New Title: Weather Effects

Fortunately, we never had a direct impact from a tropical cyclone. However, we did have effects from a variety of weather systems (including the fringe effects of Hurricane Alex) and partially explains the oil impacts in certain regions. So, the title could be changed to either "wind effects" or "weather effects." It should also be noted the work is transitioning to fate and transport since we're using NCOM model data. It is our plan to add weathering effects based on oil spill modeling literature and simulate the entire oil spill life cycle...all of which would be detailed in a proposal should we get the request.

Phase 1 Project: Hurricane Effects – Leader, Dr. Pat Fitzpatrick, Geosystems Research Institute

Collaborators: Drs. Yee Lau; Chris Hill; Haldun Karan, Geosystems Research Institute

The Deepwater Horizon oil spill already poses a large environmental threat to the Gulf of Mexico region. However, the imminent impact of tropical cyclones on this situation is unclear. Although destructive to coastal property, hurricanes often dilute local pollutants through ocean mixing and storm surge flushing, and occasionally with heavy rainfall. However, the Valdez oil spill was actually expanded by an extratropical cyclone which contained tropical-storm force winds. This event demands an immediate investigation of this hurricane season's possibilities.

As already demonstrated by the relatively large error margins from NOAA's oil spill trajectory forecasts, oil spill modeling currently contains a number of uncertainties. These models must capture the following processes affecting oil spill distribution: advection, spreading, evaporation, dissolution, dispersion, mixing, and emulsification. Accurate input of winds and ocean currents is also required. Both tropical cyclones and oil spills occur in a data-starved environment, further complicating determination of these storms' impact.

Hierarchies of oil spill models have been developed, differing in computer platform capability and mathematical complexity. They include "budget", 2D, and 3D models. "Budget" models request basic input such as: initial oil concentration, a time series of winds, wave, water temperature, salinity, sediment load, ocean current, type of oil release (instantaneous or continuous) to make a scalar calculation in a region. One example is the NOAA ADIOS2 model. 2D models generally assume oil concentrations travel with the ocean currents plus an additional 3% contribution from surface winds, diffused with each time step. Some also include weather processes which modify the oil substance with time. Examples include the MMS Oil-Spill Risk Analysis (OSRA) model, DHI's MIKE 2D, NOAA's GNOME model, and other models discussed in the literature. 3D models use a concentration transport equation that requires input from an ocean models and surface weather data. Most 3D models include weather processes as well, although it can be instructive to see use the transport equation alone. One example is DHI's MIKE 3 PT model. Other examples include the models discussed in Guo et al. (2009) and Chao et al. (2001).

Tropical cyclones presents additional modeling challenges, involving the coupling of surface winds to an ocean model to accurately represent storm-driven currents, mixing, and upwelling. The winds may be from pre-determined 2D parametric wind fields based on gradient wind equations (such as the Holland wind profile), or from an atmospheric model which responds to ocean temperature (i.e., two-way

coupling) such as the Hurricane WRF (HWRF) which is coupled to the Princeton Ocean Model (POM). Wave heights may be determined based on the Bretshneider empirical equations, or using a wave model such as Wavewatch III. The storm surge can be simulated using models such as SLOSH or ADCIRC.
Task A Objectives: Due to the complexity and variety of oil spill models, as well as account for model uncertainty, the best approach is to run an ensemble of oil spill models. Since results are needed quickly, a detailed scientific assessment will be postponed until Phase 2. Phase 1 will focus on providing results to six tropical cyclone scenarios using several modeling approaches. Recommendations for further research in Phase 2 will also be made based on these results for studies after the 2010 Gulf hurricane season. This research will be coordinated with LSU via Dr. Jim Chen, since they have expertise with GNOME and MIKE. We will also coordinate with FEMA and USACE to obtain their hurricane simulation results produced for flood mapping and levee design, respectively.
Primary task objectives are to achieve primary objectives 1 and 6 by:

- Providing a forecast ensemble using budget, 2D, and 3D models for six tropical cyclone scenarios by 15 August 2010. The scenarios are subdivided into landfall west (central Louisiana) and east (Pensacola) of the oil spill, with intensities of tropical storm, Category 2, and Category 4.
- Developing a research strategy for Phase 2 that performs detailed analyses of hindcast oil spill simulations for the 2010 hurricane season.

Subtask A1: Model simulations

- Run ADIOS2 for tropical storm scenarios. Its algorithms are not valid for hurricane-force winds.
- Run GNOME in standard mode and diagnostic mode for all six scenarios using parametric wind hurricane calculations.
- Run MIKE 3 PT for all six scenarios using output for all six scenarios using input from HWRF model
- Run multiple versions of a 2D oil spill trajectory forecast using input from HWRF model, based on the following equations. Denoting the zonal speed component as *u*, meridional speed component as *v*, the oil drift speed can be computed as

$$u_d = u_o + 0.03u_a \quad ; v_d = v_o + 0.03v_a$$

where the subscripts d, o, a and are for drift, ocean, and air, respectively. These values will be determined from HWRF output. The parcel distance ΔS per timestep $\Delta t$by diffusion is:

$$\Delta S = [R]_0^1 (12D_H \Delta t)$$

where $[R]_0^1$ is the random number in the interval 0-1, D_H is the horizontal diffusion. Multiple versions will be performed by varying surface D_H. In one version, D_H will be determined by the POM model output from HWRF, currently computed by the Smagorinsky formulation. In other versions, it will vary from 5-15 m^2s^{-1} . Simulations without the random number component will also be performed.
The displacement *L* of each parcel per timestep will be calculated by:

$$L_x(\Delta t) = u_d \Delta t + \Delta S \quad ; L_y(\Delta t) = v_d \Delta t + \Delta S$$

Repeat the above methodology, except include a 3D trajectory component where vertical ocean velocities from HWRF are included and vertical diffusion from the KP formulation is used. Initial oil concentrations will assume an exponentially decreasing profile to 1.5 times the ocean wave height based on the results of Delvigne and Sweeney (1989).

- Time permitting, we will also vary oil concentrations, assuming the spill is stopped by early August and that other oil containment efforts have also been successful.
- Particle transport calculations will be performed using a concentration transport equation already available in HWRF.

Subtask A2: Results Transfer and Display

Graphics of the simulations (Task D) will be presented online at the NGI website with summaries in August and provided to Tasks B-C. A consensus plot will also be displayed. Discussion of the sensitivity to diffusion will be included. The potential shoreline impact will be examined to east and west landfall scenarios and by intensity. Natural dispersion by wave and current action will also be explored.

Subtask A3: Recommendations

By November, the impact of the 2010 hurricane season on the oil spill will be known. Recommendations will include details on: 1) a validation study of 2010 Gulf of Mexico tropical cyclones using the various models; 2) model deficiencies; and 3) budget calculations of the weathering processes in hurricane conditions. We may also recommend the development of a community model for oil spills, similar to the developmental approaches currently in use for several ocean, meteorology, and storm surge models.

Subtask A4. Sensitivity Testing

Additional analyses will be performed to examine the effect of other influences, including changes in water temperature as defined by subtask E1 and to provide detailed predictions for the field sites employed in Tasks B and C.

Phase 2 Tasks: Continue above with …

- More wind and ocean current analysis for the case study period
- Applying the Lagrangian particle tracker-diffusion model to the case study period using NCOM ocean currents
- GRI Starkville personnel apply additional visualization techniques for the Lagrangian model ensemble (Moved to “APPLY” Cluster)

Future tasks

- The closure of the Mississippi River Gulf Outlet last year may have benefitted the eastern marsh by decreasing tidal influences. This should be studied.
- The benefit of the fully opened diversions and the man-made sand berms requires examination.
- The software can be expanded to include vertical interactions and oil-weathering terms. The development of a consortium to develop a oil-spill community model needs to also be explored.
- The inclusion of dispersants in oil spill models is a difficult problem that requires

exploration.

- Validation of any oil spill model is required. Furthermore, the model's initial fields, as well as the influence of currents and winds, requires an optimal variational analysis approach similar to data assimilation techniques used in meteorology and oceanography.
- An overall understanding of why some areas had high oil impact while others did not is needed.
- Such studies will also assist in understanding the fate of the oil.

Task A: Oil spill modeling for tropical weather events for Northern Gulf Coast

Mississippi State University
Geosystems Research Institute, Stennis Space Center

Pat Fitzpatrick
Yee Lau
Chris Hill
Haldun Karan

Research tasks

- Task 1: software for predicting oil movement for 2010 hurricane
- Task 2: Case study for June 20-July 10, focused on impacts of tropical cyclone and a tropical low

Task 1: software for predicting oil movement
for 2010 hurricane

Beta version of oil spill

- In-house developed Lagrangian particle tracker with random walk diffusion model. Based on oil model journal articles (references available upon request)
- Cartesian grid with flexible domain and grid spacing.
- Input: latitude and longitude of oil pollution, wind, current, array of random numbers
- Three million pseudo-random numbers uniformly distributed between 0 and 1 are generated by the efficient Mersenne Twister algorithm. This modern technique has passed stringent "diehard" and NIS tests for randomness, and will generate an incredibly long sequence of numbers ($2^{19937}-1$) before repeating. The initial seed is randomly obtained from machine noise (/dev/urandom on Linux machines)

Hurricane scenarios

• Storm surge simulation was conducted using the ADCIRC model

• The example scenario involved a Category 2 hurricane making landfall at Fourchon

• Currently, oil is being observed in northeast Barataria Bay, and along the beaches from Sandy Point to Chalon Pass. Much of the oil is on the seafloor and portions are moving in with tide and wind action.

• The simulations shows where this oil may be transported in a hurricane event.

• Winds and currents from ADCIRC are interpolated to oil model grid.

• Software can be used for remainder of hurricane season

Hurricane ensemble runs

• The oil moves with the "advection components" u_{adv} and v_{adv} :

$$u_{adv} = \alpha u_c + \beta u_w \qquad v_{adv} = \alpha v_c + \beta v_w$$

where u_c and v_c are the zonal (x-component) and meridional (y component) water currents, and u_w and v_w are the zonal and meridional winds.

• Oil remains on the seafloor until current is strong enough (at least 0.4 ms^{-1}) to move it.

• Wind only plays a small role in moving oil, and is β=0.03

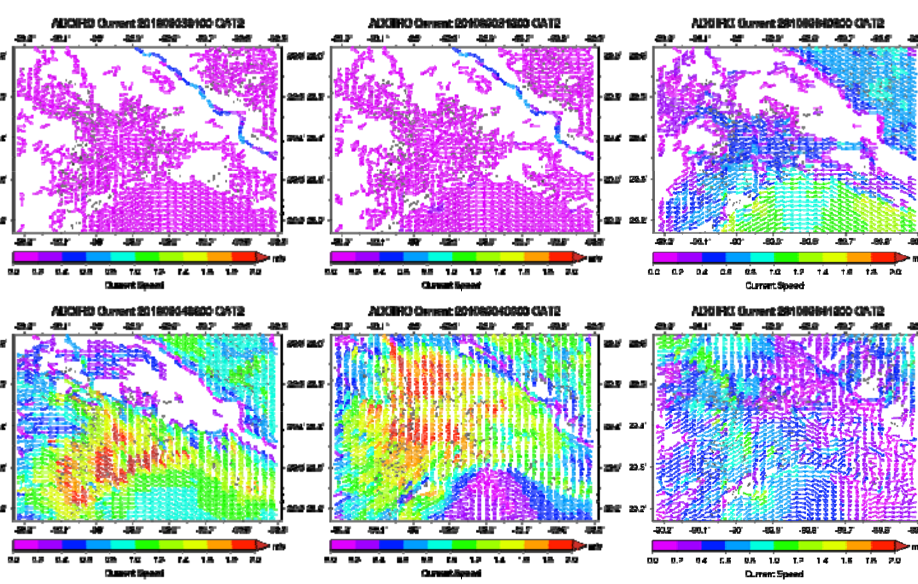
• To account for the uncertainty in current transport as well as diffusion, a combination of 9 runs were done with α=0.5, 0.6, and 0.7 and the diffusion coefficient=7, 10, and 15 m^2s^{-1}. A consensus of how the oil will propagate will emerge by assessing all nine runs.

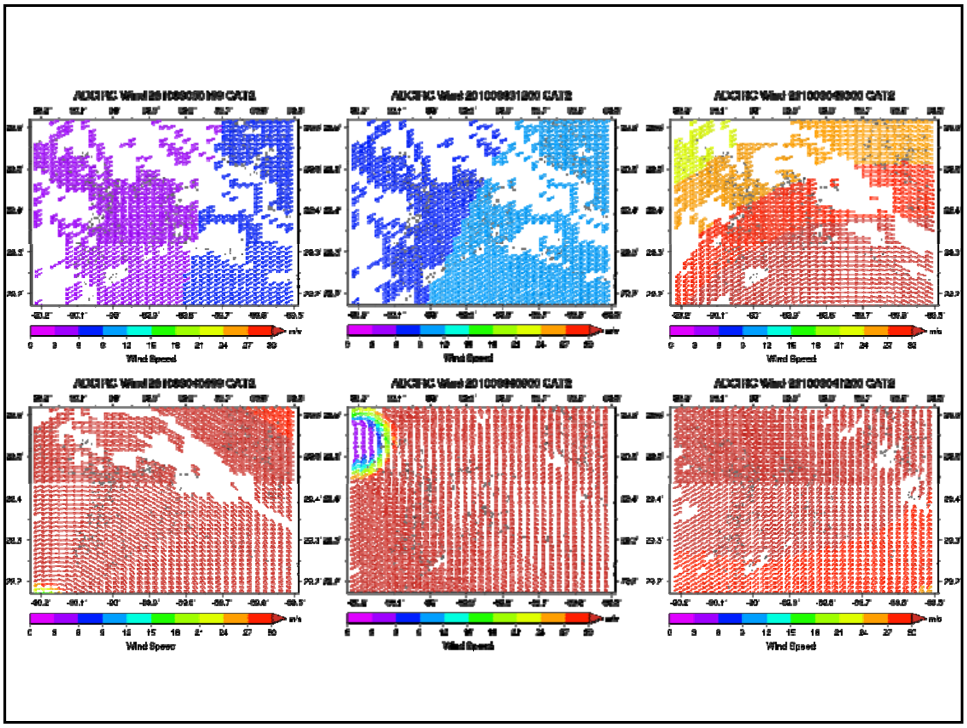
Next 4 frames show Category 2 hurricane
making landfall at Fourchon

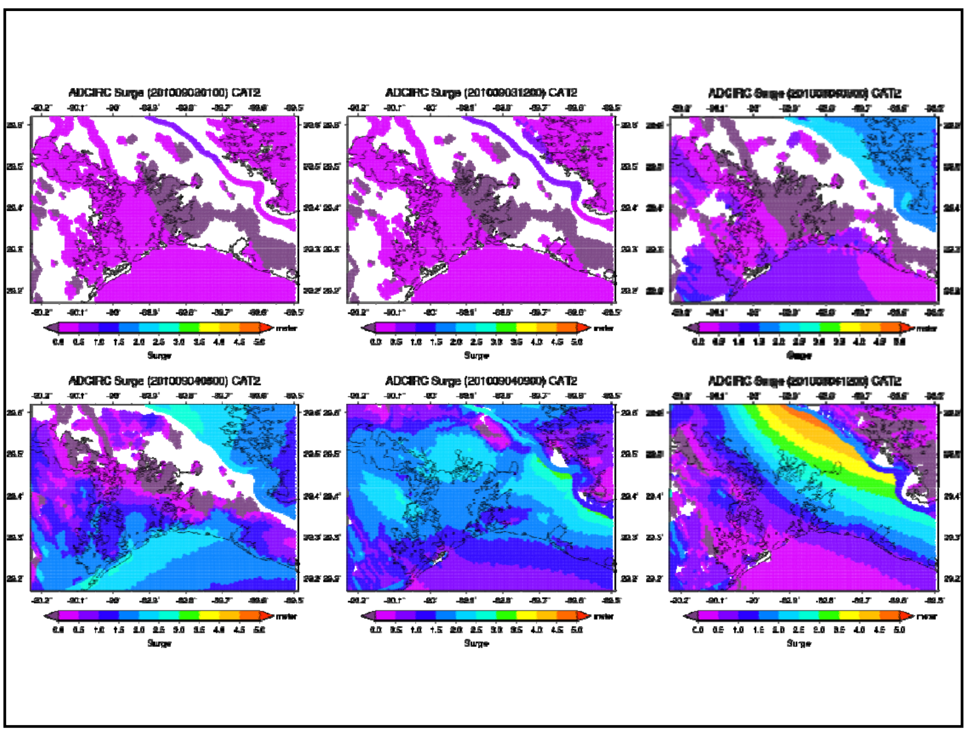
Plots show water currents, winds, storm surge,
and oil movement with α= 0.6 and the diffusion
coefficient=10 m^2s^{-1}

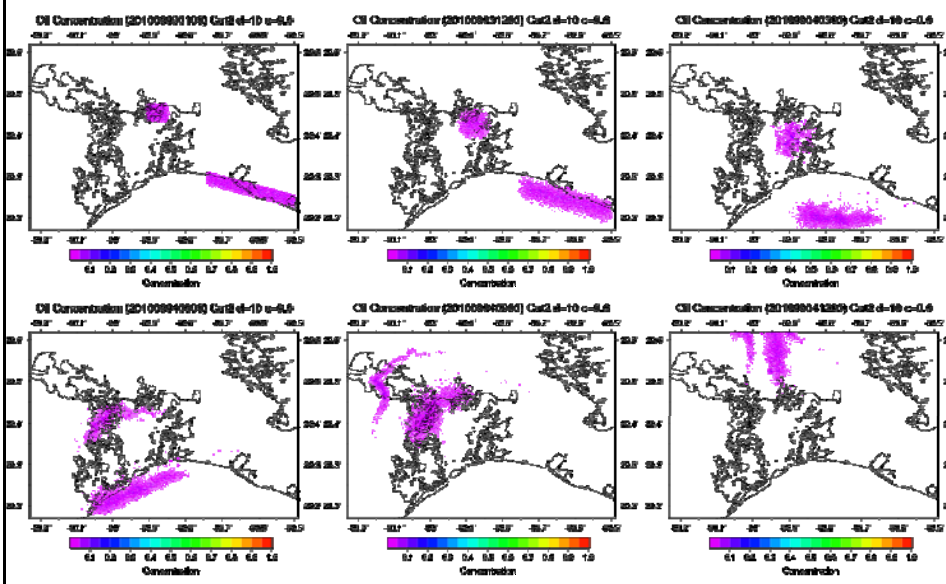
The time frame is (left to right): 15 hours before landfall; 4 hours before landfall; 3 hours before landfall; landfall (eye at Fourchon); 3 hours after landfall; and 6 hours after landfall.

They show oil moves west towards western Barataria Bay, then north, then east in a clockwise pattern




Wind Speed
m/s

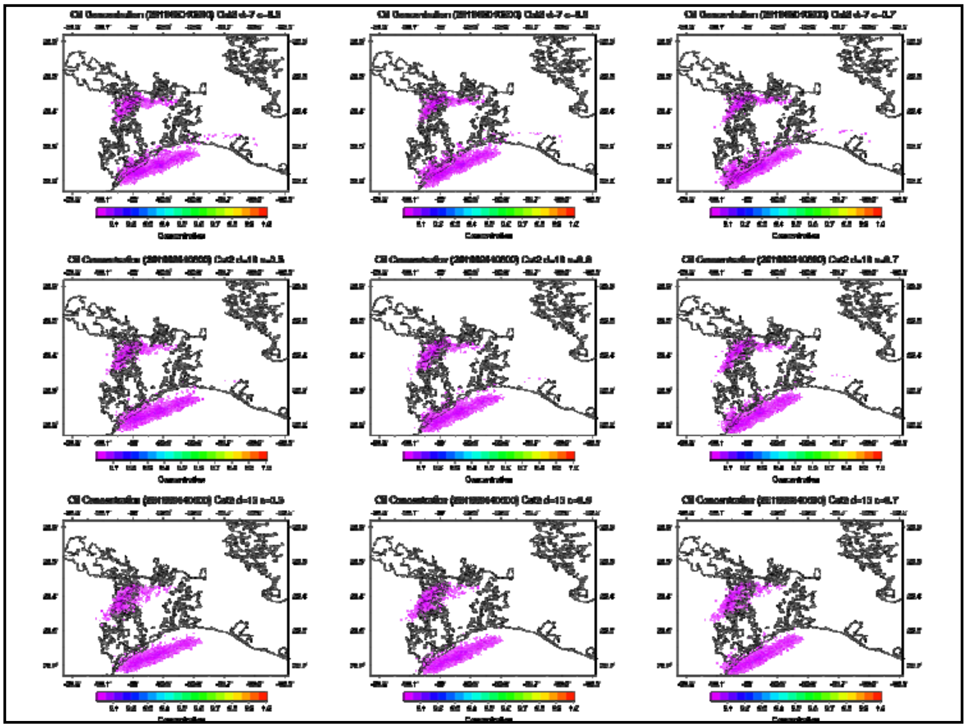

Surge
meter

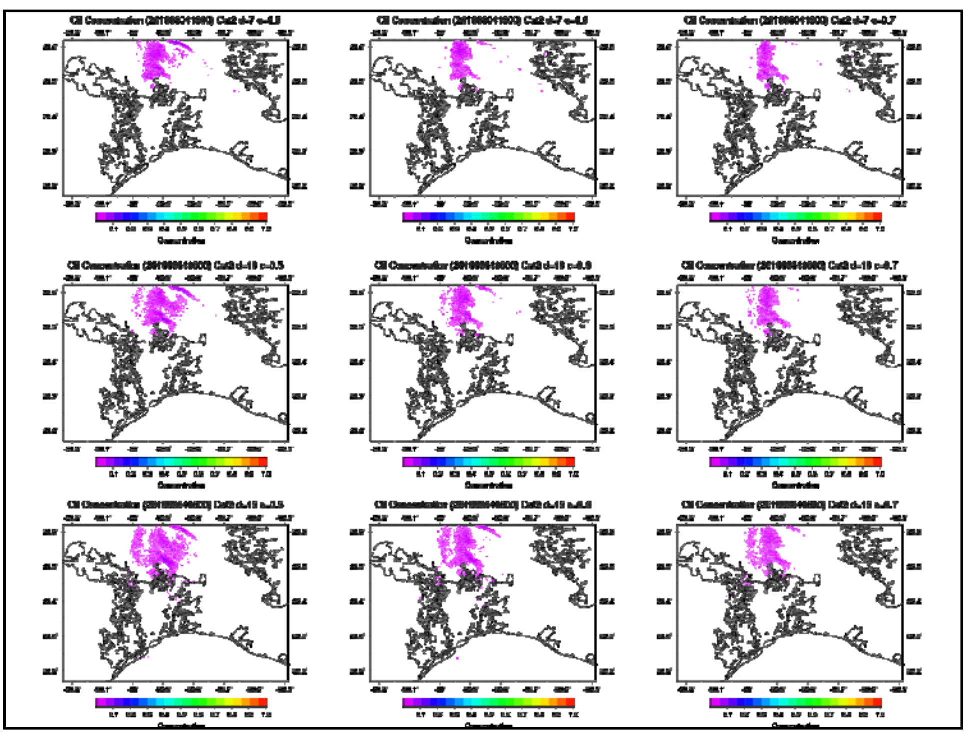


Next two frames show oil movement for combinations of α= 0.5, 0.6, and 0.7 and the diffusion coefficient=7, 10, and 15 m^2s^{-1}

The time frame is landfall (eye at Fourchon); and 12 hours after landfall.

Conclusion: for this scenario, the ensemble average suggests oil would end up in the marsh northeast of Barataria Bay, but residuals could be throughout western Barataria Bay

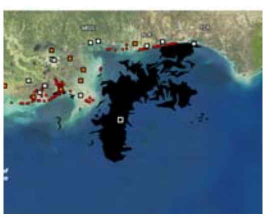




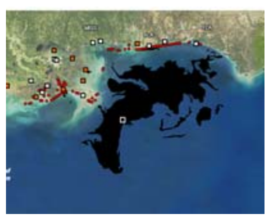
Task 2: Case study for June 20-July 10, focused on impacts of tropical cyclone and a tropical low

Times Picayune depiction of oil spill evolution (June 15-July 10)

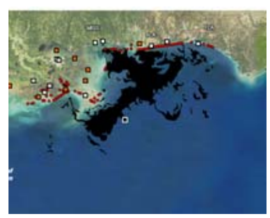
June 15



June 20



June 25



June 30

July 5

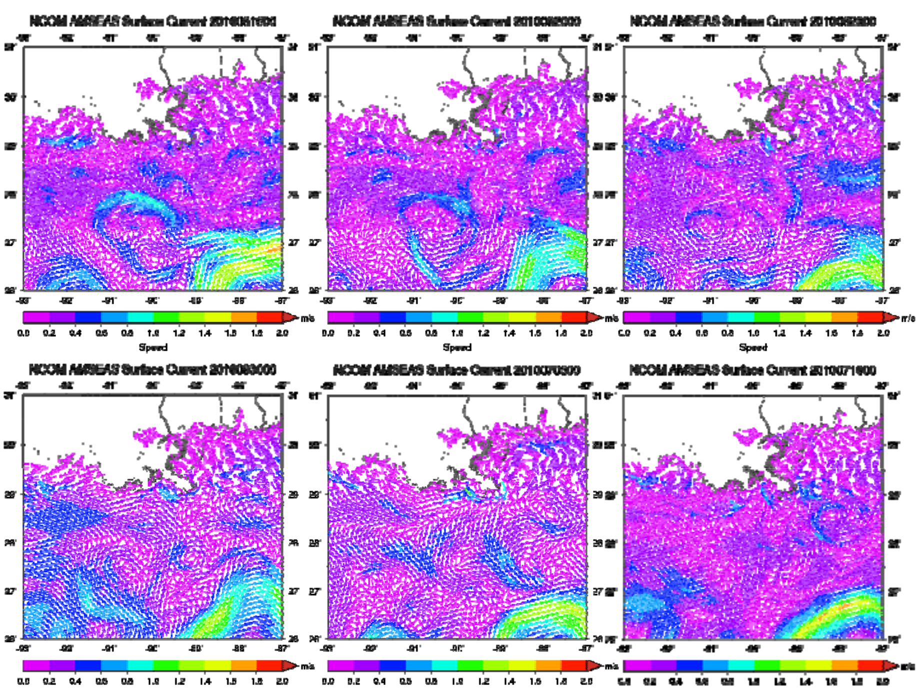
July 10

Note oil movement into Mississippi Sound and Rigolets June 25-July 5

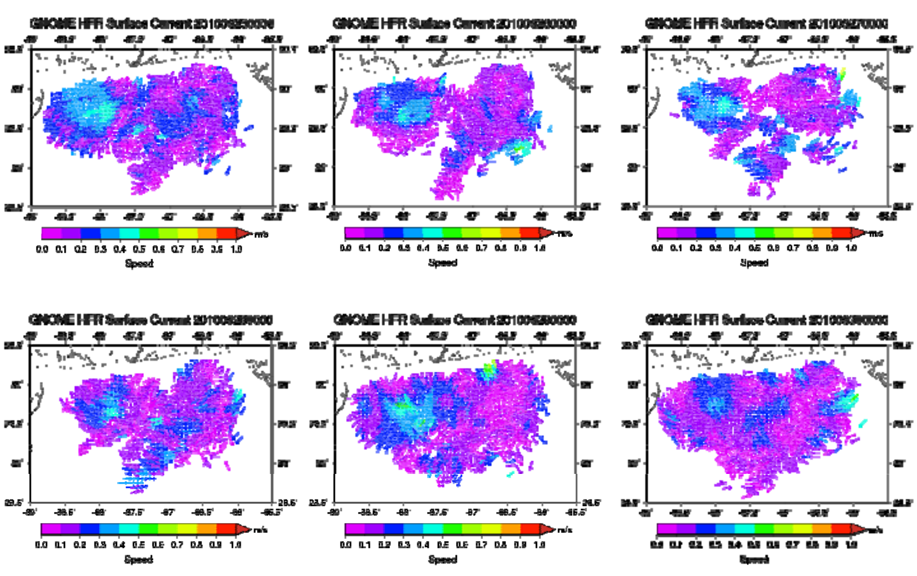
What factors contributed to oil moving inland during this period?

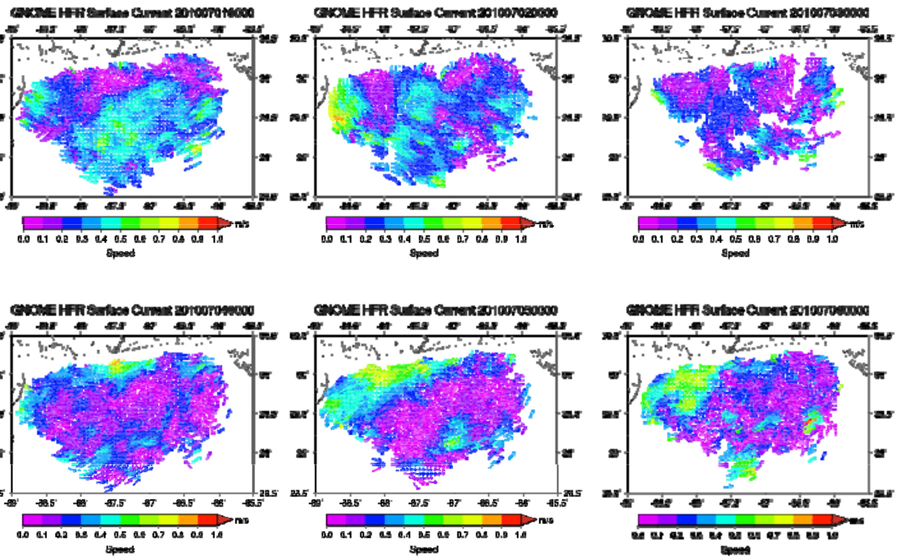
From http://www.nola.com/news/gulf-oil-spill/deepwater-disaster/index.ssf

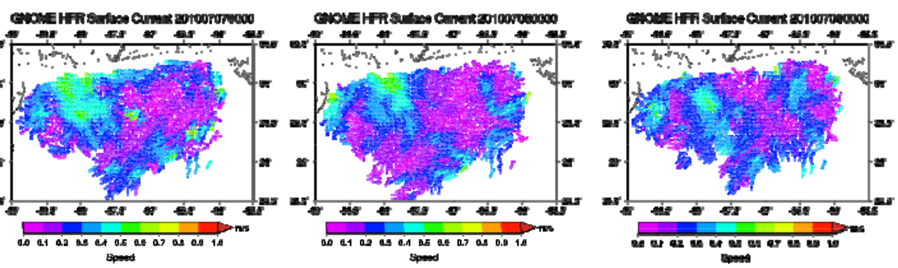
Examination of the 3-km Navy Coastal Ocean Model (NCPOM) analysis shows ocean currents off Alabama switching from southwest to southeast around June 25, then becoming easterly through at least July 5



Examination of HF radar shows similar transitions in more detail, with offshore components in between on July 2 and 3

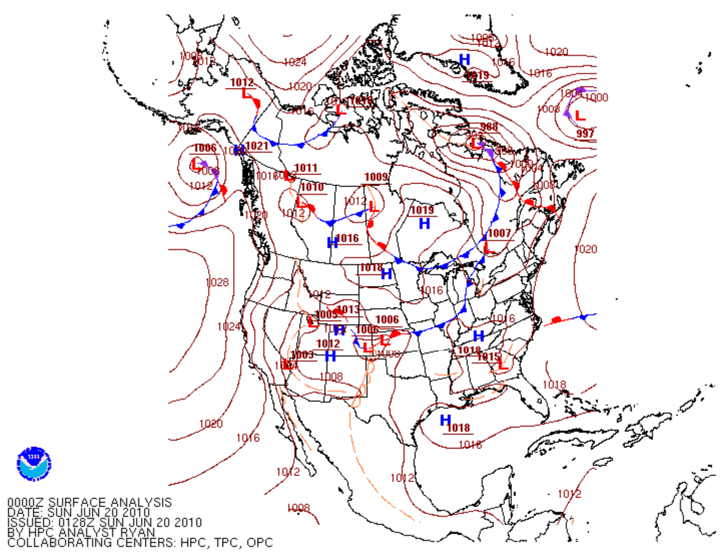


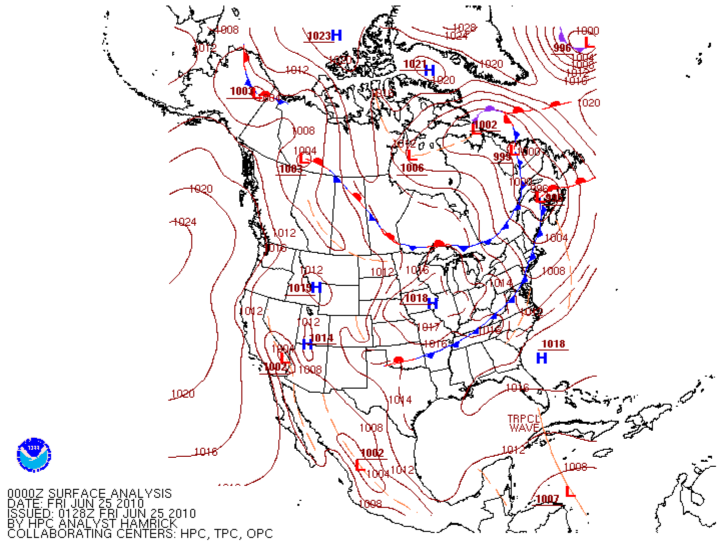




Surface maps show two main features associated with this period: Hurricane Alex, which made landfall in Mexico; and the formation of a low off the western end of a front in the Gulf that moved westward then stalled off Louisiana

The offshore front helps explain the offshore switch in water currents on July 2 and 3.

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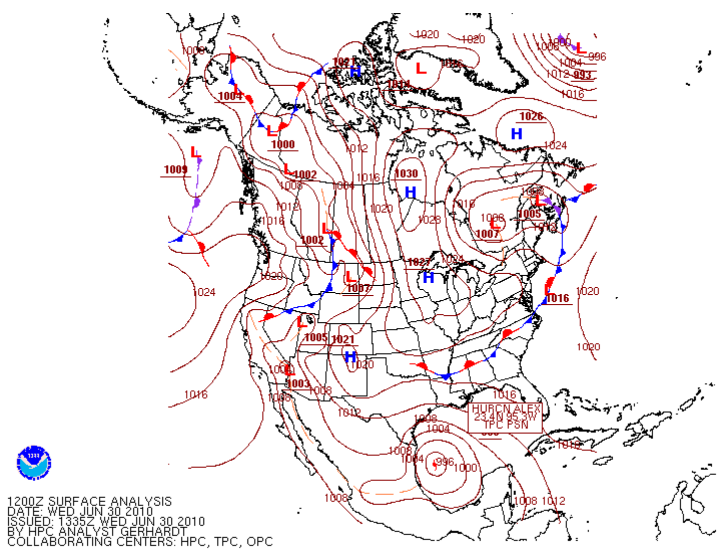
DATE: FRI JUN 25 2010
ISSUED: 0128Z FRI JUN 25 2010
BY HPC ANALYST HAMRICK
COLLABORATING CENTERS: HPC, TPC, OPC
TRPCL WAVE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DATE: WED JUN 30 2010
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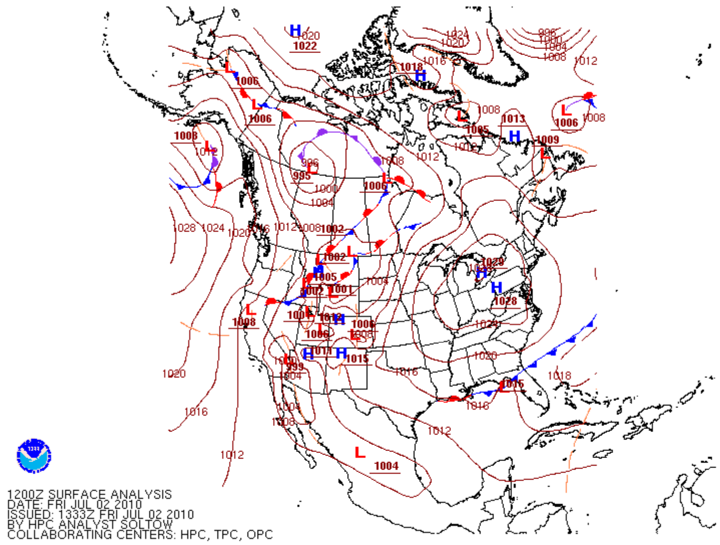
BY HPC ANALYST GERHARDT
COLLABORATING CENTERS: HPC, TPC, OPC
HURCN ALEX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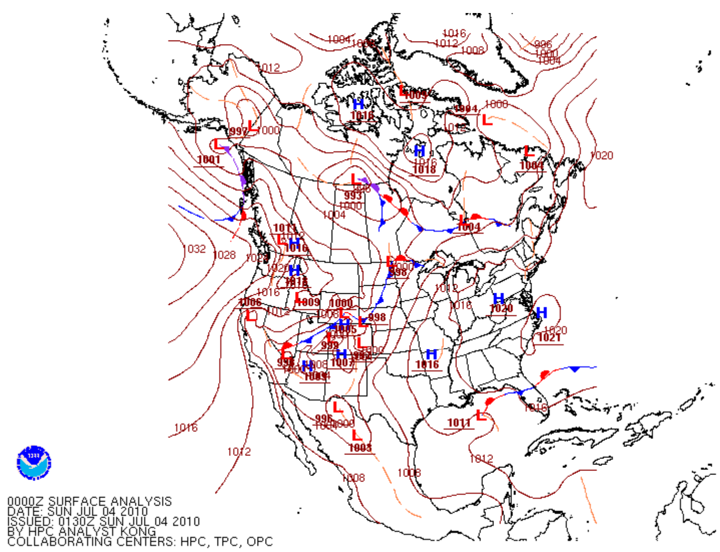
ISSUED: 1333Z FRI JUL 02 2010
BY HPC ANALYST SOLTOW
COLLABORATING CENTERS: HPC, TPC, OPC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BY HPC ANALYST KONG
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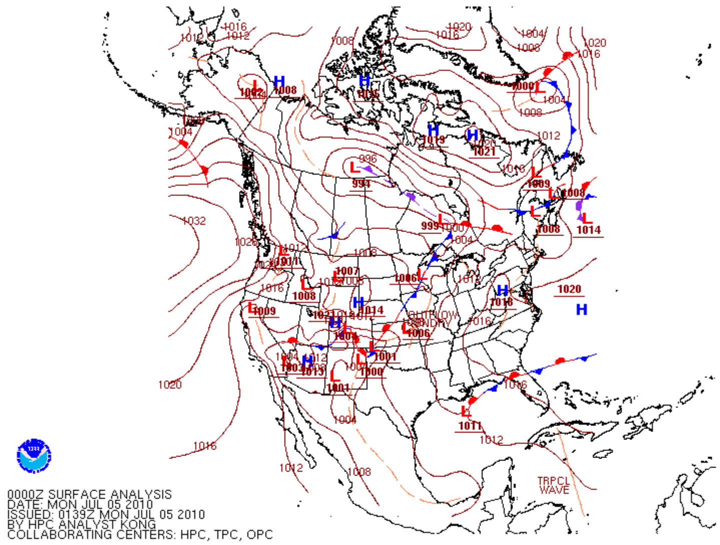
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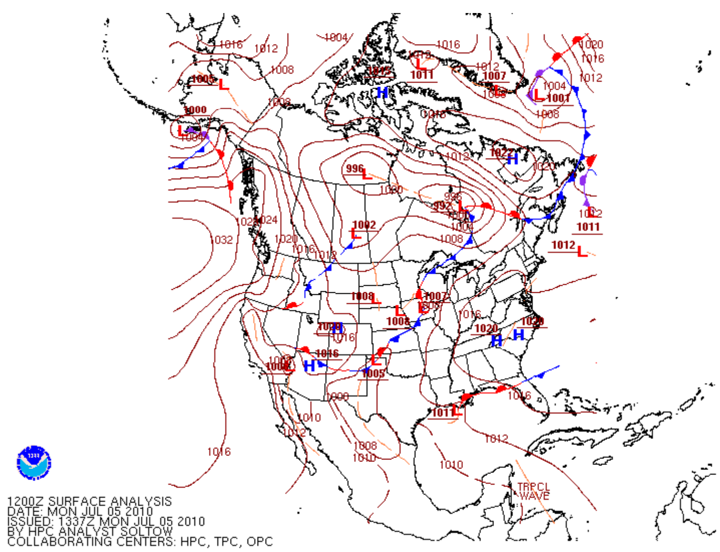
TRPCL WAVE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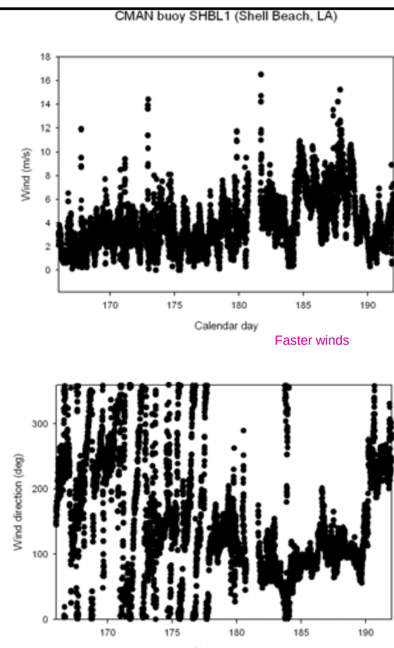
ISSUED: 1337Z MON JUL 05 2010
BY HPC ANALYST SOLTOW
COLLABORATING CENTERS: HPC, TPC, OPC
TRPCL WAVE

The next frame shows persistent easterly winds (with larger magnitude) during late June and early July at the Shell Beach, LA, CMAN station.

More buoy analysis is currently underway

Calendar day 166: June 15
Calendar day 171: June 20
Calendar day 176: June 25
Calendar day 181: June 30
Calendar day 186: July 5
Calendar day 191: July 10



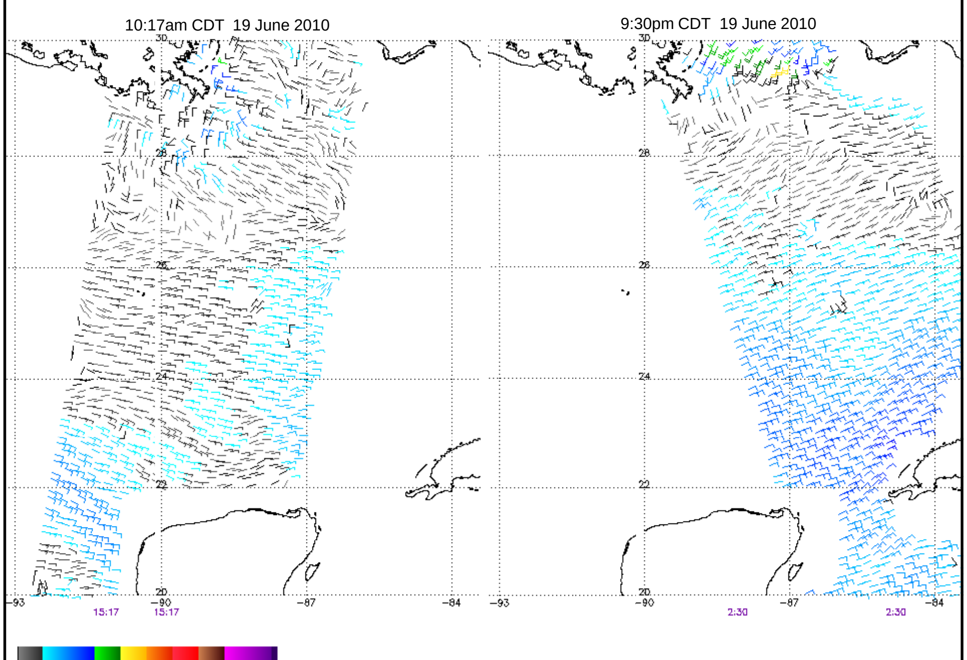
Faster winds

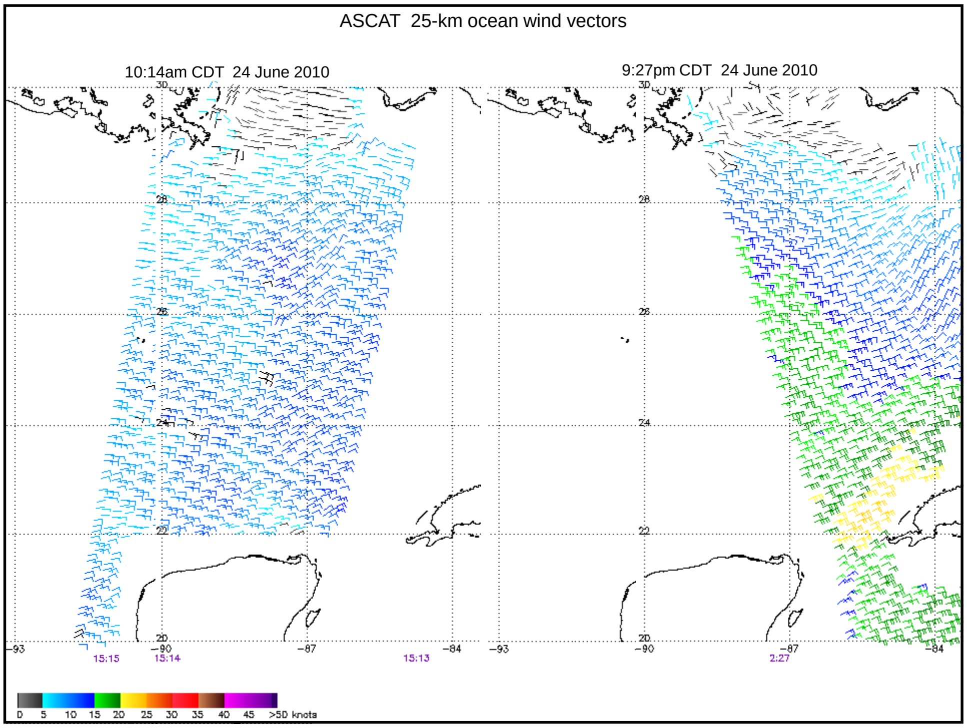
Diurnal influence of sea breeze and land breeze obvious

Persistent easterlies interrupted by frontal passage

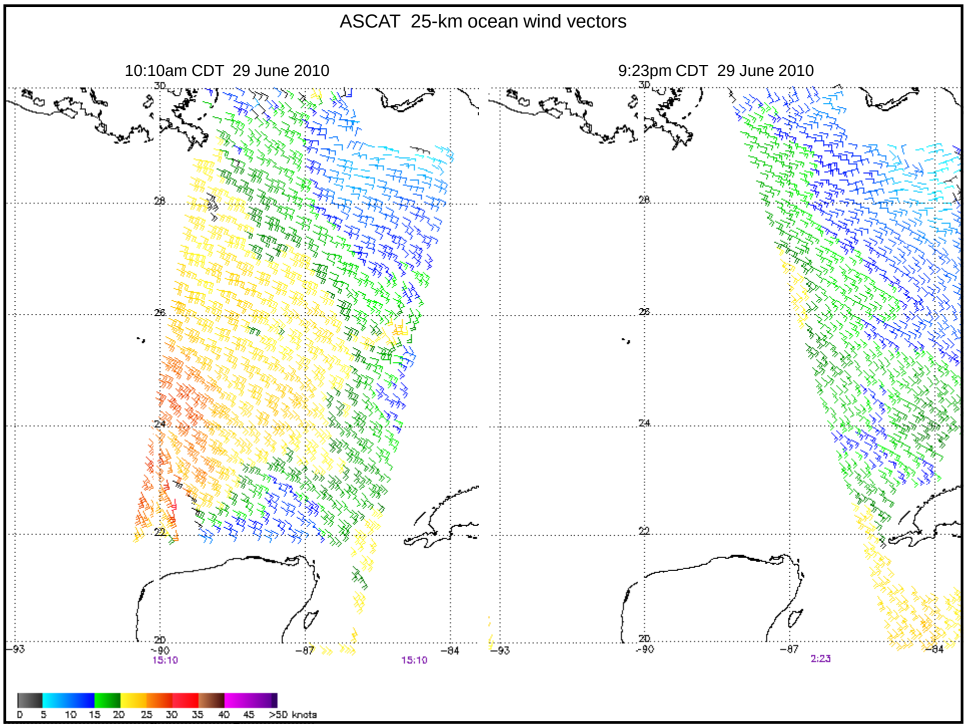
Scatterometer-derived winds also show change in wind regime in late June

ASCAT 25-km ocean wind vectors

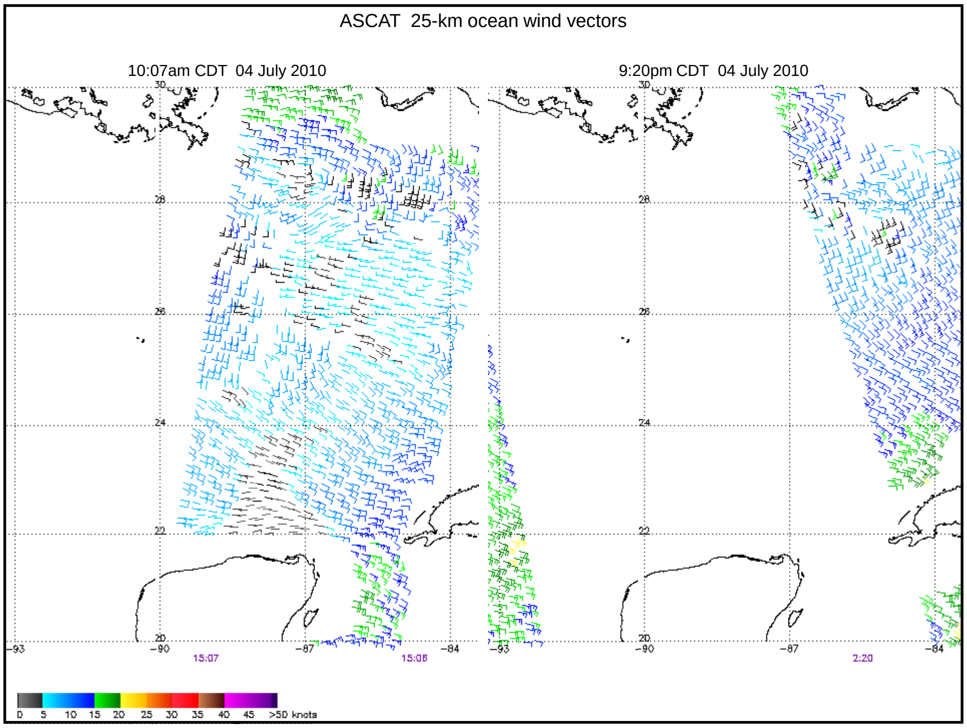




ASCAT 25-km ocean wind vectors
10:14am CDT 24 June 2010
9:27pm CDT 24 June 2010
15:15
15:14
15:13
2:27
0 5 10 15 20 25 30 35 40 45 >50 knots



ASCAT 25-km ocean wind vectors
10:10am CDT 29 June 2010
9:23pm CDT 29 June 2010
15:10
15:10
2:23
0 5 10 15 20 25 30 35 40 45 >50 knots



Ongoing tasks

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Possible future tasks

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