The link between Rossby wave breakings and weather regime transitions

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Recently, Rossby wave breakings have been linked to teleconnections such as the North Atlantic Oscillation or the Pacific-North American (Benedict et al., 2004 and Franzke et al., 2011). But no study deals with the weather regimes which are more detailed low-frequency structure than teleconnections.

This study uses the ERA40 reanalysis which covers 43 extended winters. The methodology is based on the wave-breaking detection and the low-frequency streamfunction budget.

1 – The Rossby wave breaking (RWB)

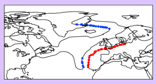
- Non-linear phenomenon defined by the large-scale and irreversible reversal of the potential vorticity gradient on isentropic surfaces.

- Two types of WB:

a) anticyclonic (AWB) b) cyclonic (CWB)

- WB detection by geometrical considerations:

(d'après Rivière, 2009)



● Zones of AWB
● Zones of CWB

Fig. 1- The 2 and 6 pvu isolines on the 330K surface for the 10/17/1965.

2 – Weather regimes (WR)

- 4 weather regimes over the North Atlantic in winter obtained by Michelangeli et al. (1995) using a dynamical cluster algorithm based on the low-frequency geopotential at 500 hPa.

- Since the jet is oriented differently, each WR causes various weathers over Europe.

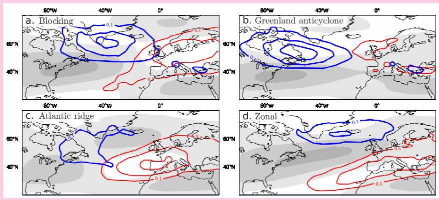


Fig. 3 - AWBs (CWBs) frequencies in red and blue (first contour of 0.1 day^{-1} and interval of 0.05 day^{-1}) averaged over 300, 315, 330 and 350 K and zonal wind in grey shadings (first contour: 20 m s^{-1} and interval: 10 m s^{-1}).

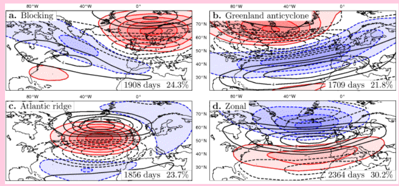


Fig. 2 - Low-frequency streamfunction in red ($\psi^L>0$) and blue ($\psi^L<0$) (first contour and interval of 25×10^5 m^2 s^{-1}) and the low-frequency zonal wind in — ($u^L>0$) and --- ($u^L<0$) (first contour and interval of 2 m s^{-1}) at 500 hPa.

- Each WR has its own characteristic WB frequency pattern. Usually at a given longitude, the higher (lower) the latitude of the jet is, the more frequent AWB (CWB) events are.

3 – Transition between weather regimes

For example: 3 days of Blocking followed by 3 days of Zonal :

Blocking	Blocking	Blocking	Zonal	Zonal	Zonal
T-3	T-2	T-1	T	T+1	T+2

Low-frequency streamfunction budget

$$\left.\begin{aligned}\partial_t\zeta &= -\eta\nabla.\mathrm{v}-\mathrm{v}.\nabla\eta\\ \mathbf{v} &= \overline{\mathbf{v}}+\mathbf{v}^L+\mathbf{v}^H\\ \zeta &= \overline{\zeta}+\zeta^L+\zeta^H\end{aligned}\right\}\quad \boxed{\frac{\partial\psi^L}{\partial t}=\sum_{i=1}^{5}\xi_i+R}\qquad \psi^L=\nabla^{-2}\zeta^L$$

where

$$\xi_1=-\nabla^{-2}\left\{\left(\overline{\mathrm{v}}.\nabla\zeta^L+\mathrm{v}^L.\nabla\overline{\eta}+\overline{\eta}\nabla.\mathrm{v}^L+\zeta^L\nabla.\overline{\mathrm{v}}\right)^L\right\}$$

is the linear propagation of low-frequency anomalies.

$$\xi_2=-\nabla^{-2}\left\{\left(\mathrm{v}^L.\nabla\zeta^L+\zeta^L\nabla.\mathrm{v}^L\right)^L\right\}$$

$$\xi_3=-\nabla^{-2}\left\{\left(\mathrm{v}^H.\nabla\zeta^H+\zeta^H\nabla.\mathrm{v}^H\right)^L\right\}$$

are non-linear terms linked to WBs events.

$$\xi_4=-\nabla^{-2}\left\{\left(\mathrm{v}^L.\nabla\zeta^H+\mathrm{v}^H.\nabla\zeta^L+\zeta^L\nabla.\mathrm{v}^H+\zeta^H\nabla.\mathrm{v}^L\right)^L\right\}$$

$$\xi_5=-\nabla^{-2}\left\{\left(\overline{\mathbf{v}}.\nabla\zeta^H+\mathbf{v}^H.\nabla\overline{\eta}+\overline{\eta}\nabla.\mathbf{v}^H+\zeta^H\nabla.\overline{\mathbf{v}}\right)^L\right\}$$

are both negligible.

and R is a residual term due to neglecting terms in the tendency vorticity equation.

- We then performed projections of each ξ_i onto the low-frequency streamfunction of the future regime (at T+2 days).

Zonal to Blocking

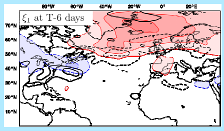


Fig. 7 - ξ_1 in red (>0) and blue (<0) (first contour and interval of 15 m^2 s^{-2}), the low-frequency zonal wind in — ($\partial_t u^L>0$) and --- ($\partial_t u^L<0$) (first contour and interval of 2×10^{-5} m s^{-2}) at 300 hPa.

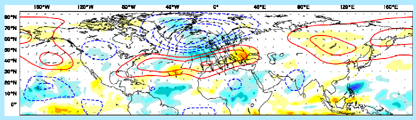


Fig. 8 - ψ^L in red (>0) and blue (<0) (first contour and interval of 2×10^6 m^2 s^{-1}), low-frequency wave activity flux (arrows) at 200 hPa and OLR^L (shadings, first contour and interval: 2 W m^{-2}) at T-6 days.

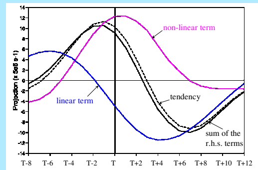
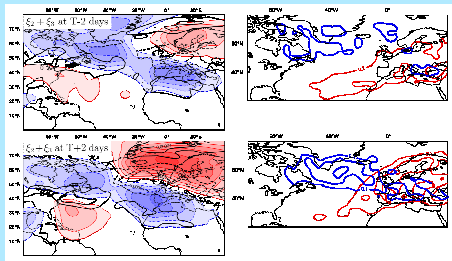


Fig. 6 – Projections at 300 hPa.

- The linear term ξ_1 causes the transition.

- Non-linear terms $\xi_2+\xi_3$ participate in the transition.

- OLR^L dipole at 40°W
→ deep convection
→ Hadley cell enhanced and energy source at 40°W-40°N
→ wave train originating at 40°N and propagating toward Asia.



less A and CWBs than the Zonal pattern

looks like the Blocking pattern

Fig. 9 - $\xi_2+\xi_3$, ξ_2 and ξ_3 in red (>0) and blue (<0) first contour and interval of 15 m^2 s^{-2}, the low-frequency zonal wind in — ($\partial_t u^L>0$) and --- ($\partial_t u^L<0$) first contour and interval of 2×10^{-5} m s^{-2} at 500 hPa and the AWBs (CWBs) frequencies in red and blue (first contour of 0.1 day^{-1} and interval of 0.05 day^{-1}).

Blocking to Greenland anticyclone

- Non-linear terms $\xi_2+\xi_3$ cause the transition.

- ξ_2 and ξ_3 are both important in the eddy-driven feedback.

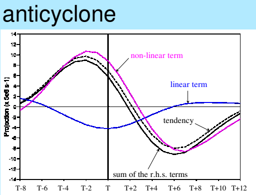
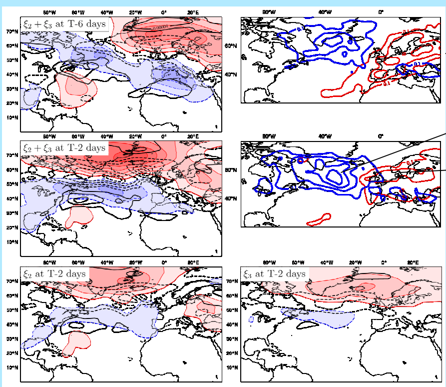


Fig. 4 – Projections at 300 hPa.



looks like the Blocking pattern

much more CWBs and less AWBs than the Blocking pattern

Fig. 5 - $\xi_2+\xi_3$, ξ_2 and ξ_3 in red (>0) and blue (<0) first contour and interval of 15 m^2 s^{-2}, the low-frequency zonal wind in — ($\partial_t u^L>0$) and --- ($\partial_t u^L<0$) first contour and interval of 2×10^{-5} m s^{-2} at 300 hPa and the AWBs (CWBs) frequencies in red and blue (first contour of 0.1 day^{-1} and interval of 0.05 day^{-1}).

Conclusion

- Two precursors:

- A linear precursor which is linked to a teleconnection Tropics-Extratropics with the propagation of a low-frequency quasi-stationnary wave train excited by convection anomalies in the Atlantic tropics at T-6 days and propagating towards Asia for the Z to B transition.

- A non-linear precursor directly linked to the RWBs and therefore to the eddy-driven jet feedback acting at T-2 days for the B to GA transition.

- RWBs participate in the reinforcement of the regimes but can also participate in the transition (e.g. B to GA transition).

- The non-linear interaction amongst the low-frequency transient eddies is as important as the non-linear interaction amongst the high-frequency transient eddies.

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