THE EFFECTS OF SEA SURFACE TEMPERATURE GRADIENTS ON SURFACE TURBULENT FLUXES

John Steffen and Mark A. Bourassa

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Florida State University
Changes in surface winds due to SST gradients are poorly modeled in NWP and climate models, potentially resulting in large errors in surface turbulent fluxes and the energy budget.

Coupled air-sea modeling and higher resolution observations provide a more detailed representation of small-scale surface processes and could improve the representation of the energy budget within climate models.

Our goal is to determine how large of a difference in surface turbulent fluxes of momentum, sensible heat, and latent heat occurs due to overlooking the correlated variability in SSTs, winds, and temperatures.
Introduction

- Small spatial scale SST gradients, on the order of ~100-200 km, are associated with western boundary currents, such as the Gulf Stream and Kuroshio Extension
  - Important climatological impacts

- A positive correlation between SSTs and wind stress perturbations in these regions suggests turbulent fluxes should be enhanced over values for smoother fields

- Effects SST gradients have on surface winds and turbulent fluxes affect the ocean and atmosphere over a wide range of spatial and temporal scales
  - See the poster by Hughes and Bourassa
Winter (DJF) seasonal SST gradients (> 1 K/100 km) and data subset regions located over the Gulf Stream and the Kuroshio Extension

Winter (DJF) seasonal wind speed difference and data subset regions located over the Gulf Stream and the Kuroshio Extension
Data subsets contain areas with largest SST gradients

SST effects still occur outside of these regions, but to a lesser extent

SSTs are slowly varying

Winter (DJF) seasonal SST gradients (> 1 K/100 km) over the Kuroshio Extension
145.125°E – 175.125°W and 35.125°N – 45.125°N

Winter (DJF) seasonal SST gradients (> 1 K/100 km) over the Gulf Stream
73.375°W – 38.375°W and 35.375°N – 50.375°N
SST gradients are slightly reduced and displaced further north.

- Maximum SST gradients still reach 2.2K/100 km
  - Limit of solutions for UWPBL
Smoothing in NWP over oceans reduces signals on scales up to 8-10 times the grid spacing
- ECMWF operational grid spacing is now 15 km

NWP winds had considerably less energy at spatial scales smaller than ~1000 km (Wikle et al. 1999; Milliff et al. 2004; Chelton et al. 2006). Currently, less than ~400 km
Wind stress magnitudes are relatively weak over colder water and strong over warmer water.

Wind stress divergence is strongest for flow perpendicular to isotherms (parallel to SST gradient).

Wind stress curl is strongest for flow parallel to isotherms (perpendicular to SST gradient)

From Chelton 2005
Experimental Setup

- Two data sets created: one that adjusted surface winds in response to small scale SST gradients and one the lacked this air-sea coupling (by Paul Hughes)
  - Both data sets produced with surface pressures, 2-m air temperatures, and 2-m dew point temperatures from ERA-Interim and Reynolds Daily OISST
  - Six hourly (0, 6, 12, 18 Z) with 0.25° grid spacing covering Atlantic and Pacific Ocean basins

- Univ. of Washington Planetary Boundary Layer (UWPBL) model
  - Results in 10m wind vectors. Fluxes calculated from these winds and above variables
Bourassa (2006) surface roughness model, which includes the effects of capillary waves and sea state

Clayson, Fairall, Curry (1996) roughness length parameterizations for potential temperature and moisture

Zheng et al. (2013) transition from a smooth to rough surface

Benoit (1977) parameterization for an unstable boundary layer

Beljaars and Holtslag (1991) parameterization for a stable boundary layer

Monin-Obukhov scale length (Liu et al. 1979)
2002 – 2003 seasonal average differences in SHF (left), LHF (middle), and wind stress (right) for DJF (top row), MAM (2nd row), JJA (3rd row), and SON (bottom row)
2002-2003 seasonal PDF’s of SHF difference over the Gulf Stream

2002-2003 seasonal box plots of SHF difference over the Gulf Stream
2002-2003 seasonal PDF's of LHF difference over the Gulf Stream

Latent Heat Flux difference (W/m²)
Seasonal Wind Stress

2002-2003 seasonal PDF's of wind stress difference over the Gulf Stream

2002-2003 seasonal box plots of wind stress difference over the Gulf Stream
Dec. 2002 – Nov. 2003 monthly box plots of SHF (top) and LHF (bottom) difference over the Gulf Stream (left) and Kuroshio Extension (right)

- Monthly averaged turbulent flux differences are more sensitive to the background environment
- More spatial variability than seasonal averages
- Annual cycle is better resolved
Daily PDF’s of SHF (top) and LHF (bottom) difference over the Gulf Stream (left) and Kuroshio Extension (right) during selected high wind events

• Snapshots in the life cycle of individual synoptic-scale events that can impact storm evolution and upper oceanic properties

• Despite the same physical process taking place over the Gulf Stream and Kuroshio Extension, PDF shapes are different
Differences in surface turbulent fluxes exhibit a seasonal cycle with a peak in winter (DJF), a transitional period in spring (MAM) and fall (SON), and a minimum in summer (JJA)

- DJF averages for SHF, LHF, and Tau are 3.86 W/m², 6.84 W/m², and 0.032 N/m², respectively
- Differences are important, even in summer, for very long time scale applications such as the upper ocean energy budget (Levitus et al. 2005)

The local daily variations are much larger, and are presumably important for cyclogenesis and water mass evolution.
Boundary Layer Response

- Flow from cold to warm SST with (a) strong background winds and (b) weak background winds
- Horizontal across-front profiles of SST and air temperature below
- Vertical profiles of downstream anomalies in air temperature and pressure

From Small 2008
Additional DJF Seasons

- Consistency in PDFs among all DJF seasons is a surprising result for the Kuroshio Extension.

- Low-frequency variability in synoptic-scale environment and SST fields has a marginal effect on PDF shapes, especially for the Gulf Stream.

Figure 14: DJF seasonal PDF’s of SHF difference (top) and LHF difference (bottom) over the Gulf Stream (left) and Kuroshio Extension (right) for the years ’87 – ’88, ’88 – ’89, ’89 – ’90, ’99 – ’00, ’00 – ’01, ’01 – ’02.
Figure 15: 2003 monthly average differences in SHF (left), LHF (middle), and wind stress (right) for January (top row), April (2\textsuperscript{nd} row), July (3\textsuperscript{rd} row), and October (bottom row)
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