Remote Sensing, In-Situ Observations and High-Resolution Modeling of Low-Salinity Lenses in the Presence of Oil Slicks

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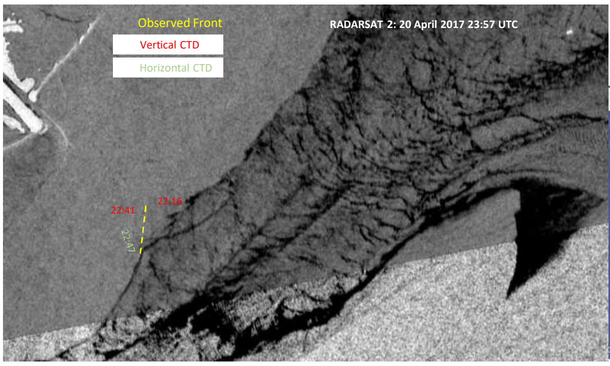
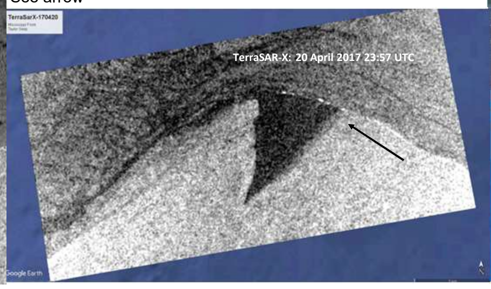
Fine-scale Features on the Sea Surface Observed in the Vicinity of a Fresh Water Front and an Oil Seep in the Gulf of Mexico

Localized sources of freshwater (river runoff, convective tropical rains) produce shallow, low-salinity lenses, which are visible from space in the sea surface salinity satellite imagery. As part of the Consortium for Advanced Research on Transport of Hydrocarbons in the Environment/Gulf of Mexico Research Initiative, we conducted a comprehensive remote sensing, in-situ, and computational experiment on the Louisiana Coast near the Mississippi River Delta in April 2017. A low intensity oil leak from a damaged oil platform (Taylor Energy) made the fine structure of the low-salinity lenses and their connection to oil slick transport visible from SAR satellites. Though the oil slicks outside of a relatively small area of the primary oil leak were very thin, down to the thickness of a monomolecular layer, they still affected short gravity-capillary waves due to the presence of surfactants. A computational fluid dynamics (CFD) model indicates that these transient near-surface lenses create significant horizontal density gradients and spread as gravity currents, influencing the oil slick propagation. The CFD simulations reveal fine-scale coherent (helical) structures at the frontal edges of the spreading freshwater lens, which significantly increase mixing. The thin oil film is effectively mixed up and dissolved at the edges of the low-salinity lenses. The lens edges can therefore serve as a barrier to the oil slick propagation. While SMOS measurements have been shown to map freshwater events in the GoM in km scale, SAR imagery though limited in areal coverage can show the direct interactions at the front due to its high resolution (down to the meter scale). The backscatter intensity at the front depends on radar wavelength. At 3 cm X-band (TS-X) a bright line showed up due to Bragg scattering at 3cm breaking waves and debris that could not be observed at the 5 cm C-band (R2). We used NRT SAR and optical imagery from Sentinel, Radarsat-2 and TSX during our in Situ campaign. The results of this project provide a better understanding of the propagation and mixing of low-salinity lenses in the upper layer of the ocean, which is important in a number of practical applications including pollution propagation in coastal waters (e.g., oil spills), open ocean dynamics (e.g., Madden-Julian Oscillation), and the interpretation of sea surface salinity satellite measurements (Aquarius, SMOS, SMAP).



Radarsat Image (C-band) showing the location of the front at the Mississippi delta and the interaction with the oil seep

While the overall observations in the two SAR images are similar, differences due to different radar wavelength and noise floor exist See arrow



TerraSAR-X Image acquired at the same time as the R-2 image

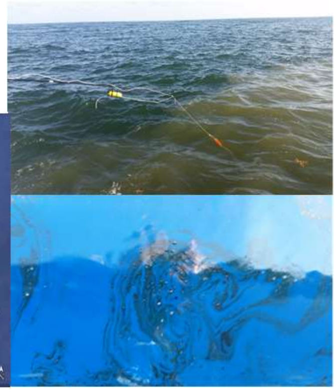
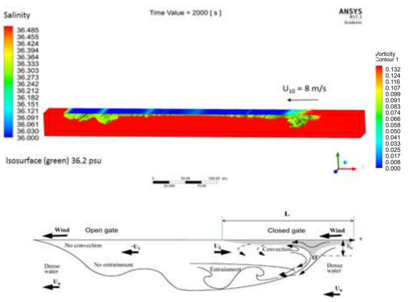
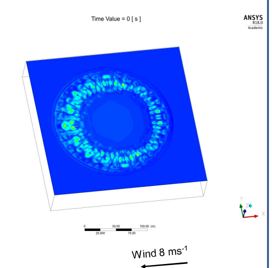


Photo of the front and oil seep during in Situ Observations

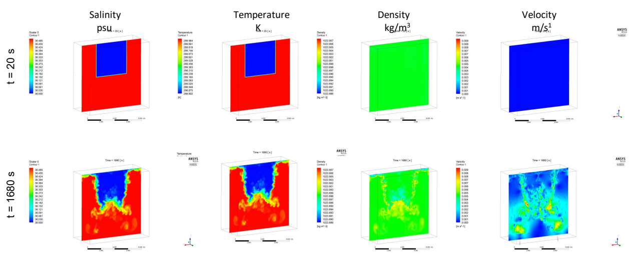
Modelling of a freshwater lens by CFD



Top view – Near Surface Vorticity

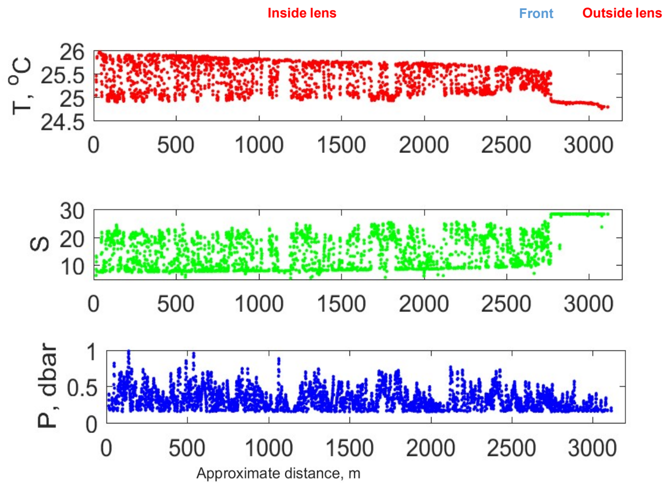


Double diffusion in a density compensated freshwater lens

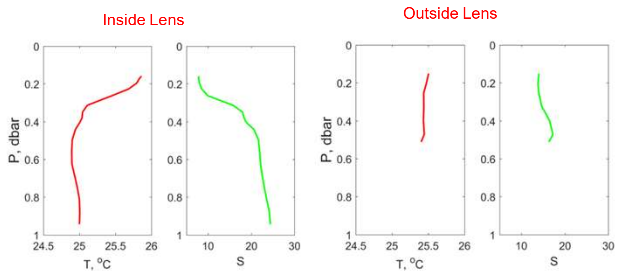


- A freshwater inflow to the upper ocean due to a stratiform rain produces freshwater anomalies, which are relatively homogeneous horizontally
- Convective rains and river run off produce localized freshwater lenses with significant horizontal density anomalies
- We have analyzed the vertical mixing and horizontal advection of salinity under stratiform and convective rains using 3D non-hydrostatic computational fluid dynamics (CFD) tools
- The model is compared with available field data including CARTHE/GoMRI field experiments SCOPE, LASER, SPLASH

Measurement - Horizontal CTD Transect on the Louisiana Coast



Vertical Structure of the Near-surface Layer on the Louisiana Coast



- Response of the upper ocean to convective rains inherently involves three-dimensional dynamics
- The gravity currents created by convective rains rapidly spread and reach either a state when temperature and salinity compensate each other in density or completely mix up with the surrounding water
- In the compensated lenses, double diffusion convection may be a prominent contributor to the vertical mixing
- Response of the upper ocean to stratiform rains as well as dynamics of the lenses that had already been compensated have a good chance to be represented by one-dimensional modeling
- A better understanding of freshwater lens dynamics is important in a number of practical applications including pollution propagation in coastal waters (e.g., oil spills) and open ocean dynamics (e.g., Madden-Julian Oscillation), and interpretation of Aquarius, SMOS, and SMAP sea surface salinity satellite measurements