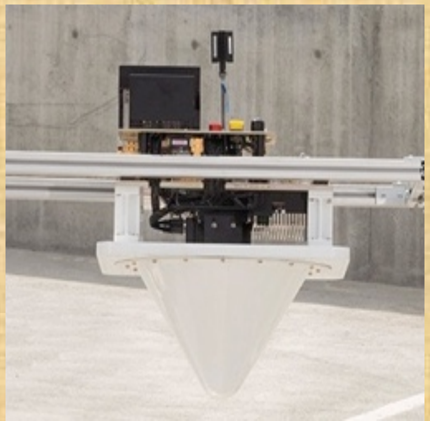
# Scale dependence of air-sea interaction: what are we missing?

Tom Farrar, Larry O'Neill, Niklas Schneider, Hyodae Seo, Ted Durland

IOVWST meeting, 4 May 2017

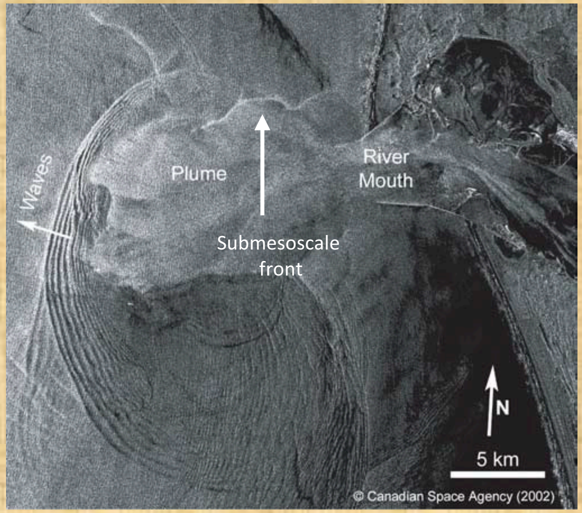
# DopplerScatt offers a quantum leap in air-sea interaction measurements: 200m resolution for wind and ocean currents, and capability for simultaneous SST measurements



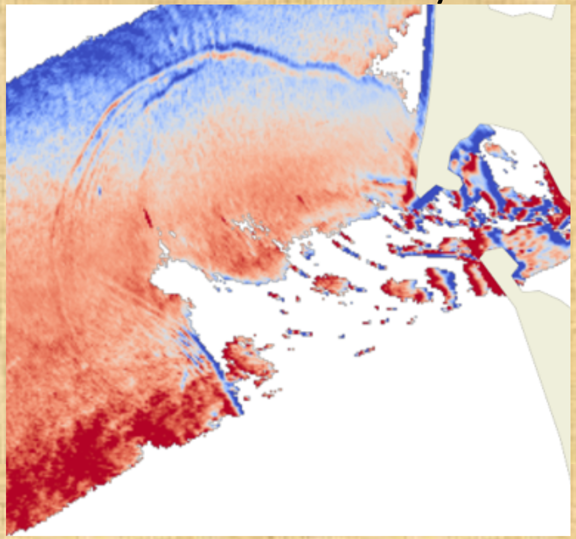
DopplerScatt instrument. It has been deployed on a DOE King Air and the NASA King Air B200.

## What can we learn about air-sea interaction with these measurements?

Satellite SAR image of the Columbia river plume




DopplerScatt fore-looking radial velocity

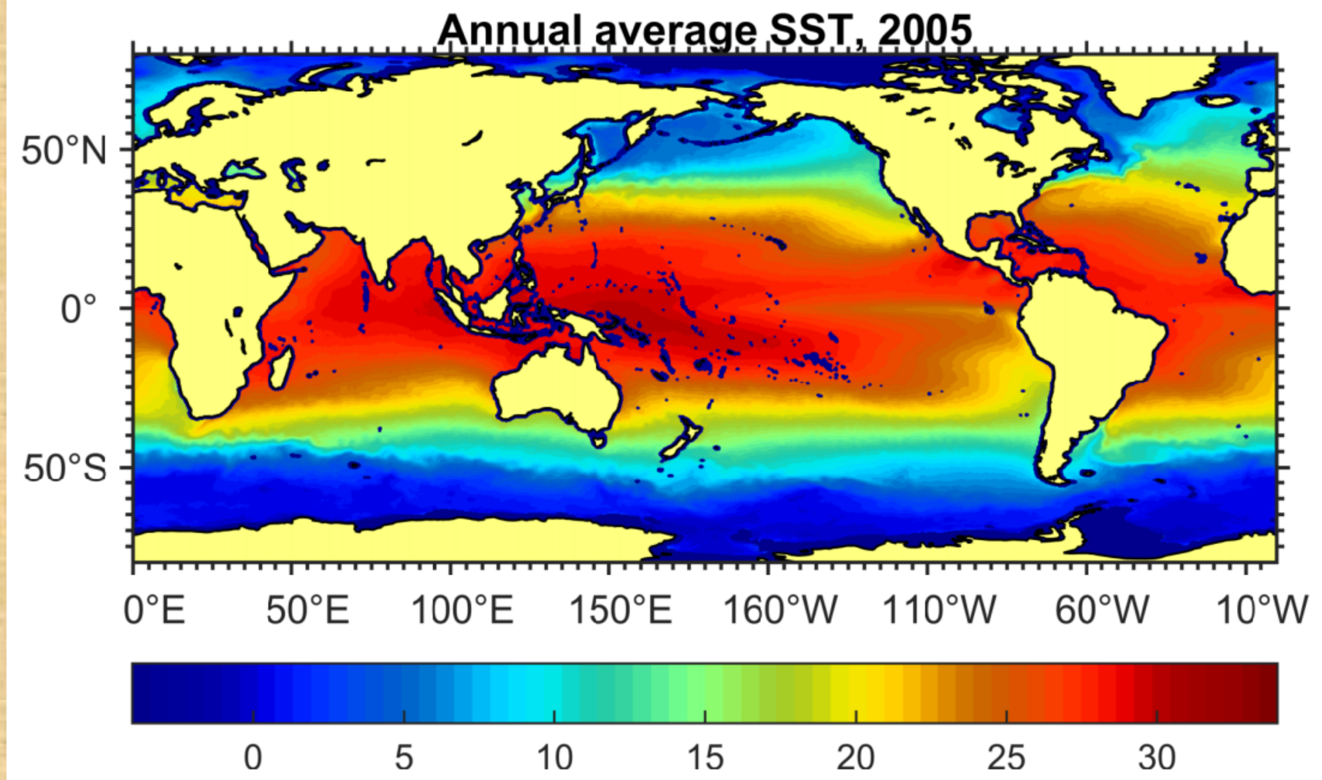


Courtesy Ernesto Rodriguez, Dragana Perkovic-Martin, and JPL DopplerScatt team

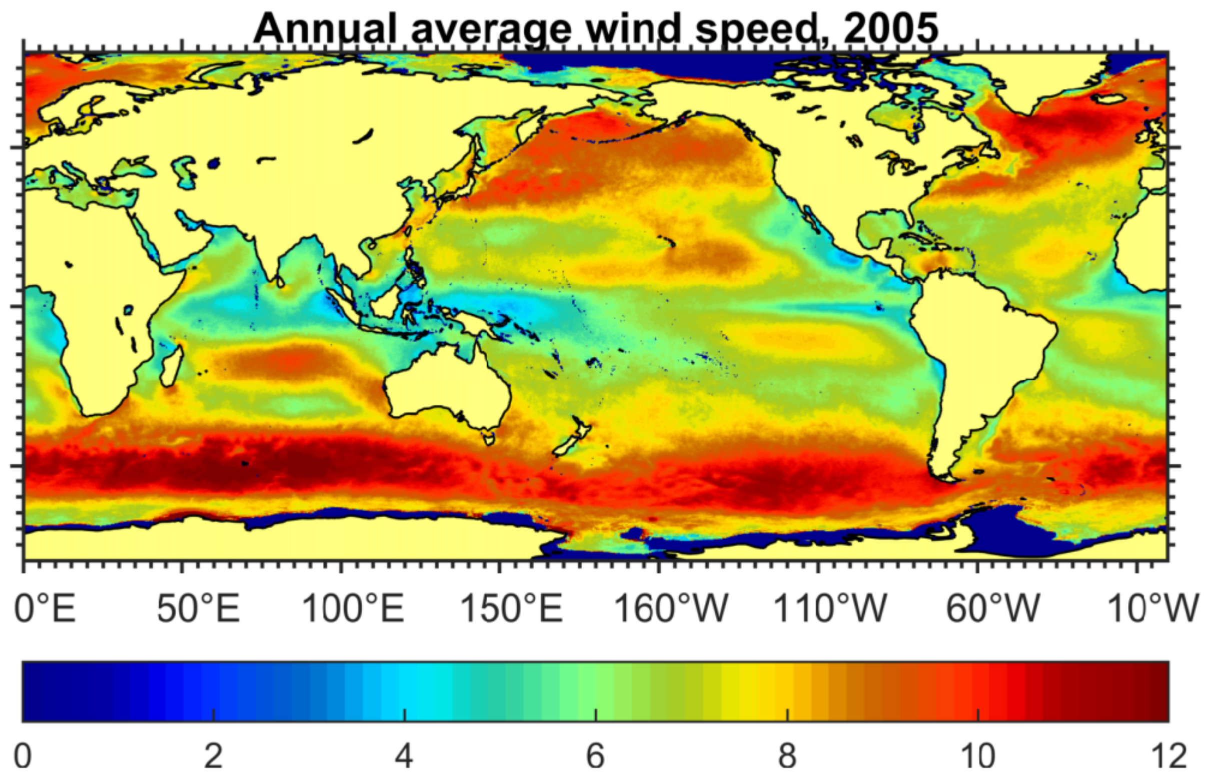
# During the past 20 years:

Scatterometer winds and microwave SST revealed that air-sea coupling is remarkably different at scales of 100-1000 kilometers than it is on scales >1000 kilometers.

SST and wind speed are negatively correlated at large scales




Windsat SST ($^{0}$C)




Windsat wind speed (m/s)

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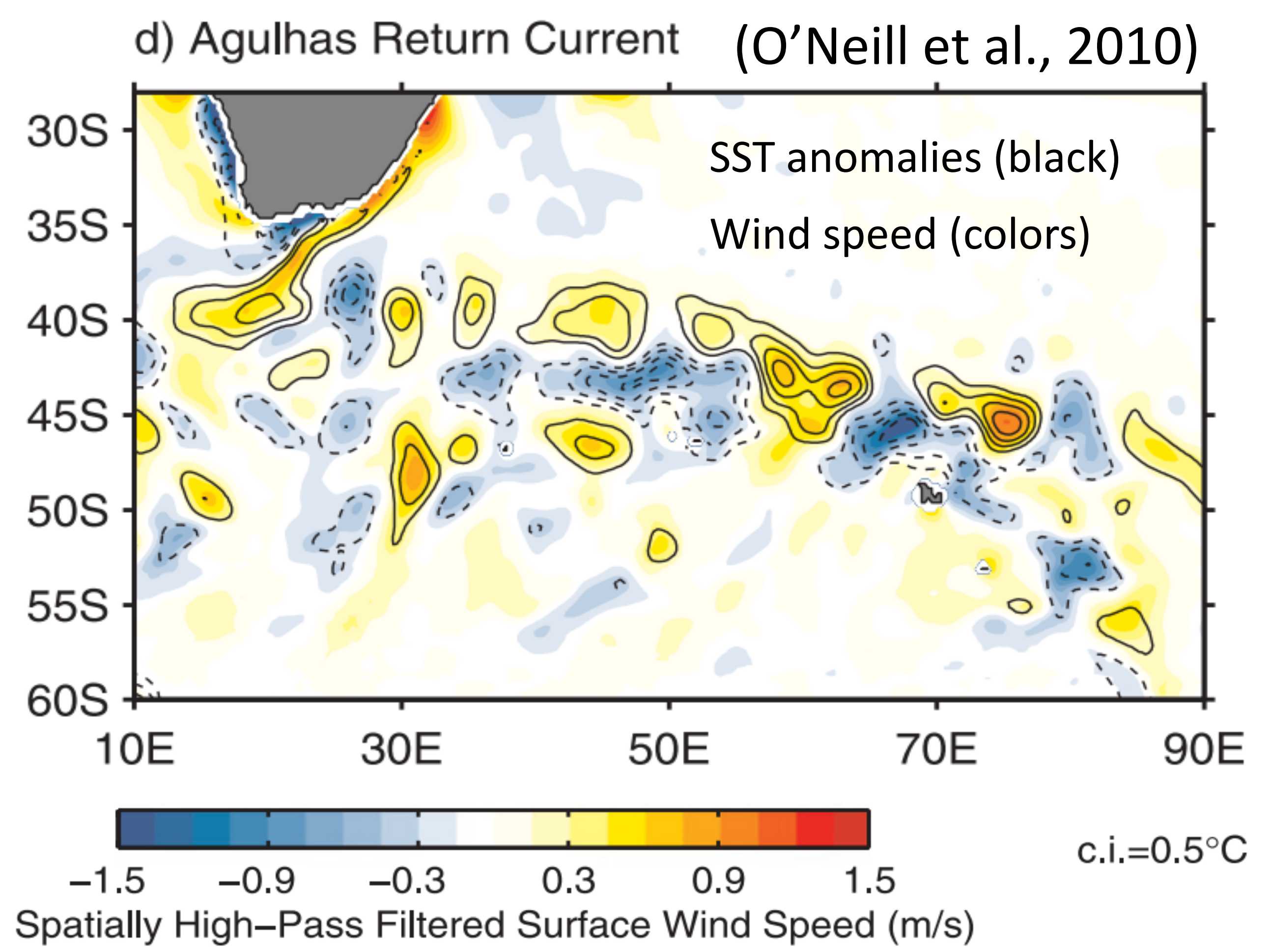
SST and wind speed are positively correlated at 100-1000km scales

→Mesoscale SST anomalies drive wind speed anomalies



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(O'Neill et al., 2010)

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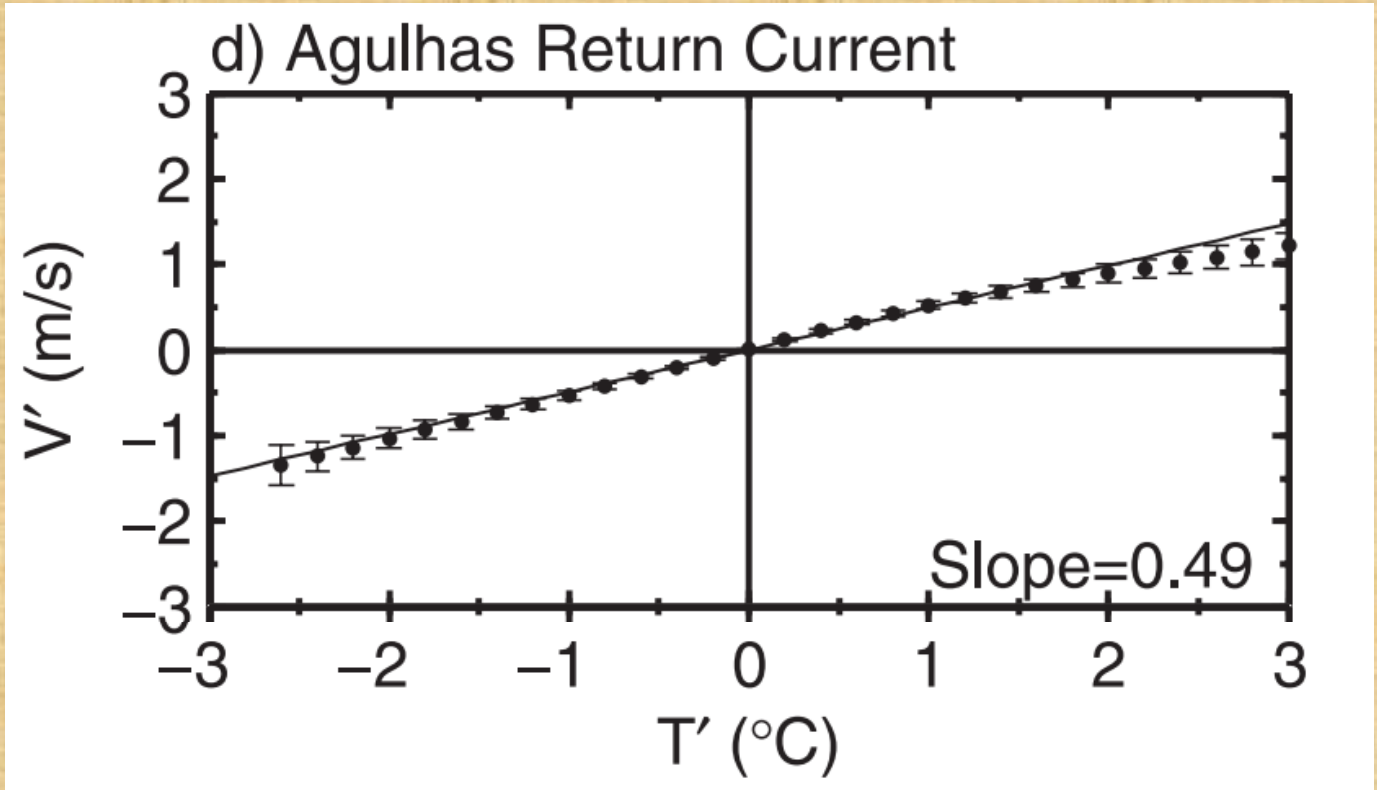
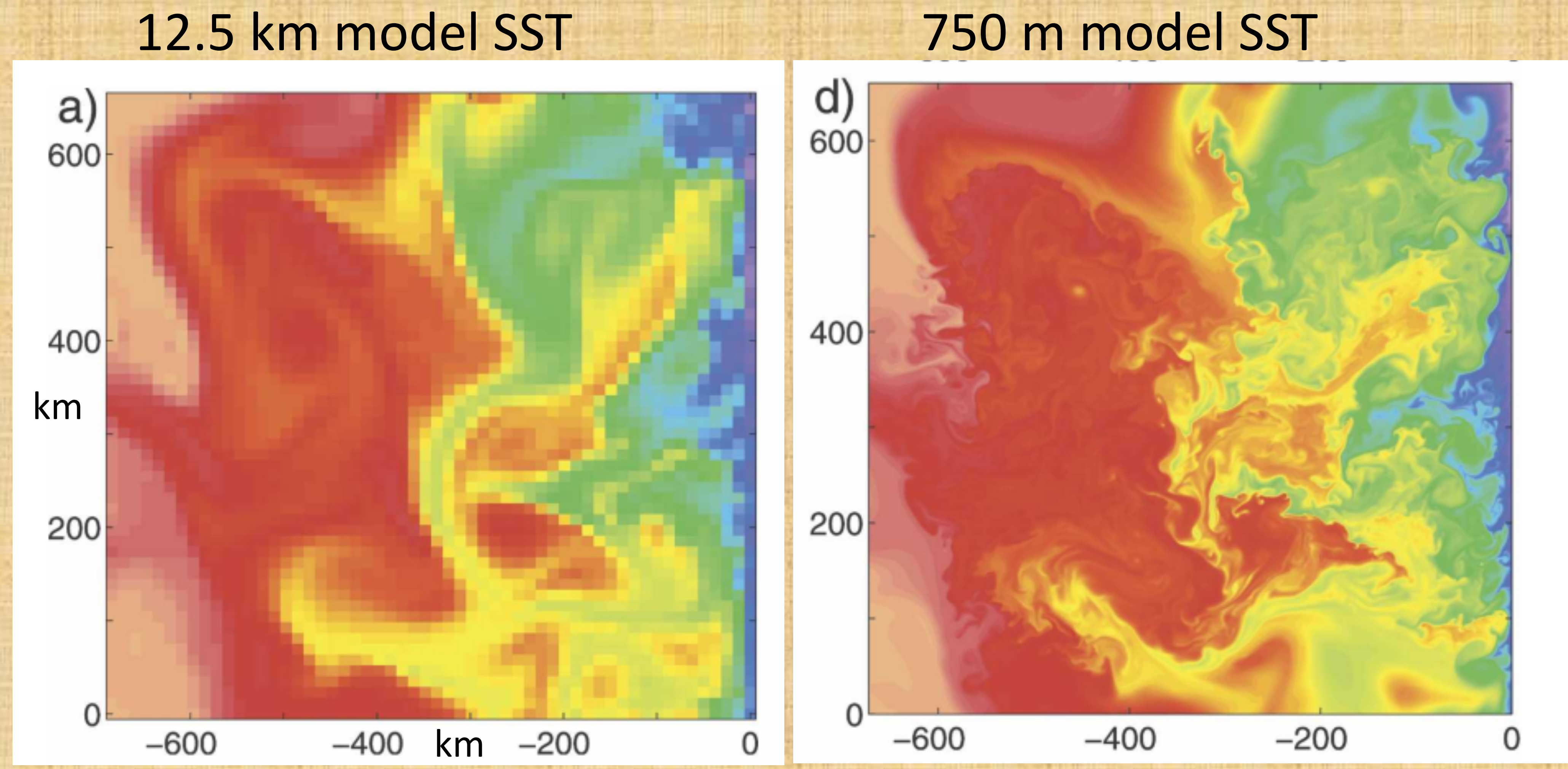


# With DopplerScatt:

We are on the verge of being able to collect simultaneous measurements of SST, currents, and wind to resolve scales down to 200m (~100x increase in resolution)

## What can we learn? How will air-sea interaction at 1-100km scales differ from what we've seen at 100-1000km scales?

# At 1-100km scales, how will air-sea interaction differ from what we've seen at 100-1000km scales?

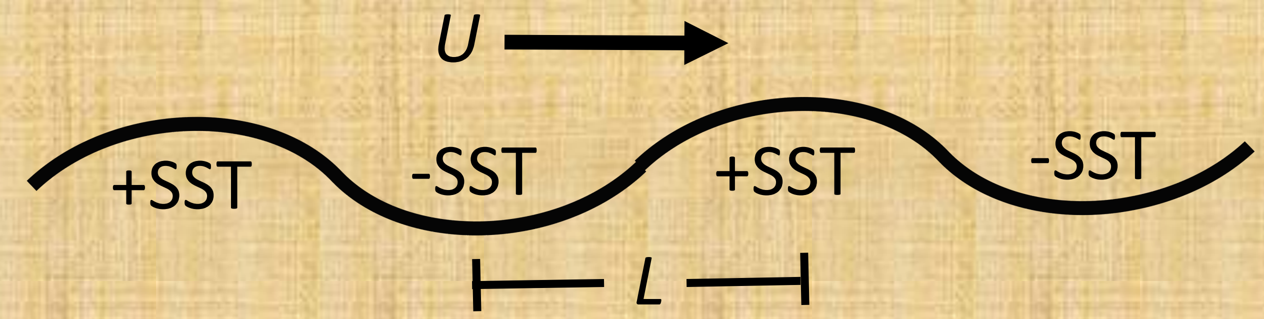



Capet et al. (2008)

# At 1-100km scales, how will air-sea interaction differ from what we've seen at 100-1000km scales?

Timescale: $T=U/L$

→For $L$=5km and $U$=7 m/s, T=12 minutes

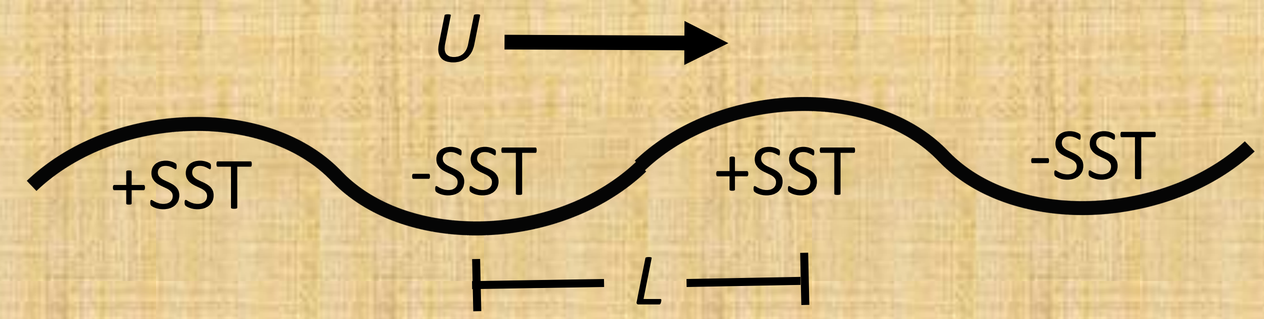


# At 1-100km scales, how will air-sea interaction differ from what we've seen at 100-1000km scales?

On one hand, 12 minutes seems like too little time for the atmospheric boundary layer to adjust to the SST field.  This suggests that the wind response may be small.

Timescale: $T=U/L$

→For $L$=5km and $U$=7 m/s, T=12 minutes

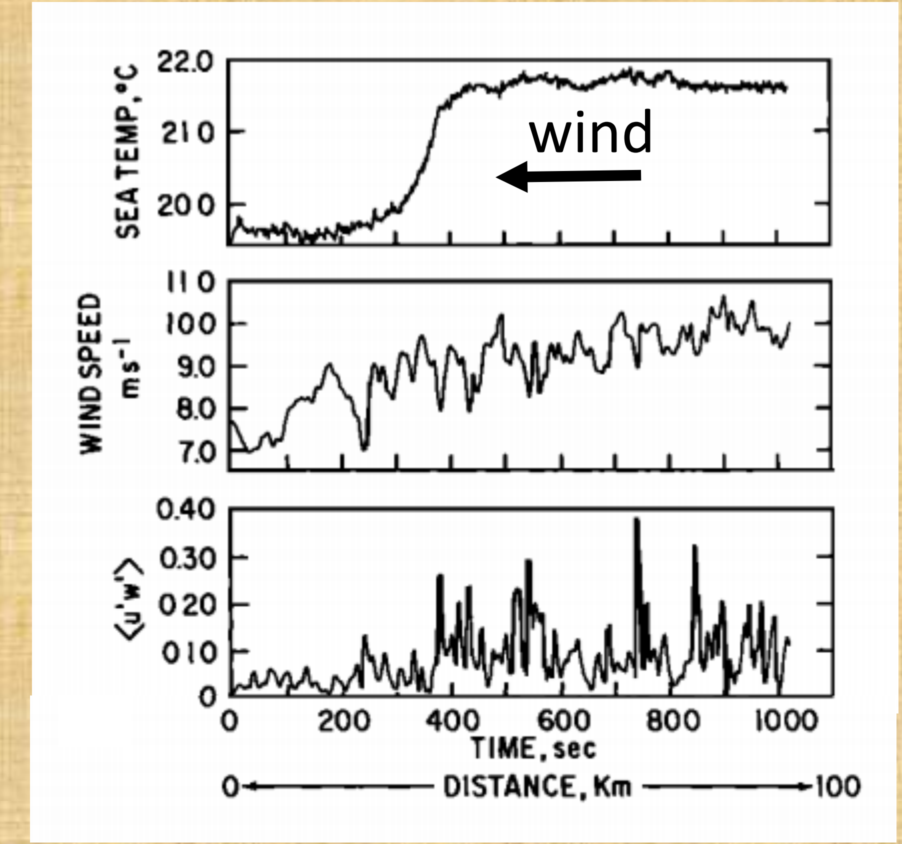


# At 1-100km scales, how will air-sea interaction differ from what we've seen at 100-1000km scales?

On the other hand, rapid changes in wind and stress across sharp SST fronts have been appreciated for decades

# At 1-100km scales, how will air-sea interaction differ from what we've seen at 100-1000km scales?

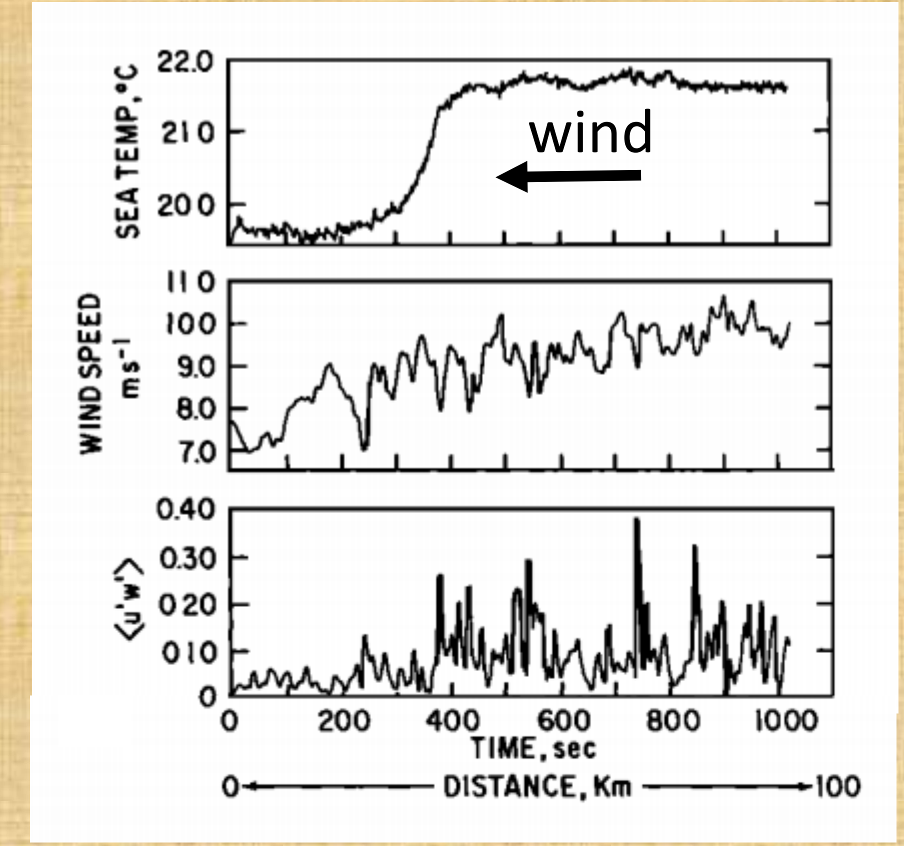
FRIEHE ET AL.: AIR-SEA FLUXES AROUND A SEA SURFACE TEMPERATURE FRONT (1991)



# At 1-100km scales, how will air-sea interaction differ from what we've seen at 100-1000km scales?

This is ~1 (m/s)/°C, about 2-3 times larger than for mesoscale observations

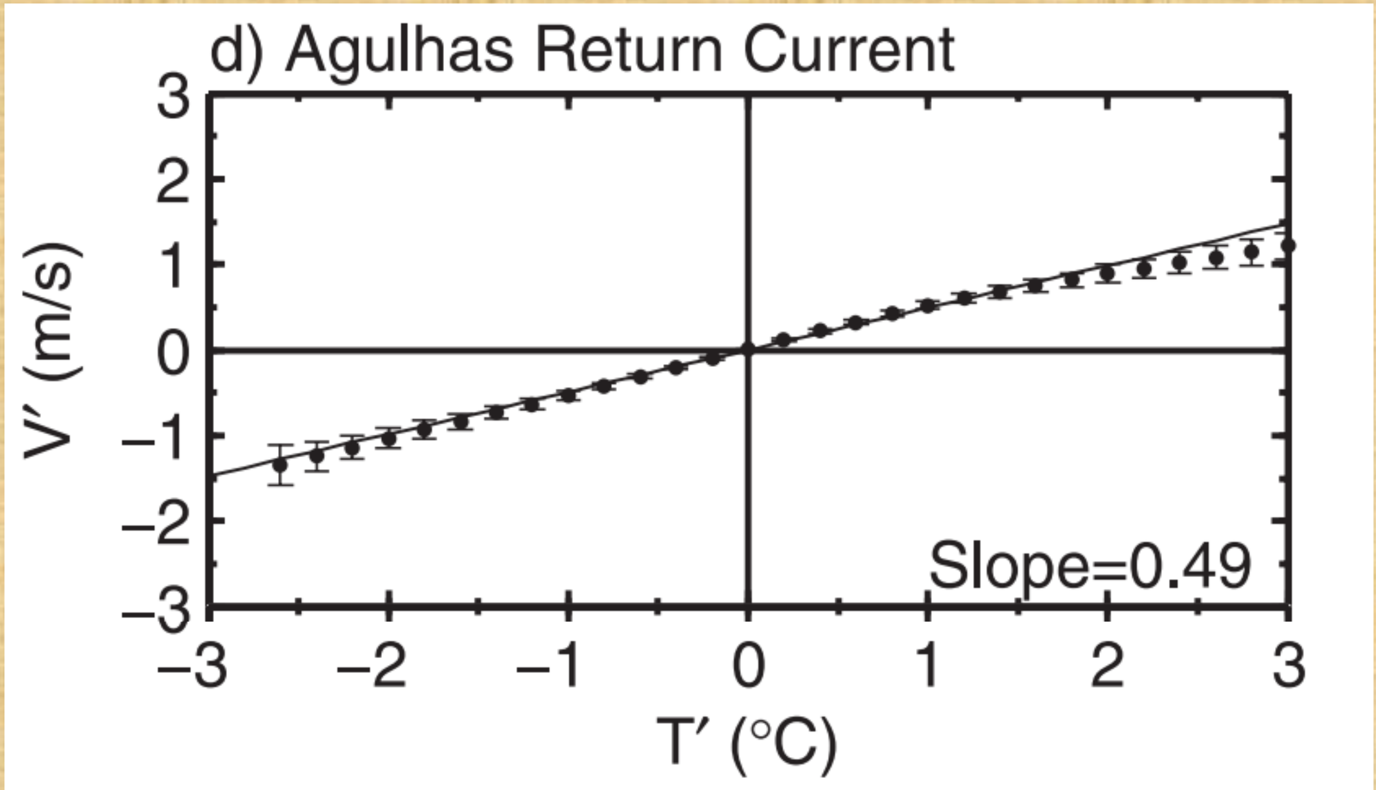
FRIEHE ET AL.: AIR-SEA FLUXES AROUND A SEA SURFACE TEMPERATURE FRONT (1991)



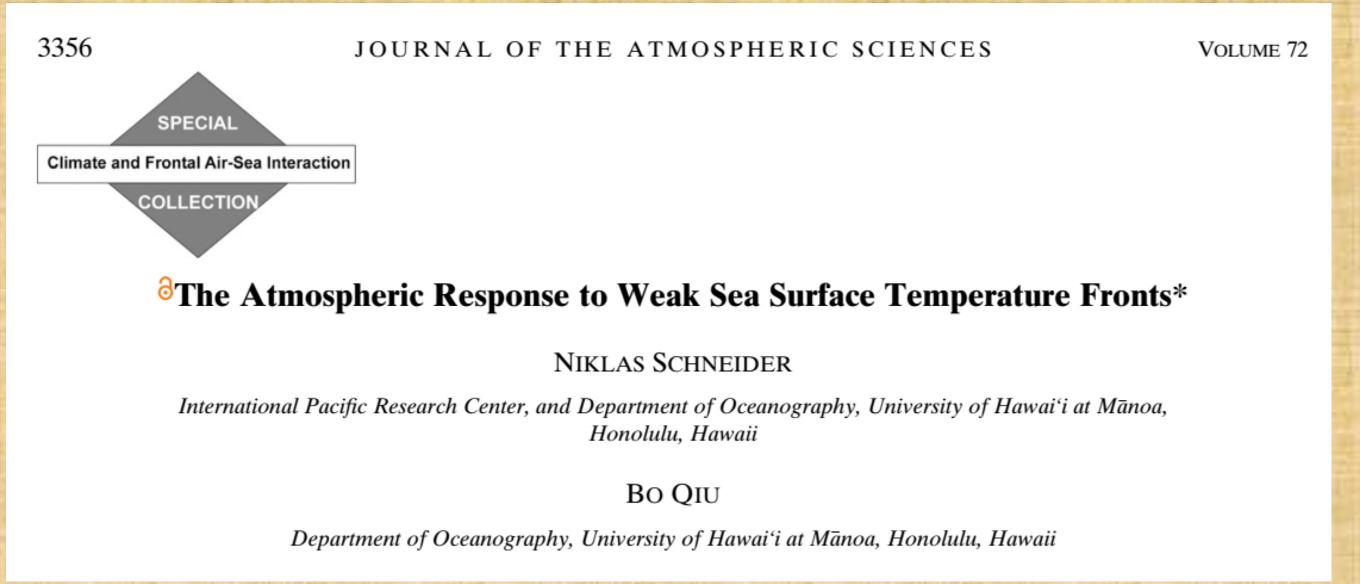
# How does the wind-SST coupling coefficient depend on spatial scale?

(O’Neill et al., 2010)

We expect these coupling coefficients to be a function of length scale



# How does the wind-SST coupling coefficient depend on spatial scale?


3356 JOURNAL OF THE ATMOSPHERIC SCIENCES VOLUME 72

SPECIAL
Climate and Frontal Air-Sea Interaction
COLLECTION

**The Atmospheric Response to Weak Sea Surface Temperature Fronts***

NIKLAS SCHNEIDER

*International Pacific Research Center, and Department of Oceanography, University of Hawai'i at Mānoa, Honolulu, Hawaii*

BO QIU

*Department of Oceanography, University of Hawai'i at Mānoa, Honolulu, Hawaii*

Theoretical model of atmospheric boundary layer response to SST perturbations, solved spectrally as a function of spatial scale.

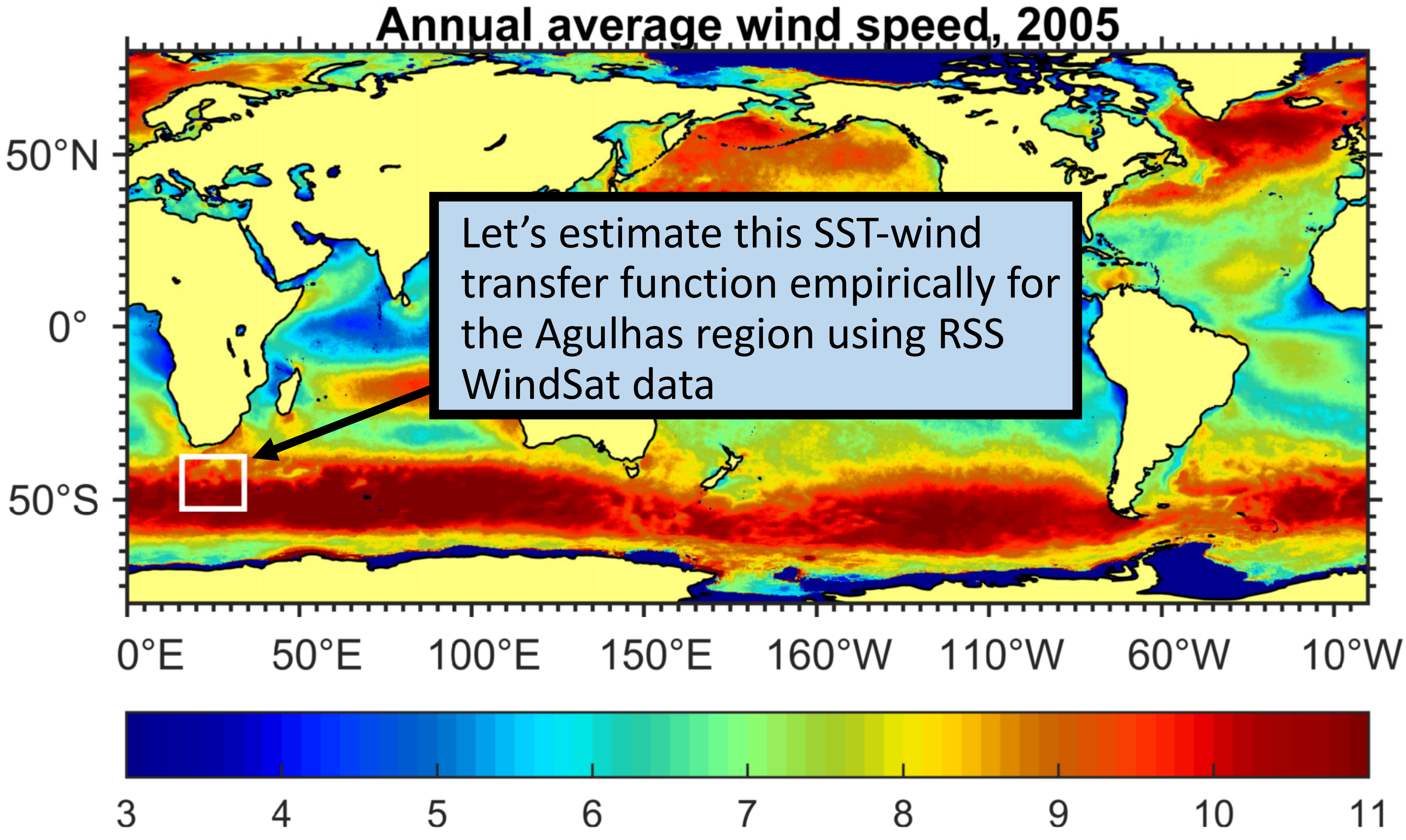
Solutions are given in Fourier (wavenumber) domain as:

$$U'(k,l)=R_U(k,l)T'(k,l)$$

Wind speed perturbation

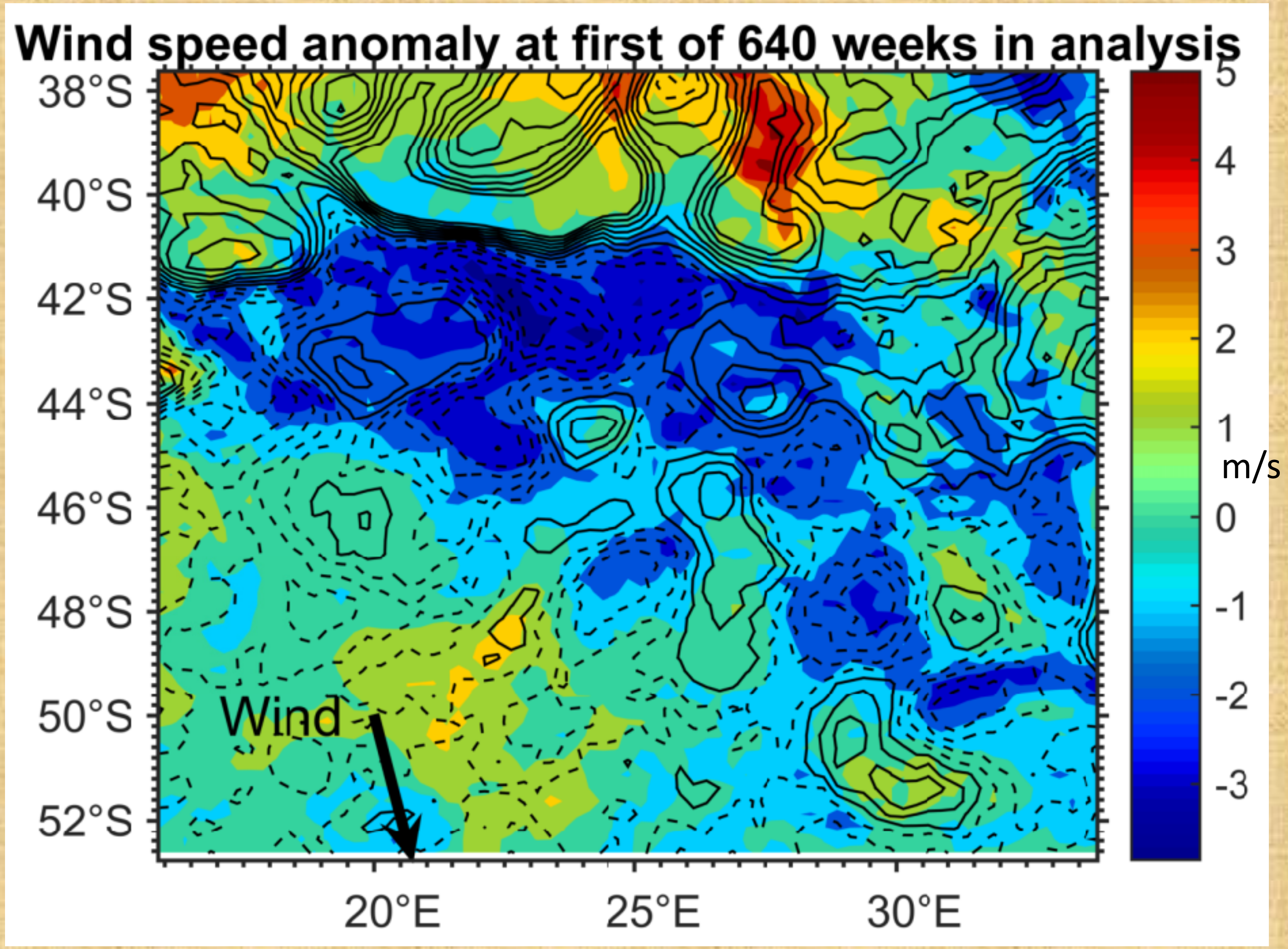
SST-wind transfer function

SST perturbation (imposed)


Annual average wind speed, 2005
50°N
0°
50°S
0°E
50°E
100°E
150°E
160°W
110°W
60°W
10°W
3
4
5
6
7
8
9
10
11
Let's estimate this SST-wind transfer function empirically for the Agulhas region using RSS WindSat data

# Empirical wind-SST transfer function

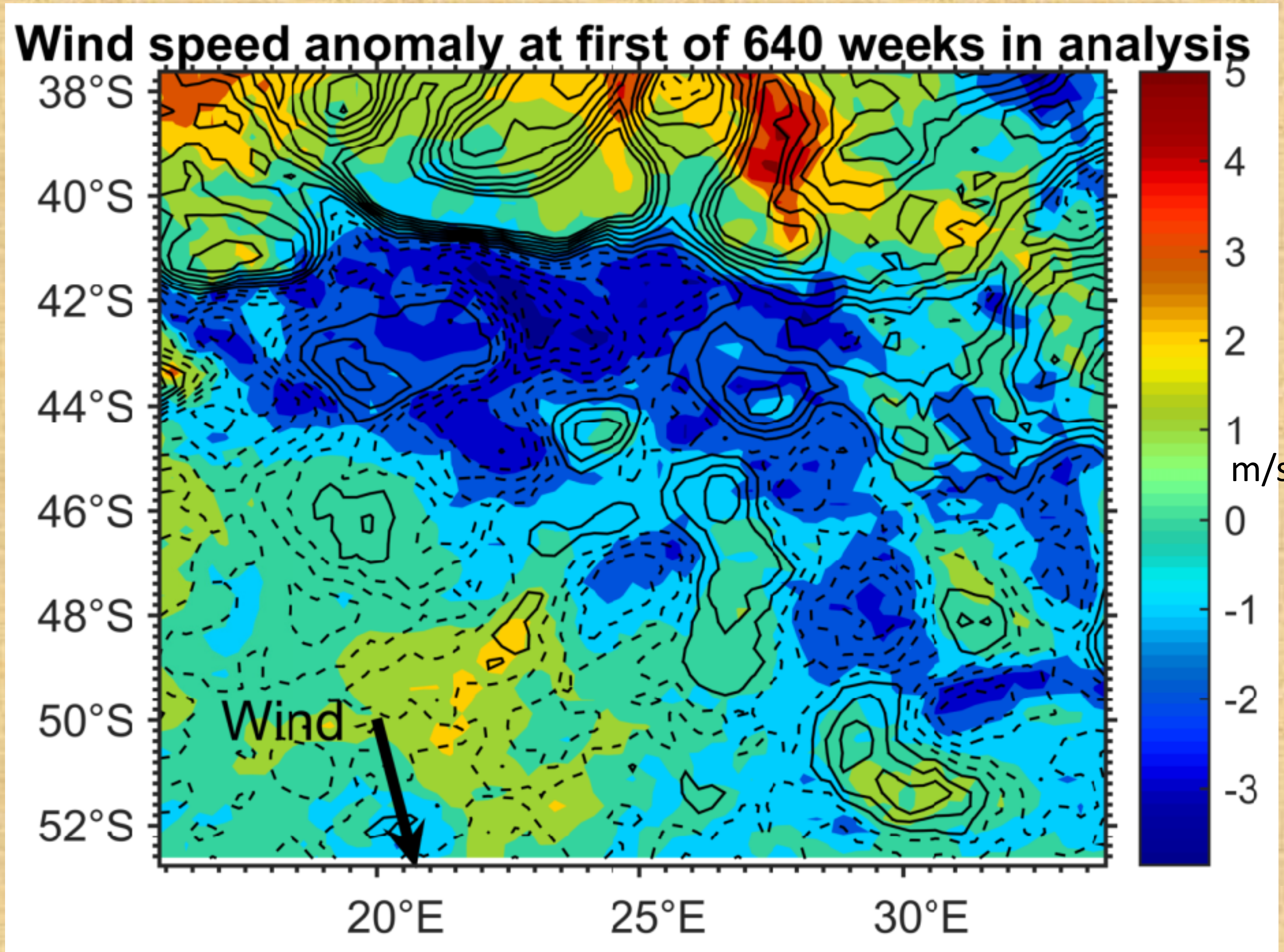
Agulhas region wind speed anomaly (colors) and SST anomaly (black)

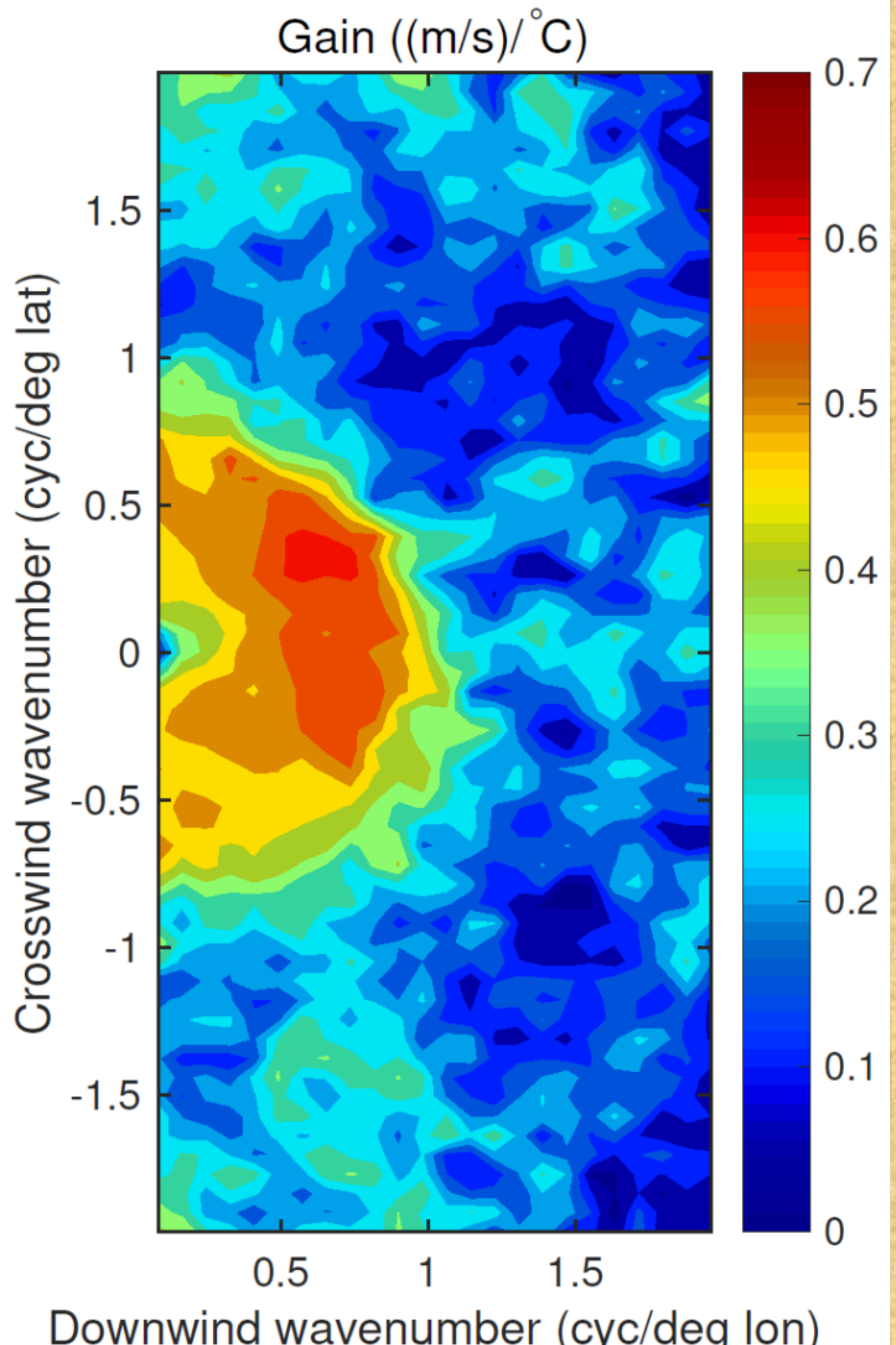



1. Using RSS WindSat data for vector winds and SST
2. For weekly average maps, rotate to wind direction
3. Compute downwind-crosswind Fourier transforms and estimate SST-wind-speed transfer function

# Empirical wind-SST transfer function

Agulhas region wind speed anomaly (colors) and SST anomaly (black)



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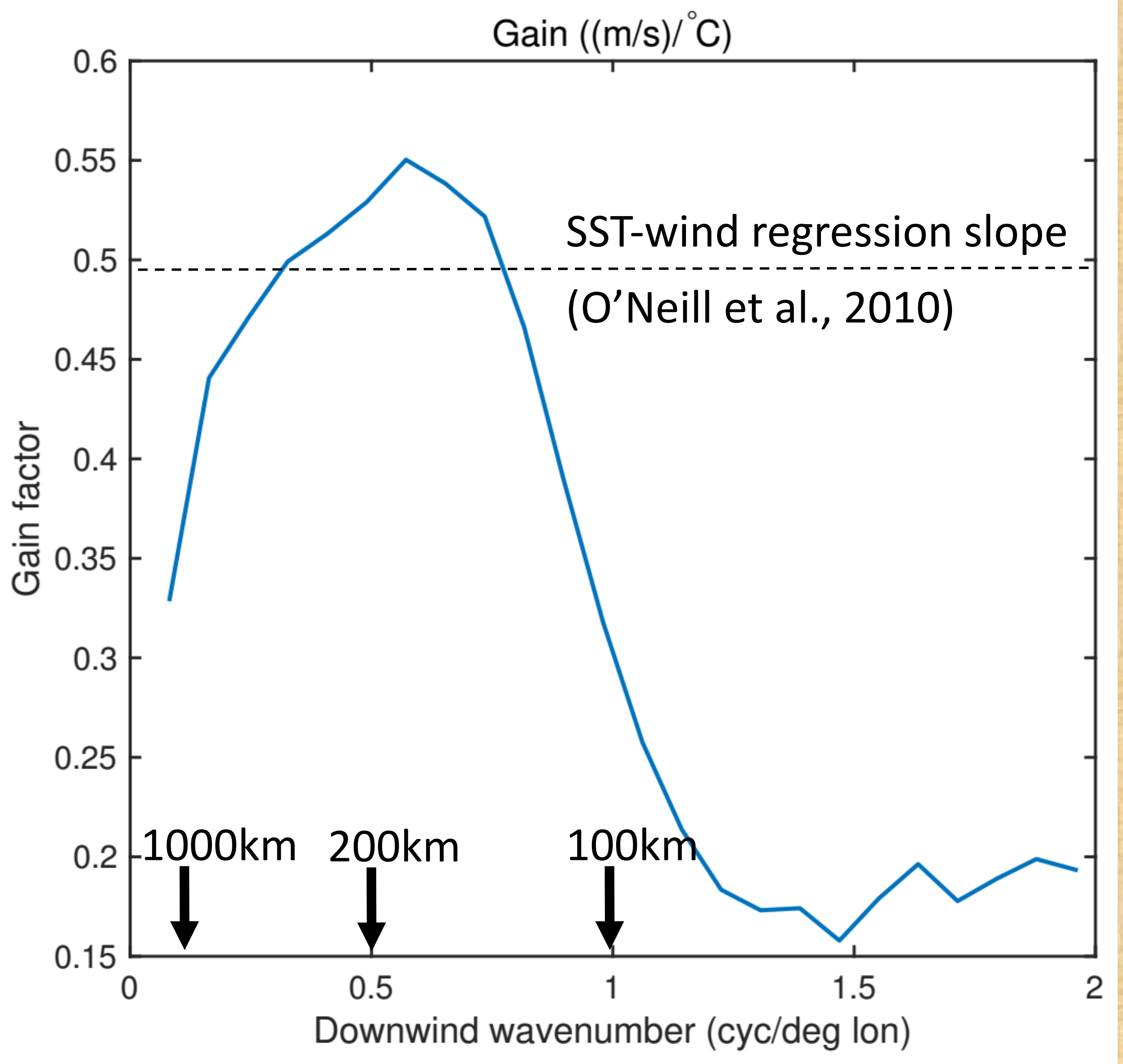


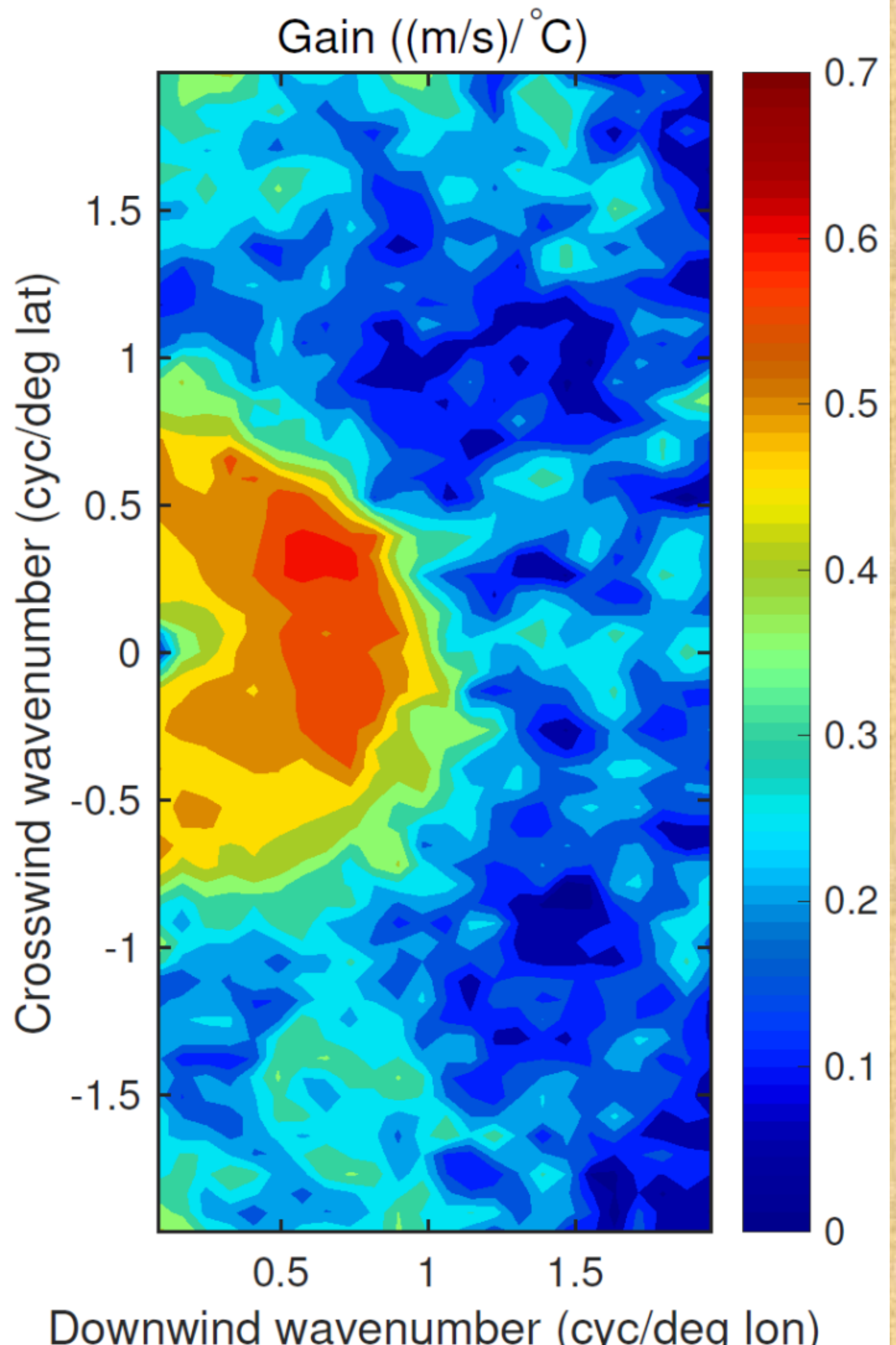

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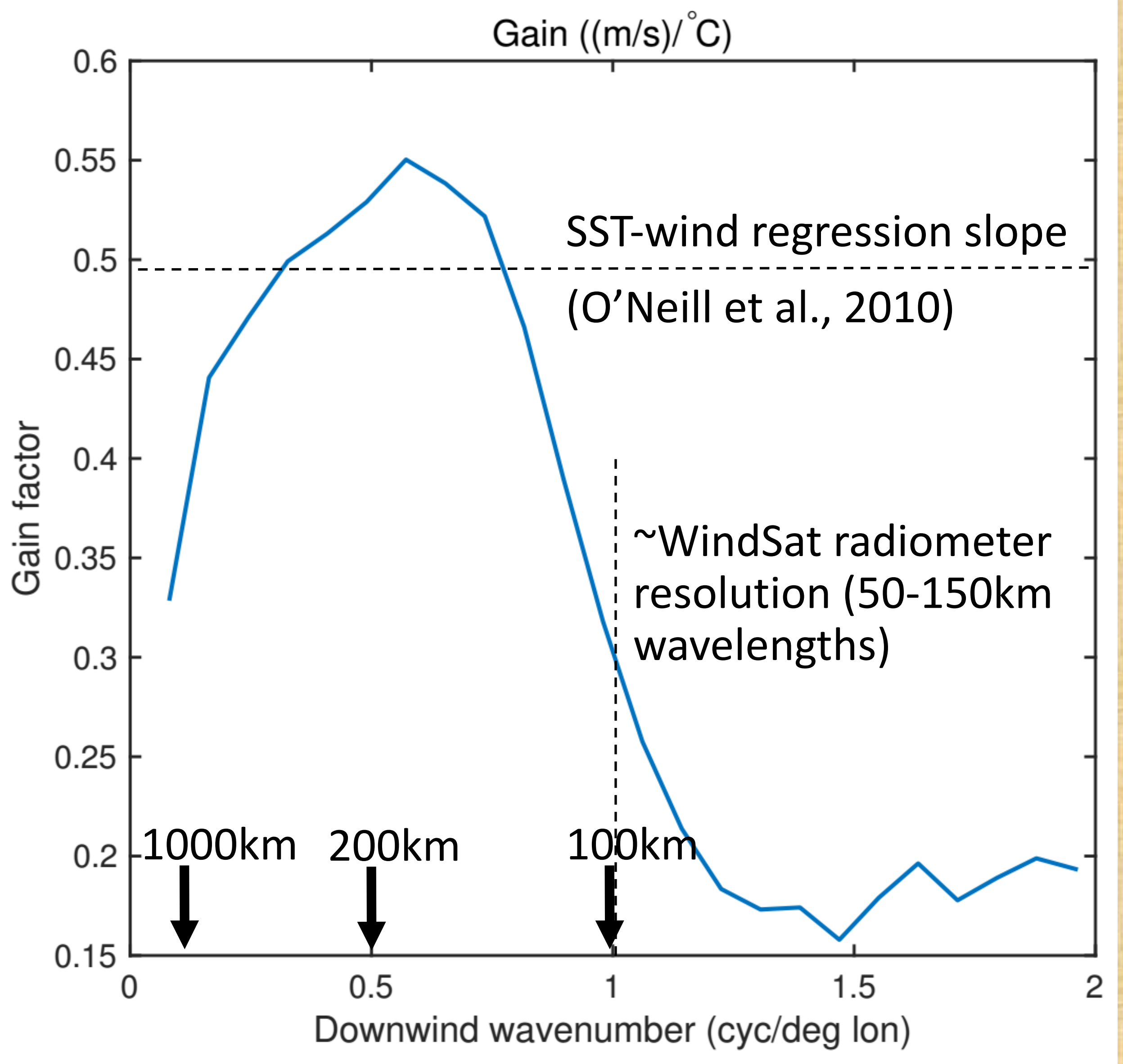
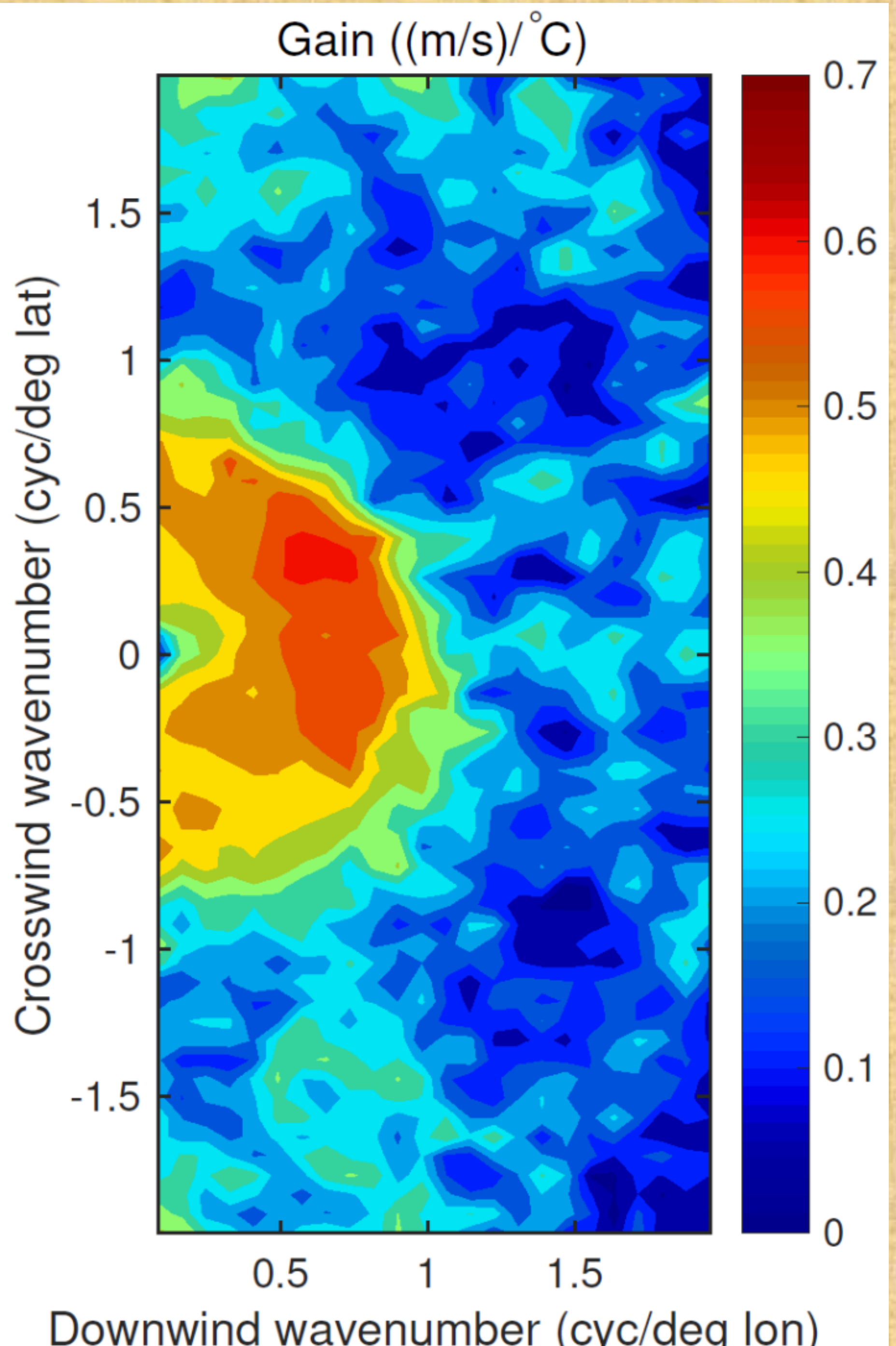


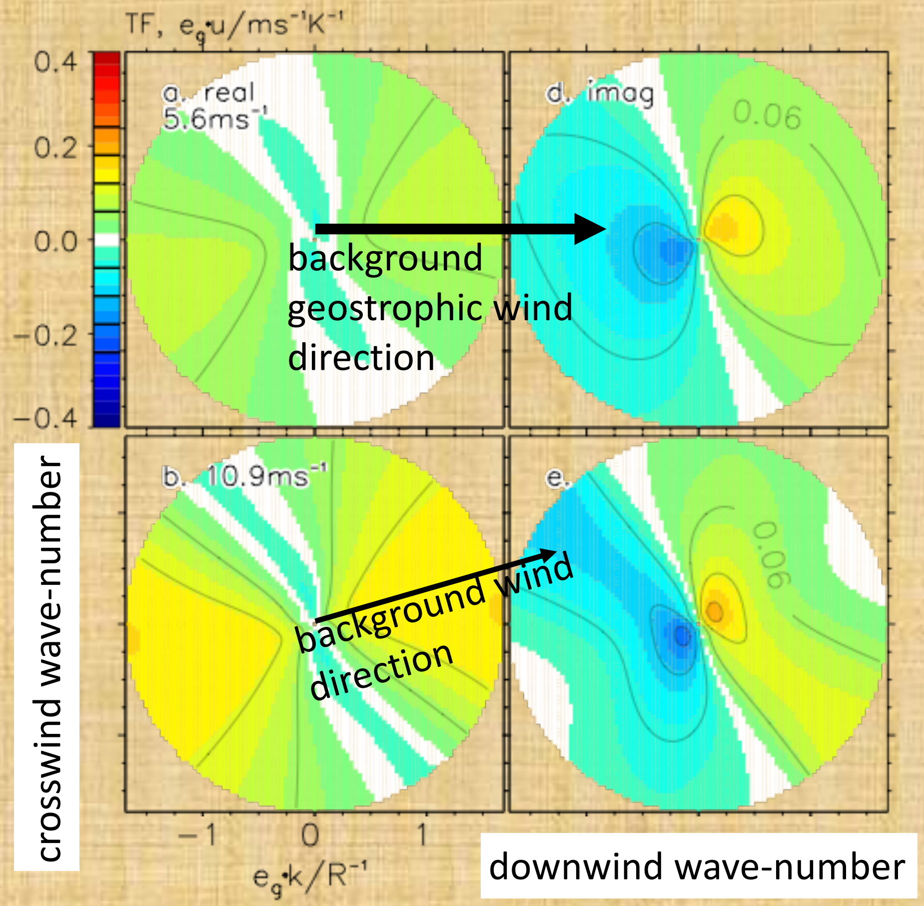
# Schneider and Qiu (2015) theoretical model of SST effects on winds

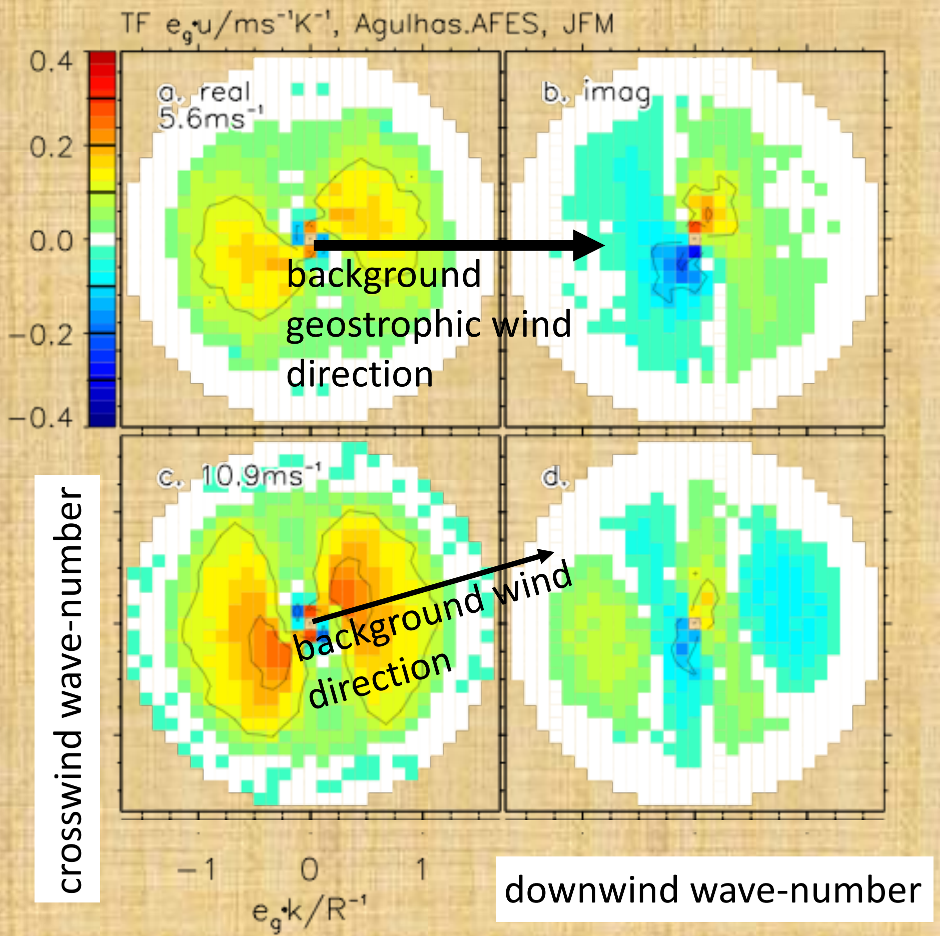
## Theory

## AFES atmospheric GCM

Low wind case

Moderate wind case



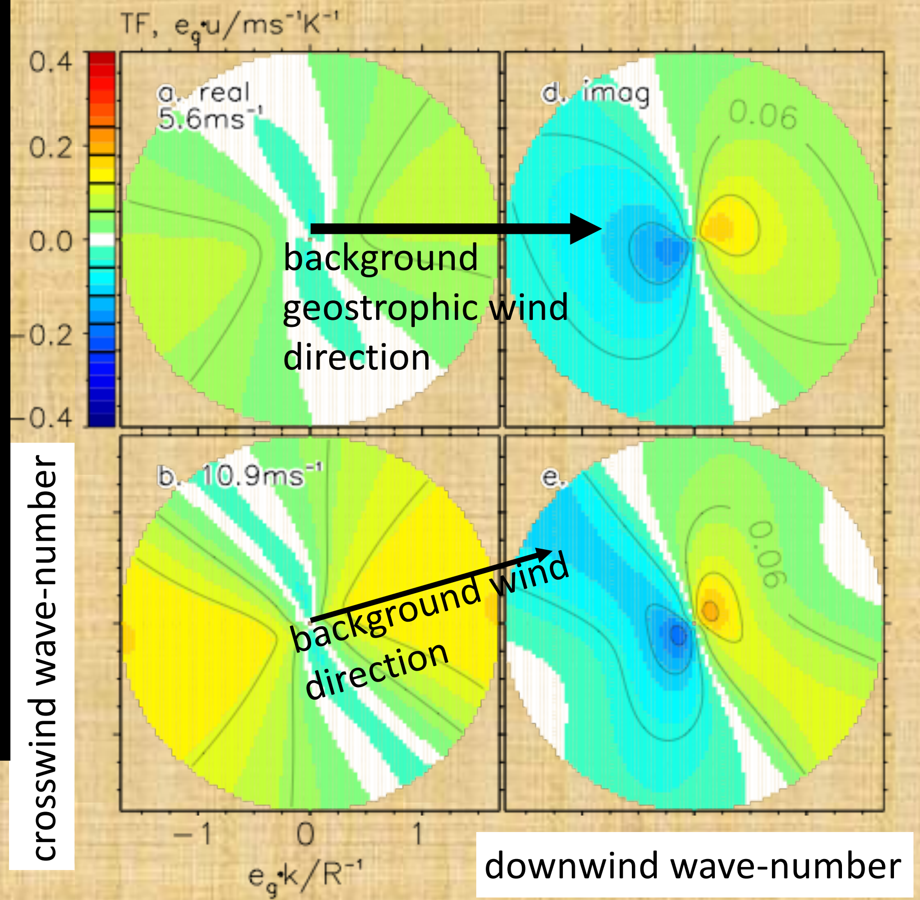
# Schneider and Qiu (2015) theoretical model of SST effects on winds

Theory has transfer function that increases with downwind wavenumber.

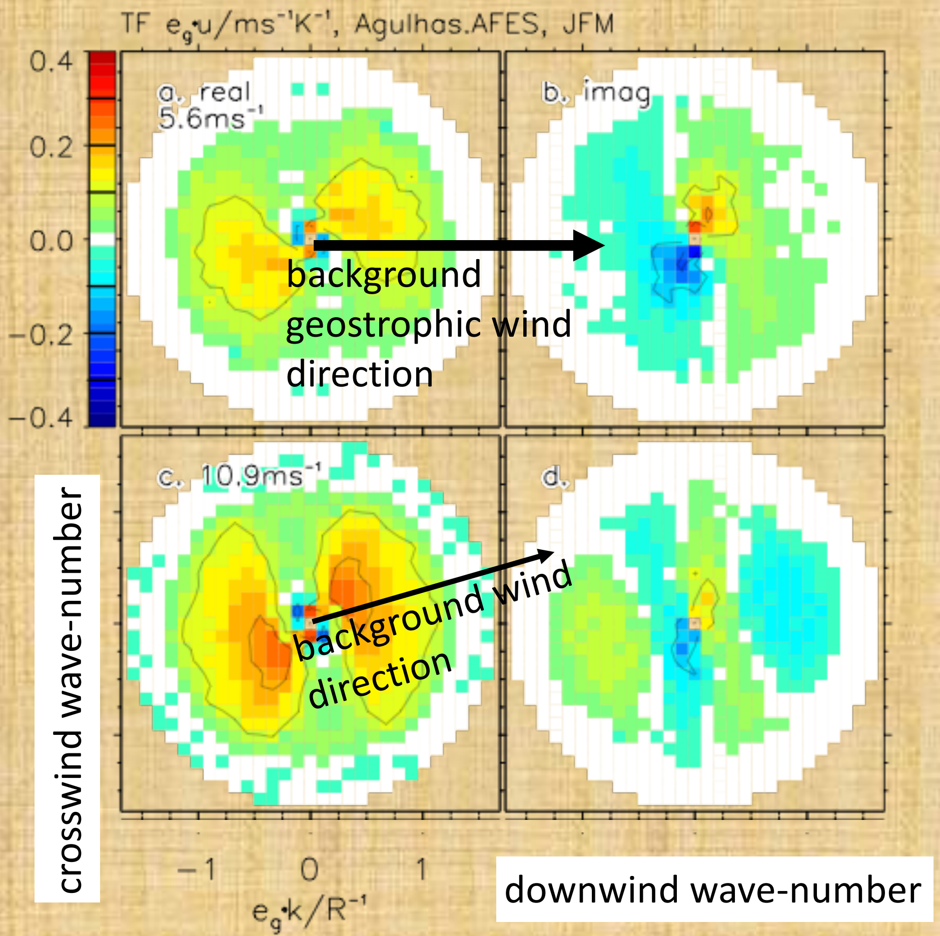
Model and WindSat estimates do not.

Does this reflect limitation of data and model resolution?

## Theory




## AFES atmospheric GCM



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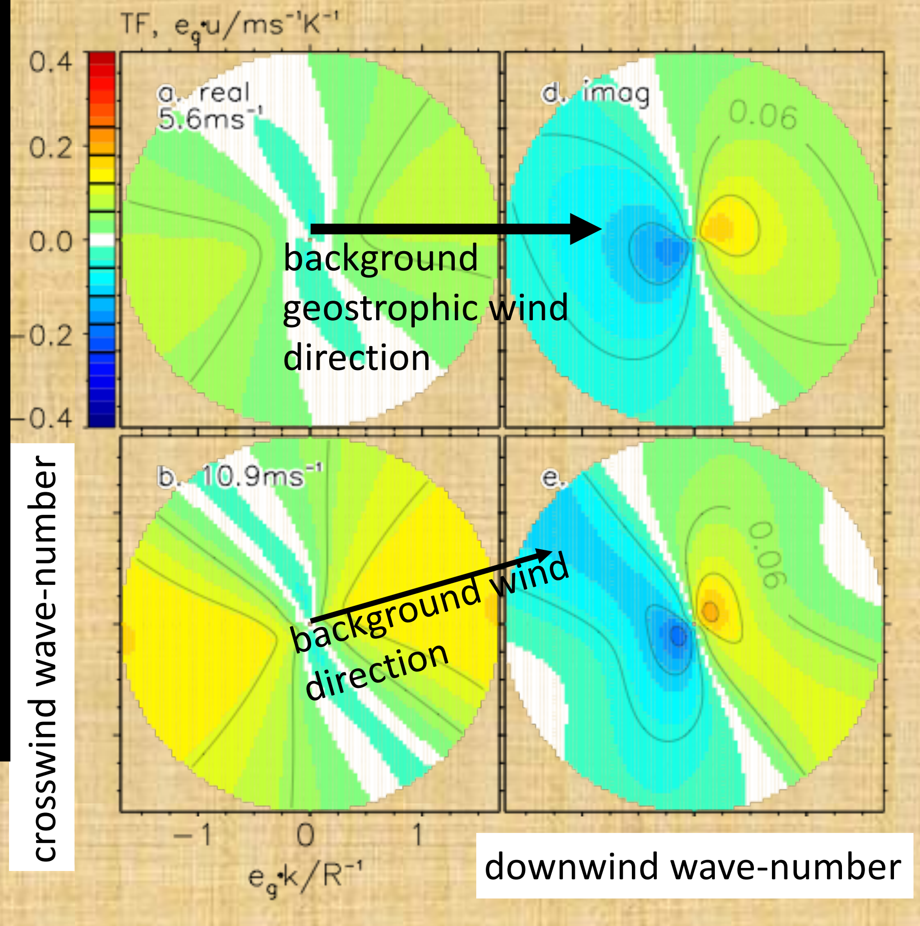
Does this reflect limitation of data and model resolution?

**Probably so**

## Theory

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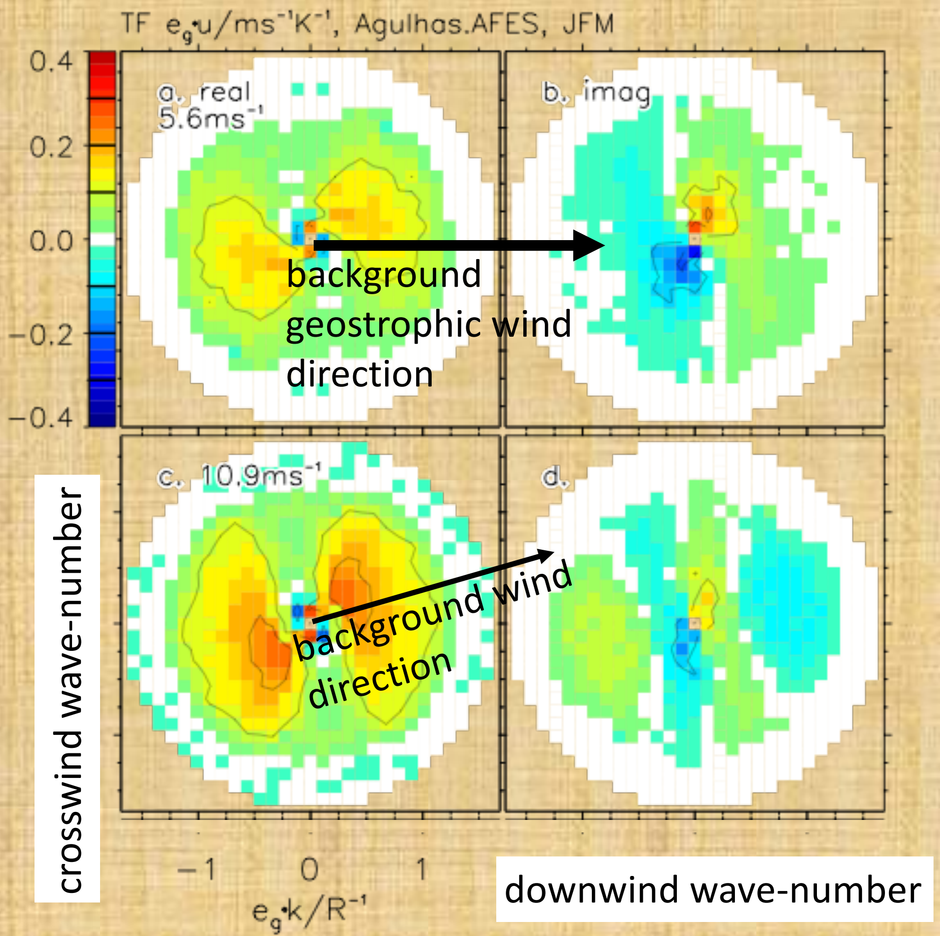
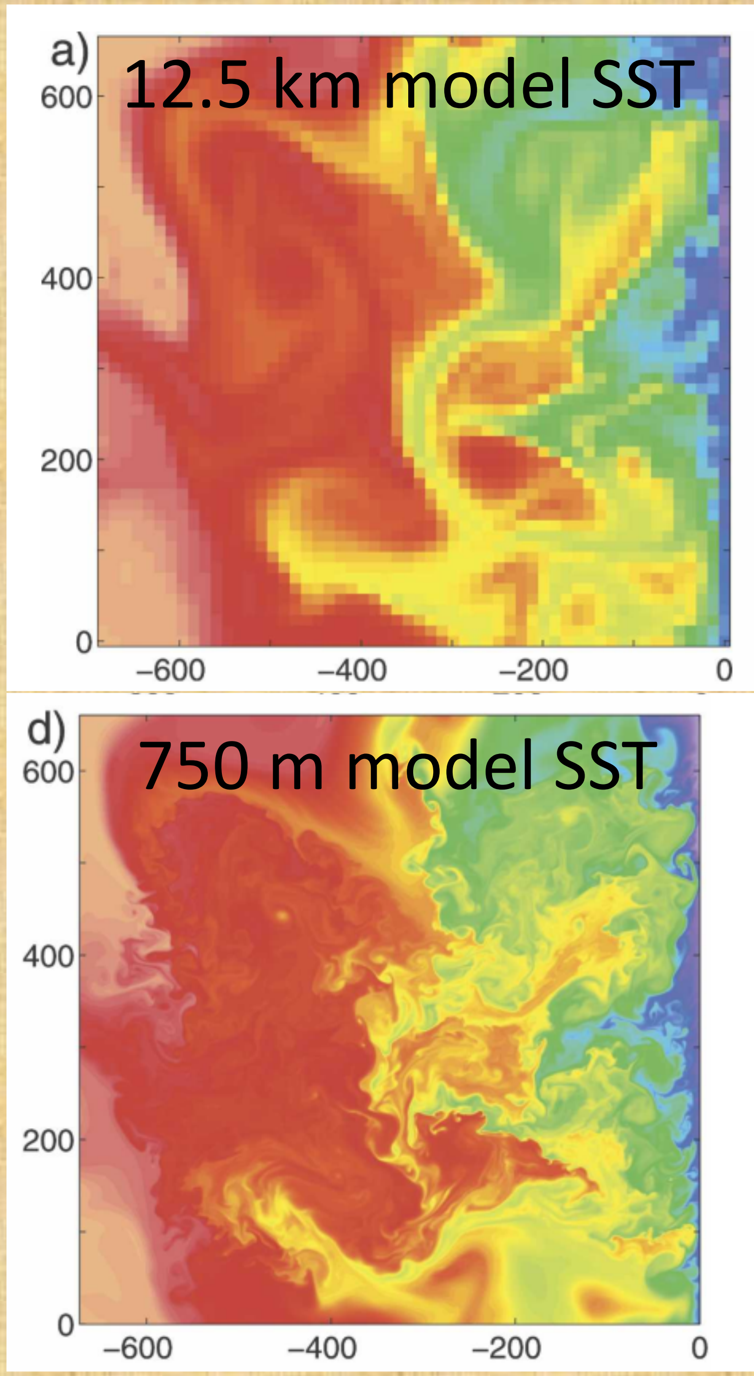


# Conclusions

1. Limited in situ observations and Schneider and Qiu (2015) theoretical model suggest wind-SST response should increase with decreasing spatial scale
2. The wind-SST transfer function appears to increase with decreasing lengthscale even more rapidly than the theoretical model predicts. (Supported by satellite observations, in situ observations, and the atmospheric GCM.)
3. DopplerScatt will provide an exciting new view of air-sea interaction– it will reveal new physics



Capet et al. (2008)

# Ma et al. (2015):Distant Influence of Kuroshio Eddies on North Pacific Weather Patterns?

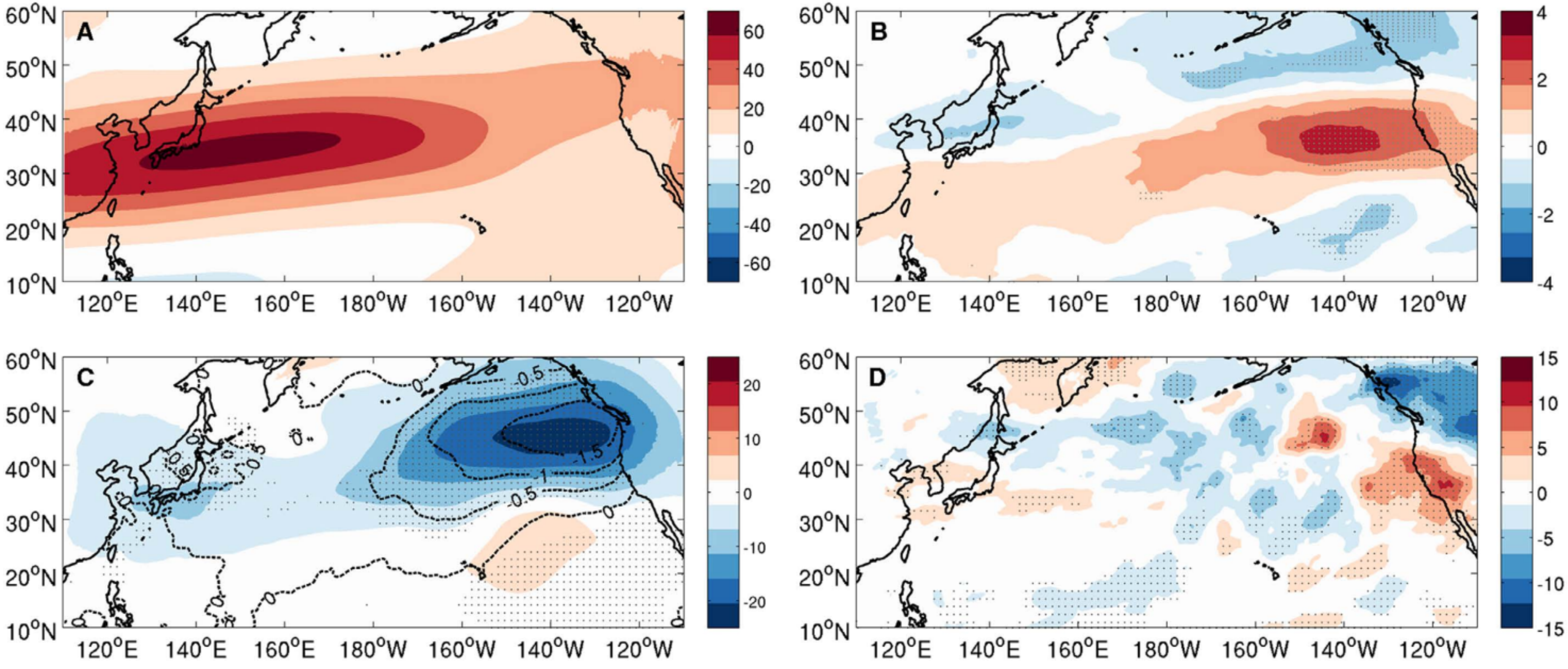
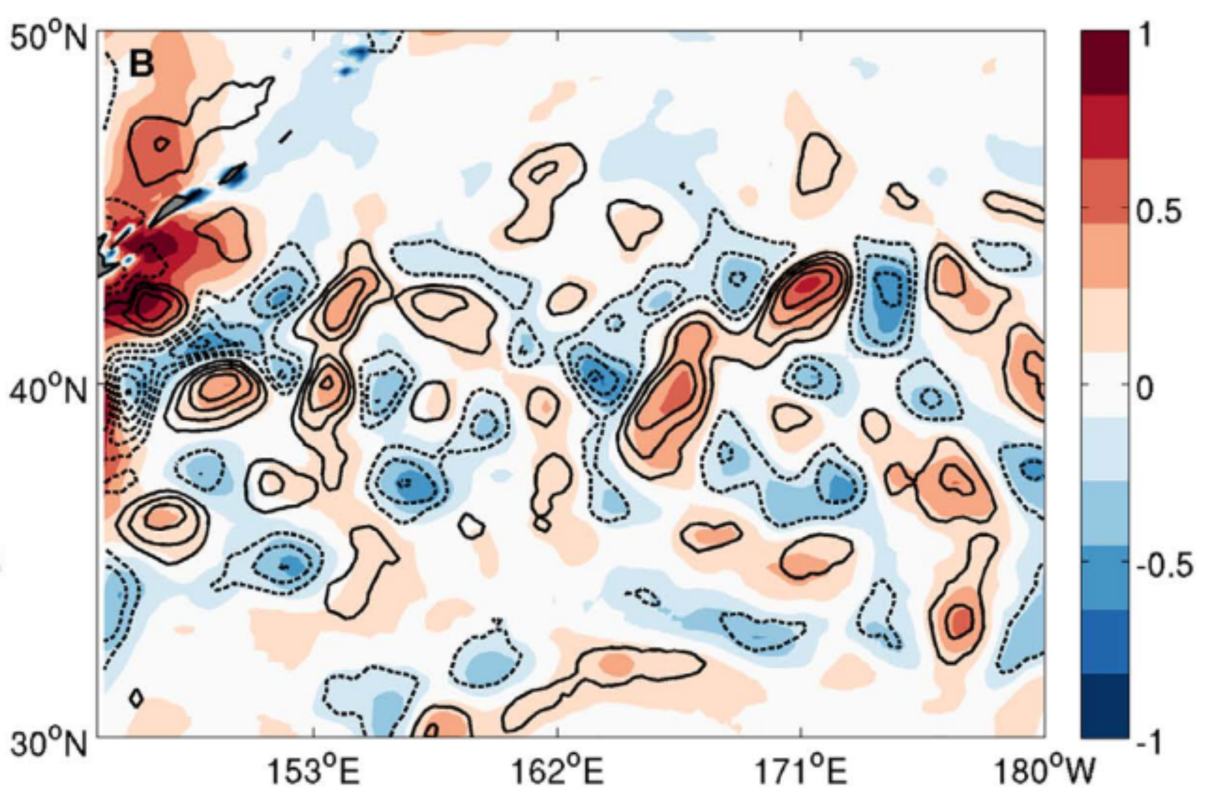



**Figure 3. Upper atmospheric response to meso-scale SST forcing.** (**A**) Winter season (NDJFM) mean zonal wind U at 300 hpa, U300 ($ms^{-1}$), in CTRL. (**B**) Difference of U300 ($ms^{-1}$), (**C**) Sea-Level-Pressure (mb) (contour) and geo-potential height at 500 hpa (Z500) (m) (color) and (**D**) transient eddy kinetic energy at 300 hpa ($m^2s^{-2}$) between MEFS and CTRL (MEFS-CTRL). The transient kinetic energy was derived using 2–8 day bandpass-filtered variables. In (**B–D**), the difference significant at 95% confidence level based on a two-sided Wilcoxon rank sum test is shaded by gray dots. The maps were generated using M_Map V1.4 package for Matlab (http://www.eos.ubc.ca/~rich/map.html).

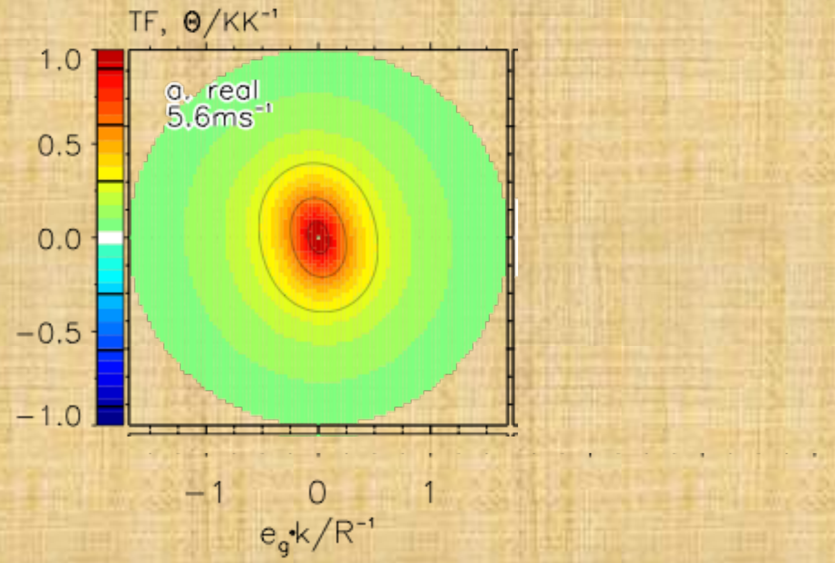
Sensible heat flux ~ U(SST-Tair)

Latent heat flux ~ U(qsat(SST)-qair)

Wind speed and SST anomalies




Schneider and Qiu (2015) prediction for Tair transfer function




Large scales: SST'-Tair'=0

Small scales: SST'-Tair'=SST'

Idealized high-resolution atmospheric simulation

(Spall, 2007)

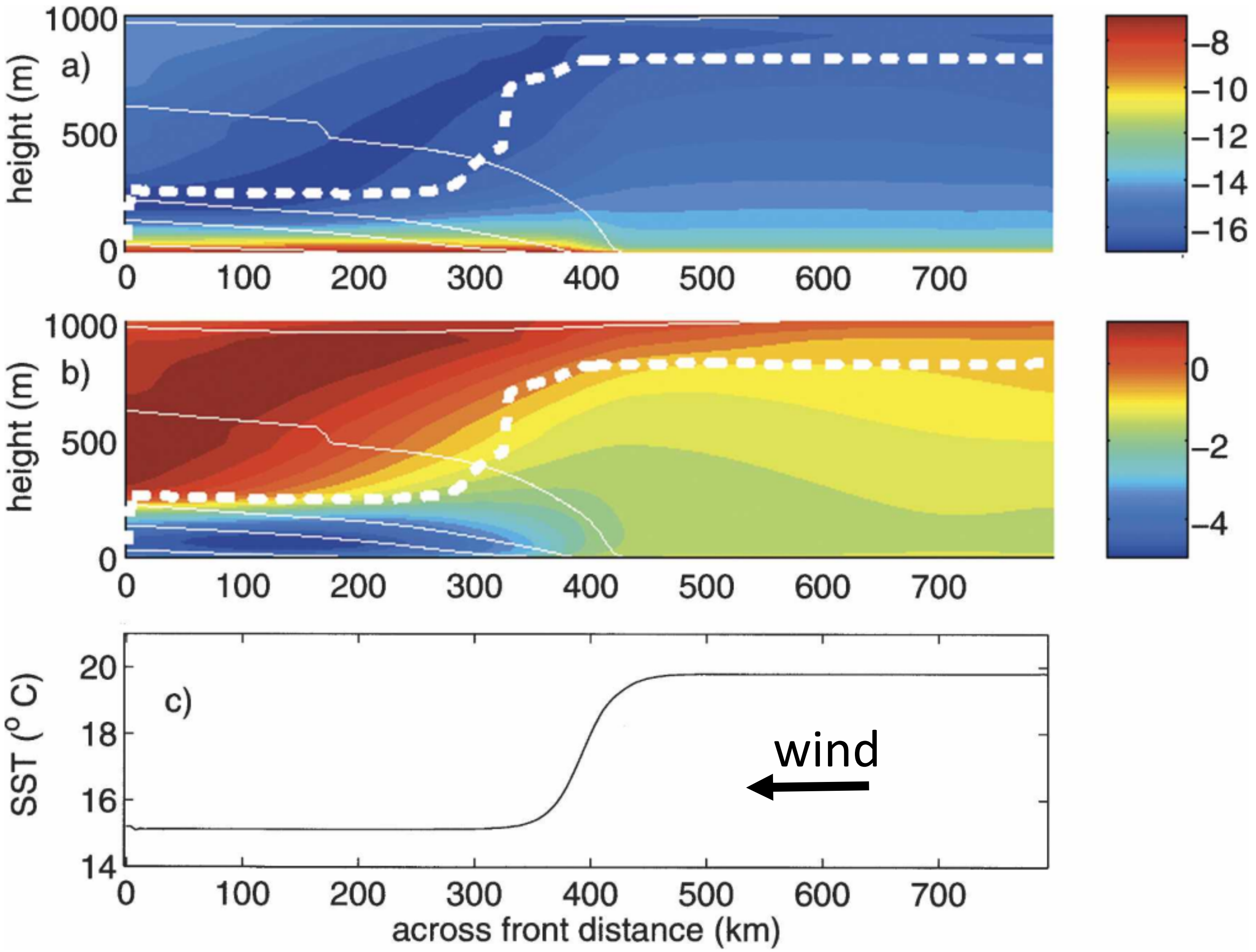
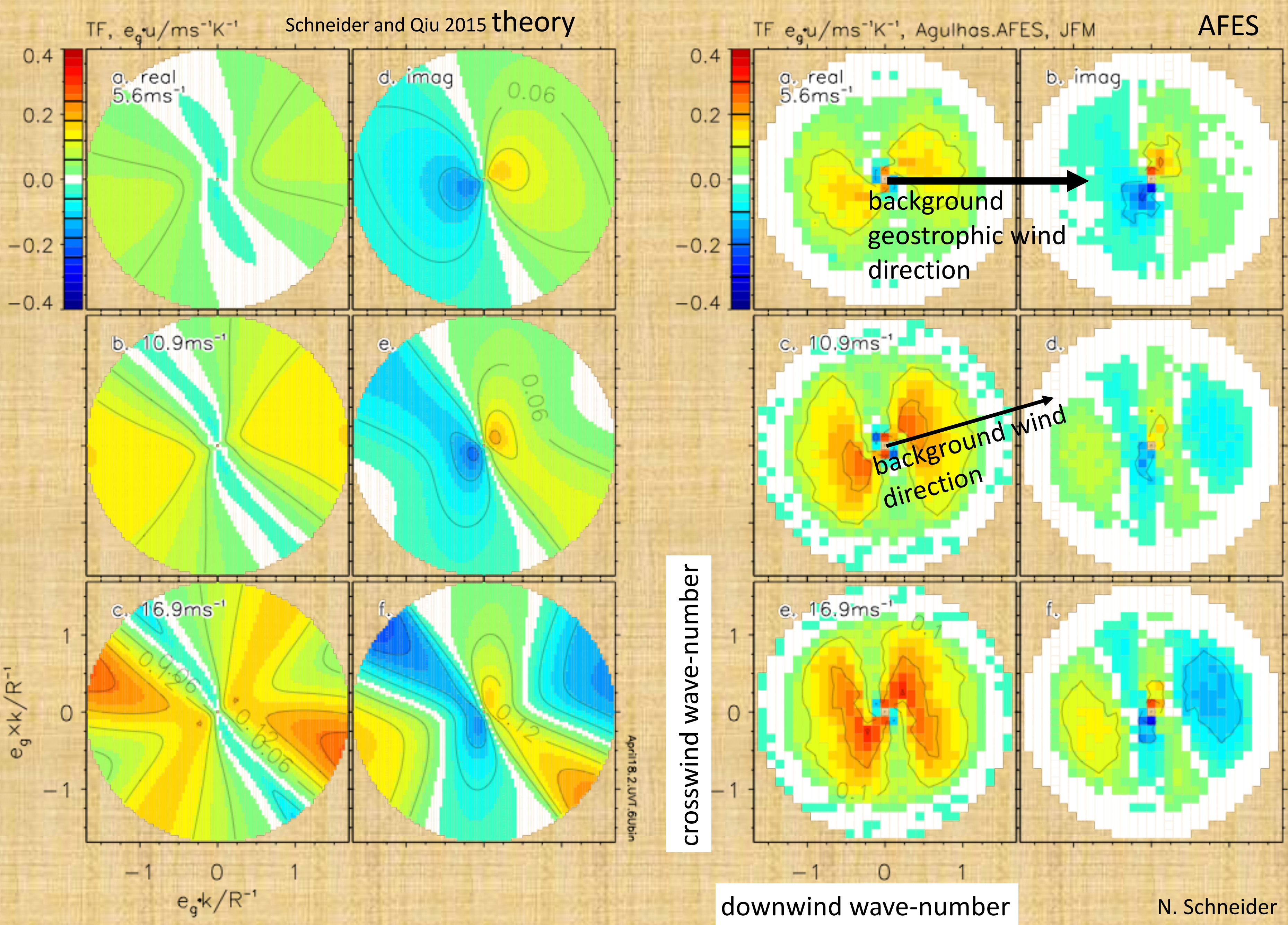


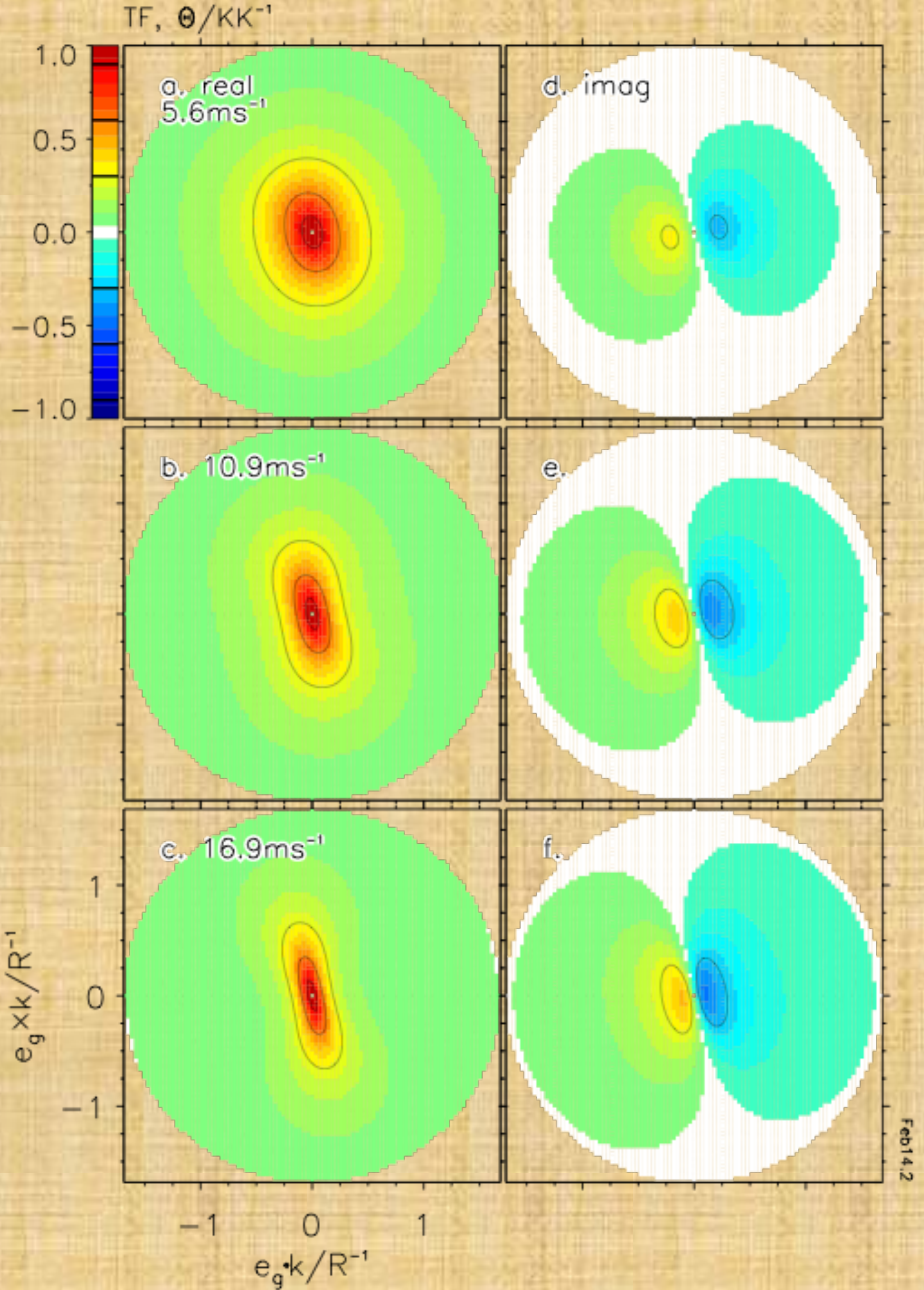

FIG. 1. Zonal sections of (a) zonal wind and (b) meridional wind (colors, units m s$^{-1}$) for the case of atmospheric flow from the warm side to the cold side of the front (right to left). Thin white contours are of potential temperature (contour interval: 1ºC) and the white dashed line is the top of the planetary boundary layer. (c) Sea surface temperature.

# Frontally induced surface winds in direction of background winds

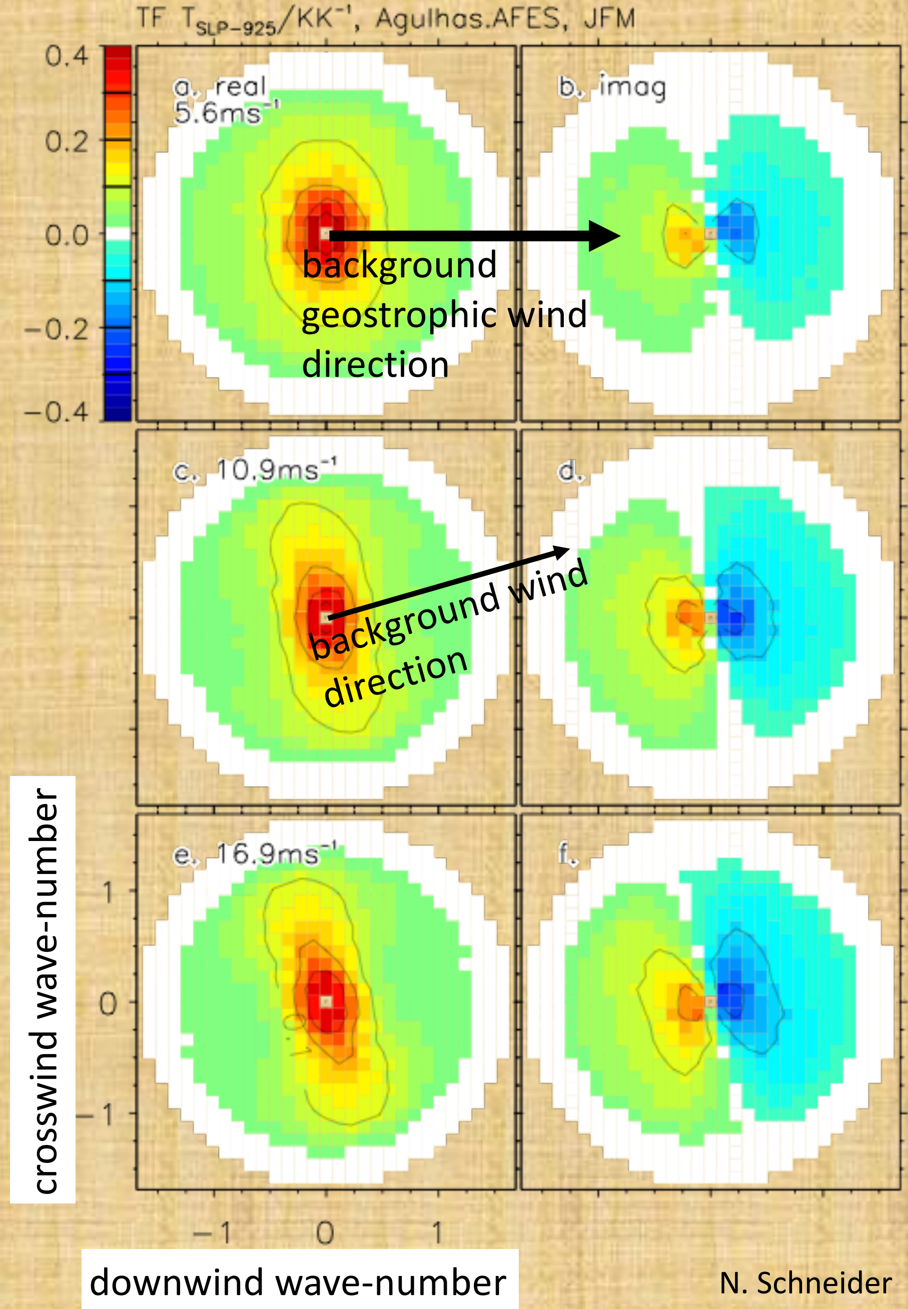



N. Schneider

## Air temperature
## linear theory (Schneider and Qiu 2015)




## Virtual temperature, surface-925hPa
## AFES




N. Schneider

DopplerScatt offers a quantum leap in air-sea interaction measurements: 200m resolution for wind and ocean currents, and capability for simultaneous SST measurements

The surface current capability of DopplerScatt is very exciting– 15 minutes of DopplerScatt data could replace 5000 current meters!