Teleconexiones

Forzamiento de ondas de Rossby desde los trópicos

Teleconexiones

A PALAVRA teleconexão significa conexão a distância e, em meteorologia, explica como anomalias que ocorrem em uma região são associadas a anomalias em regiões remotas. O termo "padrão de teleconexão", ou simplesmente "teleconexão", refere-se a um padrão recorrente e persistente de anomalias de uma determinada variável, por exemplo, pressão e circulação de grande escala, que cobre vastas áreas geográficas. Padrões de teleconexão são também conhecidos como modos preferenciais de variabilidade de baixa frequência. Embora esses padrões possam persistir por várias semanas ou meses, algumas vezes eles podem se tornar dominantes por vários anos consecutivos e, dessa forma, mostram uma parte importante da variabilidade interanual e interdecenal da circulação atmosférica.

As primeiras evidências de teleconexões globais surgiram nas análises de dados de pressão em superfície disponíveis no final do século XIX (p.ex. Hildebrandsson, 1897; Lockyer e Lockyer, 1904). Quase duas décadas mais tarde, Walker (1924) identificou três grandes oscilações atmosféricas: a Oscilação do Atlântico Norte (OAN), a Oscilação do Pacífico Norte (OPN) e a Oscilação Sul (OS), que possui centros de ação nos trópicos do HS. Em um artigo posterior, Walker e Bliss (1932, p. 60)

Essas conclusões basearam-se em correlações de pressão em superfície, temperatura e precipitação obtidas de estações de superfície muito distantes entre si. Na época de sua divulgação, seus resultados não foram bem aceitos pela comunidade científica, uma vez que a ideia era extremamente nova e controversa. A OS voltou a ser estudada quando

Teleconnections

- Existence of large scale correlations in the flow at remote locations.

- Take the form of standing waves with fixed nodes and antinodes of low-frequency oscillations.

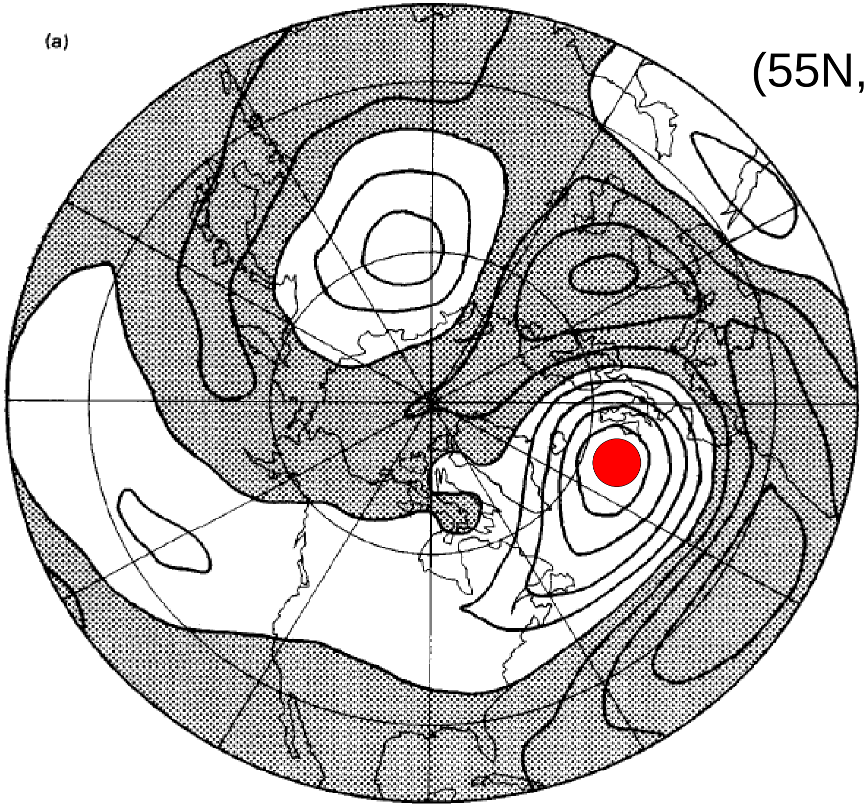
- Often orientated in such a way as to indicate connections between tropical and midlatitude low frequency transients.

- How to detect teleconnection patterns?
  - Use monthly mean data
  - Simplest method, correlation matrix: where Qi(t) is a variable (time,space)

$$r_{ij} = \frac{\overline{Q'_i Q'_j}}{\overline{Q'^2_i}^{1/2}\,\overline{Q'^2_j}^{1/2}}.$$

Teleconnections 500mb geopotential height (DJF)

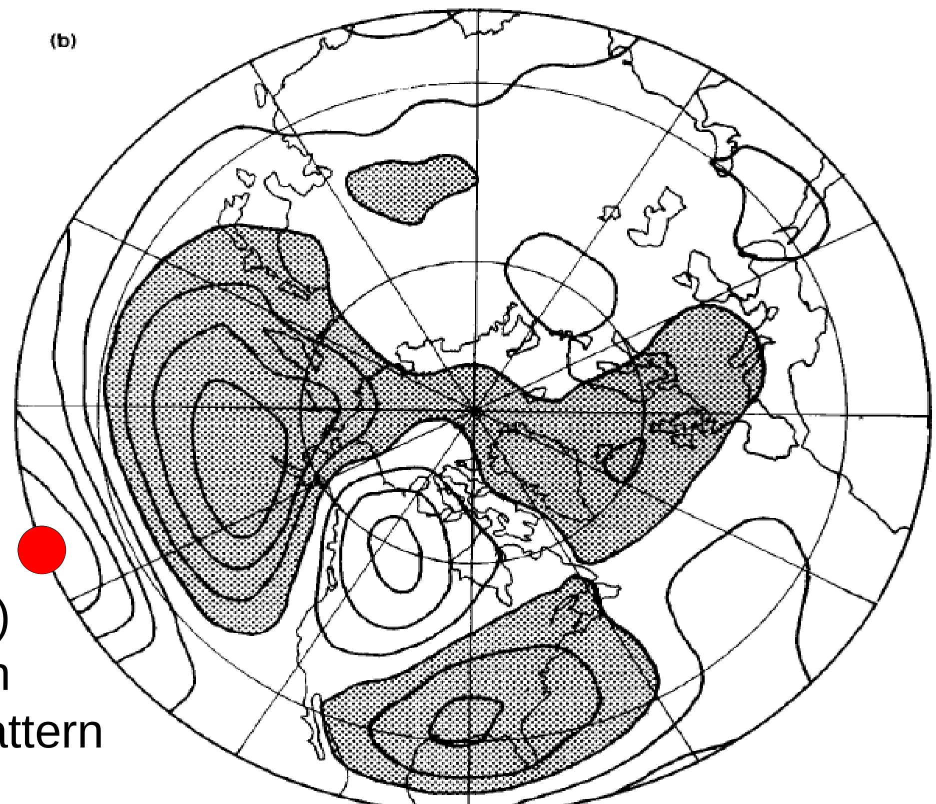
(a)



(55N, 20W)

Trains of waves are very similar to Rossby wavetrains.

(b)

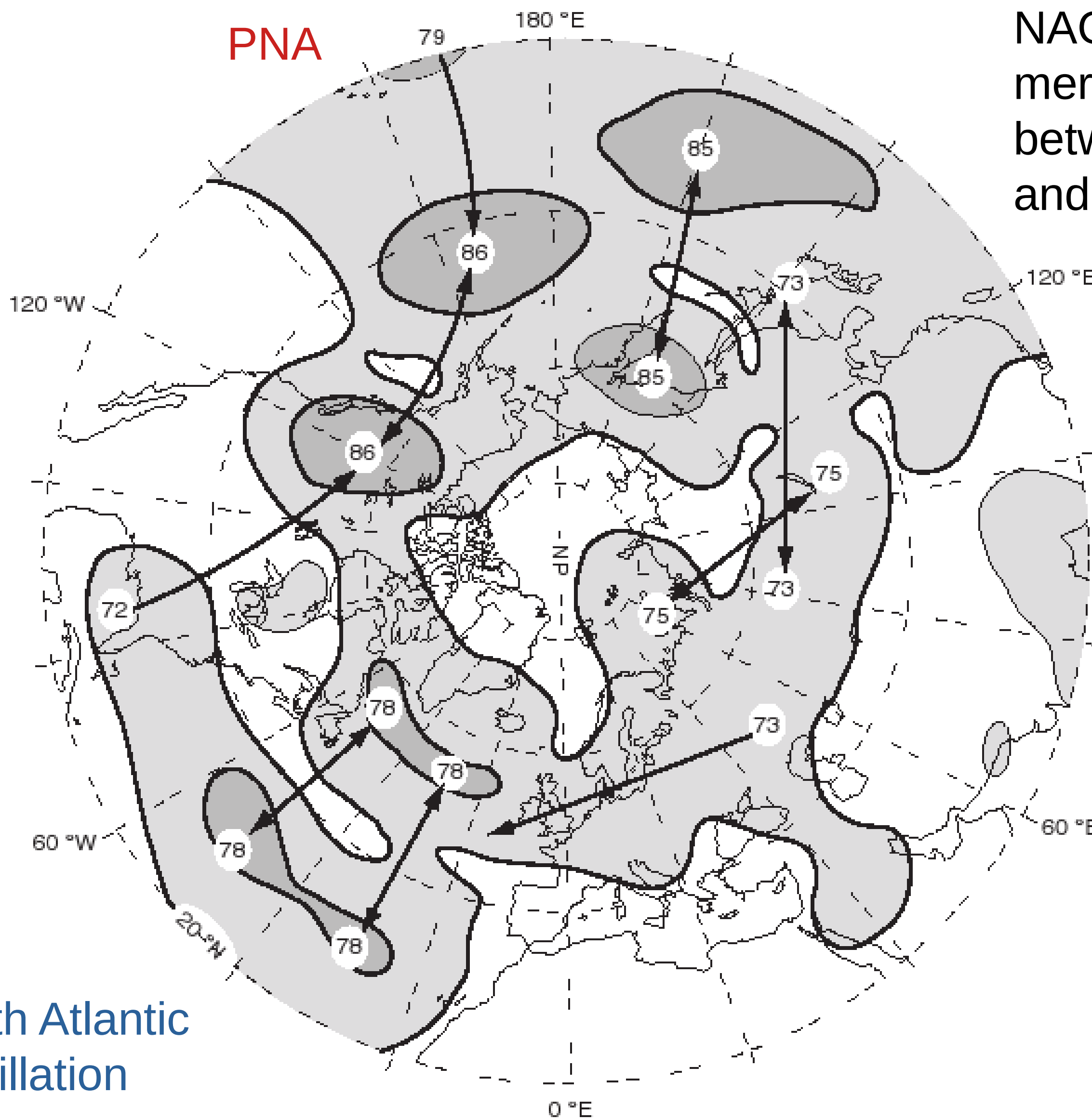


(20N, 160W)
Pacific North
American pattern

Wallace & Gutzler 1981

Teleconnectivity map $T_i = |\min r_{ij}|$

PNA



NAO and PNA represent a meridional connection between tropics/subtropics and midlatitudes

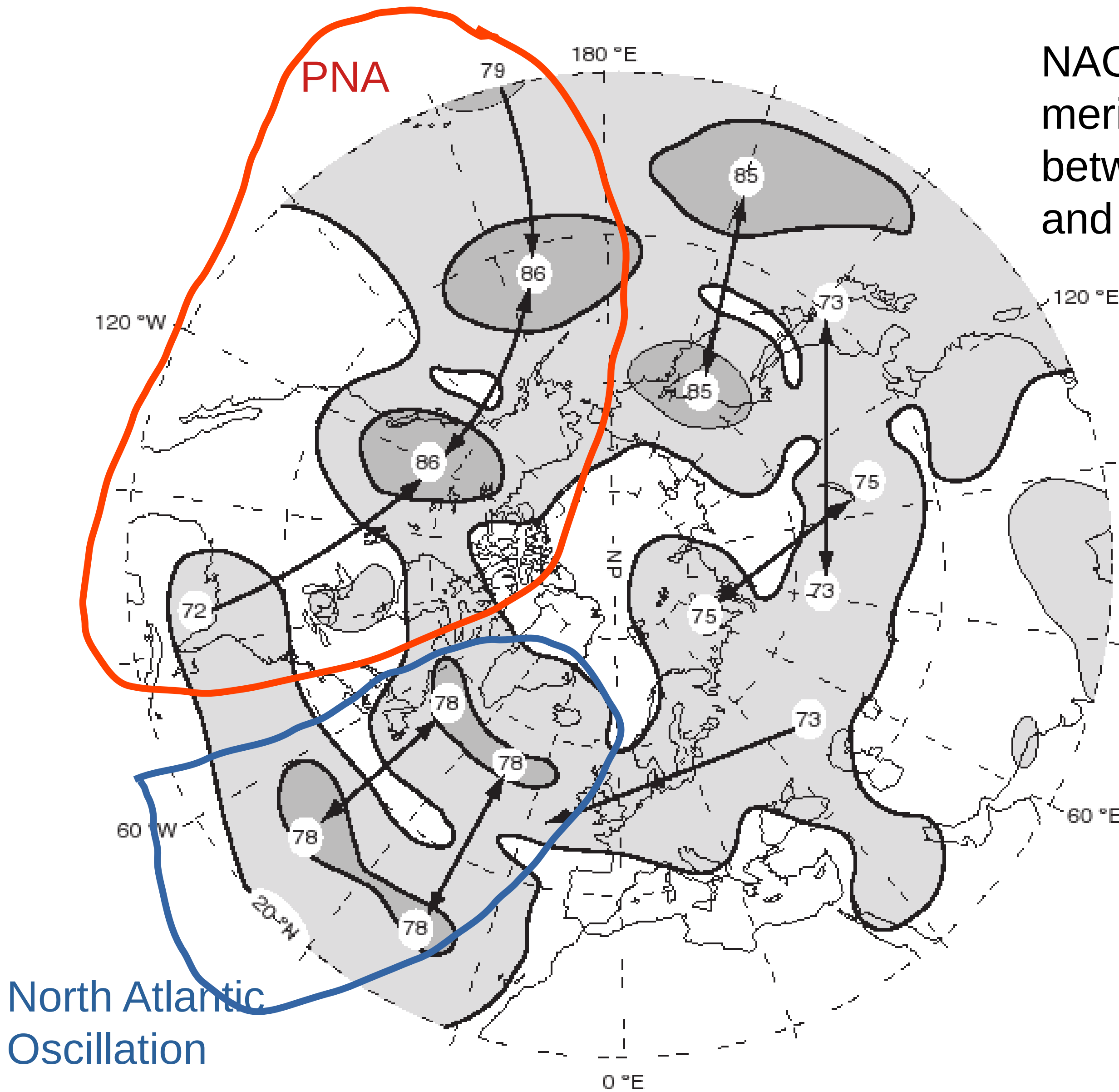
North Atlantic Oscillation

Wallace & Gutzler 1981

Teleconnectivity map

$T_i = |\min r_{ij}|$

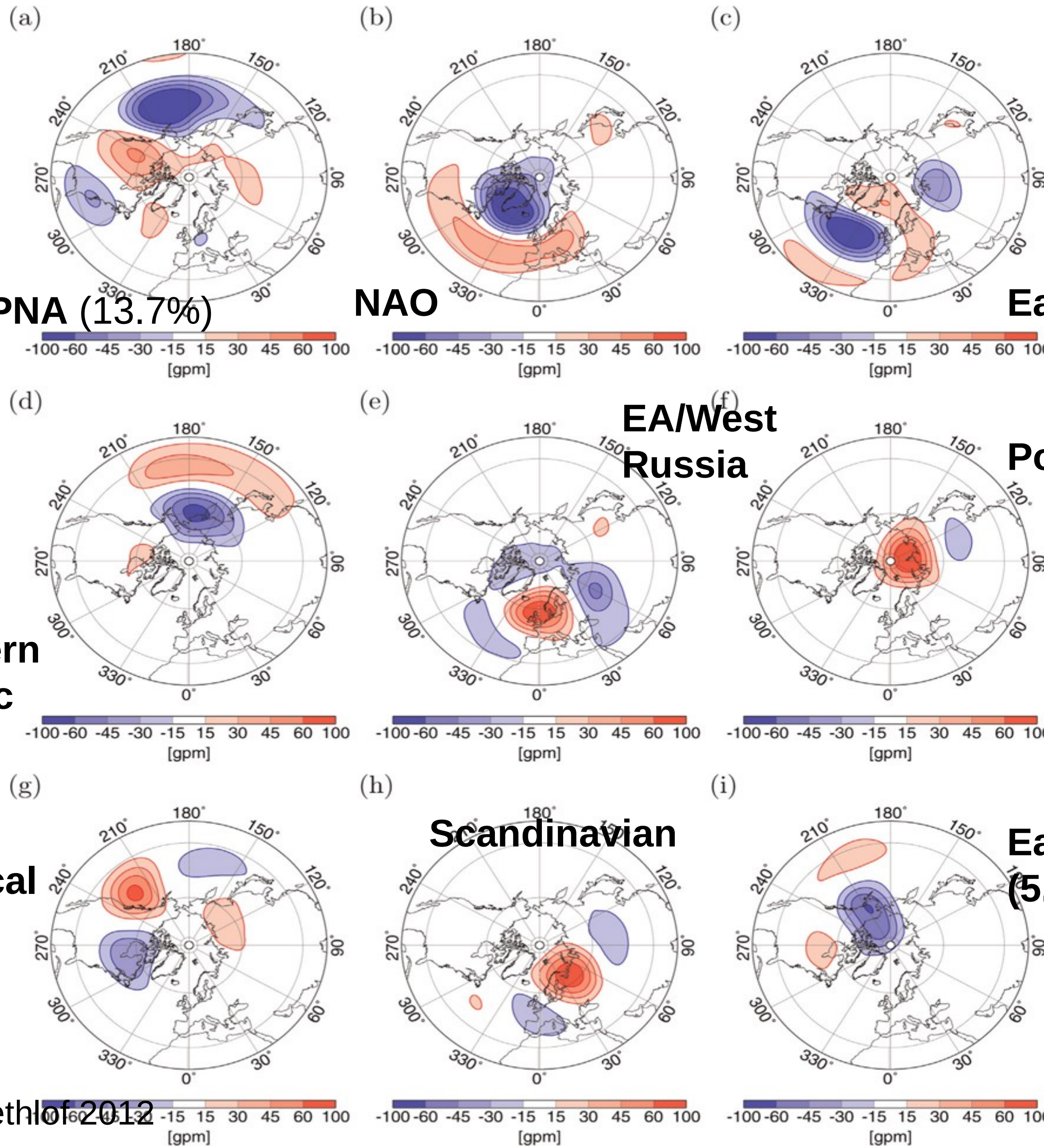
NAO and PNA represent a meridional connection between tropics/subtropics and midlatitudes



Wallace & Gutzler 1981

DJF, 500mb

EOFs



PNA (13.7%)

NAO

East Atlantic

Western Pacific

EA/West Russia

Polar

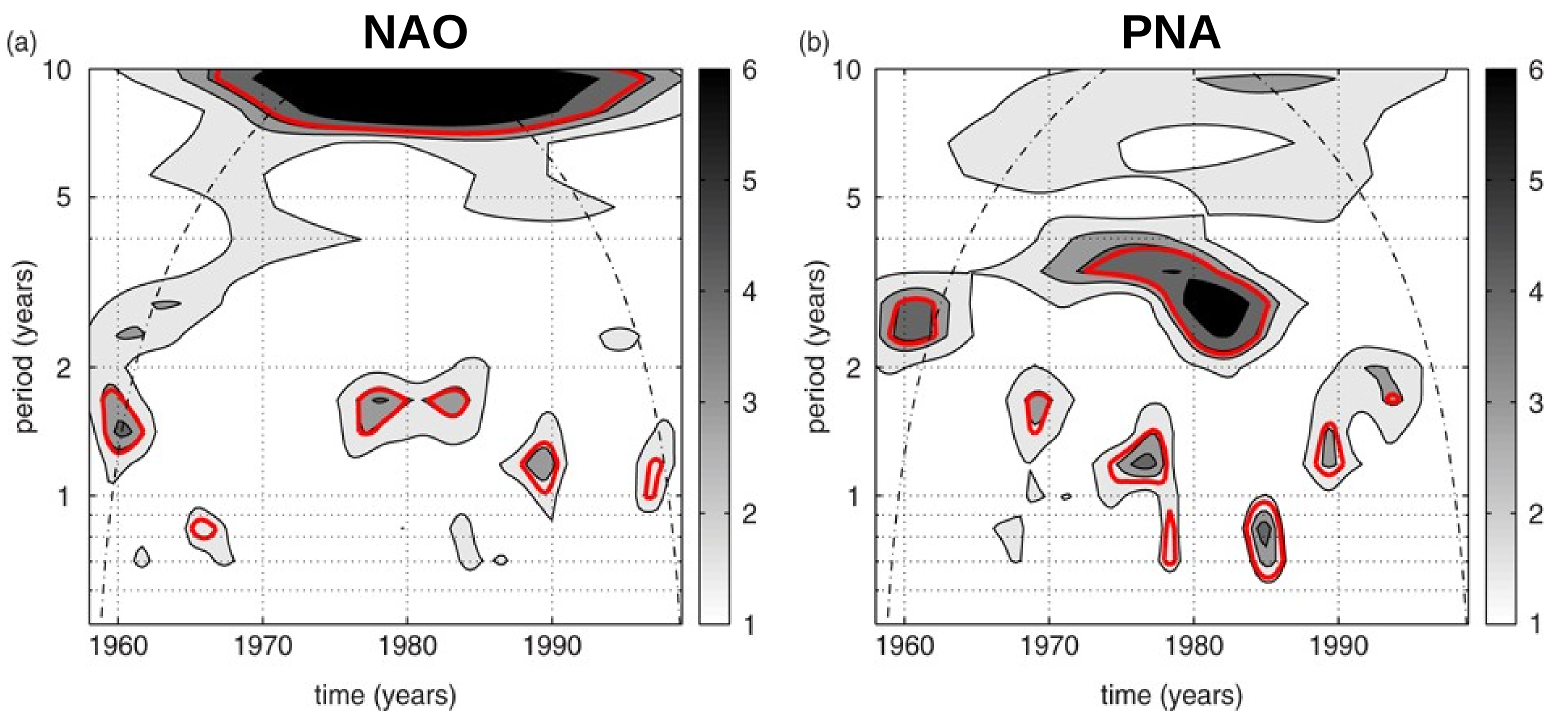
Tropical NH

Scandinavian

East Pacific (5.7%)

Handorf & Dethlof 2012

Wavelet Power spectrum



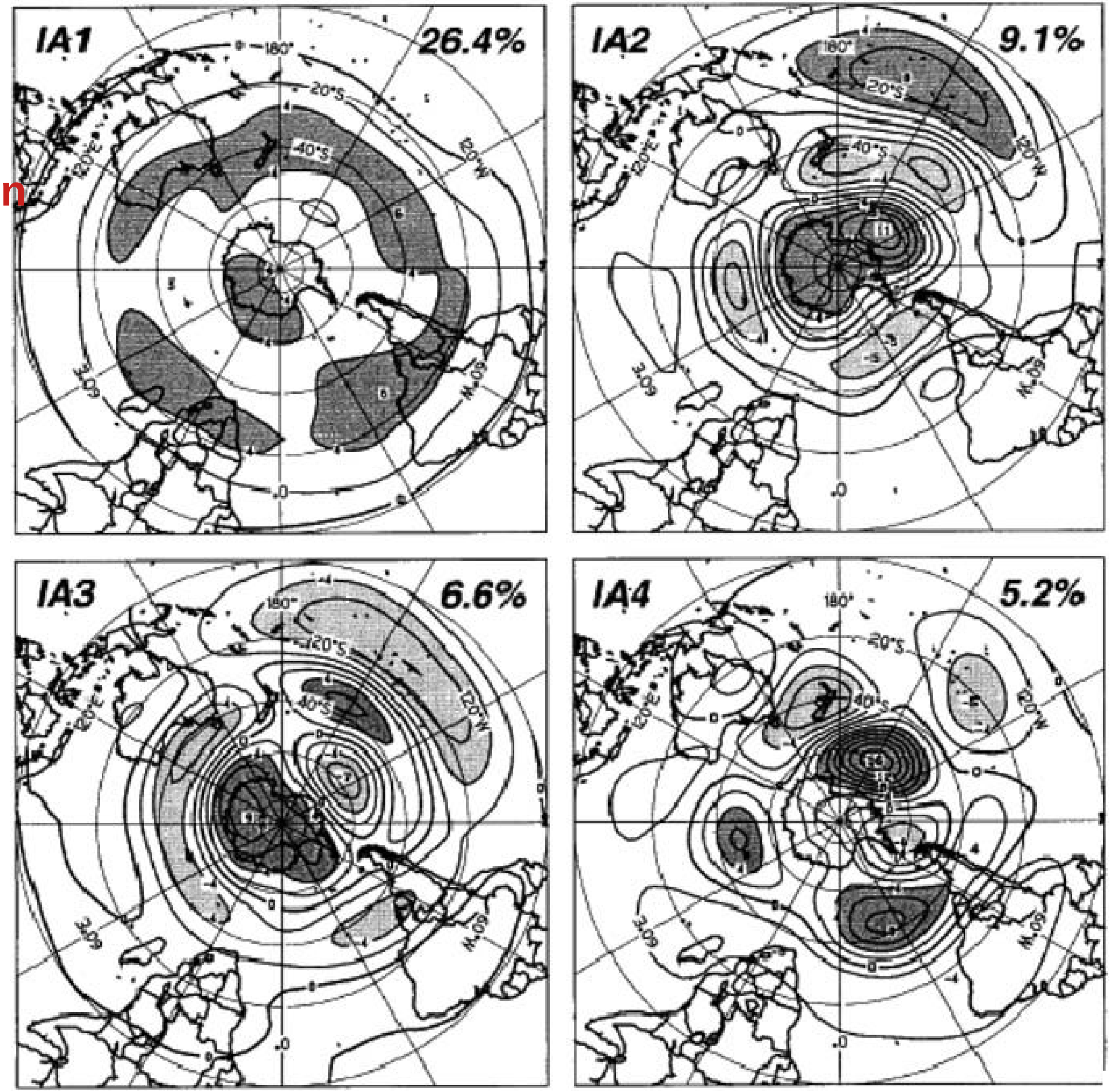
No preferred time scale for NAO and PNA during whole period, but NAO has a significant 8 yr peak and PNA a 2-4 yr significant band.

Handorf & Dethlof 2012

300mb

Southern Annular Mode

Pacific South American 1



Pacific South American 2

Kidson 1999

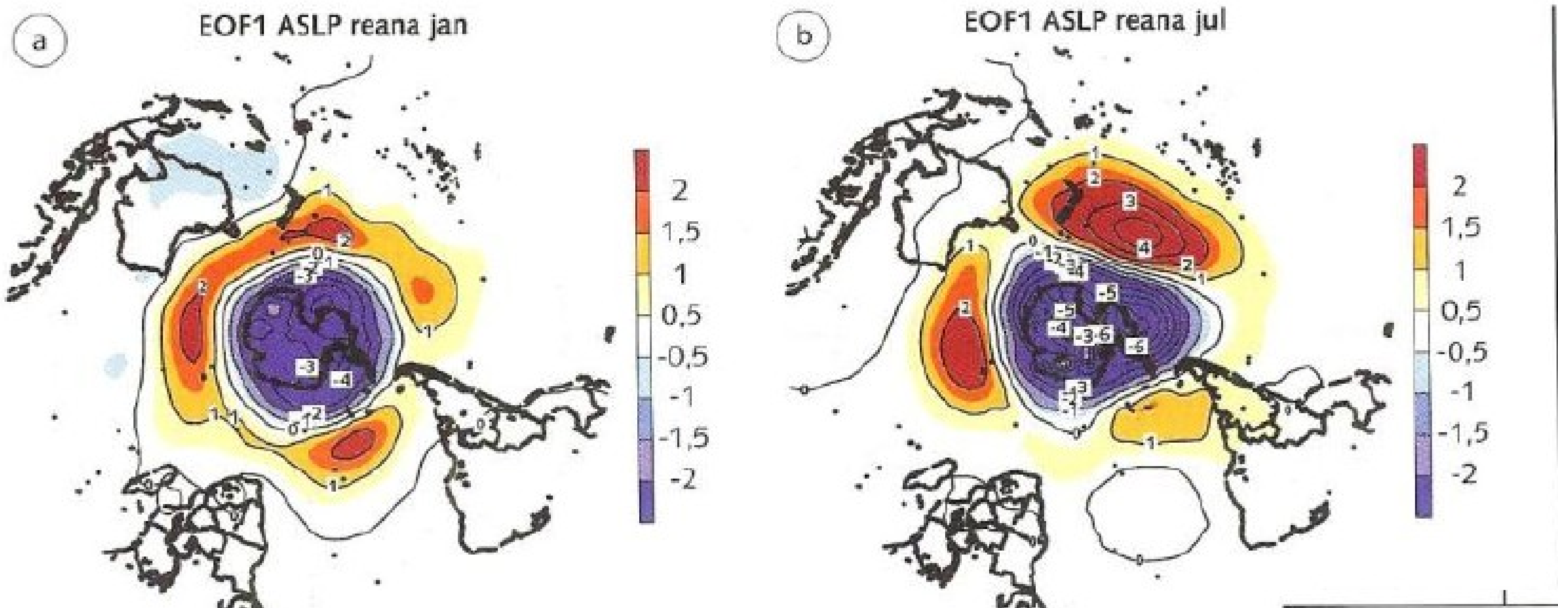
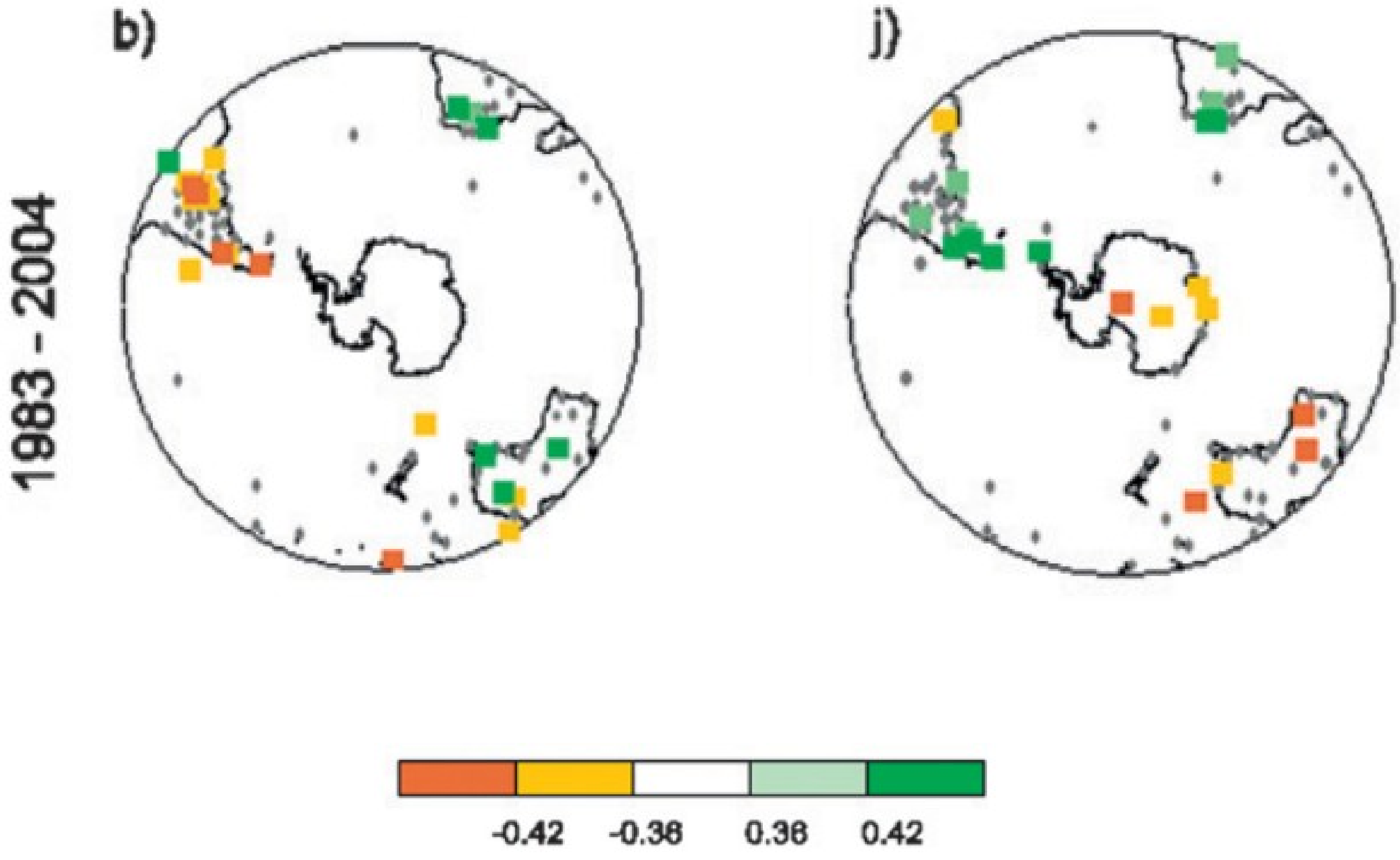


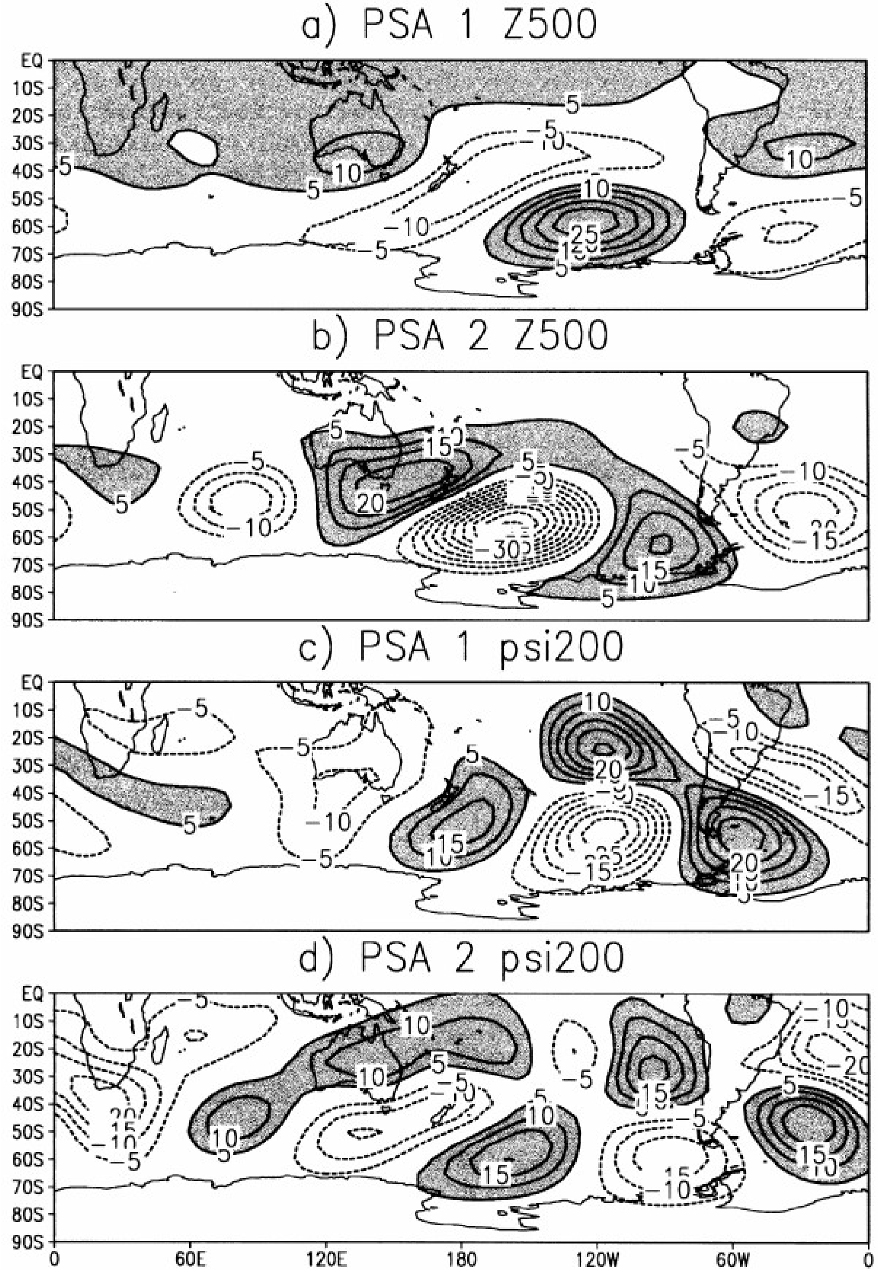
Fig. 20.4 Padrão da OA obtido no primeiro modo de variabilidade interanual com anomalias de pressão ao nível do mar em (a) janeiro; (b) julho

SAM = OA

SAM disminuye RR y aumenta T sobre sudeste S.A.

Precipitaciones **OND** Temperatura





Mo & Paegle 2001

Figure 1. (a) EOF 2 (PSA1) and (b) EOF 3 (PSA2) of the 500-hPa seasonal mean height anomalies. Contour interval five non-dimensional units. Zero contours are omitted, positive loadings are shaded. (c) Same as (a) but for EOF 3 of the 200-hPa eddy streamfunction anomalies (psi200) with zonal means removed, and (d) same as (c) but for EOF 4

Tropically forced Rossby wave trains

- The similarity between teleconnection patterns and trains of steady Rossby waves suggests that propagation of waves with zero, or small, phase speed is a likely mechanism that can give rise to teleconnection patterns.

- The patterns could be excited by a tropical heating anomaly consequence of warmer than usual SST.

Warm SST → ascent → tropical heating →

vorticity generation → Rossby wave

How can an SST anomaly excite extratropical waves?

Consider the vorticity equation at 200mb (no friction)

$$\frac{\partial \zeta}{\partial t} + \boldsymbol{v} . \nabla \zeta = -\zeta D \qquad D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}, \quad \zeta = f + \xi$$

If

$$\boldsymbol{v} = \boldsymbol{v}_\psi + \boldsymbol{v}_\chi$$

$$\boldsymbol{v}_\psi = k \, x \nabla \psi, \quad \boldsymbol{v}_\chi = \nabla \chi$$

Rotational Divergent

Then

$$\xi = \nabla^2 \psi, \quad D = \nabla^2 \chi$$

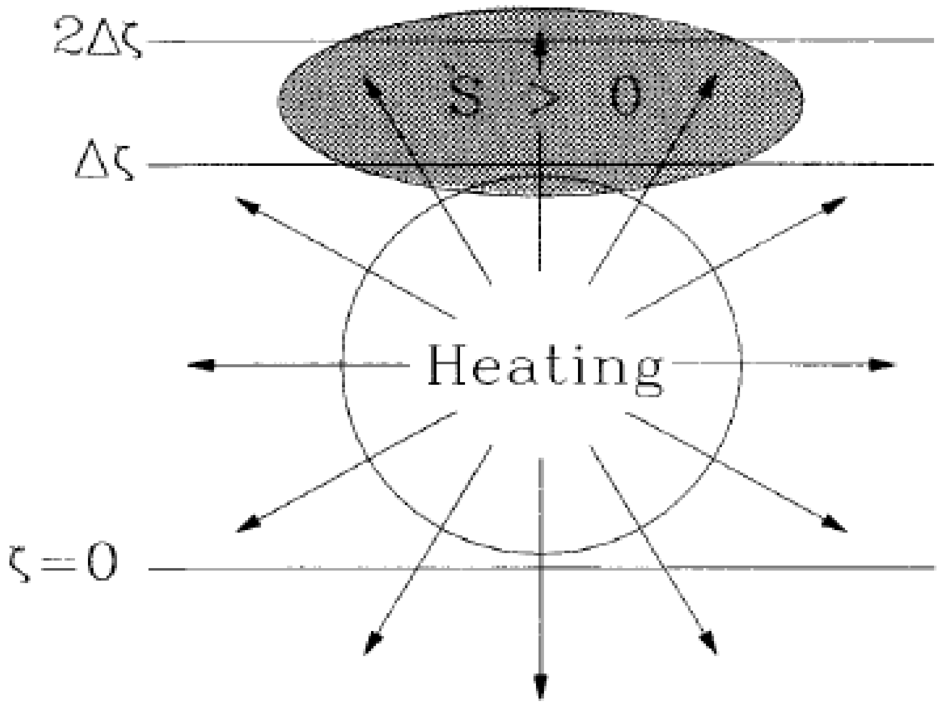
$$\frac{\partial \zeta}{\partial t} + \boldsymbol{v}_\psi . \nabla \zeta = -\zeta D - v_\chi . \nabla \zeta$$

Rossby wave propagation

Rossby wave source (S)
Vortex stretching + advection of vorticity

$$S = -\nabla \cdot (\mathbf{v}_\chi \zeta).$$

We can now see how Rossby waves can be excited by tropical heating, even though ζ is often small in the vicinity of the heating. The divergent flow will be largest around the edge of the heating region, outside the region where D is large. The gradients of ζ become large as one approaches the subtropics, and so S can be large in the subtropics, either side of a tropical heating maximum. Figure 8.5 illustrates this schematically.



Large divergent flow close to subtropics where vorticity increases

Fig. 8.5. Schematic illustration of the forcing of a train of Rossby waves by a maximum of tropical heating. The hatched region indicates the region where Rossby wave source function is large.

James (1993)

Rossby wave sources are maximum in subtropics even though divergence is maximum in equatorial areas.

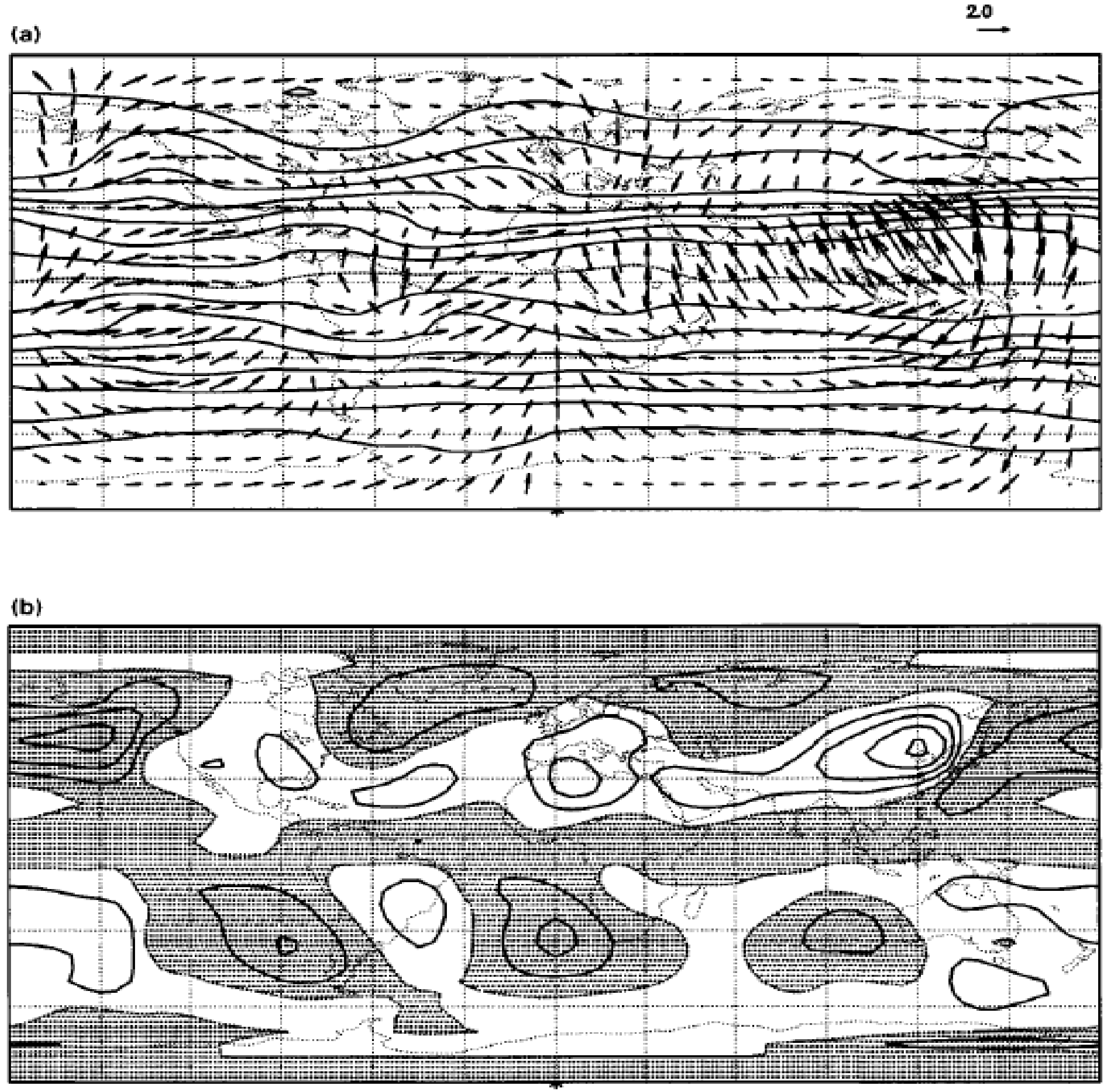
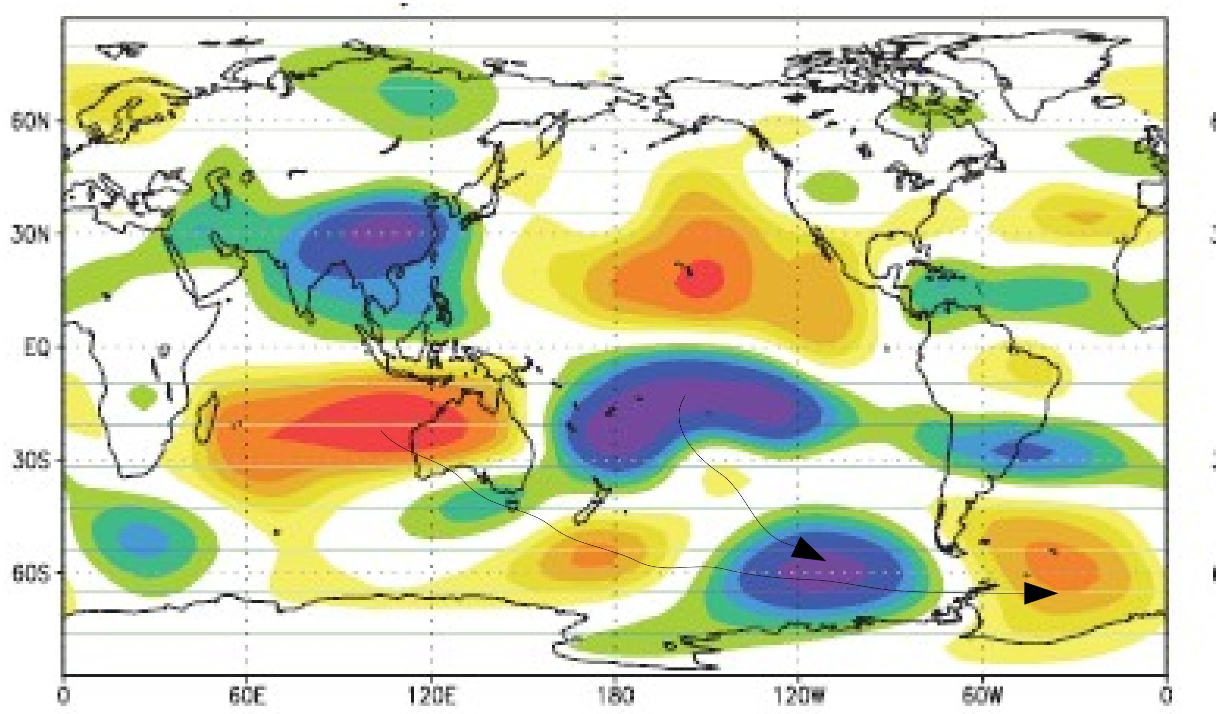


Fig. 8.6. The Rossby wave source S for DJF, 1979–89 at 15 kPa. (a) Contours of absolute vorticity ζ, contour interval $2 \times 10^{-5}\,\mathrm{s}^{-1}$, and vectors of the divergent wind $\mathbf{v}_\chi$. The sample vector indicates $2\,\mathrm{m\,s}^{-1}$. (b) S, contour interval $5 \times 10^{-11}\,\mathrm{s}^{-2}$, with shading indicating negative values.

During El Niño the atmospheric heating anomaly generates wave trains in the upper atmosphere that connect remote regions.



Why do they follow that path?

Consider a mean flow of the form U=U(y), linearize the barotropic vorticity equation, assume (eddy relative vort)<dU/dy and consider that the forcing is concentrated in a small region. We obtain

$$\frac{\partial \zeta}{\partial t}+\boldsymbol{v}.\nabla \zeta=-\zeta D \quad \Longrightarrow \quad \frac{\partial \xi^*}{\partial t}+U\frac{\partial \xi^*}{\partial x}+(\beta-U_{yy})\frac{\partial \psi^*}{\partial x}=0.$$

Searching for solutions of the form $\xi^* = \mathbf{Z}e^{i(kx+ly-\omega t)}$

We get the dispersion relation of Rossby waves

$$\omega = Uk-(\beta-U_{yy})k/K^2.$$

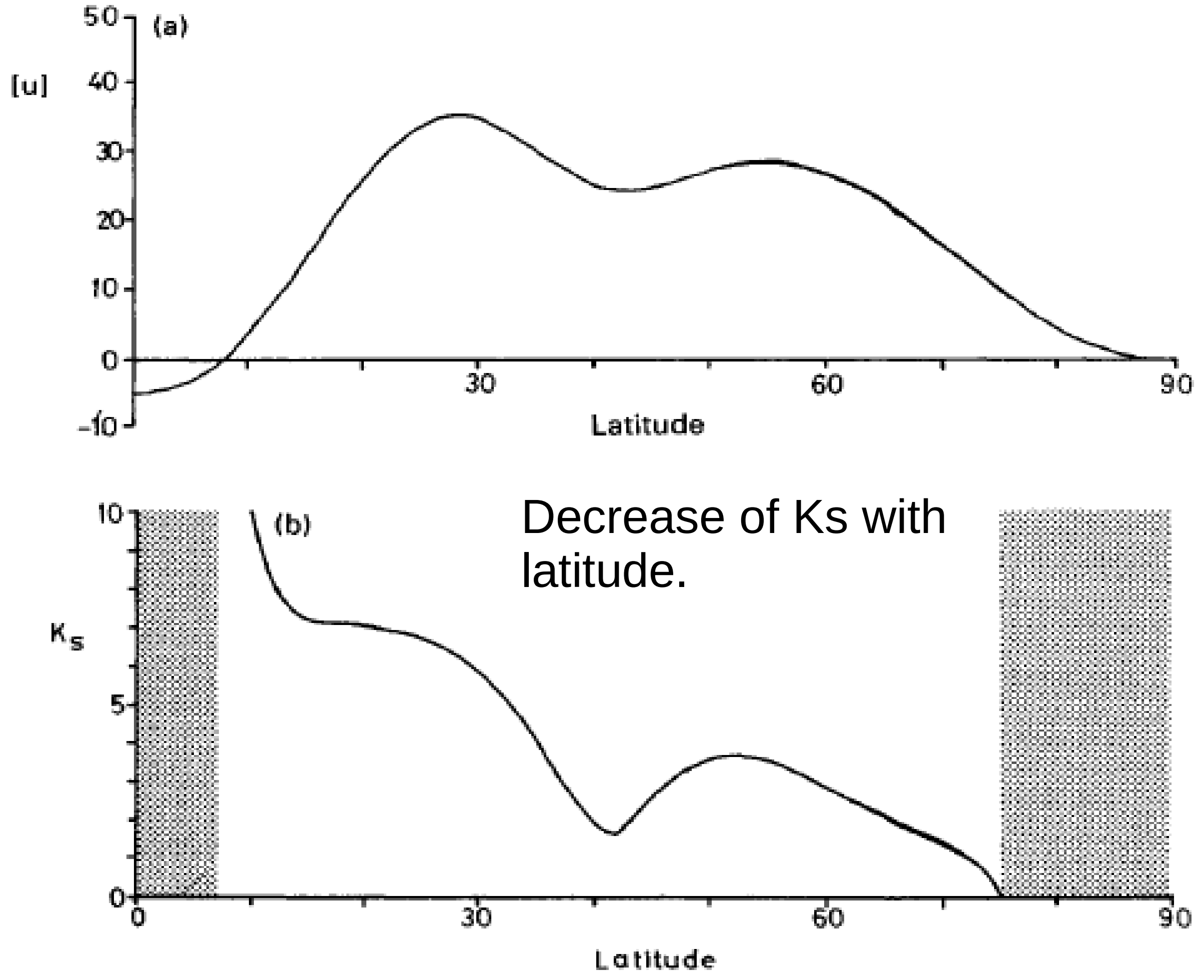
which are westward propagating waves (relative to the mean flow) ($K=k^2+l^2$).

For steady Rossby waves w=0 and $l=\pm\left\{(\beta-U_{yy})/U-k^2\right\}^{1/2}$

l is real (allowing existence of waves) if $K_s = ((\beta-U_{yy})/U)^{1/2} > k$

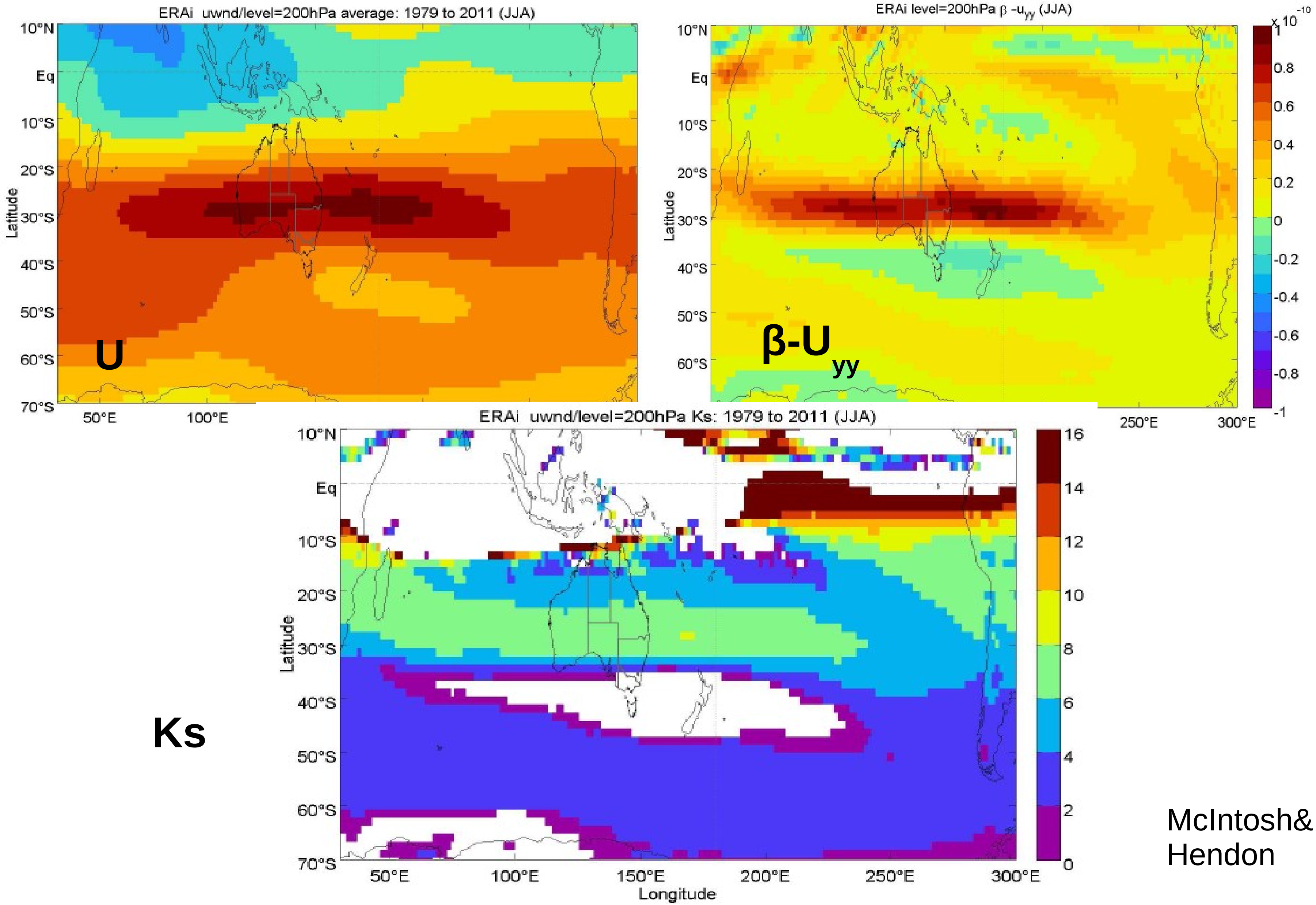
Since $\beta > U_{yy}$ there is no wave propagation in easterlies ($U<0$).

than k. A typical tropospheric zonal wind is $15\,\mathrm{m\ s^{-1}}$; at $45\,°\mathrm{N}$, β is $1.6 \times 10^{-11}\,\mathrm{m^{-1}\,s^{-1}}$. Assuming that U_{yy} is small compared to β, we find that the total steady wavenumber is $1.04 \times 10^{-6}\,\mathrm{m^{-1}}$, which corresponds to zonal wavenumber 4 or 5 at this latitude. Near the tropospheric jet core, $-U_{yy}$ can be large, and could increase the total steady wavenumber. Equatorward of the jet, U is smaller and β is larger, so we anticipate a general increase in K_s as the subtropics are approached. Figure 6.9 shows K_s calculated using the 30 kPa zonal wind for the southern hemisphere 1979 winter by way of example. The K_s is imaginary north of $9\,°\mathrm{S}$ and has very large values



Decrease of Ks with latitude.

Fig. 6.9. (a) The 30 kPa zonal wind observed during the southern hemisphere FGGE winter. (b) The corresponding total steady wavenumber K_s. (From James 1988.)



McIntosh&
Hendon

If propagation is possible we want to find the path of the wave.

Group velocity

$$c_{gx} = 2(\beta - U_{yy})k^2/K^4,\ c_{gy} = 2(\beta - U_{yy})kl/K^4.$$

Then the propagation direction is given by (w.r.t zonal direction)

$$\alpha = \tan^{-1}(c_{gy}/c_{gx}) = \tan^{-1}(l/k).$$

And the magnitude of the group velocity can be written as

$$|\mathbf{c_g}| = 2U\cos\alpha.$$

which states that when the propagation is zonal the speed is 2U and when nearly meridional the velocity is small.

becomes small. Returning to the example of steady Rossby waves excited at 45 °N in a zonal wind of 15 m s^{-1}, consider propagation of packets with zonal wavenumber 3, that is, with $k = 6.7 \times 10^{-7}\,m^{-1}$. Since K_s was found to be $1.03 \times 10^{-6}\,m^{-1}$, and we must have $l^2 = K_s^2 - k^2$, it follows that $l = 7.8 \times 10^{-7}\,m^{-1}$. The packet will propagate in a direction making an angle of 49° with the zonal direction, and the group speed in this direction will be 20 m s^{-1}. The reader may quickly verify that such a packet will require around one day to influence a latitude 20° further poleward.

As the wave propagates meridionally the (β-U_{yy}) changes. If those changes happen over a distance that is large compared with the wavelength of the wave it is possible to make predictions about the path of the wave using the WKB (Wentzel-Kramers-Brillouin) approximation.

The condition might be true in the zonal, but not in the meridional direction.

Under the assumption of U=U(y) the wave number k will remain constant and l will change in order to satisfy the local dispersion relationship as the wave moves meridionally.

For stationary Rossby waves the propagation will be given by

$$k\ constant\ ,\quad k^2+l^2=Ks^2$$

$$\frac{dx}{dt}=\frac{2(\beta-U_{yy})k^2}{K^4}$$

$$\frac{dy}{dt}=\frac{2(\beta-U_{yy})k\,l}{K^4}$$

$$K_s = \sqrt{(\beta - U_{yy})/U}.$$

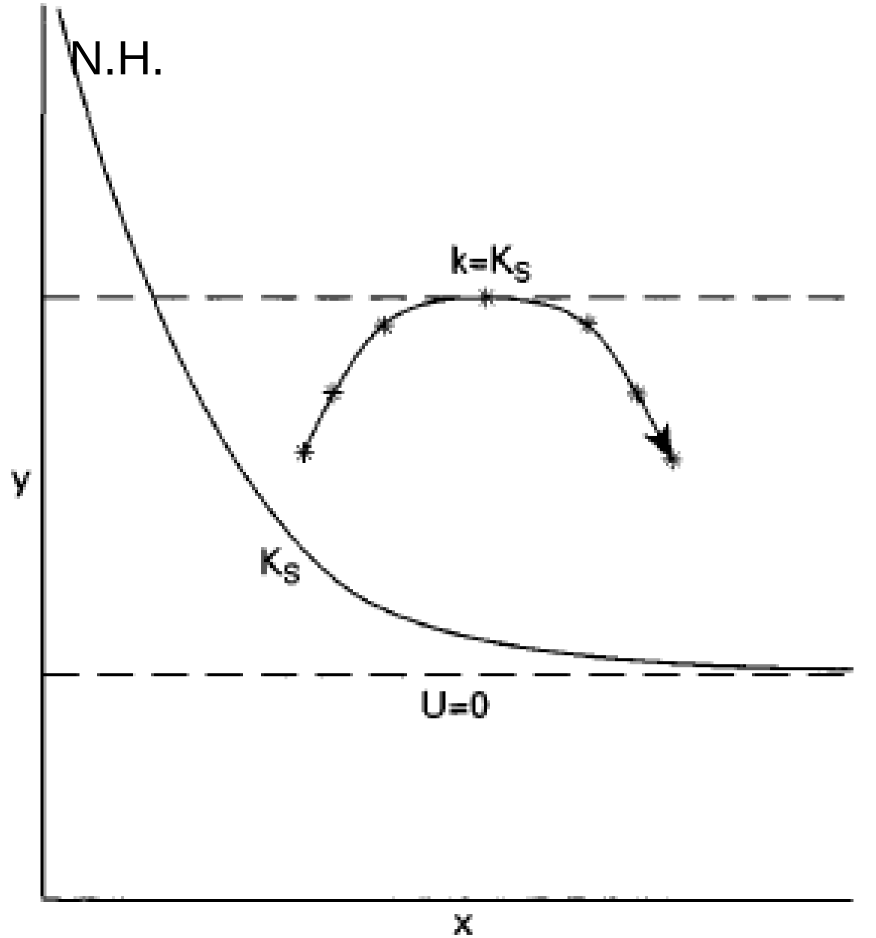
$$k \; constant\,, \quad k^2 + l^2 = Ks^2$$

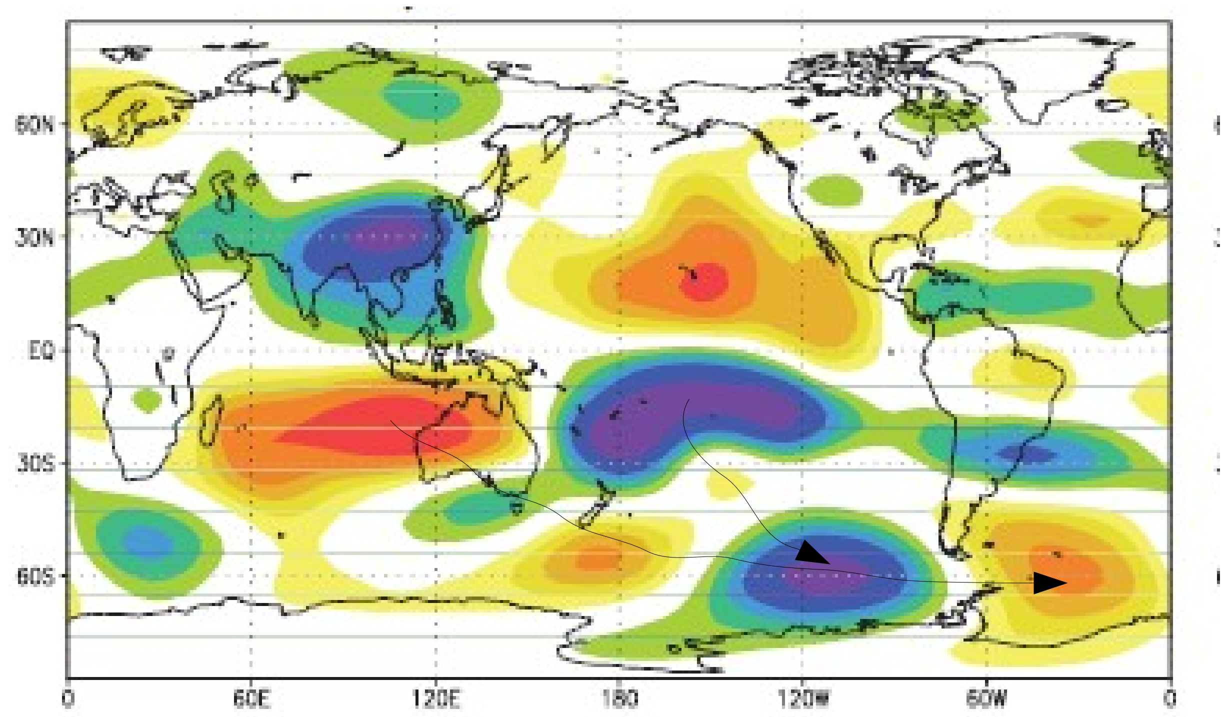
Example of a tropically
forced wave

β decreases with latitude
Uyy is max in jet streams

At Uyy=β Ks becomes
imaginary.

Aproximation breaks, l becomes
negative and wave is refracted




60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0

Waves “reflect” at maximum of upper level winds

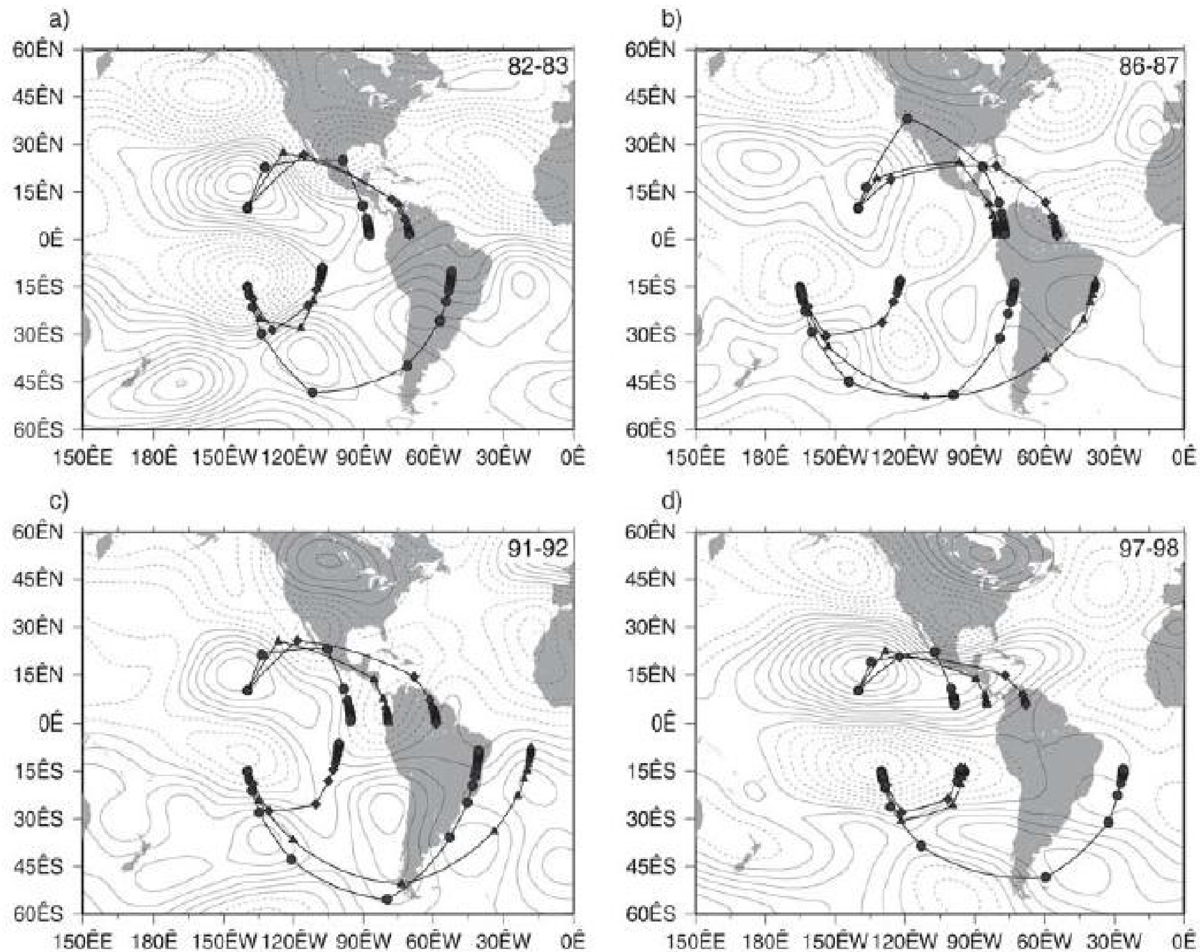
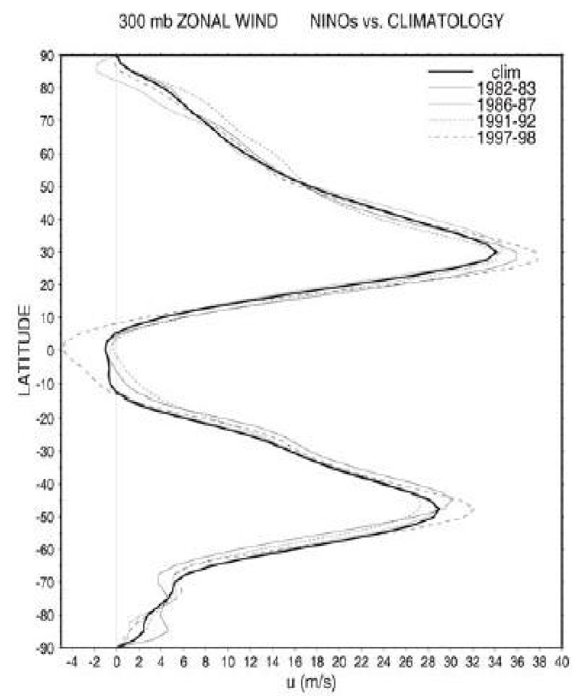


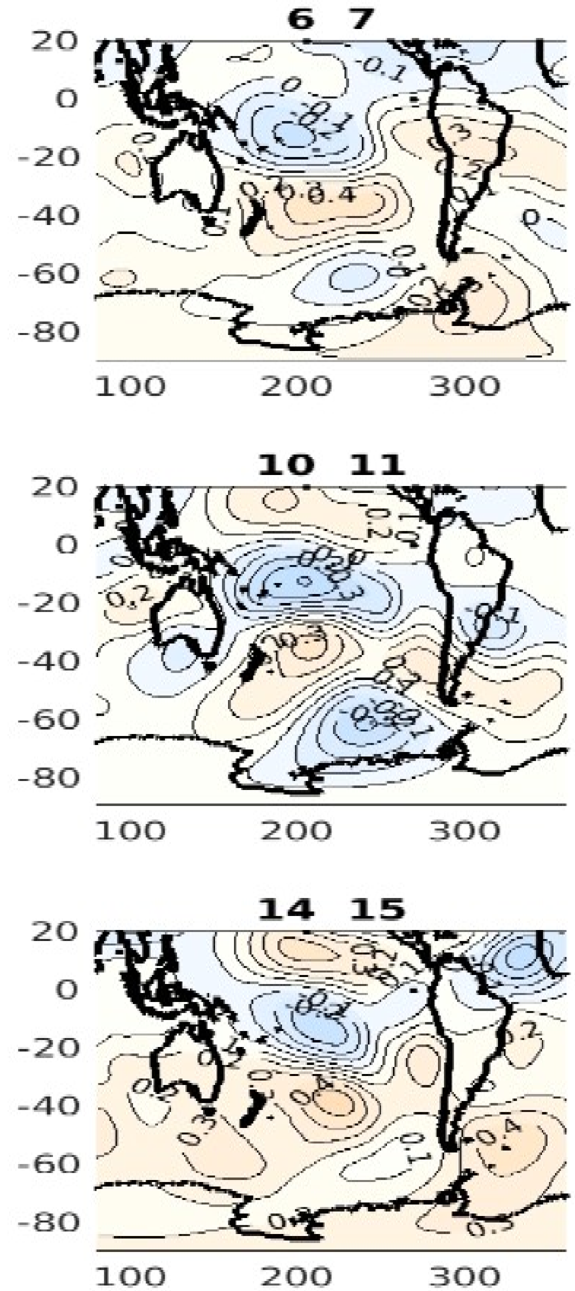
Fig. 6. Streamfunction anomaly at 250 hPa for four different El Niño years: (a) 82-83, (b) 86-87, (c) 91-92, and (d) 97-98. In each picture it is shown the ray path for the zonal wavenumbers 3 (circle), 4 (triangle) and 5 (square) (see text for details). The contour interval of the streamfuction is $5 \cdot 10^5\ s^{-1}$.



:al DJF zonally averaged zonal wind (ms^{-1}) at 300 hPa for the NCEP c
32-83, 1986-87, 1991-92 and 1997-98. The line representation of eacl
picture.

Magaña&Ambrizzi 2005

Since the mean flow changes seasonally, the Rossby wave response to tropical forcing changes.



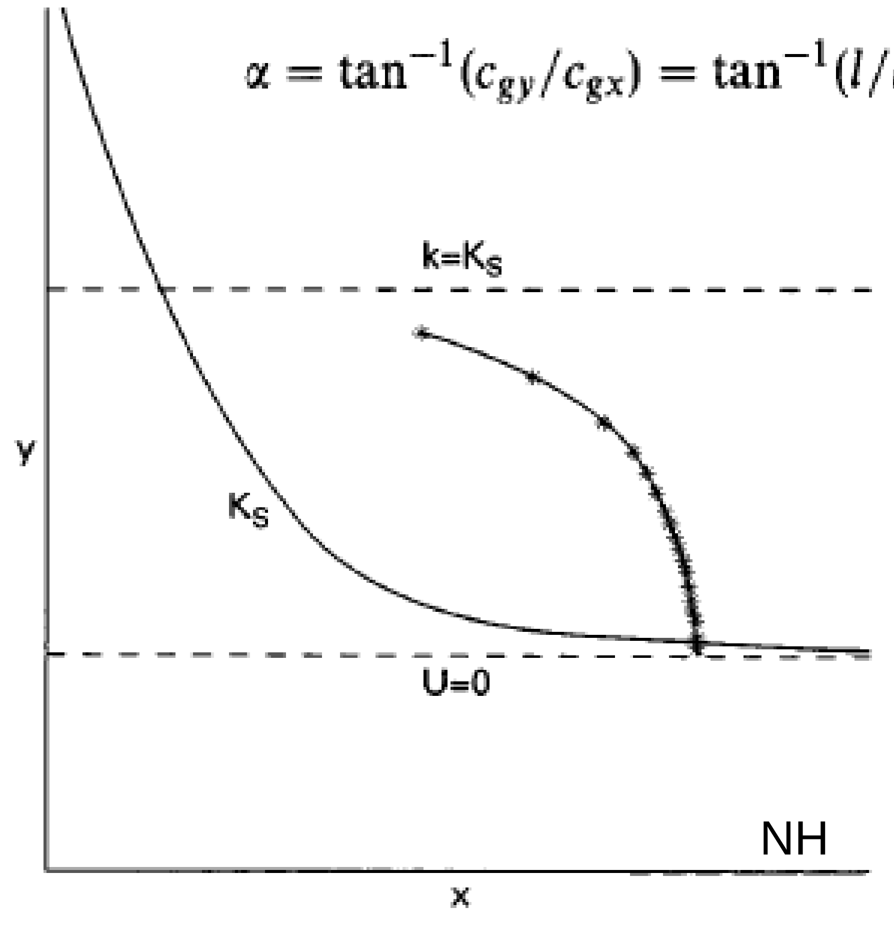
$$K_s = \sqrt{(\beta - U_{yy})/U}. \quad k \; constant\,, \quad k^2 + l^2 = Ks^2$$

Example of a Rossby wave generated in extratropics: orography, land-sea contrasts, excitation by transient baroclinic systems

U=0 is a critical line because Ks becomes large and then imaginary.

As Ks becomes large, l also does, and the meridional group velocity decreases. The wave will be "absorbed" at the critical latitude.

$$\alpha = \tan^{-1}(c_{gy}/c_{gx}) = \tan^{-1}(l/k).$$



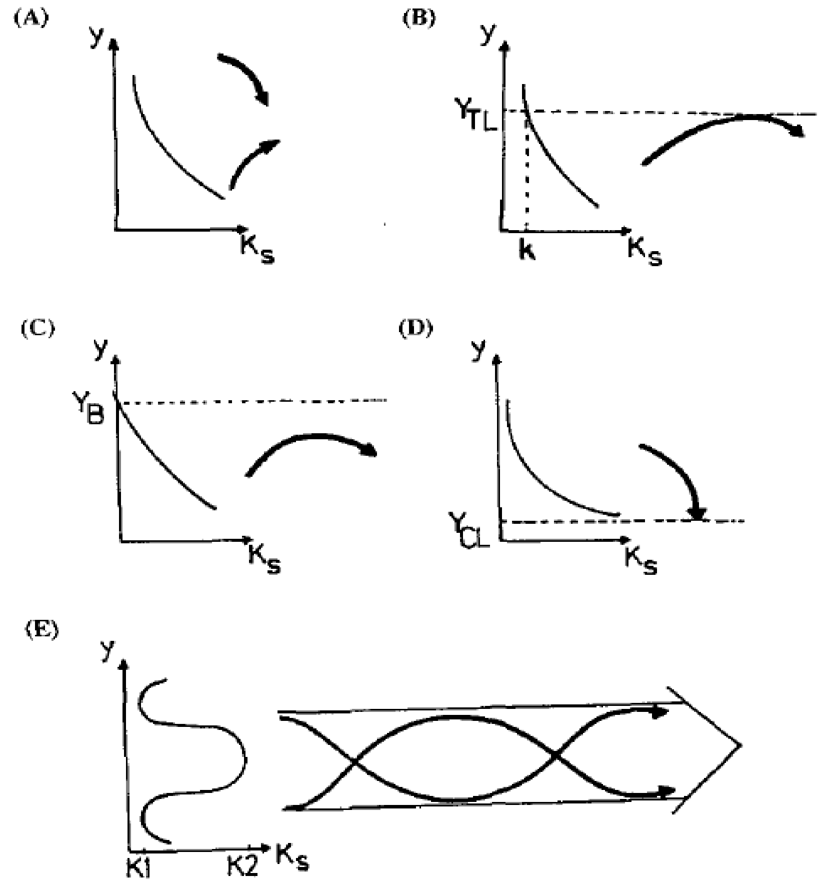


FIG. 2. Schematic stationary Rossby wavenumber (K_s) profiles and ray path refraction. In each panel, K_s is shown as a function of y and schematic ray paths are shown by heavy lines with arrowheads. (a) simple refraction; (b) reflection from a turning latitude Y_{TL} at which $K_s = k$; (c) reflection of all wavenumbers before a latitude Y_B at which $\beta_* = 0$; (d) refraction into a critical latitude Y_{CL} at which $\bar{U} = 0$; (e) waveguide effect of a K_s maximum. For more discussion see text.

Diciembre-Febrero

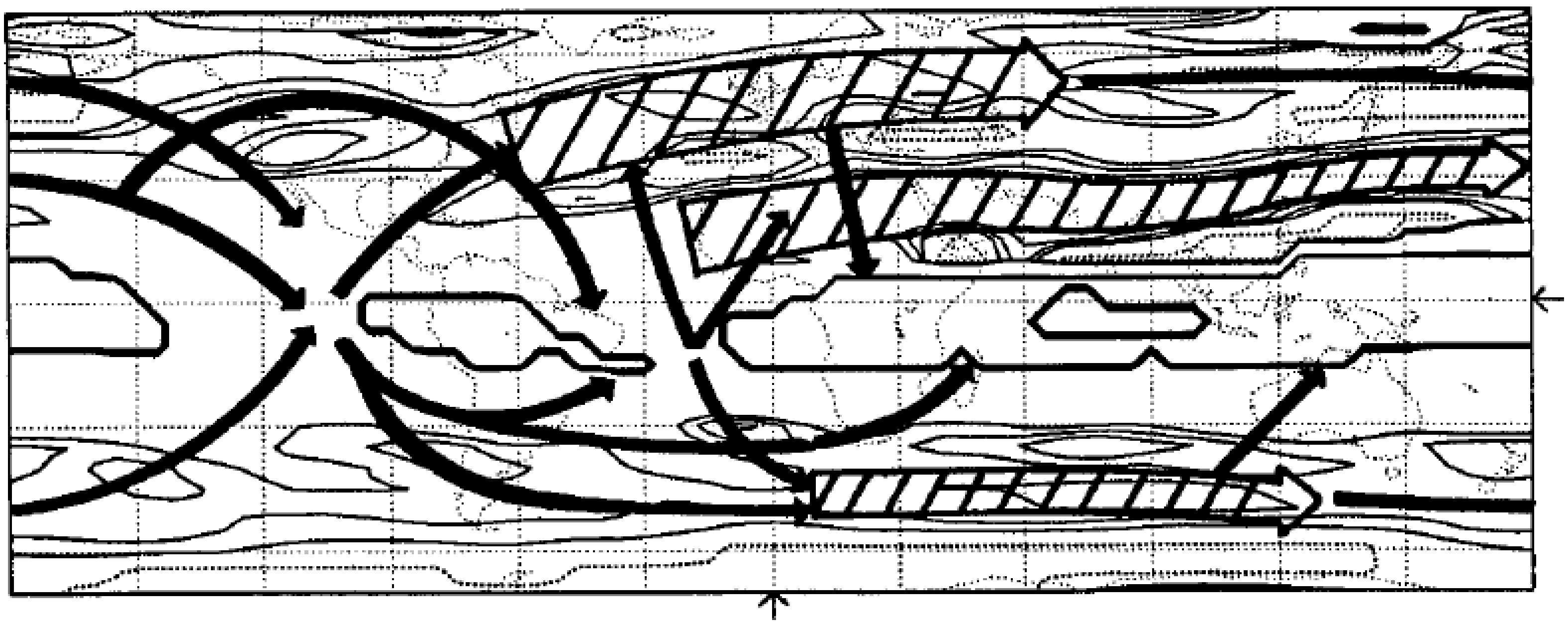


FIG. 13. A schematic summary of the waveguides shown by the cross-hatched shafted arrows, and the preferred propagation patterns, indicated by the single-shafted arrows, deduced from the range of experiments depicted in Fig. 4. The background contours are those for K_s equal to 0, 4, 5, 6, and 25–30 taken from Fig. 3c.

Ambrizzi & Hoskins 1993

In principle the hemispheres are independent because there are mainly easterlies in the tropics. Except in the “westerly duct”

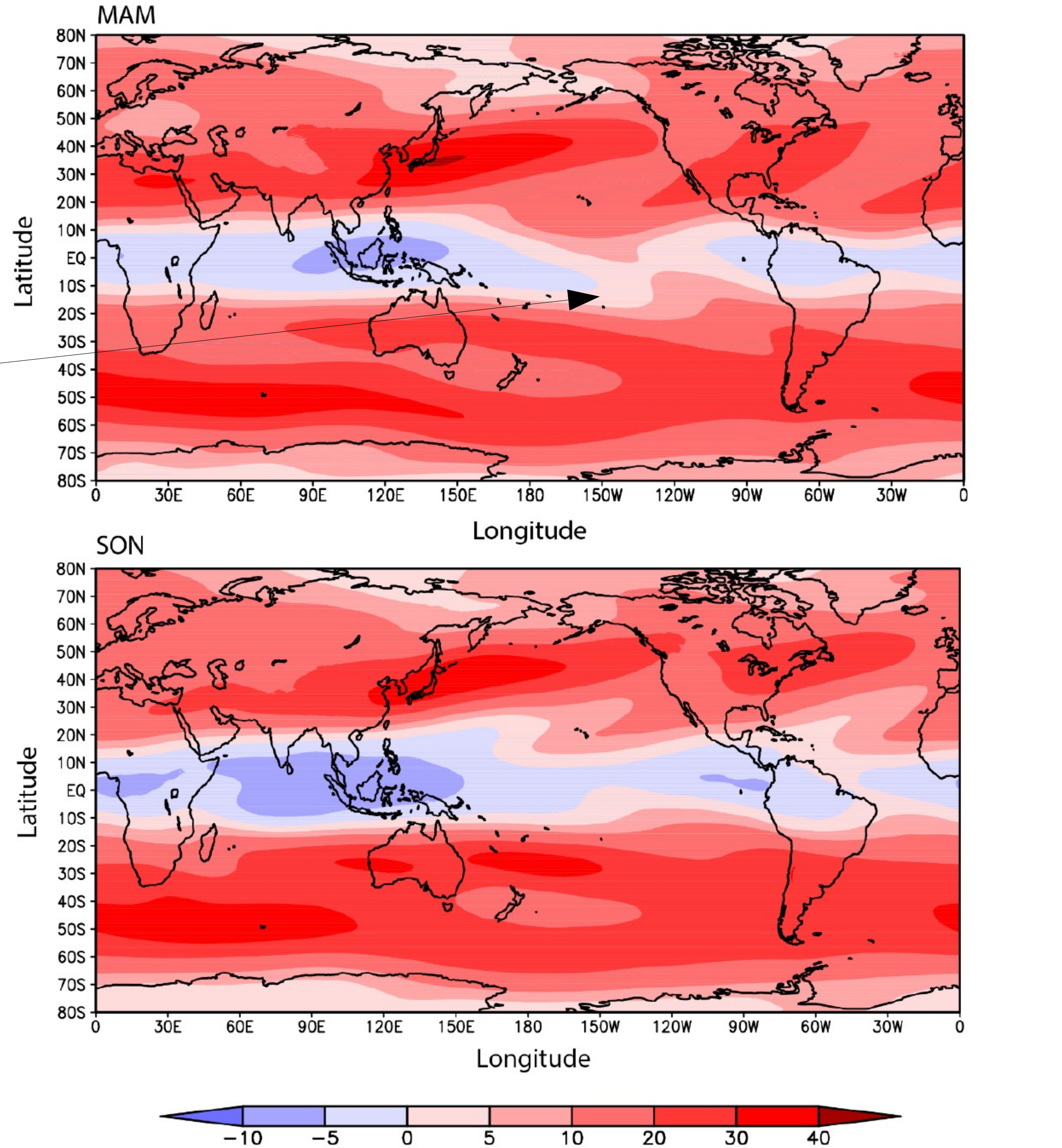


FIG.1. Zonal wind (m s^{-1}) for 300 hPa based on Era-Interim Reanalysis data for the climatological period 1979-2016 in MAM and SON. Contour interval is 5 m s^{-1}.

Freitas et al 2024

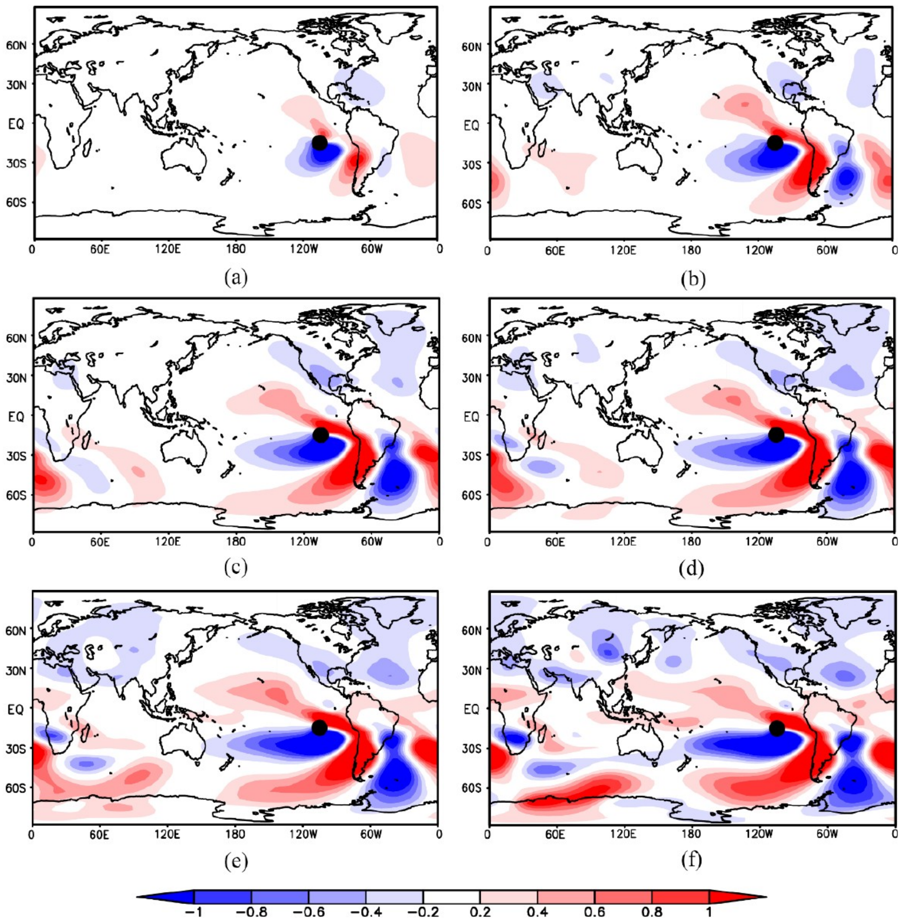


FIG.9. Streamfunction response ($\psi = 0.2 \text{ x } 10^6\, m^2\, s^{-1}$) in MAM to the source (2K.day^{-1}) located at 15ºS, 10

(black circle) for a) day 4, b) day 7, c) day 10, d) day 12, e) day 15, f) day 20.

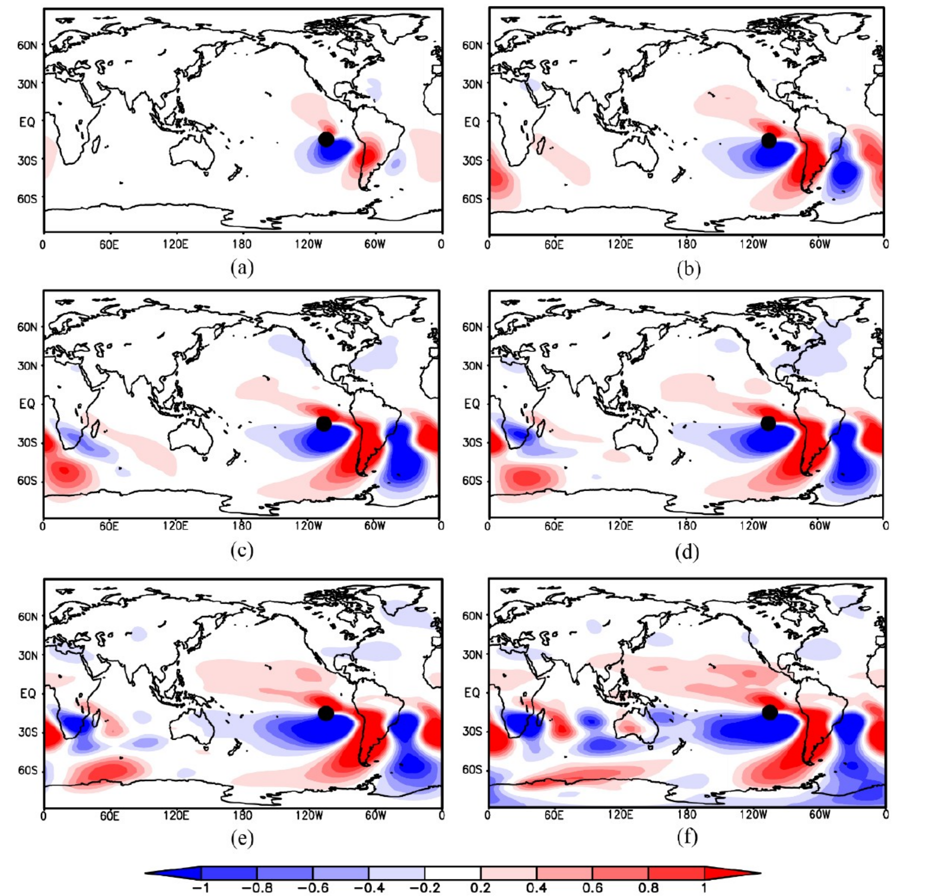


FIG.10. Streamfunction response ($\psi = 0.2 \text{ x } 10^6\, m^2\, s^{-1}$) in SON to the source (2K.day^{-1}) located at 15ºS, 105ºW

(black circle) for a) day 4, b) day 7, c) day 10, d) day 12, e) day 15, f) day 20.

Freitas et al 2024

This section has emphasized the propagation of Rossby waves from the tropics into the midlatitudes. A significant part of the low frequency variance, including persistent flow anomalies in the midlatitudes, can be related to such propagation, and hence to anomalies in the tropical ocean circulation. However, it should be remembered that most of the observed low frequency and steady Rossby wave activity originates in the midlatitudes and propagates mainly towards the tropics. This is clearly demonstrated by the steady momentum fluxes which are predominantly poleward. The midlatitude sources of Rossby waves are orography and ocean–land contrasts, as well as excitation of Rossby waves by maturing transient baroclinic systems.