Impact of Sea Surface Temperature Anomalies on Low-Level Cloudiness and Mesoscale Organization of Trade Wind Cumulus in the Northwestern Atlantic

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1. Background

Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction Campaign (ATOMIC): [1]

- Campaign region: lower branch of the northeasterly trade wind (see Fig.1.1)
- SST spatial variation within 1°C
- Oceanic dynamical regime:
  transition from mesoscale $O(R_o)<<1$ to submesoscale $O(R_o)\sim1$

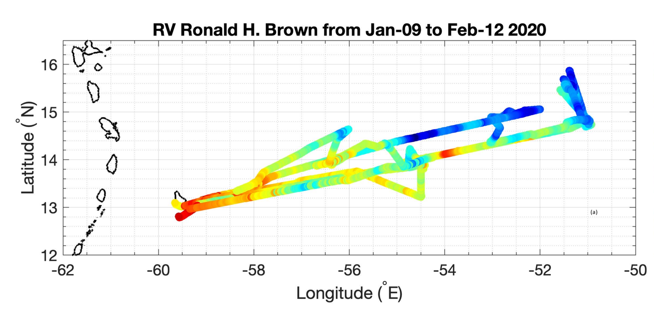
Shallow Trade Cumulus:

- cloud top capped by the trade wind inversion (2km~3km)
- mainly organized into four different mesoscale patterns [2] (see Fig 2.2)
- cool our planet and resilient to global warming, at the heart of long-standing uncertainties in climate model[4]

Questions and Objectives:

Q1: Does the relatively weak and fine-scale spatial variation of sea surface temperature (SST) in the ATOMIC region affect shallow cumulus cloudiness?
- ➢ Seek evidence from observations. *(this poster)*

Q2: If so, does it play a role in the formation of any of the mesoscale organizations in the ATOMIC region?
- ➢ Obtain process-level understanding from cloud-resolving Large Eddy Simulations *(on-going work)*



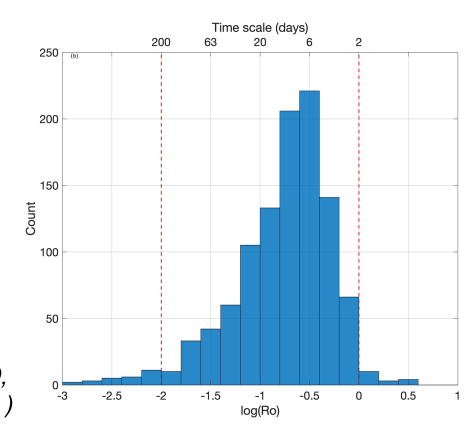


Figure 1.1 ATOMIC sampling region and its characteristics. *(a): SST sampled along RV Ronald H. Brown (RHB) tracks between Jan 09, 2020 and Feb 12, 2020 UTC. (b): Distribution of Rossby number ($R_o=|\zeta|/f$) estimated from surface current along 7 straight RHB transects where SST variance is in the upper quartile.*

2. Data & Methods

I. Data:

A. ATOMIC field data from RHB and wave gliders
- 10-minute surface wind speed (U_{10})
- 10-minute sea surface temperature

B. Satellite data:
- 5-km daily GOES-POES blended L4 SST product
- 2-km hourly GOES-16 L3C cloud mask
  → 5-km daily averaged cloud cover fraction

C. ERA5 Reanalysis (daily, 0.25°)
- Surface wind speed U_{10}
- Potential temperature profiles (θ)
- Lower Tropospheric Stability ($\theta_{700}-\theta_{1000}$)

II. Methods:

A. Wavelet coherence analysis on field data
- ➢ Follow recipes developed in [5]
- ➢ Assumption: SST and surface wind measured along transects represent mainly spatial variation.

B. Statistical analysis on satellite data[6],[7]
1. Relationship between daily cloud cover fraction anomalies and effective downwind SST gradient ($\vec{u}\cdot\nabla SST$).
2. Feature-based composite analysis:
   - ➢ Object-based feature detection method based on connectivity (*Dias et al. 2012*)
     - Two types of features: warm (>0.1°C), cold (<-0.1°C)
       SST spatial anomaly: $SST_d(x,y) - \langle SST_d\rangle_{600km}(x,y)$
       where $\langle SST_d\rangle_{600km}$: *Gaussian low-pass filtered at 600km*
   - ➢ Composite in a feature-centered, normalized and surface wind aligned coordinate.

Premises:

1. If the SST features have consistent impacts on cloudiness → some local changes in it (relative to when these impacts are negligible.)
2. Requirements for consistencies:
   - Features are less transient relative to the clouds (√)
   - Favorable atmospheric environments

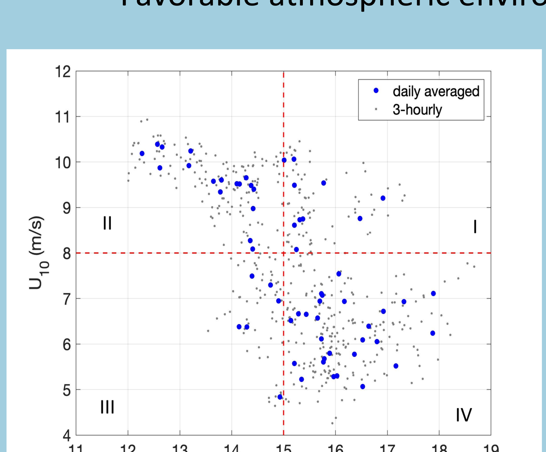
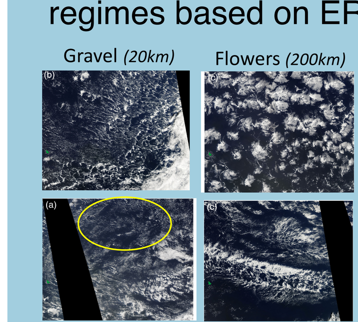


Figure 2.2 Definition of four atmospheric regimes based on ERA5 U_{10} and LTS.[3]



cloud organizations associated with the 4 regimes

Adapted from Stevens et al. (2020) [2]

3. Results

I. Local coherence between surface wind and SST

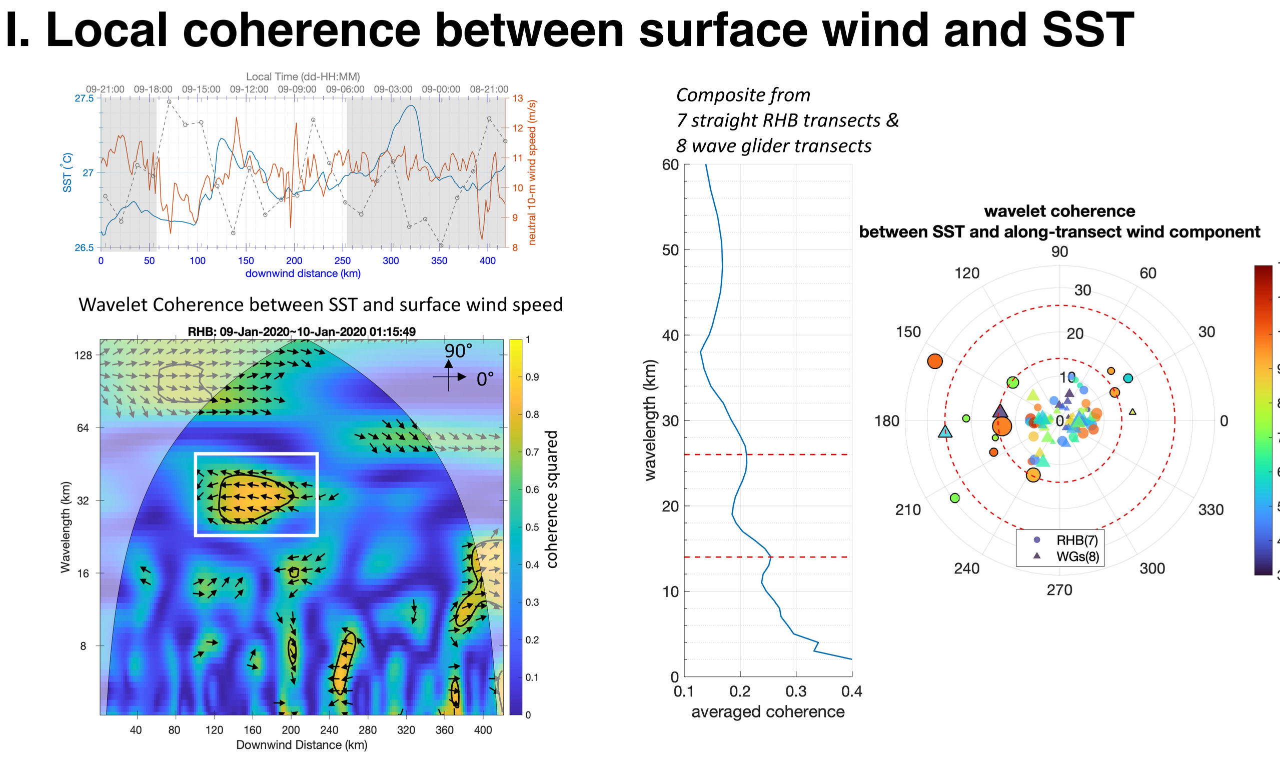


Figure 3.1 Covariation of SST and surface wind

- **Left panels:** An wavelet coherence example on Jan 9, 2020 where two warm features were capture along the RHB transect.
- **Middle panel:** Surface wind and SST correlates well at 14 km and 26 km on average.
- **Right panel:** The significant coherence regions at the two characteristic length scales roughly have two different phases
  - ~30°, positive correlation, with surface wind lags SST by a phase of 30° (downward mixing mechanism?)
  - ~180°, surface wind is out of phase from SST (wind forces the ocean or pressure adjustment mechanism is in play)

II. Relative change in cloudiness in different atmospheric regimes and its relationship with SST gradients

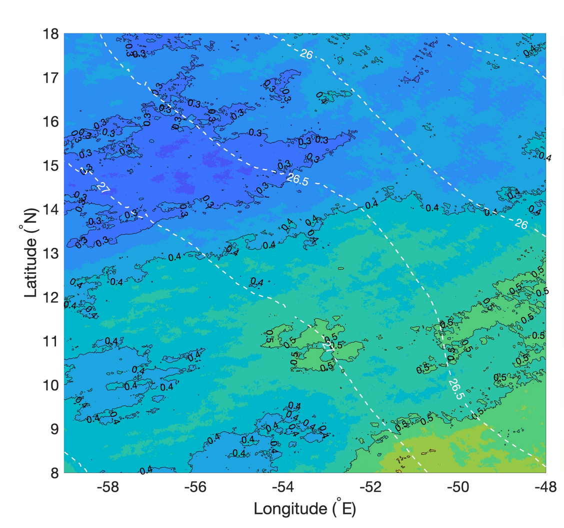


Figure 3.2 Cloudiness (occurrence frequency) during the 2-month data period.

White-dashed contours: 2-month mean large-scale SST

Assumption: influence of the fine-scale SST variability on cloudiness is assumed to be weak in this two-month mean state.

- Overall, we see that the cloudiness increases from northwest (~0.3) to southeast (0.5)

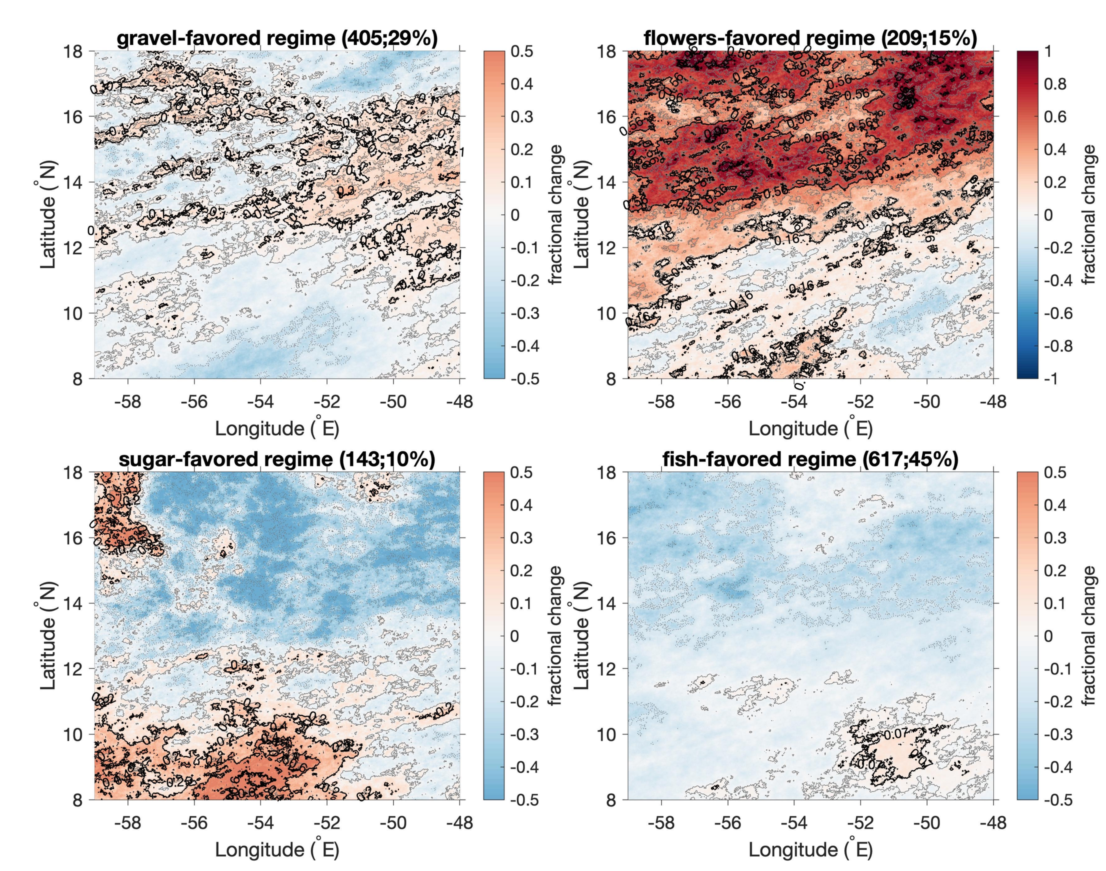


Figure 3.3 Relative change of cloudiness relative to the reference state in four atmospheric regimes.

The first level of the thick black contours: 95% confidence level for positive fractional change

Cloudiness hotspots: significant localized increases in cloudiness; an indication of inhomogeneity in the environment. (e.g., influence from SST warm anomalies)

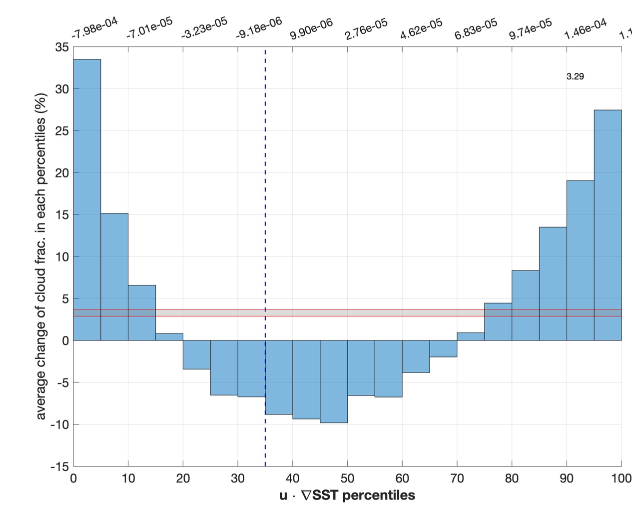


Figure 3.4 Relative change of daily-mean cloudiness from the 2-month "climatology" as a function of effective downwind SST gradients.

Blue dashed line: percentile where the SST gradients change sign. (<0: warm-to-cold gradient; >0: cold-to-warm gradient)
Red shaded horizontal bar: 95% range of expected values in the null hypothesis.

- On average, enhanced daily-mean cloudiness is associated with extreme SST gradients.

III. Feature based composite analysis

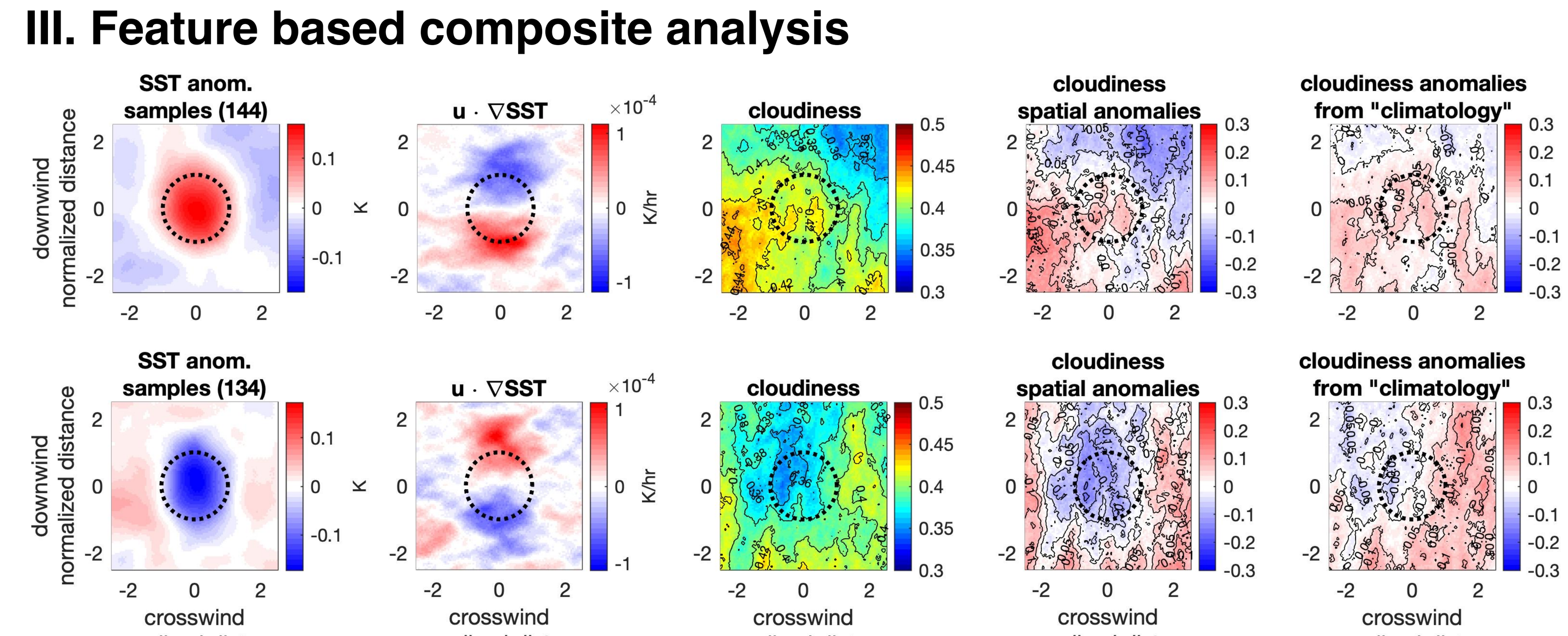


Figure 3.5 Composites of cloudiness and its anomalies over warm and cold features in the gravel-favored atmospheric regime.

x/y-axis: cross-wind/downwind distance normalized by radius of the features
Dotted circle: radius = 1

- Relative to the spatial mean cloudiness (cloud cover fraction), cloudiness increases (decreases) by 5~10% over the center of the warm (cold) features;
- Relative to the 2-month mean cloudiness: ~5% increase of cloudiness over the center of warm features, on average, no significant change of cloudiness over cold features.

4. Summary

- Over scales of 14 km and 26 km, surface wind and SST are mostly be out of phase along 15 RHB and wave glider transects.
- On average, daily cloud fraction increases relative to the 2-month "climatology" for strong SST gradients, regardless of the sign.
- Composite analysis shows that in the gravel regime (U10>8m/s, LTS<15K), 5-10% spatial anomalies in cloudiness occur within 1 equivalent radius of both warm and cold features.
- These results together suggest that atmospheric response to the weak SST gradients in ATOMIC sampling region is likely different from that in region with strong SST gradients. (Hypothesis: pressure adjustment mechanism > downwind momentum mixing mechanism in ATOMIC.)

References:

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