Sea surface height observational capabilities: from mesoscale to submesoscale

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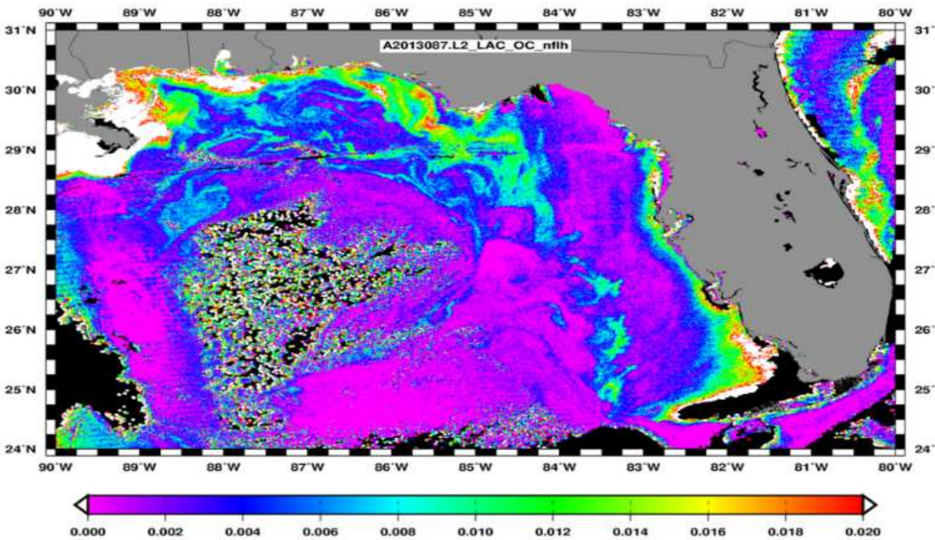
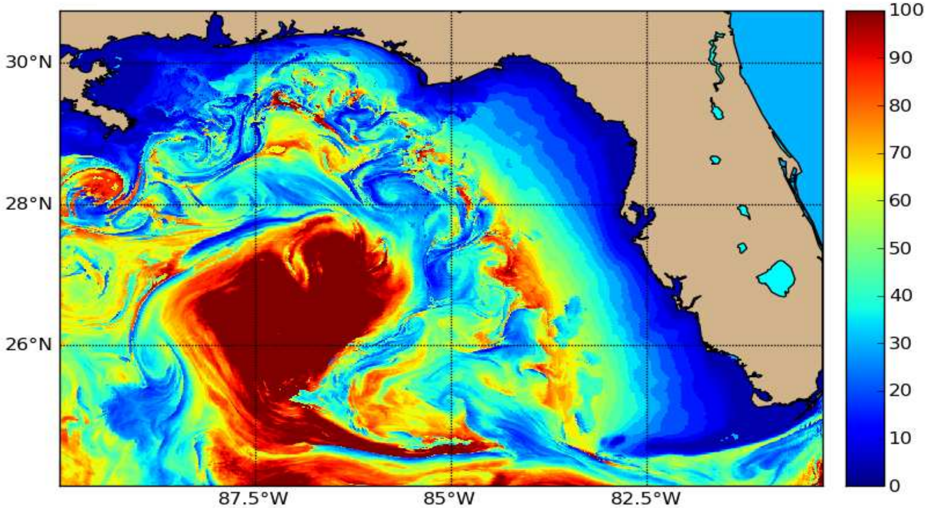
Satellite-observed seaweed



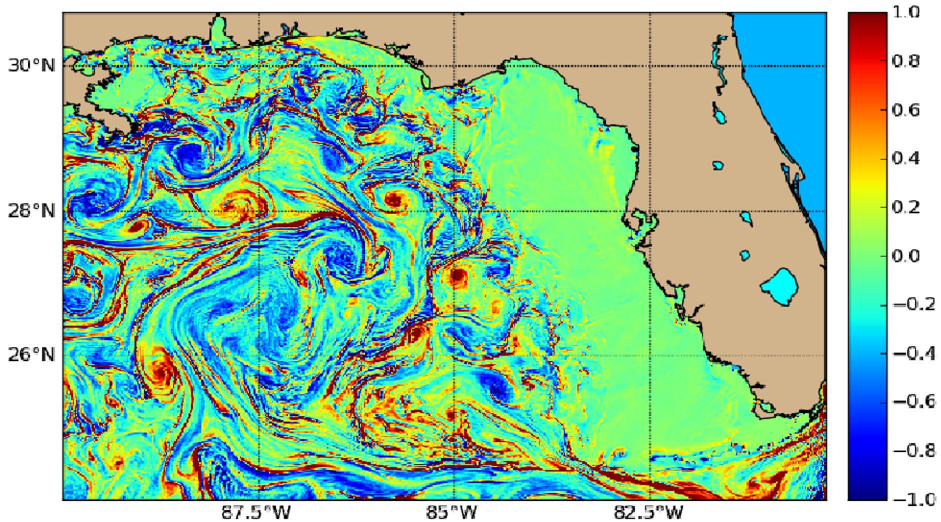
- There is a significant portion of the ocean we cannot predict
- We have the capability to dynamically represent this portion
- Observations are lacking

1 km resolution model

Mixed Layer Depth



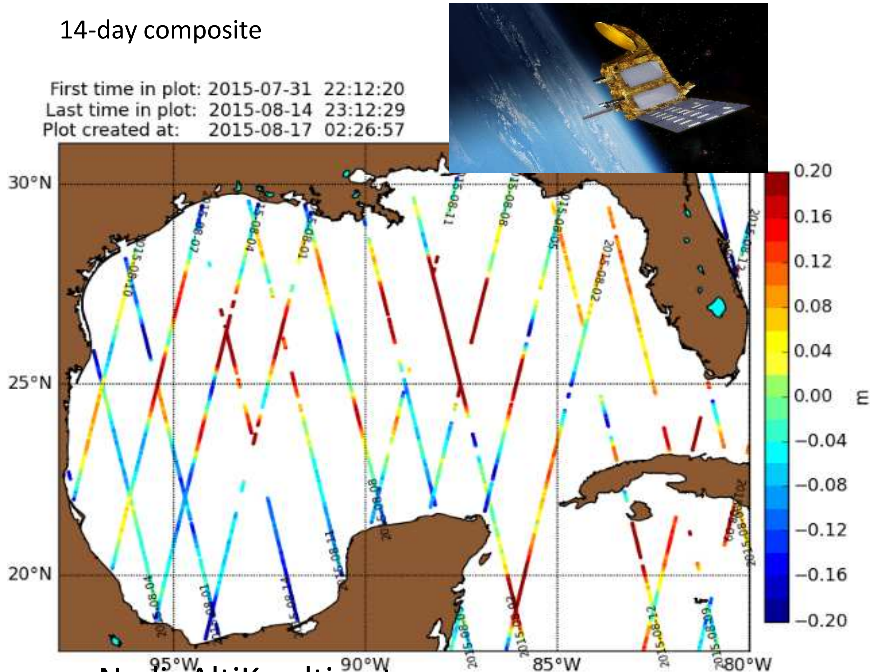
Vorticity / f



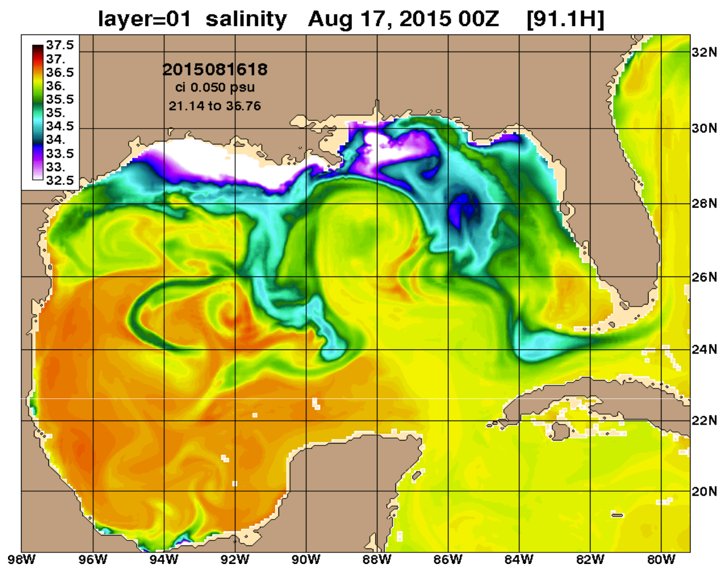
Presently

- Present predictions target mesoscale
- Observations and forecast models are consistent

14-day composite



Nadir AltiKa altimeter
Sea surface height
~315 km between tracks



9 km global model
Surface salinity

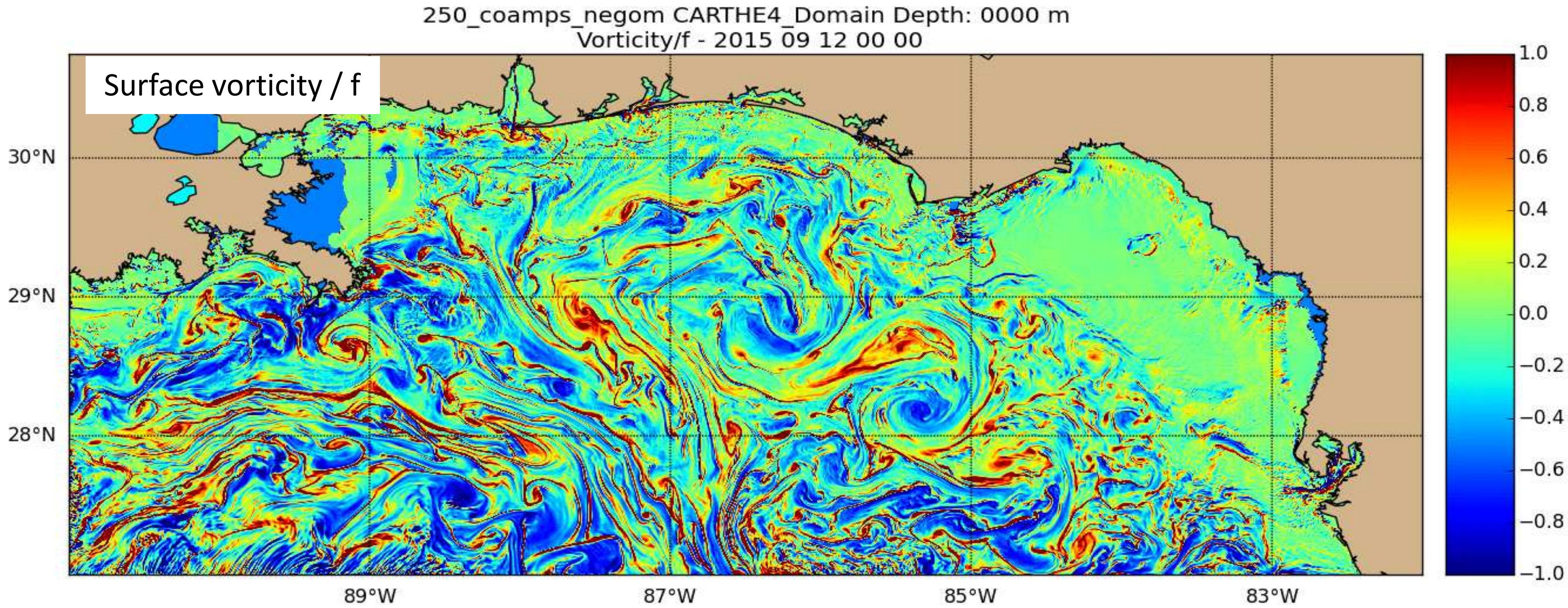
Present altimeter sea surface height

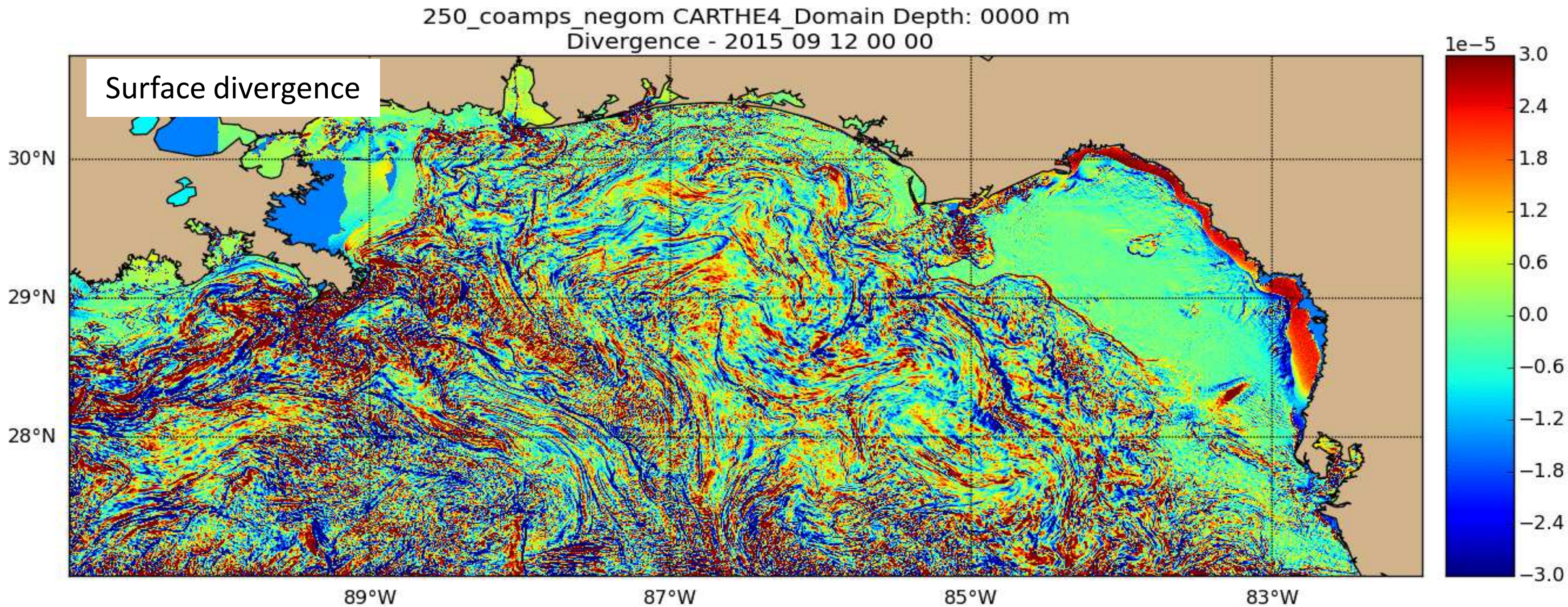
- Nadir point measurement
- 14 km average footprint
- Enables mesoscale forecasting

Present forecast capability

- Mesoscale
- Order 200 km
- Consistent with observations

Mesoscale prediction is consistent across observations, models, assimilation


250_coamps_negom CARTHE4_Domain Depth: 0000 m
Vorticity/f - 2015 09 12 00 00
Surface vorticity / f
30°N
29°N
28°N
89°W
87°W
85°W
83°W
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0

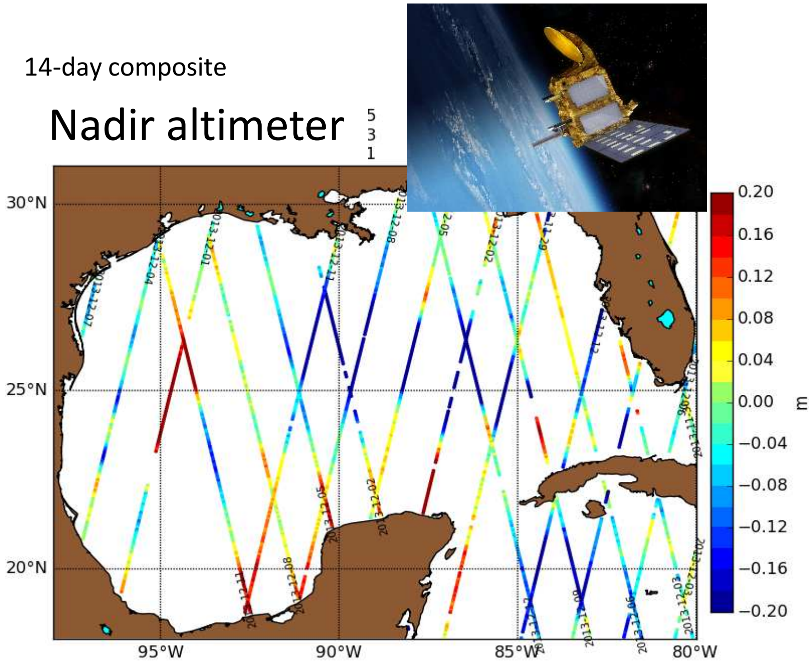

250_coamps_negom CARTHE4_Domain Depth: 0000 m
Divergence - 2015 09 12 00 00
Surface divergence
30°N
29°N
28°N
89°W
87°W
85°W
83°W
1e−5
3.0
2.4
1.8
1.2
0.6
0.0
−0.6
−1.2
−1.8
−2.4
−3.0

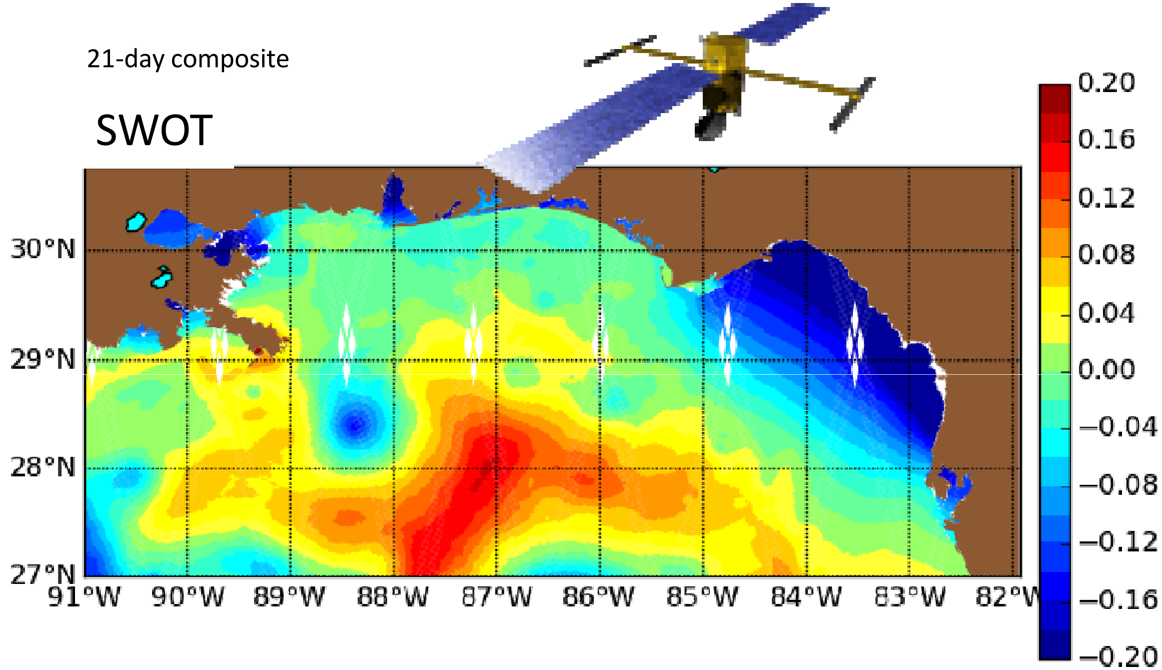
Technical Challenges

SWOT will extend to a new dynamical regime: the submesoscale

Submesoscale resolving model prediction skill has not been demonstrated

Using observations, correct of both mesoscale and submesoscale simultaneously





Present altimeter sea surface height

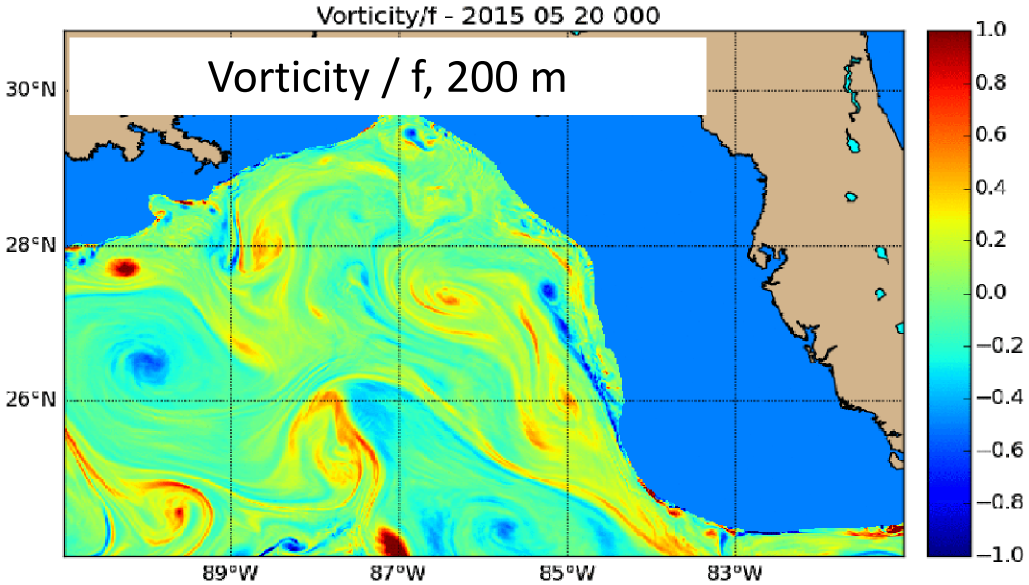
- Nadir point measurement
- 14 km average footprint
- Enables mesoscale forecasting

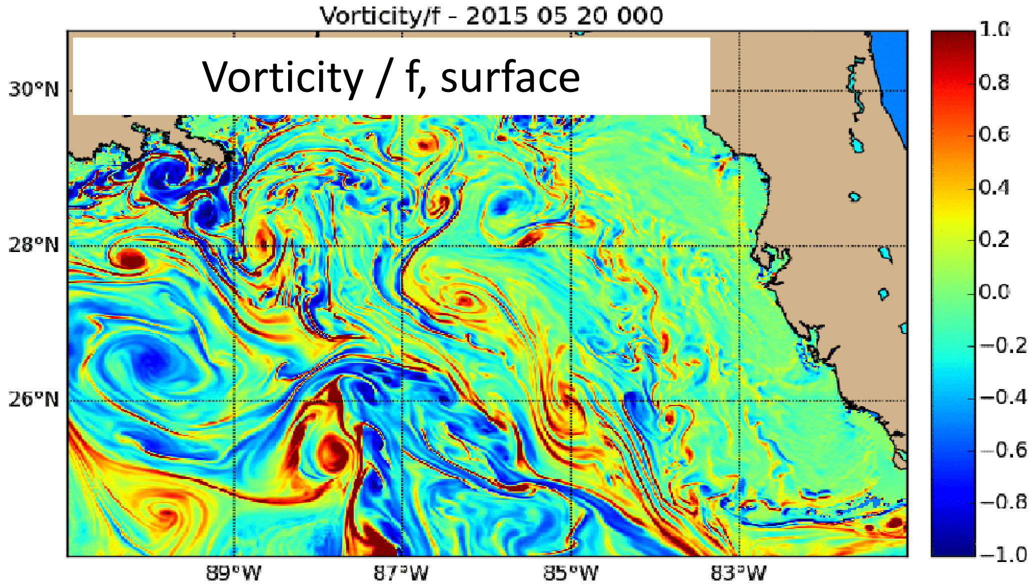
Future from SWOT

- Resolves submesoscale
- Noise not considered today

Challenge: Relating observations to submesoscale

What are the challenges moving prediction to submesoscale?





Mesoscale

- Available potential energy in vertical thermocline variations
- Geostrophically balanced
- Large scale (200 km)
- Large amplitude signal (10-40 cm RMS)
- Correcting models is relatively easy

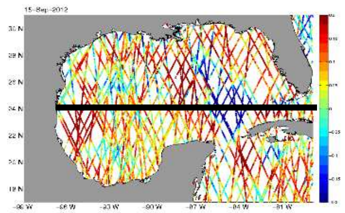
Submesoscale

- Available potential energy in mixed layer, lateral density variations
- First order geostrophically balanced, but ageostrophic dynamics (semi-geostrophic)
- Small scale (down to 10 km)
- Small amplitude
- We have no idea how to correct models

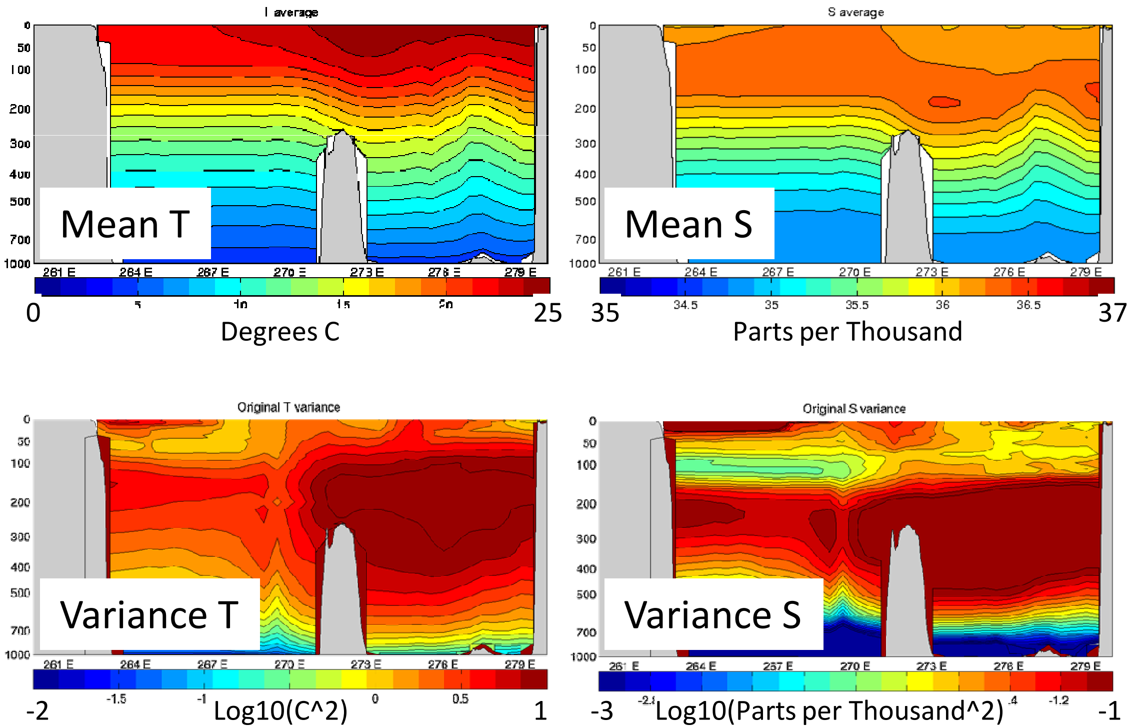
Dynamically, submesoscale is very different

Why is mesoscale relatively easy?

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



January 24° N



- Mesoscale energy is derived from baroclinic conversion of available potential to kinetic energy in the thermocline
- T&S structure in the thermocline is controlled by integration of global forcing (heat and momentum flux)
- Inertia is large
- Thermocline and halocline are not going to change dramatically
- Relations to thermocline T&S are not going to change dramatically
- Prediction systems can get away with terrible sins such as ignoring geostrophy and correcting only T&S

Mesoscale driven by energy conversion from potential to kinetic in the thermocline

Mesoscale relations

- Surface height anomaly
- Temperature (180 m)
- Salinity (180 m)

Mesoscale driven by energy conversion from potential to kinetic in the thermocline

Mesoscale relations

Impossible d'afficher l'image. Votre ordinateur manque peut-être de mémoire pour ouvrir l'image ou l'image est endommagée. Redémarrez l'ordinateur, puis ouvrez à nouveau le fichier. Si le x rouge est toujours affiché, vous devrez peut-être supprimer l'image avant de la réinsérer.

Peeling away the tidal, annual, semiannual layer of the onion

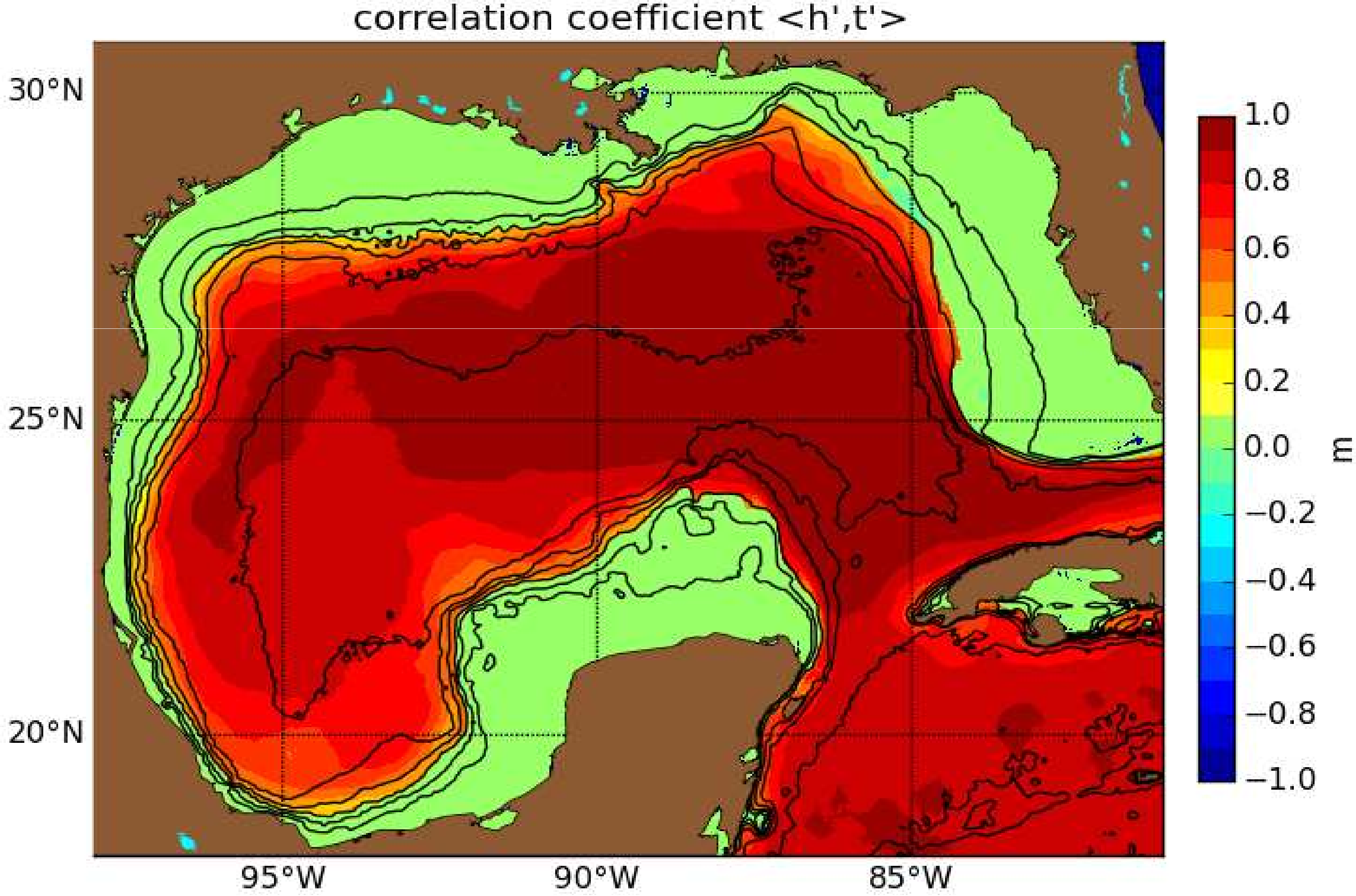
- Surface height anomaly
- Temperature (180 m)
- Salinity (180 m)

Mesoscale driven by energy conversion from potential to kinetic in the thermocline

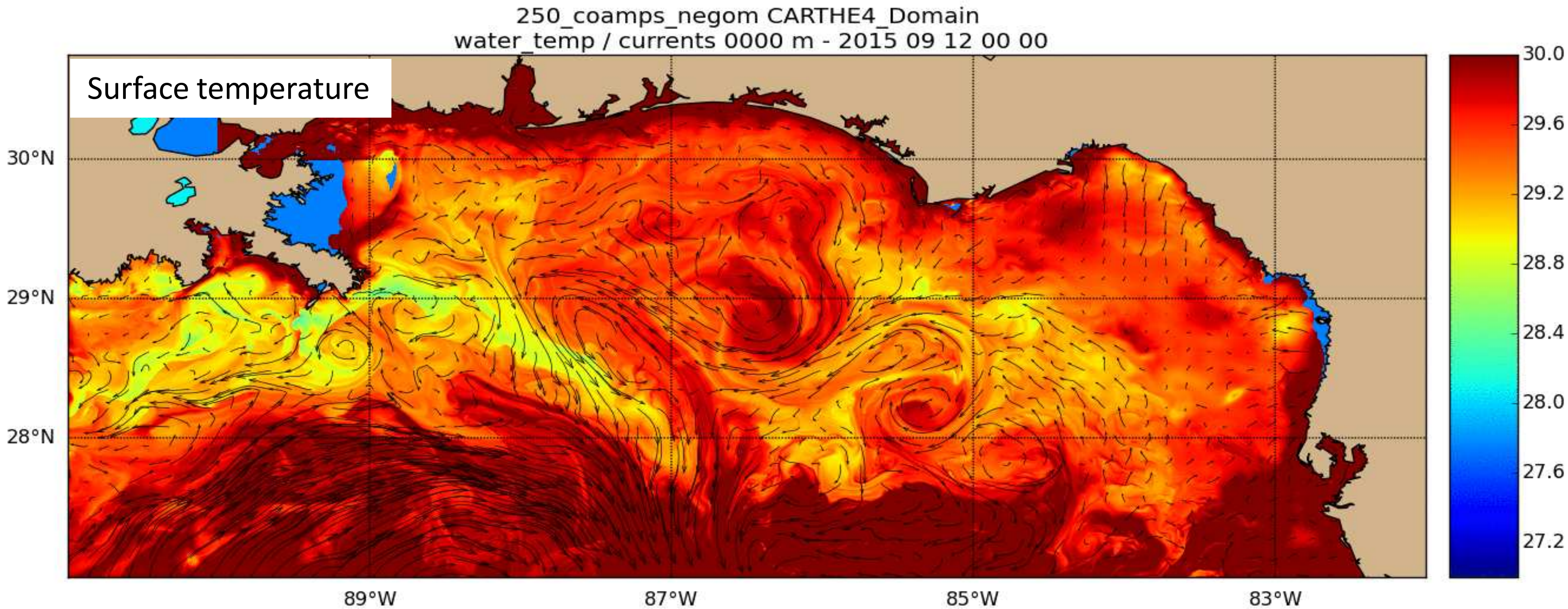
Why is mesoscale relatively easy?

Peeling away the tidal, annual, semiannual layer of the onion

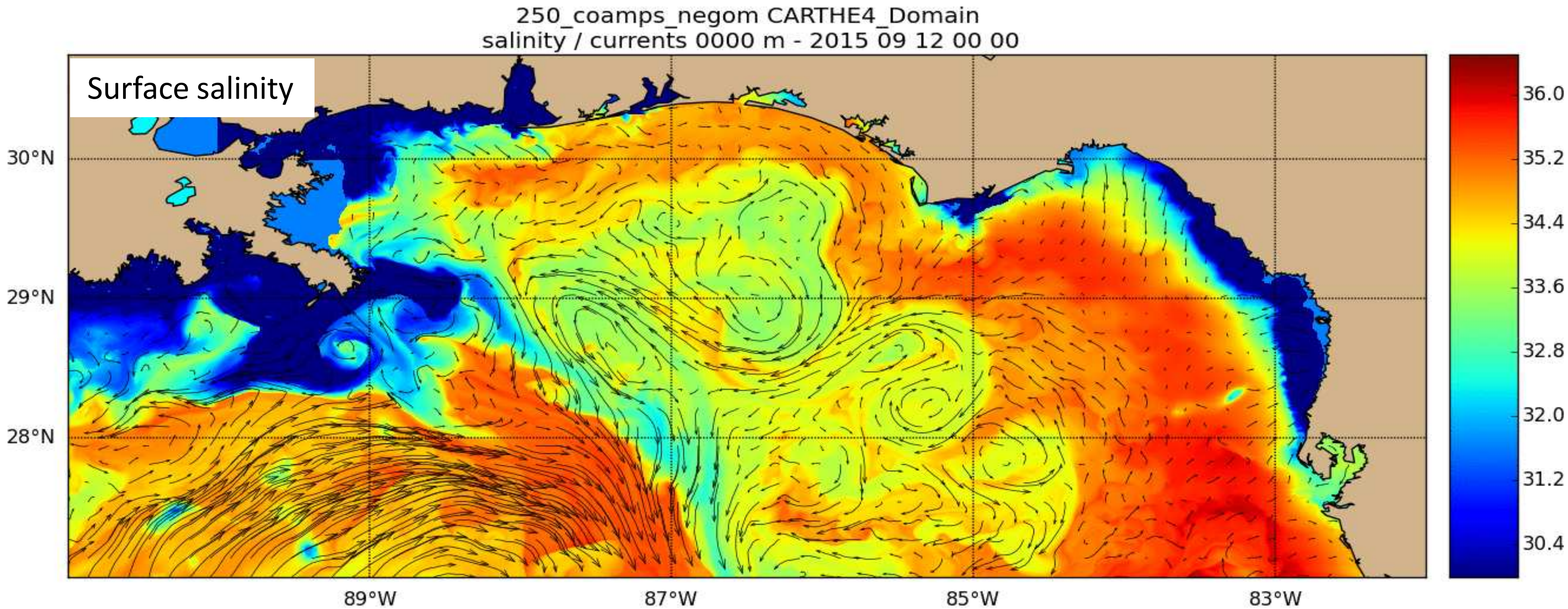
Example of 3-year model SSHA to T’ correlation at 180 m



Correlation between sea surface height and thermocline variations is relatively easy

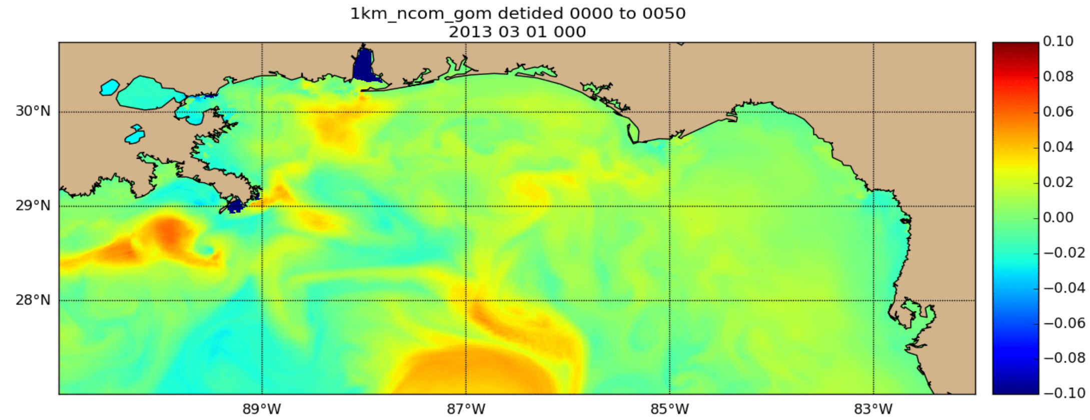


250_coamps_negom CARTHE4_Domain
water_temp / currents 0000 m - 2015 09 12 00 00
Surface temperature
30°N
29°N
28°N
89°W
87°W
85°W
83°W
30.0
29.6
29.2
28.8
28.4
28.0
27.6
27.2

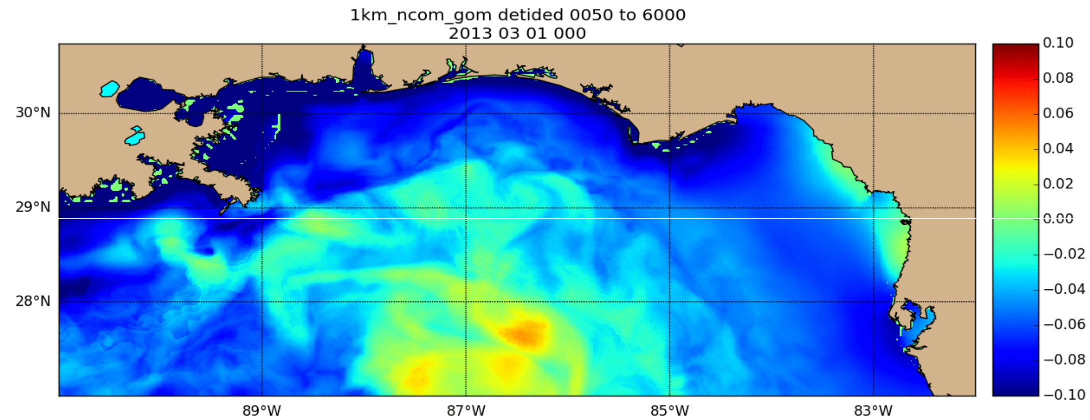


250_coamps_negom CARTHE4_Domain
salinity / currents 0000 m - 2015 09 12 00 00
Surface salinity
30°N
29°N
28°N
89°W
87°W
85°W
83°W
36.0
35.2
34.4
33.6
32.8
32.0
31.2
30.4

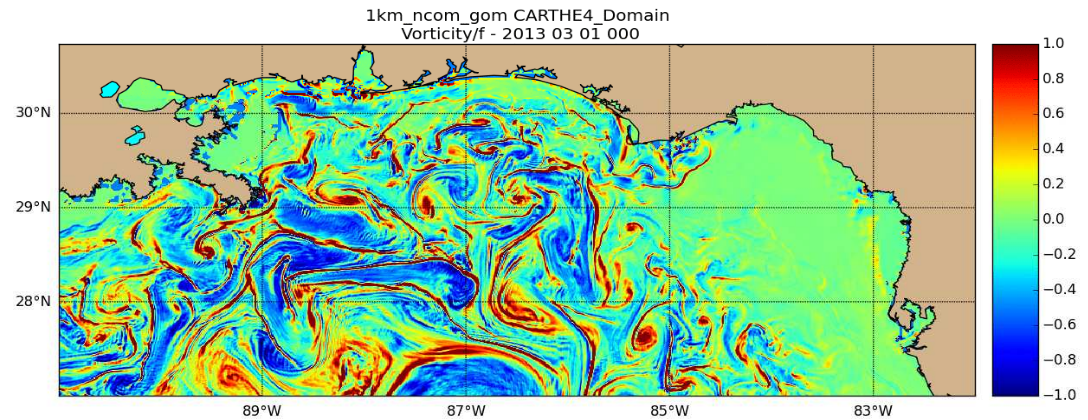
Peeling away the mesoscale layer of the onion



Steric height
Surface relative to 50 m
+/- 10 cm

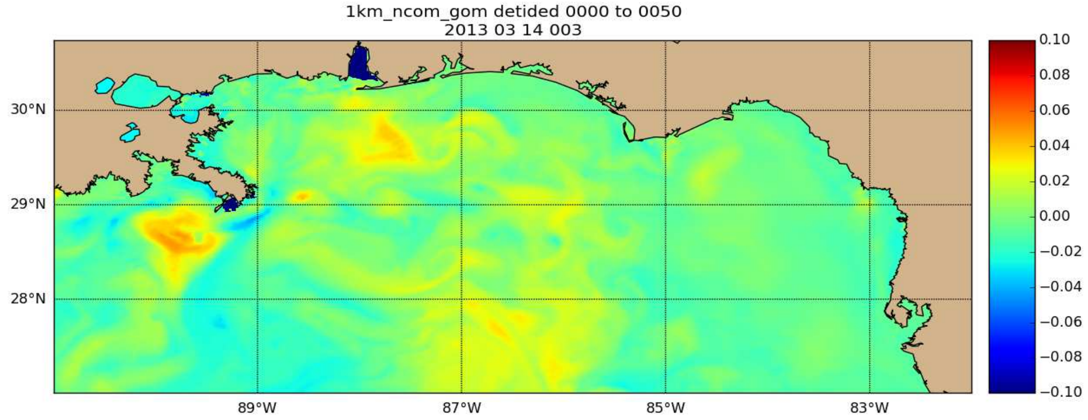


SSH – tides - Steric height
50 m relative to bottom
+/- 10 cm

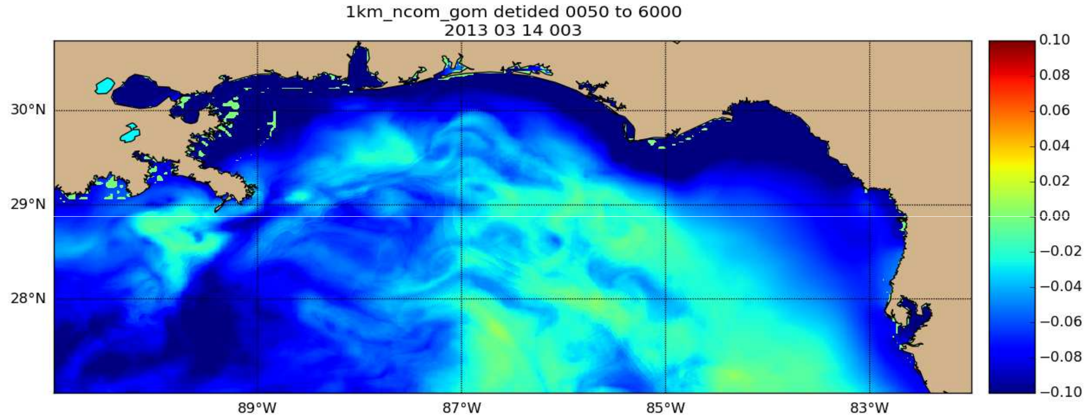


Vorticity / f

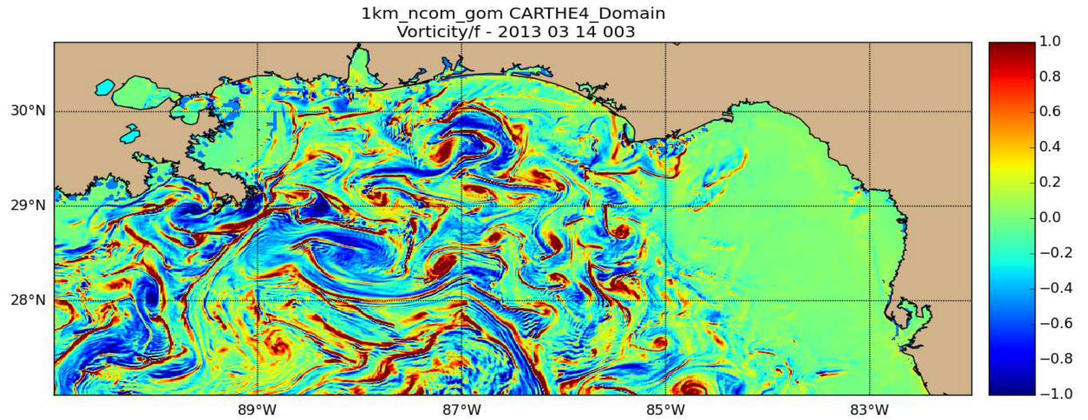
Peeling away the mesoscale layer of the onion



Steric height
Surface relative to 50 m
+/- 10 cm



SSH – tides - Steric height
50 m relative to bottom
+/- 10 cm

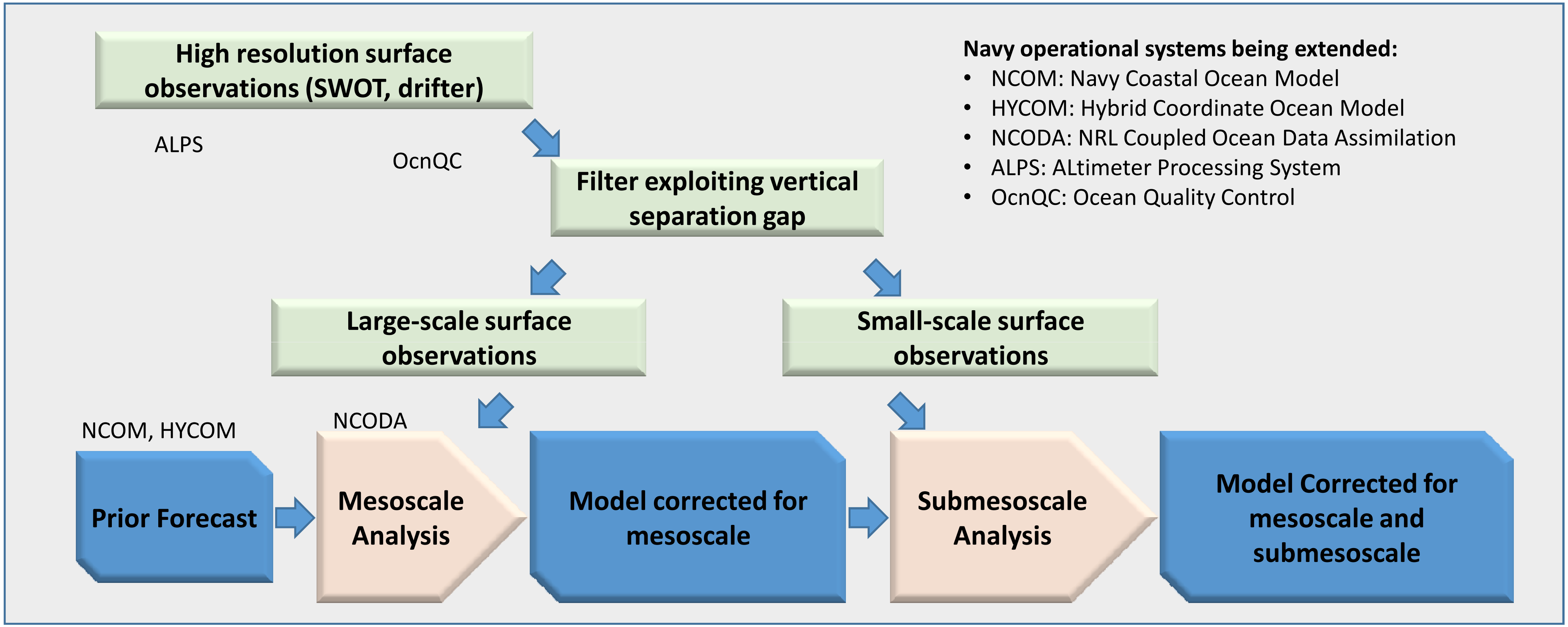


Vorticity / f

The mesoscale and submesoscale are becoming separable, but we are not there yet

Where is this headed?

Separate the analyses



Approach to a generalized solution, first the mesoscale

Mesoscale dynamical relations:

Dynamical relation	Physical source	Related variables
$\rho = \rho_o + \alpha(x,z)T + \beta(x,z)S$	**Equation of state**	**T&S to density**
$\nabla h(x)\nabla\zeta = \nabla\square\int_{h(x)}^{0}\int_{z}^{0}\nabla\rho(x,z')dz'dz$	**Integral continuity**	**Density to sea surface height**
$p = g\left[\rho_o\zeta(x) + \int_{z}^{0}\rho(x,z')dz'\right]$	**Hydrostatic pressure**	**Density and sea surface height to pressure**
$\vec{u} = \frac{1}{f(x)\rho_o}k \times \nabla p$	**Geostrophic velocity**	**Pressure to velocity**

These relations define a mesoscale dynamical operator mapping T&S to sea surface height and velocity

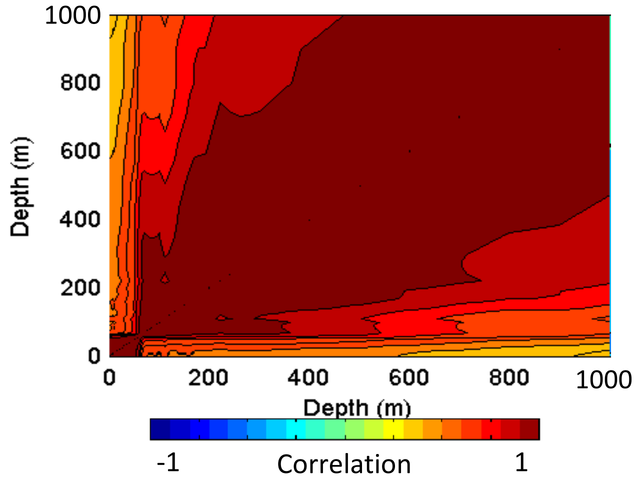
$$\begin{bmatrix}\zeta\\ \vec{u}\end{bmatrix} = \mathbf{L}_{\mathbf{M}}\begin{bmatrix}T\\ S\end{bmatrix}$$

If we know the temperature and salinity relations (e.g. from historical data), given as $\mathbf{B}$

The relations between all variables are simply

$$\left\langle \begin{bmatrix}T\\ S\\ \zeta\\ \vec{u}\end{bmatrix}\begin{bmatrix}T\\ S\\ \zeta\\ \vec{u}\end{bmatrix}^T \right\rangle = \begin{bmatrix}\mathbf{B} & \mathbf{B}\mathbf{L}_{\mathbf{M}}^{\mathbf{T}}\\ \mathbf{L}_{\mathbf{M}}\mathbf{B} & \mathbf{L}_{\mathbf{M}}\mathbf{B}\mathbf{L}_{\mathbf{M}}^{\mathbf{T}}\end{bmatrix}$$

Example of temperature autocorrelation built in NRL 6.2 Improved Synthetic Profile project



M. Yaremchuk, P. Martin, Implementation of a balance operator in NCOM, NRL Memorandum report submitted, 2015.

A generalized approach isolates the dynamical relations within the solution process

Approach to a generalized solution, submesoscale

Submesoscale dynamical relations:

Dynamical relation	Physical source	Related variables
$\rho = \rho_o + \alpha(x,z)T + \beta(x,z)S$	Equation of state	T&S to density
Total water depth $h(x)$ must reflect mixed layer extent	Integrated continuity	Density to sea surface height
$p = g\left[\rho_o \zeta(x) + \int_z^0 \rho(x,z')dz'\right]$	Hydrostatic pressure	Density and sea surface height to pressure
Ageostrophic balance defined by semi-geostrophic dynamics	Momentum equations	Pressure to velocity

These relations define a mesoscale dynamical operator mapping T&S to sea surface height and velocity

$$\begin{bmatrix} \zeta \\ \vec{u} \end{bmatrix} = \mathbf{L}_{\mathbf{SM}} \begin{bmatrix} T \\ S \end{bmatrix}$$

If we know the temperature and salinity relations (e.g. from model experiments), given as $\mathbf{B}_{\mathbf{SM}}$

Where we are presently working

The relations between all variables are simply

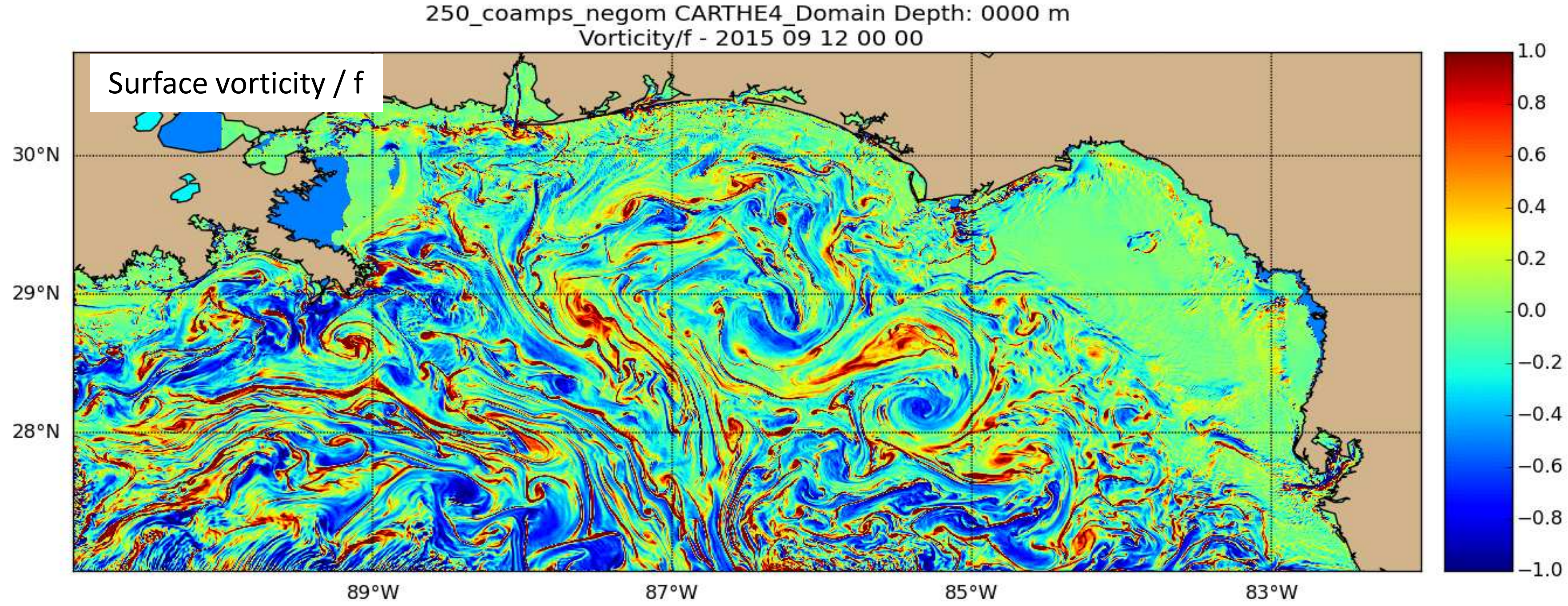
$$\left\langle \begin{bmatrix} T \\ S \\ \zeta \\ \vec{u} \end{bmatrix} \begin{bmatrix} T \\ S \\ \zeta \\ \vec{u} \end{bmatrix}^T \right\rangle = \begin{bmatrix} \mathbf{B}_{\mathbf{SM}} & \mathbf{B}_{\mathbf{SM}} \mathbf{L}_{\mathbf{SM}}^{\mathbf{T}} \\ \mathbf{L}_{\mathbf{SM}} \mathbf{B}_{\mathbf{SM}} & \mathbf{L}_{\mathbf{SM}} \mathbf{B}_{\mathbf{SM}} \mathbf{L}_{\mathbf{SM}}^{\mathbf{T}} \end{bmatrix}$$

The solution process for the submesoscale becomes the same as the mesoscale.

Only the dynamical relation changes.

M. Yaremchuk, P. Martin, Implementation of a balance operator in NCOM, NRL Memorandum report submitted, 2015.

A generalized approach isolates the dynamical relations within the solution process


250_coamps_negom CARTHE4_Domain Depth: 0000 m
Vorticity/f - 2015 09 12 00 00
Surface vorticity / f
30°N
29°N
28°N
89°W
87°W
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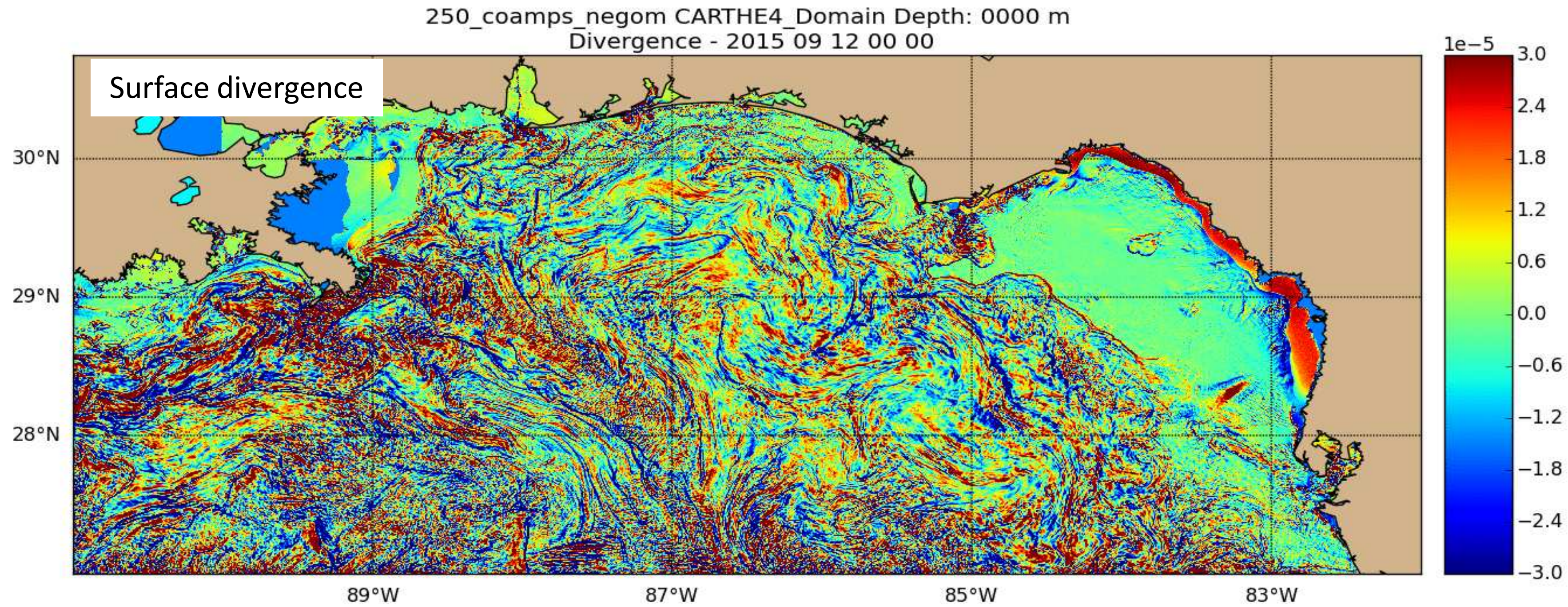
83°W
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0


250_coamps_negom CARTHE4_Domain Depth: 0000 m
Divergence - 2015 09 12 00 00
Surface divergence
30°N
29°N
28°N
89°W
87°W
85°W
83°W
1e−5
3.0
2.4
1.8
1.2
0.6
0.0
−0.6
−1.2
−1.8
−2.4
−3.0