AI34A–2367

Wind–Wave Interactions: Exploring Swell Wave Influence on Wind Direction

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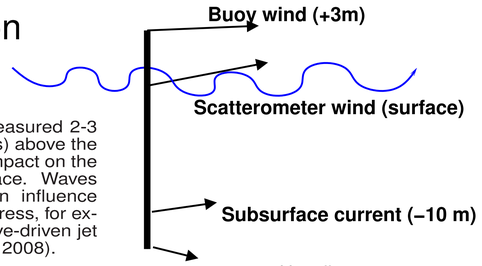
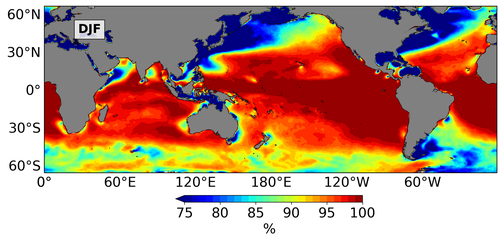
1. Introduction



Winds are traditionally measured 2-3 meters (or even 10 meters) above the ocean surface, but their impact on the ocean occurs at the surface. Waves and other processes can influence surface winds and wind stress, for example by producing a wave-driven jet (e.g. Hanley and Belcher, 2008).

Usually waves are assumed to be wind-driven and aligned with the wind, but over much of the ocean, remotely forced swell waves dominate over locally-forced wind waves.



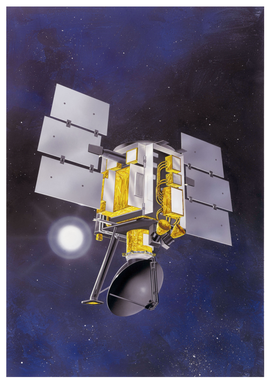
The "probability of swell" is near 100% throughout the tropics, and wind waves have comparatively little impact. (For more details, see Luke Colosi's poster AI34B-2385, Colosi et al, 2020.)

Our question: Can swell wave effects produce differences in direction between measured anemometer winds and satellite winds? Correspondingly, can the direction of wind stress at the surface differ from the direction of wind above the surface?

2. Data: Stratus Mooring Case Study

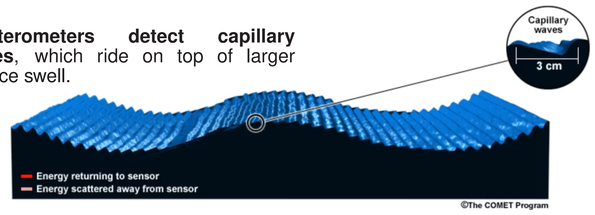
The Stratus mooring in the southeast Pacific serves as a test case.

The anemometer is 3 m above the ocean surface. The mooring has been in operation since 2000 and includes measurements of upper ocean velocity.

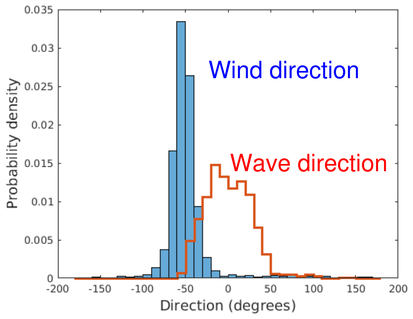


QuikSCAT scatterometer winds are extracted from the buoy site from 2000 to 2010. We also examine the Cross-Calibrated Multi-Platform (CCMP) multi-satellite wind product, which is available over a slightly longer time period but includes passive wind-speed-only satellite products and reanalysis winds.

Scatterometers detect capillary waves, which ride on top of larger surface swell.

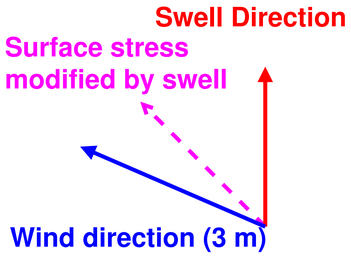


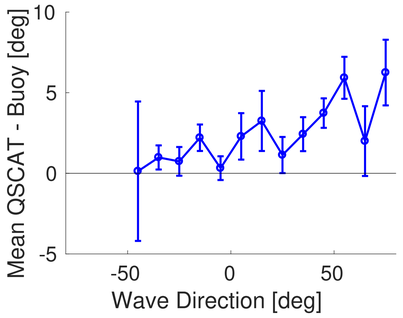
3. Directional bias depends on wave direction



Wave directions at the Stratus site differ from wind directions. Based on WaveWatch3 fields, the median wave direction is 50° to the right of the wind.

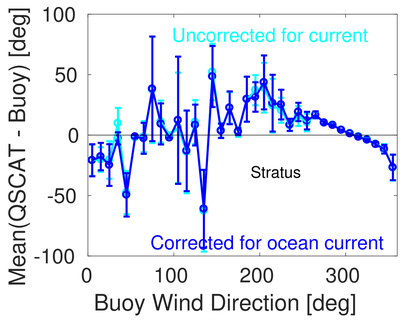
Swell waves could modify surface wind direction either by establishing a wave-driven jet or by modifying the orientation of surface capillary waves. Can such an effect be detected?



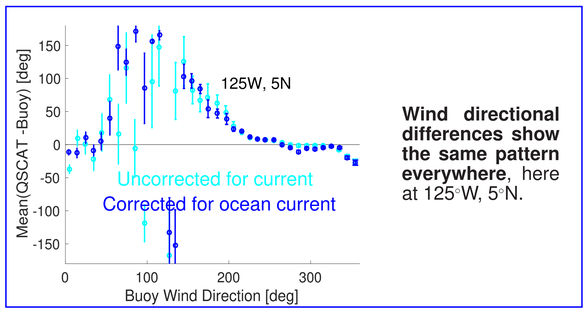


Directional difference between surface (QuikSCAT) and 3 meters (Stratus buoy) as a function of wave direction. As the wave direction increases relative to the prevailing wind direction, the surface winds differ more in direction relative to above-surface winds.

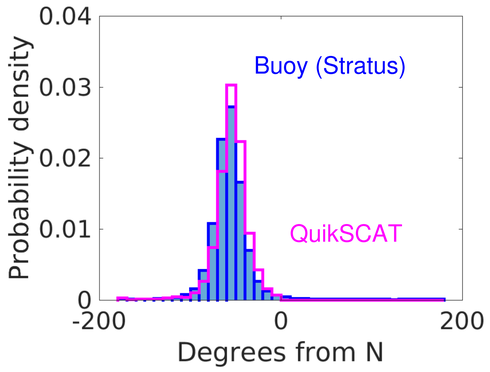
4. Sidebar warning: As a function of wind direction, directional bias is a statistical artifact



Surface (QuikSCAT) minus 3-meter (buoy) wind directional differences at the Stratus site also vary as a function wind direction. Biases tend to be positive for wind directions less than the median direction and negative when wind direction exceeds the median direction. This is a statistical effect that tells us more about random errors than about properties of near-surface winds.



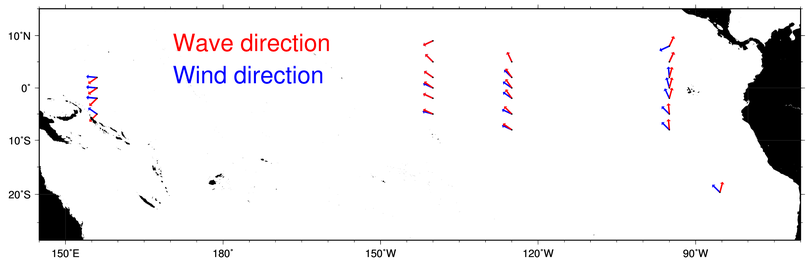
Wind directional differences show the same pattern everywhere, here at 125°W, 5°N.



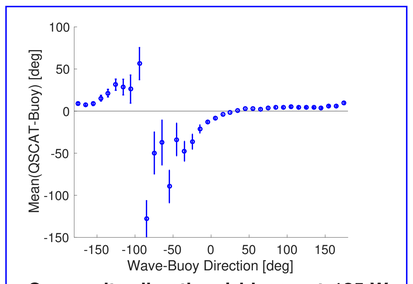
Probability density functions for surface and 3-meter winds strongly overlap. Consider a case when buoy winds are shifted clockwise relative to median direction. Then a randomly selected surface wind is likely to be oriented several degrees counter-clockwise relative to the buoy wind. This will result in a negative QuikSCAT minus Buoy directional difference. In the opposite situation, when buoy winds are shifted counter-clockwise relative to their median direction, a randomly selected surface wind is likely to lead to a postive directional difference.

Effectively, the downward slope in directional biases would be expected for any two fields that share a preferred directionality but are otherwise uncorrelated.

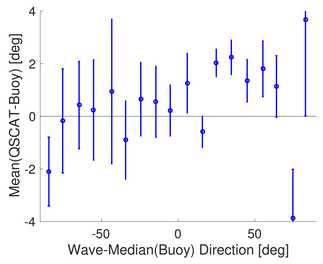
5. Wind vs wave directional differences vary through the tropics



Most probable wind and wave directions from buoy sites throughout the tropics show that wave directions are often, but not always, more meridional, while winds are more zonal. This is consistent with remotely forced swell waves from high latitude storms propagating in a different direction than waves from local winds.



Composite directional biases at 125°W show that surface minus buoy wind biases are biased clockwise when waves are rotated clockwise relative to the wind. This too is an artifact. Since both axes are referenced to buoy winds, the result is exaggerated because anomalous buoy wind events appear on both axes.



Surface winds are biased clockwise relative to 3-m winds when waves are rotated clockwise relative to median wind. The effect is small, but consistent with the hypothesis that wave effects modulate the apparent surface wind stress.

6. Summary

- Surface (i.e. scatterometer) and buoy (i.e. 3-m anemometer) winds show small directional biases, even after correcting for ocean currents. These biases are not explained by the Ekman spiral in the atmospheric boundary layer or in the upper ocean.
- Outside of high latitudes swell waves often propagate in directions that are not aligned with storms.
- The difference in alignment of swell waves and wind can potentially induce a wave-generated surface stress that can account for directional biases between buoy and scatterometer winds.
- These results have implications for interpreting scatterometer-derived surface winds and wind stress, particularly in low-wind, high-swell regions.

7. Next steps

- This preliminary analysis uses Wave Watch 3 only from 2002 so needs to be extended in time and in space to encompass the global buoy system.
- Seasonal and interannual variability will also need to be assessed.

References

Colosi, L, A. B. Villas Bôas, and S. T. Gille, 2020: The seasonal cycle of significant wave height in the ocean: Local vs remote forcing, in preparation, J. Geophys. Res. - Oceans.

Hanley, K. E. and S. E. Belcher, 2008: Wave-driven wind jets in the marine atmospheric boundary layer, J. Atmos. Sci., 65, 2646-2660, doi:10.1175/2007JAS2562.1.

Acknowledgments. This work has been supported by NASA through the Ocean Vector Winds Science Team.