Calculating Fluxes from Satellite EN Wind: Accounting for Stability Effects

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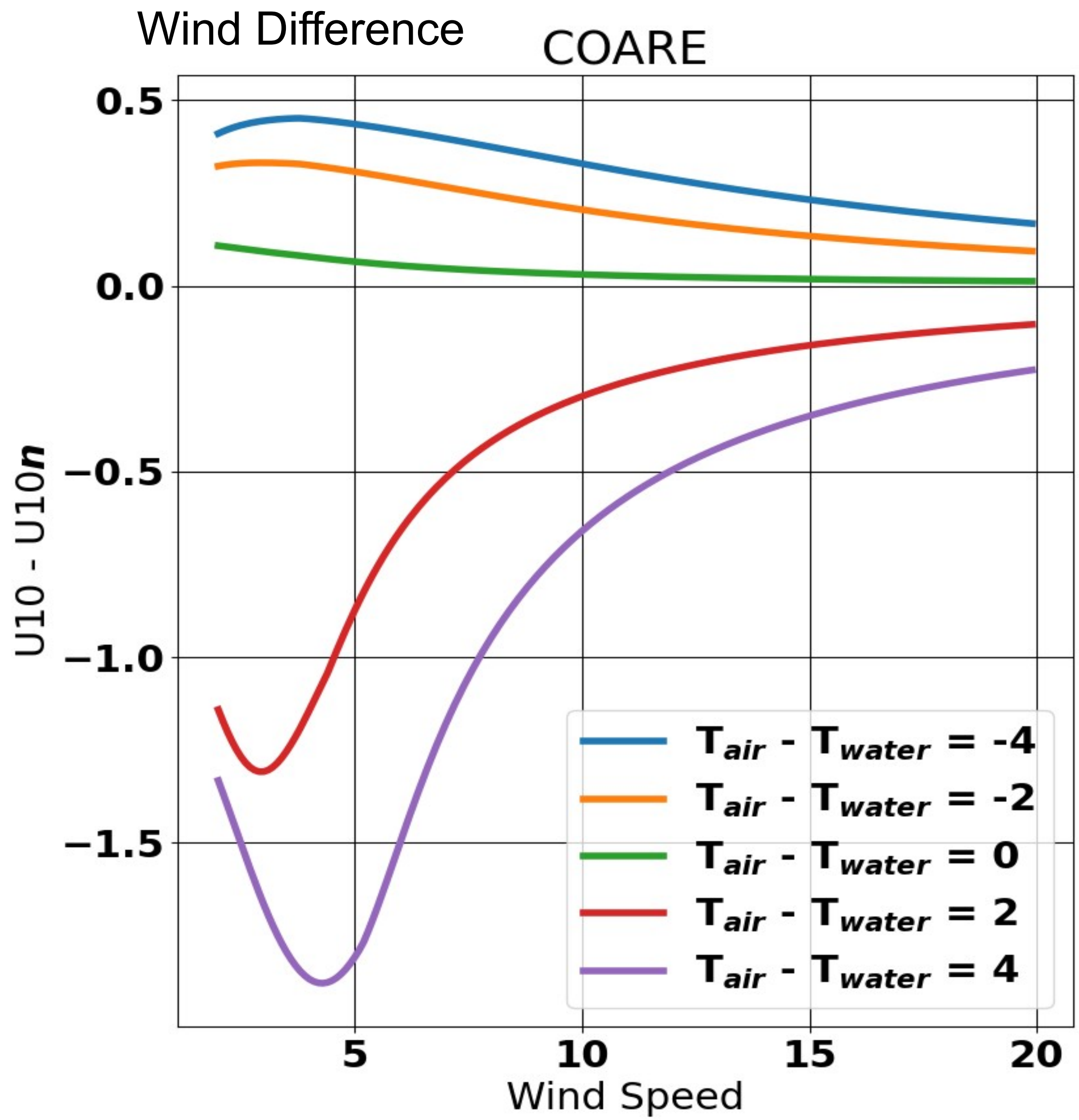
Scatterometer Wind Concept

- Satellite wind data from radar signals relate to wind stress, not wind speeds
- Commonly known as Equivalent Neutral (EN) winds
- EN winds are a theoretical concept and hold validity exclusively under neutral atmospheric conditions (see the next slide)
- Often used in bulk formulas to calculate sensible and latent heat fluxes
- However, stability-related biases can introduce significant errors in flux estimates (see the next slide)

Significance
(Synthetic data ex.)

Stable: Tair – Twater > 0
Unstable: Tair – Twater < 0

- differences between U10 and U10 EN winds are more when atmospheric conditions are highly stable or unstable
- during low wind speed conditions under pronounced atmospheric stability, the discrepancies can become substantial



*moisture also plays important role (not included in this example)

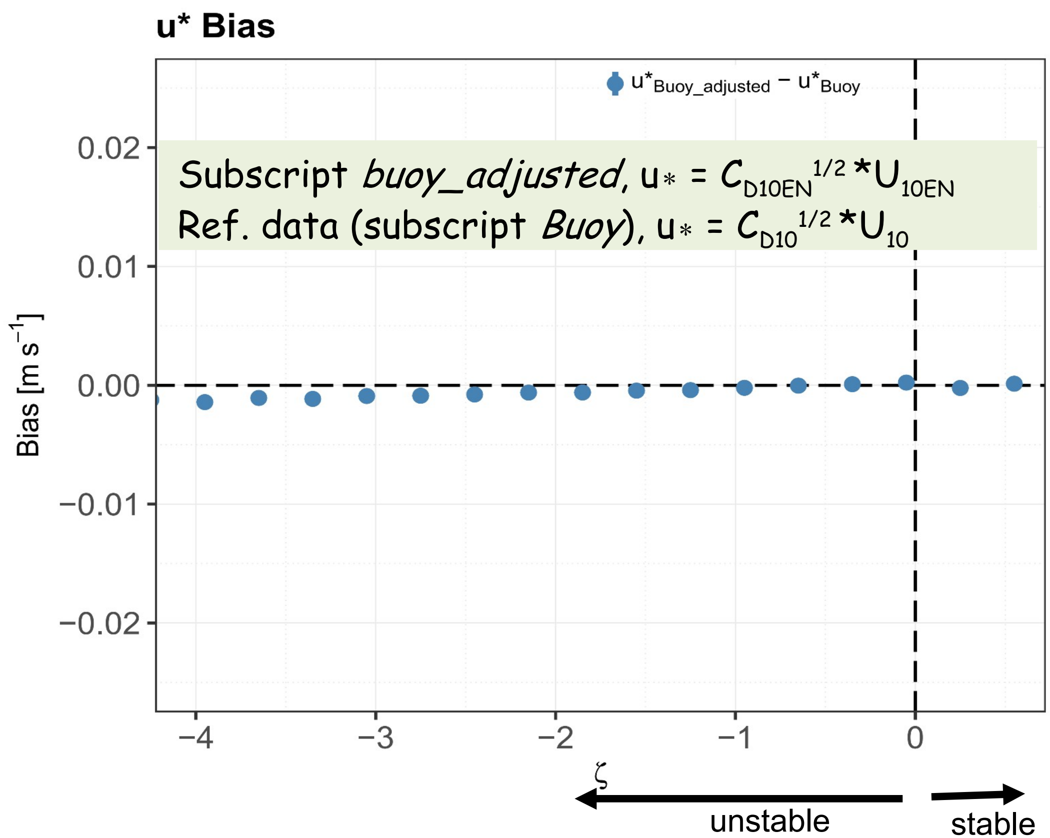
Motivation..

- The calculation of surface turbulent stress (τ) from wind speed requires knowledge of the atmospheric stratification. In terms of a drag coefficient (C_D), surface stress is defined as,

$$\tau = \rho C_{D10} U_{10} |U_{10}|$$

- A key advantage of EN winds is that surface stress can be estimated without accounting for atmospheric stability—requiring only air density and a neutral drag coefficient (Bourassa et al., 2010)

$$\tau = \rho C_{D10EN} U_{10EN} |U_{10EN}|$$
$$= \rho u_* |u_*|$$



Turbulent Flux Calculation

- The parameter u_* can be used in the computation of **sensible heat (SHF) and latent heat (LHF) fluxes**, represented as follows,

$$SHF = -\rho C_p \theta_* |u_*|,$$
$$LHF = -\rho L_v q_* |u_*|$$

- where ρ is the air density, θ_* and q_* are scaling parameters analogous to u_*, C_p is the specific heat of air, and L_v is the latent heat of vaporization

- Enhancing the accuracy of modeled values of u_* contributes to refining the accuracy of modeled surface turbulent fluxes

- *NOTE: COARE Bulk algorithm assumes stability included winds as input for the flux calculation*

CYGNSS Flux Experiment

- **CYGNSS_unadjusted:** assumes equivalent neutral winds from CYGNSS; uses COARE as is:
  - $(u^* = C_{D10}^{1/2} * U_{10EN})$,

- **CYGNSS_adjusted:** assumes equivalent neutral winds from CYGNSS with COARE corrections:
  - $(u_* = C_{D10EN}^{1/2} * U_{10EN})$

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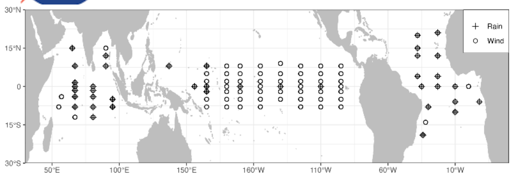
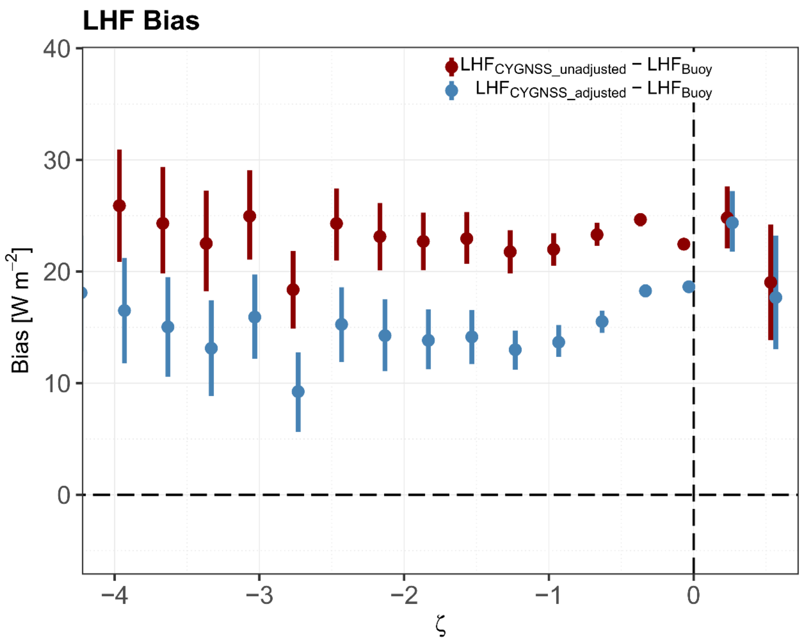
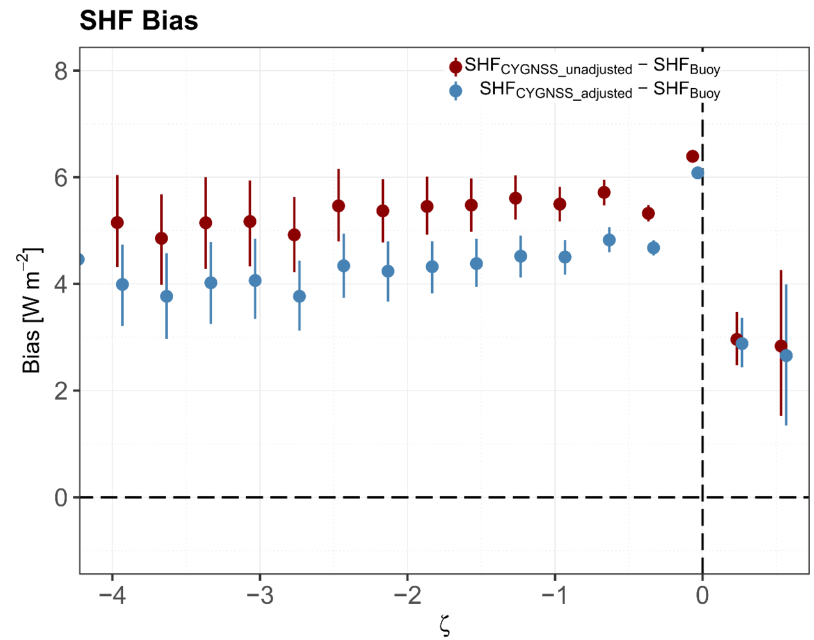


CYGNSS vs. Buoy

Aggregated whole Tropical Buoy stations (2018-2023)





In Flux **unadjusted**, u* is $C_{D10}^{1/2}$ *U_{10EN} => default in COARE

adjusted, u* = $C_{D10EN}^{1/2}$ *U_{10EN} => changes made in COARE

Reference data (subscript Buoy), u* = $C_{D10}^{1/2}$ *U_{10}

- CYGNSS_adjusted (blue curve) demonstrate a closer alignment (reduction of 10-20 Wm-2) with buoy-measured fluxes than CYGNSS_unadjusted (red curve)
- The biases tend to reach a minimum at the transition from stable to unstable atmospheric stratification and towards stable conditions

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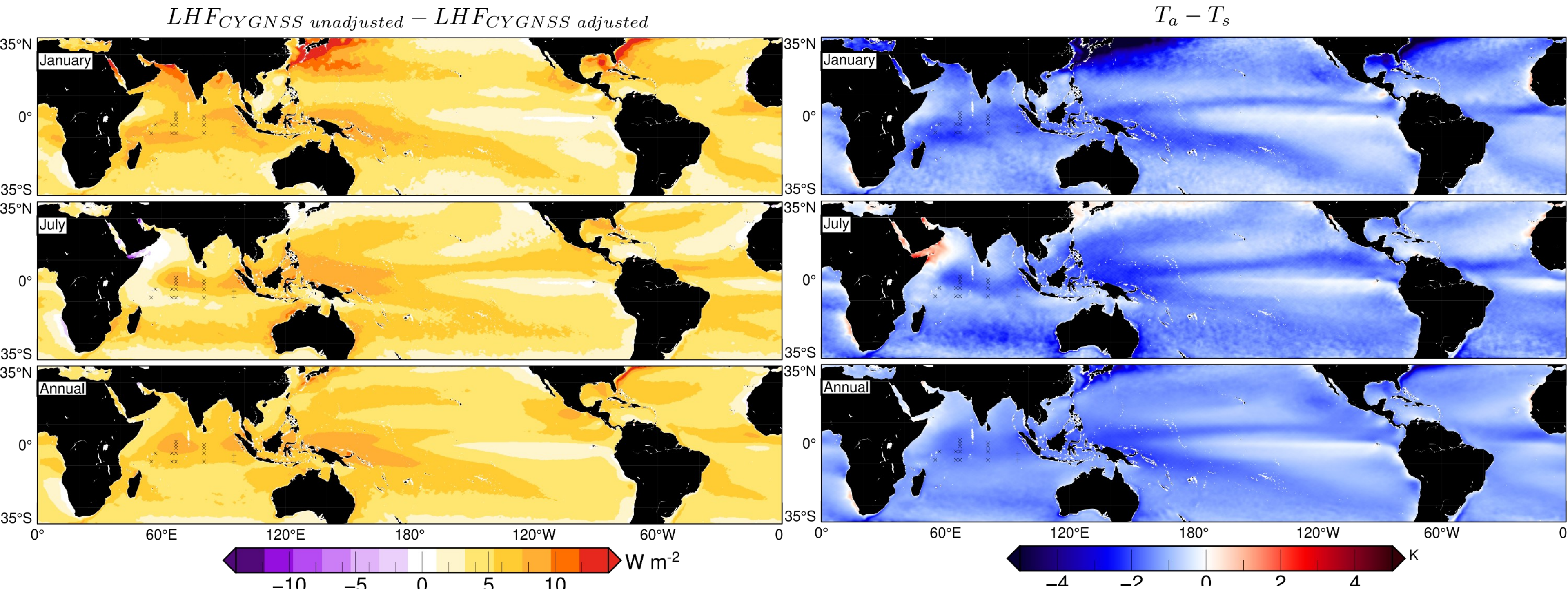
CYGNSS LHF (left) & Temperature (right) Difference



- Adjusted CYGNSS LHF generally shows reduced magnitudes
- Kuroshio and Western Boundary Currents show LHF differences up to 15–20 W/m² in January
- Notable differences appear in Arabian and Red Sea
- Most biases emerge in areas characterized by highly unstable atmospheric conditions

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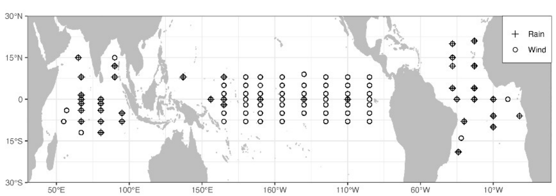
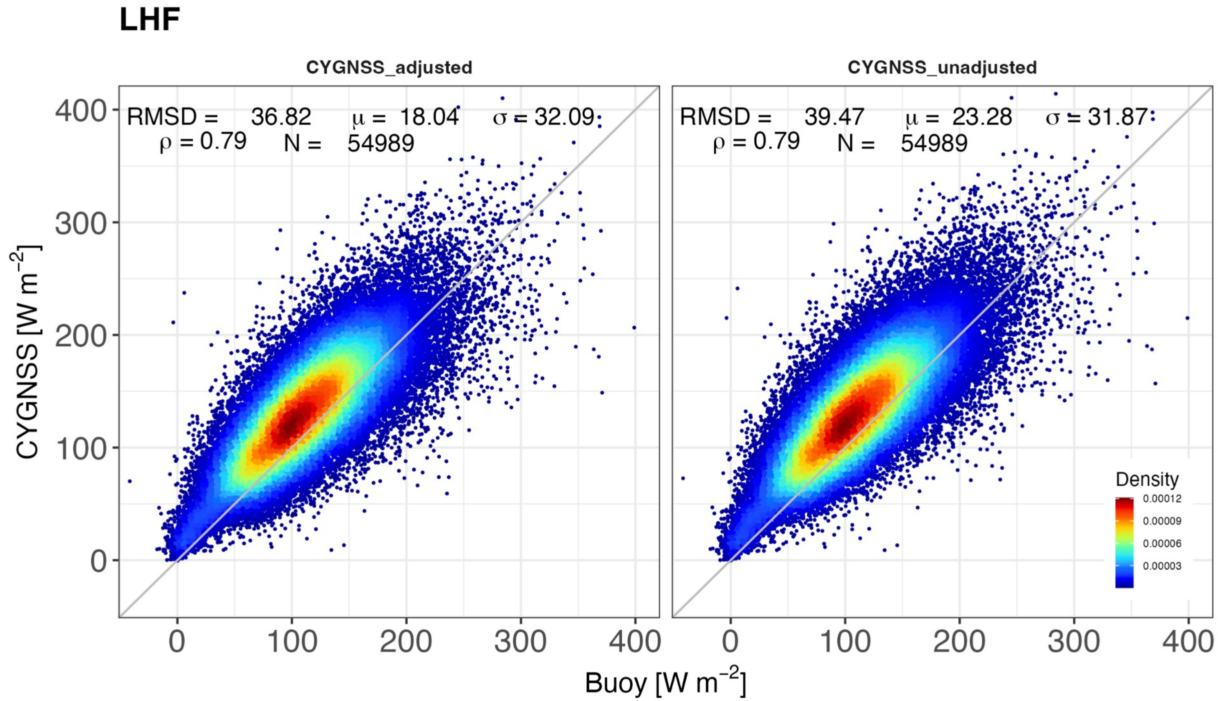
CYGNSS Flux Scatterplot

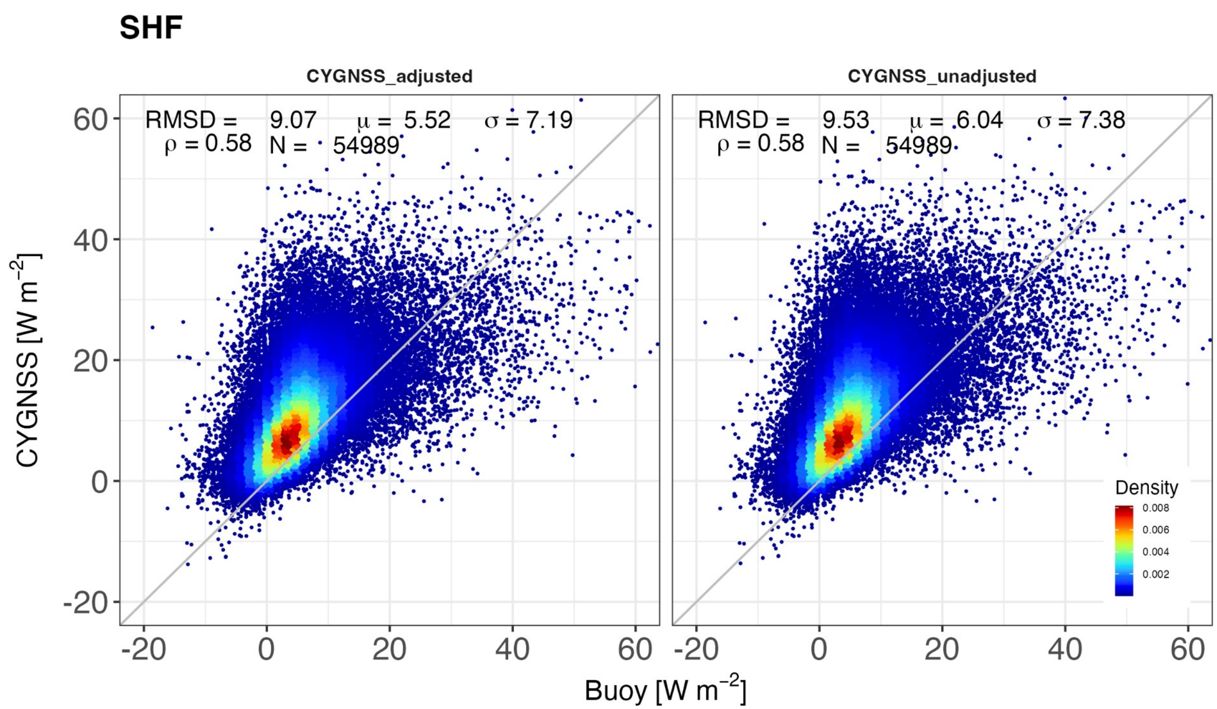
Aggregated whole Tropical Buoy stations (2018-2023)



Improved statistics in adjusted (left panel) over unadjusted (right panel)

μ - mean difference (CYGNSS– buoy)
σ - standard deviation (CYGNSS – buoy)
RMSD- root mean square difference
ρ - Corr. Coeff.





Summary

- Scatterometer retrieved EN winds represent theoretical wind scenario in neutral atmospheric stratification
- The Bourassa & Hughes (2018) approach enables precise surface flux estimates using the EN winds
- CYGNSS and tropical buoy data confirm its effectiveness across stability regimes
- Differences between default and modified COARE setups are notable (~15-25 W/m^2 LHF) in highly unstable atmospheric conditions
- The CYGNSS heat flux products based on the modified COARE algorithm are available on the JPL PO.DAAC server

Thank you for your kind attention!

- Backup slide

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CYGNSS Surface Heat Fluxes

Crespo et al., 2019 (Rem. Sens.)

- Publicly released Science/Climate data product consisted of an estimate of Sensible and Latent heat flux
- Uses COARE 3.5 Bulk Algorithm
- Flux calculation utilizes L2 CYGNSS Wind Products
- Uses ERA5 for thermodynamic variables
- Currently validated up to 25 m s-1
- Limiting factors: transfer coefficients, sea salt spray, uncertainties in the Reanalysis data over convective regions

CYGNSS

$$LHF = L_{vl}\rho_d C_{DE} U (q_s - q_a)$$
$$SHF = c_p \rho_d C_{DH} U (T_s - T_a)$$

ERA5

$$C_D(z/z_0, z/L, G) = \frac{-\overline{uw}}{U_r S_r} = \frac{-\overline{uw}}{U_r^2 G} = \left[\frac{\kappa}{\ln(z/z_0) - \psi_m(z/L)}\right]^2,$$

Surface-layer Stability

Stability function

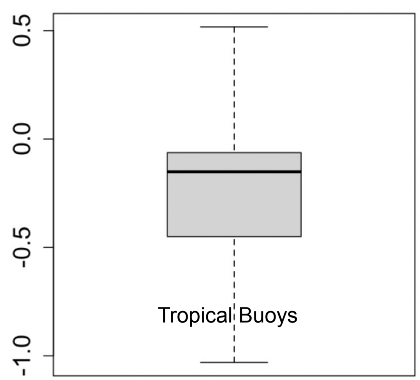
$$U_{10} = \frac{u_*}{k}\left[\ln\left(\frac{Z_{10}}{z_0}\right) - \psi\left(\frac{Z_{10}}{L}\right)\right]$$

under neutrally-stratified condition

$$U_{10EN} = \frac{u_*}{k}\ln\left(\frac{Z_{10}}{z_o}\right)$$

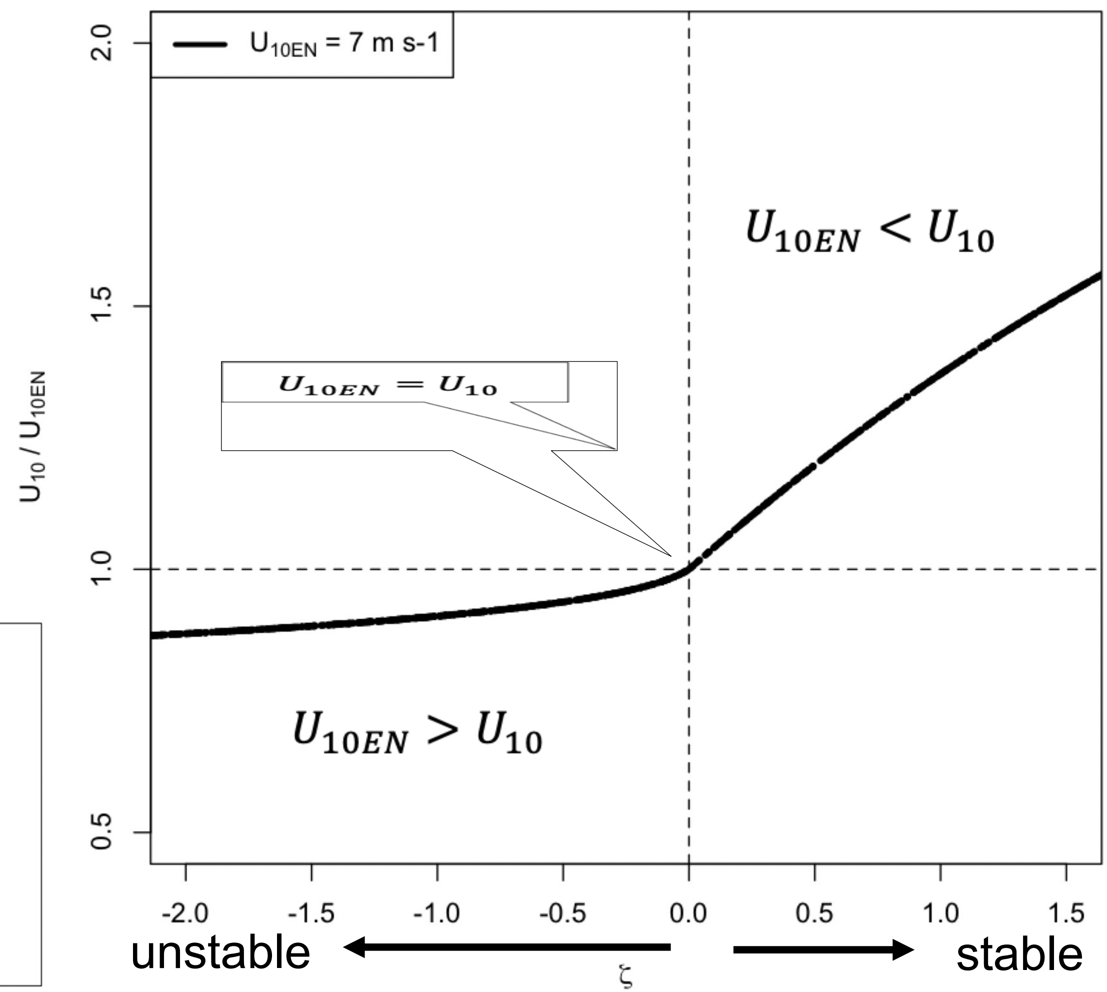
Stability parameter (dimensionless)

$$\zeta = \frac{Z_{10}}{L}$$



Most data sample fall at near-neutral conditions and thus EN winds are generally assumed to be a good approx..

COARE 3.6 theoretical curve



Z_{10} measurement height, L is the Obukhov length, z_0 the surface roughness, u_* the frictional velocity

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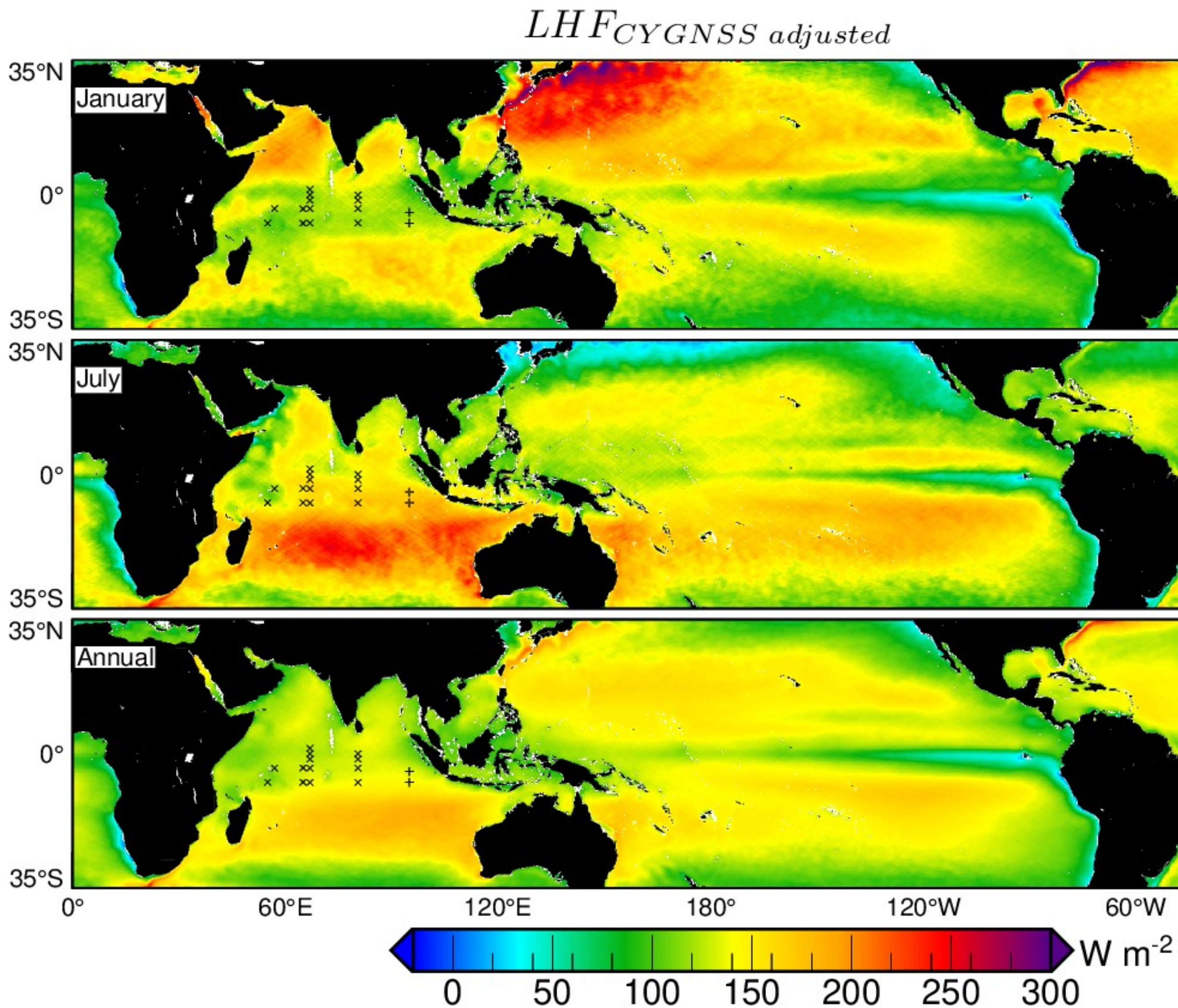

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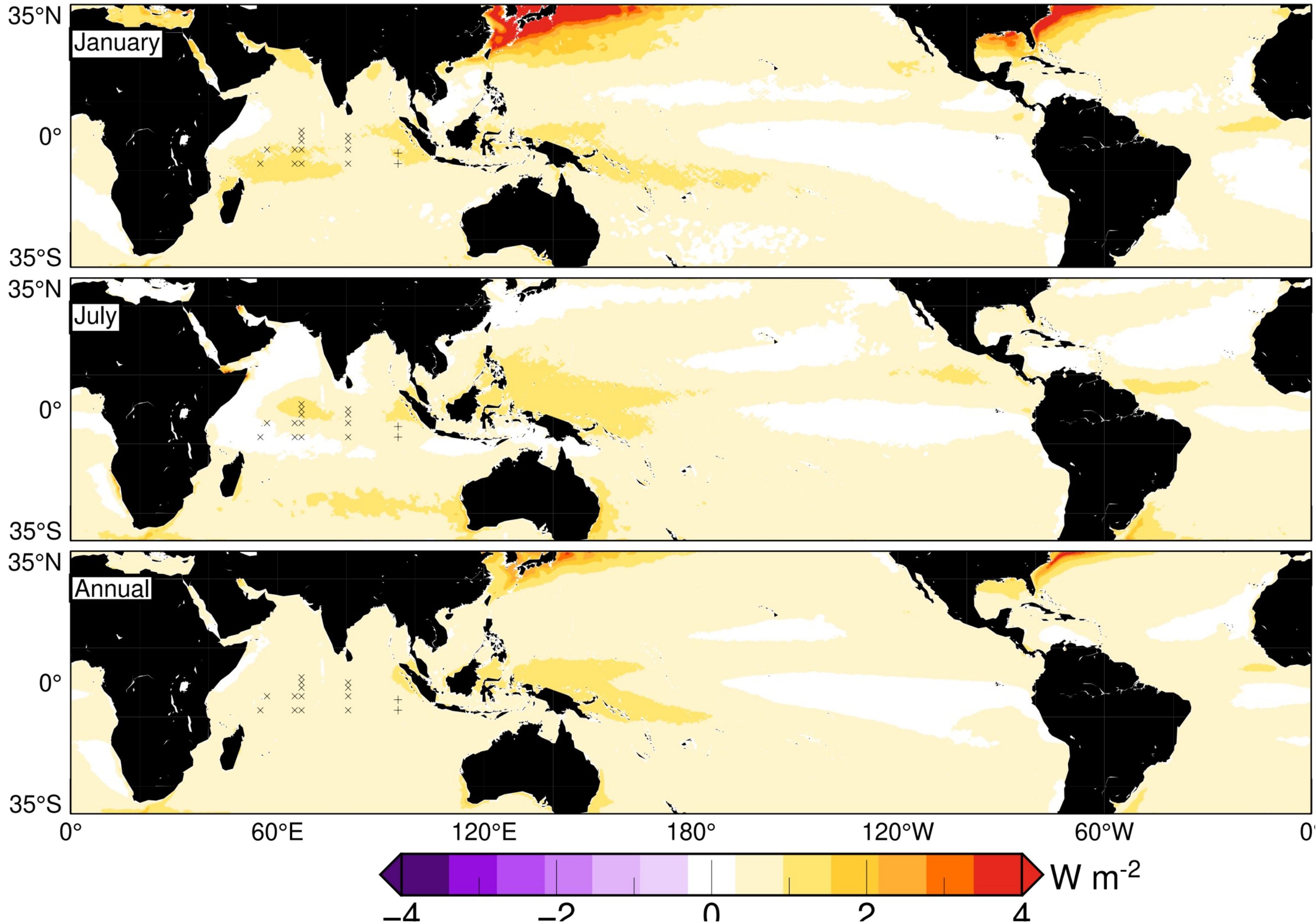
CYGNSS SHF Difference

$$SHF_{CYGNSS\ unadjusted} - SHF_{CYGNSS\ adjusted}$$



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