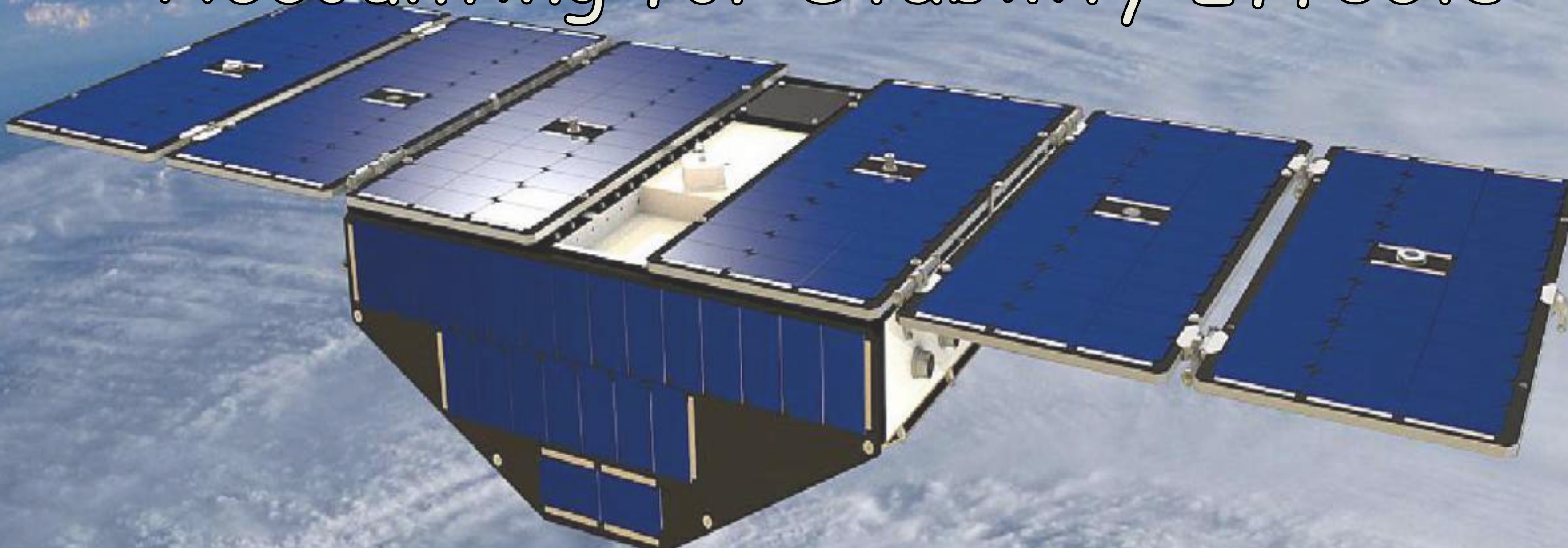
Advancing CYGNSS Derived Ocean Surface Turbulent Fluxes: Accounting for Stability Effects



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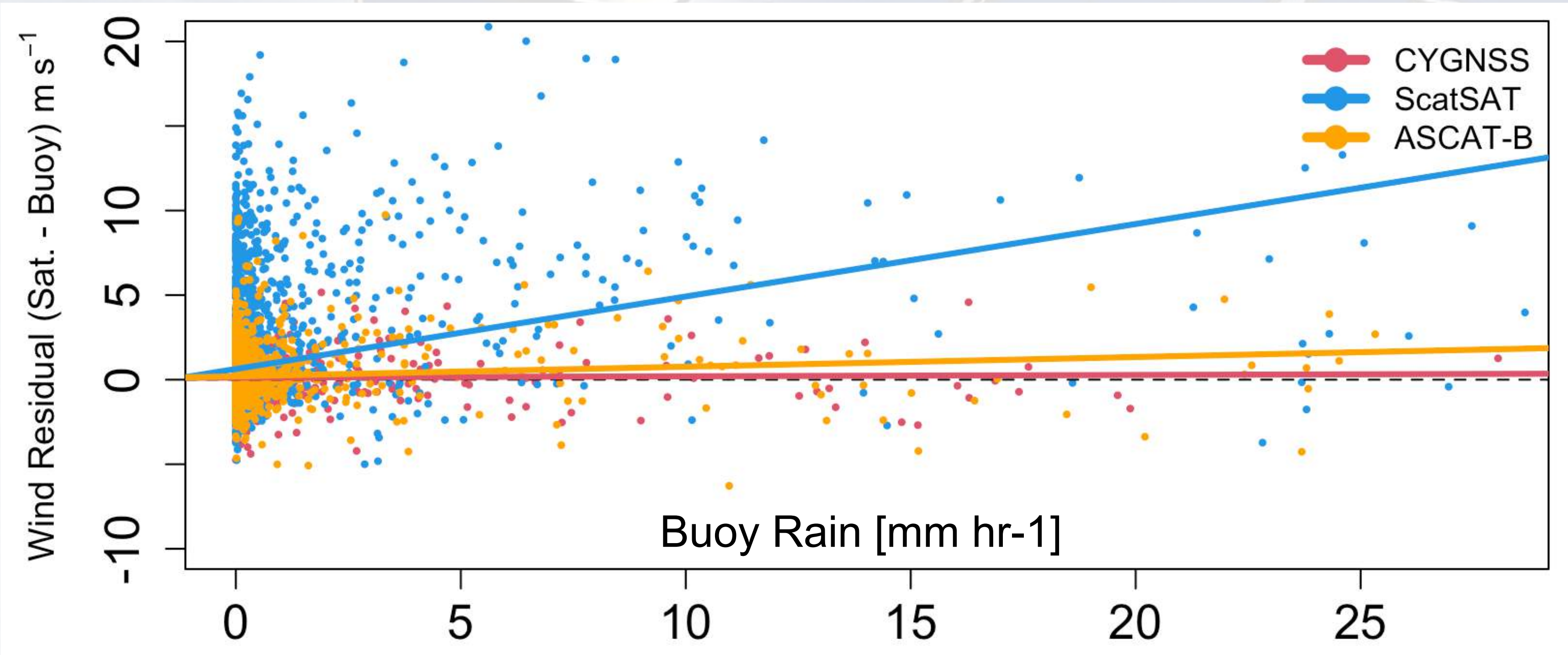
CYGNSS Key Features

- The NASA CYGNSS mission:
  - provides near surface wind speed over the tropical ocean
  - aims to measure surface winds in the inner core of tropical cyclones
  - eight spacecraft, non-Sunsynchronous- high spatial/temporal sampling rate
  - L-band- usefulness in heavy precipitation conditions



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

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

ERA5

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

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, discrepancies occur due to stability-dependent biases, leading to biased flux estimations

Surface-layer Stability

Stability function

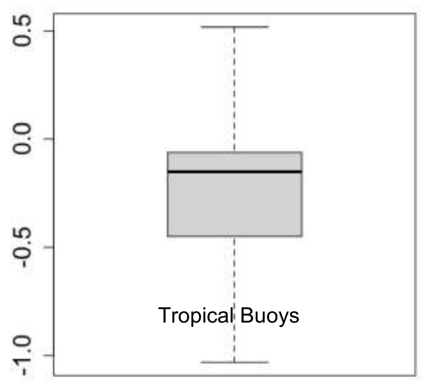
$$U_{10} = \frac{u_*}{k}\left[\ln\left(\frac{Z_{10}}{z_0}\right) - \psi\left(\frac{Z_{10}}{L}\right)\right]$$

under neutrally-stratified condition

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

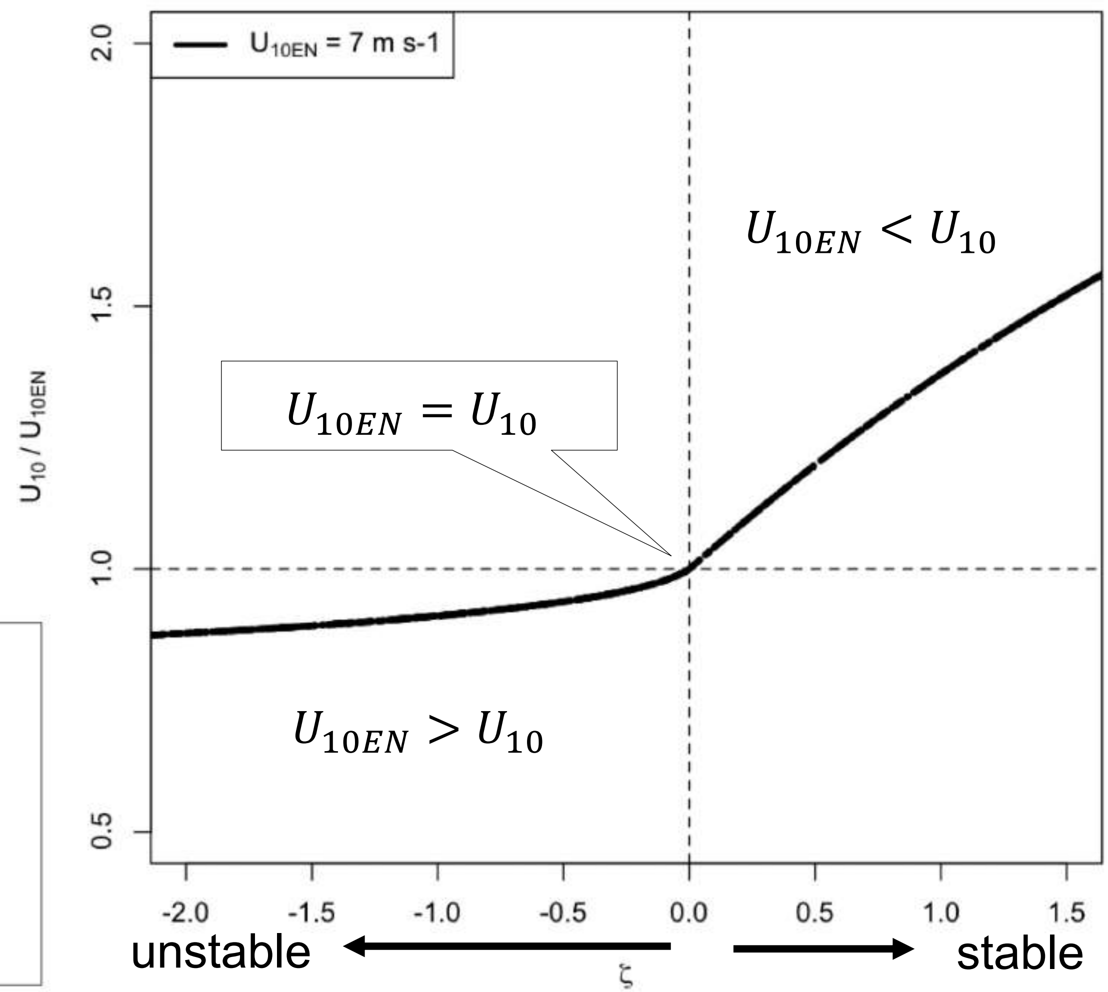
Stability parameter (dimensionless)

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



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



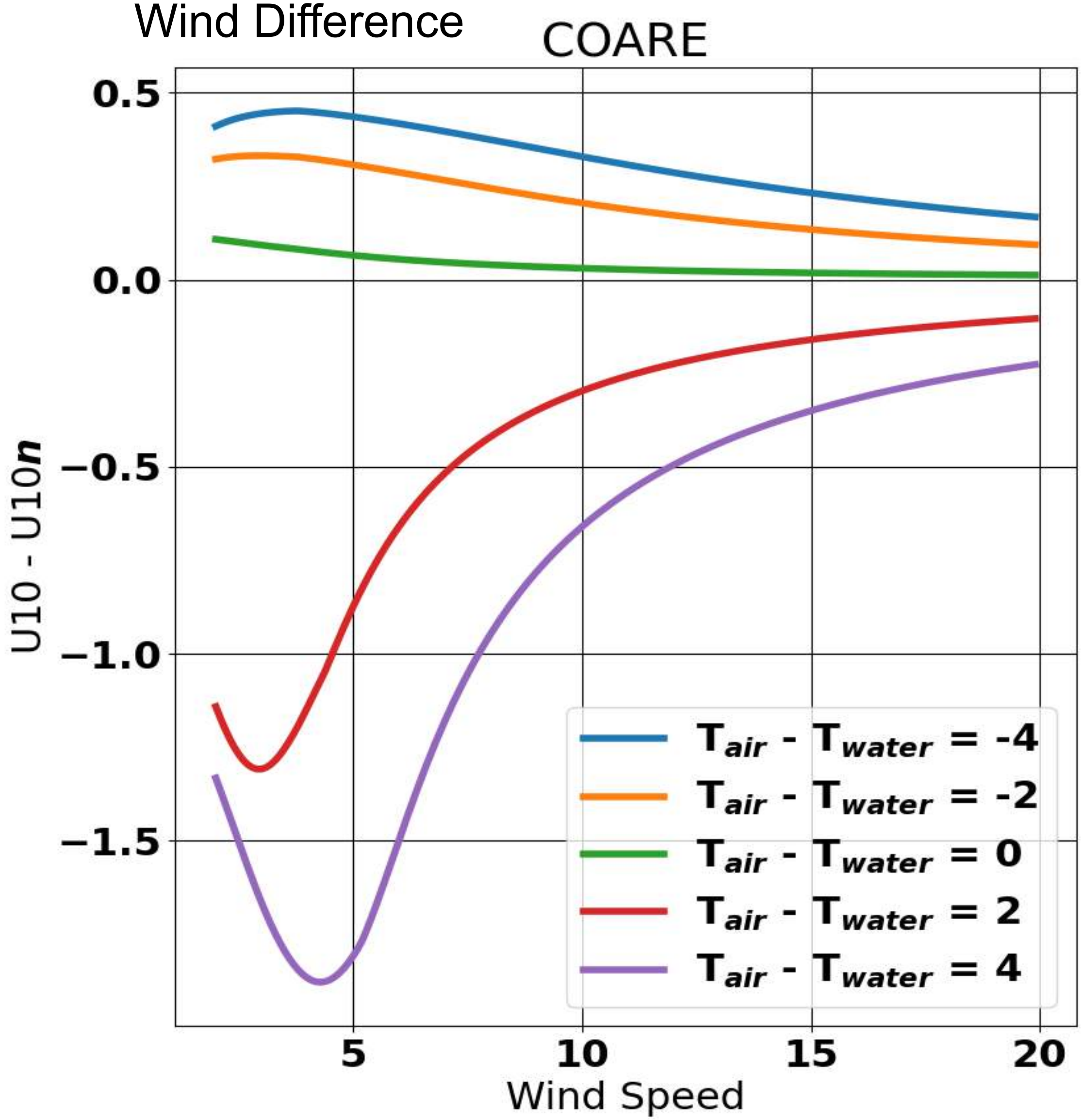
Z_{10} measurement height, L is the Obukhov length, z_0 the surface roughness, u_* the frictional velocity

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

Wind Difference



*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,

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

- An outstanding benefit of equivalent neutral winds is their independence from atmospheric stability considerations when determining surface stress. All that's necessary is knowledge of air density and a neutral drag coefficient (Bourassa et al, 2010).

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

- Stress can also be modeled in terms of the friction velocity (u_*):

$$\tau = \rho\ u_* |u_*|,$$

where $u_* = C_{D10EN}^{1/2} * U_{10EN}$ which is equivalent to $C_{D10}^{1/2} * U_{10}$

Turbulent Flux Calculation

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

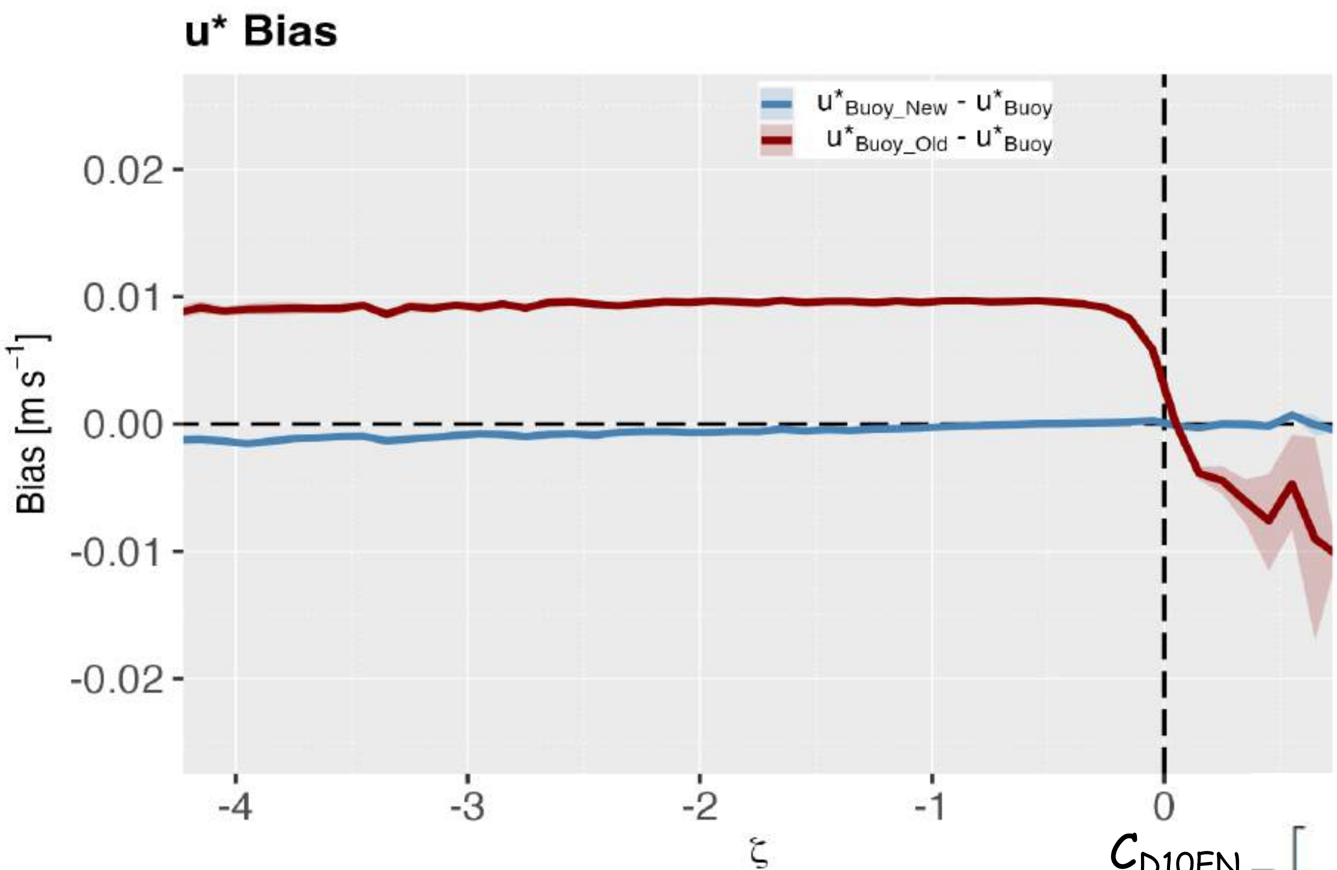
$$SHF = -\rho C_p \theta_* |u_*|,$$
$$LHF = -\rho L_v q_* |u_*|$$

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

Tropical Buoy Data Example

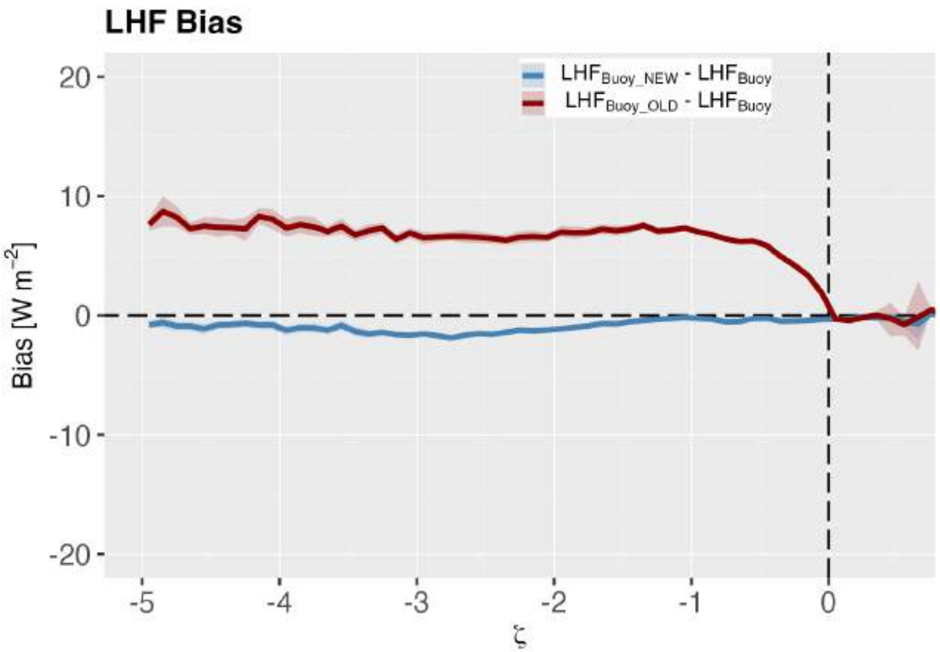


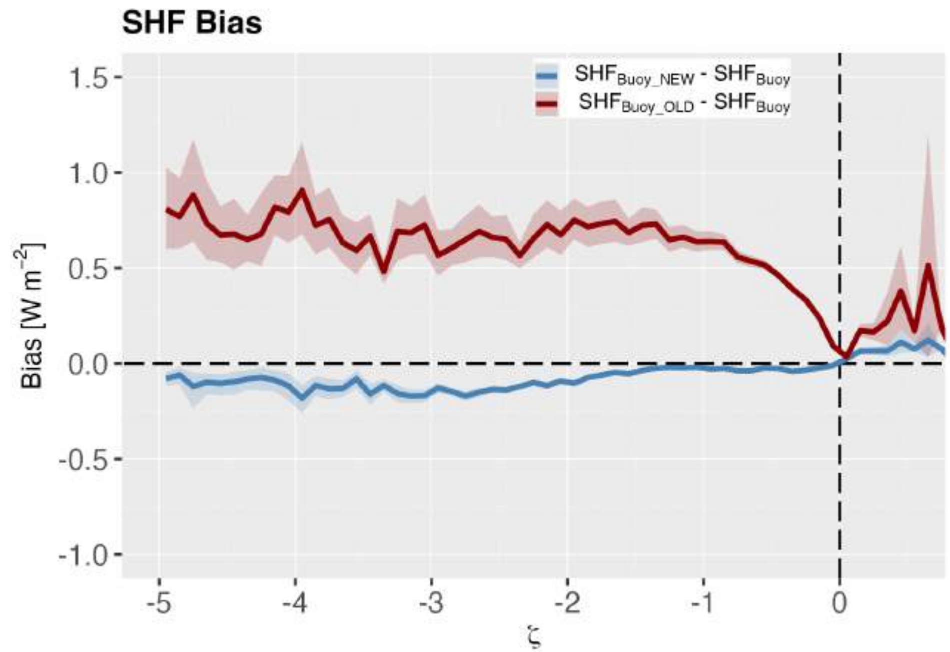
$$C_{D10EN} = \left[\frac{\kappa}{\ln(z/z_0) - \psi_m(z/L)}\right]^2,$$

subscript OLD, u∗ is $C_{D10}^{1/2} * U_{10EN}$
subscript NEW, u∗ = $C_{D10EN}^{1/2} * U_{10EN}$
Reference data (subscript Buoy) use stability info, u∗ = $C_{D10}^{1/2} * U_{10}$

- OLD (red curve) biases increase with increase in instability
- Biases are minimal at the stable-to-unstable transition
- Using the NEW (blue curve) u∗ closely mirrors the reference u*

Tropical Buoy Data Example





In Flux subscript OLD, $u_* $ is $C_{D10}^{1/2} * U_{10EN}$
subscript NEW, $u_* = C_{D10EN}^{1/2} * U_{10EN}$
Reference data (subscript Buoy) use stability info, $u_* = C_{D10}^{1/2} * U_{10}$

- LHF or SHF Buoy OLD (red curve) biases increase with increase in instability
- Biases are minimal at the stable-to-unstable transition
- Using the NEW (blue curve) u_* closely mirrors the true Real Buoy Fluxes

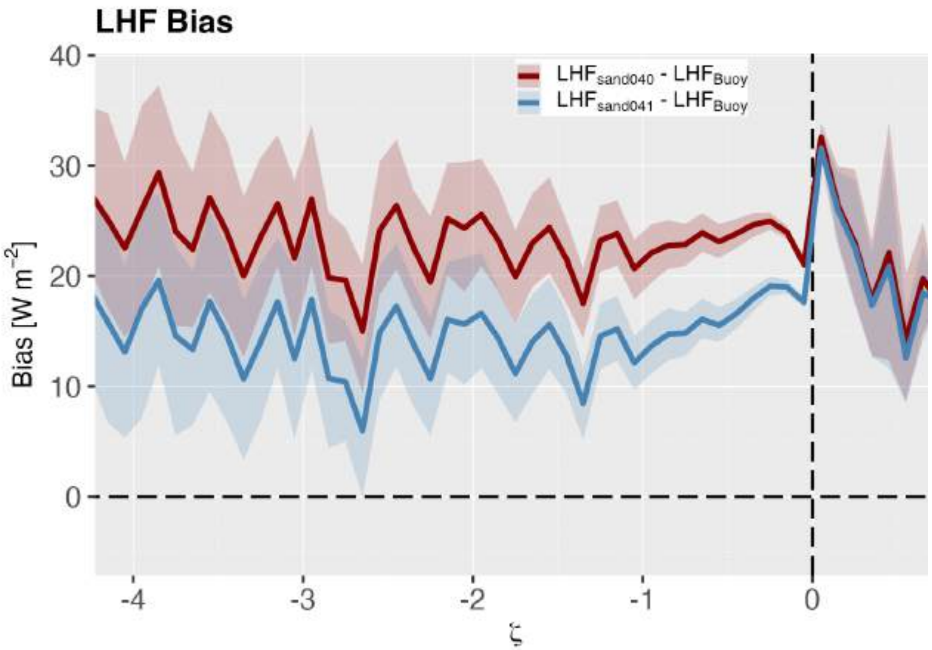
CYGNSS Experiment

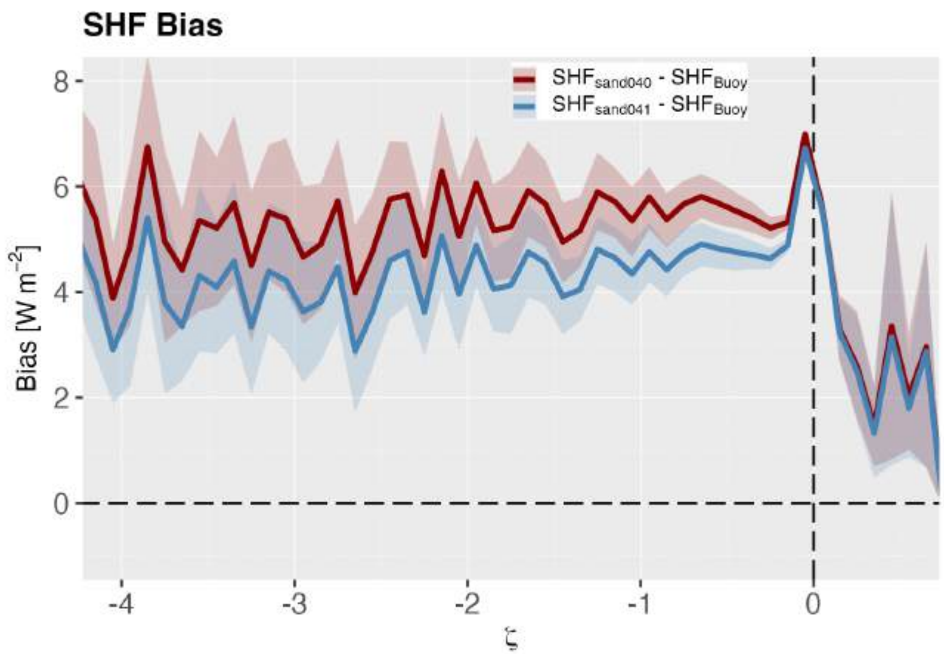
Sand040: assumes equivalent neutral winds from CYGNSS; uses COARE as is: ($u^*=c_{D10}{}^{1/2}*U_{10}$),

Sand041: assumes equivalent neutral winds from CYGNSS with COARE corrections:

$$(u_* = c_{D10EN}{}^{1/2} * U_{10EN})$$

CYGNSS Data
Aggregated whole Tropical Buoy stations (2018-2023)





In Flux sand040, u∗ is $C_{D10}^{1/2} * U_{10EN}$ => default in COARE
sand041, u∗ = $C_{D10EN}^{1/2} * U_{10EN}$ => changes made in COARE
Reference data (subscript Buoy) use stability info, u∗ = $C_{D10}^{1/2} * U_{10}$

- CYGNSS sand041 (blue curve) demonstrate a closer alignment (reduction of 10-20 Wm-2) with buoy-measured fluxes than CYGNSS sand040 (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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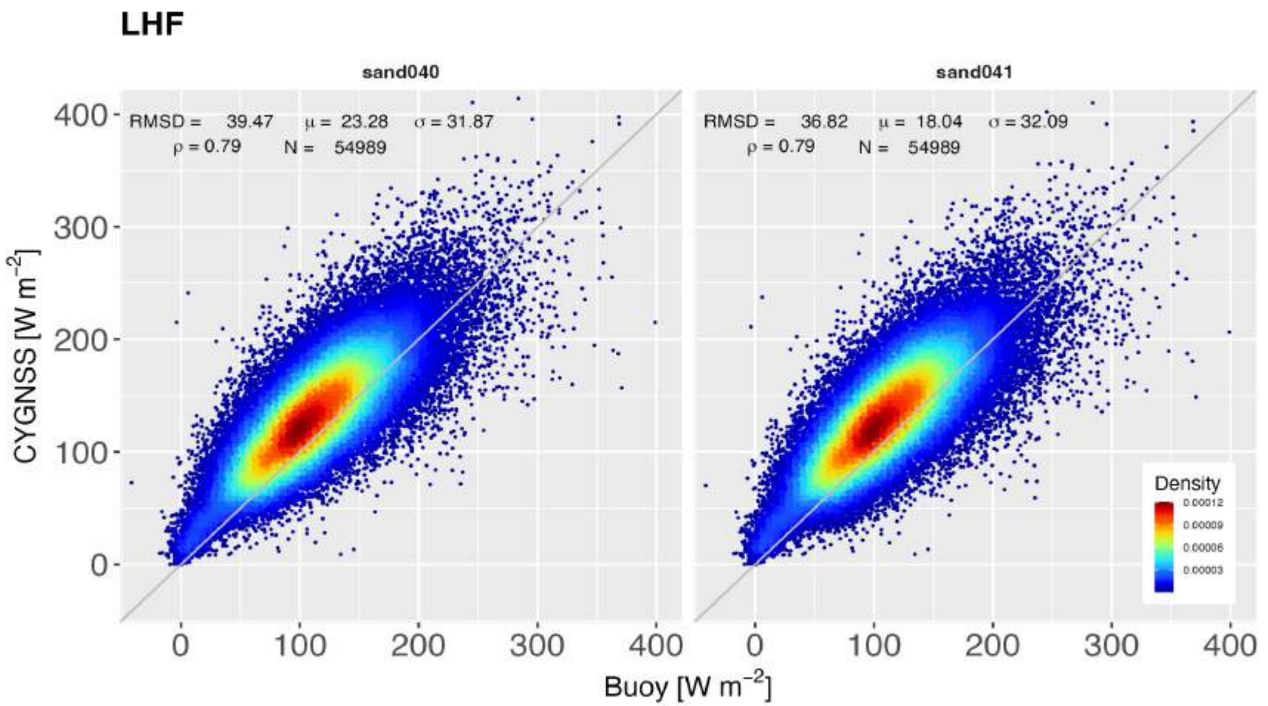
CYGNSS FDS Flux Scatterplot

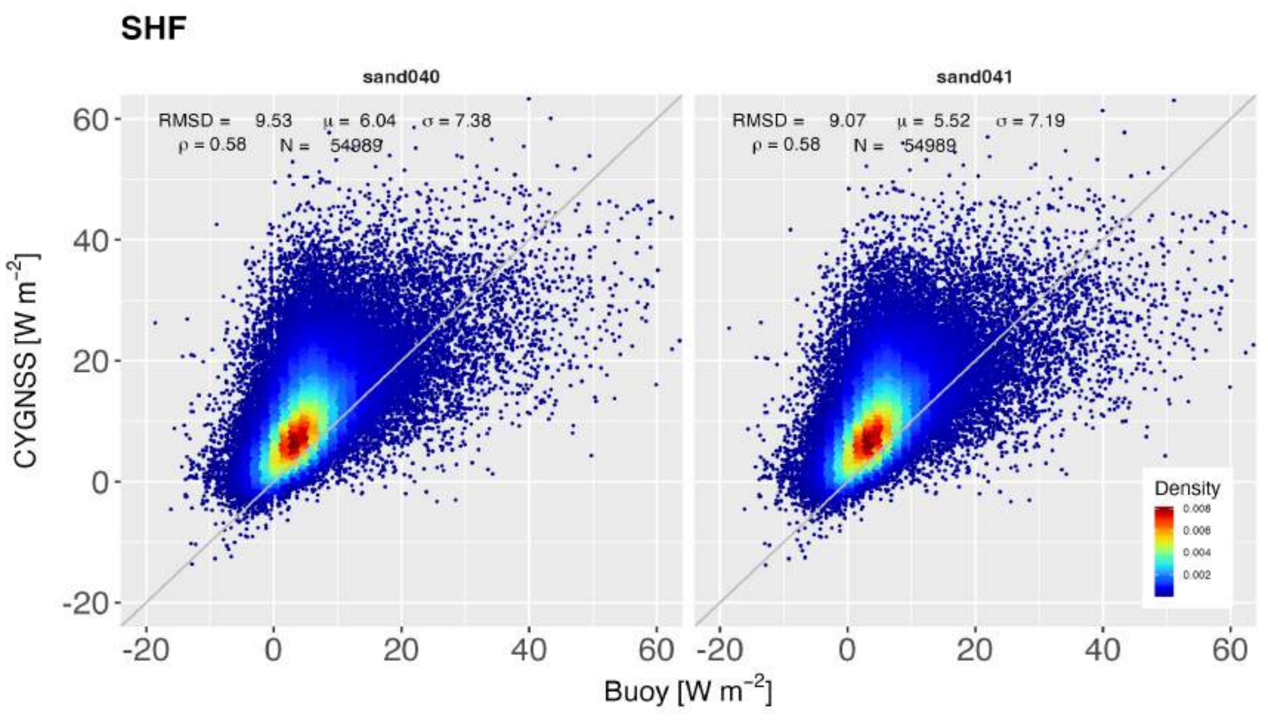
Aggregated whole Tropical Buoy stations (2018-2023)

Improved statistics in sand041 over sand040

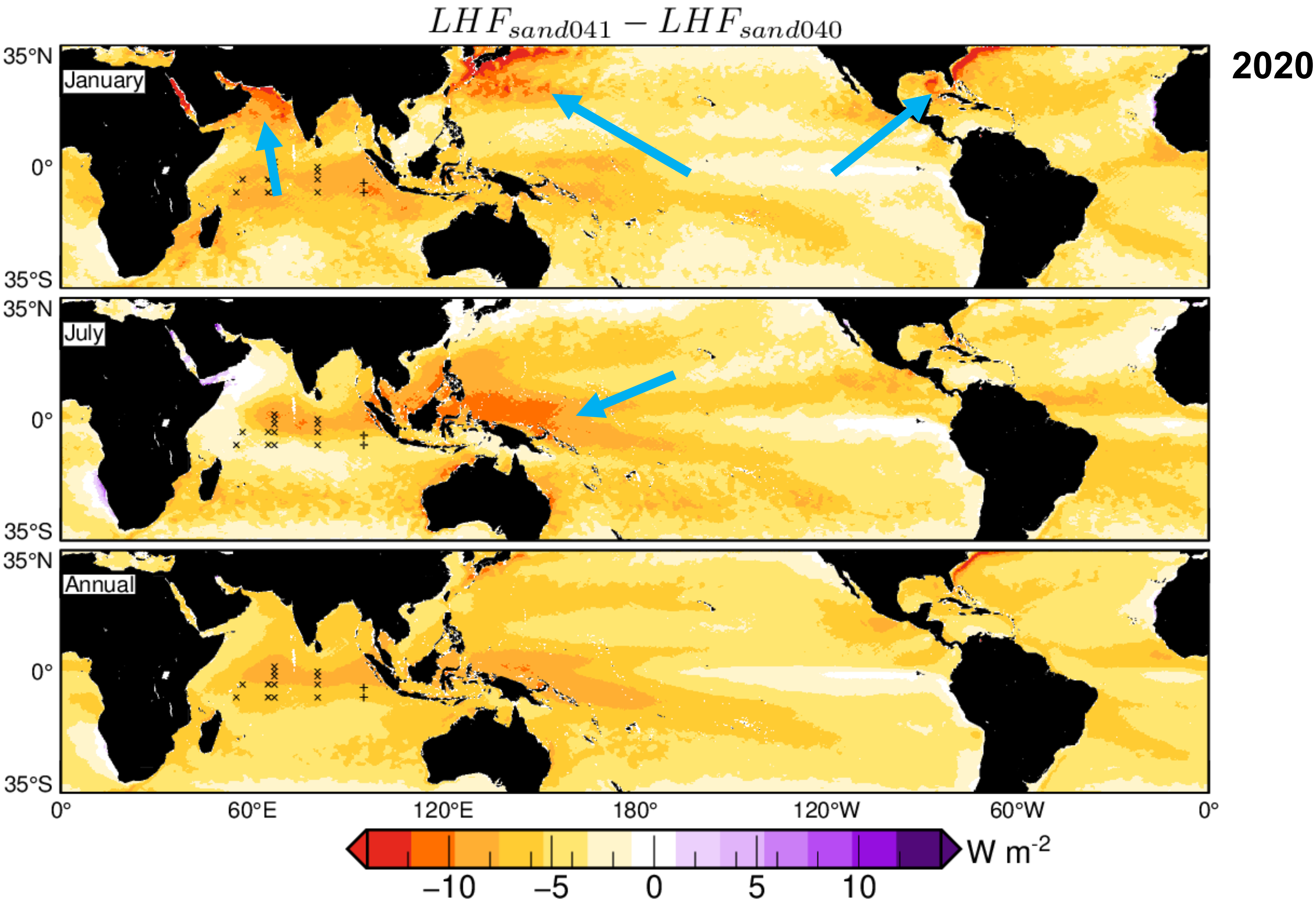
	LHF		SHF	
	sand040	sand041	sand040	sand041
RMSD	39.47	36.82	9.53	9.07
μ	23.28	18.04	6.04	5.52
σ	31.87	32.09	7.38	7.19
r	0.79	0.79	0.58	0.58

μ - mean difference (CYGNSS– buoy)
$\boldsymbol{\sigma}$ - standard deviation (CYGNSS – buoy)
RMSD- root mean square difference
ρ - Corr. Coeff.





CYGNSS LHF Difference



Most biases emerge in areas characterized by highly unstable atmospheric conditions (see the next slide)

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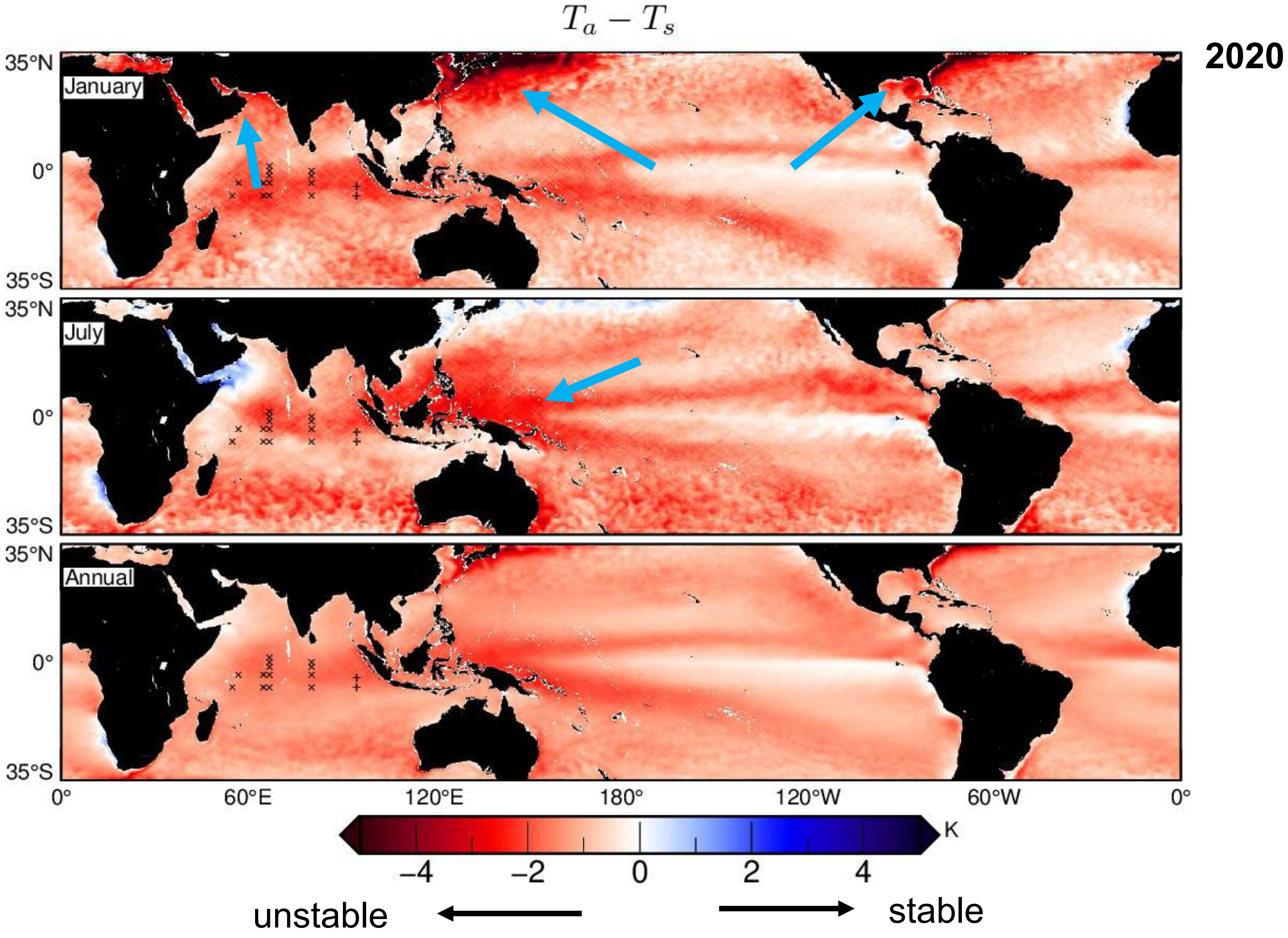
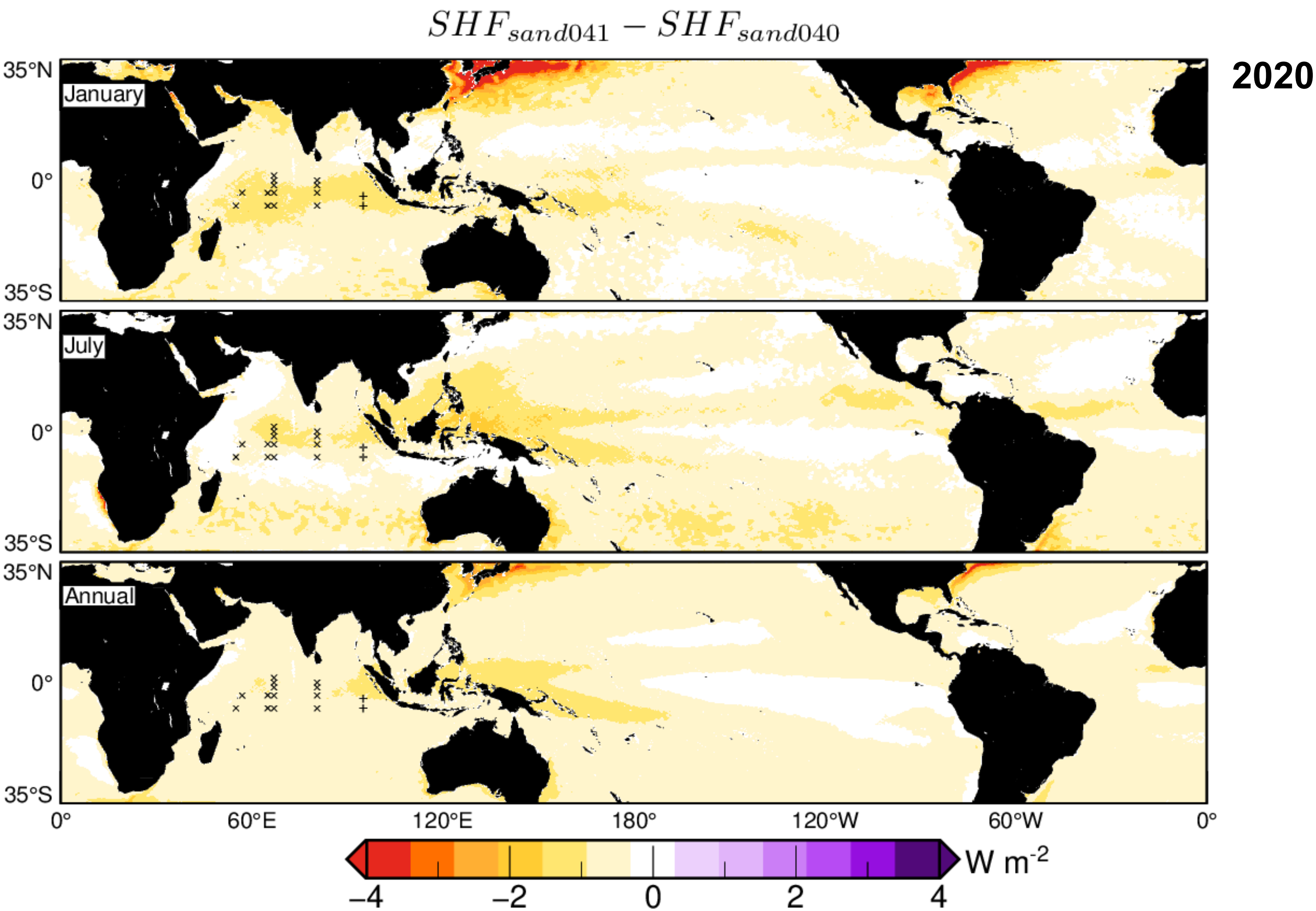
Atmospheric Stratification



CYGNSS SHF Difference



Most biases emerge in areas characterized by highly unstable atmospheric conditions

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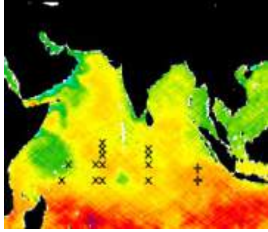
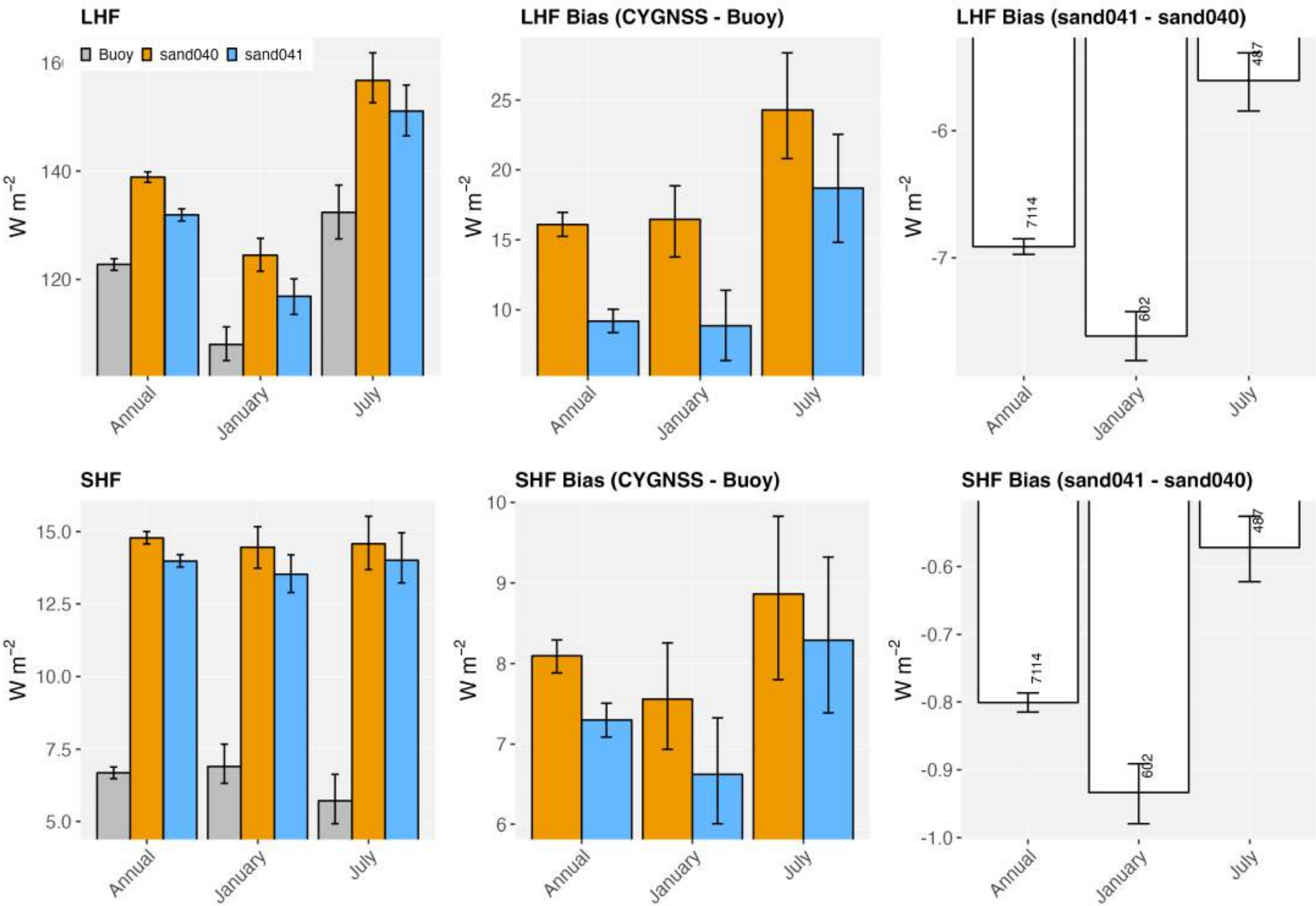
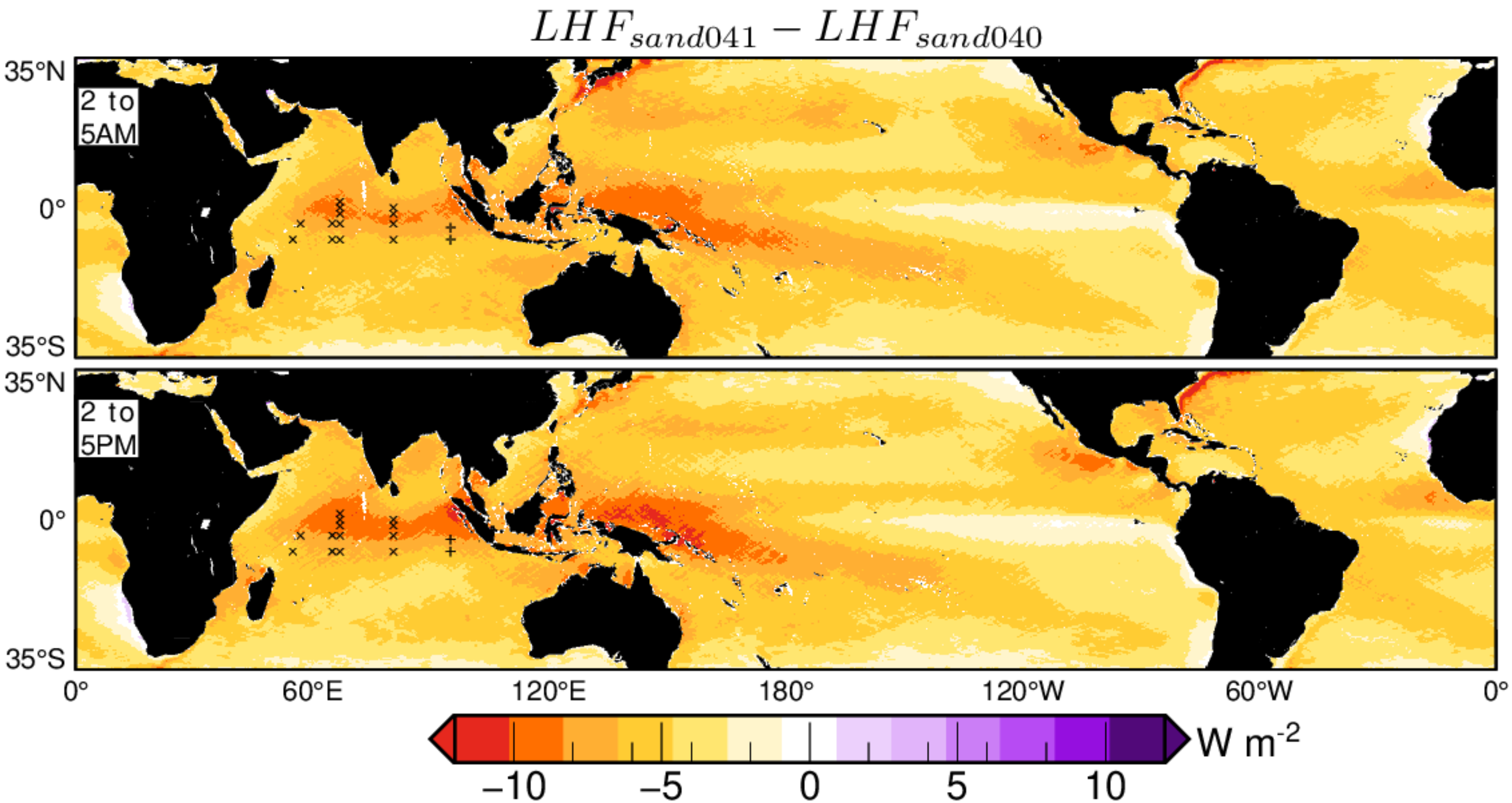
Comparison with buoys in Indian Ocean (2018-2023)





CYGNSS LHF Difference (Diurnal) 2020



Preliminary Summary

Scatterometer retrieved EN winds represent theoretical wind scenario in neutral atmospheric stratification

Proposed Bourassa & Hughes (2018) method suggests precise surface flux estimation using buoy data in all weather conditions

CYGNSS show closer alignment between estimated fluxes and buoy-measured fluxes

Differences between default and modified COARE setups are notable (~15-25 W/m^2 LHF) in highly unstable atmospheric conditions

- sand041 fluxes will be published PO.DAAC later this summer as SDR v3.2

Thank you for your kind attention!

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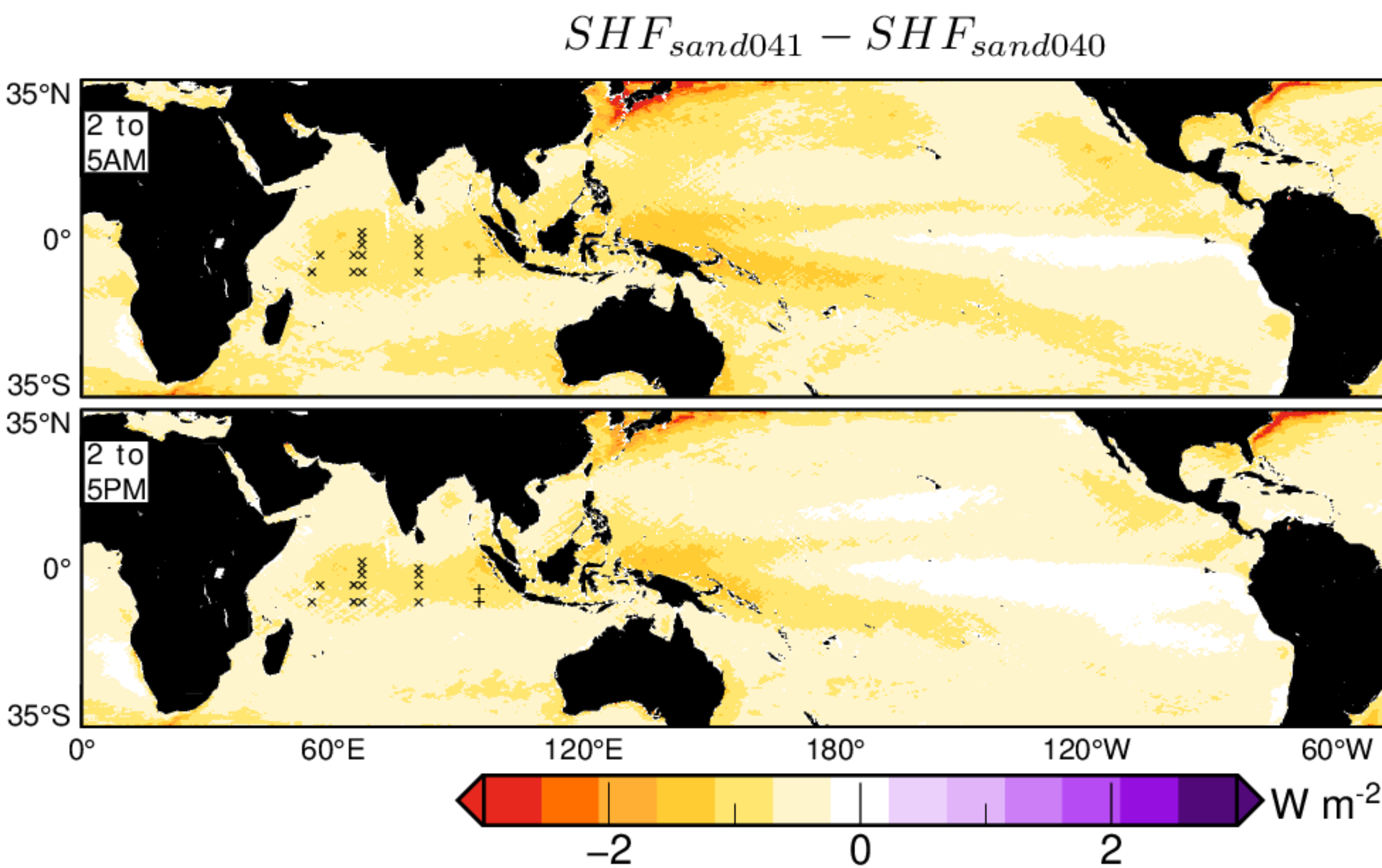
CYGNSS SHF Difference (Diurnal) 2020



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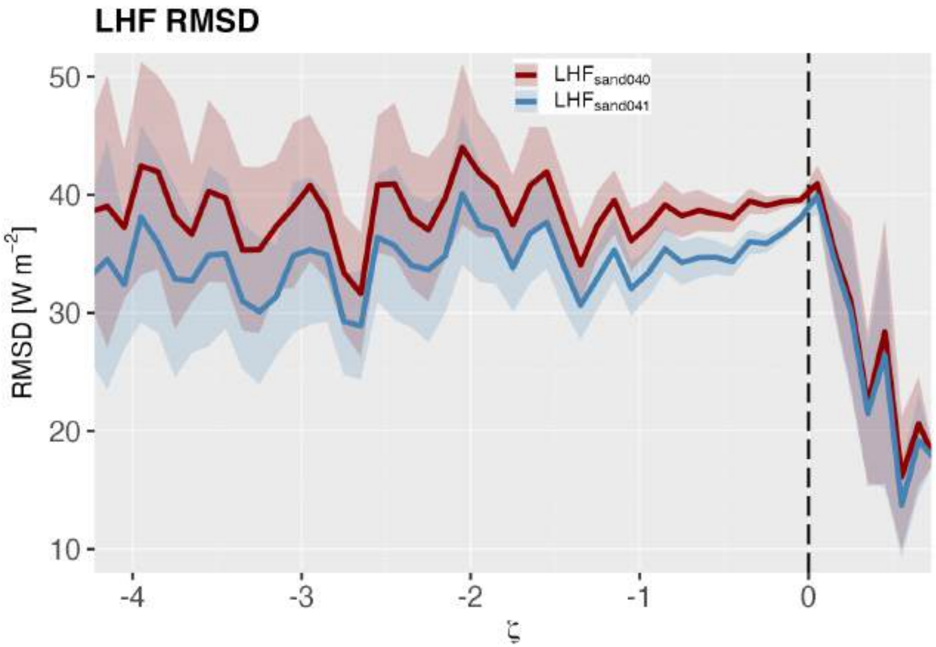
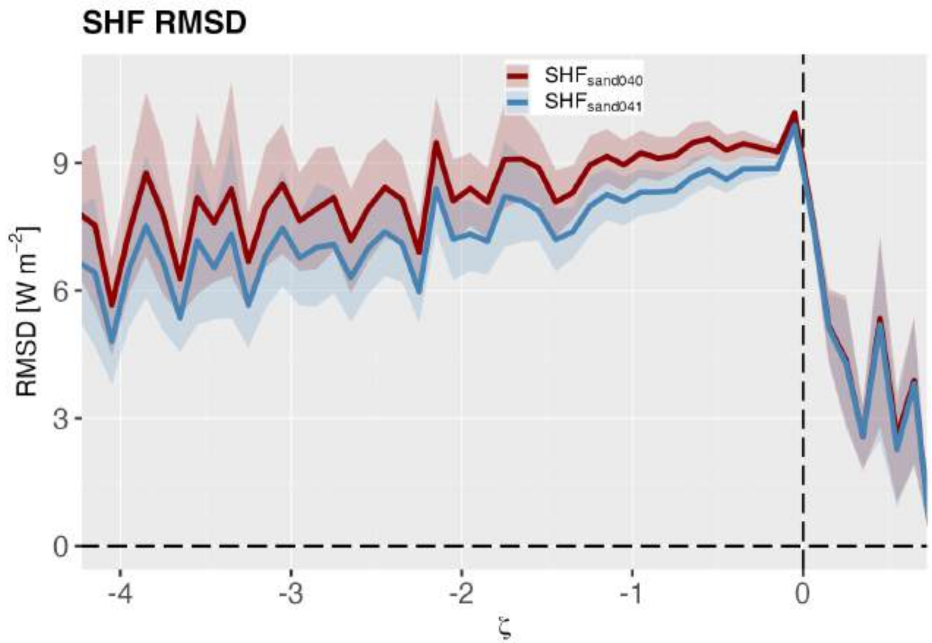
CYGNSS Data

Aggregated whole Tropical Buoy stations (2018-2023)





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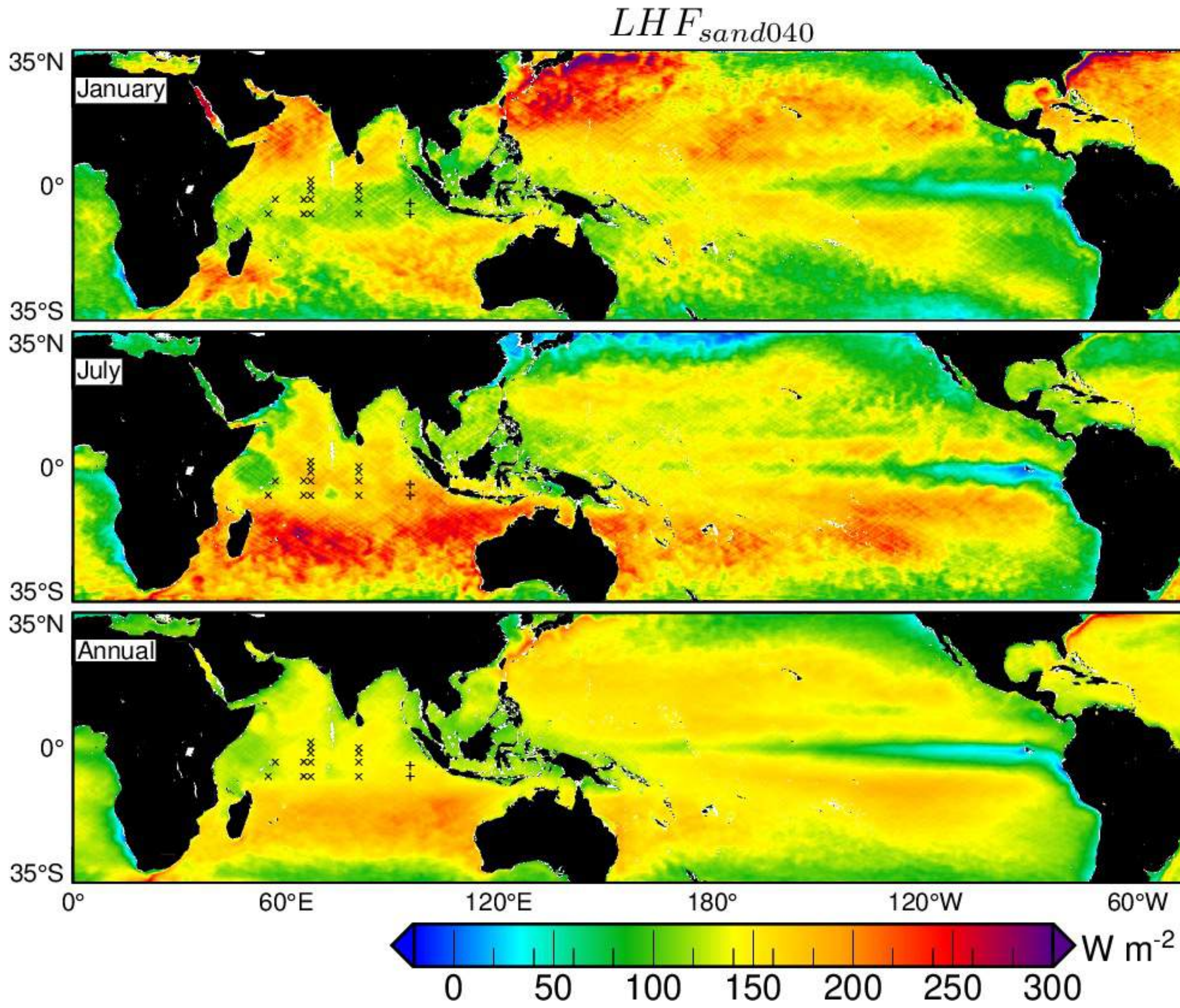

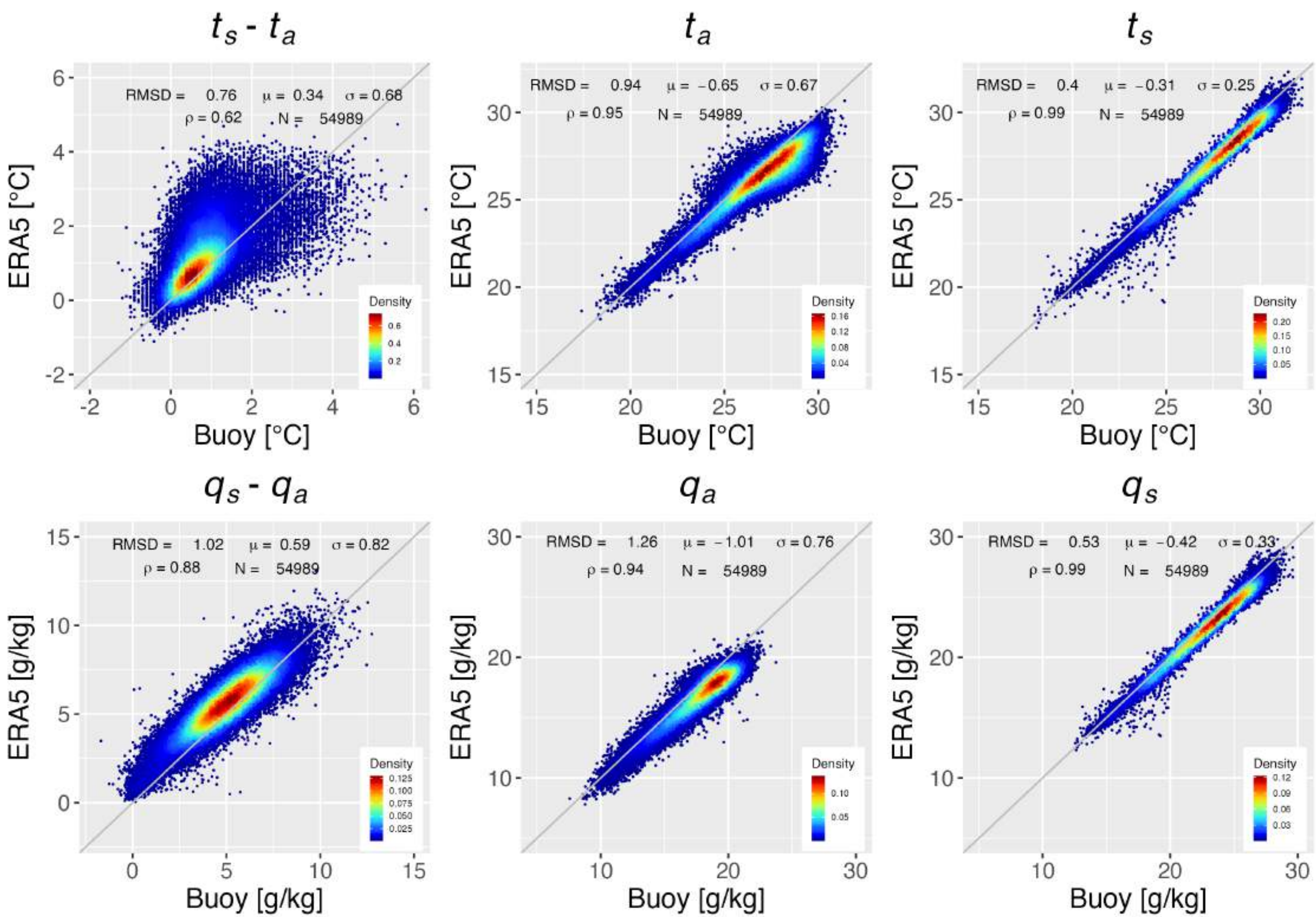
ts - ta
RMSD = 0.76 μ = 0.34 σ = 0.68
ρ = 0.62 N = 54989
ta
RMSD = 0.94 μ = −0.65 σ = 0.67
ρ = 0.95 N = 54989
ts
RMSD = 0.4 μ = −0.31 σ = 0.25
ρ = 0.99 N = 54989
ERA5 [°C]
Buoy [°C]
Density
qs - qa
RMSD = 1.02 μ = 0.59 σ = 0.82
ρ = 0.88 N = 54989
qa
RMSD = 1.26 μ = −1.01 σ = 0.76
ρ = 0.94 N = 54989
qs
RMSD = 0.53 μ = −0.42 σ = 0.33
ρ = 0.99 N = 54989
ERA5 [g/kg]
Buoy [g/kg]

Buoy Air sea parameters in Indian Ocean