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A positive eddy feedback acting on the North Atlantic oscillation.

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A positive eddy feedback acting on the latitudinal variations of the large-scale jets. Implications for the NAO.

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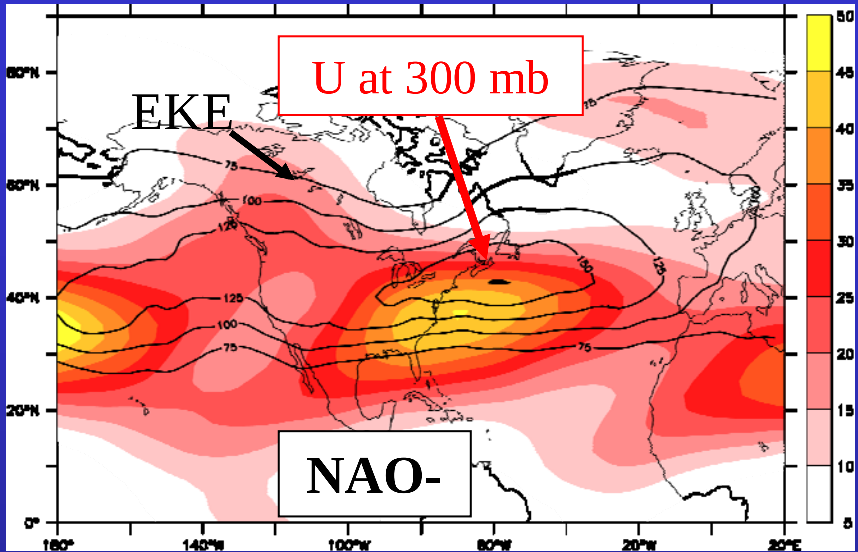
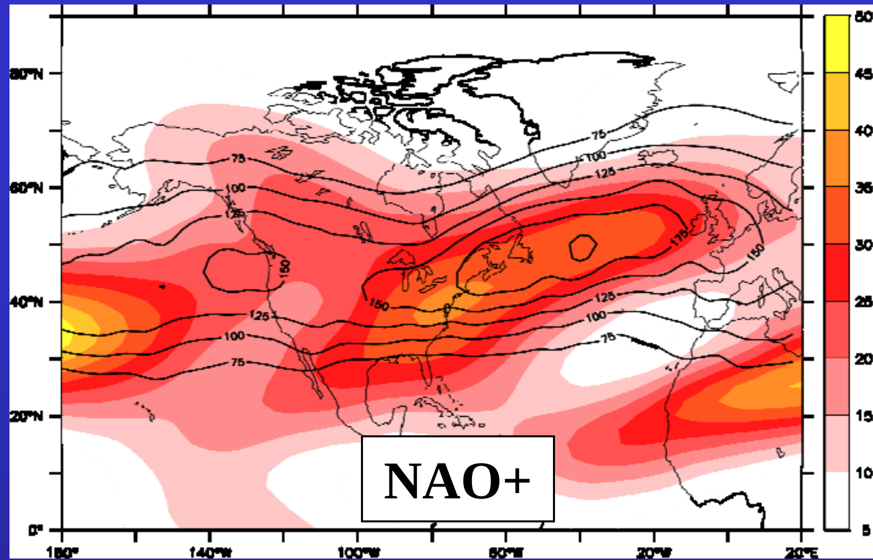
Introduction: NAO and jet structures





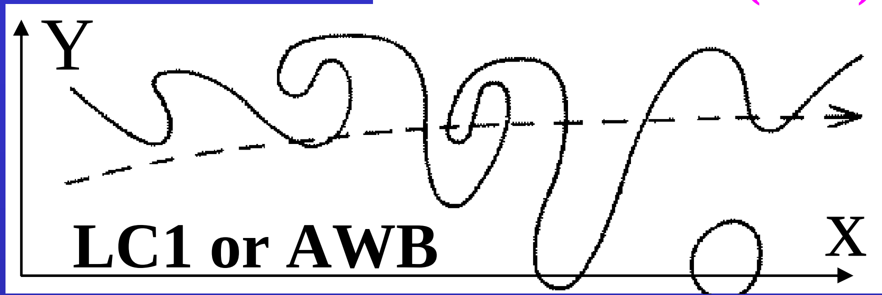
• **Eddy feedback onto the large-scale flow characterized by wave breaking. It plays a crucial role in the teleconnections.**

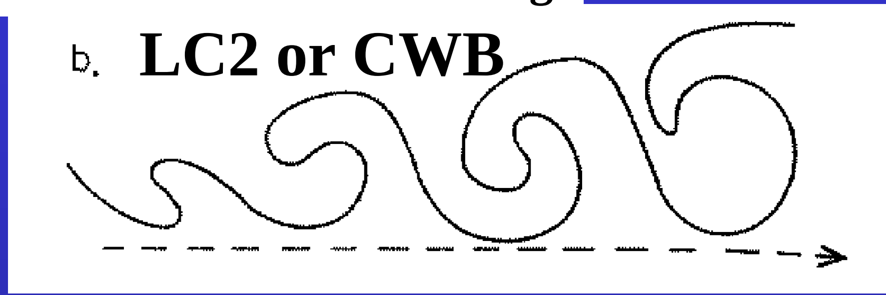
NAO: **see e.g., Benedict et al. (2004); Franzke et al. (2004); Rivière and Orlanski (2007); Martius et al. (2007); Strong and Magnusdottir (2008); Woollings et al. (2008).**

For example, Negative NAO has more CWB events than usual
Positive NAO ………… AWB events ………….

Introduction: wave breaking

Thorncroft et al. (1993): **Two kinds of wave breaking**



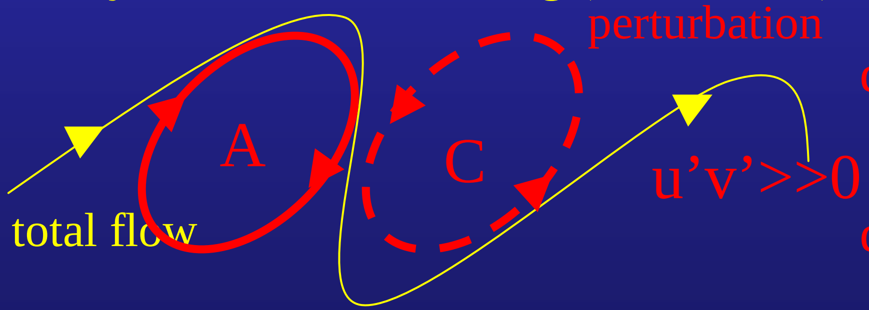


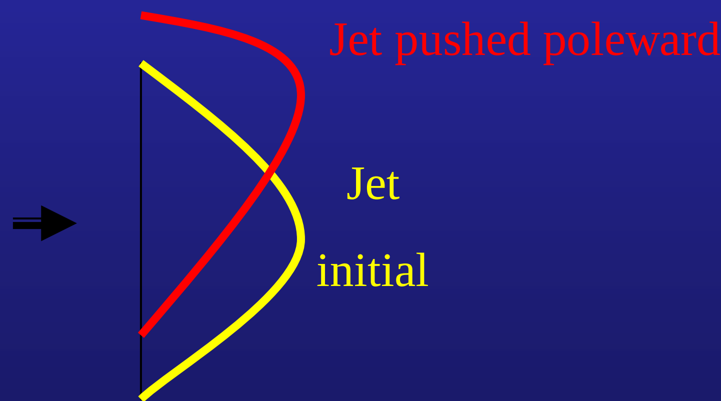
Low freq evolution $\Rightarrow$ $\overline{D}\overline{u} \approx f_0 \overline{v}^* + \nabla.\mathbf{E}$ with $\mathbf{E} \equiv \left((\overline{v'^2} - \overline{u'^2})/2, -\overline{u'v'}\right)$

Hoskins et al. (1983); Trenberth (1986)

HF eddy feedback

Anticyclonic wave breaking (SW-NE tilt)





Wave-breaking modifies the jet latitude but what about the impact of the jet latitude onto the wave-breaking processes ?

Refractive index (QG context)

Eddy streamfunction

$$\frac{\partial^2 \psi'}{\partial y^2} + n^2 \psi' = 0$$

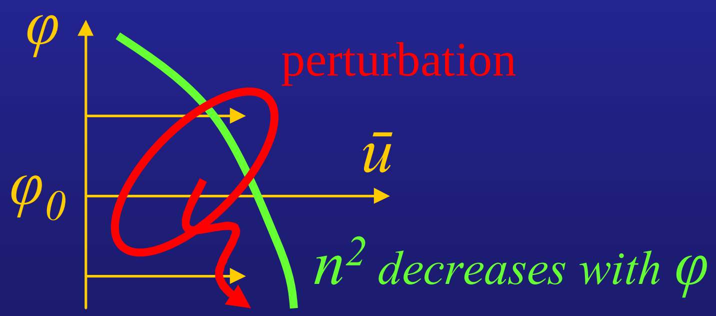
PV gradient

$$n^2 \approx \left(\frac{\partial \bar{q} / \partial y}{\bar{u} - c a \cos\varphi} - \frac{m^2}{a^2 \cos^2 \varphi} \right)$$

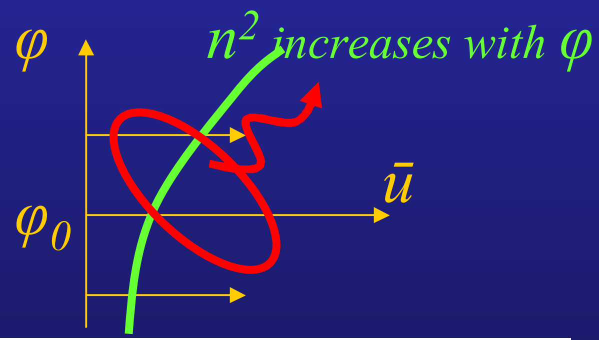
a earth's radius, f Coriolis parameter, c phase velocity, m wavenumber, u zonal wind, φ latitude

Classical linear results:

For $n^2>0$, waves propagate and are refracted toward larger n^2;
for $n^2<0$, waves are evanescent !



Eddies are SW-NE tilted, E-vectors are equatorward, waves propagate equatorward



Eddies are NW-SE tilted, E-vectors are poleward, waves propagate poleward

Two competing effects involved in the PV gradient

$$n^2 \approx \left(\frac{\partial \bar{q} / \partial y}{\bar{u} - ca \cos\varphi} - \frac{m^2}{a^2 \cos^2 \varphi} \right)$$

Matsuno (1970)

$$\partial \bar{q} / \partial y = \underbrace{\frac{1}{a}\frac{\partial f}{\partial \varphi} + \frac{1}{a}\frac{\partial \bar{\zeta}}{\partial \varphi}}_{\text{AV}} \underbrace{- f^2 \frac{\partial}{\partial p}\left[\left(\frac{\rho g}{N}\right)^2 \frac{\partial \bar{u}}{\partial p}\right]}_{\text{ST}}$$

A zonal symmetric jet at latitude φ_0 ($\bar{u}(\varphi-\varphi_0)= \bar{u}(\varphi+\varphi_0)$) has usually an asymmetric PV gradient due to f variations and metric terms !

AV makes stronger n^2 on the south side (in particular at upper levels) whereas ST increases n^2 on the north side (especially at low levels)

1. ST favours the cyclonic tilt (and CWB) whereas AV promotes more the anticyclonic tilt (AWB)

2. The AV and ST effects are respectively more and less efficient with increasing latitude. Hence, AWB and CWB are more and less probable for high-latitude jets than low-latitude ones.

Aquaplanet models

1.Quasi-geostrophic (QG) model (Marshall and Molteni, 1993): global spectral 3-**level** model in spherical geometry at T42 truncation. It solves the PV prognostic equations:

$$\frac{\partial q_i}{\partial t} = -J(\psi_i, q_i) - D(\psi_1, \psi_2, \psi_3)$$

Subscripts 1, 2 and 3 denote the 3 layers 200, 500 and 800 hPa.

where

$$q_1 = \nabla^2\psi_1 + f - R_1^{-2}(\psi_1 - \psi_2)$$

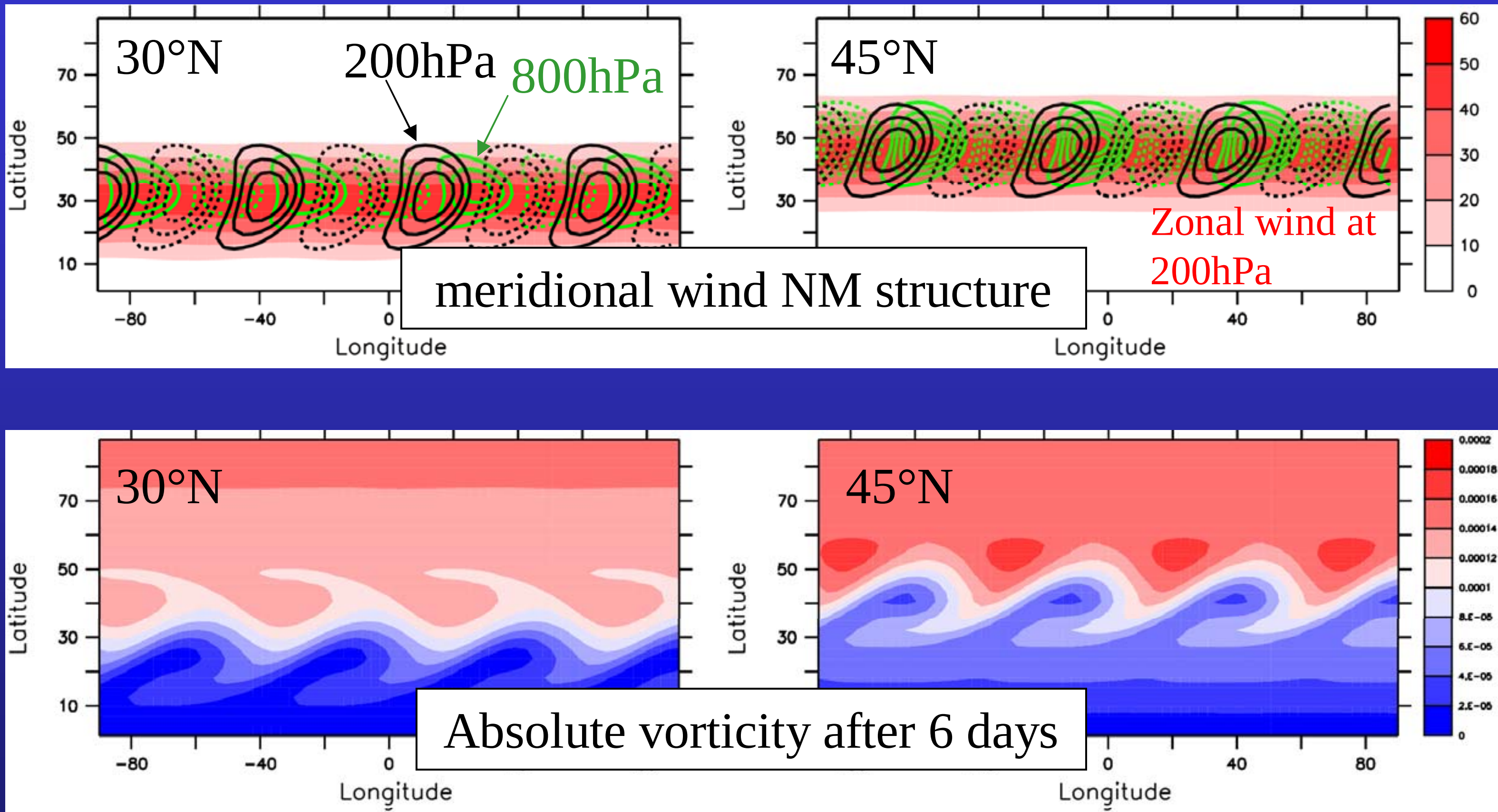
$$q_2 = \nabla^2\psi_2 + f + R_1^{-2}(\psi_1 - \psi_2) - R_2^{-2}(\psi_2 - \psi_3)$$

$$q_3 = \nabla^2\psi_3 + f + R_2^{-2}(\psi_2 - \psi_3)$$

Due to constant Rossby radii of deformation (R_1=660kms, R_2=400kms), **the stretching effect is not present**!

2. Primitive-equations (PE) model (http://www.mi.uni-hamburg.de , Fraedrich et al., 2005): dry version of a global atmospheric model on the sphere using 10 sigma levels at T42.

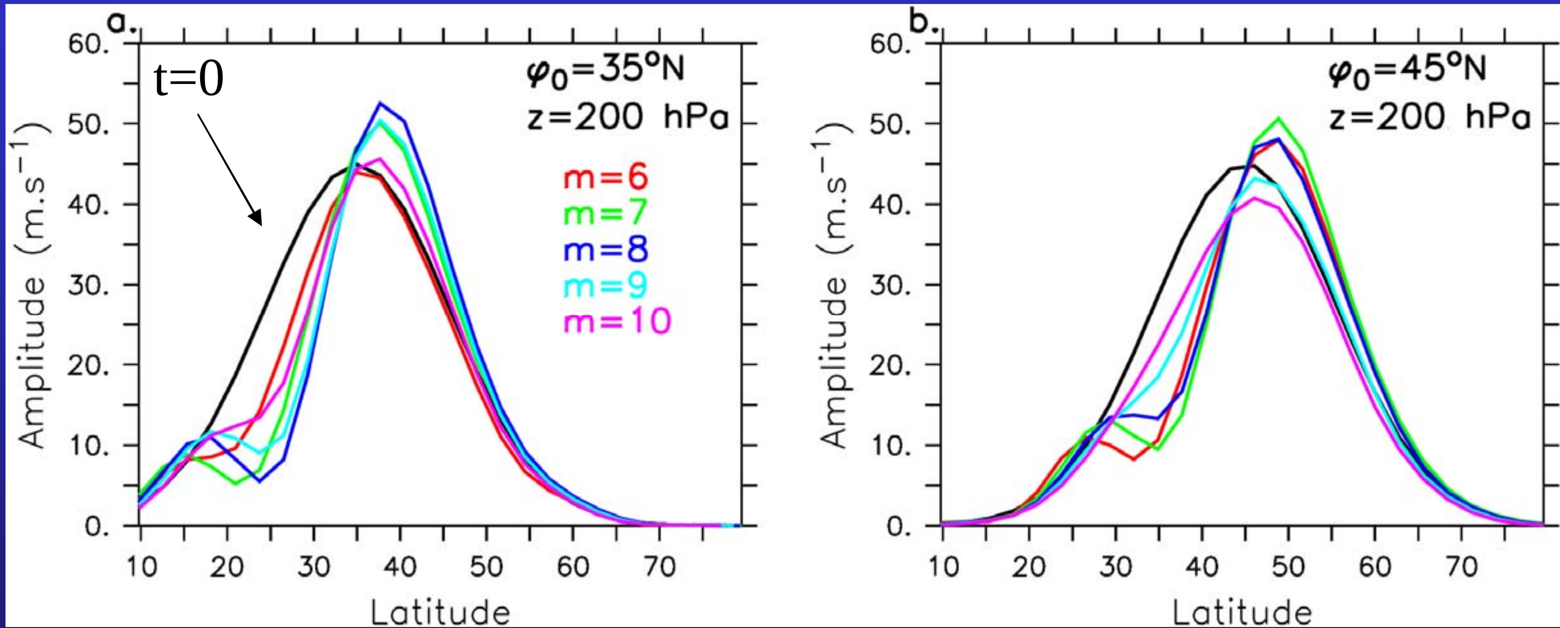
I. Normal-mode analysis in the QG model: spatial structure and nonlinear evolution for m=7



(i) Only the anticyclonic (SW-NE) tilt is visible (essentially at upper levels)!
(ii) The AWB signature dominates in the nonlinear stage. It is more pronounced for the 45° jet.

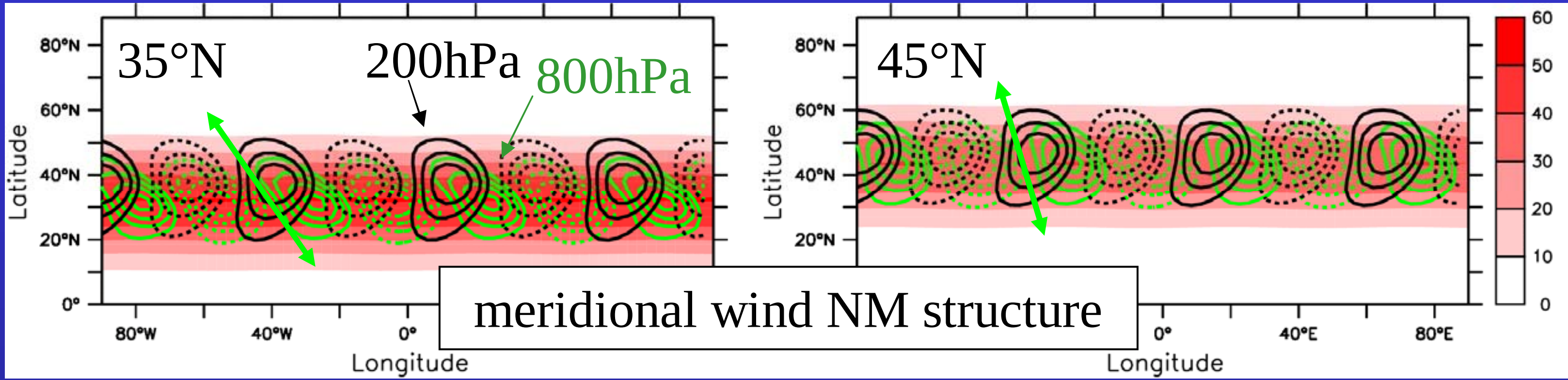
Normal-mode analysis in the QG model: Jet evolution after 10 days

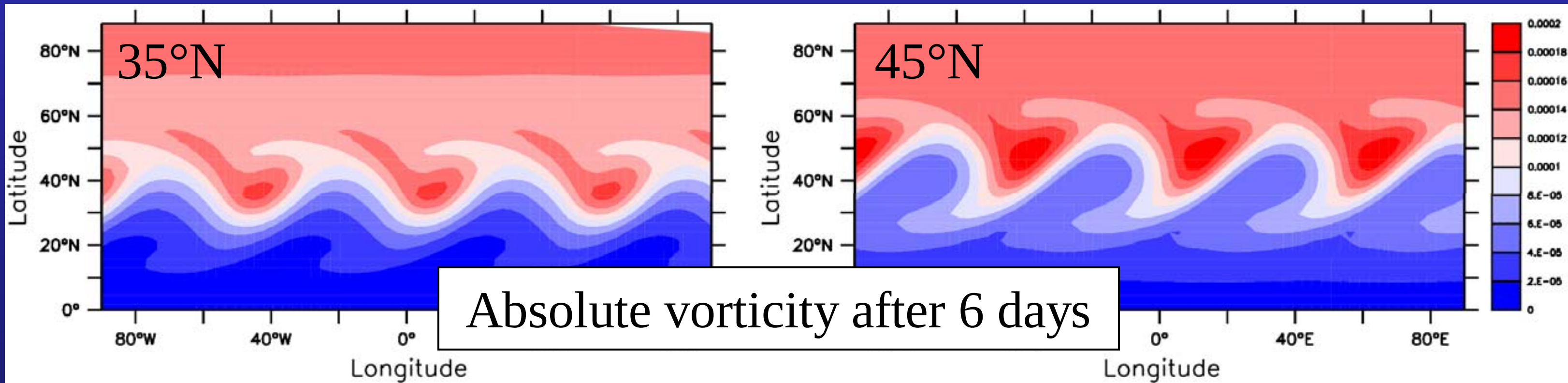
Jet at t=0 (black) and at t=10d (color)



All wavenumbers push the jet poleward with essentially AWB features in the QG model!

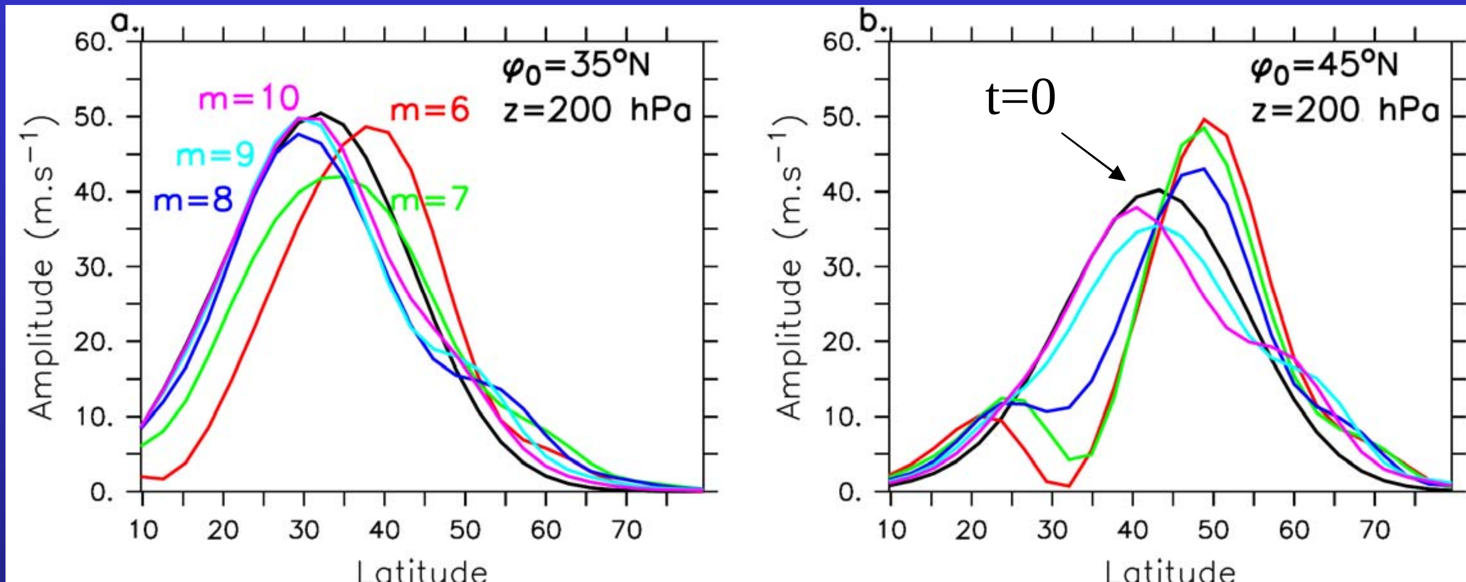
Normal-mode analysis in the PE model: spatial structure and nonlinear evolution for m=7





(i) The cyclonic (anticyclonic) tilt dominates at lower (upper) levels
(ii) The cyclonic (anticyclonic) tilt is more pronounced for the 35° (45°) jet
(iii) AWB is more present for the 45° jet. Slight differences in NM initial structures are accentuated in their nonlinear evolution !

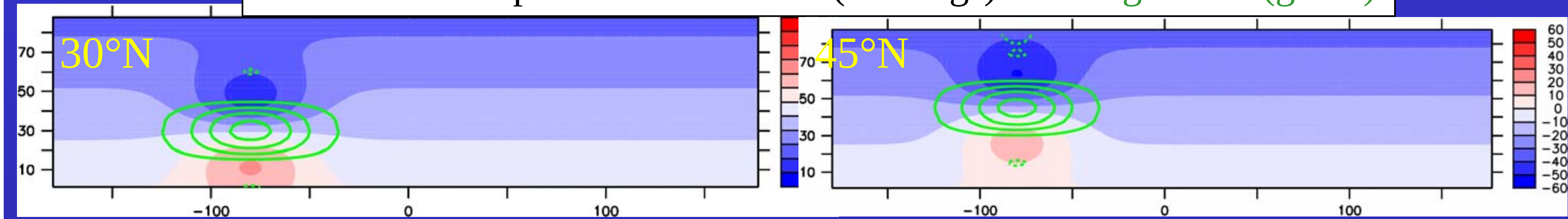
Normal-mode analysis in the PE model:
Jet evolution after 10 days



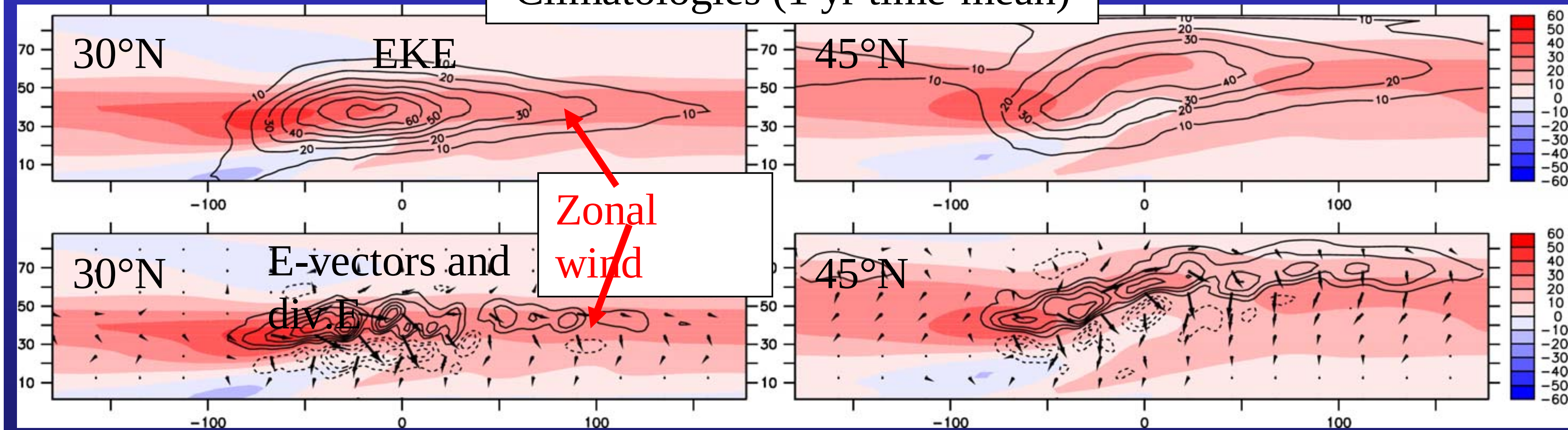
(i) The lowest wavenumbers tend to push the jet poleward and the highest ones equatorward.
(ii) Transition occurs between the 35° and the 45° jets for intermediate wavenumbers (look at wavenumber 8!). It pushes the jet poleward for the 45° jet and equatorward for the 35° jet.

II. Relaxation toward localized temperature anomalies
Long-term runs: QG model, zonal case, T42

Restoration temperature at 650 hPa (shadings) and its gradient (green)



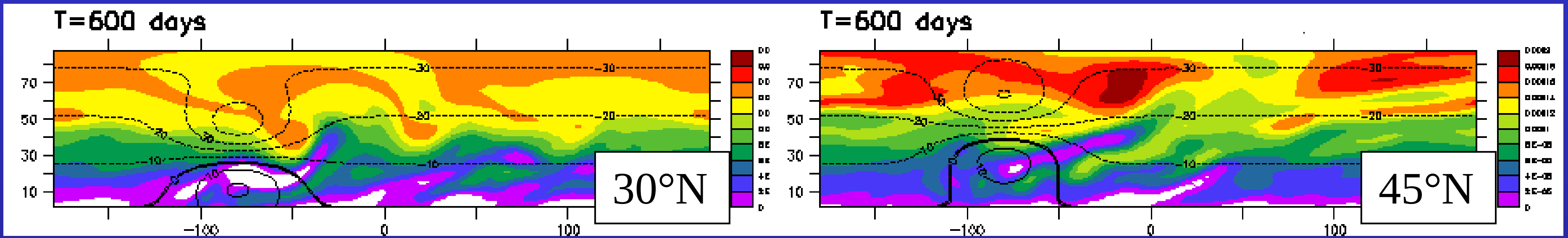
Climatologies (1 yr time-mean)



(i) Eddy-driven jet pushed poleward in regions of maximum EKE. It gets a SW-NE orientation in both cases. E-vectors point equatorward.
(ii) Double-jet structure in regions of maximum EKE in both cases.
(iii) In the 45° case, the jet is pushed more poleward than in the 30° one.

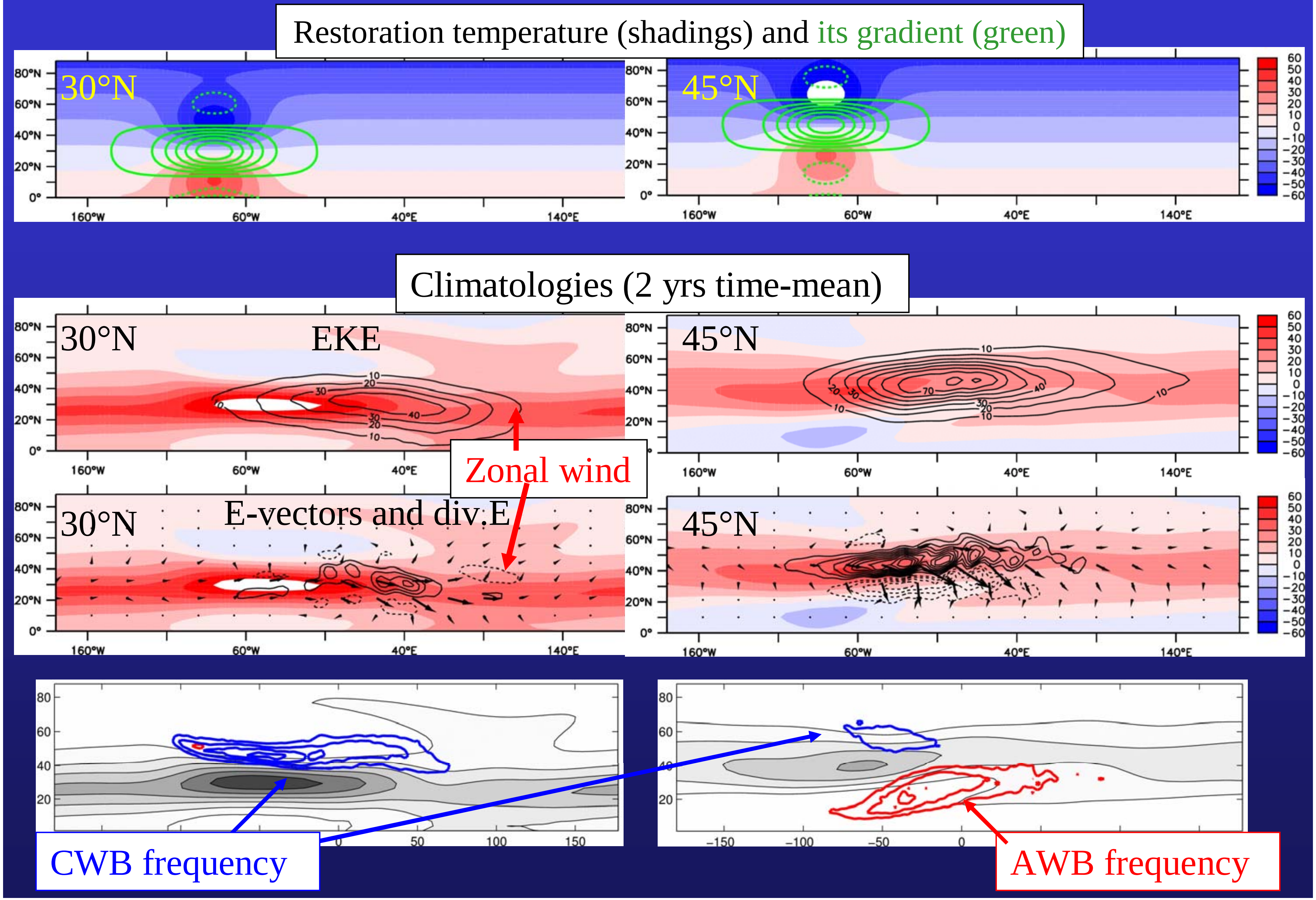
Long-term runs: QG model, zonal case, T42

Absolute vorticity snapshot at 200hPa (shadings) and temperature restoration (contours)



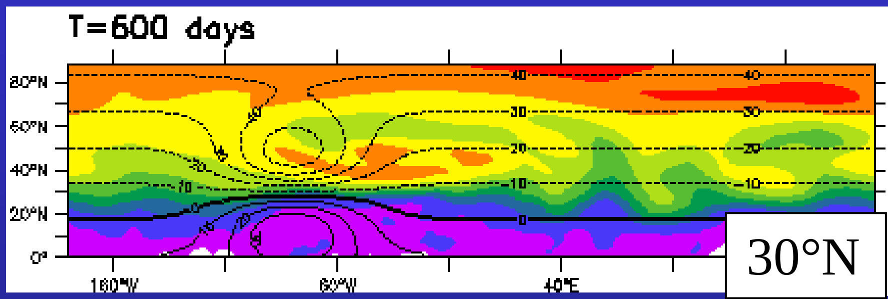
AWB dominates in both cases !! It is characterized by thin cyclonic tongues that are SW-NE stretched

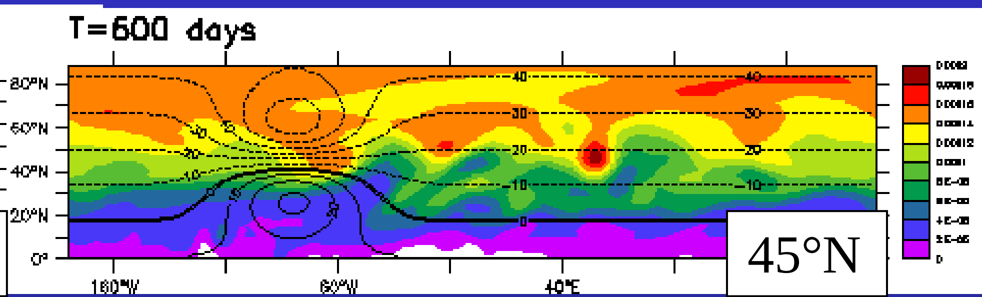
Long-term runs: PE model, zonal case, T42



Long-term runs: PE model, zonal case, T42

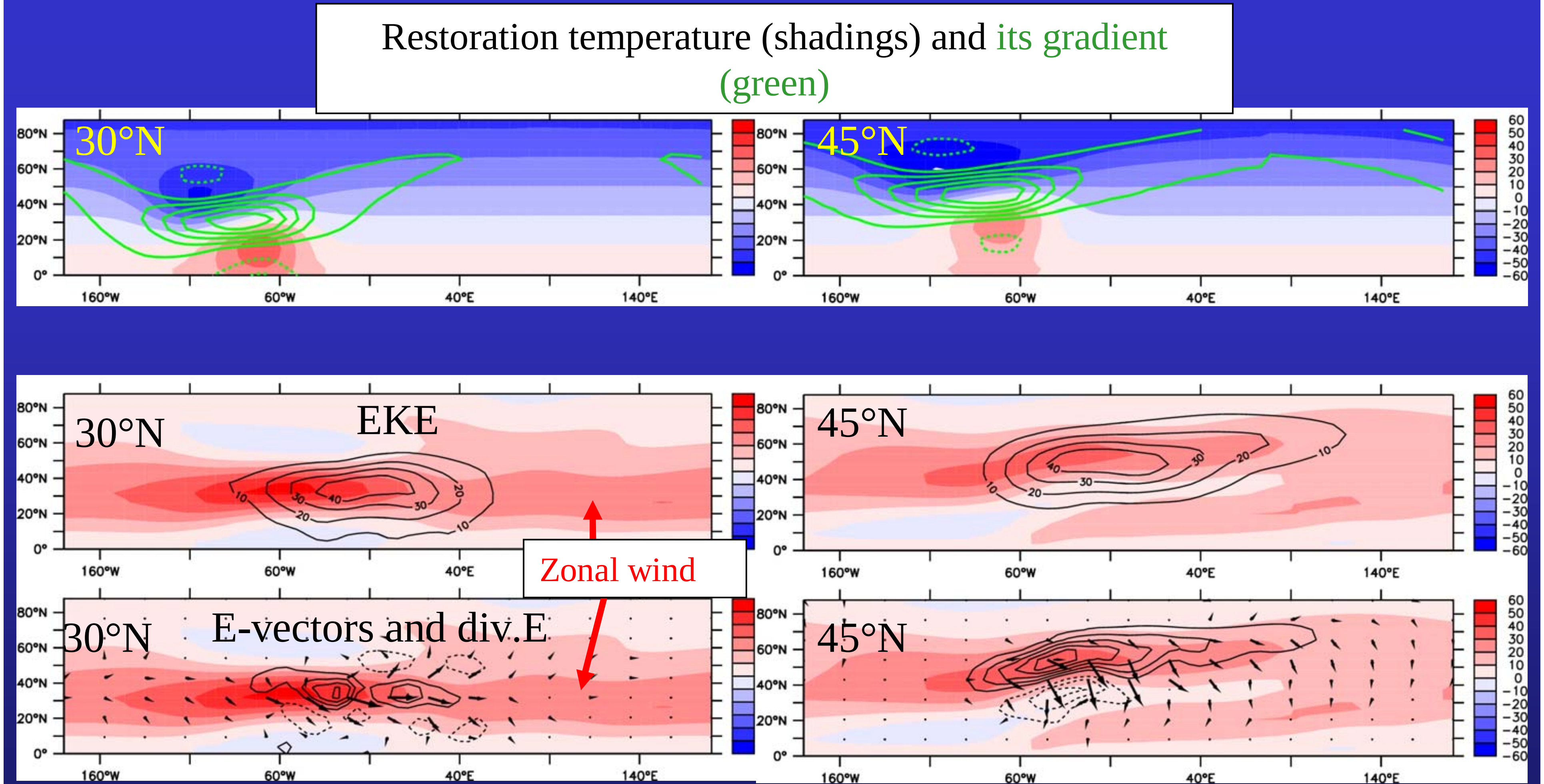
Absolute vorticity snapshot at 200hPa (shadings) and temperature restoration (contours)



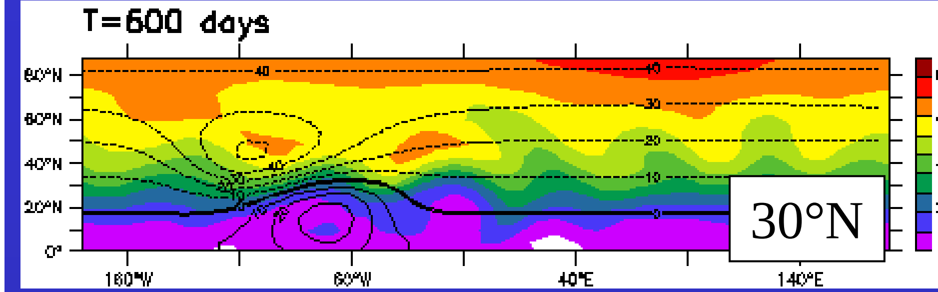


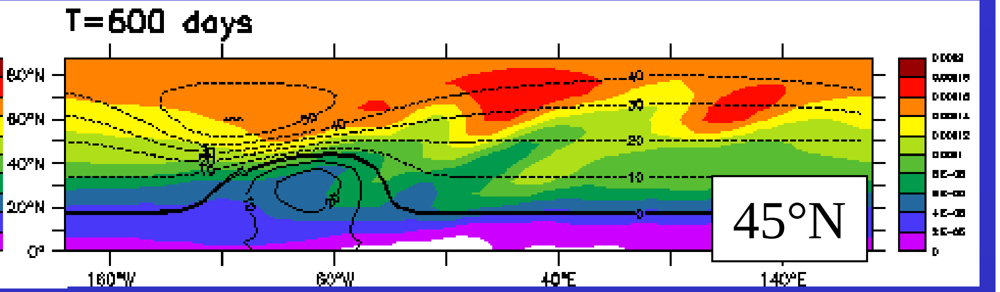
AWB dominates for the 45° case and CWB for the 35° case !!

Long-term runs: PE model, more realistic case, T21



Same conclusions as before for a more realistic temperature-restoration field and other resolutions.





Conclusions

Already known: AWB favored by absolute vorticity asymmetries
(James, 1995; Orlanski, 2003)

New points:

• Stretching term asymmetry favours CWB, especially at low levels.

• CWB rare in the QG model due to the absence of the ST effect.

• AWB is more probable for jets or low-level baroclinicity fields located more in the north. The reverse for CWB.

• A positive eddy feedback acting on the NAO: during NAO+, the jet is more in the north making more probable AWB that acts to maintain or shift the jet poleward. paper submitted to JAS

Application: impact of SSTs anomalies on the NAO

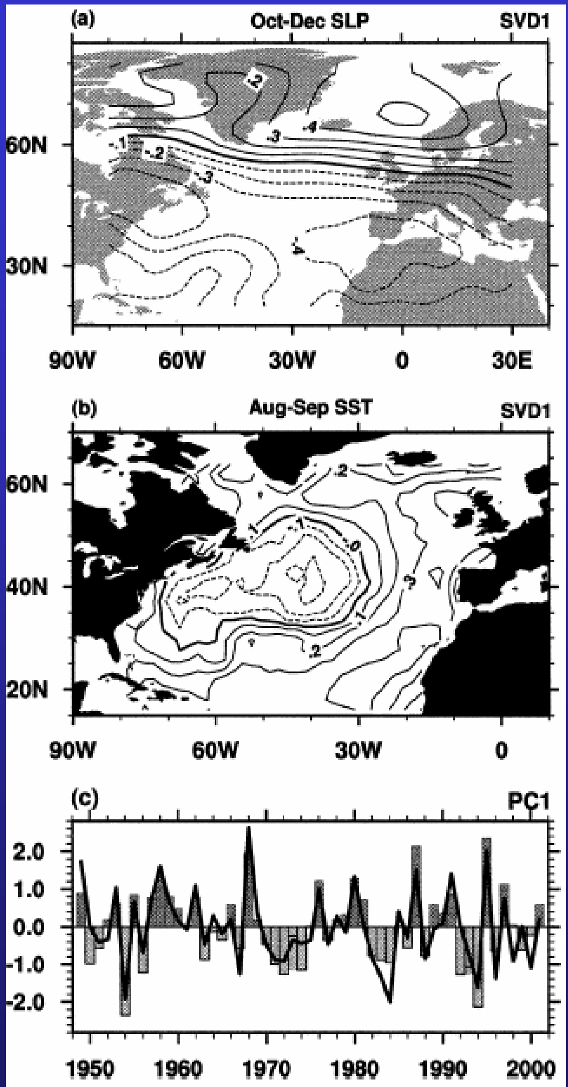


FIG. 1. First singular value decomposition modes calculated between (a) OND SLP (hPa) and (b) AS SST (°C) computed from NCEP–NCAR over the 1949–2001 period. The covariance between the two modes is equal to 63.9%. Contour intervals are respectively 0.1 hPa and 0.1°C. (c) Normalized time series related to the AS SST (bars) and OND SLP (solid line) leading SVD mode. The correlation between the two PC time series reaches 0.72 (significant at 99%).

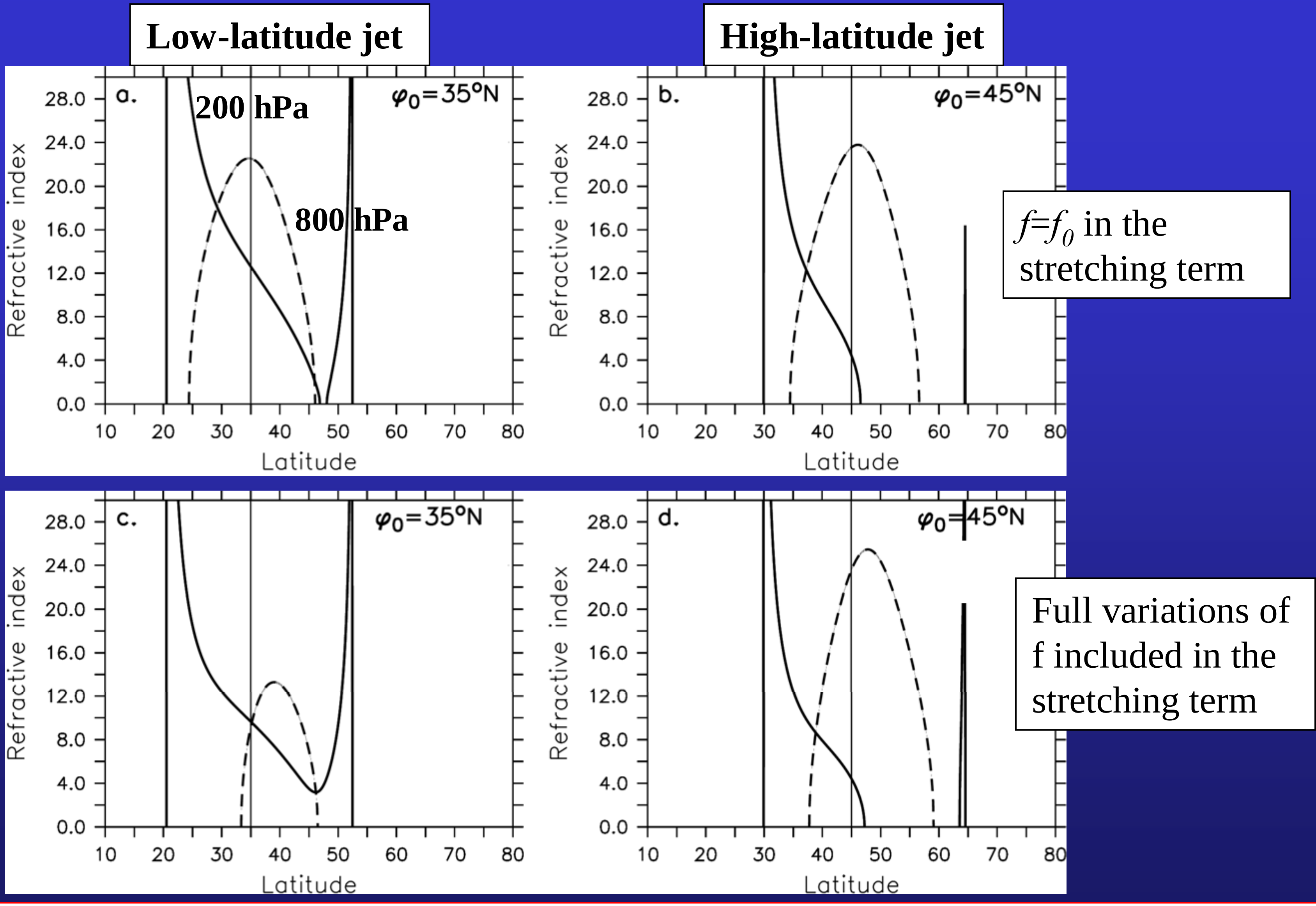
1st EOF SLP (Oct-Dec)

Correlations between summer SSTs anomalies and early winter NAO (Cassou et al., 2004).

1st EOF SST (Aug-Sep): « horseshoe » anomaly

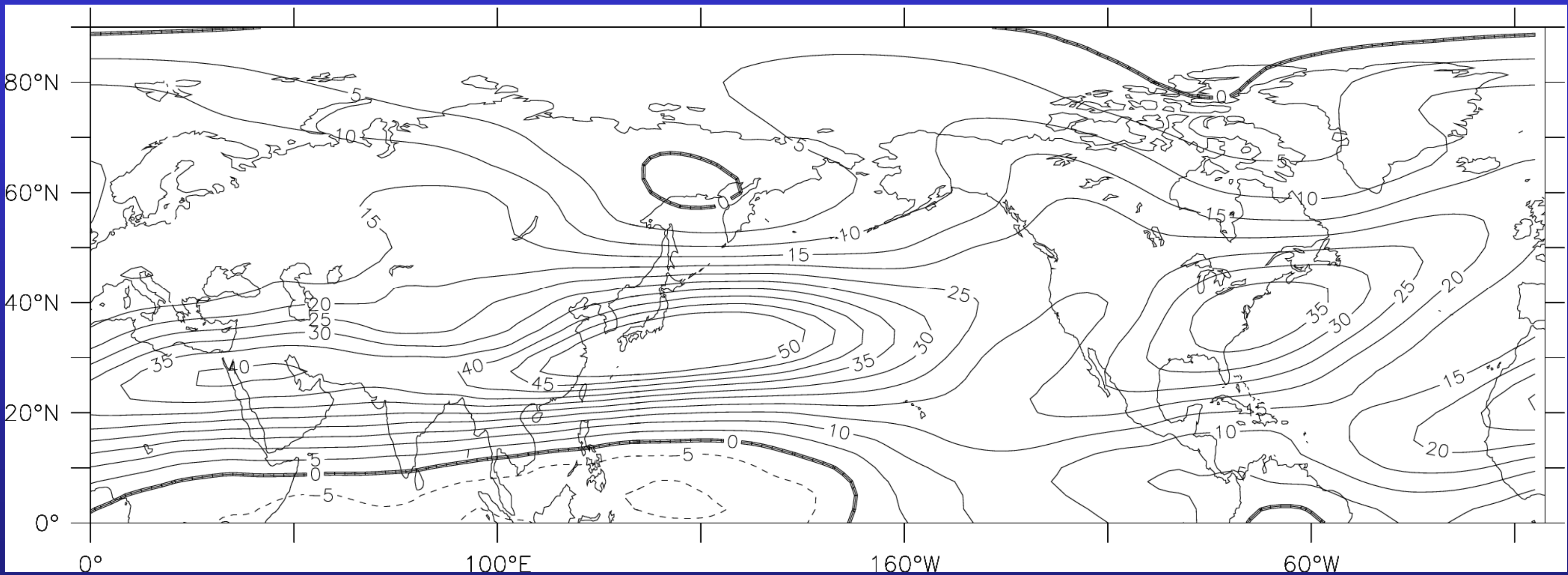
Possible interpretation: Increase of $-\partial_y SST$ in the south and decrease in the north favors more CWB and less AWB.

Effect of jet-latitude on the refractive index

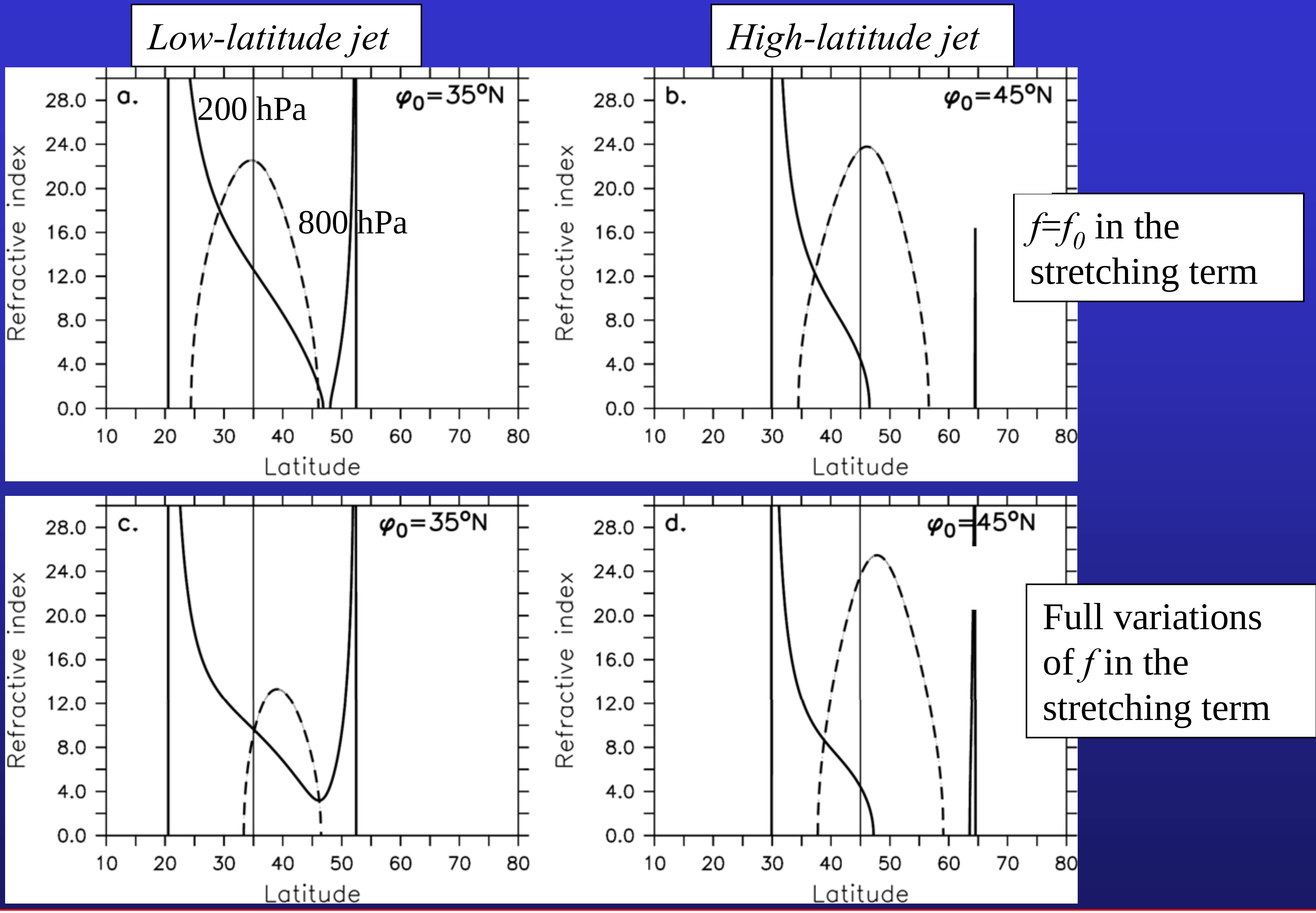


As the jet latitude decreases, the cyclonic and anticyclonic tilt become more and less probable respectively.

Zonal wind winter climatology in the Northern Hemisphere between 1950 and 1999



The jet latitude effect on the refractive index



As the jet latitude decreases, the cyclonic tilt at low levels and the anticyclonic tilt at upper levels becomes more and less probable.