Photo: Ray Collins

Using High-Wind Observations to Constrain a Seastate-Dependent Air-Sea Heat Flux Parameterization with Spray for Use in Coupled Atmosphere-Wave-Ocean Models

Benjamin Barr[1], Hyodae Seo[1], Cesar Sauvage[1], Carol Anne Clayson[1], and Jim Edson[1]

[1]Woods Hole Oceanographic Institution

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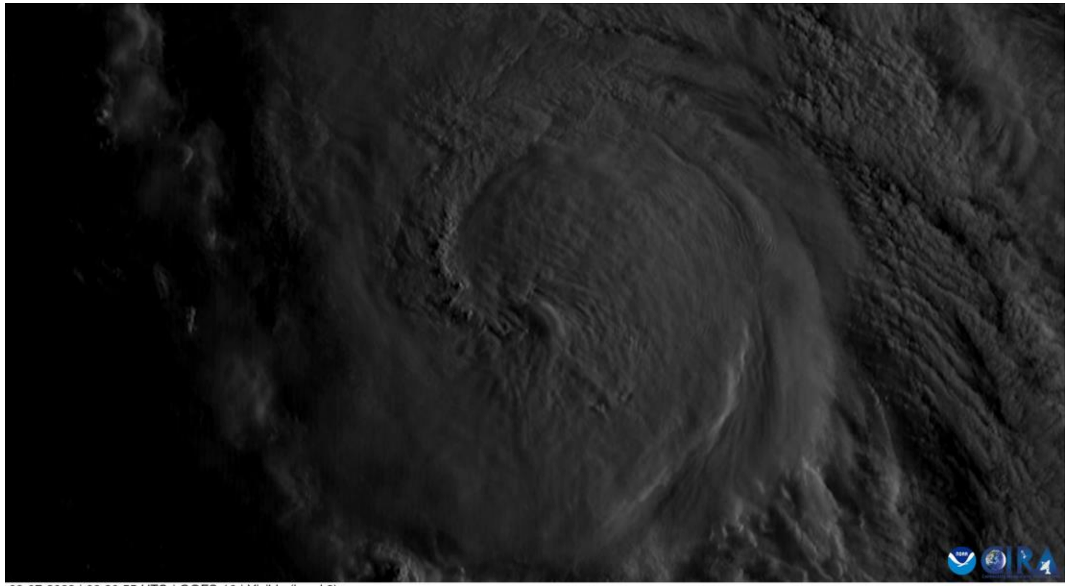
benjamin.barr@whoi.edu

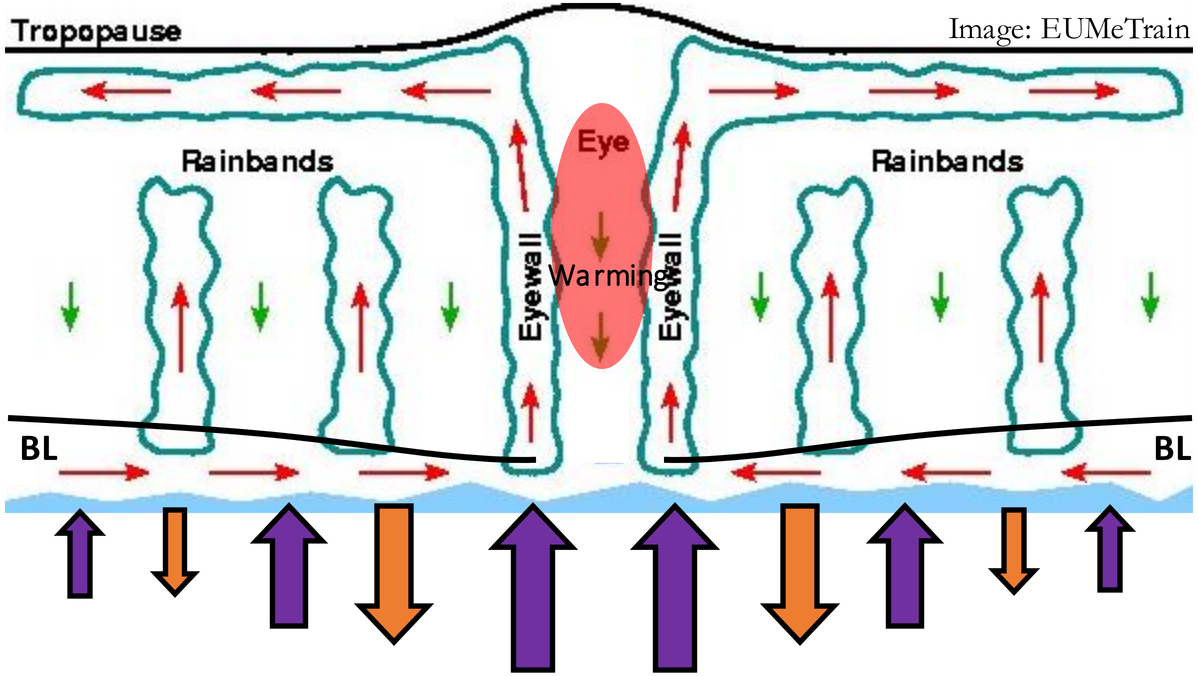
Air-Sea Heat Fluxes Affect TC Structure and Intensity

Hurricane Lee (2023)
12-hour GOES-East Visible, Cat 1 → Cat 4



09-07-2023 | 09:30:55 UTC | GOES-16 | Visible (band 2)

Secondary Circulation

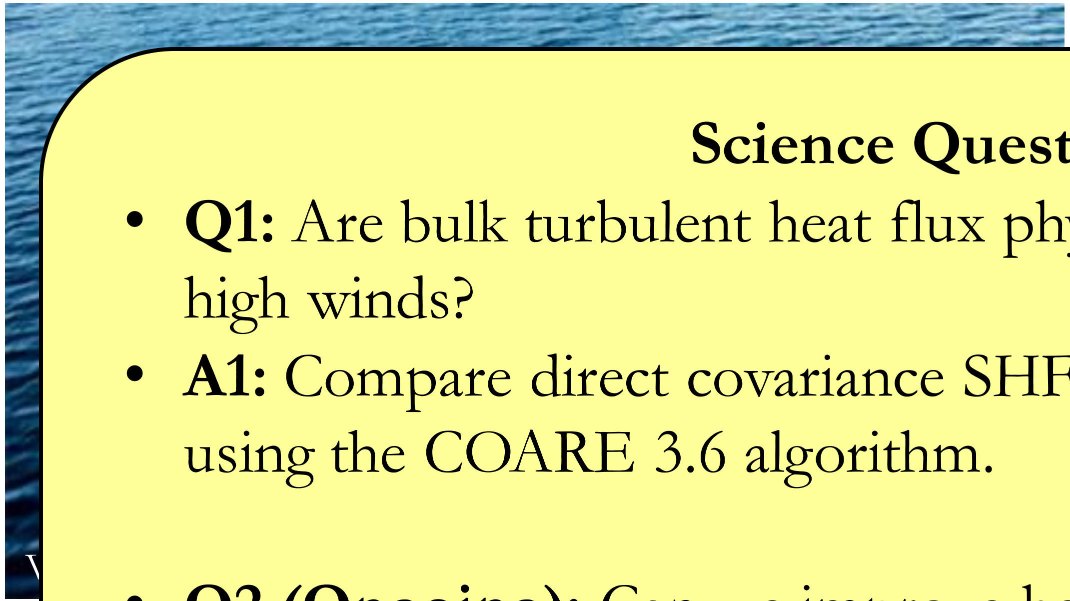


Surface Momentum Flux

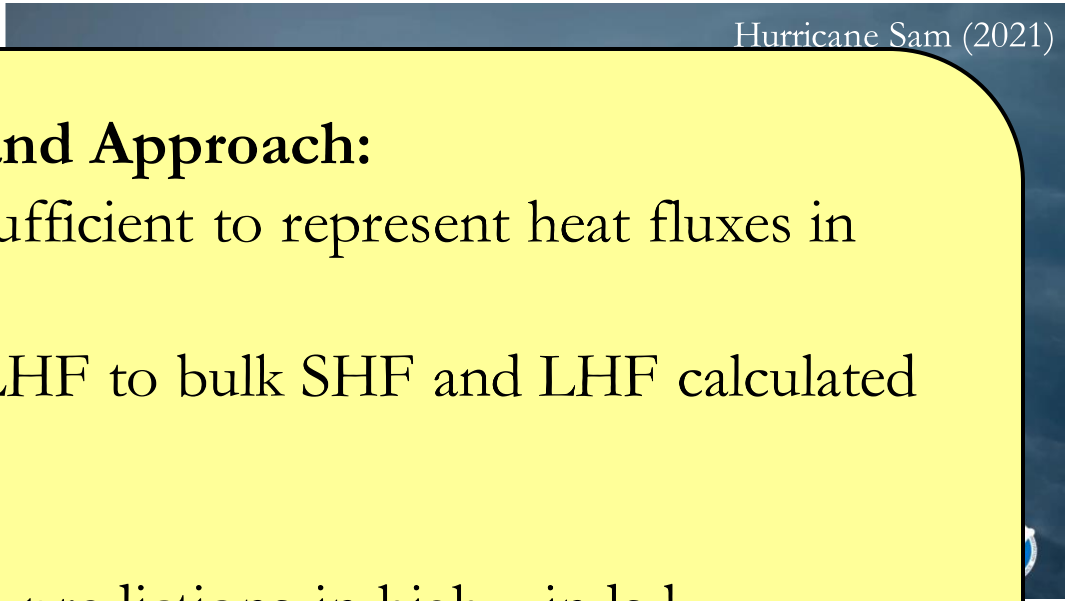
Surface Enthalpy Flux
(Sensible and Latent Heat)

Surface Heat and Momentum Fluxes

The Air-Sea Interface in Low Winds



The Air-Sea Interface in High Winds



Science Questions and Approach:

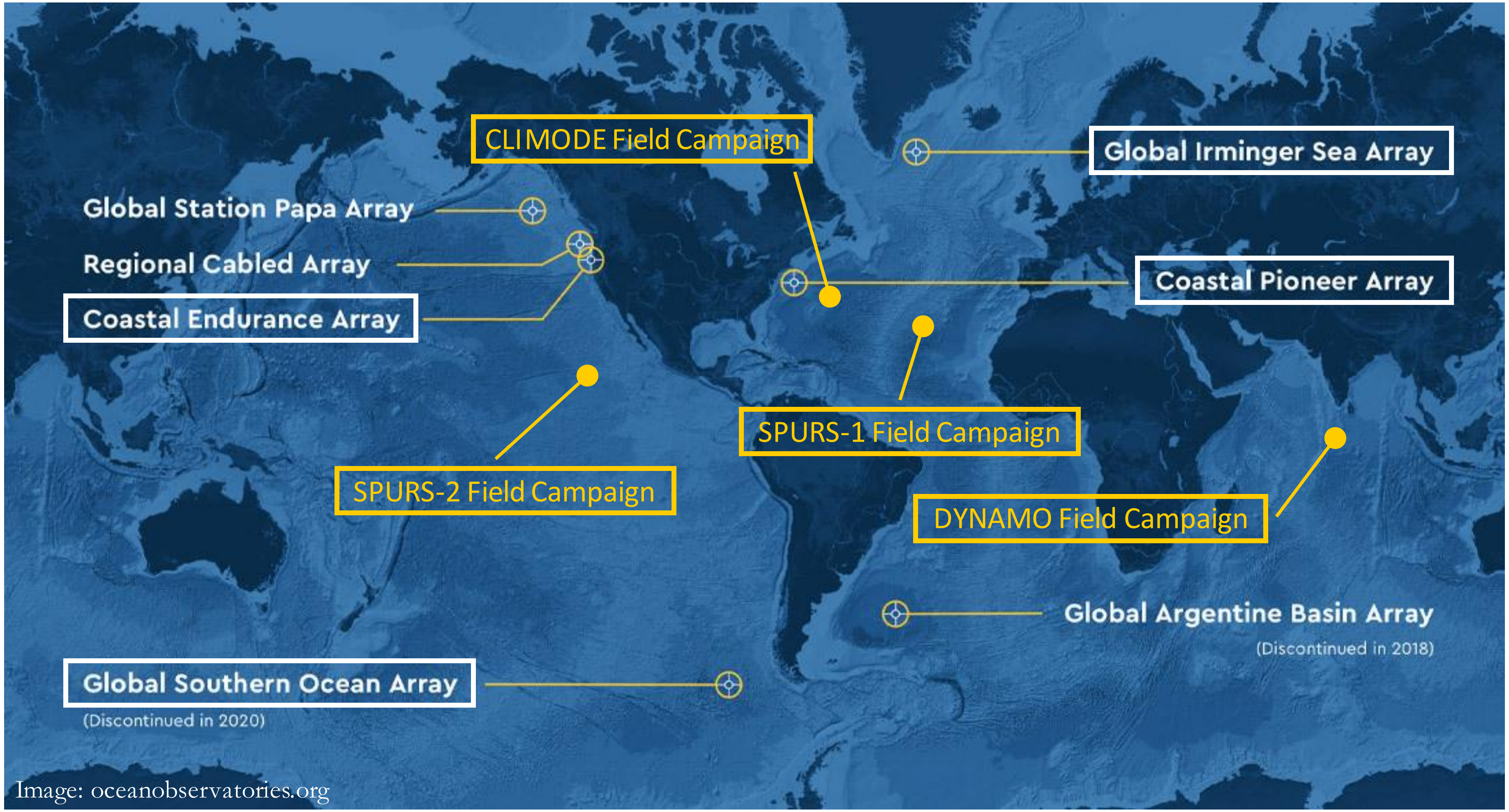
- **Q1:** Are bulk turbulent heat flux physics sufficient to represent heat fluxes in high winds?
- **A1:** Compare direct covariance SHF and LHF to bulk SHF and LHF calculated using the COARE 3.6 algorithm.

- **Q2 (Ongoing):** Can we improve heat flux predictions in high winds by incorporating sea spray physics?
- **A2:** Add sea spray physics to COARE 3.6 algorithm, calibrate, and test.

$$\left[\ln(10/z_0) - \psi_M\right]\left[\ln(10/z_{0t}) - \psi_H\right] \quad \ldots \theta_{10})C_{h10}$$

$$\text{LHF} = \rho L_v \overline{q'w'} \quad = \rho L_v U_{10}(q_s - q_{10}) \left[\frac{\kappa}{\ln(10/z_0) - \psi_M}\right]\left[\frac{\kappa}{\ln(10/z_{0q}) - \psi_H}\right] = \rho L_v U_{10}(q_s - q_{10}) C_{e10}$$

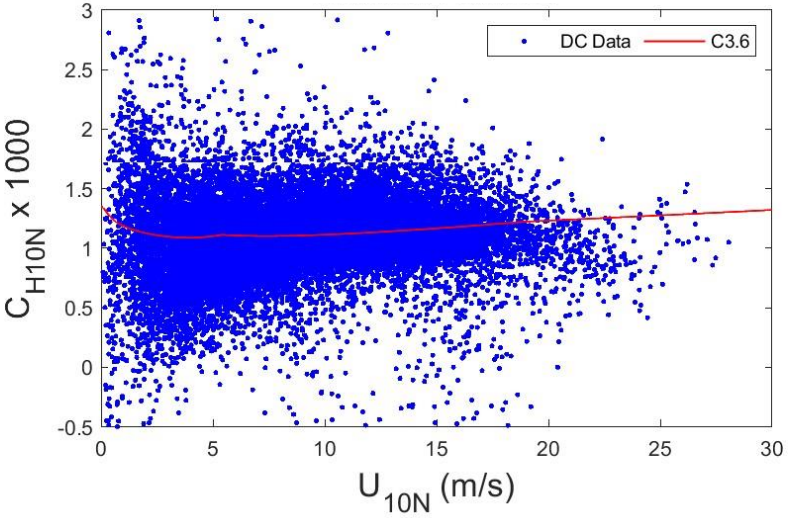
Direct Covariance Datasets – OOI and More

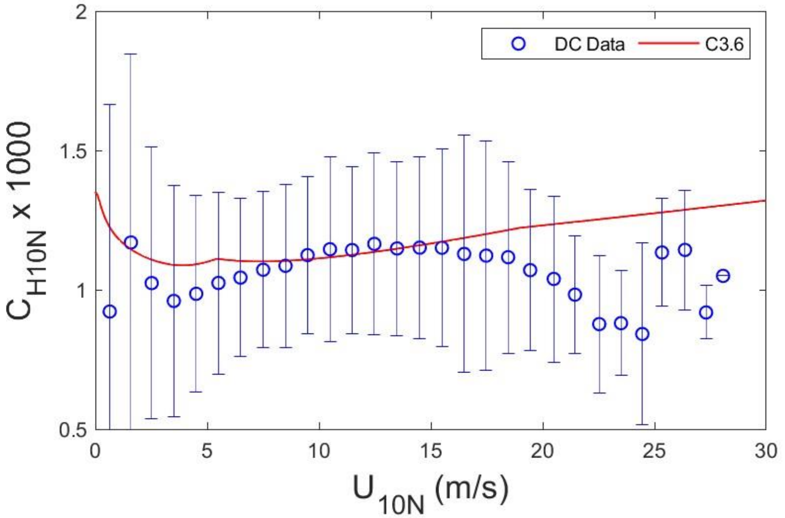


- **Sonic Anemometer**
  - Momentum flux
  - Sonic buoyancy flux (~sensible heat)
- **Infrared Gas Analyzer**
  - Latent heat flux
- **20 min averages, hourly**
- **"Good Data" Values**
  - Mom flux: 51,000
  - SHF: 20,000
  - LHF: 17,000 – but very few for $U_{10} > 20$ m/s!

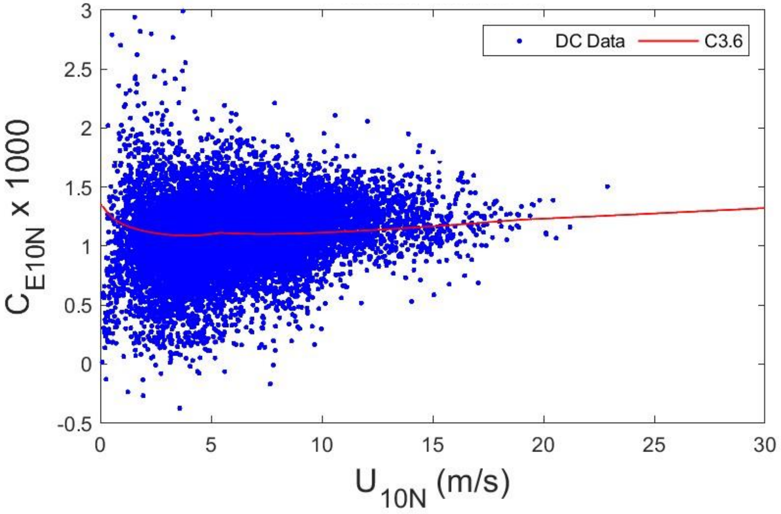
Sensible and Latent Heat Show Divergent Behavior in High Winds

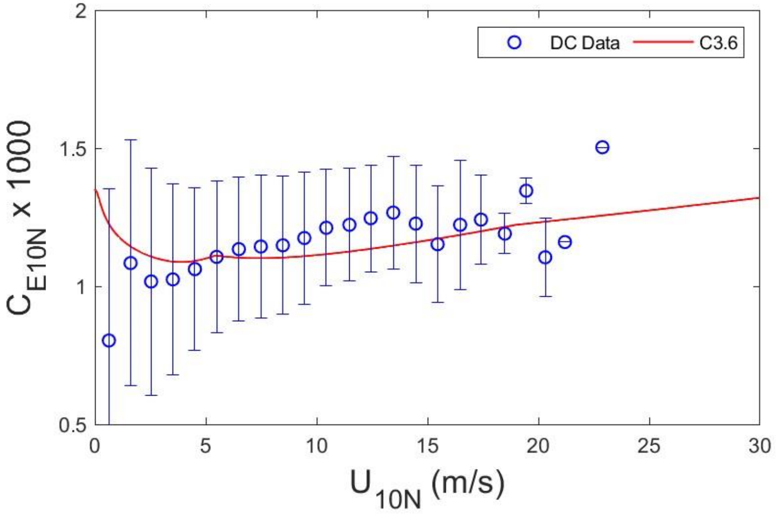
Sensible Heat



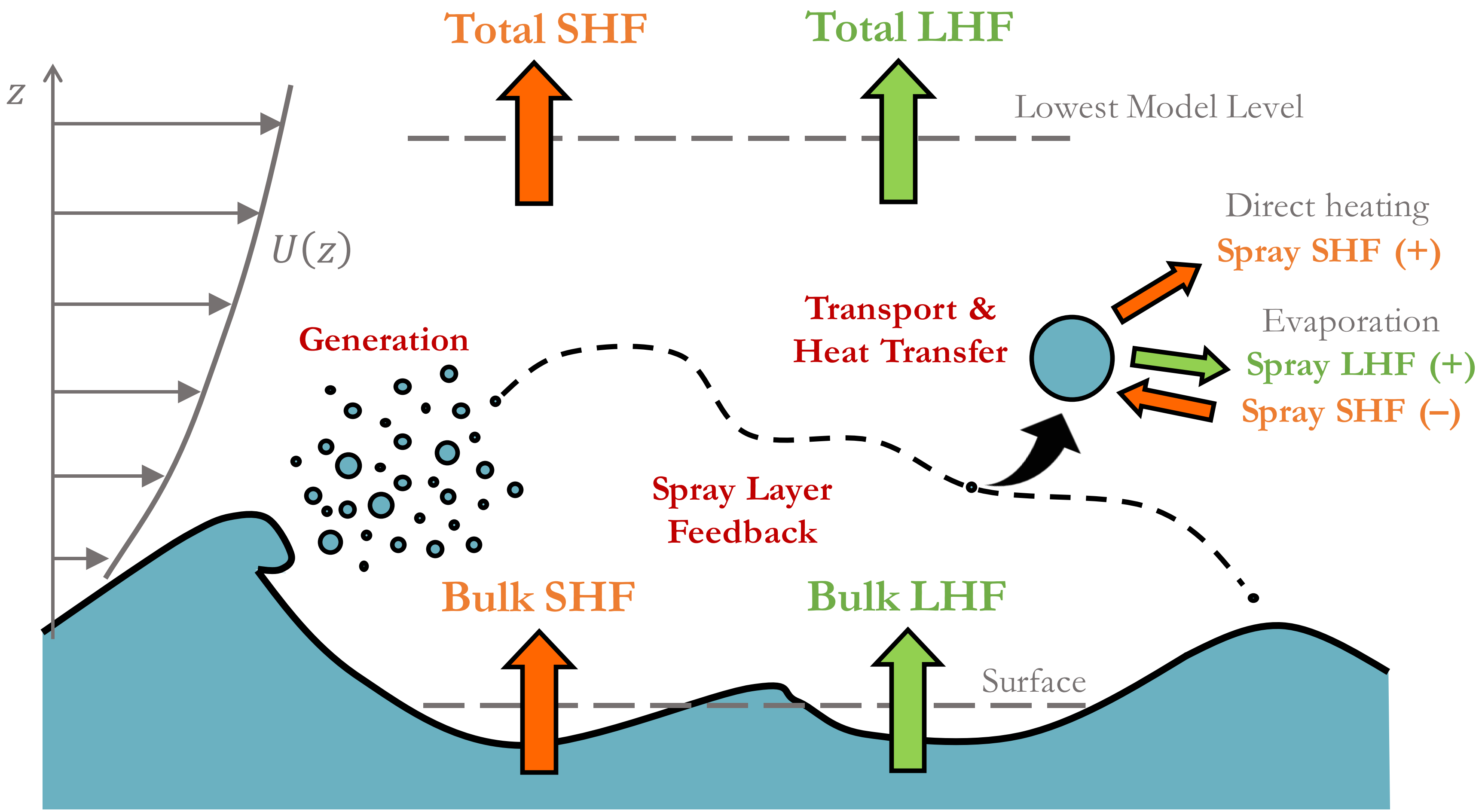


Latent Heat



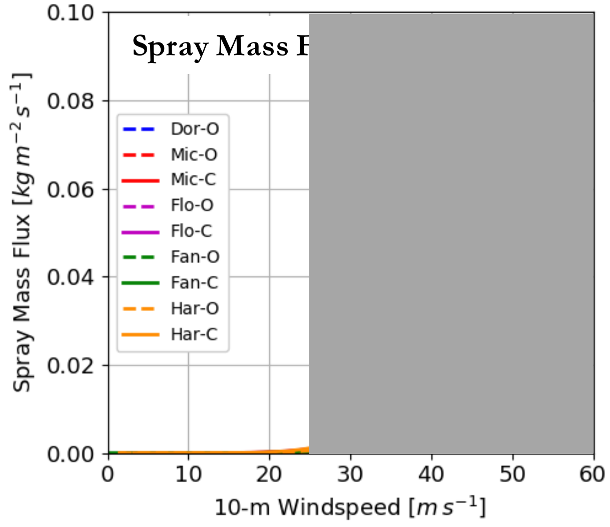


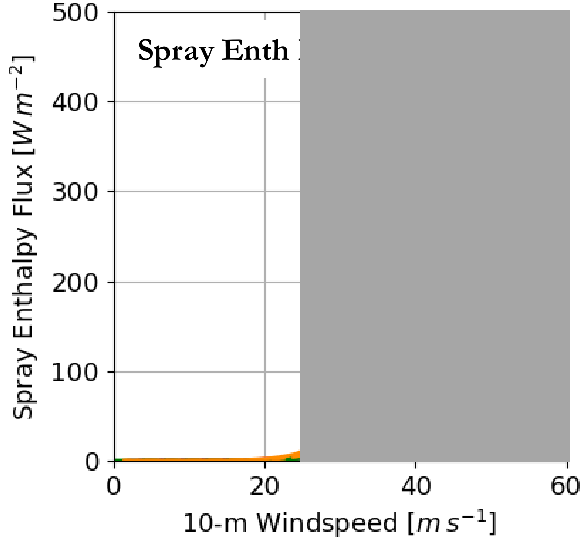
Heat Fluxes with Spray

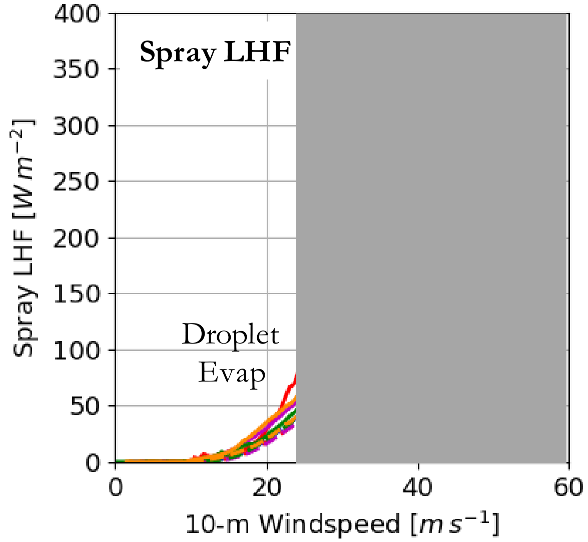


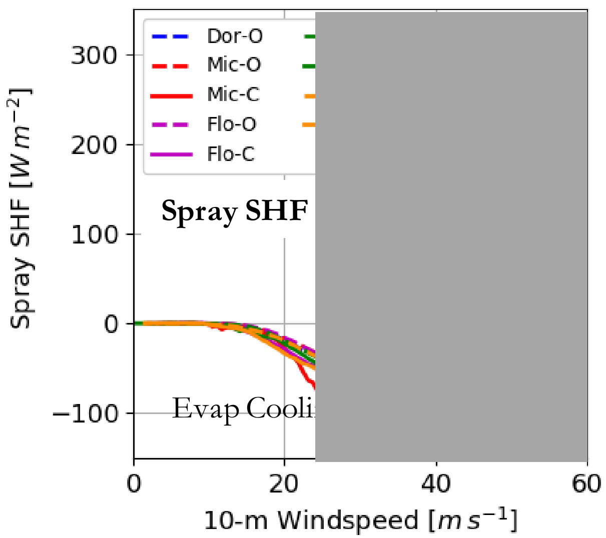
Model derivation in: Barr, Chen, and Fairall (2023), JAS.

Spray SH, LH, and Enthalpy Fluxes Have Different Behavior



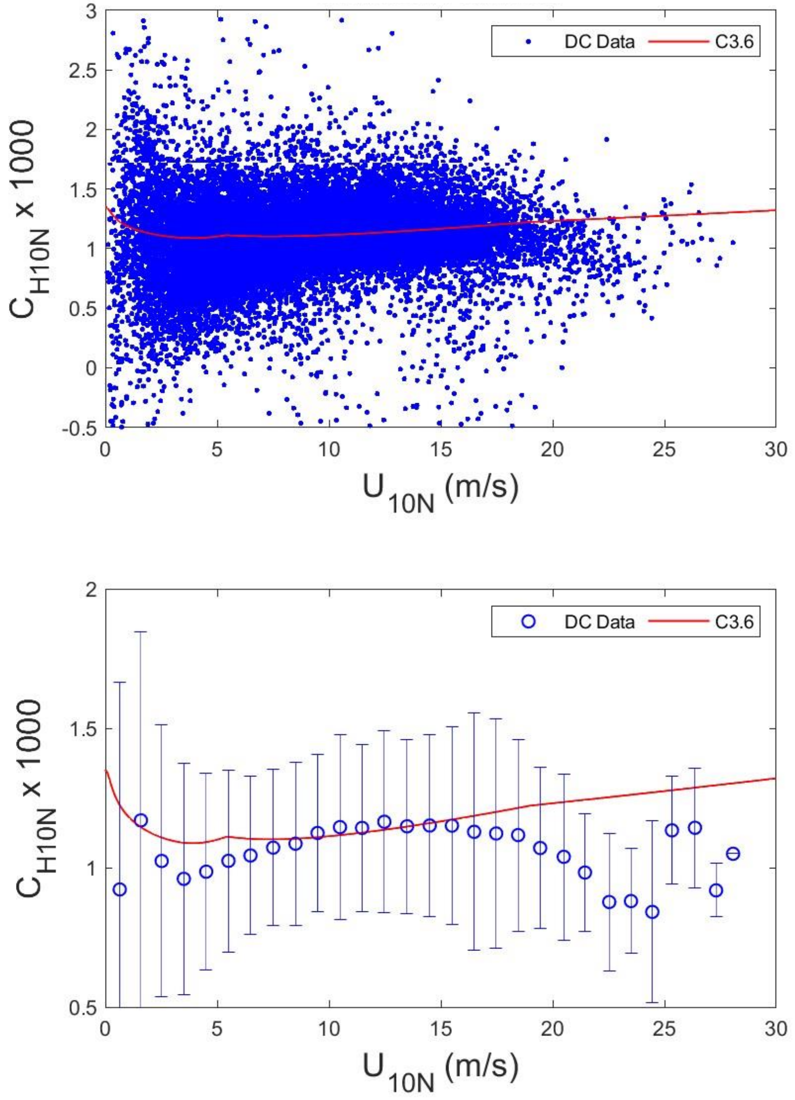




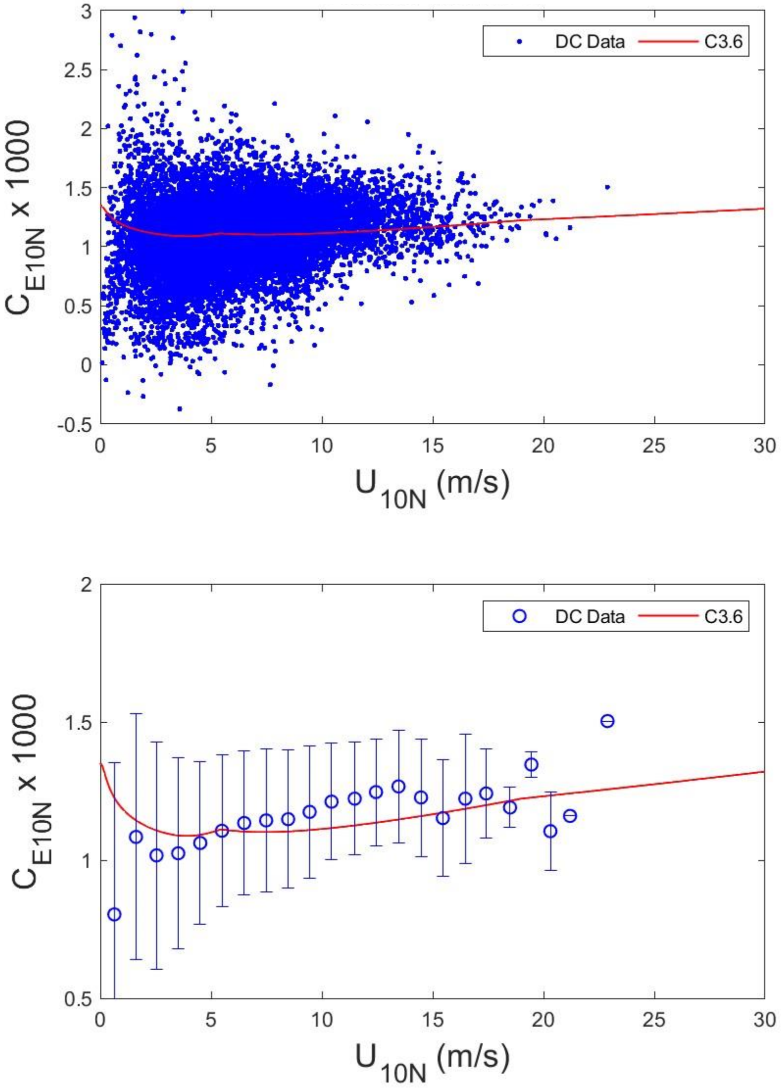


Spray Physics Explains Divergent Heat Flux Behavior

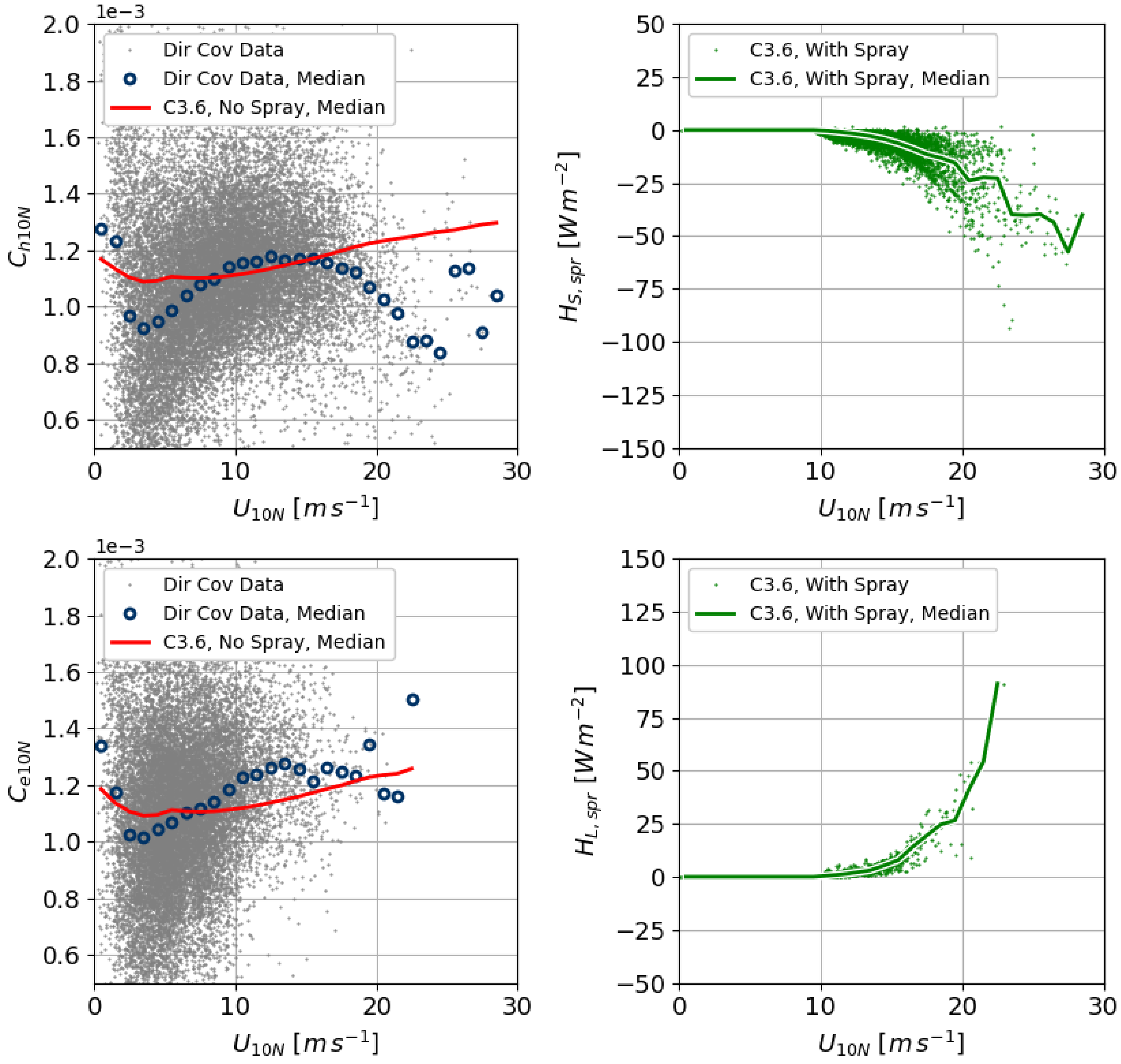
Sensible Heat



Latent Heat



Spray Physics Improves Prediction of Sensible and Latent Heat Fluxes



Conclusions and Next Steps

- Conclusions
  1. Bulk turbulent physics does not seem sufficient for representing heat fluxes in high winds (i.e., U_{10} > 20 m/s).
  2. By incorporating spray heat fluxes into the COARE algorithm (ongoing), we anticipate improvement in heat flux predictions.
- Next Steps
  1. Direct covariance sonic temperature (i.e., buoyancy) flux is routinely measured, but latent heat flux is not. Both are needed to improve parameterization of heat fluxes with spray. **OOI sites are well positioned (e.g., Irminger Sea) and well suited for augmentation with direct covariance latent heat flux systems to get these important measurements.**
  2. The parameters controlling spray generation in high winds are not firmly established. We need observations of spray, fluxes, and the wave field in high winds and further work to understand air-sea-wave coupled physics in this regime. This will facilitate inclusion of wave-based spray physics in coupled atmosphere-wave-ocean modeling systems.

benjamin.barr@whoi.edu

Backup: Seastate-Dependent Spray Generation

- Wind-based generation is based on whitecap fraction and assumes a fixed droplet size distribution.
- Barr et al. (2023) introduce an updated sea spray generation function (SSGF) based on Fairall et al. (2009).

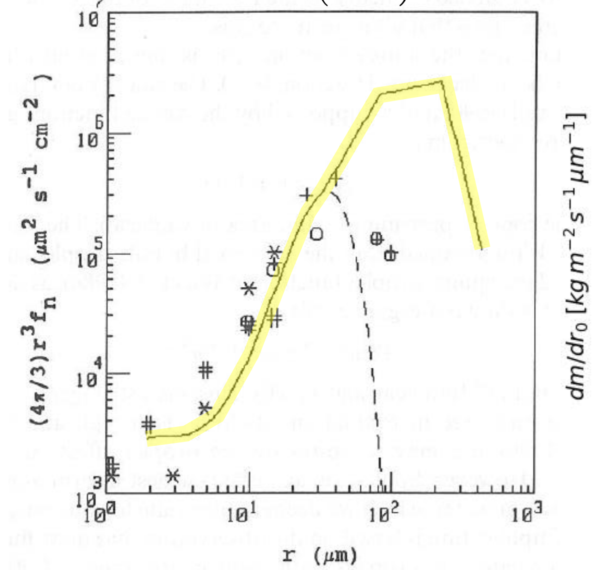
$$\frac{dm}{dr_0} = \frac{C_1 f_s \rho_{sw} \tilde{\varepsilon} r_0 W_{SS}}{3\sigma_{surf}} \exp\left[-\frac{3}{2} C_2 \alpha_k \left(\frac{\pi \eta_k}{r_0}\right)^{4/3}\right] \times \frac{1}{2}\left[1 + \text{erf}\left(\frac{U_{h,rel} - \frac{v_g}{C_3 s_m}}{C_4 \sigma_h} - C_5\right)\right]$$

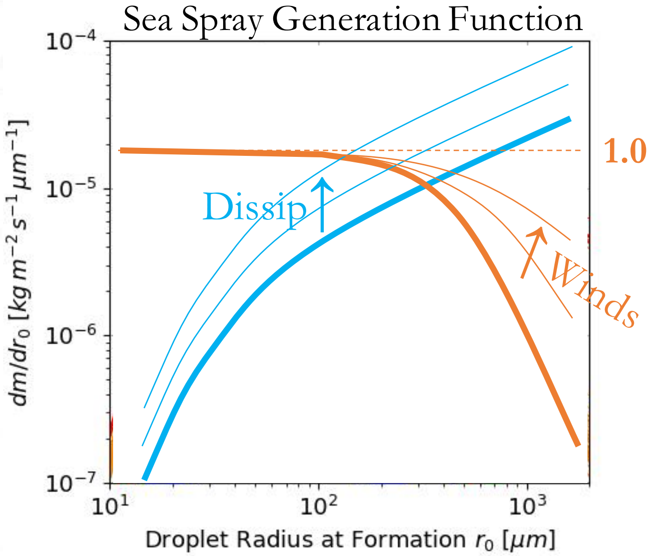
Rate of Formation | Ejection Probability

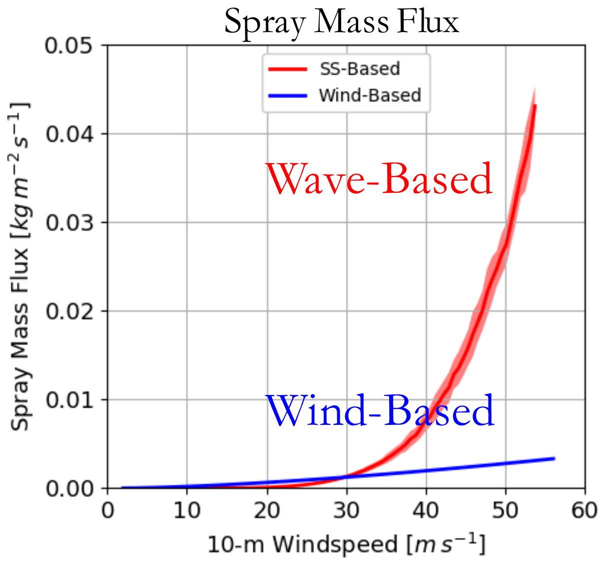
Wind-Wave Properties Used:

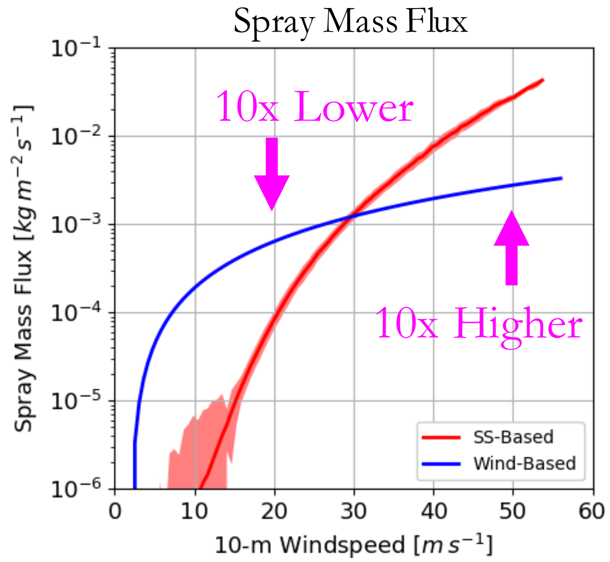
- Surface windspeed
- Wave energy dissipation flux
- Significant wave height
- Dominant phase speed
- Mean squared waveslope
- Wind stress

Fairall et al. (1994) SSGF

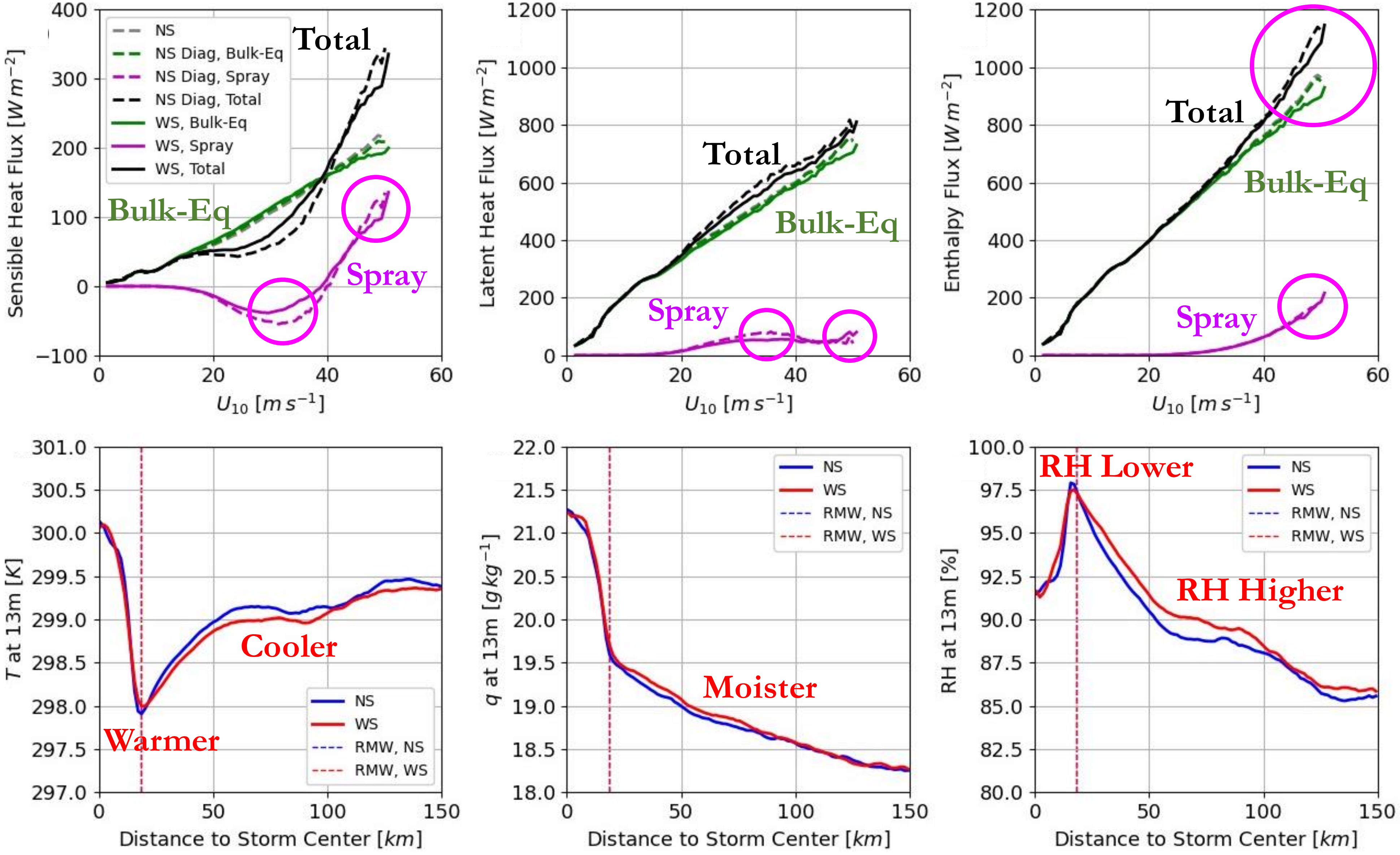




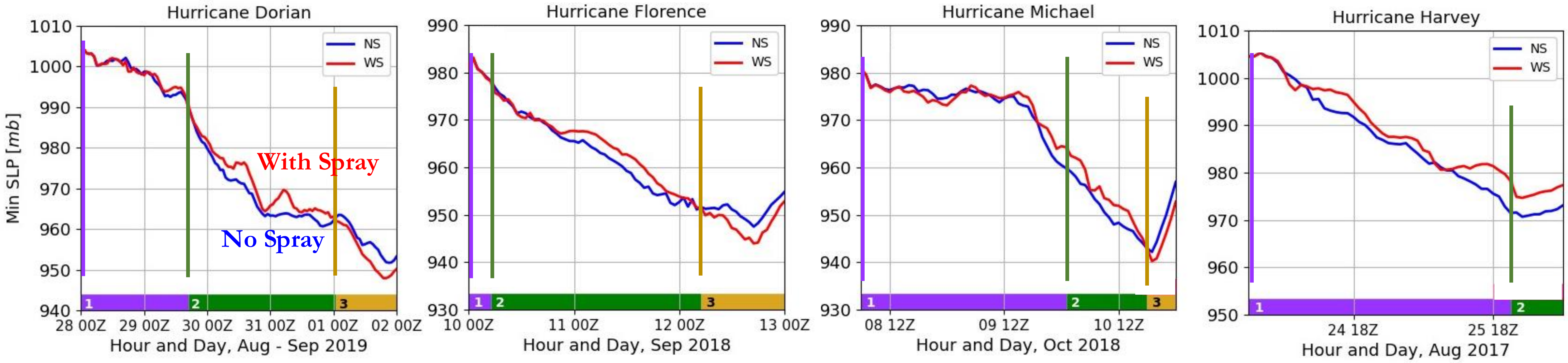




Backup: Spray in the Fully Coupled System



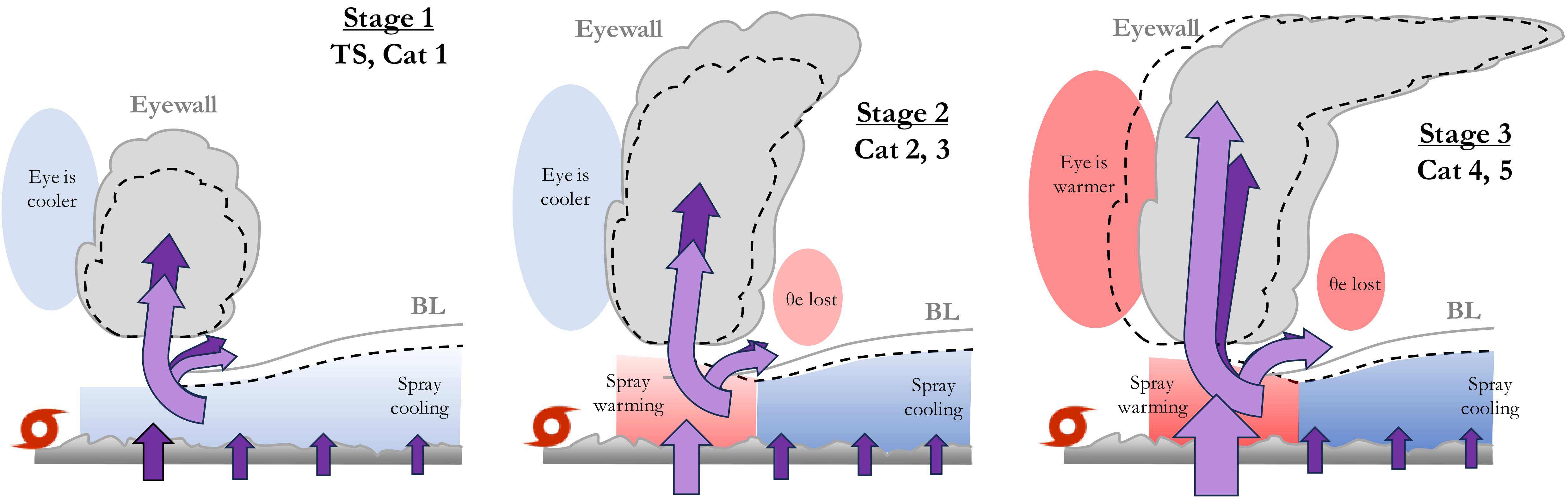
Backup: Three Stages of Spray Impact on Intensity



Spray **cooling suppresses** eyewall deep convection and intensification.
Spray **warming promotes** eyewall deep convection and intensification.

- Stage 1: Spray SHF < 0 everywhere. **Cooling weakens storms.**
- Stage 2: Spray SHF > 0 under eyewall. **Warming starts the comeback.**
- Stage 3: WS MSLP < NS MSLP. **Net influence strengthens storms.**

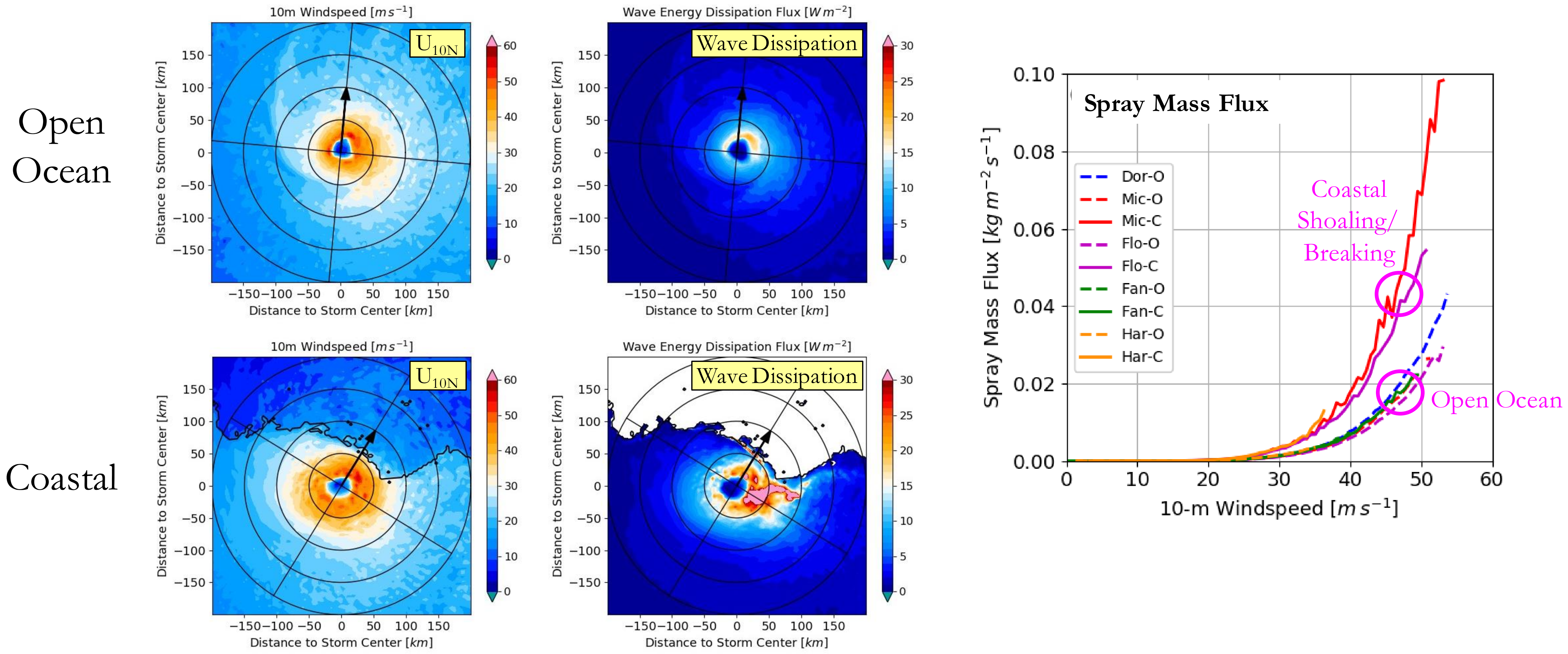
Backup: Summary of Spray's Impact on TC Structure and Intensity



- **Stage 1**: Spray evaporation cools the BL, suppressing eyewall convection. Spray weakens storms.
- **Stage 2**: Spray warms under the eyewall, but this is counteracted by structural inefficiency. Spray weakens storms. However, increasing spray heating under the eyewall eventually invigorates deep convection.
- **Stage 3:** Continued warming by spray fuels deep convection, producing a stronger storm.

Backup: Coastal Interaction Affects Waves and Spray

Hurricane Michael



Backup: Sensitivity to Uncertainty in Spray Generation (Florence)