What Drives the Spatial Variability of the Stokes Drift?

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Introduction

- The **Stokes drift** is the net drift of particles in the direction of wave propagation.
- Synoptic-scale winds drive large scale surface wave variability. However, wind, wave, and current coupling[1] can lead to wave variability at scales shorter than storm scales.

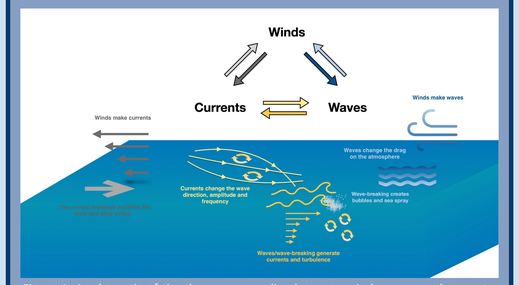


Figure 1: A schematic of the three-way coupling between wind, waves, and currents. Examples of these interactions are indicated, with the color corresponding to the direction of interaction indicted by the prism. From Villas Bôas and Pizzo 2021[1].

- In the past decade, numerical modeling work[2,3] as well as novel remote sensing[4] and *in-situ* observations[5] have shown that **currents can drive submeso-to-mesoscale variability in the wave field.**
- Observations during the S-MODE campaign show that **winds over the ocean have kilometer-scale variability[6].** Recent numerical modeling work at NASA have resolved winds $\mathcal{O}$(10 km) using a coupled ocean-atmosphere modeling framework[7].

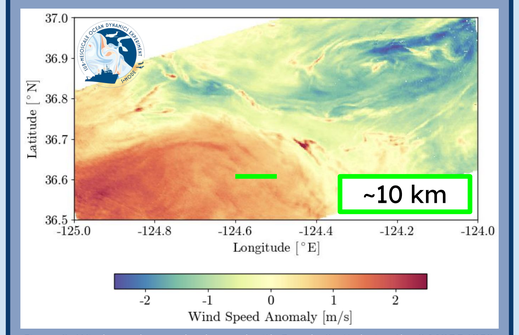
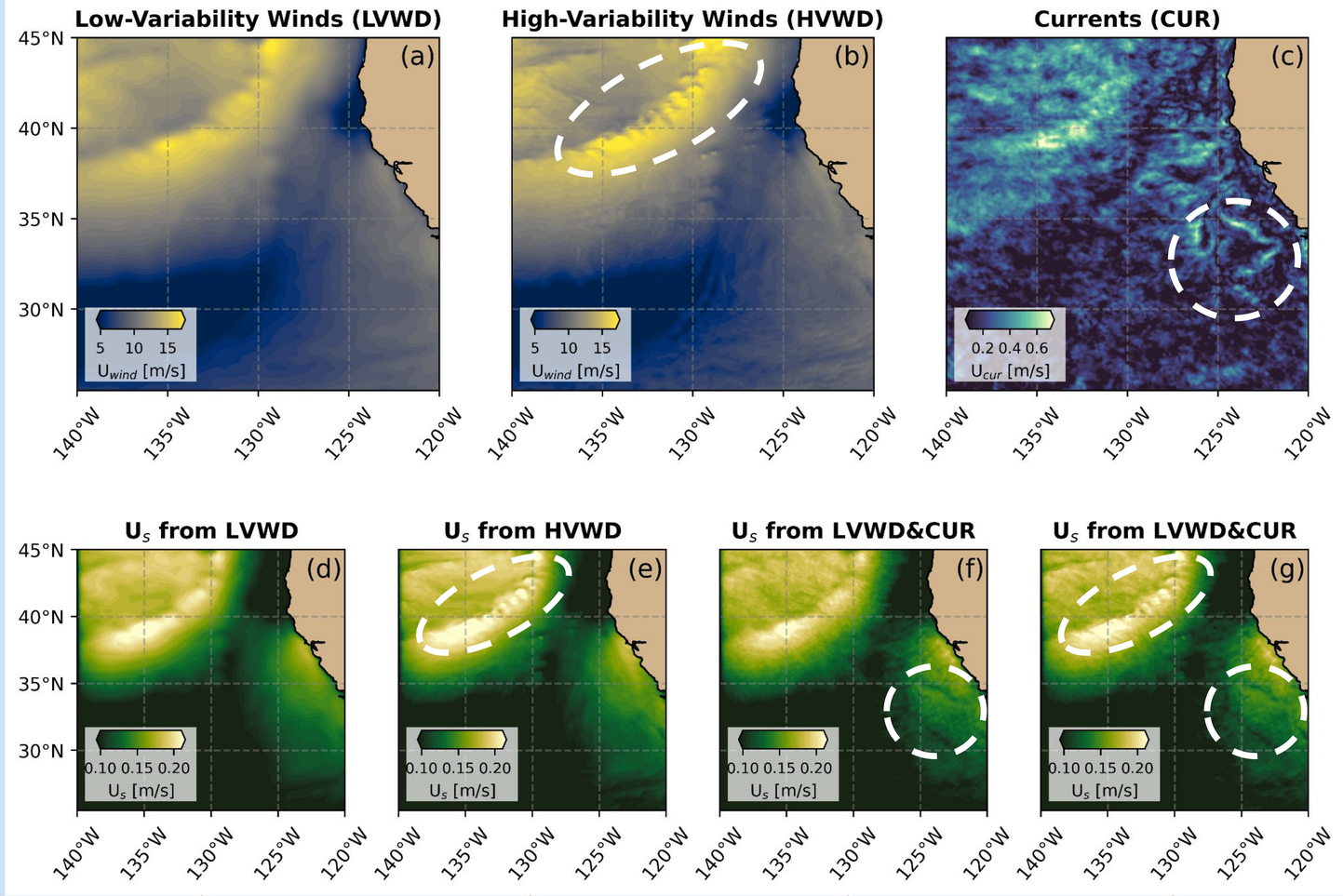


Figure 2: Wind speed anomaly observed with DopplerScatt during the S-MODE IOP2. From Alex Wineteer, pers. comm. 2026.

Q1: What is the role of high-wavenumber wind variability in the spatial variability of Stokes drift?
Q2: How, and at what scales, do currents impact the spatial variability of Stokes drift?

Spatial gradients in the Stokes Drift are driven by winds and currents.

Variability $\mathcal{O}$(1,000 km) | Variability down to $\mathcal{O}$(10 km)



Operational standard– only captures large-scale variability driven by the wind

High wavenumber wind variability imprints on the Stokes drift

Currents introduce "patchiness" and coherent features that are independent of the local wind

High wavenumber wind features and current-driven coherent features and patchiness

Quantification

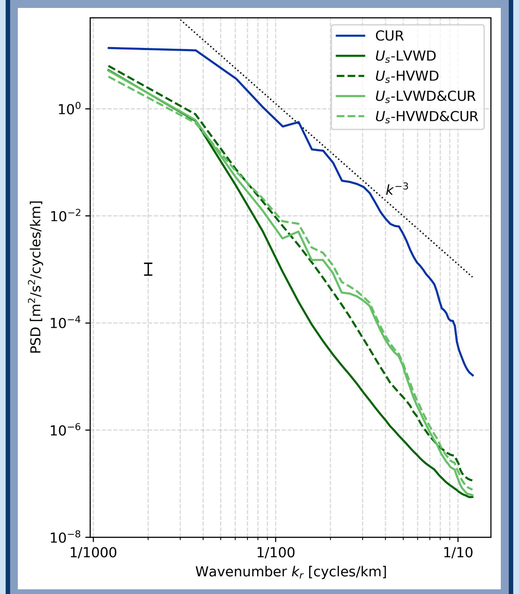


Figure 3: Isotropic wavenumber spectra of currents (CUR) and Stokes drift (U_s) from WAVEWATCH III forced with low-variability winds (U_s-LVWD), high-variability winds (U_s-HVWD), LVWD and CUR (U_s-LVWD&CUR) HVWD and CUR (U_s-HVWD&CUR). Spectra were averaged over the entire model period. The error bars in the bottom right assume independent measurements 7 days, and applies to all spectra.

- **High-wavenumber wind variability increases the variability of the Stokes drift by 10×** at scales shorter than 100 km.
- **Current effects on waves enhance the variability by 13×** at scales shorter than 100 km, and changes the shape of the Stokes drift spectrum to match that of the currents.
- **Both high-wavenumber wind variability and current effects on waves enhance the variability of the Stokes drift by 20×** at scales shorter than 100 km.

Conclusions

- **High-wavenumber wind variability and current effects on waves drive variability in the Stokes drift.** Both of these processes are modulating it at scales $\mathcal{O}$(10-100 km), but current effects on waves introduce variability that is independent of the local wind field.
- This work lays the groundwork to **investigate the spatial variability of other coupled processes like Langmuir turbulence.**

References

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