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Satellite and in situ Observations of Marine Boundary Layer Adjustment to an Unstable-to-Stable Stratification Transition

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ABSTRACT:

We present a case study of marine boundary layer adjustment to a sharp change in near-surface stratification from slightly unstable to stable. The stratification change was induced by a sea surface temperature front associated with the western edge of the Gulf Stream at the edge of the continental shelf. This case is unique in that a low flying research aircraft acquired near-surface flux and surface wave information in coordination with a synthetic aperture radar image acquisition from the Canadian Space Agency RADARSAT-1 satellite. Serendipitously, the NASA QuikSCAT scatterometer sampled the same region within twelve minutes of the SAR image. Four issues of scientific interest are revealed in this analysis.

(4) We find clear evidence of a near total collapse of the boundary layer at the leading edge of the stably stratified region;

(5) The near-surface winds at the leading edge of the cooler sea surface appear to reduce below the threshold (~2 m s^{-1}) necessary for inducing the cm-scale capillary/small gravity waves that produce the Bragg scattering of the SAR (or scatterometer) microwave radar beam;

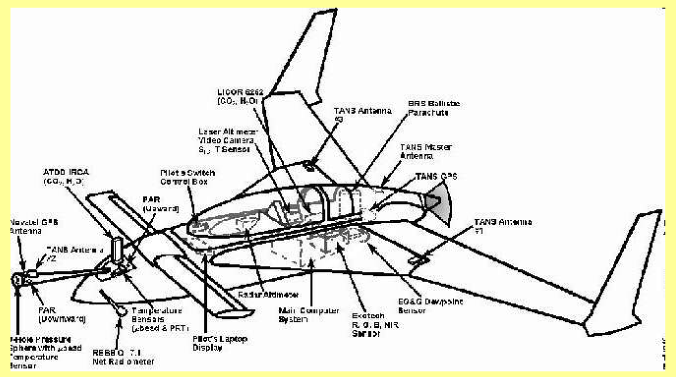
(6) The SAR wind retrievals and bulk flux model estimates of the surface wind disagree with the in situ data in the stably stratified region;

(7) The low surface wind speeds in the stably-stratified near-shore region allow (presumably) natural surfactants to collect on the sea surface. These allow the SAR image to resolve spiral eddies on the sea surface, which provide a visualization of the ocean surface vortices that are induced by horizontal shear instabilities in the surface currents.

ONR-Sponsored Shoaling Waves Experiment (SHOWEX) off the coast of Duck, North Carolina, USA, Nov-Dec, 1999.

Available data:

- RadarSAT overpass at 25 November, 1999, 22:52 UTC.
- LongEZ aircraft flying "SAR L-pattern" at ~z = 28 m from ~22:30 to 23:00 UTC.
  - Ku-band Radar Altimeter measures total wave mean square slope (MSS).
  - Triangle of laser altimeters measures MSS for l > 2m.
  - Turbulence flux probes (processed at OSU)
- QuikSCAT satellite scatterometer overpass at 22:40 UTC.
  - MERS Ultra-high resolution processing at 2.5 km
- RSMAS ASIS flux buoys
- National Data Buoy Center (NDBC) buoy and CMAN station mean winds, temperatures and significant wave height.



- SAR backscatter is due to Bragg scattering off cm-scale gravity-capillary waves on sea surface.
- Normally laser returns (footprint ~1.5 x 2.4 cm) are from specular reflection off small wavelets on the sea surface. For smooth sea surfaces, reflection is geometric optics and depends on orientation of the sea surface to receiver.
- Hypothesis: Wind stress falls below the critical value for windwave formation (nominally 2 ms-1 in neutral stratification with no surface currents). Internal boundary layer decouples the surface from the wind above.

Test of Hypothesis: Laser glint (fraction of total returns per sample period) is overall very low on this day and much reduced during Leg2. This implies no gravity capillary waves and lasers are in geometric optics mode.

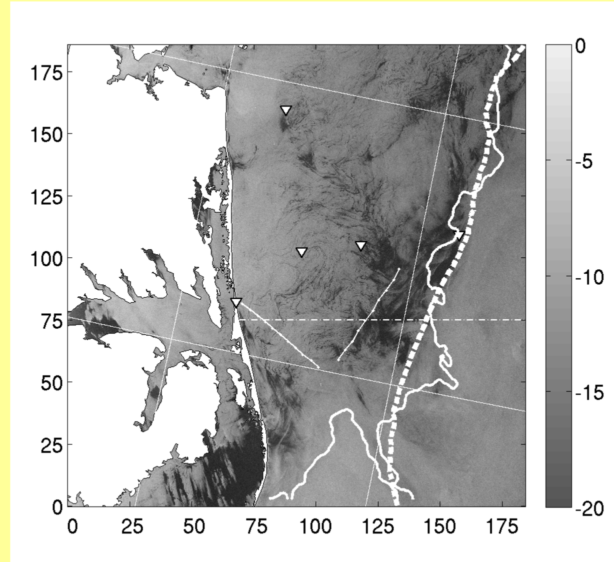


Figure 1: RadarSAT-1 SAR σ_0 acquired 25 Nov., 1999, 22:52 UTC. LongEZ flight legs are indicated as lines with dots at the flux data locations. Thick dashed line shows the -60 m isobath. Solid line shows the 22° C isotherm from three-day averaged IR SST data. Dash-dot line shows location of cross section shown in Figure 2. The 75oW and 76°W longitude and 36°N and 37°N latitude lines are shown. Buoy locations are marked by triangles. SAR image is Copyright ©1999, Canadian Space Agency.

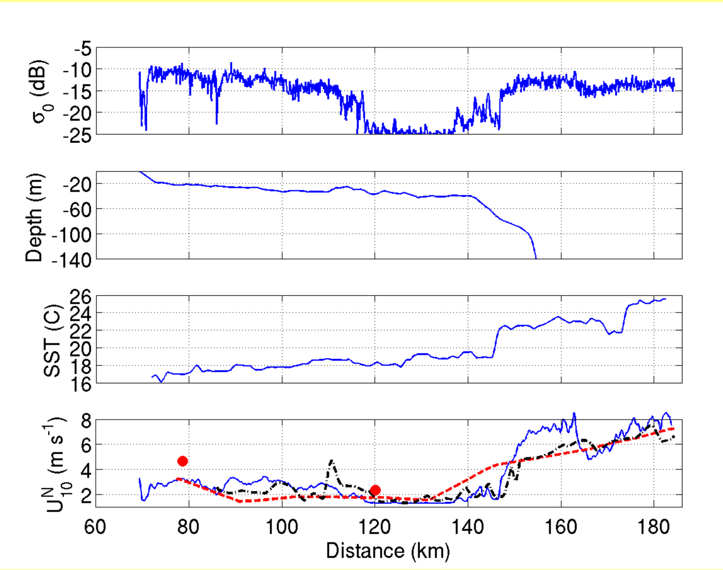


Figure 2: Cross section plot across SAR scene. (a) σ_0. (b) depth. (c) Three-day average SST from satellite IR. (d) from SAR (solid), 12.5 km QuikSCAT (dashed), 2.5 km QuikSCAT (dash-dot), LongEZ (crosses). from LongEZ flight legs are marked by dots

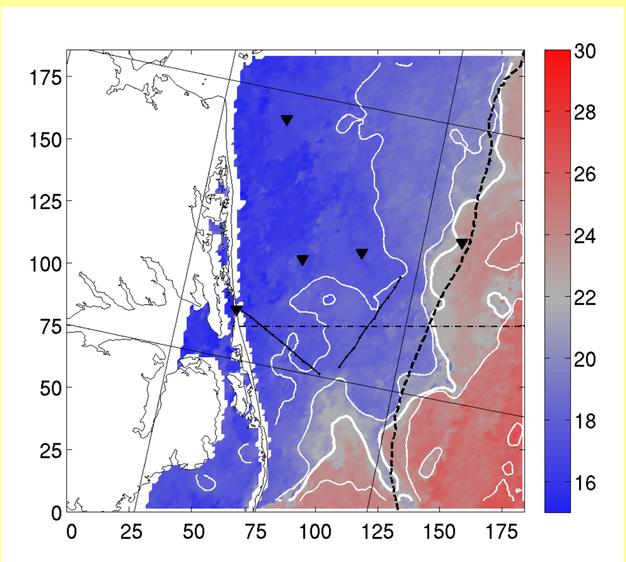


Figure 3: Three-day average SST from AVHRR IR data. Approximate contours at 2° intervals are plotted in white; the thick contour is 22°. The cross-section line, LongEZ flight path, -60 m isobath and buoy locations are as in Figure 1

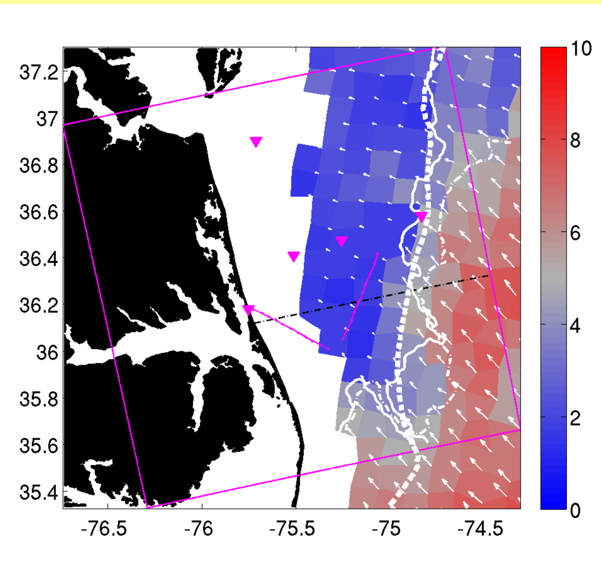


Figure 4: Surface wind vectors from QuikSCAT scatterometer, 25 Nov, 1999, 22:40 UTC, standard 12.5 km processing. The outline of the SAR image is drawn. The cross-section line, LongEZ flight path, -60 m isobath and buoy locations are as in Figure 1.

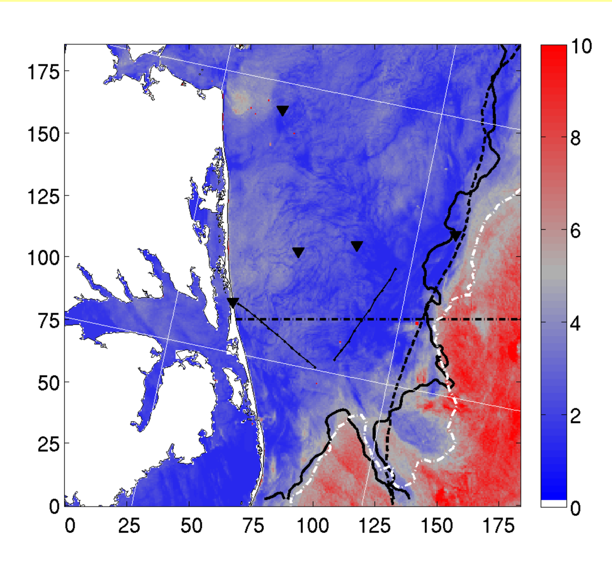


Figure 6: CMOD4 from RadarSAT-1 SAR at 600 m pixels. White dash-dot line indicates 5 m s^{-1} isotach from 2.5 km QuikSCAT product. The cross-section line, LongEZ flight path, -60 m isobath and buoy locations are as in Figure 1

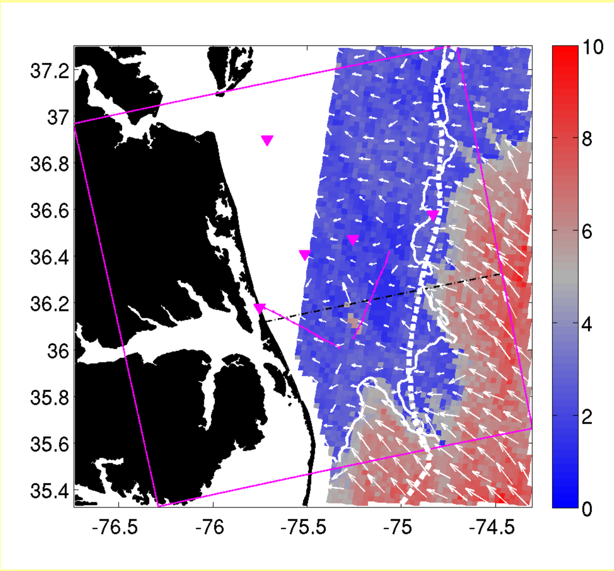


Figure 5: As in Figure 4, but for the UHR 2.5 km processing.

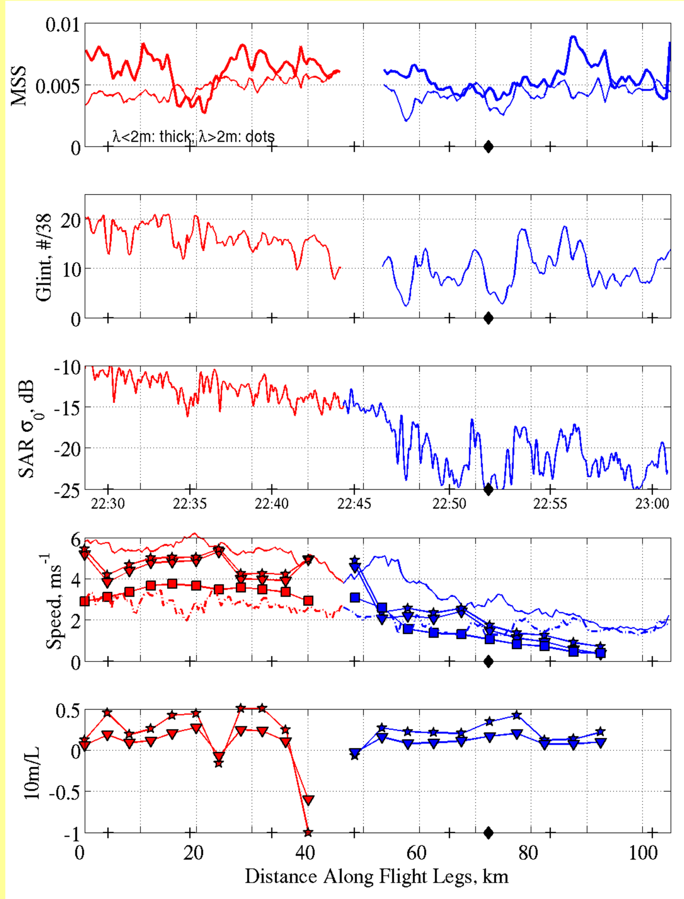


Figure 7: Data from the LongEZ flight legs. The x-axis is distance along the flight track with times indicated below panel (c). Leg 1 is plotted in red and Leg 2 in blue. The time of the SAR overpass is indicated by the black diamonds. (a) Radar mss. Wavelengths < 2 m, thick line; wavelengths > 2 m, thin line. (b) glint. (c) SAR σ_0. (d) Wind speed. Flight level wind, solid. calculated directly from flight level data, stars. calculated from fluxes reduced to surface values, triangles. from COARE 3.0, squares. CMOD4 , dash-dot line. (e) Stratification parameter . Calculated directly from flight level winds, stars; calculated from fluxed reduced to surface values, triangles.

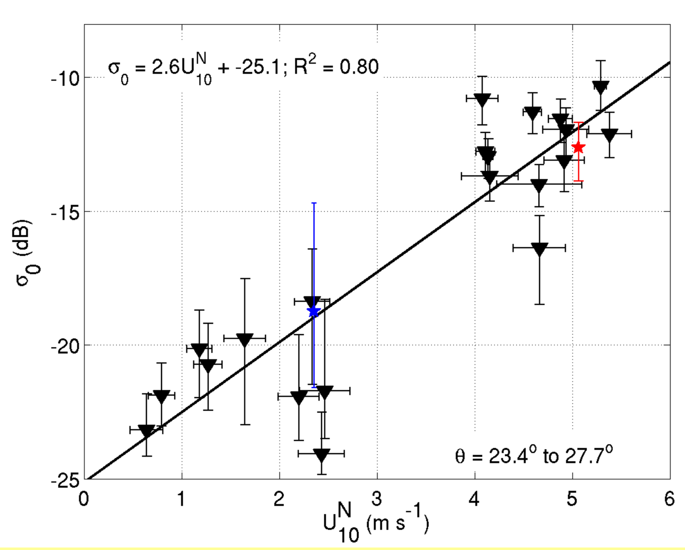


Figure 8: Dependence of SAR σ_0 on LongEZ and best fit line through these data. SAR σ_0 and ASIS are plotted as stars.

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