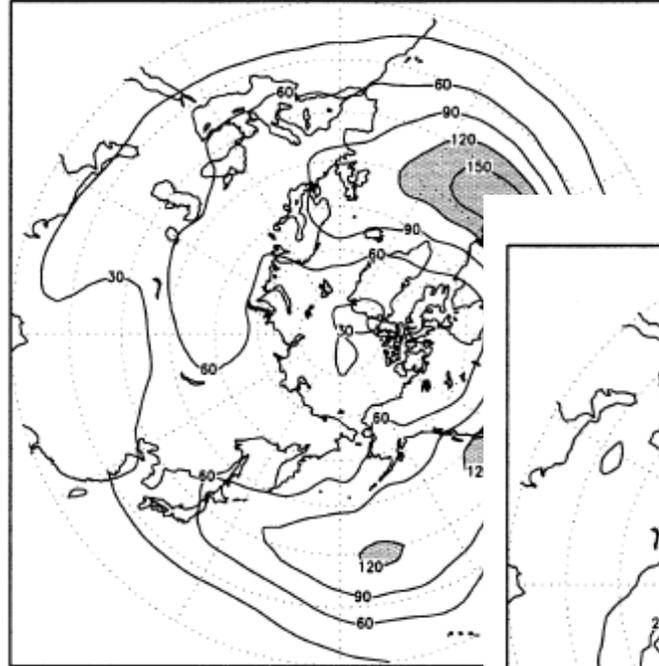
- Decadal variation



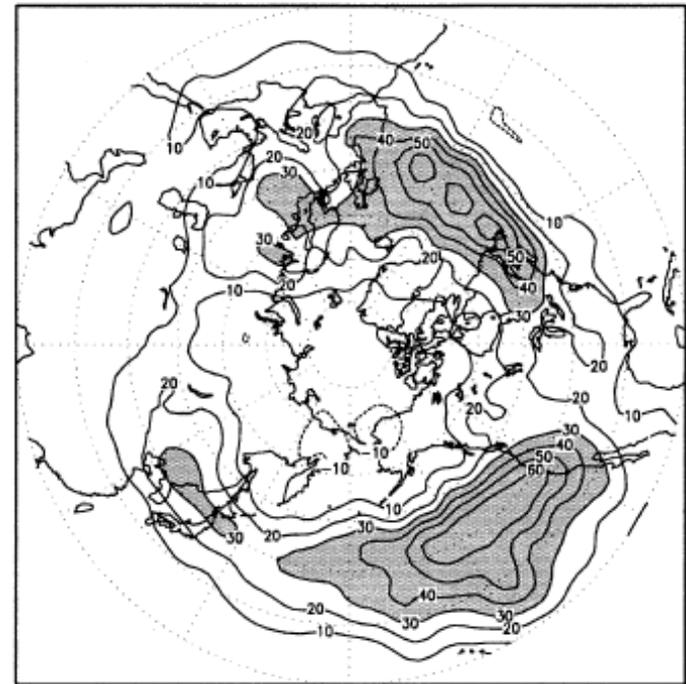
a) DJF 89/90 – 98/99



a) DJF 61/62 – 70/71



c) Difference



Stronger storm tracks during 1990s in both storm tracks, which shows significant interdecadal variabilities.



Observed features



■ Summary:

- **Structure:** zonally located in the north Pacific and north Atlantic, with the mean flow baroclinicity, jet, eddy activity, eddy heat and momentum flux in different zonal distribution.
- **Seasonal variation:** different variations between the Pacific and Atlantic storm tracks; for the Pacific storm zone, mid-winter minimum observed.
- **Inter-annual variation:** Pacific storm track shifts equatorward and downstream during El Nino years.
- **Decadal variation:** variations in intensity occur in both storm zones, with the storm tracks in the 1990s stronger than in the 1960s.



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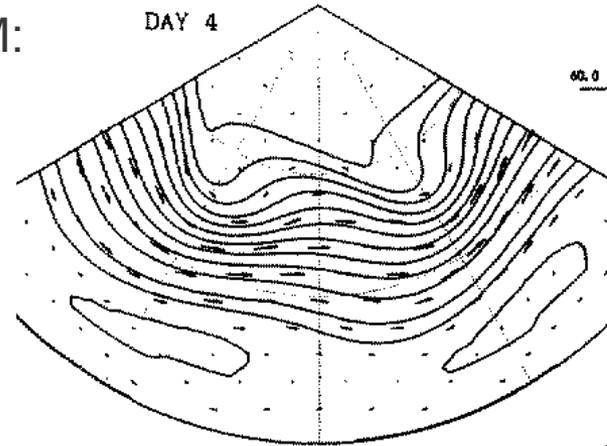
Storm track dynamics

- from the baroclinic eddy life cycle

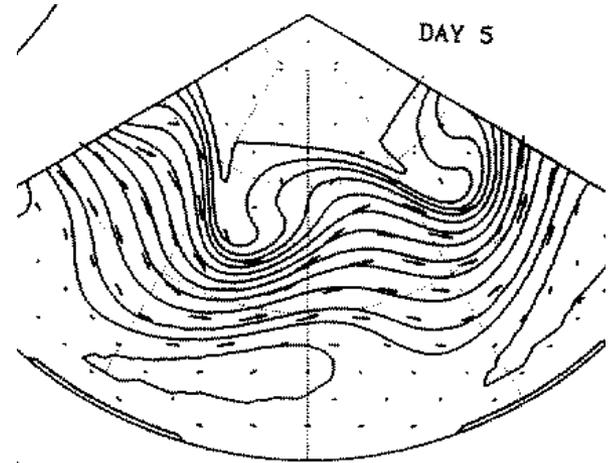


- Eddies' development with idealized GCM:

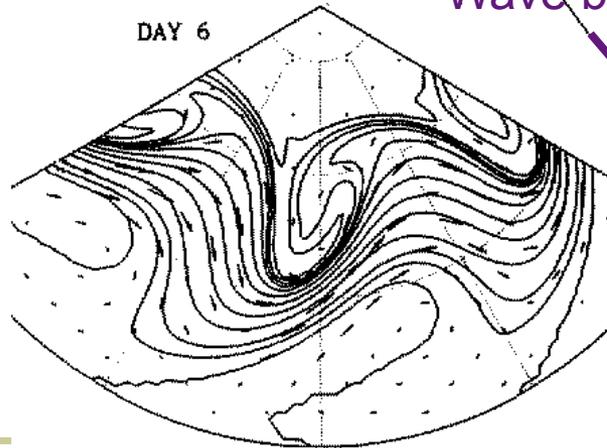
Small amplitude perturbations



DAY 5

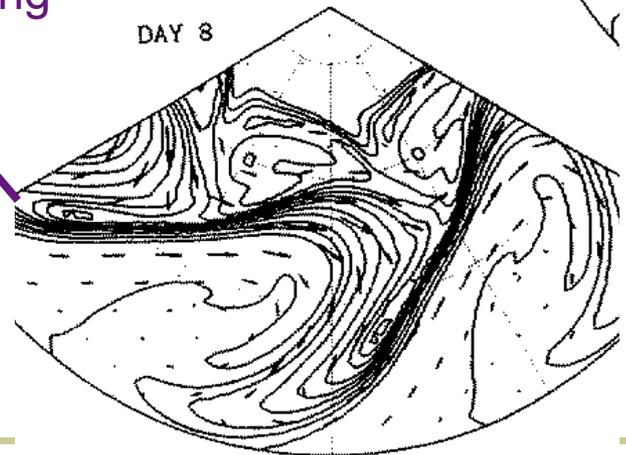


Finite amplitude perturbations



Wave breaking

DAY 8

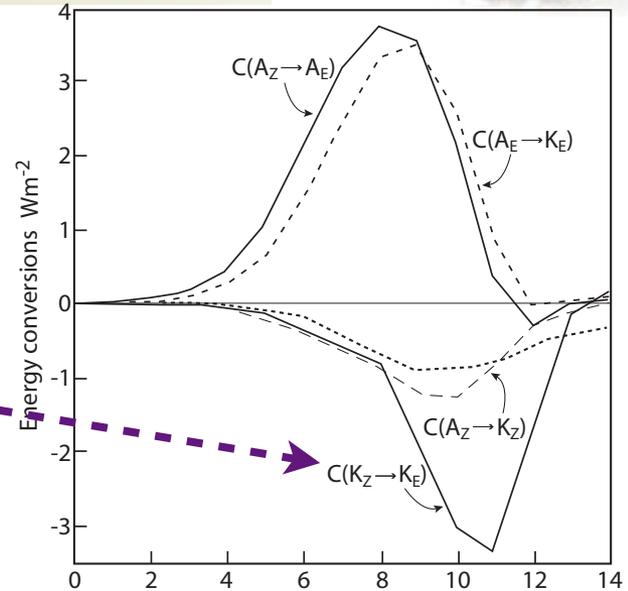
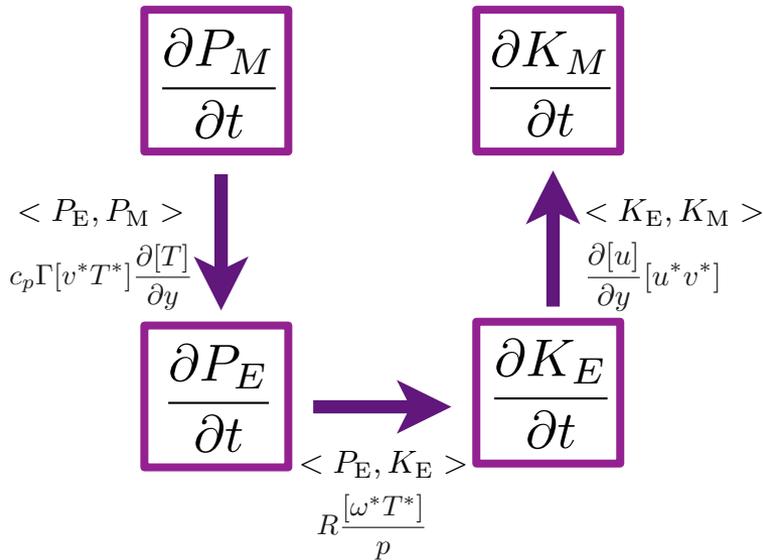


(Thorncroft et al, 1993, Q.J.R.)



Storm track dynamics

- from the baroclinic eddy life cycle



Baroclinic eddy life cycle in **time**:

Relatively small amplitude pert.



Baroclinic growth



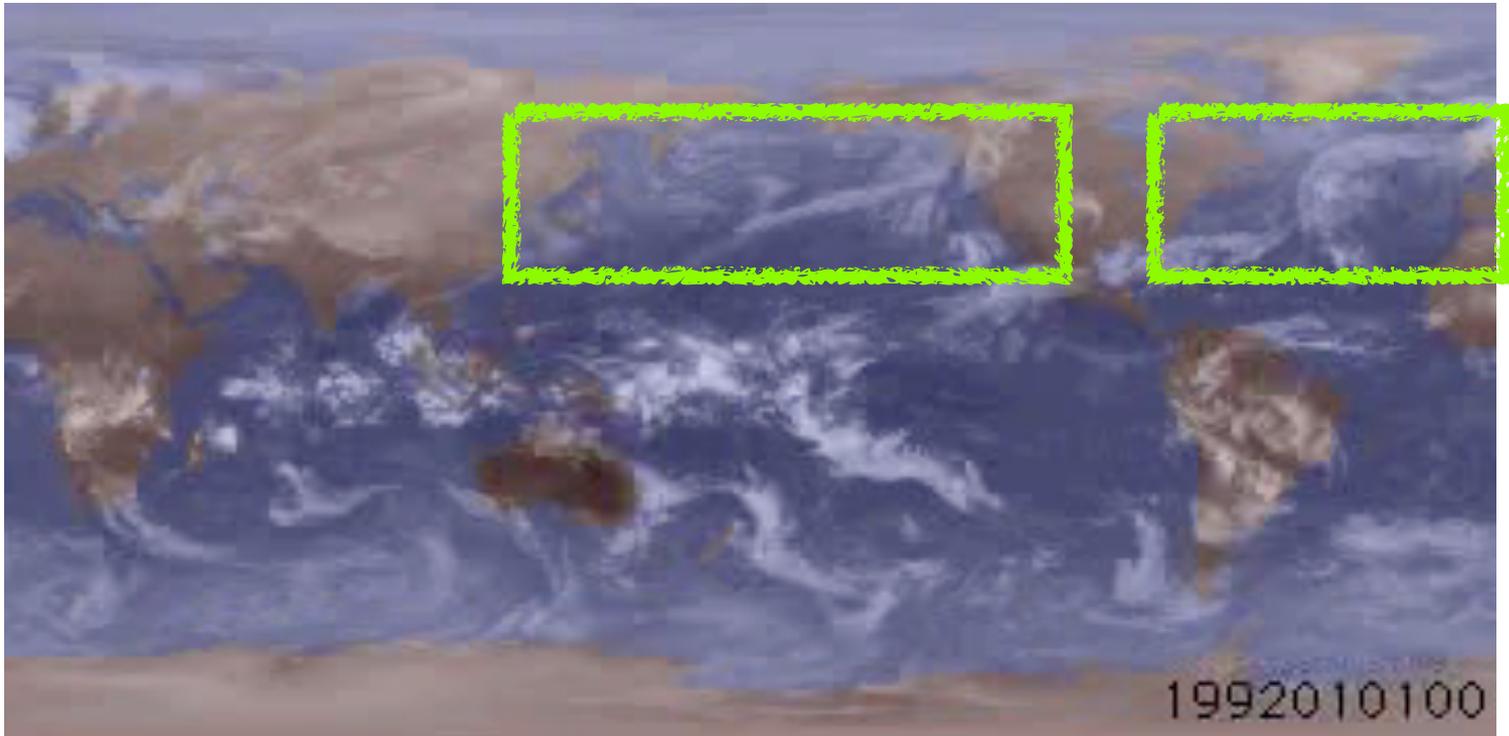
Finite amplitude perturbation



Barotropic decay

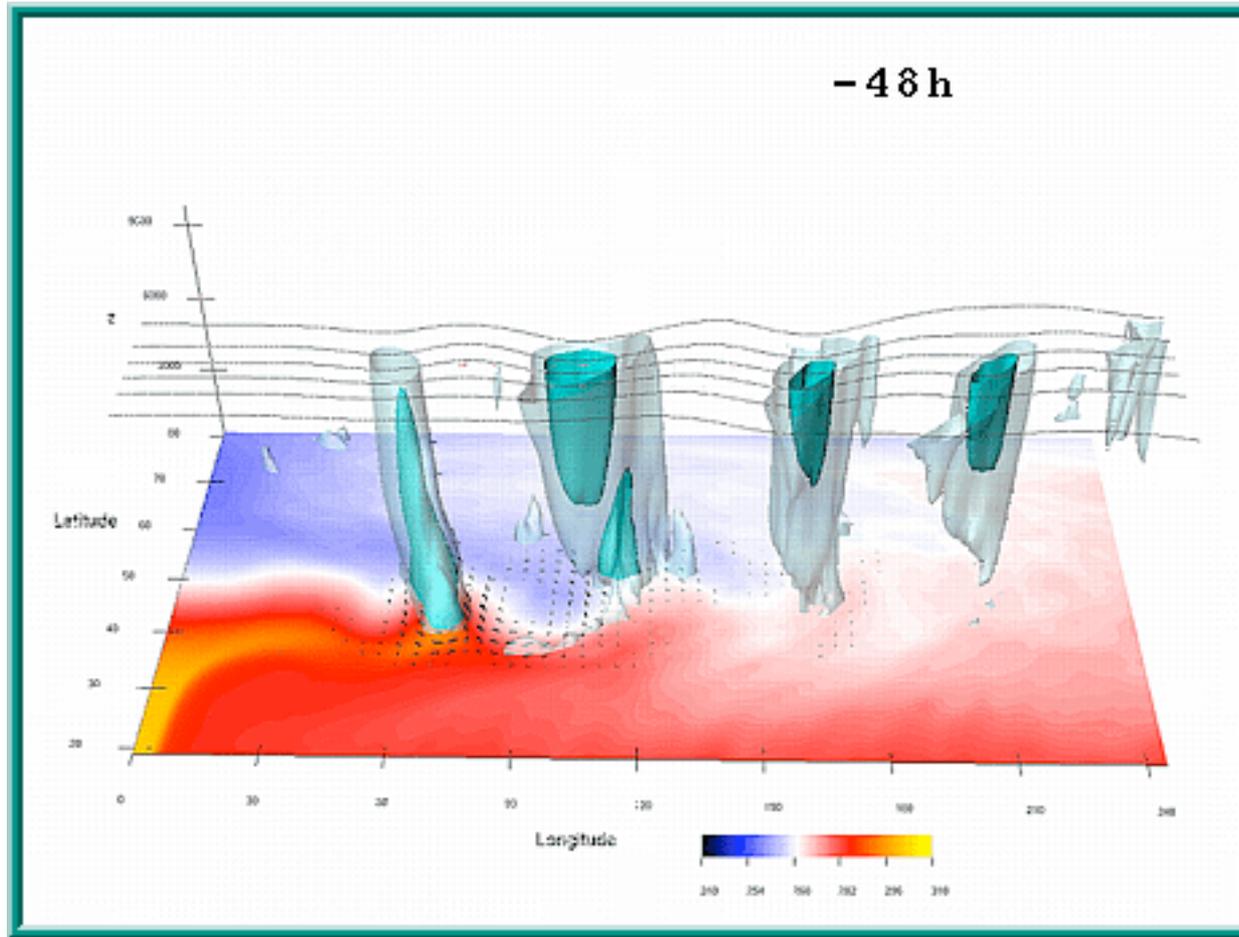


Storm track dynamics





Storm track dynamics



Numerical simulation
from Orlandi



Storm track dynamics

- from the baroclinic eddy life cycle



Baroclinic eddy life cycle in **time**:

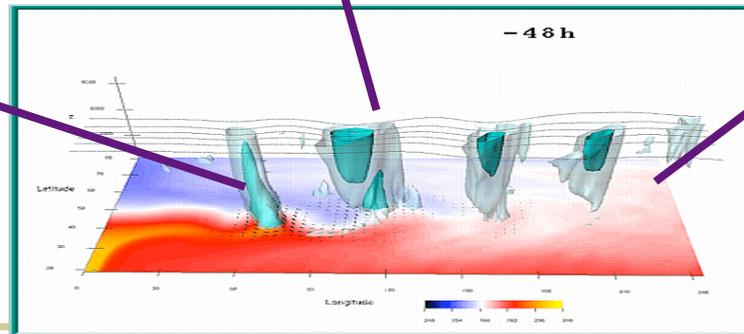


Storm track structure can heuristically equate with an eddy life cycle in **space**:

Upstream end: perturbations are introduced and begin develop. (entrance region)

develop in space and time

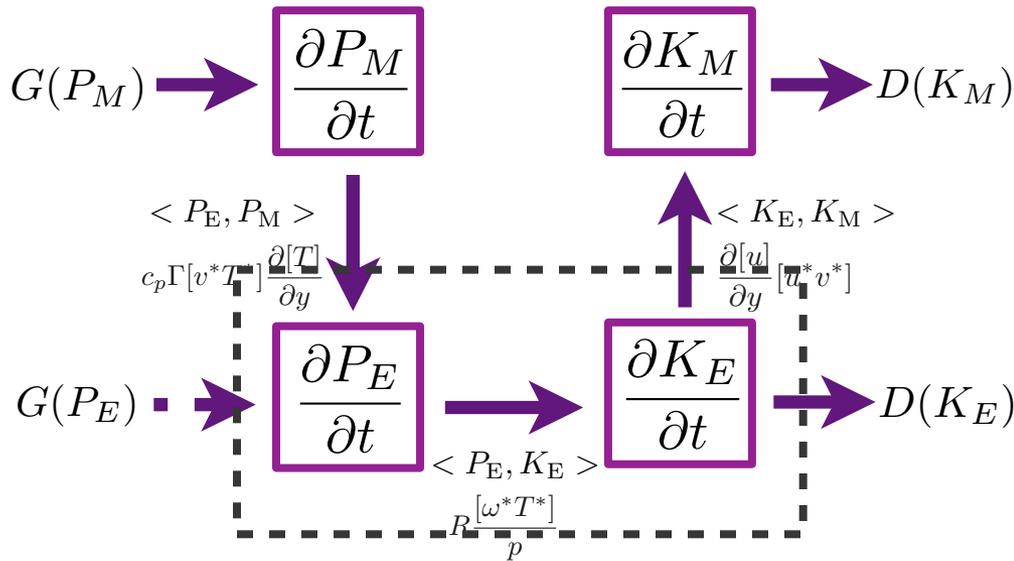
Downstream end: decay stage of the eddy life cycle. (exit region)



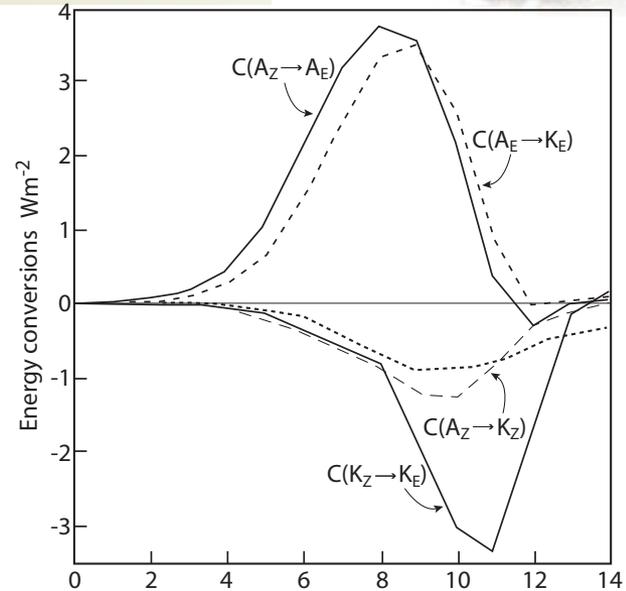


Storm track dynamics

- Transient eddy energy budget



Total eddy energy



Numerical results from Simmons and Hoskins, 1978, JAS

For storm tracks, define a **total transient eddy energy**:

$$E = K_{TE} + P_{TE} = \frac{1}{2} \overline{(u'^2 + v'^2)} + \frac{c_p}{2} \Gamma \overline{(T'^2)} = \frac{1}{2} \overline{(u'^2 + v'^2)} - \frac{\alpha_m}{2\theta_m} \frac{\overline{\theta'^2}}{\partial \theta_s / \partial p}$$

$$A' = A - \bar{A}, \text{ "m" denotes mean quantities, } \alpha = 1/\rho$$



Storm track dynamics

- Transient eddy energy budget



For storm tracks, define a **total transient eddy energy**:

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Transient eddy energy budget:

$$\frac{\partial E}{\partial t} = \nabla \cdot \overline{(\mathbf{v}E + \mathbf{v}'_a \phi')} + \frac{\alpha_m}{\theta_m} \frac{\overline{\mathbf{v}'\theta'}}{\partial\theta_s/\partial p} \cdot \nabla\theta - \overline{\mathbf{v}' \cdot (\mathbf{v}' \cdot \nabla)V_m} - \text{diss} + \text{diab}$$

advective energy flux

baroclinic generation

barotropic conversion

$D(K_E)$

$G(P_E)$

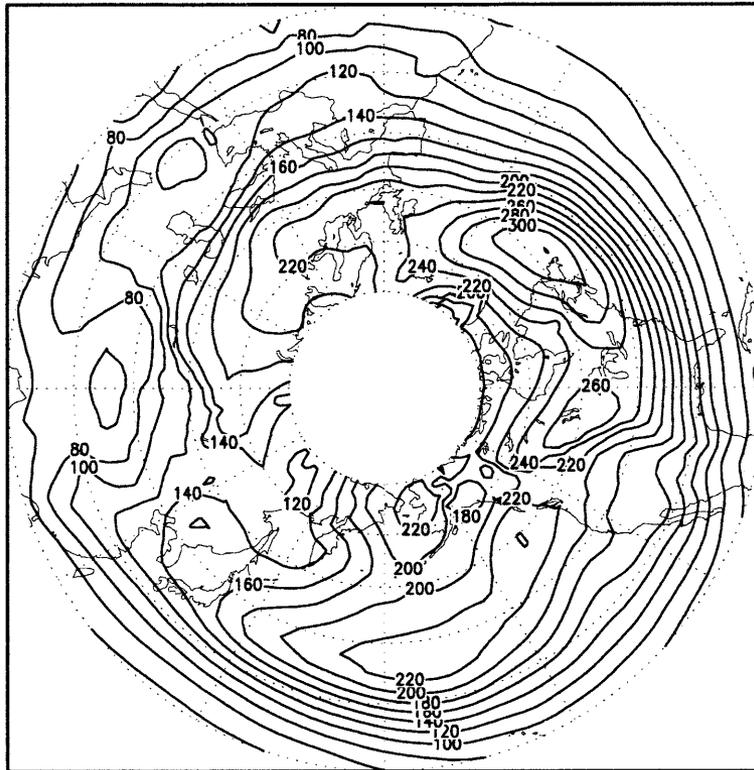


Storm track dynamics

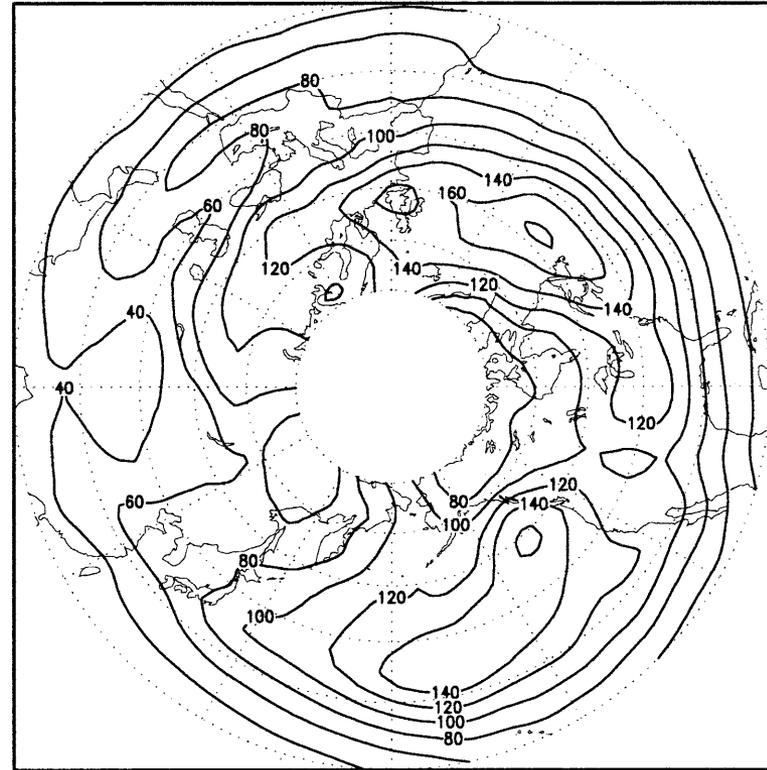
- Transient eddy energy budget



a) Total eddy energy



b) Eddy kinetic energy



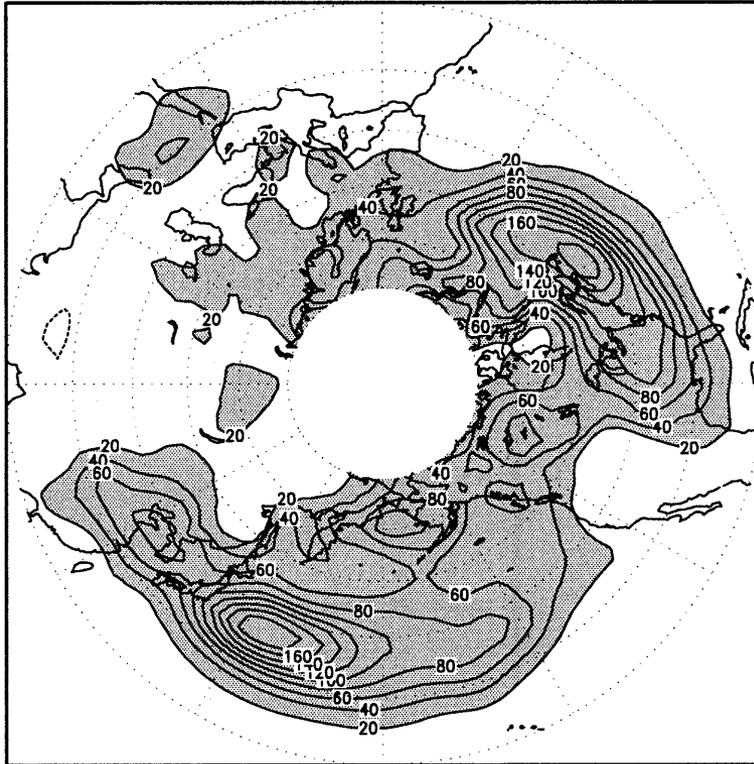


Storm track dynamics

- Transient eddy energy budget

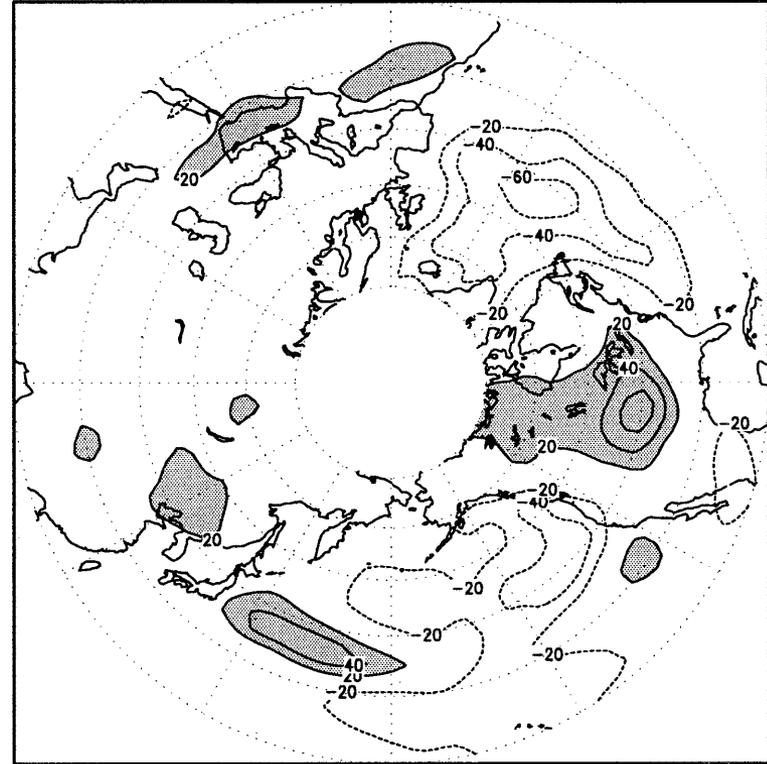


c) baroclinic conversion



Located upstream

d) barotropic conversion



Positive over the entrance region
negative over the exit region

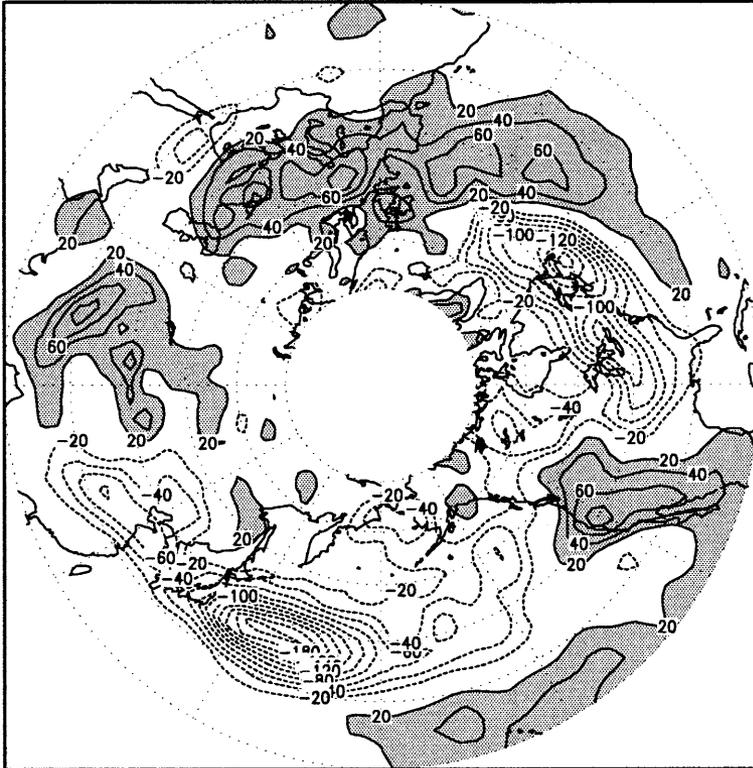


Storm track dynamics

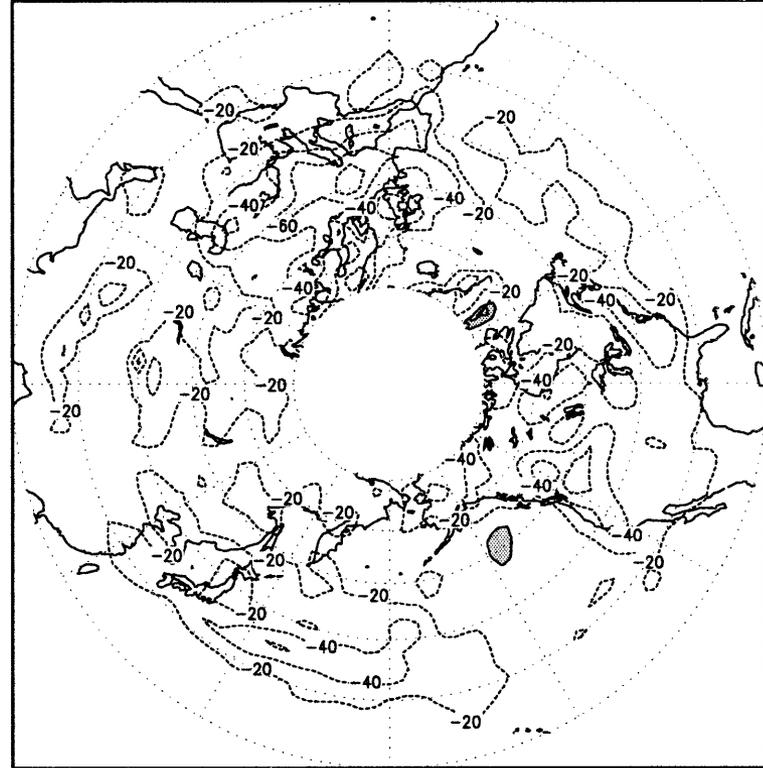
- Transient eddy energy budget



e) energy flux



f) mechanical dissipation



energy sink

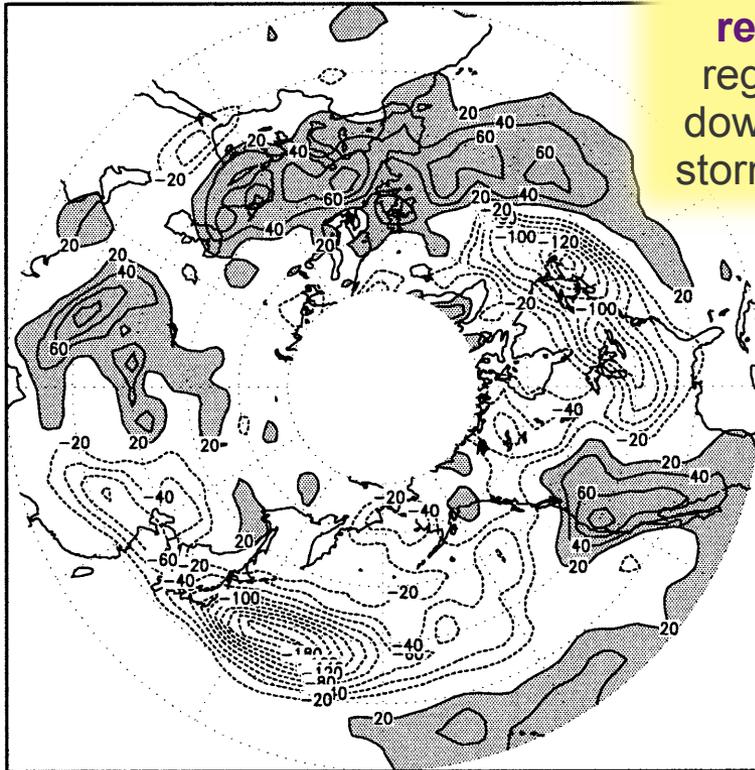


Storm track dynamics

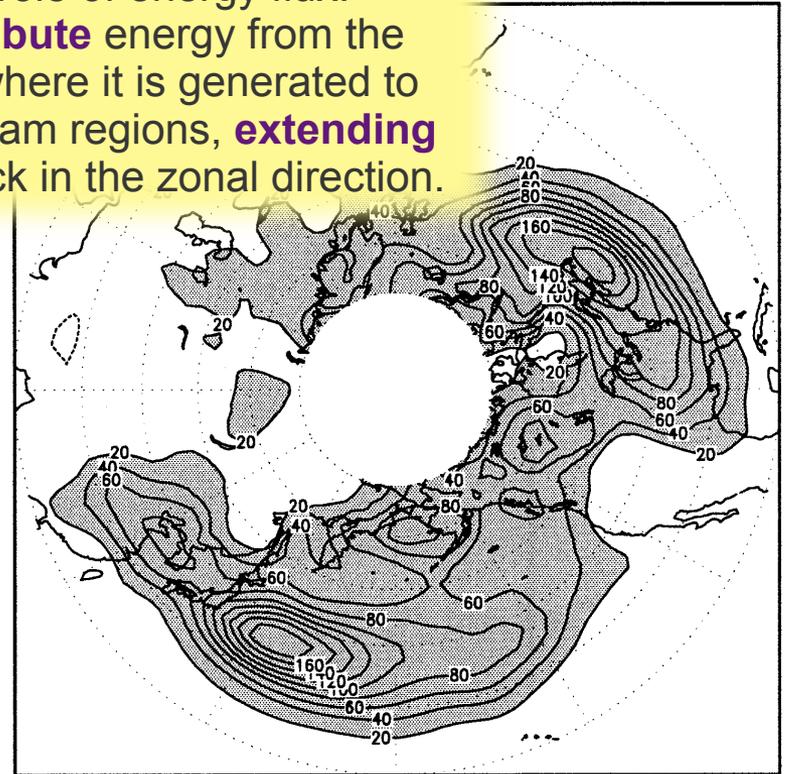
- Transient eddy energy budget



e) energy flux



The role of energy flux: **redistribute** energy from the region where it is generated to downstream regions, **extending** storm track in the zonal direction.



Strongly compensate the baroclinic conversion term in the entrance region.

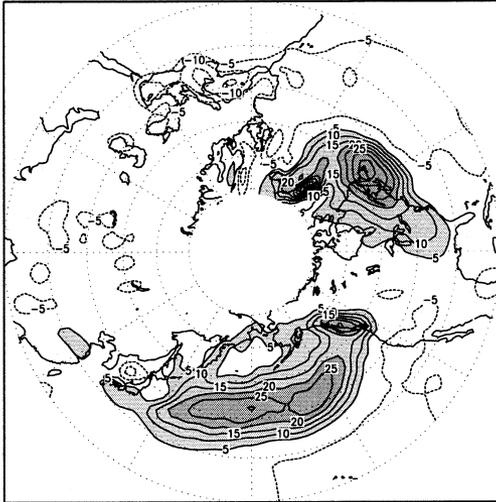


Storm track dynamics

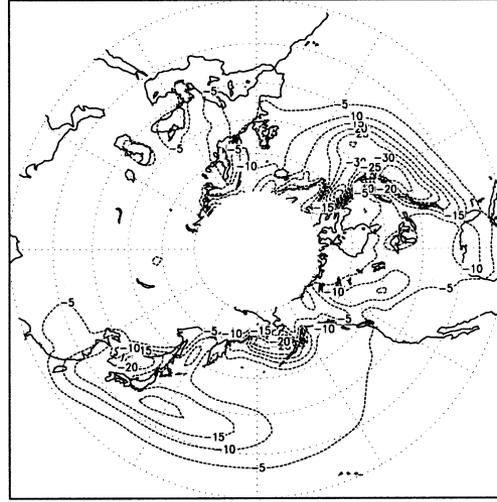
- Transient eddy energy budget



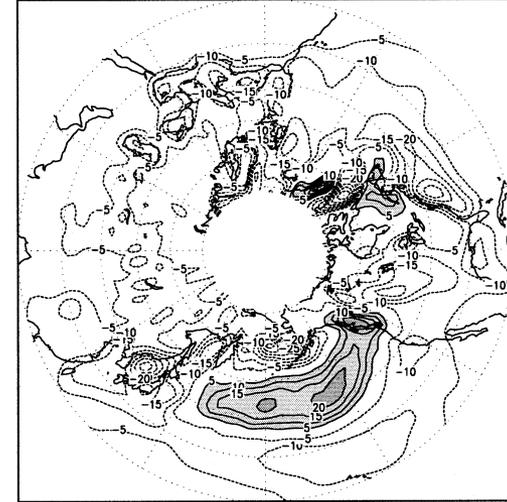
a) G(PE) moist heating



b) G(PE) sensible heating



c) Total G(PE)



Moist heating: strong along the storm tracks, with the maximum generation rate over the storm track entrance region. (large-scale condensation dominant)

Sensible heating: a strongly negative contribution along the continental east coasts.

Total effect: difference between Pacific and Atlantic region. In the mid and exit regions of **Pacific** storm track, latent heating dominant and enhancing the eddy energy; in the **Atlantic** region, sensible heating dominant.

from Chang et al, JC, 2002



Discussions



- Though the structure of the storm tracks can be partially understood from the view of baroclinic energy cycle occurring in space, many questions are left:
 - **Structure:** a (causal) relationship between the variability eddies and that of the background flow; the feedbacks between storm track anomalies and the slowly varying planetary-scale flow? e.g. what determines how far downstream of the region of the max baroclinicity the storm tracks extend? Whether the storm track properties can be solely determined by the mean flow? The group propagation of storms...
 - **Seasonal variation:** the reason of mid-winter minimum?
 - **Inter-annual variation:** the detailed mechanism of Pacific storm track shift between El nino and La nina years?
 - **Decadal variation:** the reason for decadal variation and its relation to the global warming?
 - **Simulations:** AGCM and storm track model



Reference



Chang E.K.M., Lee S., and Swanson K. (2002). Storm track dynamics. *J. Climate*, 15, 2163–2183.

Hoskins B.J. and Hodges K.I. (2002). New perspectives on the Northern Hemisphere winter storm tracks. *J. Atmos. Sci.*, 59, 1041–1061.

Vallis, G. K. and Gerber, E. P. 2008. Local and Hemispheric Dynamics of the North Atlantic Oscillation, Annular Patterns and the Zonal Index. *Dyn. Atmos. Oceans*, 44, 184-212.

Penny, S., Roe, G. H., and Battisti, D. S., The source of the midwinter suppression in storminess over the North Pacific, *J. Climate* , 2010.