Quantifying and interpreting sources of error when estimating currents from altimetry

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1. Coastal-open ocean exchange

Current variability at wavelengths shorter than 100 km (about 4 × the local Rossby radius of deformation) plays a key role in lateral exchanges in the ocean. Currents are associated with structures such as filaments in the California Current System (CCS) that are predominantly geostrophic but that are blurred out in altimetric gridded products. However, a significant fraction of this variability is not in geostrophic balance which may result in i) a poor fit between geostrophic altimetric currents and in situ currents, and ii) errors in geostrophic or cyclogeostrophic velocity estimates because of "contamination" of the sea surface height (SSH). Our goal is to identify the scales for which we can estimate geostrophic currents from altimeters and to assess contamination due to loss of balance.

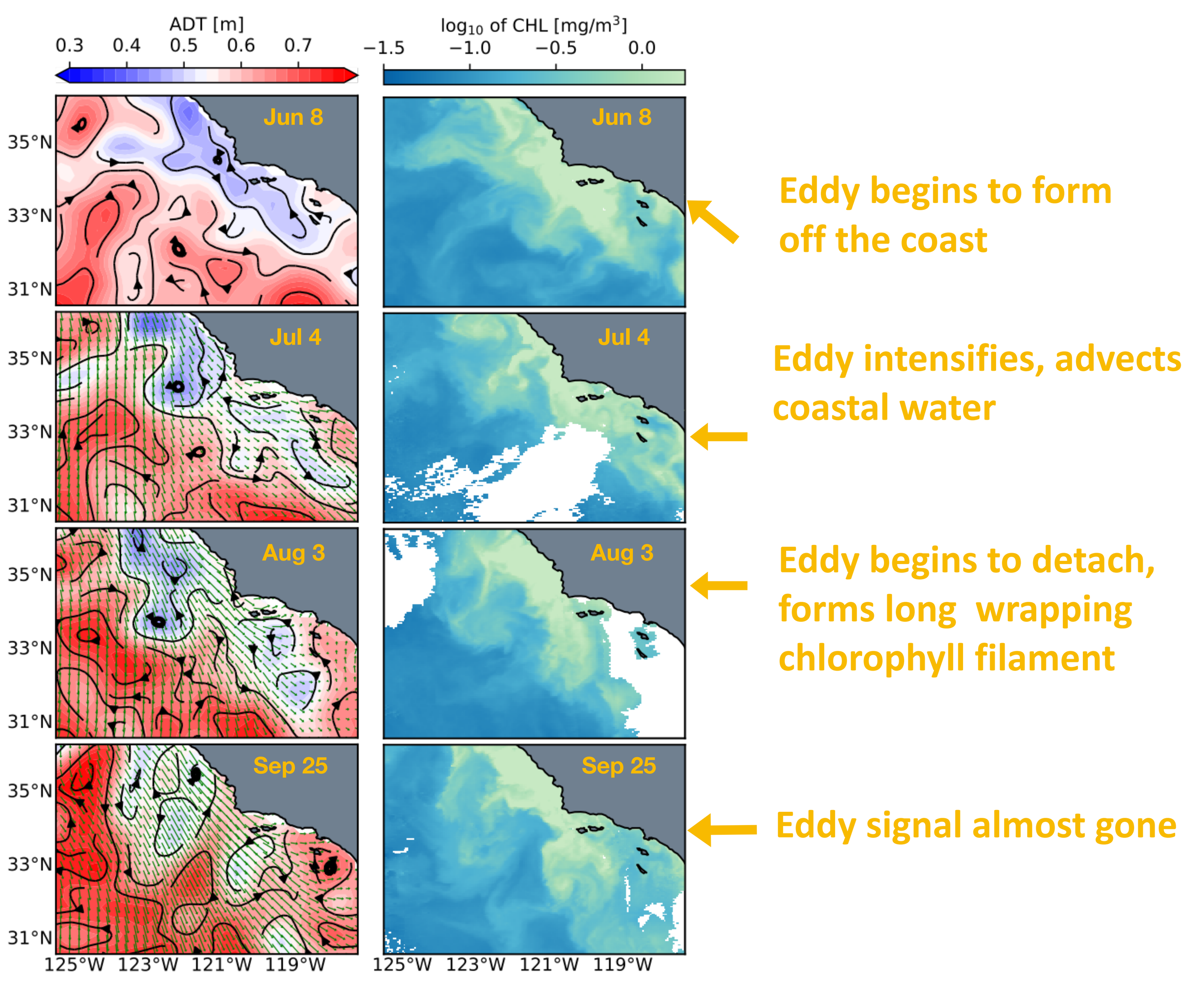

Fig. 1: Temporal evolution in summer 2020 of a coastal-open ocean exchange driven by an offshore cyclonic eddy. The right panels show the AVISO DUACS absolute dynamical topography (ADT) and associated circulation. The left panels are satellite chlorophyll images. In early August, a thin upwelling filament interacts with the eddy offshore.

2. Geostrophic velocity from High Frequency Radars (HFR)

We estimate geostrophic velocity from hourly 6-km HFR data by isolating the rotational component of the velocity field through a Helmholtz decomposition (Fig. 2), subsequently de-tiding and demodulating out the near-inertial motions, and iteratively low-pass filtering in time until the root-mean-square (RMS) Rossby number is order 10^{-2}.

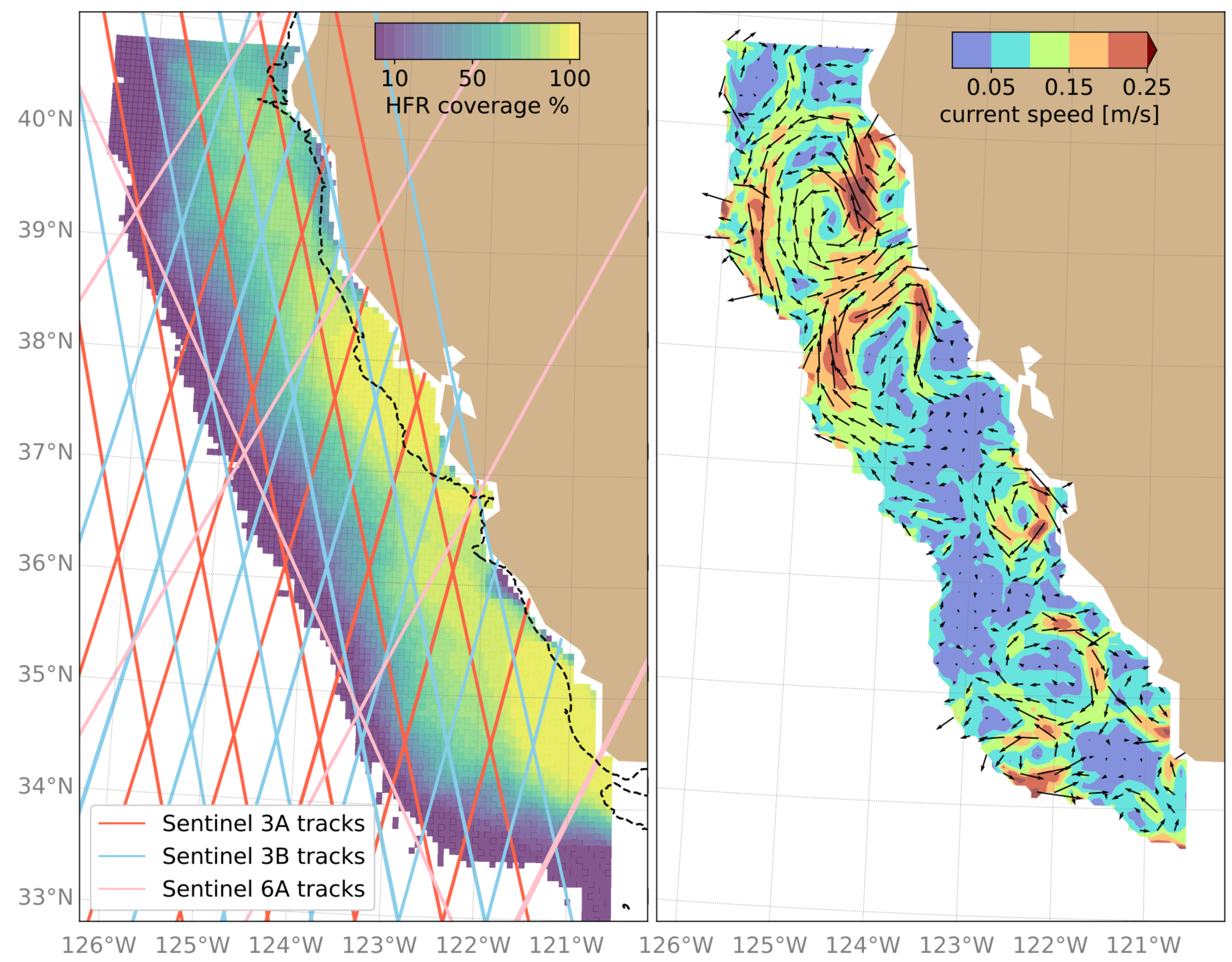

Fig. 2: HFR coverage and tracks for Sentinel 3A,B and 6A altimeters (left panel) and a snapshot of rotational currents inferred from HFR after a Helmholtz decomposition, de-tiding and demodulation (right panel).

3. Along-track geostrophic velocities from Sentinels

We obtain geostrophic velocity in the cross-track direction from Sentinel 3A, B and Sentinel 6A measurements after applying all available corrections.

- After we subtract the internal tides from HRET (Zaron, 2019), we compute the SSH slopes and geostrophic velocities using the optimal difference operator from Powell and Leben (2004) to minimize random white noise. A window length for the Powell and Leben filter of ~70 km is determined from the wave-vortex decomposition of shipboard ADCP data. A common-period mean is subtracted from both products.

- We compute the difference between the geostrophic velocity from altimetry and geostrophic velocities from HFR interpolated along-track. Because sign differences are very rare (i.e. the component directions almost always agree), RMS difference (Fig. 3 left, red bars) reveal a bias in the altimetry geostrophic current estimates.

- RMS differences normalized by the RMS currents at scales of 50-100 km are similar to those at larger scales (Fig. 3 right). While altimetry-HFR correlations are typically above 0.80, the normalized RMSs indicate general poor skill (>1).

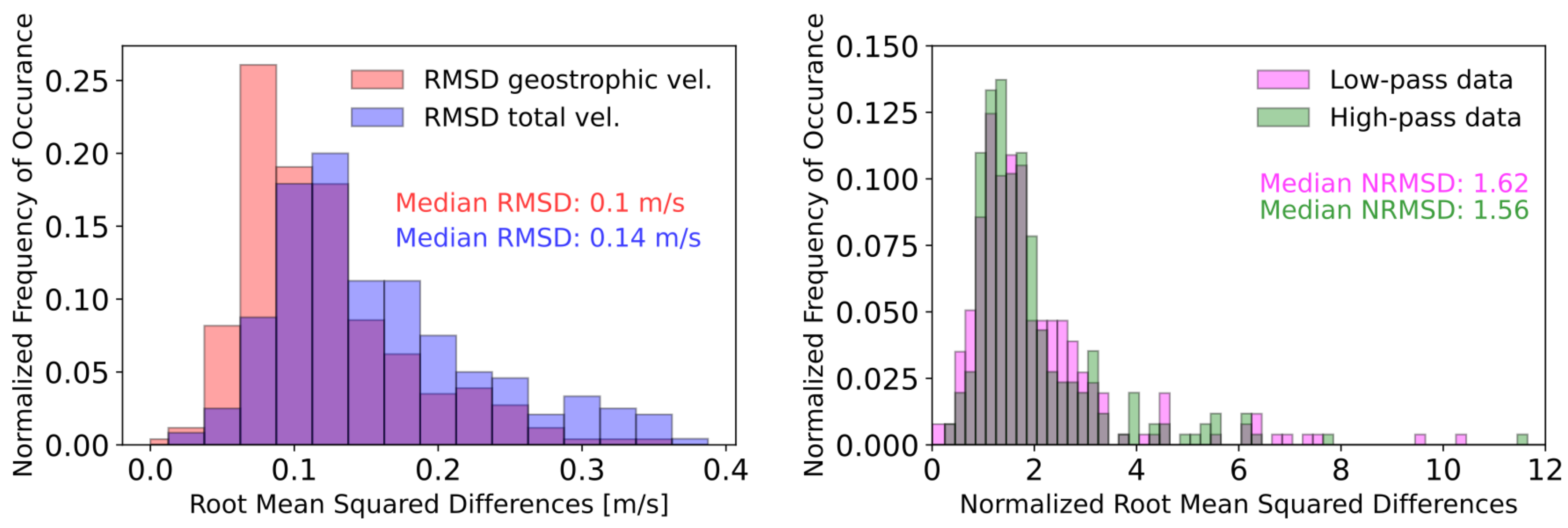

Fig. 3: (left) Histograms of the root-mean-square differences (RMSD) between along-track altimetry derived currents and HFR. Binning RMSDs calculated along-track for various HFR-overlapping tracks (Fig. 2 left) and multiple cycles. (right) Histogram of geostrophic currents RMSD normalized by the RMS of HFR current for large-scale (low-passed 100 km) and small-scale (band-passed 50-100 km) flows.

Key points

- **Joint analysis of HFR and along-track altimetry indicate that non-geostrophic processes and correlated residual errors contaminate SSH measurements, degrading geostrophic velocity estimate at all scales observed here.**
- **These preliminary results suggest that utilization of in situ dynamical information could improve the geostrophic velocity estimation for sub-100 km scales in the CCS. While further optimization of filter window scale and, for HFR, filter time scales, is possible, our next effort will be focused on reducing SSH contamination. SWOT data may be useful in this effort.**
- **Ongoing work with HFR and ADCP observations will provide tools to better quantify the improvement in velocity estimation and the impact on lateral heat fluxes.**

4. Loss of geostrophic balance

In situ data indicate that ageostrophic currents remain significant up to 200 km scales and 30-day periods (Fig. 4). RMS differences increase when using total observed HFR currents (Fig. 3, left, blue colors), but by a smaller fraction than the relative contribution of the ageostrophic flow to the total current.

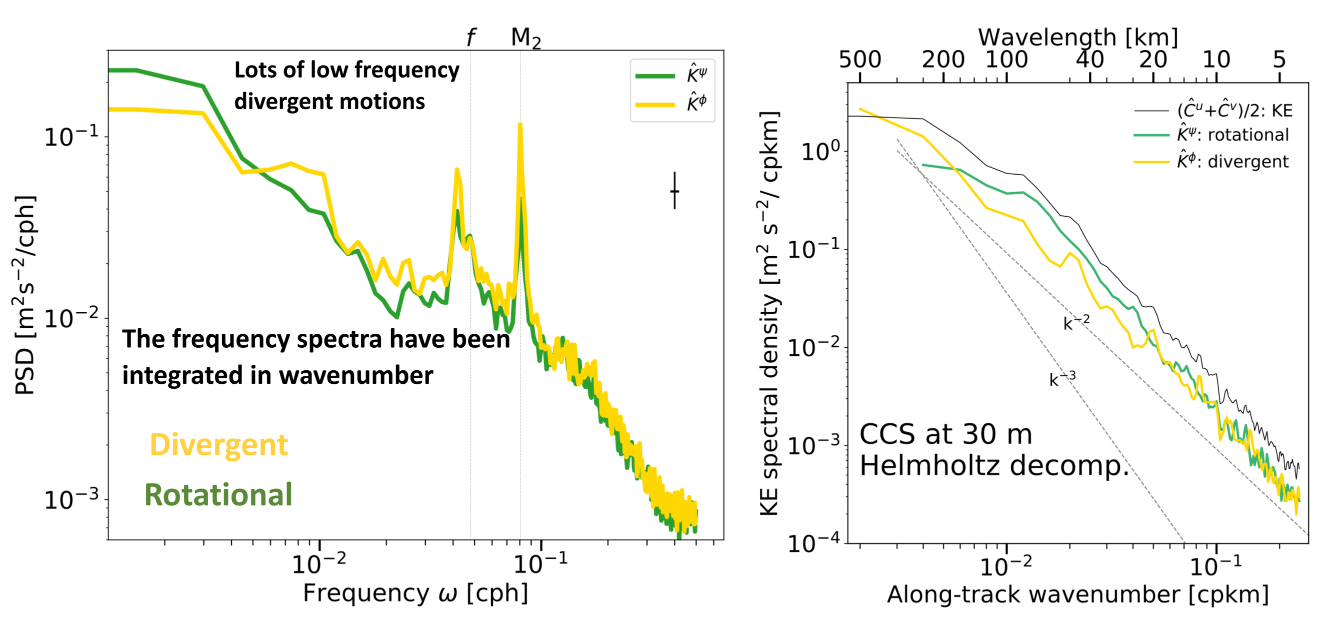

Fig. 4: Frequency spectrum of rotational and divergent velocities from HFR averaged over the domain. Wavenumber spectrum of rotational and divergent kinetic energy from shipboard ADCP measurements within the HFR and altimetry domain.

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Powell, Brian S., and Robert R. Leben, An Optimal Filter for Geostrophic Mesoscale Currents from Along-Track Satellite Altimetry. *Journal of Atmospheric and Oceanic Technology*, **21**(10), 2004, 1633–42, https://doi.org/10.1175/1520-0426(2004)021<1633:AOFFGM>2.0.CO;2.

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