A new dynamical interpretation of the role played by the left-exit region of the large-scale upper-level jet.

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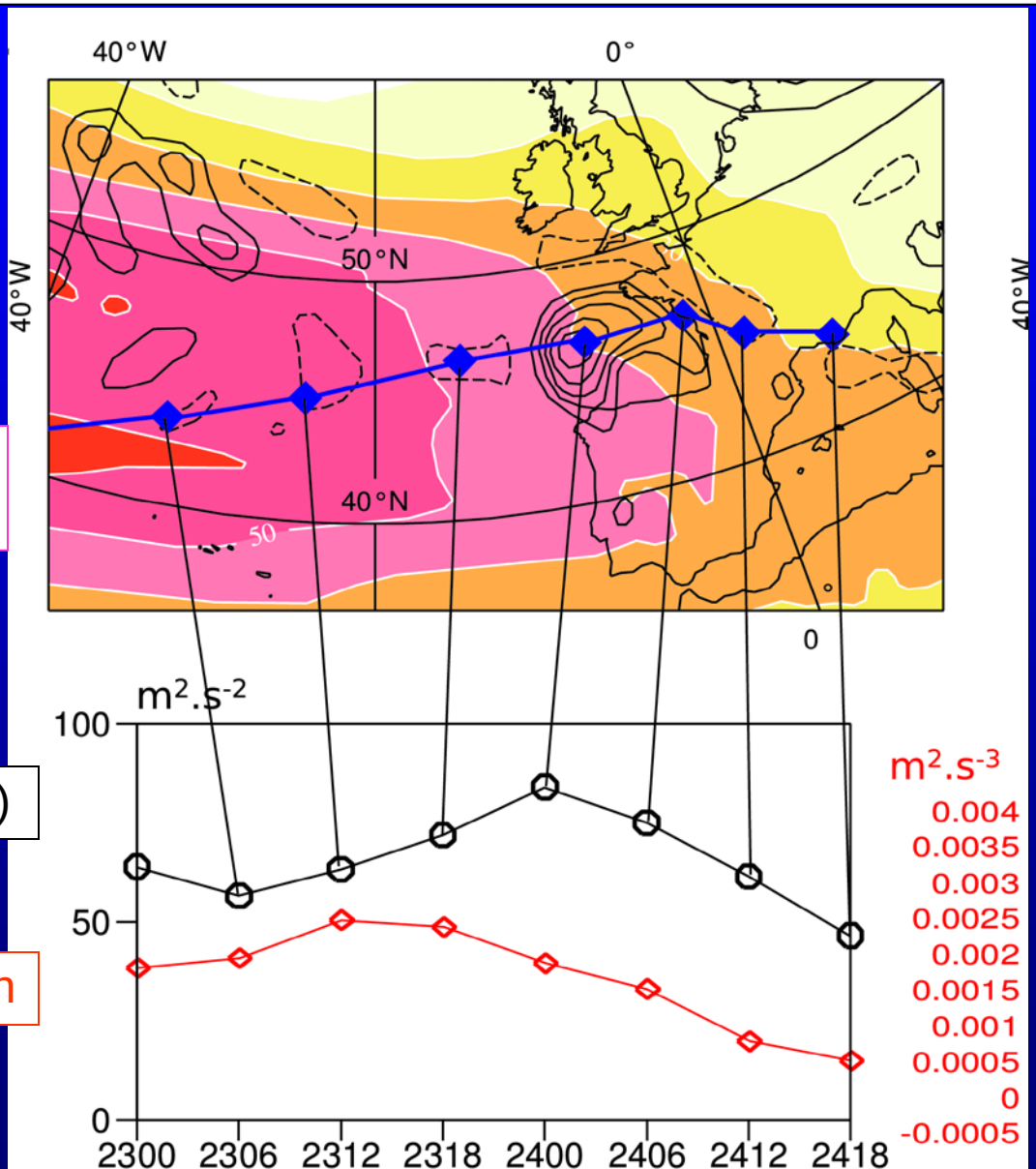
Example of cyclone deepening in the left-exit region of a large-scale jet

« Klaus » (22-24 january 2009)

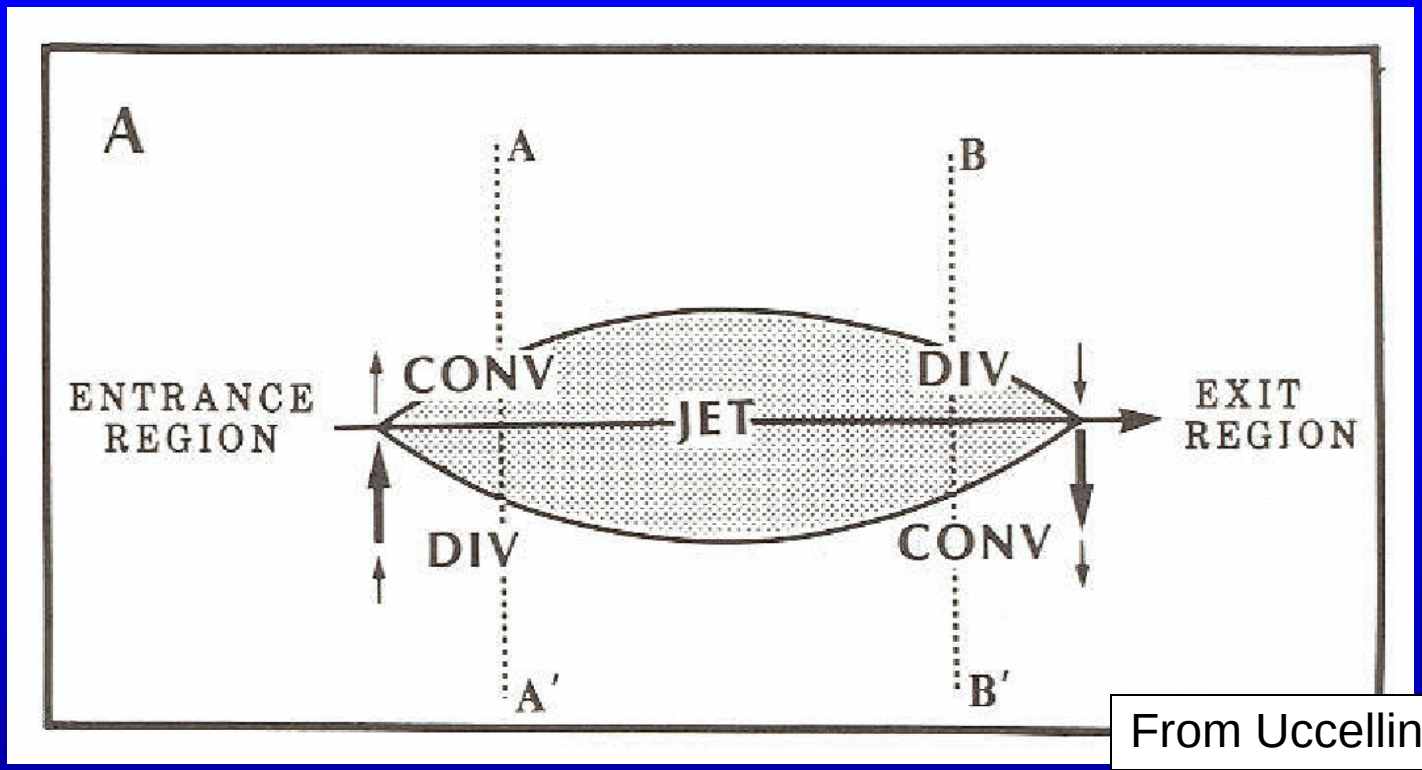
Low-frequency wind magnitude at 300hPa

EKE (500-900 hPa)

Baroclinic conversion



Classical interpretation: analogy with the jet-streak case



From Uccellini (1990)

$$fv_a = u_g \frac{\partial u_g}{\partial x}$$

The left-exit region of an upper-level jet should be more cyclogenetic

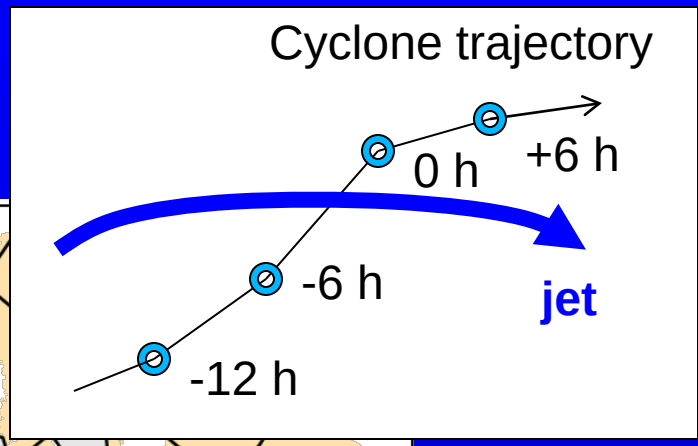
Few questions to be addressed

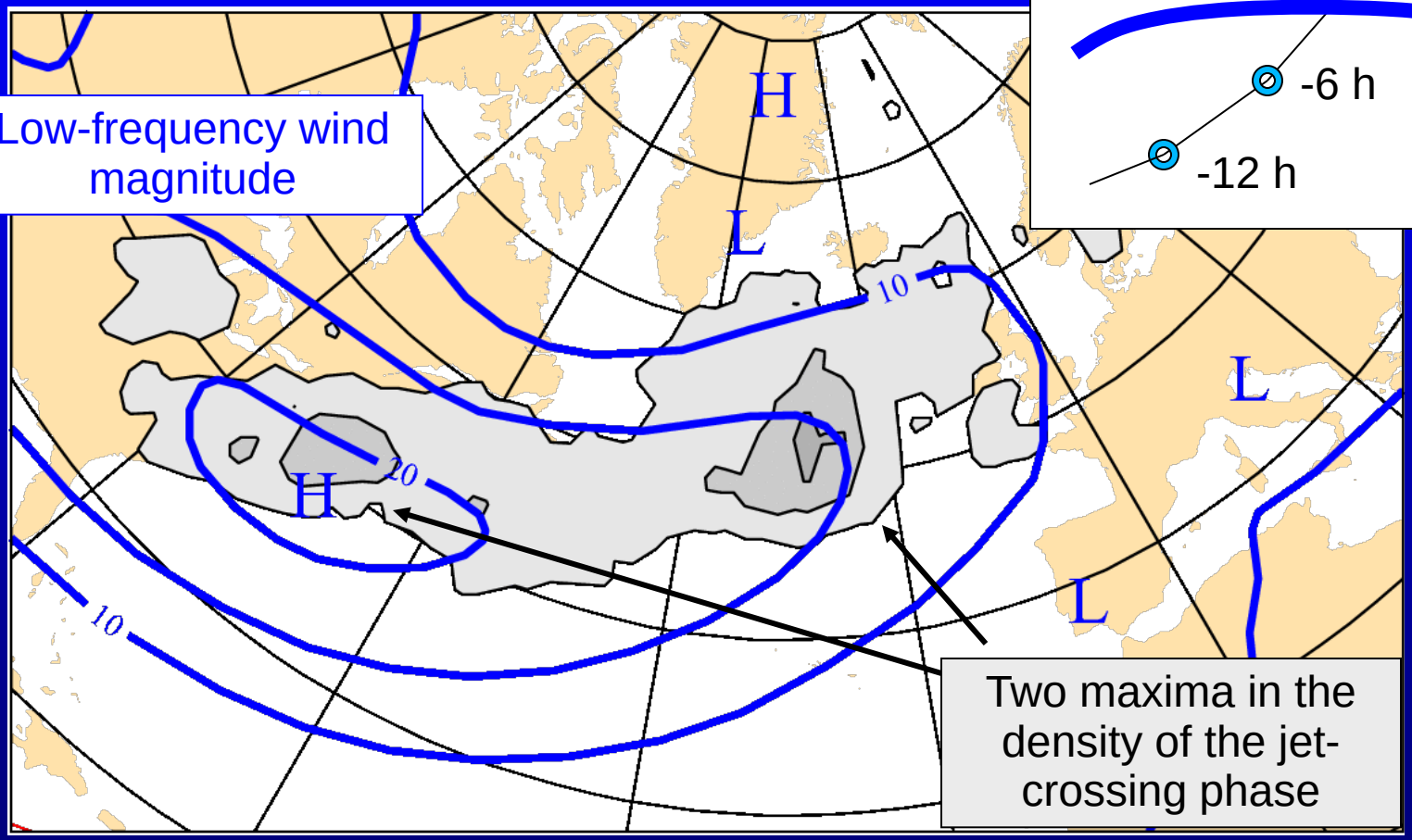
- **Is the left-exit region a preferential zone for the jet-crossing phase ? Why ?**
- **Is it generally accompanied by a stronger deepening of the extratropical cyclone ?**
- **Can it be really interpreted in terms of the analogy with the left-exit region of a jet streak ?** *It is not trivial because a jet streak is a high-frequency feature and a large-scale jet projects onto the low-frequency part of the flow*

Is the left-exit region a preferential zone for the jet-crossing phase ?

Data and method: ERA40 and use of Ayrault (1998)'s tracking algorithm

Tracking of relative vorticity maxima at 850 hPa.





3199 trajectories have crossed the large-scale jet (16 oct – 15 Apr; 1957-2002) !

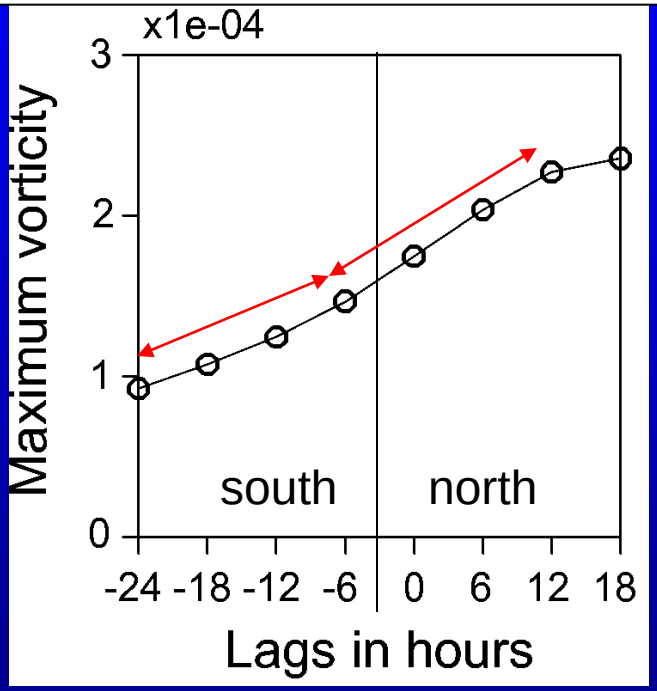
Representativeness of the jet-crossing phase in the North Atlantic

Threshold for vorticity at 850 hPa	Number of trajectories	Number of cases crossing the upper jet	percentage
0	65573	3199	5%
$2\ 10^{-4}\ s^{-1}$	2996	873	29%
$2{,}5\ 10^{-4}\ s^{-1}$	858	335	39%
$3\ 10^{-4}\ s^{-1}$	164	83	50%

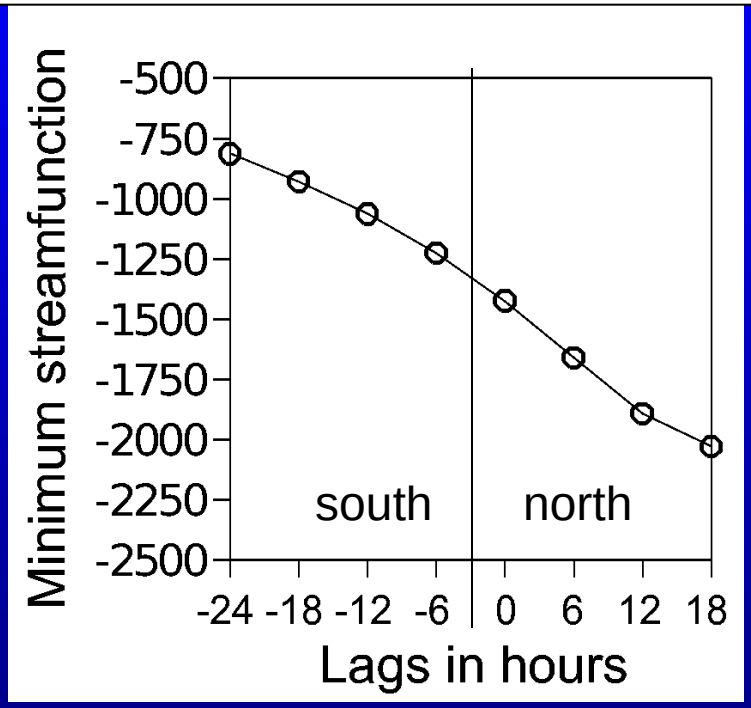
Half of the strongest storms have crossed the upper-level large-scale jet !

Is there a stronger deepening during the jet-crossing phase ?

Relative vorticity maximum at 850 hPa

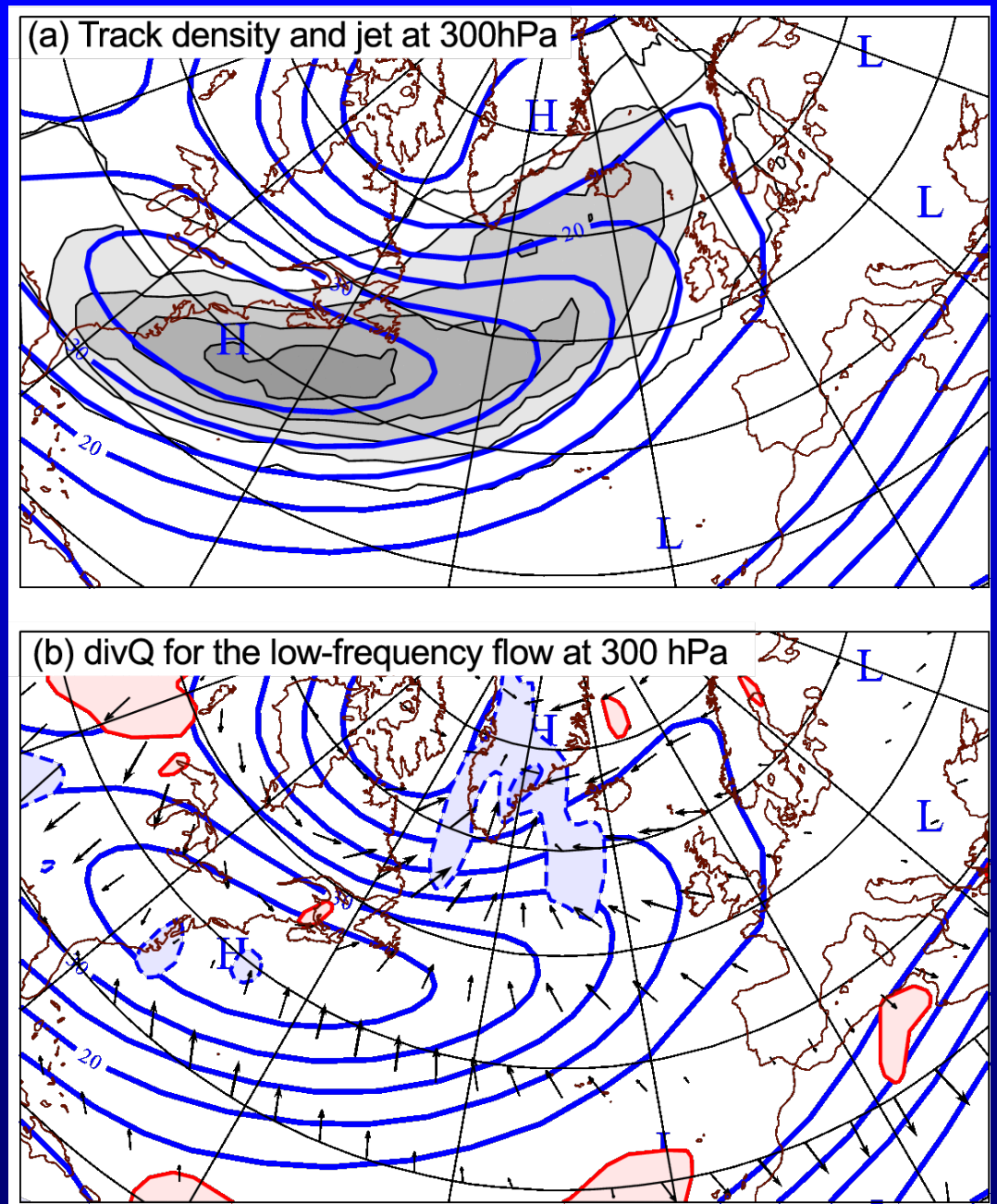


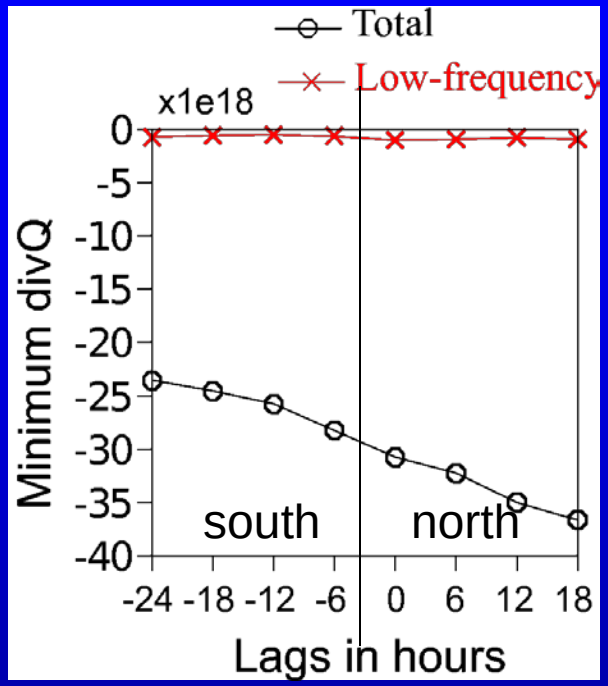
High-freq streamfunction minimum at 850 hPa



Average made over 335 trajectories (threshold: 2,5 10^{-4} s^{-1})

Looking at the ageostrophic transverse circulation ?





There is a need to revisit the jet-crossing phase and the reasons of the strong deepening during and after the crossing !

Role of the effective deformation

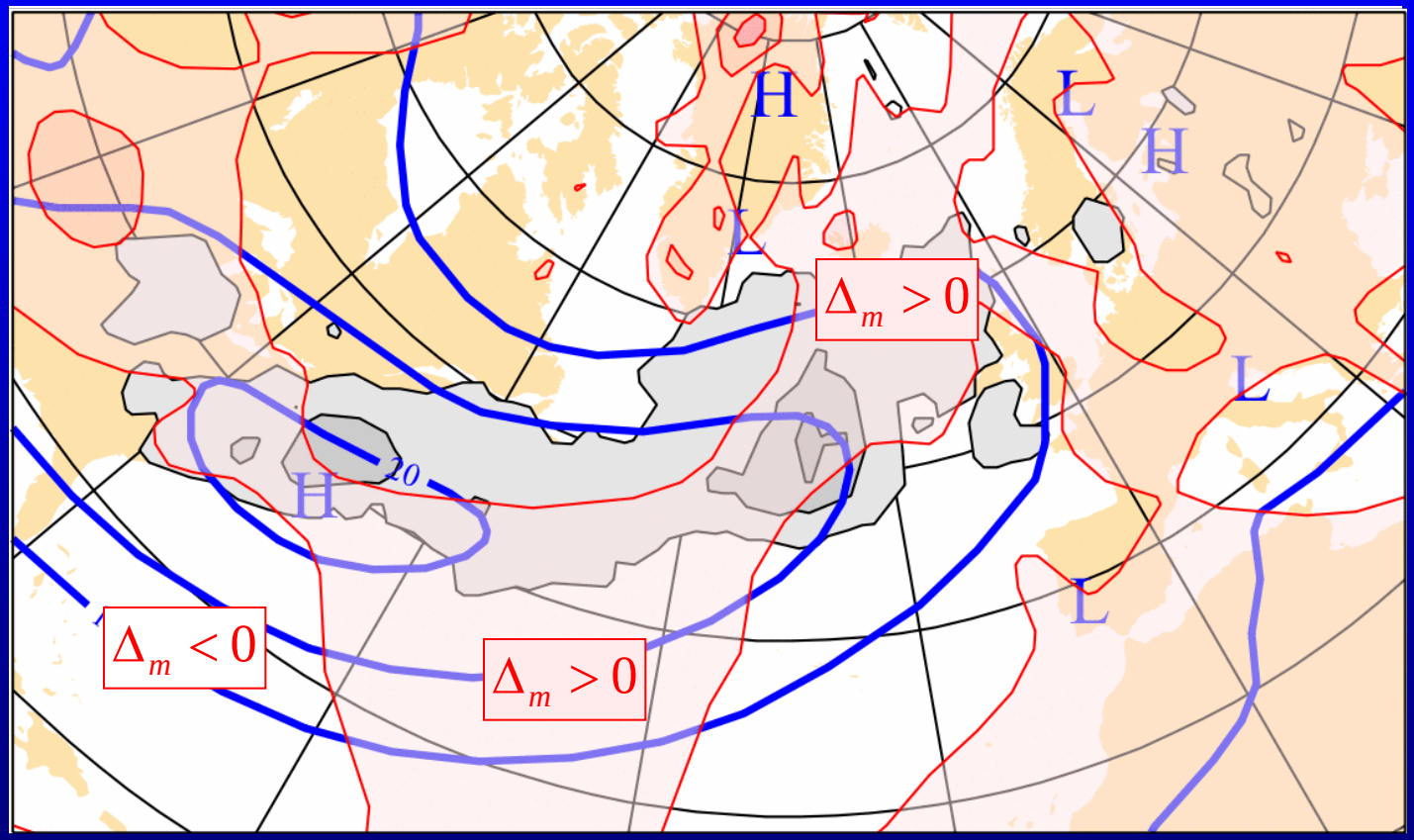
$$\Delta_m = \left|\mathbf{D}_m\right|^2 - \zeta_m^{\ 2}$$

Effective deformation

LF deformation magnitude

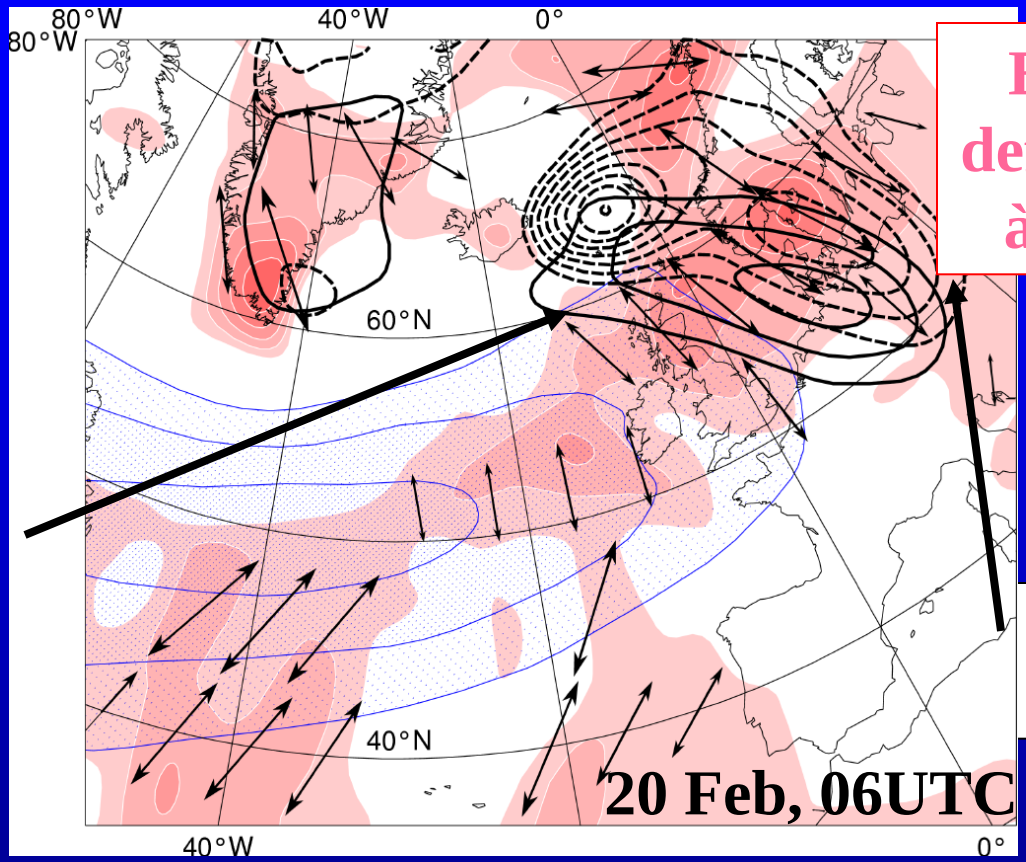
LF vorticity

A synoptic eddy will be stretched in zones of strong deformation magnitude and weak rotation



Why is the saddle point of the effective deformation a preferential zone for the jet-crossing phase ?

An example: the jet-crossing phase of POI17 of FASTEX



Effective deformation à 500hPa

Upper disturbance
(Z HF, 350hPa)

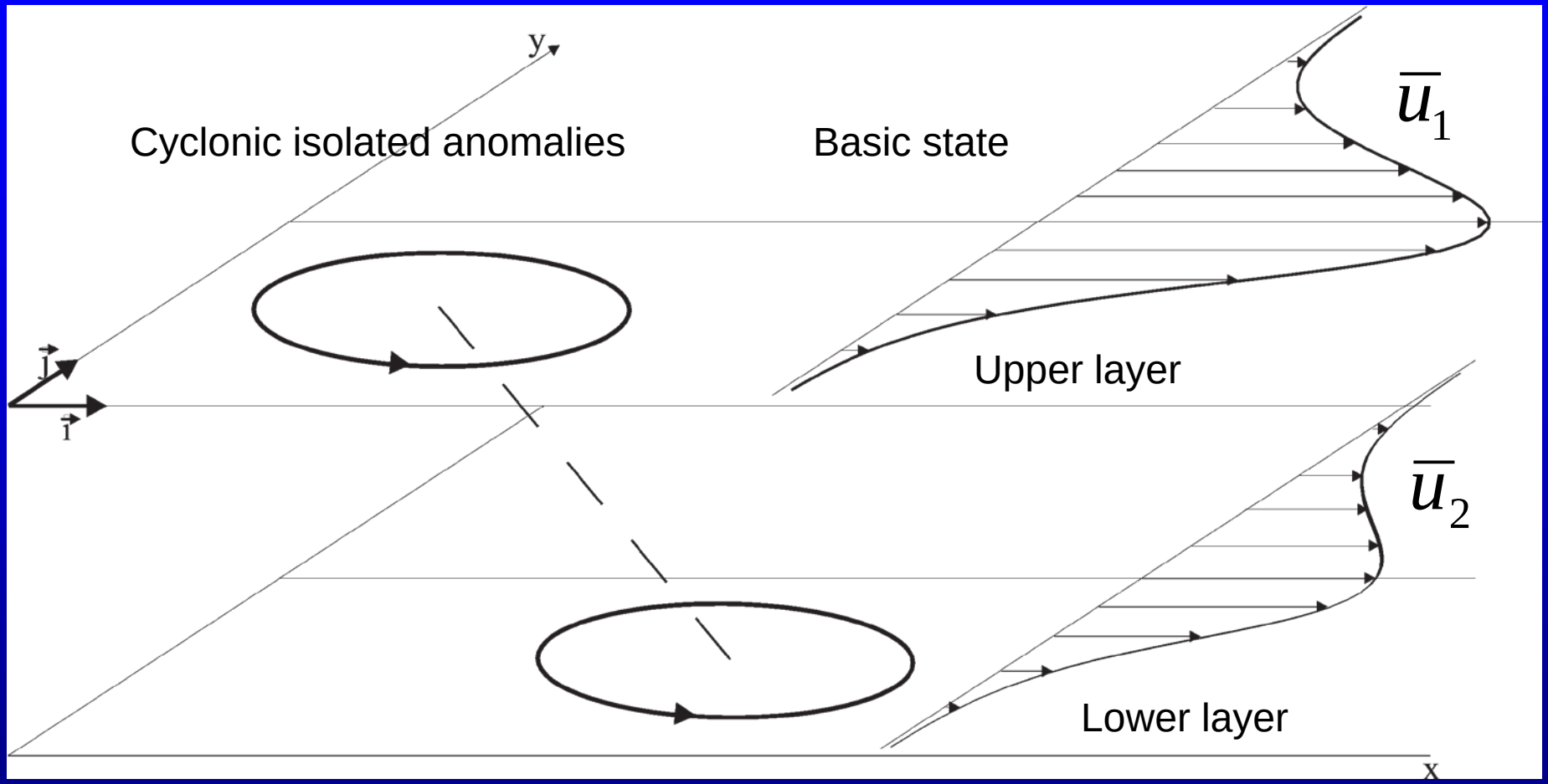
Surface cyclone
(Z HF, 900hPa)

Transient barotropic growth + a new phase of baroclinic interaction is triggered between the cyclone and the upper disturbance as they cross the barotropic critical region

(Rivière and Joly, 2006)

Reproducing the jet-crossing phase in a very idealized framework

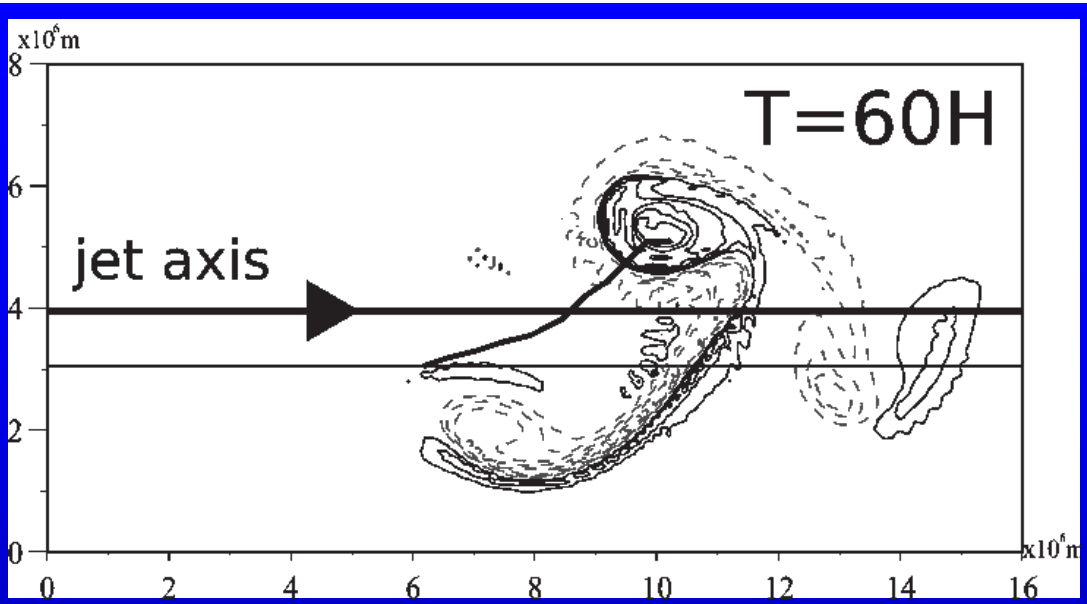
Quasi-geostrophic two-layer model

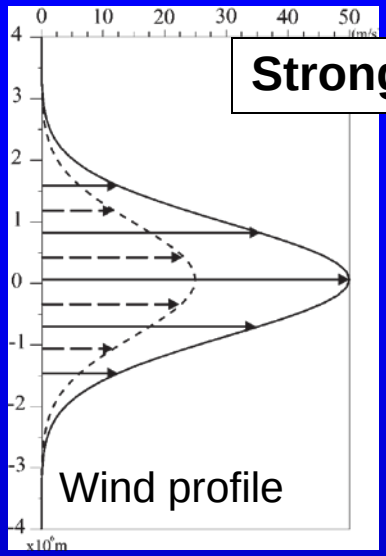


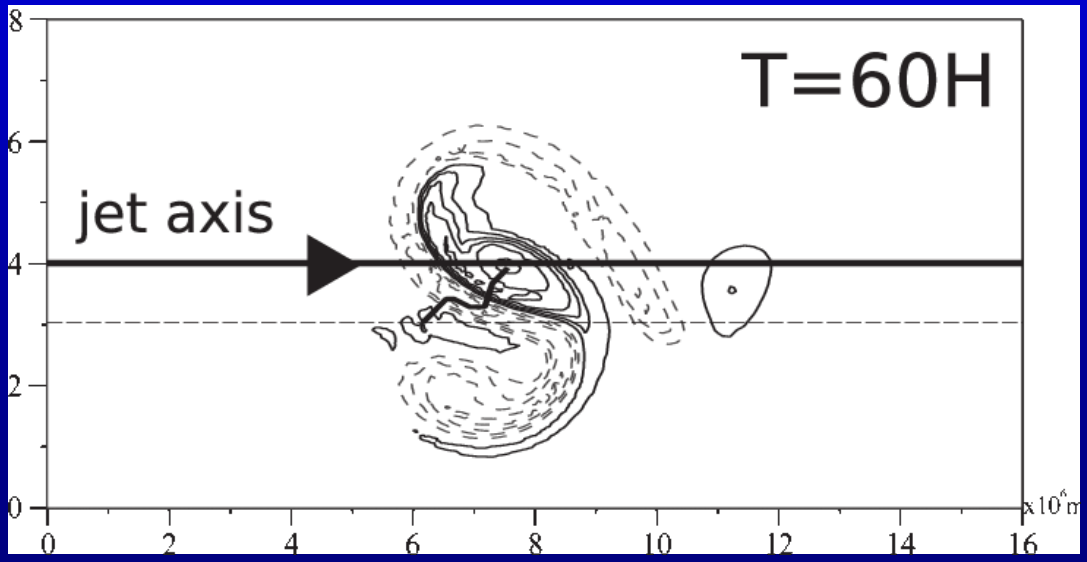
$$q_1 = \Delta\psi_1 + f - \lambda^{-2}(\psi_1 - \psi_2)$$
$$q_2 = \Delta\psi_2 + f + \lambda^{-2}(\psi_1 - \psi_2)$$

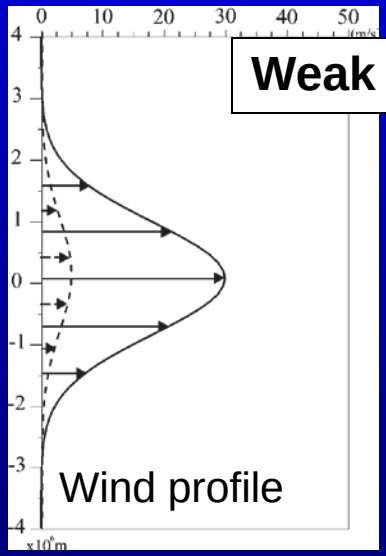
$$\partial_t q_k + \mathbf{u_k}.\nabla q_k = 0$$

Role of the barotropic jet in the jet-crossing phase







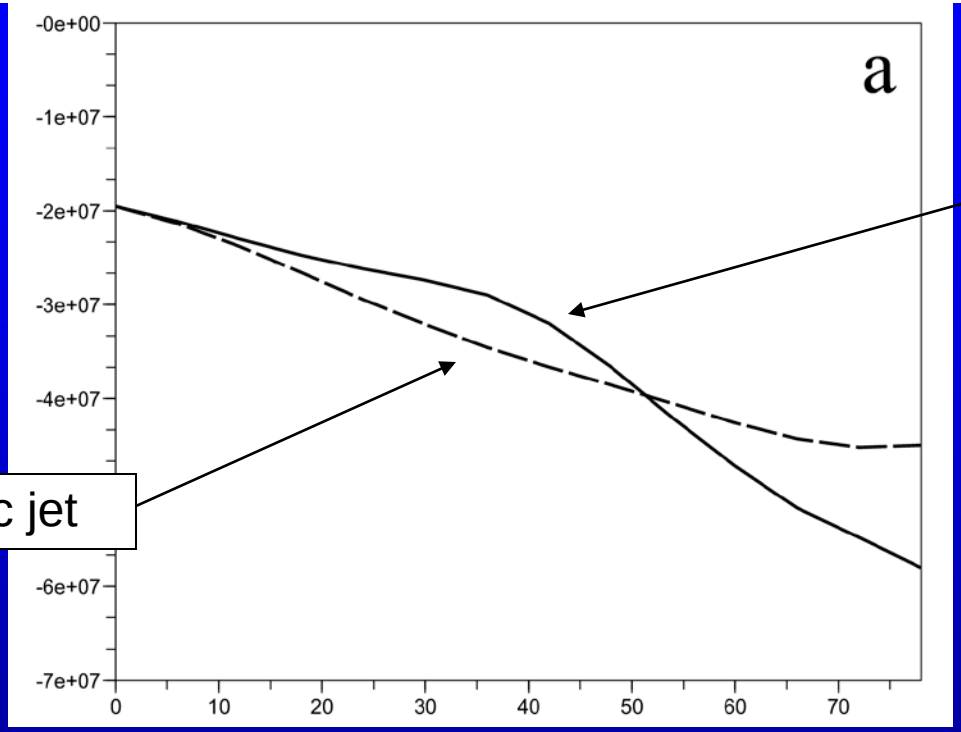


The stronger the barotropic jet, the quicker the displacement of the surface cyclone perpendicular to the jet will be !

Gilet et al. (2009)

Role of the barotropic jet in the jet-crossing phase

Perturbation streamfunction minimum as function of time



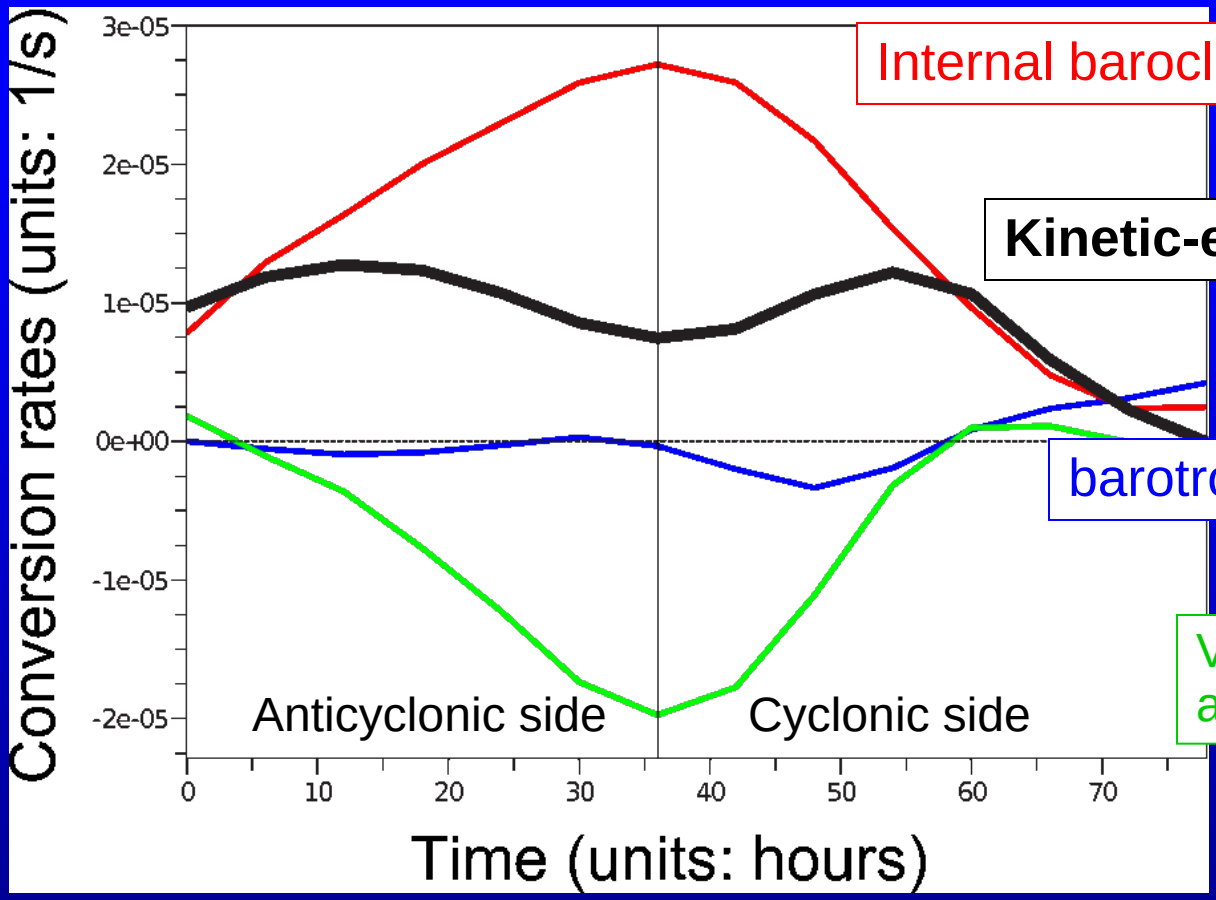
Strong barotropic jet

weak barotropic jet

- **Weak barotropic jet: no jet-crossing phase and one sustained deepening stage**
- **Strong barotropic jet: a jet-crossing phase and two distinct phases of deepening**

→ Nonlinearities counteract the linear stabilizing effect of the barotropic governor (James, 87)

Kinetic-energy budget during the jet-crossing phase in the lower layer



Internal baroclinic conversion $-\omega'\theta'$

Kinetic-energy growth rate

barotropic conversion $-\mathbf{u}'.(\mathbf{u}'.\nabla\overline{\mathbf{u}})$

Vertical geopotential ageostrophic fluxes $-\dfrac{\partial(\omega'\Phi')}{\partial p}$

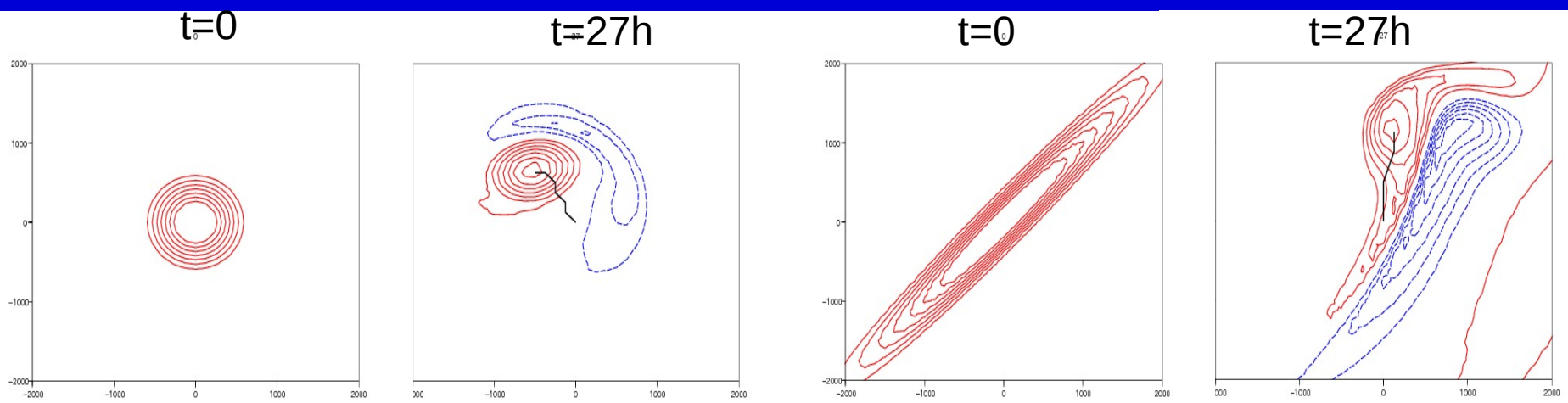
The key energy term is $-\dfrac{\partial\omega'}{\partial p}\Phi' = -\dfrac{\partial(\omega'\Phi')}{\partial p} - h\omega'\theta'$

Same as for POI17 of FASTEX (Rivière & Joly, 2006)

Why is the barotropic jet a key parameter for the jet-crossing phase ?

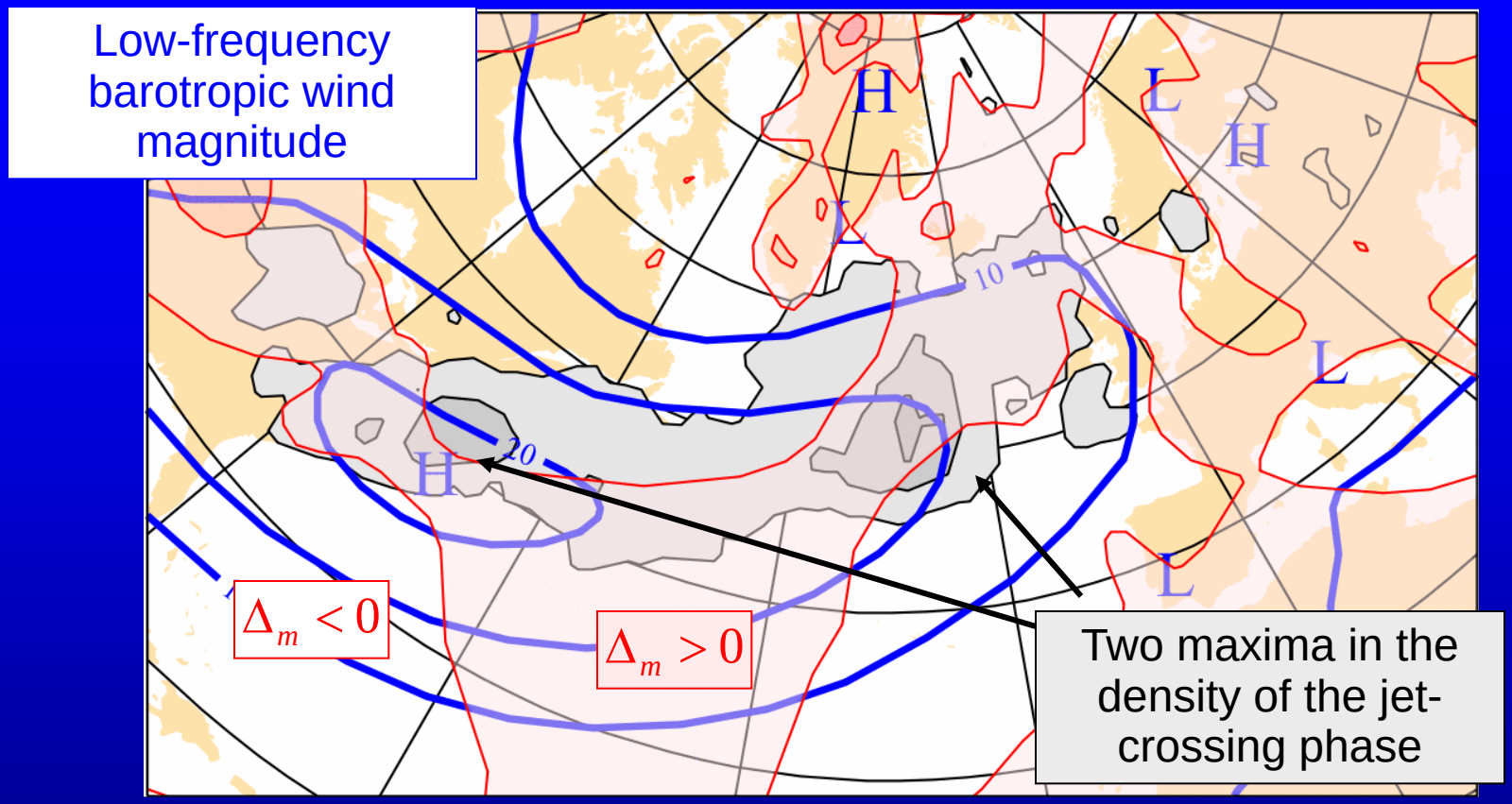
- It is a generalization in a baroclinic synoptic context of the so-called beta drift. It is a well-known nonlinear phenomenon: the beta gyres move the cyclones poleward.
- This has been extensively studied in tropical cyclone motion (Holland,1983) and oceanic vortices (McWilliams & Flierl, 1979) but not in a midlatitude atmospheric context !

Barotropic simulations on a beta-plane; no background flow



the **more stretched** the cyclone, the **stronger the anticyclone**, and the **quicker** the northward motion !
The **stronger the barotropic jet**, the stronger the vertically averaged PV gradient, the **greater the effective beta**.

The combined effects of the deformation and the beta drift



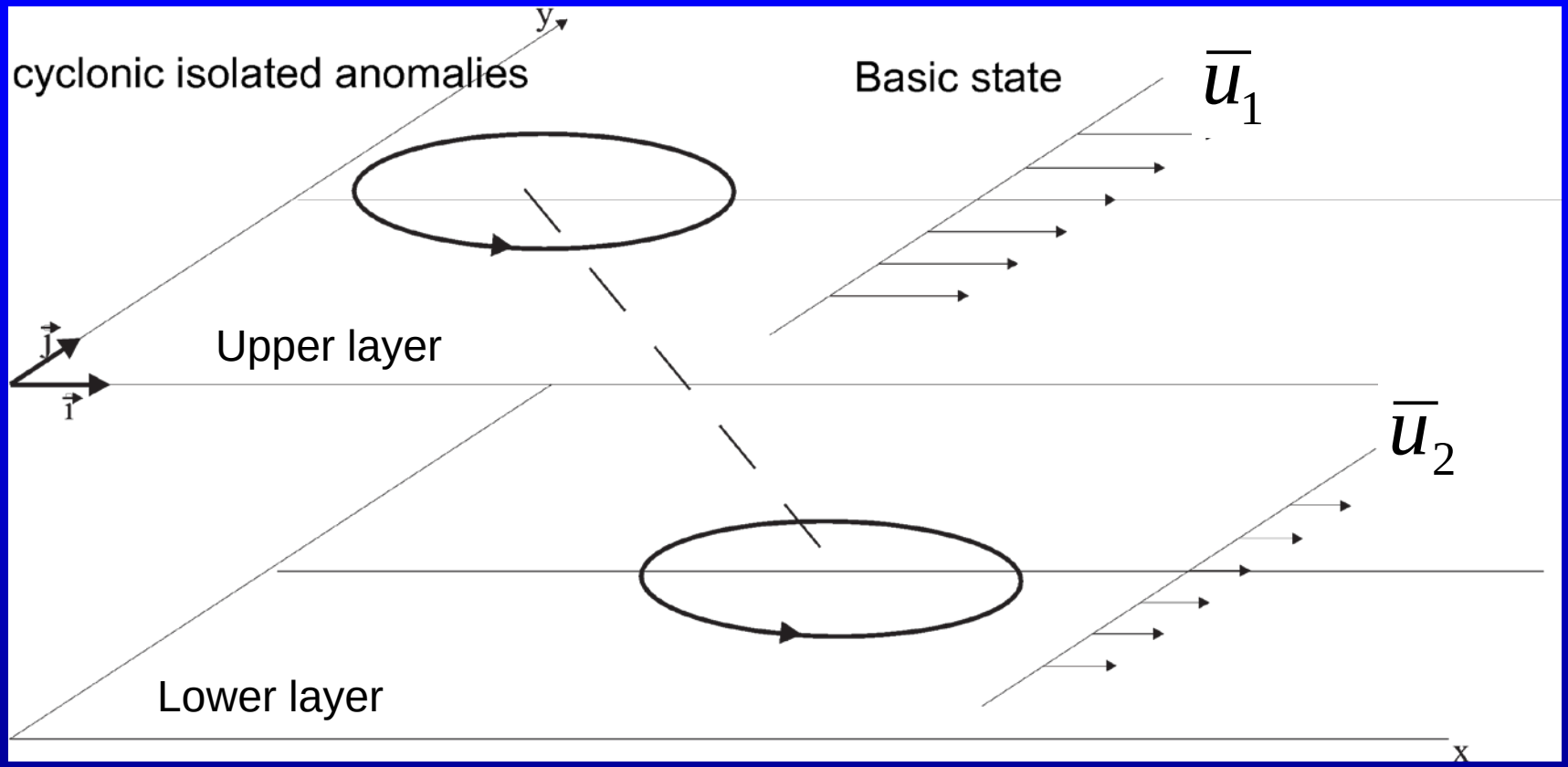
- **Zones of weak (strong) effective deformation → slow (rapid) displacement perpendicular to the jet**
- **The first preferential zone is due to a strong barotropic jet while the second preferential zone is due to a more efficient poleward drift for stretched synoptic perturbations.**

Conclusions and some perspectives

- The cyclogenetic character of the transverse ageostrophic circulation in the left-exit region of the large-scale jet cannot explain quantitatively the explosive growth of surface cyclones.
- The deepening of a cyclone during and after the jet-crossing phase can be reproduced in a very idealized framework (2 layer QG model + zonal jet) without the presence of transverse ageostrophic motion.
- The mechanism explaining the cyclone motion perpendicular to the jet is a generalisat° of the beta drift. The key factor is the barotropic PV gradient.
- The saddle point of the effective deformation is a preferential zone for the jet-crossing phase. It is due to a more efficient drift for eddies located upstream of that region which are strongly stretched.

- Try to get a more qualitative argument to explain why the cold side of the jet is more cyclogenetic than the warm side.
- An attempt to create the large-scale configuration of the European storms of December 1999. Use of a semi-geostrophic model.

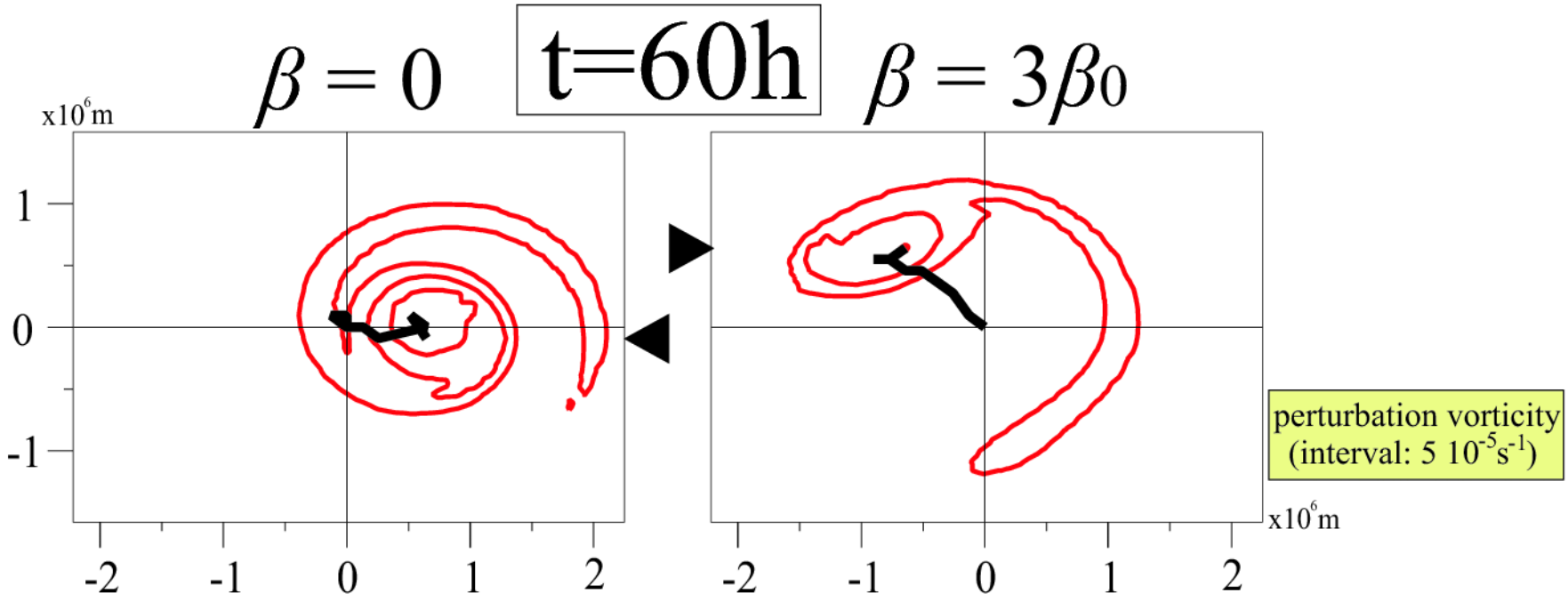
Idealized simulations in a QG two-layer model: uniform vertical shear



$$\frac{\partial \overline{q}_1}{\partial y} = \beta + \lambda^{-2}(\overline{u}_1 - \overline{u}_2)$$

$$\frac{\partial \overline{q}_2}{\partial y} = \beta - \lambda^{-2}(\overline{u}_1 - \overline{u}_2)$$

Idealized simulations in a QG two-layer model: uniform vertical shear



The key parameter for the latitudinal motion is beta or the vertically averaged PV gradient !

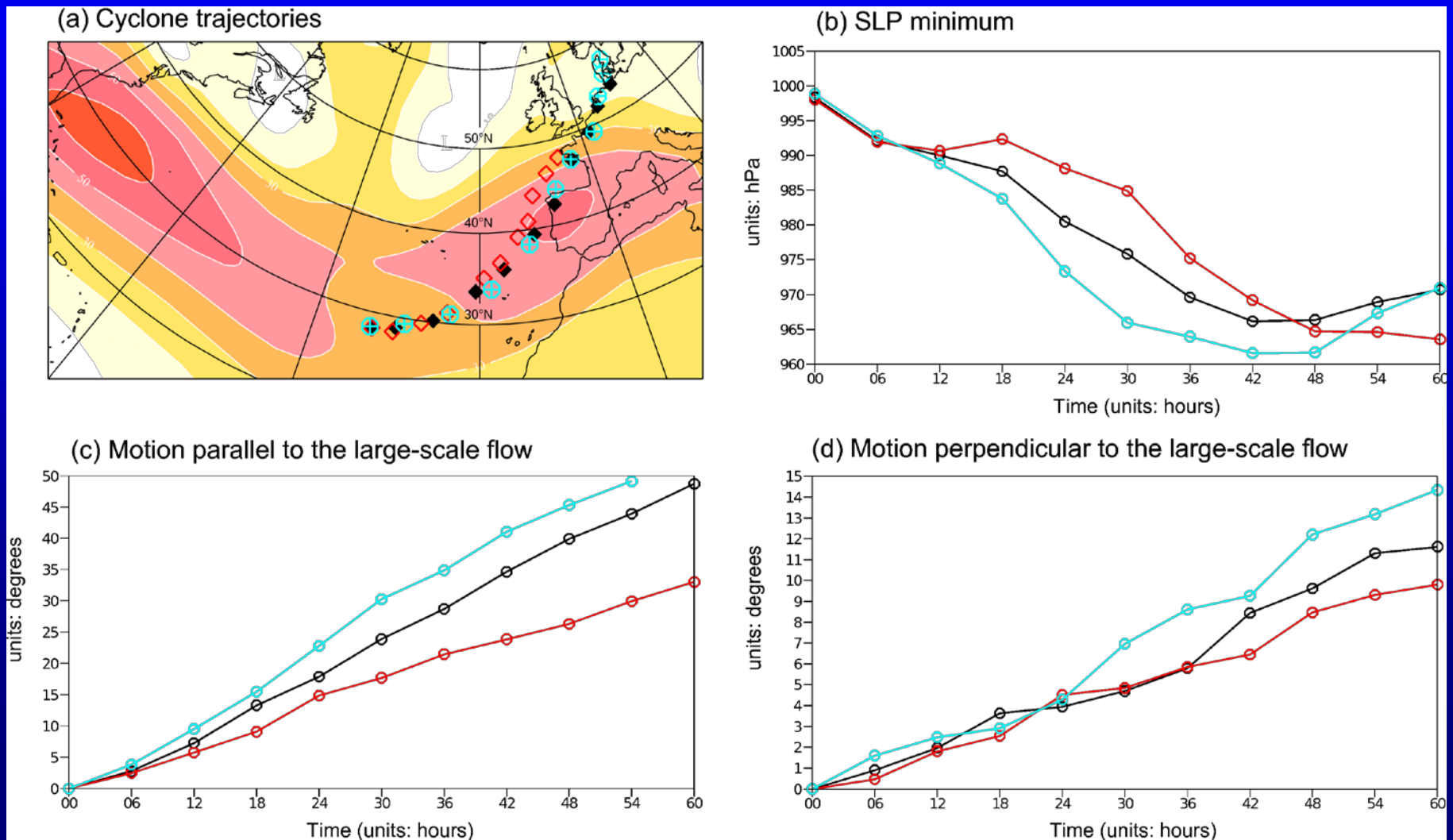
Role of the barotropic jet during the jet-crossing phase of Xinthia

Three simulations with the use of the Meteo-France global model ARPEGE

CTRL: forecast starting from operational analysis

Barotropic jet intensified

Barotropic jet reduced

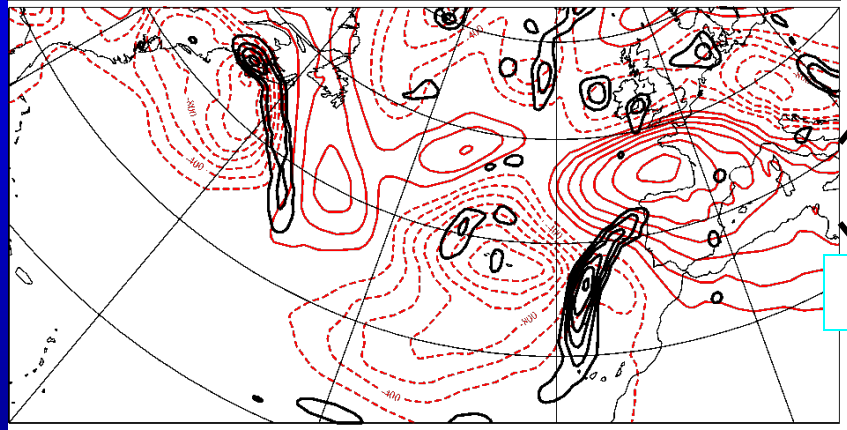


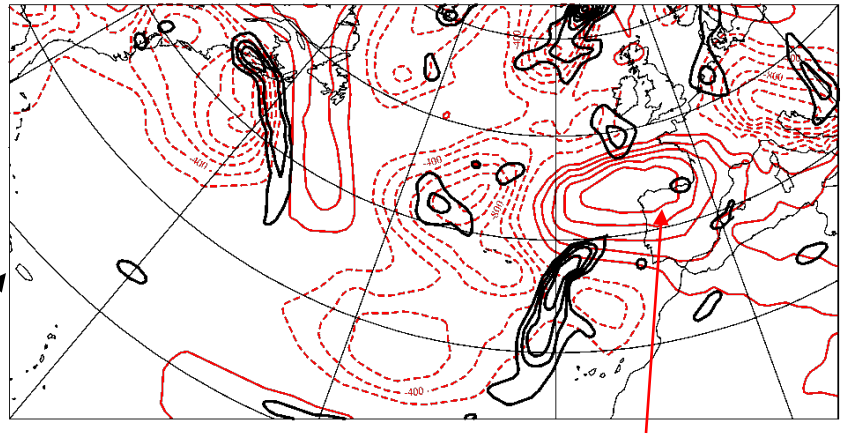
Role of the barotropic jet during the jet-crossing phase of Xinthia

Three simulations with the use of the Meteo-France global model ARPEGE

Weaker barotropic jet → weaker anticyclone

CTRL: forecast starting from operational analysis





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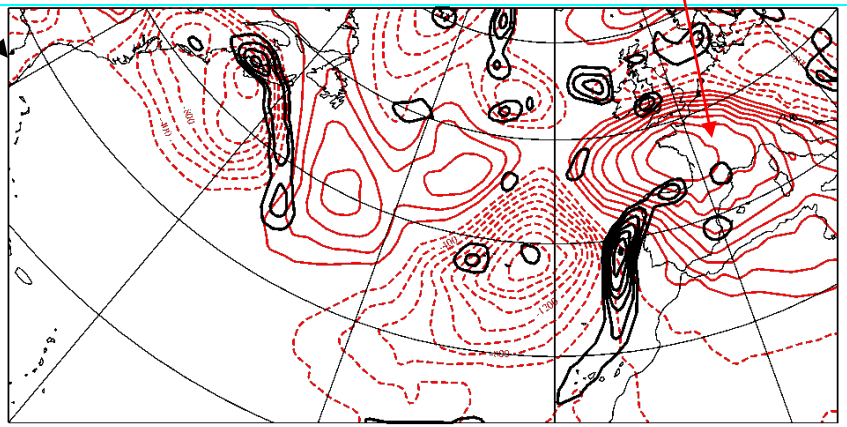
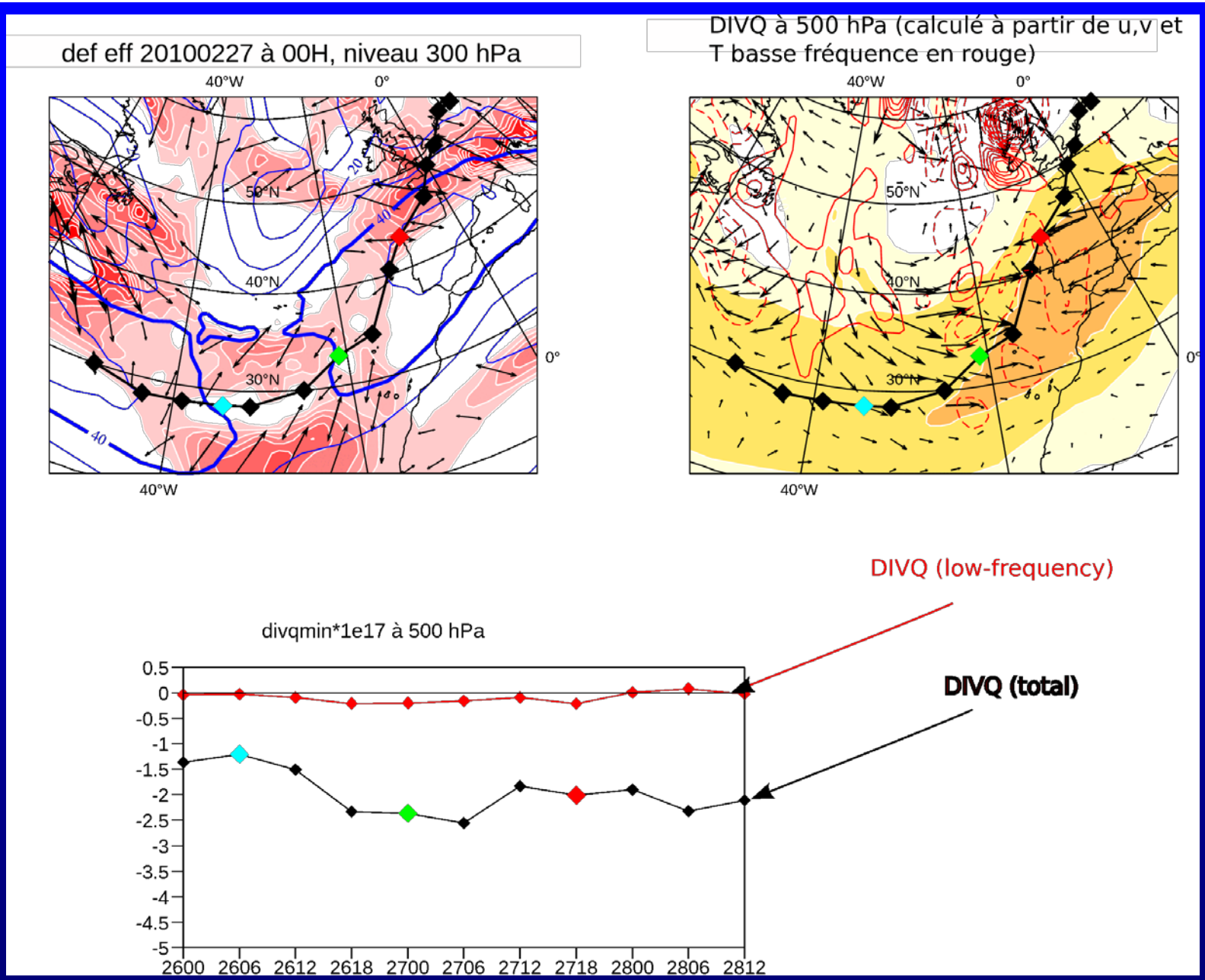
Stronger barotropic jet → stronger anticyclone



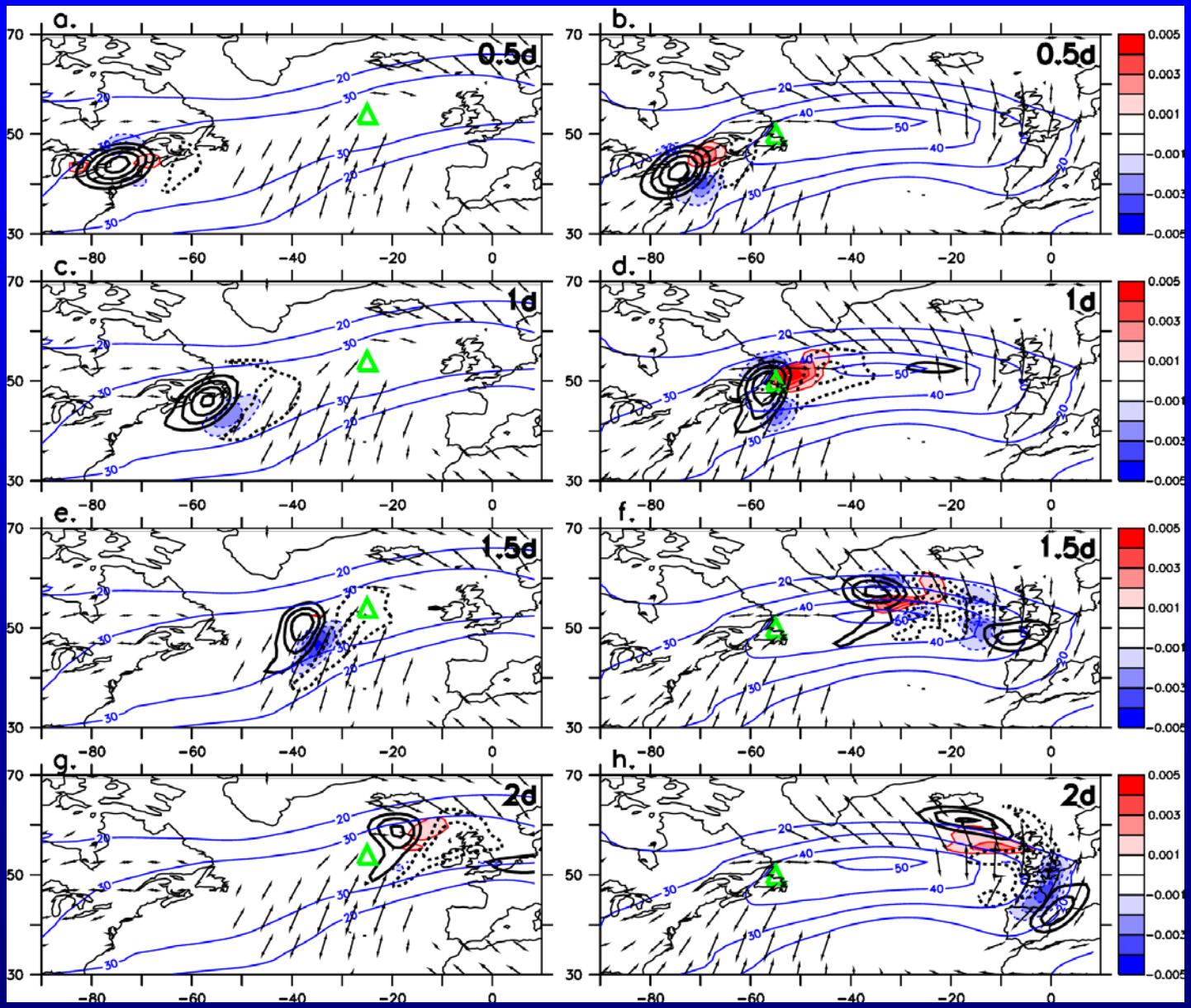
Z (high-freq) at 300hPa

Rel Vor at 850 hPa

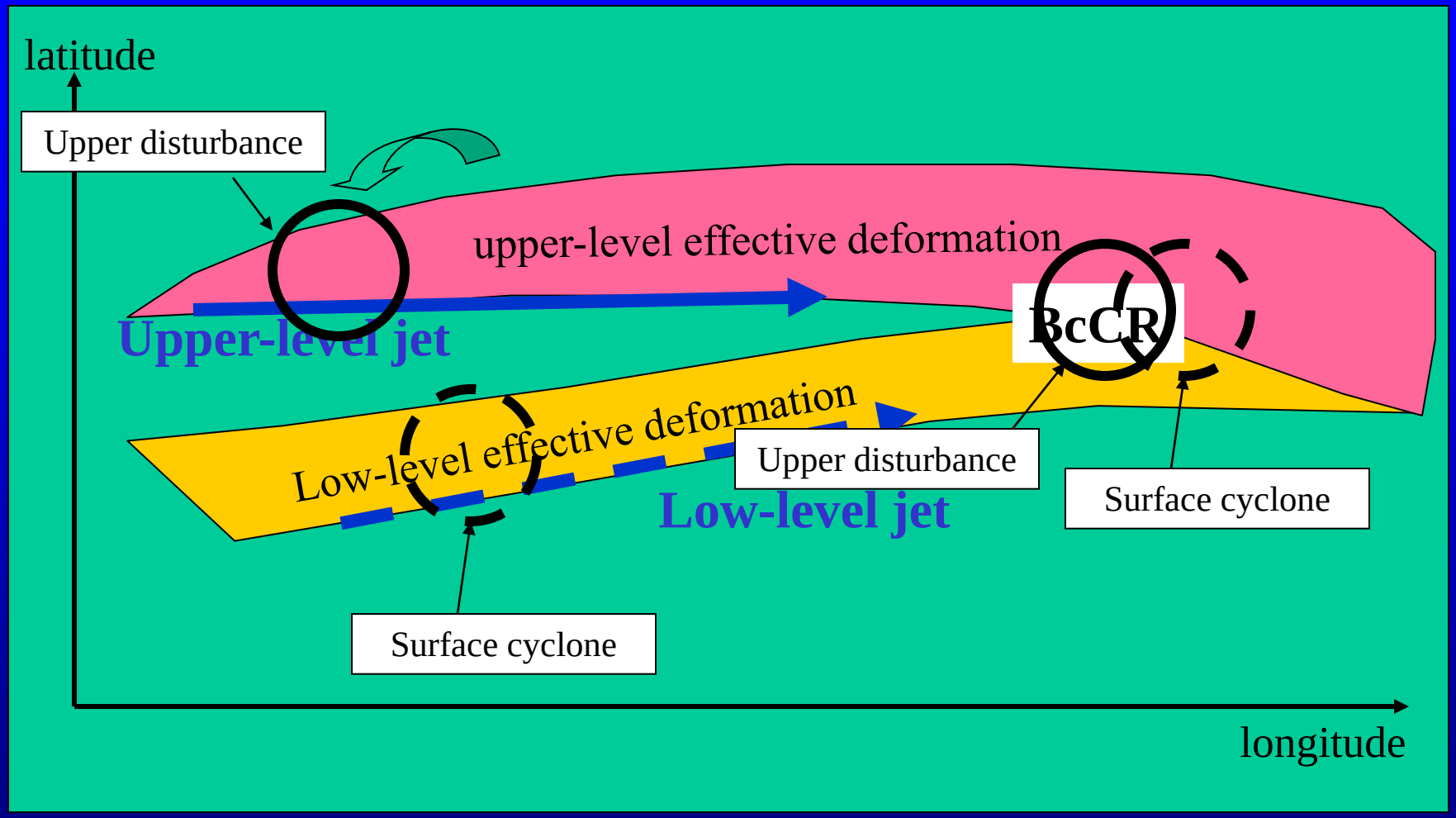
Role of the effective deformation during the jet-crossing phase of Xinthia



Barotropic simulations on the sphere: comparison between two jets



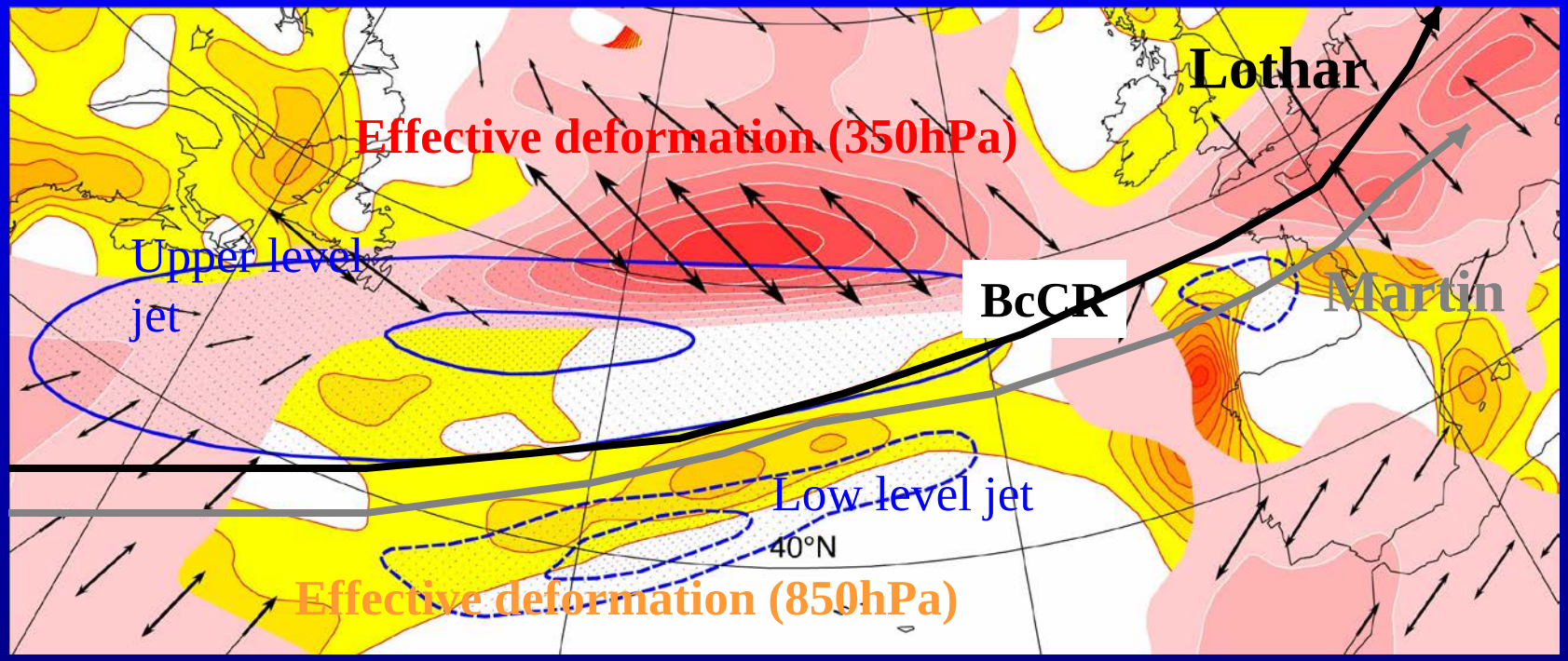
Baroclinic critical region: schematic



Optimal configuration is only possible in the eastern side around BcCR to satisfy constraints exerted by the large-scale flow

Baroclinic critical region: 1st example

Christmas 1999



Trajectories of the two storms well captured by the effective deformation at low levels