A multi-satellite, multi-scale investigation of marine atmospheric boundary layer impacts on low-level cloud variability

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Explore Connections between PBL Clouds & Coherent Structures

Modis clouds: PBL cloud Classes
Sugar, Gravel, Fish, Flowers

S-1 SAR: PBL CS classes & related stratification regimes

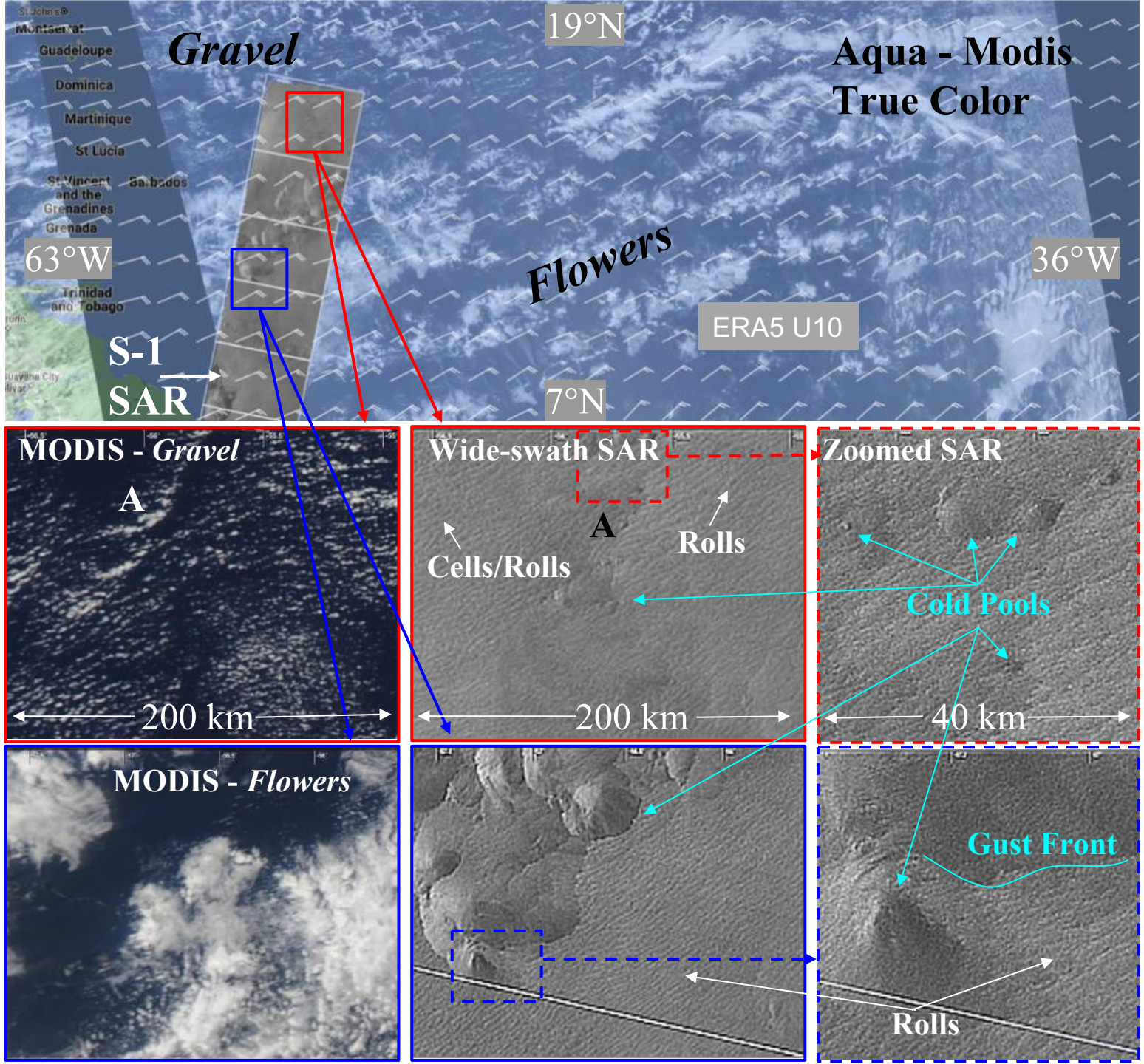
Hypothesis

PBL cloud classes & PBL CS change states due to changes within the same stratification regime

Changes in CS classes can induce profound differences in the fluxes across the PBL (more so than surface fluxes)

Expect: Cloud patterns are affected by the CS.

Motivation: Cloud-Radiative Feedback



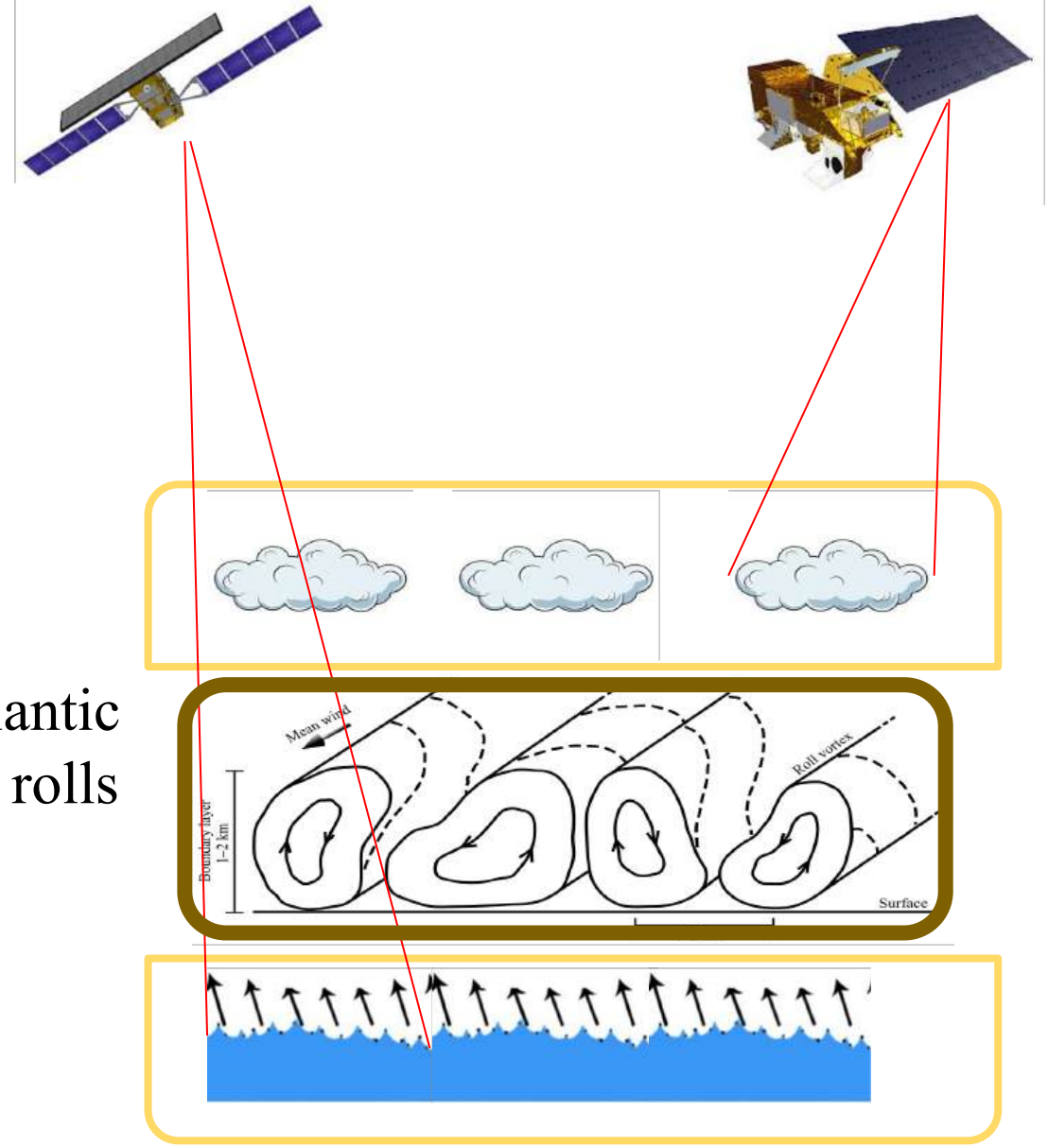
Outline

Marine Atmospheric Boundary Layer - MABL

1) Introduction
   a) Clouds patterns - top of MABL
   b) SAR surface textures - bottom of MABL
   c) MABL sandwich

1) Results - trade wind boundary layer of the NW Atlantic
   a) MABL bifurcation - a continuum of cells and rolls
   b) Cloud type vs SAR classes

1) Outlook

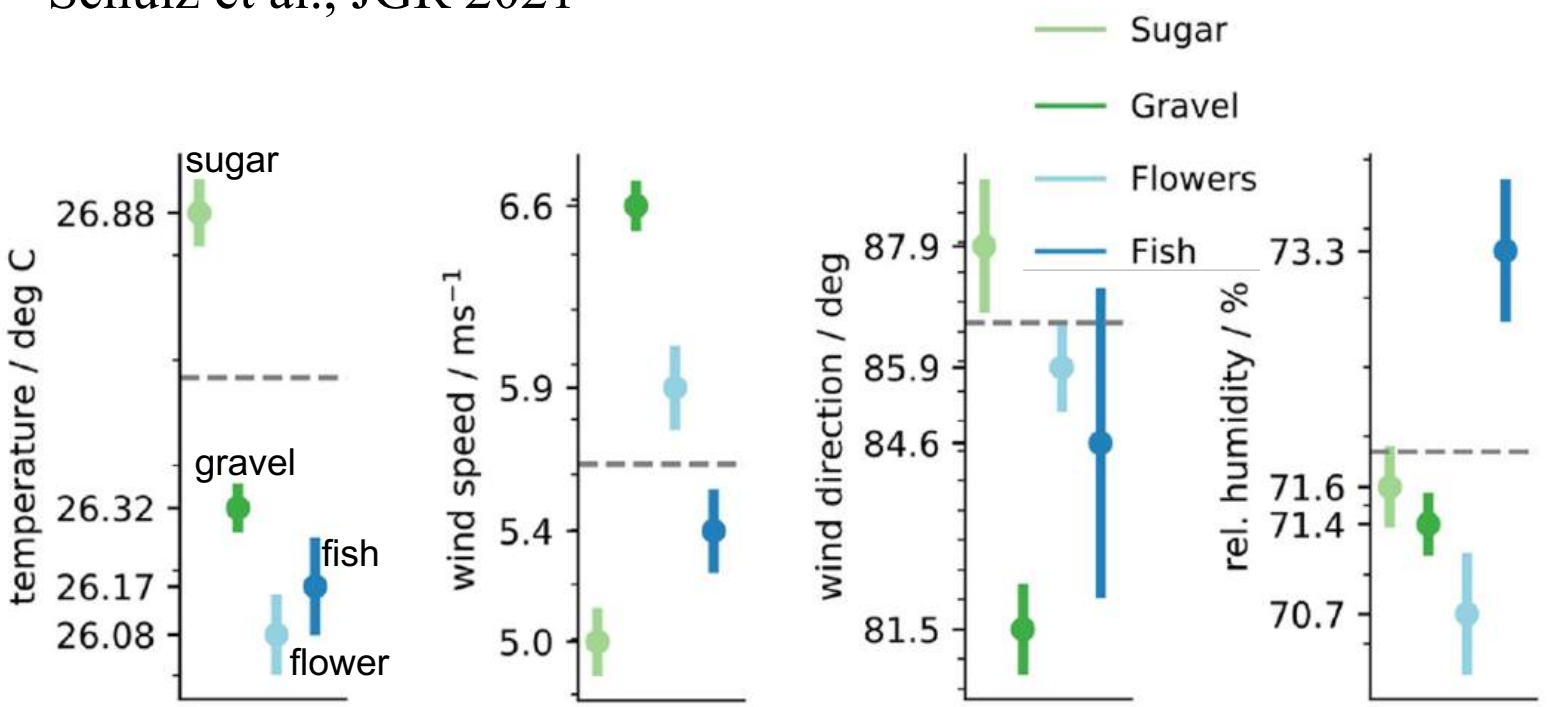


Coherent Structures leave imprint in SAR images

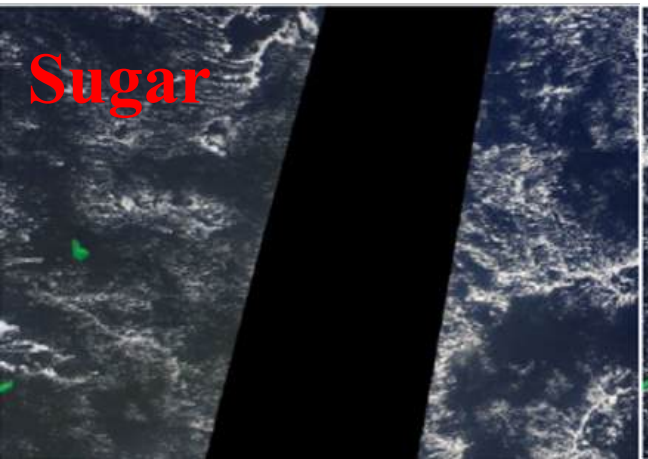
Cloud classes - *top of MABL*

Mean States Associated with PBL Cloud Types

Schulz et al., JGR 2021



- Clouds patterns strongly relate to wind speeds and directions
- Sugar->Fish->Flowers->Gravel
  - Low to high wind speed
  - E to NE wind direction
- Changes in temperature and moisture



SAR textures and stratification - *bottom of MABL*

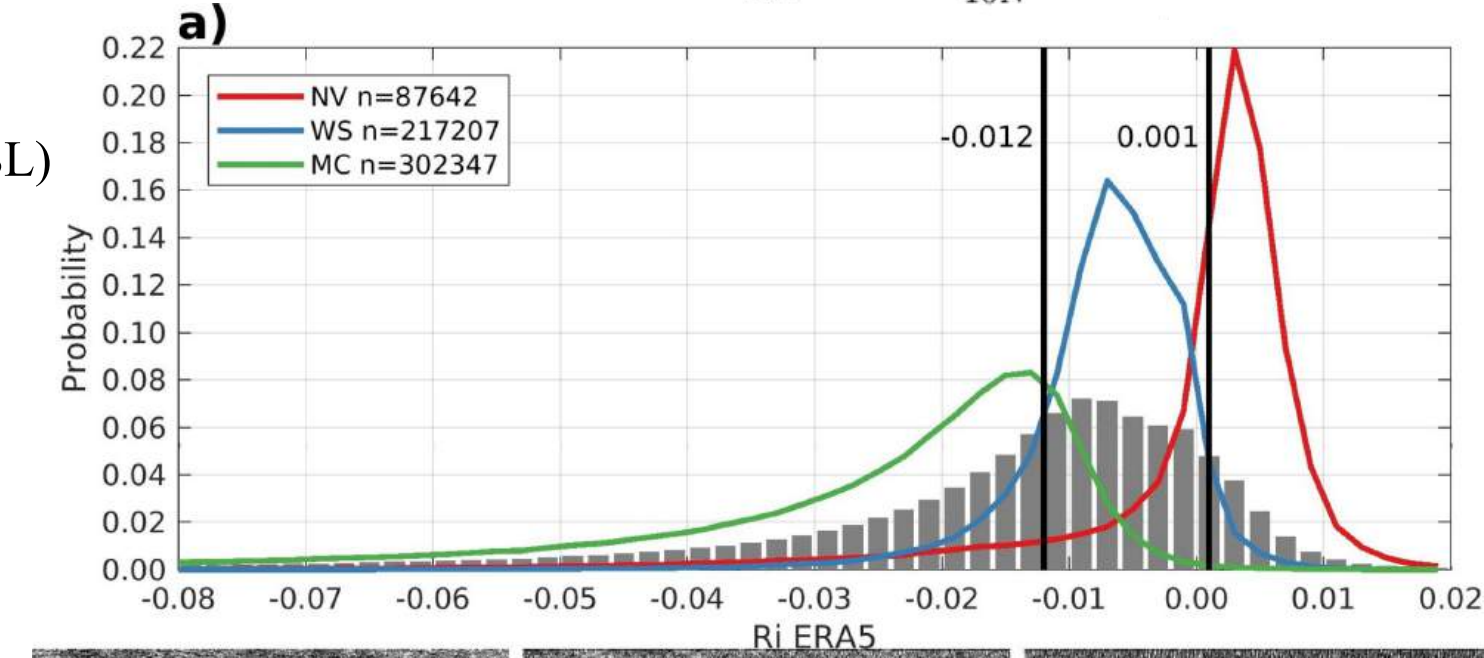
$$Ri = \frac{g}{T_{10v}} \frac{z_{10}\,(T_{10v} - SST_v)}{U_{10N}^2}$$

- 2016-2019 Sentinel-1A/B SAR images
- CNN classifies the SAR textures:
  1) Microscale Convection (MC) - unstable (UBL)
     Cells - convection
  1) Wind Streaks (WS) - near neutral (NNBL)
     Rolls - forced convection
  1) Negligible Variability (NV) - stable (SBL)
     No PBL variability

SAR Textures map to *Ri* (from ERA5)

- Based on PDFs, implicit coherent structure bands

1) UBL: $Ri < -0.012$
2) NNBL: $-0.012 \leq Ri < 0.001$
3) SBL: $Ri \geq 0.001$



Stopa et al., GRL 2022

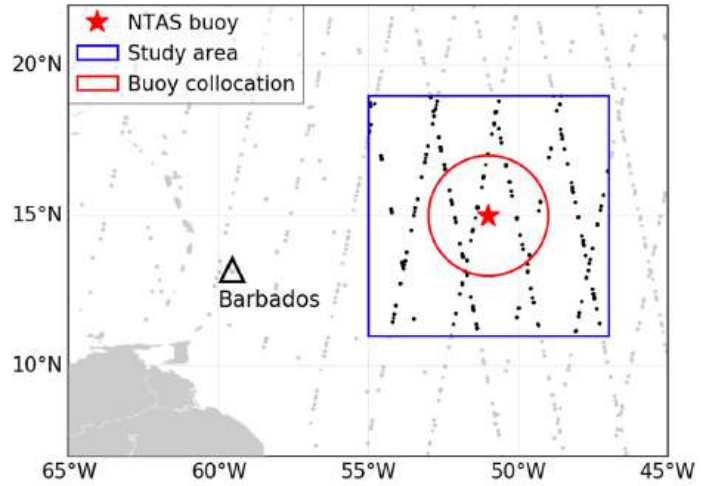
Morphology of trade wind boundary layer observed by SAR

- Hand-tagged SAR images - 8° box centered at NTAS
- 4200 images or 350 images/month
- Results are independent of "voting" strategy and expert
- Region is an ideal place for study of the MABL - consistent winds across large regions minimal changes in SST

Classes

1. **WS = Wind Streaks:** only rolls
2. **WS>MC:** WS dominate over MC
3. **WS~MC:** WS and MC are present w/ equal strength
4. **WS<MC:** MC dominate over WS
5. **MC = Micro-scale convection:** - only cells

- **99% have rolls or cells**



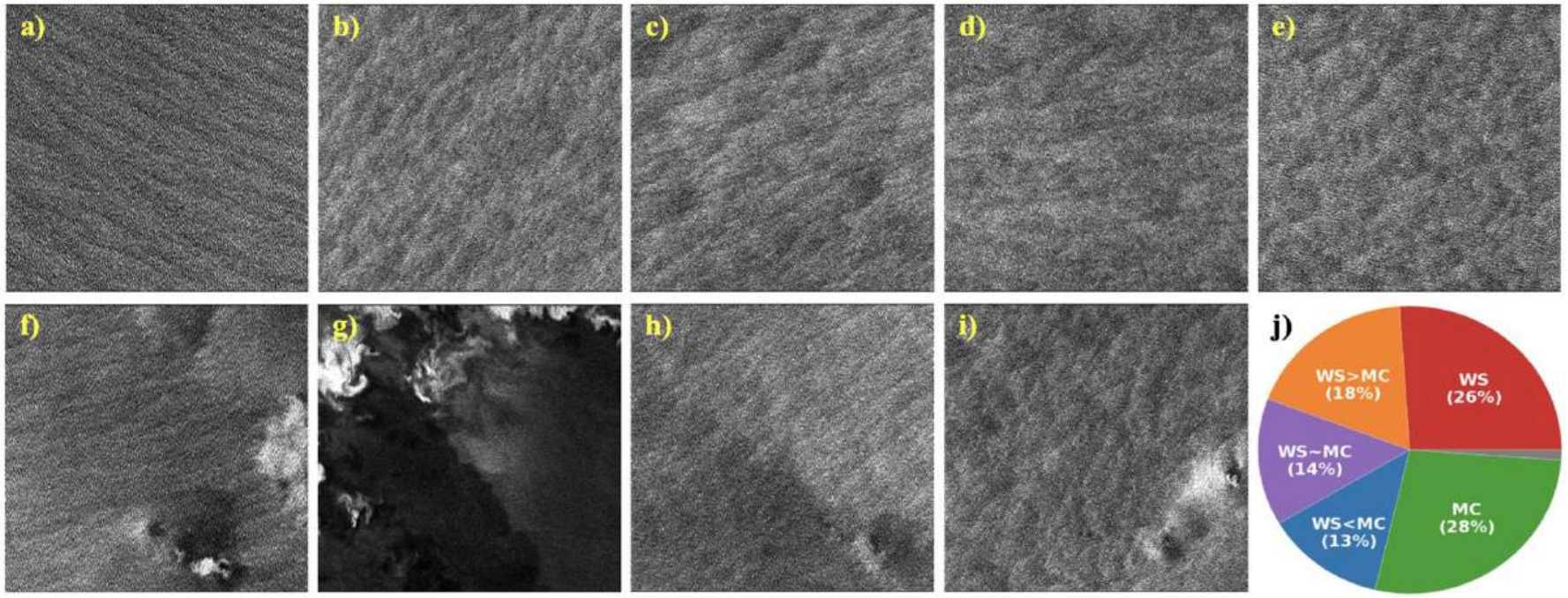
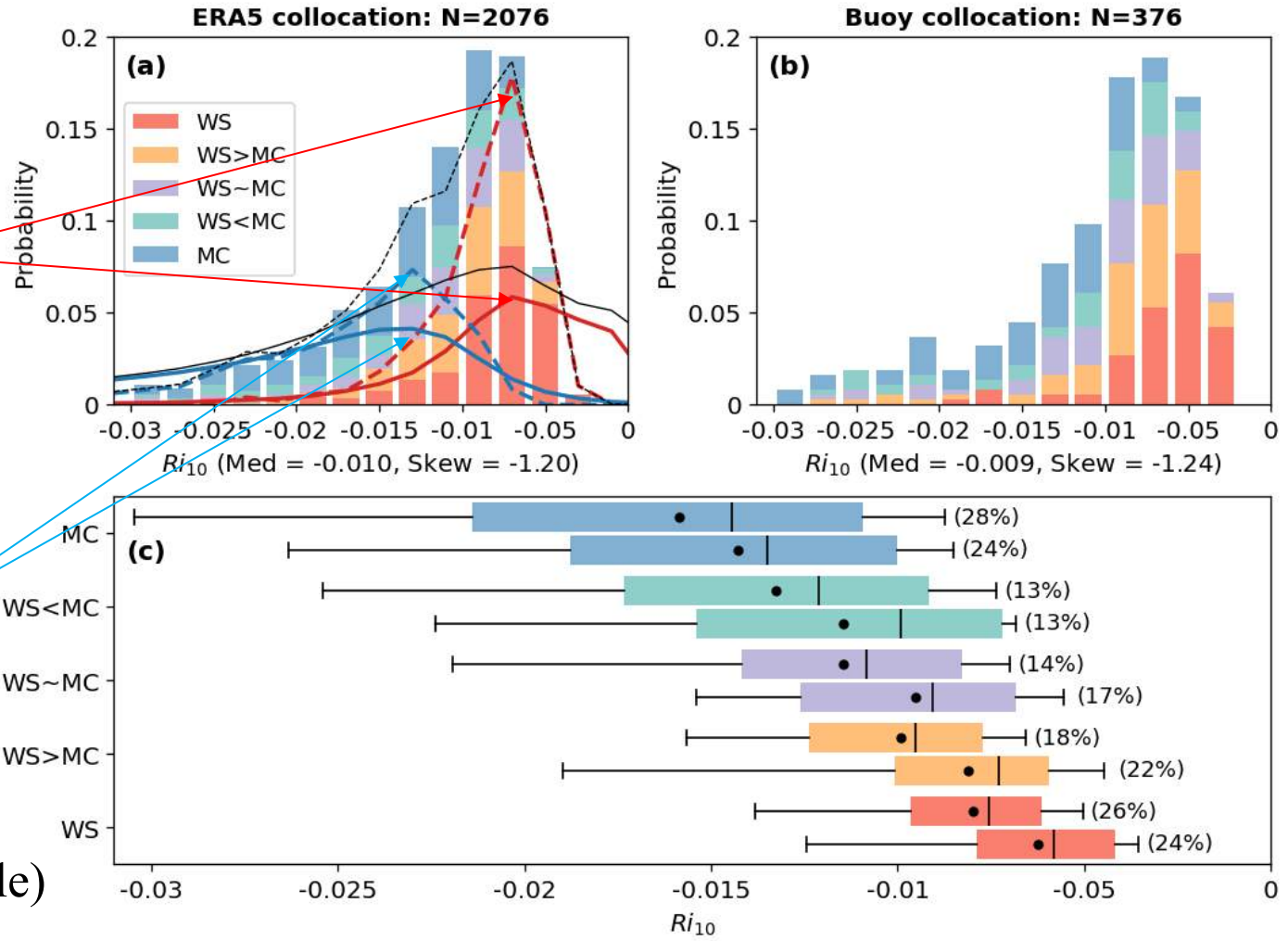


Figure 1. Sampling of WV2 images. **(a)-(e)** Examples of MABL CS classes. In order: WS, WS>MC, WS~MC, WS<MC and MC. **(f)** WS with RC and CP in lower portion. (**g**) No CS with RC and possible large CP (**h**) CS transformation across GF, WS upper right, WS > MC lower left. CP in lower right corner. (**i**) MC > WS with CP in lower right corner **(j)** Populations fractions of these five MABL CS classes.

Morphology related to stratification

Note that the near-neutral (PBL **ROLLS**) regime is **~twice as likely in this region** (dashed) as it is globally (solid, curves from slide 2)

Note that the convective regime (PBL **CELLS**) regime is **comparable to global averages** (solid, curves from slide 2)



WS→MC: Ri becomes more negative (more unstable)

MC→WS: Ri becomes more positive (more stable)

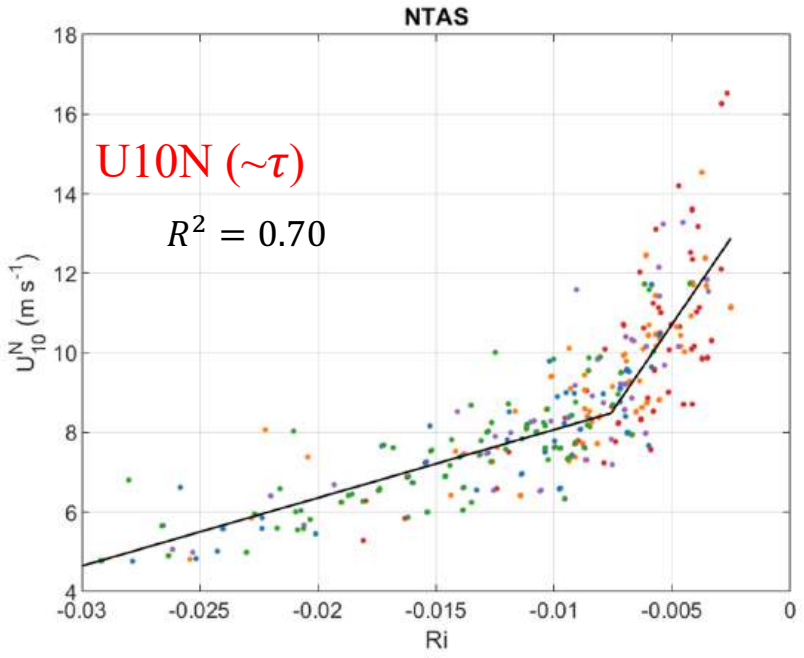
- Confirm Grossman, (1982) BOMEX
- **Differences between NTAS and ERA5 …**

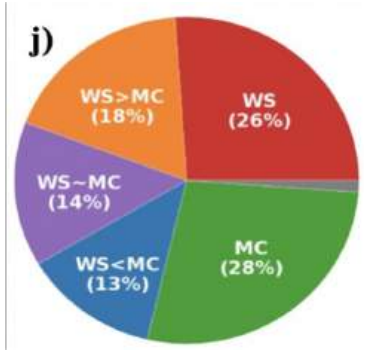
Figure 2. (a) probability histogram for ERA5 with contributions for each CS Class indicated in color. Solid black line is probability and blue and red lines are MC and WS probabilities from the global dataset used in Stopa et al. (2022). Dashed lines for the global dataset images falling within the NTAS lat.-long. box. **(b)** As in (a), but for NTAS buoy collocations. **(c)** Boxplots pairs of for the five CS classes. Upper is ERA5, lower is NTAS. Mean values are indicated by dots. Whiskers at 10th and 90th percentiles. Percentages of total counts in parentheses.

PBL Classes and Buoy Data

- Piecewise bilinear fit
- Transition when roll signature appears:
- Ri_{crit} = -0.0075 for both Stress & Qflux (latent heat flux)
- Determined by the fit

- **U10N controls stratification**
- Moderate/Weak relationship with moisture flux
- Water vapor is a trace gas, follows eddies. Mesoscale & temporal variability in q_{air}
- No relationship with buoyancy flux
- Temperature is property of the fluid and can adjust independently of eddies

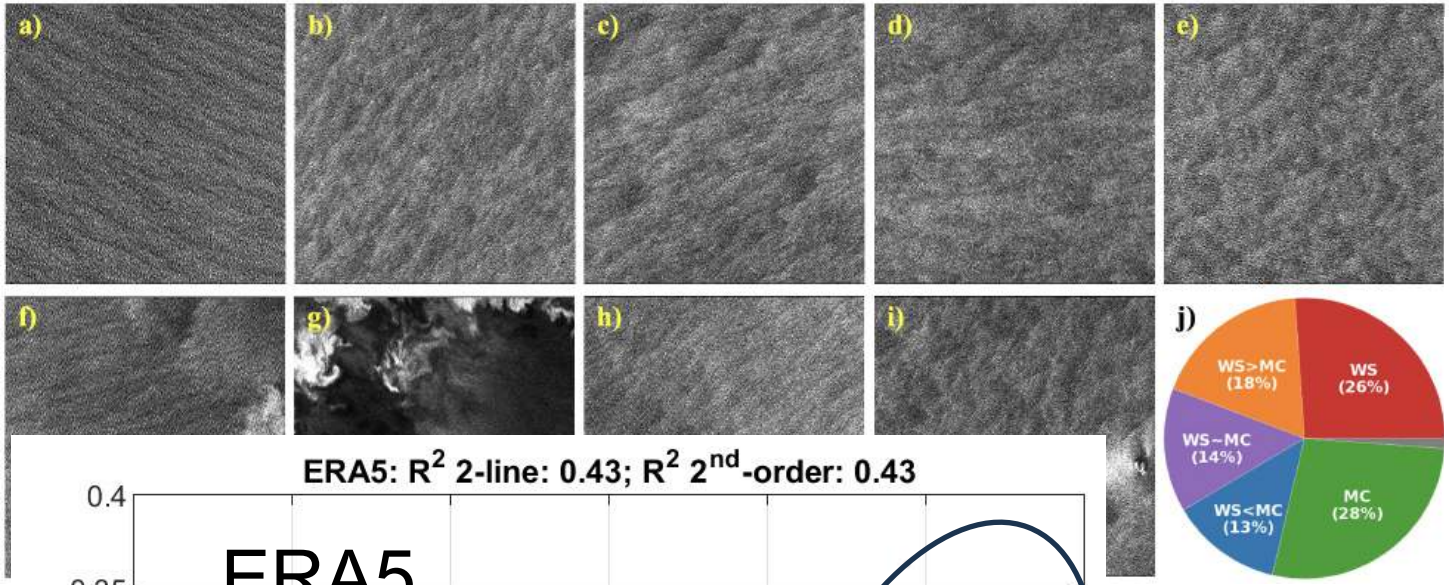


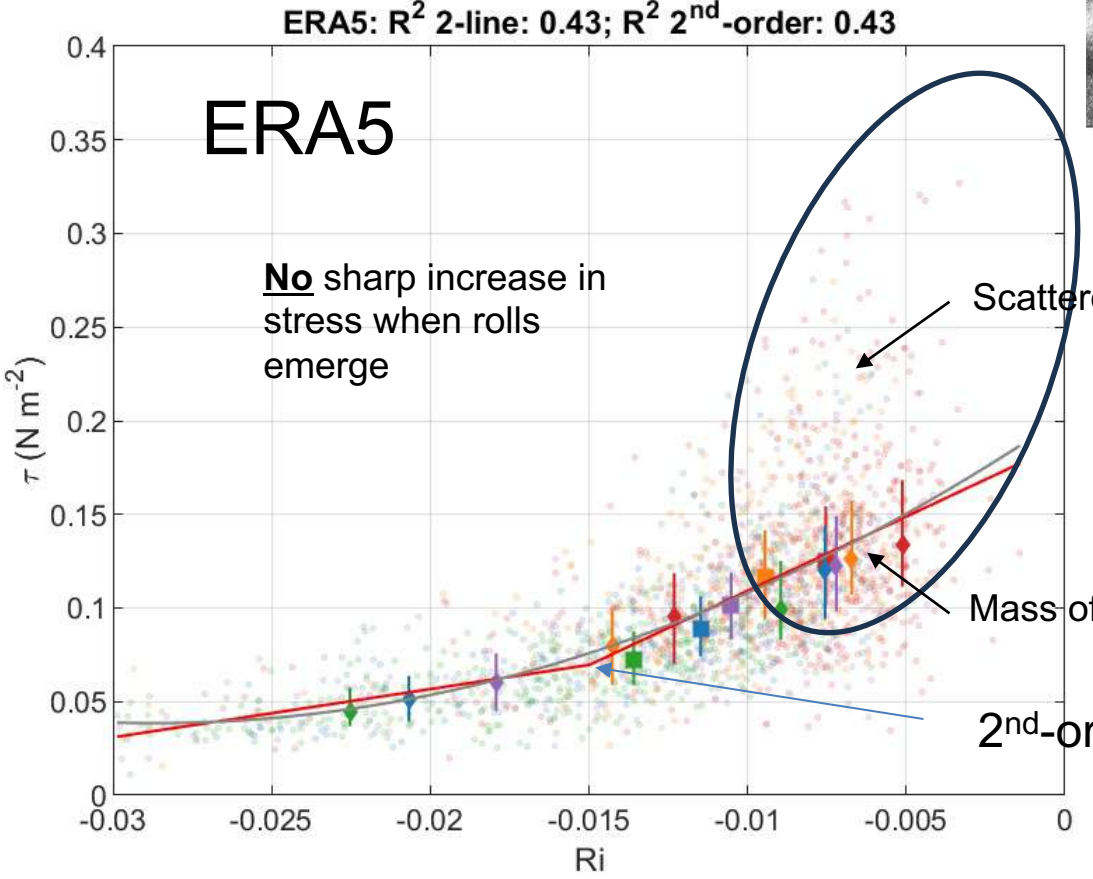


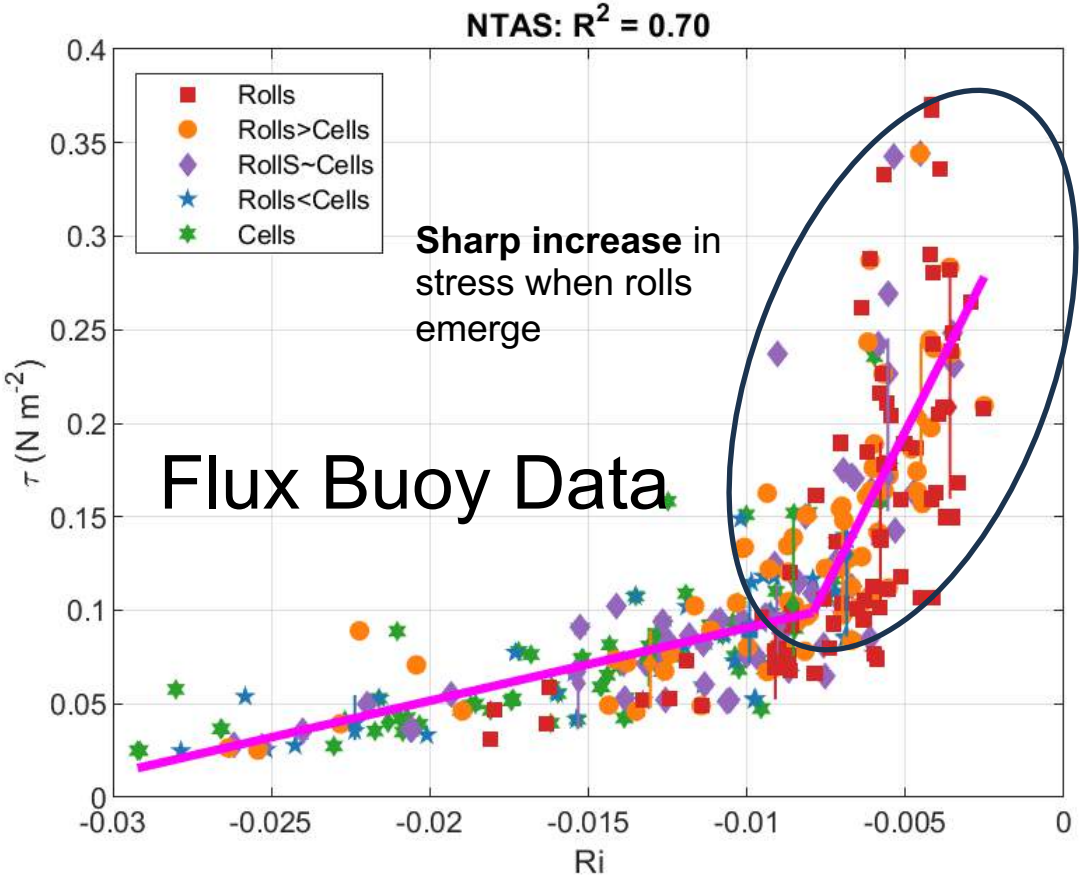
Color Scheme

HYPOTHESIS:

1. Natural variability in U10 tends to neutralize PBL, shifting mean state toward rolls.
2. **Rolls induce non-gradient momentum flux in addition to homogeneous Reynolds Stress**
3. Changes slope of U10(Ri)



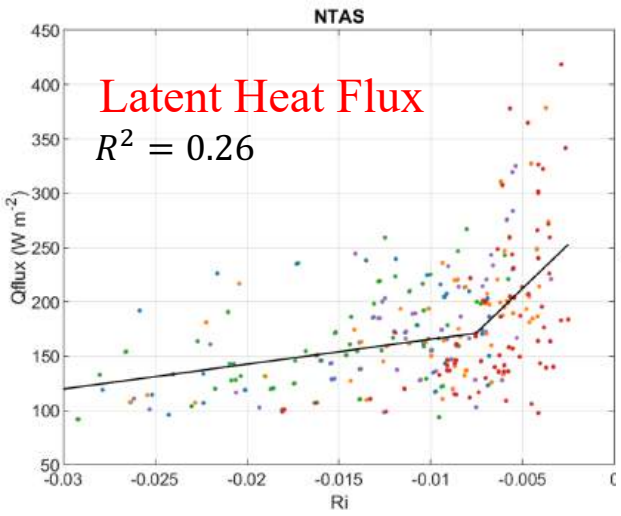


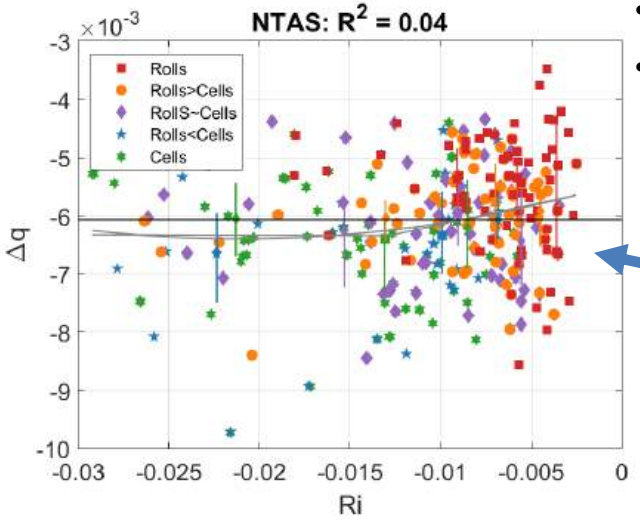


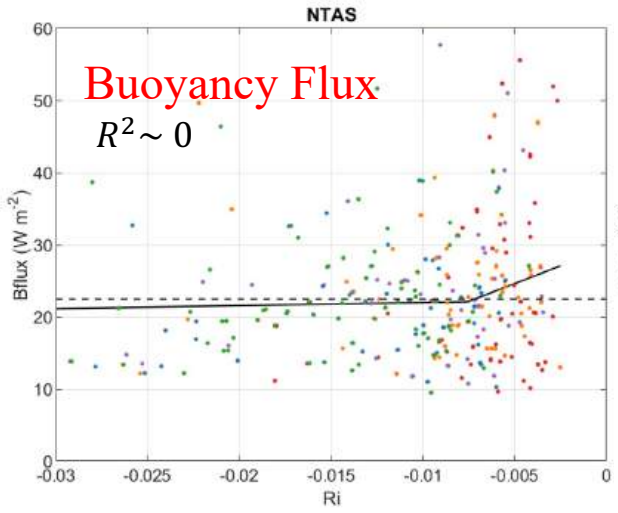
2nd-order fit is equivalent to bilinear fit

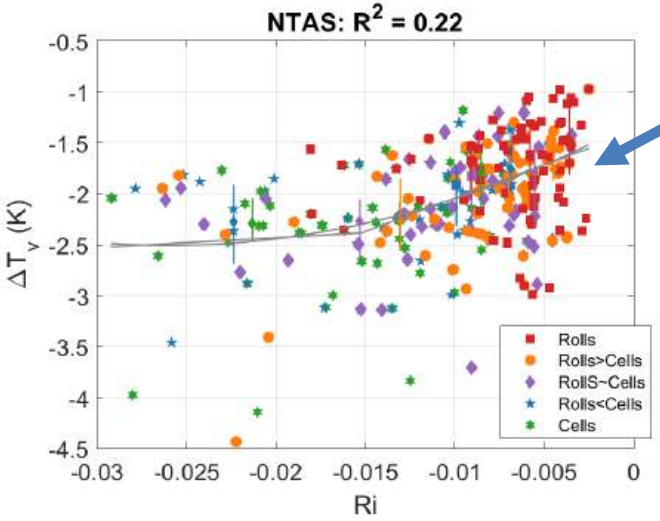
Atlantic Trade Winds Region Upwind of Bermuda

Cautionary Note on Direct Surface Flux Retrievals Using SAR Texture









- **Stratification is primary control on CS**
- **Frequently U10 controls stratification**
  - Latent Heat Flux
    - Δq has large variance
      - mesoscale & temporal variability
    - Δq uncorrelated with Ri
    - **Ri (hence CS) has lower predictability**
      - $R^2 = 0.26$
      - Speed effect "blurred"
  - Buoyancy Flux (~sensible heat flux)
    - $|\Delta T_v|$ anticorrelates with Ri
      - Unknown (to us) reason
    - **Nets to NO predictability with RI (CS)**
      - $R^2 \sim 0$
      - Speed effect neutralized

NTAS Buoy

Of course: High predictability of stratification (Ri) & Stress/Wind

Cloud Type Vs SAR classes

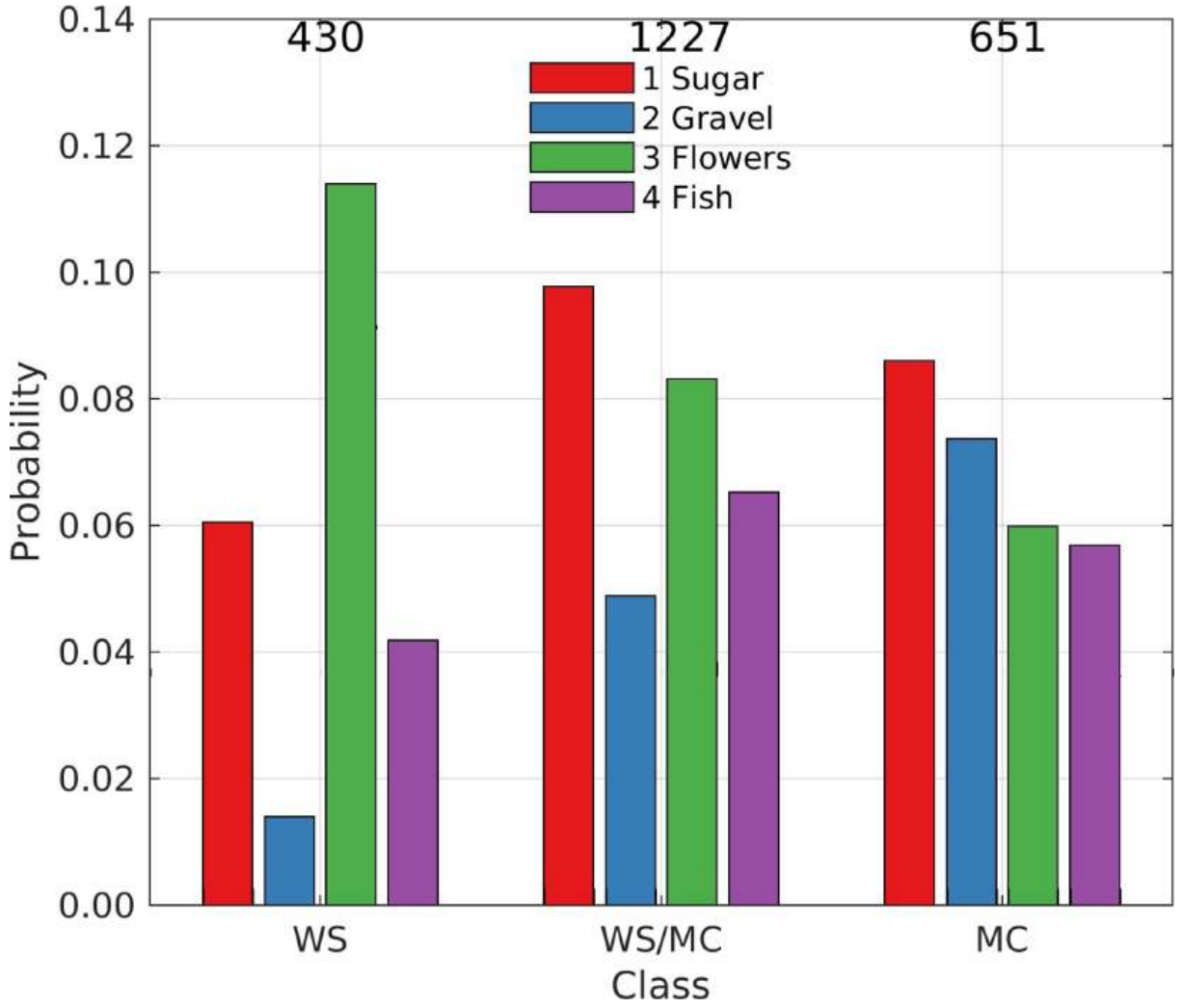
- Hand-tagged database near NTAS
- Simplified to uniform images & 3 classes: WS, WS/MC, MC

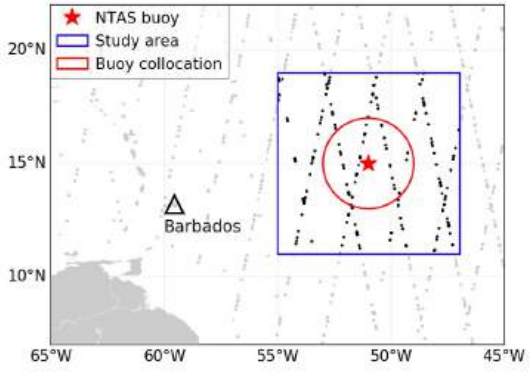
Note:

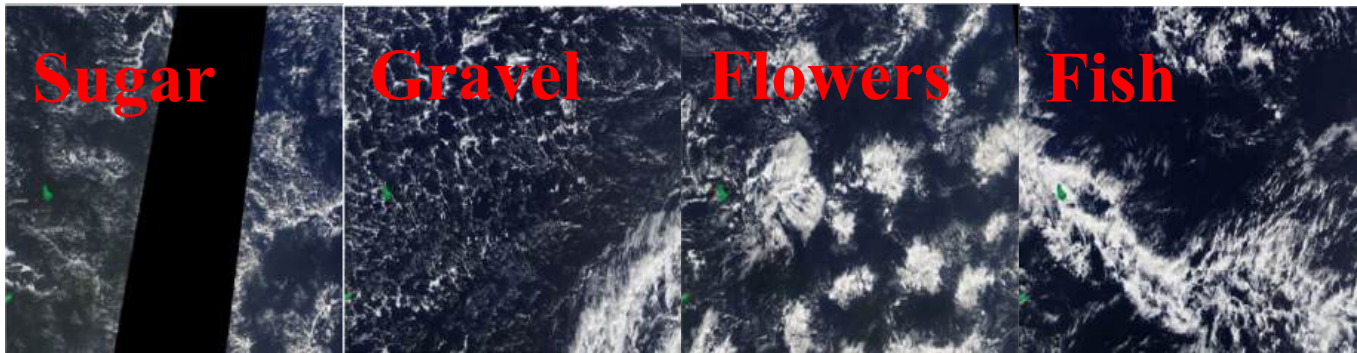
- WS→WS/MC→MC: increasing gravel & fish & sugar
- WS→WS/MC→MC: decreasing flowers

Next up:

- WindSAT and/or COWVR moisture flux convergence
- Examine ASCAT wind MLE (cone-distance)

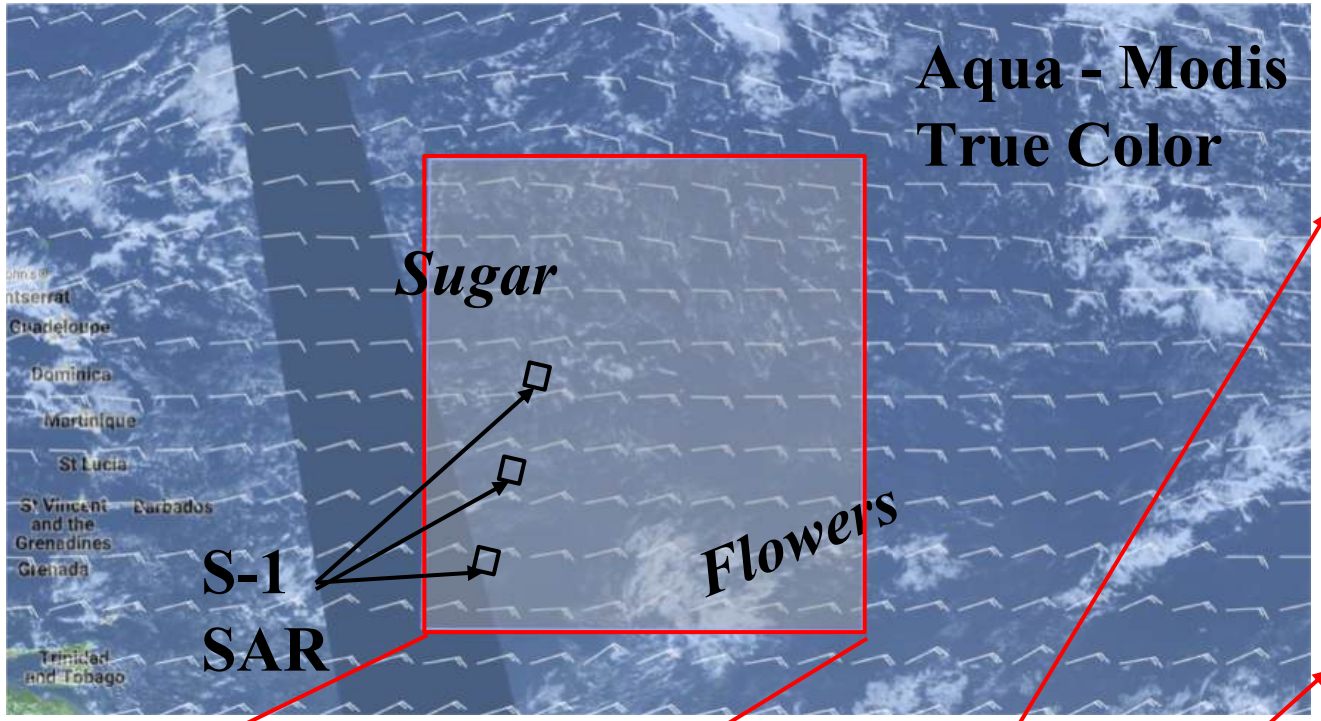


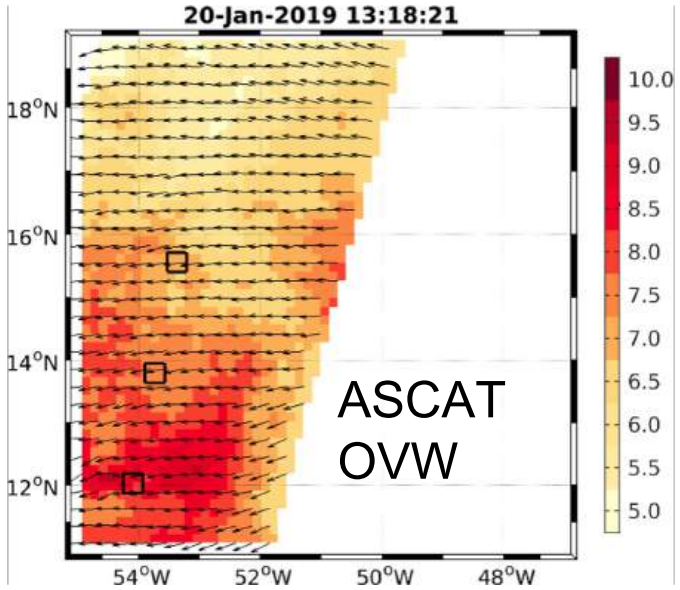


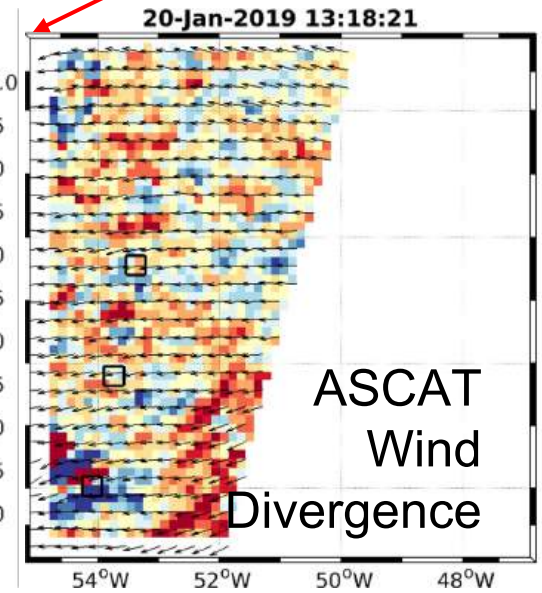


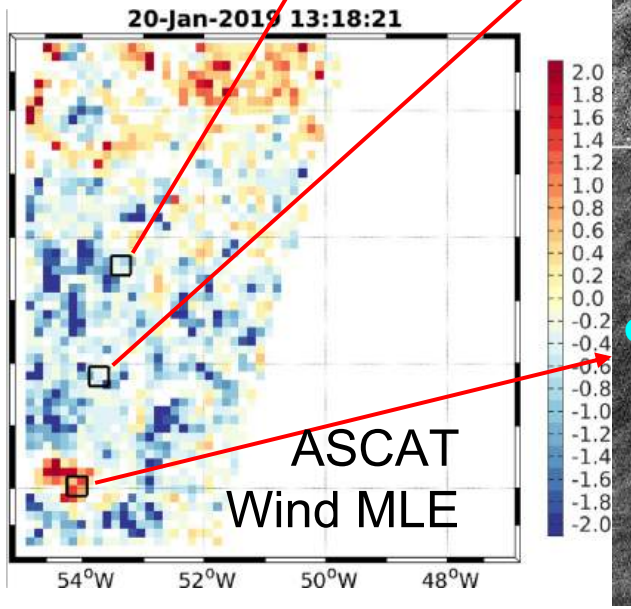
OVW/SAR

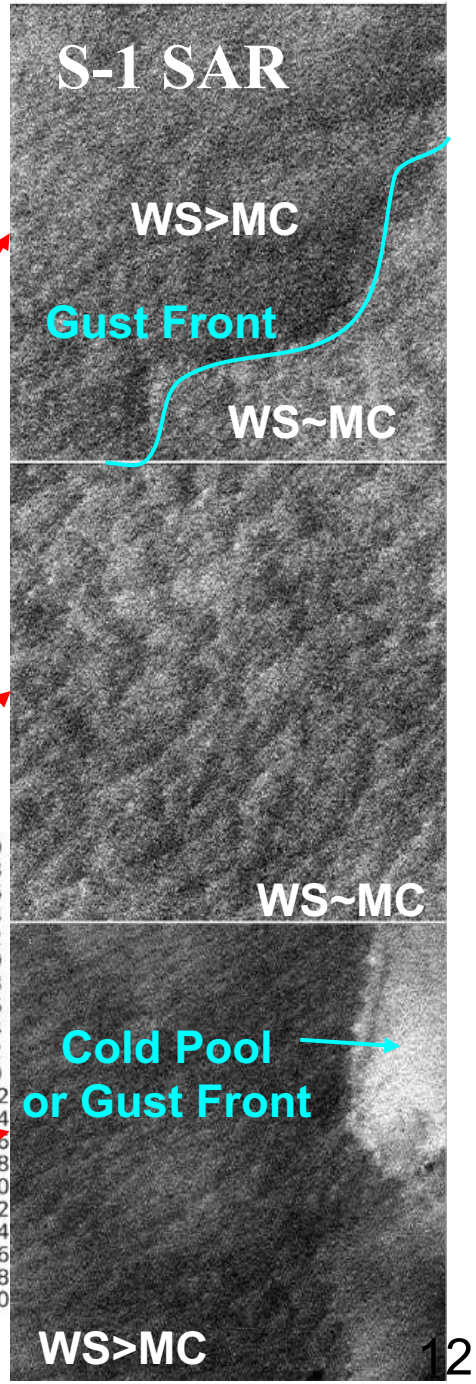
Combination of scales and technologies for 20 Jan. 2019 showing the regional scales from Modis Aqua visual cloud imagery 17:30 UTC, mesoscale surface wind vectors from ASCAT at 13:12 UTC, and localized fine-scale turbulence in the MABL from SAR WV images at 09:26 UTC. SAR images have N at the top of the image.











Summary

- Start of new OVWST project
  - Regular meetings with UW (CICOS & Atmos. Sci.) PBL Cloud experts (Shulz & Eastman)
  - Established data sharing & preliminary dataset explorations & combinations
  - Begun exploration of Eurec4 data
  - New SAR classification model completed, will soon have much improved/longer SAR dataset & ERA5 collocations