A Synergist View of the Marine Atmospheric Boundary Layer and Low-Level Clouds

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Motivation

Low-level clouds in the winter trade wind boundary layer (TWBL) over the tropical ocean play a significant role in Earth's radiation budget, but their net cooling effect varies greatly among different climate models, imposing predictive uncertainties. Recent research indicates that models may be limited in their ability to predict tropical cloud variability because they focus solely on local thermodynamic variables and ignore mesoscale changes (100-1000 km) in the ocean-atmosphere system. Research based on visual/infrared satellite imagery has identified 4 distinct mesoscale cloud organizations in the tropical NW Atlantic, each of which has varying impacts on the net radiation budget. Simultaneously, our group has been using high-resolution satellite radar data to classify coherent structures within the sub-cloud marine atmospheric boundary layer (MABL). We show that shifts between distinct, well-known cellular and roll vortex fields within the MABL are also controlled by relatively small changes in the surface layer stratification, which is most often controlled by the surface wind speed (see Fig. ?). This project seeks to investigate connections between these two research directions where we expect that the combination of satellite synthetic aperture radar (SAR) and ocean wind vector data plus satellite cloud and cloud property measurements can offer unique satellite-based observations of turbulent MABL states under the varying mesoscale organization of clouds in the tropics. Consequently, the guiding questions are:

1) Do time/space shifts between the MABL large-scale eddy field (cell-to-roll) at the mesoscale and at diel cycles help explain the varying low-level cloud fraction in the trade wind regions?
2) How does wind field variability impact both processes and perhaps their coupling?

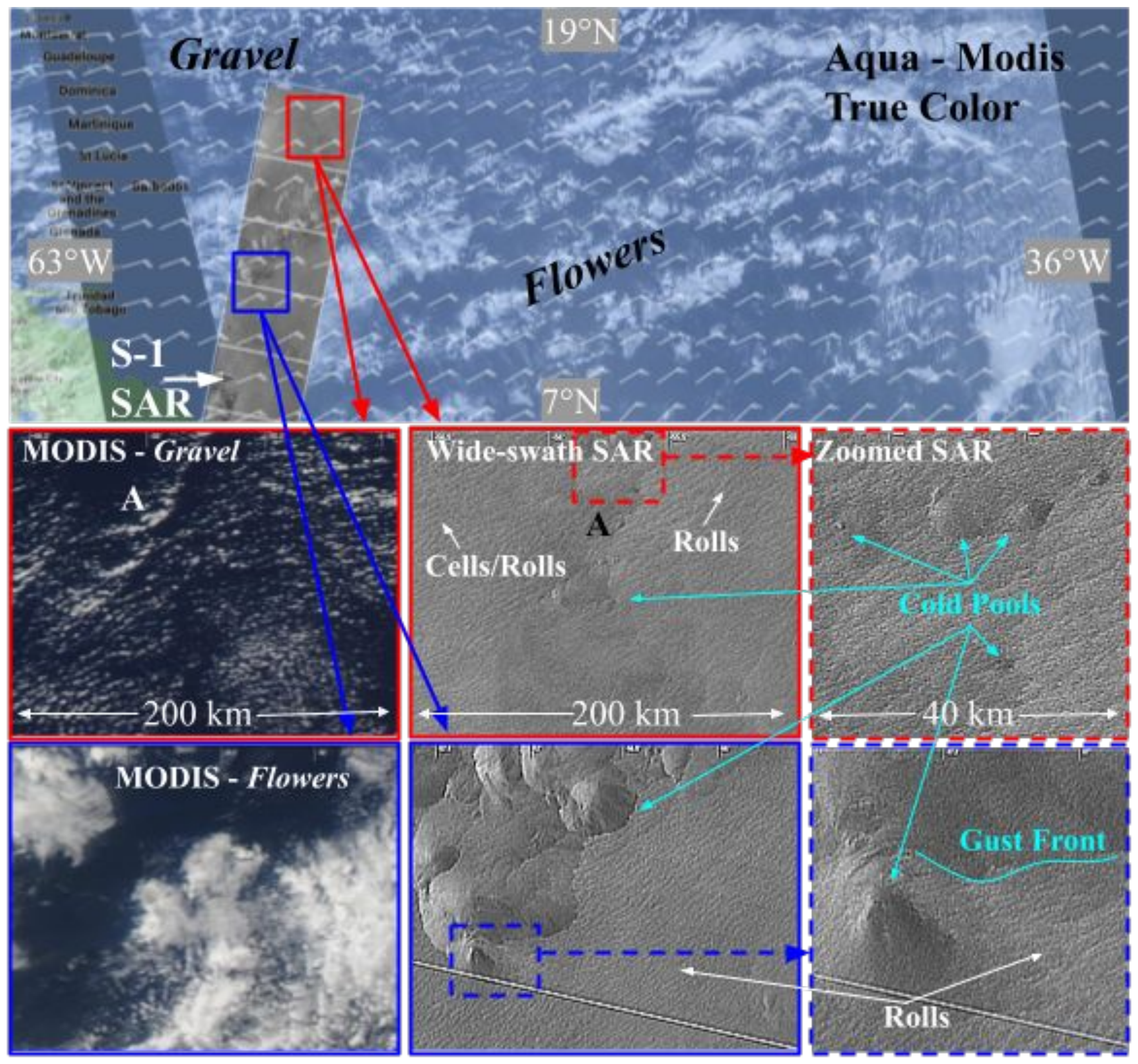


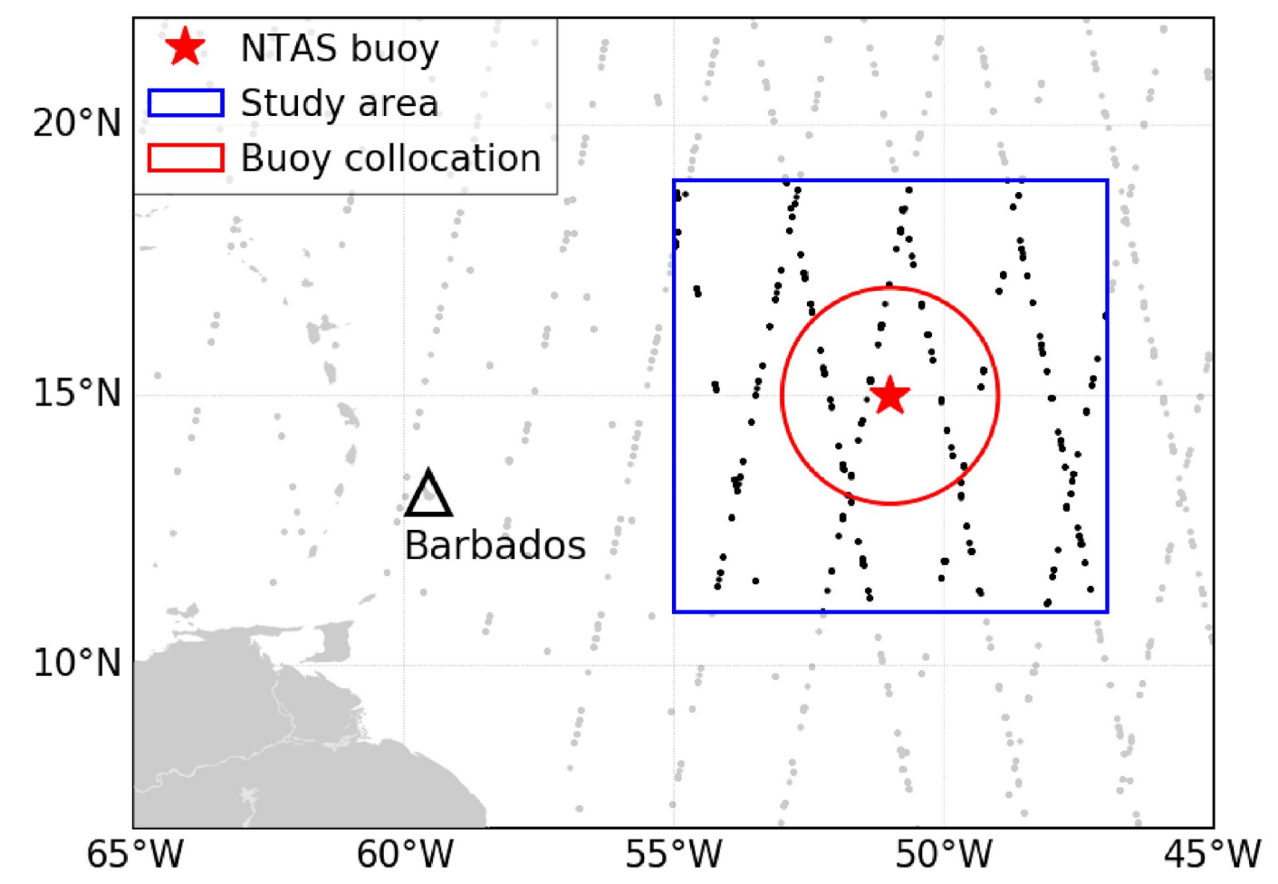
Figure 1 (left) Project synopsis linking mesoscale clouds and wind vectors to submesoscale sea surface variability in the NW Atlantic trade wind region.

The top and left panels are the true color images from Modis (Aqua) on 13 February 2020. The ERA5 surface wind barbs are overlaid on the MODIS image.

A close-in-time, ultra-high resolution (~15 m pixels) Sentinel-1 IW SAR image captures fine-scale features of the boundary layer structures.

Readily apparent are boundary layer states like roll vortices (rolls), cellular convection (cells), mixed rolls/cells, gust fronts, and cold pools.

2) Morphology of the NW trade wind boundary layer



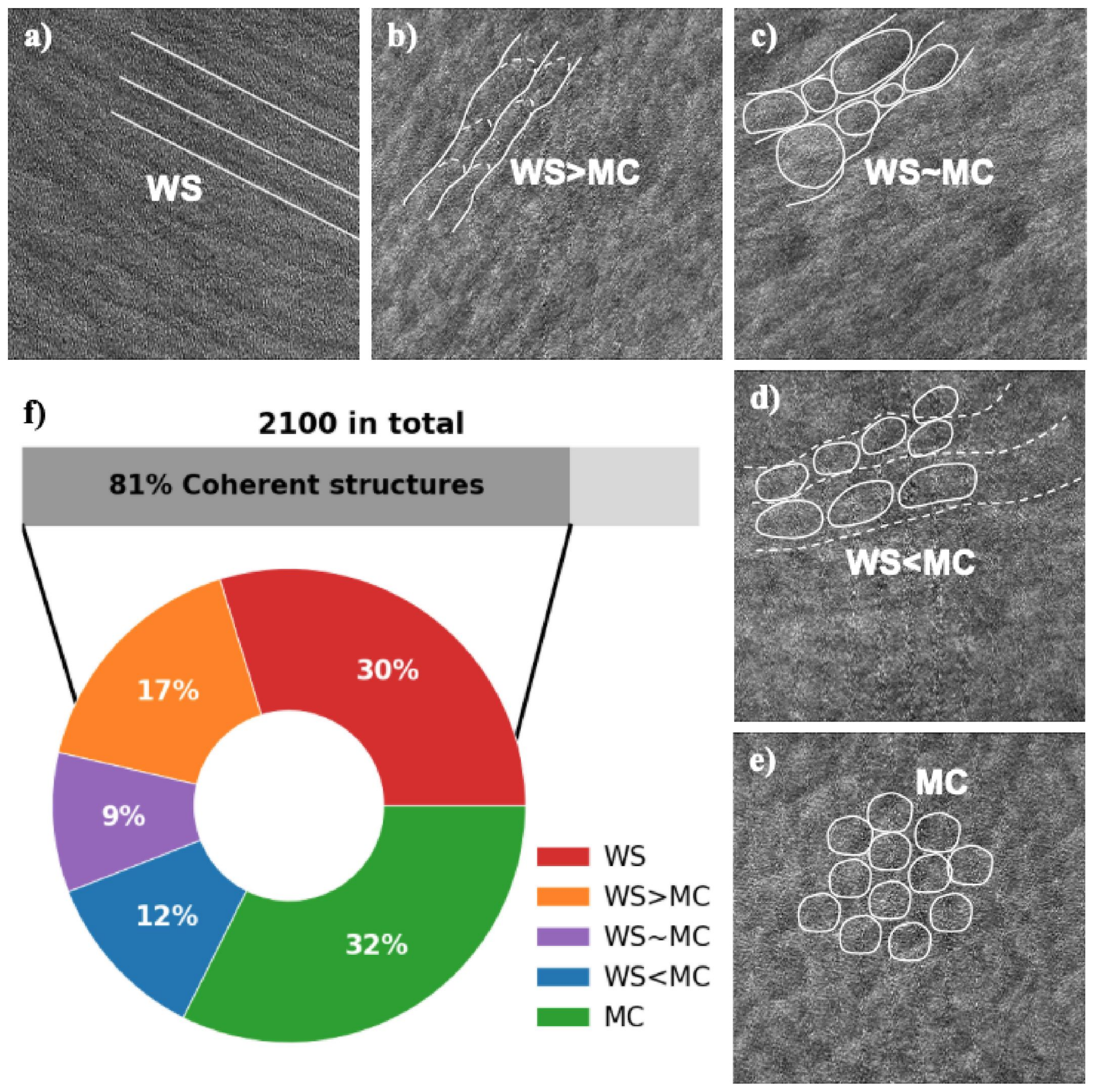


Figure 2 (above): Area of interest (blue box): S-1 wave mode acquisitions from Jan-Jun.

Figure 3 (left): (a)-(e) 5-class definitions of coherent structures in the TWBL:
WS - wind streaks
MC - micro-scale convection

(f) Statistical distribution from our hand-tagged results
- *81% of the images have* *__homogenous__* *imprints of WS or MC*
- ***>97%*** *of the images have WS or MC imprints when including images with rain*
- Equal distribution of 1) WS 2) mixed WS/MC 3) MC

3) Synergist Approach

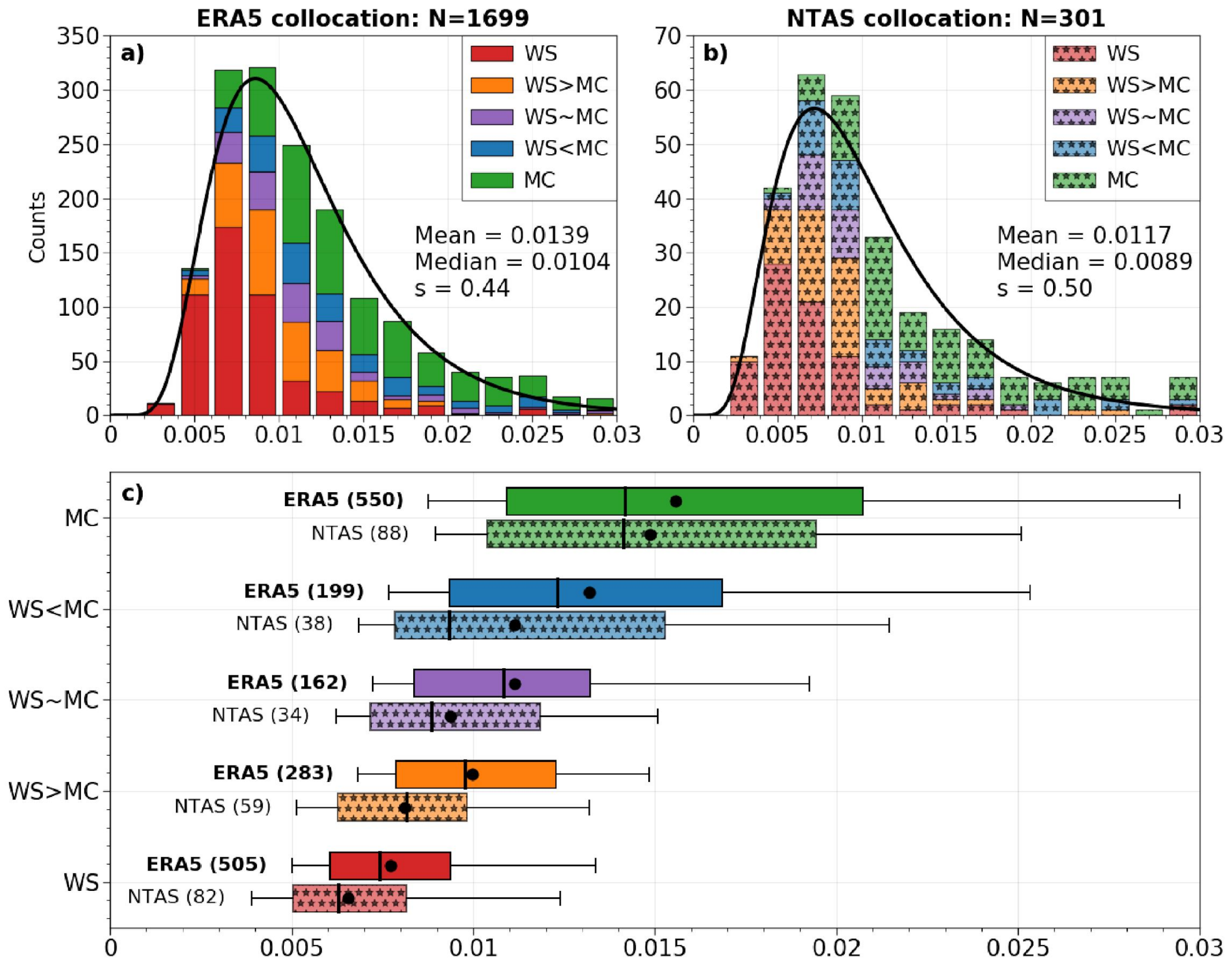
__Textures to observations/reanalysis__

Figure 4 (right): Roll-to-cell transitions associated with the surface-level MABL stratification. Panels (a) and (b) show the number of WS, WS>MC, WS~MC, WS<MC, and MC in 0.02 Ri bins calculated from ERA5 and NTAS.

Panel (c) shows the Ri distribution of the 5 coherent structure classes relative to Ri. The dot represents the mean. The vertical line represents the median. The boxes represent the 25 and 75th percentiles and the whisker extend represents the 10 and 90th percentiles.

Continuous transition WS→MC as Ri(↓)
↳agrees with Grossman (1982)

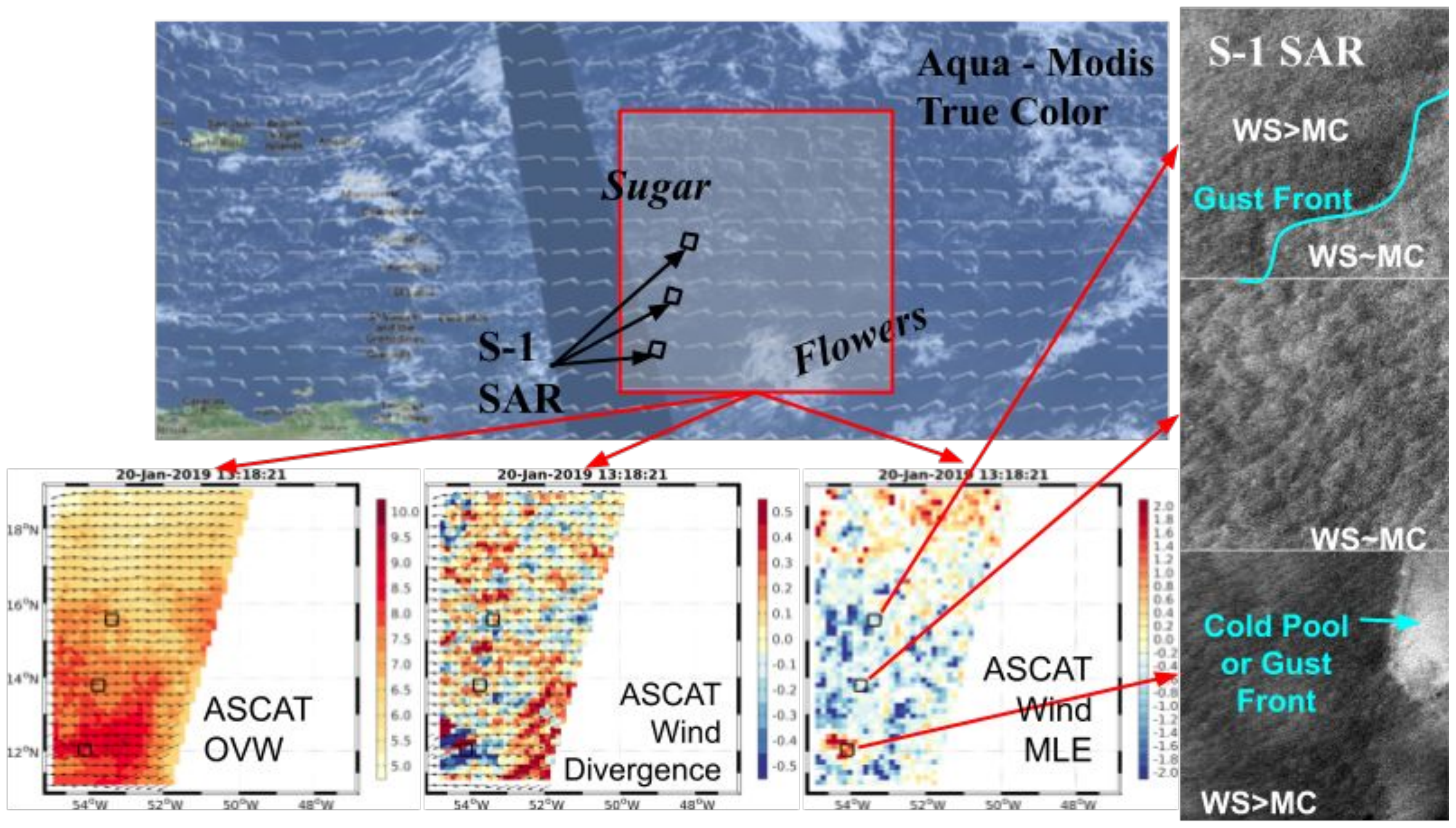
Textures of CS map to stratification
↳agrees with Stopa et al. (2022)



__ERA5/NTAS__ - colocated to each satellite image
z_{10} = 10 m
T_{10v} = virtual air temperature at 10 m
SST_v = virtual sea surface temperature
U_{10N} = wind speed at 10 m elevation
$T_{10v} = T_{10}(1+0.61q_{10})$, q_{10}= air humidity at 10 m

__Richardson Number__

$$Ri = \frac{g}{T_{10v}} \frac{z_{10}\left(T_{10v} - SST_v\right)}{U_{10N}^2}$$



__Synergy between Technologies and scales__

Figure 5 (above): Combination of scales and technologies for 20 January 2019.
- *Regional scales from Modis-Aqua visual cloud imagery*
- *Mesoscale surface wind vectors from ASCAT at 13:18 UTC*
- *Fine-scale turbulence in the MABL from SAR WV images at 09:26 UTC - correspondence between wind divergence and MLE error…*

4) Outlook

►Future work will focus on a region overlapping with historical and active studies (BOMEX and EUREC4/Atomic) in the NW Atlantic trade-wind region, windward of Barbados

►Further investigate the "bs_distance" parameter (Portabella et al., 2012) vs. SAR CS information in the trades with an eye toward assessment of scatterometer sub-grid variability

►The project will evaluate cloud, SAR-derived MABL states, and OVW parameters to determine possible relationships between them including the submesoscale and mesoscale controls

5) References

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