Open research questions in ocean observations and modeling and their impact on hurricane predictions

Isaac Ginis
Graduate School of Oceanography
University of Rhode Island

Key Messages

- Hurricane prediction models require ***SST and currents*** to accurately compute air–sea heat and momentum fluxes.

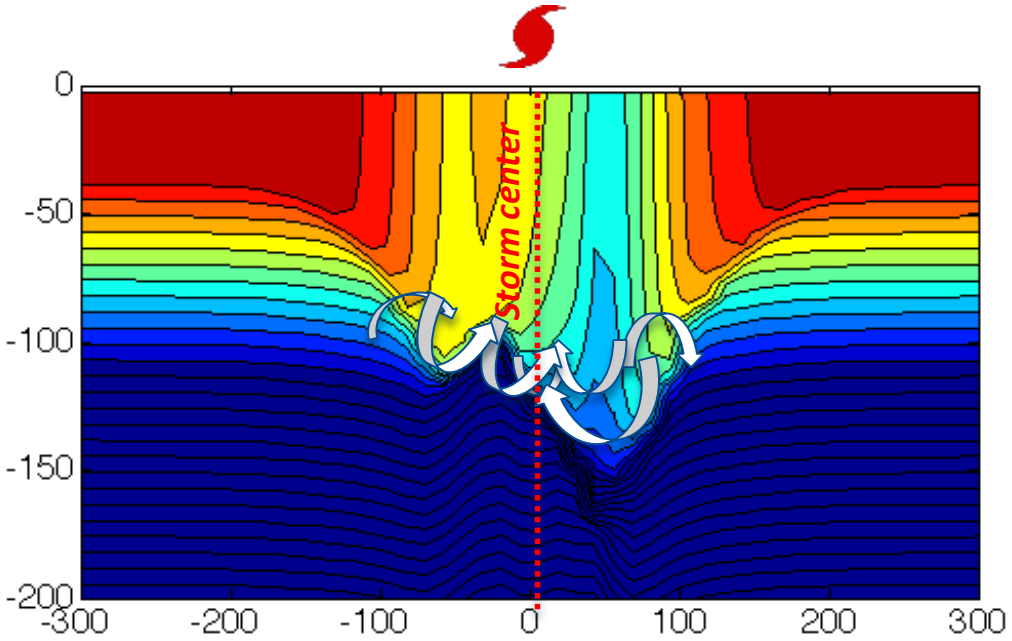
- Predictions of hurricane intensity require coupled atmosphere-wave-ocean numerical models with ***sea-state dependent*** parameterizations of air-sea fluxes and upper-ocean response.

- **Ocean state** measurements under the hurricane's inner core are necessary to improve the ocean model physical parameterizations and evaluation.

Upper-ocean Response: 1D processes

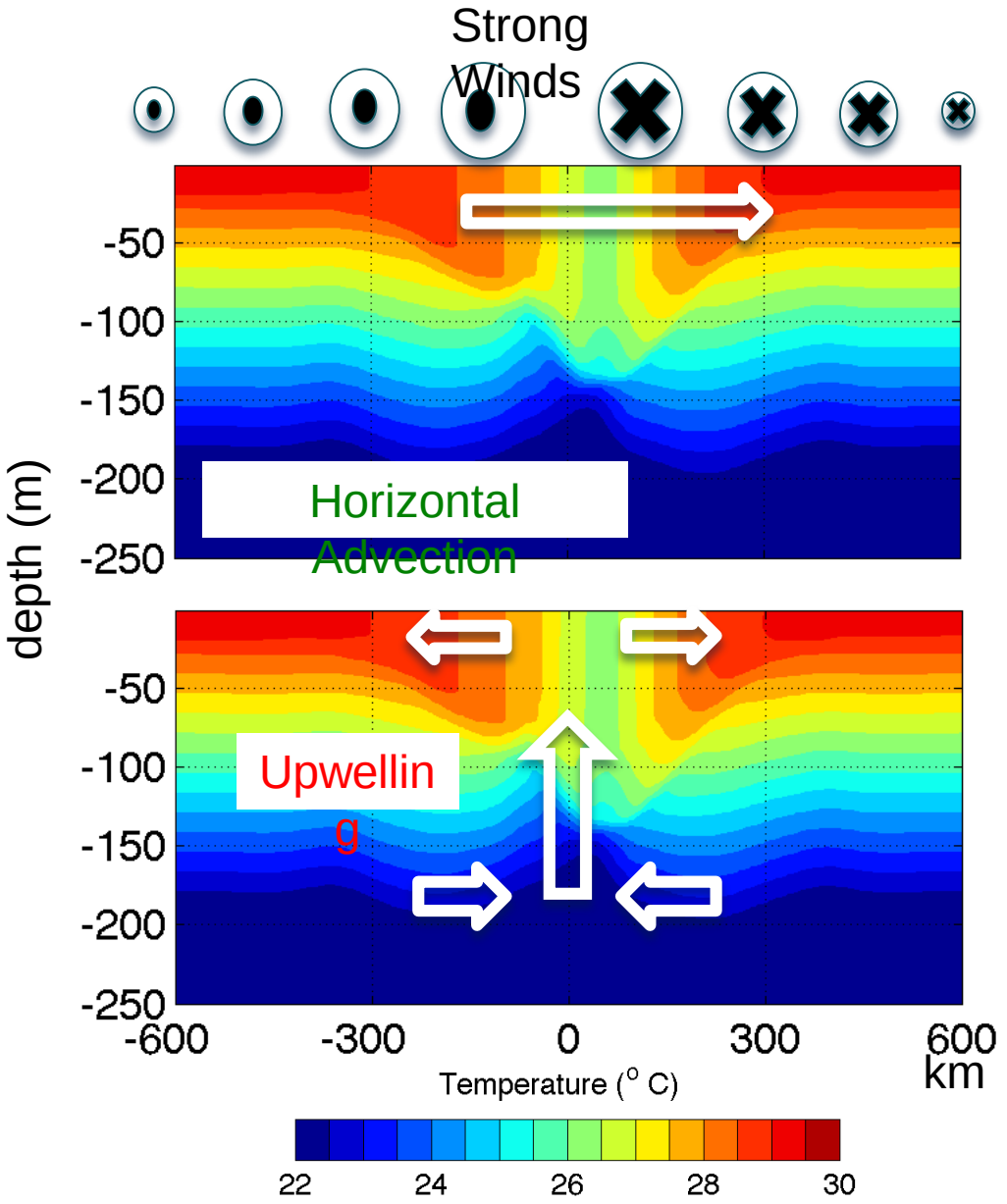
The SST and current responses to wind forcing are determined by **turbulent mixing** throughout the upper-ocean boundary layer.

Turbulent mixing drives ~85% of SST cooling.



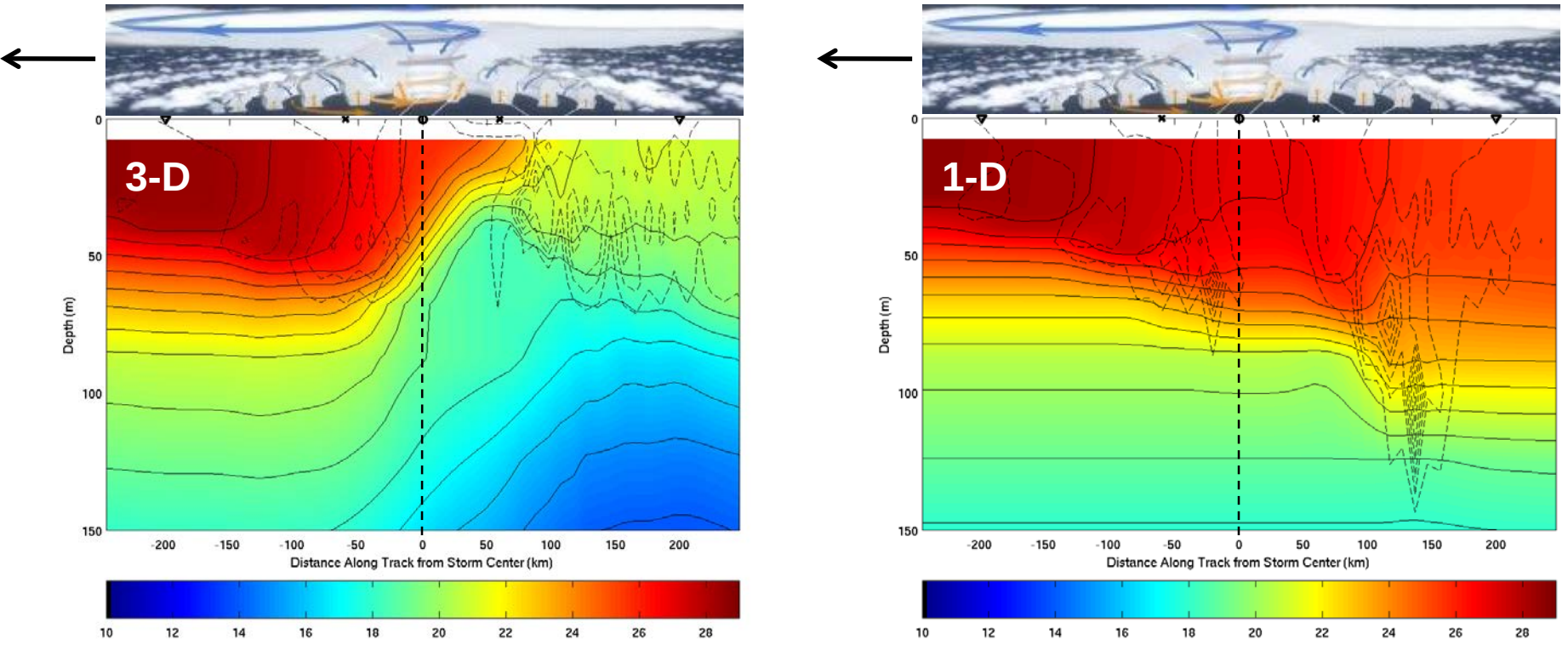
Upper-ocean Response: 3D processes

Hurricane induced upwelling and horizontal advection can enhance and/or modify SST cooling.



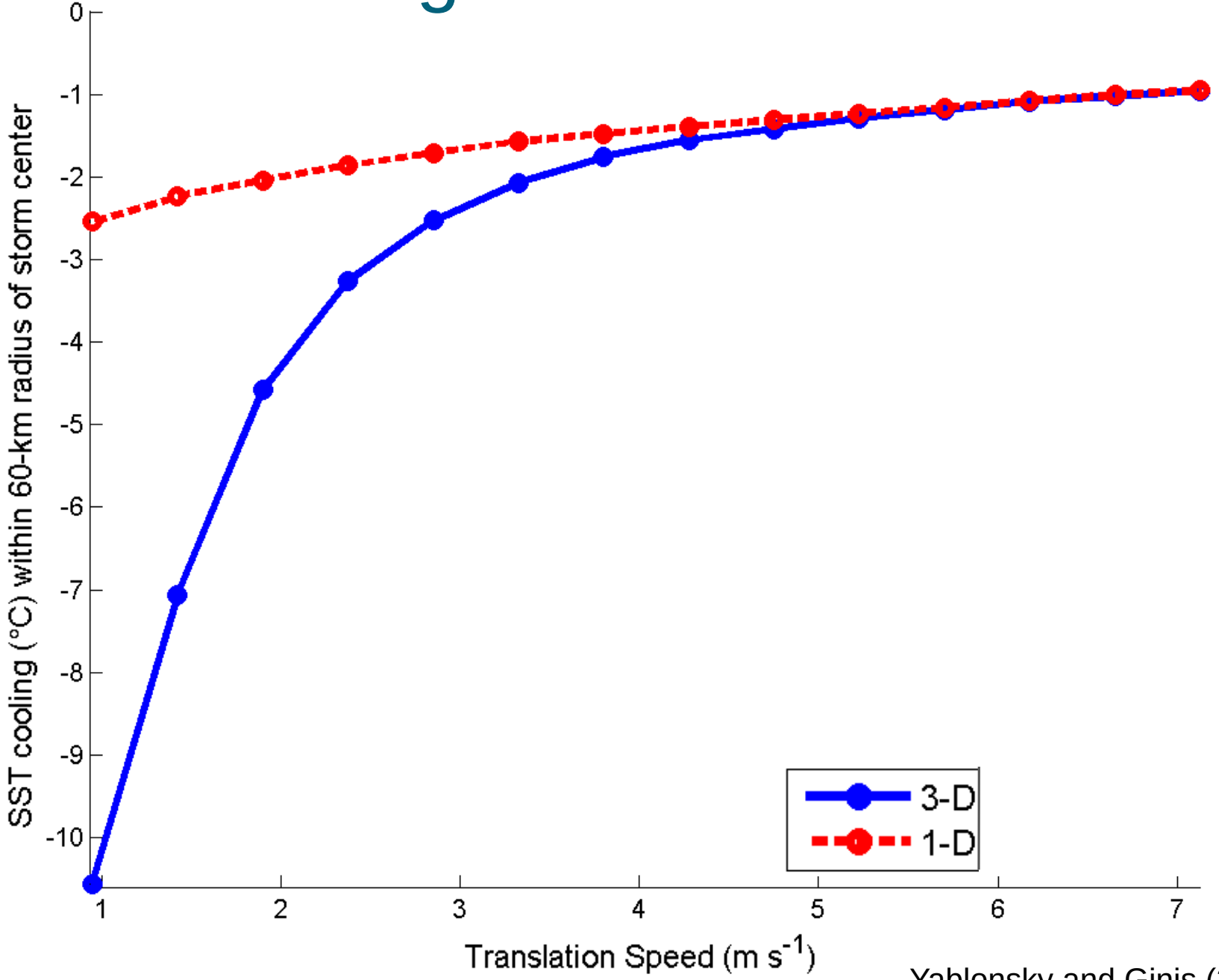
Upper-ocean Response in 1D and 3D models

U_T=2.4 m s^{-1}



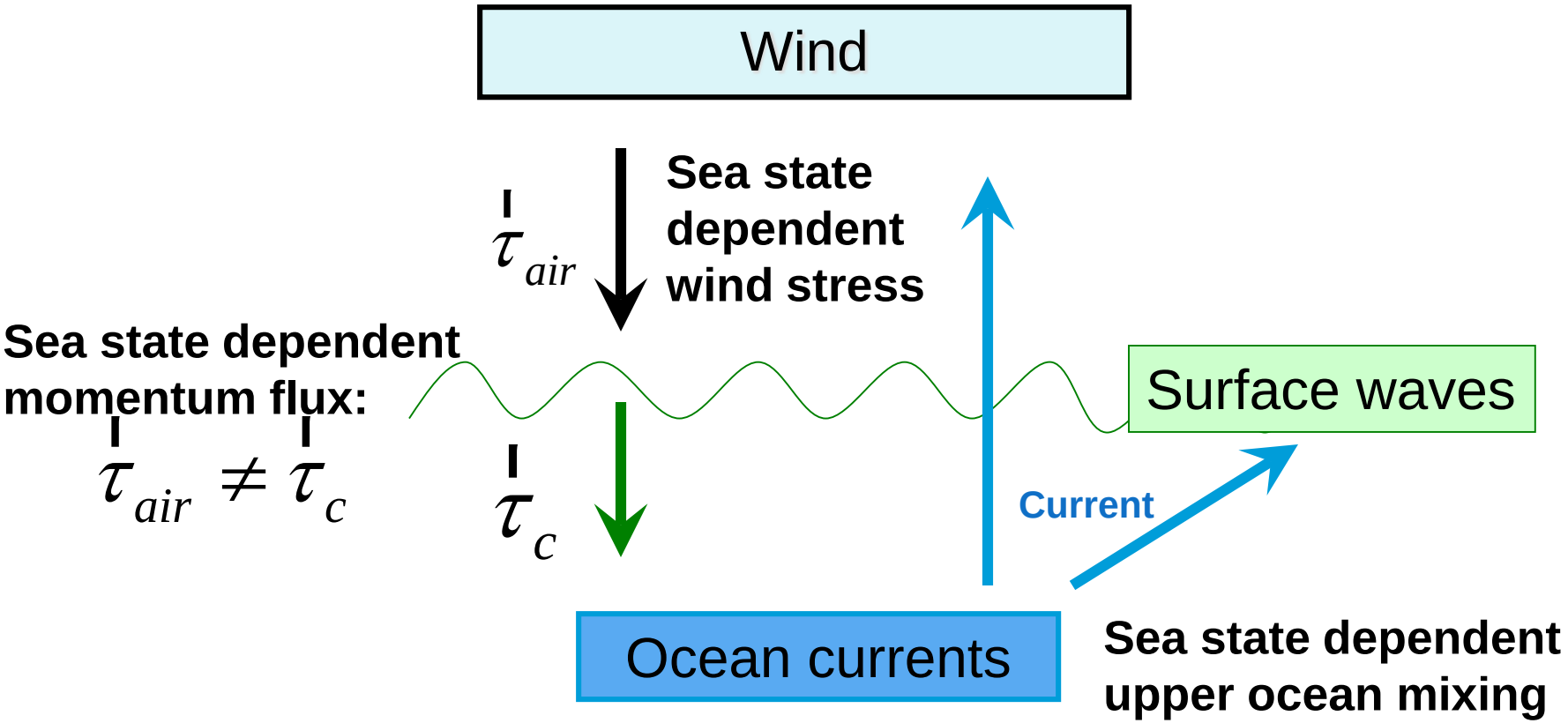
Yablonsky and Ginis (2009)

SST Cooling in 1D and 3D models



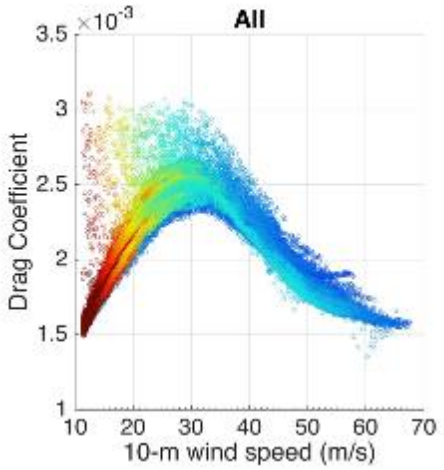
Yablonsky and Ginis (2009)

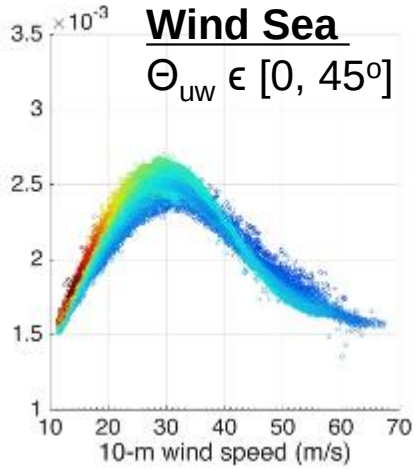
Wind-Wave-Current Interactions in Hurricanes

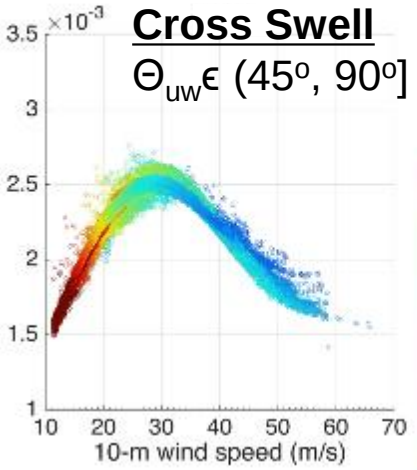


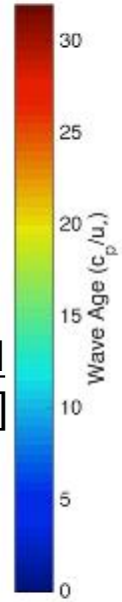
Sea state dependent effects are not currently included in the U.S. operational hurricane models.

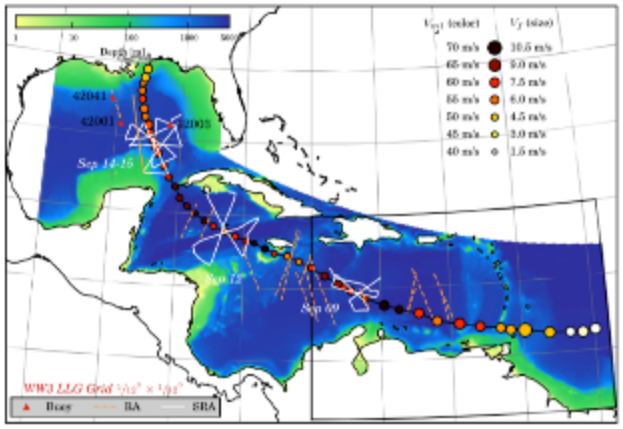
Sea State Dependent Drag Coefficient
WW3 Wave Model: Hurricane Ivan (2004)



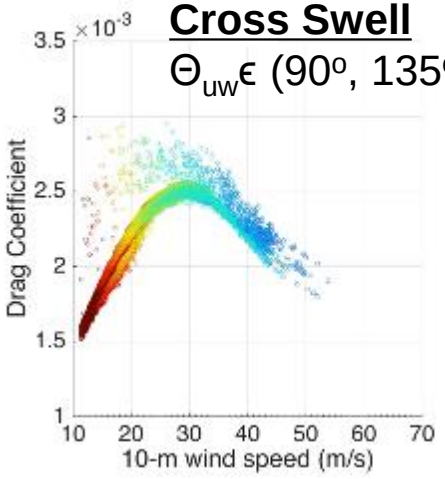


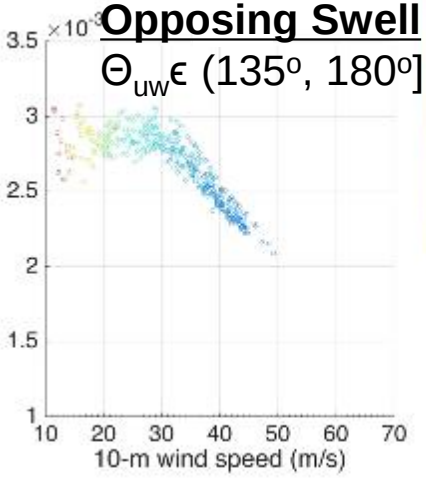




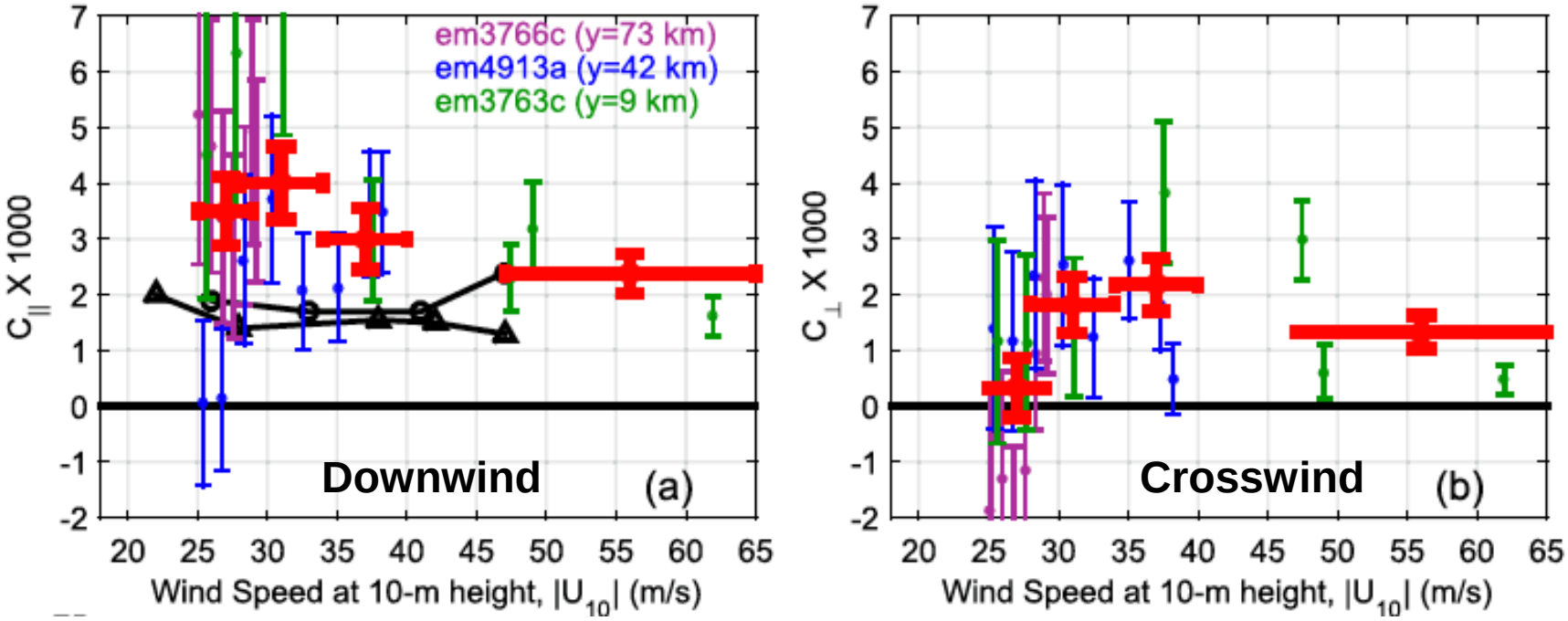


Adopted from Liu et al. 2017





Sea State Dependent Drag Coefficient
EM-APEX Floats: Typhoon Megi (2010)



Hsu et al. (2017)

Momentum flux into ocean and the drag coefficient can be estimated from high-resolution current velocity profiles.

Vertical Mixing Parameterizations in Operational TC-Ocean Coupled Models

Turbulent flux terms are assumed proportional to the vertical shear of the mean variables, e.g.

Momentum

$$\overline{w'u'}(z) = -K\left(\frac{\partial \bar{u}}{\partial z}\right)$$

Temperature

$$\overline{w'\theta'}(z) = -K\left(\frac{\partial \bar{\theta}}{\partial z}\right)$$

The turbulent mixing coefficient K is parameterized using either

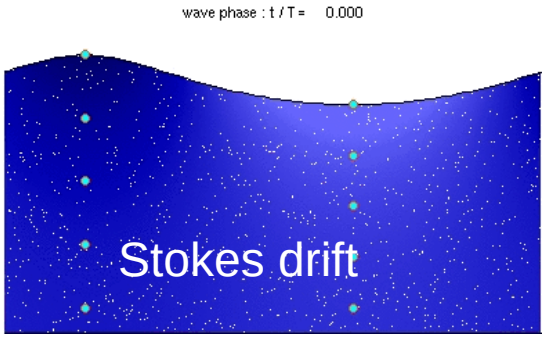
(1) Mellor–Yamada level 2.5 turbulence closure model (Princeton Ocean model) or
(2) K-Profile Parameterization (HYCOM)

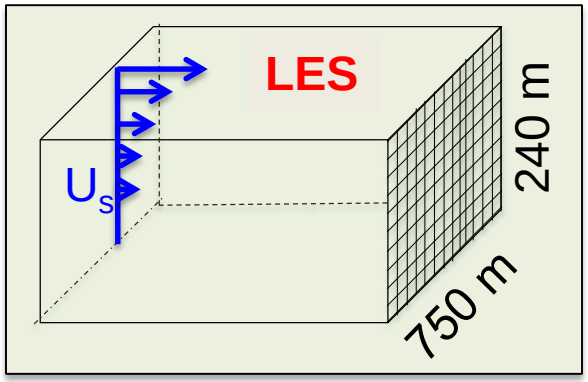
These parameterizations do not *explicitly* account for the effects of surface waves on upper ocean mixing

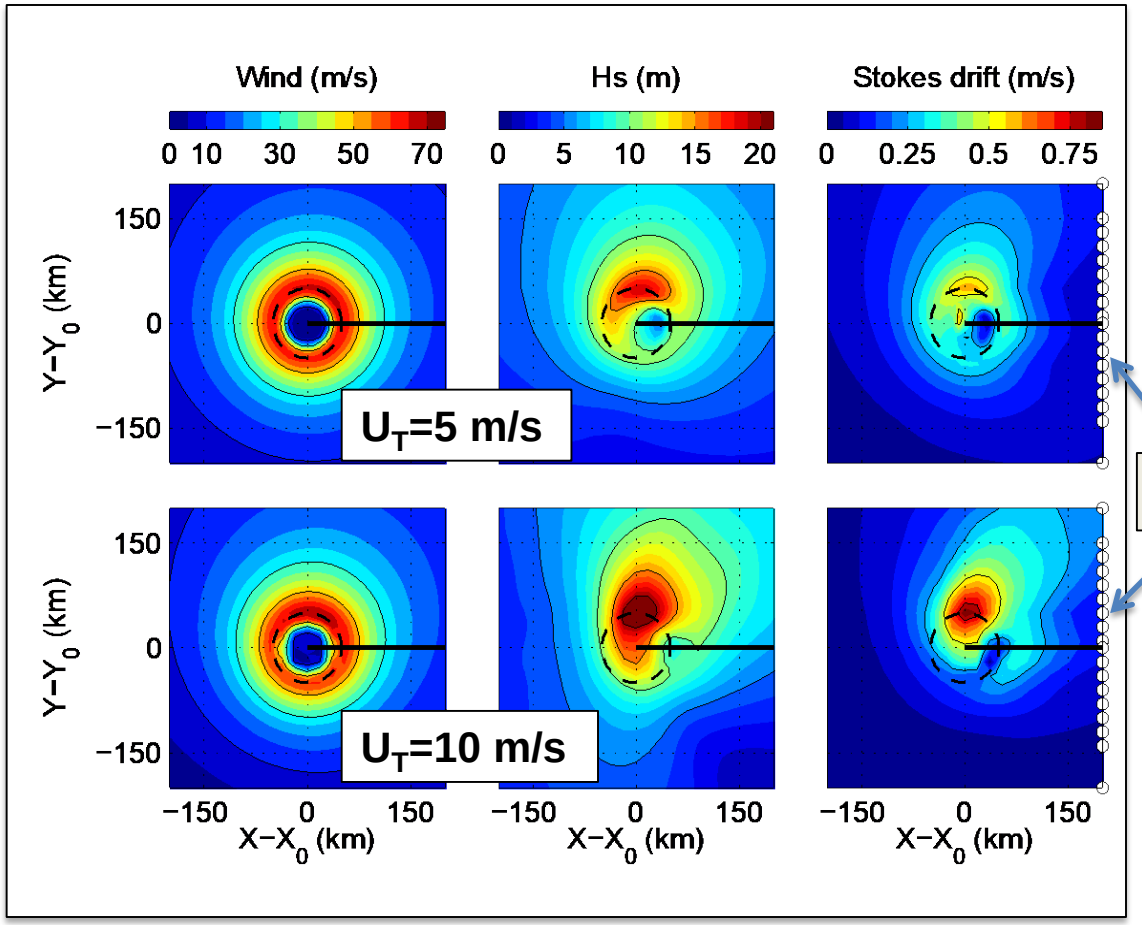
Impact of Waves on Upper-ocean Response: LES Simulations

An idealized hurricane is translated westward.

Waves are simulated by WaveWatch III.







Large Eddy Simulation (LES) model is positioned across the track (white circles)

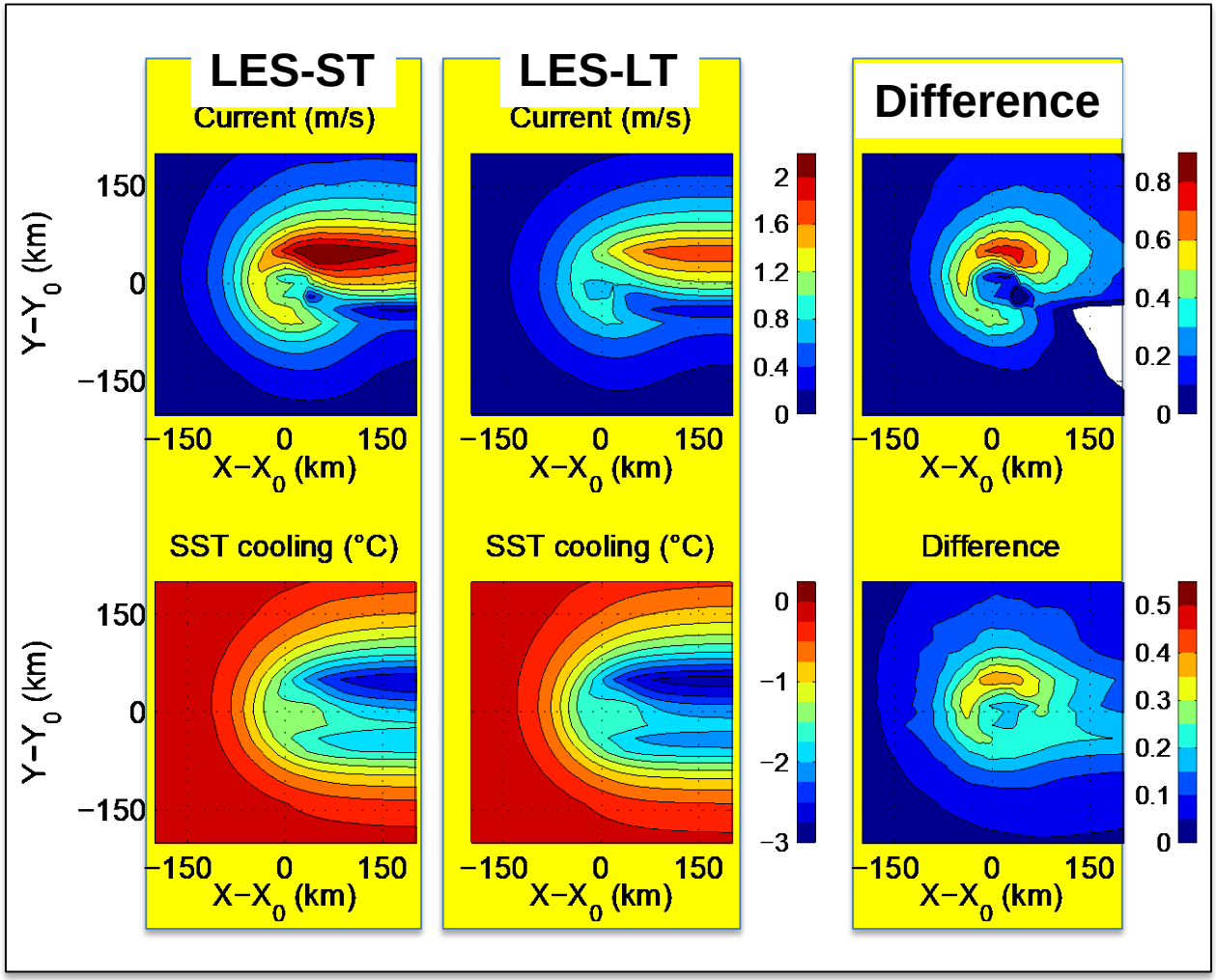
Sullivan et al, 2012, Rabe et al. 2015, Reichl et al, 2016

Impact of Waves on Upper-ocean Response: LES Simulations

Langmuir turbulence results from interaction between the wave-driven Stokes drift and wind-driven current.

LES-ST:
Shear-driven turbulence only

LES-LT:
Shear-driven & Langmuir turbulence



By enhancing vertical mixing Langmuir turbulence 1) reduces surface currents and 2) enhances SST cooling

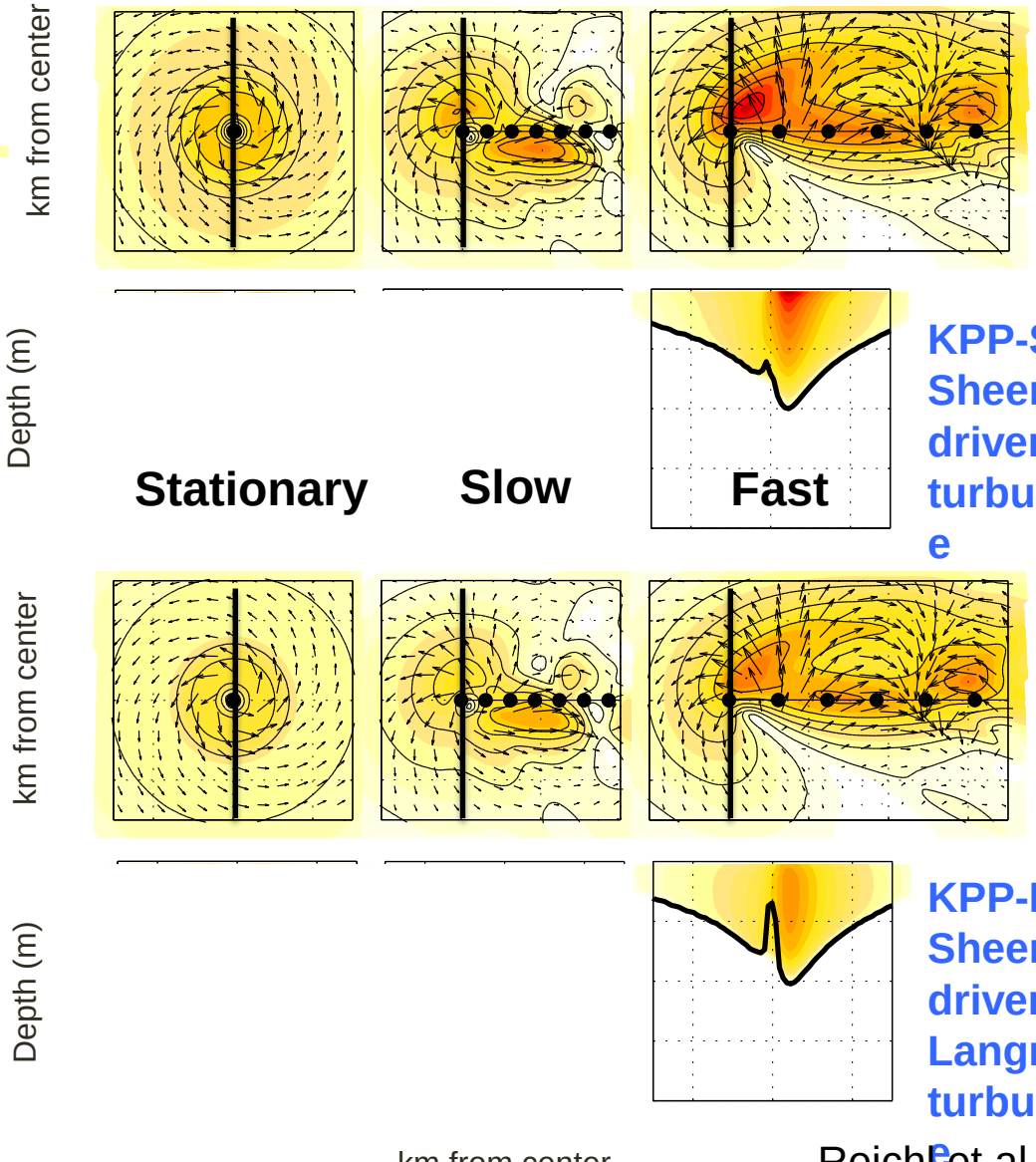
Reichl et al, 2016

Impact of Waves on Upper-ocean Response: 3D Ocean Model

An idealized hurricane is translated westward. Three translation speeds:
0 (stationary), 2.7 (slow), and 5.8 (fast) m/s.

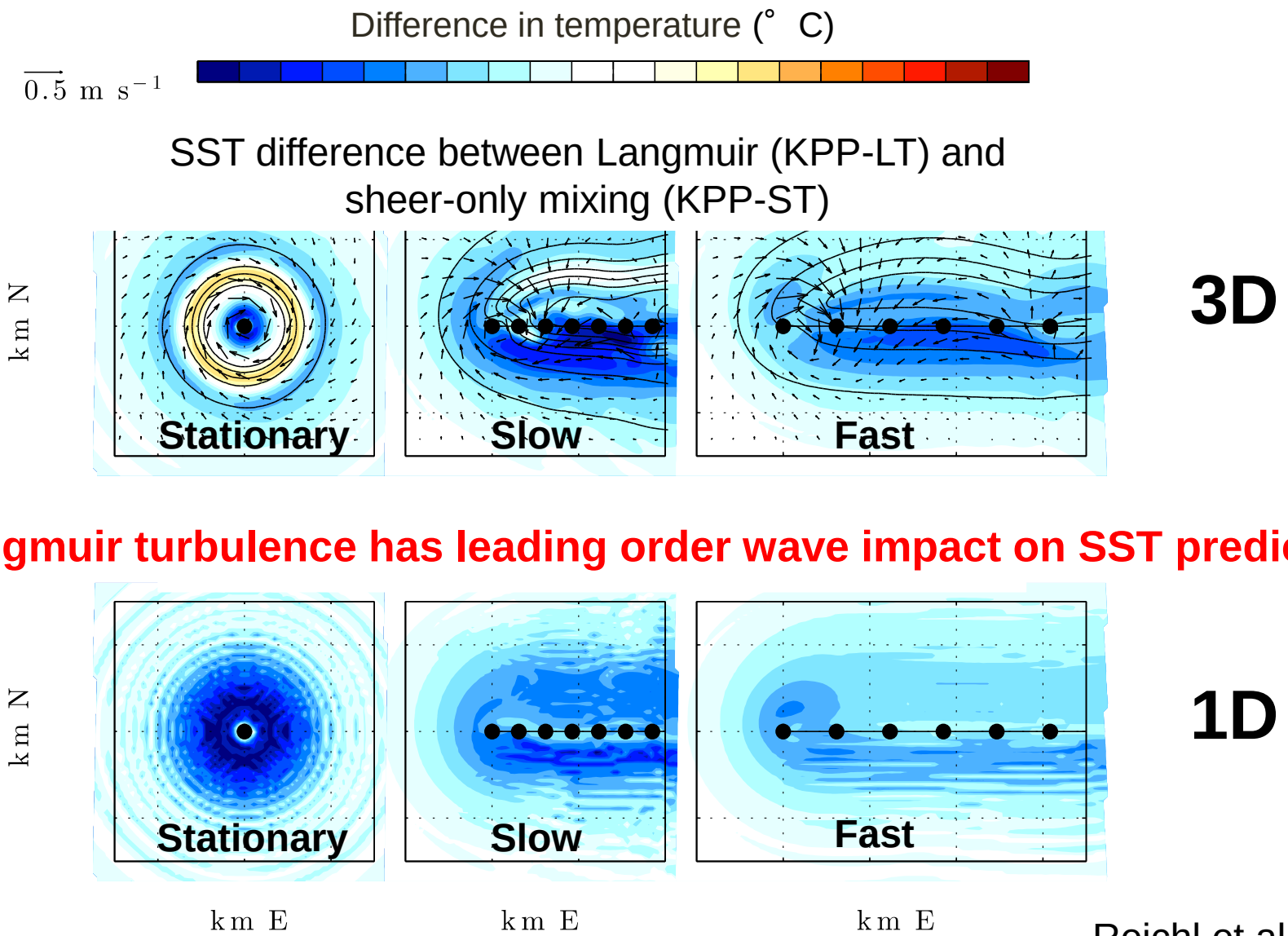
KPP-ST predicts strong surface currents and vertical current shear.

KPP-LT predicts much weaker surface currents and current shear.



Reichl et al, 2016

Impact of Waves on Upper-ocean Response: 3D and 1D Ocean Models



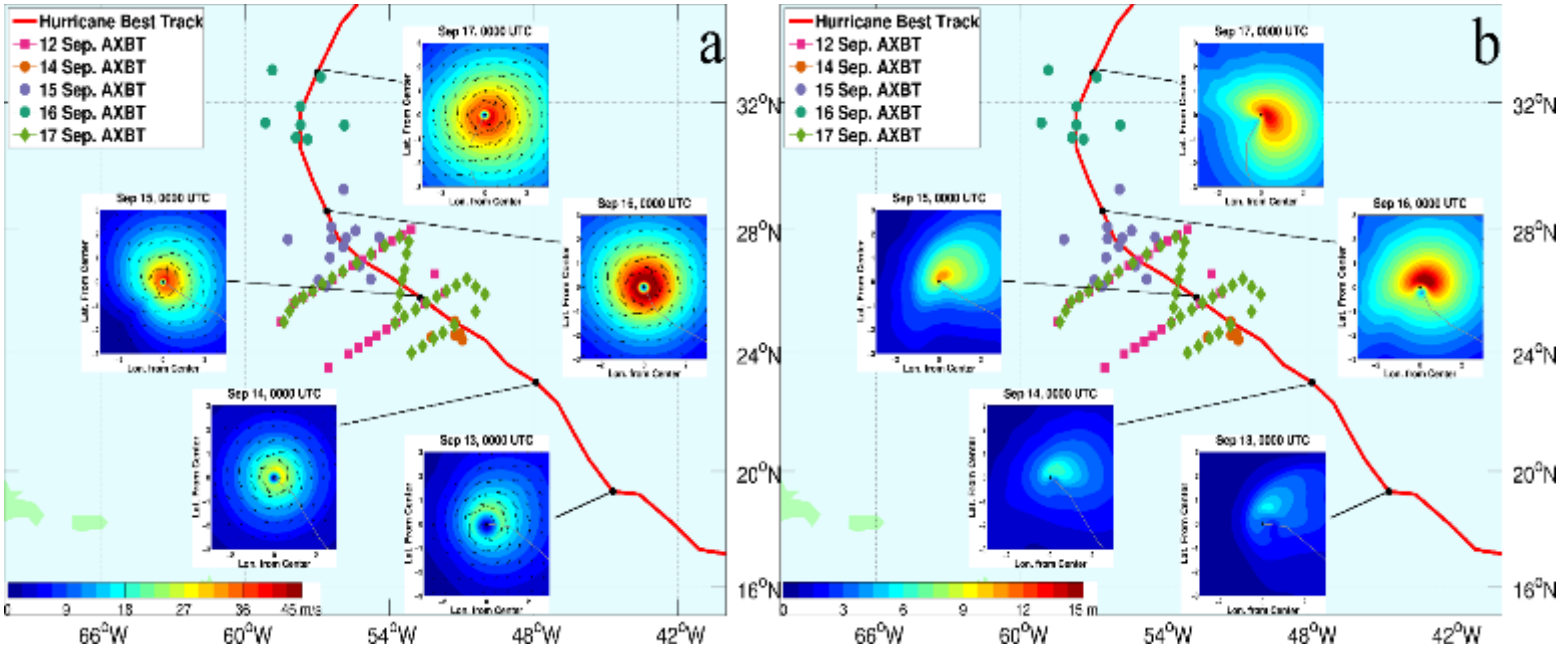
Langmuir turbulence has leading order wave impact on SST prediction

Reichl et al. 2016

Impact of Waves on Upper-ocean Response: Hurricane Edouard (2014)

Model wind fields based on TC vitals

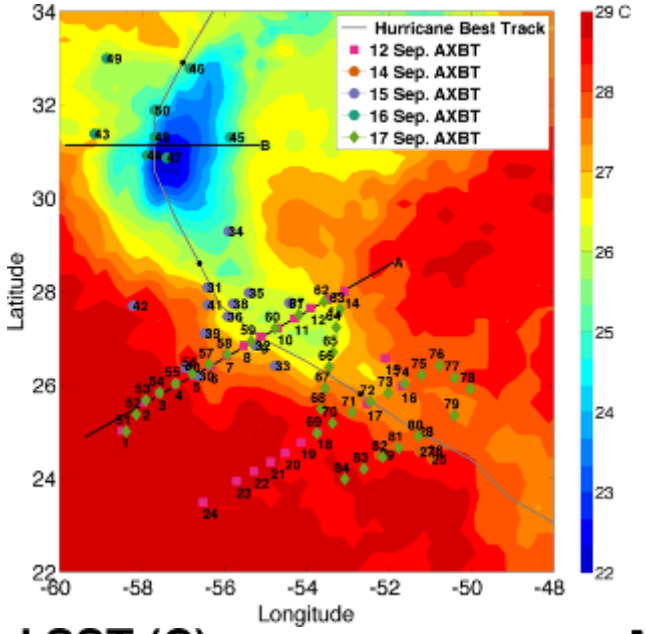
WW3 significant wave heights

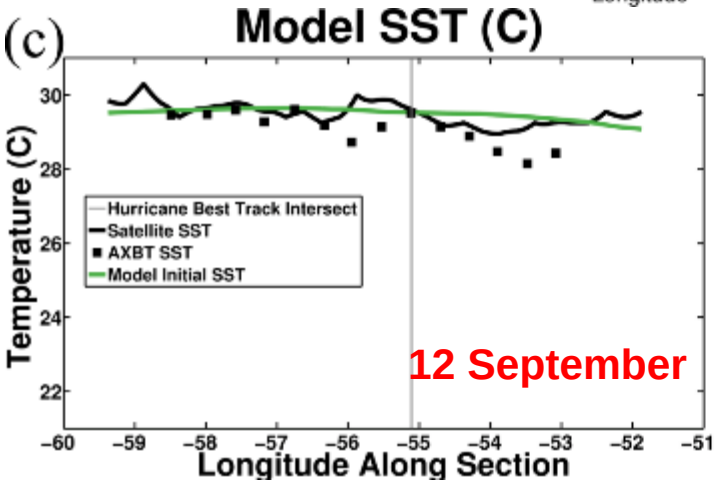


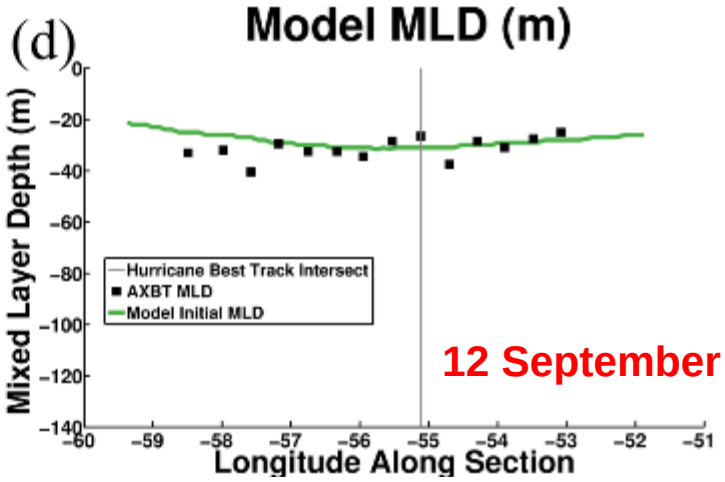
84 AXBTs were deployed by NOAA HRD on September 12, 14, 15, 16 and 17.

Blair et al. 2017

Impact of Waves on Upper-ocean Response: Hurricane Edouard (2014)





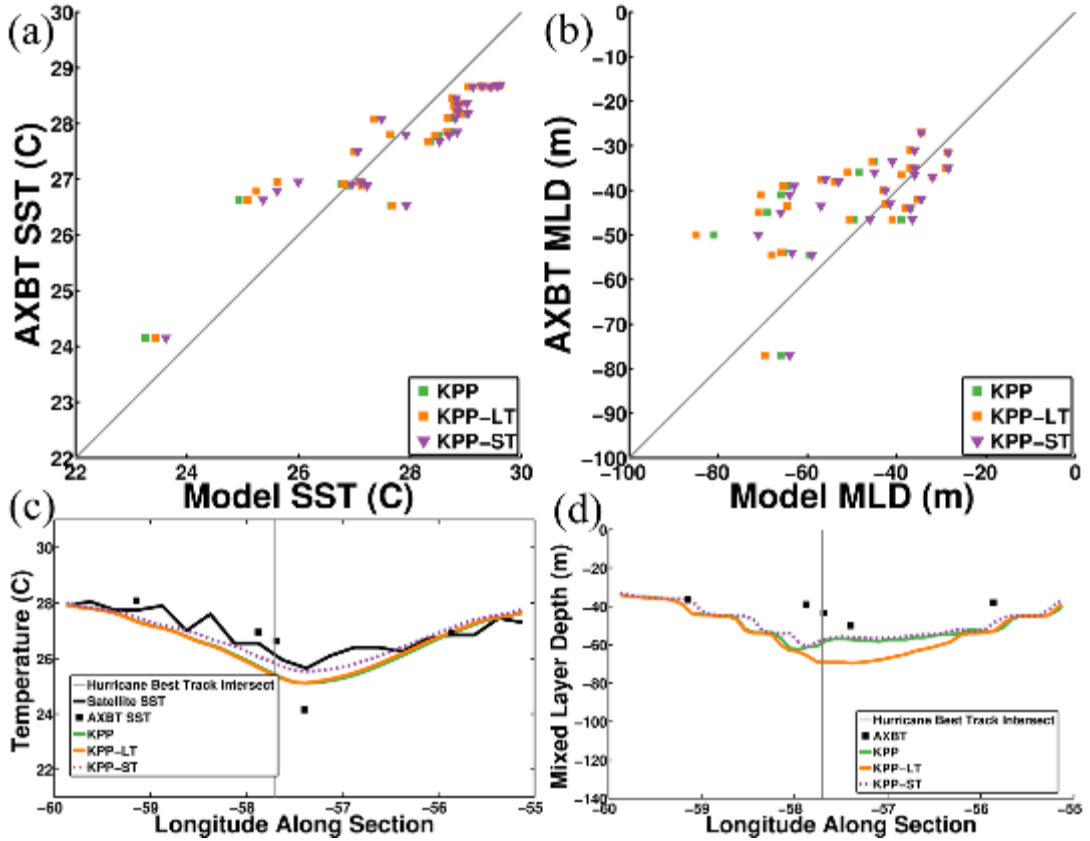


Blair et al. 2017

Impact of Waves on Upper-ocean Response: Hurricane Edouard (2014)

LES-ST: Shear-driven turbulence only

LES-LT: Shear-driven & Langmuir turbulence



AXBTs deployed near the storm on September 14, 15, and 16

Evaluation is inconclusive due to absence of current measurements and sparse temperature measurements under hurricane's inner core.

Blair et al. 2017

Summary

- Wave model simulations indicate significant sea state dependence of the *drag coefficient* under hurricane conditions.

- LES and ocean model simulations indicate significant impact of wave-driven *Langmuir turbulence* on the ocean response to a hurricane.

- Explicitly resolving sea state dependent processes in coupled *hurricane-wave-ocean models* will lead to increased accuracy in predicting the ocean response and hurricane intensity.

- Direct observations of ocean currents, waves and temperatures are *necessary* to fully examine the impact of sea state dependent processes under hurricane conditions and to evaluate coupled model results.