Jason-3 Altimeter Assimilation in Operational Ocean Prediction

Gregg Jacobs (Naval Research Laboratory)
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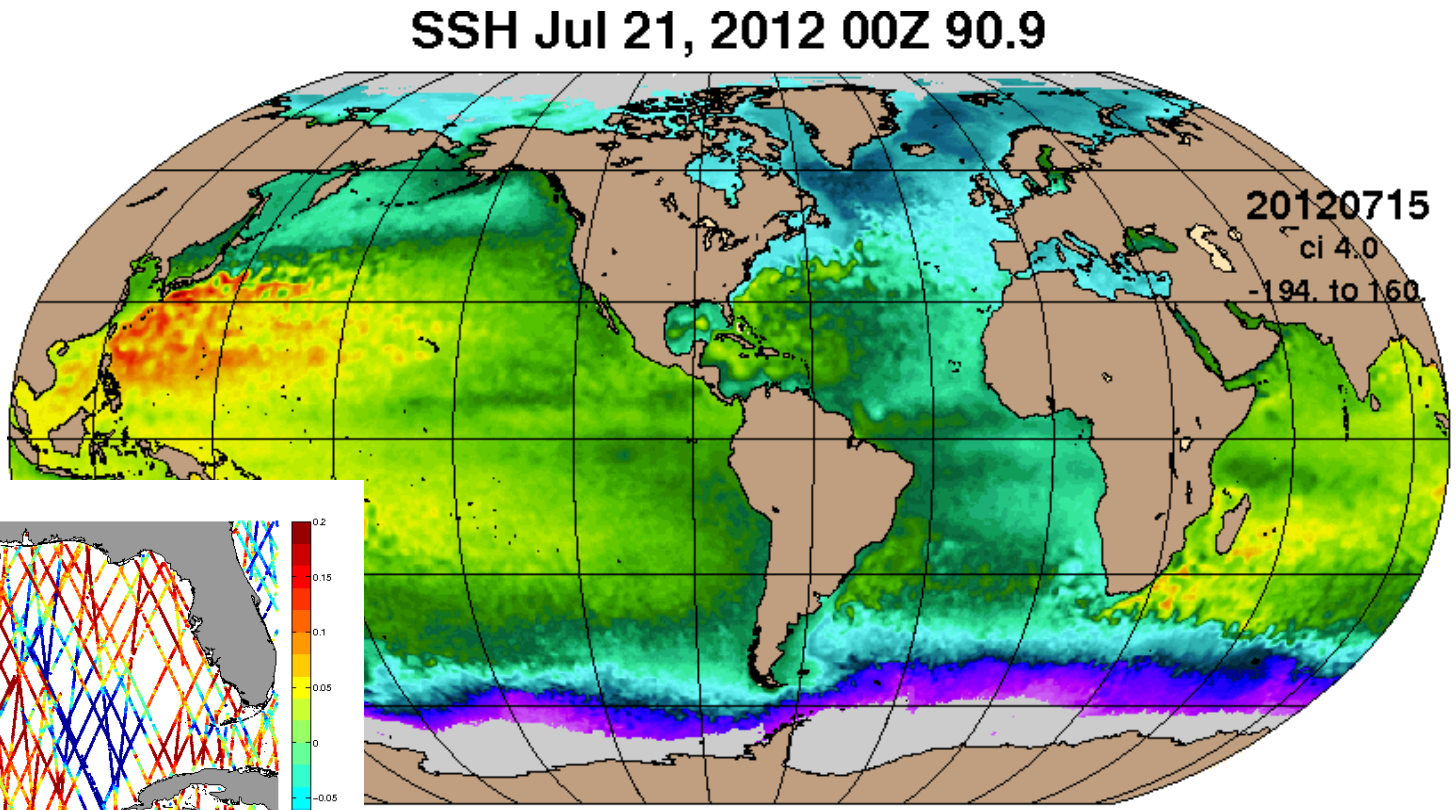
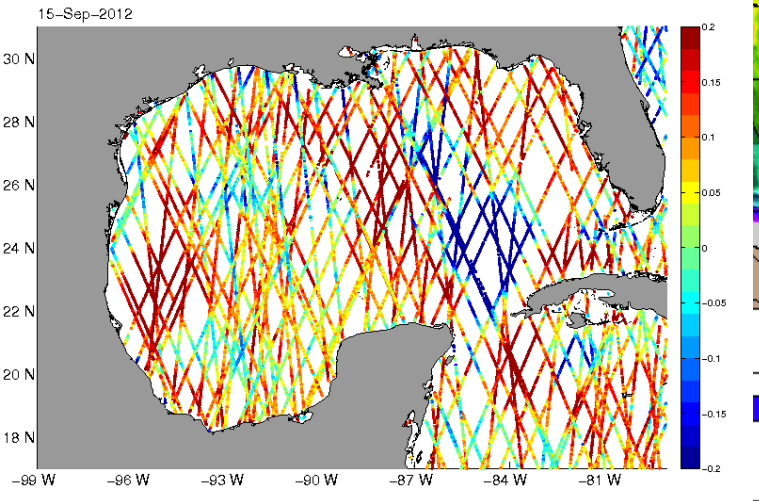


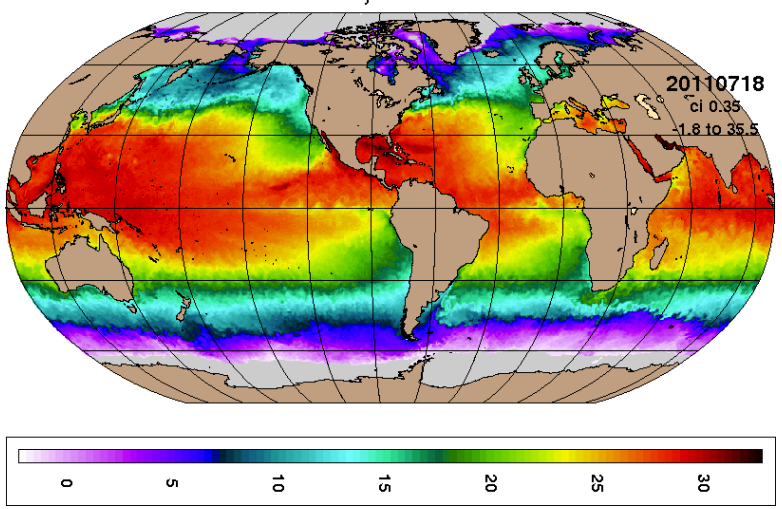
Sep 15, 2012



Integration of altimeter data into national ocean prediction infrastructure

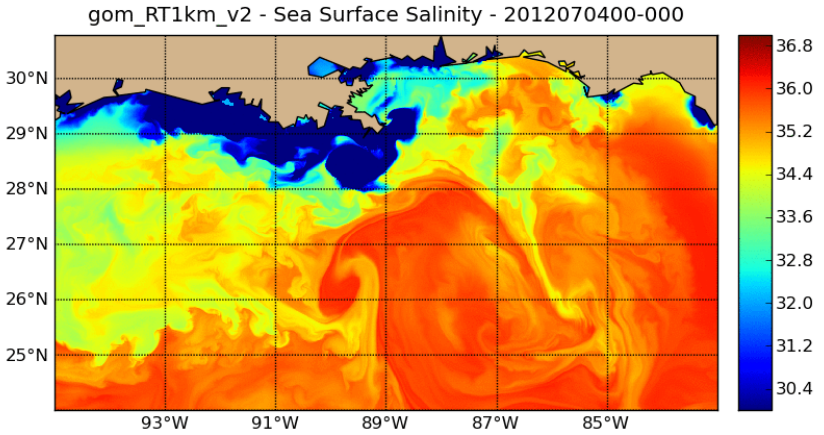
- Hurricane forecasts
- Surface wave field verification
- Global ocean prediction
  - Search and rescue efforts
  - Fisheries information
  - Seasonal outlooks
- Higher resolution nested prediction
  - Search and rescue efforts
  - Fisheries information
  - Public safety

Global 1/12 HYCOM SST

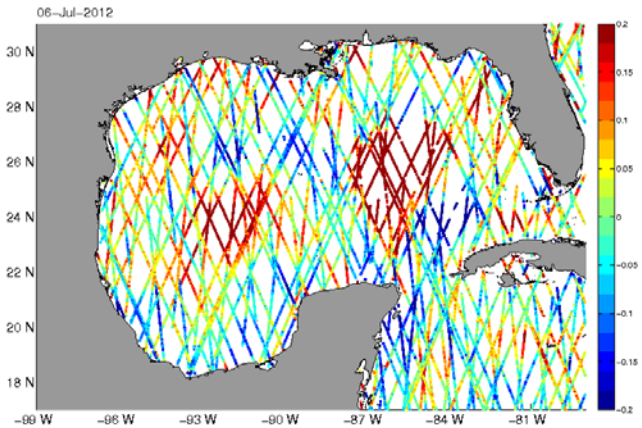


Without satellite altimeter observations, what stops?
Mesoscale ocean model forecast capability

Nested 1km NCOM SSS

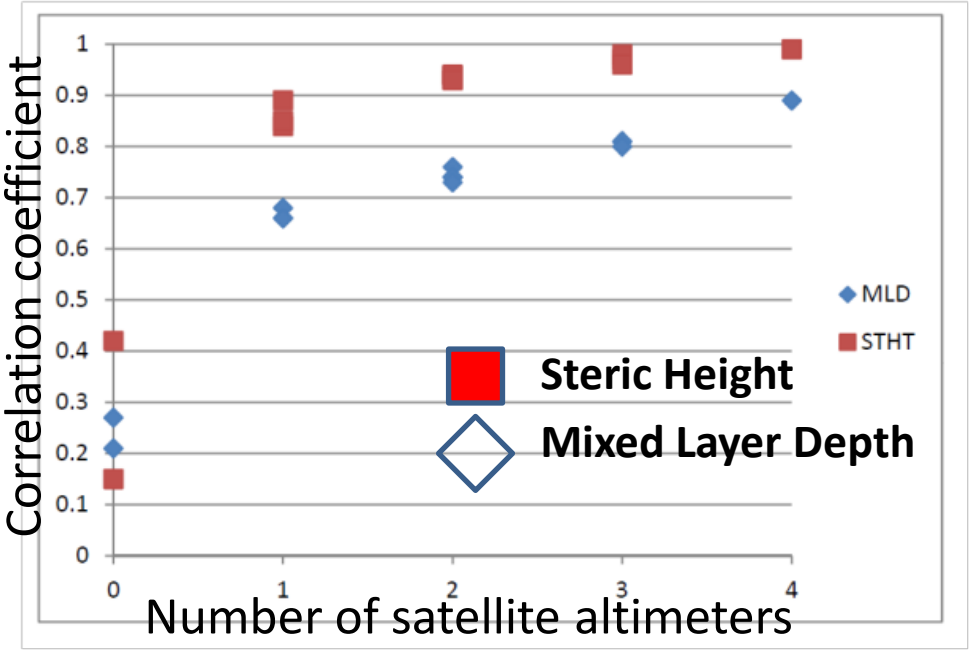


Altimeter SSH
- Jason-2
- Jason-1G
- CryoSat2



Importance of SSH to mesoscale ocean forecasting

Observation System Experiments over 1.5 years using permutations of 4 real altimeter data sets during Jun 2004 – Dec 2005



Bottom Line Up Front

- **With no altimeters, there is no skill**
- **Altimeter data is the only satellite data that provides mesoscale dynamics information below the skin (Steric Height)**
- **The ocean mesoscale controls the surface (Mixed Layer Depth)**
- **One of the 'no altimeter' experiments includes all other data (satellite SST, ARGO, ship of opportunity), and no skill results**
- **In situ data is not sufficient to enable mesoscale forecasting**

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Without satellite altimeter observations, what stops?
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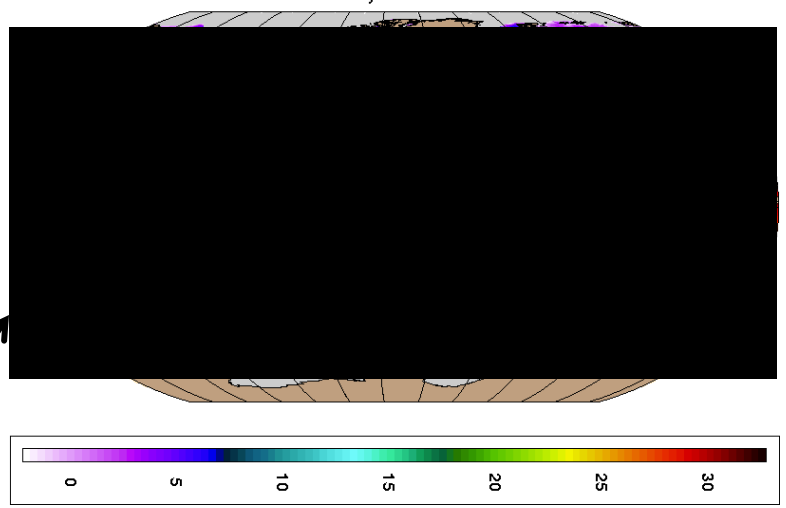
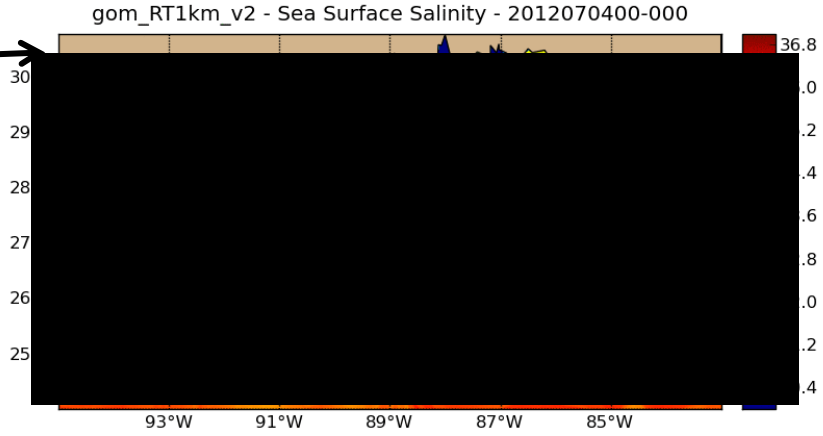


Nested 1km NCOM SSS



Altimeter SSH
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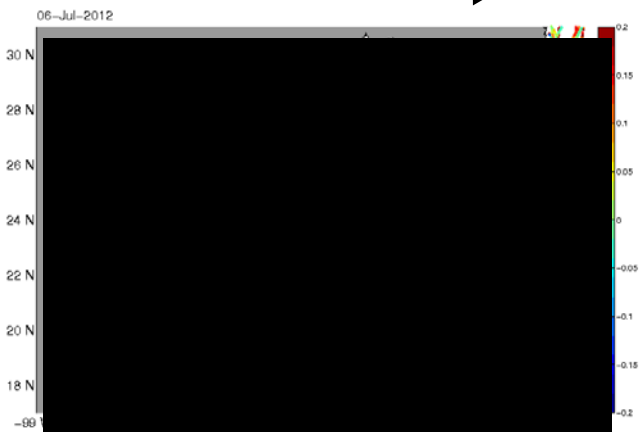
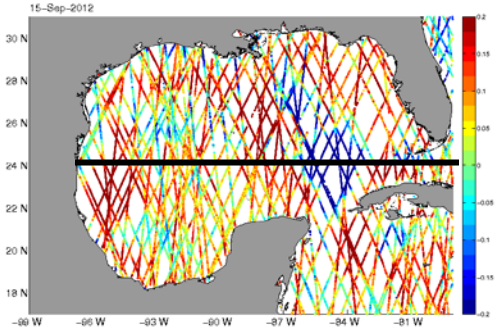


Necessity for altimeter data to oceanography

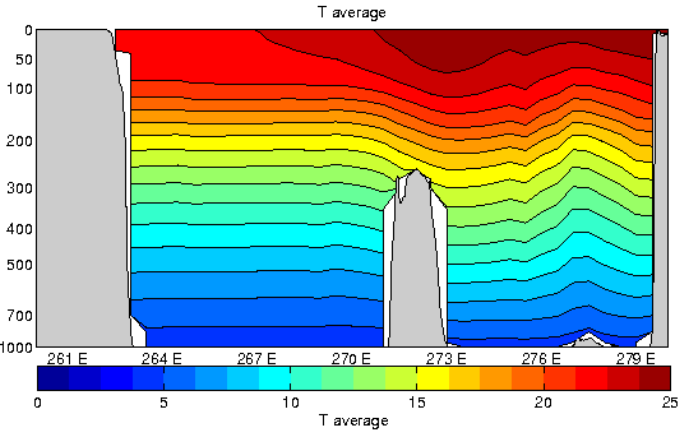
Historical data (from 1900 to present)
1/2° gridding
Provides mean, variance and covariance

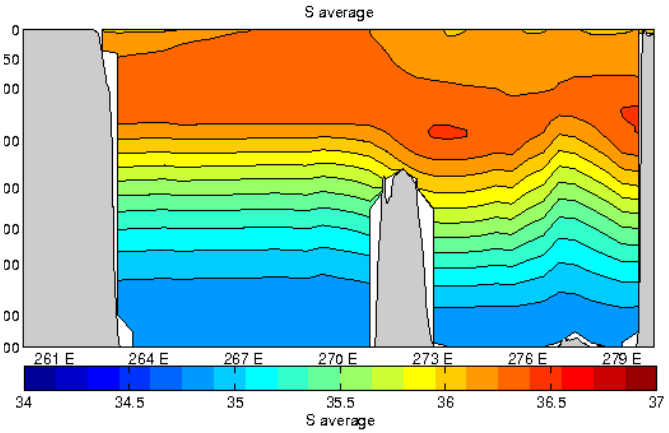
January 24° N



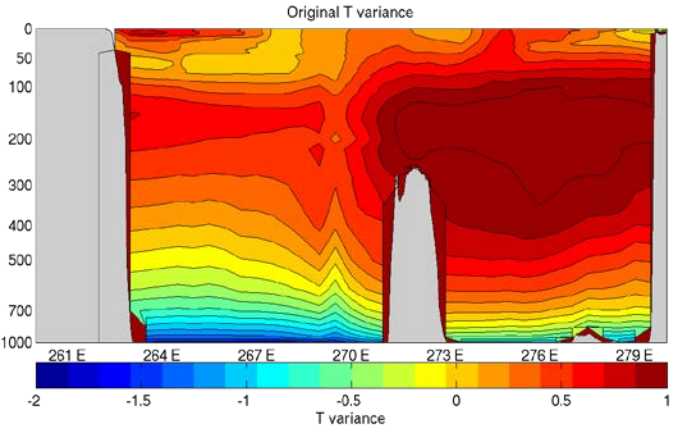
T

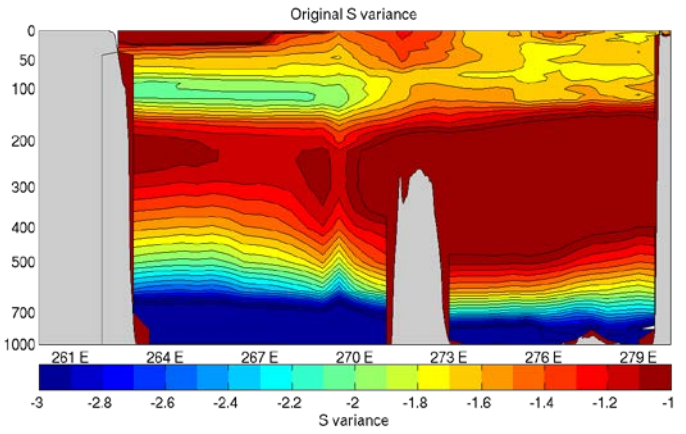
S





Mean





Variance

New data set, same result, SSH is most influential

A few pedantic definitions

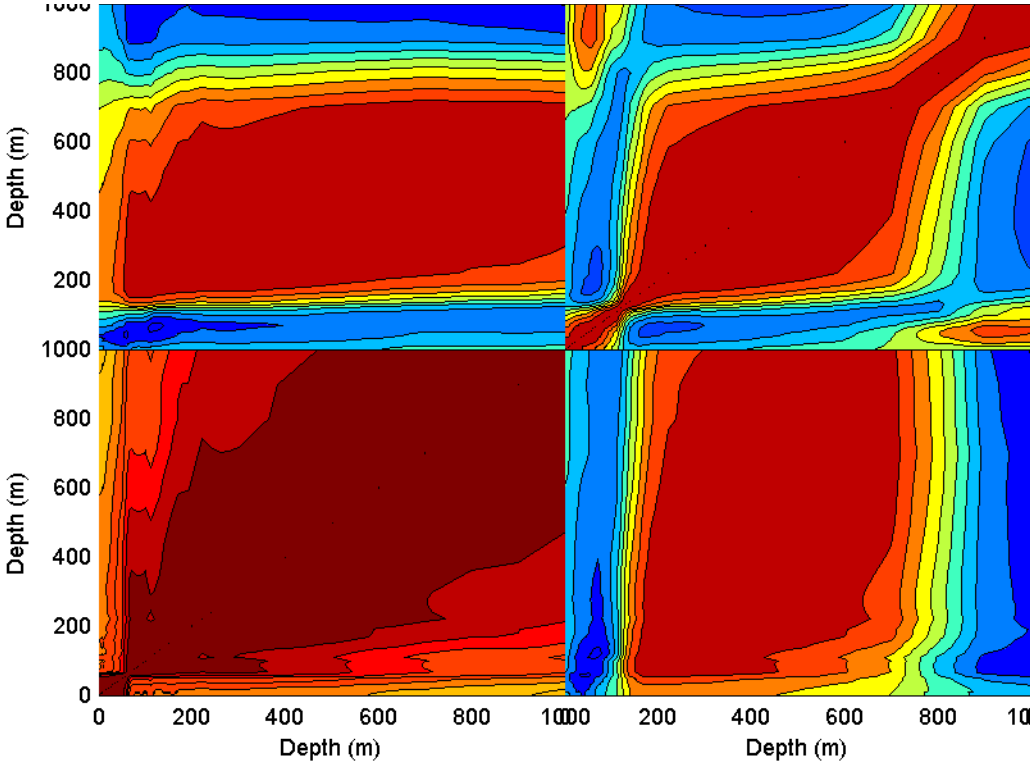
$\langle \acute{X}\acute{X}^T \rangle$ Cross covariance

$$X = \begin{bmatrix} T_1 \\ \vdots \\ T_N \\ S_1 \\ \vdots \\ S_N \end{bmatrix}$$ State

$$\bar{X} = \begin{bmatrix} \overline{T_1} \\ \vdots \\ \overline{T_N} \\ \overline{S_1} \\ \vdots \\ \overline{S_N} \end{bmatrix}$$ Average

$$\acute{X} = \begin{bmatrix} T_1 - \overline{T_1} \\ \vdots \\ T_N - \overline{T_N} \\ S_1 - \overline{S_1} \\ \vdots \\ S_N - \overline{S_N} \end{bmatrix}$$ Anomaly

T S



S

T

Cross Correlation at one point (275°E, 24°N, February, Gulf of Mexico in Loop Current just off Cuba)

Relation between SSH and T&S through geopotential

Variations in T&S result in displacements of geopotential (surfaces of constant pressure)

δ is a linearization of specific volume anomaly (linearized around mean state)

G is an integral over pressure of specific anomaly

$$\acute{\varphi} = G\delta \begin{bmatrix} \acute{T}_1 \\ \vdots \\ \acute{T}_N \\ \acute{S}_1 \\ \vdots \\ \acute{S}_N \end{bmatrix}$$

Extend the T,S anomaly vector to include geopotential anomaly

$$\acute{Y} = \begin{bmatrix} \acute{T}_1 \\ \vdots \\ \acute{T}_N \\ \acute{S}_1 \\ \vdots \\ \acute{S}_N \\ \acute{\varphi}_1 \\ \vdots \\ \acute{\varphi}_N \end{bmatrix}$$

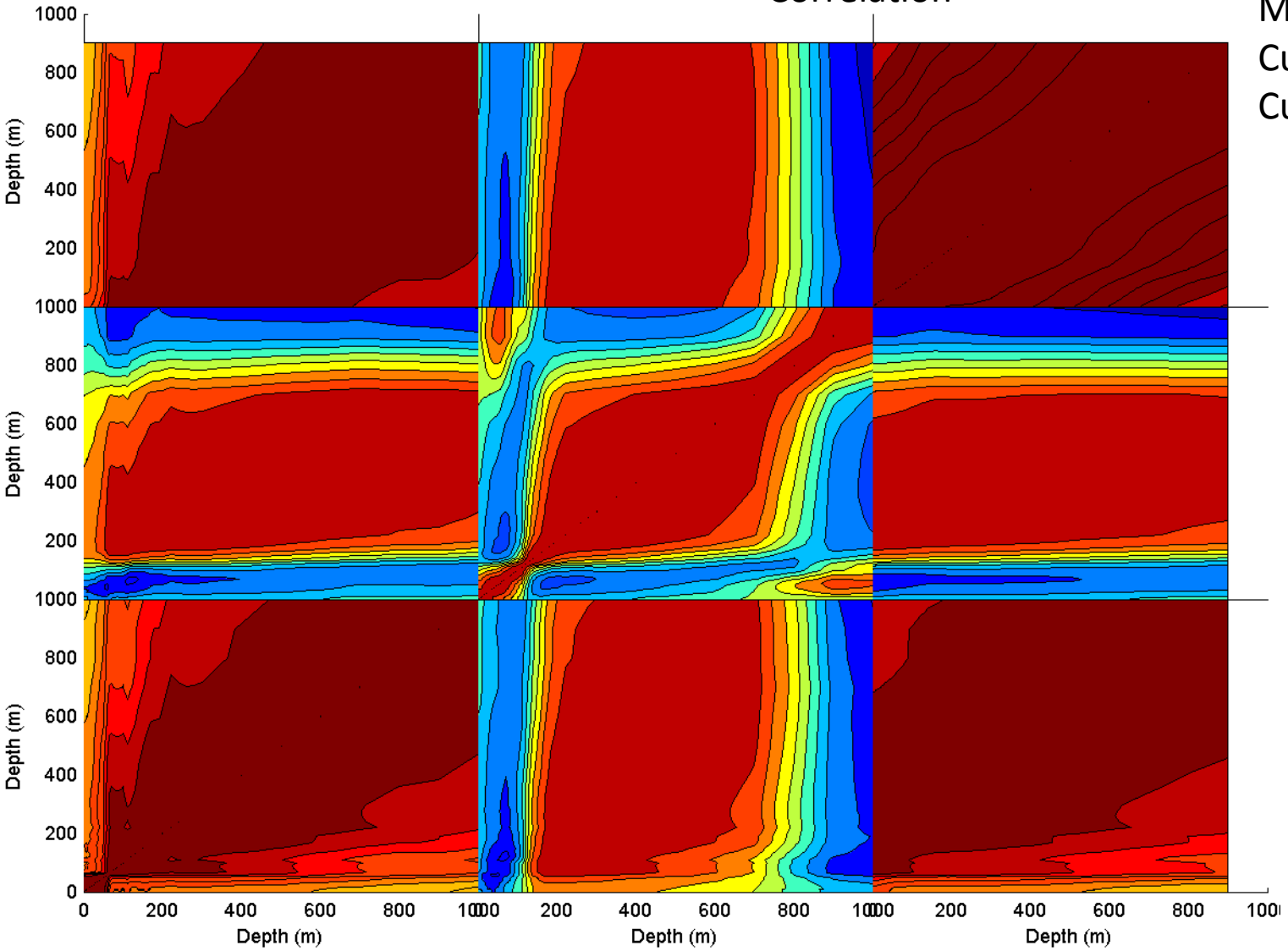
$$B = \langle \acute{Y}\acute{Y}^T \rangle = \begin{bmatrix} \acute{X}\acute{X}^T & \acute{X}\acute{X}^T\delta^T G^T \\ G^T\delta^T\acute{X}^T\acute{X} & \delta\acute{G}X\acute{X}^T G^T\delta^T \end{bmatrix}$$

Temperature, Salinity, Geopotential covariances

$$B = \langle \acute{Y}\acute{Y}^T \rangle = \begin{bmatrix} \acute{X}\acute{X}^T & \acute{X}\acute{X}^T \delta^T G^T \\ G^T \delta^T \acute{X}^T \acute{X} & \delta \acute{G} X \acute{X}^T G^T \delta^T \end{bmatrix}$$

T S Correlation G

Cross Correlation February, 275°E, 24°N, Gulf of Mexico in Loop Current just off Cuba



What is the effect of a single satellite observation

Addressed from the perspective of the in situ data

$$\acute{Y} = \begin{bmatrix} \acute{T}_1 \\ \vdots \\ \acute{T}_N \\ \acute{S}_1 \\ \vdots \\ \acute{S}_N \\ \acute{\varphi}_1 \\ \vdots \\ \acute{\varphi}_N \end{bmatrix} \qquad B = \langle \acute{Y}\acute{Y}^T \rangle = \begin{bmatrix} \acute{X}\acute{X}^T & \acute{X}\acute{X}^T\delta^T G^T \\ G^T\delta^T\acute{X}^T\acute{X} & \delta\acute{G}X\acute{X}^T G^T\delta^T \end{bmatrix}$$

$$P^A = (I - KH)B$$

$$K = BH^T(HBH^T + R)^{-1}$$

Posterior variance is a function of

- Background variance B
- Observation operator H
- Observation error R (let's assume observation has errors smaller than the variance, so R is small)

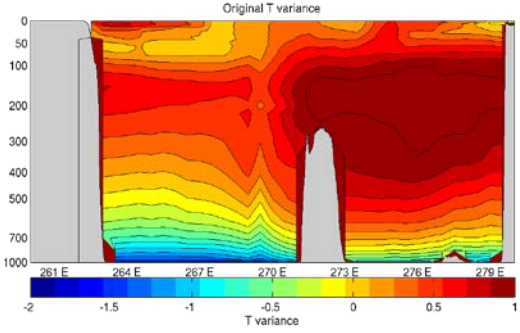
Because we now have B,
We can compute the impact of a satellite observation of T,S or G

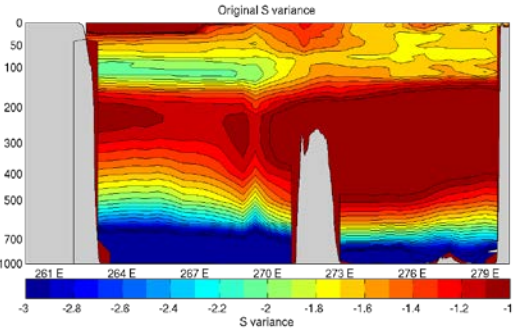
24°N Feb

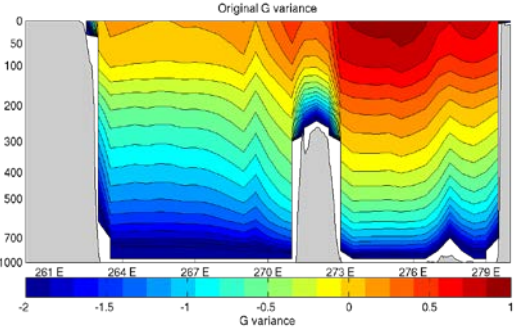
T

S

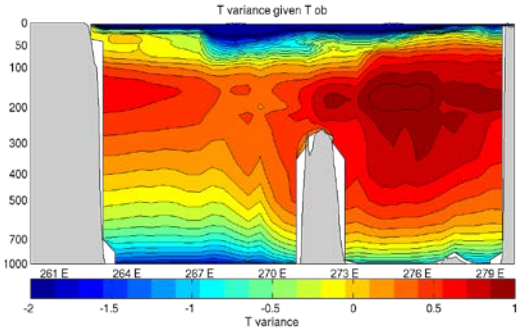
G

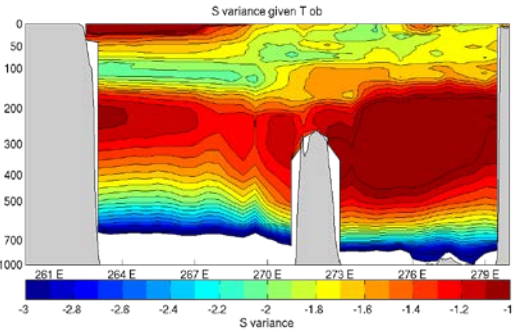


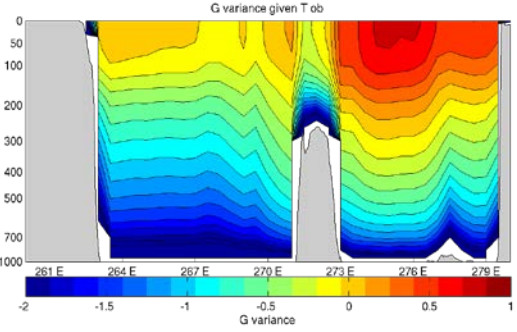




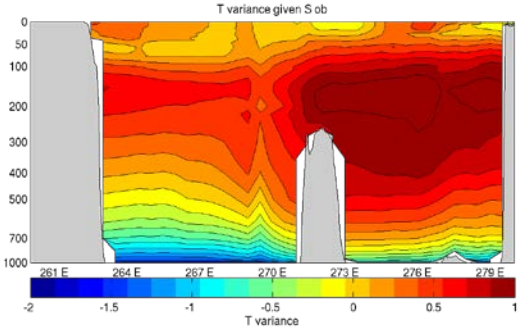
Original Variance

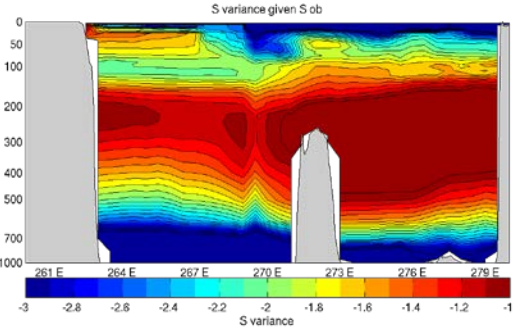


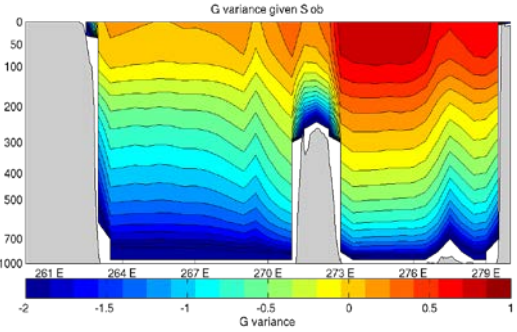




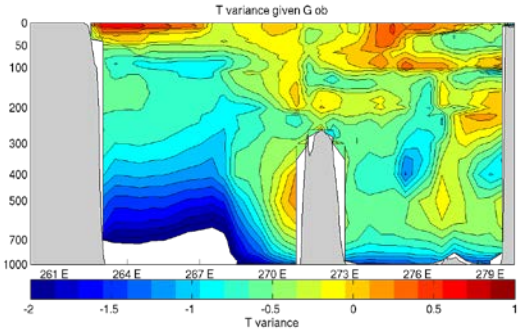
Variance given SST

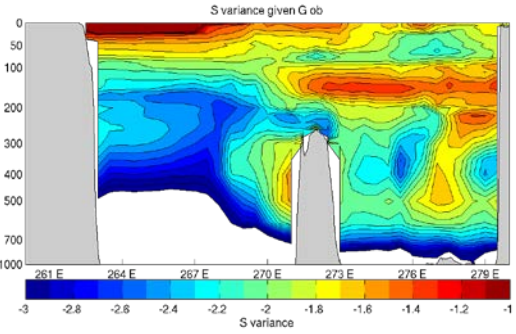


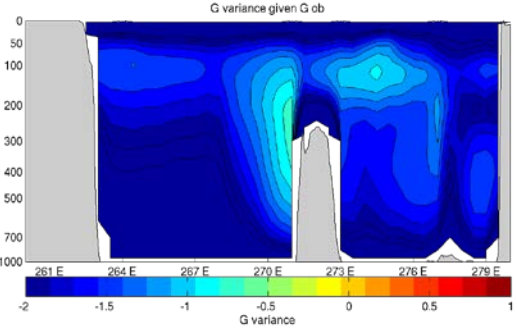




Variance given SSS



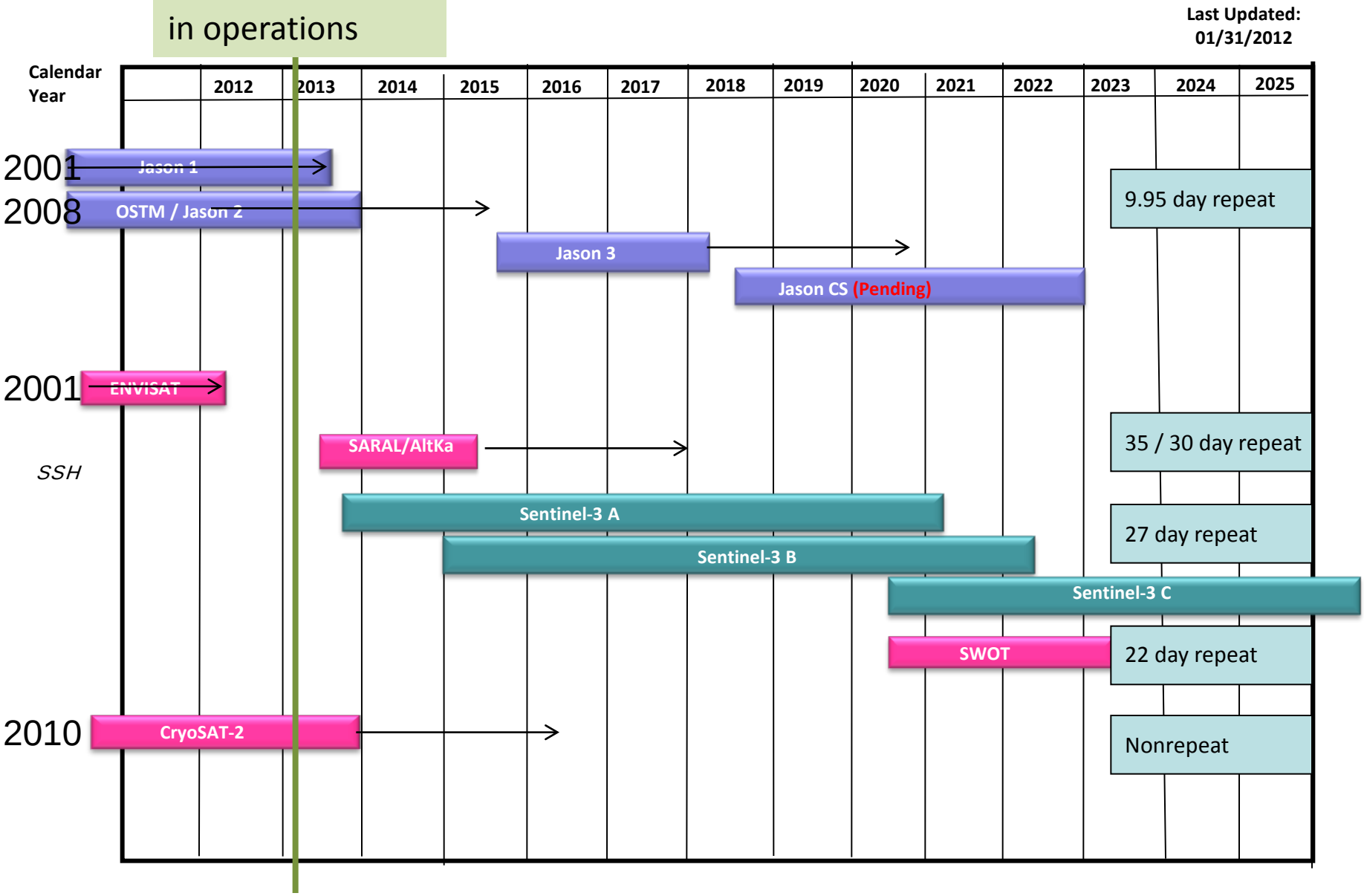




Variance given SSH

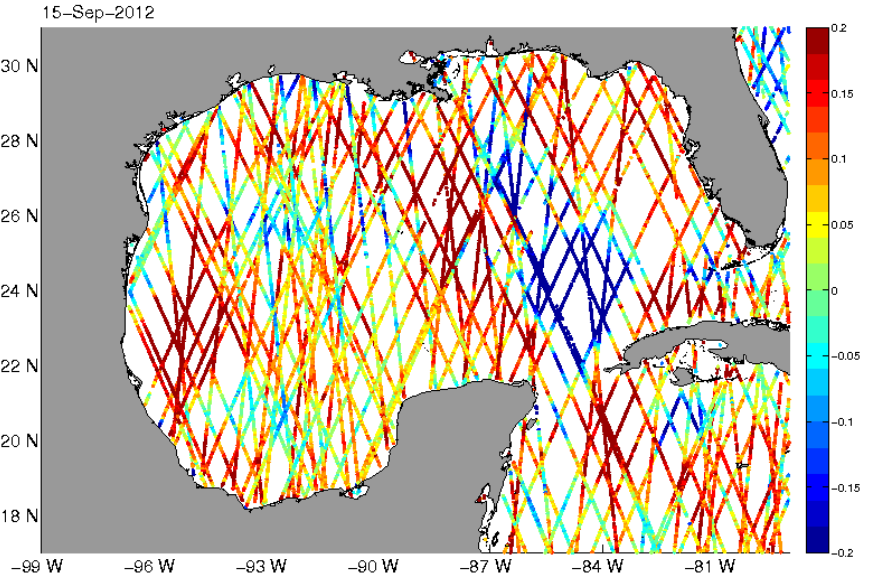
Sea Surface Height Sensing Platforms

All available data in operations



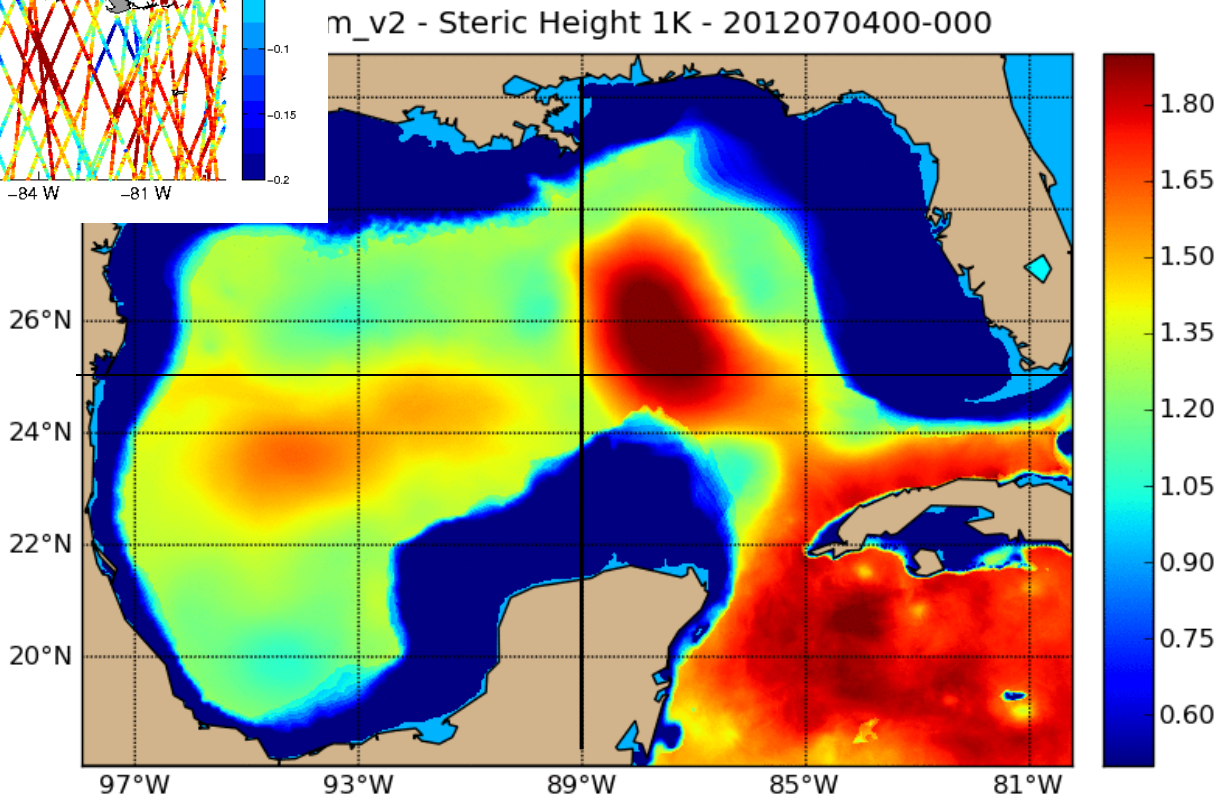
Range of dynamics are captured in observations

35 day composite 15 Sep, 2012



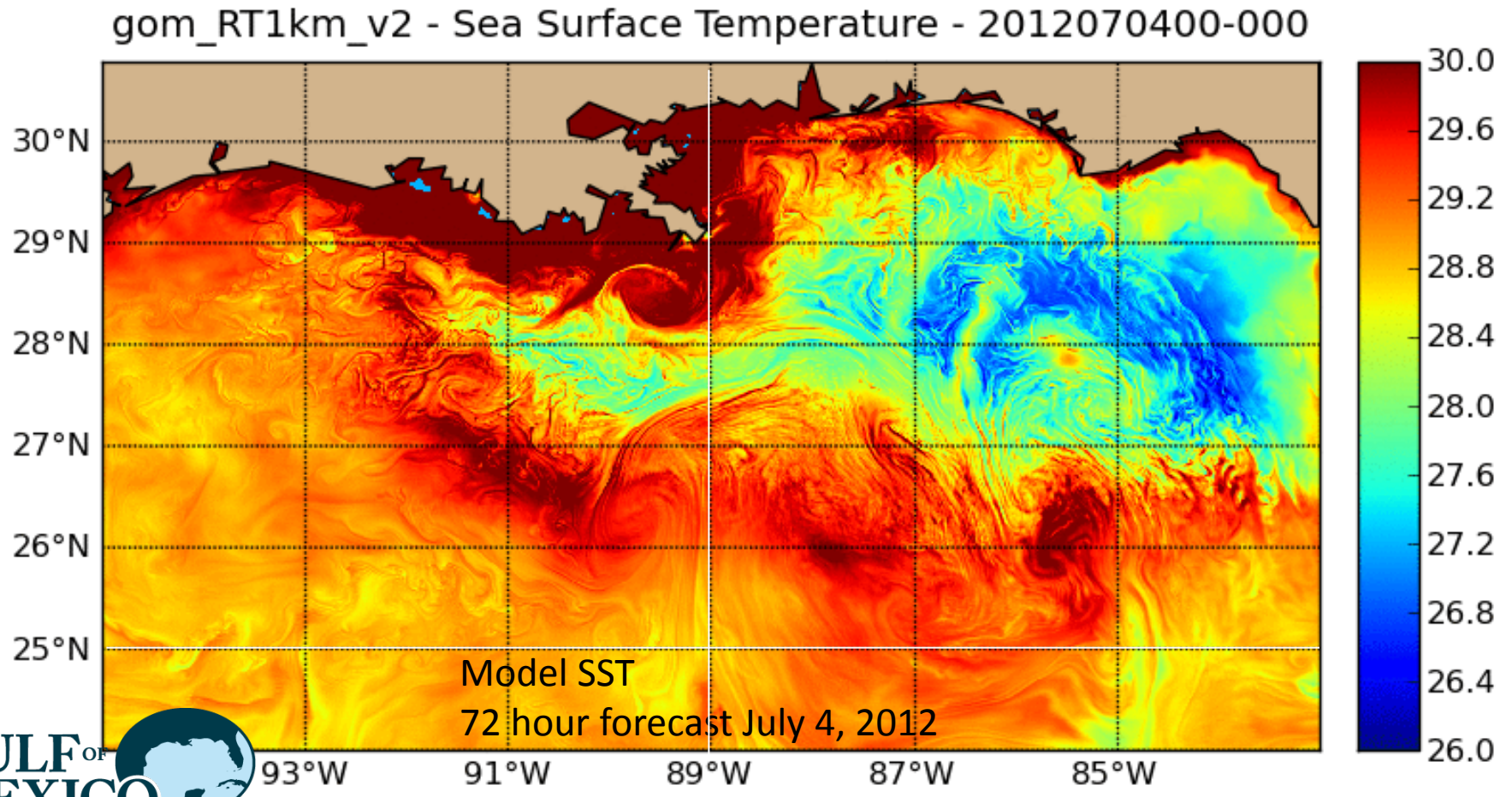
- 1km horizontal resolution model
- Nested in global model
- Daily 72 hour forecasts
- Assimilating satellite SSHA (Jason-2, Jason-1G, CryoSat2), SST and in situ
- Reproduces the large scale dynamic height

Model Steric Height
72 hour forecast July 4, 2012



Model physics extends observations

- Mesoscale density field is pulled and strained by the velocity field
- Vertical secondary circulations develop
- Cooler waters are transported to the surface along fronts
- Impacts chemistry, biology, fisheries, HABS, recreational, commercial, coastal management



GULF OF MEXICO RESEARCH INITIATIVE

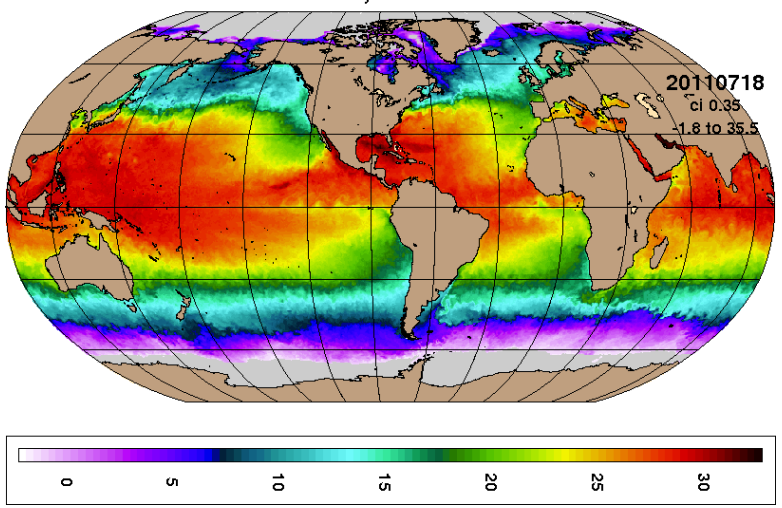
Summary

Altimeter observations have the dominant effect over in situ and other satellite observations

Without altimeter observations, mesoscale ocean prediction ends

Jason-3 scheduled for FY15 will continue to enable mesoscale ocean forecasting

Global 1/12 HYCOM SST



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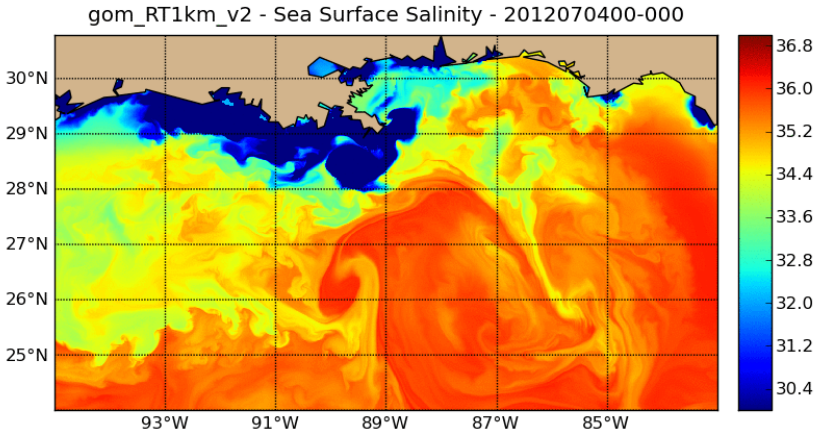

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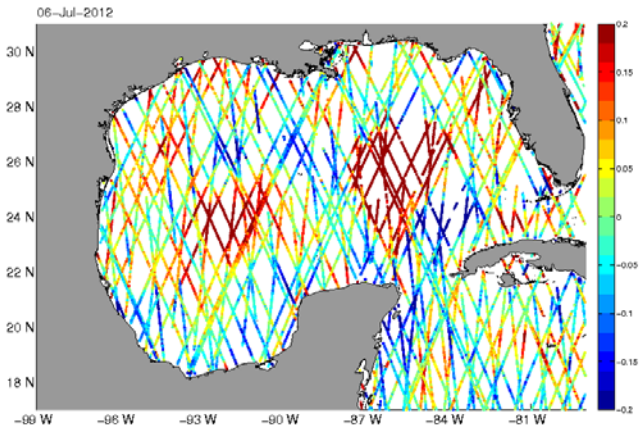
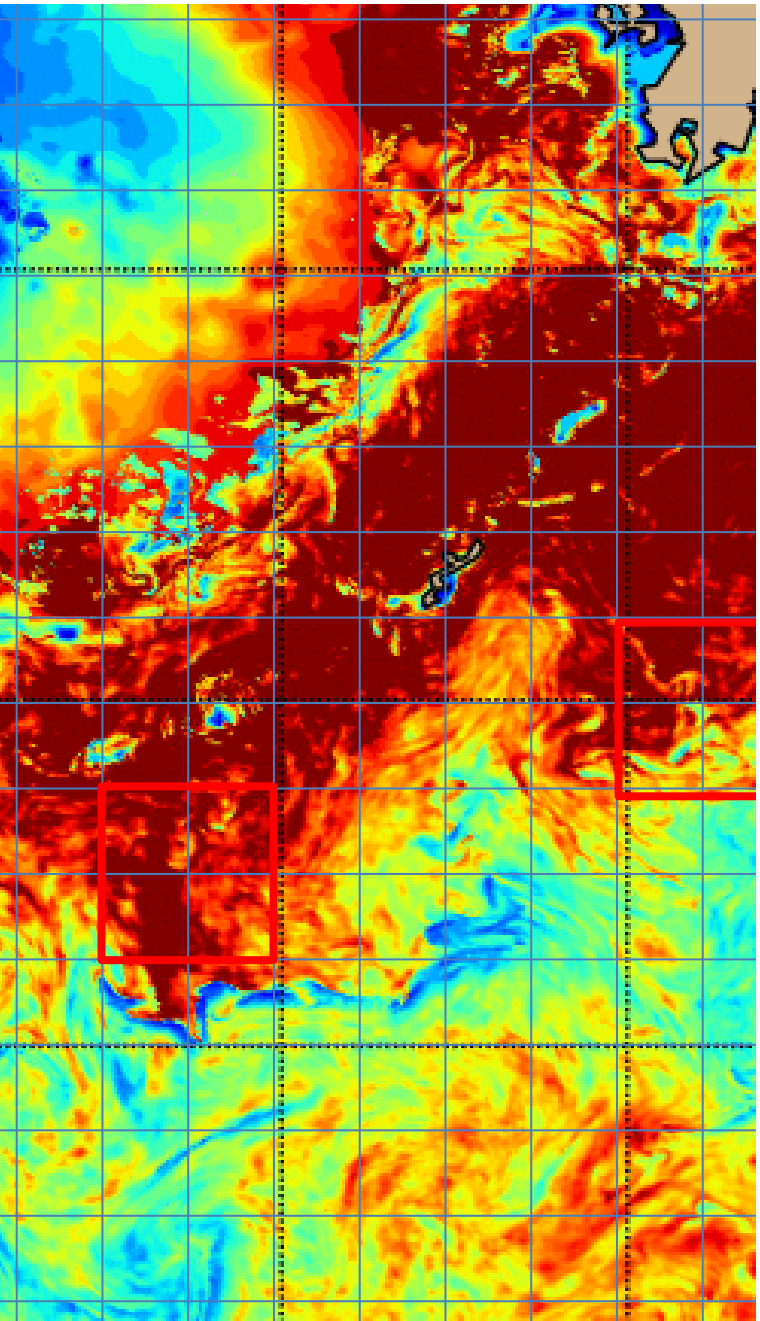
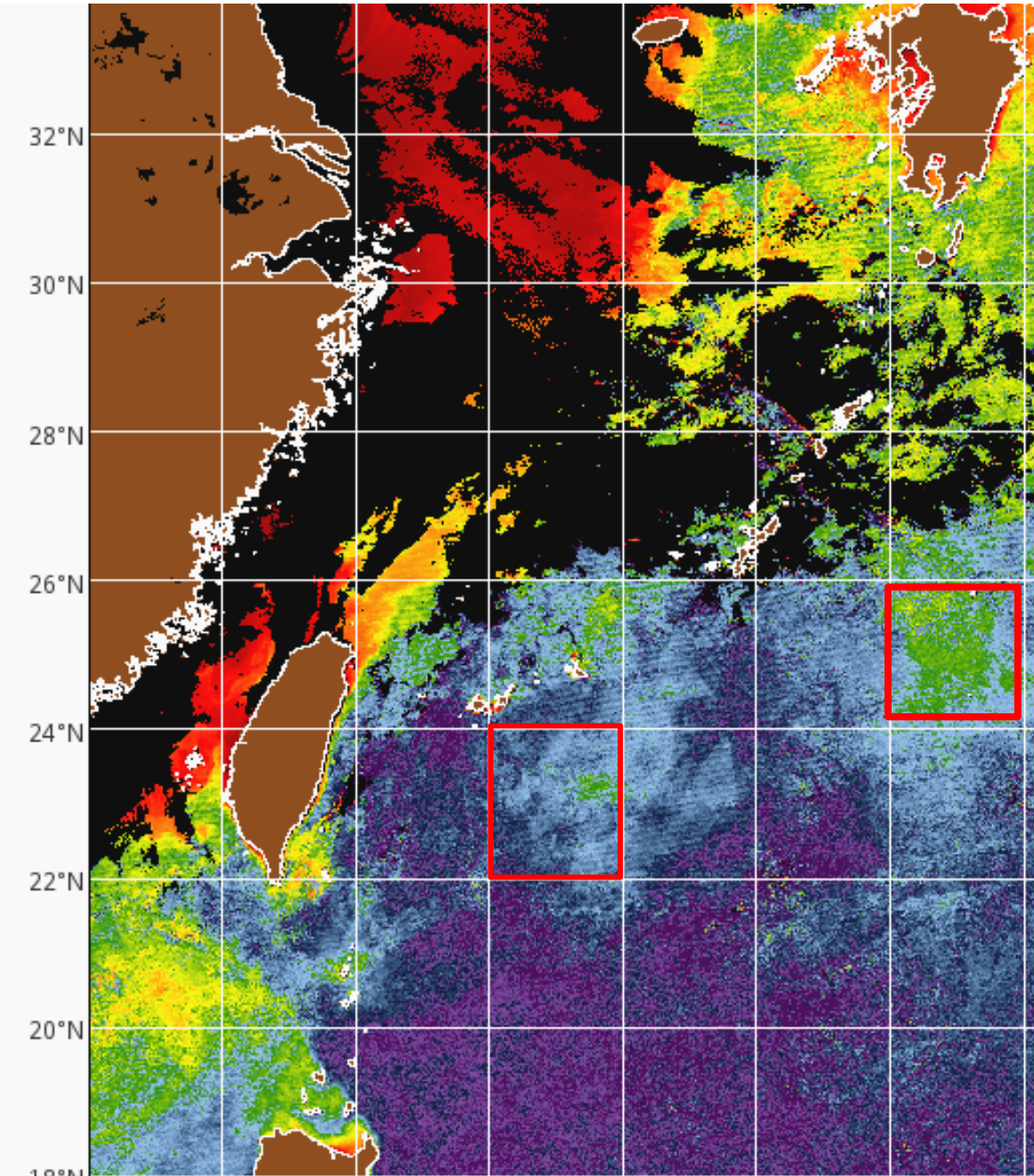


Surface structure controls biological activity





MODIS SST

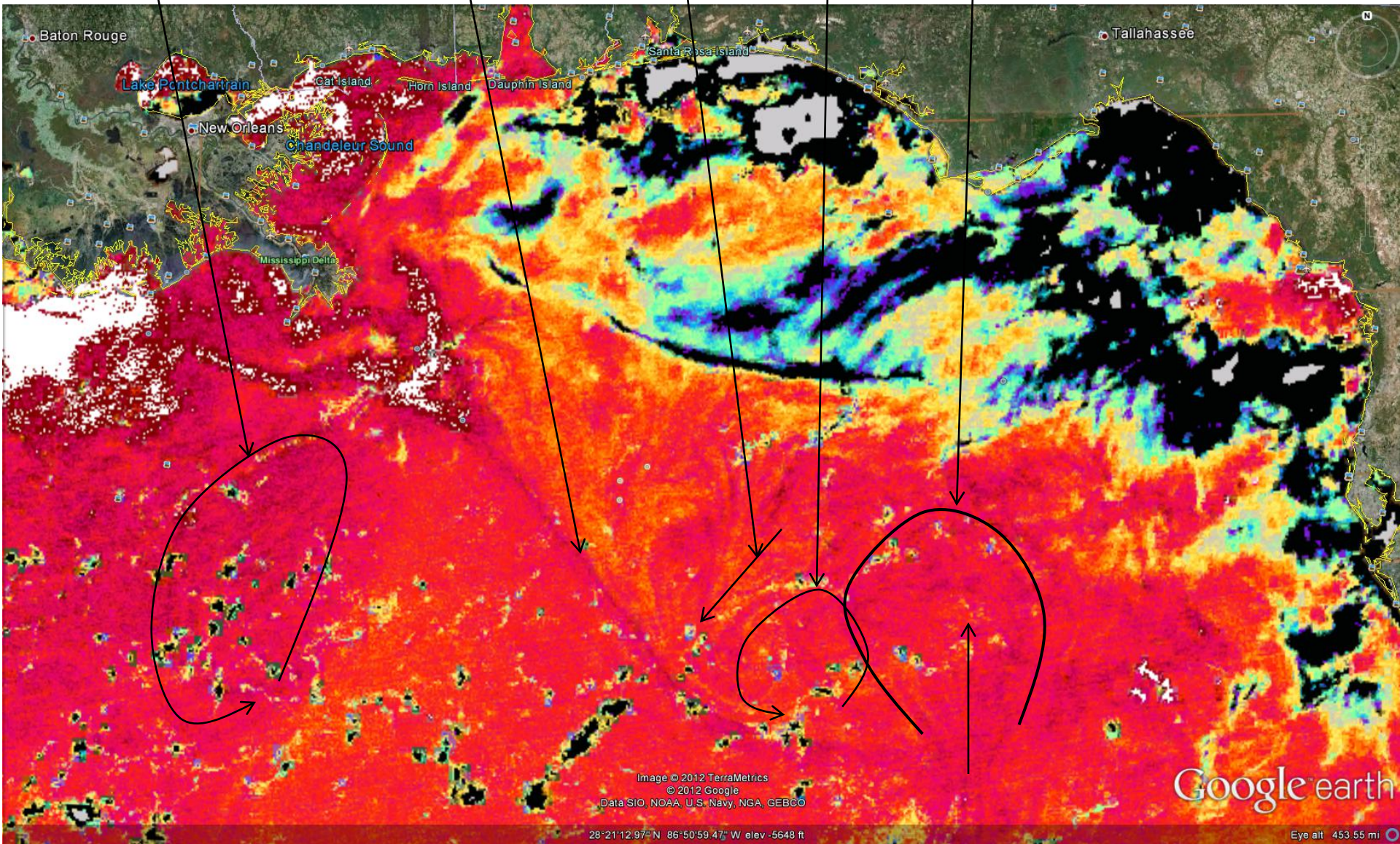
Appears to be a northward flow

Cyclone

Cyclone

Clear front

Southwest flow



MODIS SST with 1km NCOM surface currents

The model cyclone is further west than observed

Cyclone

Clear front

Southwest flow

Appears to be a northward flow

Cyclone