Diagnosing tidal modulation from high frequency radar

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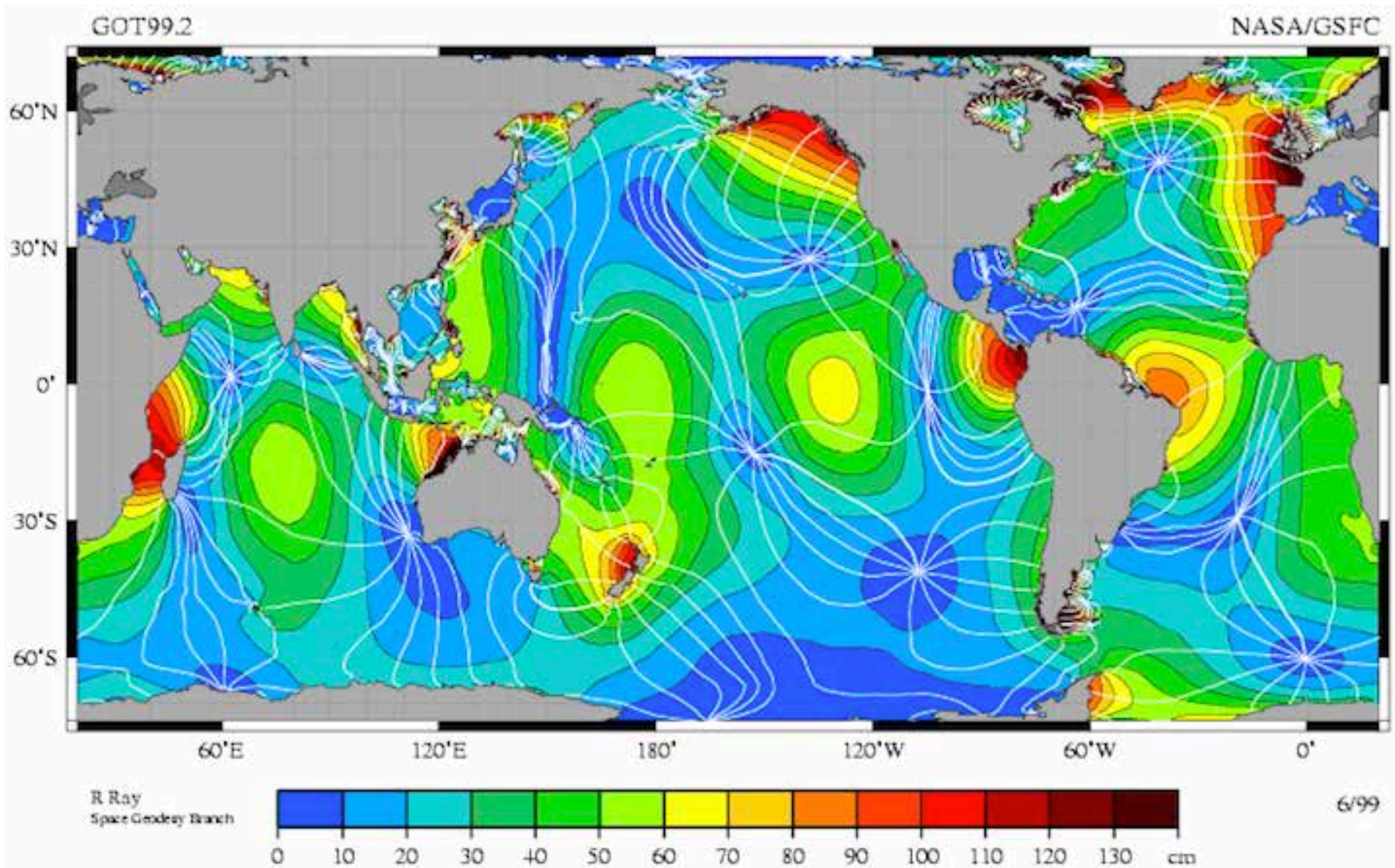
Background image: https://tidesandcurrents.noaa.gov/hfradar/

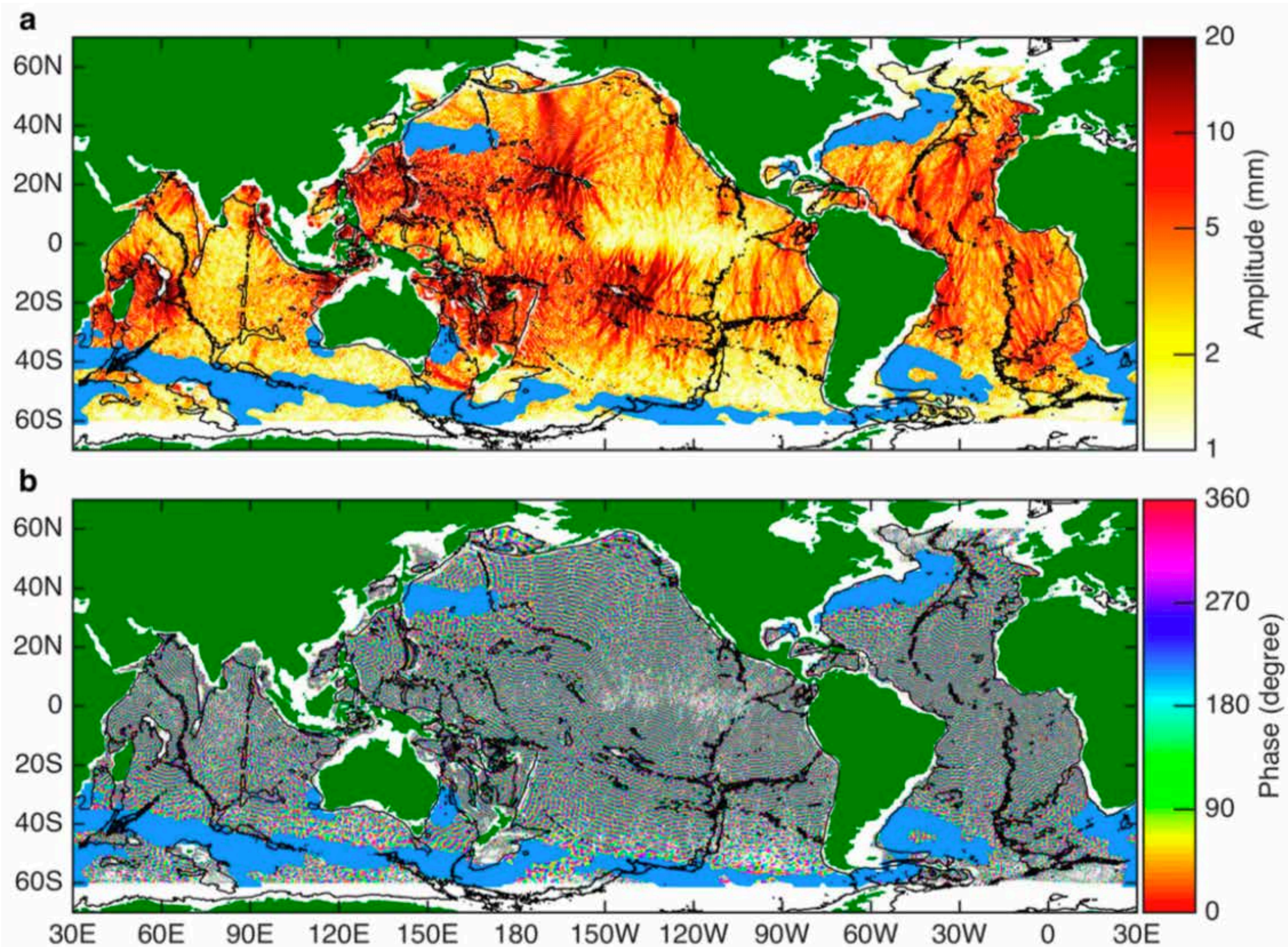
Conventional view of tides



Global barotropic M2 tide, color = SSH amplitude, white lines = phase lines

https://svs.gsfc.nasa.gov/stories/topex/tides.html

Mode-1 internal M_2 tides



Complicated spatial structure of amplitude and phase described by Zhao et al. (2016)

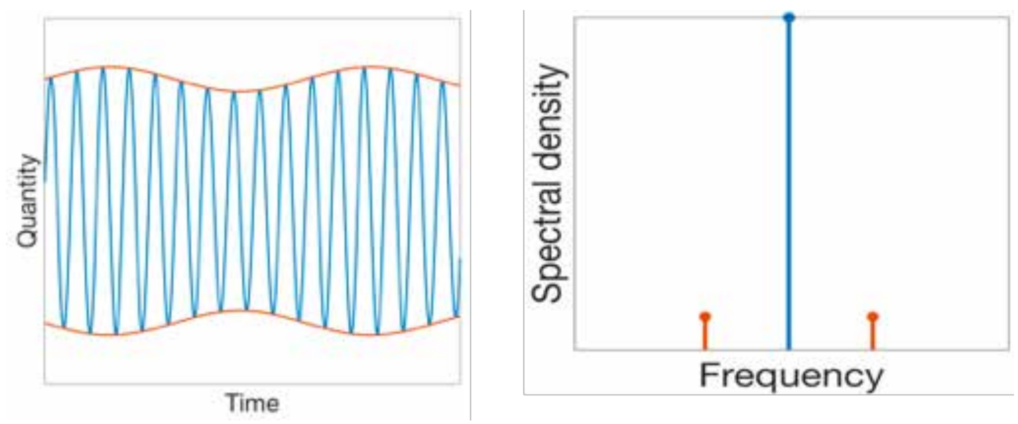
Outline

- Motivation/goals
- Data set: high frequency radar surface current time series
- Methods: harmonic spectral analysis
- Results: spectral characteristics, spatial structure of tidal signals
- Bonus (if there is time): wind and stratification

Relevance to SWOT

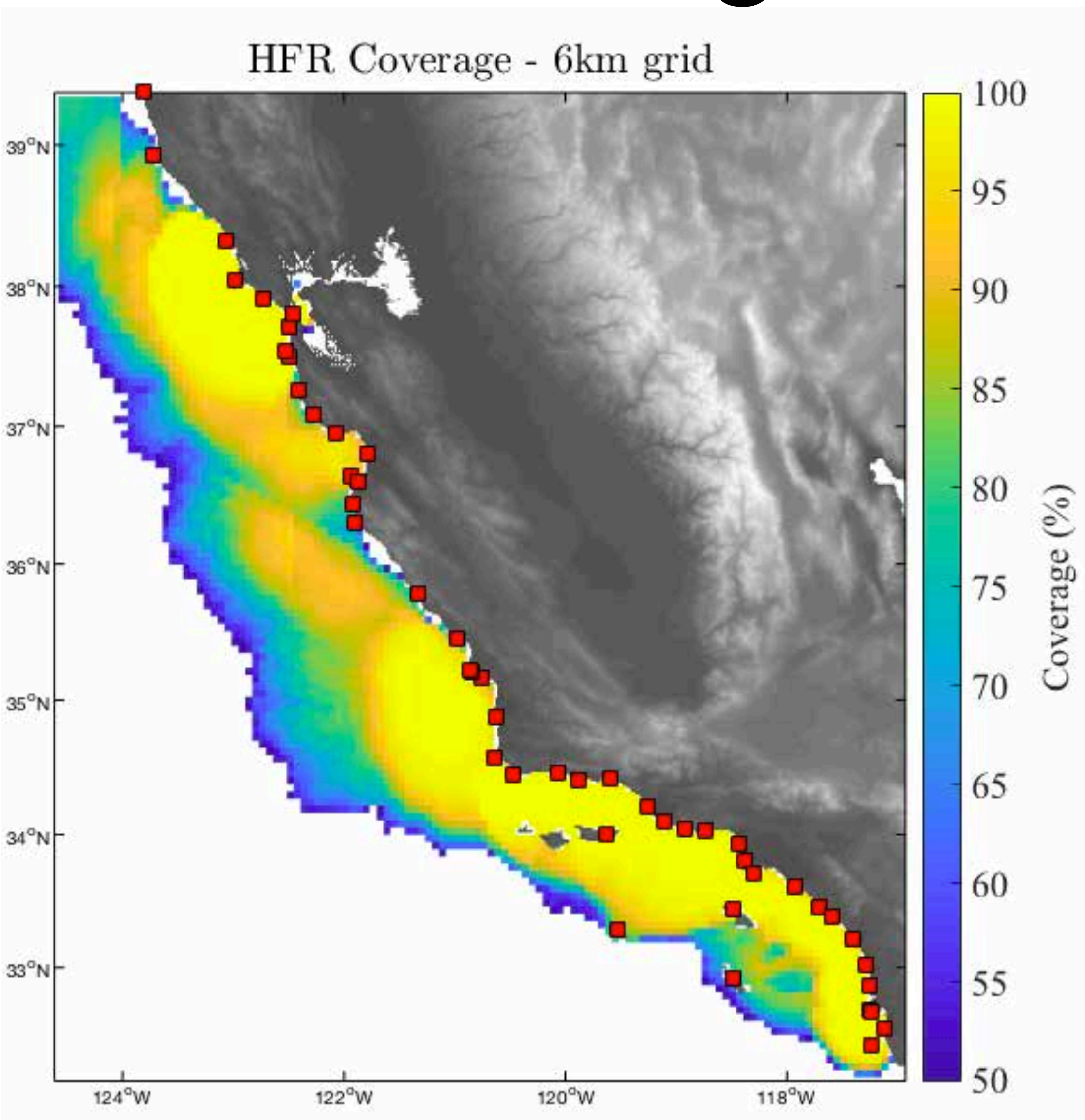
- How predictable is the internal tide?

- Low frequency processes, especially the annual cycle, seem to modulate the tidal signal.



- Understanding smaller-scale effects on currents will be imperative for SWOT, due to its unprecedented resolution.

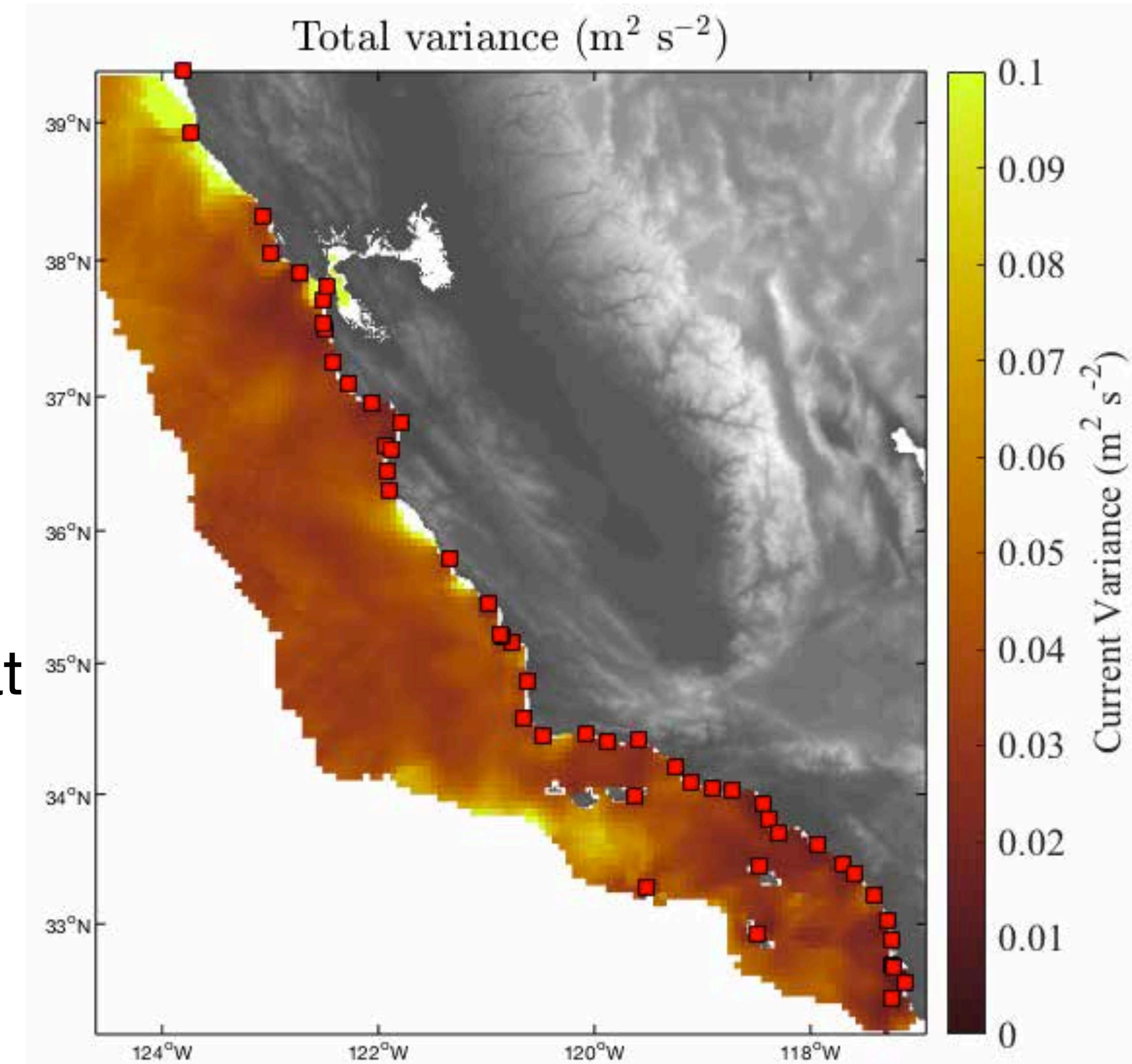
Coastal High Frequency Radar



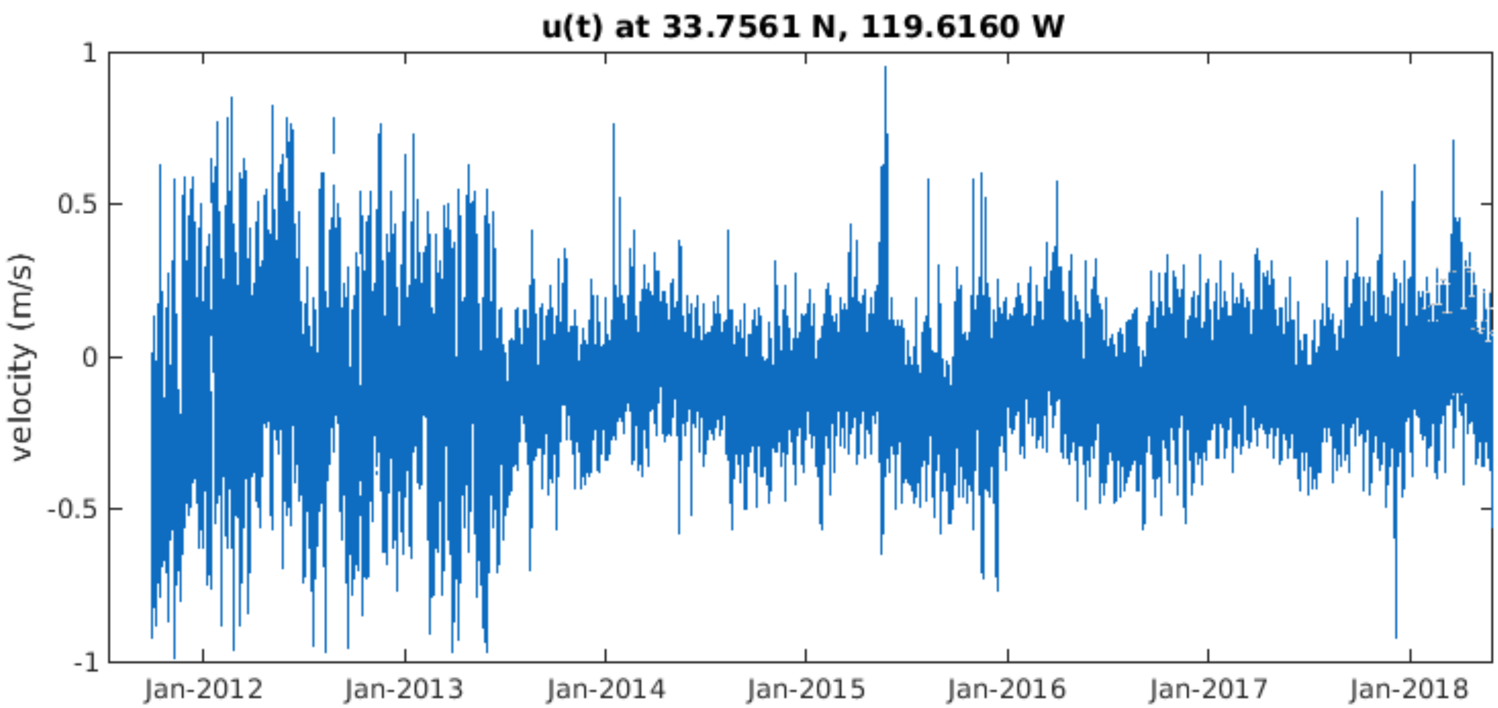
- Coastal HFR stations along the California coast. Measures surface currents using Bragg scattering, radar frequencies of 5-40 MHz.
- Displayed: 6km gridded data, 6+ years hourly sampled, good coverage ~100 km offshore; 2km and 1km data also available online
- Coverage depends on proximity to at least two antennae.
- Useful to assess predictions of internal tide

Total variance of current field

- Uncertainties are sensitive to the distance from antennae, may be unreliable far away or at poor angles.



Sample time series

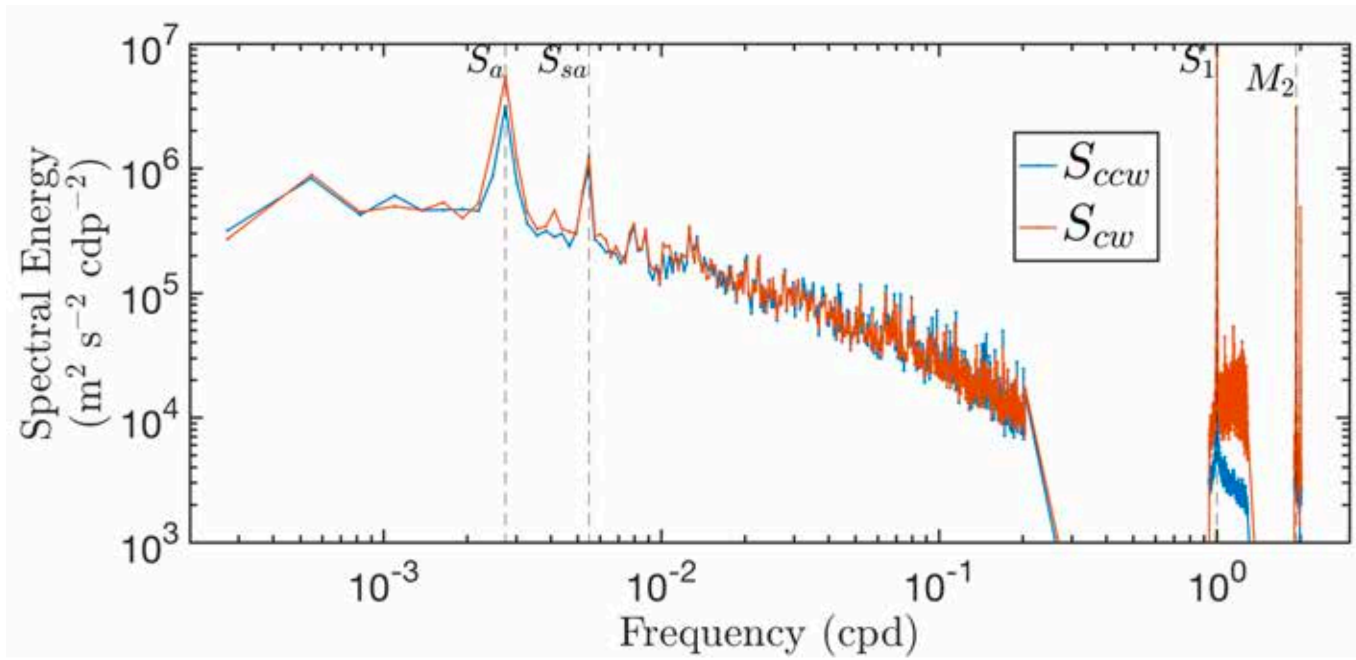


- Note underlying annual cycle.
- Anomalous observations need to be considered (e.g. antenna upgrade, storms)

Methods overview

- Harmonic analysis of tidal constituents and nearby frequencies to quantify modulation. Account for strong low frequencies and forced peaks.

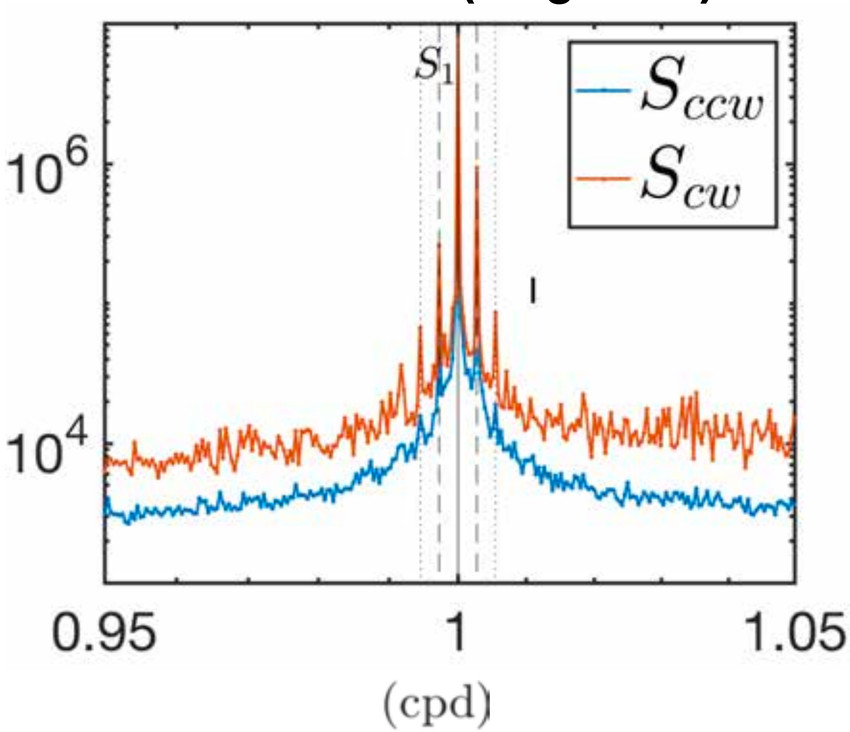
- Essentially an unconventional Fourier transform, but:
    - Can account for frequencies lower than the fundamental
    - Models exact tidal frequencies
    - Good for data with gaps



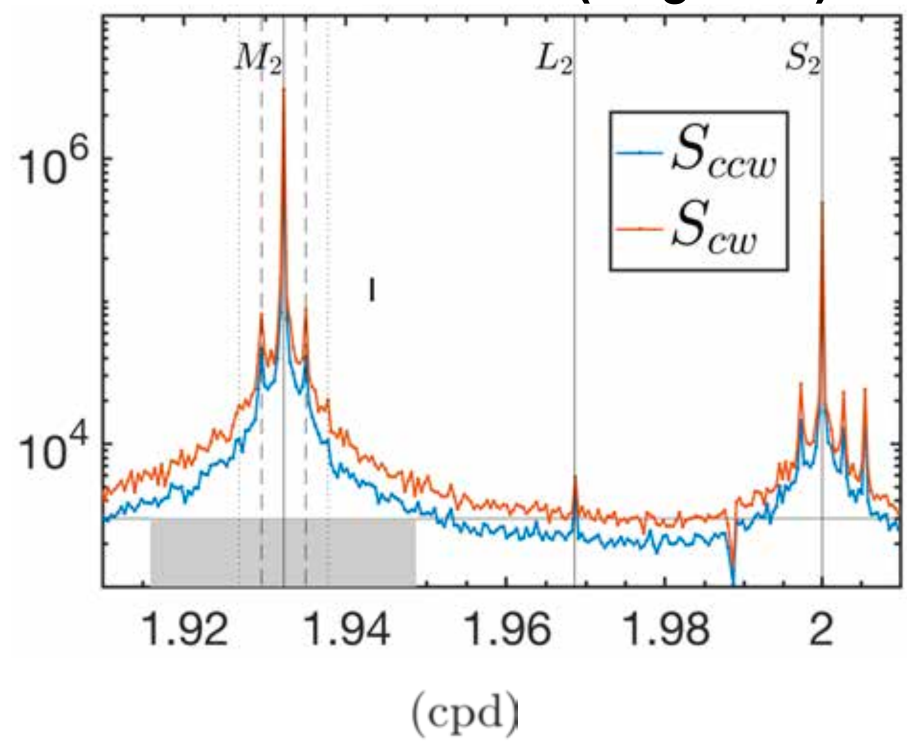
Domain-averaged: strong annual and semiannual signal in current, as well as peaks at the diurnal and semidiurnal frequencies. Near-inertial oscillations are apparent.

Rotary spectral characteristics

Diurnal band (magnified)

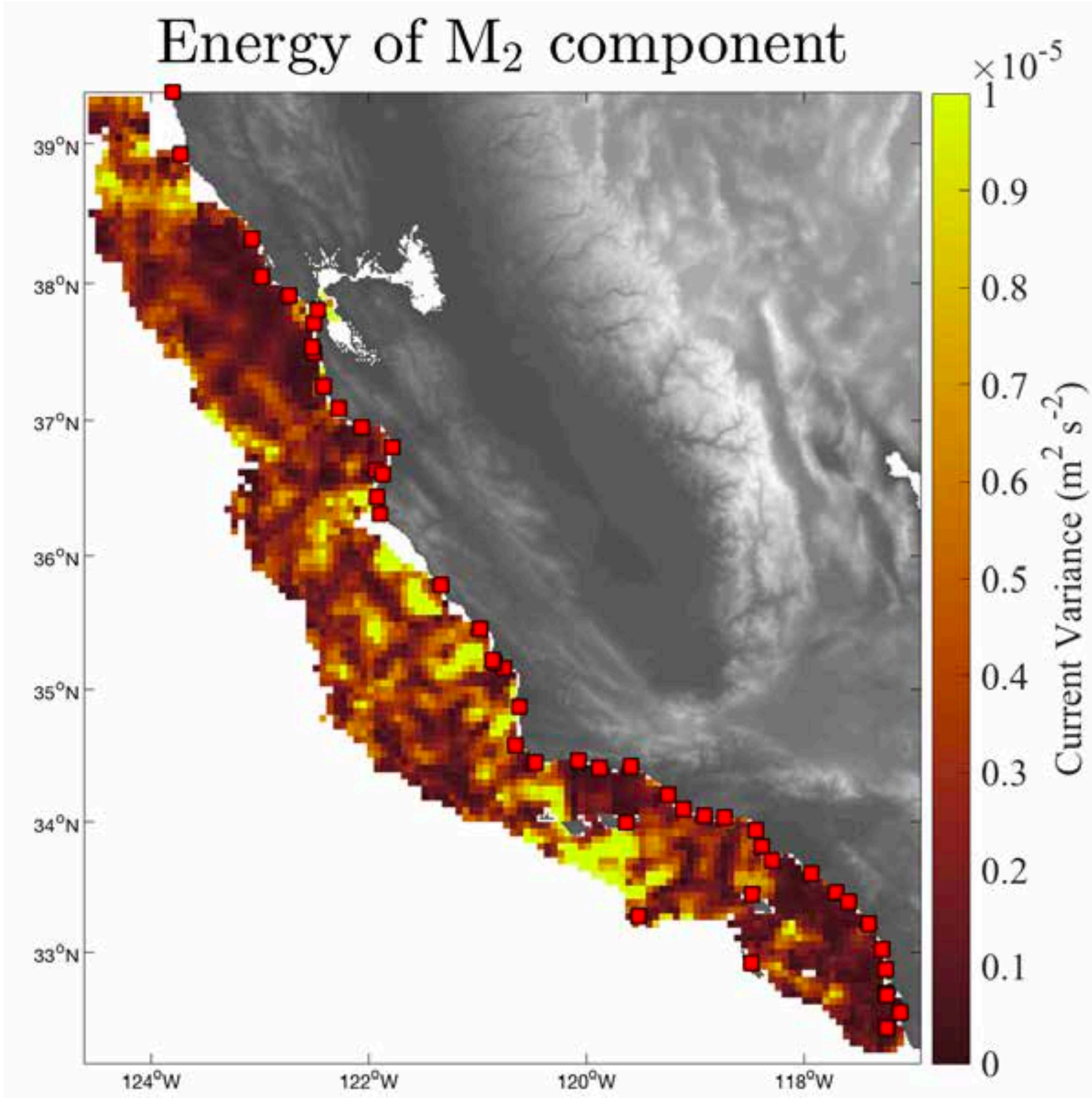


Semidiurnal band (magnified)



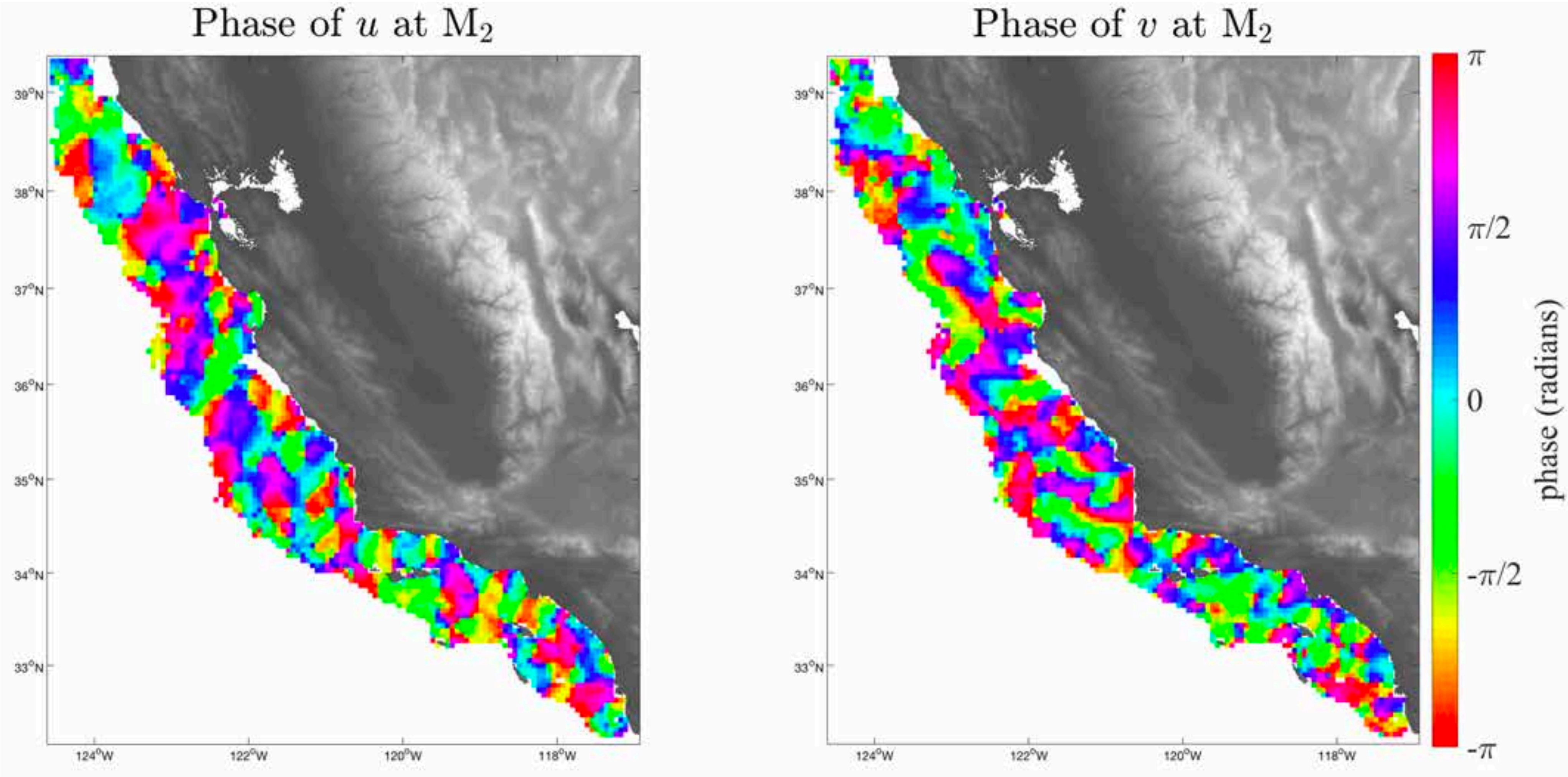
- Cusp-like behavior near tidal peaks and discrete sidebands indicate modulation. These would be poorly resolved without multiyear records.

Energy at M2



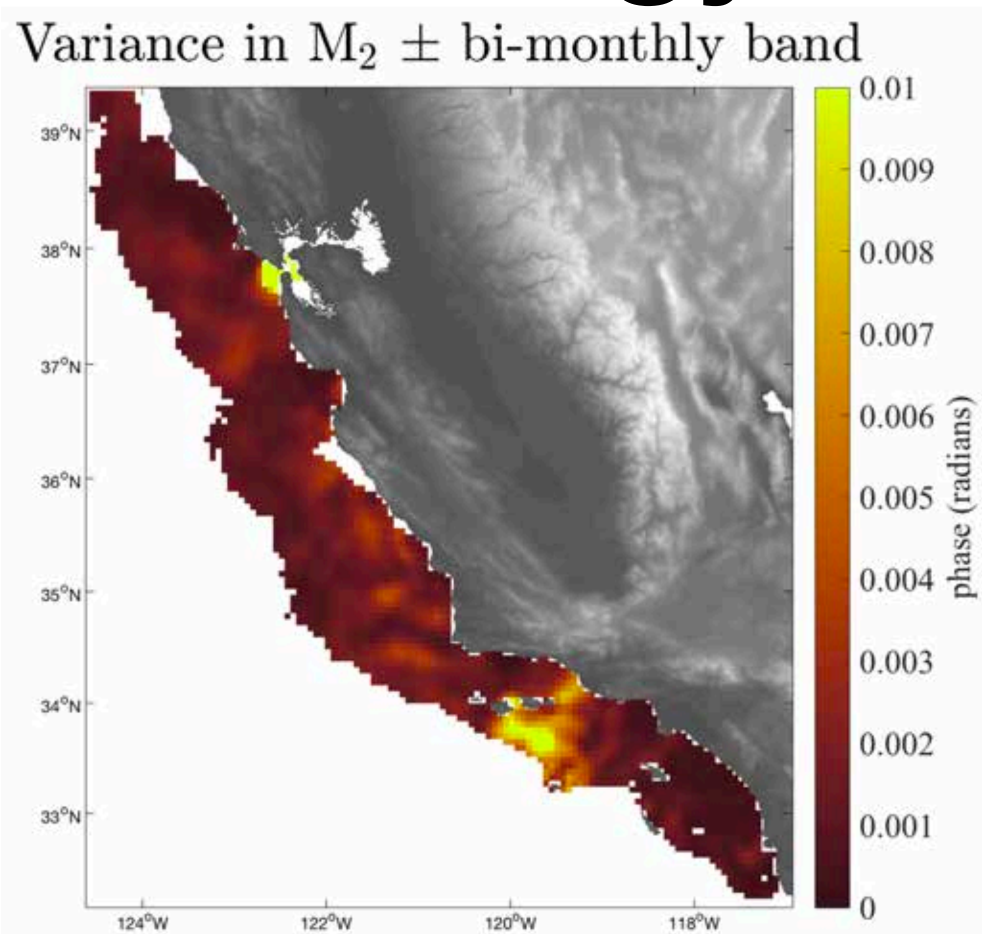
- Shows hotspots of tidal energy and spatial scale/structure

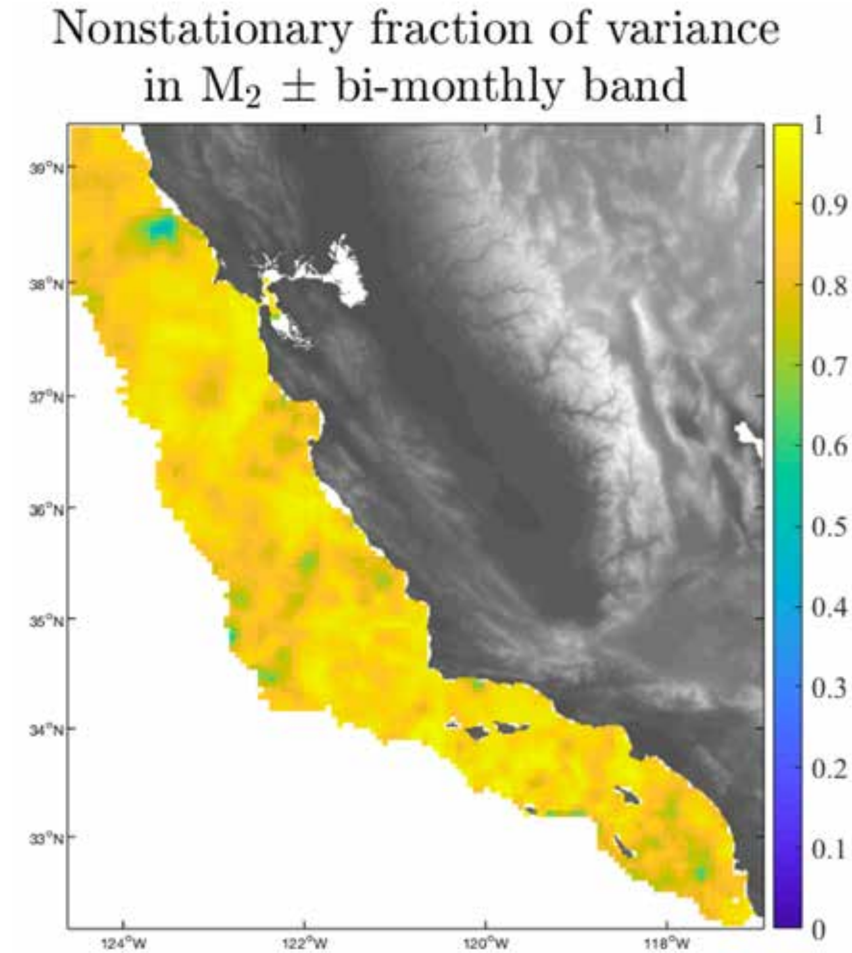
Phase structure of the M2



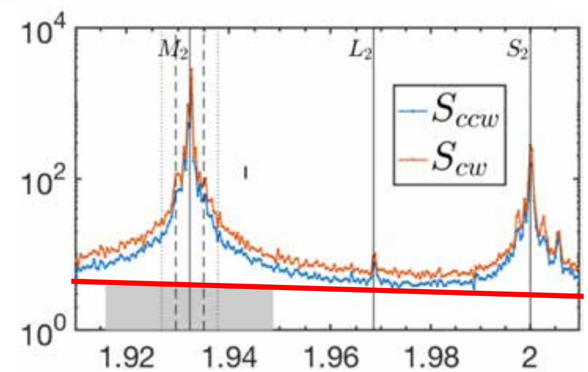
Phase of the M_2-coherent surface current as given by harmonic coefficients. The phase structure has spatial scales much shorter than those of the barotropic tide, as inferred from SSH. This implies a significant baroclinic component.

Energy in M2 Band



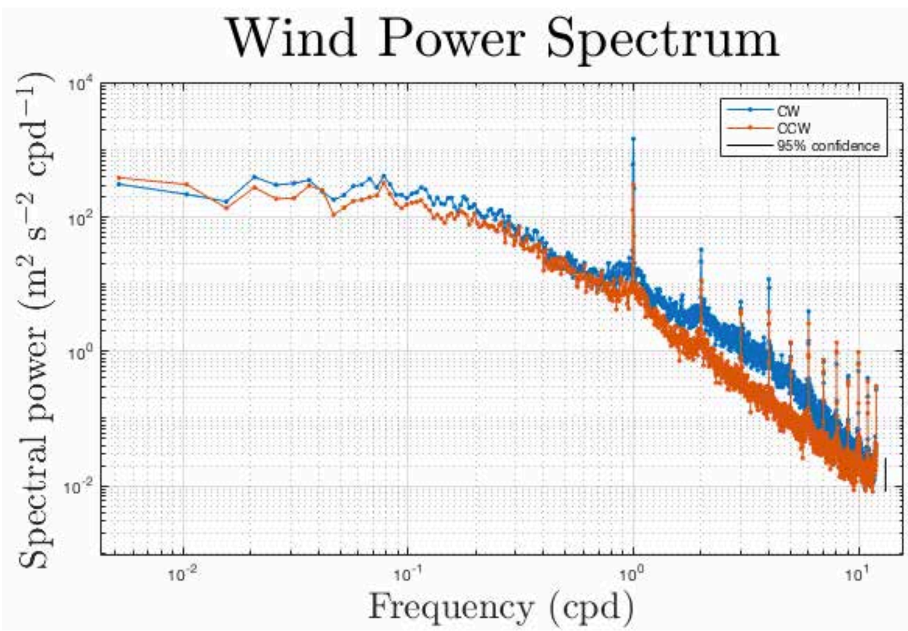


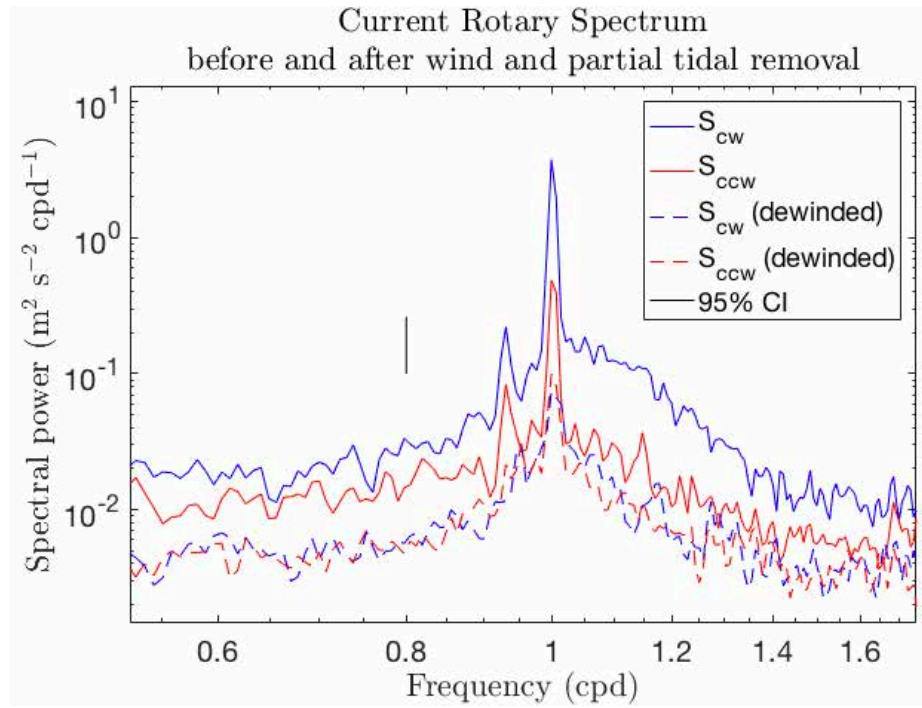
- Total energy in band is similar to the exact tidal energy, but is slightly smoother.
- Fraction of “non-stationary” energy varies spatially, but is almost always >0.7



Wind power and removal: preliminary

ERA5:





$$\vec{u}(t) = \sum_{k=0}^{M} \vec{g}(k\Delta t)\,\vec{w}(t - k\Delta t) + \vec{r}(t)$$

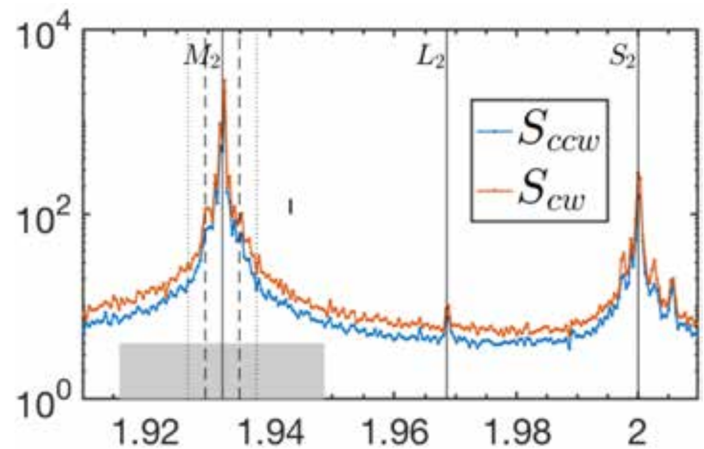
Current = lagged response*lagged wind + residual

Fontán and Cornuelle (2014)

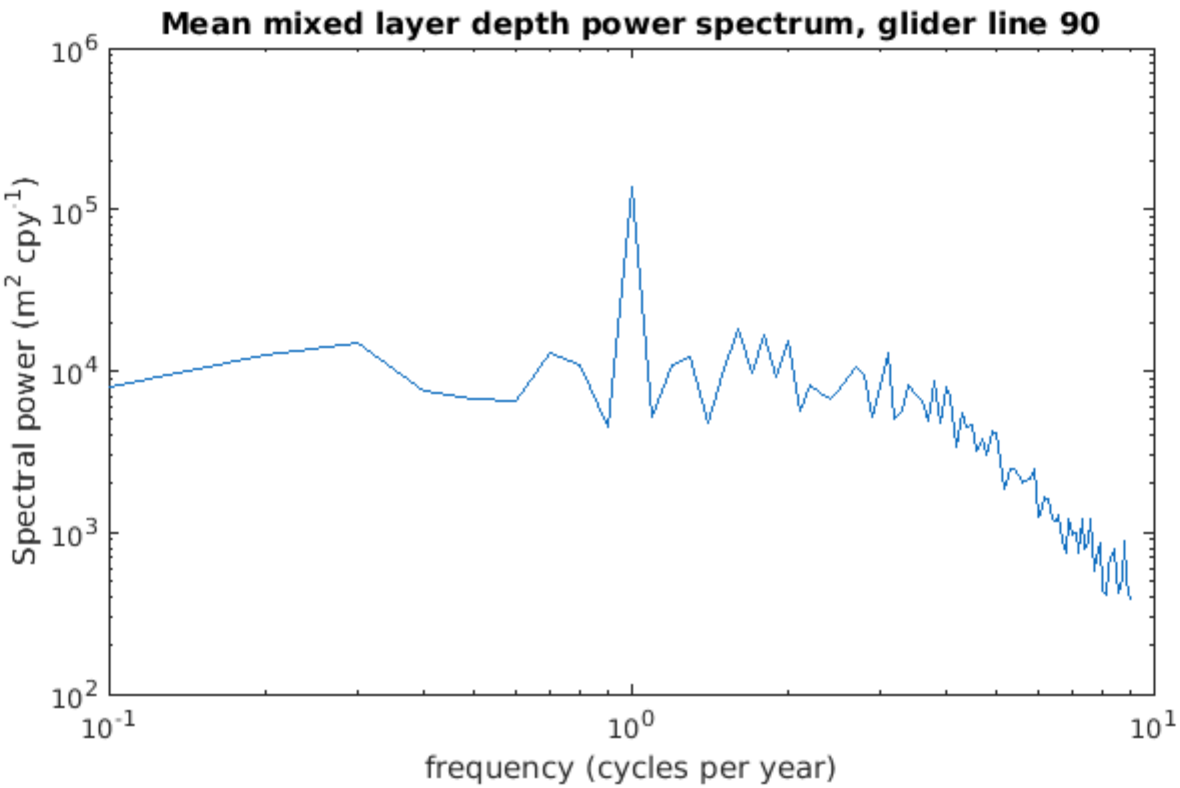
Summary

- We use harmonic analysis to decompose HFR surface current measurements to evaluate non-stationary tidal energy.
- Near-tidal energy indicates modulation of the internal tide by other processes, especially at the annual frequency.
- The spatial structure of tidal signals suggests significant baroclinicity in tidal surface currents.

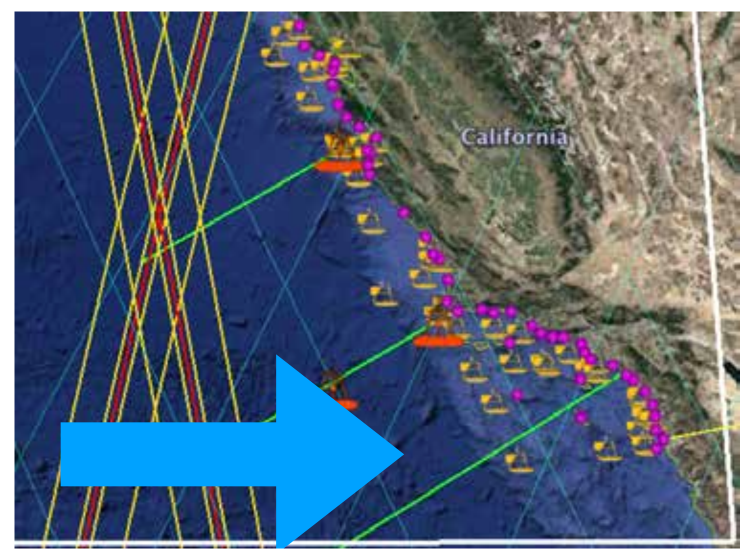
Semidiurnal band (magnified)



The Effect of Stratification



- Average power spectrum (using harmonic method) along glider line 90. Note the strong annual cycle.



Variance in M_2 ± bi-monthly band