# Impact of frontal eddy dynamics on the Loop Current variability during free and data assimilative HYCOM simulations


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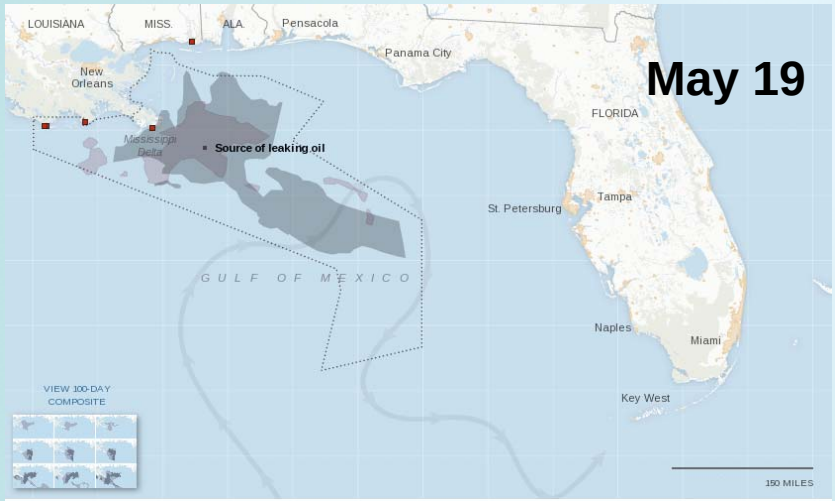
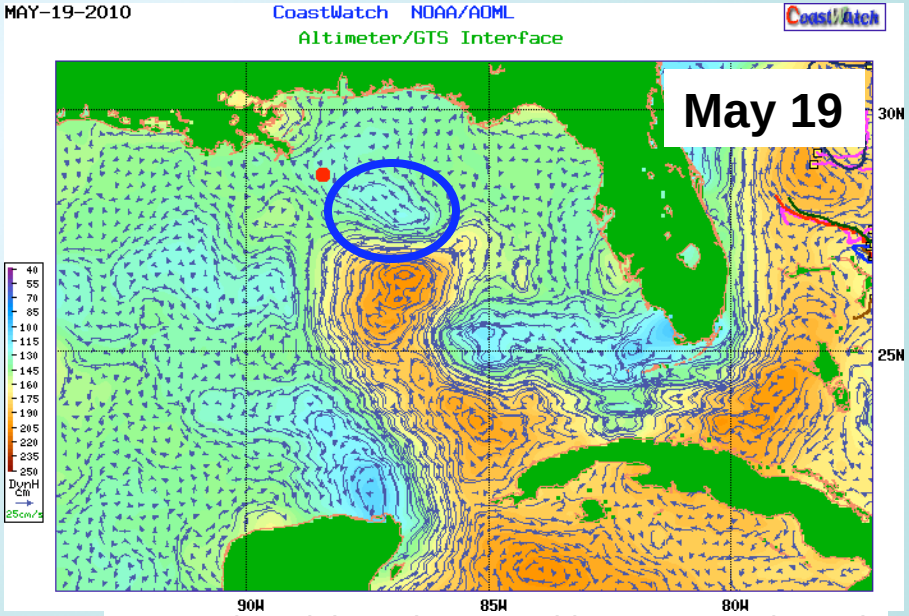
**<u>Overarching objective</u>:** **Develop a data assimilative system in the Gulf of Mexico for ocean forecasting and observation array design (OSSEs)**

**<u>General framework</u>:**

- The **Loop Current** extension and evolution in the **Gulf of Mexico** are very sensitive to **frontal dynamics**
- Illustrated during the **Deepwater Horizon** oil spill



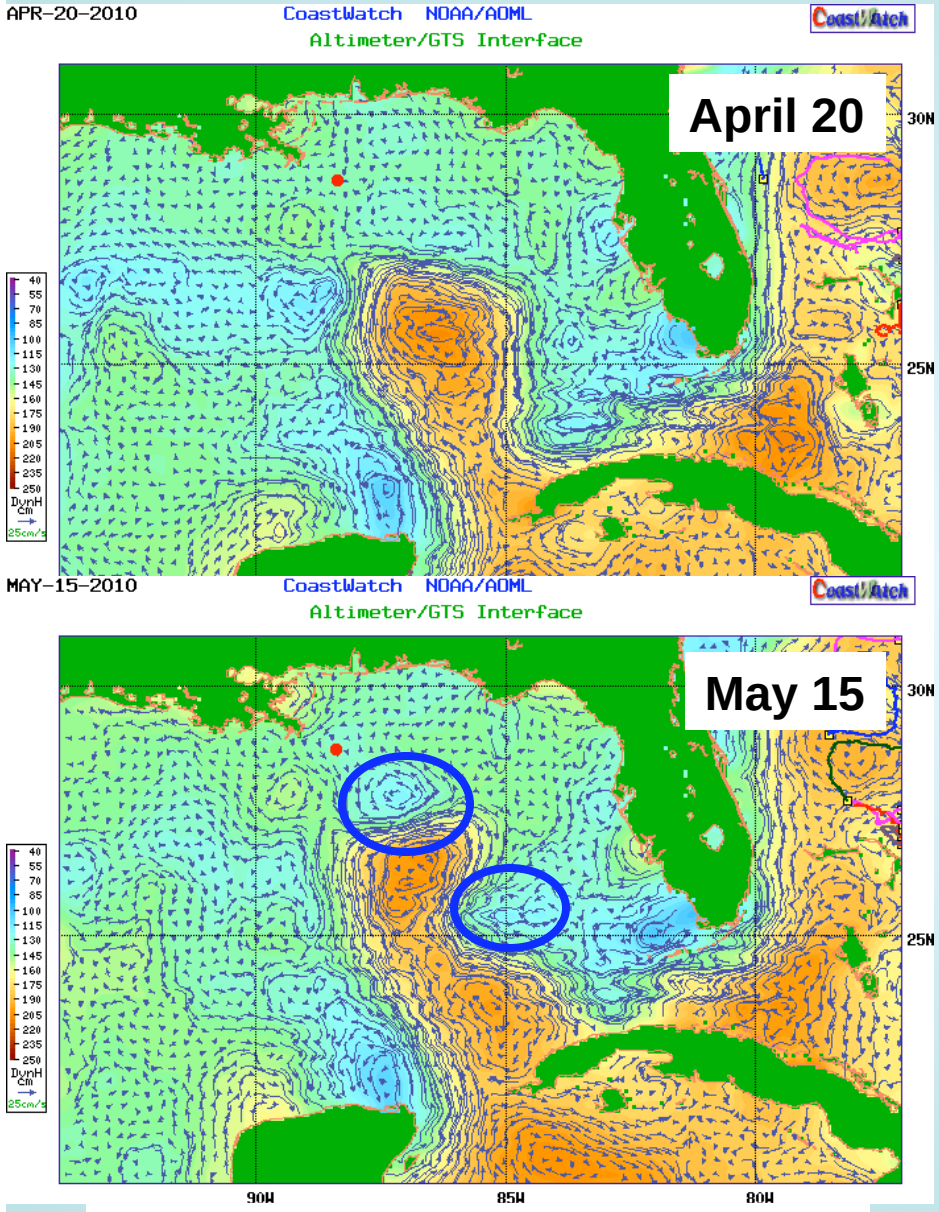

*Extension of oil at the surface of the Gulf, based on NOAA analysis (The New York Times)*




*Dynamic Height and geostrophic currents estimated based on altimetry (NOAA/AOML)*

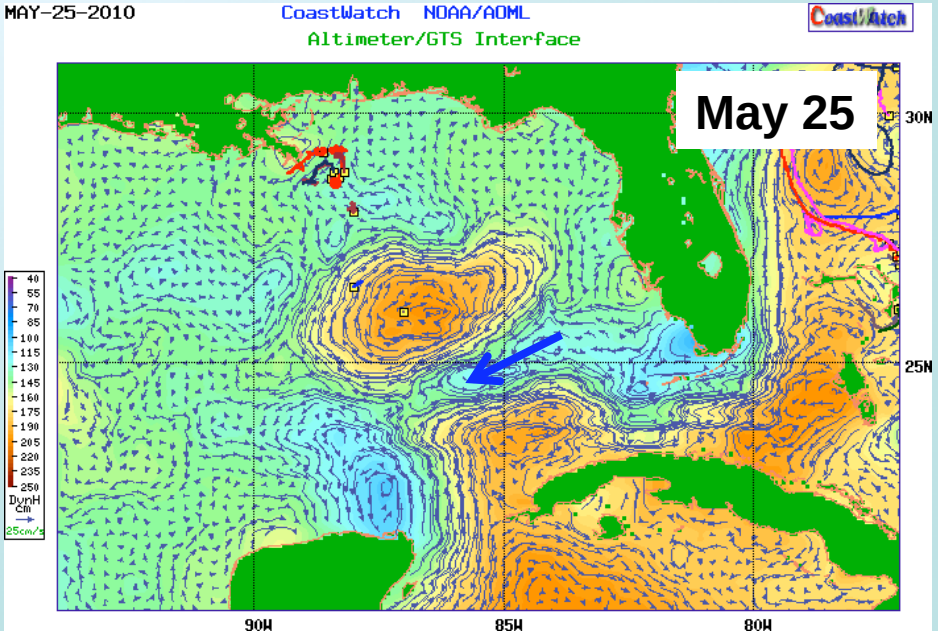
- Around mid-May, the oil slick is entrained within **a frontal cyclone**
- **Risk of entrainment into the LC** : estimated ~2 weeks from south Florida

# Loop Current dynamics (spring-summer 2010)

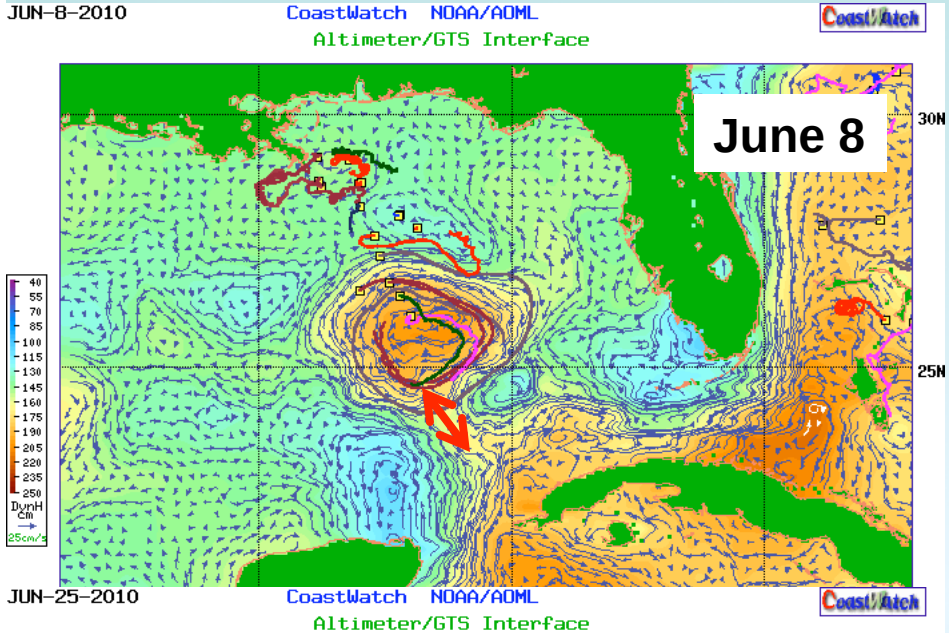



*Dynamic Height and geostrophic currents estimated based on altimetry (NOAA/AOML)*

- **Initially**, the Loop Current (LC) is well **extended** in the Gulf of Mexico (GoM), but still south of the DWH rig
- It is surrounded by several **frontal cyclone**s, and one **anticyclone** west of the DWH rig
- In the following weeks, frontal eddies **strengthen** and the LC bends eastward
- Around **May 25**, the warm core ring named **Eddy Franklin** detaches

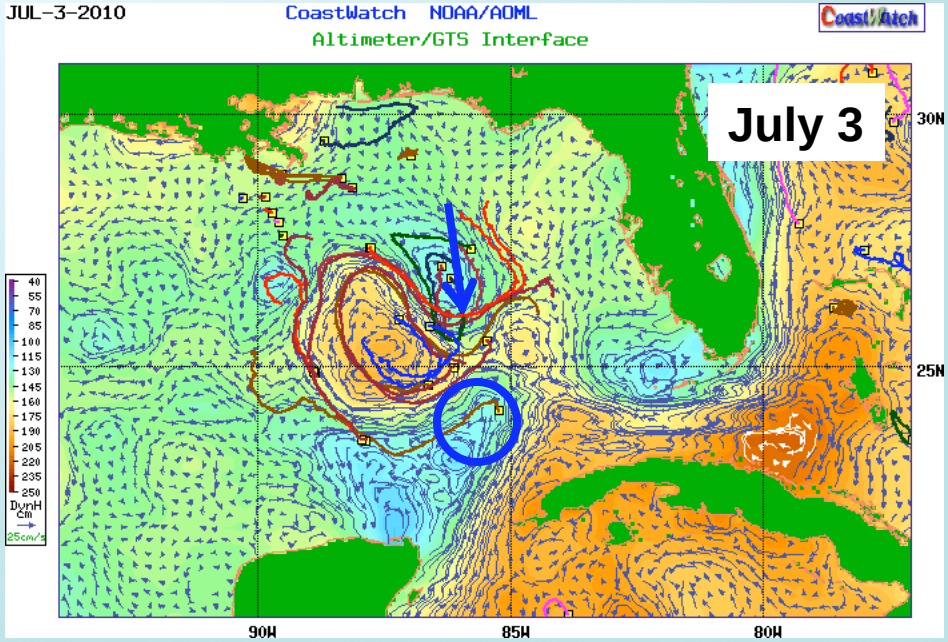


# Loop Current dynamics (spring-summer 2010)

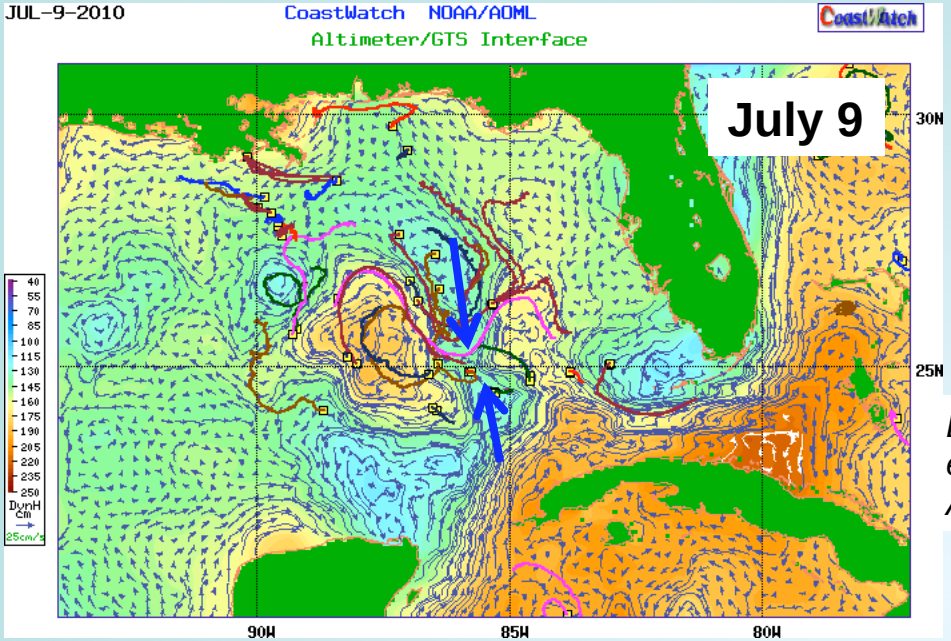



*Dynamic Height and geostrophic currents estimated based on altimetry (NOAA/AOML). In color are drifter trajectories*

- **In June,** Eddy Franklin partially re-attaches to the LC
- The **frontal cyclone** originally north of the LC **migrates southward**
- An eddy **forms along the Campeche Bank**, west of the LC



# Loop Current dynamics (spring-summer 2010)




• Under the combined influence of the 2 frontal eddies, Eddy Franklin fully detaches **early July**

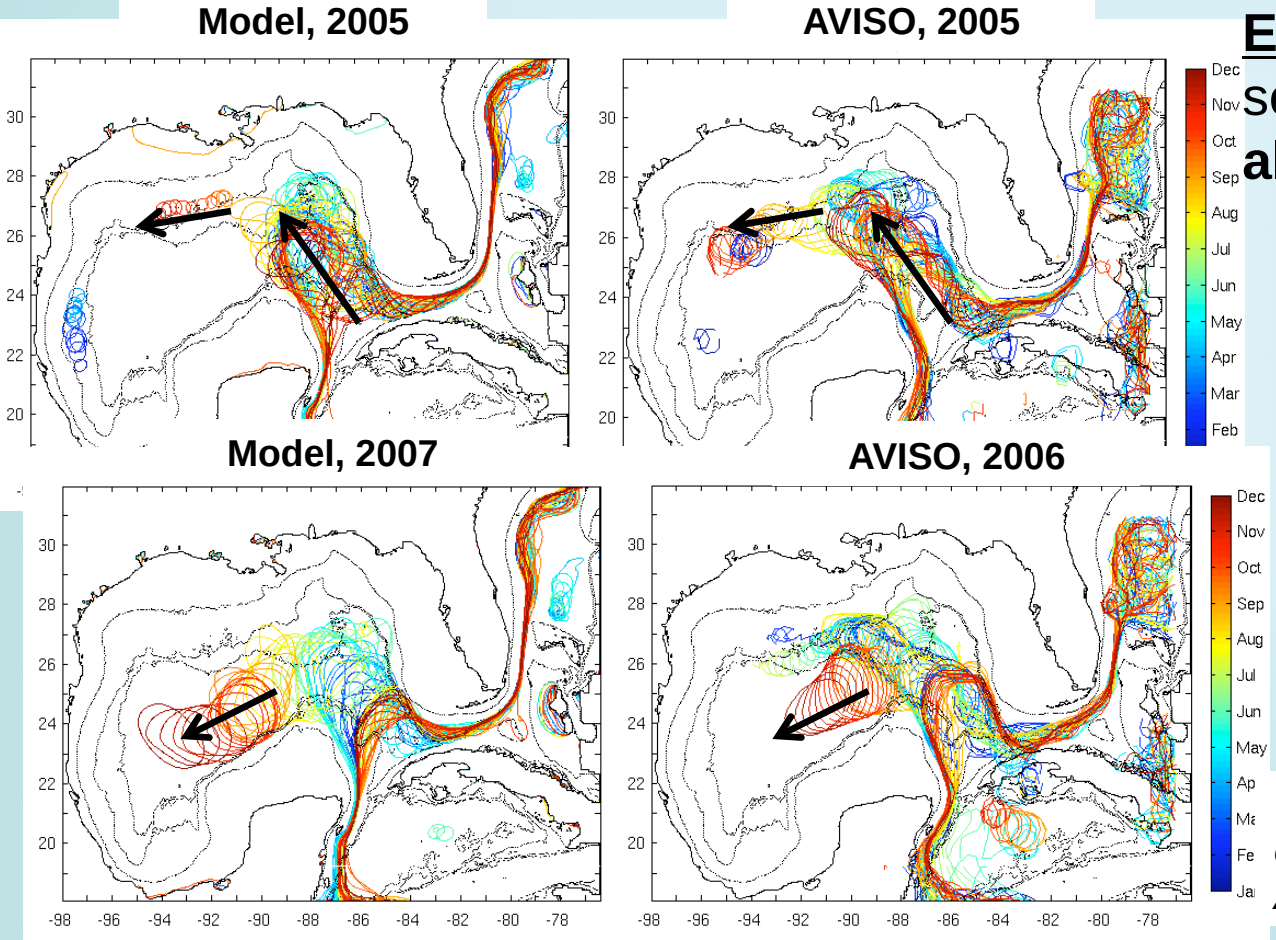
*Dynamic Height and geostrophic currents estimated based on altimetry (NOAA/ AOML). In color are drifter trajectories*

• Modeling the Loop Current dynamics requires a sufficiently **high resolution** model to account for mesoscale dynamics. This implies the use of a **regional model**.

• The data assimilation should benefit **from error statistics adapted to the local dynamics**

## STEP 1 : Free run simulation

- GoM-HYCOM **1/25 degree**, 26 vertical layers, **5 years** (2004-2008)
- Atmospheric forcing: COAMPS (27 km, 3h)
- IC: 1-yr simulation run at NRL
- BC: climatology from 4 years of Hycom Atlantic simulation



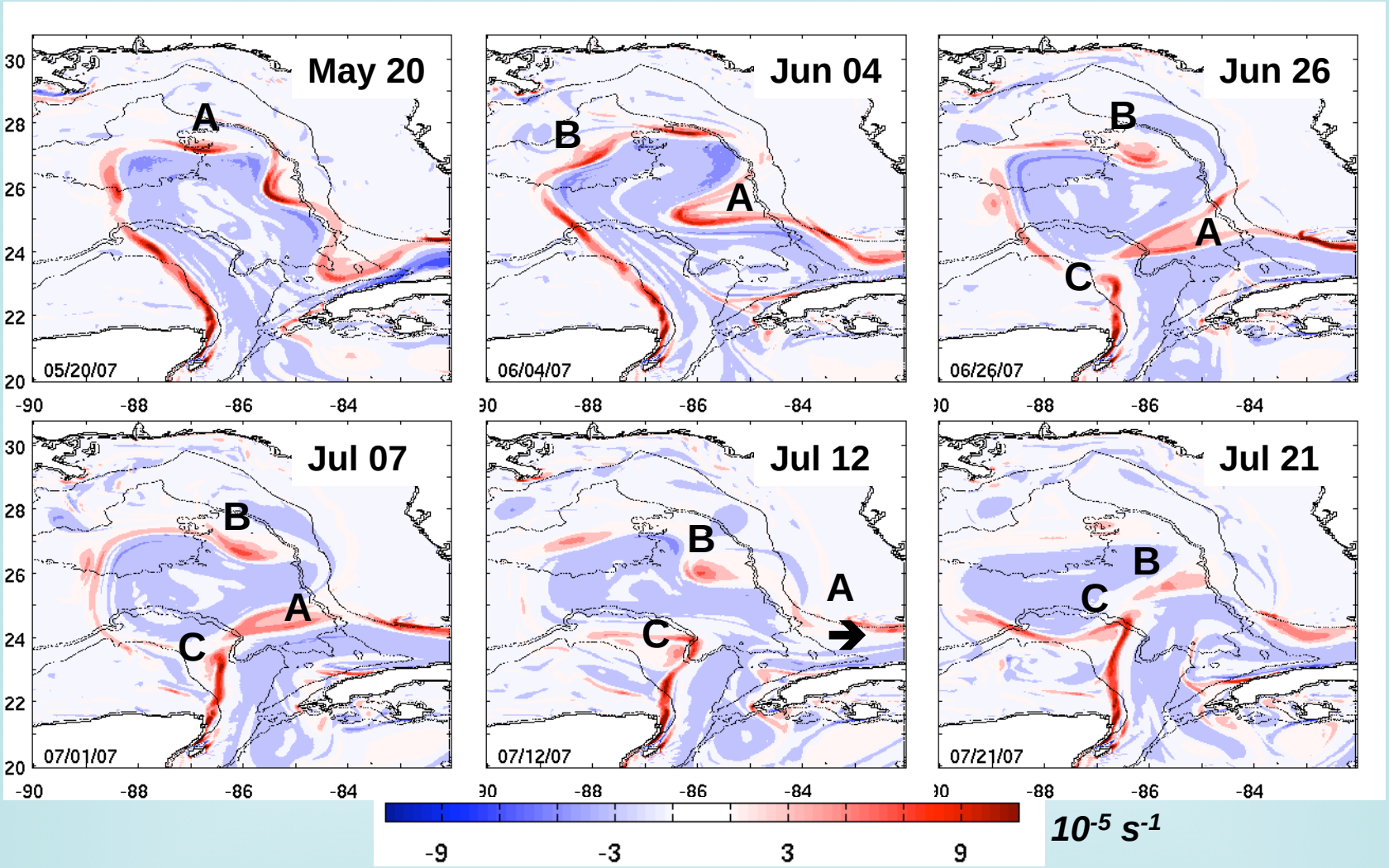

**<u>Evaluation</u>** : comparison of sea surface heights with **altimetry**

- realistic **extension** of the LC
- eddy shedding
  - along the **northern Gulf shelf**
  - in the **center** of the GoM

*Time evolution of **LC and eddy contours** based on model ssh and Aviso absolute dynamic topography)*

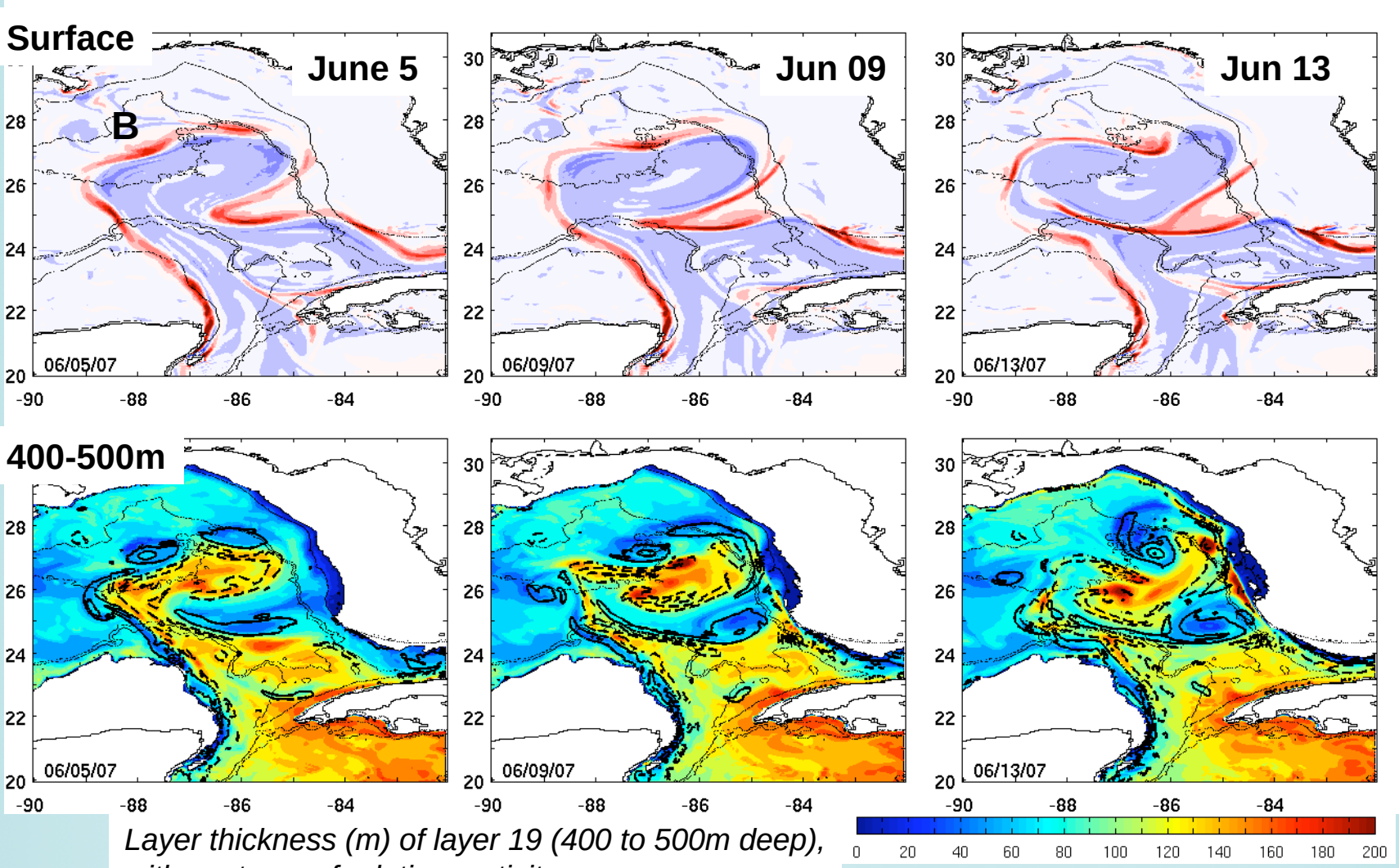
- other evaluation: SST, *in situ* moorings and buoys

## **Surface relative vorticity** *May 5 - July 21, 2007 (free run)*




- sequence **comparable** to the DWH oil spill case
- interactions eddy/eddy, eddy/current

# Intensification of a frontal eddy in the Northern Gulf




*Layer thickness (m) of layer 19 (400 to 500m deep), with contours of relative vorticity*

- surface and in-depth **intensification** of cyclonic vorticity
- increase of layer thickness: **vortex stretching**

## STEP 1 / Conclusions:

• Frontal eddies play a **crucial role** in the Loop Current ring separation, by interacting with each other as well as with the current

• Deepening topography along the northern edge of the LC seems to favor **frontal cyclone intensification** (vortex stretching)

• We have developed a good candidate for a **nature run,** suitable for Loop Current **frontal dynamics** studies. A **realistic** nature run ensures that the results from OSSEs are relevant for observational array design.

## STEP 2: High resolution data assimilative (predictive) model

- Hycom **1/50 degree**, 20 vertical layers, focus on **DWH oil spill** event
- Same attributes as free-run: atmospheric forcing (COAMPS), IC (NCODA simulation) and BC (climatology Hycom Atlantic simulation)
- **Data assimilation** : Singular Evolutive Extended Kalman (**SEEK**) filter (Pham et al., 1998) – allows choice of dominant modes according to the most relevant state:

Analyzed state: $\mathbf{x}^a = \mathbf{x}^f + \mathbf{K}(\mathbf{y} - \mathbf{H}\mathbf{x}^f)$ ,

where $\mathbf{K} = \mathbf{P}^f\mathbf{H}^T(\mathbf{H}\mathbf{P}^f\mathbf{H}^T + \mathbf{R})^{-1}$ is the *gain* matrix,

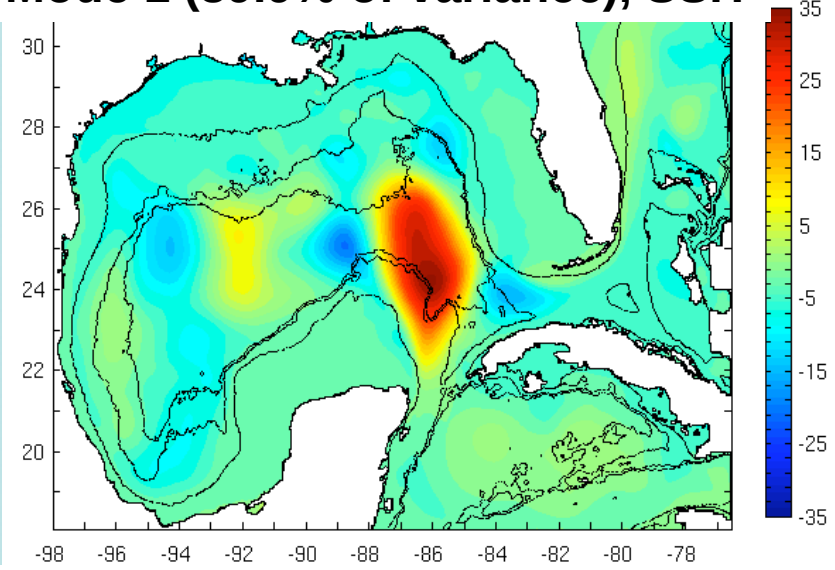
with $\mathbf{P}^f$ the model error covariance matrix, and $\mathbf{R}$ the observation error covariance matrix.

In the SEEK filter, $\mathbf{P}^f = \frac{1}{M-1}\sum_{m=1}^{M}\mathbf{S}_m^f\mathbf{S}_m^{f\,T}$, with $\mathbf{S}_m^f$ being the most **dominant EOF** modes (1 to M)

- here : **multivariate EOFs** (SSH, barotropic velocities, 3D velocities, temperature, salinity)
- **static EOFs** pre-calculated from a long-term free run, from **periods where the LC is at an extended phase**

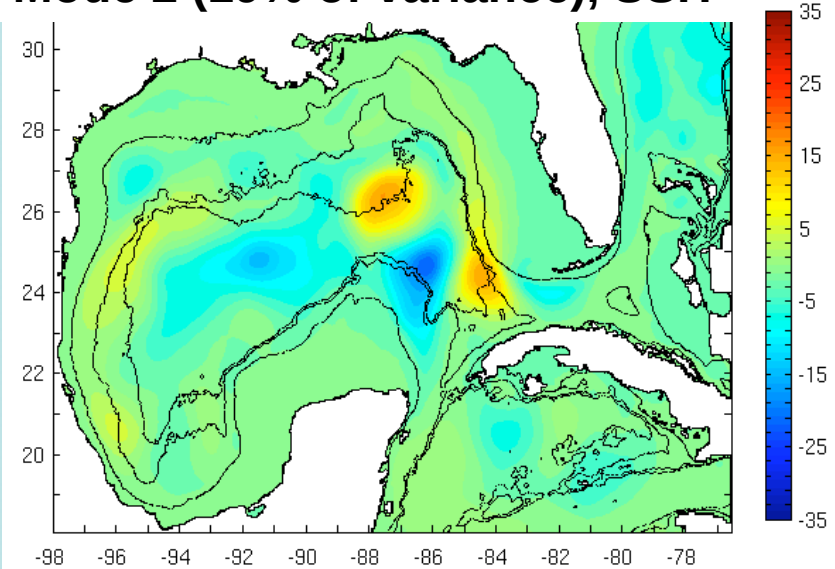
# Dominant modes in the EOF decomposition

**Mode 1 (39.9% of variance), SSH**

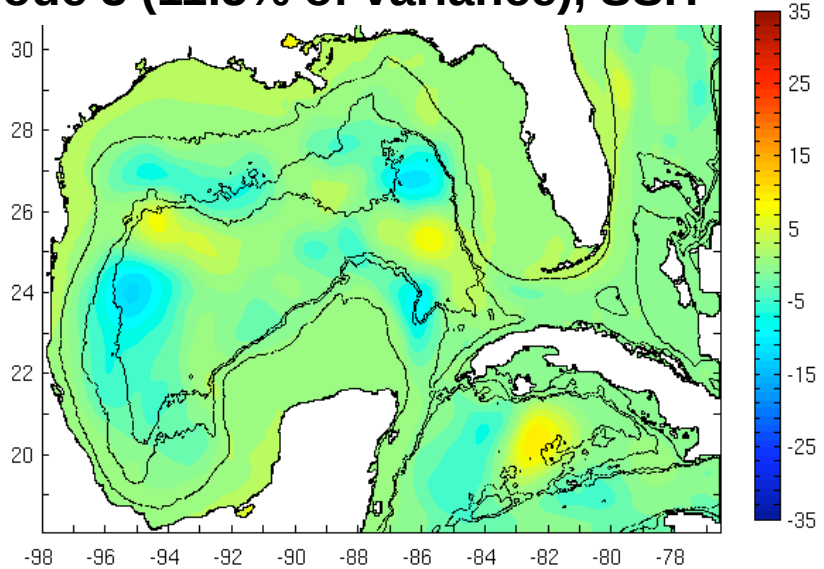



- **mode 1**: main signature in the area of **expansion of the LC** + frontal eddies
- **modes 2 and 3** : signature of **mesoscale dynamics** in the LC area

**Mode 2 (19% of variance), SSH**



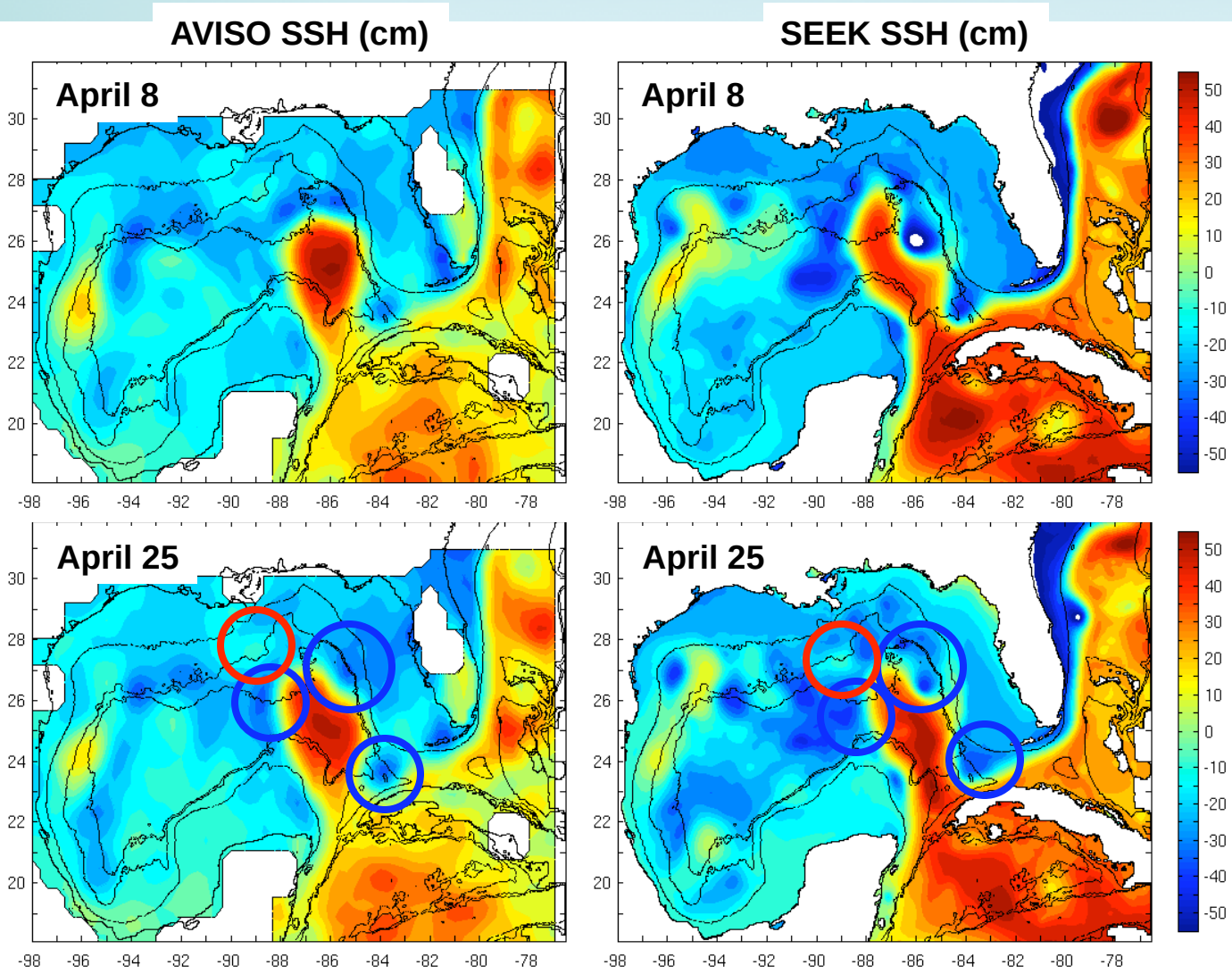

**Mode 3 (11.5% of variance), SSH**




*Signature in SSH (cm) of the first 3 modes in the EOF basis used for the SEEK filter*

# 1st data assimilation experiment (SEEK1: DA of SSH only)

- Assimilation of Jason-1 and Jason-2 **along-track sea level anomaly**
- Analysis based on altimetry observations imposed on **all** variables
- *Free running Hycom 1/50* from 1/1/2010, data assimilation **April 8 - May 28**

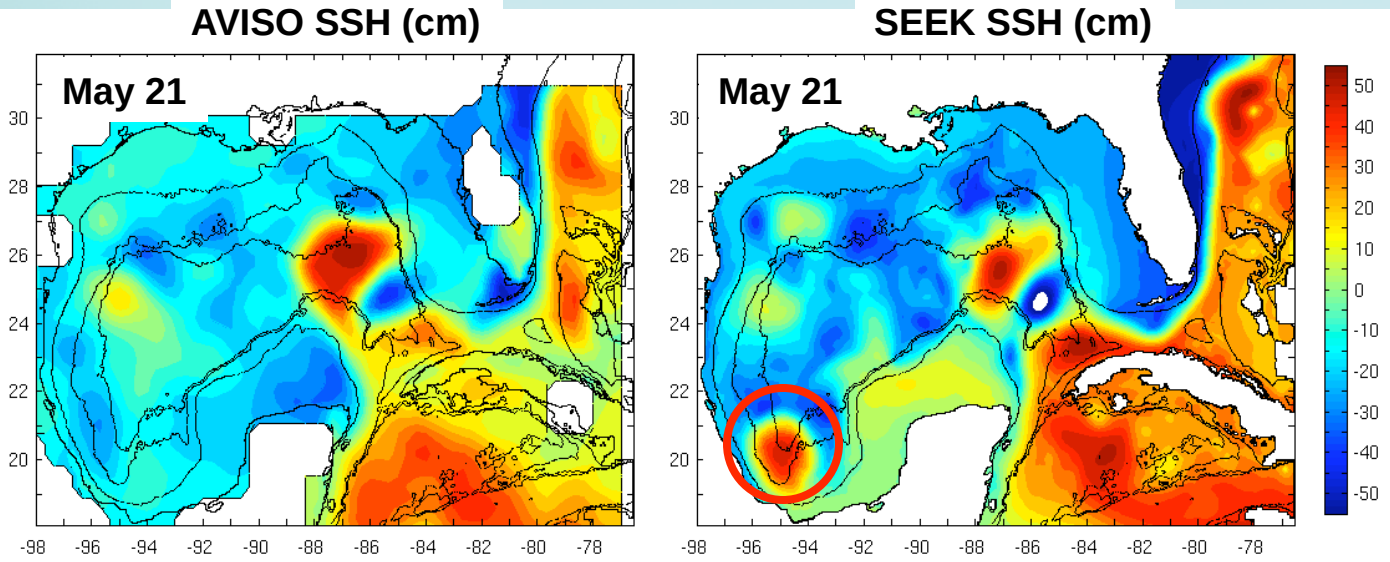



- April 8: the LC is extended, but **not in the same position** as observed
- After 2 weeks, the **assimilation succeeds** in putting the LC dynamics right
- Especially, **frontal eddies** are **well located**

*Observed Mean Absolute Dynamic Topography (AVISO, cm) and modeled SSH (cm) with data assimilation*

# 1st data assimilation experiment (SEEK1: DA of SSH only)

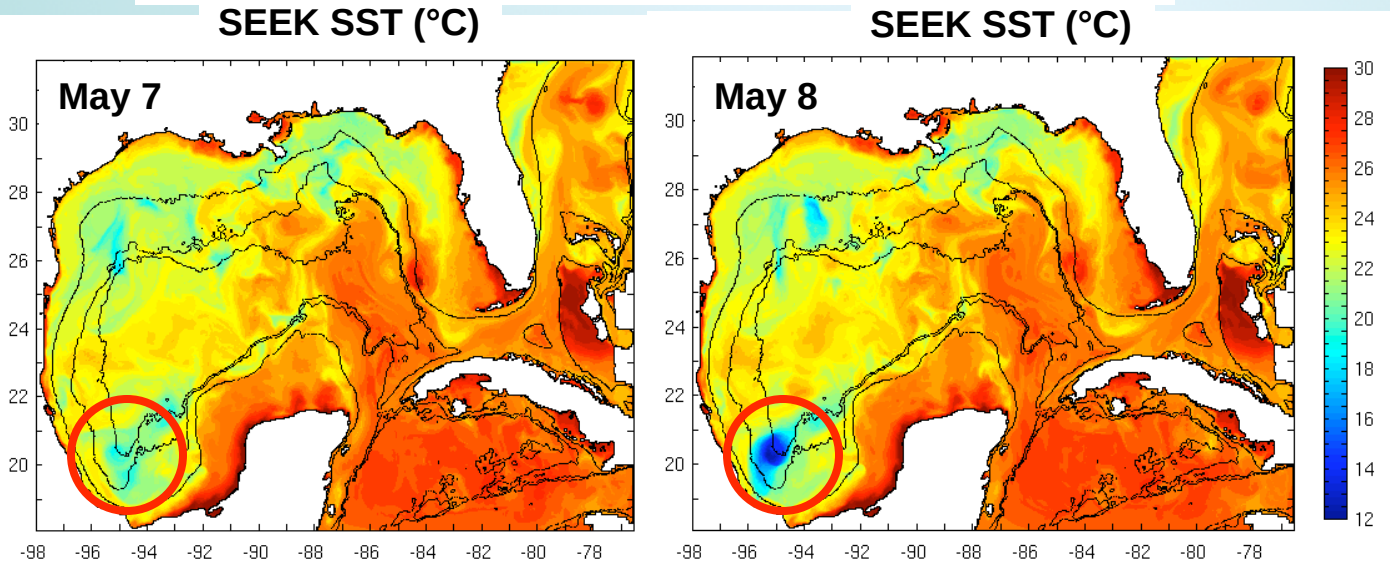
• Late May : separation of Eddy Franklin




*Observed Mean Absolute Dynamic Topography (AVISO, cm) and modeled SSH (cm) with data assimilation*

• The separation of Eddy Franklin takes place on **May 19**, earlier than observed

• Formation of a **spurious anticyclone** in the western Gulf



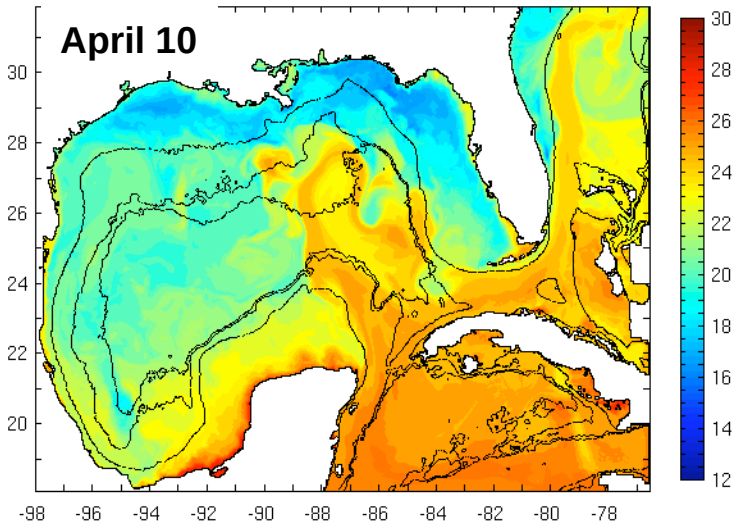

*Modeled SST (°C) with data assimilation*

• Associated with **unrealistic** cold anomaly in SST => **unrealistic correlation from the EOFs**

## 2nd data assimilation experiment (SEEK2: DA of SSH + SST)

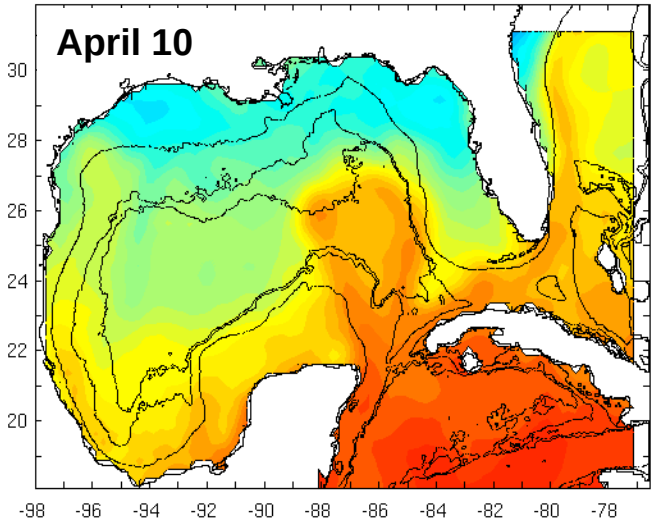
- Observed SSH affect : model SSH, currents, layer thickness
- Observed SST affect : model temperature only

**SEEK-1 SST (°C) – DA: SSH only**

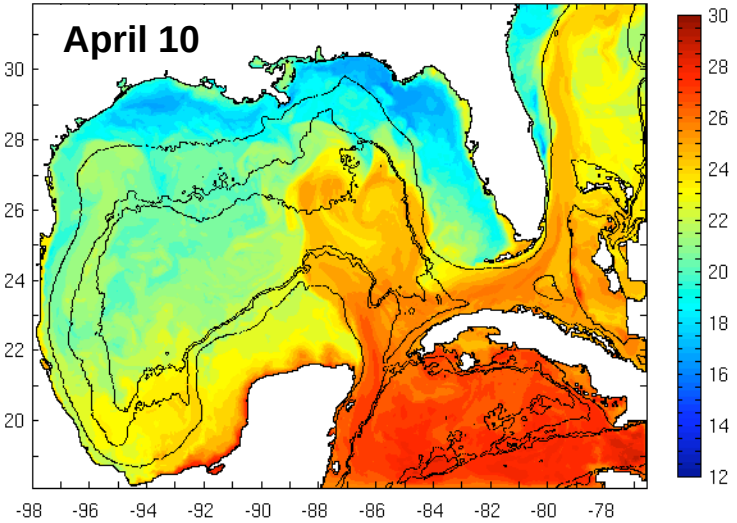



- **Without** SST assimilation : **cold bias**
- **With** SST assimilation : cold bias **fixed in a few days**
- **Dynamics** are efficiently corrected by SSH (so far)

**Observed SST (°C)**




**SEEK-2 SST (°C) – DA: SSH+SST**




*Modeled SST (°C) for the 1st SEEK experiment (only SSH assimilated), observed by satellite (AMSR-AVHRR), and modeled for the 2nd SEEK experiment (SSH+SST assimilated)*

## STEP 2/ Conclusions:

• GoM-HYCOM 1/50 (SEEK): Data assimilation set up for simulating the LC dynamics during the **Deepwater Horizon oil spill** event with assimilation of **real observations** (along-track altimetry and SST) – advantageous due to **EOF decomposition** based on periods that represent the extended Loop Current phase

• Preliminary results : (a) SEEK1 (SSH assimilation only) gives **satisfactory LC dynamics** with **frontal eddies**, but: **cold bias** impacting cyclone growth; (b) expanding to SEEK2 (**SSH+SST** assimilation) quickly fixes the cold bias

• The predictive model seems successful in assimilating **real observations**, therefore it should be **well tuned for twin experiments**.

## Perspectives

- Test the SEEK with **refined EOF basis**
- Assimilate in situ **profiles** (temperature, salinity)
- Demonstrate the **capability** of running a **real-time forecasting system** for the Gulf of Mexico by the RSMAS-AOML group

***Thanks!***