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39th Conference on Weather Analysis and Forecasting

離岸氣象塔量測資料對海表面粗糙度之數據 分析

On the quantities describing the ocean surface roughness reduced from the offshore met tower data

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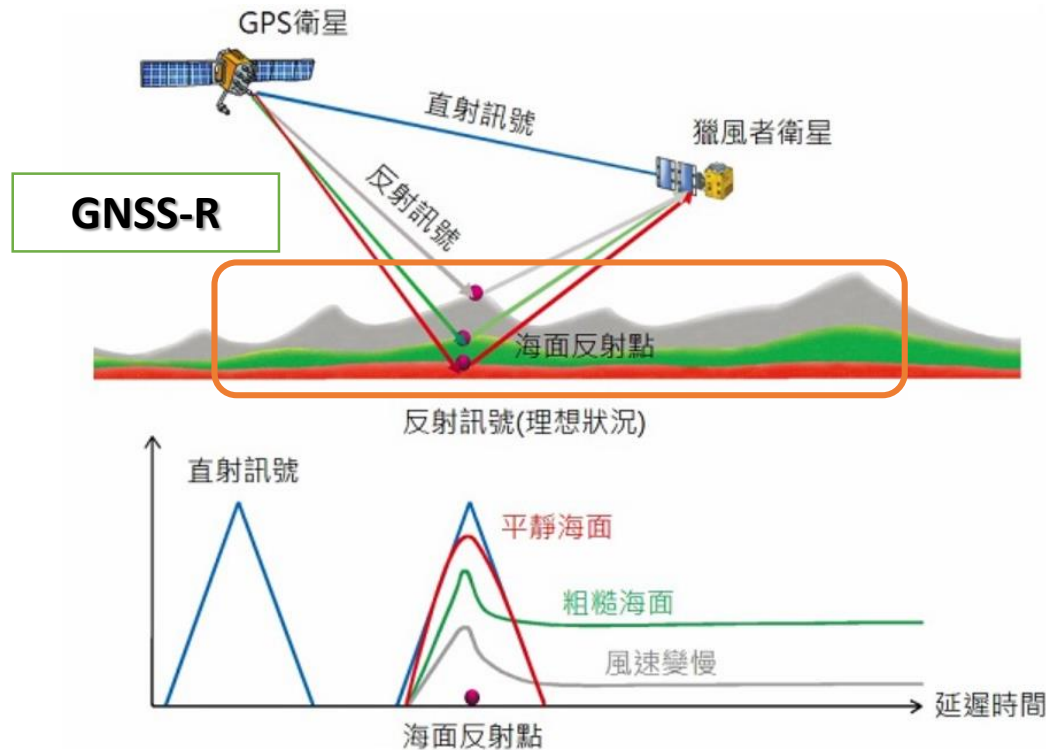
Presenter: 紀惠珊¹ (Chi, H.-S.)

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Research Background

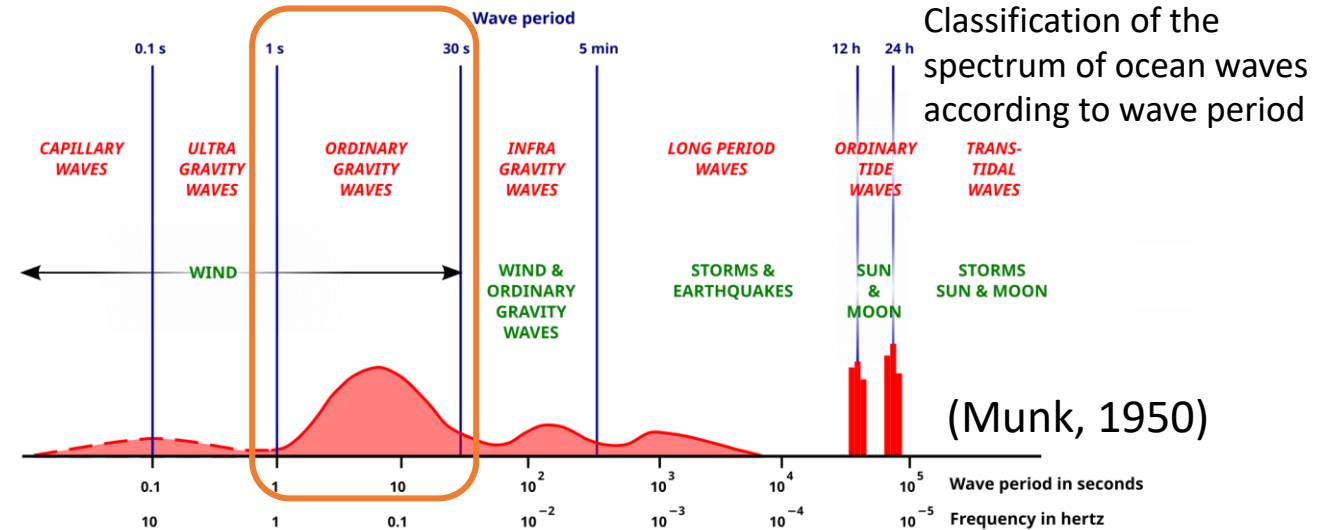
Before using the GNSS reflectometry (GNSS-R) method to retrieve the information of wind over an ocean surface, roughness of ocean surface is important to investigate. And roughness is due to wind driven waves essentially.



Functionality of GNSS-R

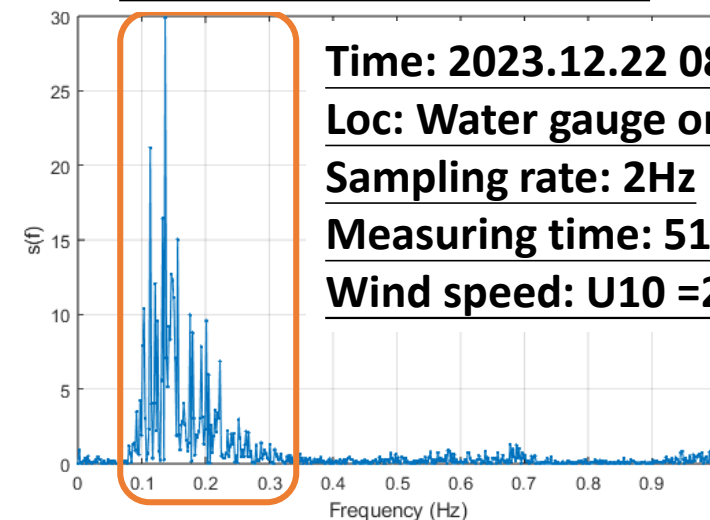
(Source: National Institutes of Applied Research and TASA)

The ocean surface roughness under wind and wave measurements are discussed further.



Example:

Wave Frequency Spectrum



Time: 2023.12.22 08:00

Loc: Water gauge on an offshore met tower

Sampling rate: 2Hz

Measuring time: 512s

Wind speed: $U_{10} = 20.6$ m/s

Offshore met tower

- 永傳能源公司的福海海氣象觀測塔
- 彰化芳苑鄉外海8公里處
- Tower height: 86 m



Ultrasonic meter:

Observation items: Wind speed(u , v , w , and total wind speed; m/s), wind direction

Sampling rate: 2 Hz

Instrument height: 30 m

Observation frequency: Once every 20 minutes (three times per hour), each lasting 512 seconds



Water gauges:

Observation items: Water level variation(m), wave height(m), period(s), wave direction

Sampling rate: 2 Hz

Instrument height: 25 m

Observation frequency: Once every 20 minutes (three times per hour), each lasting 512 seconds

Characteristic quantities of roughness

	Unit	Methodology	References	Roughness Equations	Original or Related equations
0	m	Logarithmic law for neutral stability	(Sutton, 1949)	$z_0 = z / \exp\left(\frac{\kappa u(z)}{u^*}\right)$	$u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right)$ $u_* = \left[(\overline{u'w'})^2 + (\overline{v'w'})^2 \right]^{\frac{1}{4}} \text{ - (American Meteorological Society)}$
1	m	ks from Nickuradse (Roughness in the pipe)	(Nickuradse, 1950) (Schlichting, 1968)	$ks = z / \exp\left(\frac{\kappa u(z)}{u^*} - 8.5\kappa\right)$	$\frac{V}{u^*} = \frac{1}{\kappa} \ln\left(\frac{z}{ks}\right) + 8.5$ $V = u(z)$
2	m	Charnock constant	(Charnock, 1955) (Garratt, 1977) (Wu, 1980) (Kitaigorodskii, 1970)	$z_0 = a * \frac{u^{*2}}{g}$ <p>, where $a = 0.014 \sim 0.035$</p>	
3-1		MSS (Mean Square Slope)	(Cox and Munk, 1954)	$MSS = \int_{k_l}^{k_u} k^2 \mathcal{S}(k) dk$ <p>, where $k_u = 0.202$ as the upper limit, $k_l = 0$ as the lower limit of the wave number.</p>	<p>Dispersion relationship: from f to k(wave number):</p> $\omega^2 = 4\pi^2 f^2 = gk * \tanh(kh)$ <p>, where ω: angular frequency ($\omega = 2\pi f$), h: water depth(m)</p> <p>Energy equilibrium:</p> $S(k, \theta) = S(f, \theta) * \frac{df}{dk}$ $S(f) = \frac{1}{Fs * N} * FFT(x) ^2$ <p>, where S: Spectral values over wave number k, Fs: Sampling rate, N: Length of x, x: Raw data of water gauges</p>
3-2		MSS – LPMSS (Low passed filtered MSS) (G model; General surface wave spectral model)	(Cox and Munk, 1954) (Hwang and Fan, 2018) (Hwang, 2022)	$MSS = \int k^2 \mathcal{S}(k) dk$	$\mathcal{S}(\omega) = \alpha_G g^2 \omega_p^{-5} \zeta^{-s} \exp\left[-\left(\frac{\zeta}{K}\right)^{-\beta_G}\right] \gamma_G^{\Gamma_G}$ <p>, where all variables are related to the “G model” in the references with $s(U_{10})$ and ω_p (Peak of angular freq.) as the data from the ultrasonic meter and water gauges measurement individually.</p>

Relation between MSS and NBRCS

TRITON Data(Channel 1) & CYGNSS Data

Time: 2023.12.01-2024.12.31

Collection points: the distance between two satellites is less than 25 km in an hour.

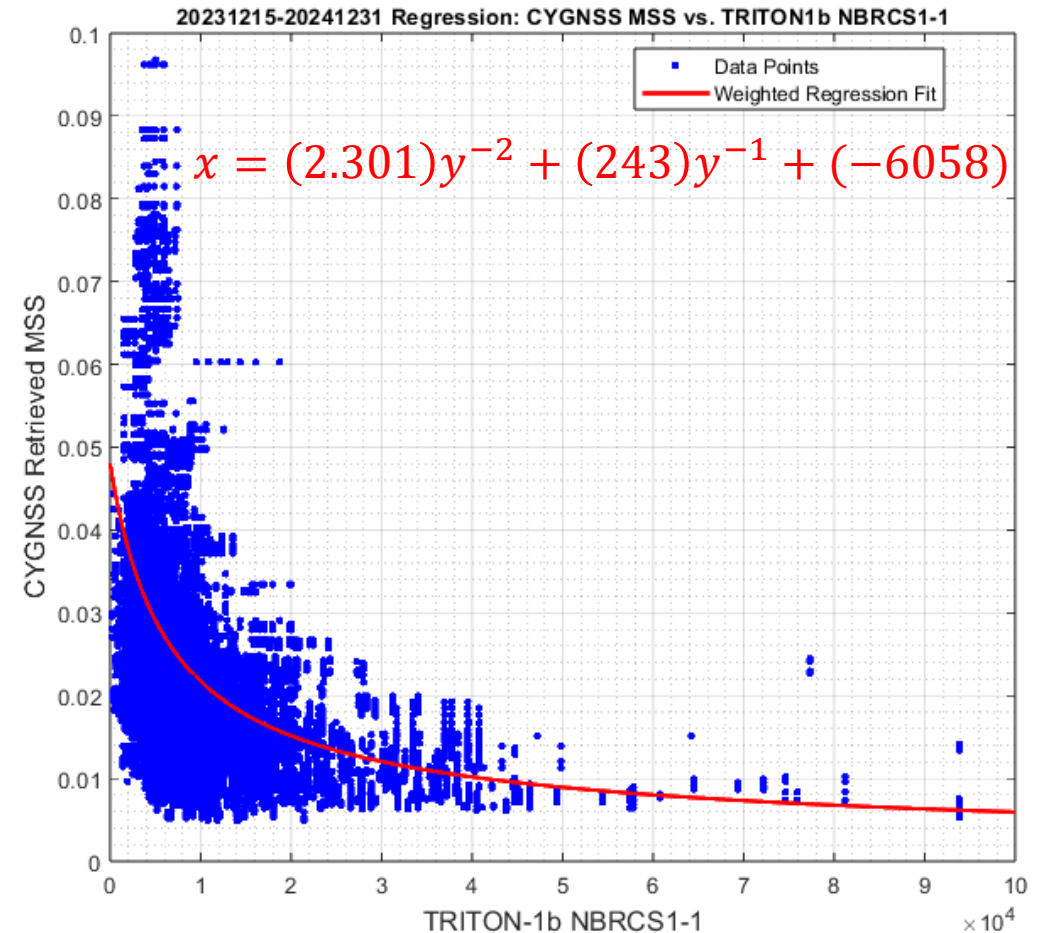
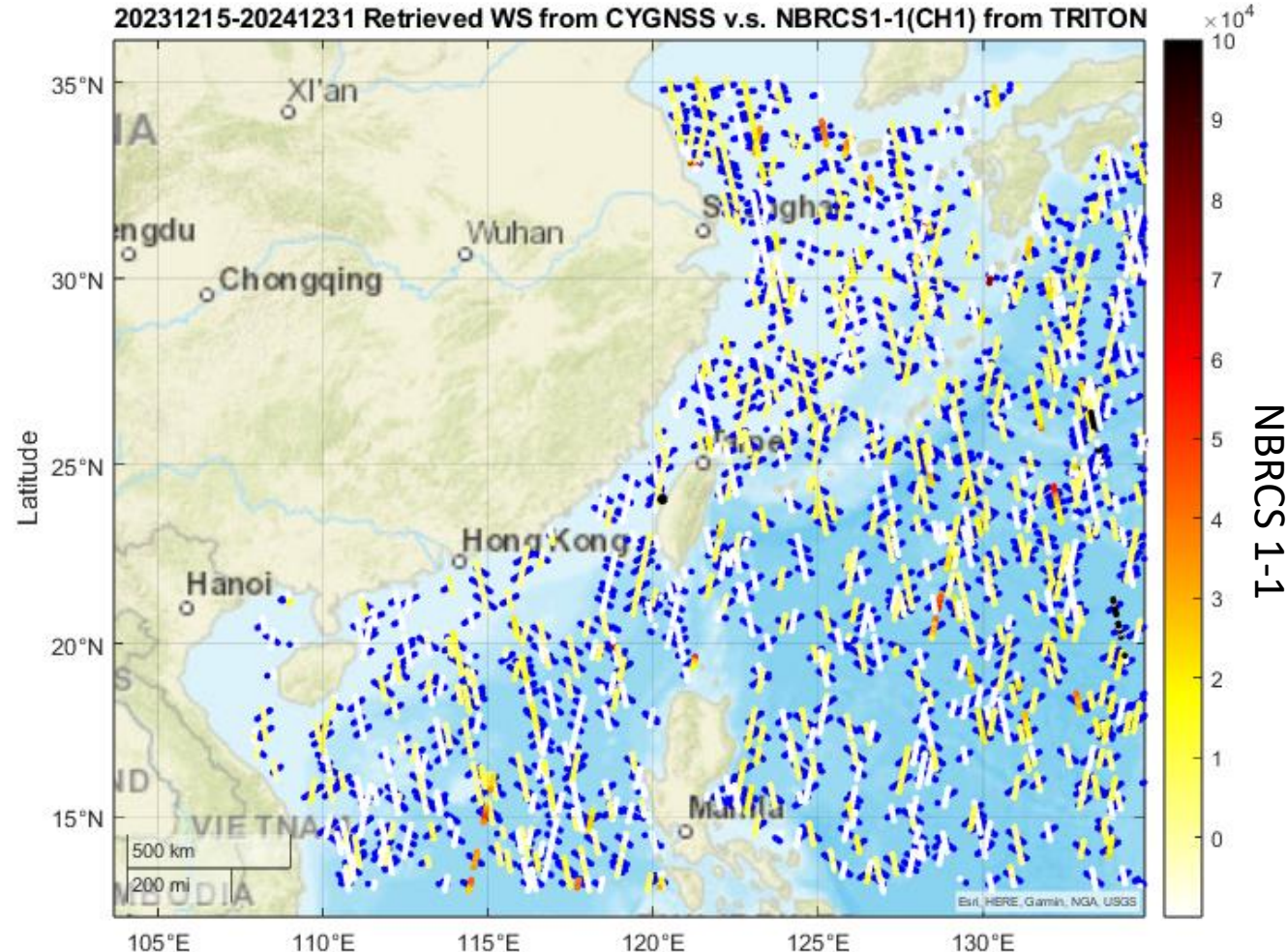
NBRCS(Normalized Bistatic Radar Cross Section):

$$\sigma_0 = \langle P(\hat{t}, \hat{f}^D) \rangle \frac{(4\pi)^3 R_0^2 R^2}{P^T G^T \lambda^2 G^R \bar{A}_{eff}}$$

↑
DDM

(TRITON Algorithm Theoretical Basis Document v1.0)

(Zavorotny and Voronovich, 2000)



Blue points: the datapoints of CYGNSS.
Color bar: the values of TRITON's NBRCS1-1

Data collection

Northeast wind period:

Wind Tower Data:

From: 2023.12.15 10:40

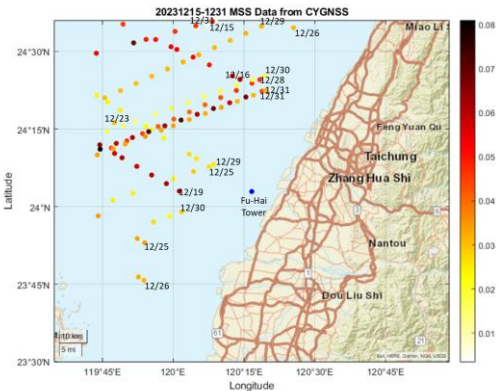
To: 2023.12.31 23:40

CYGNSS Data:

From: 2023.12.15 10:40

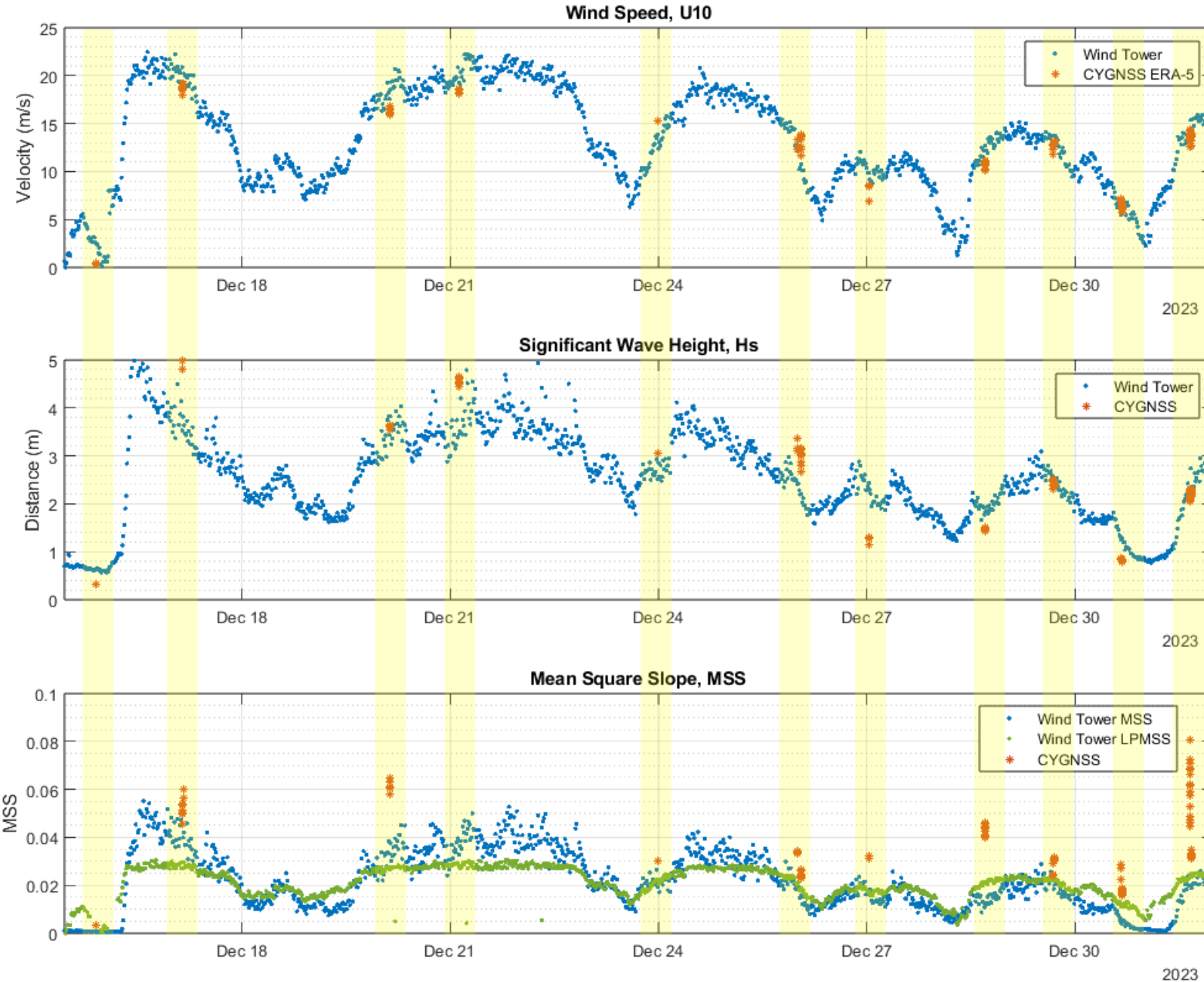
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Area: ± 0.55 degrees in latitude and longitude centered on the tower. (≈ 56 km)



High correlation between the wind tower data and CYGNSS retrieved data.

Comparison between Wind Tower Data and CYGNSS Data



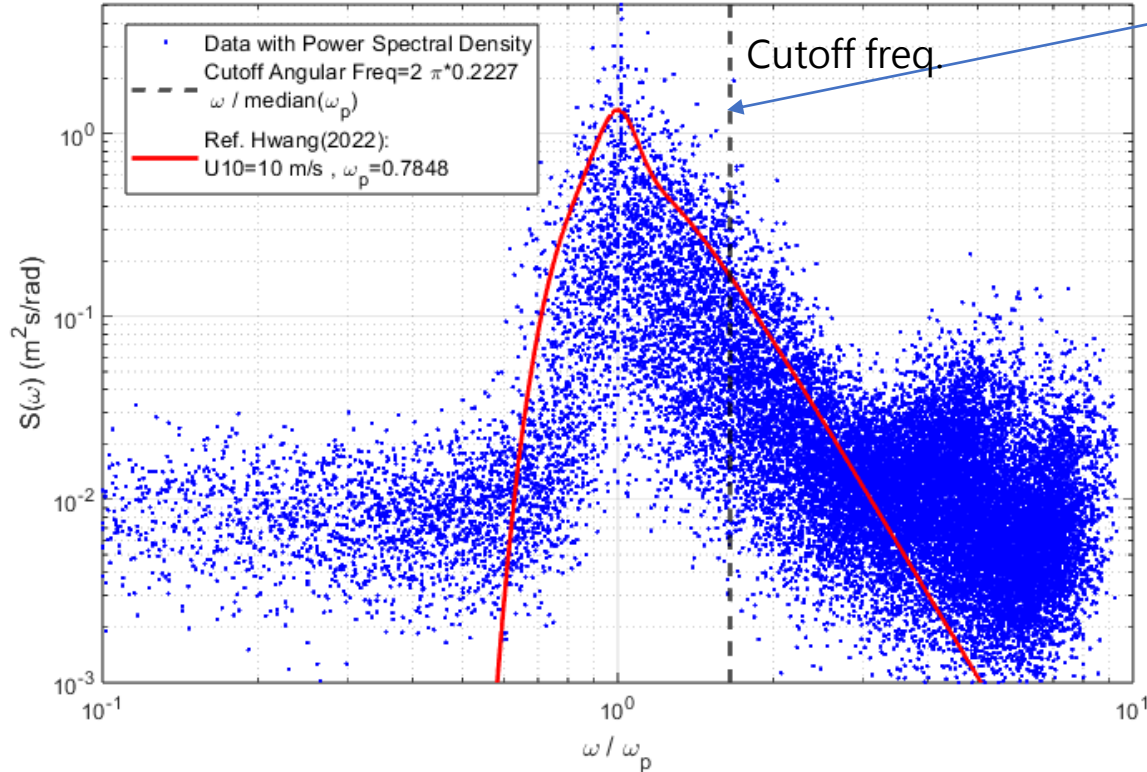
MSS analysis result

Northeast monsoon month:

From: 2023.12.15 10:40

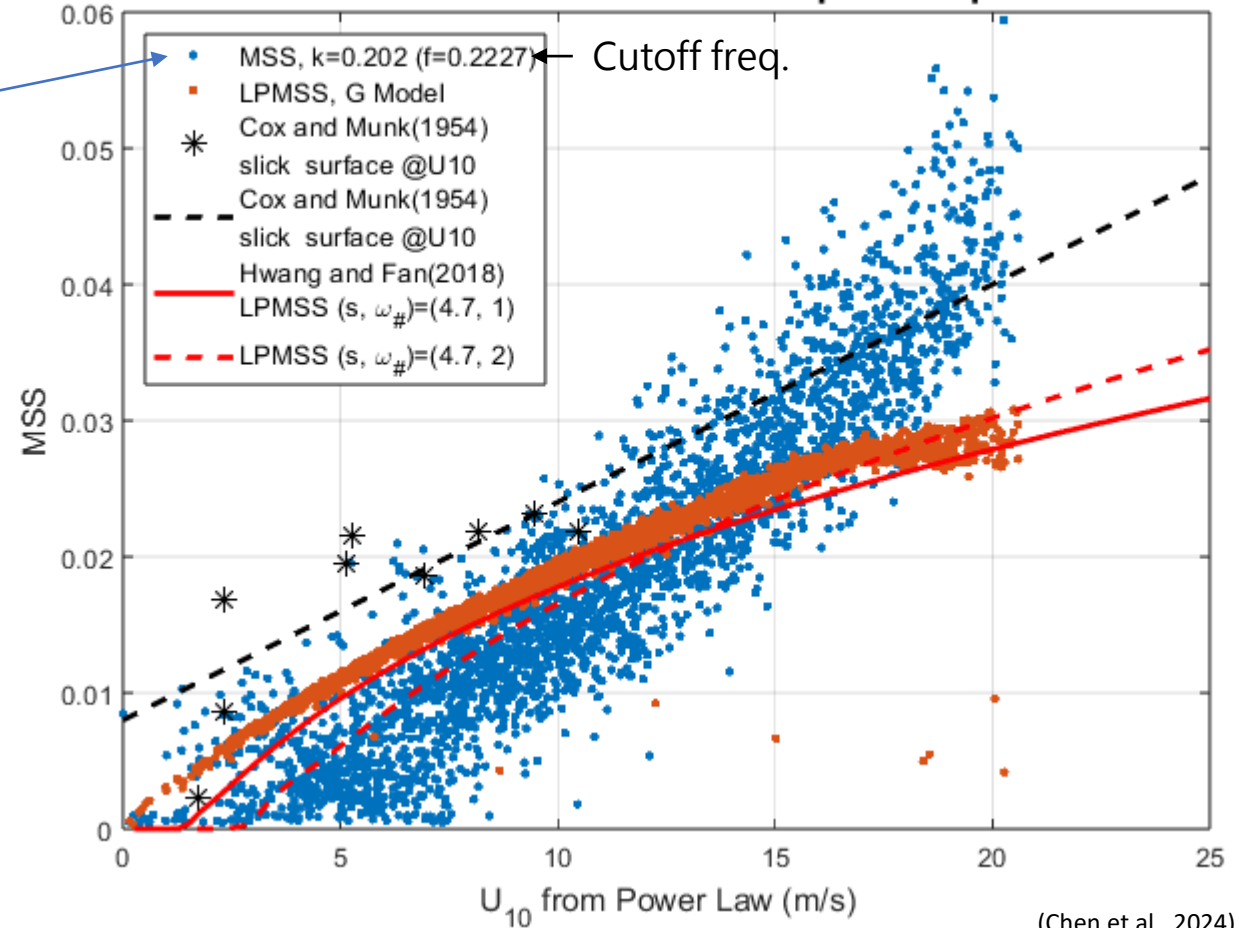
To: 2024.01.31 23:40

Wave angular freq. spectrum under $U_{10} \sim 10$ m/s



Wave spectrum from power spectral density compared with the G model spectral function (Hwang, 2022).

20231215-20240131 Mean square slope



- High wave numbers spectrum contribute significantly to the reduction in the MSS value, so the MSS analysis has used a cutoff frequency of 0.223 to reduce the errors.
- MSS and LPMSS, analyzed in this research, are highly related to the references results.

Roughness length

Northeast monsoon months:

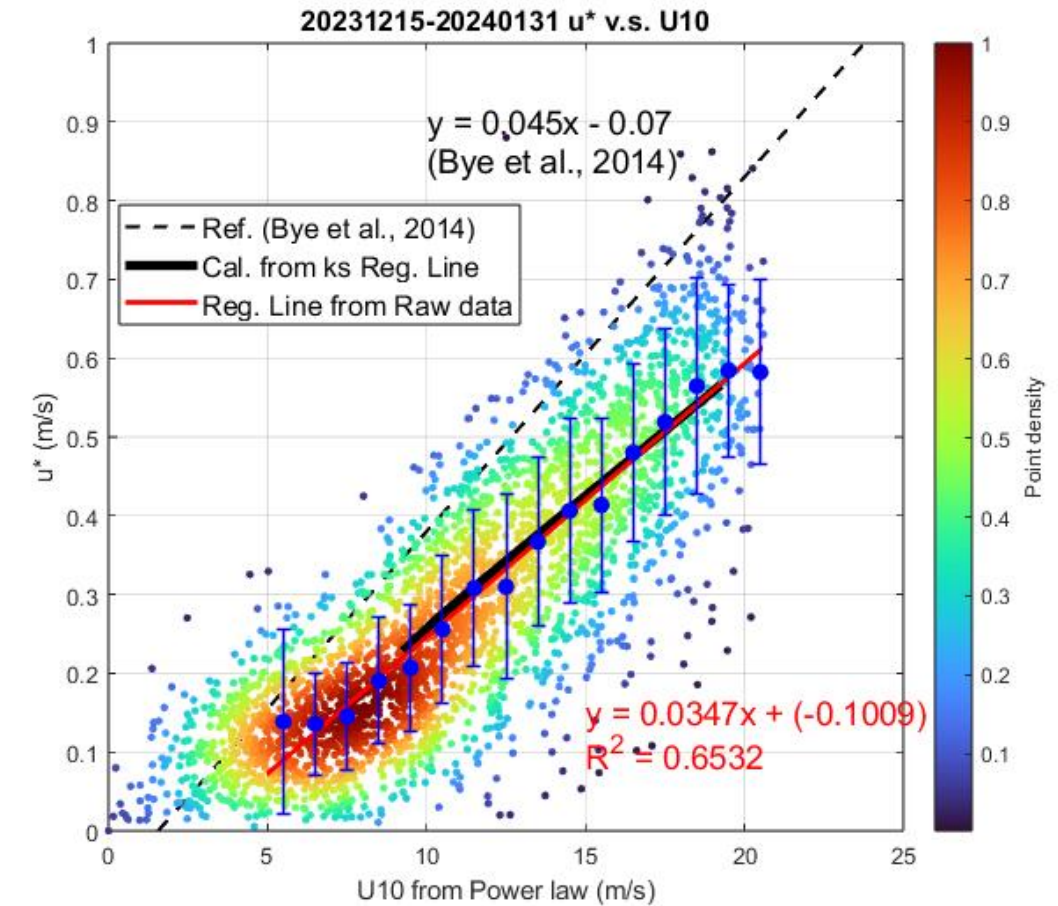
From: 2023.12.15 10:40

To: 2024.01.31 23:40

U10 (Power Law):

$$U_{10} = U \left(\frac{z_{10}}{z} \right)^{1/7}$$

	Methodology	References	Roughness Equations
1	ks from Nickuradse (Roughness in the pipe)	(Nickuradse, 1950) (Schlichting, 1968)	$ks = z / \exp\left(\frac{\kappa u(z)}{u^*} - 8.5\kappa\right)$
2	Charnock constant	(Charnock, 1955) (Garratt, 1977) (Wu, 1980) (Kitaigorodskii, 1970)	$z_0 = \alpha * \frac{u^{*2}}{g}$, where $\alpha = 0.014 \sim 0.035$

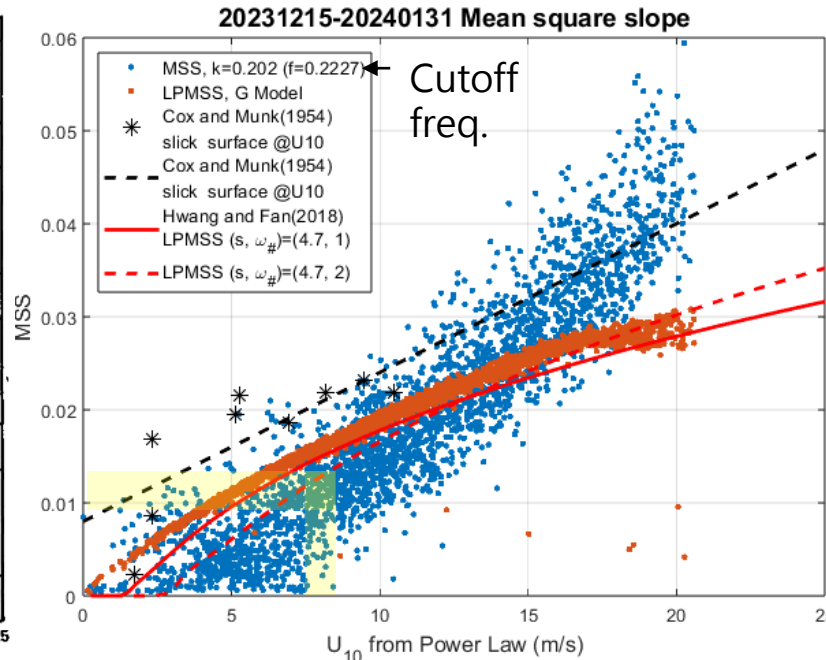
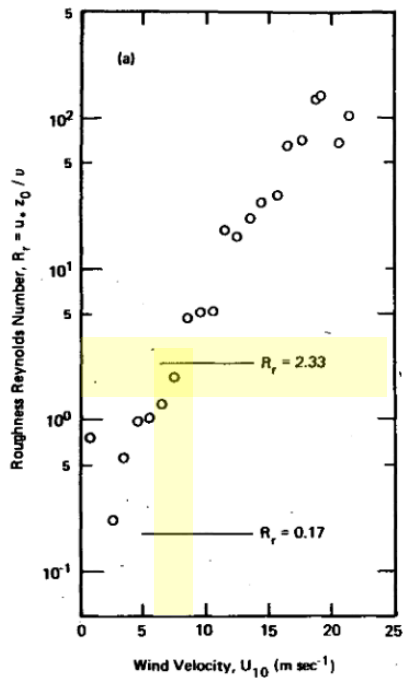


Relation with k_s , z_0 and MSS

Roughness Reynolds number (Wu, 1980):

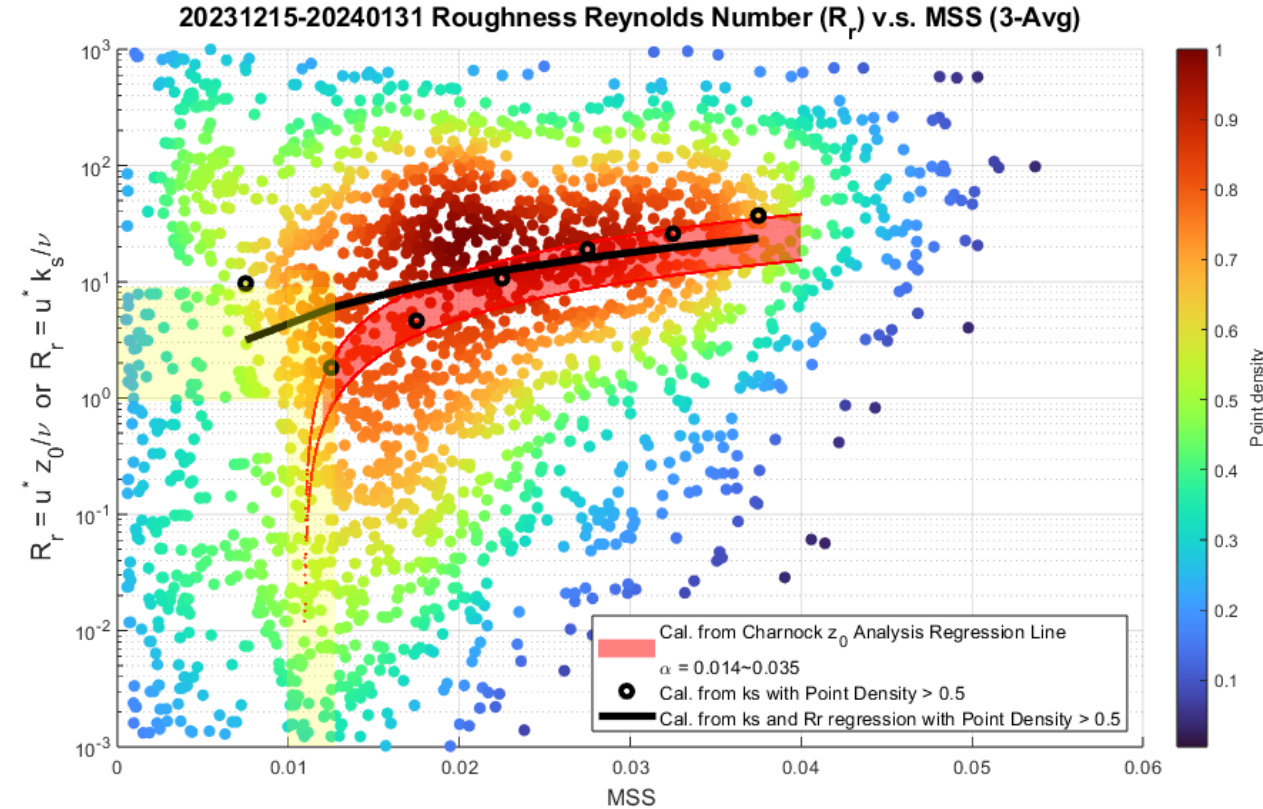
$$R_r = \frac{u^* * z_0}{\nu}$$

➤ *An hour data, which is 3 data points, have been averaged to do the R_r analysis.



As $R_r > 2.33 \rightarrow$
Aerodynamically
rough (Wu, 1980).

- MSS and U10 have a liner relationship.(Cox and Munk, 1954)



- Under our data, as $U_{10} \sim 8$ m/s
- \rightarrow $MSS \sim 0.0125$ (Middle Figure)
- $\rightarrow R_r \sim 7.6$ based on k_s & $R_r \sim 2.3$ based on z_0

Under our analysis, the relationship between each roughness represented variables are supplied.

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Thanks for your attention !