Using SAR to diagnose boundary layer stratification change at the ocean meso-to-submesocale

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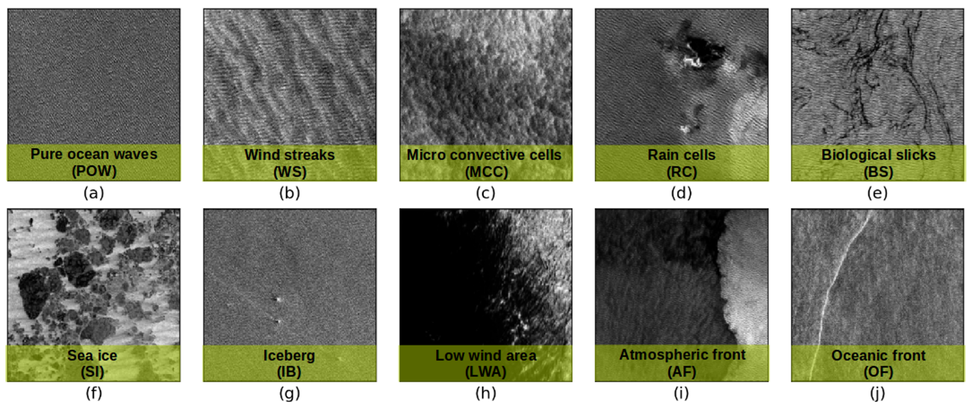
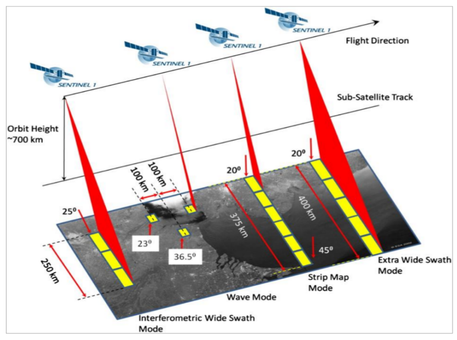


Abstract

One well known remote sensing tool for assessing surface wind changes on the ocean at spatial scales of less than 1km is synthetic aperture radar (SAR). Recently, our team has also shown that SAR data can also be used to quantify the presence or absence or several classes of coherent boundary layer structures (CS) that in turn reflect the basic state of the surface layer stratification, either unstable, near neutral, or stable. Given the interest in how surface fluxes drive atmospheric and oceanic responses in conditions with large horizontal ocean temperature gradients, we propose that one potential diagnostic to explore is spatial/temporal transition in coherent boundary layer structures, and the attendant changes in thermal vs. shear control in the ABL. Basic machine learning methods developed for SAR data interpretation and supporting a recently-published global SAR stratification study will be reviewed. Global and regional scale examples of SAR-observed coherent structure transitions will be discussed. Such data could be used to assess how well numerical model parameterizations and their fluxes switch between observed CS regimes, if they address CS flux enhancements appropriately, and how well large eddy simulation models are able to predict the characteristic of these structures across changes in surface ocean temperature.

Global Sentinel-1 C-band SAR Wave Mode (WV)

- Acquisitions

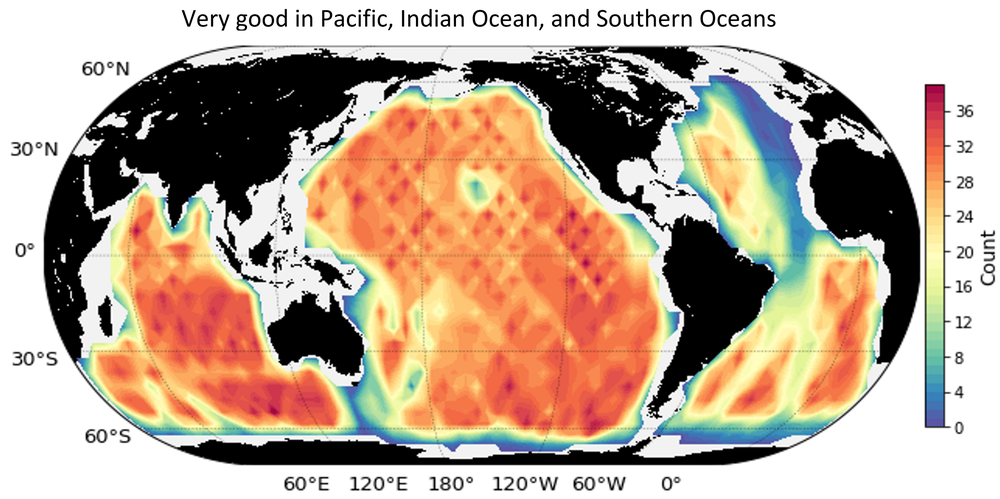


Mode	Incidence Angle (°)	Resolution (RA*AZ)	Swath Width	Polarization
Wave	22-25 35-38	5×5 m	20×20 km	HH,VV

- S-1A starting in 2016, S-1B in 2017
- 20 × 20 km, 5 m spatial resolution, offshore only
- Two incidence angles: 23° (WV1) & 36.5° (WV2)
- Routine acquisition quasi-globally
- ~60,000 images/month/satellite

- Global coverage at a weekly-monthly timeframe

Very good in Pacific, Indian Ocean, and Southern Oceans



Spatial gridded monthly average of Sentinel-1A WV2 acquisitions in 2016 and 2017. The color denotes # of SAR imagettes in each 5° by 5° grid box

Example : Seasonal and spatial air-sea flux change across Arabian Sea and Tropical Indian Ocean

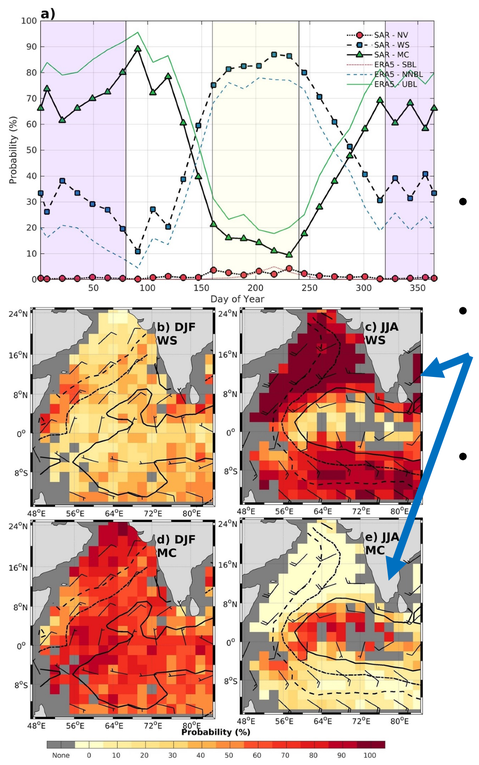


Figure 4. Relative occurrence rates between SAR-detected MC and WS images in the western Indian Ocean. Panel (a) gives the biweekly regional averages. It also shows time series of averages among the three study BL stratification classes using ERA5 *Ri* data. The maps in 2° bin-averaged seasonal WC and MC rates from December–February (DJF) and June–August (JJA) monsoon periods. The surface wind vectors are given as the barbs (direction from) where a full barb is 10 knots. The SST_v 27, 28, and 29°C contours are given as the dotted lines, dash-dot, and solid, lines. These wind and SST_v information are obtained by averaging ERA5 over our larger overall WV2 data set and not the 27% of selected images to show the climatology.

North-Western Indian Ocean Basin Monsoon

- Bi-weekly averages shows change from near neutral in winter to unstable in summer
- Equatorial SST change in JJA clearly aligns with BL stratification and coherent structure change observed using SAR
- Basin-wide patterns captured
  - Mostly WS JJA southerly flow (Summer)
  - Mostly MC in DJF northerly flow (Winter)

SAR-inferred BL coherent structures map to BL stratification

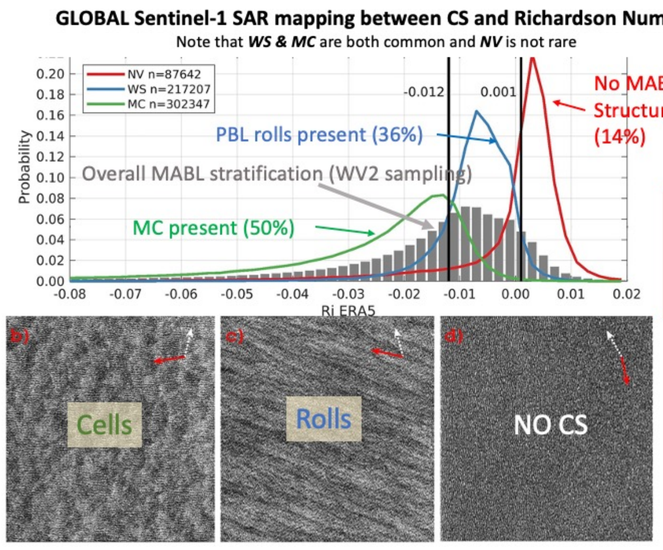


Figure 1. (a) PDFs of MABL *Ri* estimated from ERA5 for cells (unstable), streaks (near stable), and negligible atmospheric variability (stable) detection from SAR. The shaded gray PDF denotes the entire WV2 population. Representative SAR images for (b) unstable $Ri = -0.032$, $U_{10}^N = 5.3$ ms^{-1}, $\Delta T_v = -2.81°$, (c) near-neutral $Ri = -0.006$, $U_{10}^N = 9.8$ ms^{-1}, $\Delta T_v = -1.74°$, and (d) stable $Ri = 0.005$, $U_{10}^N = 7.6$ ms^{-1}, $\Delta T_v = 0.84°$ MABL states. The white dashed arrow points north and the red solid arrow is the ERA5 wind direction.

3 primary MABL states via CS:

- MC: ("Micro-Convection") = unstable
- WS: ("Wind Streaks", "rolls") = neutral
- NoVar: ("No MABL CS") = stable

Stopa et al., 2022 *GRL using Global Sentinel 1 SAR*

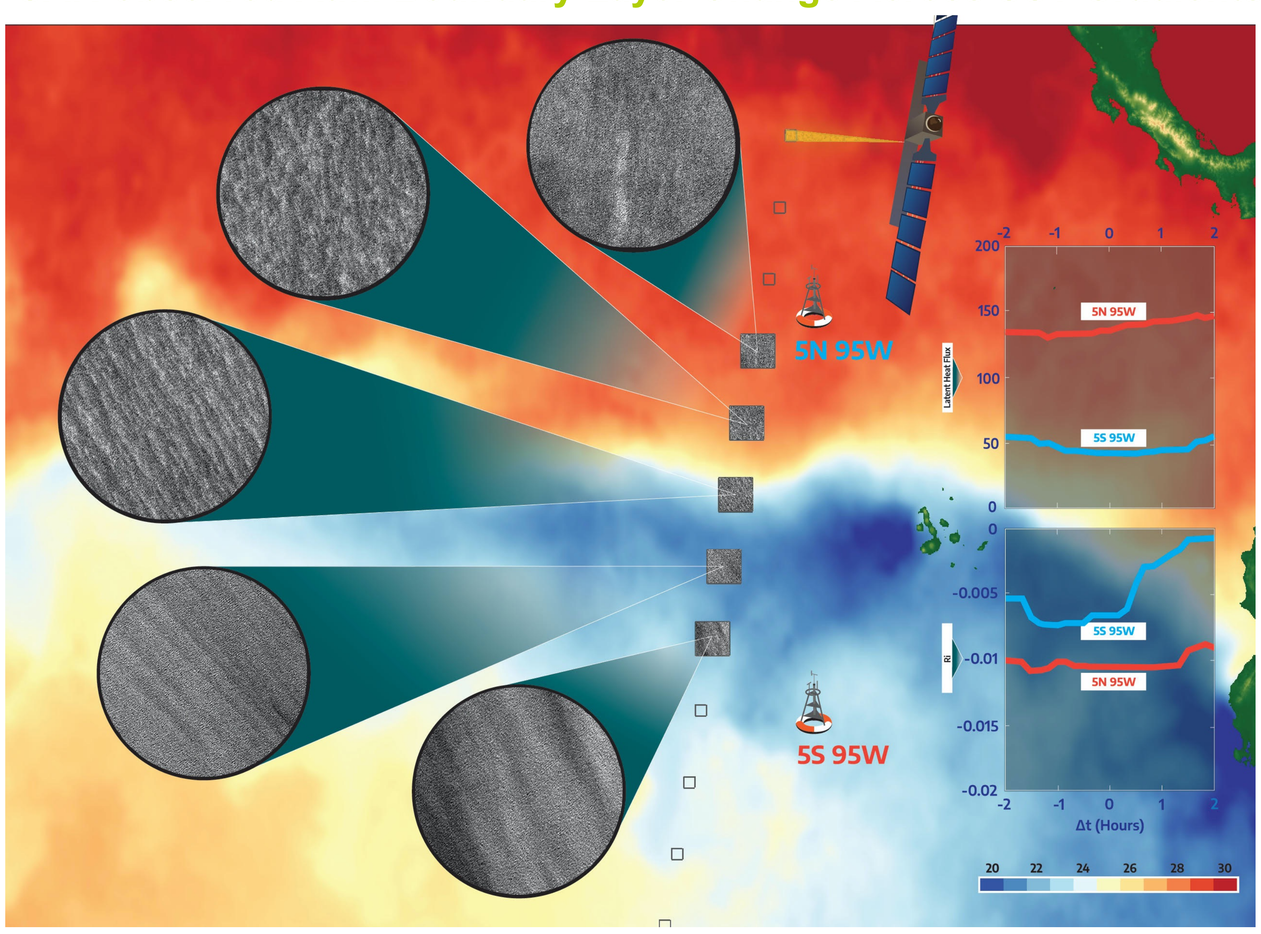
Neural net image classifier (CMwv)

~600,000 highest-confidence WV2 images used

ERA5 surface layer reference for stratification

- $Ri = \frac{g}{T_v}\frac{z_{10}(T_v - SST_v)}{U_{10}^{N\,2}}$ (stratification)
- $\frac{z_{10}}{L} \sim 10Ri$

SAR-observed Atm. Boundary Layer Change Across SST Gradients



Eastern Tropical Pacific Example NECC

- SAR imagettes collected across NECC every 100 km along TAO buoy array (buoy latent heat flux and Ri time series at right)
- South to north crossing of 8 deg. SST gradient
- Evidence of latitudinal change in BL coherent structures (wind streaks to south and cellular in unstable northern region)

Summary and perspectives

Workshop question 4: What are key analysis approaches and diagnostics of air-sea coupling which could guide modeling and observational strategies, including time and space scale dependencies and specific variables and processes?

New 'Routine' Observational Tool:

- Satellite SAR detects boundary layer coherent structure (CS) type
- CS relates to state of surface layer stratification (unstable-to-stable)
- Spatial scales of 1-1000 km including seasonal mapping capability

Possible Discussion question:

Could such stratification information provide a new useful diagnostic for model/data comparisons and improved flux prediction?

Able to better assess/validate BL flux and BL parameterizations across SST gradients of SL stability, CS… within LES and high resolution coupled models?

References

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[2] Stopa, J. E., et al. (2022). Automated global classification of surface layer stratification using high-resolution sea surface roughness measurements by satellite synthetic aperture radar. Geophysical Research Letters, 49, e2022GL098686.

[3] Brilouet, P.-E., et al. (2023). Trade wind boundary layer turbulence and shallow precipitating convection: New insights combining SAR images, satellite brightness temperature, and airborne in situ measurements. Geophysical Research Letters, 50, e2022GL102180.

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