Low-frequency oscillations in the atmosphere induced by a mid-latitude SST front

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Motivation

- **Do mid-latitude SSTs affect the atmosphere above ?**
- **Does extratropical oceanic variability affect climate variability ?**

Mid-oceanic thermal fronts, such as the *Gulf Stream* and *Kuroshio Extension*, are permanent features of the mid-latitude ocean circulation.

The circulation in the atmospheric marine boundary layer (**AMBL**) adjusts to changes in the oceanic surface conditions within several hours. The AMBL reaches heights of 600–1200 m.

We use a hierarchy of models:

- Idealized, quasi-geostrophic (**QG**) — barotropic (**BT**) and baroclinic (**BC**) models;
- Global circulation model (**GCM**) — LMD-Z.

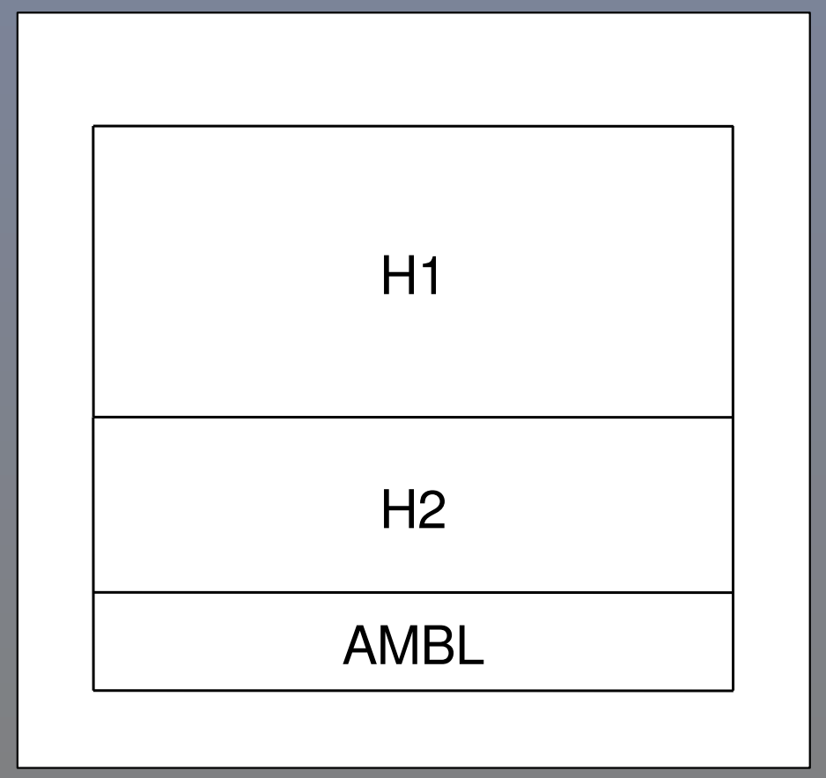
Presentation of the idealized models

We study the flow induced by an East–West-oriented SST front of finite zonal extent (600 km). The SST front has the pattern :

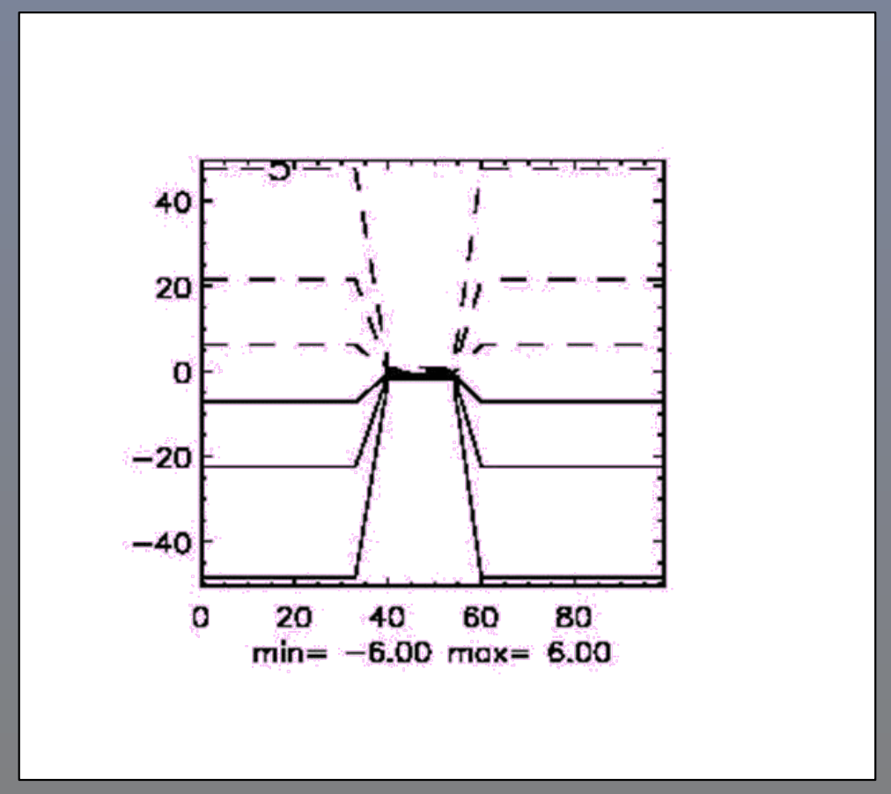
$$T(y) = -T*\tanh\left(\frac{y}{50\text{km}}\right)$$

The atmospheric model is composed of a steady, analytical **AMBL** and a time-dependent, **QG BC model** with two modes in the vertical (corresponding to two layers).

The computational domain is **5000 km x 5000 km**, with a grid spacing of **50 km**.



AMBL : 0.8 km depth + the two layers of the free atmosphere = 10 km total.



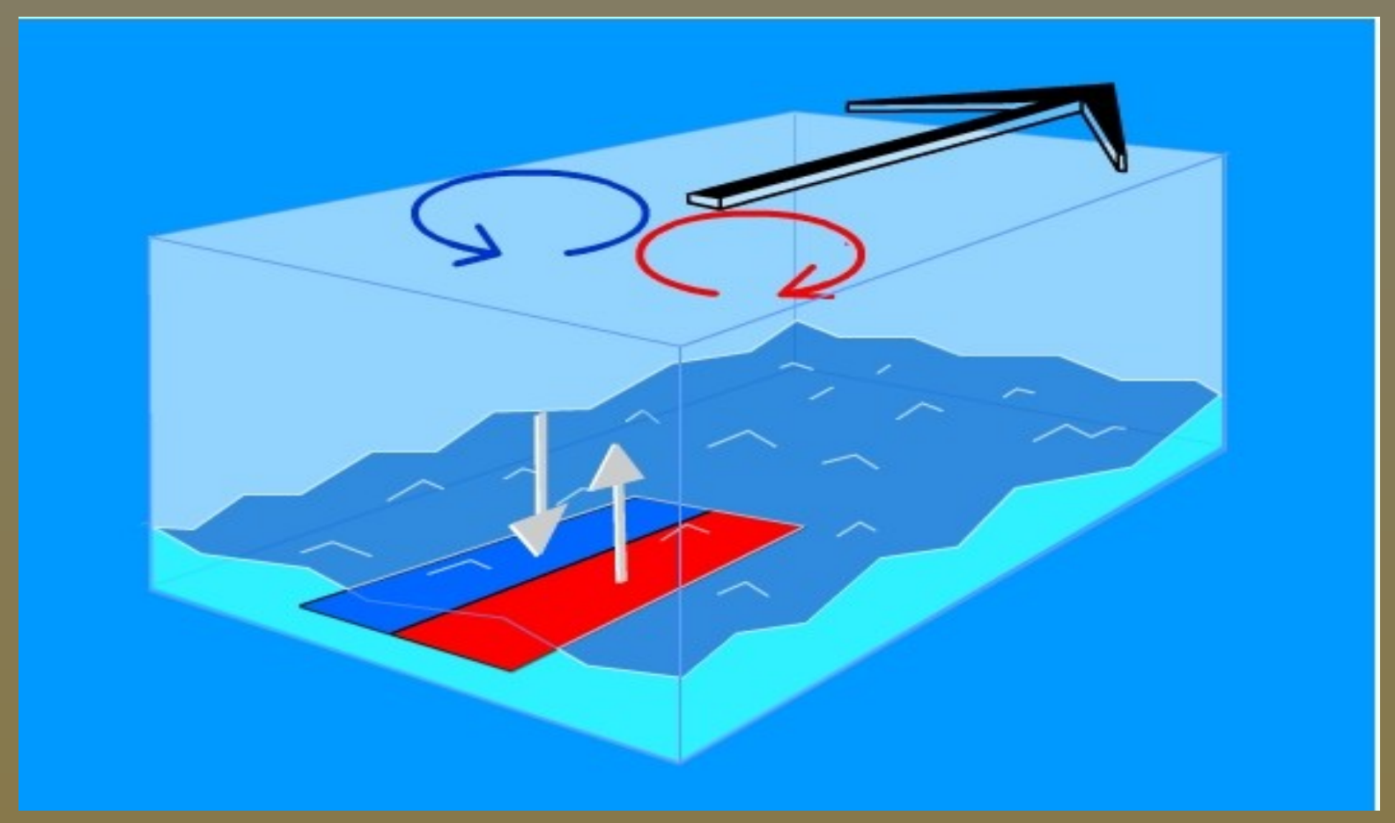
SST front: length 600 km, width ~ 100 km, strength T^* = 6.1°C.

The vertical velocity ***w***, at the top H_E of the **AMBL**:

$$w(H_E) = -\int_0^{H_E}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)dz = \gamma\nabla^2\psi - \alpha\nabla^2 T$$

Mechanical component

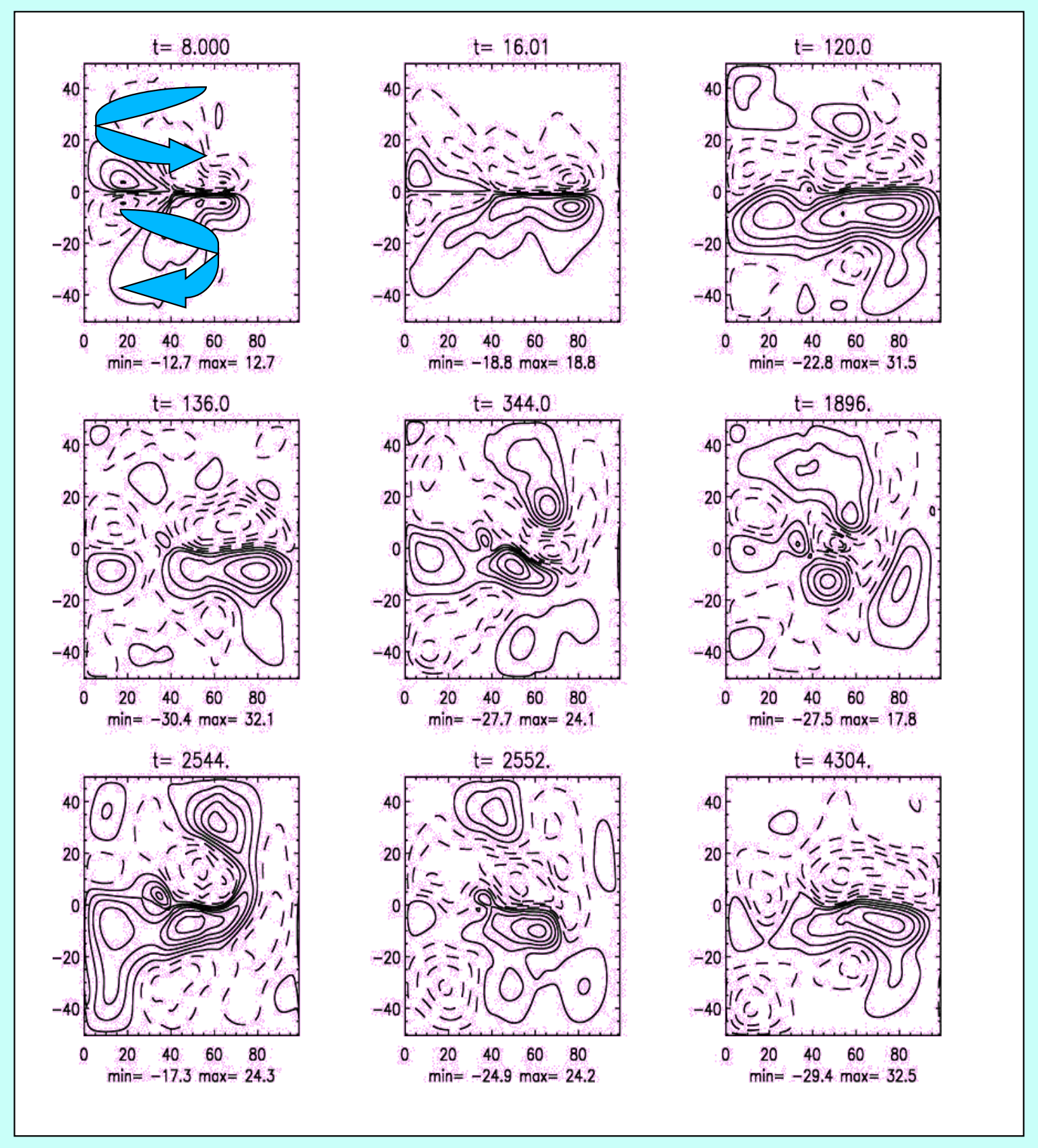
Thermal component



This mechanism spins up an eastward jet in the free atmosphere; see Feliks *et al.* (2007).

Results for the idealized models

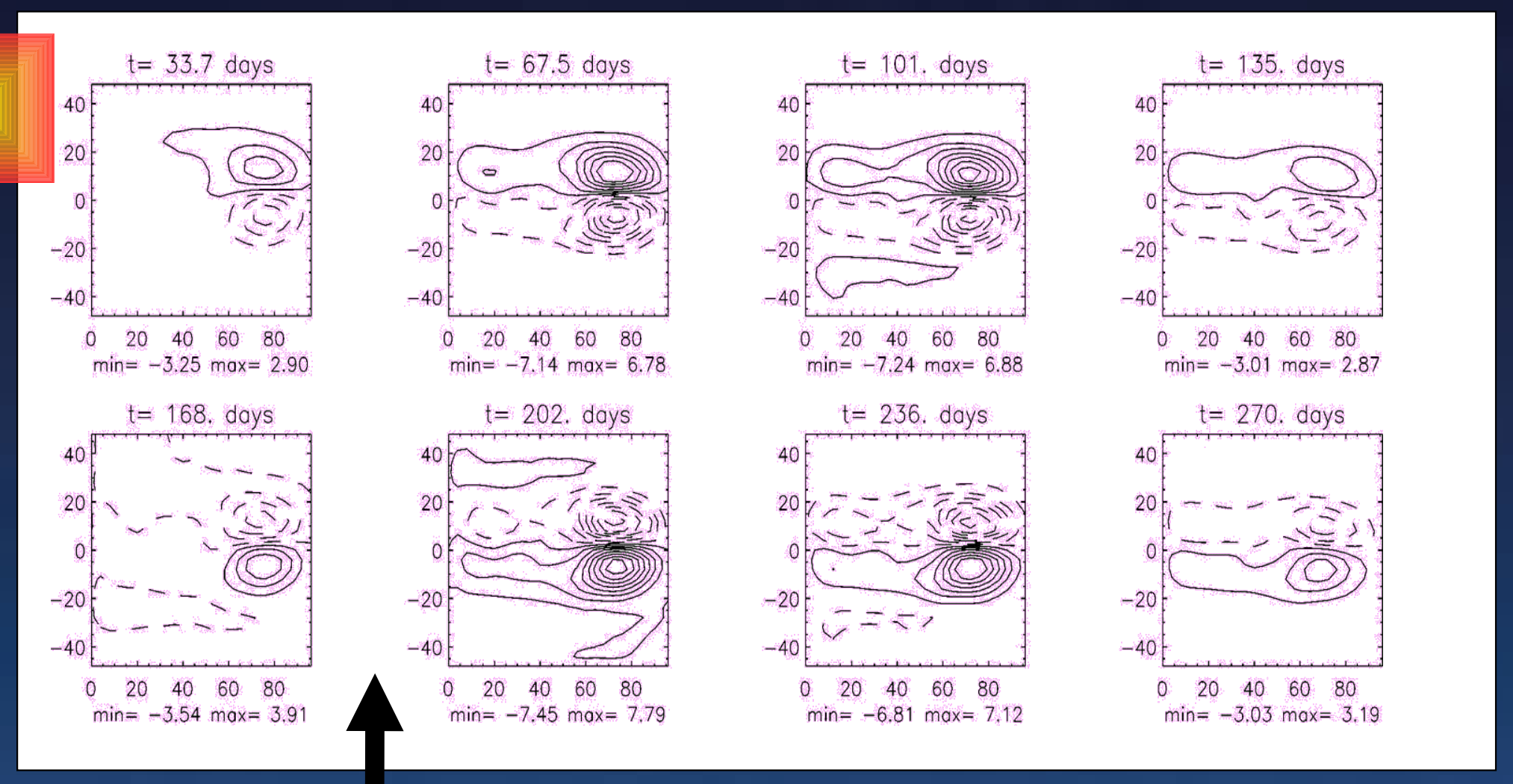
Barotropic Mode



SST, domain 5000km*5000km

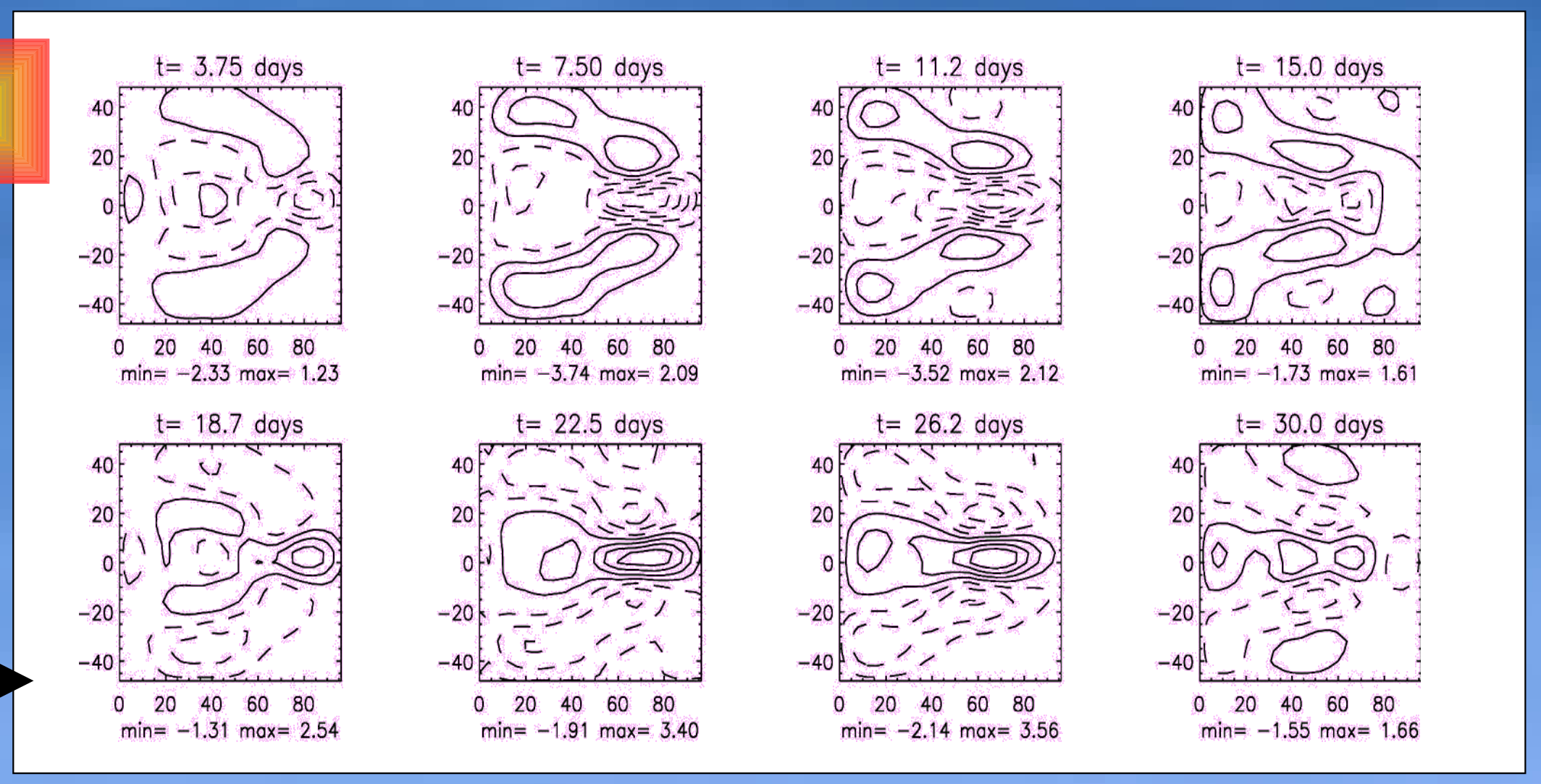
Three kinds of unstable oscillatory modes

1



Antisymmetric instabilities are **baroclinic**, and have a standing-dipole structure; their dominant **period is 270 days**.

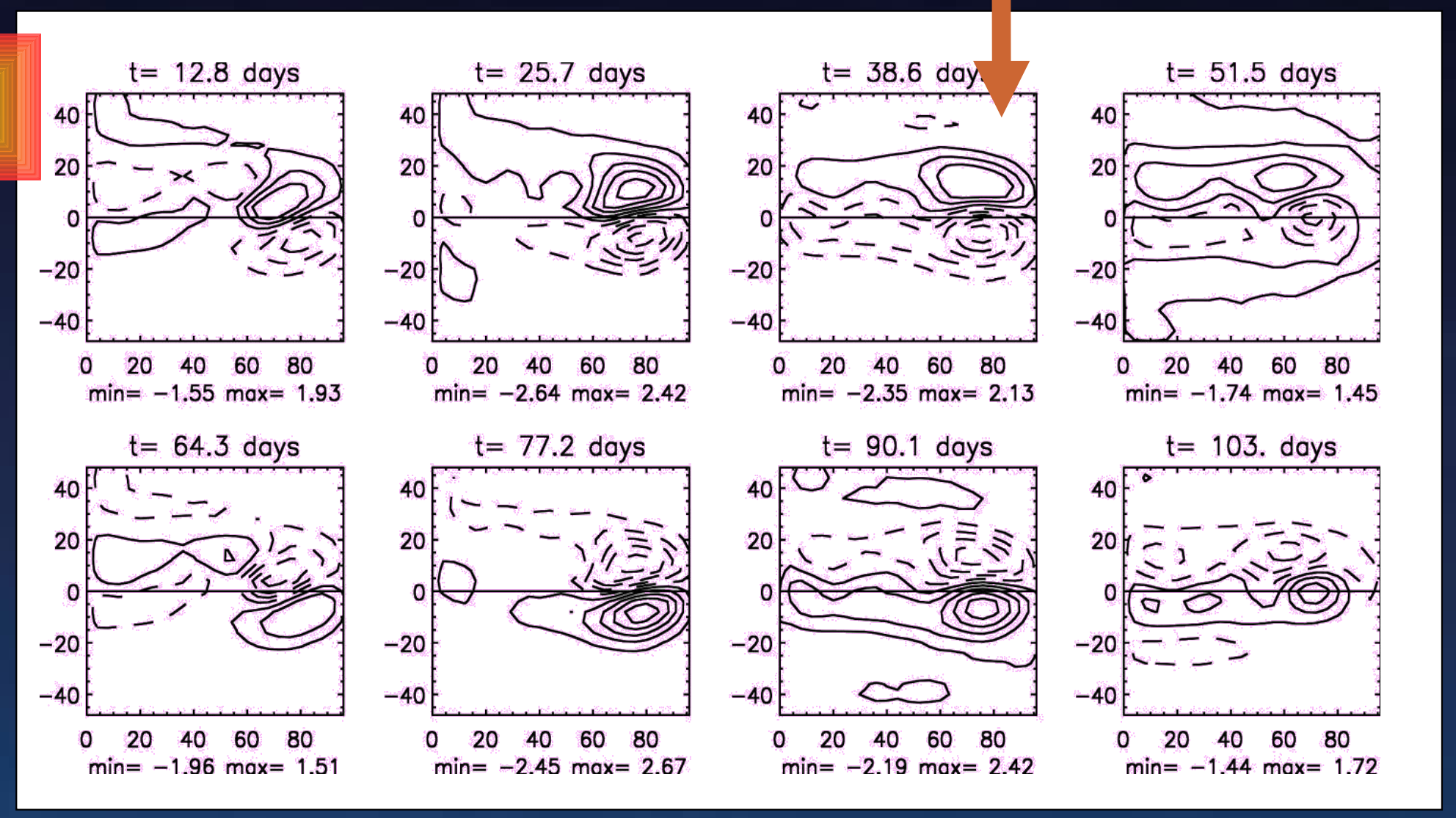
2



Symmetric instabilities are **barotropic**, develop at the eastern edge of the eastward jet, and the dominant **period is 30 days**;this mode was also obtained in an equivalent-**BT** model (see also Feliks *et al.*, 2004).

Northward-propagating instabilities have **two standing parts**, antisymmetric and symmetric, and the dominant **period is 103 days**; the spatio-temporal evolution of this mode resembles the observed 70-day mode of Plaut & Vautard (1994).

3



Conclusions from the idealized model

The SST front spins up an eastward jet in the free atmosphere.

Three kinds of unstable oscillatory modes are obtained:

(1) **symmetric** due to **barotropic** instability, with a period of **30 days**;

(2) **antisymmetric** due to **baroclinic** instability, with a period of **6–8 months**;

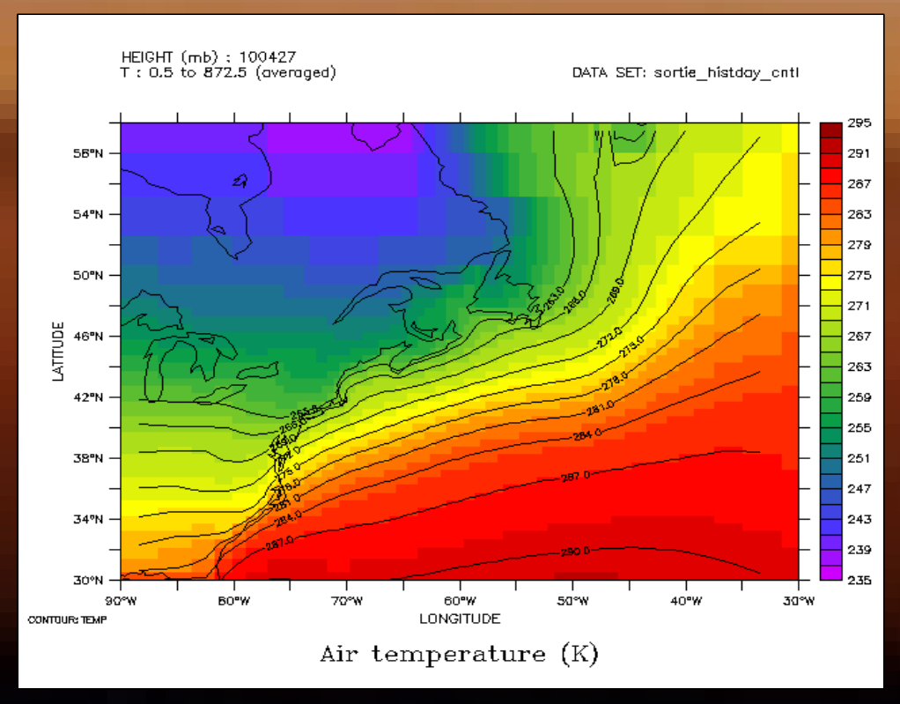
(3) and a **northward-propagating mode,** with an antisymmetric and a symmetric component, having a period of **2–3 months**.

These effects depend on the atmospheric model's having a sufficiently high resolution, of at least 50 km x 50 km!

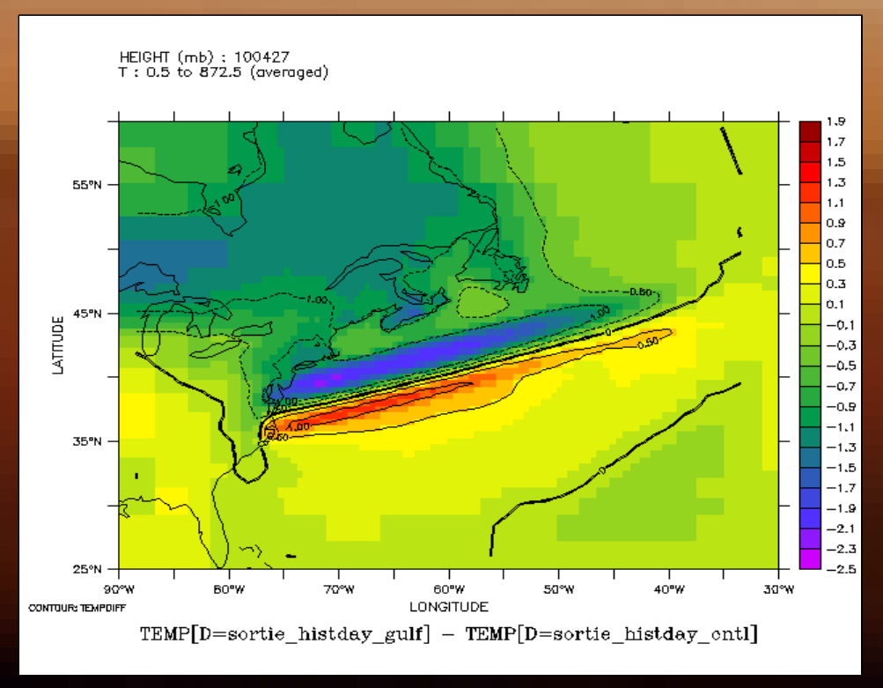
Presentation of the GCM

The idealized-model study strongly suggests that the mid-latitude oceans can influence low-frequency atmospheric variability above them, provided oceanic fronts (like the Gulf Stream and Kuroshio) are sufficiently well resolved spatially.

We use an IPCC-class GCM, namely LMD-Z, and a realistic time-averaged Gulf Stream SST front. The model is integrated with a high-resolution **zoom** (hence the **'Z' in** LMD-Z) in **the Gulf Stream area** to resolve correctly the effects of the front.



SST of the standard, low-resolution simulation.



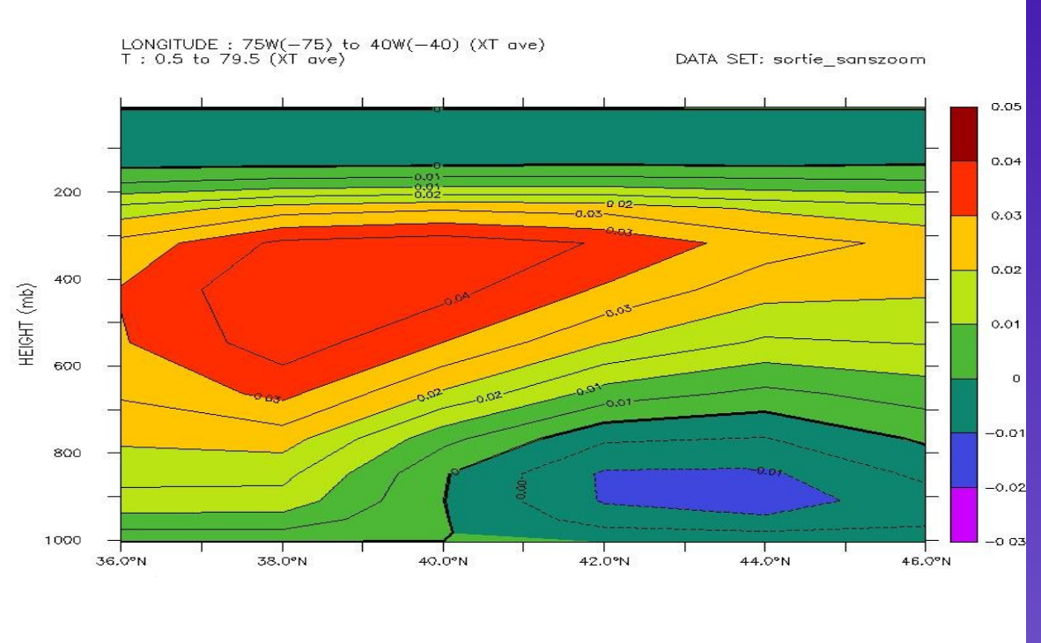
A higher-resolution, more realistic thermal-front anomaly has been added, with an angle of 25°.

The **zoom** is centered at (60°W, 40°N) and the zoomed area is 20° lat. by 40° long. The model has 19 levels, from 0 to 7.4 km. The resolution is 3° outside the zoom. The period of integration is 800 days for the 25°-angle simulation.

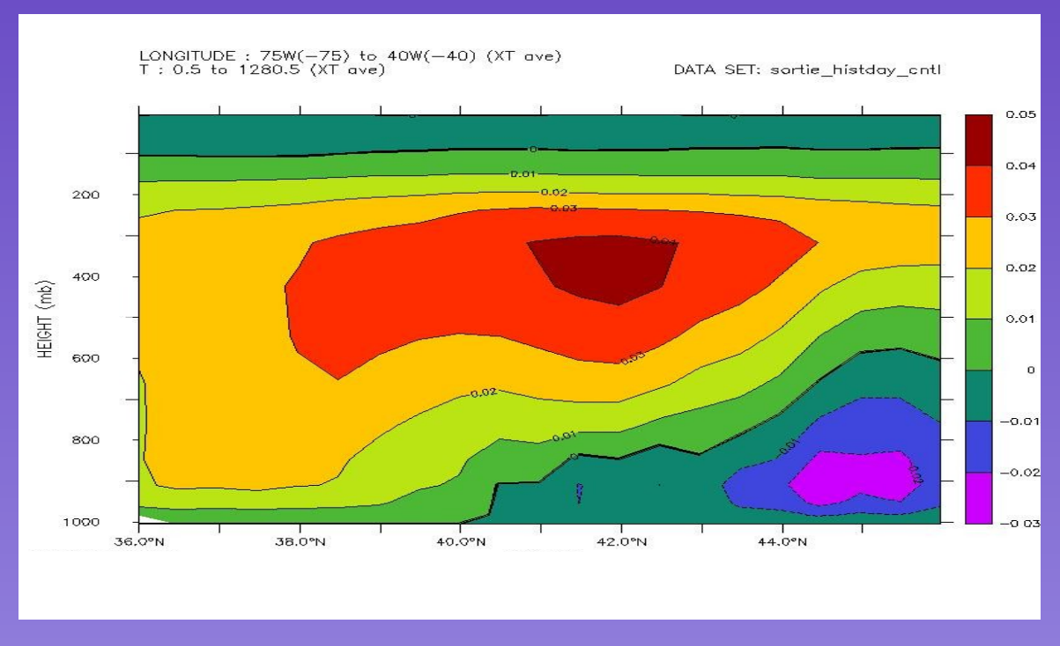
Results for the GCM

Mean *w* averaged from 70°W to 40°W.

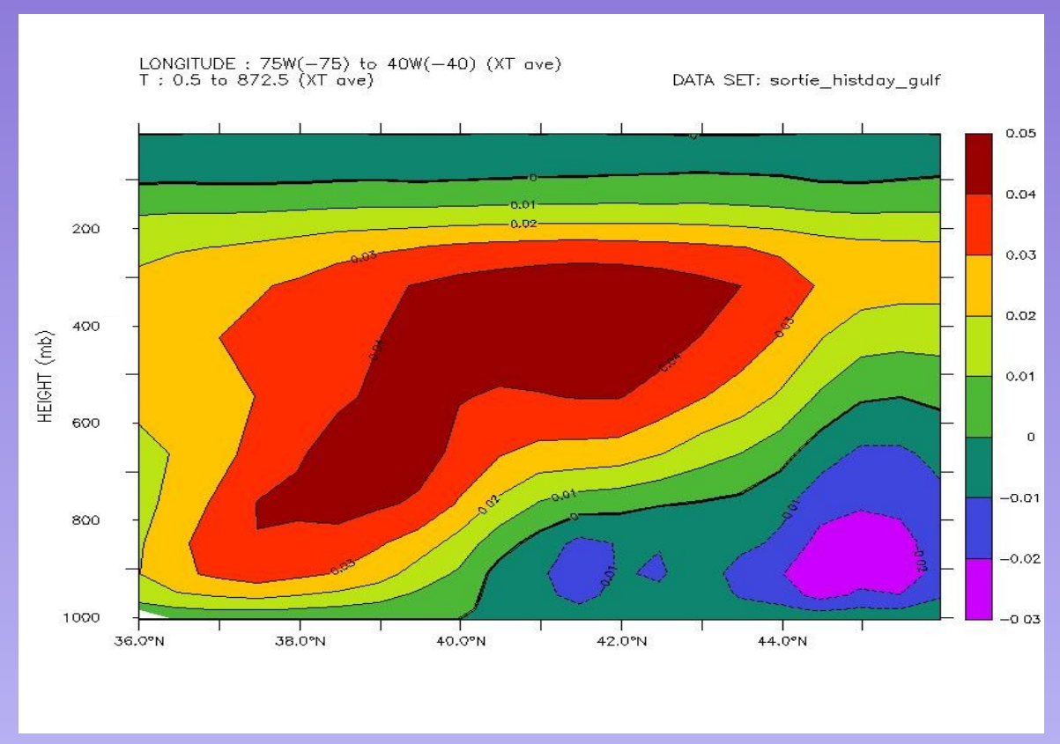
Height *vs.* latitude cross-section; red/blue means +ve/–ve upward velocity.



Without Zoom & without SST front

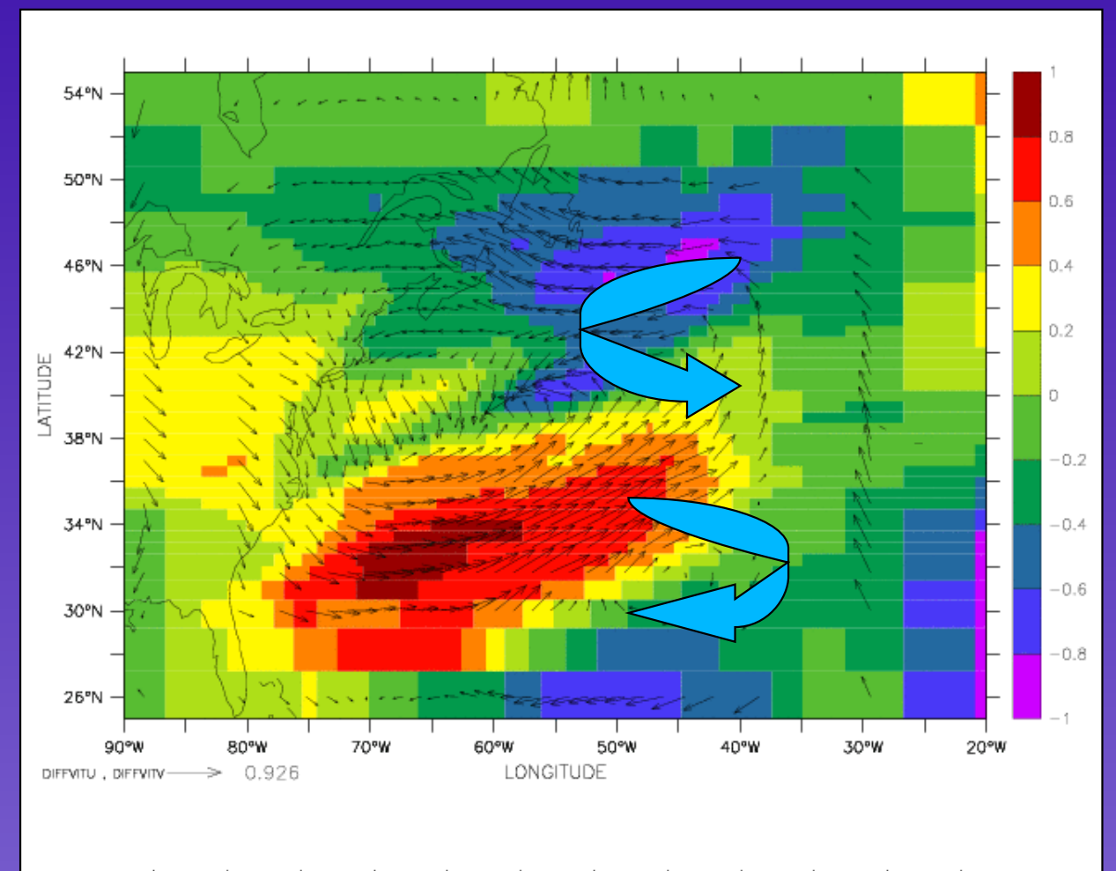


With Zoom & without SST front

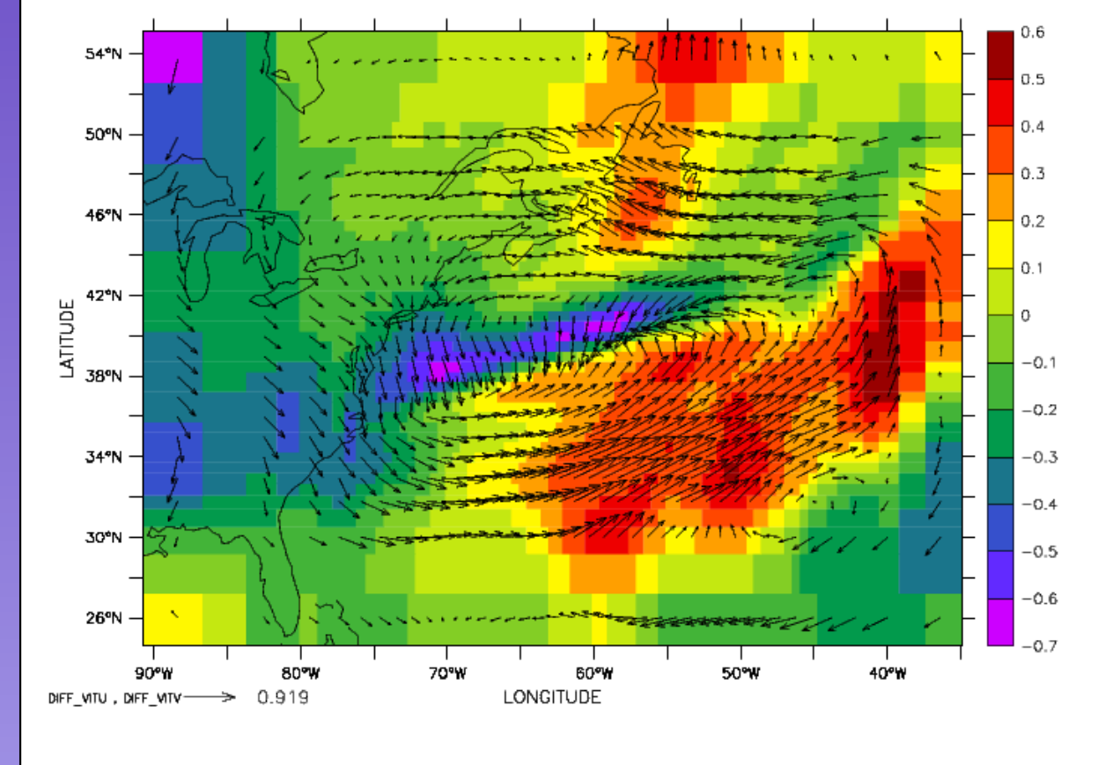


With Zoom & with SST front

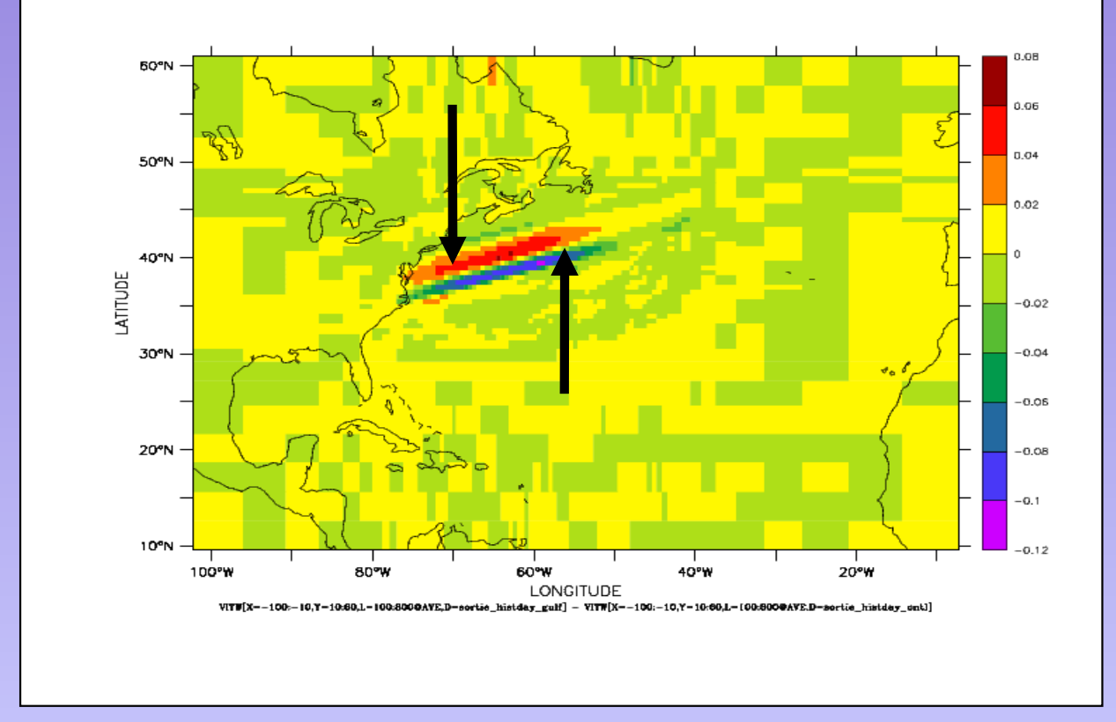
In agreement with Minobe et *al.* (2008) & Song et *al.* (2006) but for **SST forcing only** (not SLP+SST).



Mean horizontal wind anomalies *u* for the lower levels (15 to 19) of the troposphere; Gulf-Stream axis inclination of 25°.



Mean meridional wind anomalies *v*. Notice near-surface southward flow above the SST-front, and the recirculation gyres of Feliks *et al.* (2007).



w in Pa s^{-1} for the realistic simulation at the 18th level. Air descends over the cold side of the front, and ascends over the warm side.

References

Feliks, Y., M. Ghil, & E. Simonnet, 2004, Low-frequency variability in the midlatitude atmosphere induced by an oceanic thermal front. *J. Atmos. Sci.*, **61**, 961–981.
Feliks, Y., M. Ghil, & E. Simonnet, 2007, Low-frequency variability in the midlatitude baroclinic atmosphere induced by an oceanic thermal front. *J. Atmos. Sci.*, **64**, 97–116.
Minobe, S., A. Kuwano-Yoshida, N. Komori, S.-P. Xie & R. Justin Small, 2008, Influence of the Gulf Stream on the troposphere, *Nature*, **452**, doi:10.1038/nature06690.
Plaut, G., & R. Vautard, 1994, Spells of oscillations and weather regimes in the low-frequency dynamics of the Northern Hemisphere. *J. Atmos. Sci.*, **51**, 210–236.
Song,Q.,P. Cornillon, & T. Hara, 2006, Surface wind response to oceanic fronts, *J. Geophys. Res.*, **111**, C12006, doi:10.1029/2006JC003680.