The Oil Trajectory:
## How it behaved in the Gulf of Mexico and why, and where might residual oil be heading?

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University of South Florida

CSDMS Meeting, San Antonio TX
October 16, 2010

Deepwater Horizon Oil Spill

Surface oil inferred from satellite imagery (*Hu et al.* 2009) superimposed with modeled ocean currents and SST
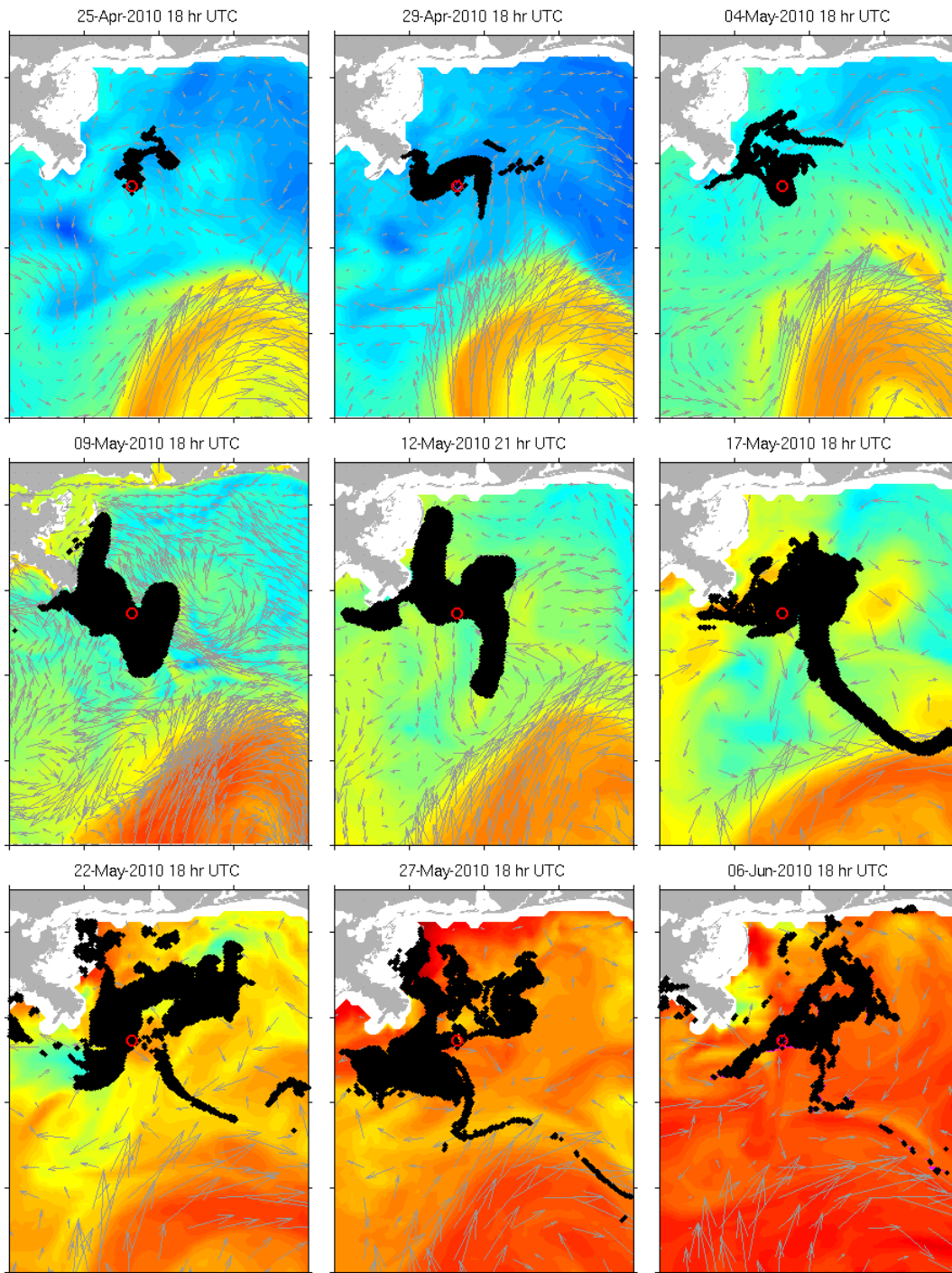
➤ The area of the surface oil slick grew with time during Apr - May.

➤ Surface oil was entrained in the Loop Current system in mid May.

➤ Surface oil decreased on June 6.

Now that the spill is stemmed:

**How did the CMS-USF Ocean Circulation Group respond?**

What are some continuing (environmental) concerns?

What are some lessons (to be) learned?

Rapid Response from a Coordinated Program of Coastal Ocean Observing and Modeling.

Observing by moorings, HF-radar, profilers, gliders, drifters, and satellite analyses.

Modeling is based on ROMS nested in Global HYCOM and now also FVCOM nested in HYCOM.

http://ocgweb.marine.usf.edu
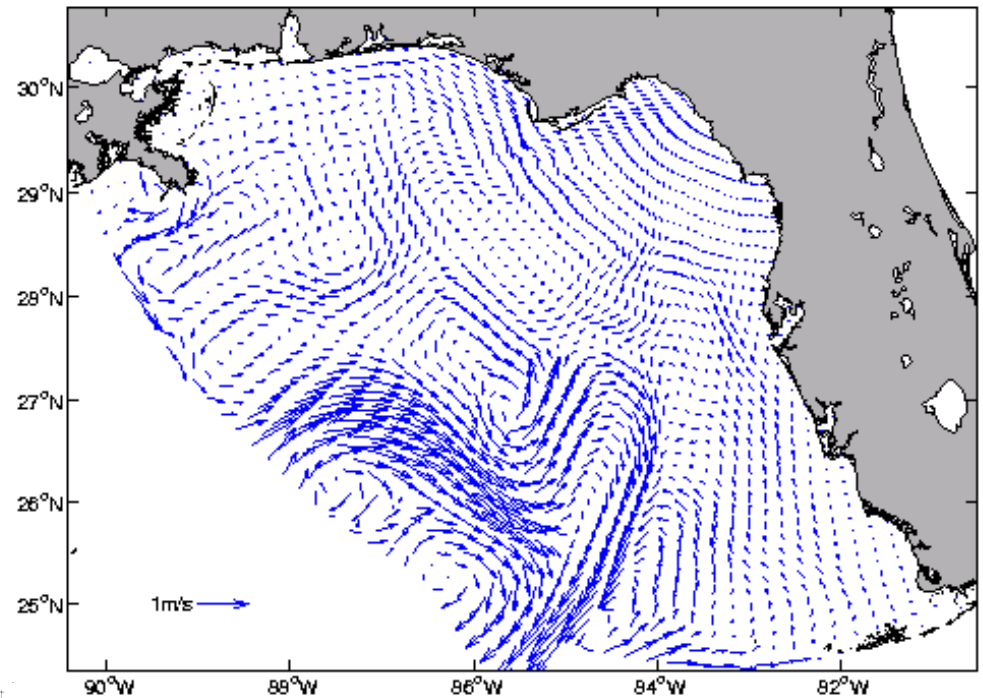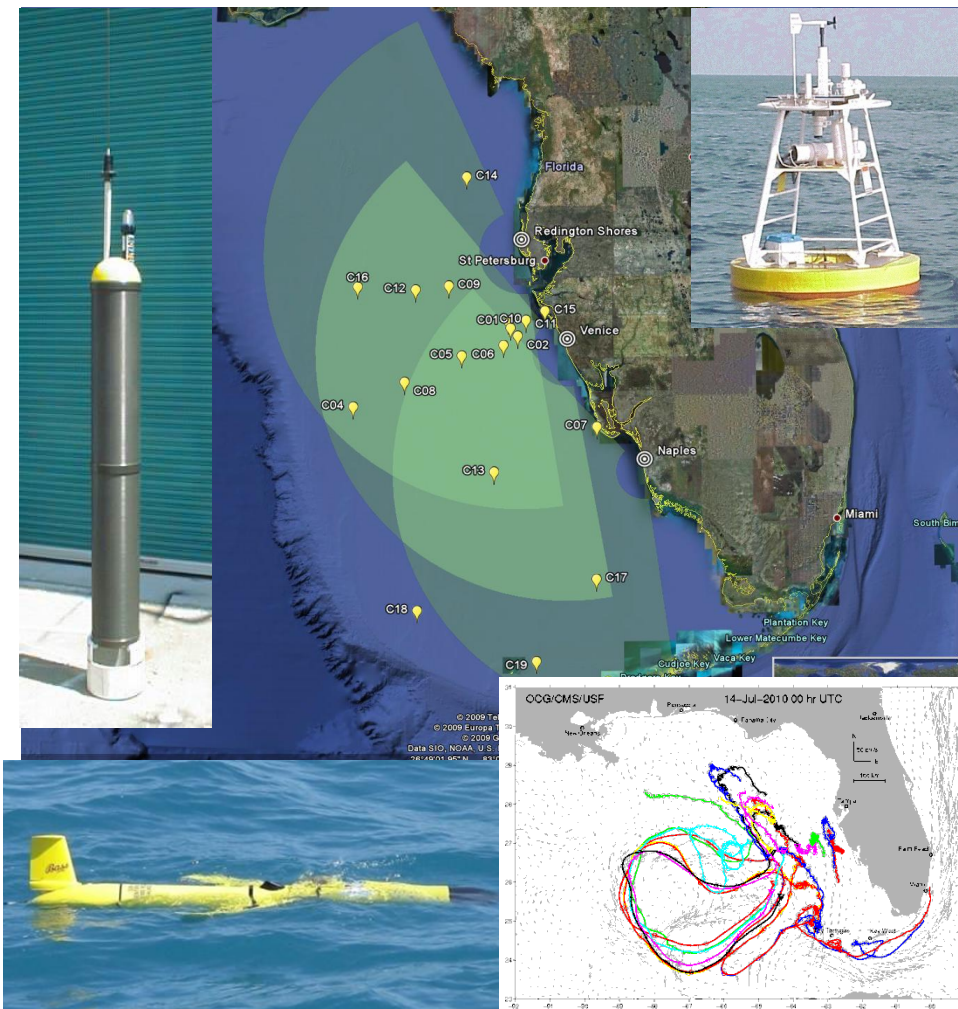
The CMS-USF-OCG Response:
Daily updates on the web and regular briefings distributed as ppts (example below)

Oil Spill Tracking in the Eastern Gulf of Mexico

Robert H. Weisberg

with

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College of Marine Science
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and assistance from the HYCOM consortium

July 11, 2010

Oil Spill Tracking in the Eastern Gulf of Mexico

Beginning on 4/22 we applied numerical ocean circulation models for tracking oil spilled from the Deepwater Horizon (Macondo) well. We are now using an ensemble of six different models:

- **USF WFS ROMS nested in HYCOM,**
- **Navy Global HYCOM,**
- **Navy GOM HYCOM**
- **NOAA RTOFS (also HYCOM).**
- **NCSU SABGOM (ROMS nested in HYCOM).**
- **Navy NCOM IAS**

The oil patch location is initialized using satellite imagery, and we simulate the movement of virtual surface particles carried by the models' velocity fields.

Simulations, updated daily, include periods of both hindcast and 3.5 day forecasts (using forecast winds).

Predictions are compared with observations when satellite imagery is available, and the predictions are being used by NOAA in their forecasts.

Subsurface trajectories from the well site are also updated daily.

Real time velocity observations from moorings and HF-radar are also used.

All information is publicly available at http://ocgweb.marine.usf.edu and ppt briefings are provided to agencies and others.

7/11 Forecast Update

The ocean circulation determines where oil may go.

Deep ocean currents (the Loop current and its eddies) tend to stay in deep water; shallow water currents tend to stay in shallow water, and this explains why the Mississippi River delta and the region of Pensacola FL where the first land areas oiled. There the continental shelf is narrow and deep water is in proximity to land.

Once oil was in shallow water it progressed more easily along shore, which is why we saw more coastal communities affected. The latest imagery interpretation suggests less oil in general and less in shallow water.

Shown in the following two slides are surface trajectory forecasts with the USF eastern G of M model (ROMS nested in HYCOM), the Navy GOM HYCOM, and an ensemble of four models (the previous two, plus the Navy Global HYCOM and the NCSU SABGOM), all driven by forecast winds (NOAA/NCEP or Navy/NOGAPS).

Movement along the coast is in response to winds and LC/eddy interactions with the shelf slope. Over the past two weeks easterly winds and a relaxation in eddy/slope interaction shifted near shore oil back west, which was good news for Florida. However, the winds for the next few days are forecast to be westerly, and the WFS circulation is now upwelling. Oil will move eastward near-term.

The Loop current, which shed an eddy around 5/20, is undergoing a torturous path. It now appears to be detached from the eddy. How this will evolve cannot be predicted. It remains possible for the Loop Current in the future to extend northward to the well site (e.g., see movie loop at http://ocgweb.marine.usf.edu.)
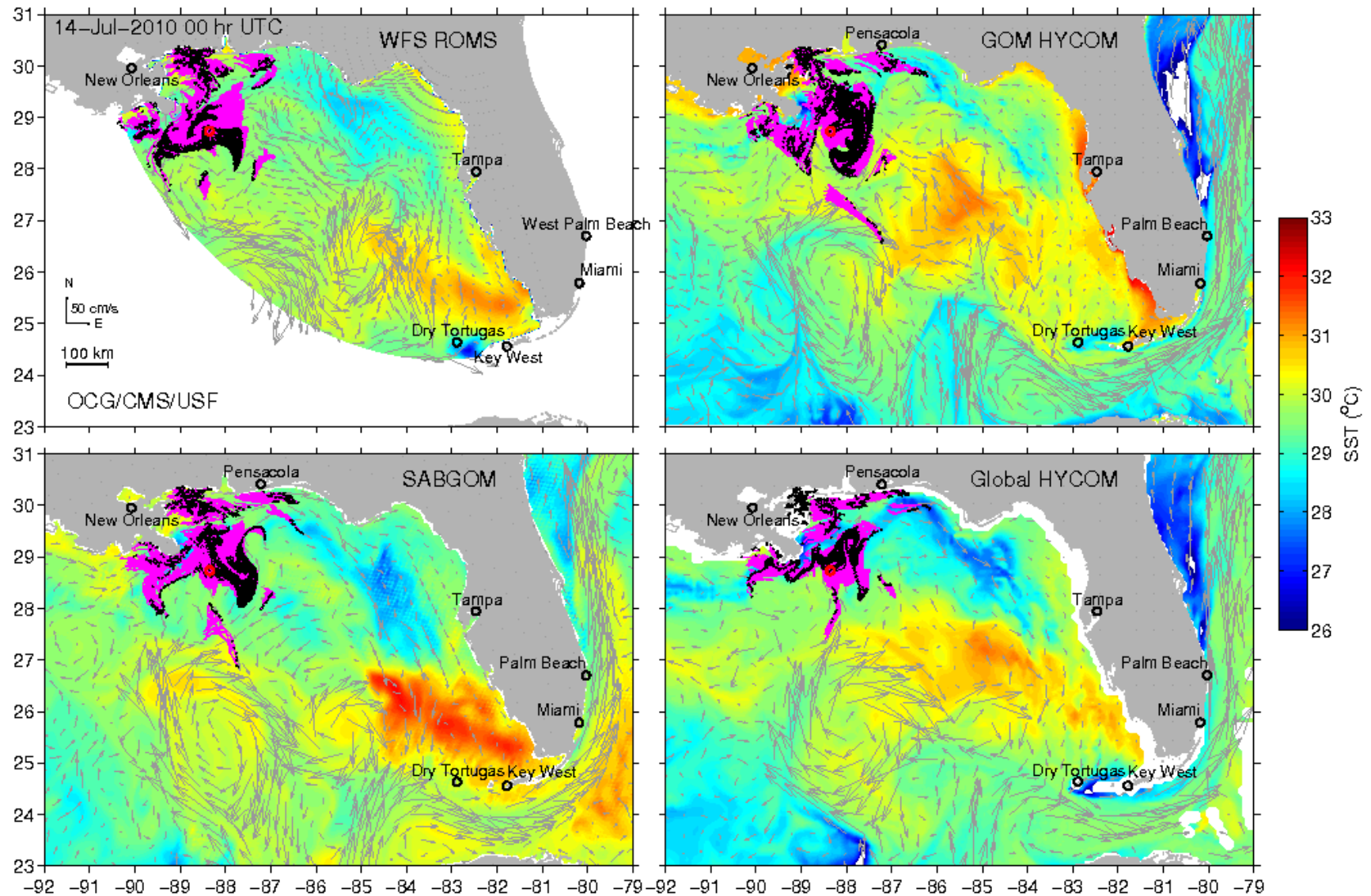
USF WFS Nowcast/Forecast Model
Initialized 7/10 with Prediction at 7/14
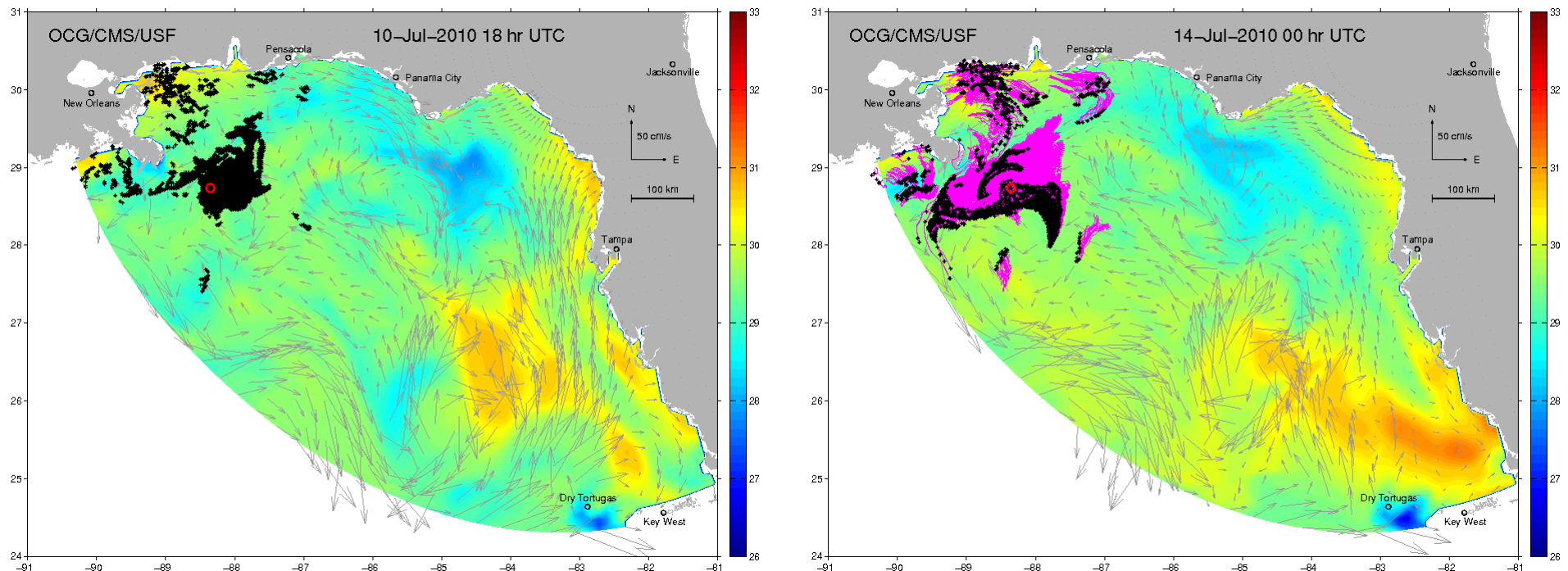
Using 3-hourly USF WFS model results we estimate trajectories emanating from the well site by releasing new particles every 3 hours starting from a 07/10 spill initialization using satellite imagery.
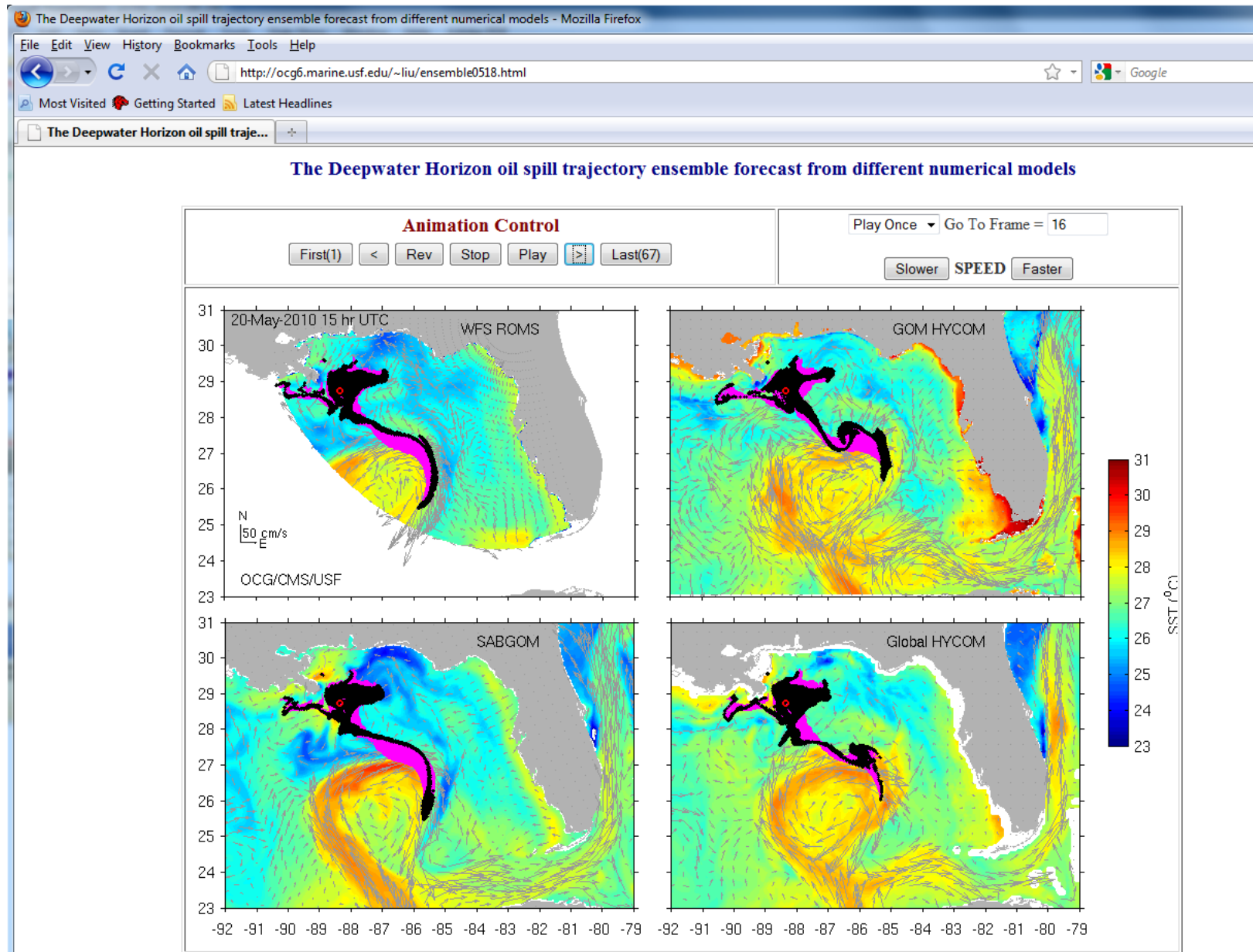
http://ocgweb.marine.usf.edu

Ensemble Forecast (4 of 6 Models) Initialized 7/10 with Prediction at 7/14

http://ocgweb.marine.usf.edu

Web-based Animations with Interactive Functions

Surface Oil Trajectory Nowcast/Forecast System

http://ocgweb.marine.usf.edu/~liu/oil.html

Loop Current Update

Ocean surface color imagery was spotty last week due to clouds. The LC and eddy pathways remain torturous, and what may happen is unknown.

The process of eddy shedding is also evident in analyses of surface currents from satellite altimetry using the geostrophic approximation, and from these satellite altimetry-derived surface currents we can estimate pathlines for virtual particles carried by the currents.

By deploying actual satellite tracked drifters, and overlaying these on modeled currents, we can further appreciate the movement by the currents.

While we cannot predict what the near-term evolution of the Loop Current may be, historical observations show that eddy reattachment is common and that the Loop Current can extend right up to the well site, which is situated on the continental slope. As examples please see the movie loop at http://ocgweb.marine.usf.edu under products, second line down. It remains possible that large amounts of oil can flow to the Florida Straits and east coast. For now, however, the eddy appears to be separating to the west

The interactions between the easternmost edges of the LC and its eddy with the shelf slope resulted in flows on the shelf tending to move oil eastward there. This was countered over the past two weeks by strong SE winds. The situation is subject to change owing to winds and LC/eddy interactions with the shelf slope. The winds and LC/eddy interactions will continue to be variable.

Oil Location Superimposed on Surface Color

Image credit: USF College of Marine Science, Optical Oceanography Lab and IMaRS

Color index: July 10, 2010, 19:15 GMT

Oil slick: July 10, 2010, 19:15 GMT

X: oil rig location
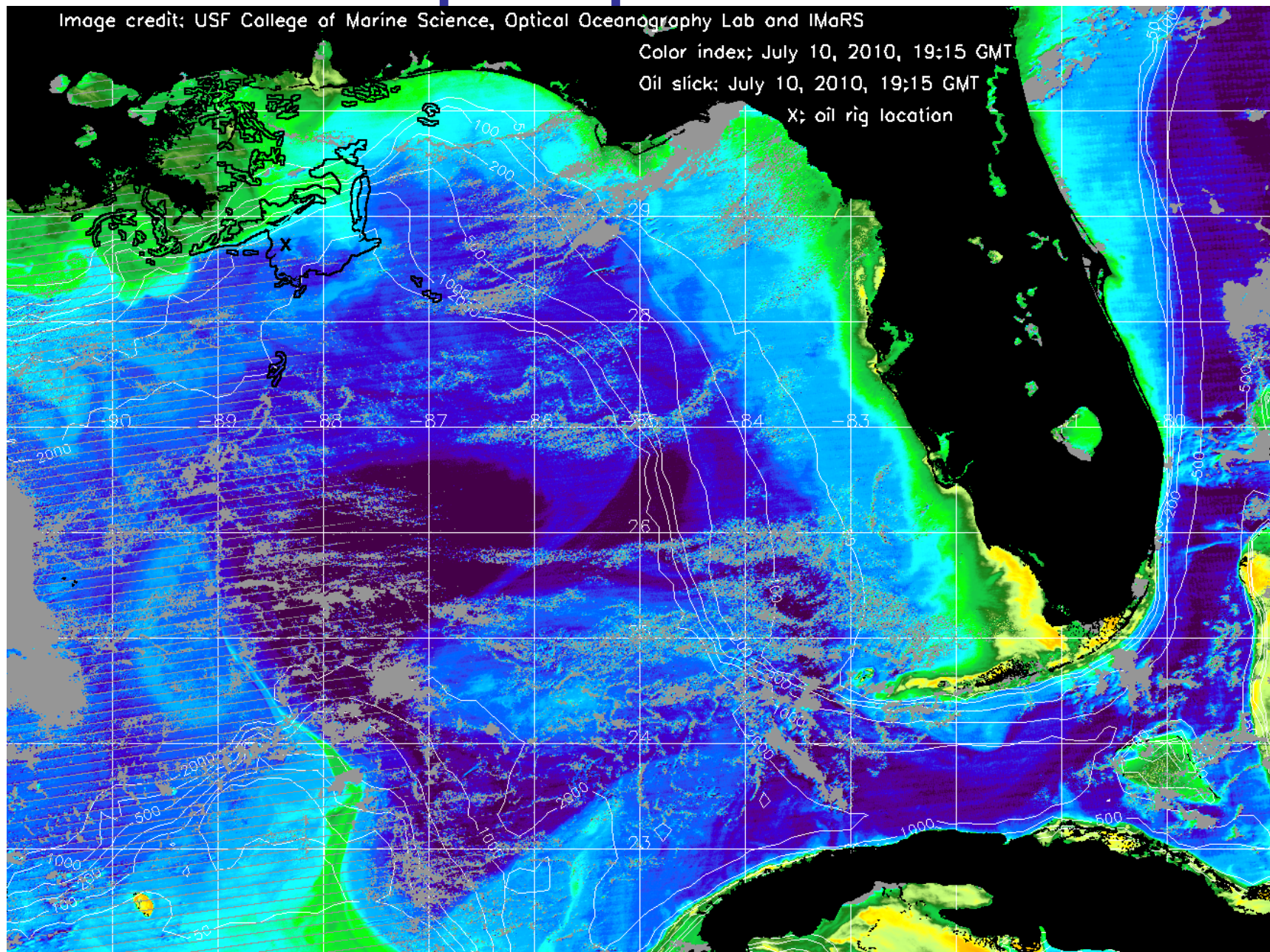
From C. Hu, CMS-USF in collaboration with OCG

LC-FC-GS System as Determined Using Satellite Altimetry
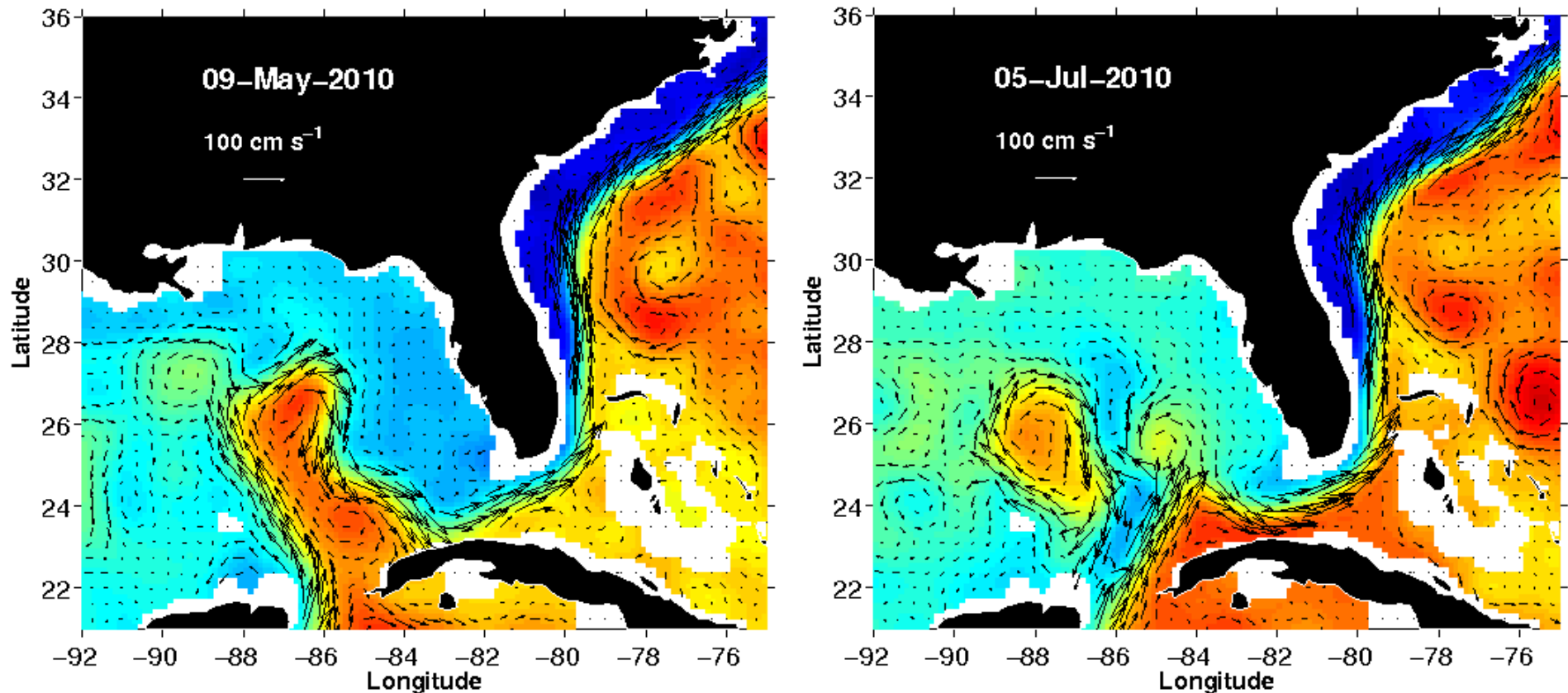
We use sea surface height (SSH) anomalies from AVISO combined with a mean SSH field to estimate absolute SSH. We then estimate surface currents via the geostrophic approximation, which is excellent in deep water. The colors are SSH (red being high, blue low); the arrows are the surface currents. A succession of estimates shows the eddy evolution. The eddy separated from the LC around 5/20 and again on 7/2.

LC-FC-GS System as Determined Using Satellite Altimetry, Plus Virtual Surface Drifters to Trace the Pathways

Travel times (mean and SD from an 8 year analysis):

YS to FS: 20 ± 9 days
FS to CH: 15 ± 2 days

NOTE: Cloud-free SST is product (background color) is now flawed by too much cloud cover for too many days.

12-Jul-2010 12:00:00 UTC

USF, OCG, SEACOOS
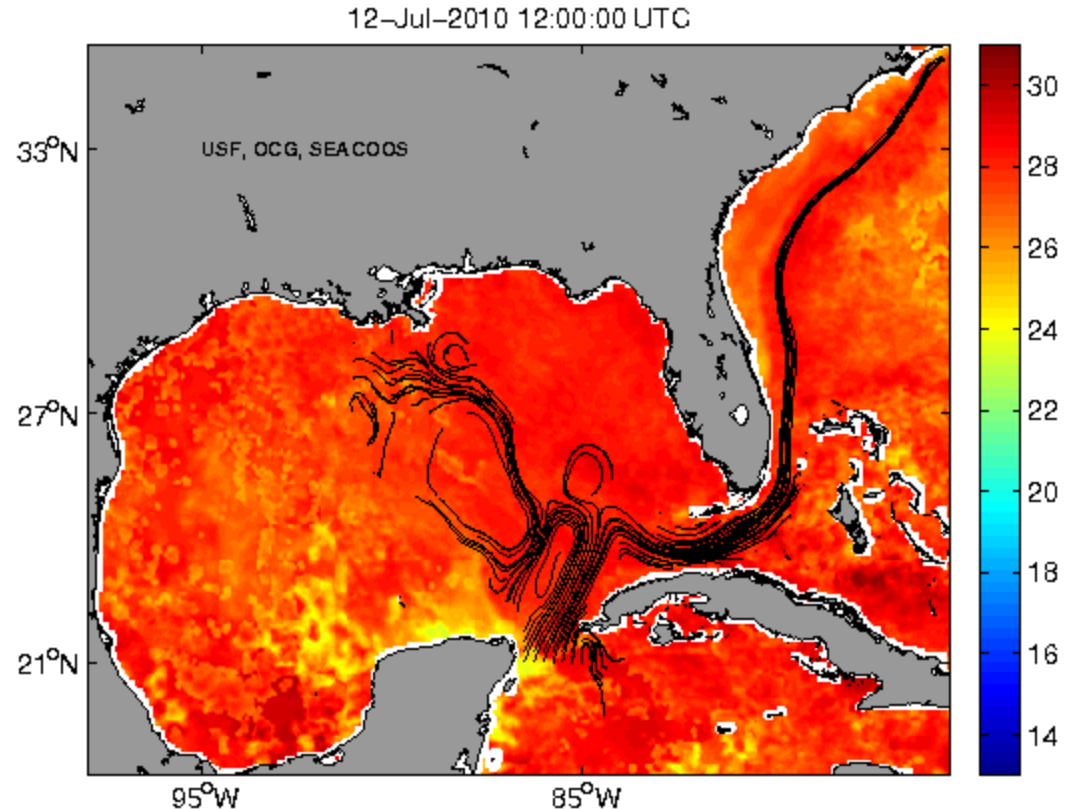
We do a 2-week hindcast/forecast of virtual drifter pathlines, assuming movement with the surface geostrophic currents.
These are publicly available at http://ocgweb.marine.usf.edu
Click on geostrophic drifters.

Satellite-Tracked Surface Drifter Movie: Drifters Superimposed on HYCOM Modeled Currents
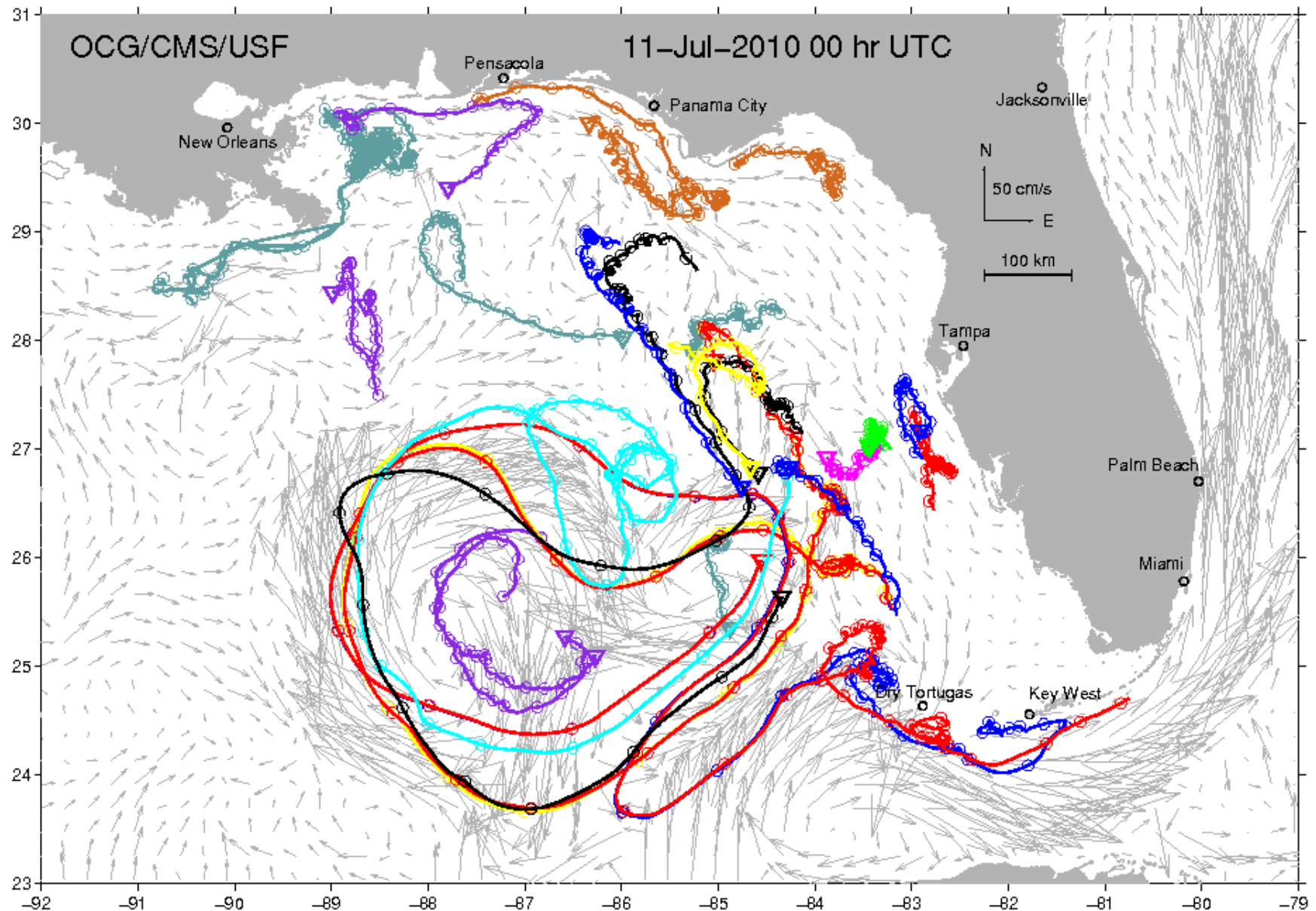
West Florida Shelf Currents

Sustained long-term observations demonstrate that a mean circulation exists from north to south across the WFS.

Sustained long-term observations also demonstrate that a seasonal variation exists about the long-term mean. In summertime, the monthly mean currents actually reverse to be from south to north. Daily weather changes, however, can further alter these currents, which is why we must run the forecast models shown previously.

The good news for Florida is that the monthly mean currents in summer will slow the movement of oil to the WFS. The bad news is that if oil is still present in fall then a reversal in the monthly mean currents will hasten the movement of oil to the WFS.

Easterly winds over the past week resulted in oil moving westward along the northern GofM shelf. LC and eddy interactions with the shelf slope also abated somewhat. These two factors provided a reprieve to oil advancing onto the WFS. However, these factors are now reversed, and winds are forecast westerly for the next few days.

We continue to observe the currents with a set of moored buoys, each containing instrumentation for measuring the water velocity. Also used are high frequency radars and surface drifters.   All now show an upwelling circulation on the WFS.

Mean surface geostrophic velocity
(*Rio et al.* 2005)

Mean **winds** & depth-averaged vel
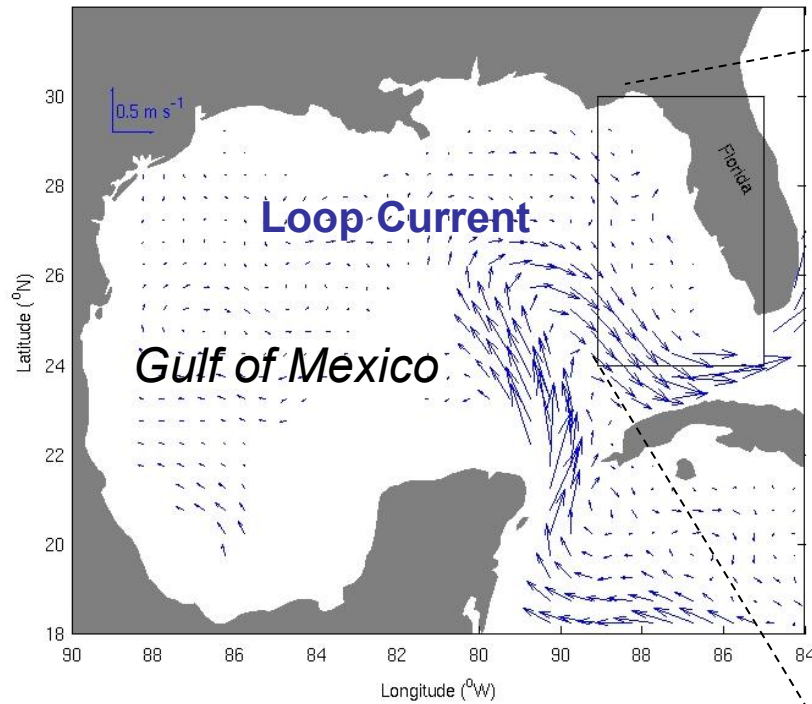
Mean wind stress
Mean currents (μ)
Standard errors ($\mu \pm \varepsilon$)
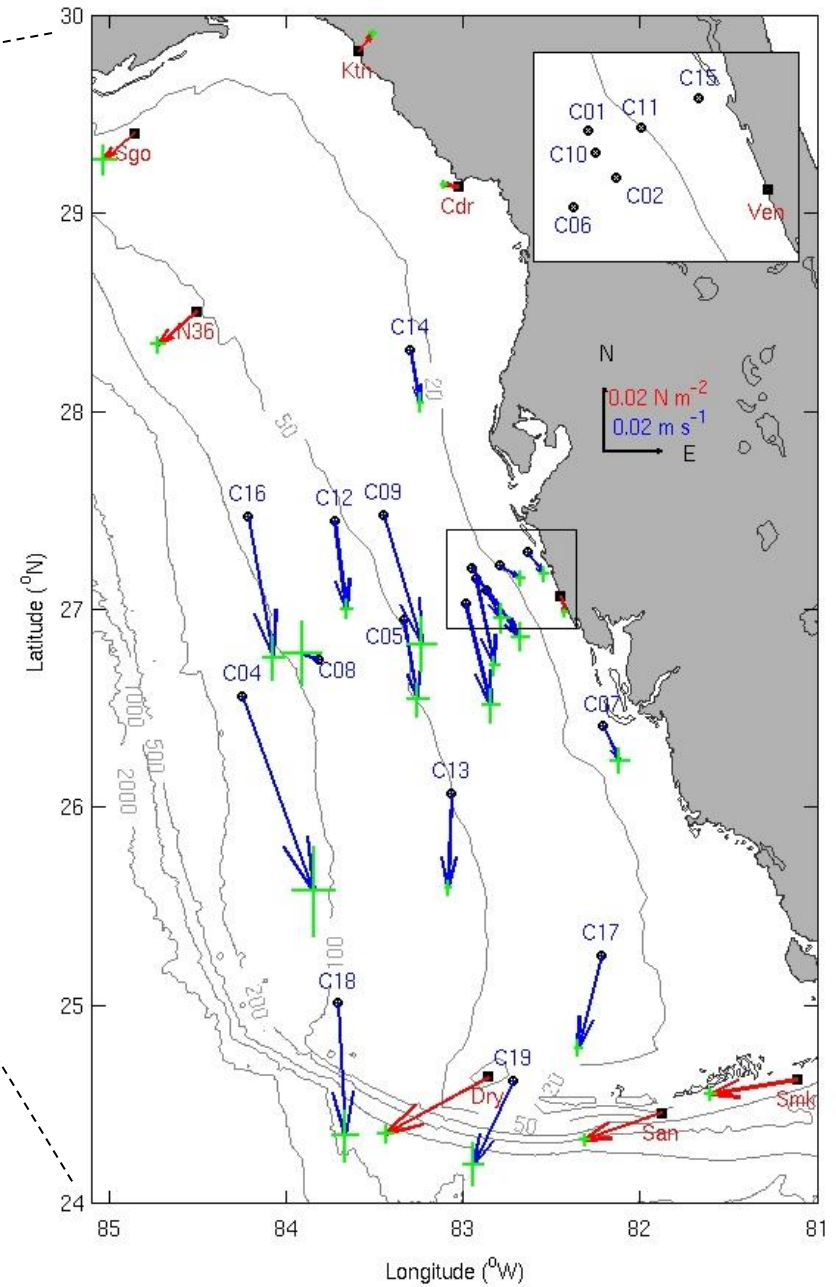
West Florida Shelf Seasonal Variability

West Florida Shelf COMPS Data

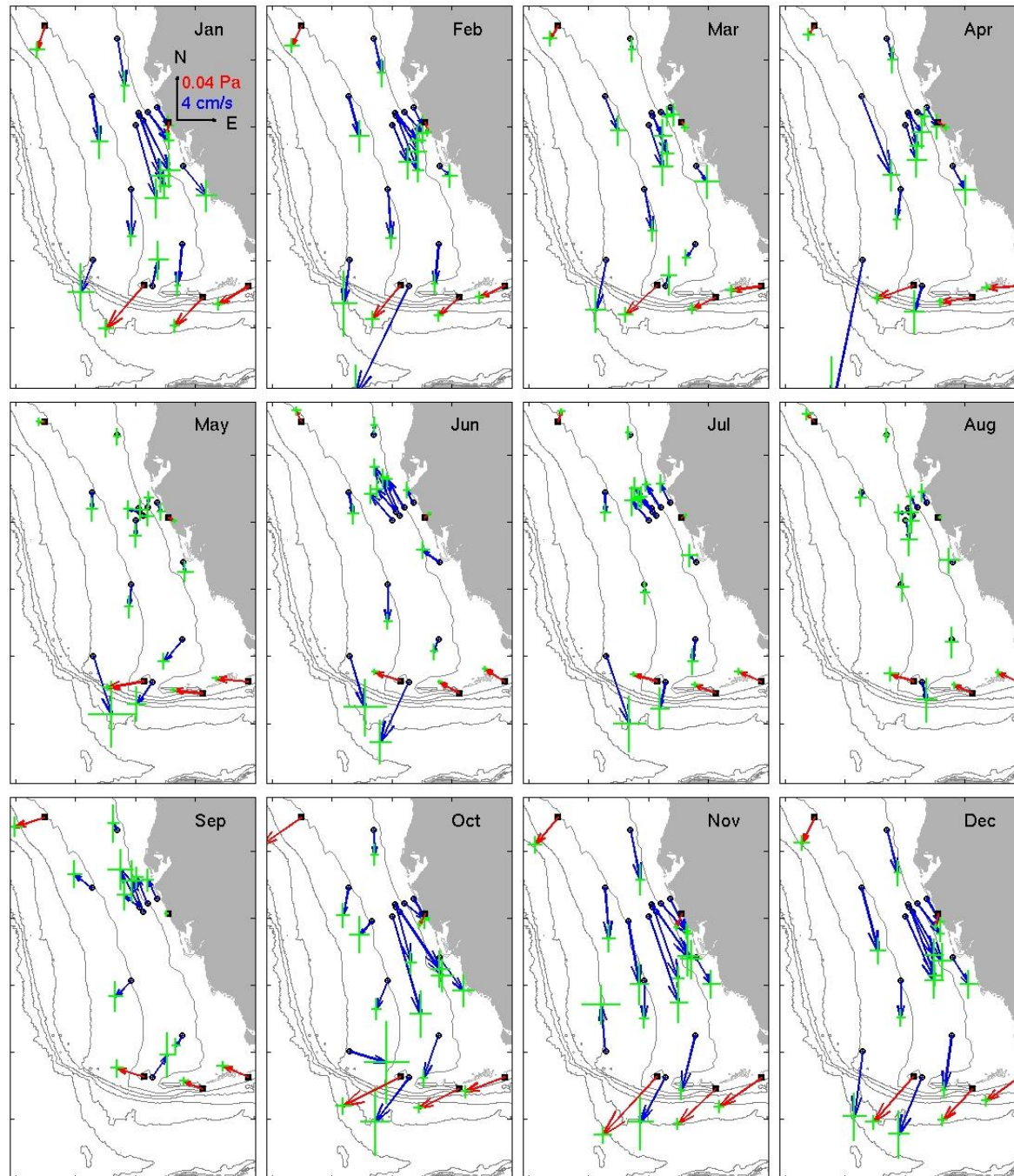We presently maintain four surface moorings with real time telemetry for surface meteorology, water column currents, and temperature and salinity. Two additional moorings had to be retrieved last year for lack of funding. The remaining systems also remain in jeopardy.

The next slide shows the location of the four moorings, and the second slide shows the real time currents for the past few days (E-W component of velocity on the left; N-S component on the right). The WFS was in a strongly upwelling state of motion as oil moved eastward in the north. This abated over the past 1-2 weeks, but the situation just reversed. The interactions of the LC and eddy are important factors, along with the winds (now westerly).

We also maintain HF-radars on the WFS for monitoring surface currents. These work well when the winds and hence waves are well developed. Summertime generally shows spotty coverage because of weak winds and hence at times no waves. An upwelling circulation (southward currents) is now observed.

Along with the moored buoys and HF-radar are a limited number of satellite-tracked surfaced drifters. These are all essential parts of a Coastal Ocean Observing System because no single sensor or sensor delivery system is adequate, and the same can be said of models, as previously shown.

WFS COMPS Real Time Moorings: Ocean Circulation Group, CMS-USF
http://ocgweb.marine.usf.edu and http://comps.marine.usf.edu
Moorings C10, C12, C14 are active; C13 to be repaired; others (C16 and C17) are no longer deployed due to lack of funding.

COMPS
Coastal Ocean Monitoring and Prediction System

Coastal Ocean Monitoring & Prediction System

Home   News   Links   COMPS Contacts   USF HF Radar

C12
Responsible agency: USF
Latitude: 27.498 N (27° 29' 8.80" N)
Longitude: 83.721 W (83° 43' 2.60" W)
Latest Observations: 06-20-2010 14:30:00 (UTC)
Select units: Metric

Direction
112

Gusts
1.4 m/s

Speed
1.31 m/s

Asimet Winds From
Return to directions

Map | Satellite | Hybrid

C14
C12
C10
C13

R.H. Weisberg, P.I. coastal ocean observations
M.E. Luther, P.I., coastline observations
C. Merz, Coordinator

HF-radar

The OCG-CMS-USF operates an HF-radar array for surface currents with CODAR units at Redington Beach, Venice (joint with Mote), and Naples. Two new WERA systems were recently deployed at Ft. DeSoto Park and Venice.

HF-radar works well when there are sufficient waves offshore. This is often problematic in summertime when weak winds result in flat seas. Intermittencies are therefore expected in summertime for HF-radar on the WFS.

Liu et al. (2010) JOAT.
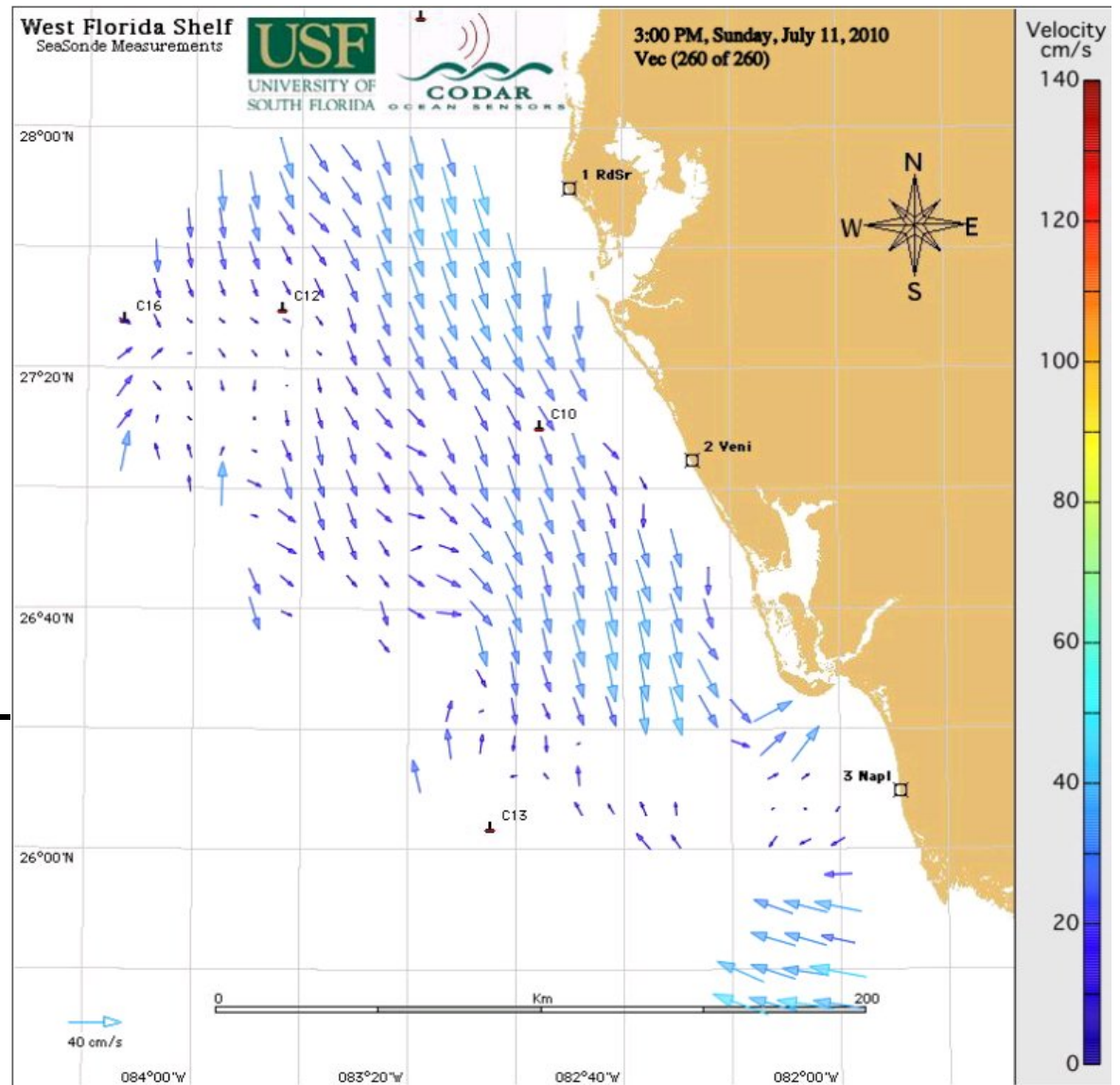
Subsurface Currents

Along with trajectory tracking at the surface we track virtual particles carried by the currents below the surface. Not knowing the depth of subsurface hydrocarbons we track particles continually released at nine different depths (between 1400m and 50m) using the USF eastern G of M model (ROMS nested in HYCOM).

Being that the WFS is generally an upwelling favorable environment, it is not uncommon for cold water to appear along the coast line. Such cold water originates seaward of the shelf break in the northeastern G of M. So if subsurface hydrocarbons upwell across the shelf break then an added threat to the benthos and the coast line may exist as these waters move landward within the bottom Ekman layer. The threat, of course, will depend upon concentrations and decay of toxic materials.

Errors in modeled trajectories grow with time. Reinitialization data exist at the surface but not at depth. Being that a potential hydrocarbon threat exists at depth, it is important that systematic surveys of subsurface hydrocarbons be conducted on a regular basis, either directly of with calibrated proxies.

Subsurface Trajectories (4/20-7/11)

http://ocgweb.marine.usf.edu
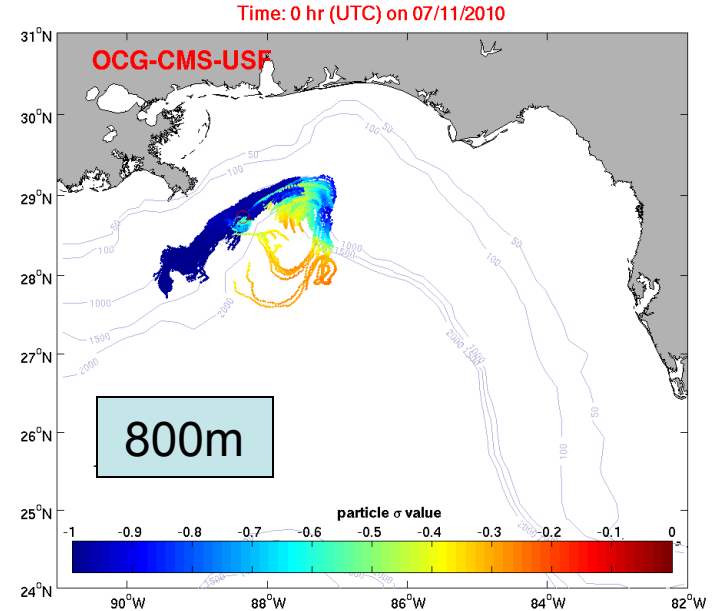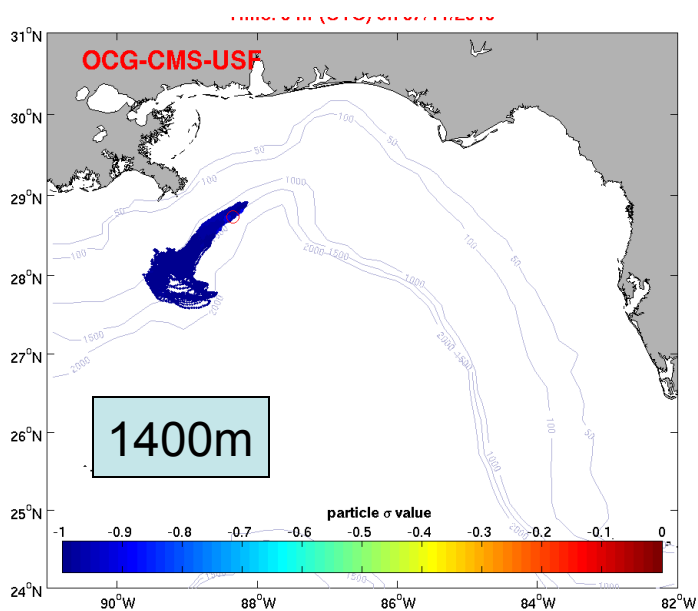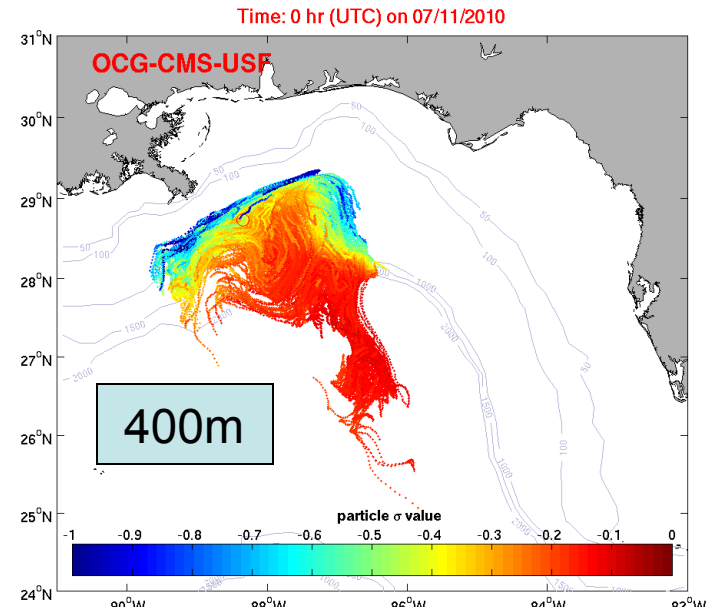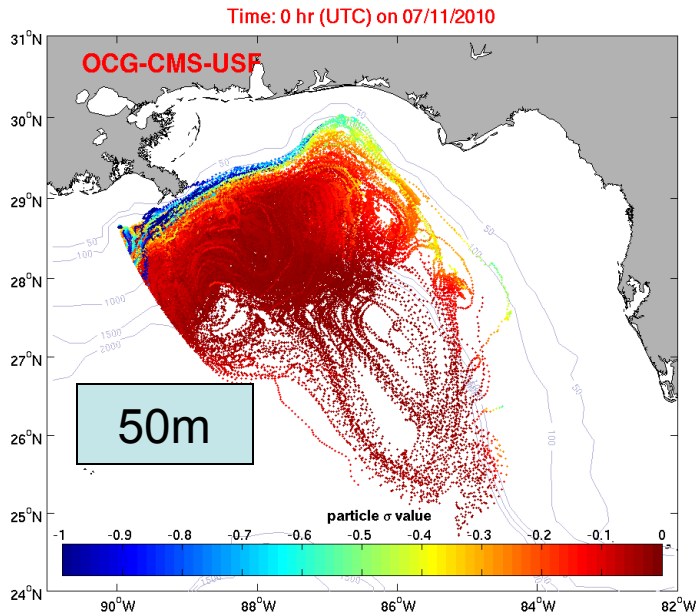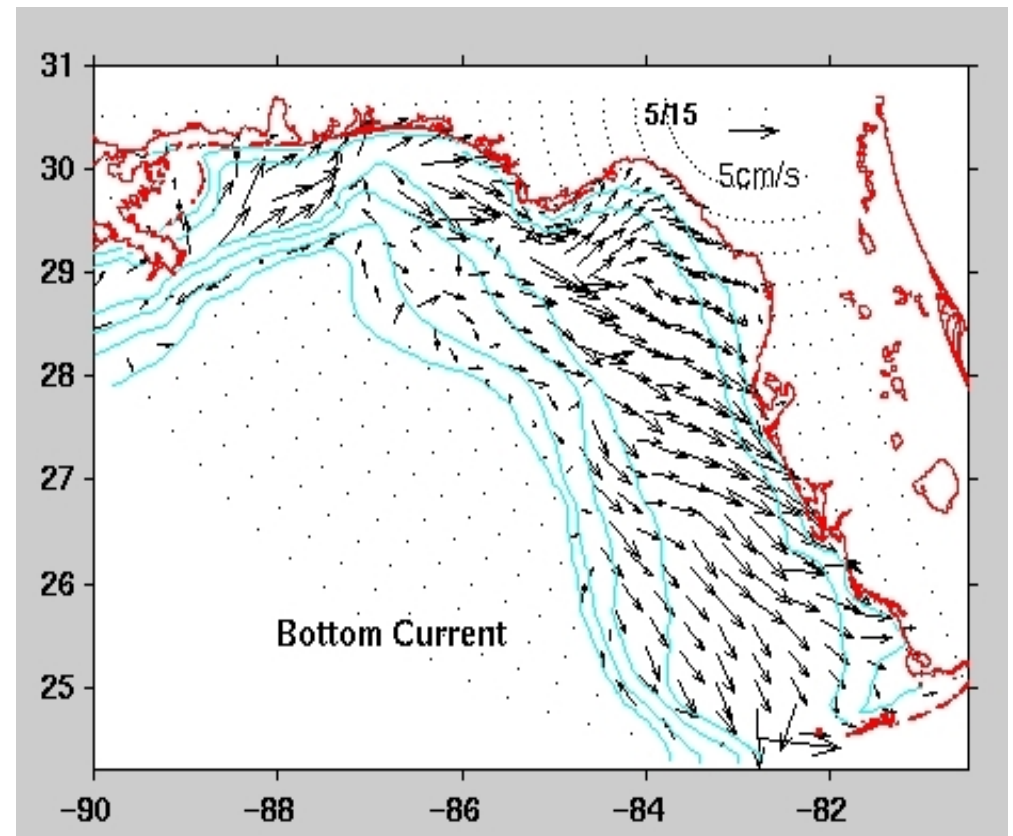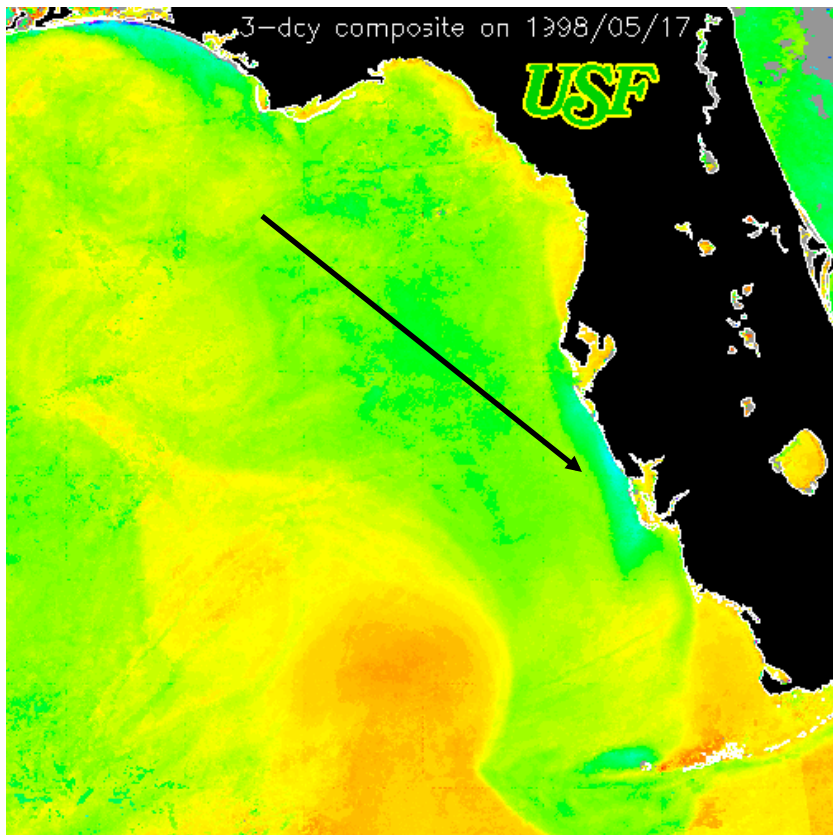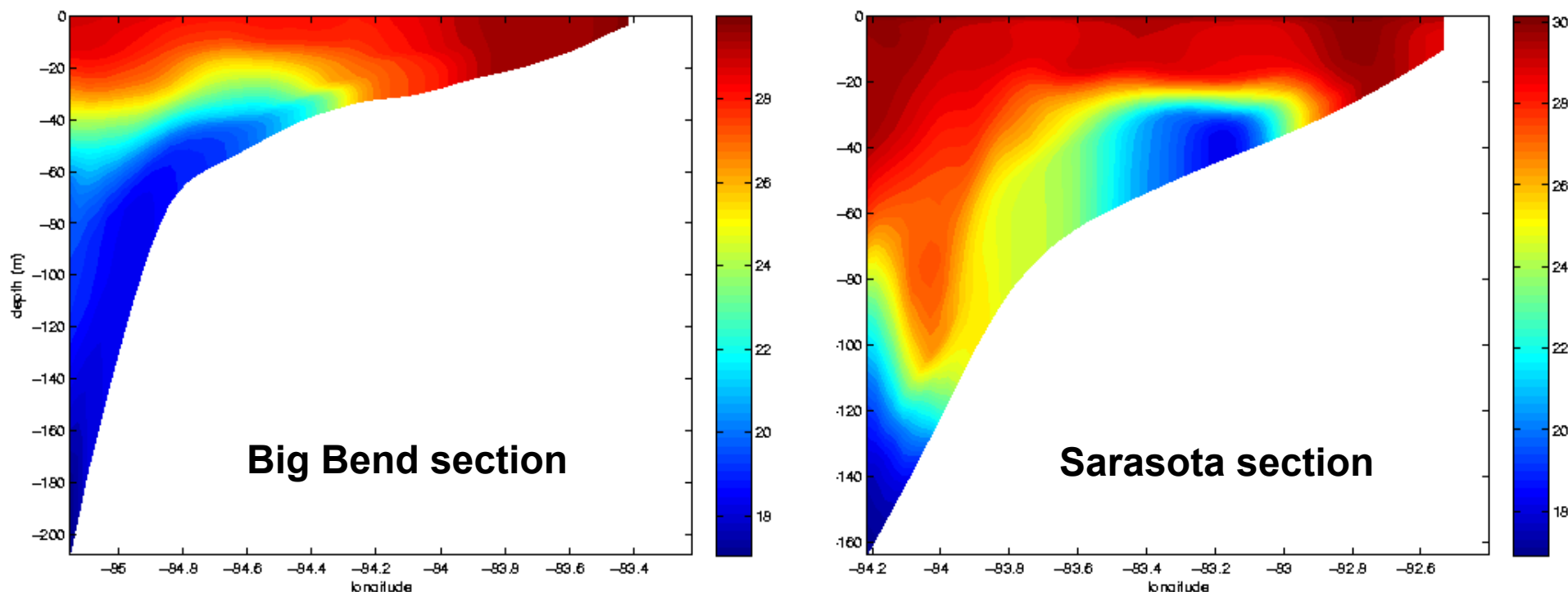
Subsurface Oil Can Approach the Beach Via the Bottom Ekman Layer

May 1998 provides an example in which a prolonged upwelling event provided connectivity from the Florida Big Bend shelf break to the Sanibel coast ~300 km away.

Model-Simulated Upwelling on the WFS

The upwelling implied by some of the drifter and mooring data is also seen in cross-sections of temperature simulated by the WFS N/F model. Observations by gliders deployed both by the CMS-USF and by Mote/Rutgers confirm this. The continuation of all of these observations, along with the modeling, are of critical importance toward monitoring the potential effects of oil on WFS waters and beaches. Note that the upwelling increased over the past week, consistent with the observed flows on the WFS. It is the coordination between observations and models that allow us to understand the behaviors on the WFS.

Was our work used?

All Visitors

http://ocgweb.marine.usf.edu

Nearshore
Surface Oil Forecast
Deepwater Horizon MC252

NOAA/NOS/OR&R   Nearshore

Estimate for: 1200 CDT, Wednesday, 6/16/10
Date Prepared: 2100 CDT, Sunday, 6/13/10
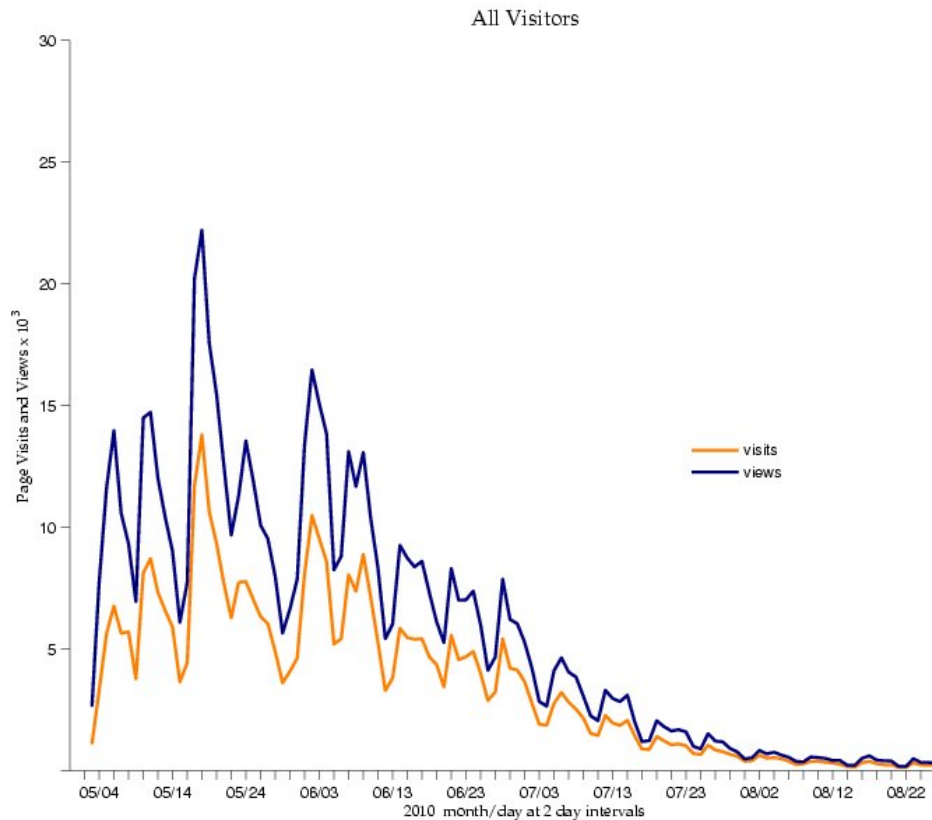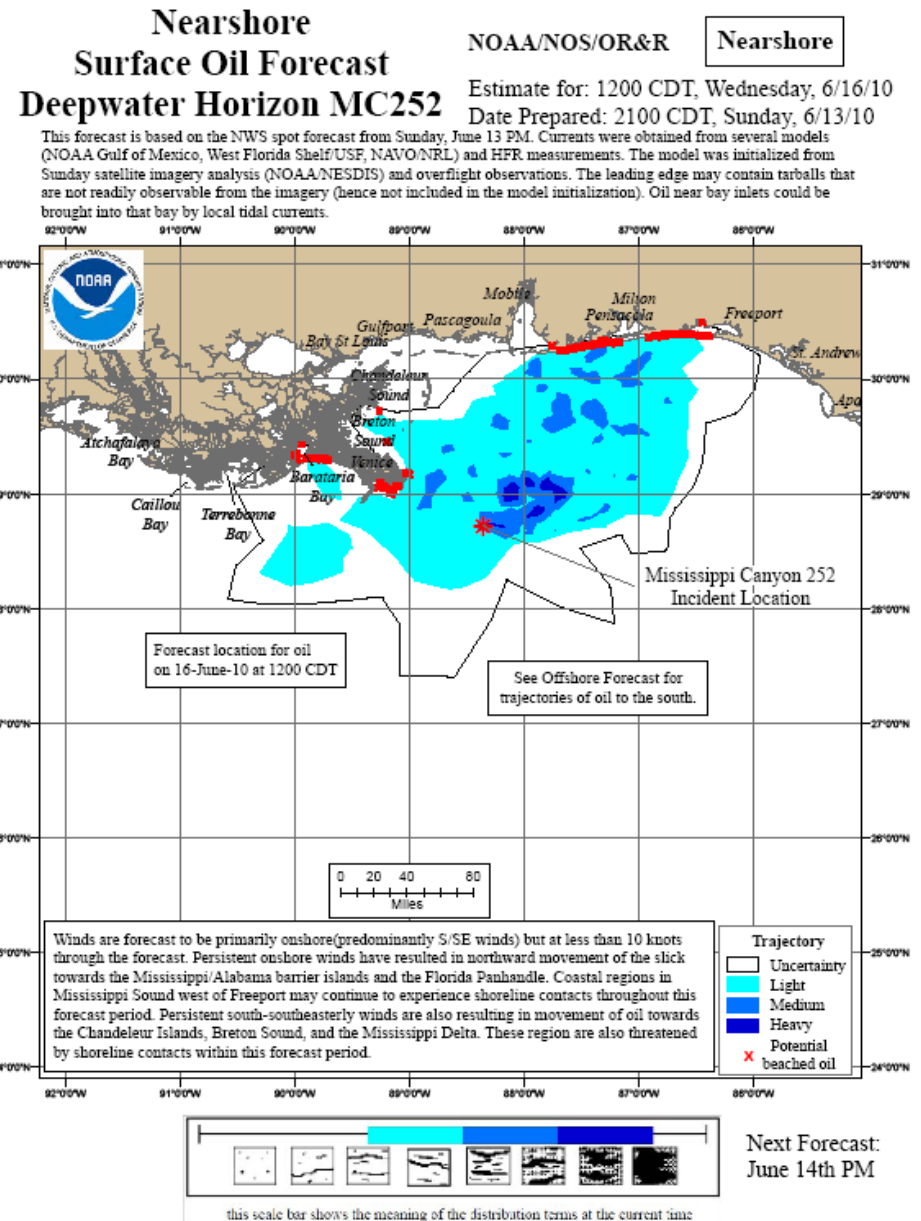
Trajectory Model Performance
Model forecast vs. Satellite Observation

The trajectory model does not have:
(1) Evaporation
(2) Emulsification
(3) Dispersion
(4) Mitigation (fire, dispersant)
(5)……

Pictures from
http://news.wenxuecity.com/
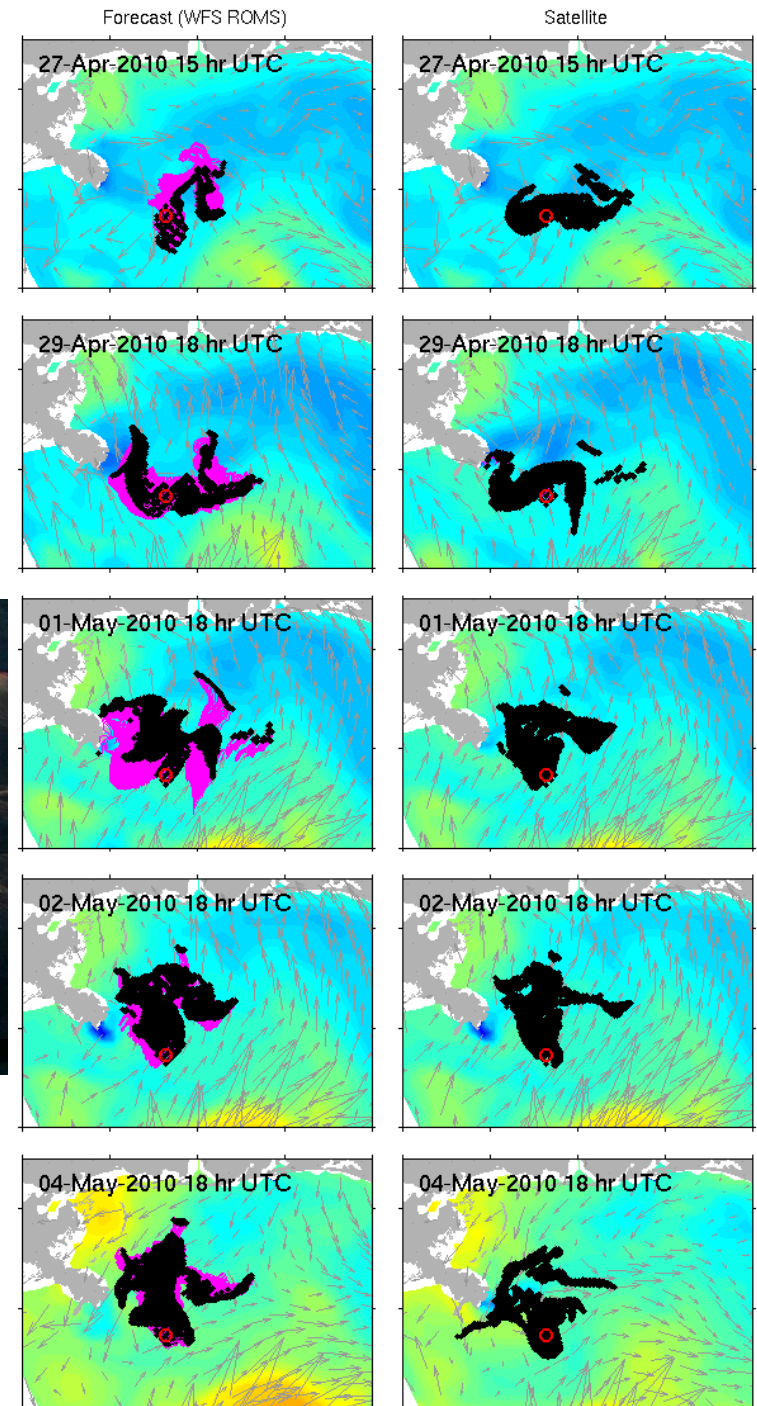
Small Oil Patches Spotted in the Loop Current on 5/20/2010

These small oil patches entrained in the Loop Current and elsewhere can not be seen from satellite imagery.

Aircraft photo (86°52'35", 27°15'20")
05/20/2010

(from Florida Fish and Wildlife Conservation Commission)
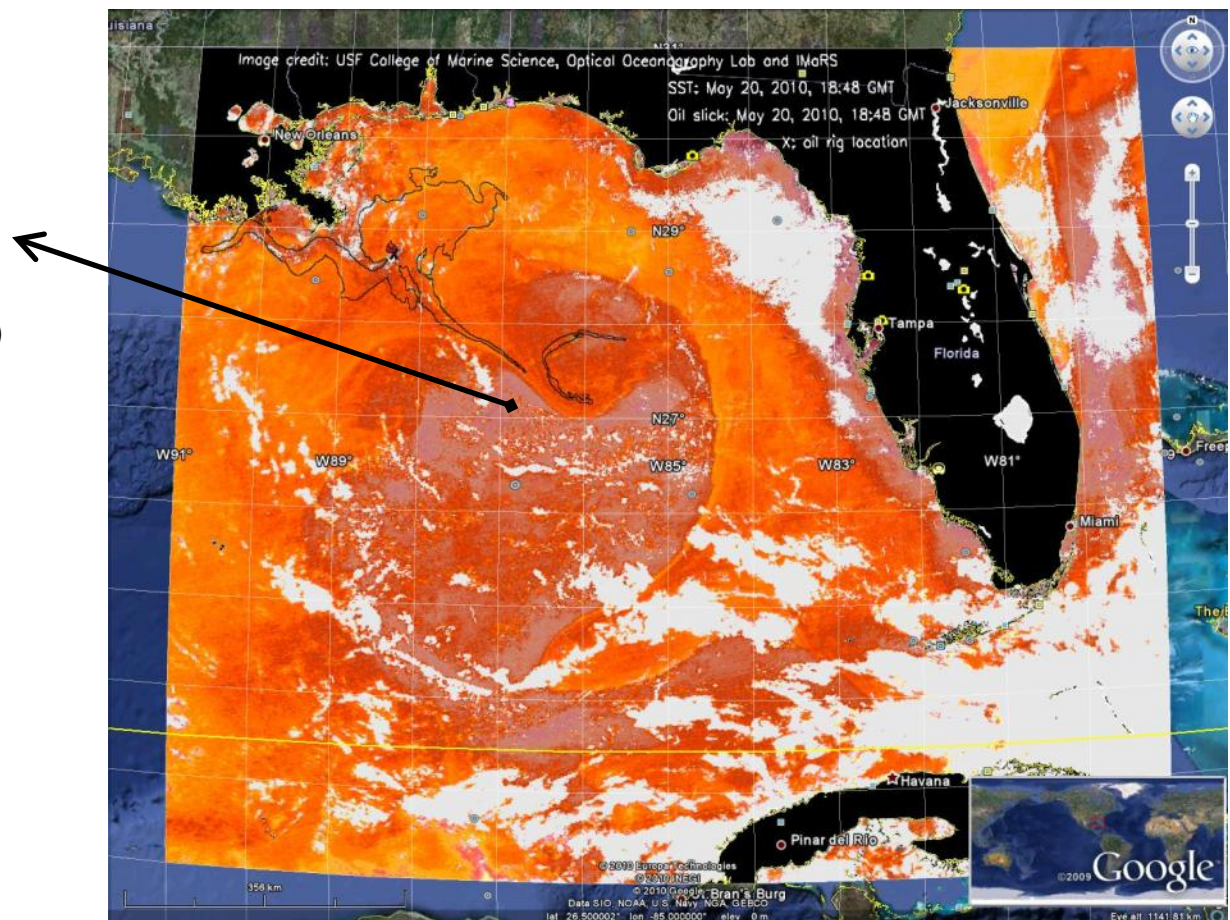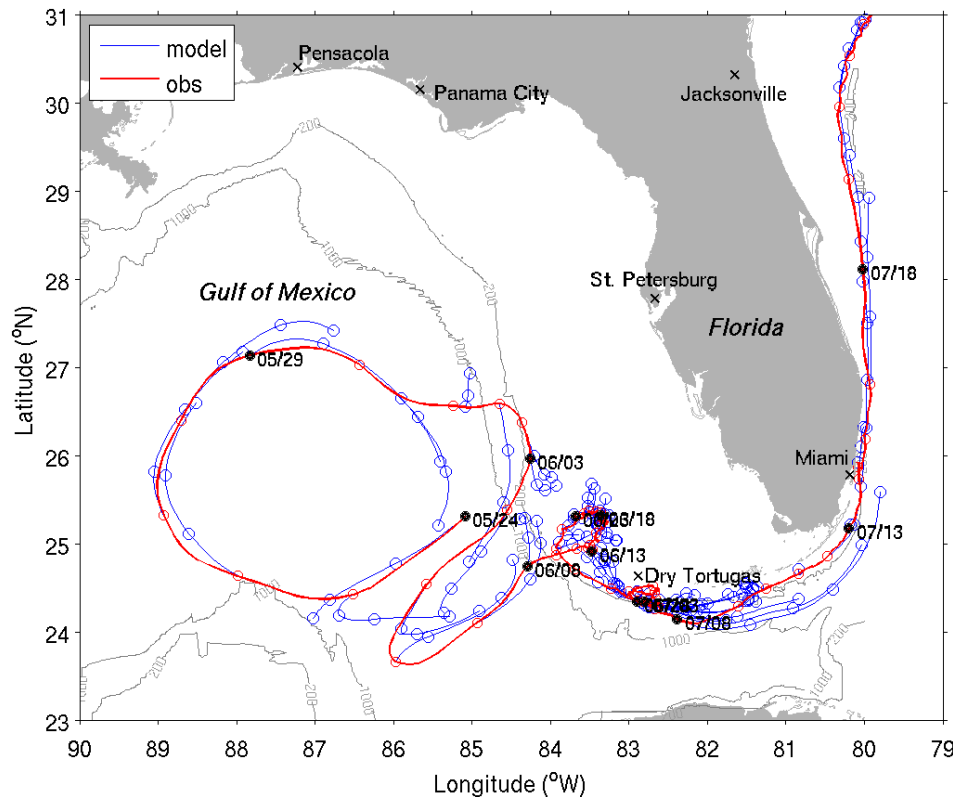
Performance of Global HYCOM-Based Surface Trajectory Model
(ongoing work)

Virtual drifters are re-initialized everyday from the observed location of the satellite-tracked drifter, and simulated for three days.

The separation distance between the endpoints of the modeled and observed trajectories is used to quantify the Lagrangian discrepancy.

Performance of Global HYCOM-Based Surface Trajectory Model

(All USF drifters, May - Aug 2010)

OCG/CMS/USF   04-Sep-2010 00 hr UTC
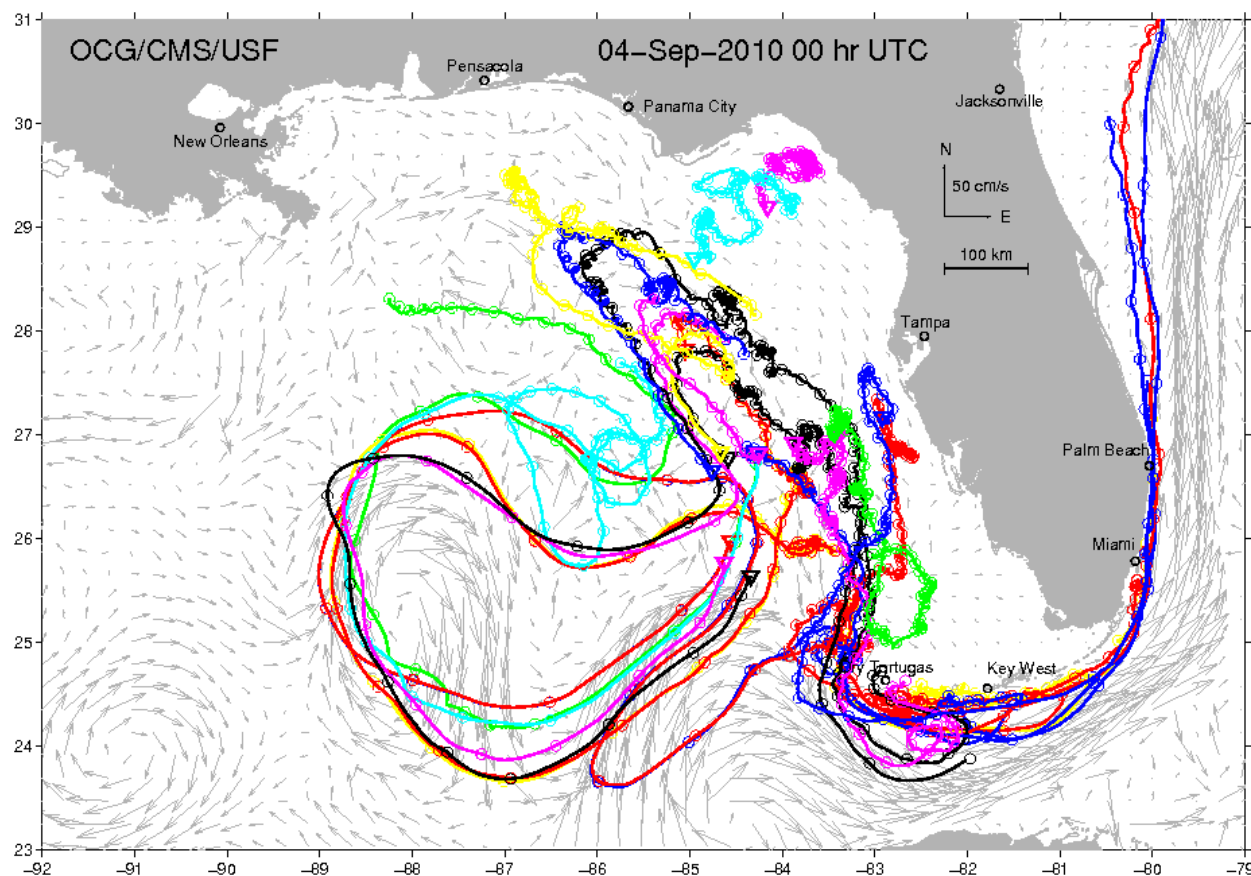
Better than previous results: average Lagrangian discrepancy of 78 km after 3 days of drift (*Price et al.* 2006)
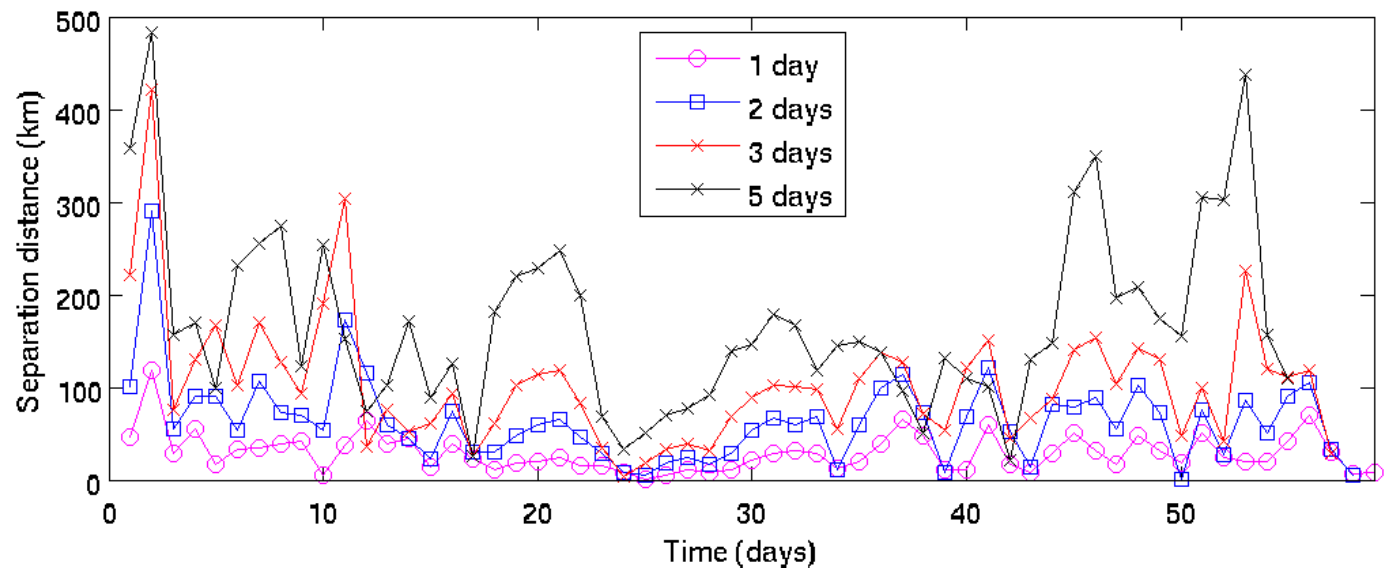
(a) 1-day discrepancy:
mean = 18 km
std = 16 km
min = 0 km
max = 129 km
(total obs 854 days)

(b) 2-day discrepancy:
mean = 38 km
std = 37 km
min = 1 km
max = 292 km
(total obs 853 days)

(c) 3-day discrepancy:
mean = 57 km
std = 58 km
min = 0 km
max = 461 km
(total obs 851 days)

(d) 5-day discrepancy:
mean = 89 km
std = 90 km
min = 1 km
max = 730 km
(total obs 847 days)
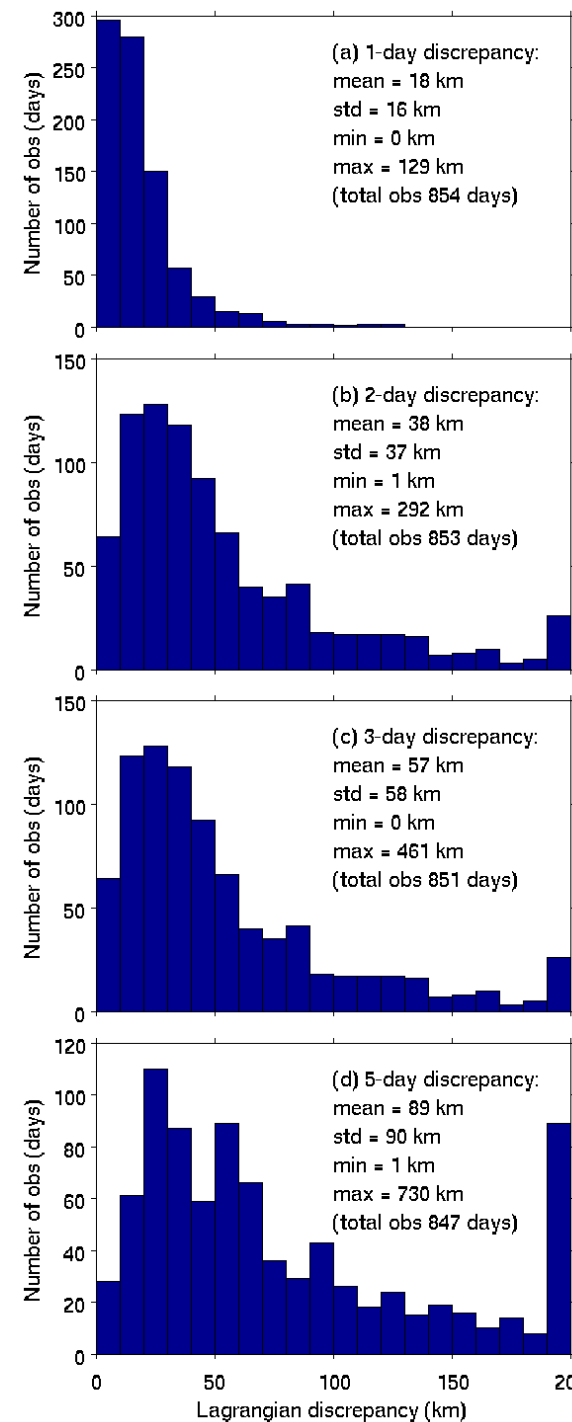
New model construction whose development was accelerated because of the oil spill.

Along with ROMS we now also nest FVCOM in HYCOM to connect both the deep-ocean and the estuaries with the coastal ocean. This work was accelerated in preparation for oil possibility approaching the west Florida estuaries.
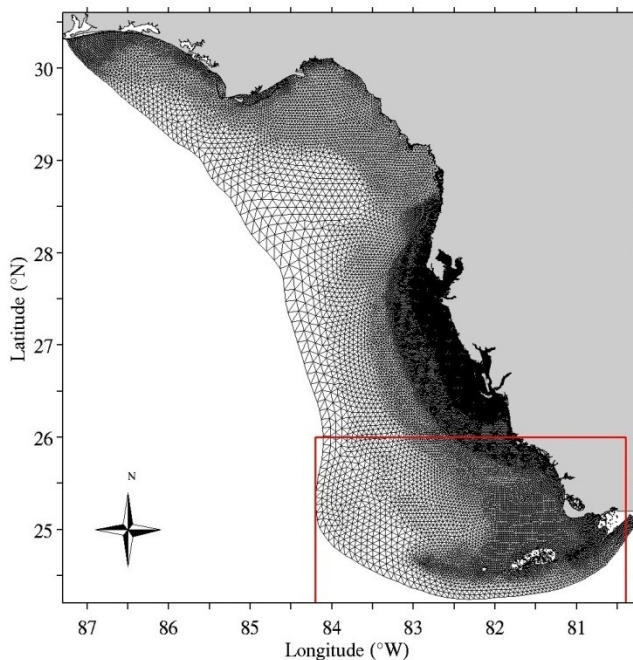
Overall model domain   **Enlargement for FL Keys**   **Data comparison**

What are some continuing environmental concerns?

- **What is the spatial (both horizontal and vertical) extent of the subsurface oil?**
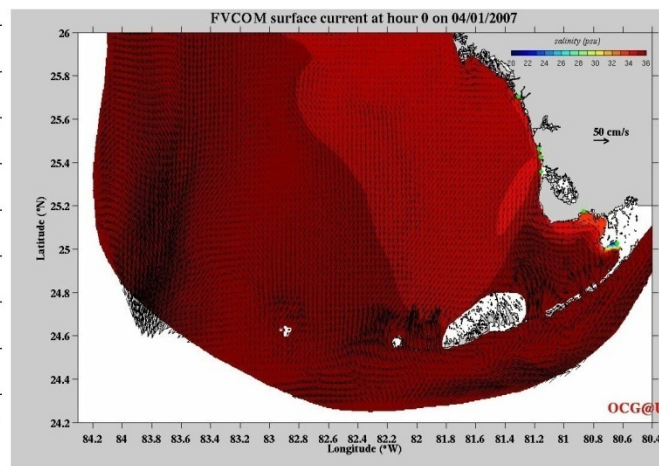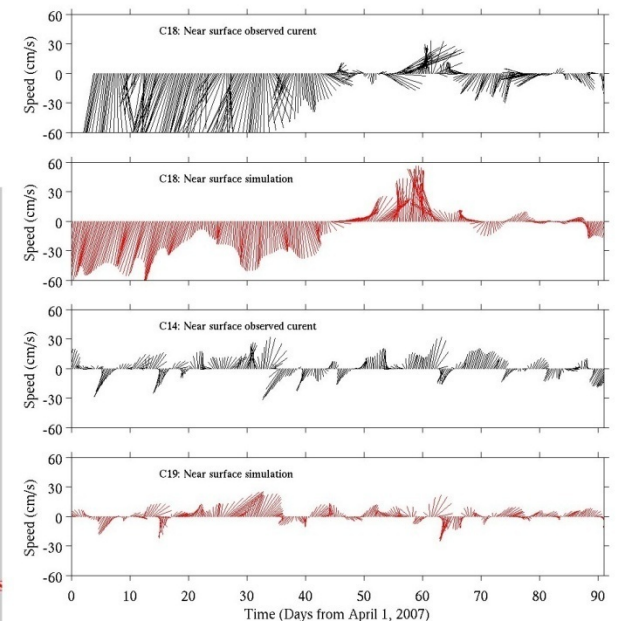 This information is needed to reinitialize ocean circulation models for the purpose of tracking where these hydrocarbons and related dispersants will head.

- **What are the concentrations of the hydrocarbons and dispersants?**
  We know that these concentrations are low, simply on the basis of how much oil was leaked relative to the volume over which it has spread. Nevertheless, there are concentrations for which these materials may be harmful.

- **What concentrations are toxic to marine life, and how quickly might toxic levels bio-accumulate up the food chain?**

- **What are the rates of chemical decomposition or biological consumption,**
  i.e., how quickly will the subsurface hydrocarbons/dispersants diminish to levels at which they will pose no ecological threat?

- **Florida was very lucky!**
  We must recognize that just because a larger natural disaster did not occur for Florida, such risk should not be underestimated going forward.

What are some Lessons (to be) Learned?

- Better coordination is needed between all parties: the agencies (federal, state, local), the private sector and the academics; each has an important role to play.

- Was the use of dispersants a good, or a bad, idea?

- With regard to ocean observing and modeling capabilities we were caught short. This requires remedy? A pathway forward is the implementation of an integrated ocean observing system (IOOS) as conceived a decade ago, but without adequate coordination or funding.

- The ocean is a complex system, and the behavior of oil spilled into the ocean certainly bears this out. If we are to understand our ocean ecology and thereby engage in concepts like *Ecologically-Based –Management* or *Marine Spatial Planning* then we must approach the ocean in a systematic, comprehensive, multidisciplinary way. Otherwise we will fail at environmental stewardship.

- Florida's economy is in every way touched by the ocean. We were lucky, and the BP spill gives us pause to re-evaluate how we all interact to better understanding the workings of our precious ocean resources.

Acknowledgements

Models:
- **WFS ROMS** – A. Barth, L. Zheng
- **Global HYCOM** – E. Chassignet, HYCOM Consortium
- **Navy GOM HYCOM** – O. M. Smedstad, NRL
- **SABGOM** – R. He, NCSU
- **RTOFS** – C. Lozano, NOAA/NCEP
- **NCOM IASNFS** – NRL, F. Bub, NAVO

Observations:

CMS-OCG Sea-going activities: J. Law, R. Cole, C. Merz, J. Donovan, D. Mayer, P. Smith & V. Subramanian. C. Kovach (FDEP) assisted with USF drifter deployments.

Support:

ONR, NOAA-ECOHAB, NOAA-SECOORA, State of Florida