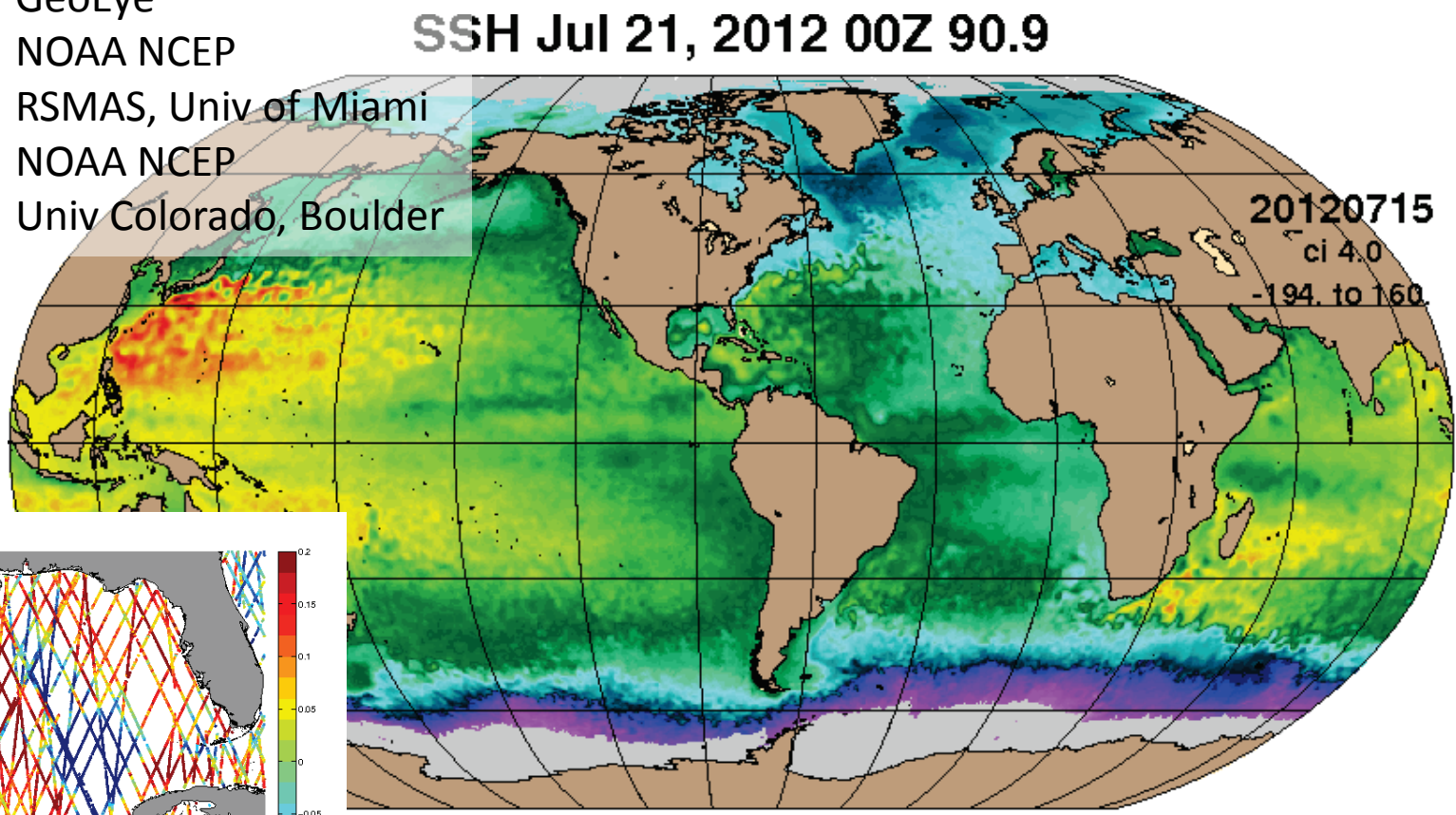
# SSH implication for operational prediction

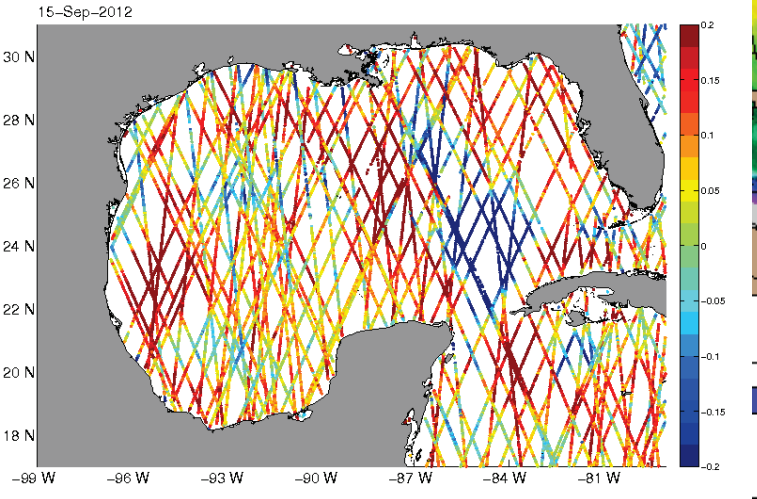
Lots of helpful inputs from:

- David Behringer NOAA NCEP
- Frank Bub NAVOCEANO
- Gustavo Goni NOAA AOML
- Greg Hammann GeoEye
- Ming Ji NOAA NCEP
- Nick Shay RSMAS, Univ of Miami
- Joe Sienkiewicz NOAA NCEP
- Bob Leben Univ Colorado, Boulder

Gregg Jacobs, NRL
John Lillibridge, NOAA



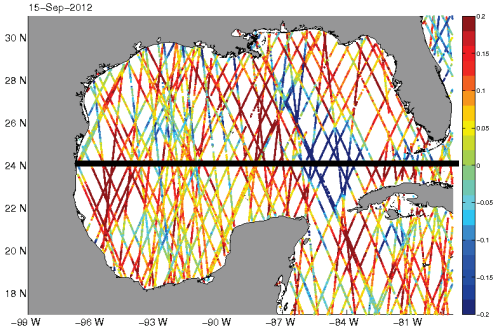

Sep 15, 2012



# New data set, same result, SSH is most influential

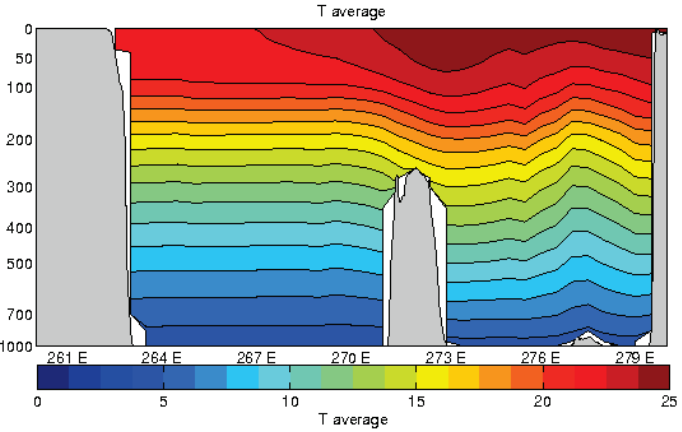
Historical data (from 1900 to present)
1/2° gridding
Provides mean, variance and covariance

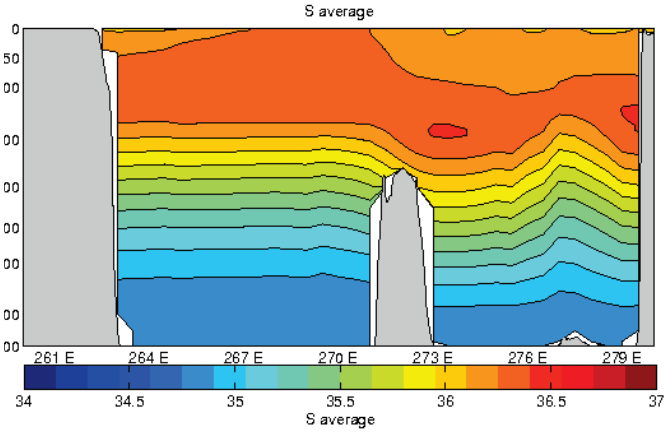
January 24° N



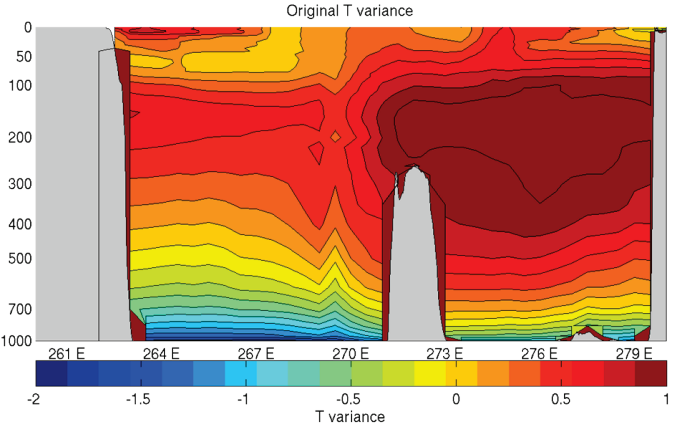

T

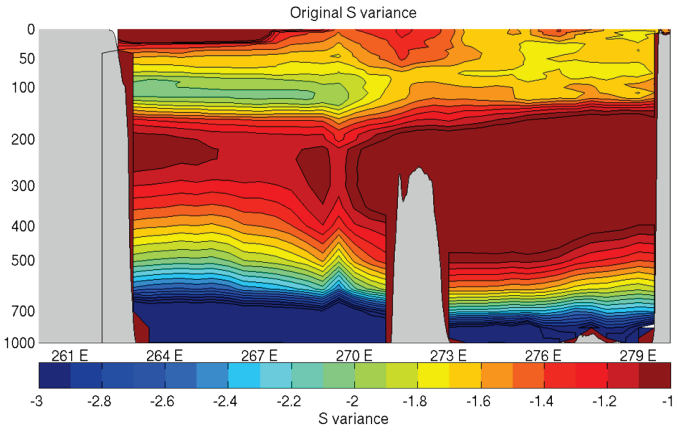
S




Mean




Variance

# New data set, same result, SSH is most influential

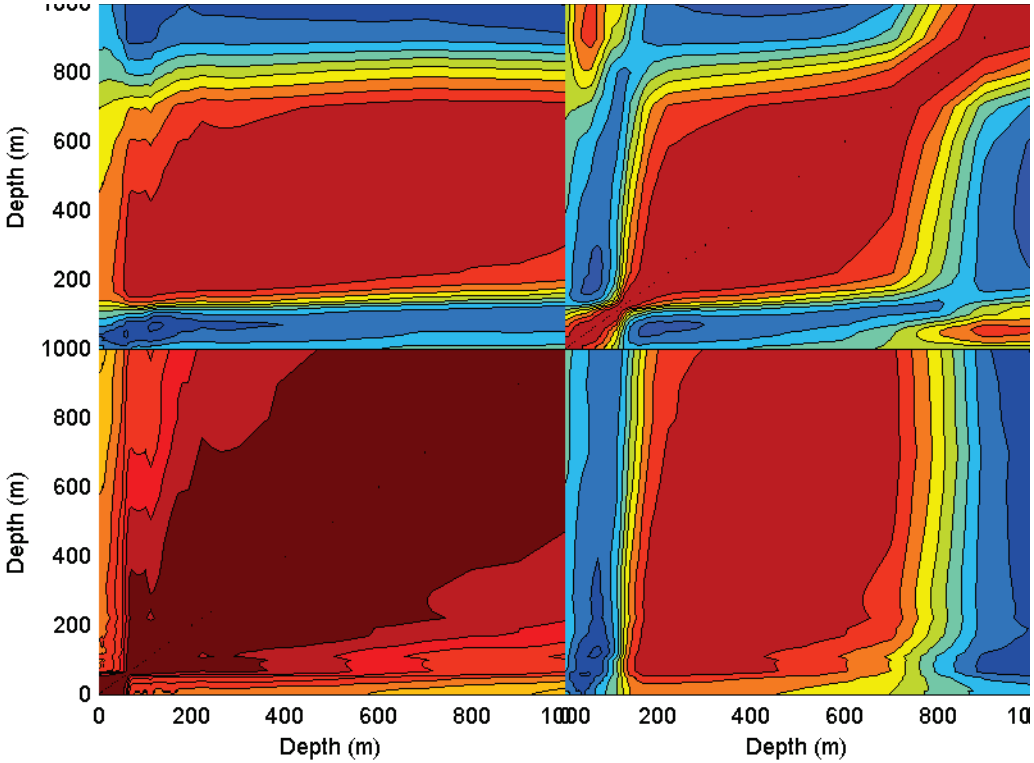
A few pedantic definitions

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

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

State Average 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)

$\delta$ 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

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

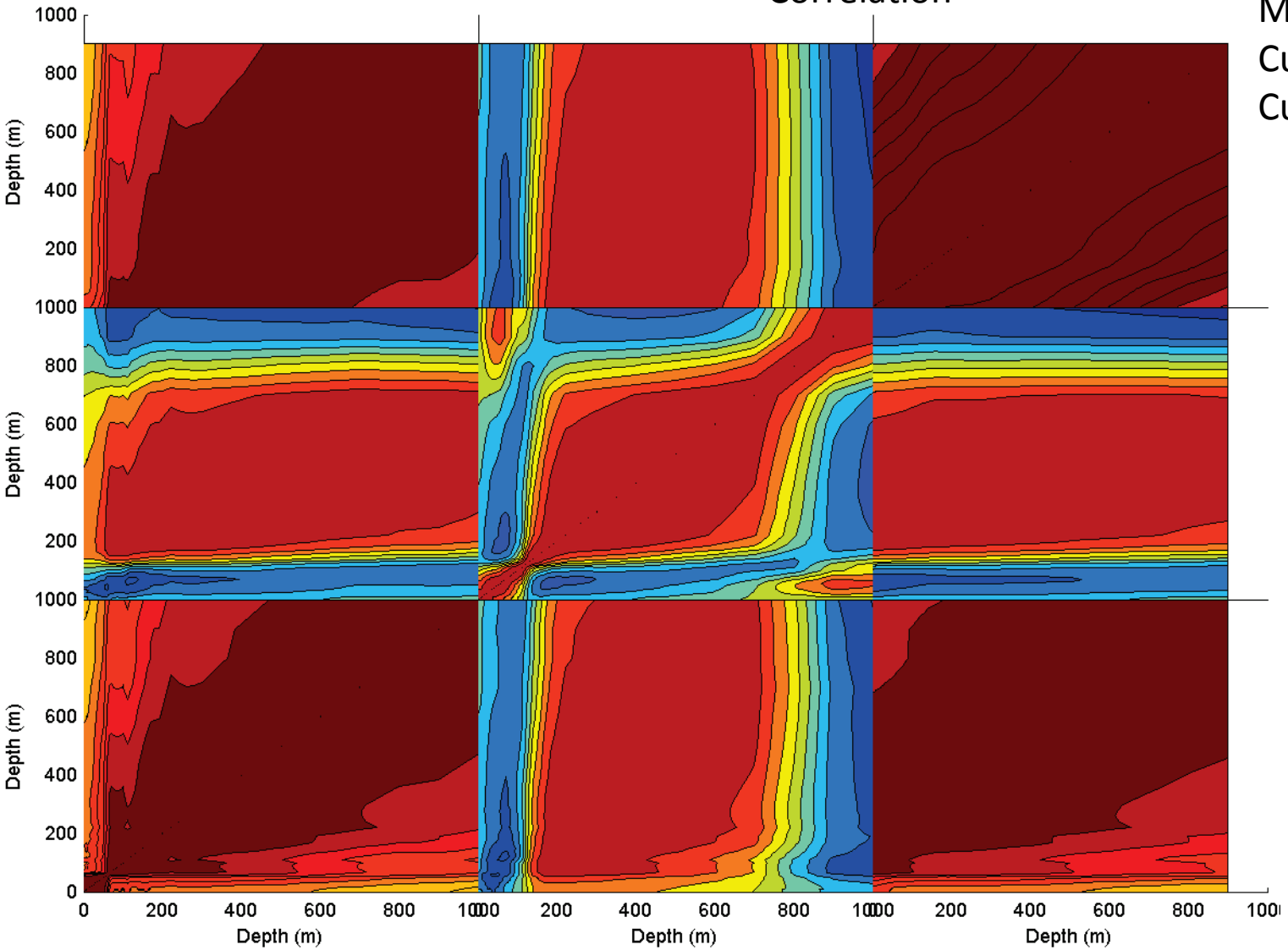
$$B = \langle \acute{Y}\acute{Y}^T \rangle = \begin{bmatrix} \acute{X}\acute{X}^T & \acute{X}\acute{X}^T\delta^T G^T \\ G^T\delta^T\acute{X}^T\acute{X} & \delta\acute{G}X\acute{X}^T G^T\delta^T \end{bmatrix}$$

# 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

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

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

$$P^F = H^T B (H^T B H + R)^{-1}$$

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)

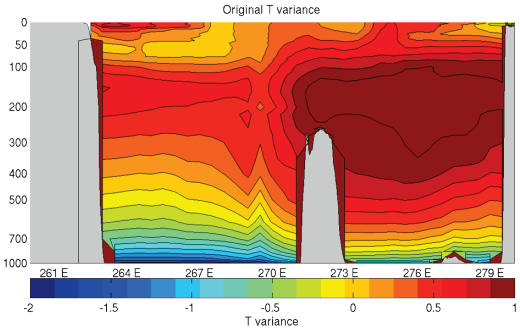
Because we now have B,
We can compute the impact of a satellite observation of T,S or G

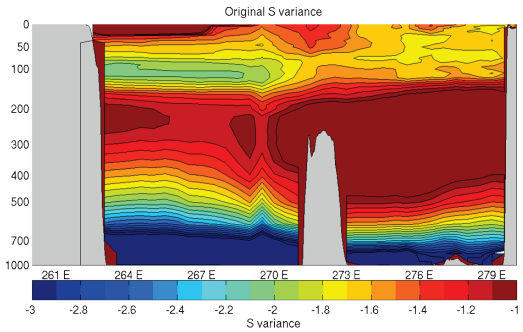
# 24°N Feb

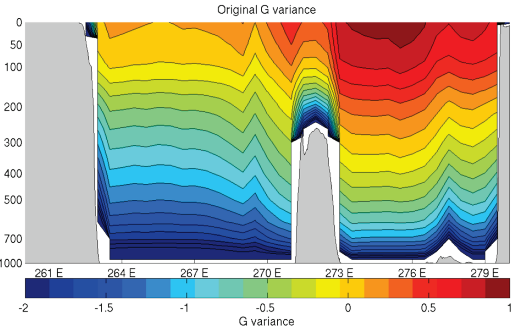
T

S

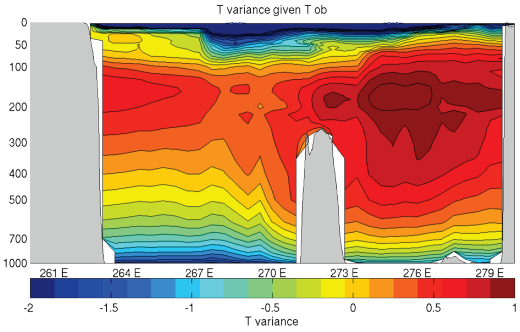
G

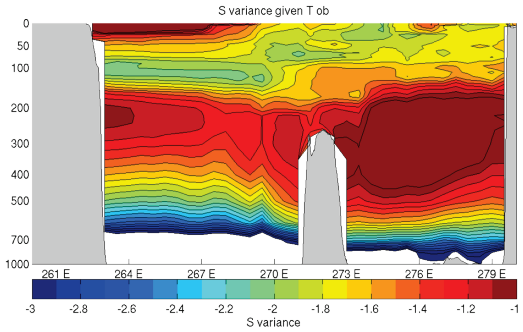


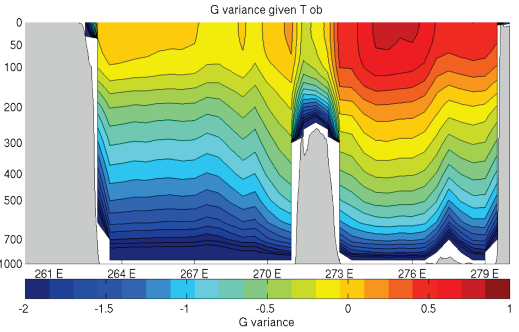



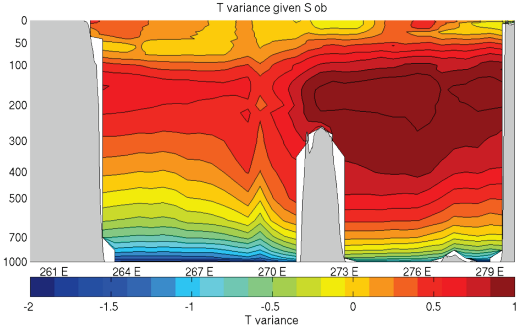

Original Variance

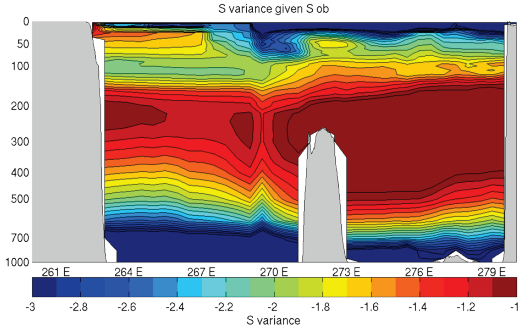


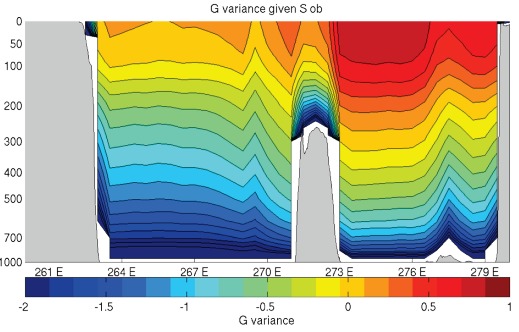



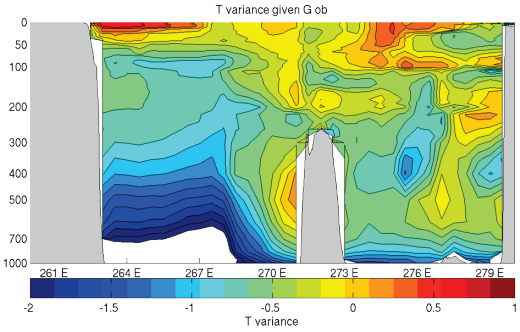

Variance given SST

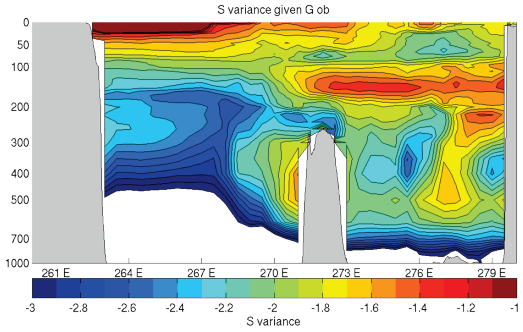


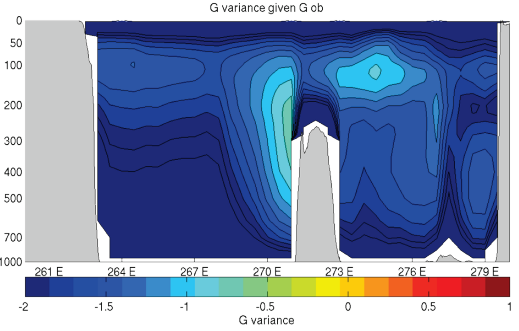




Variance given SSS



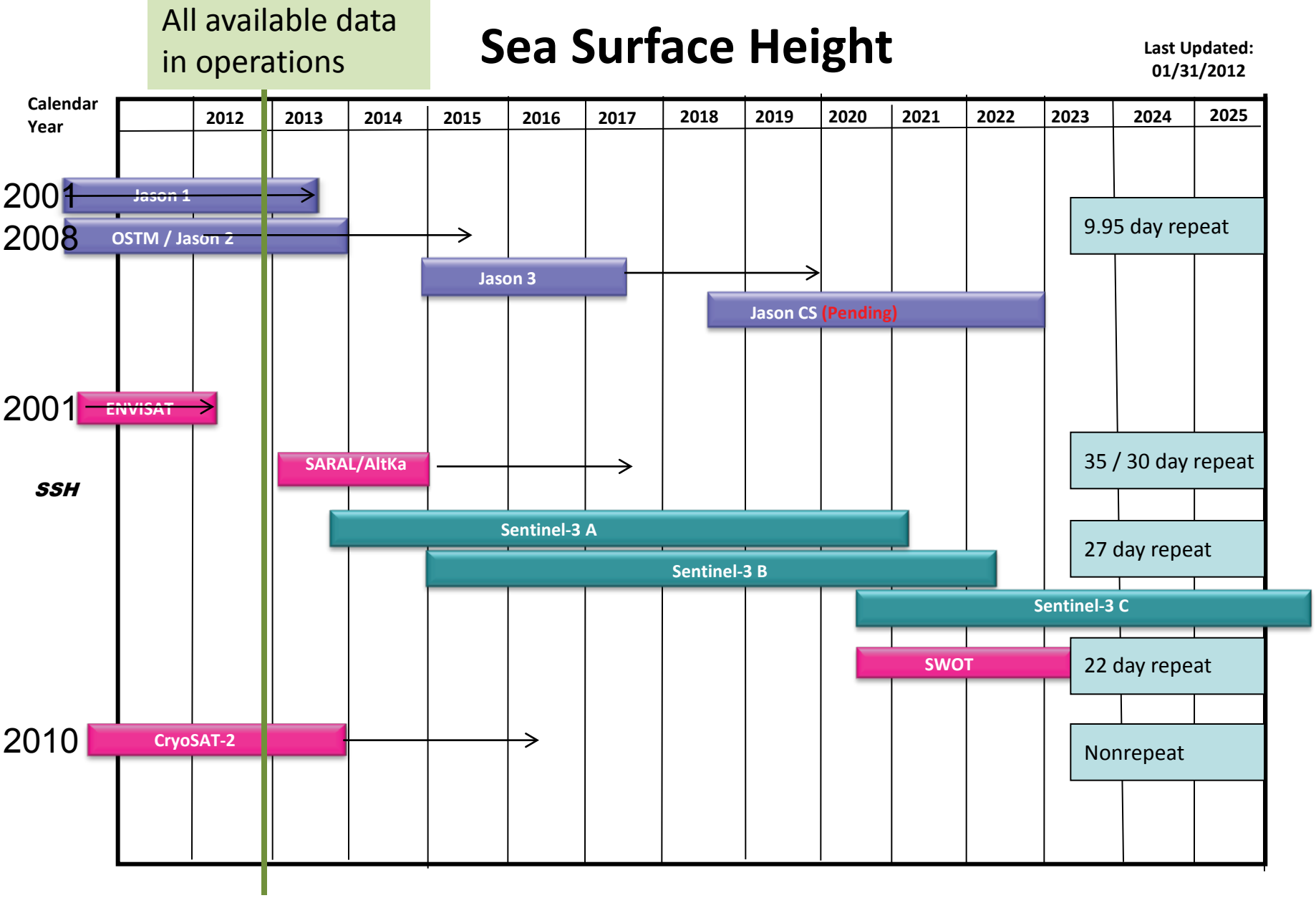




Variance given SSH

# Sea Surface Height Sensing Platforms

All available data in operations

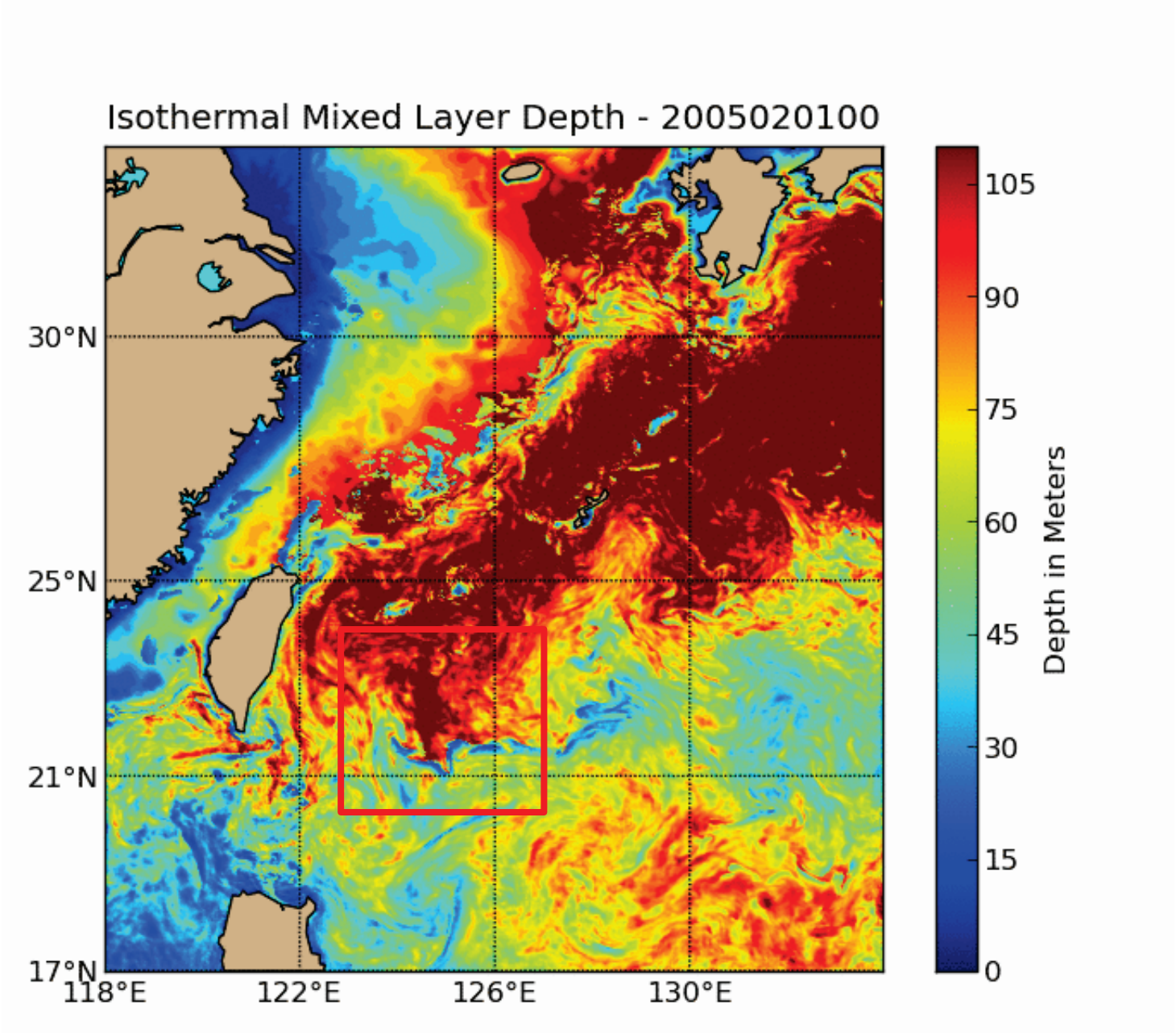


# Series of experiments

| Exp ID | Altimeter Data Sets | Satellite SST | other data | MLD correlation to nature run | STHT correlation to nature run |
|---|---|---|---|---|---|
| OSSE00 / nature run | Jason GFO ENVISAT TPXI | on | Public (01 June 2005 initial conditions) | | |
| OSSE01 | None | None | None | 0.21 | 0.15 |
| OSSE02 | None | on | Public | 0.27 | 0.42 |
| OSSE03 | Jason GFO ENVISAT TPXI | on | Public | 0.89 | 0.99 |
| OSSE04 | Jason | on | Public | 0.66 | 0.84 |
| OSSE05 | GFO | on | Public | 0.68 | 0.89 |
| OSSE06 | Jason GFO | on | Public | 0.76 | 0.94 |
| OSSE07 | ENVISAT | on | Public | 0.66 | 0.85 |
| OSSE08 | Jason ENVISAT | on | Public | 0.74 | 0.93 |
| OSSE09 | GFO ENVISAT | on | Public | 0.74 | 0.94 |
| OSSE10 | GFO Jason ENVISAT | on | Public | 0.81 | 0.97 |
| OSSE11 | GFO TPXI | on | Public | 0.74 | 0.94 |
| OSSE12 | GFO Jason TPXI | on | Public | 0.81 | 0.98 |
| OSSE13 | Jason TPXI | on | Public | 0.73 | 0.93 |
| OSSE14 | GFO ENVISAT TPXI | on | Public | 0.80 | 0.96 |

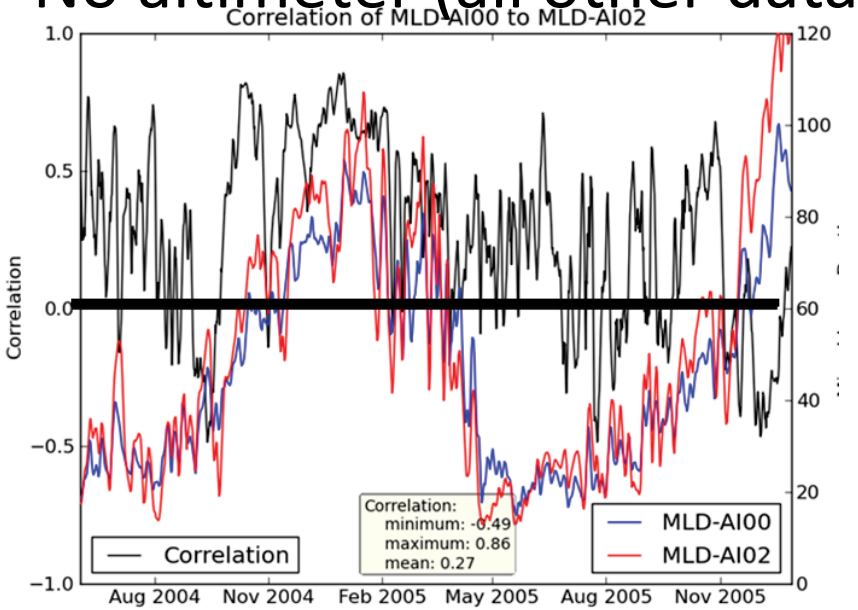
June 2004 – Dec 2005

# Spatial correlation on small scales (< 200km)

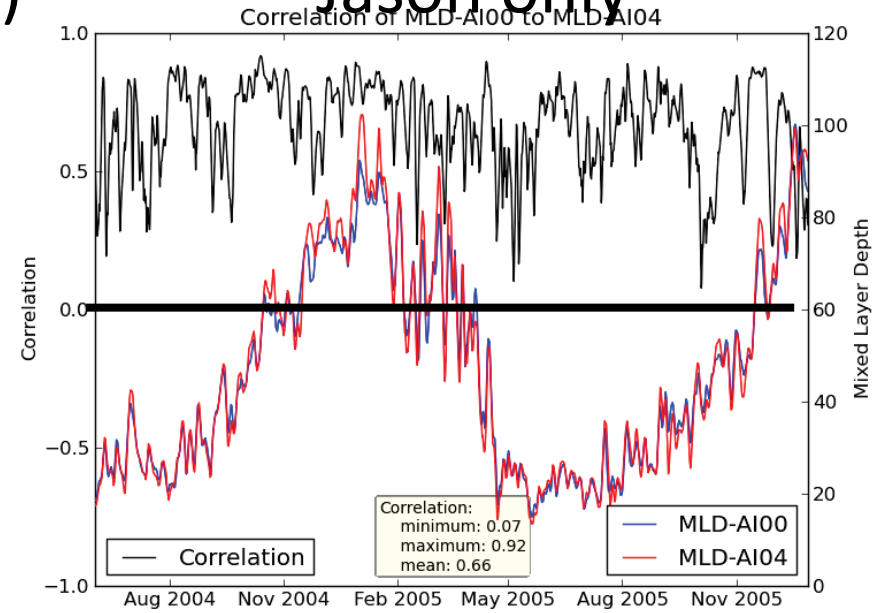


# Mixed layer depth (Nature, OSE, Correlation)

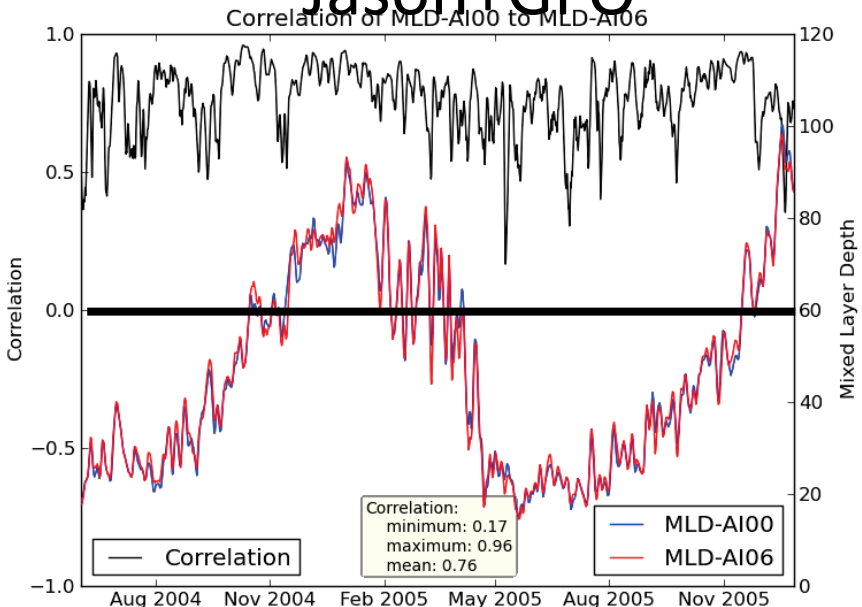
## No altimeter (all other data)



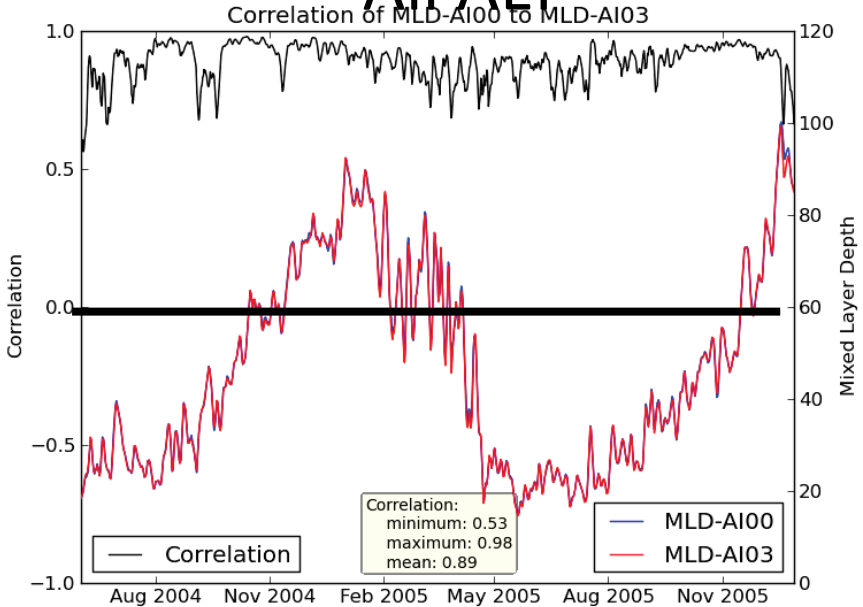

## Jason only




## Jason+GFO

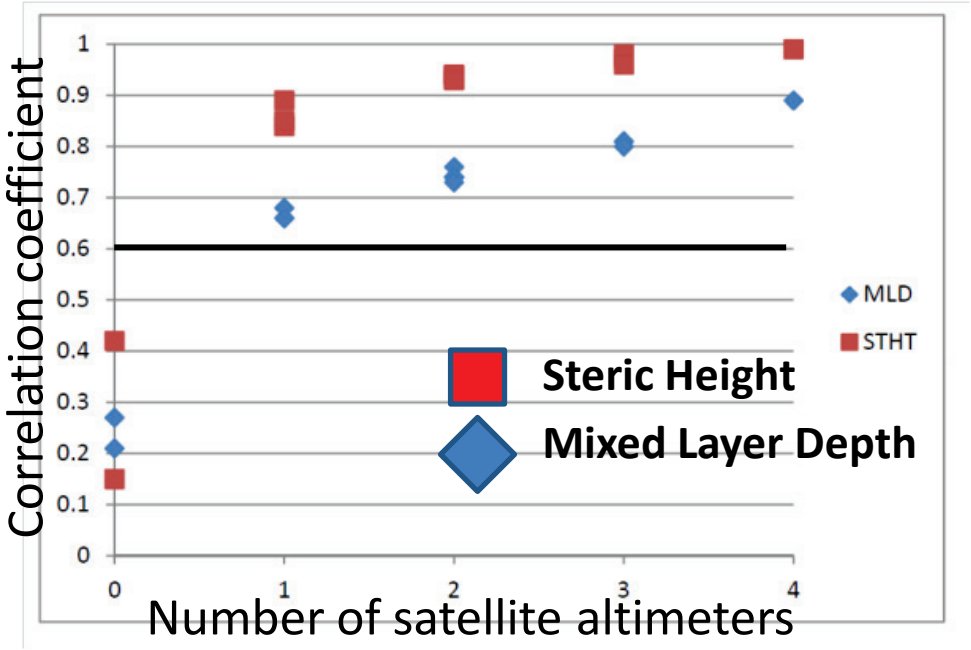



## All ALT



# Multiple SSH inputs needed to reach confident skill

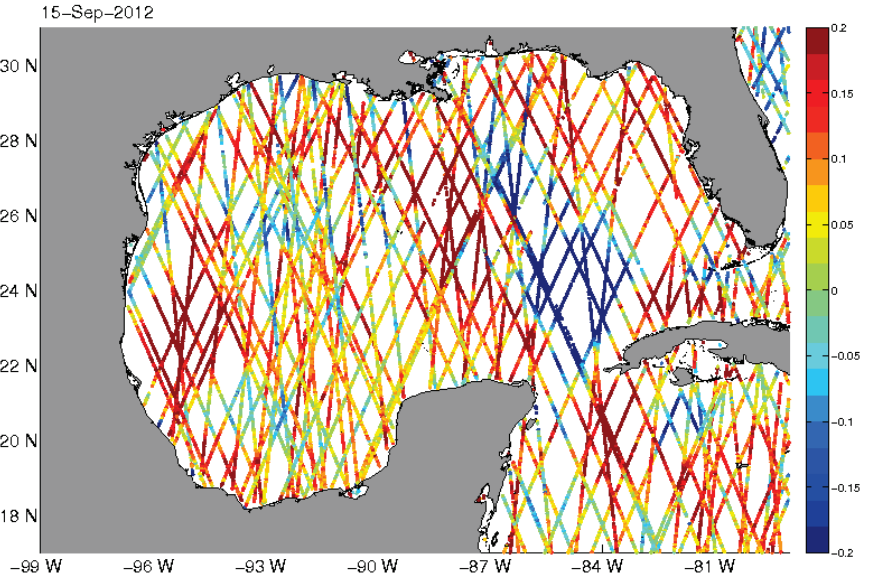
Time average over Jun 2004 – Dec 2005 of spatial correlation (features < 200km)




- **With no altimeters, there is no skill**
- **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**
- **Skill in MLD is much more sensitive to data quantity as background density structure controls MLD formation**
- **Anticyclones lead to deep MLD, cyclones to shallow MLD**

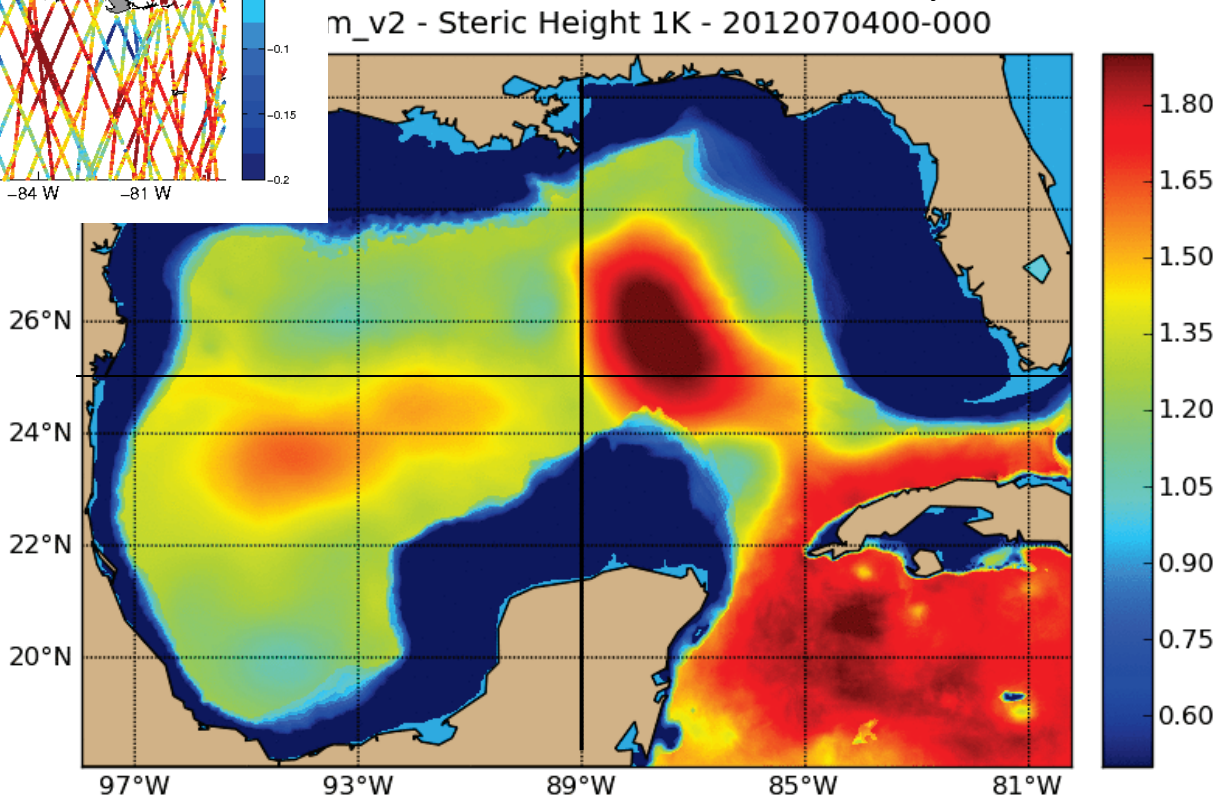
# Range of dynamics are captured in observations

35 day composite 15 Sep, 2012



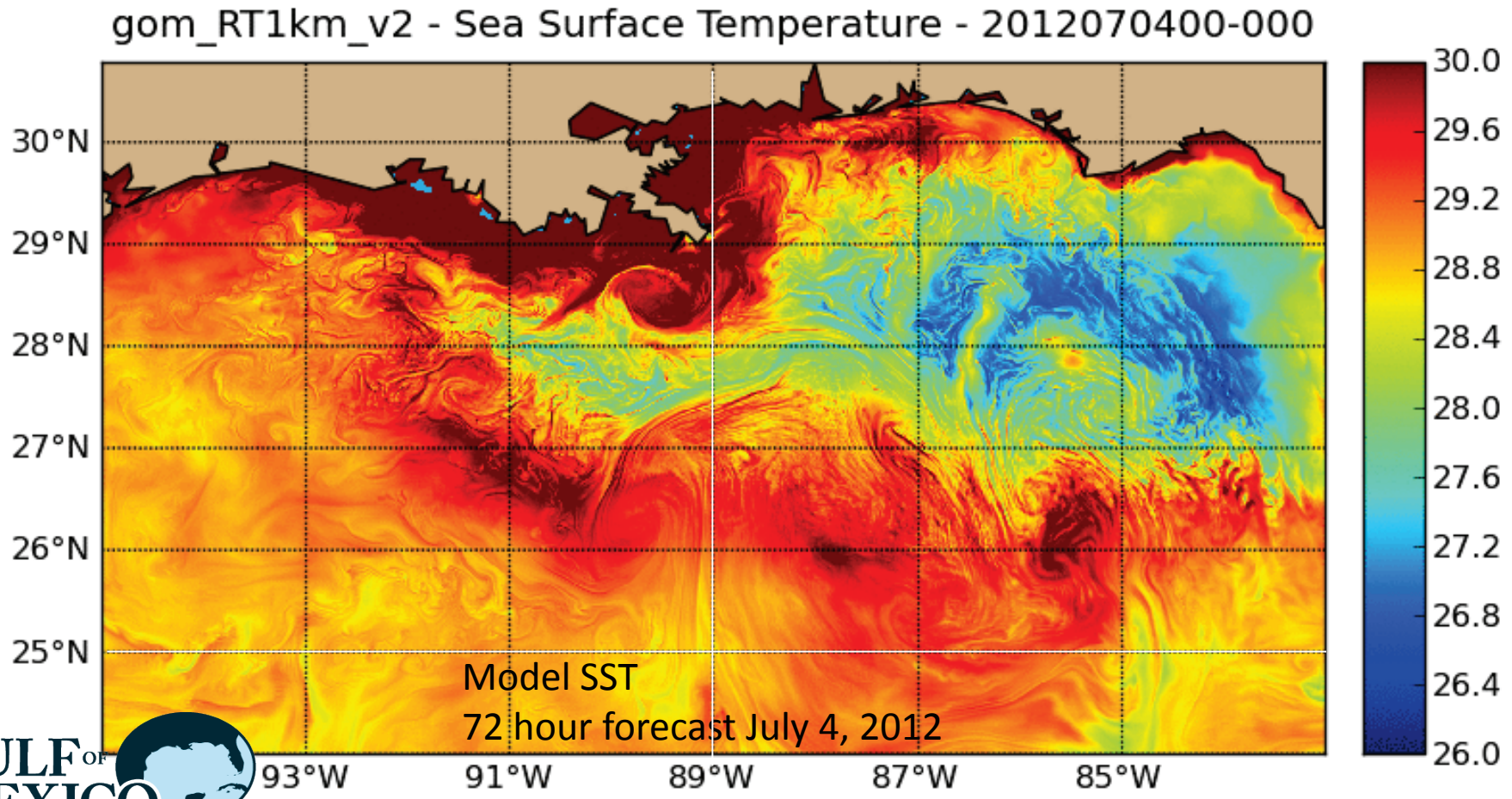

- 1km horizontal resolution model
- Nested in global model
- Daily 72 hour forecasts
- Assimilating satellite SSHA (Jason-2, Jason-1G, CryoSat2), SST and in situ
- Reproduces the large scale dynamic height

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

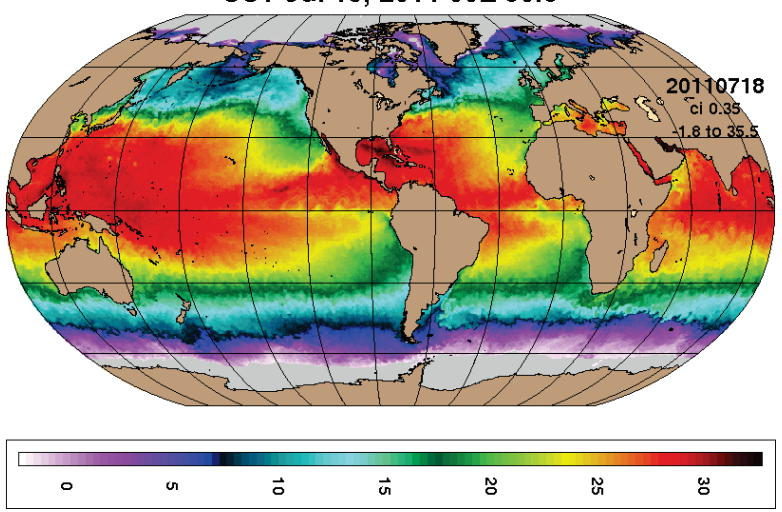
# Summary

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

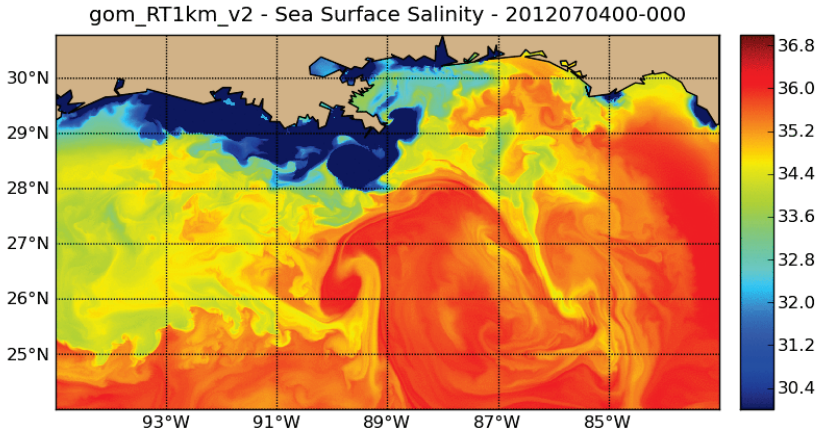
**The limiting factor at present it not accuracy and precision but coverage**

**More observations of uncorrelated error and features are required to progress**

Global 1/12 HYCOM SST

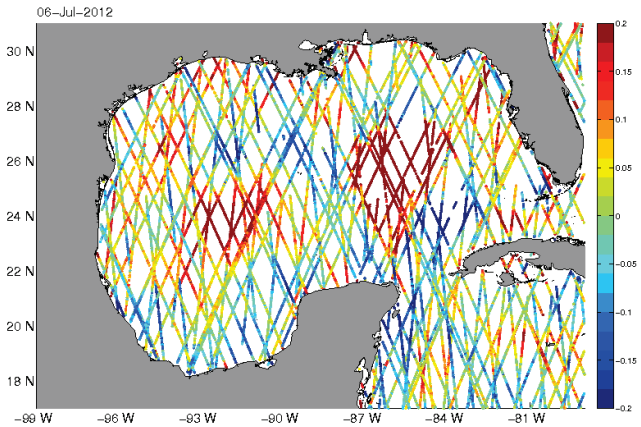



Nested 1km NCOM SSS

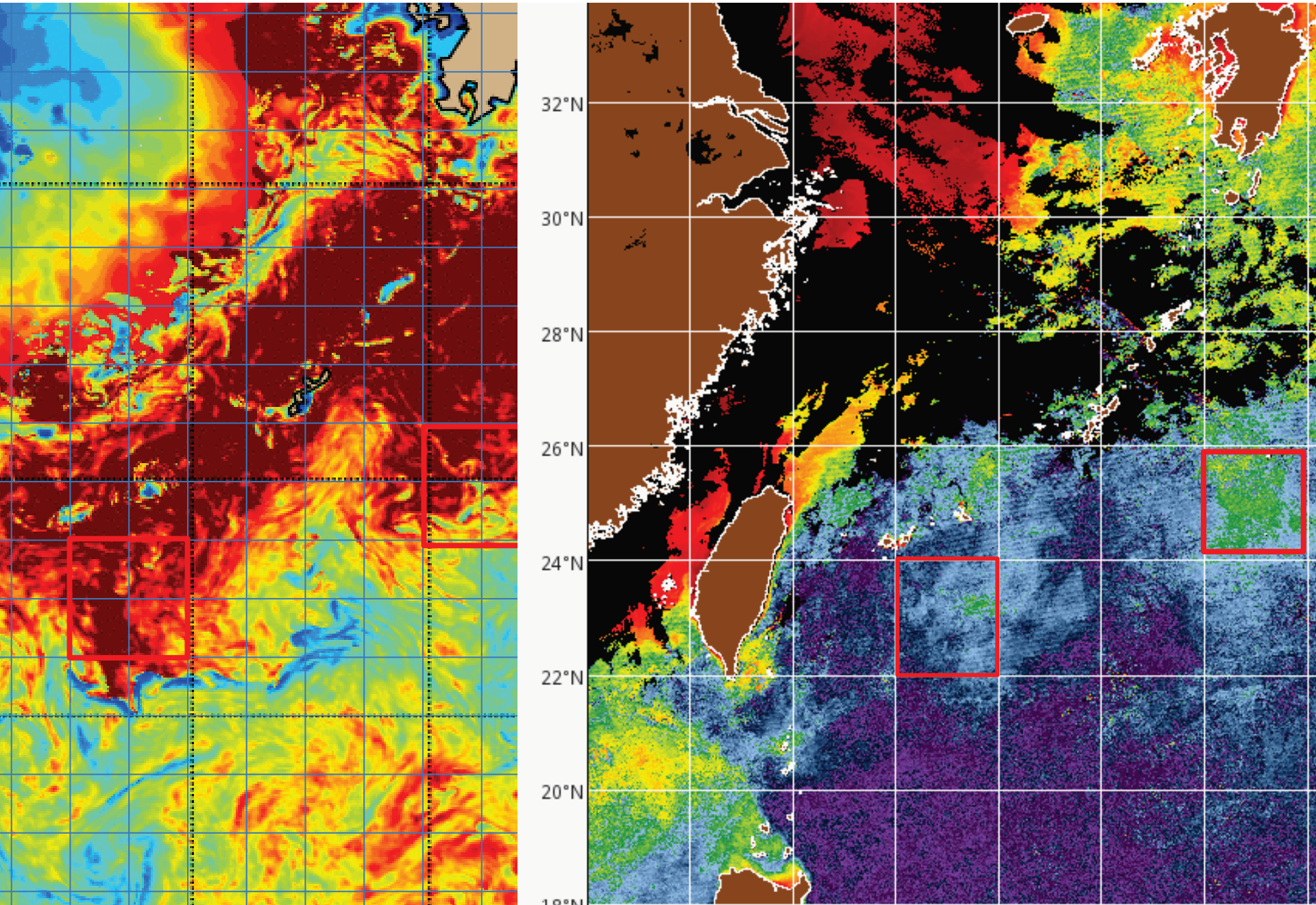



Altimeter SSH

- Jason-2
- Jason-1G
- CryoSat2



# Surface structure controls biological activity



MODIS SST

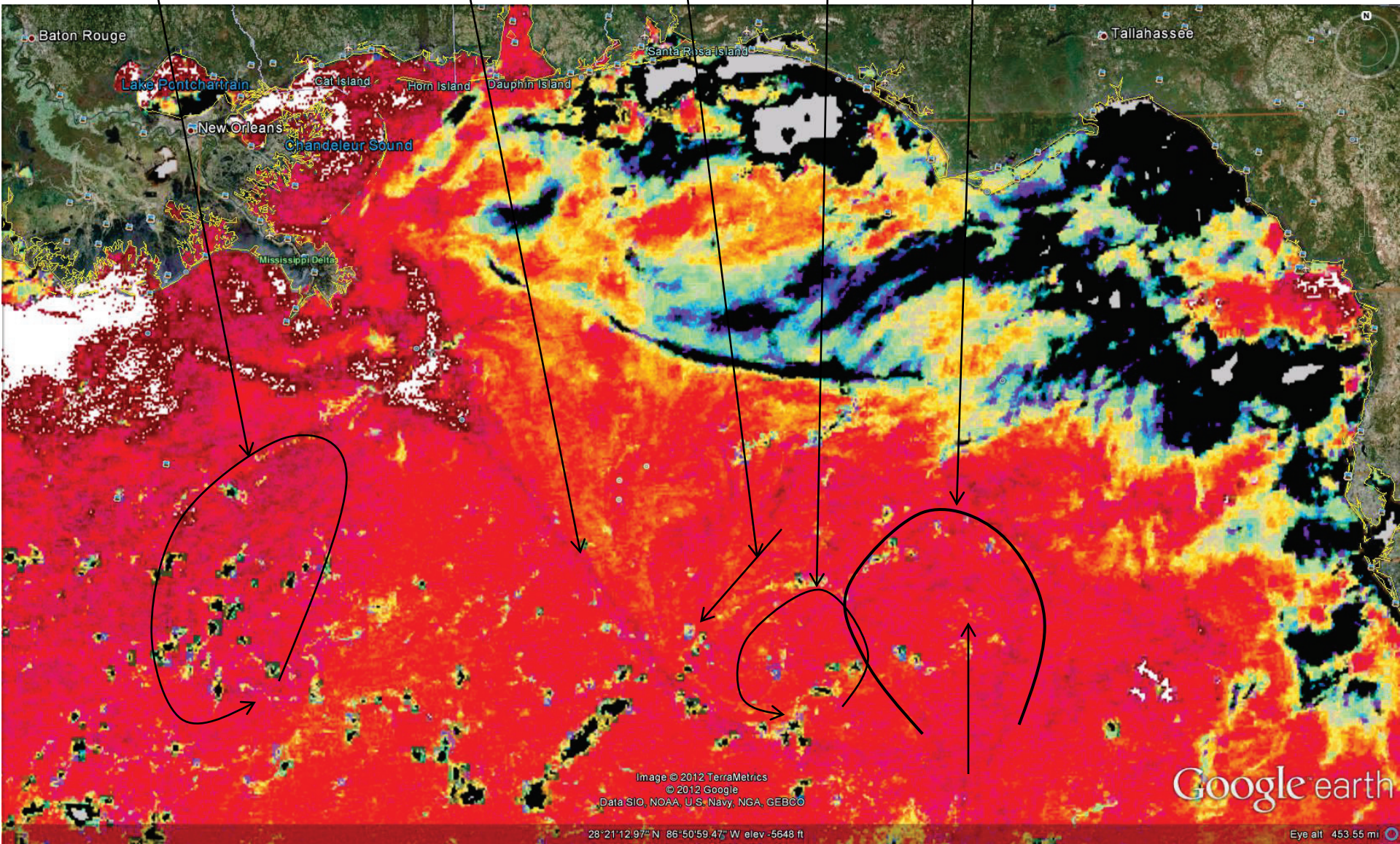
Appears to be a northward flow

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

Cyclone

Appears to be a northward flow