THE EFFECTS OF SEA SURFACE TEMPERATURE GRADIENTS ON SURFACE TURBULENT FLUXES

John Steffen and Mark A. Bourassa

Funding by NASA Climate Data Records and NASA Ocean Vector Winds Science Team

Florida State University

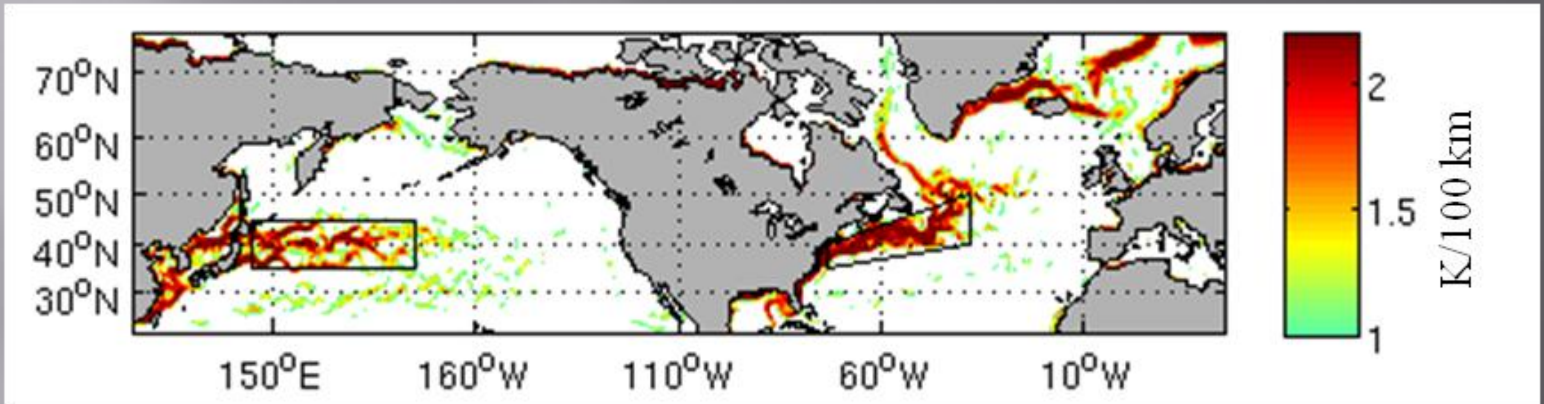
Motivation

- 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

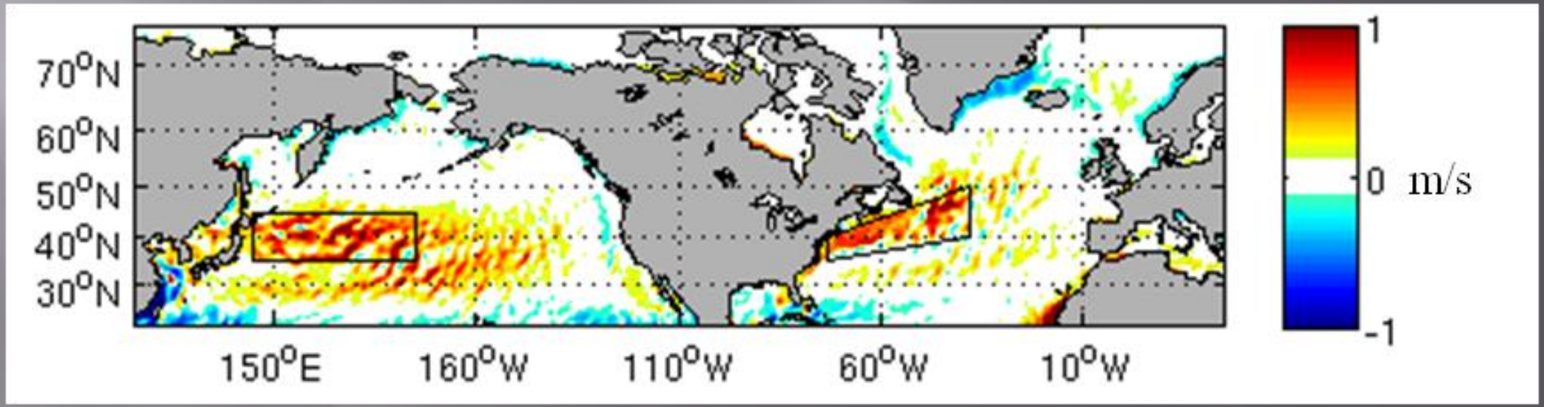
Introduction

- 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

SST Gradients and Surface Winds

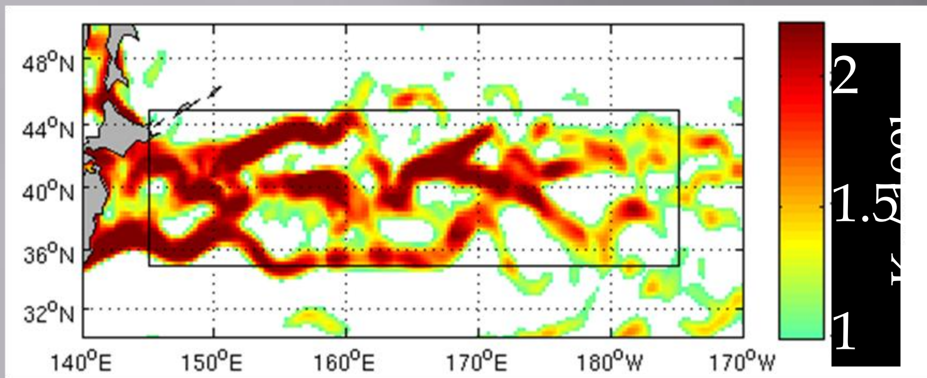


Winter (DJF) seasonal **SST gradients (> 1 K/100 km)** and data subset regions located over the Gulf Stream and the Kuroshio Extension



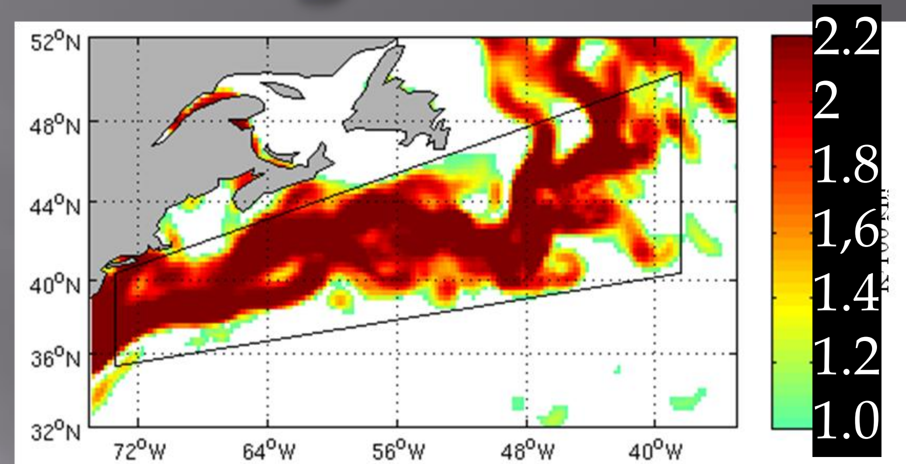
Winter (DJF) seasonal **wind speed difference** and data subset regions located over the Gulf Stream and the Kuroshio Extension

Data Subset Regions



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

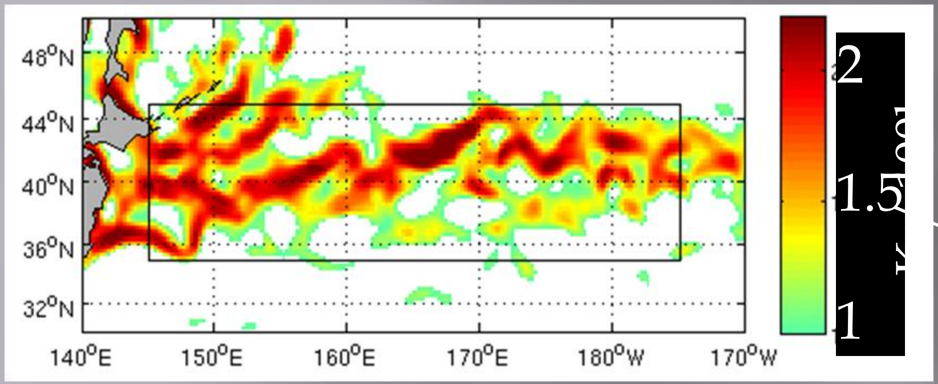


Winter (DJF) seasonal **SST gradients** (> 1 K/100 km) over the Gulf Stream

73.375°W – 38.375°W and 35.375°N – 50.375°N

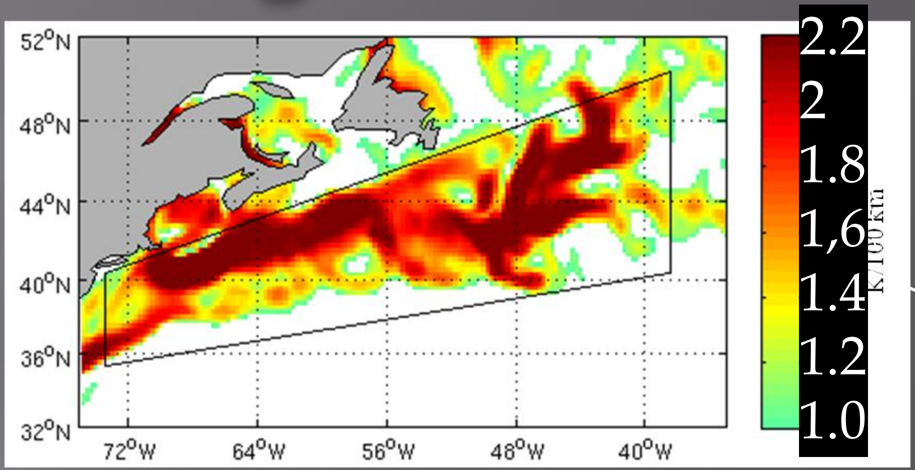
- Data subsets contain areas with largest SST gradients
- SST effects still occur outside of these regions, but to a lesser extent
- SSTs are slowly varying

Data Subset Regions



Summer (JJA) seasonal **SST gradients** (> 1 K/100 km) over the the Kuroshio Extension

145.125°E – 175.125°W and 35.125°N – 45.125°N



Summer (JJA) seasonal **SST gradients** (> 1 K/100 km) over the Gulf Stream

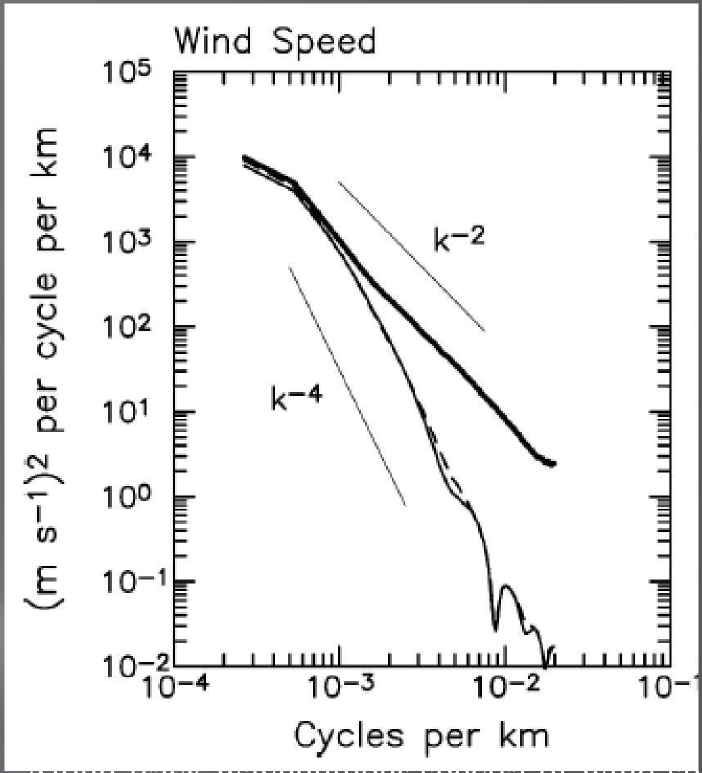
73.375°W – 38.375°W and 35.375°N – 50.375°N

- SST gradients are slightly reduced and displaced further north
- Maximum SST gradients still reach 2.2K/100 km
  - Limit of solutions for UWPBL

Spatial Smoothing in NWP

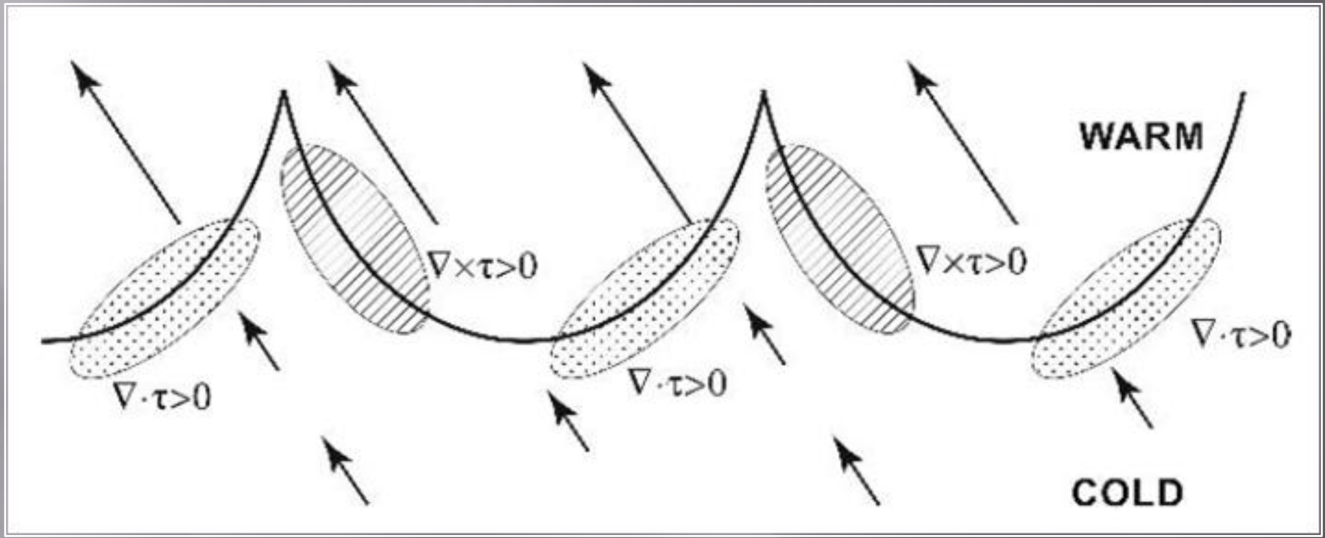
- Smoothing in NWP over oceans reduces signals on scales up to 8-10 times the grid spacing
  - ECMWF operational grid spacing is now 15 km

- 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



Along-track wavenumber spectra of wind speed in the eastern North Pacific for 2004 computed from QuikSCAT observations (heavy solid lines), NCEP analyses (thin solid lines), and ECMWF analyses (dashed lines) of 10 m winds bilinearly interpolated to the times and locations of the QuikSCAT observations. (Chelton et al. 2006)

SST-Winds Relationship



From Chelton 2005

- 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)

Experimental Setup

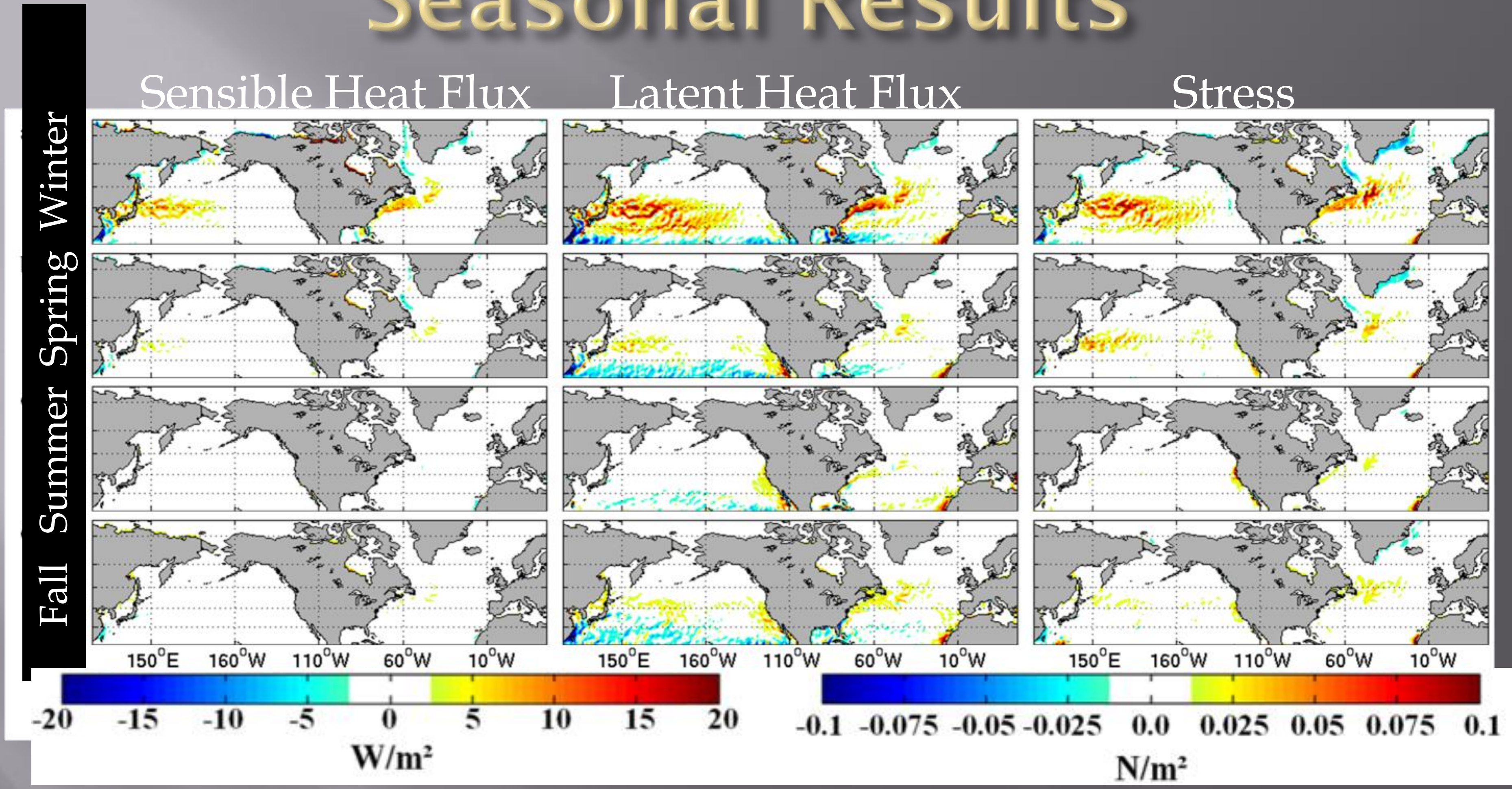
- Two data sets created: one that adjusted surface winds in response to small scale SST gradients and one the lacked this air-sea coupling (by Paul Hughes)
  - Both data sets produced with surface pressures, 2-m air temperatures, and 2-m dew point temperatures from ERA-Interim and Reynolds Daily OISST
  - Dec. 2002 – Nov. 2003 and six DJF seasons of 1987 – 88, 1988 – 89, 1989 – 90, 1999 – 00, 2000 – 01, and 2001 – 02
  - 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

MFT12 Flux Model Parameters

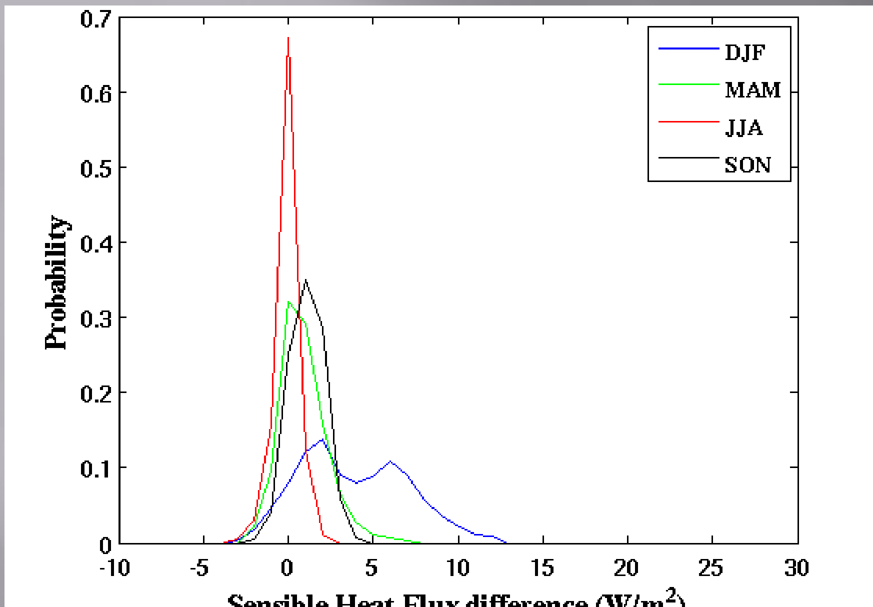
- Bourassa (2006) surface roughness model, which includes the effects of capillary waves and sea state
- Clayson, Fairall, Curry (1996) roughness length parameterizations for potential temperature and moisture
- Zheng et al. (2013) transition from a smooth to rough surface
- Benoit (1977) parameterization for an unstable boundary layer
- Beljaars and Holtslag (1991) parameterization for a stable boundary layer
- Monin-Obukhov scale length (Liu et al. 1979)

Seasonal Results

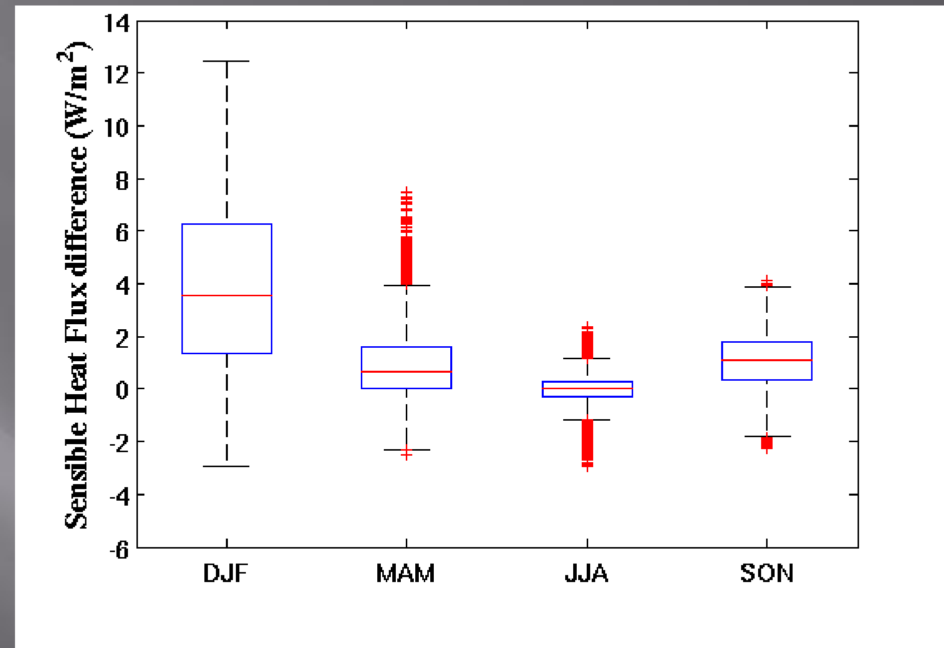


2002 – 2003 seasonal average differences in SHF (left), LHF (middle), and wind stress (right) for DJF (top row), MAM (2nd row), JJA (3rd row), and SON (bottom row)

Seasonal SHF

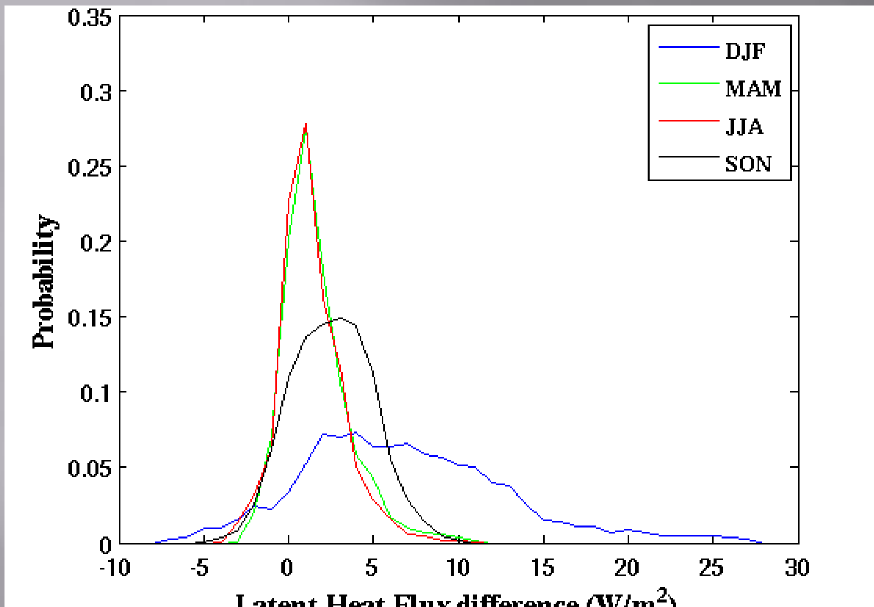


2002-2003 **seasonal PDF's of SHF**
difference over the Gulf Stream

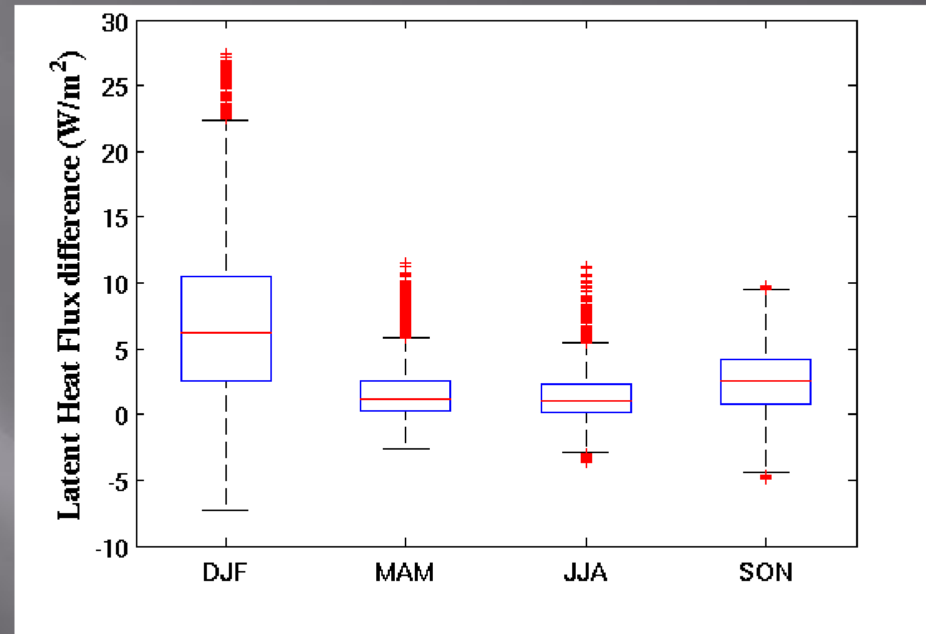


2002-2003 **seasonal box plots of SHF**
difference over the Gulf Stream

Seasonal LHF

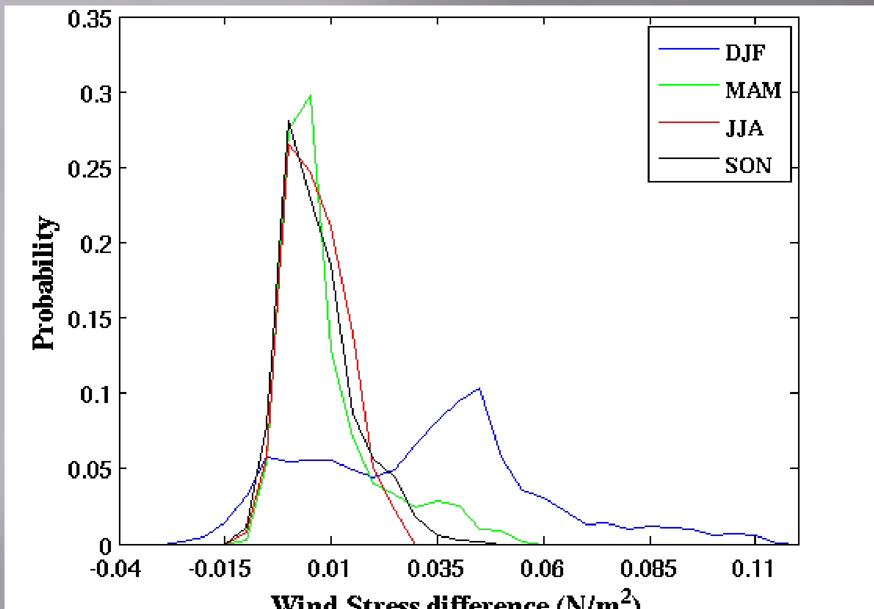


2002-2003 seasonal PDF's of **LHF difference** over the Gulf Stream

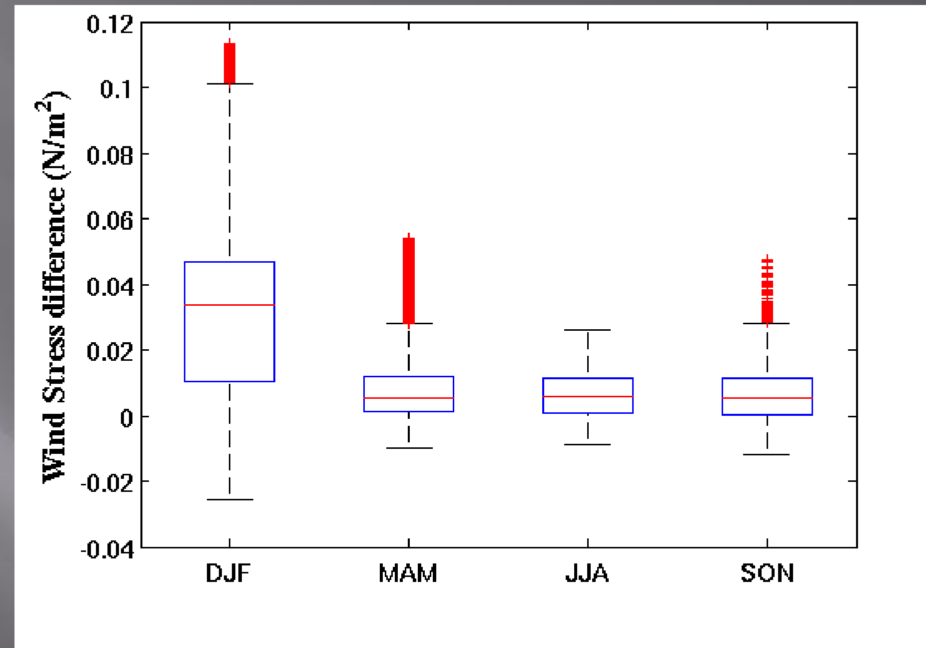


2002-2003 seasonal box plots of **LHF difference** over the Gulf Stream

Seasonal Wind Stress

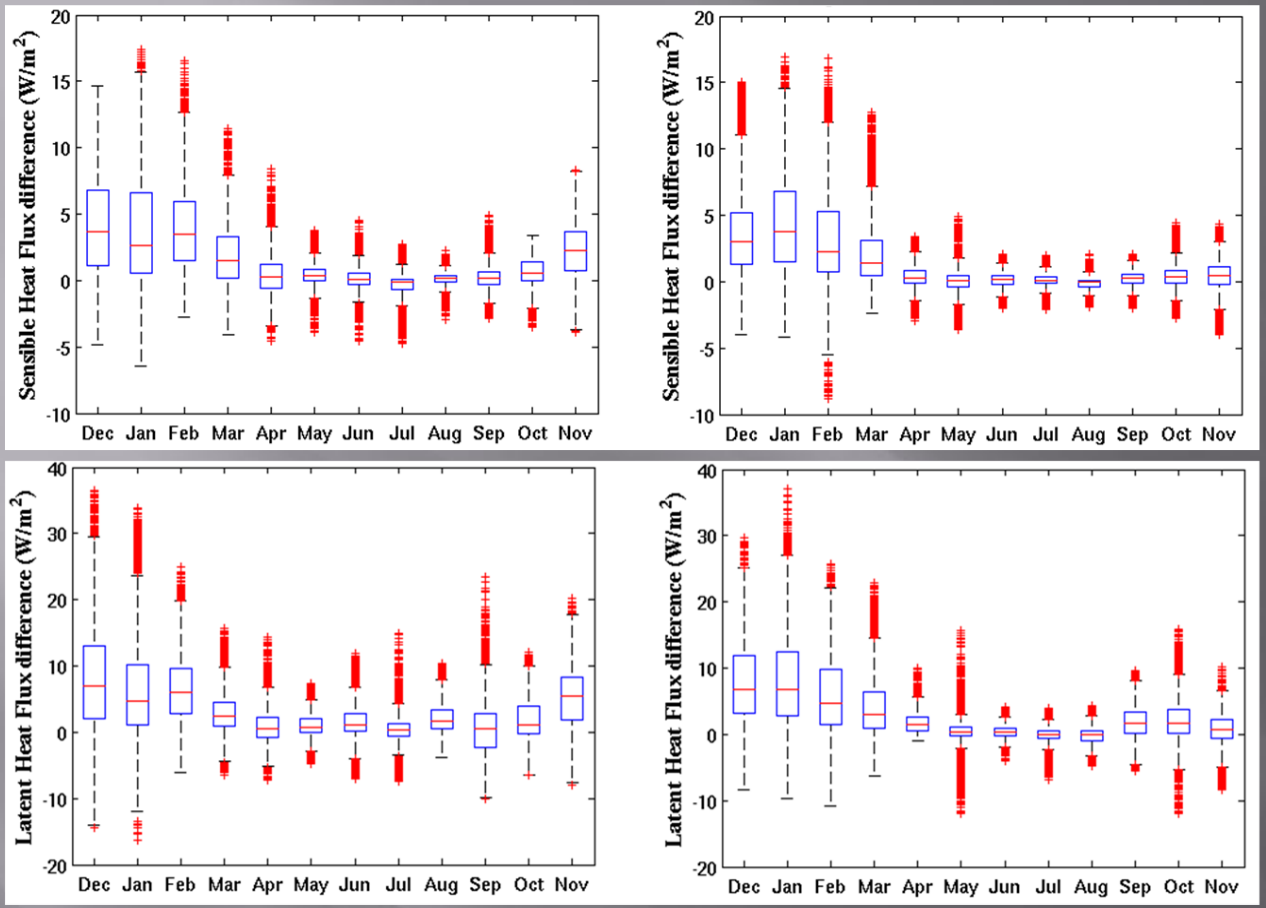


2002-2003 seasonal PDF's of
wind stress difference
over the Gulf Stream



2002-2003 seasonal box plots of
wind stress difference
over the Gulf Stream

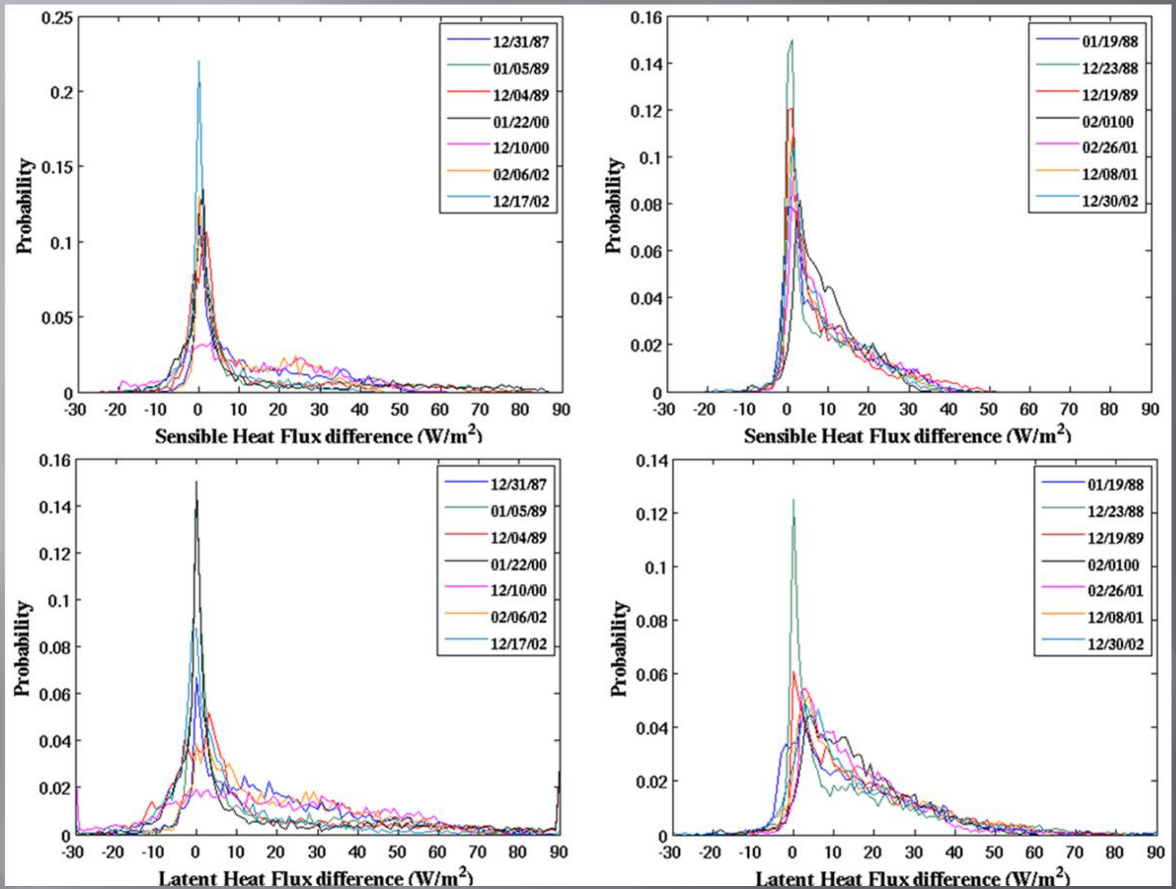
Monthly Box Plots



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 Results



Daily PDF's of SHF (top) and LHF (bottom) difference over the Gulf Stream (left) and Kuroshio Extension (right) during selected high wind events

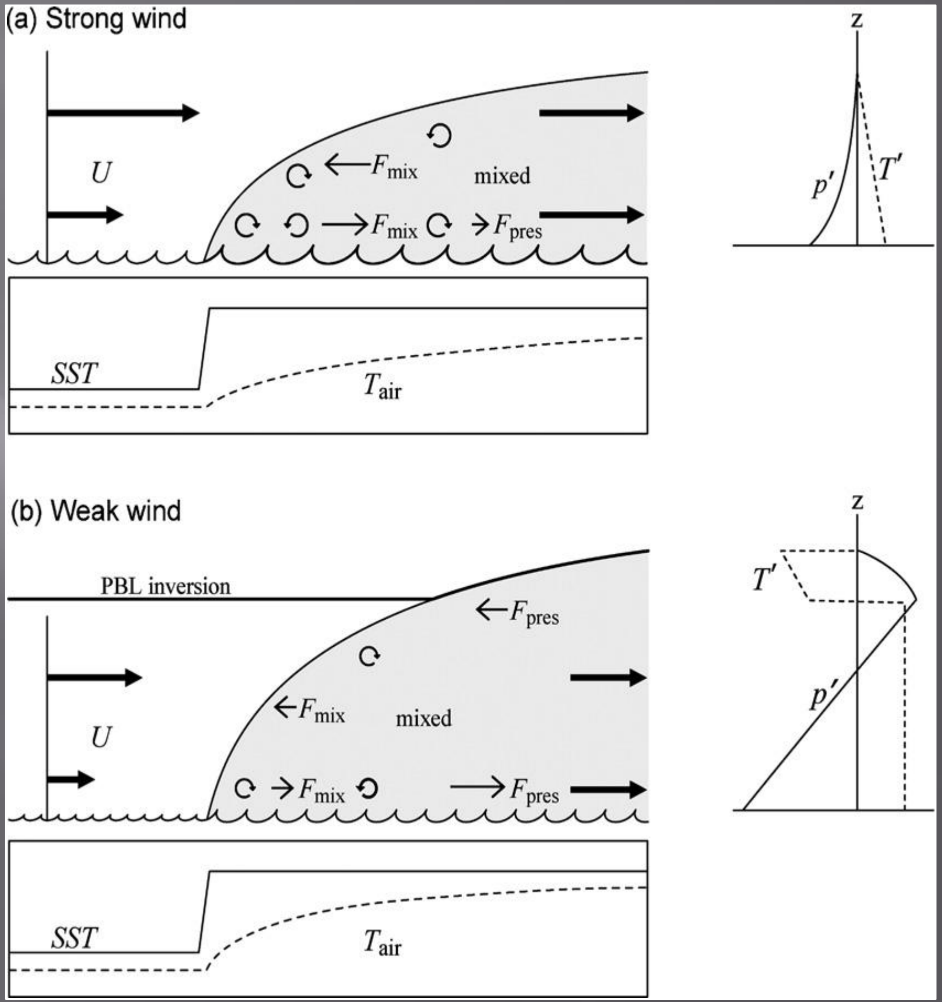
- Snapshots in the life cycle of individual synoptic-scale events that can impact storm evolution and upper oceanic properties
- Despite the same physical process taking place over the Gulf Stream and Kuroshio Extension, PDF shapes are different

Conclusions

- 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/m^2, 6.84 W/m^2, and 0.032 N/m^2, 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.

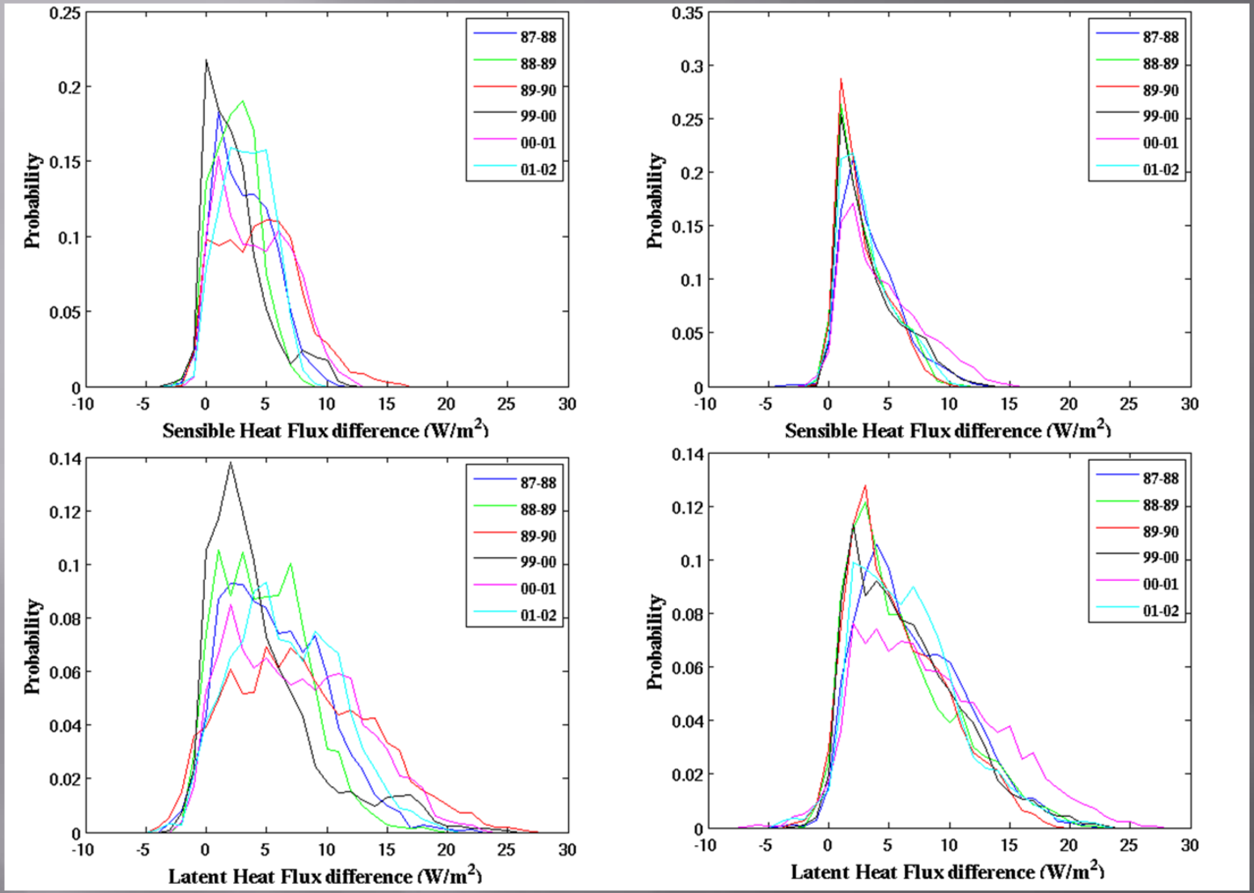
Boundary Layer Response

- Flow from cold to warm SST with (a) strong background winds and (b) weak background winds
- Horizontal acr0ss-front profiles of SST and air temperature below
- Vertical profiles of downstream anomalies in air temperature and



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.

Monthly Results

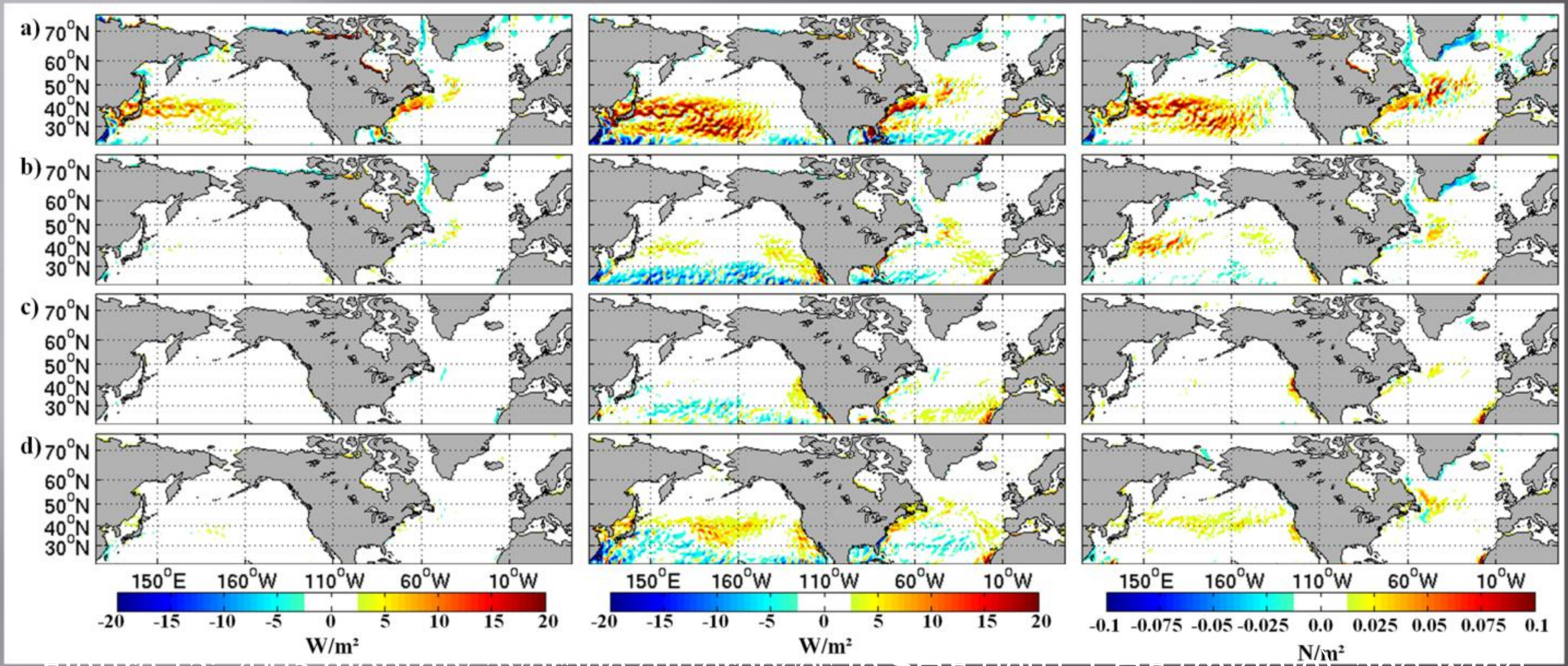


Figure 15: 2005 monthly average differences in SHF (left), LHF (middle), and wind stress (right) for January (top row), April (2nd row), July (3rd row), and October (bottom row)

SHF (W/m^2)	Mean	St. Dev.	Min.	Max
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

LHF (W/m^2)	Mean	St. Dev.	Min.	Max
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

TAU (N/m^2)	Mean	St. Dev.	Min.	Max
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

References

Beljaars, A.C. M., and A. A. M. Holtslag, (1991), Flux parameterization over land surfaces for atmospheric models, *J. Appl. Meteorol.*, **30**, 327-341.

Benoit, R., (1977), On the integral of the surface layer profile-gradient functions, *J. Appl. Meteorol.*, **16**, 859-860.

Bourassa, M. A., (2006), Satellite-based observations of surface turbulent stress during severe weather, *Atmosphere - Ocean Interactions*, **2**, 35 - 52.

Chelton, D. B., (2005), The impact of SST specification on ECMWF surface wind stress fields in the eastern tropical Pacific, *J. Climate*, **18**, 530-550.

Chelton, D. B., M. H. Freilich, J. M. Sienkiewicz, and J. M. Von Ahn, (2006), On the use of QuickSCAT scatterometer measurements of surface winds for marine weather prediction, *Mon. Wea. Rev.*, **134**, 2055-2071.

Clayson, C. A., C. W. Fairall, and J. A. Curry, (1996), Evaluation of turbulent fluxes at the ocean surface using surface renewal theory, *J. Geophys. Res.*, **101**, 28,503-28,513.

Levitus, S., J. I. Antonov, and T. Boyer, (2005), Warming of the World Ocean, 1955–2003, *Geophys. Res. Lett.*, **32,** L02604.

Liu, W. T., K. B. Katsaros, and J. A. Businger, (1979), Parameterization of air-sea exchanges of heat and water vapor including the molecular constraints at the interface, *J. Atmos. Sci.*, **36**, 1722-1735.

Milliff, R. F., J. Morzel, D. B. Chelton, and M. H. Freilich, (2004), Wind stress curl and wind stress divergence biases from rain effects on QSCAT surface wind retrievals, *J. Atmos. Ocean. Technol.*, **21**, 1216-1231.

O'Neill, L. W., (2012), Wind speed and stability effects on coupling between surface wind stress and SST observed from buoys and satellite, *J. Climate*, **25**, 1544-1569.

Small, R. J., S. P. deSzoeke, S.-P. Xie, L. O'Neill, H. Seo, Q. Song, P. Cornillon, M. Spall, and S. Minobe, (2008), Air-sea interaction over ocean fronts and eddies, *Dyn. Atmos. Oceans*, **45**, 274-319.

Wikle, C. K., R. F. Milliff, and W. G. Large, (1999), Surface wind variability on spatial scales from 1 to 1000 km observed during TOGA COARE, *J. Atmos. Sci.*, **56**, 2222-2231.

Zheng, Y., M. A. Bourassa, and P. J. Hughes, (2013), Influences of sea surface temperature gradients and surface roughness changes on the motion of surface oil: A simple idealized study, *J. Appl. Meteor. Clim.*, **52**, 1561 - 1575.