Local winds vs swell: Wave-wind interactions and the impact on scatterometer measurements

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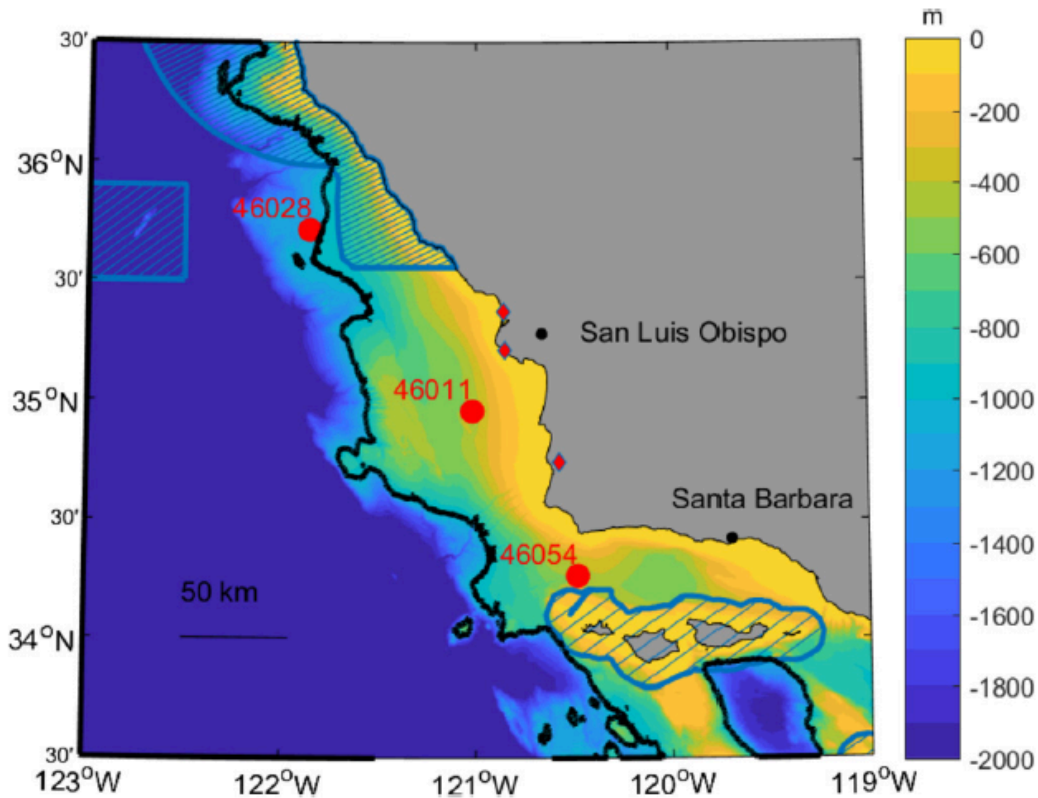
Directional offsets: scatteromer minus buoy

Buoy	Wind Product	Bias
46028	QuikSCAT	6.74°
	ASCAT	1.49°
	CCMP v2	6.51°
46011	QuikSCAT	0.44°
	ASCAT	-3.09°
	CCMP v2	2.02°
46054	QuikSCAT	1.39°
	ASCAT	-3.86°
	CCMP v2	7.78°



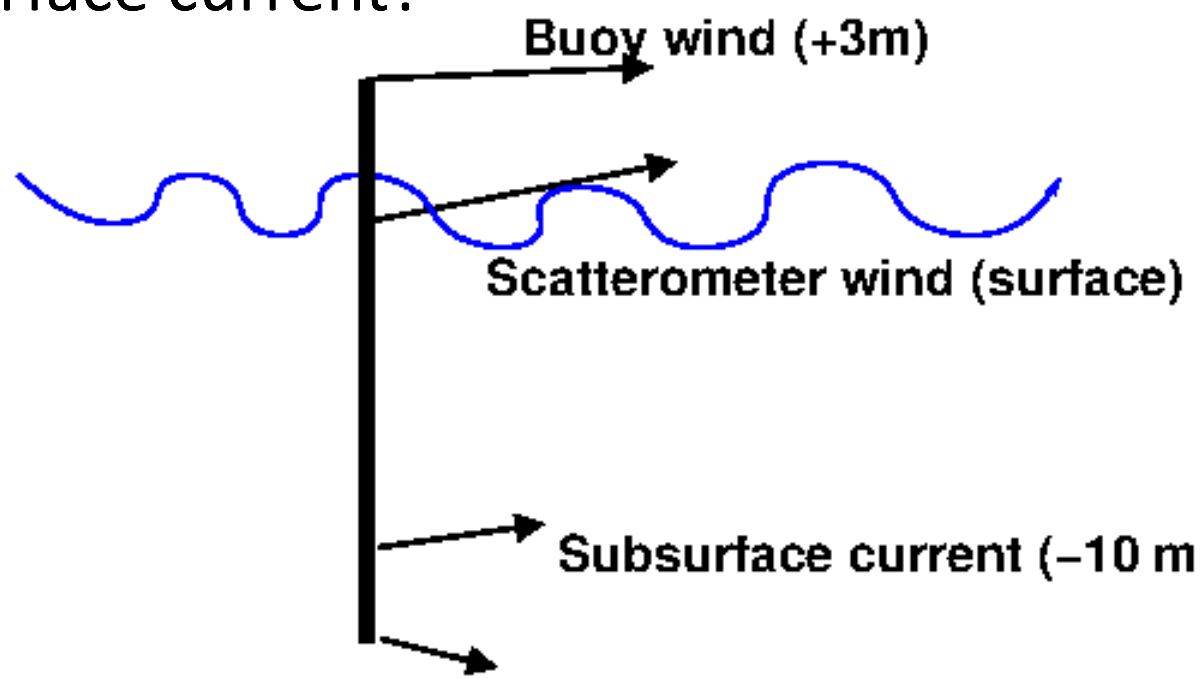
Positive values: satellite rotated clockwise relative to buoy

Wang et al, *Renewable Energy*, 2019

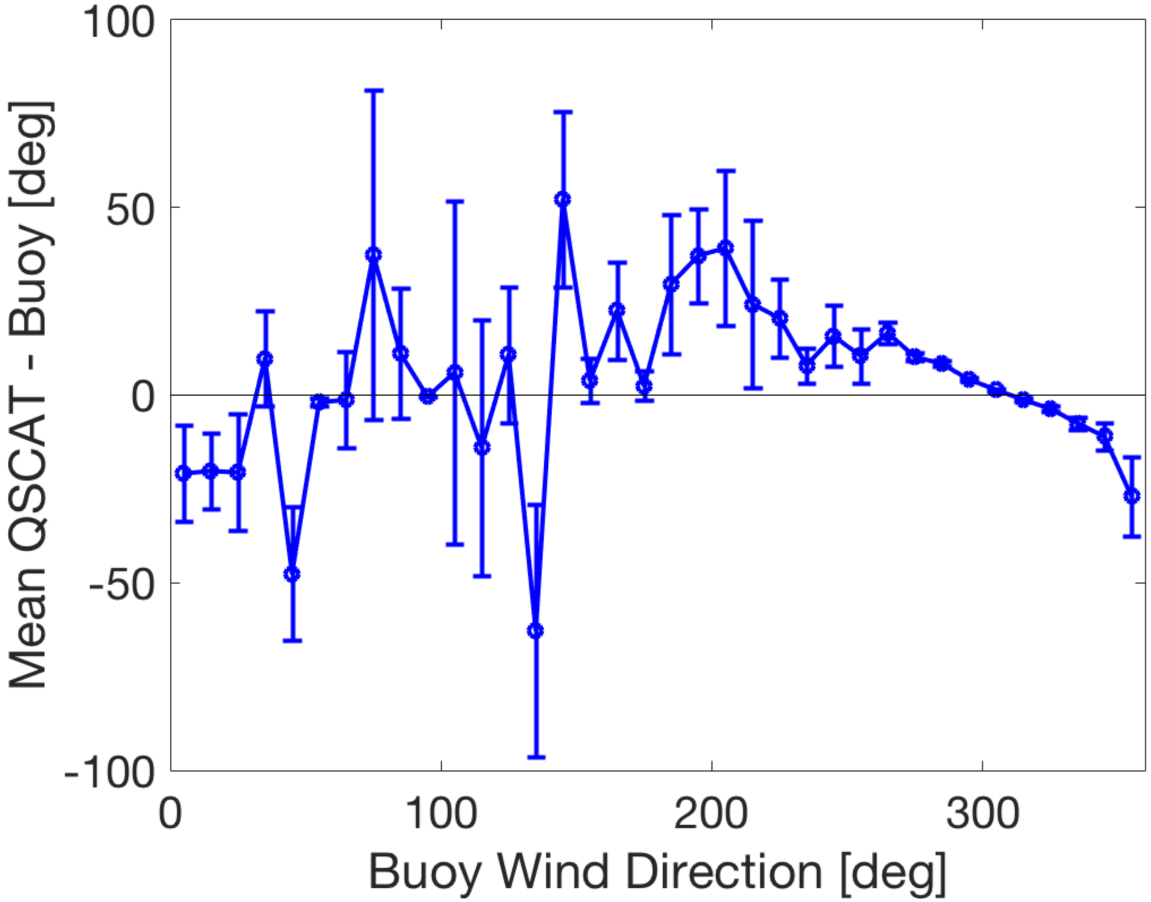
Study corrected buoy winds to 10 m height, but did not correct for ocean currents

Objectives: Buoy/satellite directional bias

- What physics can account for the bias?
  - Uncorrected ocean currents?
  - Directional change in wind with height?
  - Directional difference between measured ocean current and surface current?
  - Wave effects?

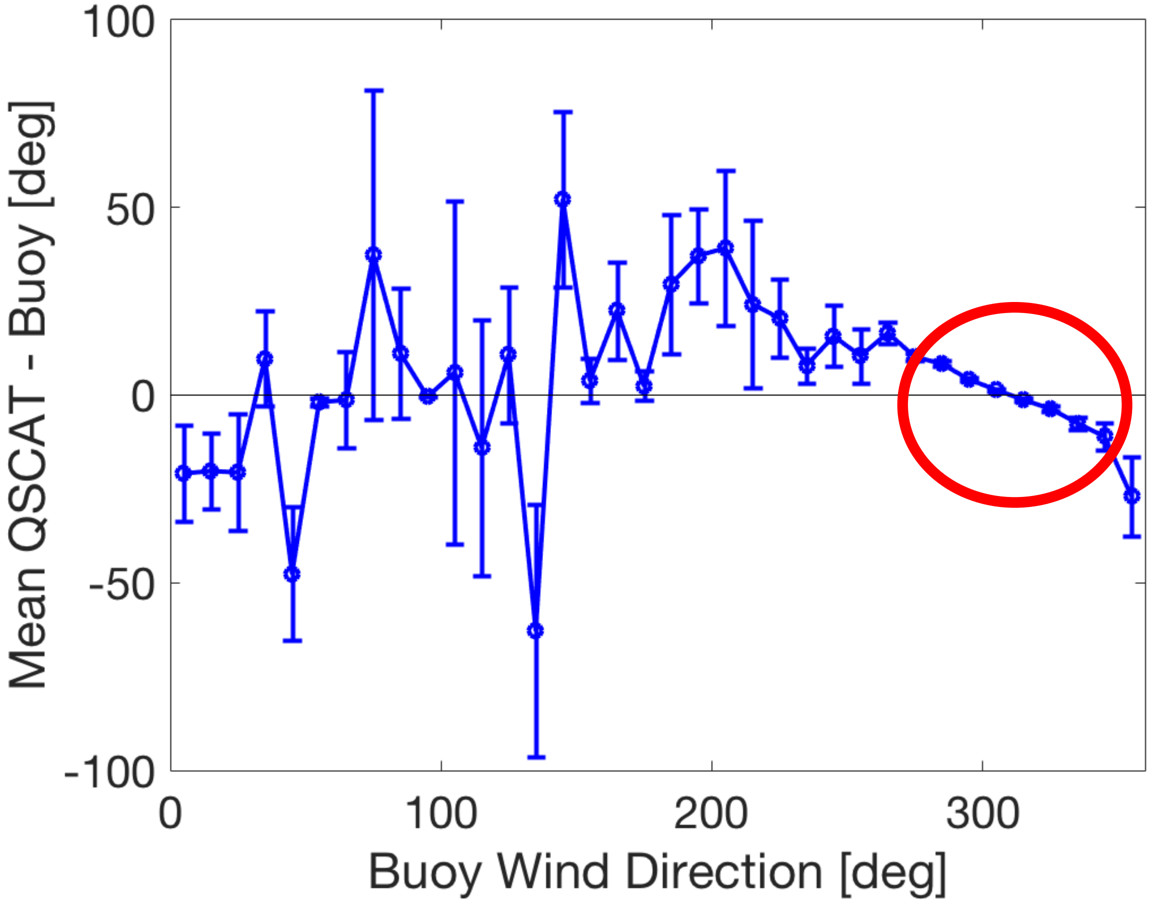


Stratus buoy: QuikSCAT minus buoy (no corrections)



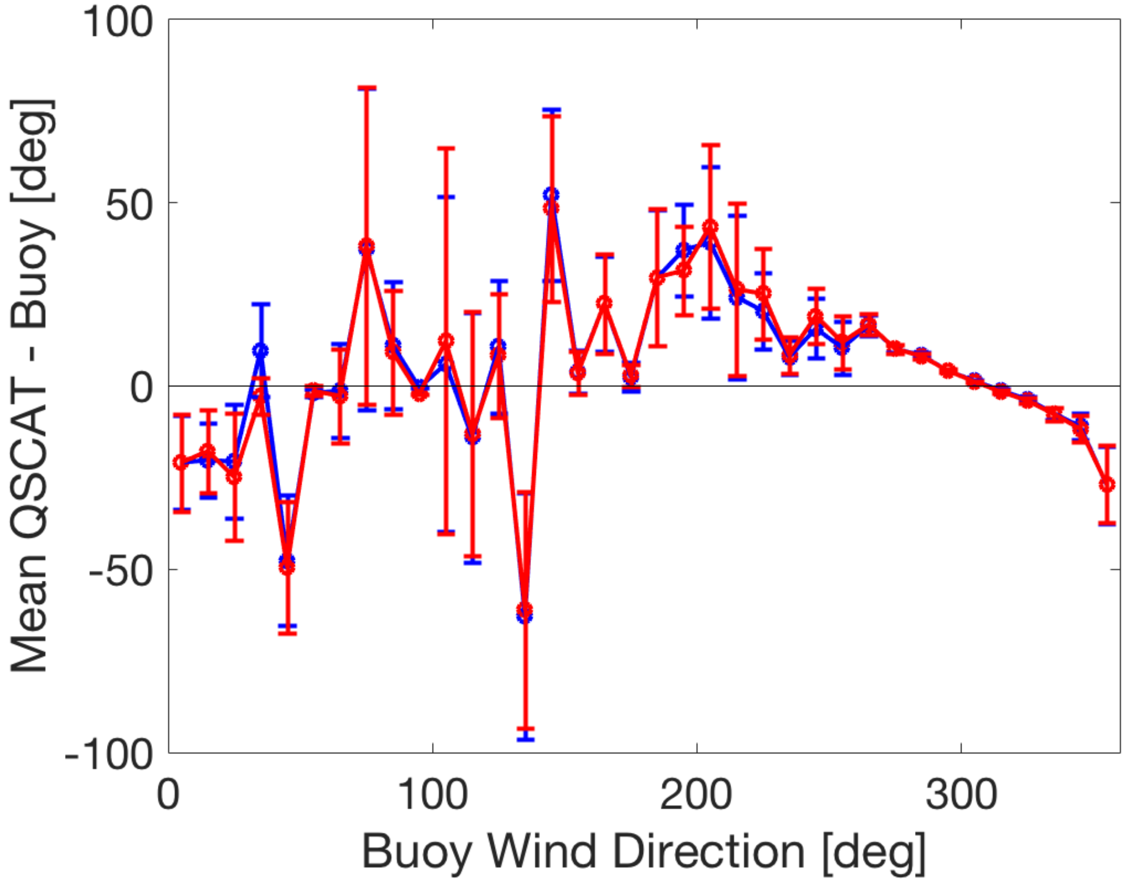
- Directional bias clearest at dominant wind angles (260-340°).
- Bias varies with wind direction.

Stratus buoy: QuikSCAT minus buoy (no corrections)



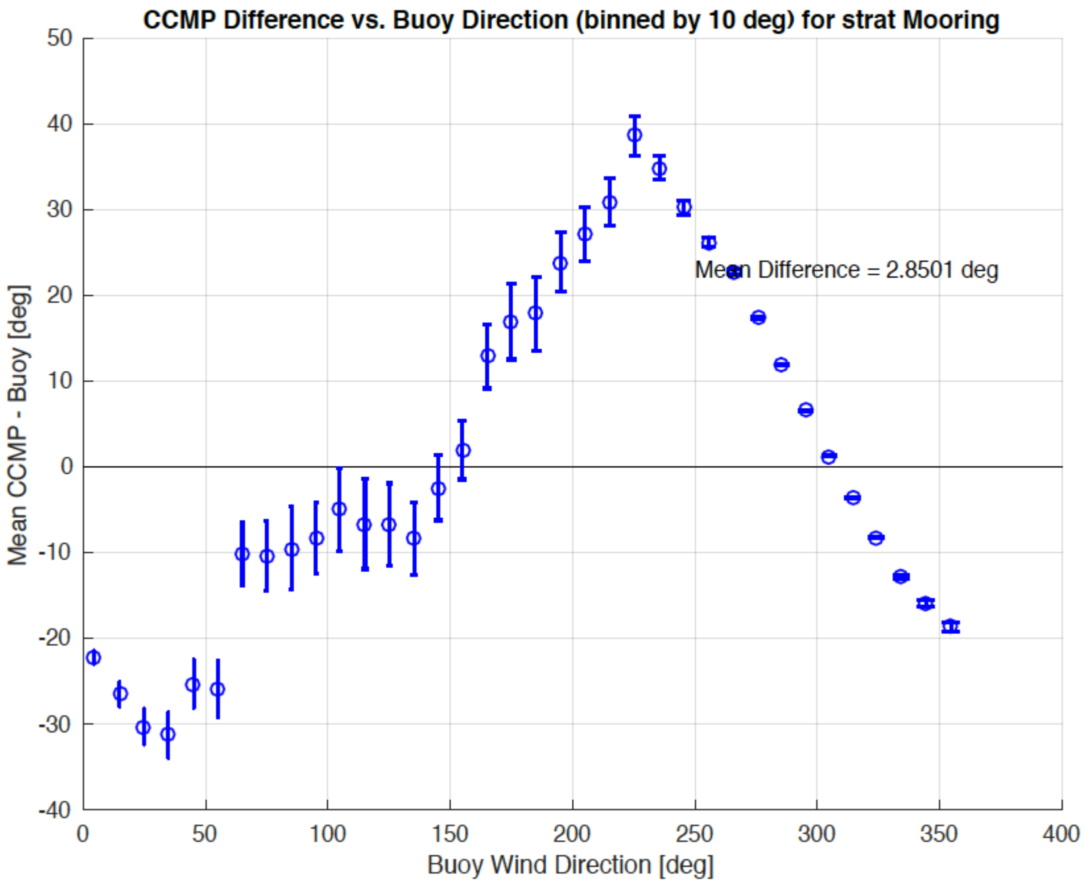
- Directional bias clearest at dominant wind angles (260-340°).
- Bias varies with wind direction.

Stratus buoy: QuikSCAT minus buoy (corrected for velocity)



- Ocean velocities low in this region.
- Bias not removed by corrected buoy winds for ocean velocity.

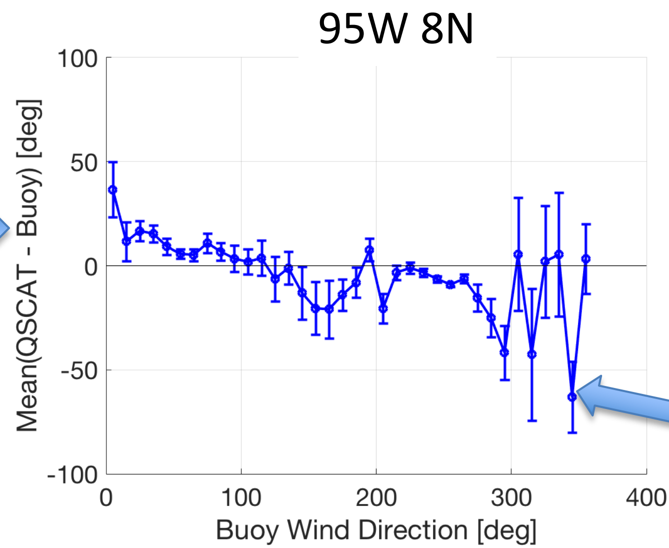
Stratus buoy: CCMP minus buoy (uncorrected for velocity)



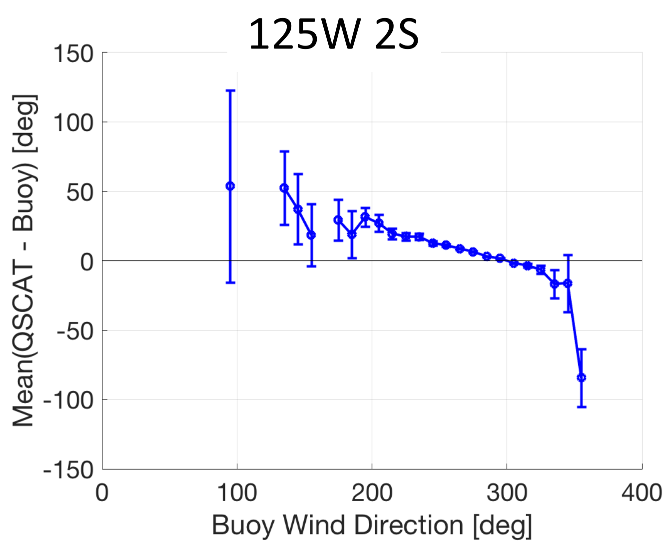
- Not just QuikSCAT
- Similar effects for ASCAT, CCMP, etc.

Pattern ubiquitous (e.g across TAO array)

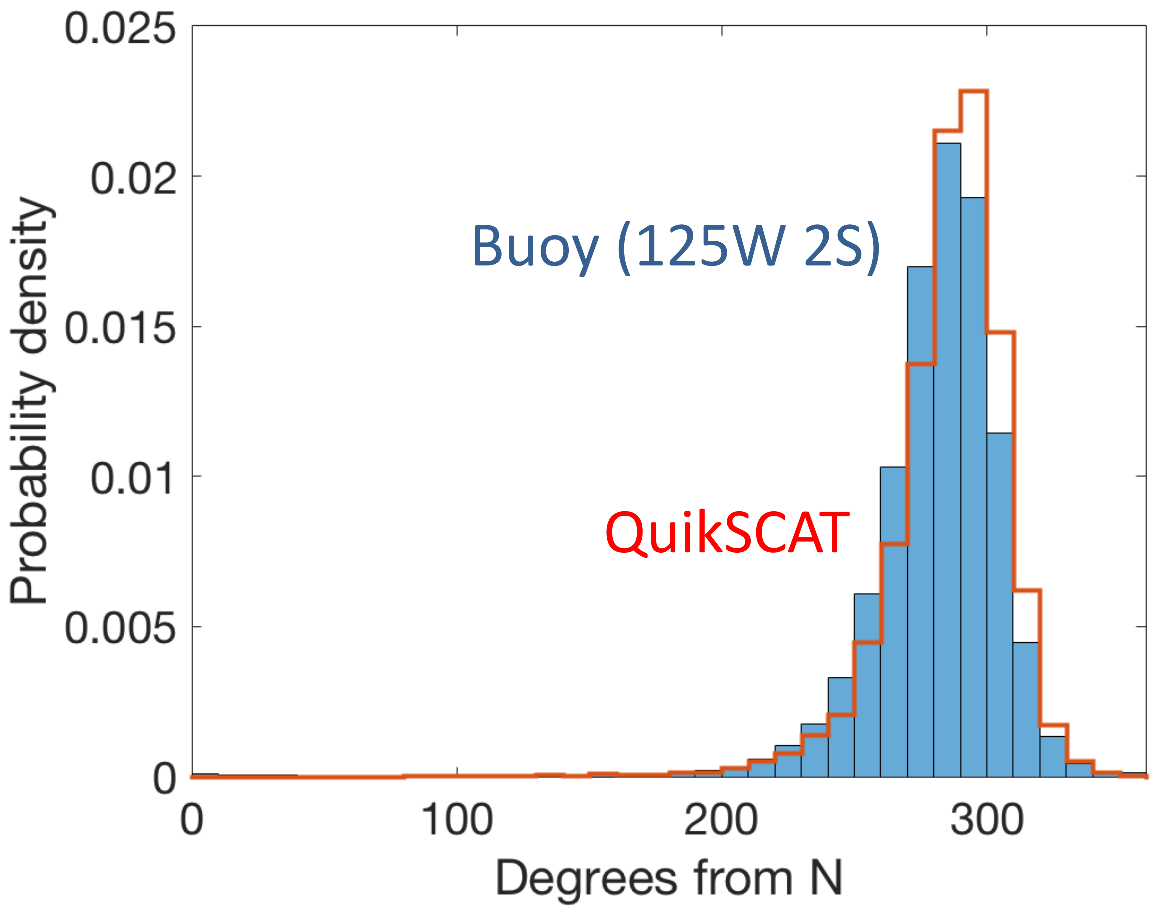
QuikSCAT rotated clockwise relative to buoy



Quickscat rotated counterclockwise relative to buoy



Statistical artifact?



Some of bias likely results from differencing random variables centered at same value.

But QuikSCAT standard deviation is smaller than buoy standard deviation.

Can there be a physical explanation for some of this?

Hypothesis #1: Ekman spiral in planetary boundary layer

Velocity spirals with height

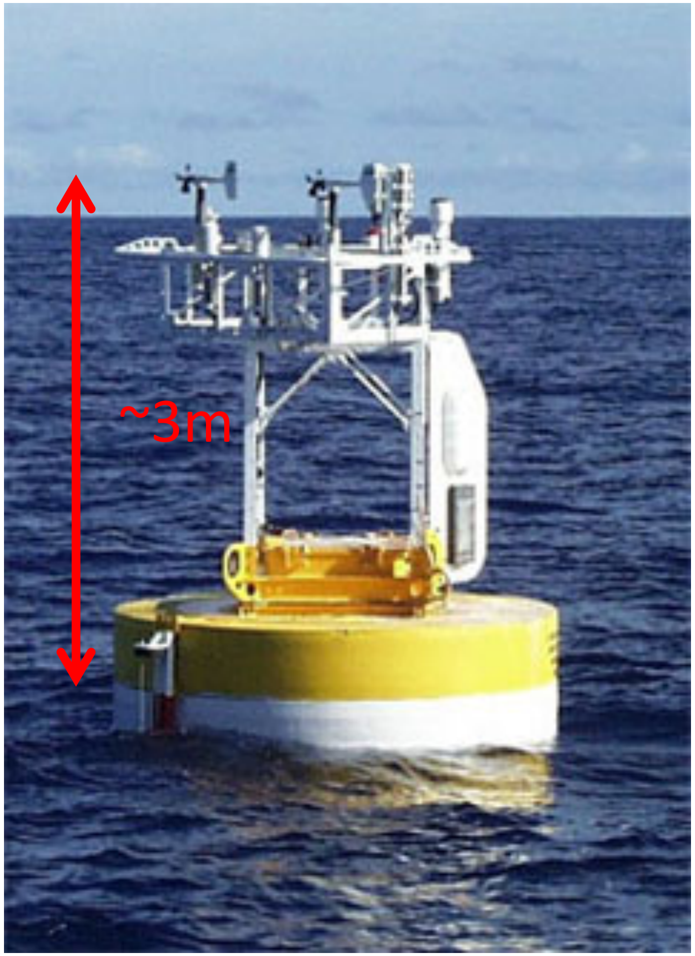
$$\mathcal{U}_e = u_g\left\{1 - \exp\left[-(1+i)\frac{z}{h_e}\right]\right\},$$

Ekman depth scale $h_e \approx 400$ m

$$h_e = (2K_m/f)^{1/2}$$

In SH: buoy to left of scatterometer

No easy way to explain bias dependence on wind direction.



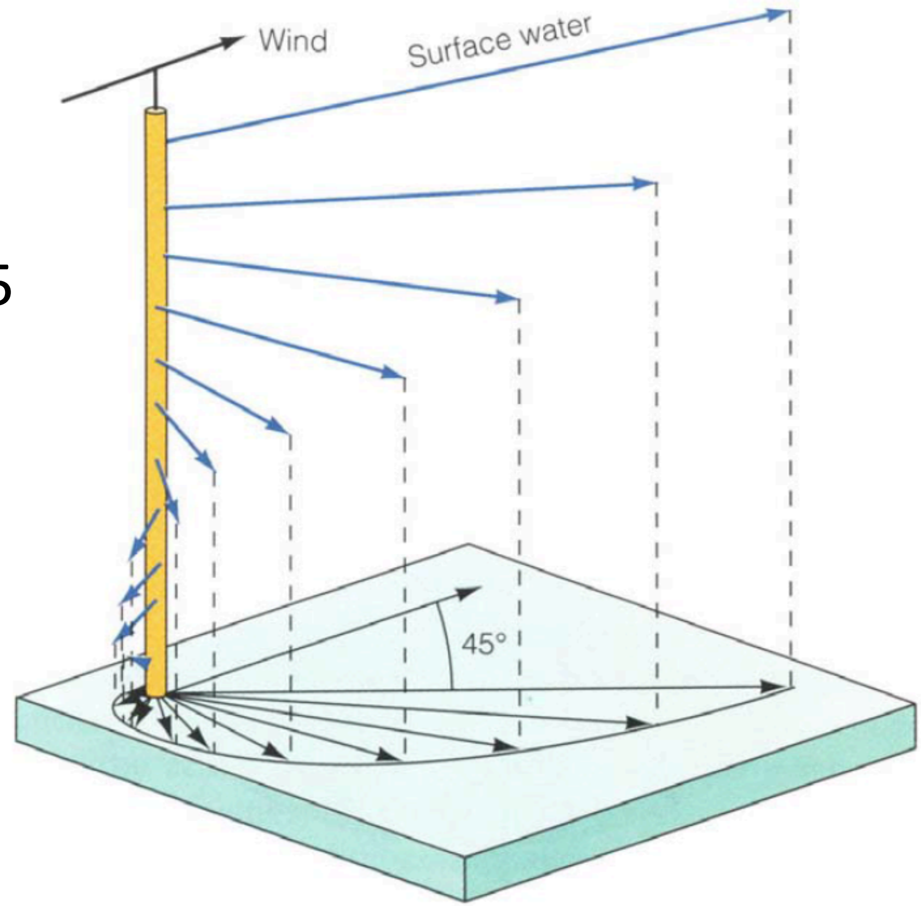
see Hanley and Belcher, JAS, 2008

Hypothesis #2: Ekman spiral in upper ocean

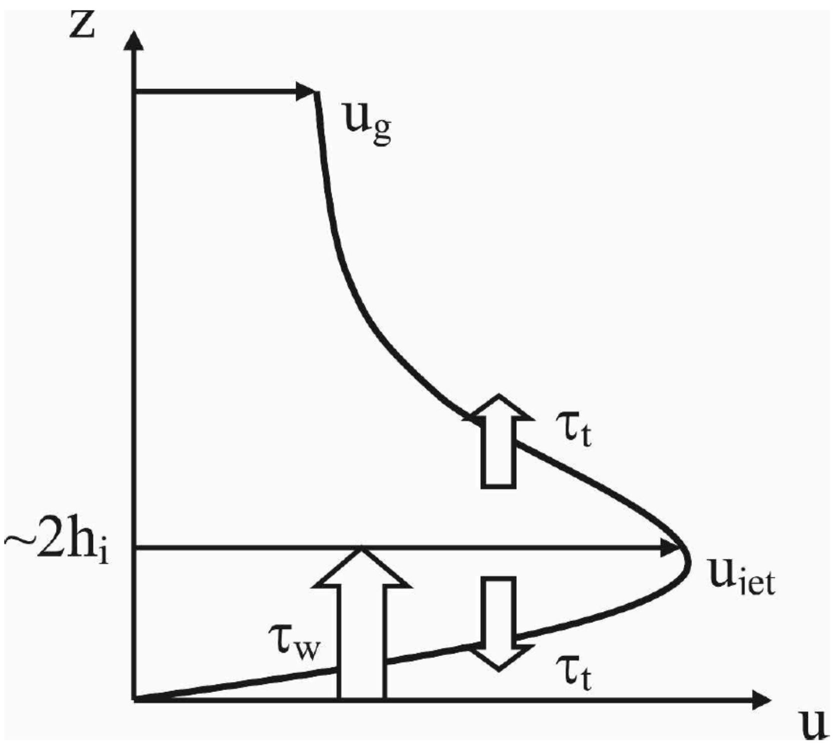
Upper ocean currents rotate relative to wind, so depth of velocity measurement (10-37.5 m) could influence results.

But …

- Current neglibly small at Stratus site
- Would not readily explain angular dependence



Surface waves influence surface stress



Wave-induced stress τ_w produces wave-driven jet (Hanley and Belcher, JAS, 2008)

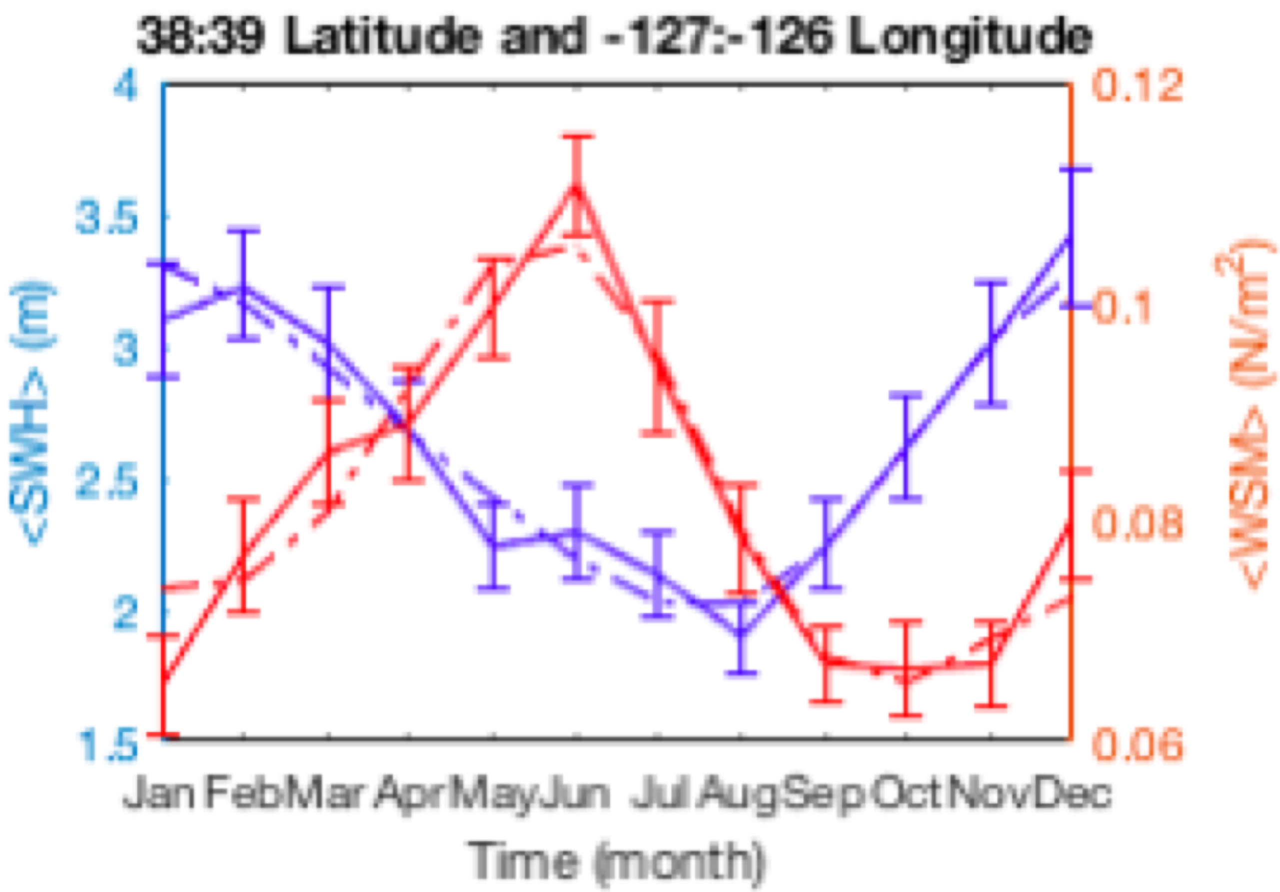
Impact scales with wave boundary layer $h_i \approx 2$ m.

What if wave stress not aligned with wind stress?

$$\mathcal{U}_w = \frac{\tau_w(0) h_i}{K_m(1 - i2h_i^2/h_e^2)} \exp\left(-\frac{z}{h_i}\right).$$

see Hanley and Belcher, JAS, 2008

Hypothesis #3: Wave-induced stress not aligned with wind

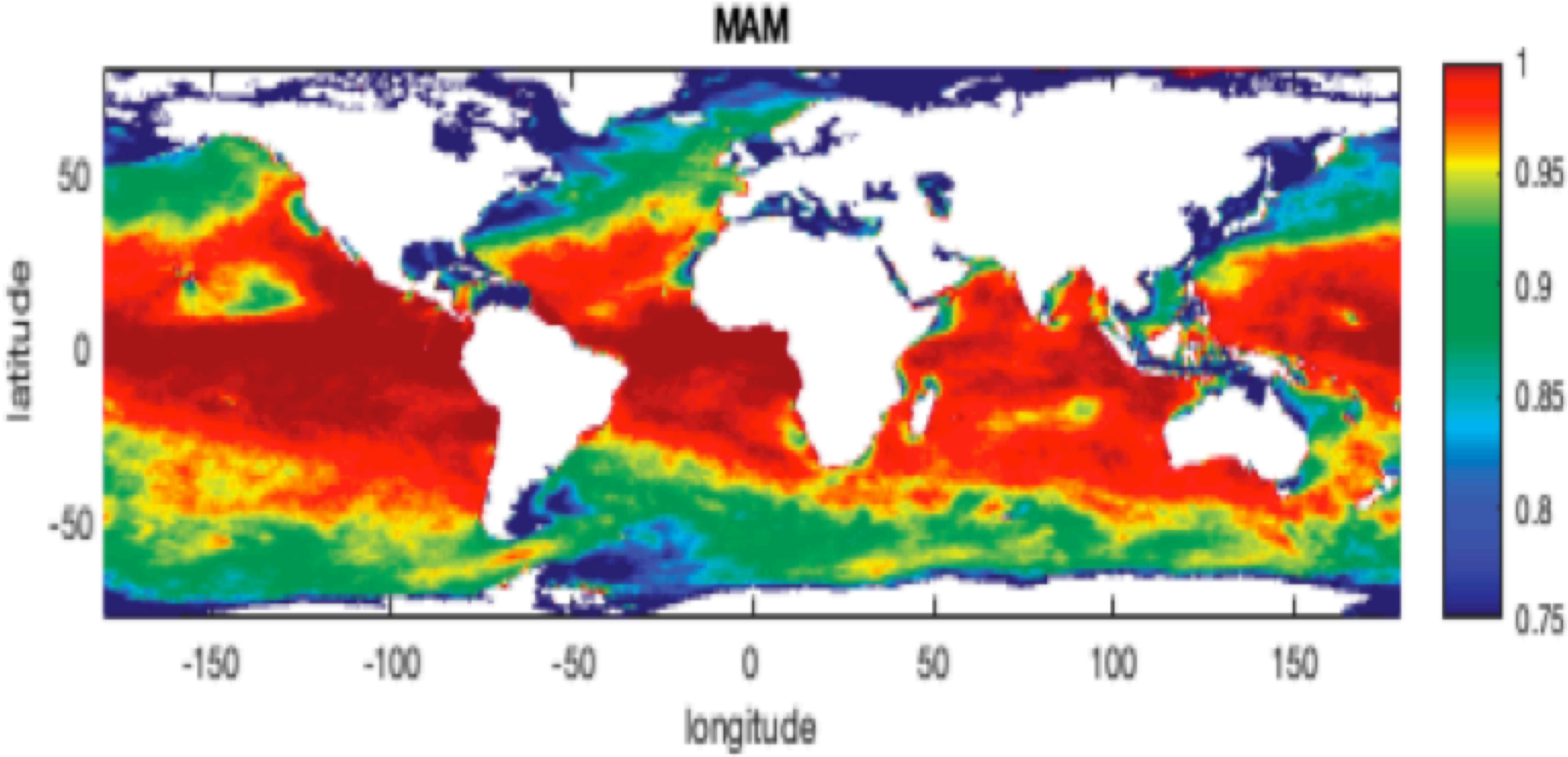


Example: California Current significant wave height peaks in winter; winds peak in summer.

Remotely forced waves need not be aligned with wind.

Adapted from Villas Bôas et al, 2017

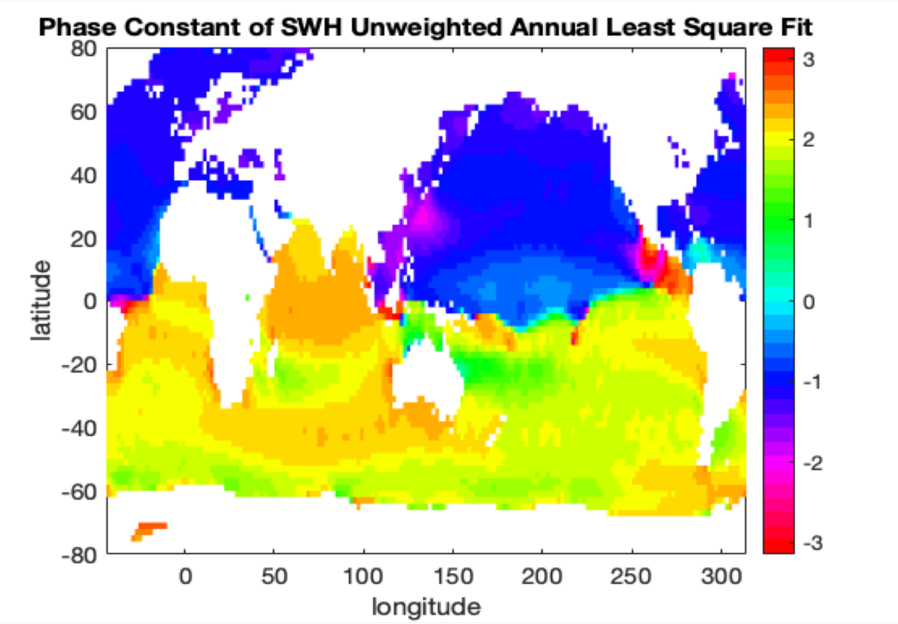
Hypothesis #3: Wave-induced stress not aligned with wind



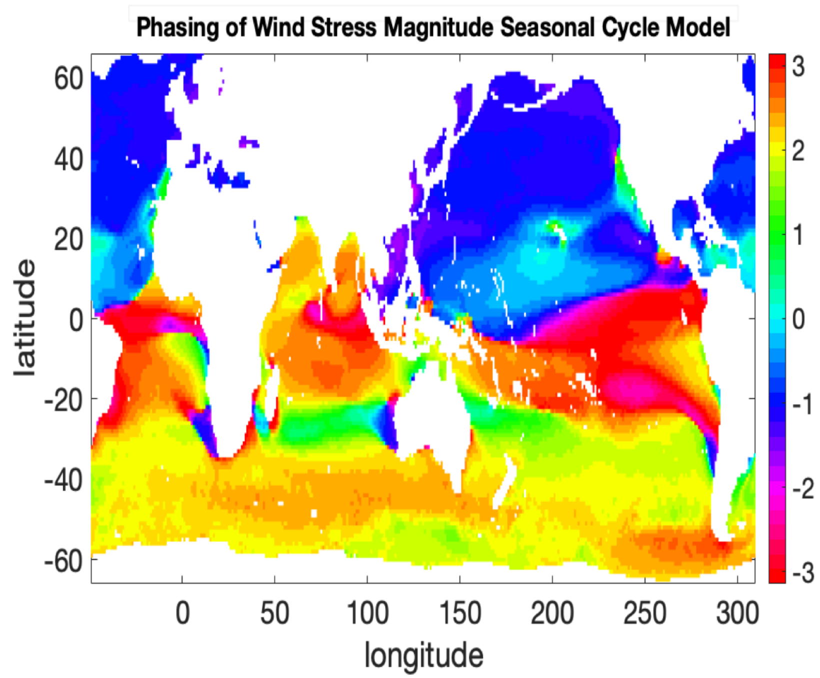
- Probability of swell rather than locally forced winds computed from wave age (2002-2011)
- Tropics dominated by swell → waves originate in remote storms

Colosi, Villas Bôas, Gille, in prep using method from Jiang and Chen, Jtech, 2013

Annual cycles: Waves and wind out of phase in many locations



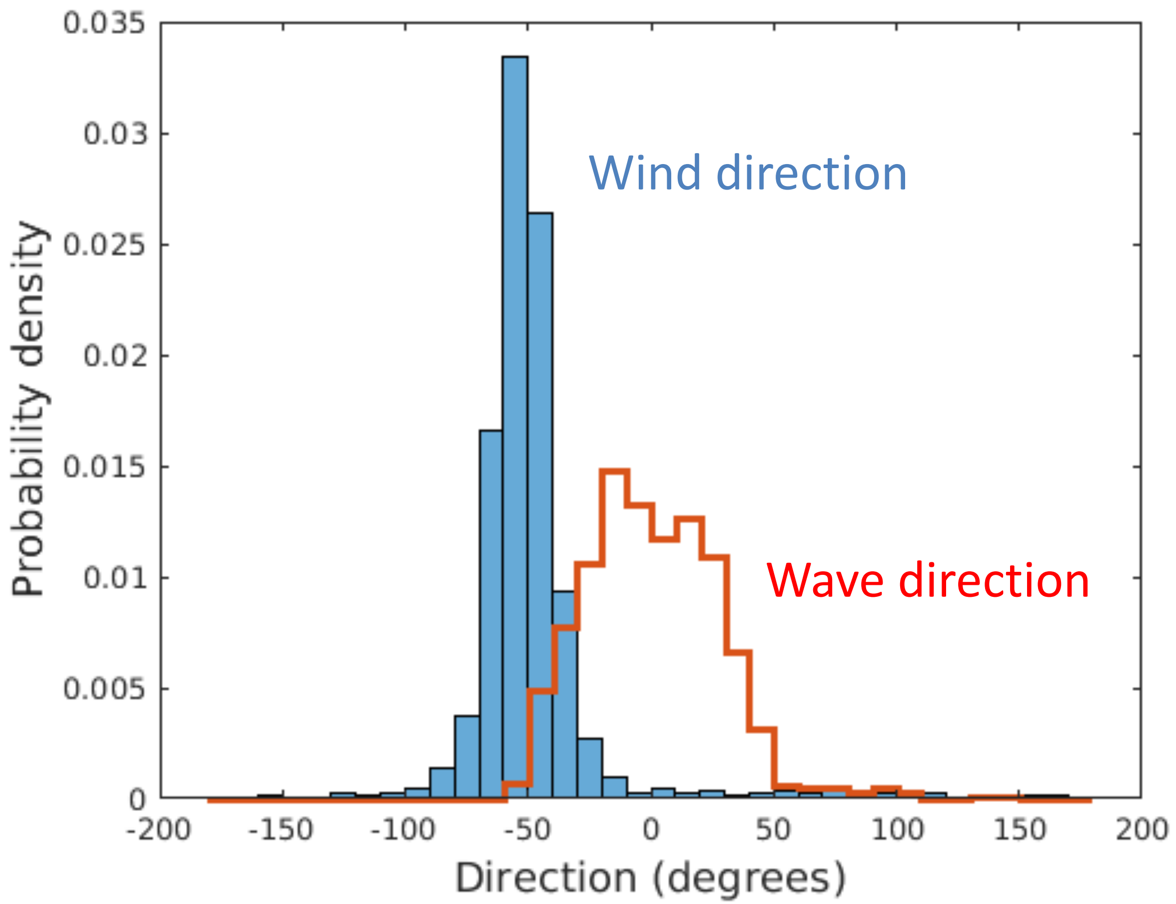
Wave phasing (Ifremer altimeter product): High waves in winter in both hemispheres



Wind phasing (CCMP): Winter storms in both hemispheres; not exactly co-located with waves

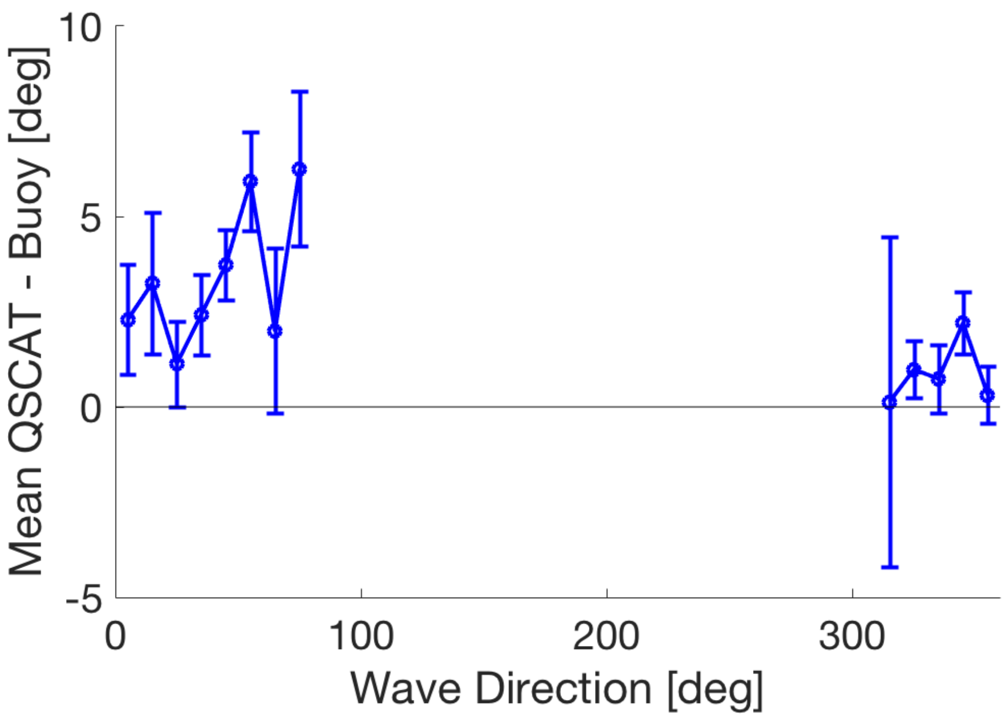
Colosi, Villas Bôas, Gille, in prep

Stratus: wind & wave directional pdfs



- Wave/wind from WaveWatch3, 2002 at Stratus site
- Median direction differs by 50°
- Implies wave induced stress to right of wind stress

Stratus buoy: QuikSCAT minus buoy (as a function of wave direction)

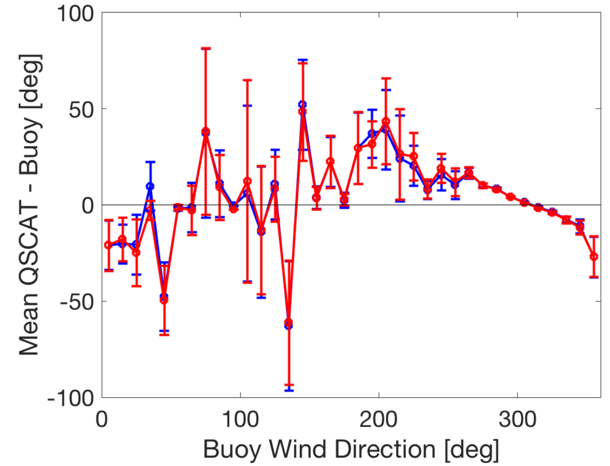


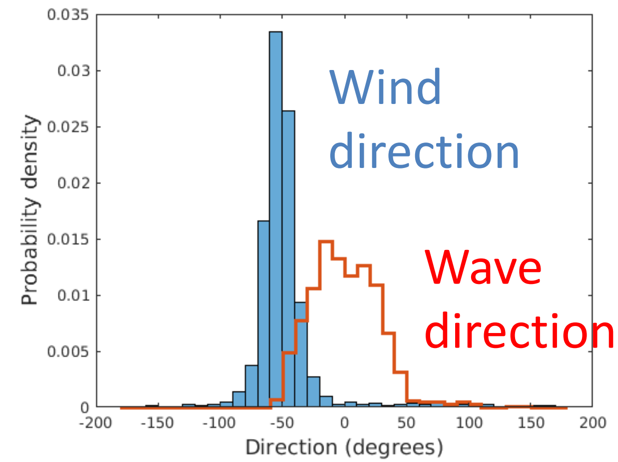
Clockwise directional bias, consistent with waves orientation to right of wind.

Larger angular separation relative to mean wind direction implies larger bias.

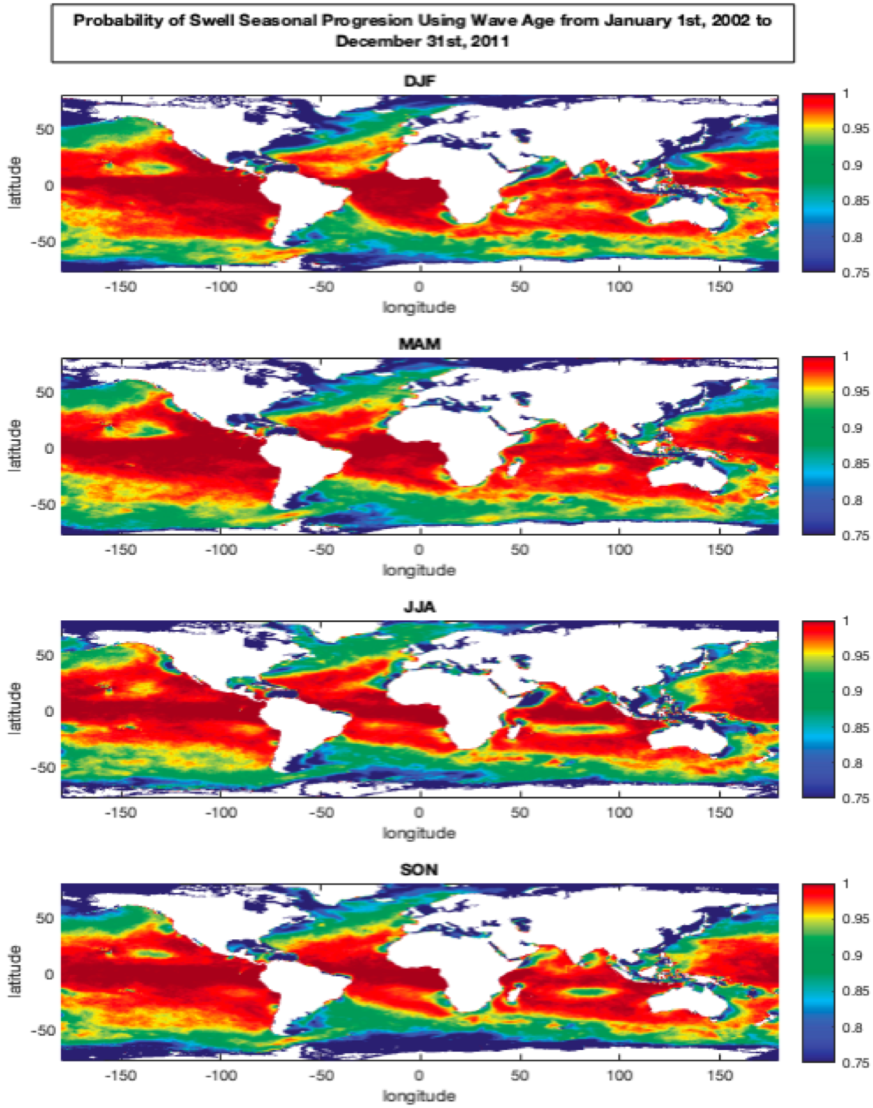
Summary/Conclusions

- Buoy and scatterometer winds show small directional biases, dependent on wind direction.
- Not Ekman spiral in atmospheric boundary layer or upper ocean.
- Plausibly partially explained by wave-induced stress from non-local swell, not aligned with wind.





Additional slide



Hypothesis #3: Wave-induced stress not aligned with wind