# The Impact of Surface Oil on Ocean Surface Stress

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## Abstract

This study using a modified coupled-ocean-atmosphere-wave-sediment modeling system (COAWST) is to explore how oil changes air-sea interaction in a manner of two-way coupling. Results highlight the substantial influences of oil-related changes in surface roughness, surface wind, surface and near surface temperatures, boundary-layer stability, and how those conditions impact surface stress and oil transport. Modeled results suggest that the major changes of surface stress are due to the oil-related changes in modeled wind and boundary-layer stability, not due to the oil-related changes in modeled roughness. However, the modeled change of surface stress from the feedback of surface oil is not large enough to cause a major impact on surface current and oil transport. Thus, the feedbacks from the surface oil presence to the oil movement itself are minor for forecasting the oil transport.

## Motivation

The key goal of this study is to provide a detailed analysis of how oil changes air-sea interaction in a two-way coupled model (COAWST; Warner et al. 2010). The modeled results are expected to highlight the oil-related changes in surface roughness, surface wind, surface and near surface temperature differences, boundary-layer stability and how those conditions cause the changes in surface stress and oil transport.

## Methods

**1.** Twin coupled modeling simulations with and without the influences of oil in the Gulf of Mexico. Time period: 2010/04/13 00:00:00–2010/07/21 00:00:00, 99 days; Coupling time interval: 1800 s

**2.** Oil coverage was determined based on a heat budget and differences in SST between oil covered and oil free surfaces

**3**. The oil-related changes in three variables (roughness length, surface wind, and boundary-layer stability) and their impacts on stress and the coupled system are examined using the Modularized Flux Testbed (**MFT** v2021.1, Bourassa et al. 1999; Bourassa 2006):

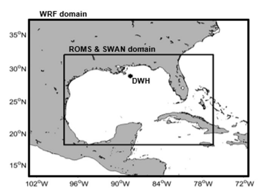


**Figure 1.** COAWST model domain.

- Surface roughness change study: Computes the differences between surface roughness for oil and water in both partial and total coverages and how those changes impact the magnitude change in surface stress.
- Surface wind change study: Determines how significant the oil-relate changes in wind speeds are to the changes in surface stress.
- Boundary-layer stability change study: Computes the oil-relate change in surface stress by taking into account the changes in boundary-layer stability.

## Innovative Roughness Length Parameterization (Zheng et al. 2013)

$$z_{0_i}=\underbrace{\beta_s \frac{0.11\nu}{|u_{*_i}|}}_{\text{Aerodynamically smooth surface}}+\left[\left(\underbrace{\left((1-A_{oil})\beta_{c,water}+\varepsilon A_{oil}\beta_{c,oil}\right)\frac{b\sigma}{\rho_W u_{*_i}^2}}_{\text{capillary waves}}\right)^2+\left(\underbrace{\left((1-A_{oil})\beta_{g,water}+\varepsilon A_{oil}\beta_{g,oil}\right)\frac{a u_{*_i}^2}{g}}_{\text{gravity waves}}\right)^2\right]^{0.5}$$

Notes: $\beta_s$, $\beta_{c,water}$, $\beta_{c,oil}$, $\beta_{g,water}$, $\beta_{g,oil}$ are weights between 0 and 1 for roughness length associated with an aerodynamically smooth surface, capillary waves on oil-free surface, capillary waves on oil surface, gravity waves on oil-free surface, gravity waves on oil surface; $A_{oil}$ is fraction of oil surface where waves are damped ($1 \lesssim A_{oil} \lesssim 1$); $\nu$ is the molecular viscosity of air, $\varepsilon$ represents the oil damping effects on capillary waves and gravity waves; $\sigma$ is surface tension (determined by SST); $\rho_w$ is water density, $a$ is Charnock's constant; $b$ is a dimensionless constant determined by laboratory observation (3), $g$ is gravity acceleration. $\beta_s = 1 - (\varepsilon A_{oil}\beta_{g,oil} + (1-A_{oil})\beta_{g,water})$.

For water surface, $\beta_{c,water}=0$ and $\beta_{g,water}=0$ for $U_{eff} < U_{lim}$. For $U_{eff} > U_{lim}$, $\beta_{c,water} = \tanh(0.4(U_{eff} - U_{lim})^3)$ and $\beta_{g,water} = \tanh(0.2(U_{eff} - U_{lim})^3)$, where $U_{lim} = 1.0\ ms^{-1}$

For oil surface, $\beta_{c,oil}=0$ and $\beta_{g,oil}=0$ for $U_{eff} < U_{lim}$. For $U_{eff} > U_{lim}$, $\beta_{c,oil} = \tanh(0.4(U_{eff} - U_{lim})^3)$ and $\beta_{g,oil} = \tanh(0.3(U_{eff} - U_{lim})^3)$, where $U_{lim} = 7.0\ ms^{-1}$

**Friction Velocity (u*):** $u_* = \frac{k_v(\vec{u}(z)-\vec{u}_S)}{\left[ln\left(\frac{z}{z_0}+1\right)-\psi(z,z_0,L)\right]}$ **Fluxes of Stress (τ):** $\frac{|\tau|}{u_*} = \rho u_*$

**Latent Heat (E):** $E = (1-A_{oil})\rho L_v |u_*| q_*$ **Sensible Heat (H):** $H = \rho C_p |u_*| \theta_*$

## COAWST Framework

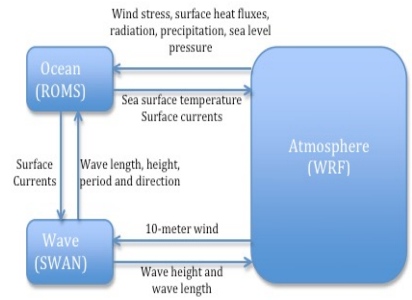


**Figure 2.** COAWST framework.

## Result I: Changes in stress due to oil-induced changes in surface roughness

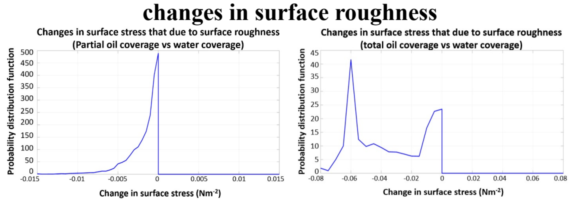


**Figure 3.** Probability distribution function (PDF) of changes in surface stress (Nm$^{-2}$) while boundary-layer stability is constant over the 2-week period (2010-04-21 to 2010-05-05) for (left) partial oil coverage surface roughness relative to a water surface and (right) for total oil coverage surface roughness relative to a water surface. The negative changes in stress terms are from the conditions where roughness is suppressed by oil. There are no positive changes due to surface oil.

## Result II: Changes in stress due to oil-induced changes in surface winds

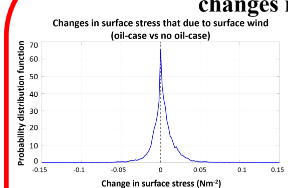


**Figure 4.** PDF of changes in surface stress (Nm$^{-2}$) for an oil-related 10-m wind relative to water-related 10-m wind while boundary-layer stability is constant over the 2-week period. There are 34.98% (51.92%) of data above the zero line on left (right) side of the curve.

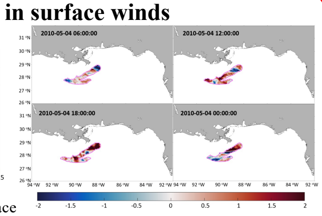


**Figure 5.** The differences between the COAWST model with oil modifications relative to the COAWST model without oil modifications of surface wind speed (shaded contours, ms$^{-1}$) on May 04 at a) 12 am, b) 6 am, c) 12 pm, and d) 6 pm UTC. The shaded red (blue) color indicates that the oil-case winds speeds are greater (less) than the no oil-case wind speed.

## Result III: Changes in stress due to oil-induced changes in boundary-layer stability

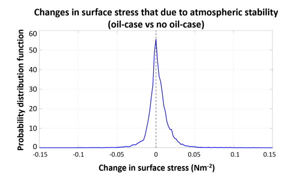


**Figure 6**. Same as Figure 4 except for boundary-layer stability while surface roughness length is constant over the 2-week period. There are 36.68% (52.21%) of data on left (right) side of the curve.

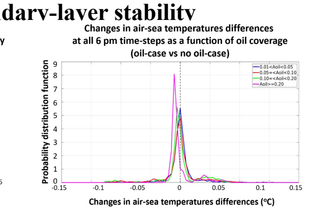


**Figure 7**. PDF of the changes in air-sea temperature differences from COAWST model with and without oil modifications over the 2-week period only for 6 pm time steps.

## Result IV: changes in stress due to oil-induced changes in surface wind speed vs. boundary-layer stability

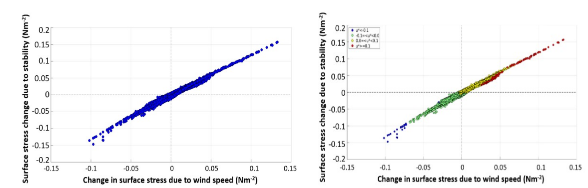


**Figure 8**. Scatterplot of (left panel) changes in stress due to boundary-layer stability vs. changes in stress due to wind speed (Nm$^{-2}$) and (right panel) changes in stress due to boundary-layer stability and the changes in stress due to wind speed (Nm$^{-2}$) as a function of friction velocity. These scatterplots were computed over the 2-week period.

## Highlighted Results

- Oil-related changes to surface roughness is not significant enough to directly cause a big impact on surface stress change (much of the surface was deemed oil free based on observed SST and a heat budget).
- Oil-related changes to 10-m wind speed are largely tied to changes in boundary-layer stability, which could play an important role in surface stress change, and
- Oil-related changes to surface stress are not large enough to cause a major impact on the surface current and oil transport.

### References

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