Assessing high-wavenumber spectral slopes (and effective resolution) in new altimeter products

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Acoustic Doppler Current Profiler data: High-wavenumber currents

California Current (Chereskin et al, submitted)

Gulf Stream Oleander (Callies and Ferrari, 2013)

Eastern Tropical Pacific (Soares et al, in prep)

Kuroshio Extension and western tropical Pacific (Qiu et al, 2017)

Drake Passage (Rocha et al, 2016)
What can we learn from new altimetry?

- Jason-1/2 ALES processing for coastal applications
- AltiKa 40-Hz data release
- Sentinel-3 SAR mode
Altimeter products

- **Sentinel 3**: SAR mode altimeter, Jan 2017 to May 2018, 20 cycles, 7 ground tracks
- **AltiKa**: October 2013 to May 2016, 25 cycles 9 ground tracks
- **Jason-1/2 ALES**: January 2002-August 2016, 557 cycles, 3 ground tracks
Altimeter processing at high wavenumber

To minimize geoid contamination:
• Remove mean sea surface height from each satellite pass: \( \eta'(x) \)
• Interpolate each pass to common latitude grid: \( \eta'(x_m) \)
• Average over all passes to obtain mean: \( <\eta(x_m)> \) (but don’t use \( \eta'(x_m) \) for calculations, because interpolation is a smoothing operation)
• Interpolate mean back onto original data points: \( <\eta(x)> \)
• Subtract mean: \( \eta'(x) - <\eta(x)> \)
Altimeter processing at high wavenumber

To minimize geoid contamination:

• Remove mean sea surface height from each satellite pass: $\eta'(x)$

• Interpolate each pass to common latitude grid: $\eta'(x_m)$

• Average over all passes to obtain mean: $<\eta(x_m)>$ (but don’t use $\eta'(x_m)$ for calculations, because interpolation is a smoothing operation)

• Interpolate mean back onto original data points: $<\eta(x)>$

• Subtract mean: $\eta'(x)-<\eta(x)>$
Altimeter processing at high wavenumber

Environmental corrections available at 1 Hz

• Interpolate to 20 or 40 Hz
• Caution: if energetic relative to signal, then expect spectral ringing
Anatomy of a wavenumber spectra

Dibarboure et al, 2014
Anatomy of a wavenumber spectra

Low wavenumbers: Geostrophic flow implies $k^{-5}$ spectrum. Should be well resolved by most altimeters.

Transition from geostrophic (balanced) to ageostrophic. Spectral slope prediction unclear.

High wavenumbers: Noise floor determined by instrument.

Spectral “bump” attributed to large satellite footprints.

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Low wavenumbers: geostrophic balance

- Hanning window
- Fourier transform both components
- Helmholtz decomposition to separate rotational and divergent components

Acoustic Doppler Current Profiler data:
1993-2004, 39 cruises

Chereskin et al, submitted, 2018
Low wavenumbers: geostrophic balance

- Rotational (balanced, geostrophic) and divergent (ageostrophic) converge at 70 km.
- Scales larger than 70 expected to be in geostrophic balance.
- Slope $k^{-2}$ for scales larger than 70 km.
- Geostrophy ($u = -g/f \, \partial \eta / \partial y$) implies $k^{-2}$ slope difference between velocity and ssh spectra

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Chereskin et al, submitted, 2018
Low wavenumbers: geostrophic balance

Geostrophic regime (scales > 70 km):

Velocity spectra: $k^{-2}$
Sea surface height: $k^{-4}$

Chereskin et al., submitted, 2018
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Dibarboure et al, 2014
Unbalanced motion: 70 to 30 km

Sea surface height spectra: $k^{-2}$

Sentinel-3, Jason, and AltiKa agree within error bars

Does agreement tell us something about true sea surface height spectrum, or is it an artifact of noise floor?

Chereskin et al, submitted, 2018
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Spectral bump regime: 30 to 3 km

Altimeters diverge

**AltiKa**: Classic spectral bump, consistent with preferential response to bright spots on ocean surface.

**Jason 1-2**: ALES processing reduces bump; step change in noise level.

**Sentinel-3**: SAR altimeter falls off gently. Short record implies noisy data that is not statistically different from Jason 1-2.

Chereskin et al, submitted, 2018
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Dibarboure et al, 2014
White noise floor: Scales smaller than 2-3 km

- **AltiKa**: Lowest noise levels
- **Jason 1-2**: Highest noise
- **Sentinel-3**: White noise, consistent with low significant wave height of region. Elsewhere Sentinel-3 has shown red spectra at high wavenumbers.

Chereskin et al, submitted, 2018
White noise floor not a foregone conclusion

- Recall: Interpolation acts as a low-pass filter
- Computing spectra from interpolated data $\eta'(x_m) - \langle \eta(x_m) \rangle$ leads to red spectrum at high wavenumbers
Conclusions

- Sentinel 3, Jason-1/2 (ALES), AltiKa consistent for geostrophic regime and imbalanced (in 70-30 km)
- Sentinel 3 has no spectral bump but otherwise similar to Jason-1/2
- High-frequency noise floors: white in all cases for California Current.