Pathways of influence on Loop Current Frontal Eddies

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Outline

- Description of the problem
- Tools
- Results
- Findings and further work

Description of the problem

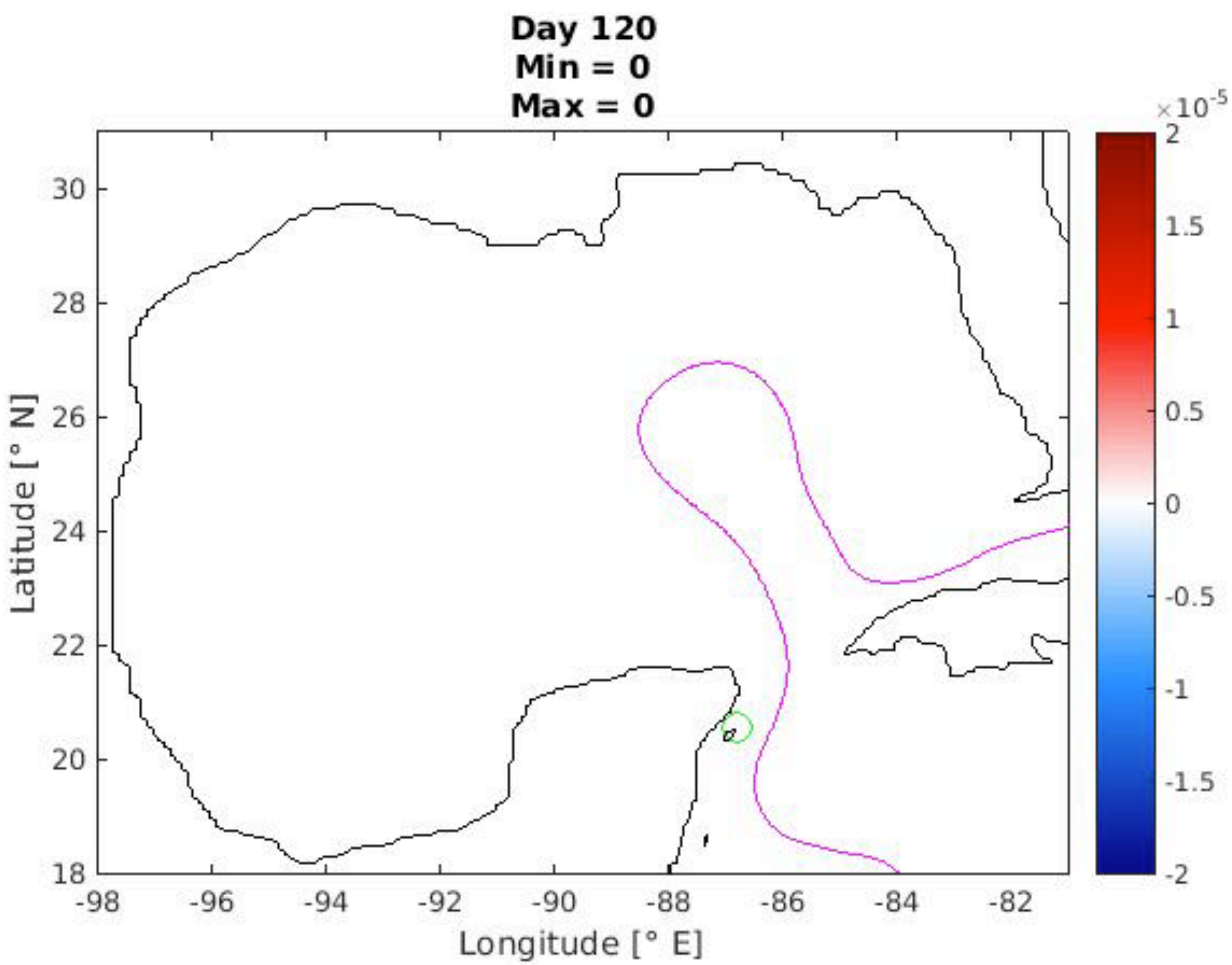
- The Loop Current dominates
- We don't know the mechanism that triggers the separation
- Several theories
- From observations and numerical models there is always a LCFE
- The question… What drives the variability of the LCFE?

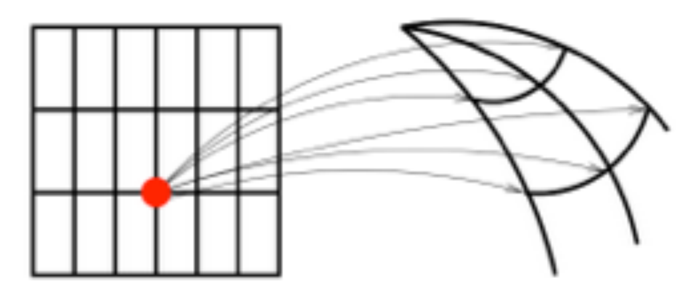
Tools

- Numerical model MITgcm and its adjoint
- Configuration that has delivered good results in the past for forecast and state estimate.

How can we identify mechanisms that affect the LCFEs?

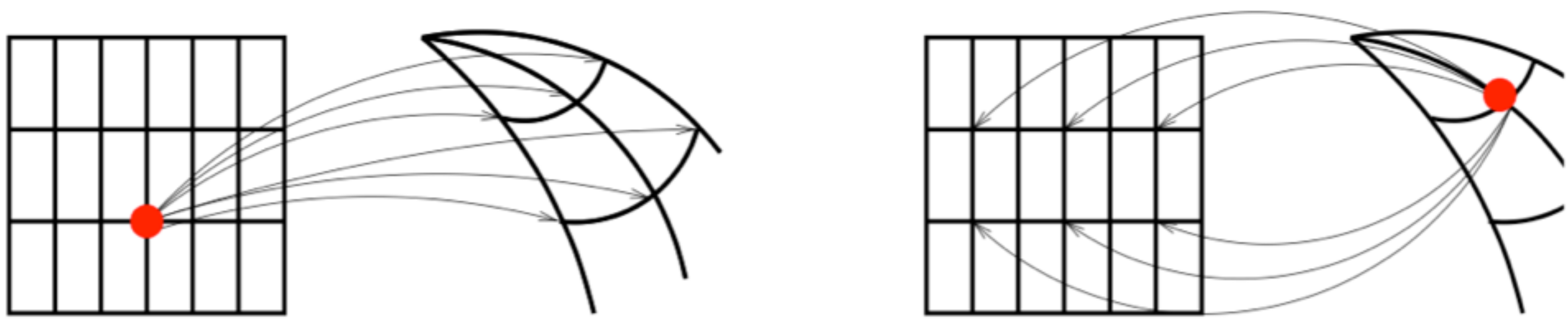
- We can do perturbations in the forward run.





finite difference approach

Adjoint



finite difference approach

adjoint approach

Adjoint limitations

- It uses a linearized version of the model…
- However we can check this out by doing forward perturbations…

The problem is to find a cost function

- How are we going to measure the strength of the LCFE?

$$J = \int_{t_1}^{t_2} \int_A \omega dA dt$$

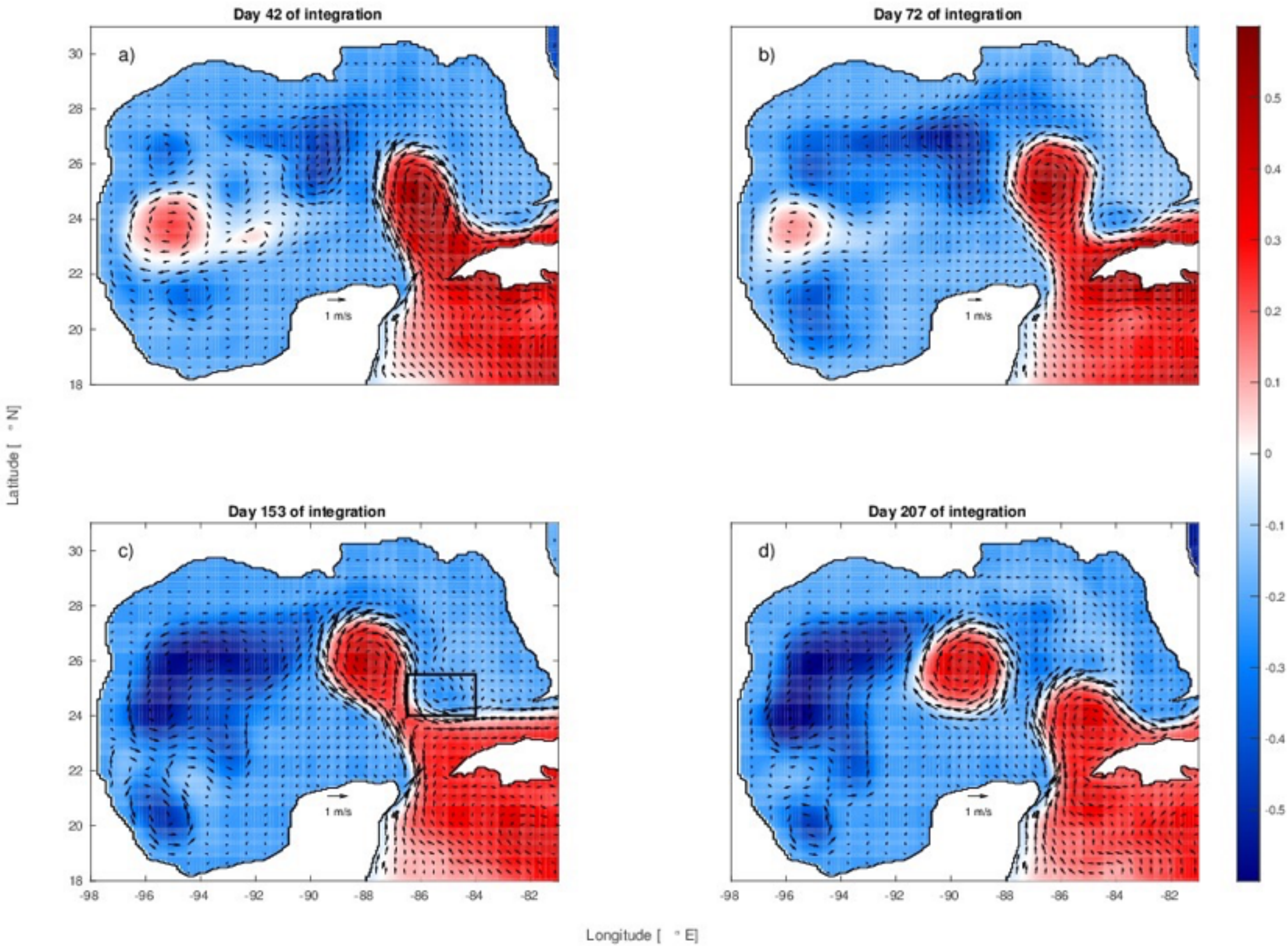
- How are we going to define the limits of the LCFE? Using the Okubo-weiss parameter

$$W = s_n^2 + s_s^2 - \omega^2$$

Summarizing the process…

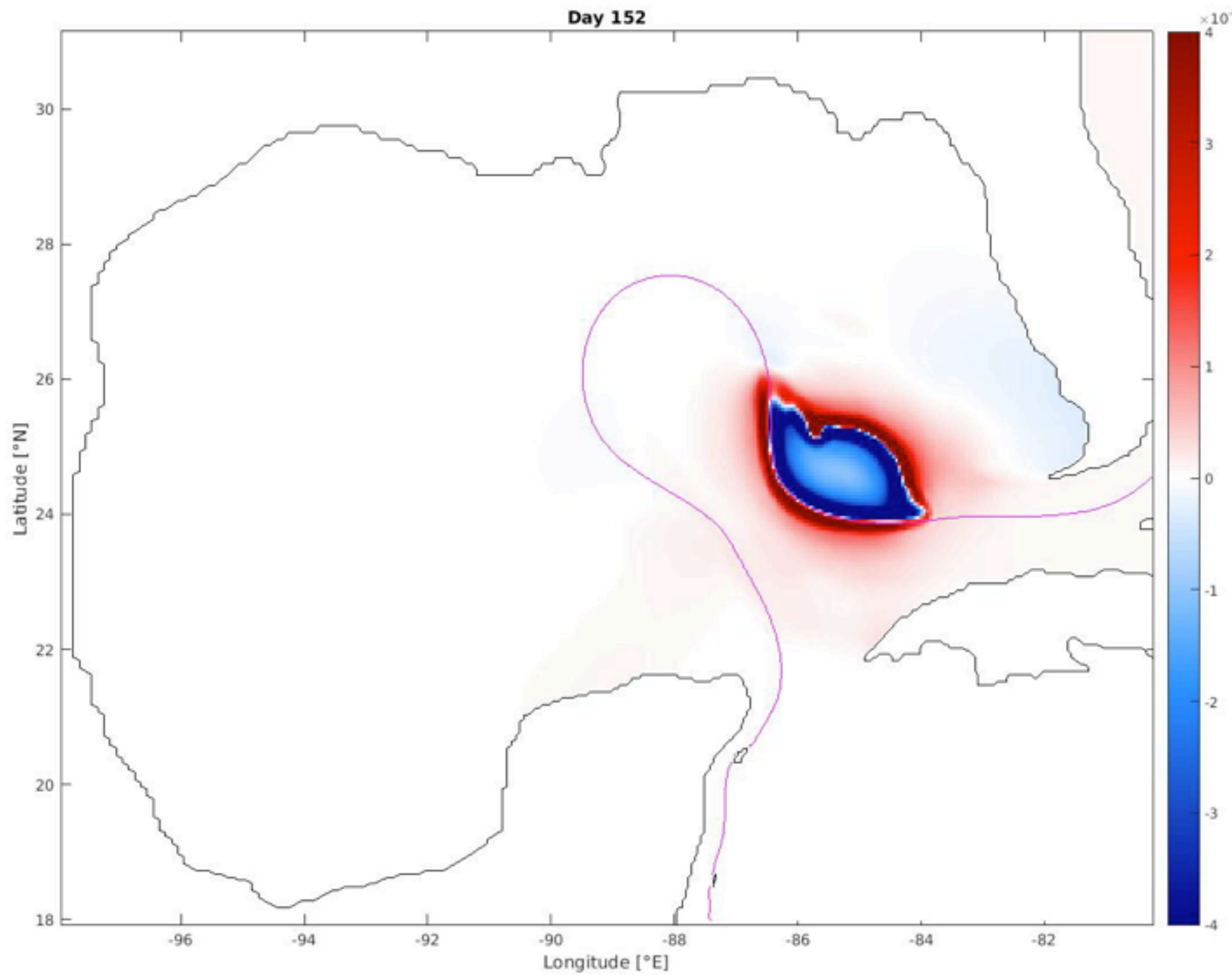
- An implementation of the model is run in forward mode
- A LCFE is identified from the model output by the Okubo-Weiss parameter
- The circulation is estimated by the summation of the vertical component of the relative vorticity within the eddy
- The adjoint model is run backward in time in order to get the evolution of the sensitivity
- Forward perturbation analysis are carried out to check the validity of linear assumption.

Forward run and LCFE



Sensitivity with respect to SSH

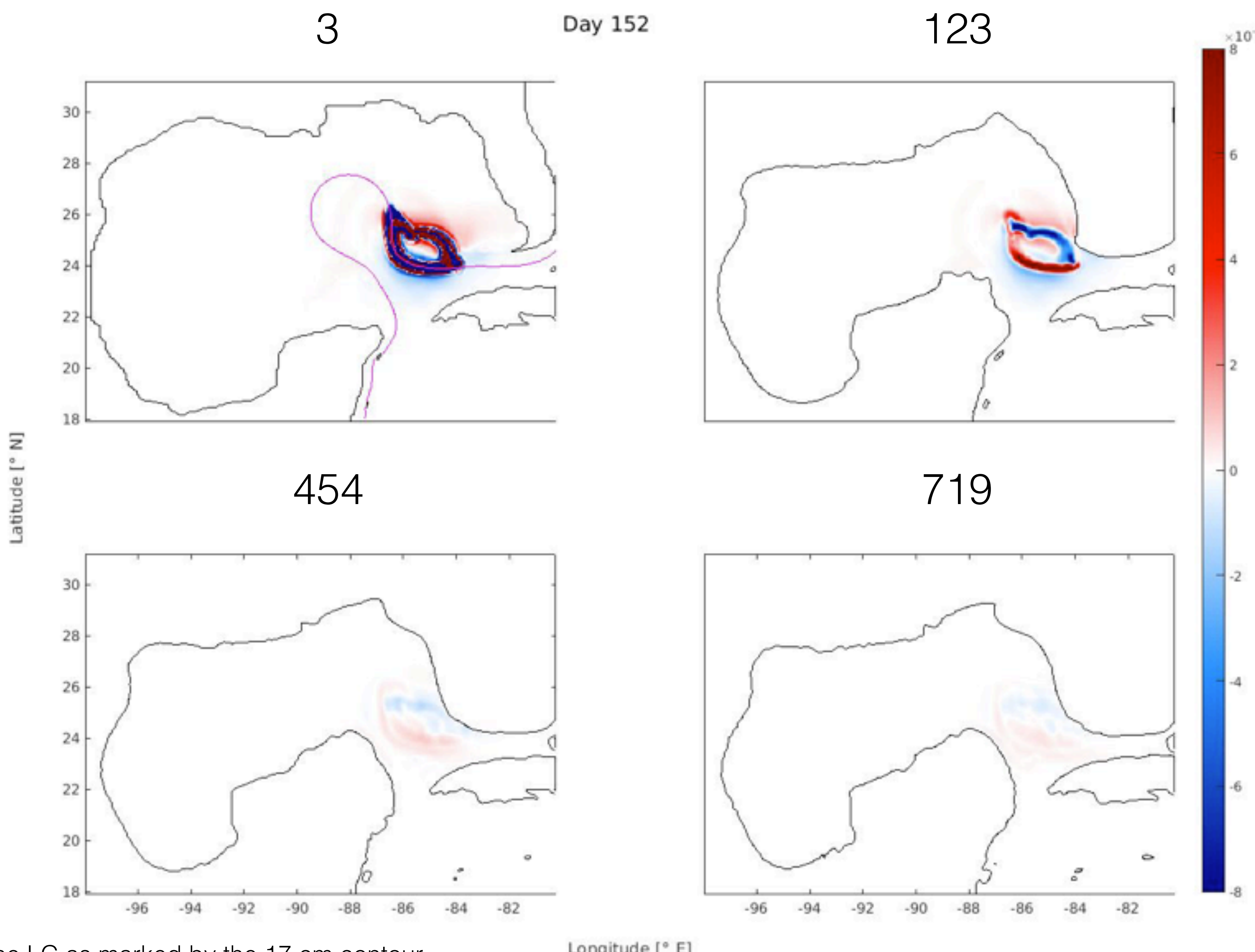
$$\frac{\partial J}{\partial \eta}$$



Limit of the LC as marked by the 17 cm contour

Sensitivity with respect to u component

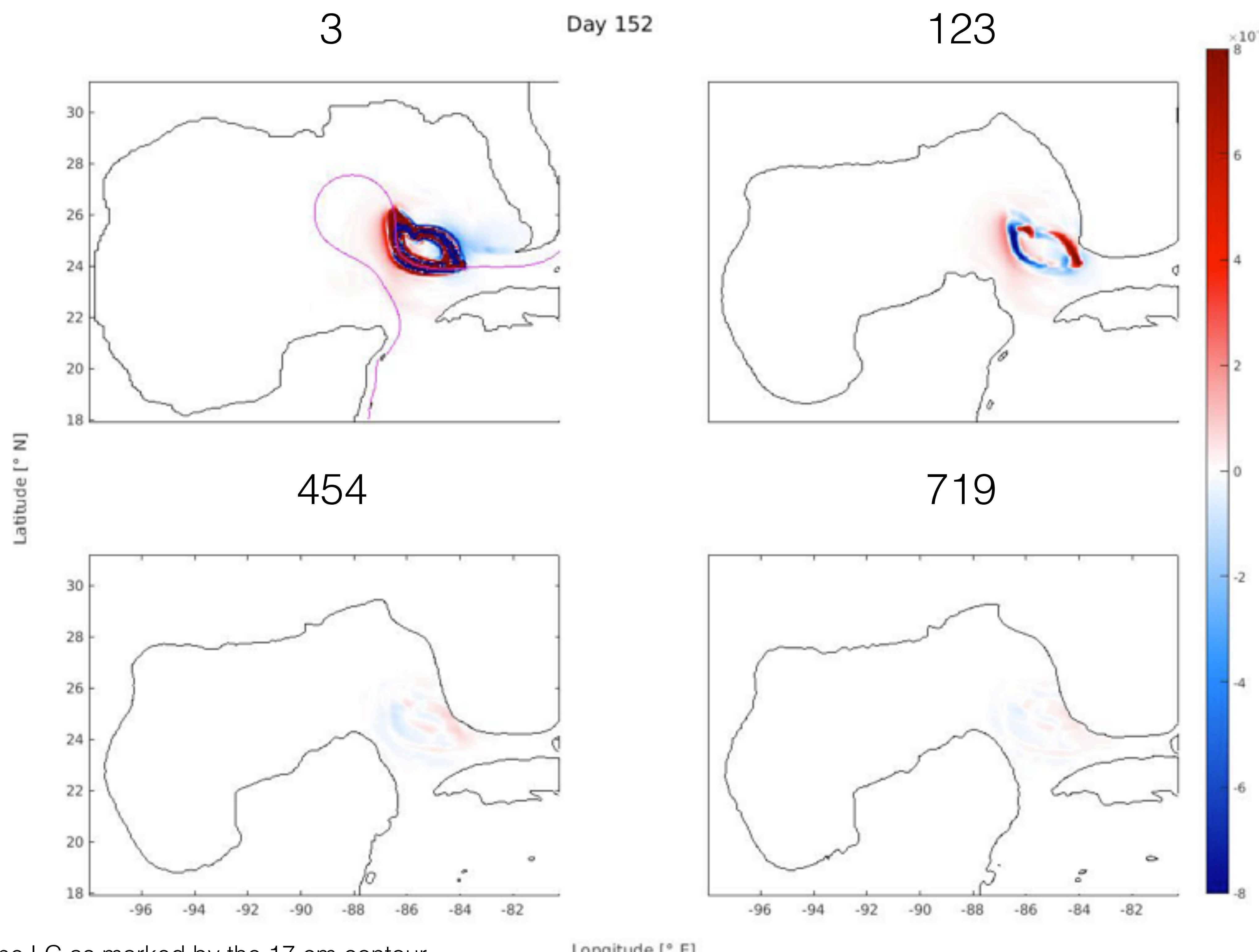
$$\frac{\partial J}{\partial u}$$



Limit of the LC as marked by the 17 cm contour

Sensitivity with respect to v component

$$\frac{\partial J}{\partial v}$$



Limit of the LC as marked by the 17 cm contour

Summarizing

- Three sources of variability were identified

    1. Along the edge of the LC

    2. From the Caribbean

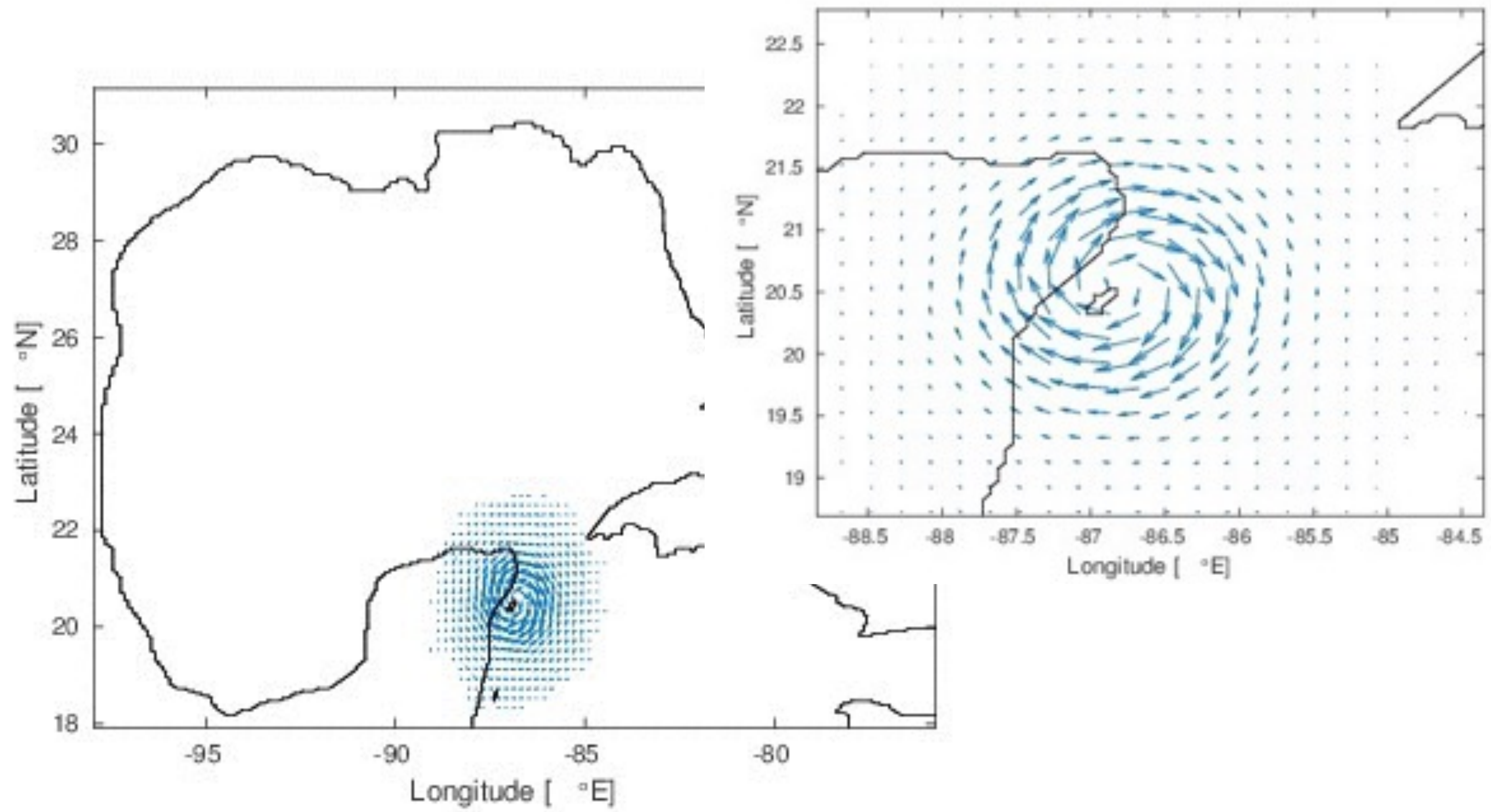
    3. From the West Gulf of Mexico

Forward perturbation

- Perturbed forward simulations allow us to:
  - Visualize the perturbation growth and propagation
  - Calculate an imperfect (but simple) estimate of nonlinearity

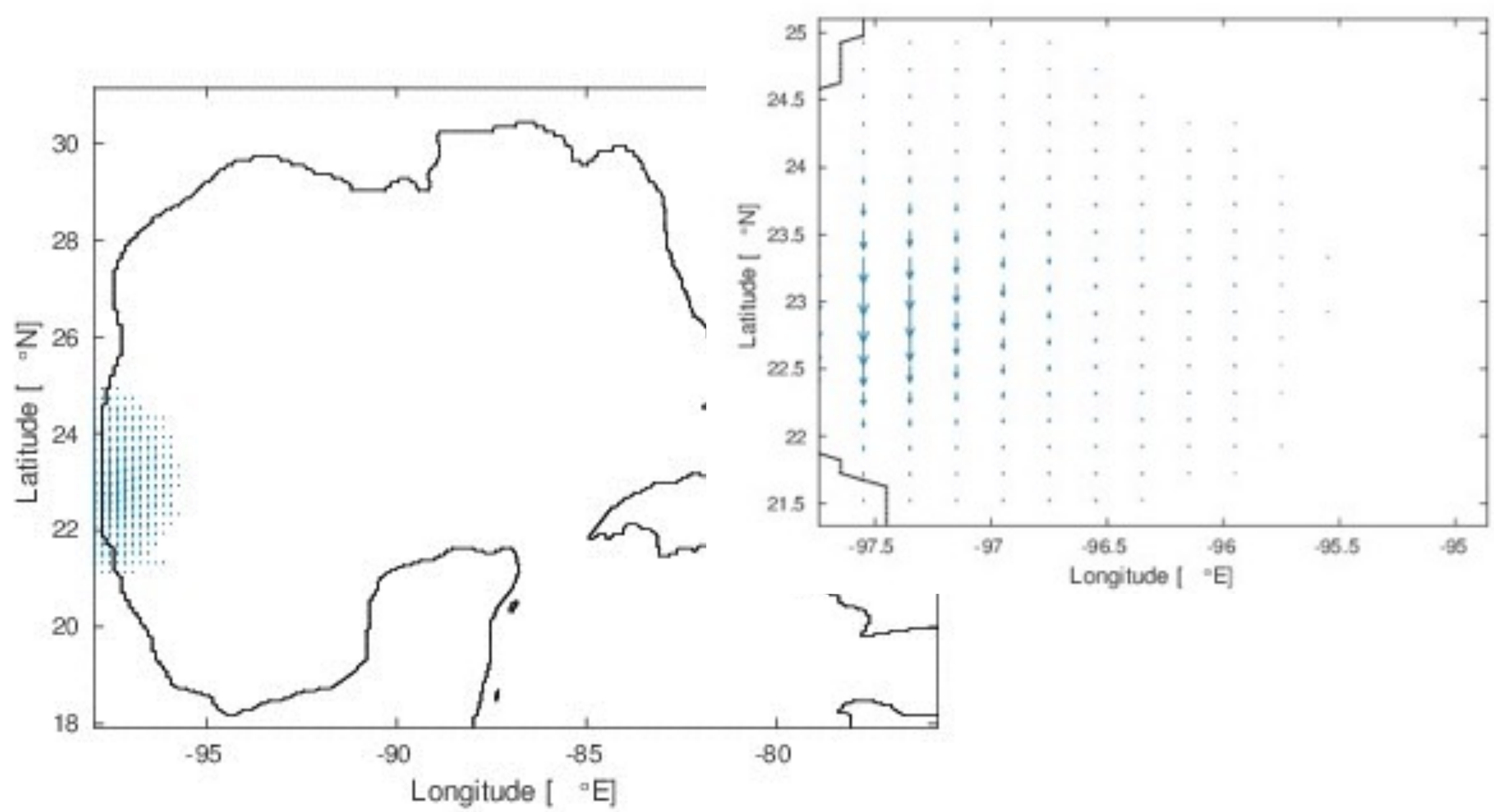
Perturbation in wind

$$\psi = Ae^{\left(-\frac{(x-x_0)^2}{2\sigma^2}-\frac{(y-y_0)^2}{2\sigma^2}\right)}$$



$$u'_{wind} = \frac{\partial \psi}{\partial y}$$

$$v'_{wind} = -\frac{\partial \psi}{\partial x}$$

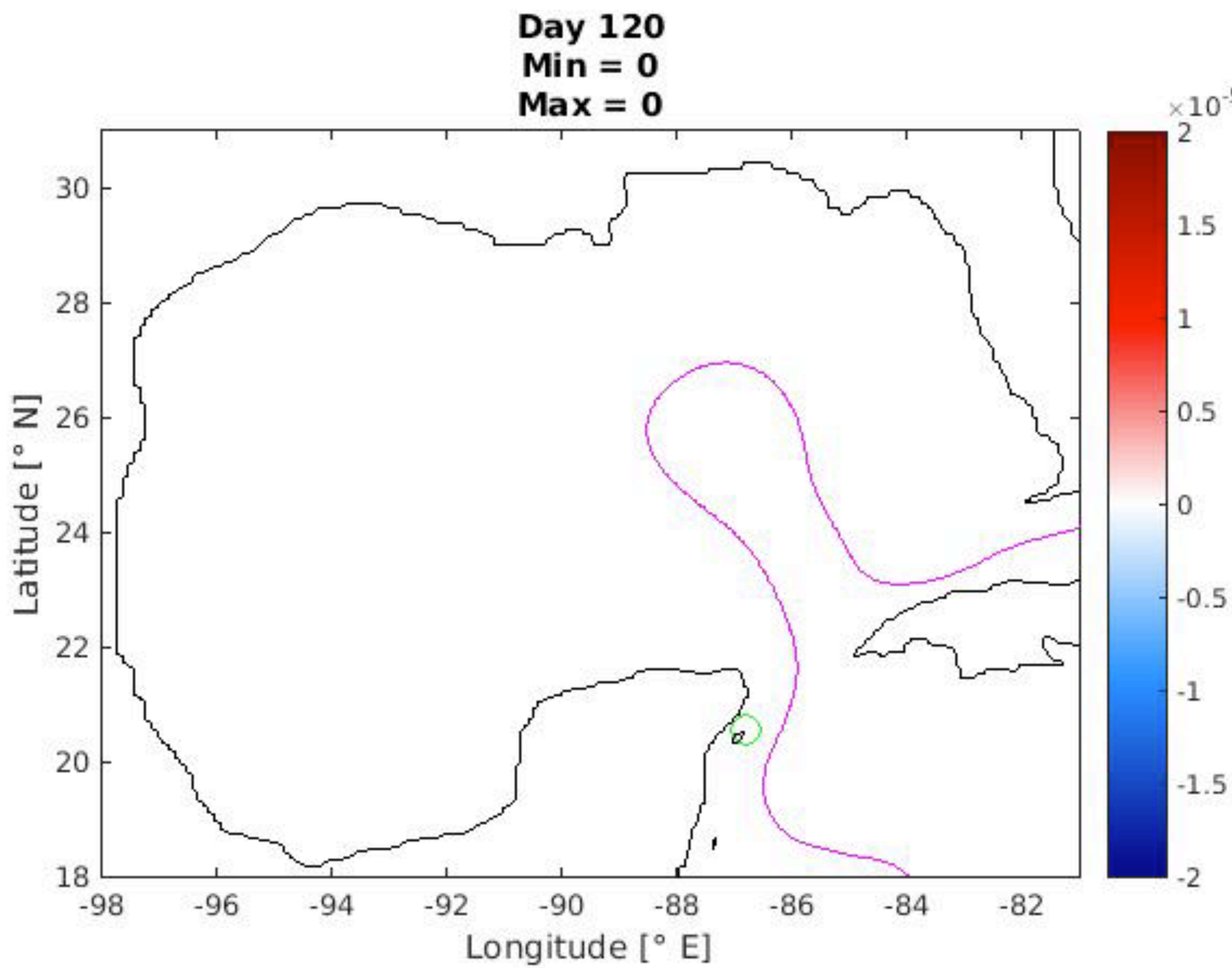


$$u'_{wind} = 0$$

$$v'_{wind} = \psi$$

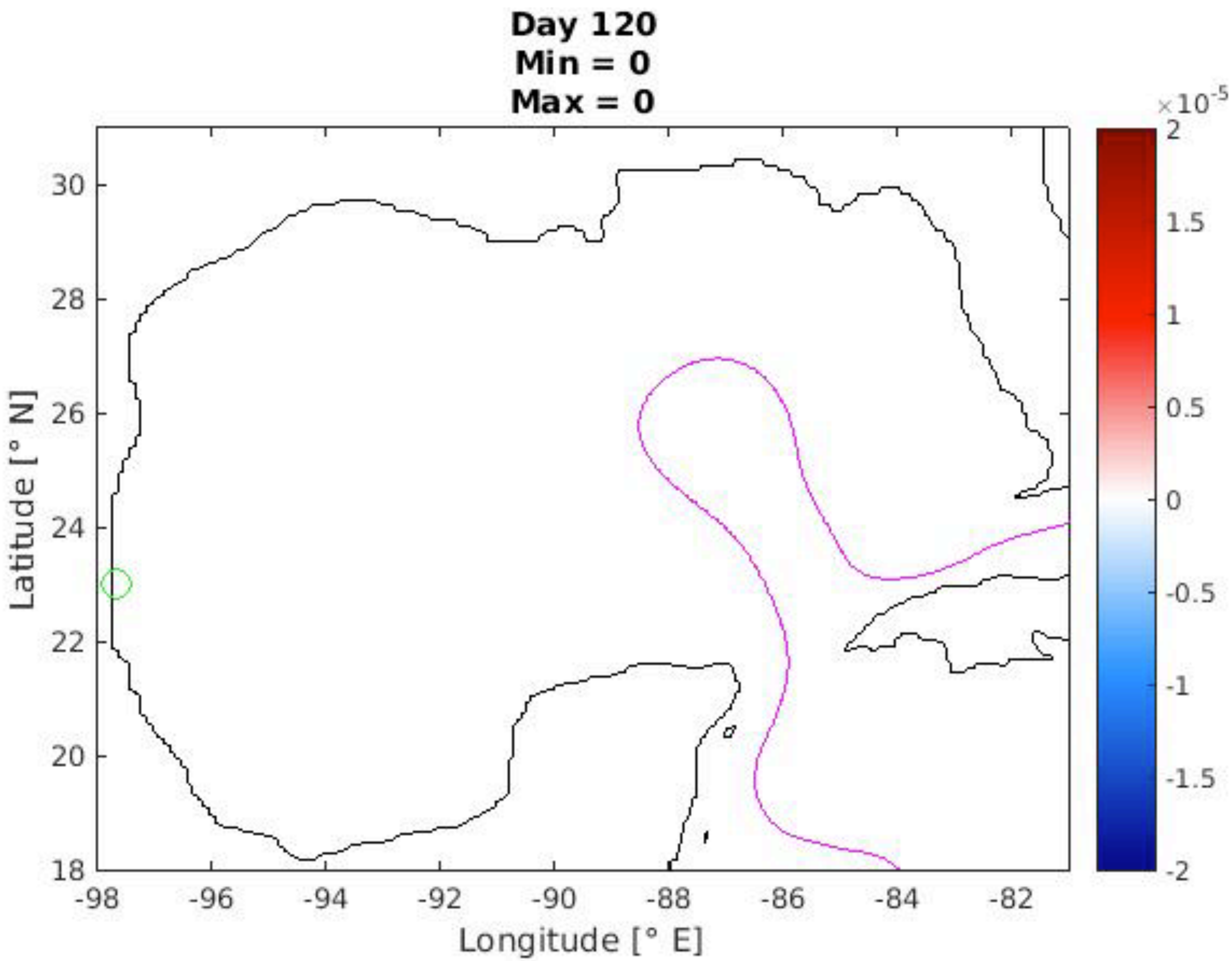
Do not pay attention to units!

Forward perturbation near Cozumel Island



Limit of the LC as marked by the 17 cm contour

Forward perturbation in the western gulf



Limit of the LC as marked by the 17 cm contour

Estimate of nonlinearity

- By doing identical positive and negative perturbation we can test the assumption of linearity in the adjoint model

$$h_+ - h_0 = h_0'\delta x + \frac{h_0''(\delta x)^2}{2!} + \frac{h_0'''(\delta x)^3}{3!} + \frac{h_0^{iv}(\delta x)^4}{4!} + O(\delta x)^5$$

$$h_- - h_0 = -h_0'\delta x + \frac{h_0''(\delta x)^2}{2!} - \frac{h_0'''(\delta x)^3}{3!} + \frac{h_0^{iv}(\delta x)^4}{4!} - O(\delta x)^5$$

$$\delta h_1 = h_+ - h_0$$

$$\delta h_2 = h_- - h_0$$

$$\delta H_1 = \frac{\delta h_1 - \delta h_2}{2}$$

$$\delta H_2 = \frac{\delta h_1 + \delta h_2}{2}$$

$$\delta H_1 \gg \delta H_2$$

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In our case linear is two order of magnitude bigger than nonlinear

Barotropic and baroclinic energy conversion terms

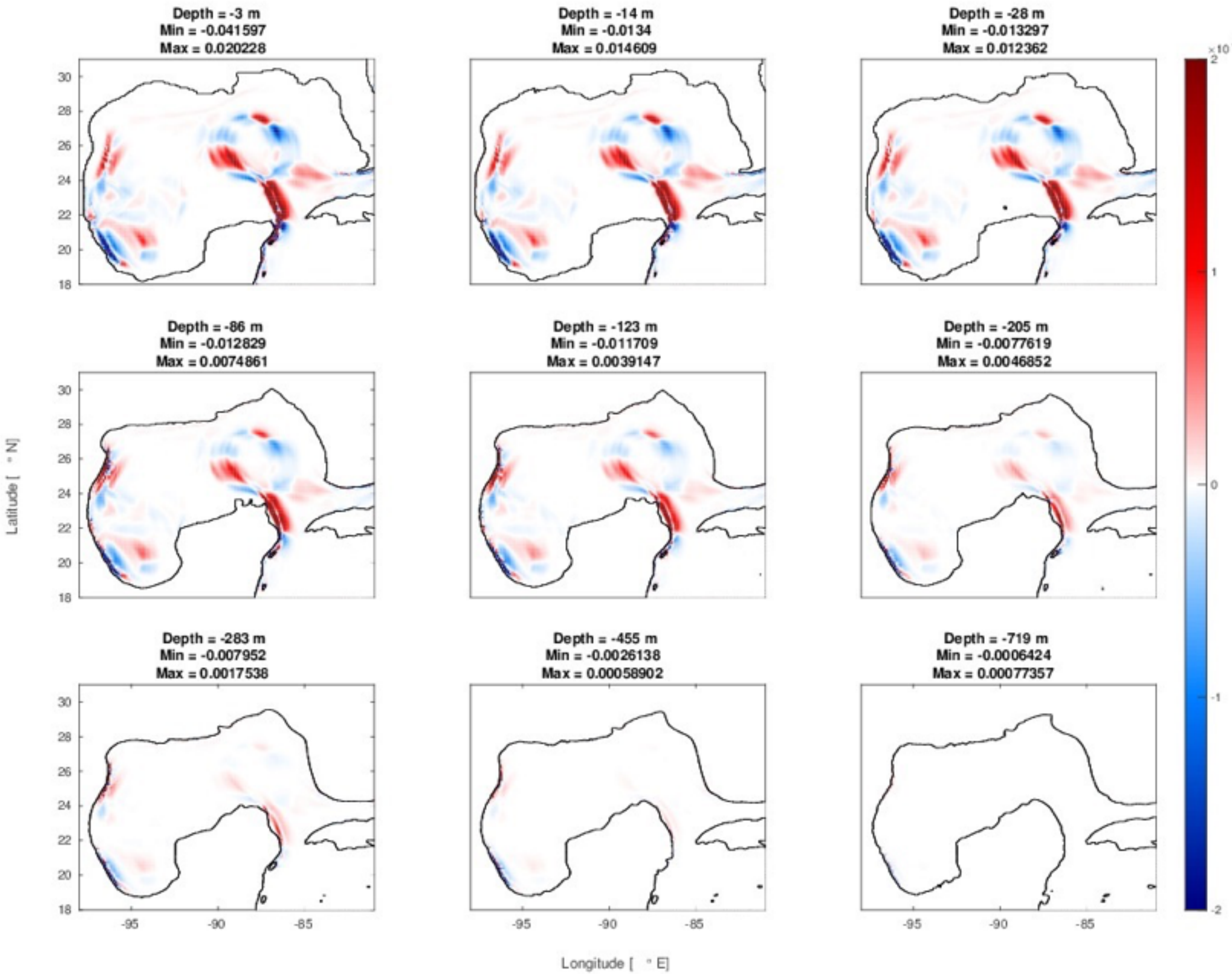
$$BT = -\left(u'u'\frac{\partial U_{LF}}{\partial x} + u'v'\left(\frac{\partial U_{LF}}{\partial y} + \frac{\partial V_{LF}}{\partial x}\right) + v'v'\frac{\partial V_{LF}}{\partial y}\right)$$

Jouanno et al., 2016

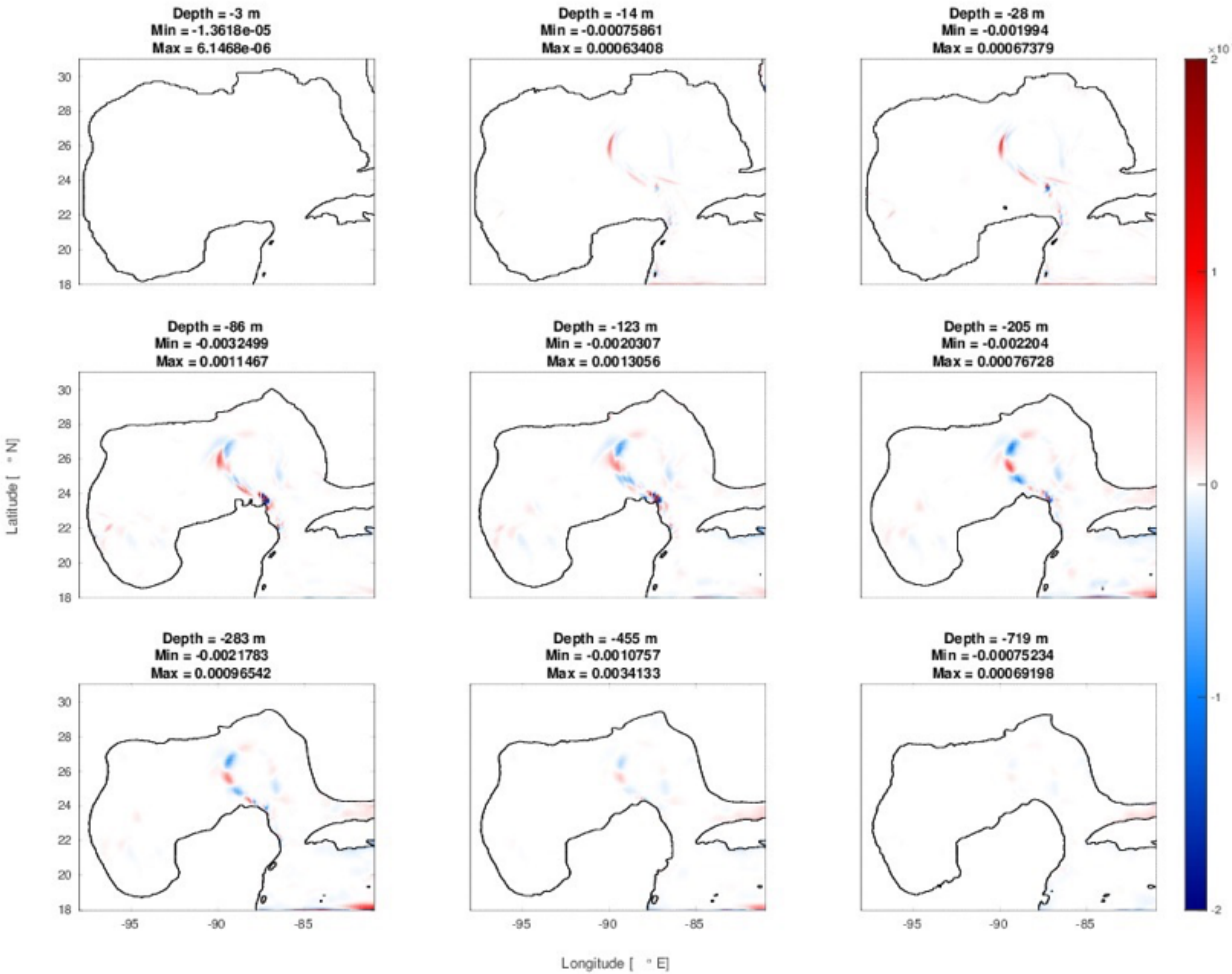
$$BC = -\frac{g}{\rho_0}\rho' w'$$

These calculations were performed over a period of 60 days

Barotropic energy conversion term



Baroclinic energy conversion term

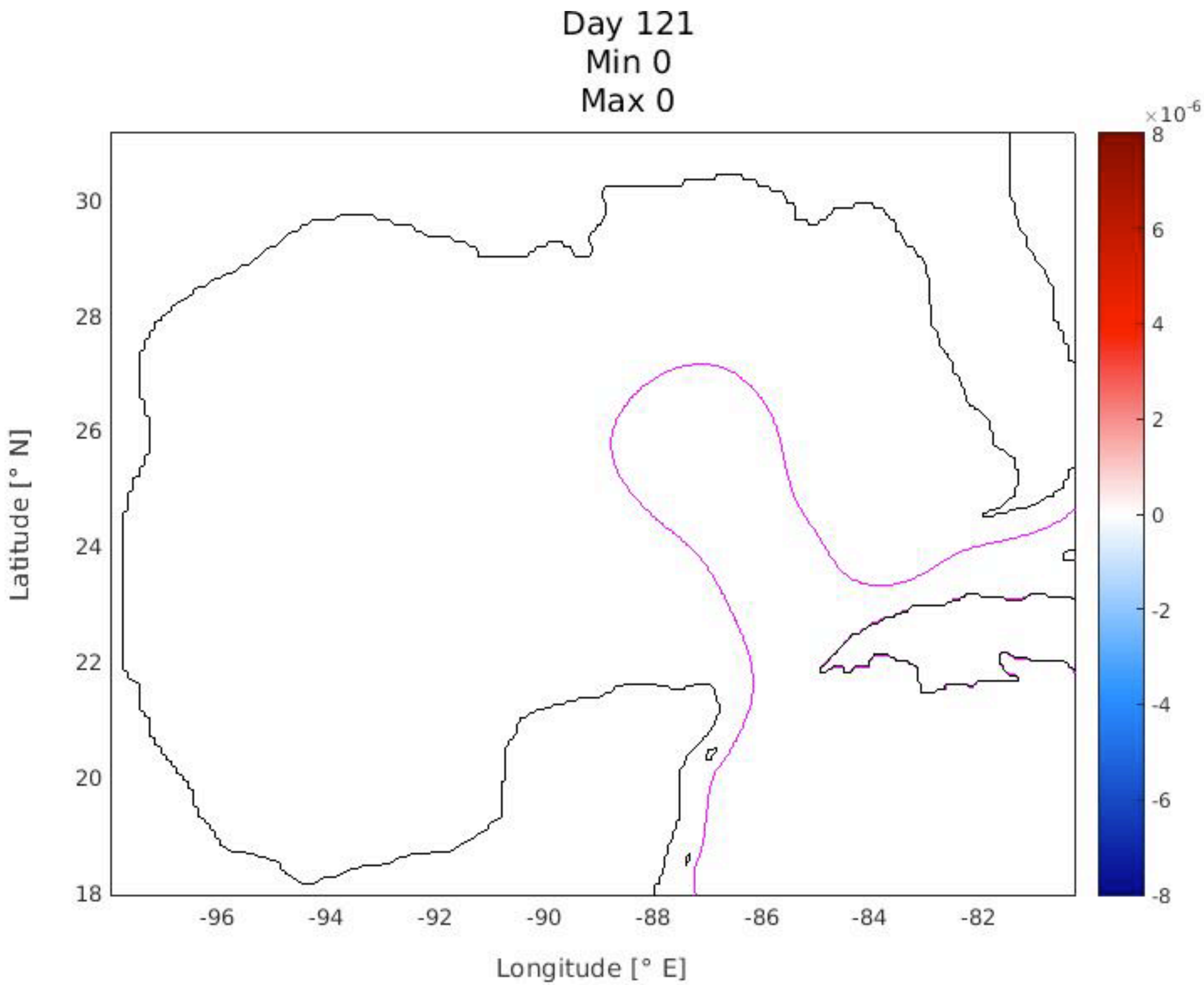


Findings…

- Three sources of variability were identified, the edge of the LC, the Caribbean and the western gulf
- Forward perturbations confirmed the conclusions obtained from adjoint calculations
- The small perturbations generated end up trapped on the edge of the LC and growing there.
- They seem to grow on the east side of the LC where they are trapped
- The generation of EKE seems to be mainly barotropic and concentrated at the surface but at certain depths baroclinic conversion term is as important as barotropic

Further analysis

- Effect of deep circulation on LCFEs
  - There is evidence that LCFEs are affected by deep circulation (LeHenaff et al 2012)
  - Our sensitivity results mark a conspicuous zone of high sensitivity down deep
  - Some forward perturbation experiments show that perturbation of 0.01 oC at 3000 m has an impact at surface particularly on the east edge of the LC as shown in this animation



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Thank you!