Momentum Flux Estimated from In-Situ Wave Spectra in the Northern Indian Ocean

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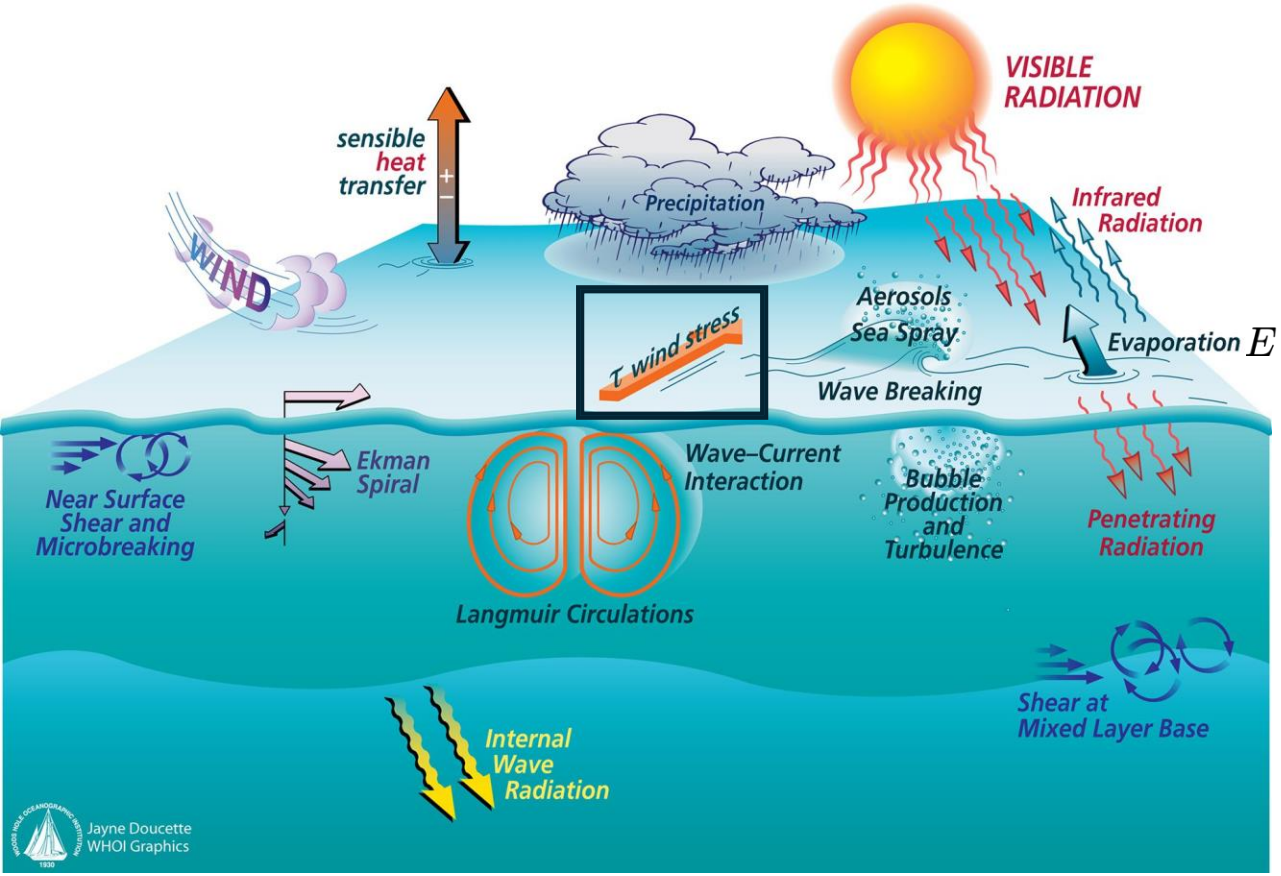
Momentum Fluxes and Waves

Wind stress is the primary mechanism for transferring **momentum and energy** between **atmosphere and ocean**, leading to **ocean circulation, surface waves, and vertical mixing.**



Edson et al. 2013

Momentum Fluxes and Waves

COARE algorithm can be used to **estimate wind stress from state variables** based on **roughness length parameters**, including accounting for **waves and wind-wave misalignments.**

Can we estimate **Momentum Fluxes** using **in-situ directional wave spectra**? (if we effectively do not measure wind speeds and other atmospheric variables)

Edson et al. 2013

Momentum Fluxes and Waves

$$\frac{d}{dt}\left(\frac{E}{f}\right) + c_g.\nabla\left(\frac{E}{f}\right) = S_{wind} - S_{brk} + S_{nl}$$

Energy

Group Velocity

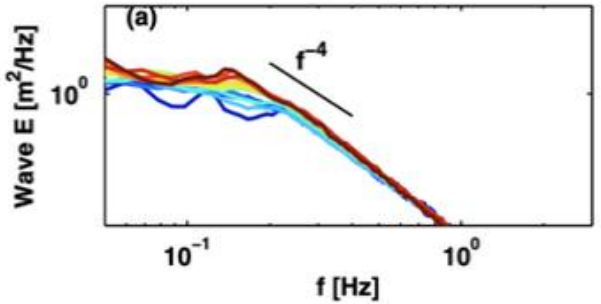
Wind input

Dissipation via Wave Breaking

Non-linear Interaction

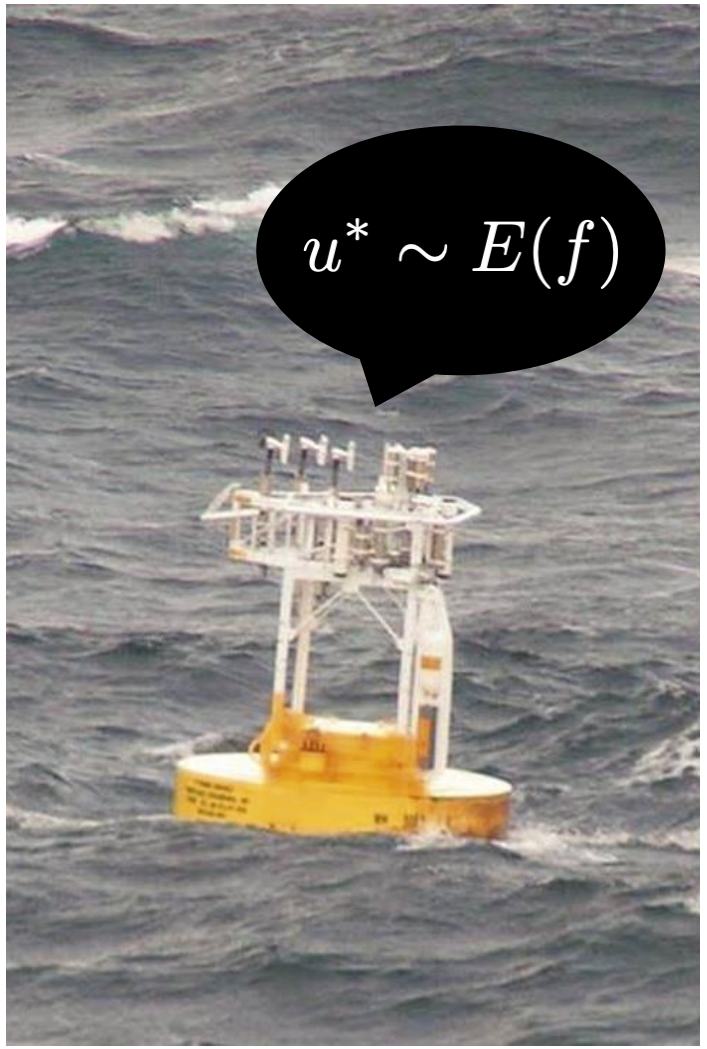
In equilibrium (wave growth is slow and flux divergence is negligible)

$$\frac{E(f)}{2\pi} = \frac{\beta I(p) g u^* f^{-4}}{16\pi^4}$$



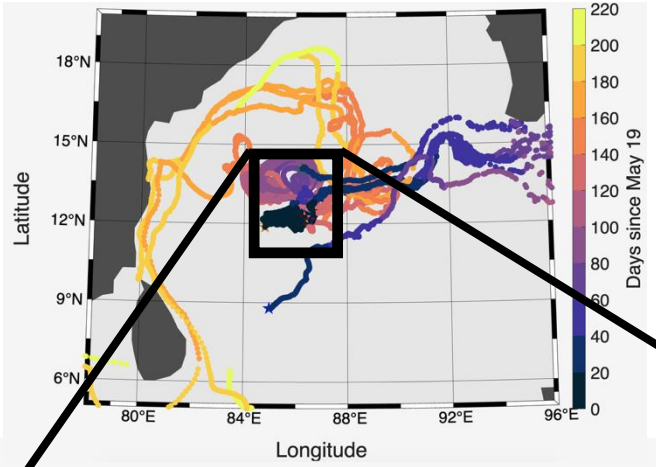
Thomson et al. 2013

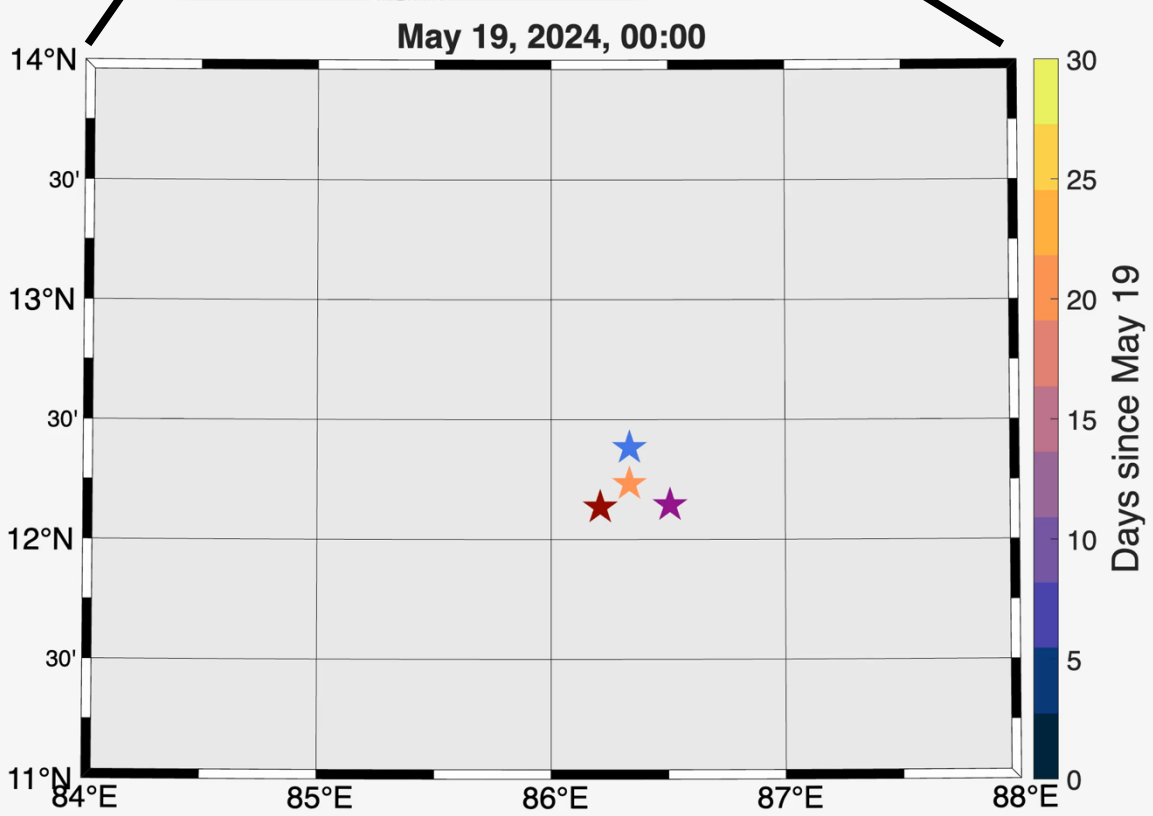
$$u_* = \int_{f_{\min}}^{f_{\max}} \frac{E(f) f^4 2\pi^3}{\beta I(p) g (f_{\max} - f_{\min})} df.$$

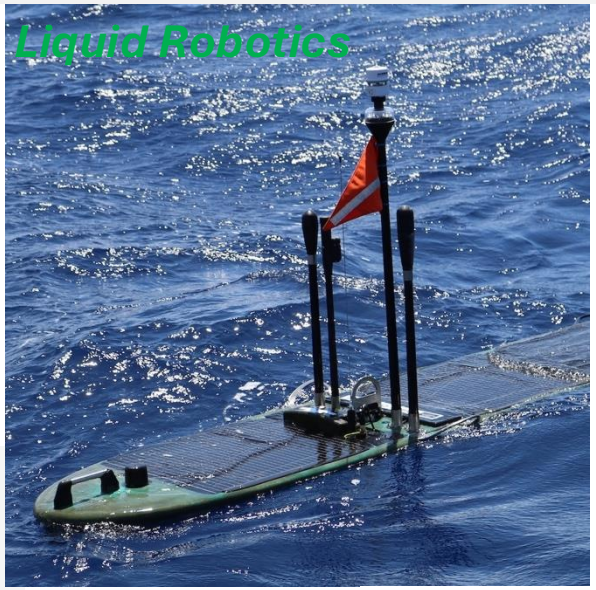


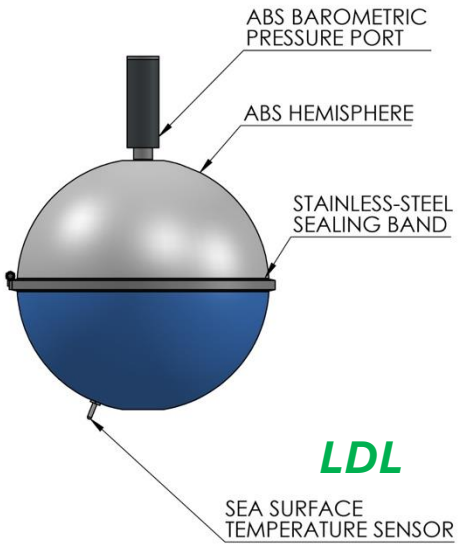
Edson et al. 2013

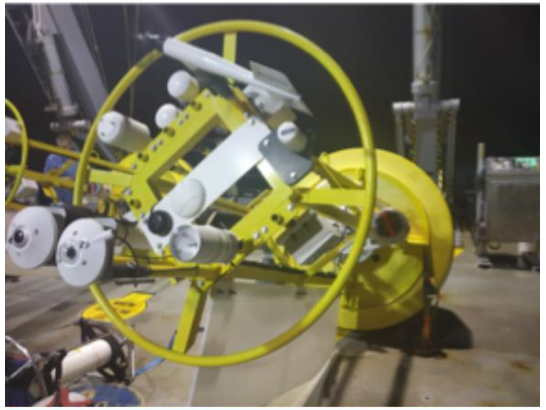
EKAMSAT cruise and instrument introduction





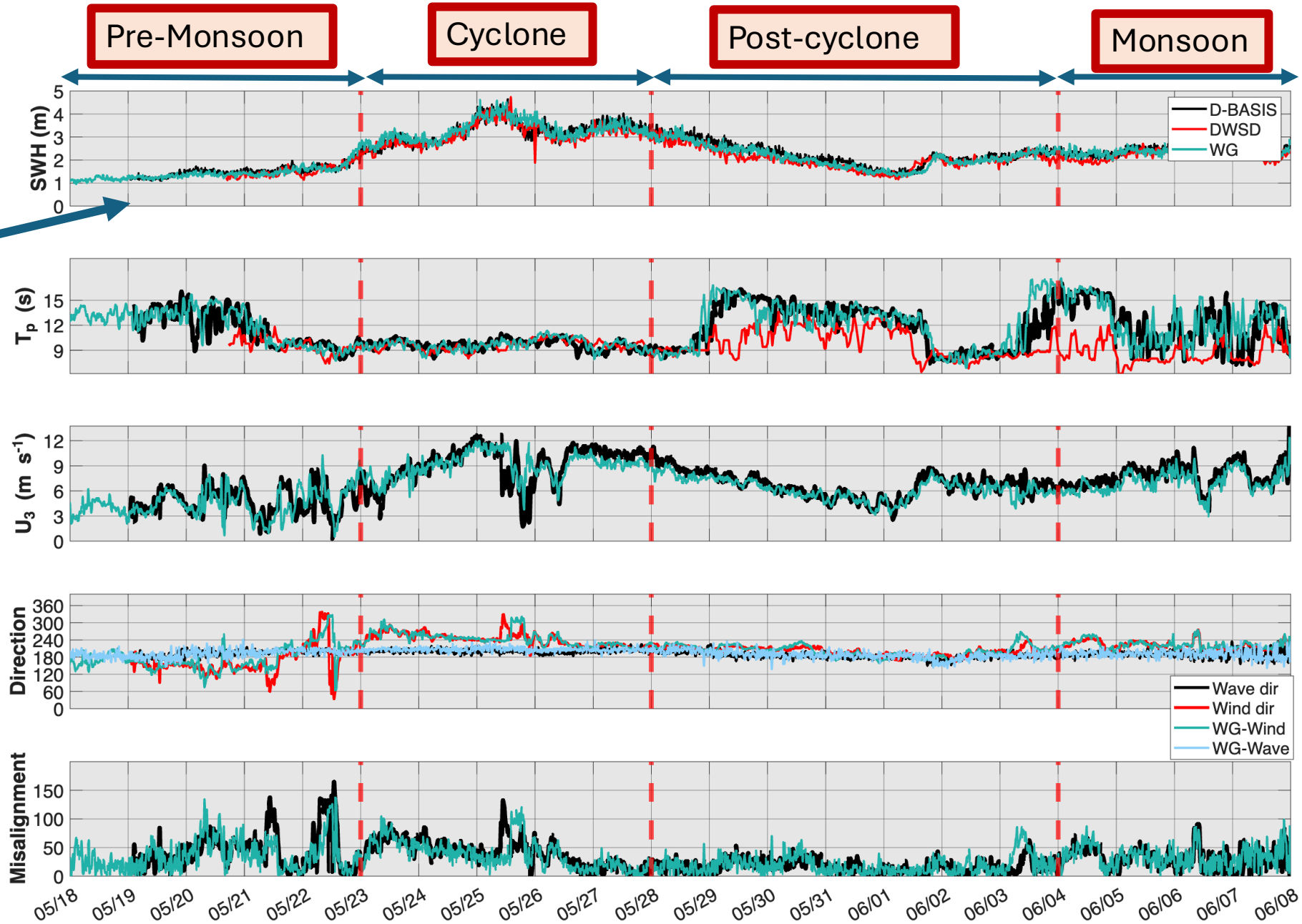






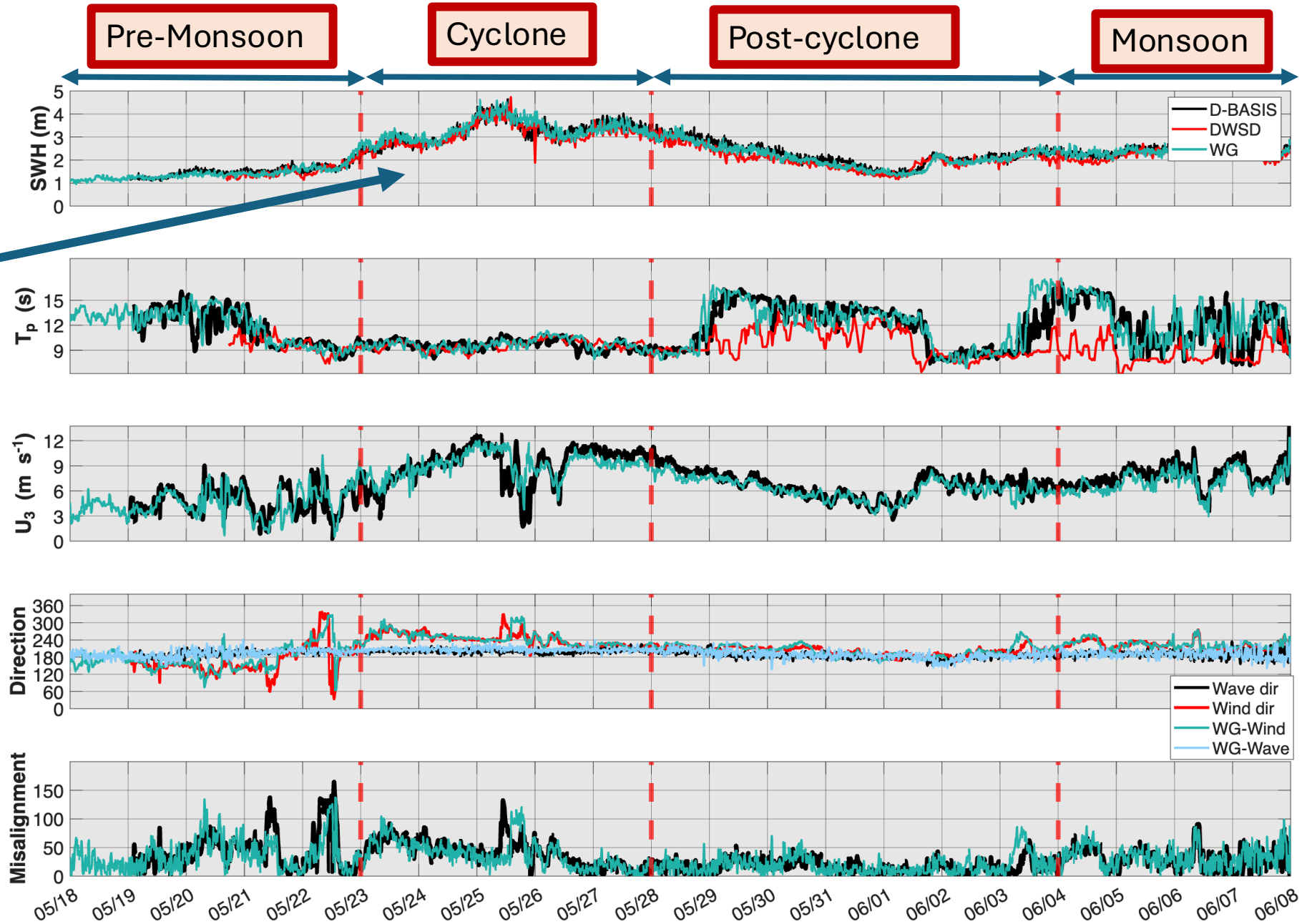
Time-Series from EKAMSAT 2024 IOP

Glossy seas dominated by **southerly swells**, **low wind speeds**, **occasional misalignment** between winds and waves



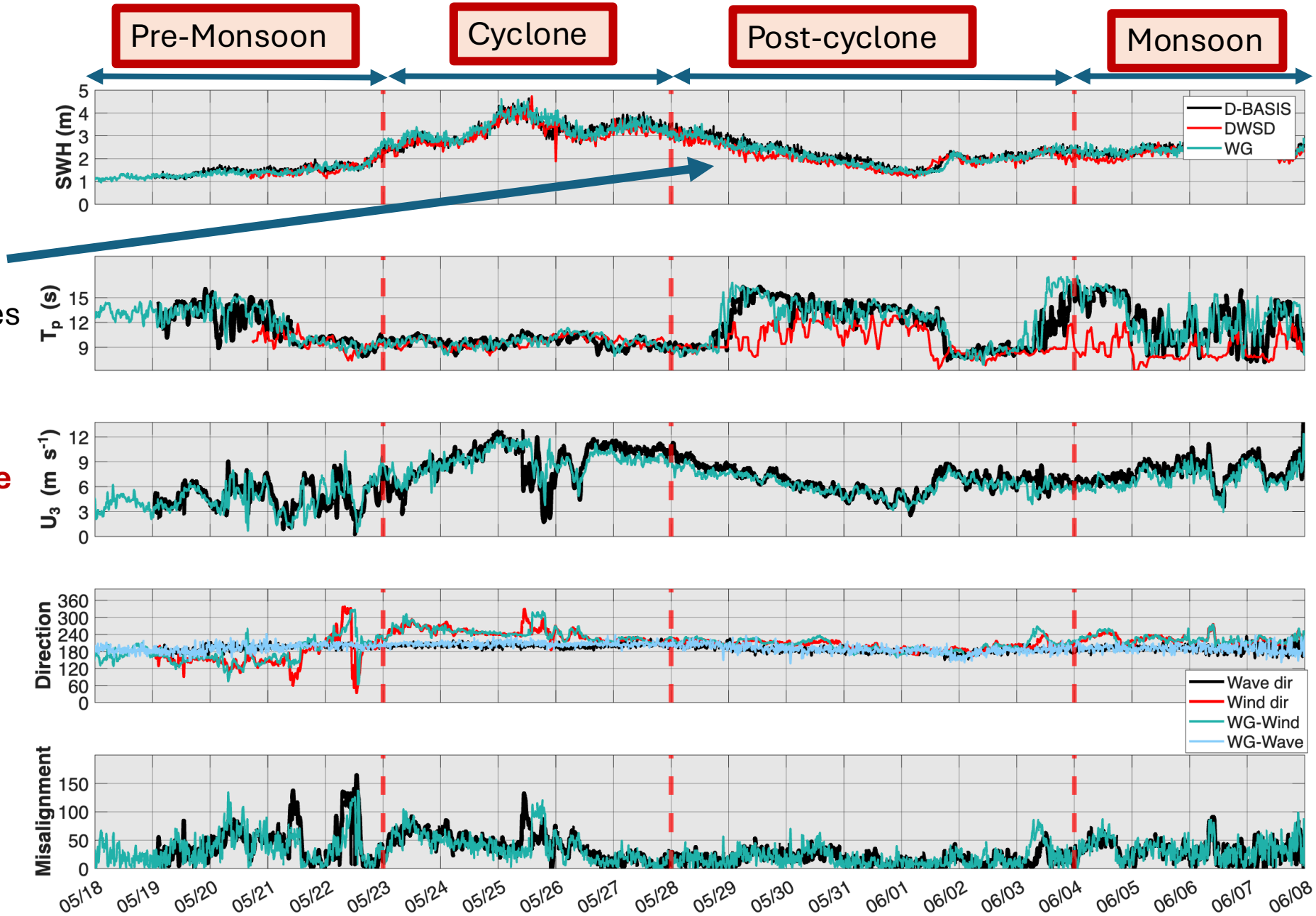
Time-Series from EKAMSAT 2024 IOP

Passage of TC Remal causes **waves to pick up, local wind-driven waves** being aligned **with winds.**



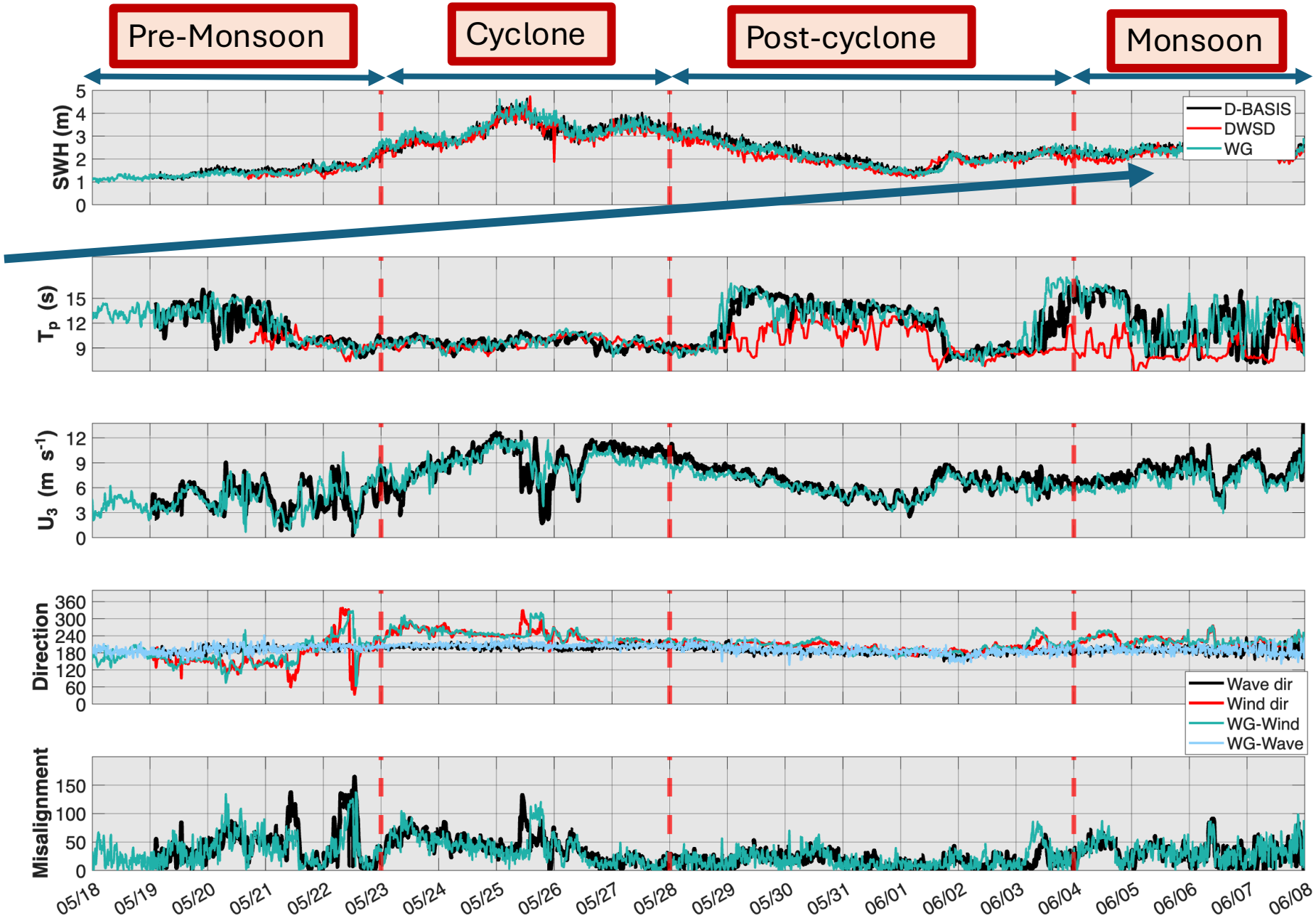
Time-Series from EKAMSAT 2024 IOP

Post-cyclone period features **wave heights slowly decreasing**, with **presence of mixed-sea conditions** which are **aligned**.

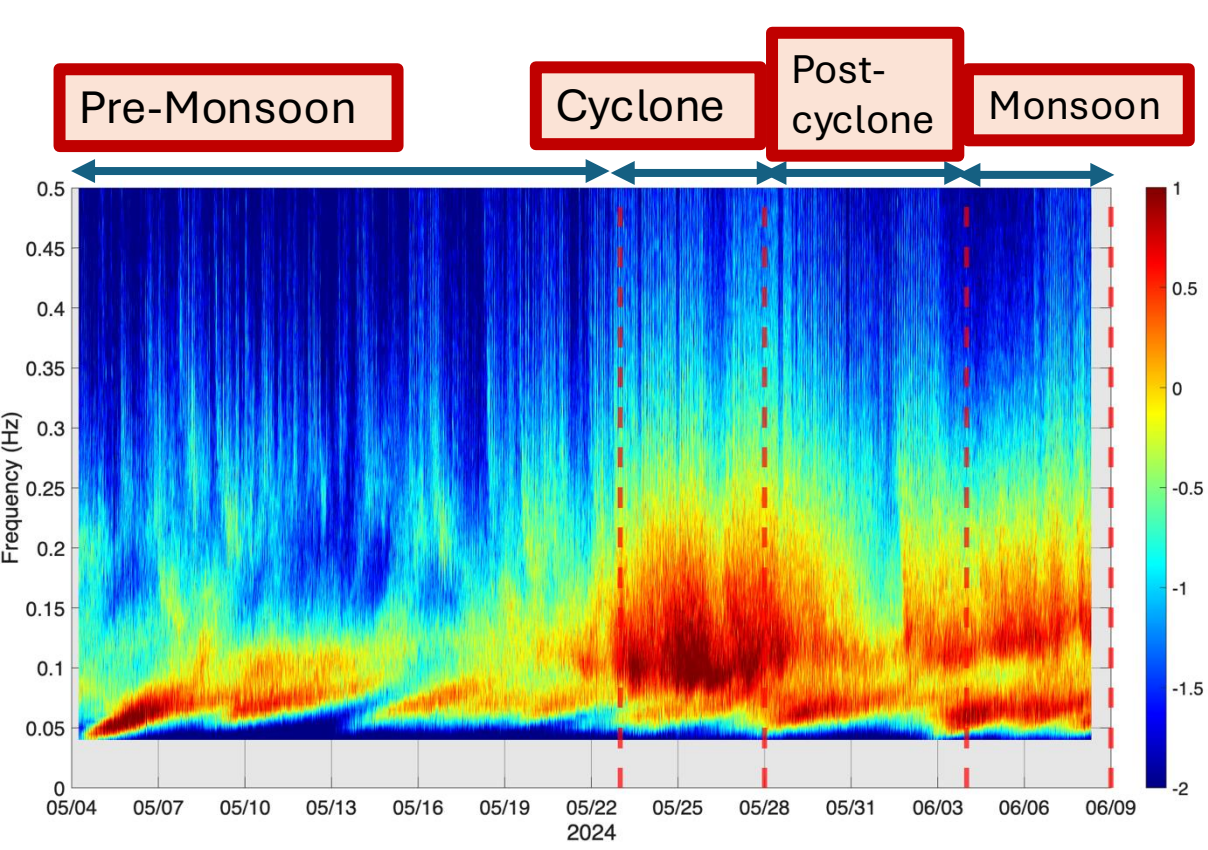


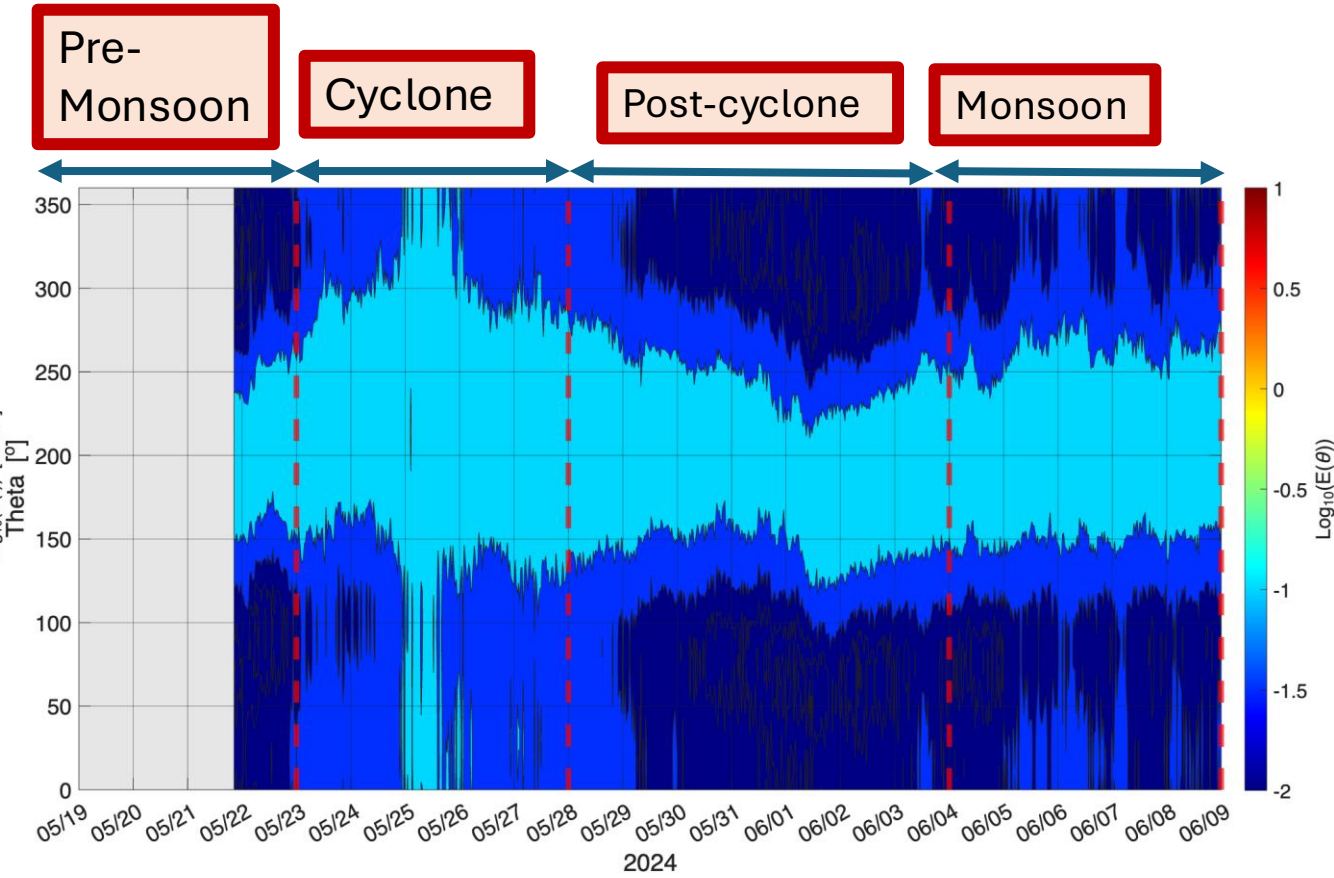
Time-Series from EKAMSAT 2024 IOP

Monsoon period features similar conditions as post-cyclone recovery .



Wave Energy Spectra

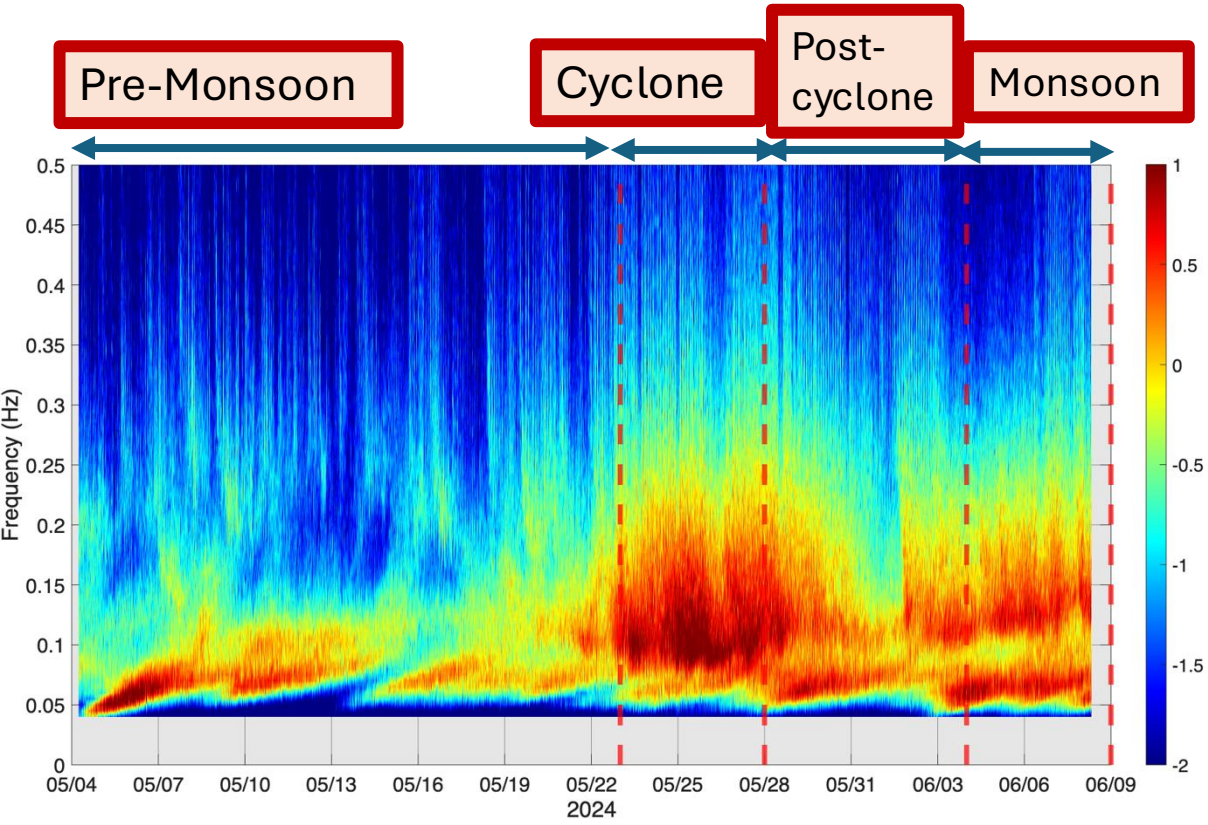




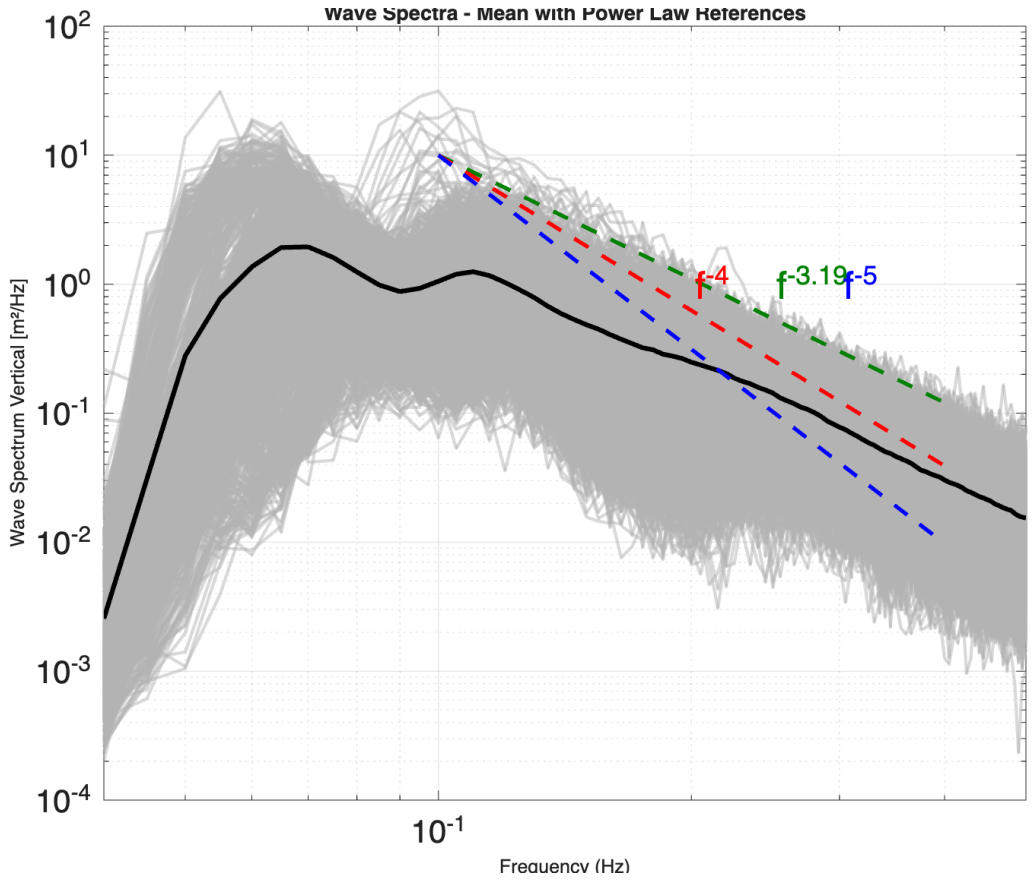
Time-series of the IOP period transitions from **low-frequency swells** to **higher frequency wind-waves** to presence of **mixed sea conditions** (simultaneous presence of wind and swell waves)

Directional spreading in waves are consistent throughout the period.

Wave Energy Spectra



Pre-Monsoon



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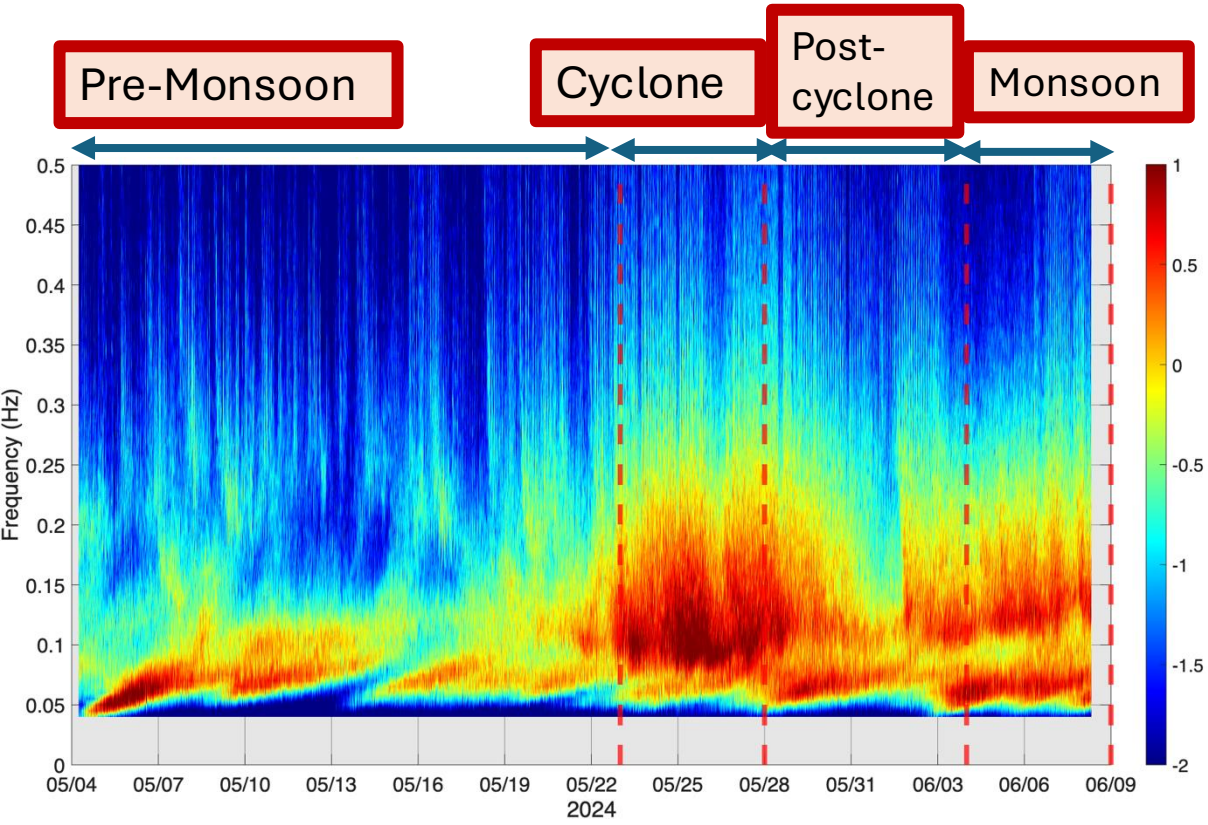

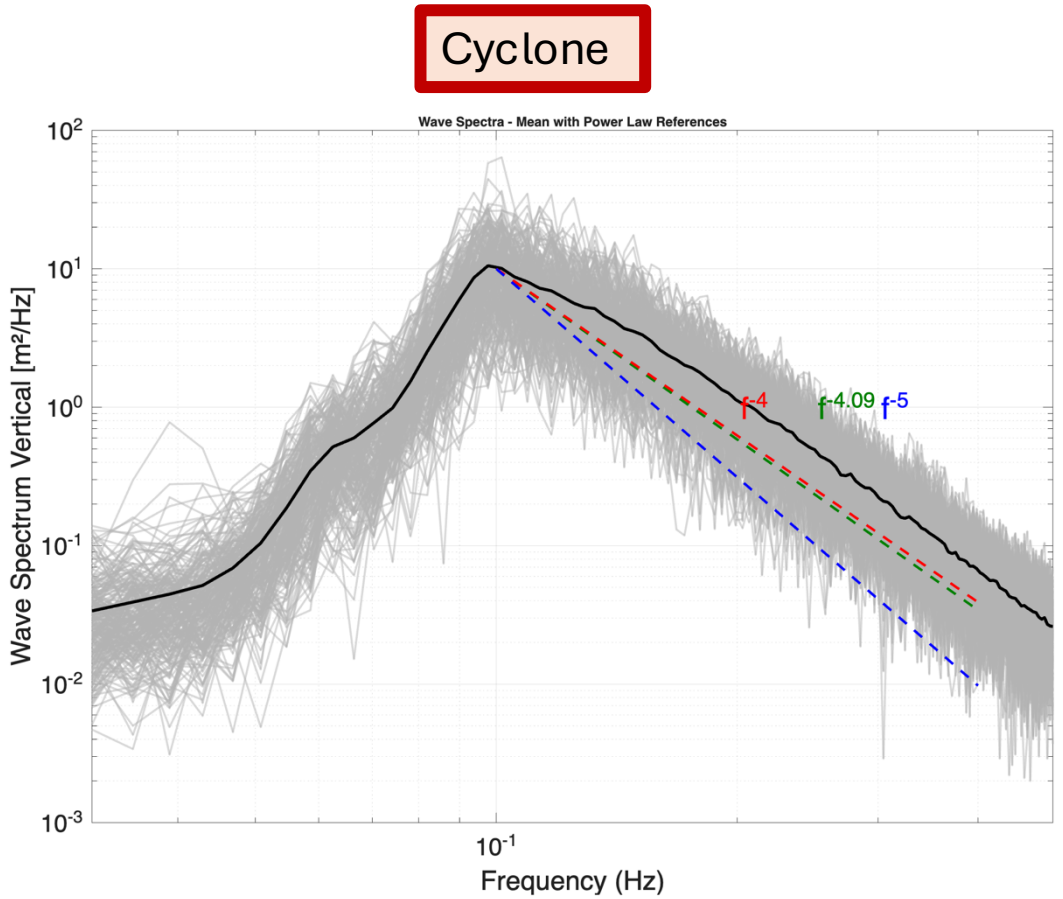

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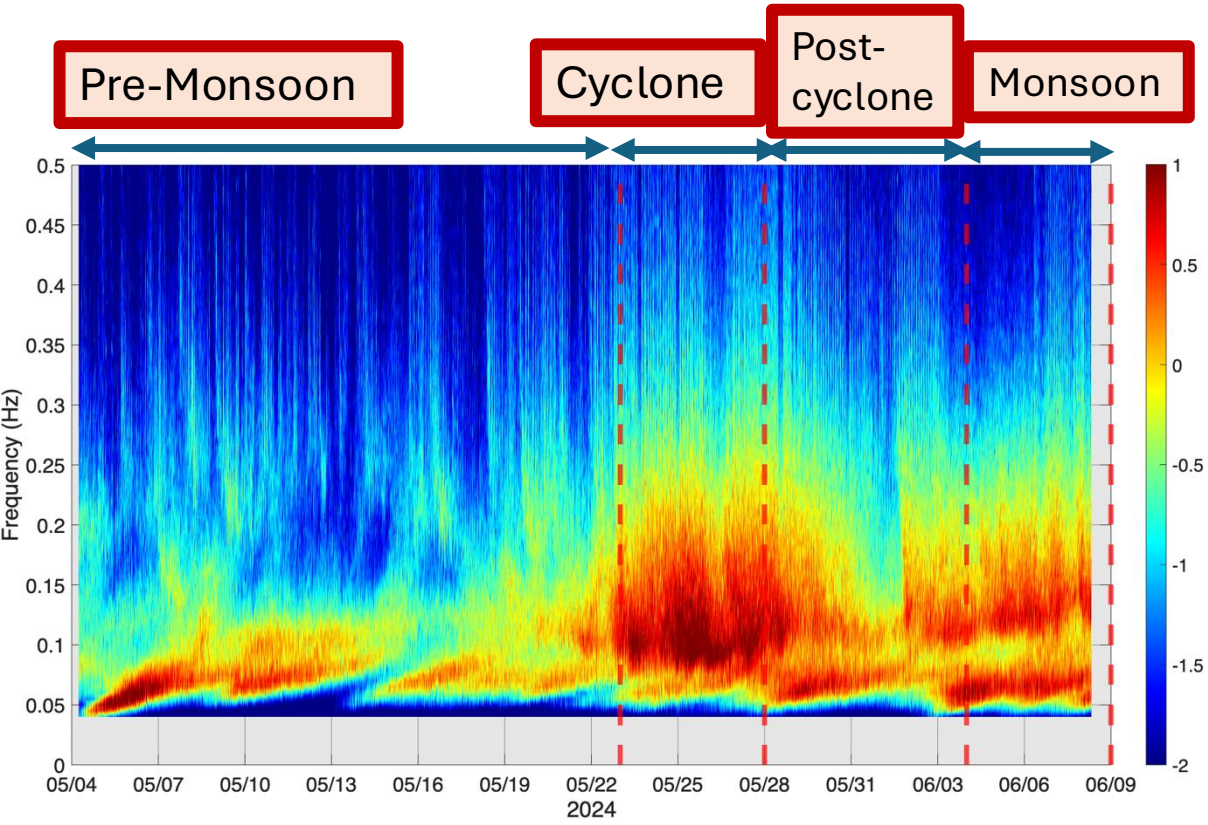
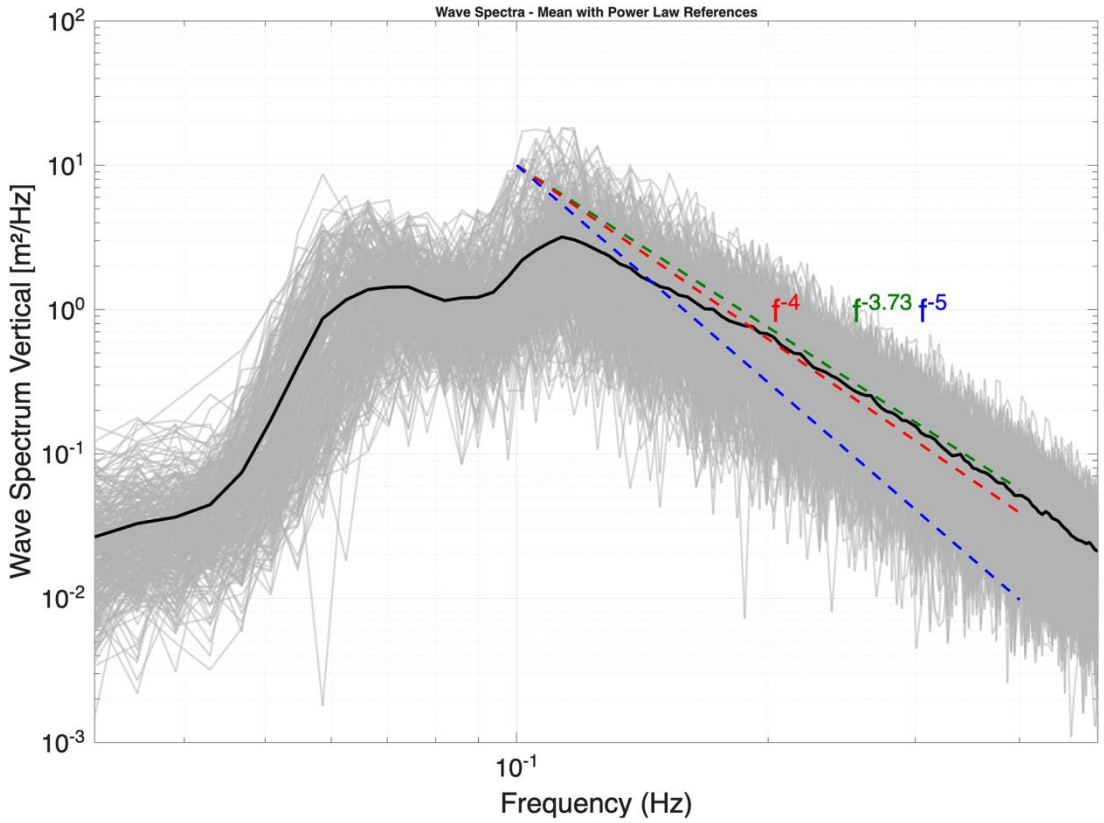


Post-cyclone



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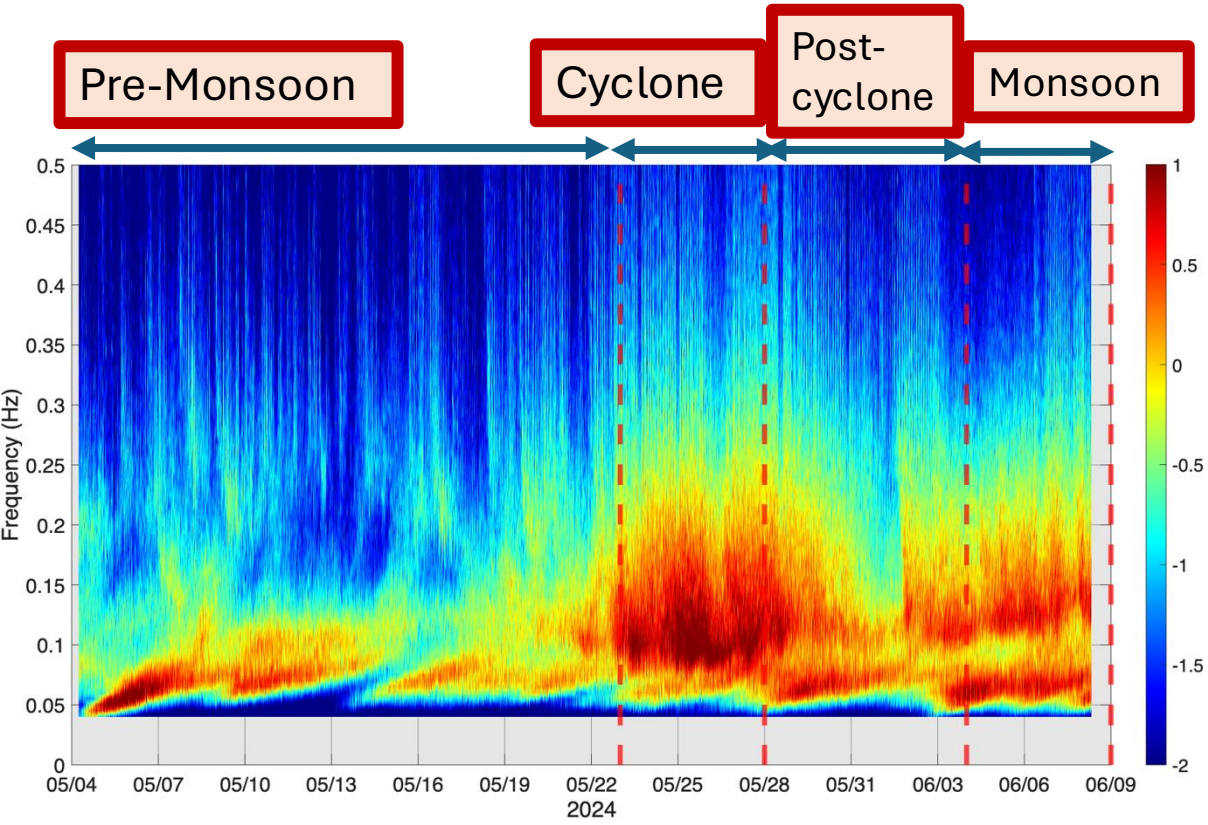

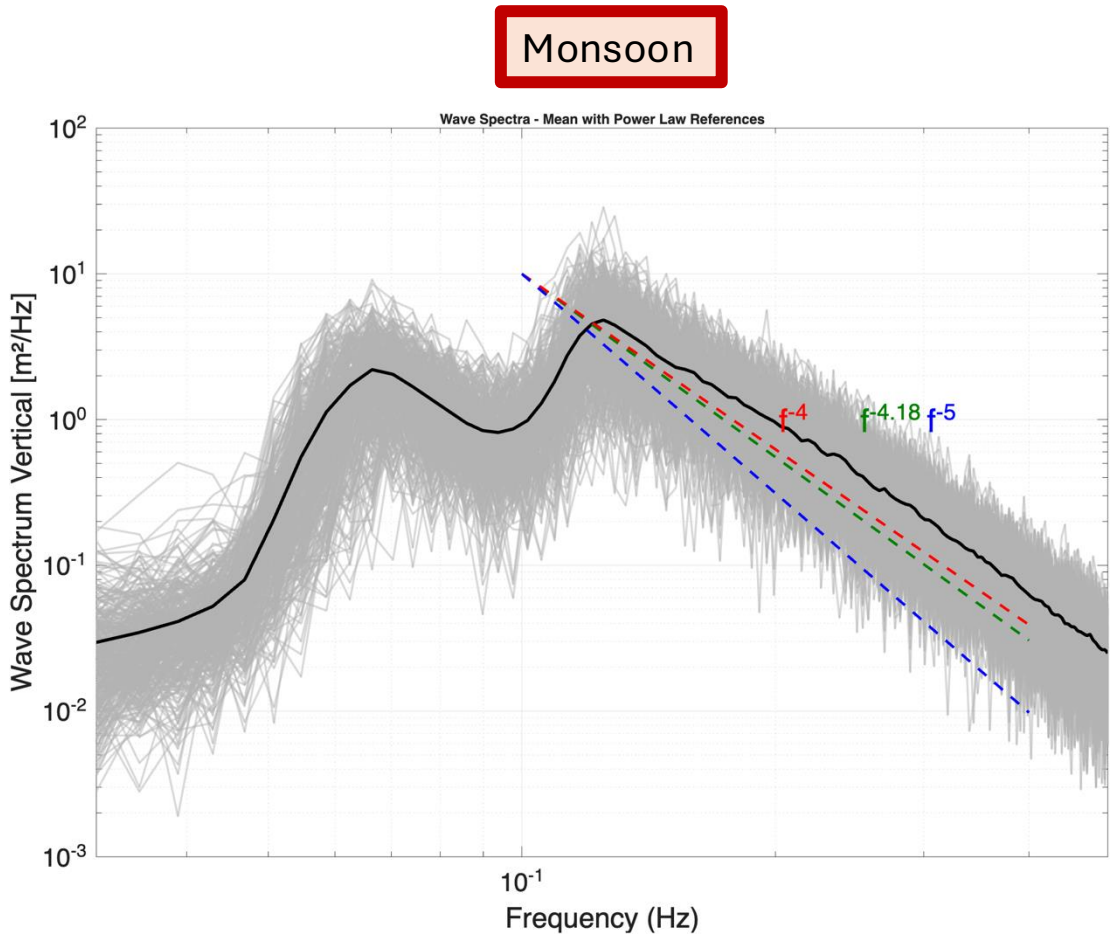

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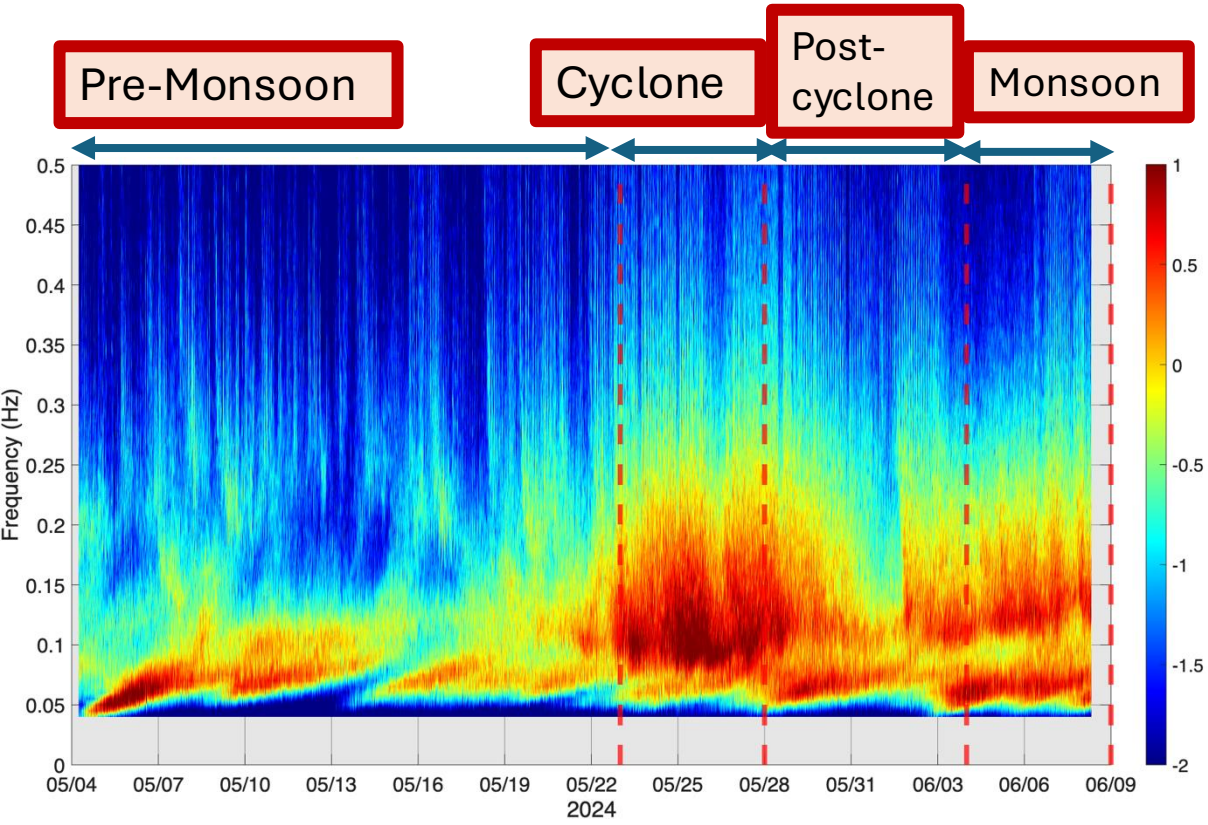
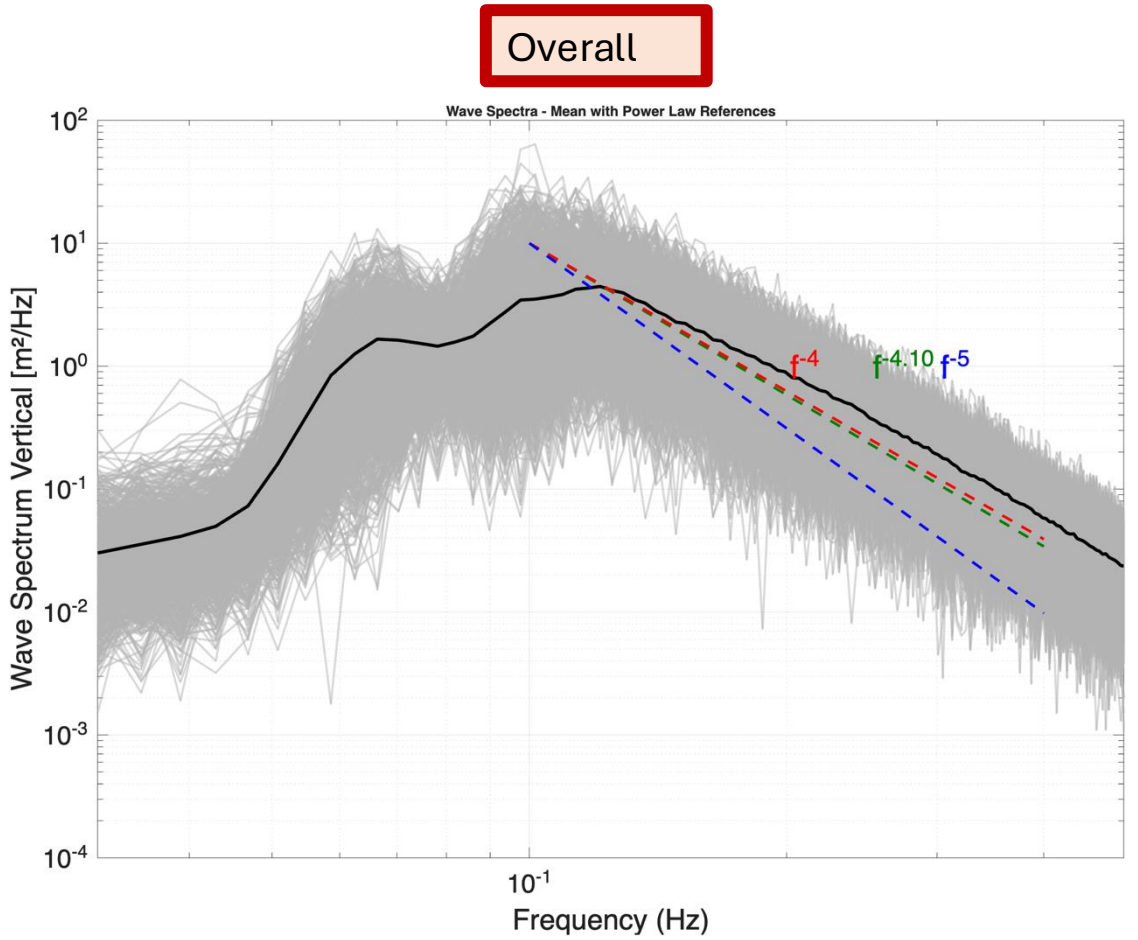
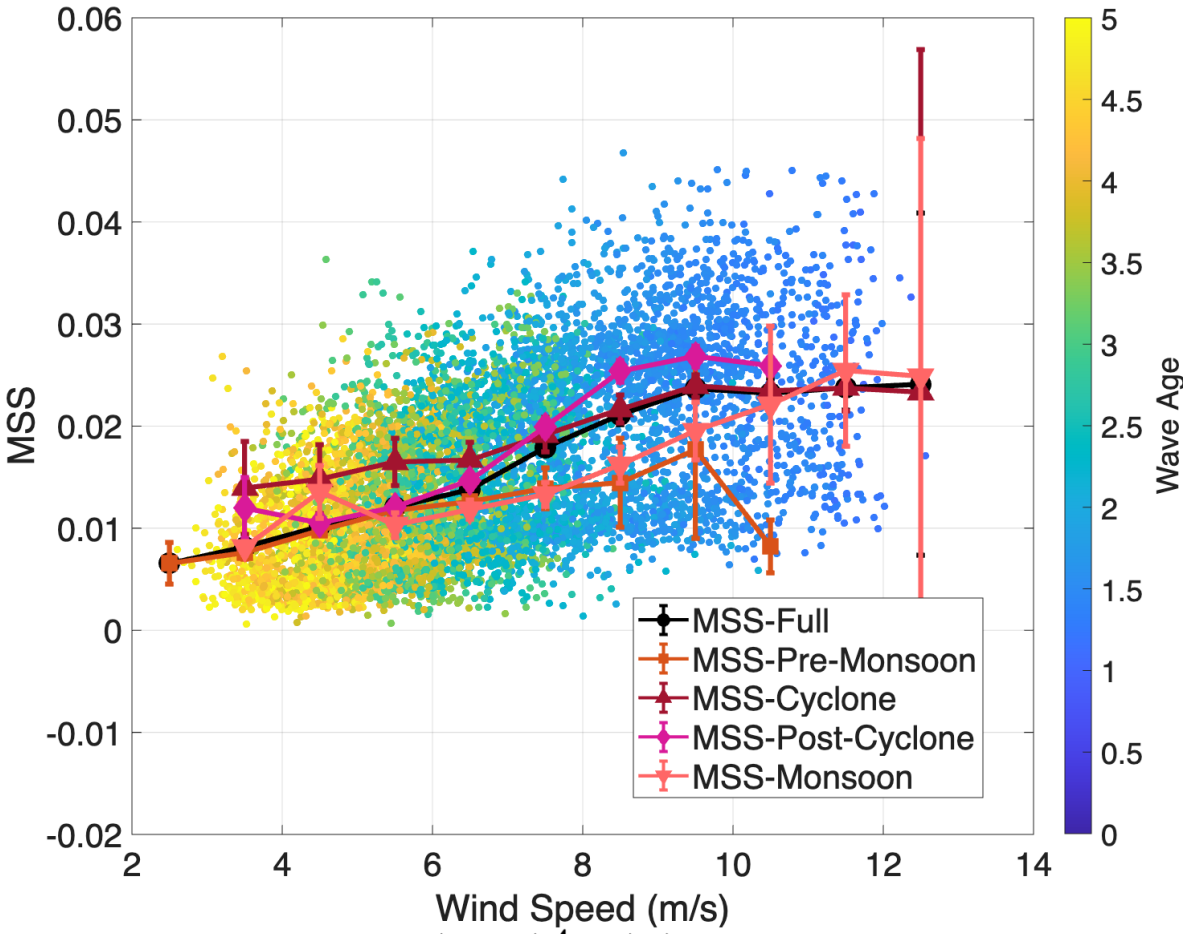




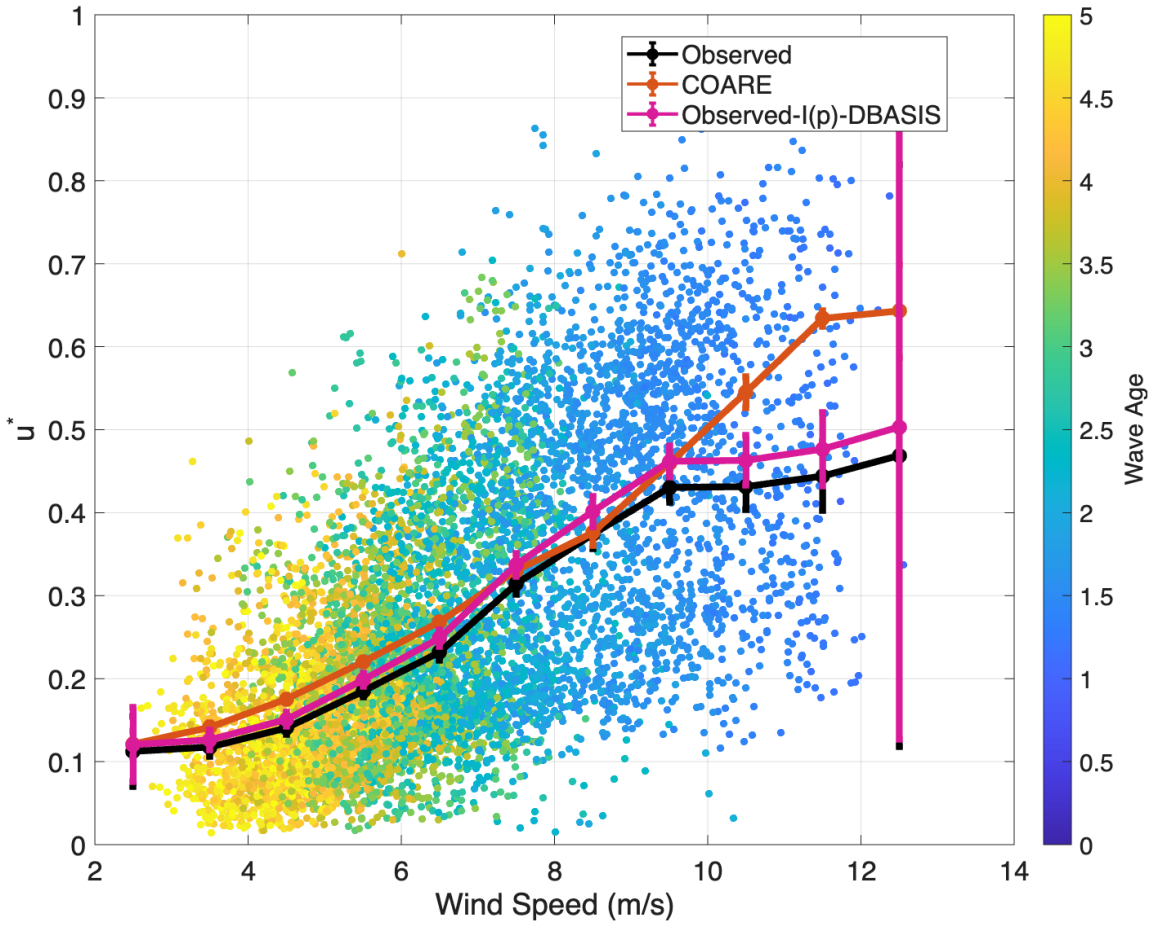
Time-series of the IOP period transitions from **low-frequency swells** to **higher frequency wind-waves** to presence of **mixed sea conditions** (simultaneous presence of wind and swell waves)

Mean-Square Slope and u*



$$mss = \int \frac{(2\pi f)^4 E(f)}{g^2} df.$$

$$\frac{u_*}{mss(eq.f)} = \frac{g}{8\pi\beta I(p)}.$$



$$I(p) = \pi - \theta_{eq} - \Delta\theta_{eq}/2$$

$$u_* = \int_{f_{\min}}^{f_{\max}} \frac{E(f) f^4 2\pi^3}{\beta I(p) g (f_{\max} - f_{\min})} df.$$

Take-Home Messages

- EKAMSAT 2024-IOP field campaign featured an interesting combination of **omni-present swells** and **periods of wind-waves**.

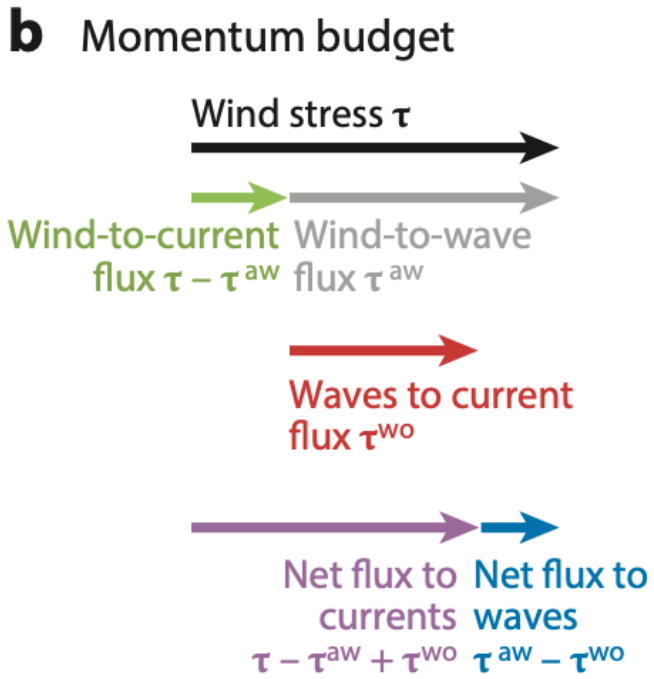
- **f^{-4}** spectral slope within the high-frequency range in the wave spectra occurs, indicating the **balance of wind-driven energy input and wave breaking**. This assumption breaks down during the presence of light-winds and swells.

- As expected, **swells** impact the **overall surface roughness**.

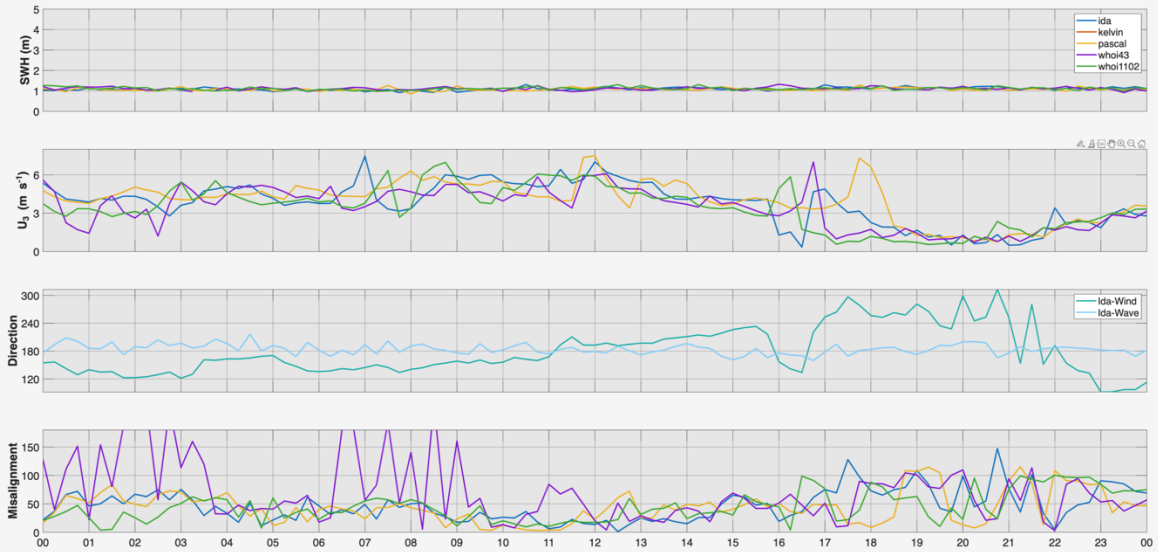
- **u^* computation** is inherently noisy but compares well from COARE estimates after averaging.

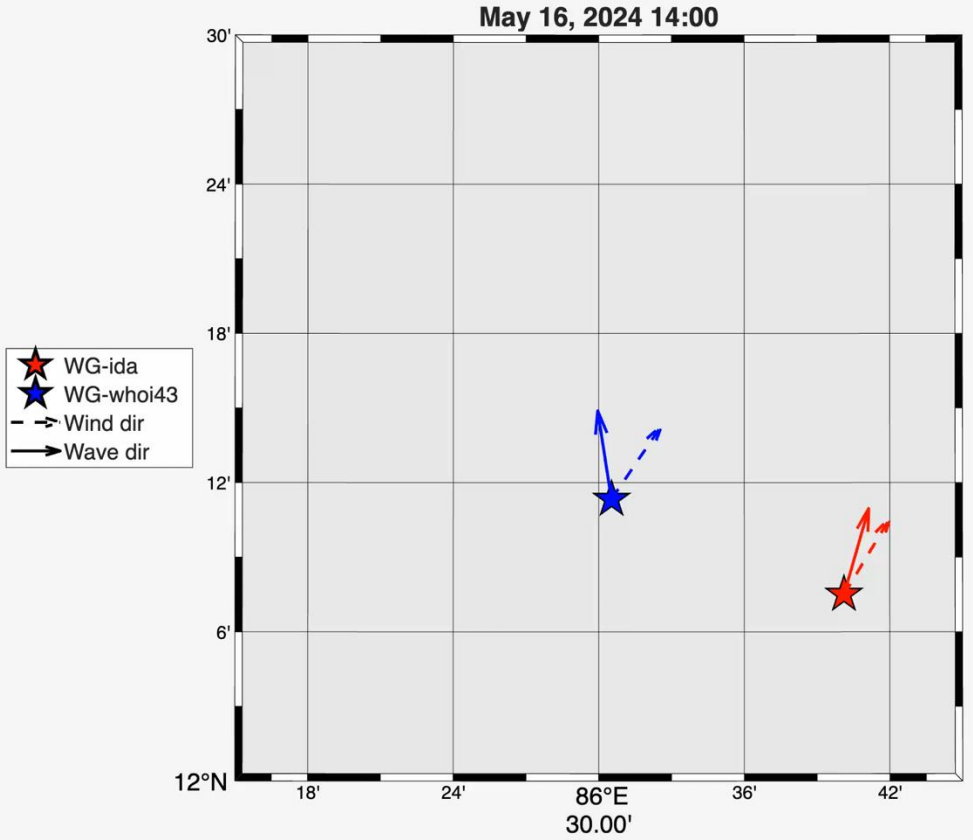
Take-Home Messages

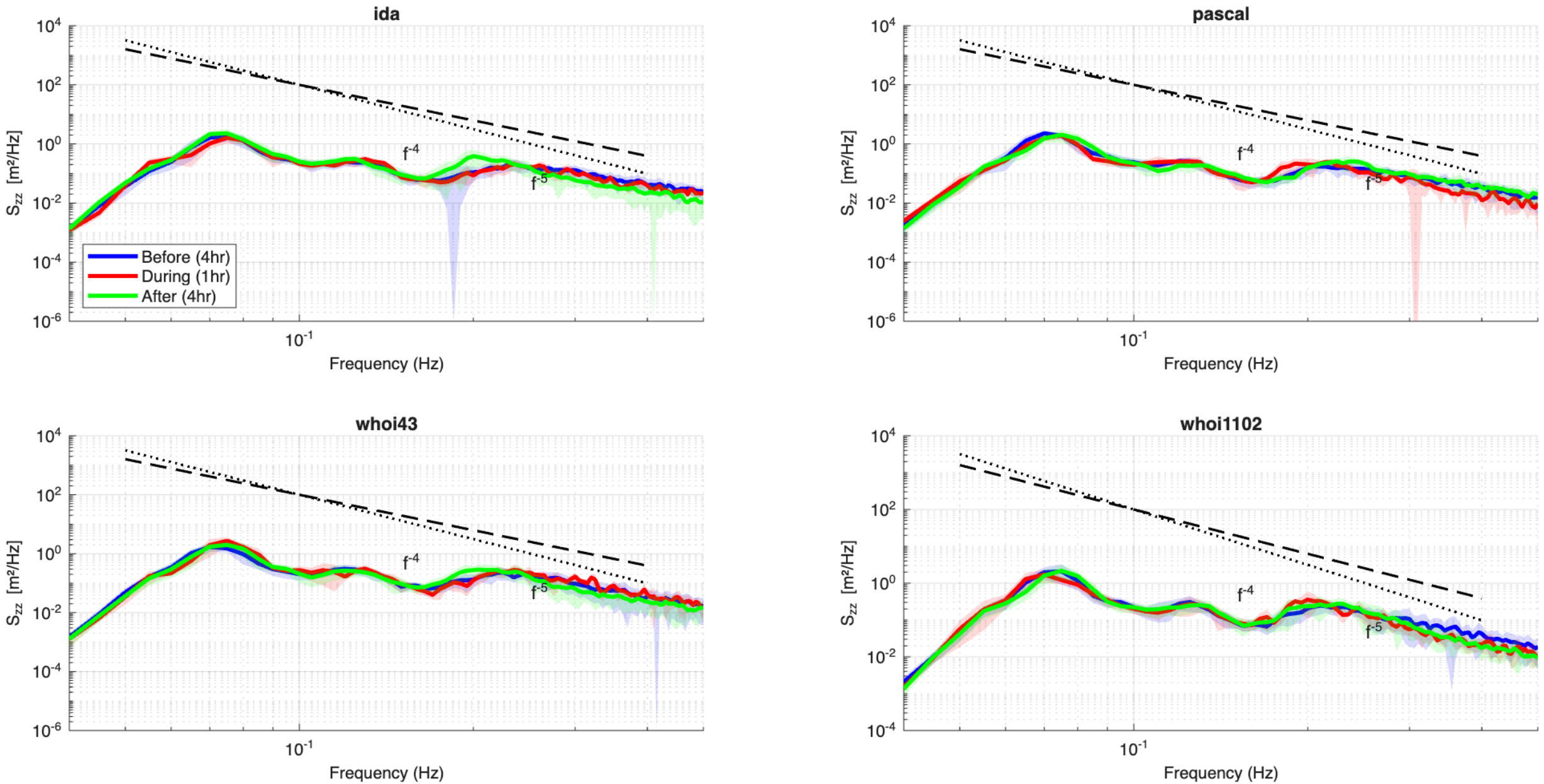
- Mismatch between **instruments:** Estimates of u^* from DBASIS look slightly off when compared to wave-drifter or Wave-Glider.
- Mismatch doesn't really mean either **COARE is erroneous**, or **measurements are faulty**- Each instrument has some sensitivity to measurements due to its size, and these are different methods.
- Some sensitivity observed due to **mixed-sea waves, misaligned waves**, we are still discussing and working on it. Plans to **incorporate 2025 IOP and 2023 Pilot data in it.**
- **Stokes drift** from wave-spectra will have similar variability (computations ongoing).



Gille et al. 2025


SWH (m)
ida
kelvin
pascal
whoi43
whoi1102
U_3 (m s^{-1})
Direction
Ida-Wind
Ida-Wave
Misalignment
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00


May 16, 2024 14:00
WG-ida
WG-whoi43
Wind dir
Wave dir
30'
24'
18'
12'
6'
12°N
18'
24'
86°E
30.00'
36'
42'


Wave Spectra Before/During/After Cold Pool — May 16 16:00
ida
pascal
whoi43
whoi1102
Before (4hr)
During (1hr)
After (4hr)
f-4
f-5
Szz [m²/Hz]
Frequency (Hz)