High-wavenumber Variability of Sea Surface Height: Evaluating Sub-100-km Scales with Altimetry, ADCP, and Model Output

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New altimeters such as AltiKa, Sentinel-3, Jason-CS, and SWOT, and new retracking methods for older altimeters offer the possibility of resolving the ocean surface at previously inaccessible scales. This leads to a fundamental question: What controls sea surface height at scales less than ~100 km?

Objectives: Evaluate physical processes governing sea surface height signals measured through altimetry

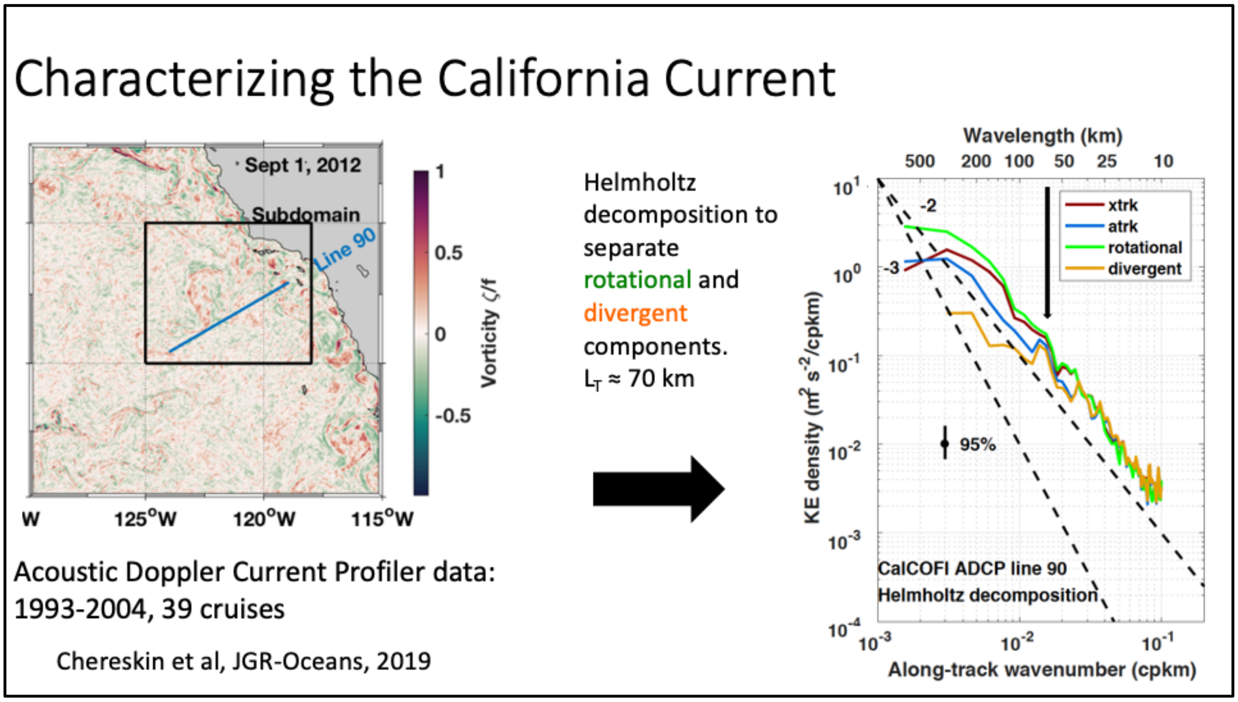
Tools:

- Sea surface height:
  - High-resolution radar altimetry, including AltiKa, Jason-1/2 with ALES reprocessing, Sentinel-3 when available
  - Laser altimetry: ICESat-2
- In situ upper-ocean velocities: Acoustic Doppler Current Profiler (ADCP) data
- Model output: MITgcm at 1/48^{o} resolution (llc4320)

Methods:

- Helmholtz decomposition and wave-vortex decomposition

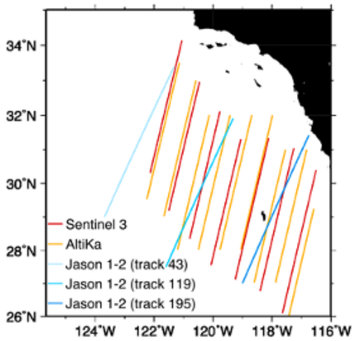
The goals of our research have focused on using in situ observations from Acoustic Doppler Current Profiler data and model output, along with high-resolution nadir altimetry, to probe the physics governing sea surface height variability in the ocean. Our work has targeted test regions in the California Current System and in the eastern Tropical Pacific.



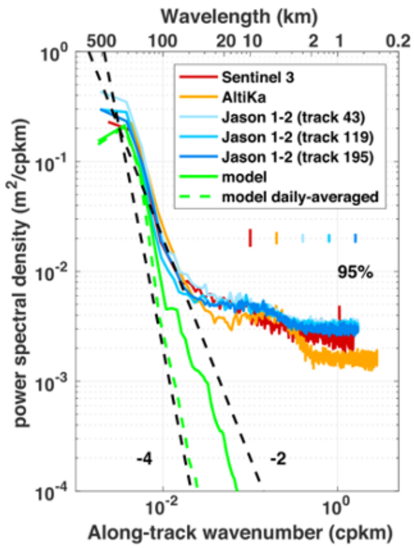
In Chereskin et al (2019) we explored variability along the well-sampled ADCP line from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) line 90. Wavenumber spectra from along track (atrk) and cross-track (xtrk) velocity components diverge at scales around 70 km. In the Helmholtz decomposition, this corresponds to the distinction between rotational flow (which is expected to be geostrophic) and divergent flow. From this we infer that geostrophy dominates the upper ocean signals for scales longer than 70 km in the California Current region.

Model –derived spectra (not shown here) show patterns that are generally consistent with in situ observations, albeit with a longer transition scale of about 125 km. Also not shown here are the seasonal effects, which are identifiable in model output but weak in the observations. See Chereskin et al (2019) for further information.

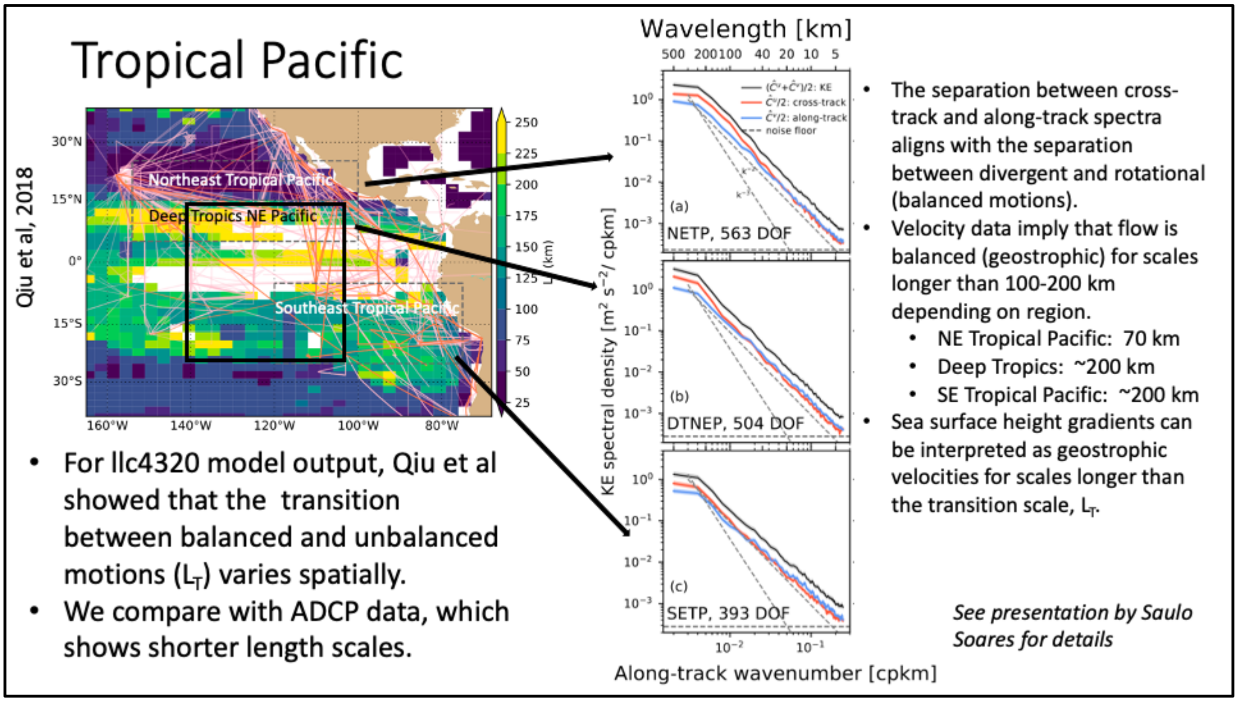
Sea surface height in the California Current



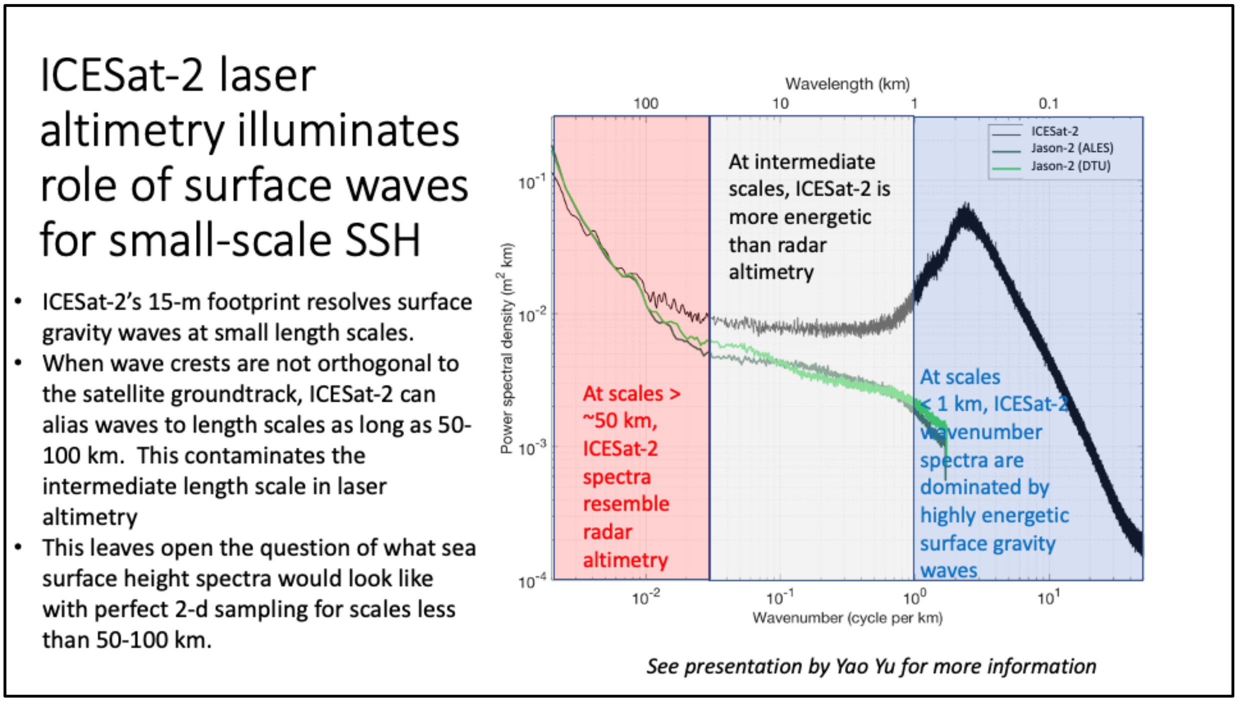
- Sea surface height spectra have a k^{-4} slope for scales longer than 70 km (consistent with slopes expected for balanced motions with k^{-2} velocity spectra).
- Spectral flattening for shorter scales is usually attributed to instrument noise but perhaps could be linked to unbalanced motions.



Wavenumber spectra from altimetry is consistent with the ADCP data in showing behavior consistent with balanced motions for scales longer than ~70 km. This suggests that altimetry is valuable for inferring geostrophic velocities for scales longer than 70 km. For scales shorter than 70 km, radar altimeters imply flatter spectra. While spectral flattening is usually attributed to instrument noise the flattening starts at about the scale at which unbalanced motions begin to be important, implying the possibility of a complex range of processes.



We extended the California Current analysis to the tropical Pacific using ADCP data spanning the region. The ADCP data come largely from previously unprocessed transects, many of which were collected when a research vessel was transiting between two sites without interruptions. Using model output, we show that results from transects are largely consistent with results from Eulerian fields (processed as Qiu et al, 2018 did). Transition scales between balanced and unbalanced motions are shorter in observations than in model output, but are still long enough to mean that scales smaller than 70 km (or longer) are likely dominated by unbalanced motions.



To further probe the structure of sea surface height at small scales, we have examined ICESat-2 observations from the tropical Pacific. ICESat-2 uses a 15 m footprint that allows it to resolve surface gravity waves. Not surprisingly, for scales smaller than 1 km, ICESat-2 data are dominated by surface gravity waves associated with long period swell, with wavelengths between from 300-1000 m. Since ICESat-2's ground track is not necessarily orthogonal to wave crests, wave energy can alias into much longer length scales. When wave crests align with the satellite ground track, the alias scale can be as long as 50-100 km. As a result, ICESat-2 has considerably more energy than radar altimeters at scales from 1-100 km. At scales longer than 100 km, ICESat-2 wavenumber spectra show good agreement with radar altimetry (as indicated in the red band in the figure).

Summary: Major findings

- Our work has used multiple data sources to explore the physical processes that occur at high wavenumber and to assess their detectability from altimetry.
- Results from ADCP data suggest that oceanic motions are balanced on long scales, and that the transition scale between balanced and unbalanced motions varies geographically. Transition scales in the equator are longer than scales in the California Current.
- Surface gravity waves provide a highly energetic signal that is readily detected with the small footprint used by ICESat-2. This can alias to scales as long as 50-100 km for swell parallel to the satellite ground track. Radar altimetry has a larger footprint and is likely to see 1/500th of the effect detected by ICESat-2.