Post-Katrina Pollutant and Contaminant Pathways: Downstream Transport or Local Retention?

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A South Florida Perspective

As part of a long-term study funded by the National Oceanic and Atmospheric Administration, researchers from NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML), the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS), and other institutions monitor the physical, chemical, and biological properties of south Florida coastal waters on a regular basis. Scientists utilize bimonthly regional hydrographic surveys, monthly bay surveys (Florida and Biscayne), moored instrumentation, Lagrangian drifters, and remote sensing techniques to gain a more comprehensive understanding of how regional flow patterns and the resulting spatial distribution of water properties are influenced by offshore processes in the Gulf of Mexico and the Straits of Florida, and by freshwater input through direct precipitation and coastal runoff from the south Florida watershed. In conjunction with this effort, a regional model has also been developed to evaluate changes in circulation and water properties around Florida Bay, the Florida Keys, and the Dry Tortugas.

South Florida's unique coastal ecosystems have been frequently influenced by remote events outside of our study area. In particular, we have episodically observed the incursion of waters originating well to the north in the Gulf of Mexico including Mississippi River water. The Loop Current/Florida Current system, with its complex eddy field, provides a delivery mechanism for this input.

It was apparent that our regional efforts alone would not suffice to determine the probability of pollutant exposures resulting from the landfall of Hurricanes Katrina and Rita. As a contribution to the overall federal response, AOML and its academic and industry collaborators, along with the State of Florida, initiated a coordinated set of oceanographic cruises, coastal and ocean drifter deployments, analyses of satellite data and numerical simulation results (HYCOM Consortium for Data Assimilation) to address this specific issue. Data and analyses were made available to the public in near real-time via the Internet: http://www.aoml.noaa.gov/ocd/hurricaneresponse.

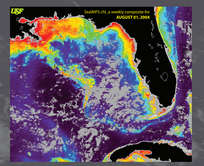
Our synthesis of the data and model results suggests that while some water originating just west of the Mississippi delta was carried offshore eventually reaching south Florida waters, coastal retention and westward alongshore transport processes were dominant in the weeks following hurricanes Katrina and Rita. Moreover, these powerful hurricanes greatly influenced the eddy field in the Gulf of Mexico, affecting subsequent pathways of Mississippi waters around the delta and beyond.

Riverine Outflow Delivered to South Florida via Loop Current

The position of the Gulf of Mexico Loop Current is highly variable. The Loop Current, joining the Yucatan Current and the Florida Current, typically becomes increasingly elongated over time, expanding into the northern Gulf of Mexico. In this elongated mode, the Loop Current may shed a warm core, anticyclonic ring. Once separated this ring will propagate into the western Gulf of Mexico and the Loop Current will retract to the south providing a more direct pathway between the Yucatan and Florida Straits. This entire process (eddy shedding) is highly variable occurring over periods of 6 to 17 months (Maul and Vukovich, 1993); the mean period is estimated at 12.4 months (Sturges and Leben, 2000). The Loop Current system has the capability (both indirectly and directly) to deliver remote river water to south Florida marine environments:

Indirect Pathway
Following ring shedding, when the Loop Current is in a state of minimal elongation, an along-isobath pressure gradient will drive southward flow of near-shore waters on the southwest Florida shelf (Hetland, et al., 1999). If the position of the Current remains more or less stable for a prolonged period of time, this mechanism can deliver coastal waters from northern Gulf sources to south Florida (Lee et al., 2002). By the nature of this mechanism, these waters will contain a mixture of all the predominant riverine discharge along the southwest Florida shelf.

Direct Pathway
Transport of Mississippi River water to the Florida Keys has been documented (Ortner et al., 1994). During periods when the Loop Current has elongated into an extremely northern position, Mississippi River water may be entrained directly into the current's shoreward front. High discharge rates, strong shelf water stratification (vertical), persistent upwelling, and favorable wind conditions all contribute to the degree of entrainment. If Mississippi River water becomes entrained in the Loop Current as a result of these factors, rapid transport to downstream regions such as south Florida can occur on the order of two to three weeks (Lee et al., 2002). In late July through early August 2004, conditions were favorable for this direct pathway. Shown to the right in a SeaWiFS chl_a ocean color map for the period, a filament of water containing high concentrations of chlorophyll can clearly be seen originating at the Mississippi River delta and extending along the Loop Current front all the way to south Florida.



Satellite imagery shows entrainment of Mississippi River water along the eastern edge of the Loop Current in 2004 (courtesy of Chuanmin Hu, USF).

Of these two pathways, indirect and direct, only the latter is a suitable mechanism for delivering significant quantities of Mississippi River water intact (i.e. with minimal mixing with other riverine sources and adjacent shelf waters) and over a relatively short period of time to south Florida. As mentioned above, the direct pathway requires that many parameters be met for entrainment and delivery. We discuss these parameters following the landfalls of Hurricanes Katrina and Rita in this poster.

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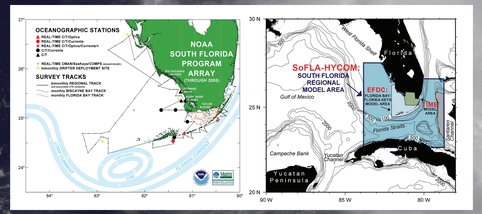
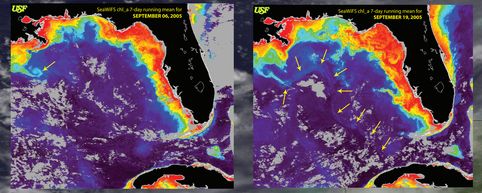
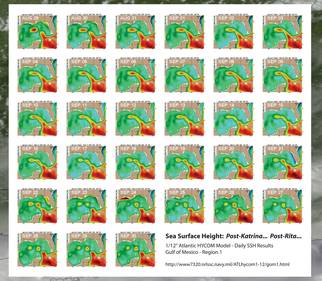


ABOVE: On the left, ongoing NOAA South Florida Program field operations are shown, including shipboard surveys, mooring locations, and drifter deployment sites. On the right, domains of the accompanying modeling efforts are displayed. The largest of the three models shown, the South Florida (SoFLA) Regional Model, is an adaptation of the HYbrid Coordinate Ocean Model (HYCOM). Nesting the SoFLA-HYCOM within a larger scale Atlantic HYCOM model allows for the accurate simulation of the interaction between shallow water dynamics around the Florida Bay and the Florida Keys reef tract with larger scale oceanic flows.





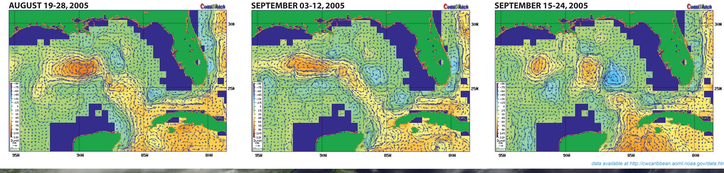
LOWER RIGHT: The two panels to the lower right show time-series plots of wind speed and direction for two National Data Buoy Center (NDBC) meteorological stations in the northern Gulf of Mexico from August through November of 2005. Following the passage of Hurricanes Katrina and Rita many stations shown on the accompanying chart failed due to storm damage. However, *Dauphin Island* and *Mobile South* remained operational. Data from both stations are similar. During the first half of September, regional winds were predominantly from the northeast. This wind drove near-shore waters in the northern Gulf westward along the coast. Additionally this wind direction was unfavorable for coastal upwelling. The lack of upwelling and of offshore transport of coastal waters during this period inhibited Mississippi River water entrainment during the September 3-11 timeframe when the Loop Current was in a favorable position for offshore removal of near-shore waters (shown above in the HYCOM model results).

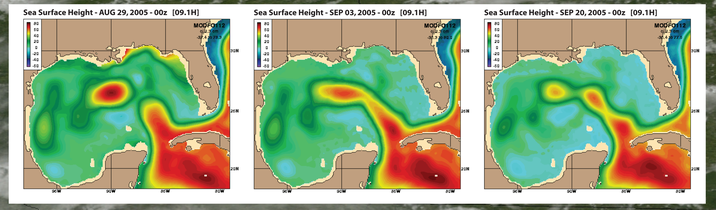
SeaWiFS Ocean Color Imagery

LOWER LEFT: September 2005 SeaWiFS chlorophyll a (chl_a) satellite imagery shows some removal of near-shore waters in the northern Gulf of Mexico via the Loop Current system. Yellow arrows in the two panels below highlight a thin filament of chlorophyll rich water originating just west of the Mississippi delta in early September. The image dated September 6th shows the initial entrainment along the shoreward edge of the Loop Current front. By the 19th of the month, the water mass had traveled to the Florida Straits. This signal was diminished through wind forced mixing as Hurricane Rita entered the Gulf of Mexico on the 20th of the month.

CoastWatch Gulf of Mexico Altimeter Data

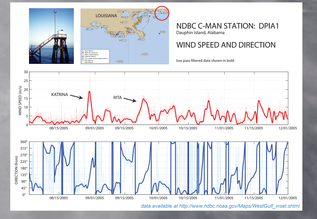
BELOW: August and September 2005 CoastWatch altimetry data (sea surface height anomaly) show the complex nature of the eddy field associated with the Loop Current system. The center panel shows the Loop Current following the early September warm core ring assimilation and the most direct pathway during the focus period for downstream transport of northern Gulf coastal waters. By the second half of the month however, this pathway had broken down (lower right).

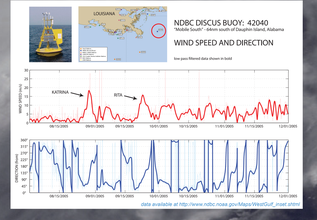




1/12° Atlantic HYCOM Model - Gulf of Mexico Sea Surface Height

ABOVE and ABOVE LEFT: The HYCOM model run for August 29, 2005 shows a clear separation between a Loop Current ring and the Loop Current as Katrina made landfall along the northern Gulf coast. In the following days, this ring was reabsorbed into the Loop Current. Subsequently, the northerly position of the resulting (now intact) loop was favorable for entrainment of near-shore water, including Mississippi River outflow, from approximately September 3-11. However, other necessary conditions (favorable wind direction, upwelling, water column stratification) were not met and entrainment during this period was minimal. By the time Rita crossed the Gulf (September 20-23) the Loop Current mechanism for entrainment had completely broken down.





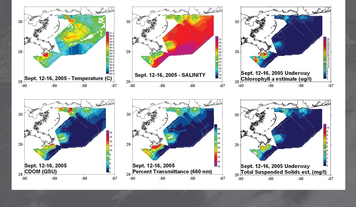
Post-Katrina Rapid Response Survey

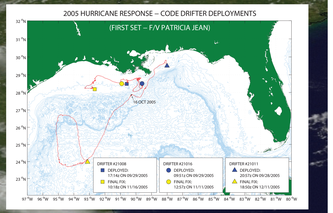
The panels shown below describe six of the physical and chemical fields recorded during the September 12-16th, 2005 interagency and interdisciplinary cruise conducted aboard the *NOAA Ship Nancy Foster*. Coordinated by the NOAA National Marine Fisheries Service (NMFS) and AOML (NOAA/OAR), the cruise served as a rapid response survey of the northern Gulf of Mexico region following the landfall of Hurricane Katrina (cruise track shown in gray). These data (parameters labeled on panels) were collected with a continuous flow seawater system while underway and the resulting surface fields assisted in directing contaminant and pathogenic sampling efforts in near-shore waters around the Mississippi delta during the course of the cruise. The resulting sampling regime, designed to make a preliminary assessment of the health of the food supply and marine ecosystem in close proximity to storm affected areas, included the following:

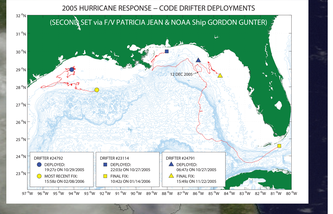
biological tissue samples (fish stock)
sediment grab samples
water column samples

Analyses of these samples for contaminants and harmful pathogens were conducted following the cruise. Preliminary results can be found at http://www.st.nmfs.gov/hurricane_katrina

From a dynamical standpoint, the data shown suggest that there was a considerable degree of local retention of post hurricane near-shore outflow, both near the mouth of the Mississippi and between Bay St. Louis and Mobile Bay. Though the survey track west of the Southwest Pass (where the Mississippi River enters the Gulf of Mexico) is limited, data fields show that river outflow is not extending towards the southeast, and is most likely spreading westward along the coastline. Regional wind data during this time period (shown to the left) would support this transport.

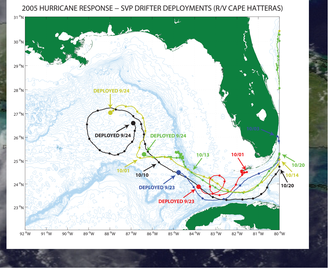






Lagrangian Drifter Deployments

Following Hurricanes Katrina and Rita, multiple satellite-tracked drifter deployments were made in the Gulf of Mexico by both research and merchant vessels enabling scientists to monitor flow patterns and transport mechanisms of the coastal ocean and of the Loop Current system in real-time.

ABOVE: The two panels above show shallow water CODE drifter deployments in the northern Gulf of Mexico. Initial retention of near-shore waters is the dominant feature seen in these trajectories.

BELOW: The *R/V Cape Hatteras* deployed five SVP drifters in the Loop Current in late September 2005. These drifter trajectories are shown in the panel below.