Wave-current Interactions in the California Current Region: Potential Implications for SWOT

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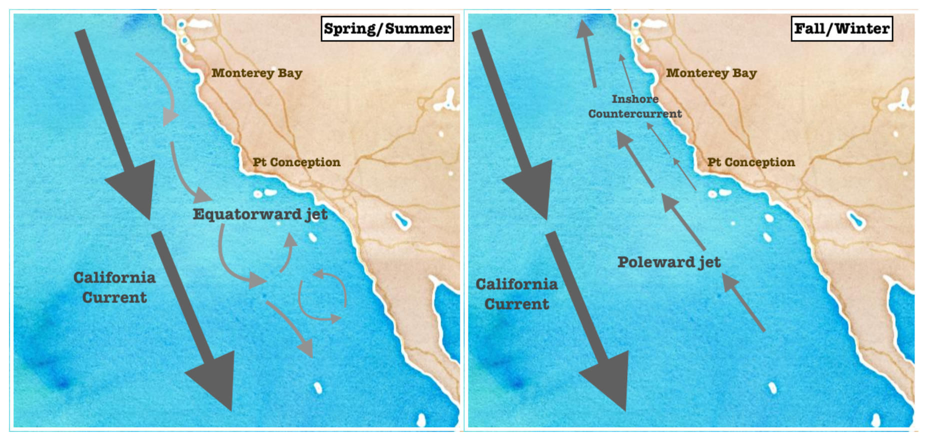
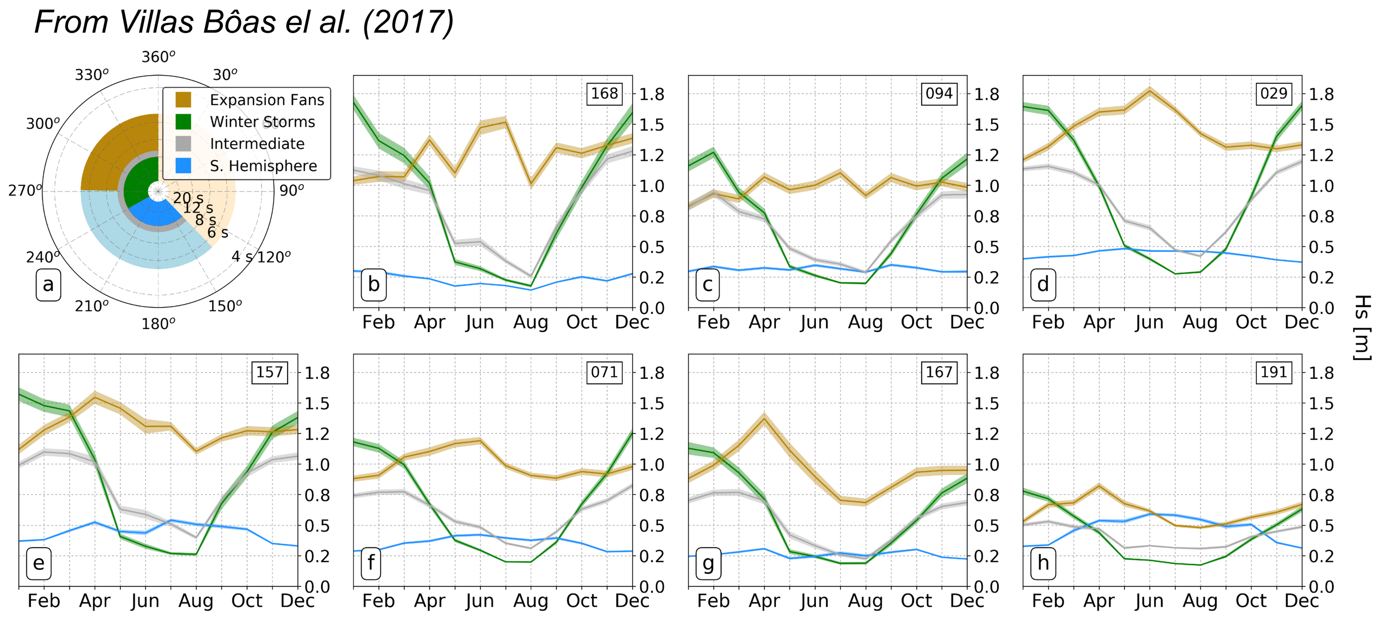
Background

Ocean **currents** modulate the **surface wave** field. These modulations have been studied for large-scale currents such as the Gulf Stream, but are **less explored** for **weak systems**, such as the California Current System (CCS). The CCS is distinguished by a broad equatorward flow offshore of 150 km. During spring and summer, a narrow equartorward jet develops inshore of 150 km as a result from coastal upwelling, enhancing **mesoscale and submesoscale activity.**



From Villas Bôas el al. (2017)



The wave field off the California coast is also characterized by strong seasonal variability. A particular aspect of this region is the influence of **regional-scale high wind events** that occur during spring and summer. These alongshore "expansion fan" winds are known to be a major forcing for waves off central/northern California, leading to relatively **short-period waves (8-10 s)** that come predominantly from the **north-northwest**; however, whether the variability of the California Current modulates the wave field remains unclear. In this context, some questions that we aim to address include:

- How do **surface waves** respond to the v**ariability of the California Current?**
- Does the **seasonality** of the **California Current** translate to **modulations** of the surface **wave** field?
- How does **including** the effects of **currents** in the wave model **improve model** comparisons against buoys and altimetry?

Data, methods, and tools

The WaveWatch III (WW3) framework:

WaveWatch III solves the action balance equation:

$$\frac{D}{Dt}N(k,\theta) = \frac{S}{\sigma}$$

where the total derivative (moving with a wave component) operates in both physical and spectral space. Currents affect the waves in WW3 by changing:

1. The **velocity** by which the **wave action is advected**:

$$\mathbf{c_g} = \mathbf{c'_g} + \mathbf{U}$$

2. The **wavenumber** of the waves:

$$\frac{d\mathbf{k}}{dt} = -\nabla(\mathbf{k}\cdot\mathbf{U}).$$

3. The **direction** of propagation of the waves **(refraction)**:

$$\frac{d\theta}{dt} = -\frac{1}{k}\hat{\mathbf{n}}\cdot\nabla(\mathbf{k}\cdot\mathbf{U})$$

4. The relative speed between the wind and the sea surface

WaveWAtch III Configuration

All runs	
Number of Frequencies	32
Number of Directions	24
Spatial Grid resolution	1/48º
Source Terms	Ardhuin et al (2010)
Wind Forcing	ECMWF 1/4º, hourly
Open boundary conditions	Global 1/2º
Experiment name	**Current forcing**
Control	No current
Globcurrent (geostrophic +Ekman)	1/3º, 3-hourly
CASE	1/16º, hourly
LLC4320	1/48º, hourly

Surface Currents:

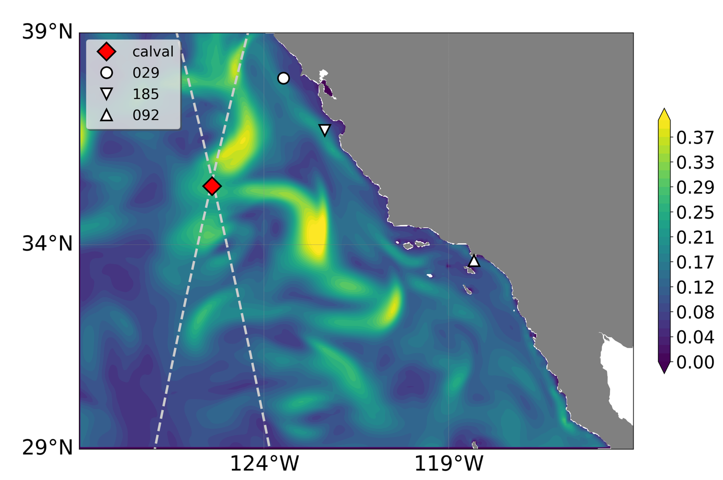
1. Globcurrent: combined geostrophic (from multi-mission altimetry) and Ekman currents (empirical from winds).

2. The California Current State Estimate (CASE): Regional configuration of the ECCO assimilation version of the MITgcm with 72 vertical levels and a horizontal resolution of 1/16 km. It assimilates glider, satellite SST, satellite SSH, XBTs, and Argo, and it is forced by The North American Mesoscale (NAM) winds. We use surface velocities for the year of 2012.

3. The LLC4320 MITgcm: A latitude-longitude-polar cap (LLC) configuration of the MITgcm with surface boundary conditions from the ECMWF. The LLC4320 simulation span from October 2011 to October 2012 and includes tidal forcing . We use surface velocities with 1/48º spatial resolution, which have also been used by Ardhuin et. al (2017)

Wave Buoys:

To interpret and validate the wave model we use significant wave height, peak period, and peak direction from The Coastal Data Information Program (CDIP) buoys.



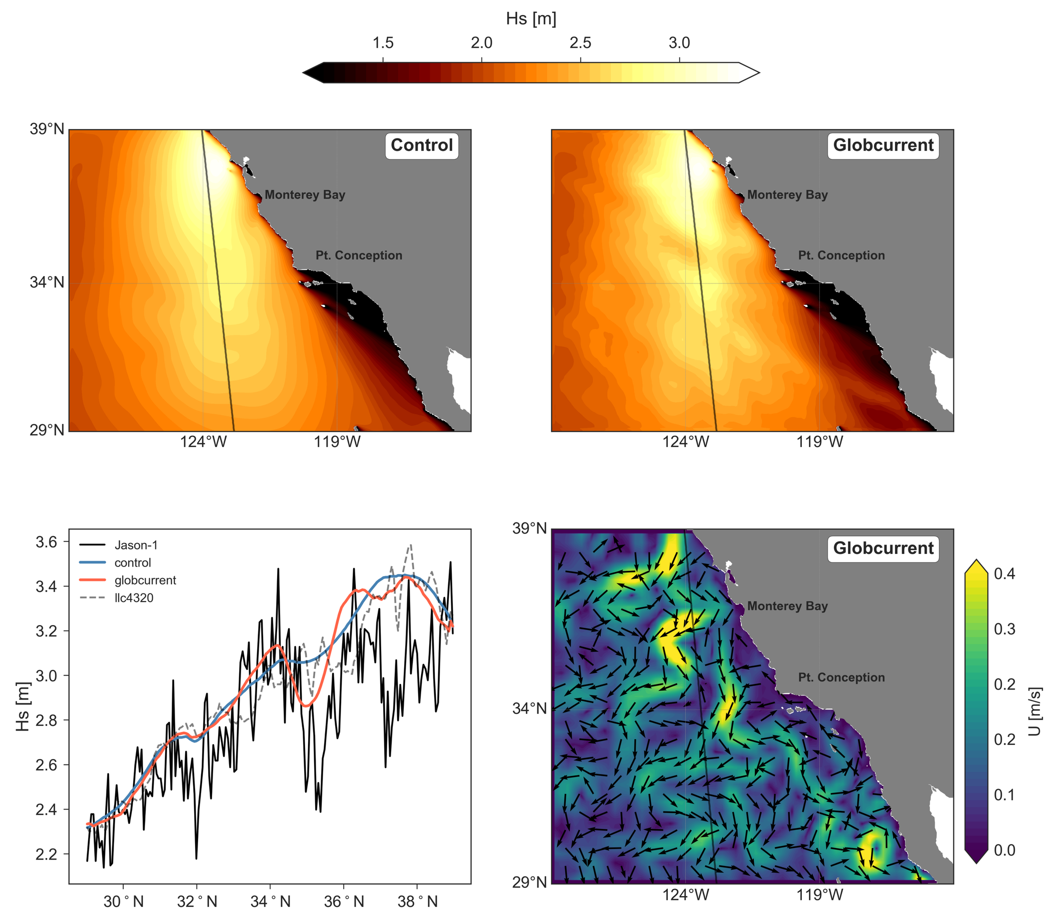
Location of selected buoys (white), potential calibration and validation site for SWOT (red diamond), and the nadir calibration and validation orbit ground track of SWOT. The background is the June 2012 surface speed from CASE.

Preliminary Results

On June 1st, 2012 the surface velocity field was characterized by **meanders and eddies** having horizontal scales of **100-300 km** and maximum **surface velocities of 45 cm/s** (bottom right).The control run of WW3 (top left) produces a smooth field of significant wave height (H_s) for that day, while the runs with currents (top right) have significantly more spatial structure.

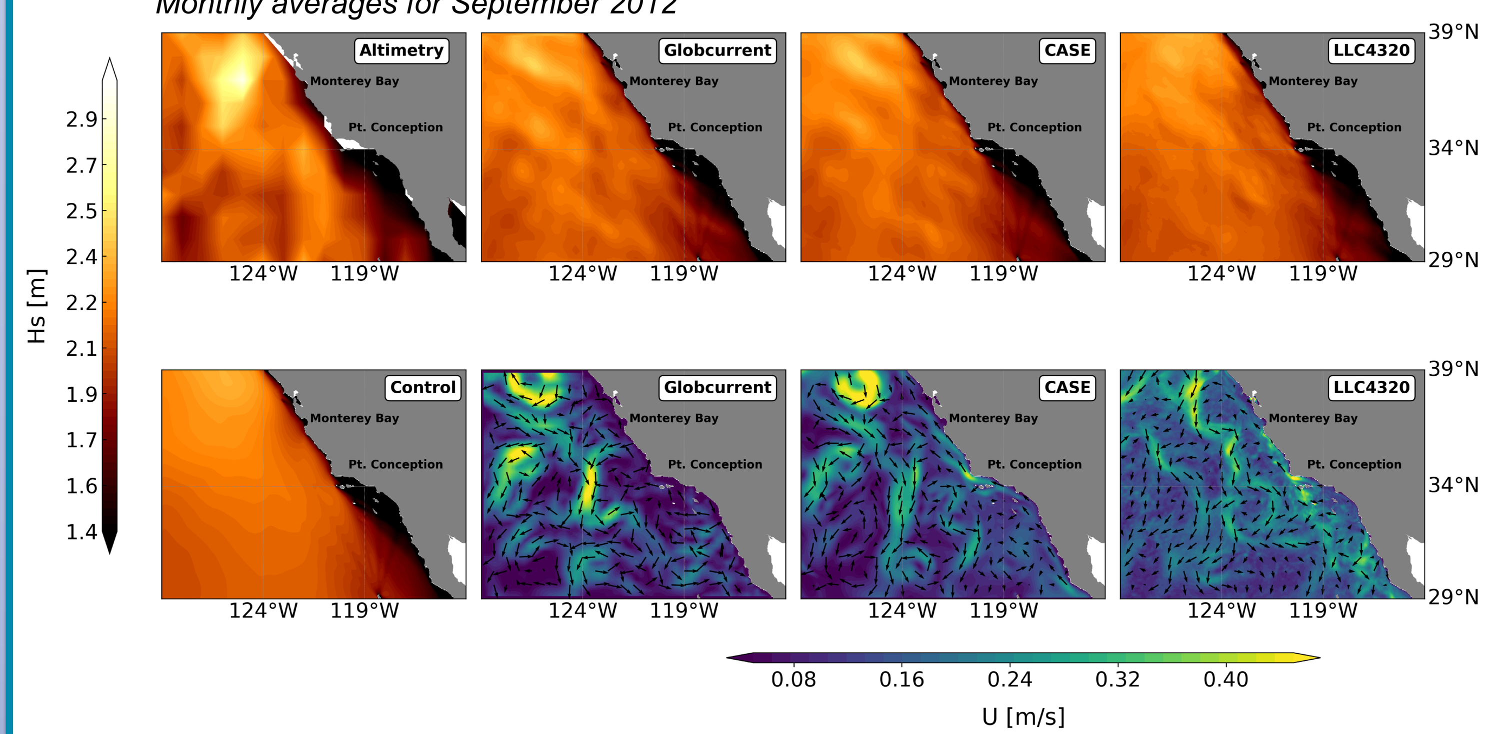
Waves from the **northwest** encounter the southward flowing meander at ~36ºN and have **their amplitude reduced via conservation of wave action**. This effect can be observed in the map of H_s from the model with currents, as well as in the measurements along a Jason-1 track (bottom left).

Romero et al. (2017) reported **gradients of up to 30%** in H_s across an upwelling jet off Bodega Bay, which are comparable to the gradients that we observe along the Jason-1 track in the bottom left panel.



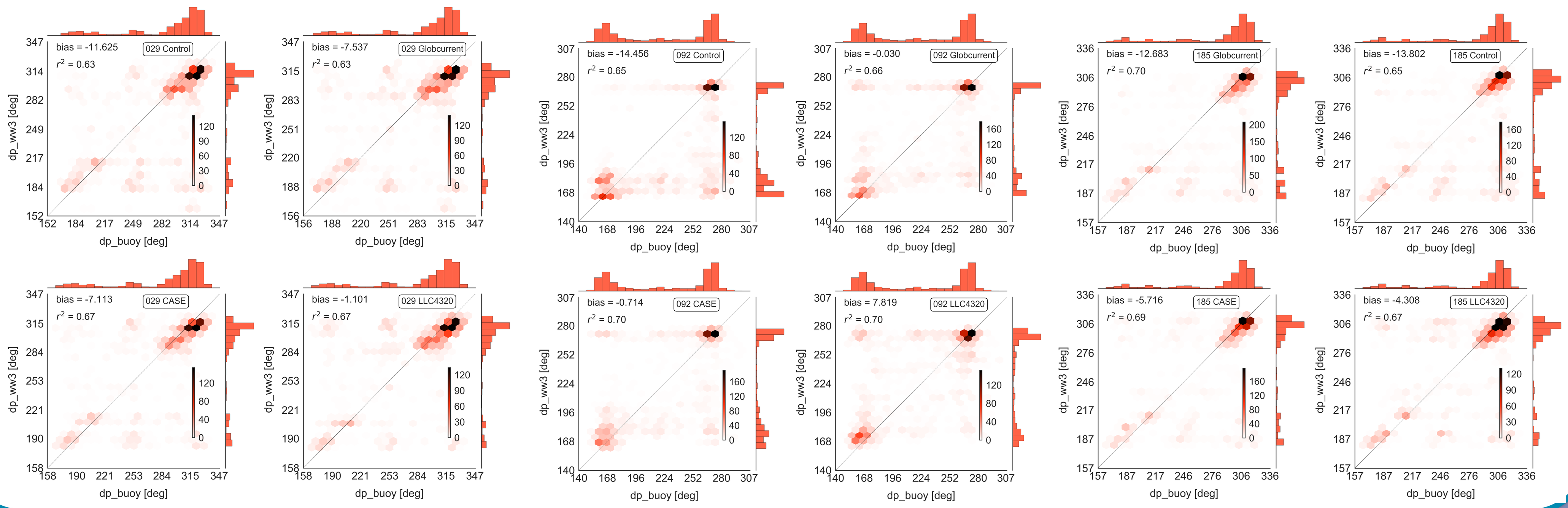
Case study for June 1st, 2012

Monthly averages for September 2012



A monthly average for the September 2012 surface velocities reveals a persistent and coherent anticyclonic eddy in the north portion of the domain. Its signature projects onto the H_s maps as a region of higher H_s near the western side of the eddy and lower on the eastern side.

Comparisons of peak direction from all WW3 runs with measurements from CDIP wave buoys suggests that allowing for wave-current interactions in WW3 can significantly improve modeled direction.



Final Remarks

- **The variability of the California Current affects the surface wave field** on both synoptic and seasonal scales. Here we have focused on significant wave height, but initial comparisons with wave buoy measurements suggest that this modulation can also be observed in other bulk parameters.
- Including the effect of surface currents on our wave model **improves correlations** between model and wave buoy **peak direction** and **reduces** the respective **biases**. Here we analyze two months of data. Future work will extend the time series and validate WW3 against all available wave buoys along the California coast.
- As satellite altimeters evolve towards resolving finer scales, knowing the wave field with precision may help the interpretation of **sea surface height** measurements at **high wavenumbers** and frequencies, which has particular **relevance for the planning of the Surface Water and Ocean Topography (SWOT)** mission.

References

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