Strongly modulated surface waves at a submesoscale front

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Surface waves interacting with a submesoscale front near Kaena Point, O'ahu, HI

Surface waves modulate the fluxes of mass, momentum and energy between the air and sea. The interactions can be pronounced at submesoscale currents, where the wave field may be strongly modulated, leading to enhanced wave steepening and breaking.

We present novel high resolution airborne remote sensing and in-situ observations of wave–current interaction at a submesoscale front near the island of O'ahu, Hawaii.

Figure 1. Enhanced deep-water wave breaking along a submesoscale ocean front, as recorded by a handheld digital single-lens reflex (DSLR) camera on 17 April 2018 near Kaena Point, O'ahu, Hawaii. Notice the abrupt change between non-breaking and breaking waves. The horizontal and vertical scales of this photograph are a few hundred meters.

Airborne observations

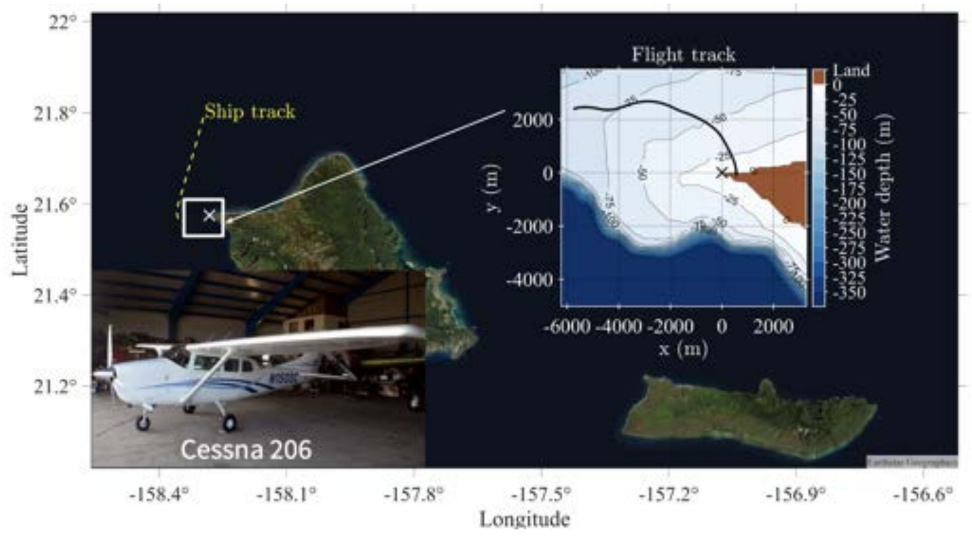


Figure 2. Modular Aerial Sensing System (MASS: Melville et al. 2016) uses lidar to capture high resolution observations of the surf wave topography and visible imagery is used to compute wave breaking statistics. The flight track and ship track are shown in the image.

In-situ observations near Kaena Point

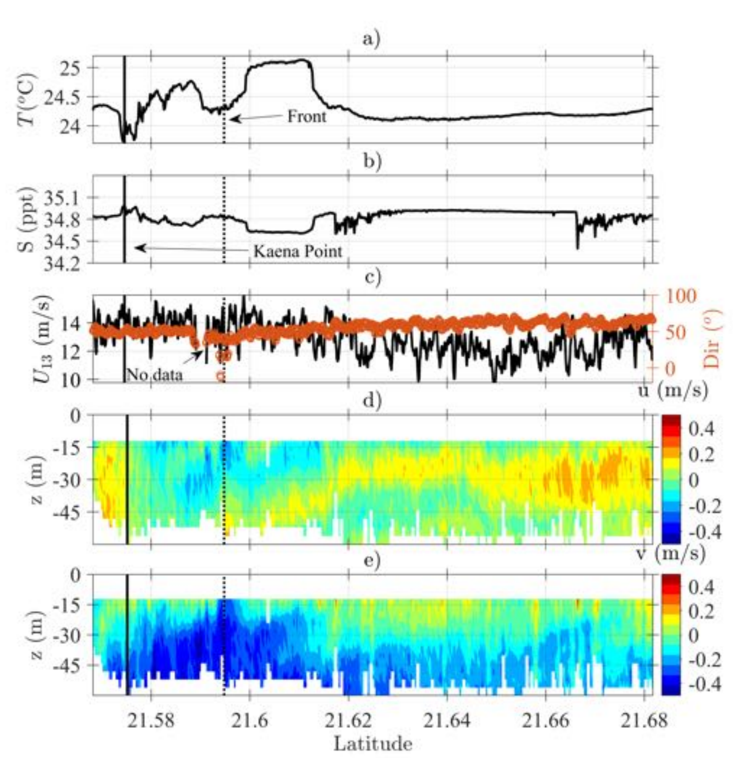
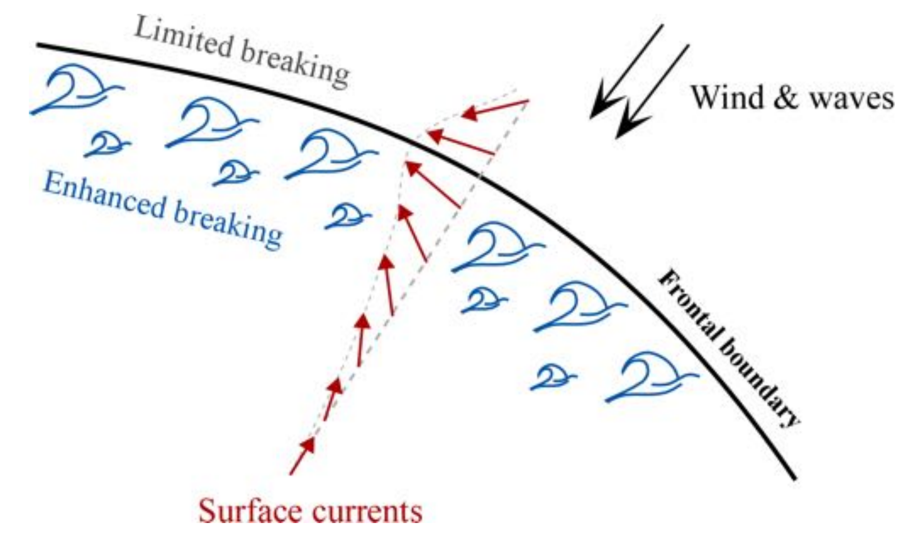


Figure 3. Ocean and wind data measured by the R/V Ka'imikai-O-Kanaloa, as a function of latitude. The vertical solid line indicates position of Kaena Point (21.575° latitude), and the dashed vertical line indicates the position of the observed submesoscale current.

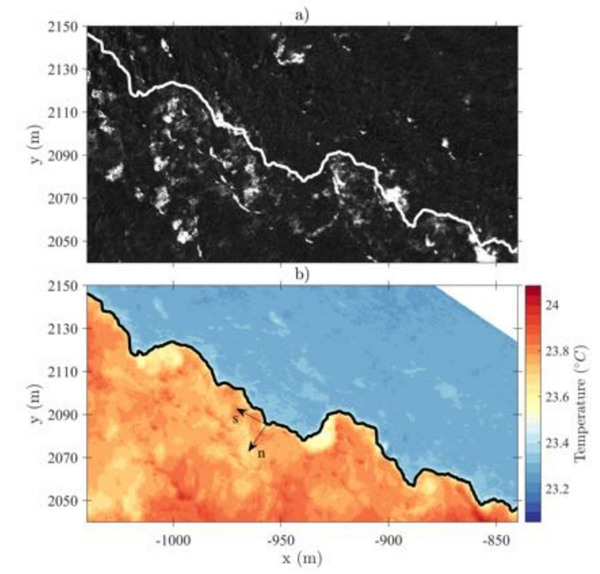
Wave-current interaction

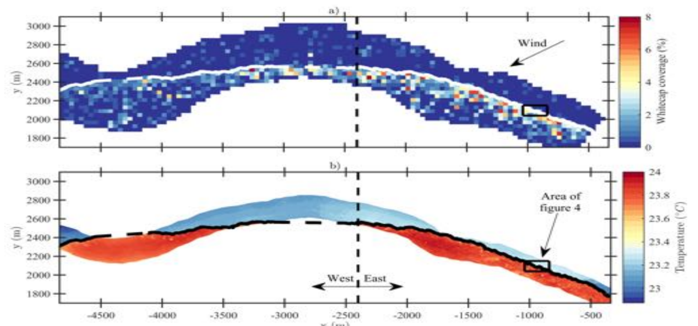
The in-situ and remote observations imply that waves steepen and break due to their interaction with the opposing currents.



A rational reference frame for wave-current interactions at a front

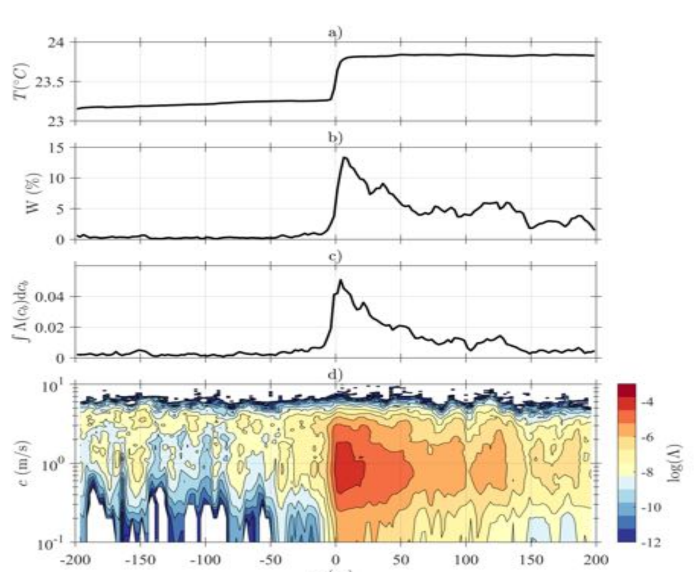
We define a tangent-normal coordinate system as (s, n), respectively. We see abrupt changes in white cap coverage and sea surface temperature as a function of distance from the front.

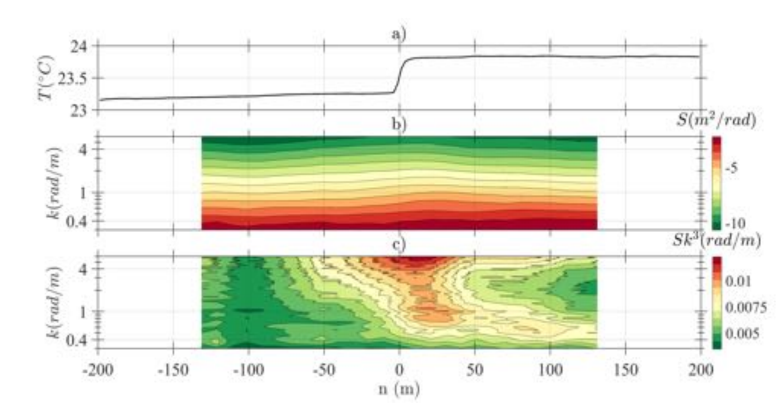




Airborne observations of rapid changes of waves across the front

The wave breaking (left) and (right) wave statistics as a function of the distance normal to the front. We see white cap coverage increases abruptly at the front. Overall, the wave breaking statistics (Phillips 1985) and its associated moments are strongly enhanced at the front. Similarly, the waves steepen at the front, with shorter waves increasing in energy.

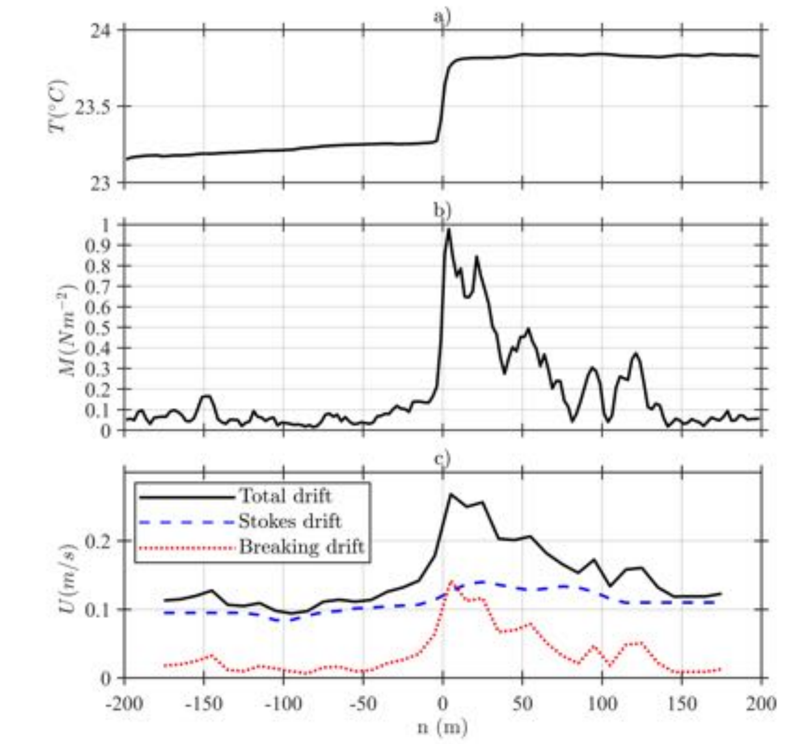




This wave modulation is consistent with the interactions observed and modelled in Lenain and Pizzo (2021), where surface waves were incident on the currents induced by an internal wave train. There, WKB theory captured the bulk scale modulations, which were most pronounced for shorter surface gravity waves.

Rapid modulation of wave and wave breaking induced stress across the front

Using the wave breaking statistic $\Lambda(c)$, we can estimate the momentum flux M to the water column from the wave field, which increases by an order of magnitude near the front. Using the formulation of Pizzo et al. (2019), we can estimate the breaking induced drift at the front and the Stokes drift at the front (Lenain and Pizzo 2020). We see that the drift is greatly increased at the front.



Waves and wave breaking statistics can be strongly modulated at submesoscale fronts

- We find strong modulation of the surface wave field across the frontal boundary, including enhanced wave breaking, that leads to significant spatial inhomogeneities in the wave and wave breaking statistics.
- The nonbreaking (i.e., Stokes) and breaking induced drifts are shown to be increased at the boundary by approximately 50% and an order of magnitude, respectively.
- The momentum flux from the wave field to the water column due to wave breaking is enhanced by an order of magnitude at the front.
- The increase in wave steepness and wave breaking implies that other important quantities for air-sea interaction, e.g. increase in gas transfer (Deike 2022) should also be increased at the front.

References

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