



Gulf of Mexico Pilot Prediction Project and some preliminary global ensemble results

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Gulf of Mexico Pilot Prediction Project (PPP)

Funded by RPSEA (Research Partnership to Secure Energy for America)

“A non-profit multi-purpose composed to federal and state labs, academia, and private industry established to facilitate.... energy or other derivative products from ultra-deepwater and unconventional natural gas and other petroleum resources”

Overall Goal:

Implement the capability to provide a long-range forecast (60 days) and the uncertainty about that forecast in an operational environment.

Major Tasks:

- 1: Control Run setup for long range forecasting
- 2: Ensemble configuration for long range forecasting
- 3: Calibration/bias-corrections via Bayesian Analysis
- 4: Construction of Joint PDF's and Maximum Likelihood Estimates (MLE's)
- 5: System validation (intercomparisons, relative skill, risk assessment, etc.)
- 6: Operational Implementation/Prototype Demonstration
(Naval Oceanographic Office)



RELO NCOM/NCODA

NCODA - NRL Coupled Ocean Data Assimilation - Cummings, QJRMS, 2005

NCOM - Navy Coastal Ocean Model – Barron, et al., Ocean Modeling, 2006

COAMPS - Coastal Ocean Atmosphere Mesoscale Prediction System

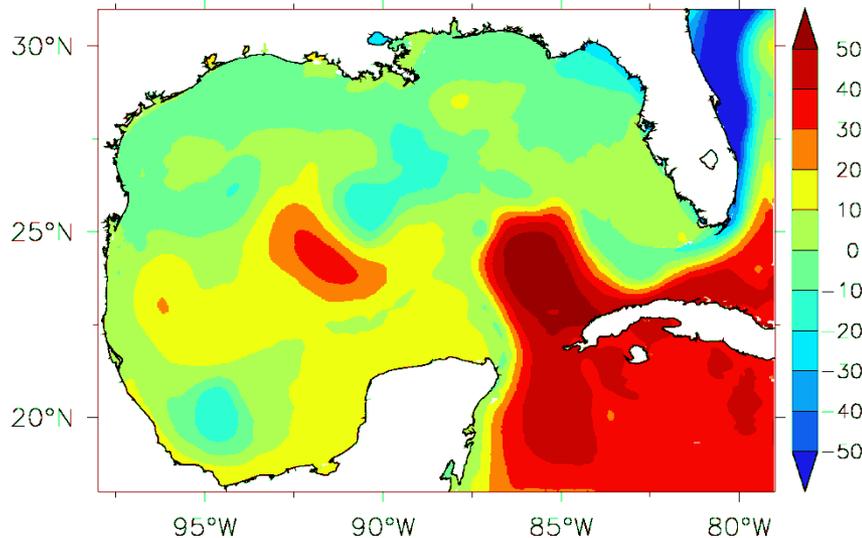
- **3km grid / 49 levels (33 sigma, 16 z)**
- **NRL DBDB2' bathymetry**
- **COAMPS 27km forcing**
- **Lateral BCs by G-HYCOM (GOFs 3.0)**
- **OSU OTIS tides at boundaries**
- **Assimilates data from any source available in real-time**
 - **Satellites (SST, SSH)**
 - ***In situ* obs (XBTs, CTDs, floats, buoys gliders, ships)**
- **3D Forecasts to 72 hours/60 days**
 - **T, S, currents, elevation**

Task 1: Running two “control runs”



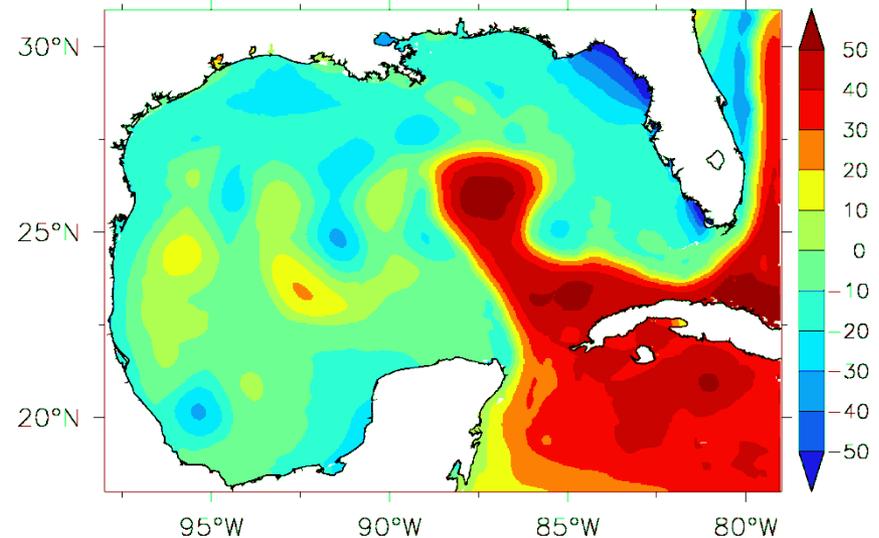
Sea Surface Height

SSH at t=000, 8-Jan-2013



Analysis valid on 8 Jan. 2013

SSH at t=60-day fcst, 9-Mar-2013



60 day (Mar. 9) forecast from 8 Jan. Analysis

Control run no. 1: Produces a 3 day forecast once per day
(assimilate local profile observations only, 24 hr window)

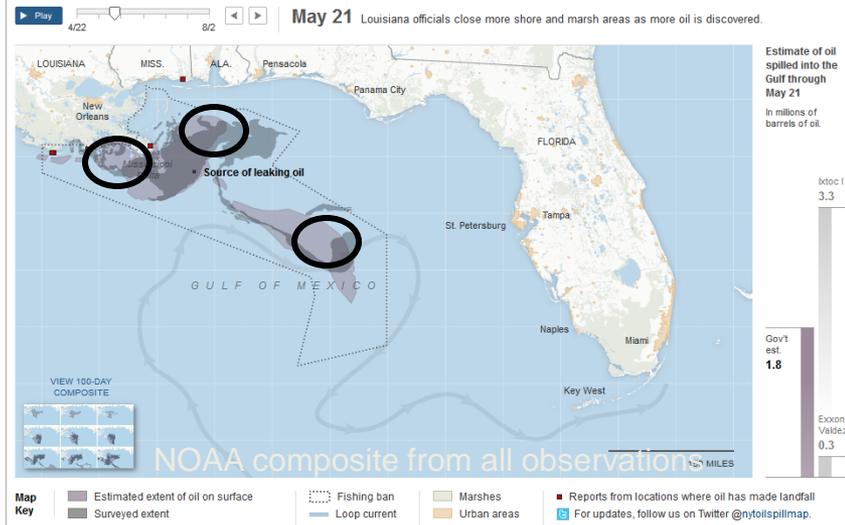
Control run no. 2: Produces a 60 day forecast once per week
(assimilate synthetic and observed profiles, 7 day window)

Note: 60 day forecasts required the construction “high-frequency” climatological forcing files (more realistic spatial and temporal variability than persistence or seasonal/annual climatology)

e.g. 2003-2012; 10 records for Jan 1 000z, 003z, 006z... - Dec. 31 021z

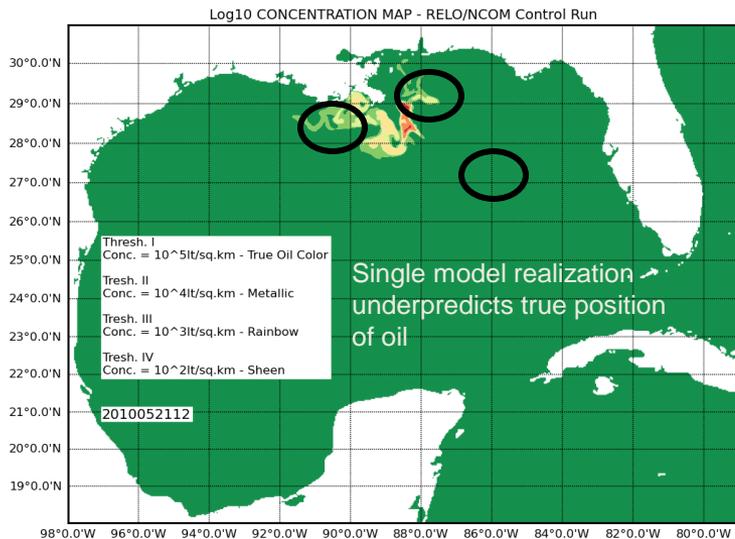
Oil Map integrating NOAA calibrated estimates and actual observations

Why Ensembles?

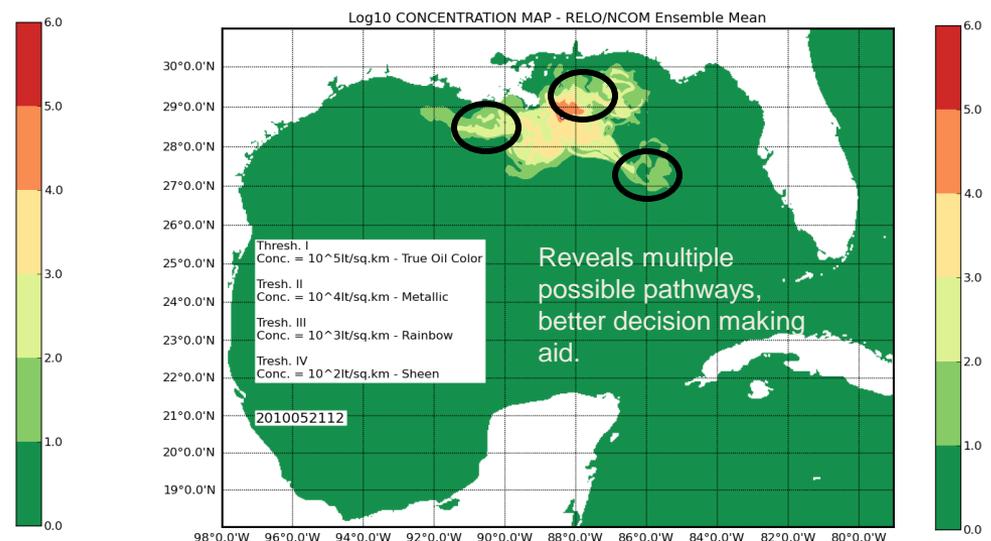


- Deterministic forecast only captures one possible trajectory and will likely diverge from reality esp. for extended range forecasts
- Done properly, ensemble will include the true state
- Ensemble provides the forecast error/uncertainty
- Ensembles can be calibrated to refine the forecast

May 21, 2010 Control Run



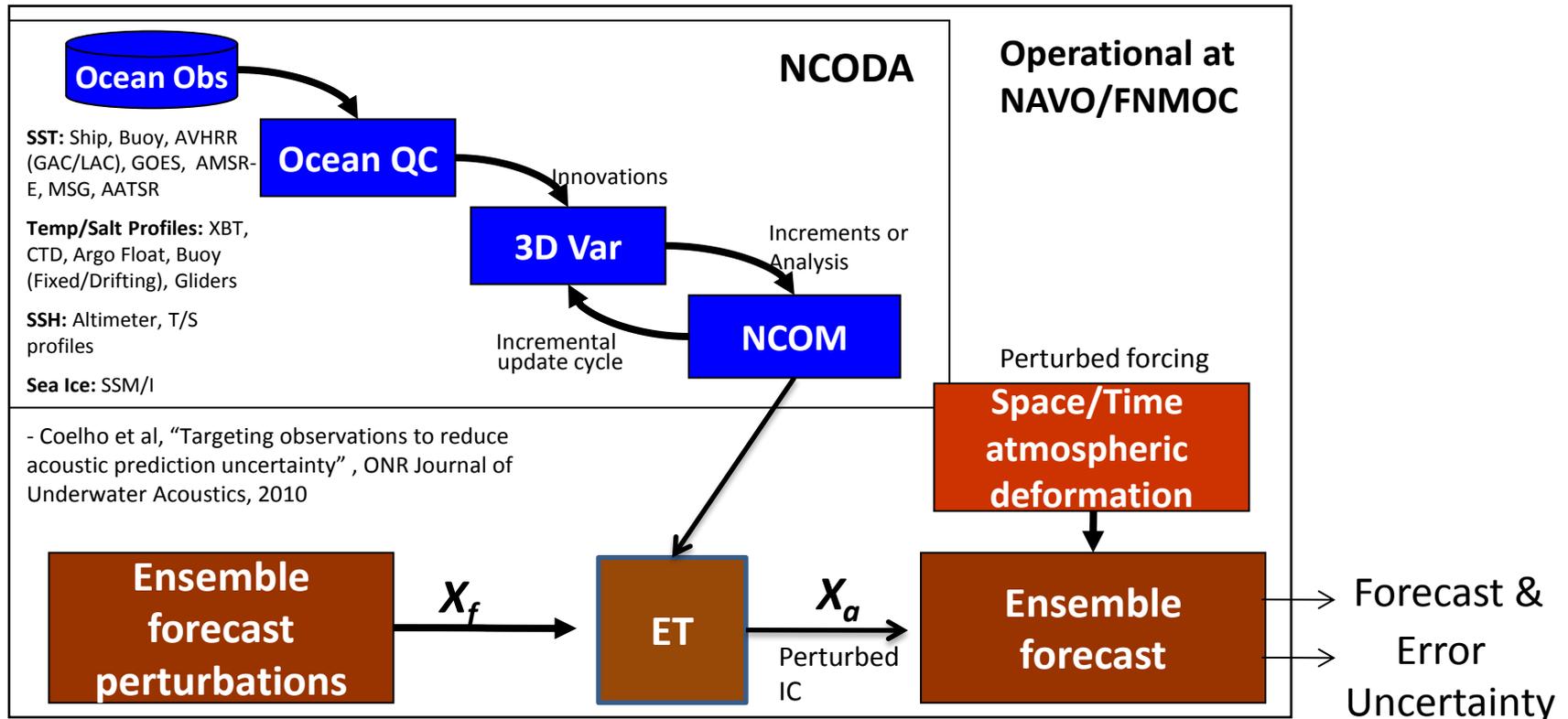
May 21, 2010 Ensemble Mean



Color bar is concentration and is correlated to thresholds from BONN agreement for oil appearance code



Ensemble Approach to Quantifying Ocean Uncertainty



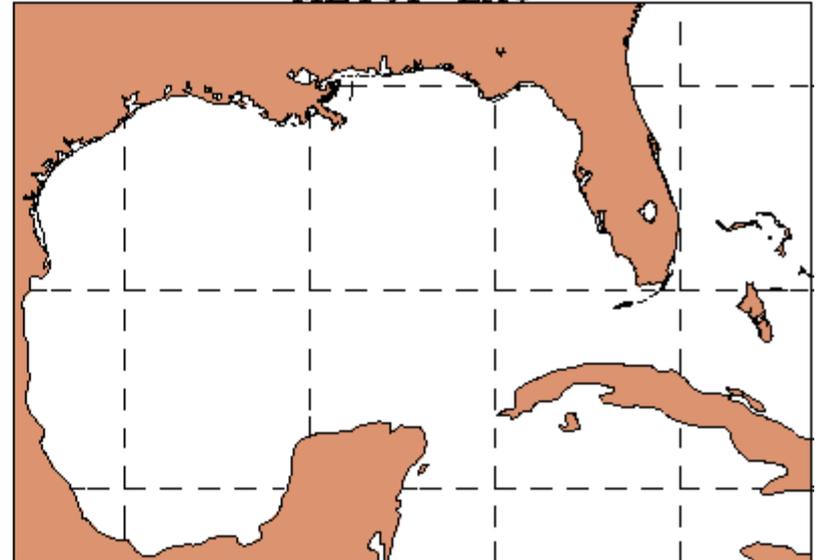
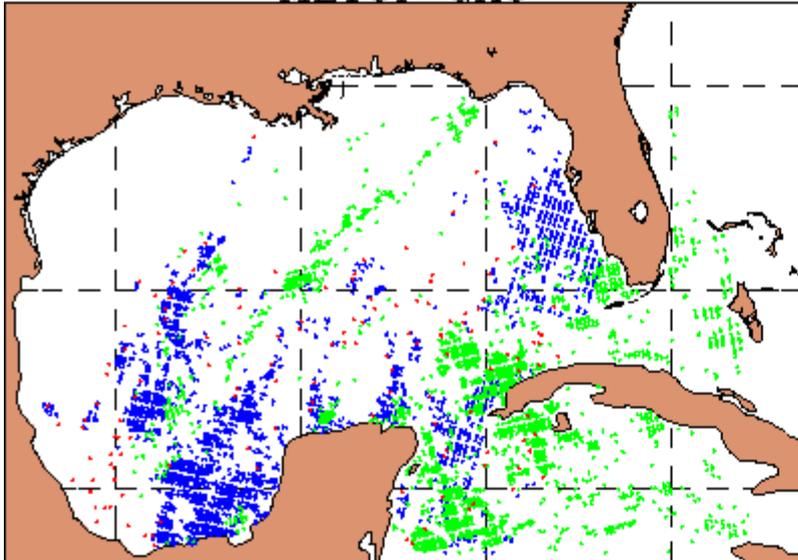
Ensemble Transform (ET) – Bishop and Tooth (1999)

The spread and growth of the Initial Condition (the perturbations) is determined by the forecast error variance via the Ensemble Transform

Analysis error estimate – standard dev. of the ensemble set

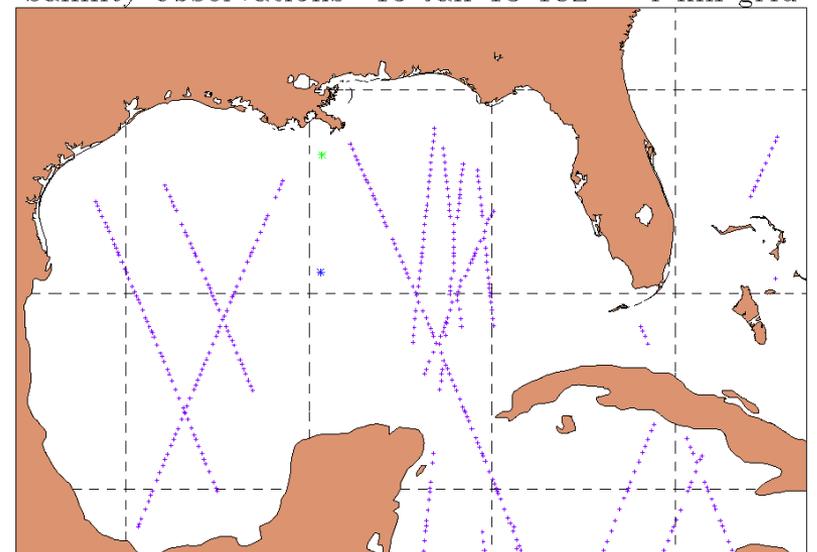
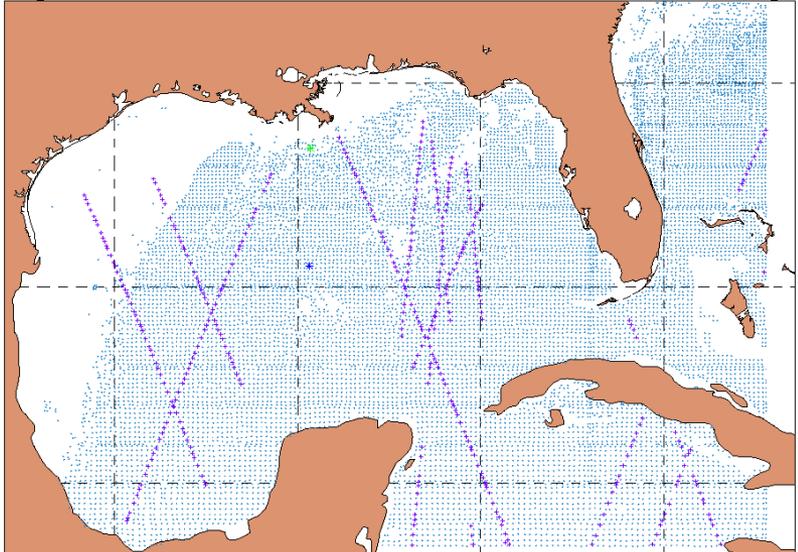
Uncertainty – described through the PD of state parameters through the ensemble

SST Observations 15 Jan 13 18Z 4 km grid
 METOP GAC METOP LAC



Temperature Observations 15 Jan 13 18Z 4 km grid

Salinity Observations 15 Jan 13 18Z 4 km grid

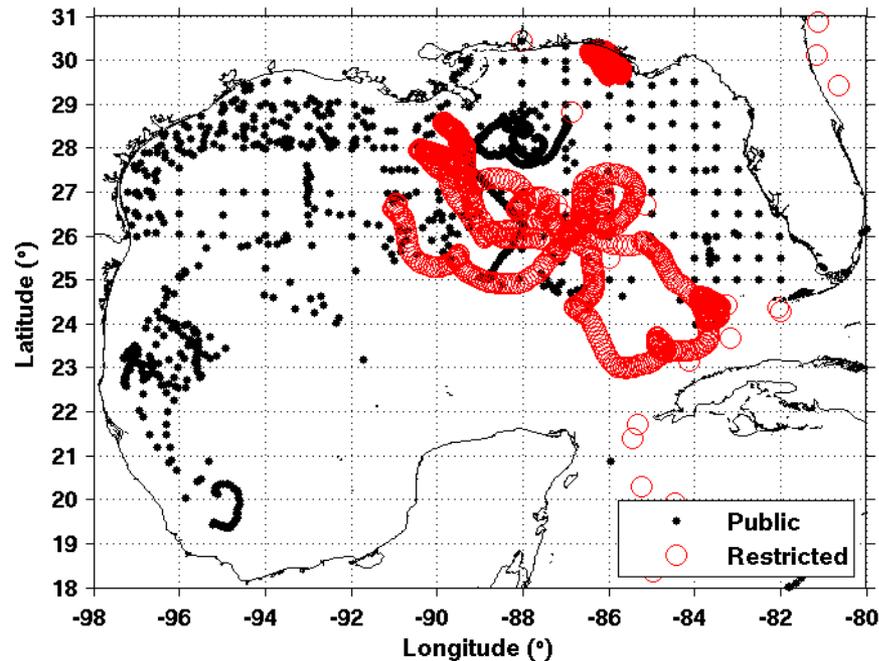


SIO Gliders in the GoM (D. Rednick, B. Cornuelle)

Gulf of Mexico Subsurface Observations, 20130101-20130725

No. of Multi-level Public Profiles = 5240

No. of Multi-level Restricted Profiles = 16694

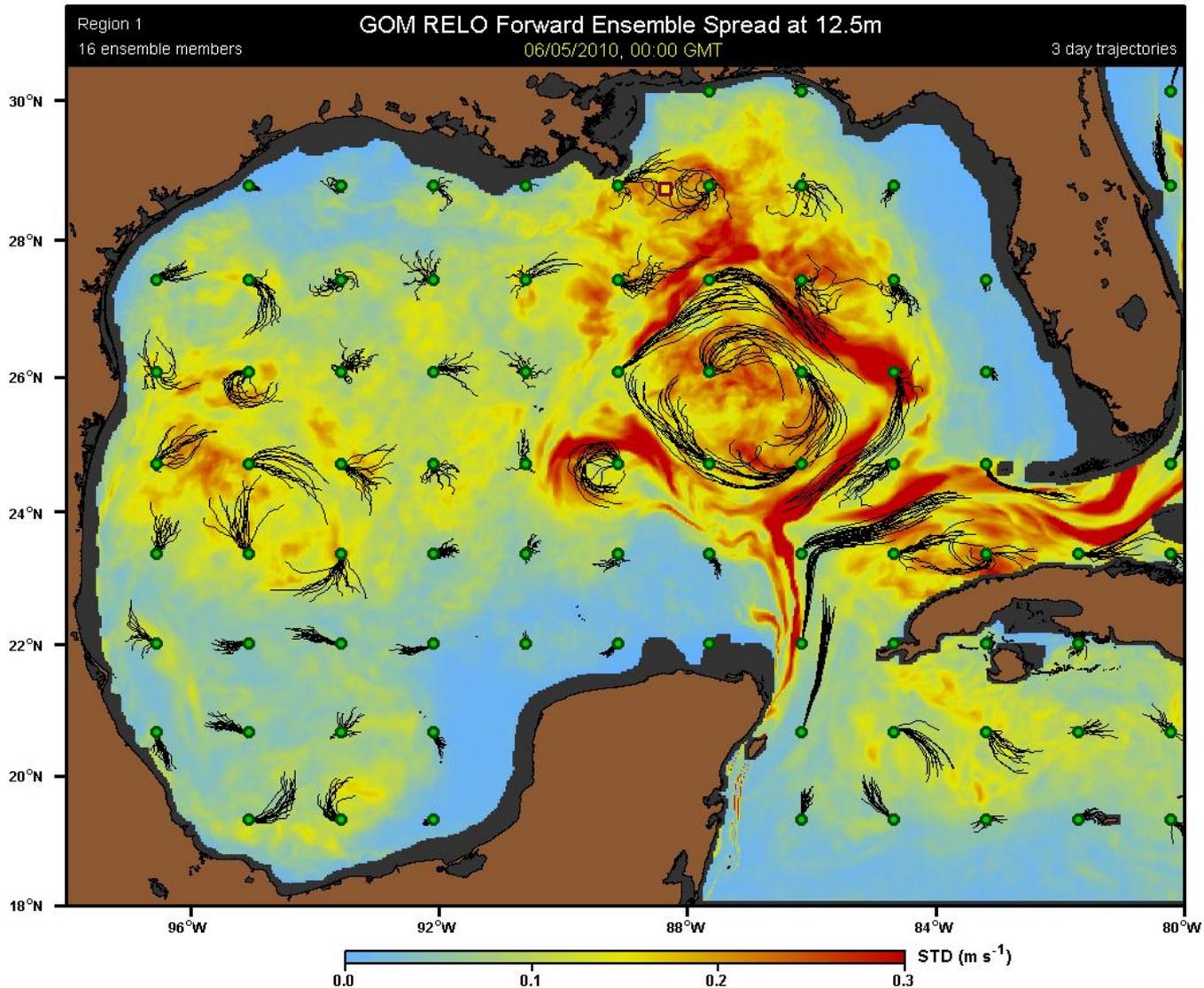


SP040 -- 01 Jan to 15 Jan

SP045 -- 15 Jan to 16 May

Sp050 -- 16 May to 25 July (continuing)

Ensemble Trajectory Forecasting



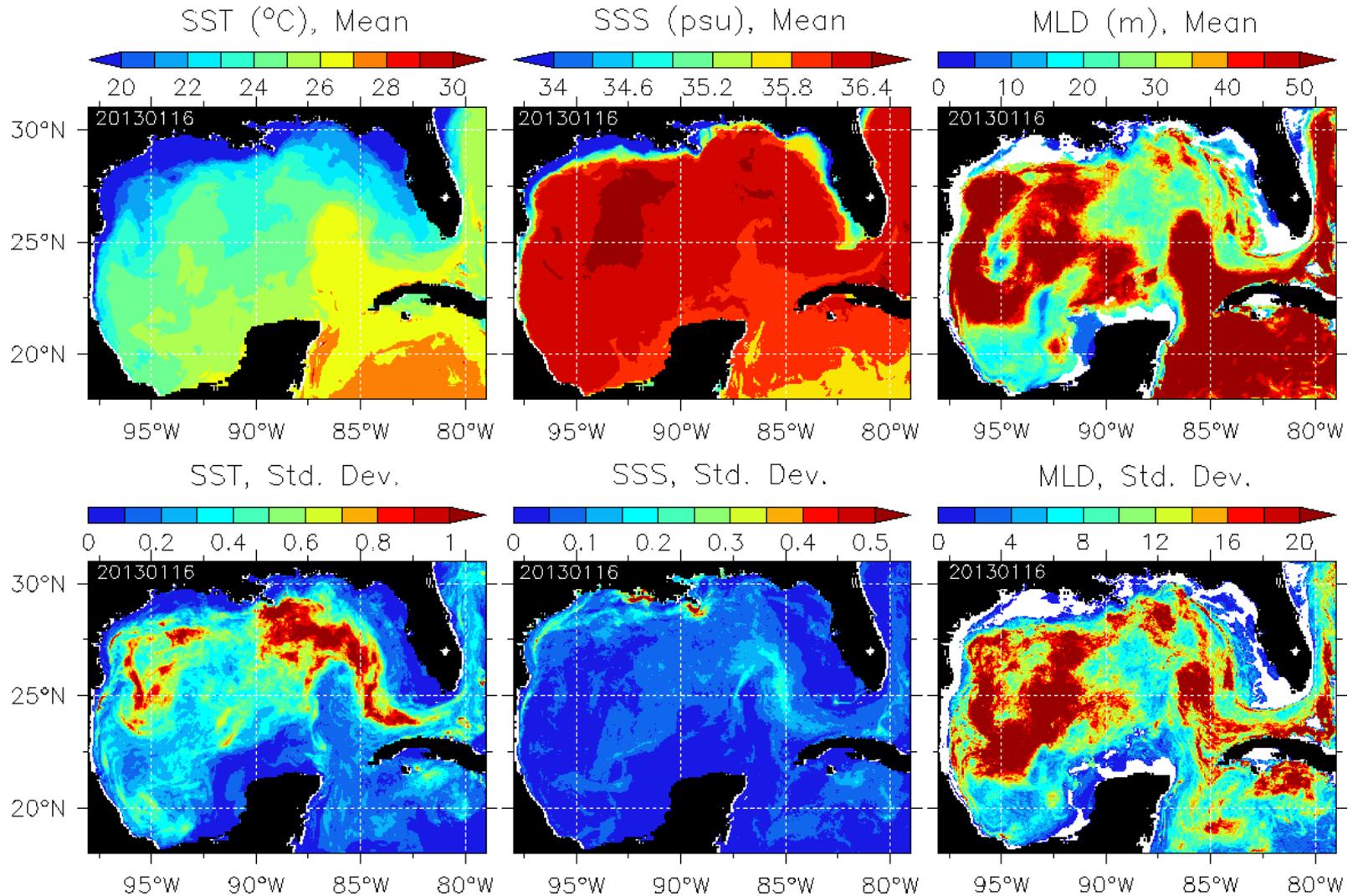
Color background is (endpoint spread/trajectory time interval) in cm/s

Courtesy: B. Lipphardt, U. Delaware



Ensemble Fields for 16 Jan. 2013 (the analysis)

Calculated over 32 ensemble members





Ensemble Forecasting Concept of Operations (CONOPS)

24 hour forecasts are run daily,
8-week forecasts are run every weekly (Sunday)

To Date:

- Jan. 27 – Mar. 24
- Feb. 03 – Mar. 31
- Feb. 10 – Apr. 07
- Feb. 17 – Apr. 14
- Feb. 24 – April 21
- Mar. 03 – Apr. 28
- Mar. 10 – May 05
- Mar. 17 – May 12
- Mar. 24 – May 19
- Mar. 31 – May 26
- Apr. 07 – Jun. 02
- Apr. 14 – Jun. 09
- Apr. 21 – Jun. 16
- Apr. 28 – Jun. 23
- May 05 – June 30

- *Currently running on NRL Linux Cluster*
- *32 ensemble members*
- *Daily run: 96 CPUs, ~ 2 hours*
- *Weekly run: 120 CPUs for 5 members, ~3.5 hours (32 members takes ~21 hours)*
- *Each member ~4.2 GB in netCDF format (~135 GB for 60-day 32 member ensemble once per day)*
- *Will eventually run at Naval Oceanographic Office (but stringent transition process and CONOPS)*

..... -

Forecast

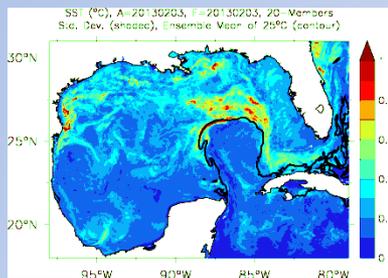
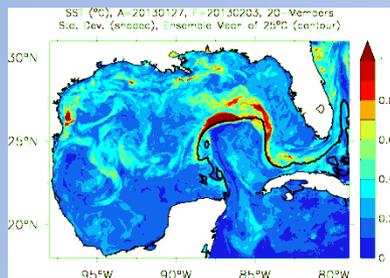
Analysis

Forecast

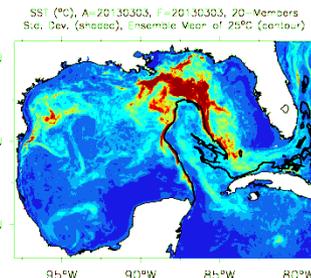
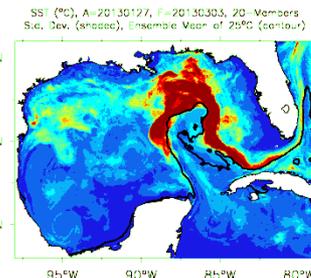
Analysis

Corresponding Analysis

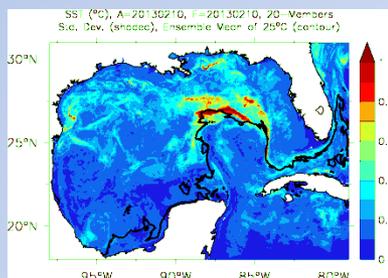
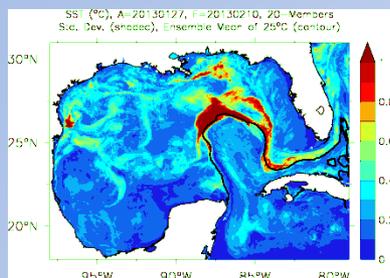
Feb. 03
1 wk.



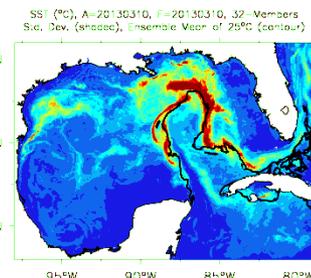
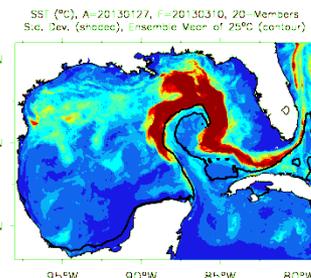
Mar. 03
5 wk.



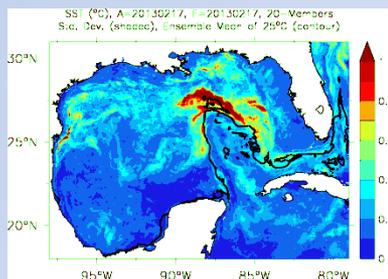
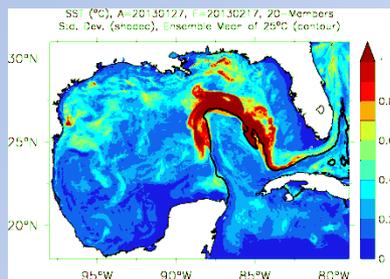
Feb. 10
2 wk.



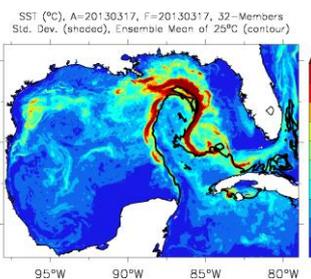
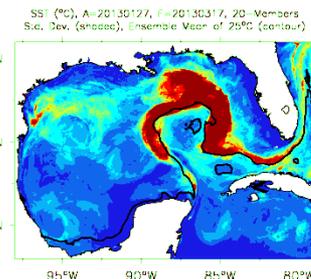
Mar. 10
6 wk.



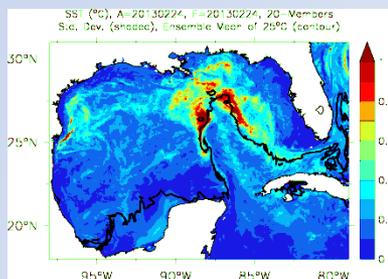
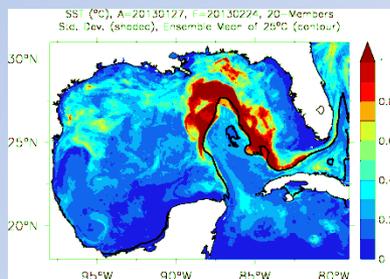
Feb. 17
3 wk.



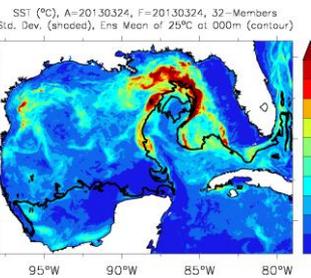
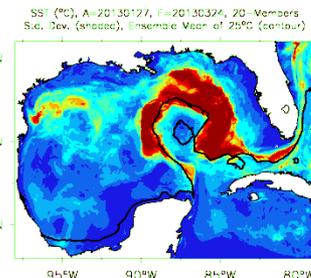
Mar. 17
7 wk.



Feb. 24
4 wk.

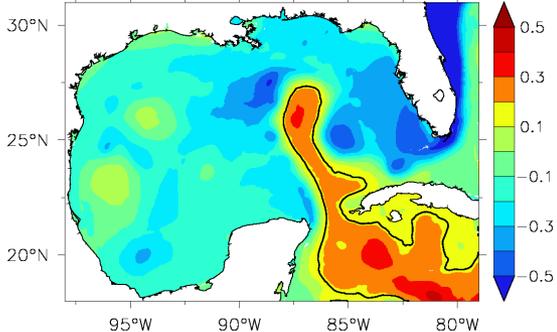


Mar. 24
8 wk.

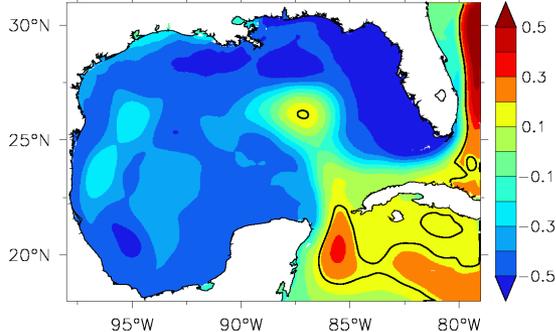


GoM Ensemble Modeling March 17 Analysis and 60-day forecast (12 May 2013)

SSH (m), A=20130317, F=20130317, 32-Members
0.17m at 000-m (contour), Ens Mean, Mean (shaded)

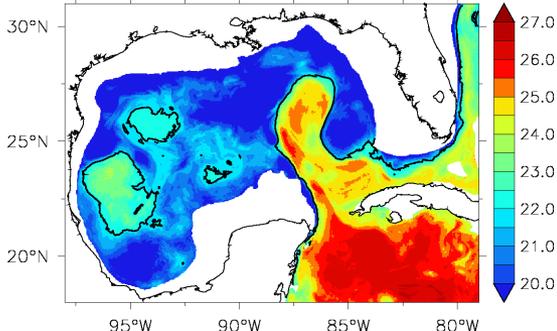


SSH (m), A=20130317, F=20130512, 32-Members
0.17m at 000-m (contour), Ens Mean, Mean (shaded)

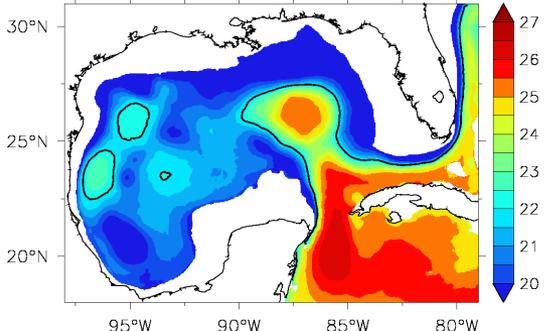


Ensemble mean 17 cm SSH

Temperature (°C), A=20130317, F=20130317, 32-Members
22°C at 100-m (contour), Ens Mean, Mean (shaded)

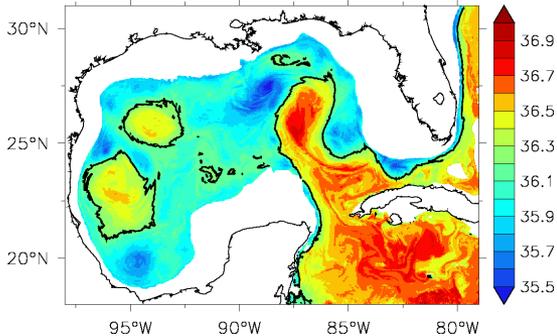


Temperature (°C), A=20130317, F=20130512, 32-Members
22°C at 100-m (contour), Ens Mean, Mean (shaded)

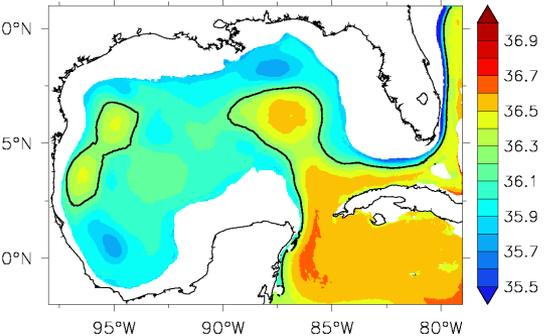


Ensemble mean temp (22C @ 100m)

Salinity (psu), A=20130317, F=20130317, 32-Members
36.2psu at 200-m (contour), Ens Mean, Mean (shaded)

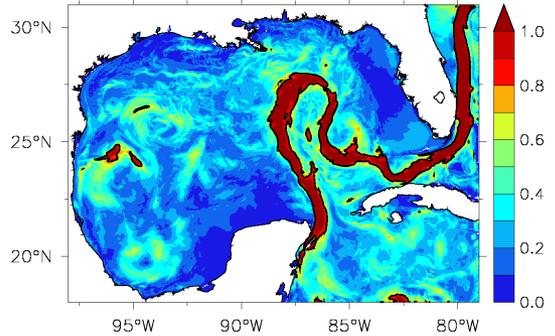


Salinity (psu), A=20130317, F=20130512, 32-Members
36.2psu at 200-m (contour), Ens Mean, Mean (shaded)

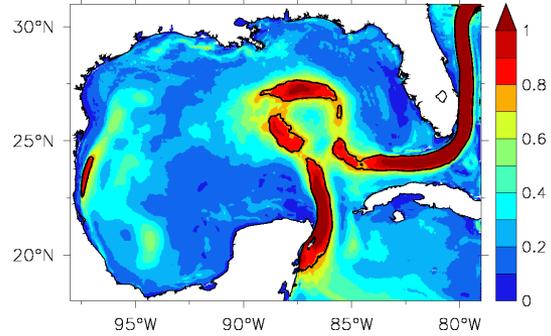


Ensemble mean salt (36.2 @ 200m)

Speed (m s⁻¹), A=20130317, F=20130317, 32-Members
0.77m s⁻¹ at 000-m (contour), Ens Mean, Mean (shaded)



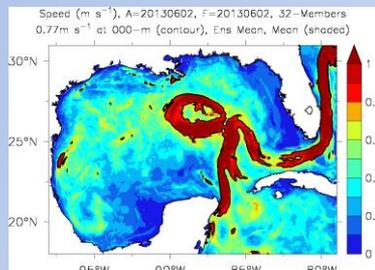
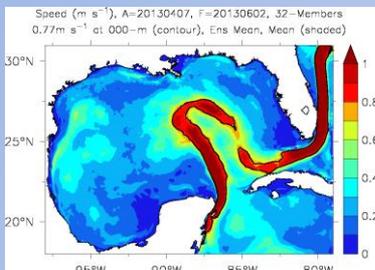
Speed (m s⁻¹), A=20130317, F=20130512, 32-Members
0.77m s⁻¹ at 000-m (contour), Ens Mean, Mean (shaded)



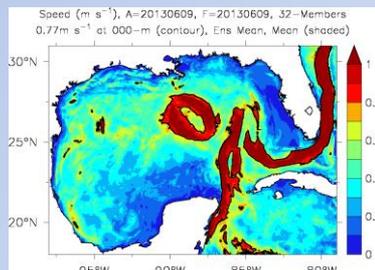
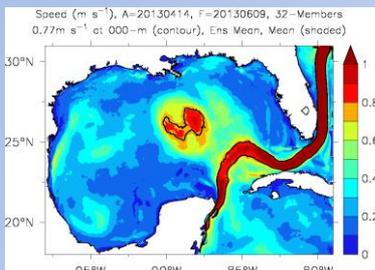
**Ensemble mean Speed
(1.5 kt isotach)**

Two Month Forecast and Corresponding (best) Analysis

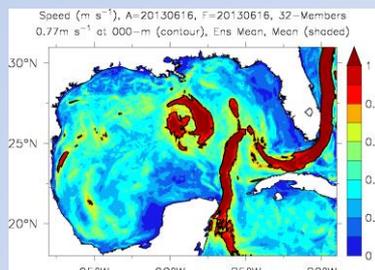
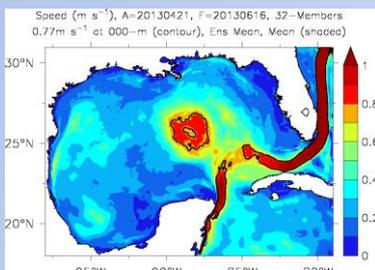
June 02



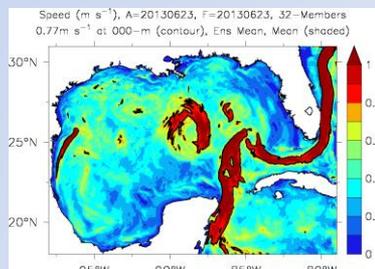
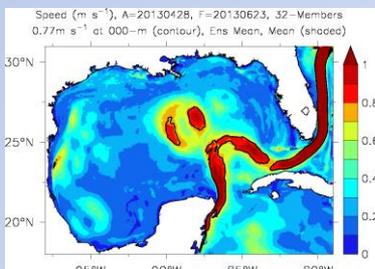
June 09



June 16



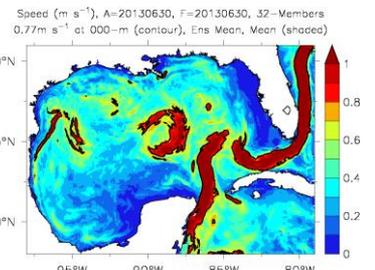
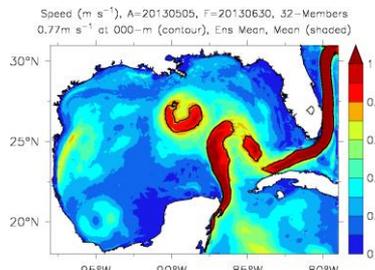
June 23



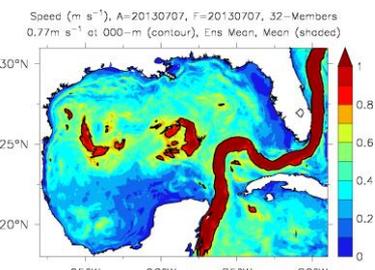
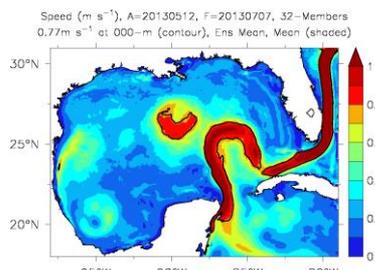
FORECAST

ANALYSIS

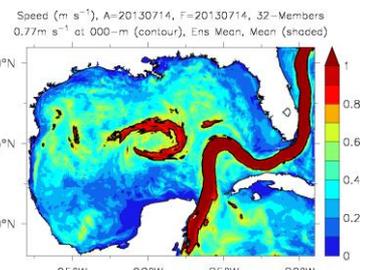
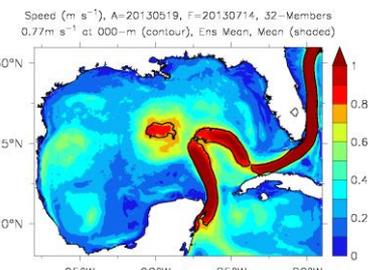
June 30



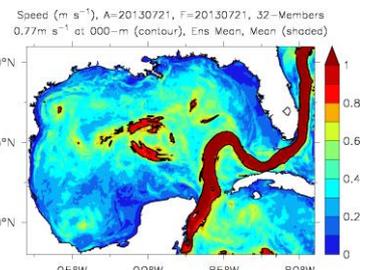
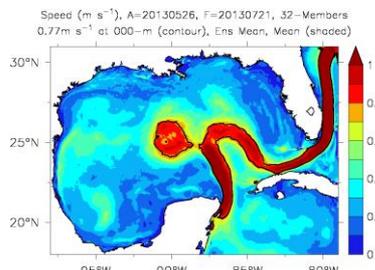
July 07



July 14



July 21



FORECAST

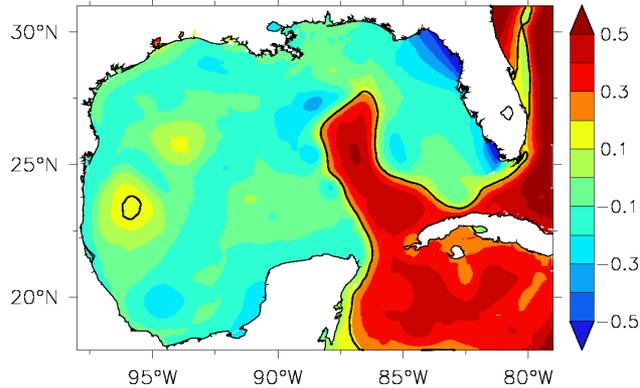
ANALYSIS



8-Week Ensemble Forecast

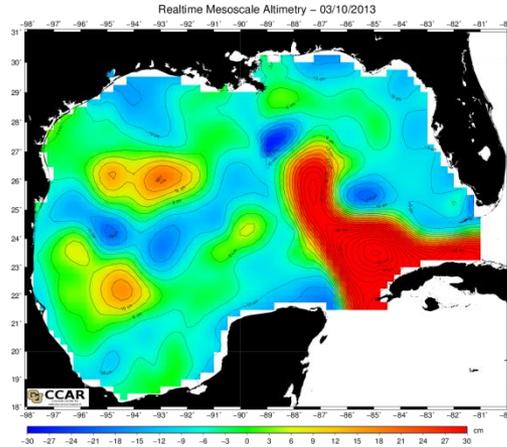
Analysis: March 10

SSH (m), A=20130310, F=20130310, 32-Members
0.17m at 000-m (contour), Ens Mean, Mean (shaded)



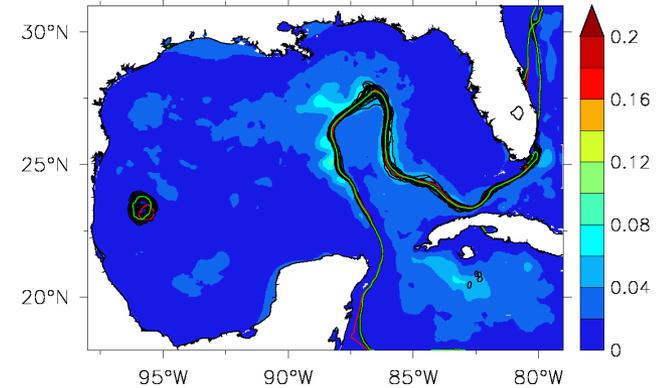
Mean (17 cm) SSH

Altimetry: March 10



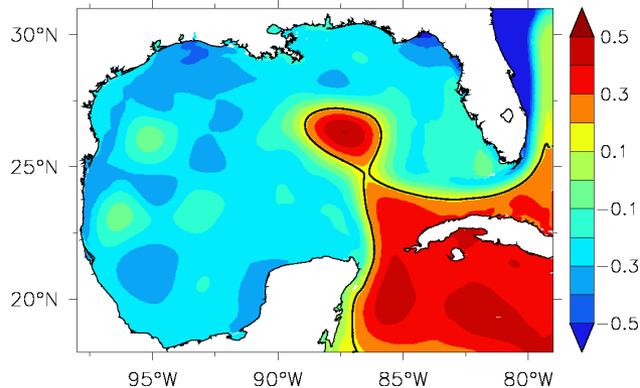
Analysis: March 10

SSH (m), A=20130310, F=20130310, 32-Members
0.17m at 000-m (contour), Control, Ens Mean, Std. Dev. (shaded)

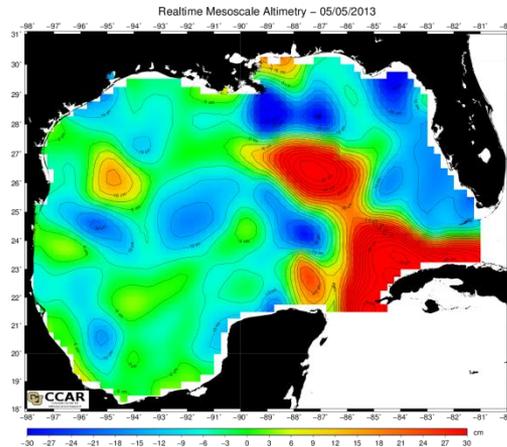


Std. Dev. (17 cm) SSH

SSH (m), A=20130310, F=20130505, 32-Members
0.17m at 000-m (contour), Ens Mean, Mean (shaded)

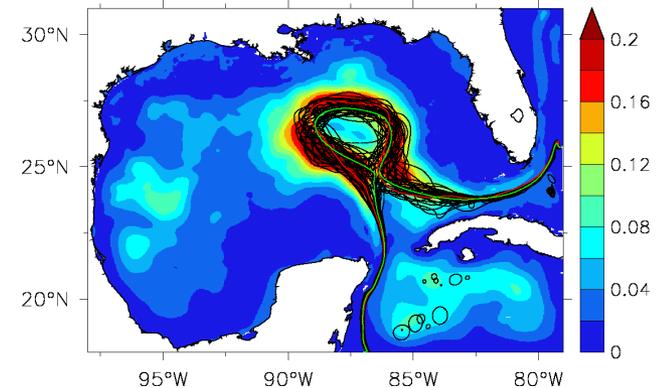


Forecast: May 05



Altimetry: May 05

SSH (m), A=20130310, F=20130505, 32-Members
0.17m at 000-m (contour), Control, Ens Mean, Std. Dev. (shaded)



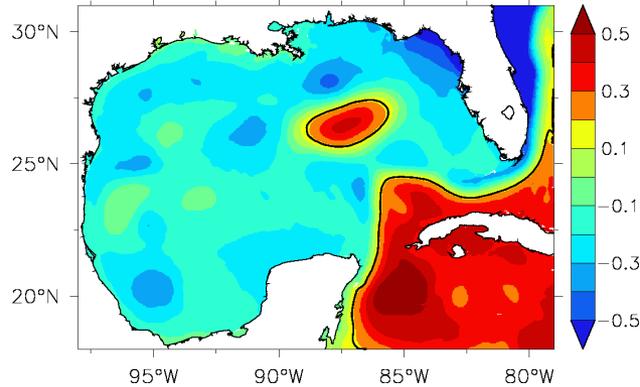
Forecast: May 05



8-Week Ensemble Forecast

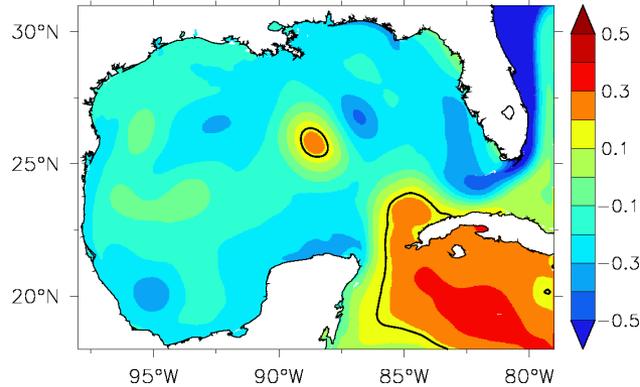
Analysis: April 21

SSH (m), A=20130421, F=20130421, 32-Members
0.17m at 000-m (contour), Ens Mean, Meqn (shaded)



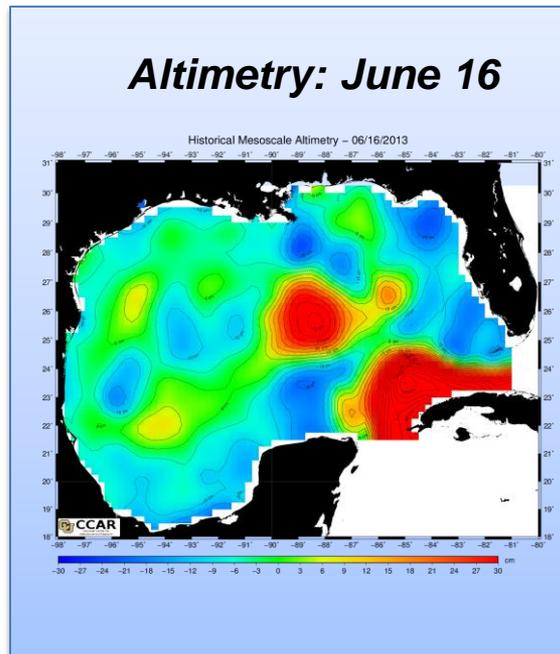
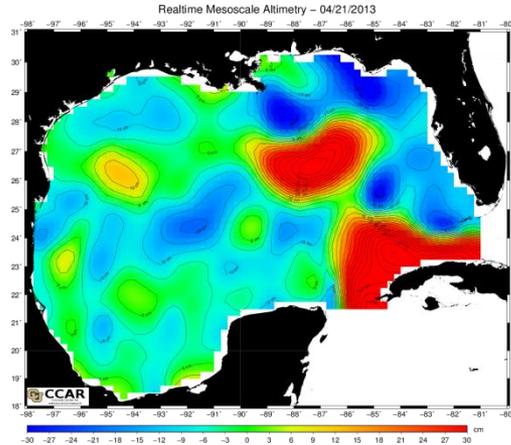
Mean (17 cm) SSH

SSH (m), A=20130421, F=20130616, 32-Members
0.17m at 000-m (contour), Ens Mean, Meqn (shaded)



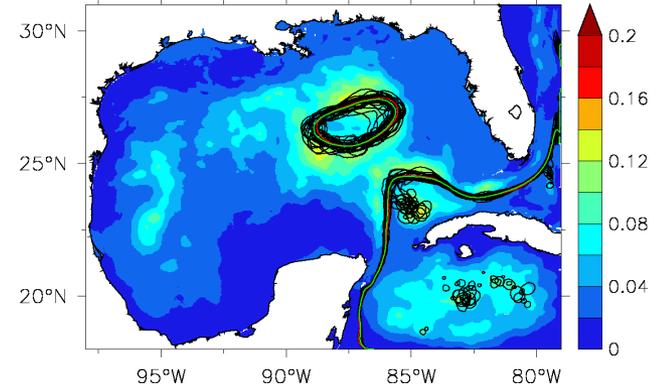
Forecast: June 16

Altimetry: April 21



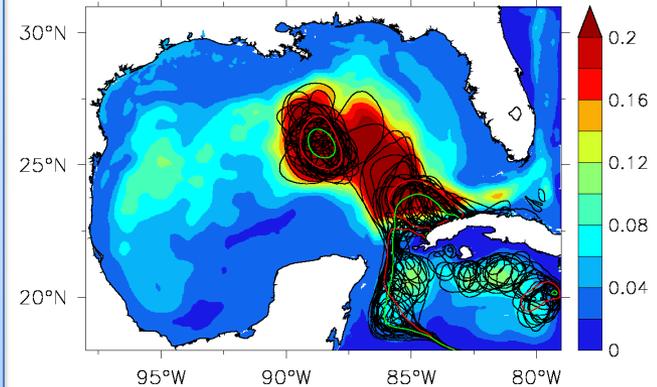
Analysis: April 21

SSH (m), A=20130421, F=20130421, 32-Members
0.17m at 000-m (contour), Control, Ens Mean, Std. Dev. (shaded)



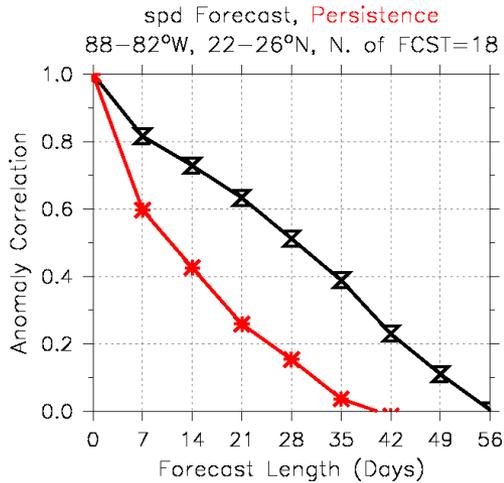
Std. Dev. (17 cm) SSH

SSH (m), A=20130421, F=20130616, 32-Members
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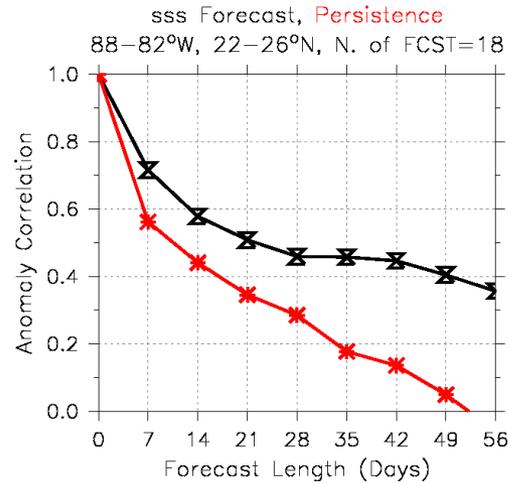


Forecast: June 16

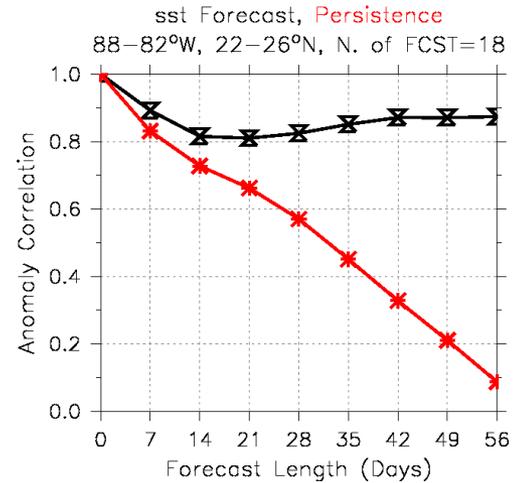
Surface Anomaly Correlations



Speed



Salinity



Temperature

- No assimilation of velocities
- Few salinity observations
- Relatively lots of temperature observations



Risk Assessment for Planning and Operations

**Weighs the likelihood of occurrence (probability)
with the severity of risk (impact threshold)**

Risk Management Matrix OPNAVINST 3500.39B		P R O B A B I L I T Y				
		A Likely	B Probable	C May	D Unlikely	
S E V E R I T Y	I Death, Loss of Asset	1	1	2	3	
	II Severe Injury, Damage	1	2	3	4	
	III Minor Injury, Damage	2	3	4	5	
	IV Minimal Threat	3	4	5	5	
		1-Critical	2-Serious	3-Moderate	4-Minor	5-Negligible

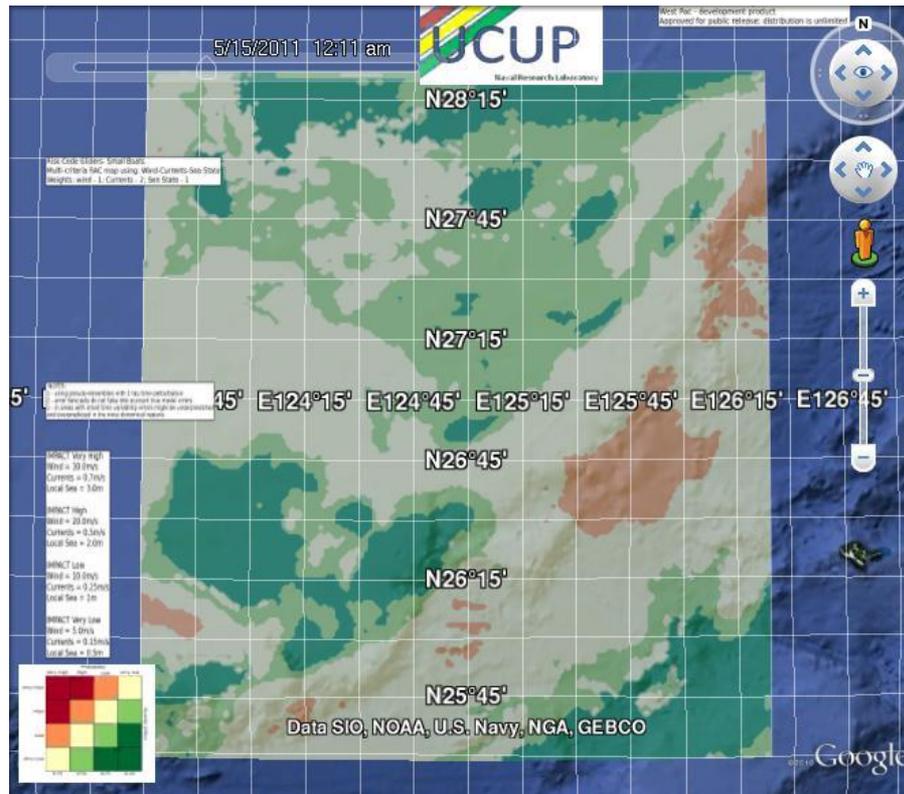
Objective: Identify areas and periods in the GOM over a 60 day long forecast where environmental conditions might produce operational impacts

- **Operations Safety/Warning System**

Variables: surface currents, vertical shear, wind, sea-state, SST, etc.

Thresholds: magnitude levels that will impose risk on operations, relative weighting and identification of individual critical levels (small boats, drill stems, etc.)

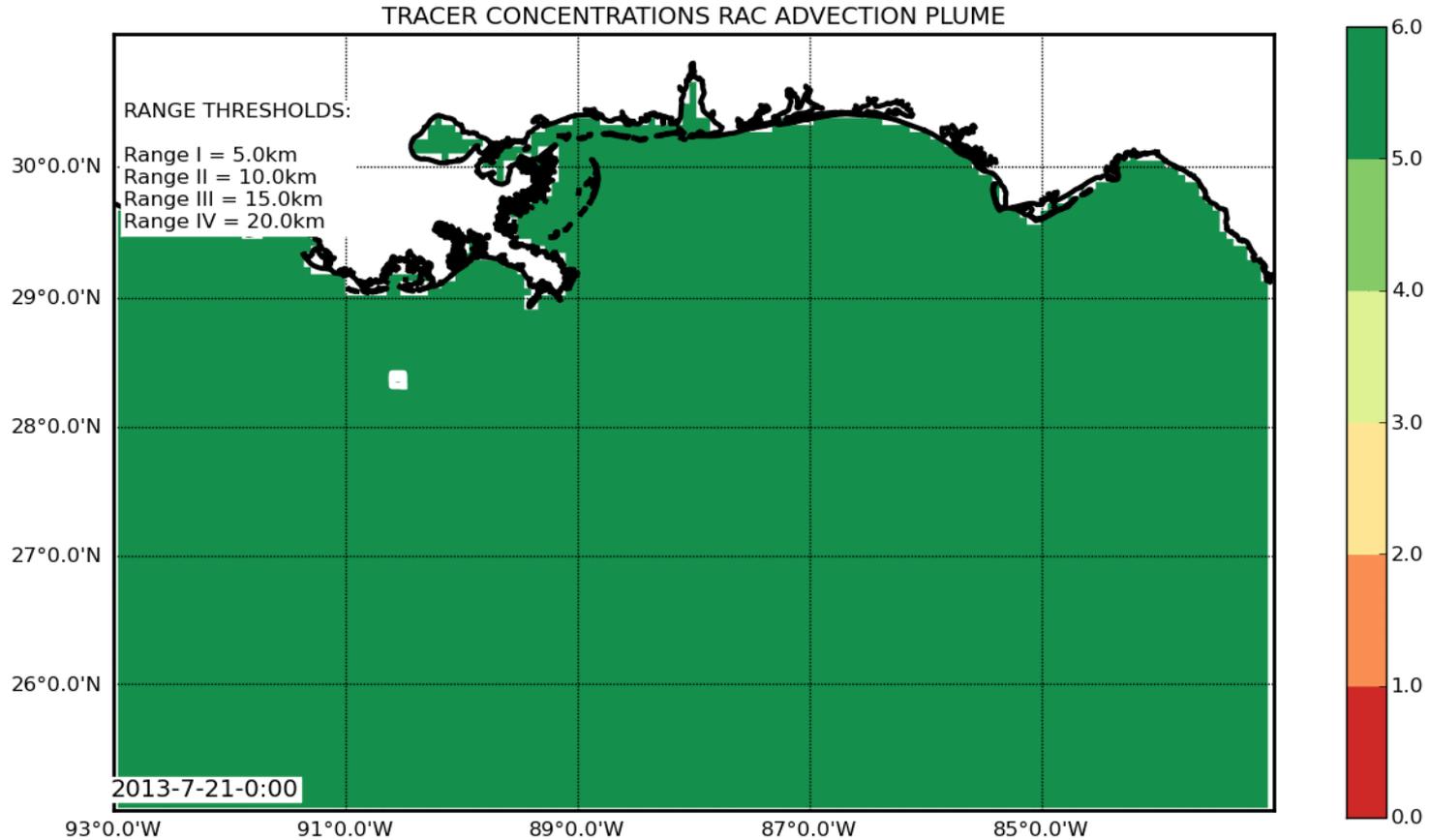
Operational Safety/Warning System



Impacts/Thresholds Examples

- **Surface Ocean Currents:**
 - very high impact if above 0.7m/s; high impact if above 0.5m/s and below 0.7m/s; moderate impact if between 0.25 and 0.5m/s; low impact if above 0.15m/s.
- **Surface Winds :**
 - very high impact if above 30m/s; high impact if above 20m/s; moderate impact if above 10m/s; low impact if above 5m/s;
- **Sea State:**
 - very high impact if above 3m; high impact if above 2m ; moderate impact if above 1m; low impact if above 0.5m.

Hercules Platform Blowout July 21, 2013

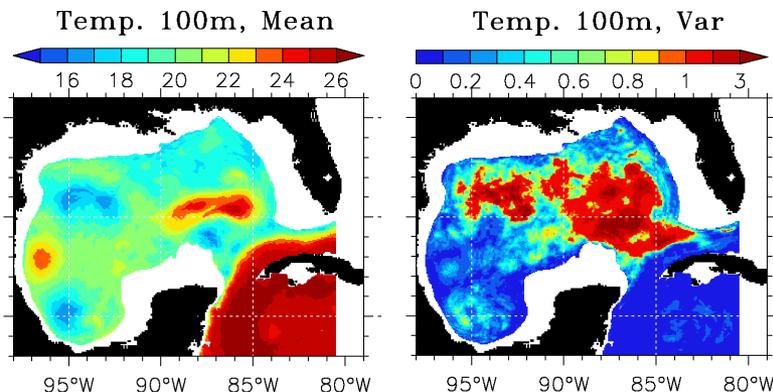


Ensemble Approach to Ocean Forecasting



Single-Model Approach:

Use one forecast system and perturb some aspect of that system (initial state and atmospheric forcing) then integrate forward to obtain a forecast.



N different ensemble realizations

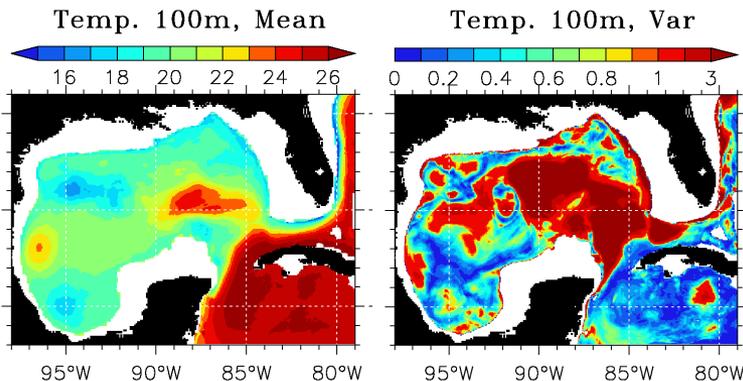
Note: Ensembles take N members as much computer time

Pro: develop one model

Con: do perturbations represent realistic variance?

Multi-Model Approach:

Use forecast systems with different designs (physics, resolution, forcing, etc.), typically run by different operational centers or labs



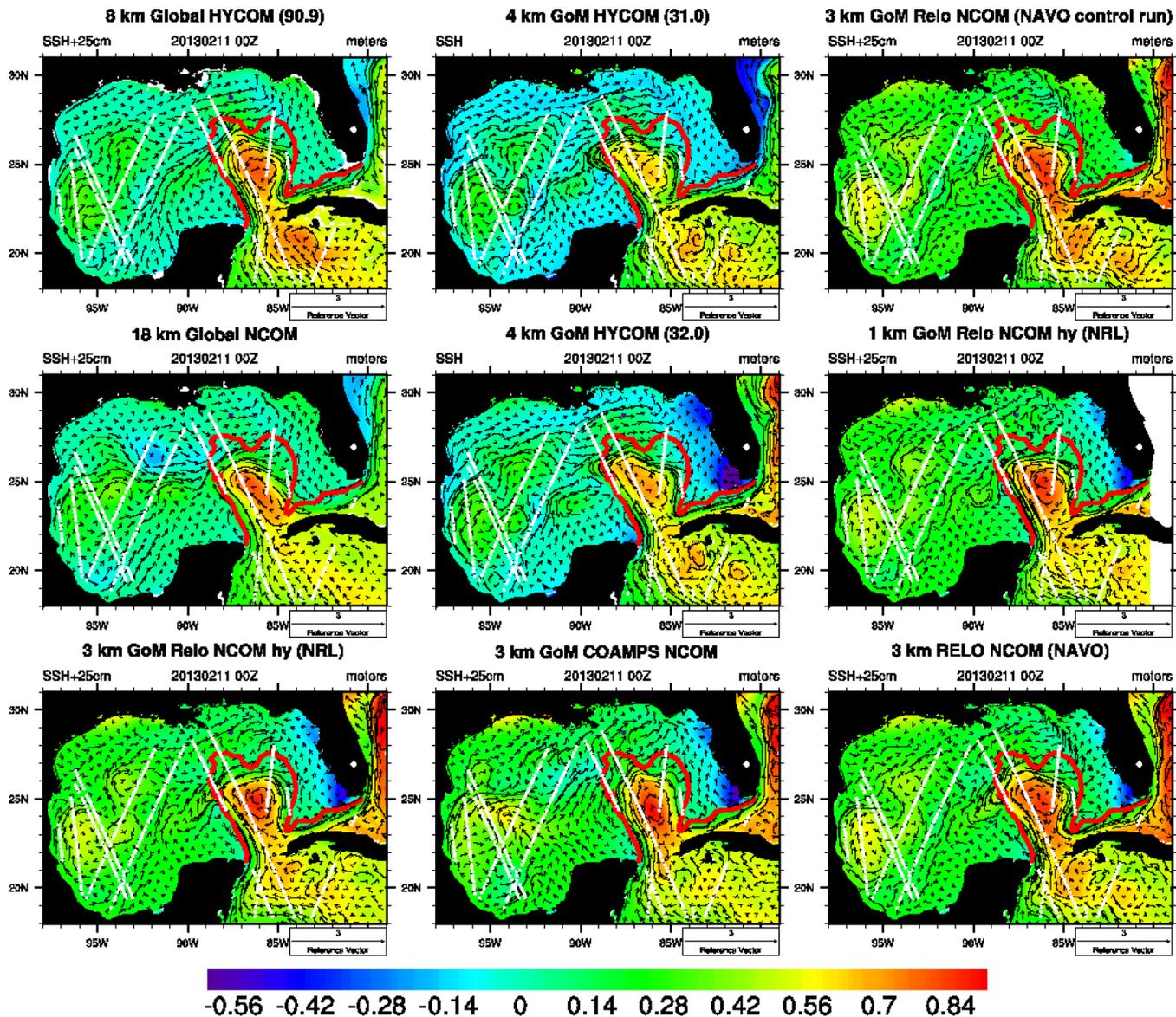
N different forecast systems

Pro: more variety across members

Con: limited number of members

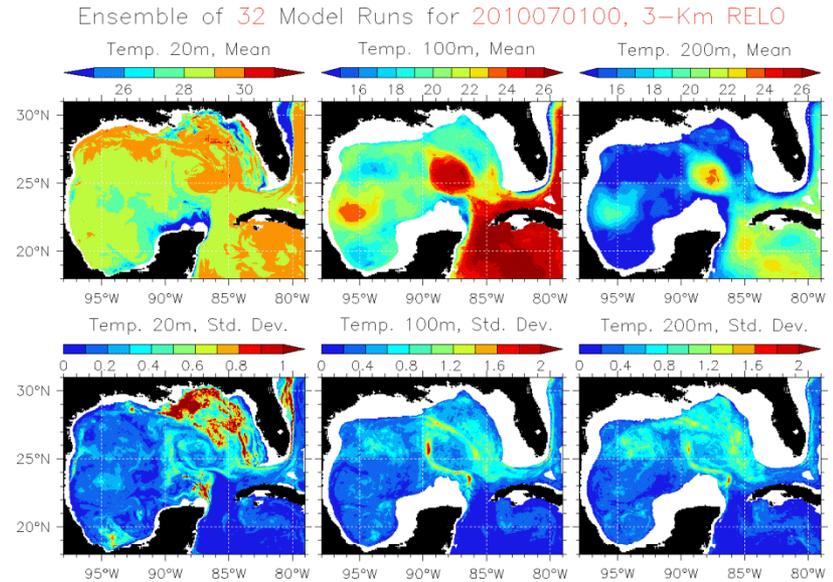
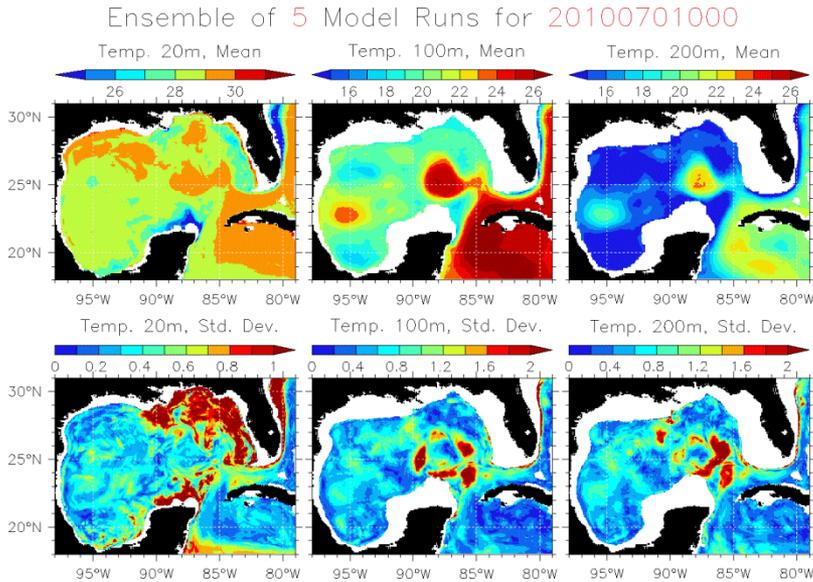
Multi-Model Comparison: Sea Surface Height

11 February 2013

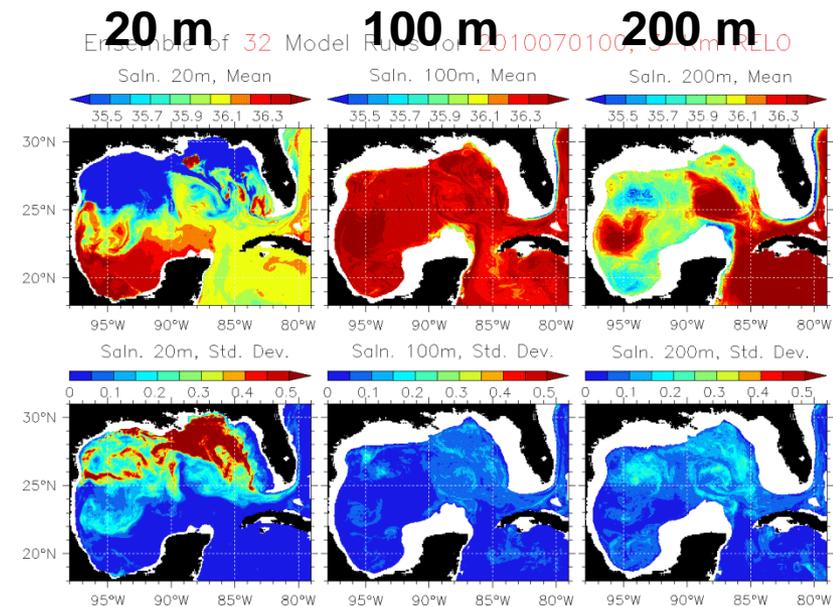
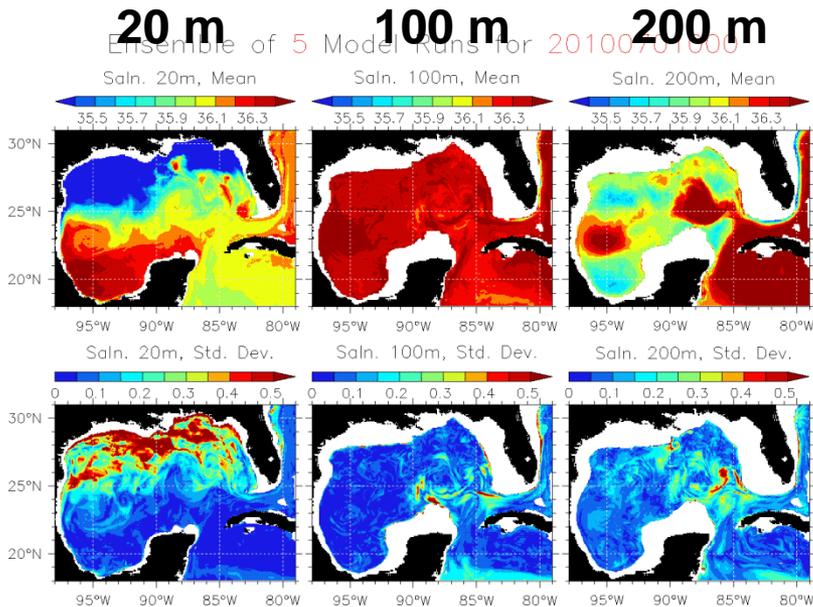


Multi-model Ensemble

32-member Single Model Ensemble



Temperature



Salinity

Global “Ensembles of Opportunity”



- There were several global experiments with ~3 month overlap that were run as part of the normal development and improvement process such that the global simulations that differ by some parameter setting or technique.
- **A very poor man’s approach; Not the proper way to develop and configure an extended range forecast capability (more on that soon).**

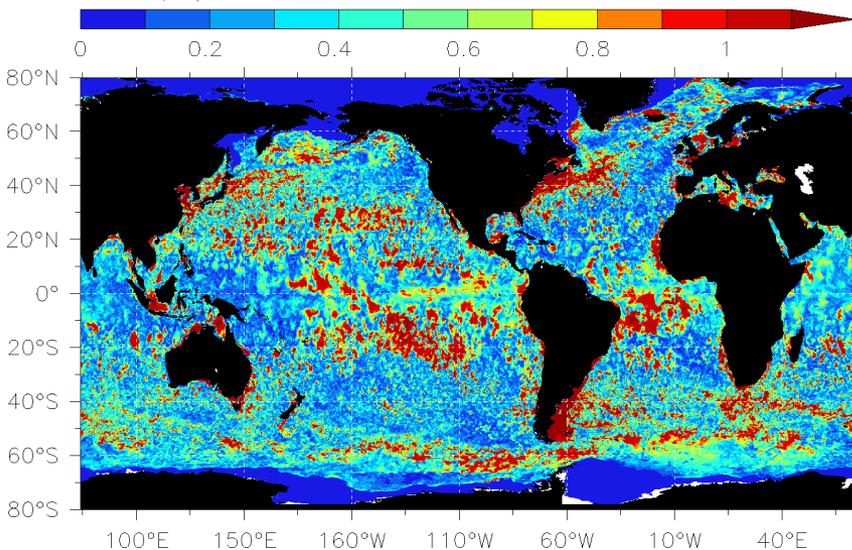
Set 1 (2007): 5 used Cooper-Haines, 3 used MODAS synthetics. Two used 35 layers instead of 27. Some used an updated version of NCODA and one used mixed layer depth to modify the MODAS synthetic, etc.)

Set 2 (2012): All 3DVar, 32 vs. 41 layers, different ocean analysis configurations

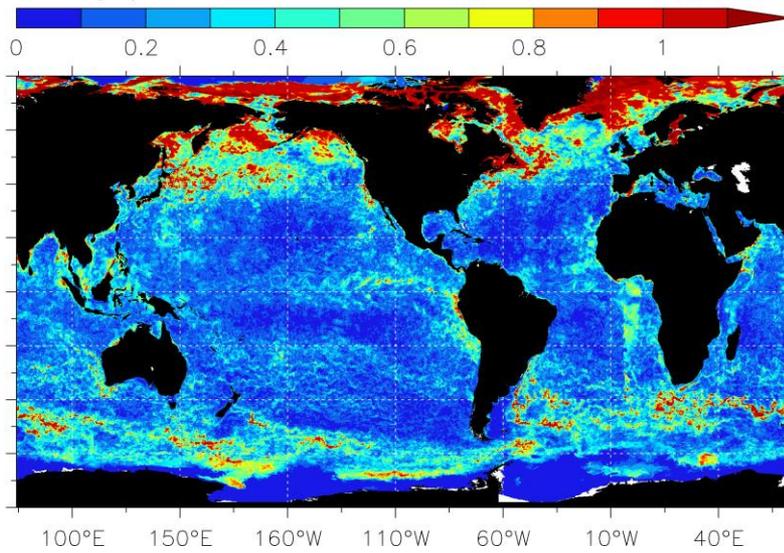
SST: Global Ensemble Variance vs. Time Variance



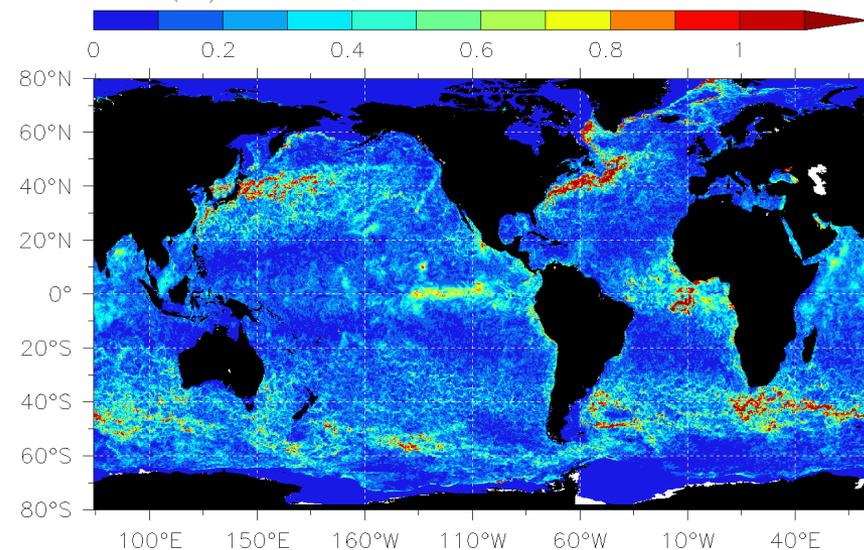
SST (°C), Std. Dev., Ensemble of 7 Members for 20120415



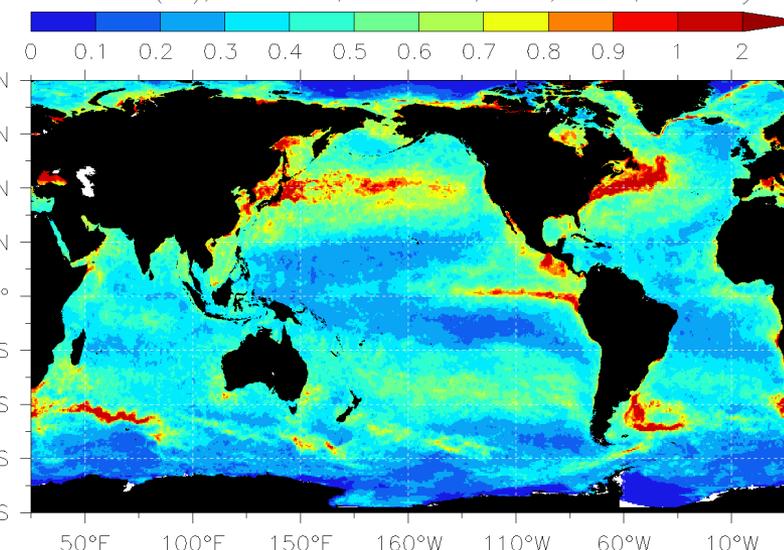
SST (°C), Std. Dev., Ensemble of 8 Members for 20070731



SST (°C), Std. Dev., Ensemble of 6 Members for 20120415



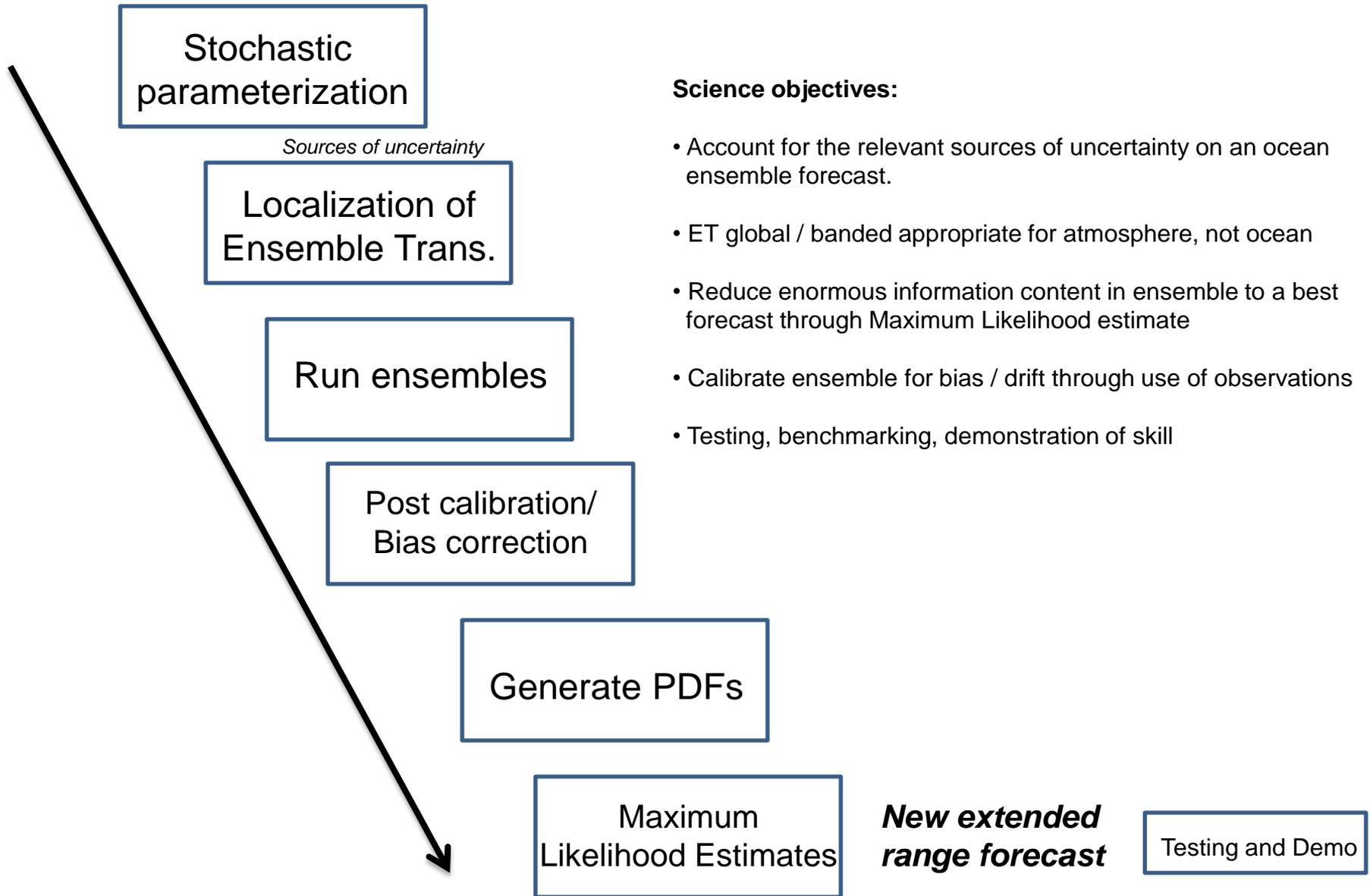
SST (°C), Std. Dev., GLBa0.08, 90.9, 2011, Anomaly



Experiment 25.0 excluded

**from one simulation
over 2008-2011.**

Objective: Extend the Range of Ocean Forecasts in Space (up to global) and in time (up to 30 days) using a stochastic forecast capability





Thanks!

***SUPPLEMENTAL SLIDES
FOLLOW***