Uncertainty Assessment of GNSS-Reflectometry for Typhoon Sea Surface Wind

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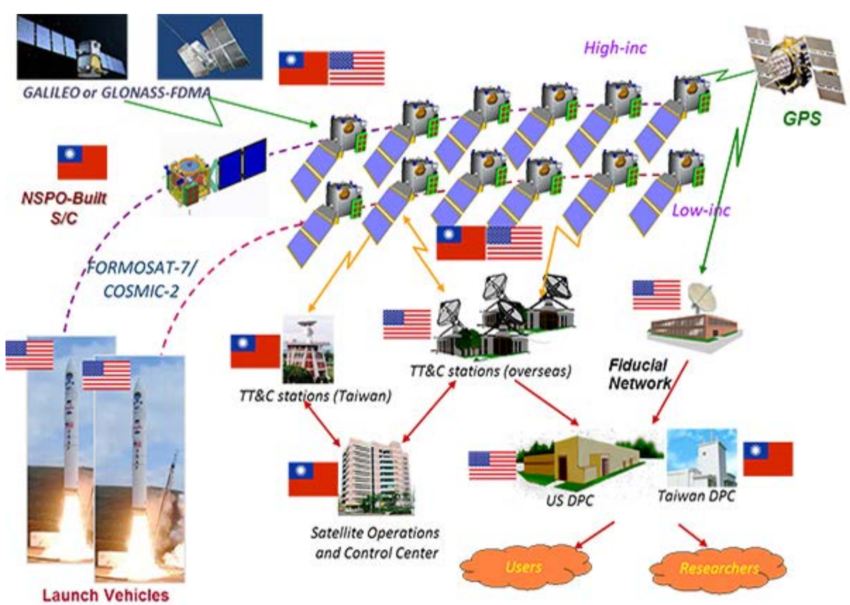
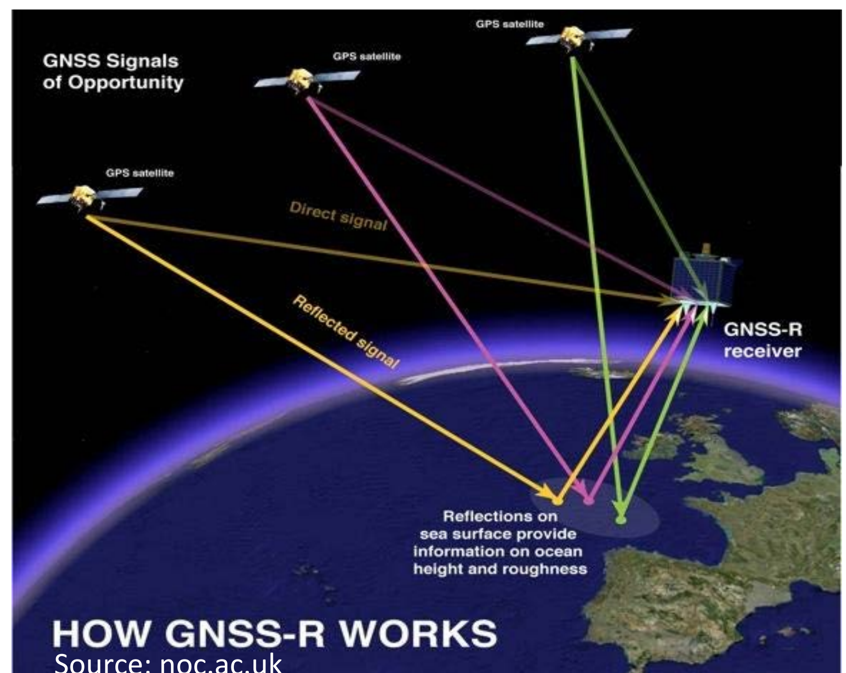
GNSS-R 目標

- 福衛七號：
  - 掩星(Radio Occultation, RO): 大氣溫度、濕度、壓力
  - **反射(Reflectometry, R):** 海面粗糙度、海面風速、土壤濕度、海冰
- 高風速觀測優勢：
  - Up to 70 m/s，與雲導風、散度計觀測互補，對於颱風監測、預報非常有用。
- NSPO is planning to launch the FORMOSA-7R (6+1) before 2020.

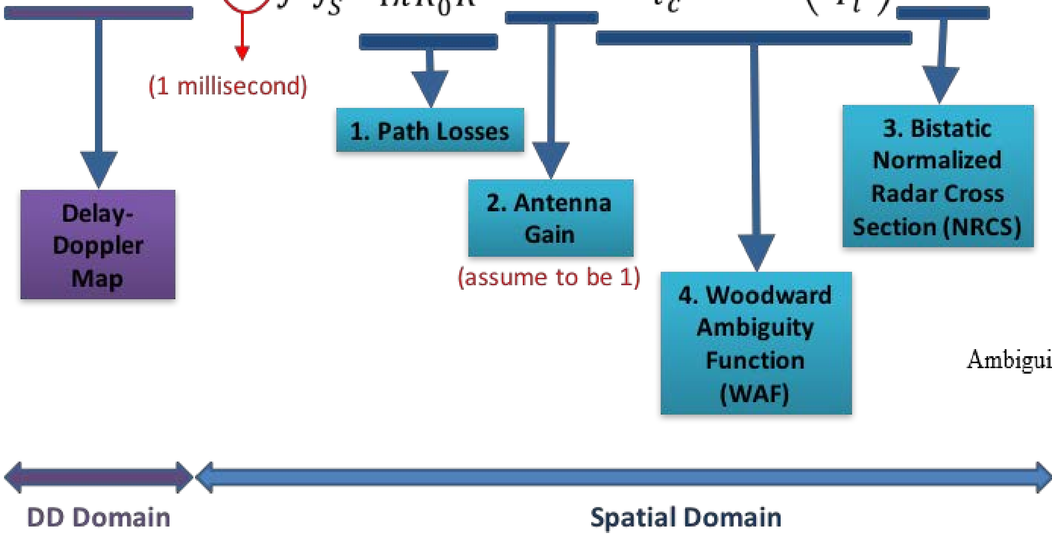


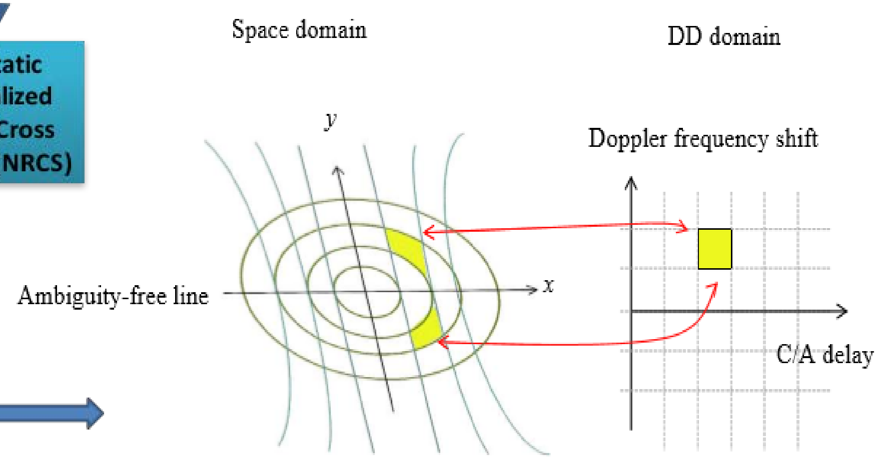


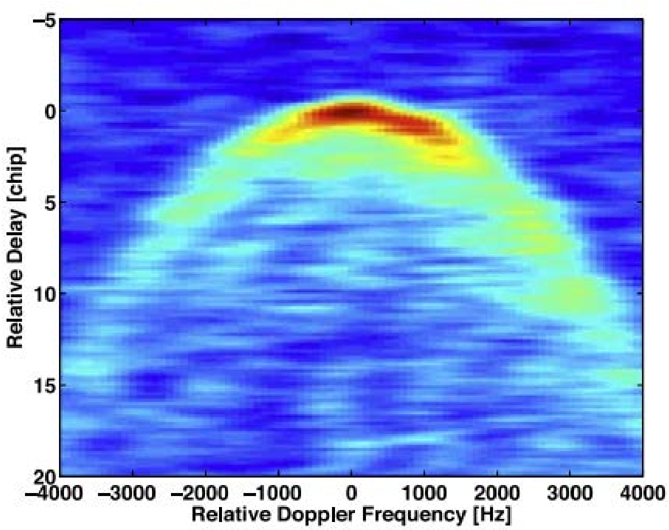
Source: noc.ac.uk

GNSS-R觀測原理與理論基礎 (Z-V model)

$$\langle P(\tau, f_D)\rangle = T_i^2 \int\int_S \frac{1}{4\pi R_0^2 R^2} D^2(\mathbf{r})\Lambda^2\left(\frac{\delta\tau}{\tau_c}\right) sinc^2\left(\frac{\delta f_D}{T_i}\right)\sigma_o(\mathbf{r})d^2r$$







$$\sigma_o(\mathbf{r}) = \frac{\pi|\Re|^2 q^4}{q_z^4} f_q\left(\frac{-\mathbf{q}_\perp}{q_z}\right)$$

$$f_q\left(\frac{-\mathbf{q}_\perp}{q_z}\right) = 1/2\pi \det(\mathbf{M}) exp\left[-\left(\frac{1}{2}\mathbf{q}_\perp^t \mathbf{M}^{-1}\mathbf{q}_\perp\right)\right]$$

$$\mathbf{q}_\perp(q_x, q_y) = \left(\frac{R_{0x}}{R_0} + \frac{R_{vx}}{R_v}, \frac{R_{0y}}{R_0} + \frac{R_{vy}}{R_v}\right)$$

$$\mathbf{M} = \begin{bmatrix} \cos(\phi) & -\sin(\phi) \\ \sin(\phi) & \cos(\phi) \end{bmatrix} \begin{bmatrix} \sigma_{up}^2 & 0 \\ 0 & \sigma_{cross}^2 \end{bmatrix} \begin{bmatrix} \cos(\phi) & \sin(\phi) \\ -\sin(\phi) & \cos(\phi) \end{bmatrix}$$

- σ_{up}^2; σ_{cross}^2 : Directional Mean Square Slopes (**DMSS**);
- ϕ: Principal Wave Slope Direction (**PWSD**).

Delay Doppler Map Average (DDMA)

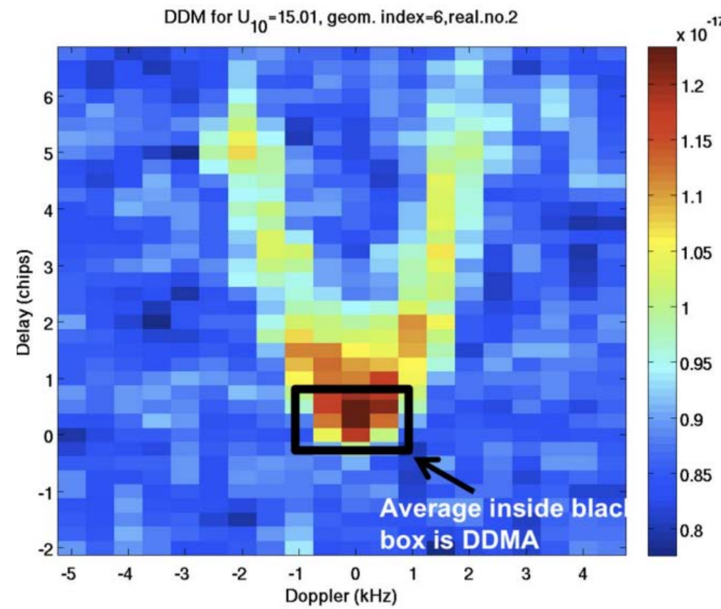
- DDMA is the average scattered power computed over the DDM around the SP:

$$DDMA_Y(\Delta\tau, \Delta f, t_i) = \frac{1}{MN} \sum_{m=1}^{M} \sum_{n=1}^{N} \bar{Y}\,(\tau_m, f_n, t_i)$$

$\Delta\tau = \tau_M - \tau_1, \Delta f = f_N - f_1$: the delay and Doppler ranges to compute DDMA

Two important parameters that characterizes the DDMA:

- The location of the SP in the DDM
- The delay and Doppler ranges over which to average DDMA



Trailing Edge Slope (TES)

The IDW also has a trailing edge whose slope responds to changes in the wind speed

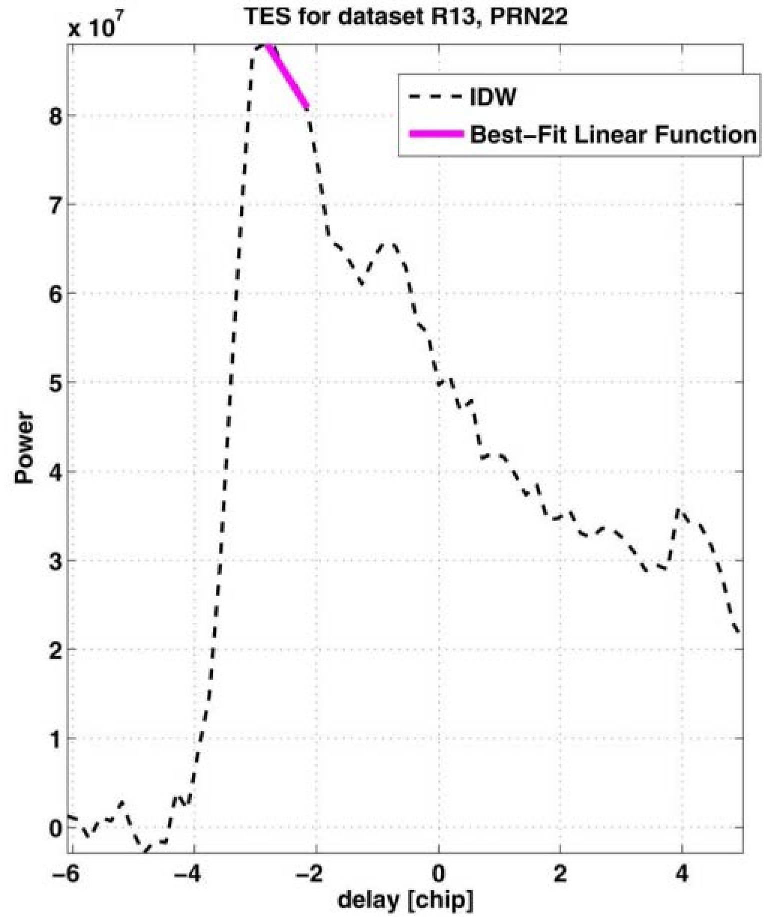
The TES is calculated as the slope of the waveform region extending from the waveform peak to 0.75 chips from the peak

The TES can be expressed as:

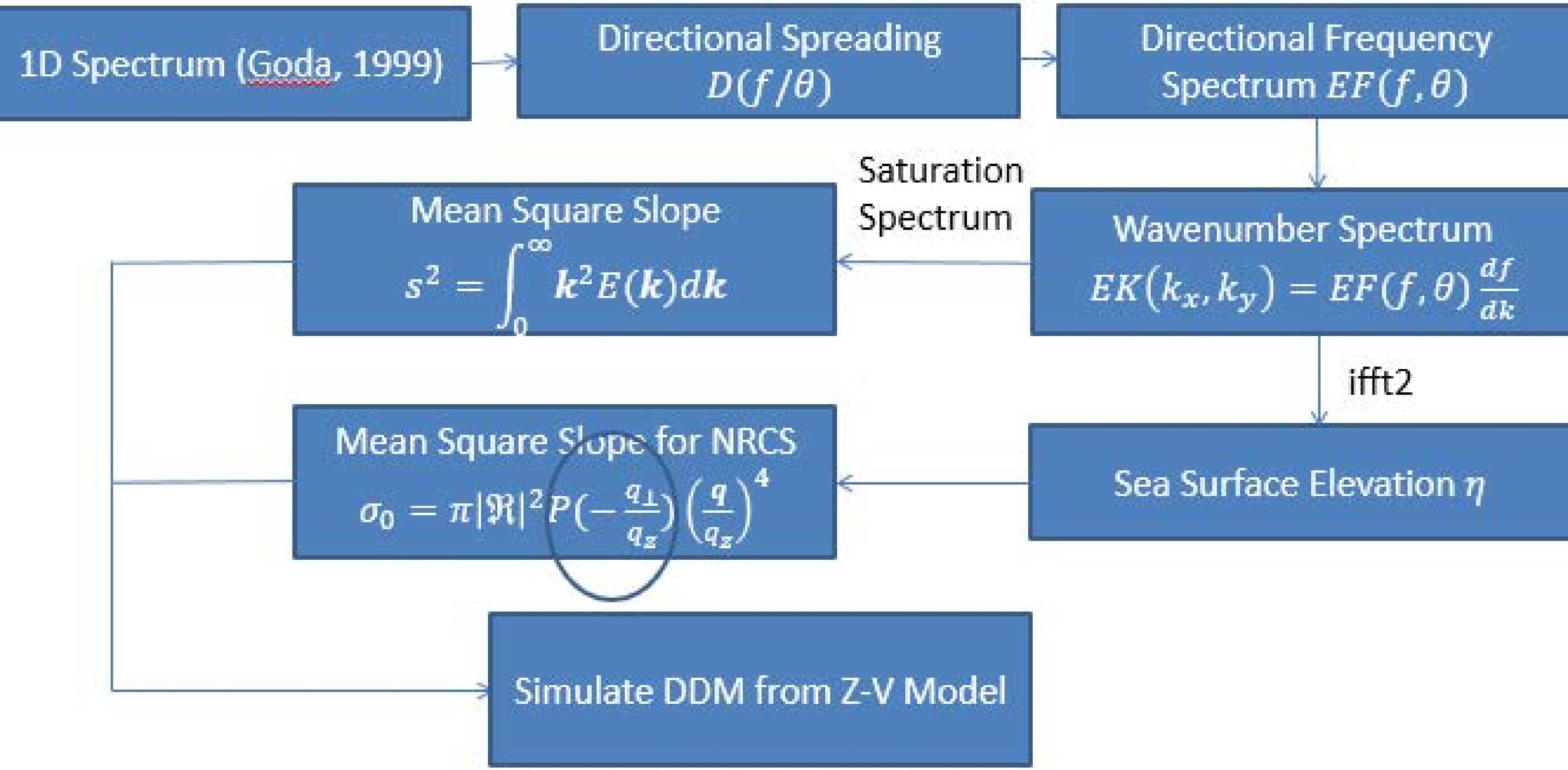
$$\beta(\Delta\tau, \Delta f, t_i) = \arg\min_{\beta, \boldsymbol{d}} \left\{ \left[\sum_{k=3}^{4} J(\tau_k, \Delta f, t_i) - (\beta\tau_k + d) \right]^2 \right\}$$

where:

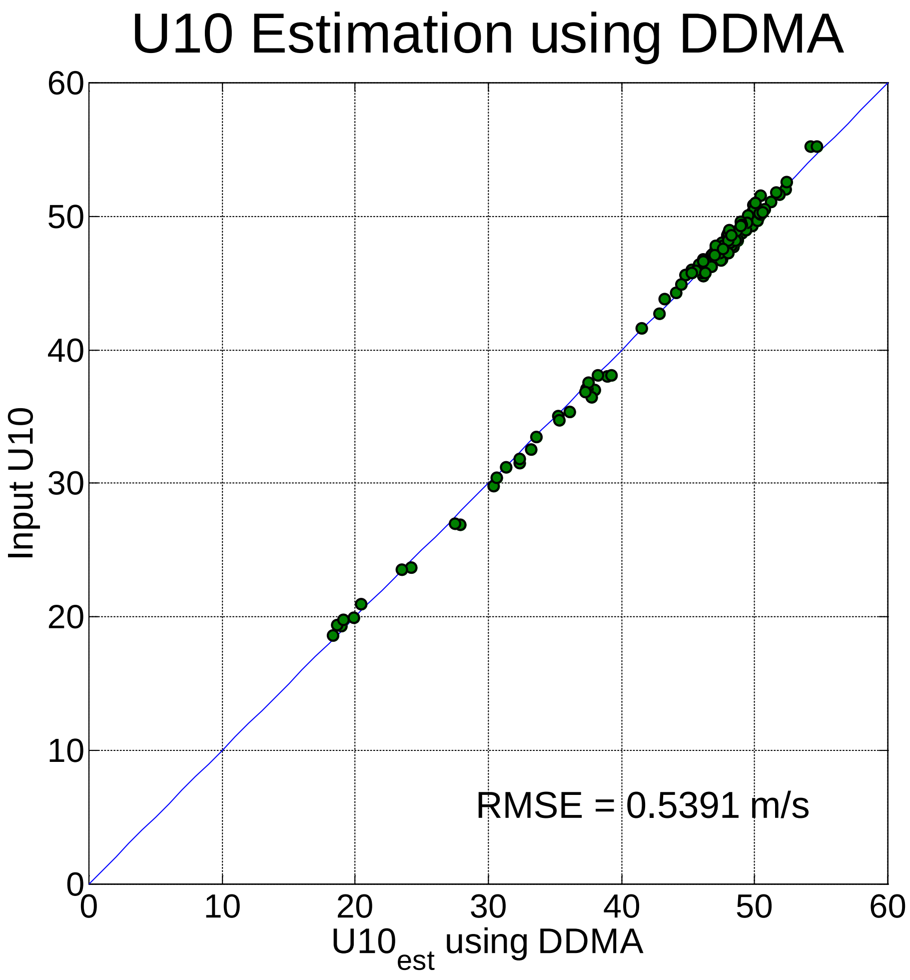
$$J(\tau_k, \Delta f, t_i) = \frac{1}{N} \sum_{n=1}^{N} \overline{Y}(\tau_k, f_n, t_i)$$

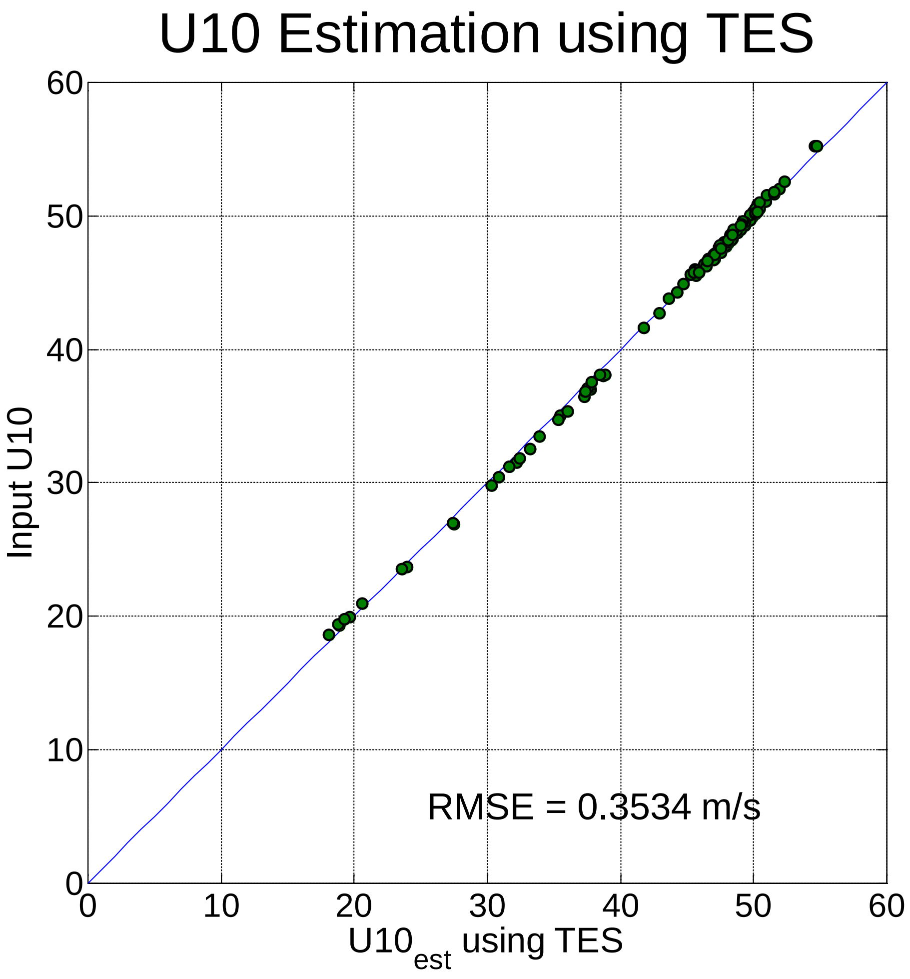


Uncertainties from Algorithm using Sea surface Simulation

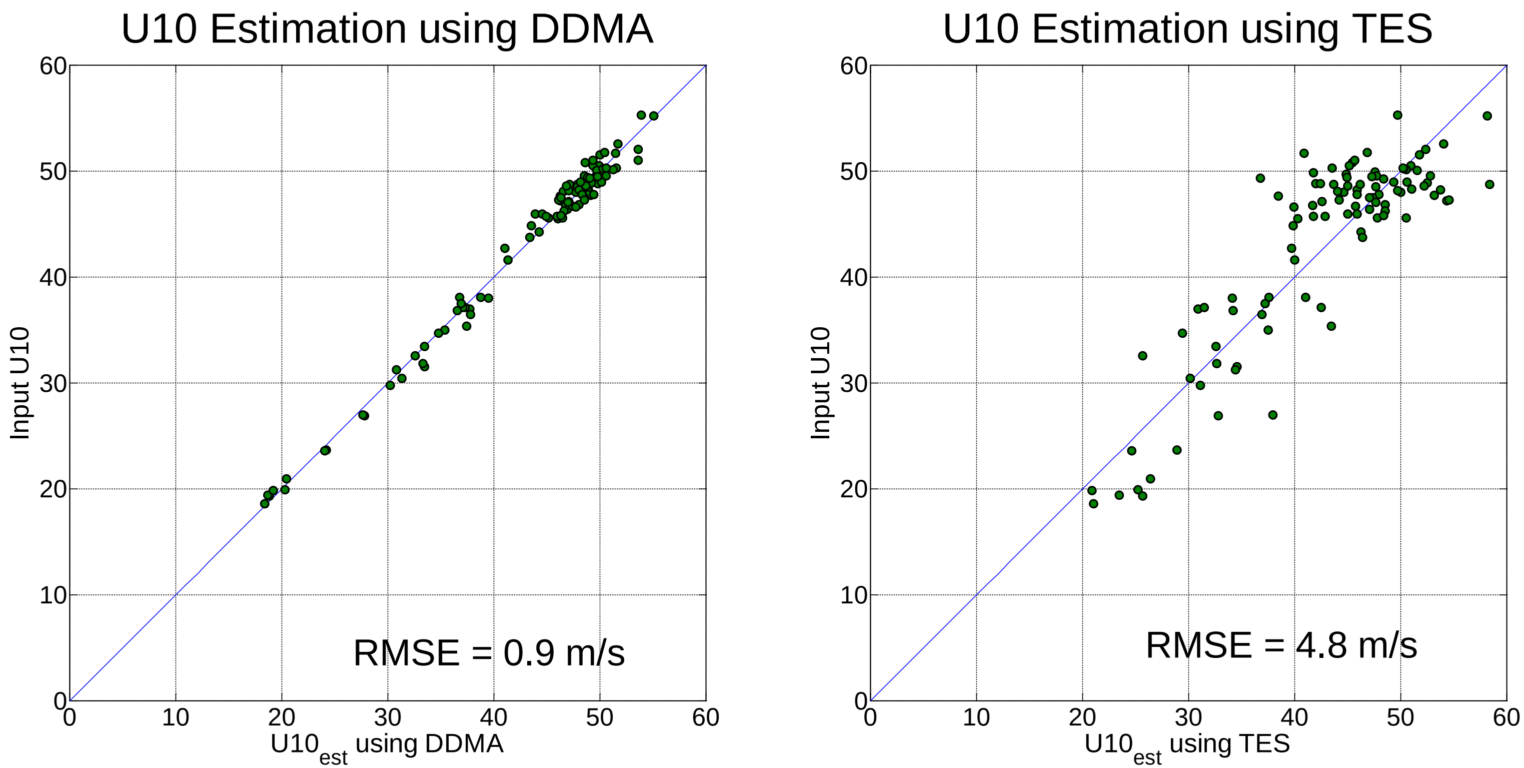


Comparison between Two Observables





Robustness of Noise Contamination in DDI



Noise Level	RMSE (m/s) Using DDMA	RMSE(m/s) Using TES
0 %	0.5391	0.3534
50%	0.9	4.8

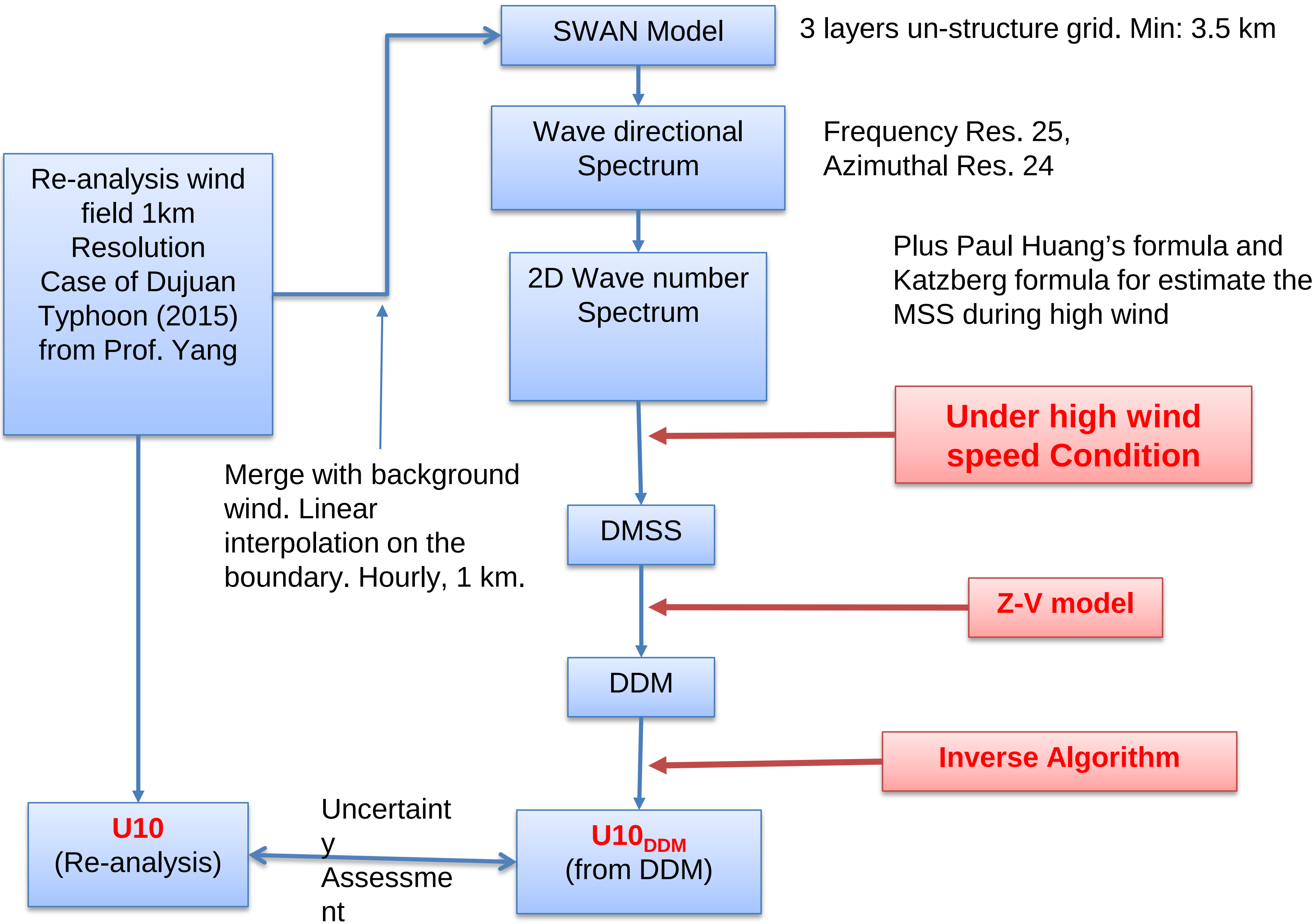
Observable DDMA show better results compare to TES

Observable TES is more sensitive to noise than DDMA

→ **Observable DDMA show more stable result compare to TES**

→ **Should improve the Wind retrieval results by combining the 2 observables.**

Uncertainty for typhoon cases



Definition of the Surface Roughness - MSS

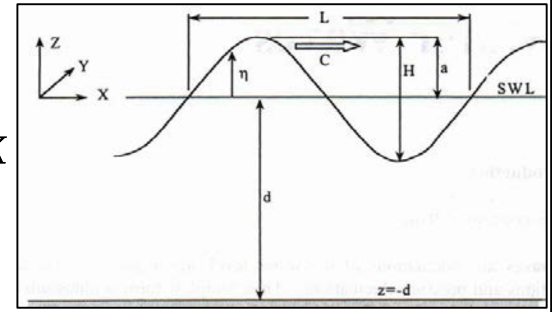
*Slope

$$S_s = \frac{H}{L} = \frac{2a}{2\pi / k} = \frac{ak}{\pi};$$

$$\sum a_i k_i = \int akdk; a = \sqrt{s(k)}$$

$$RMSS = \int k\sqrt{s(k)}dk$$

$$MSS = \int k^2 s(k)dk$$



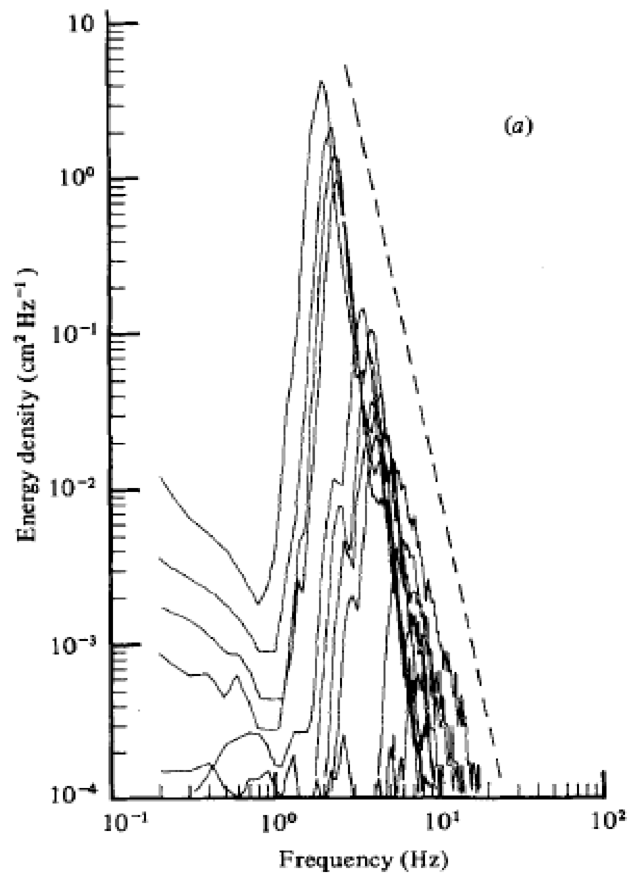
- *The higher wavenumber component contribute more to the MSS.*
- *The tail-slope of wavenumber spectra deviate from* Phillips's Equilibrium .

$$\phi(n) = \frac{\beta g^2}{n^5}, \quad for\ n \geq n_o; \quad \phi(n) = 0, otherwise.$$

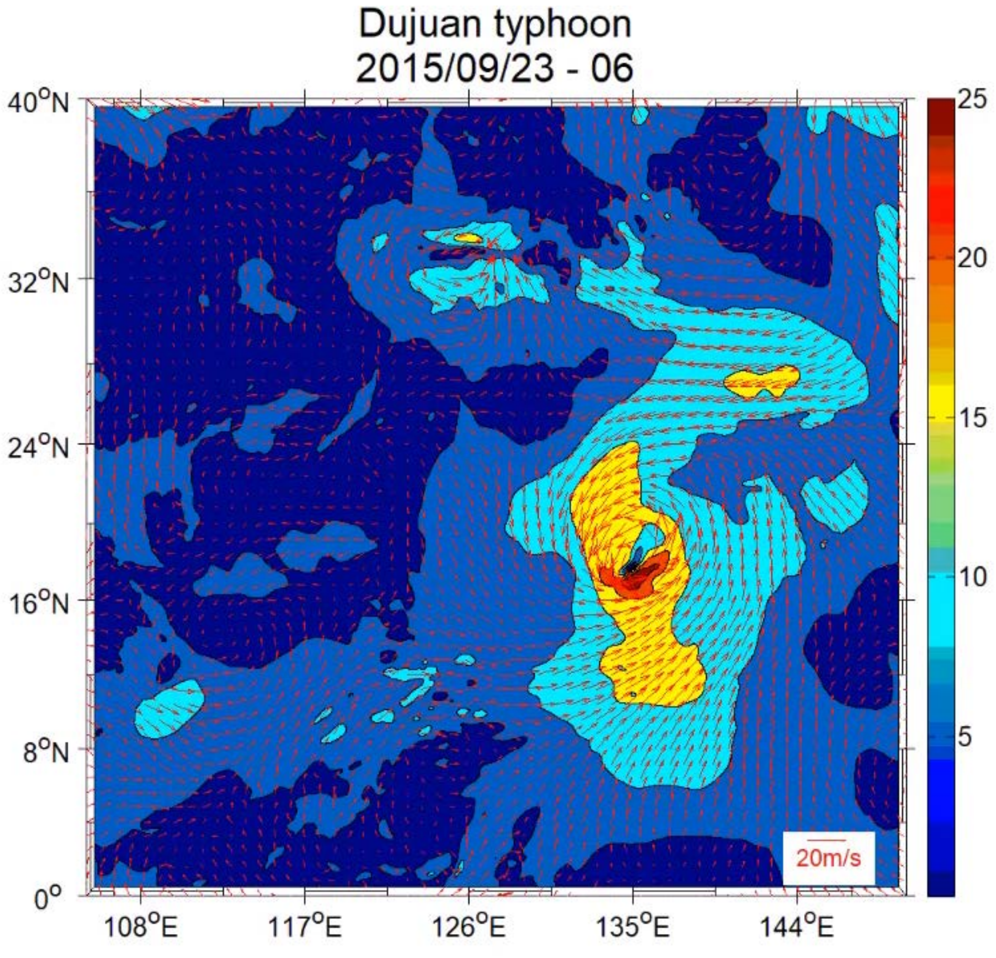
g : gravitation acceleration

n : frequency; n_o : the peak frequency

β : Phillips Equilibrium range constant



Ultra resolution typhoon wave simulation Driven by 1 km wind fields



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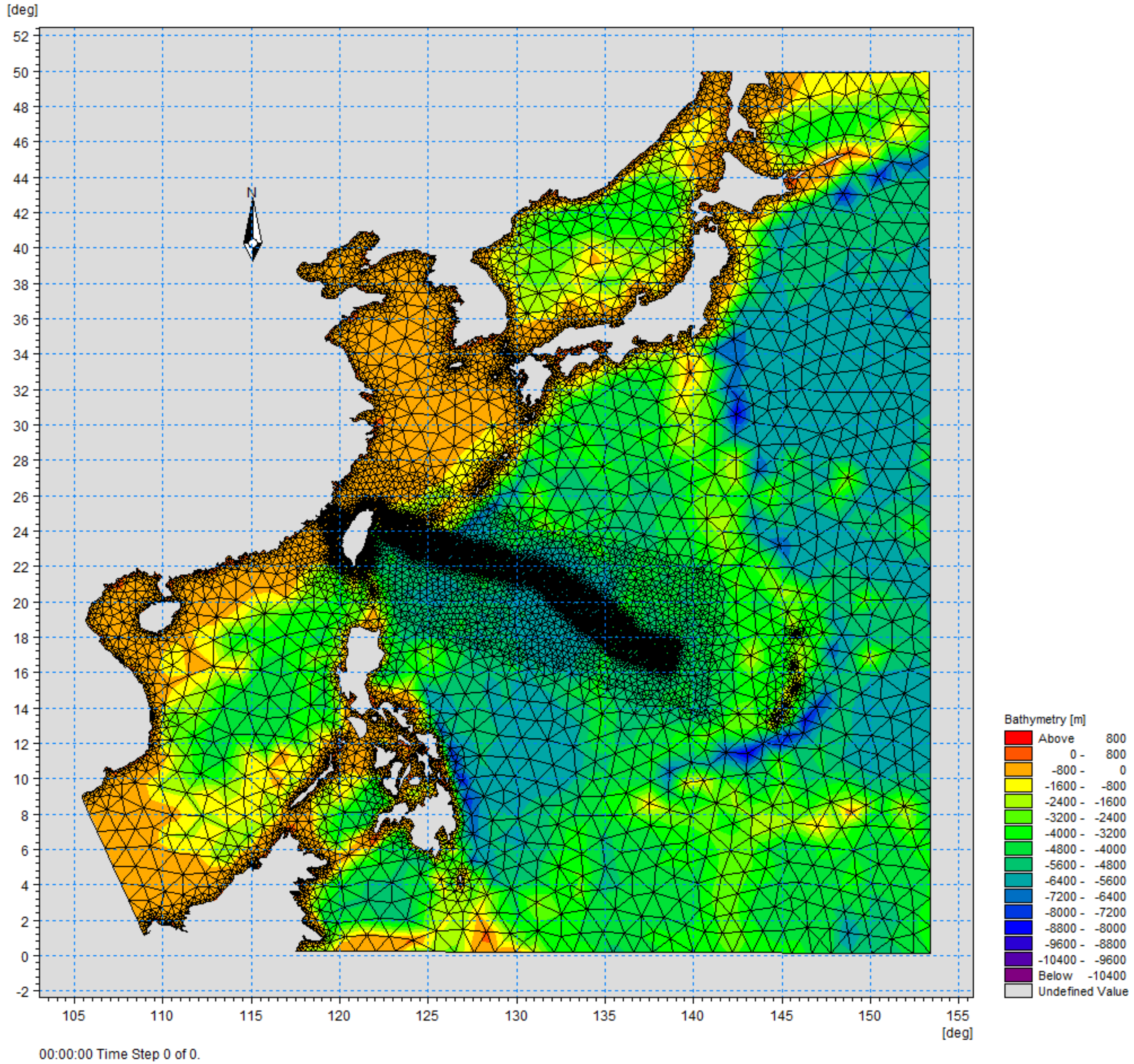
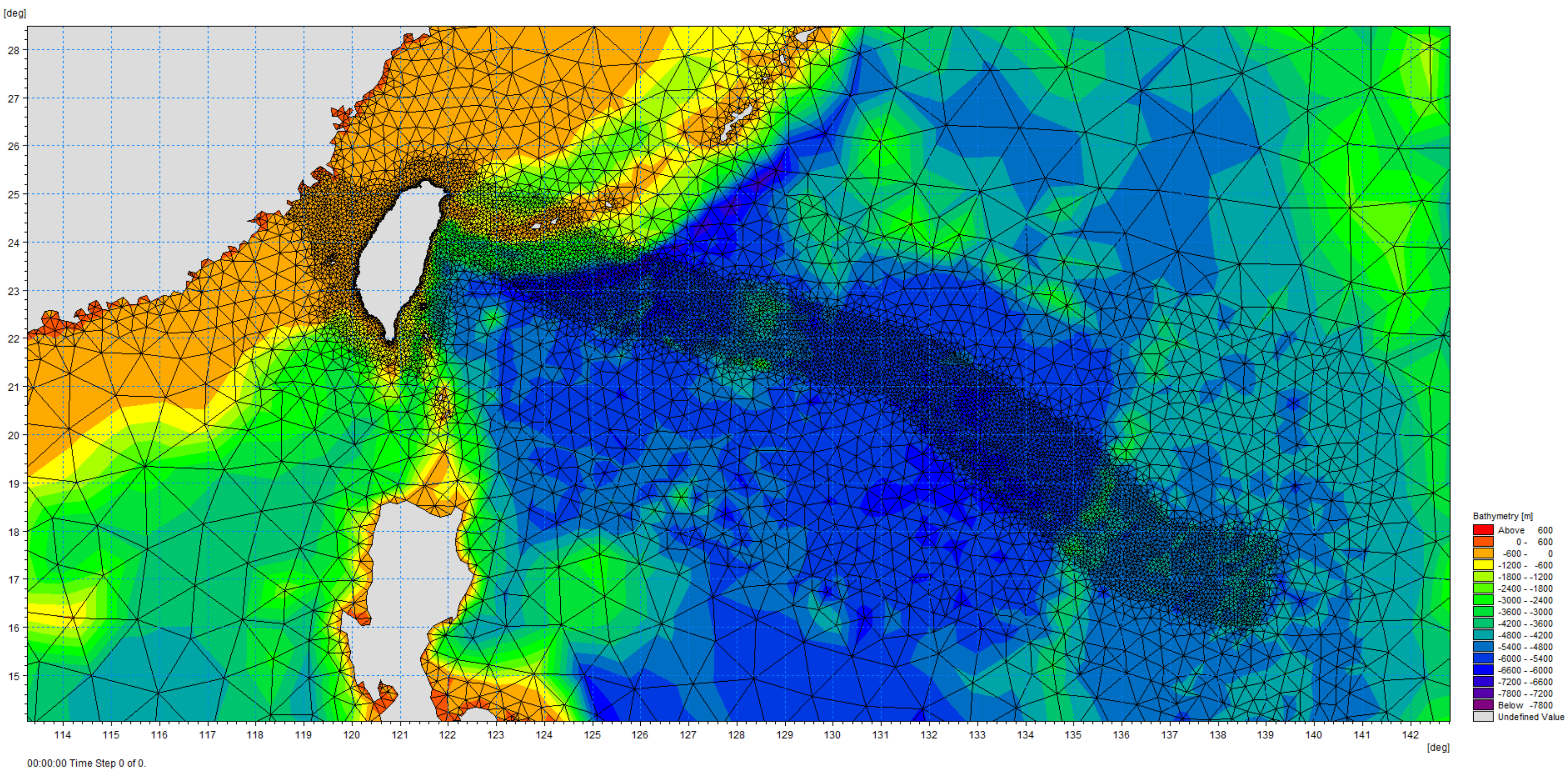
3 Layers Unstructure mesh along the typhoon trajectory




[deg]
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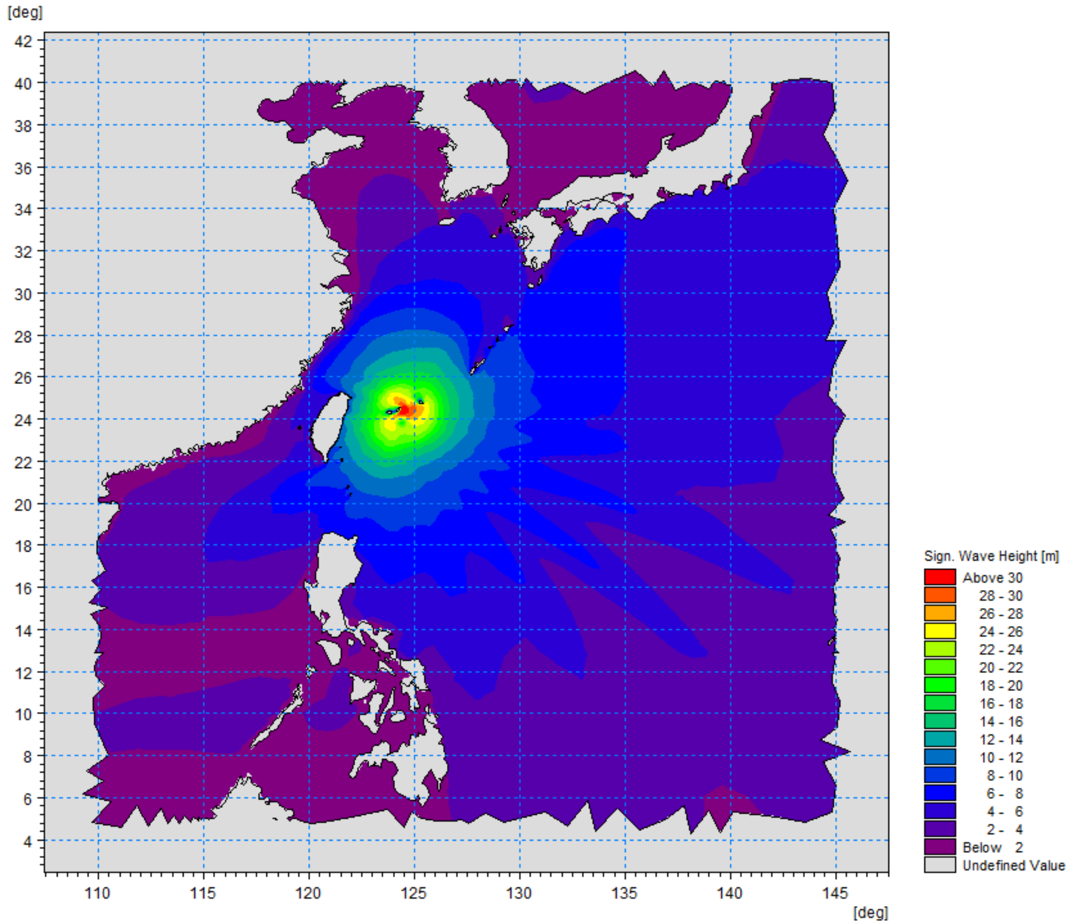
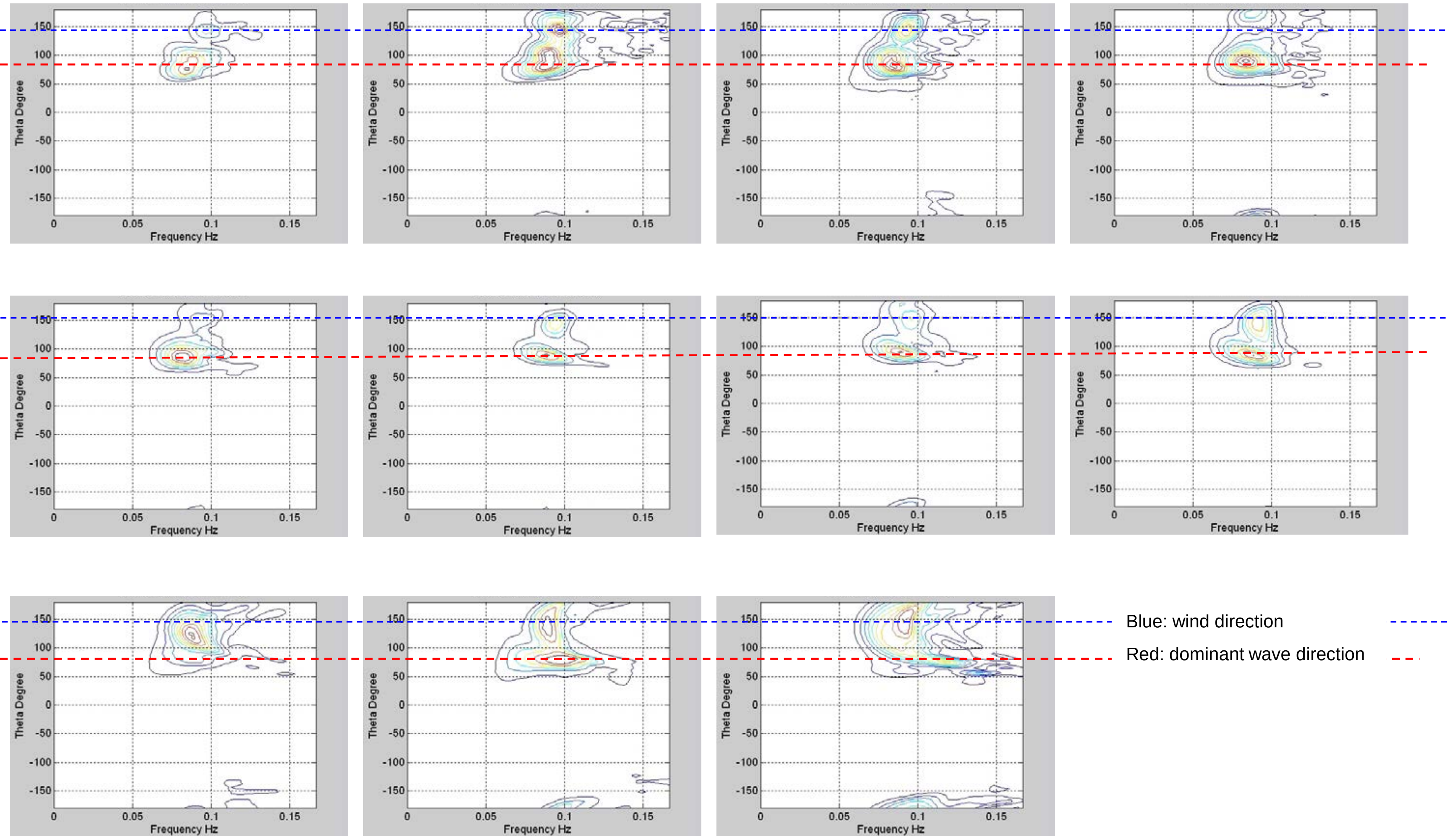
140
141
142
[deg]
Bathymetry [m]
Above 600
0 - 600
-600 - 0
-1200 - -600
-1800 - -1200
-2400 - -1800
-3000 - -2400
-3600 - -3000
-4200 - -3600
-4800 - -4200
-5400 - -4800
-6000 - -5400
-6600 - -6000
-7200 - -6600
-7800 - -7200
Below -7800
Undefined Value
00:00:00 Time Step 0 of 0.

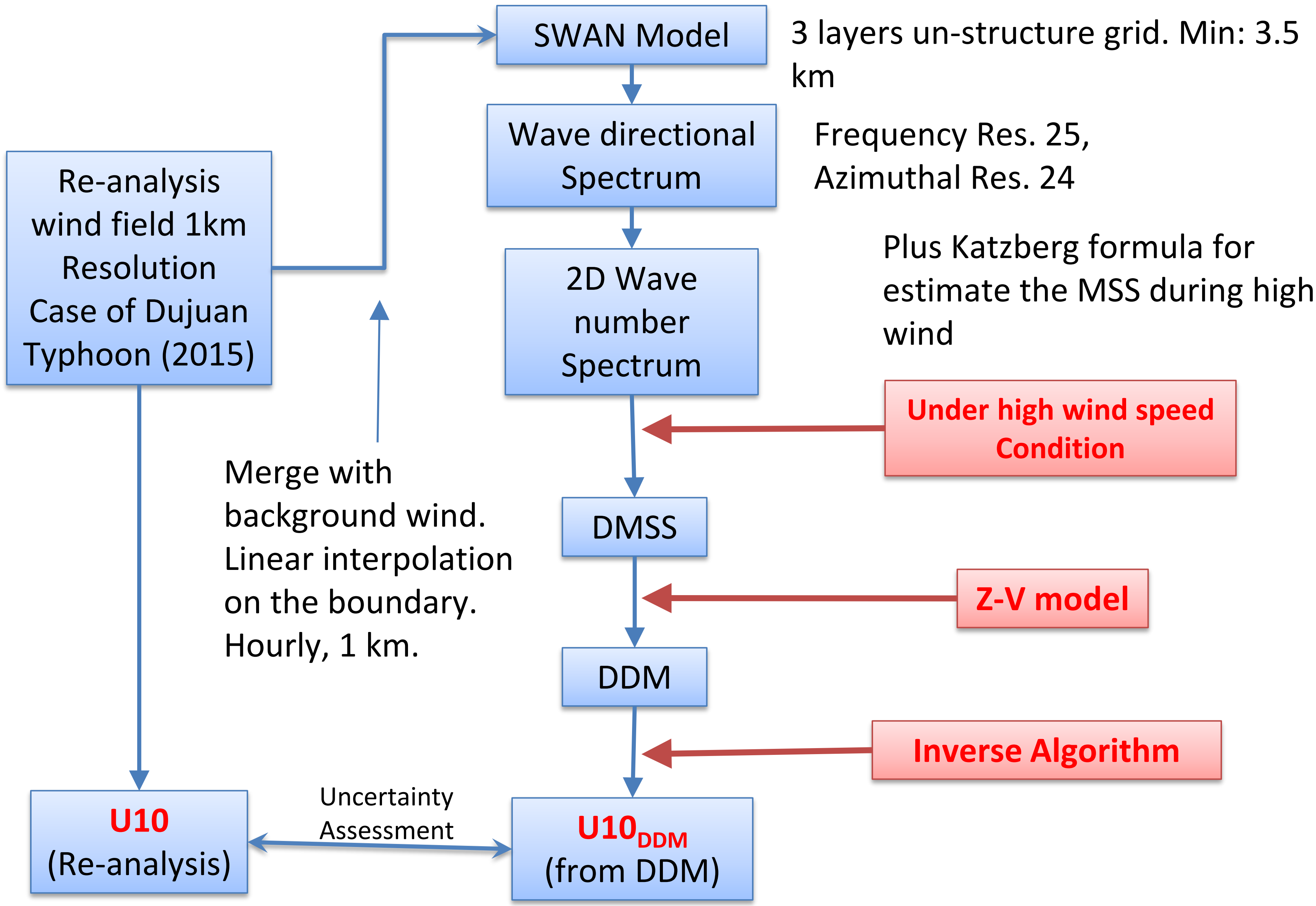


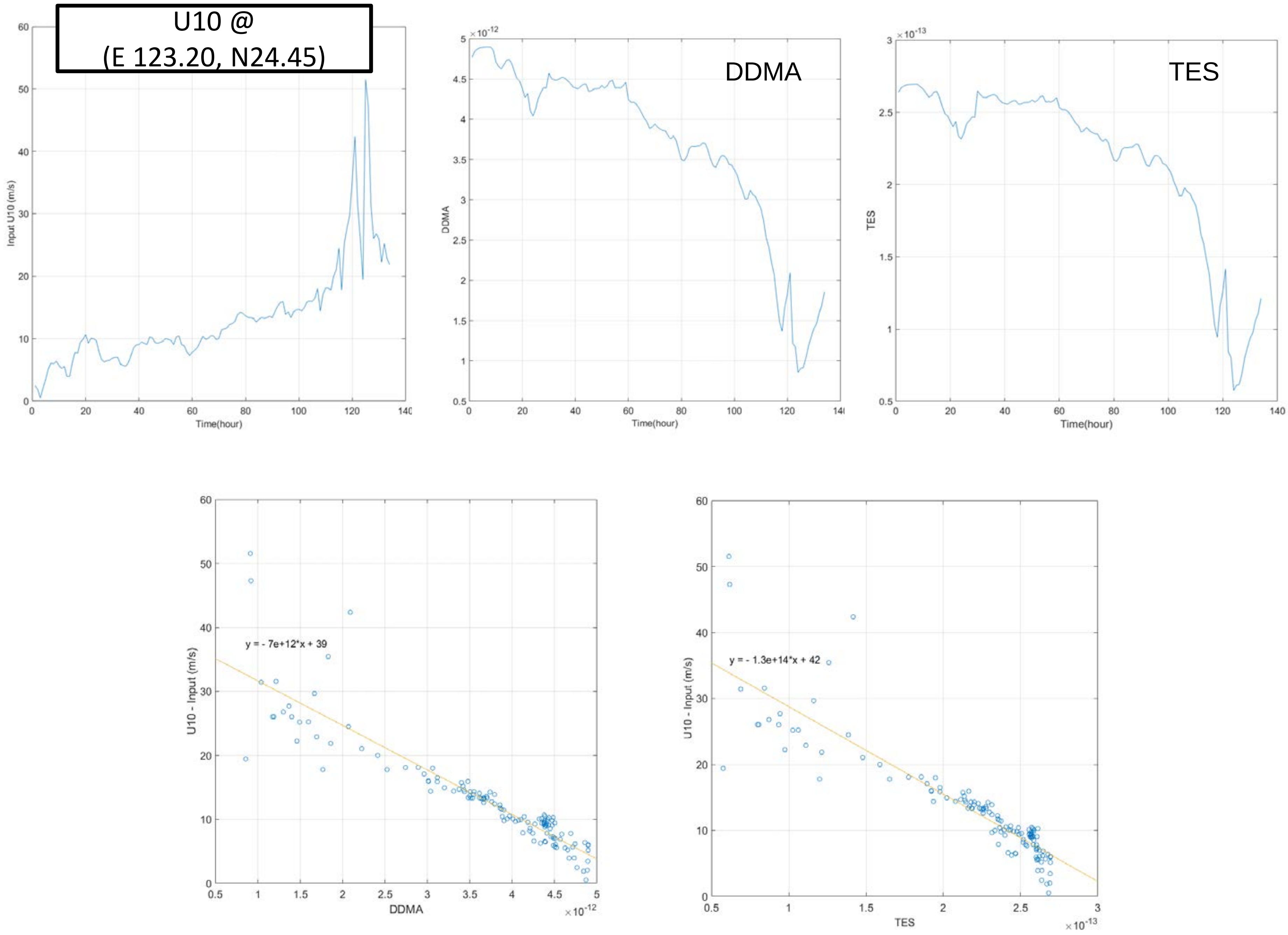
2015/9/28 03:00:00 Time Step 117 of 133.



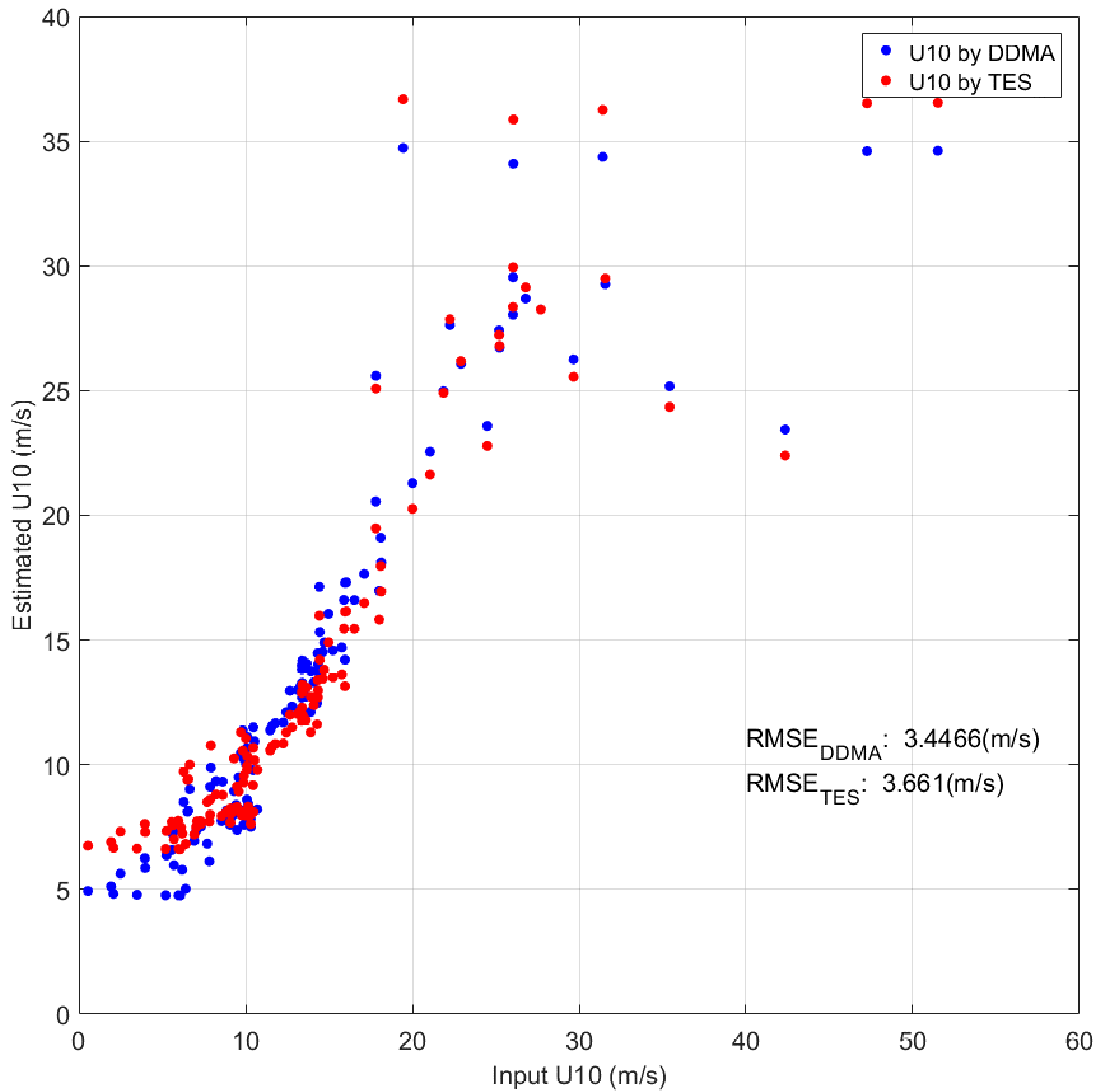
Temporal evolution of DSP at the upper-right quad near the max mind radius of the typhoon. Issue: Effects from Swell system.

How to Consider the Wave Contribution to DMSS ?

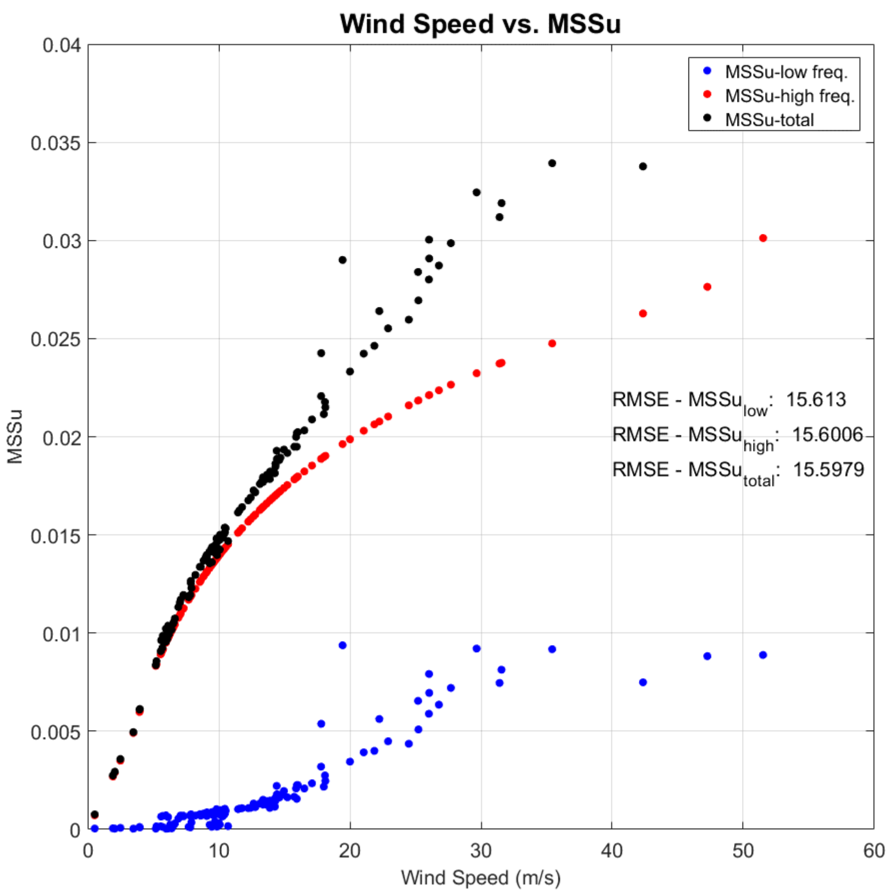


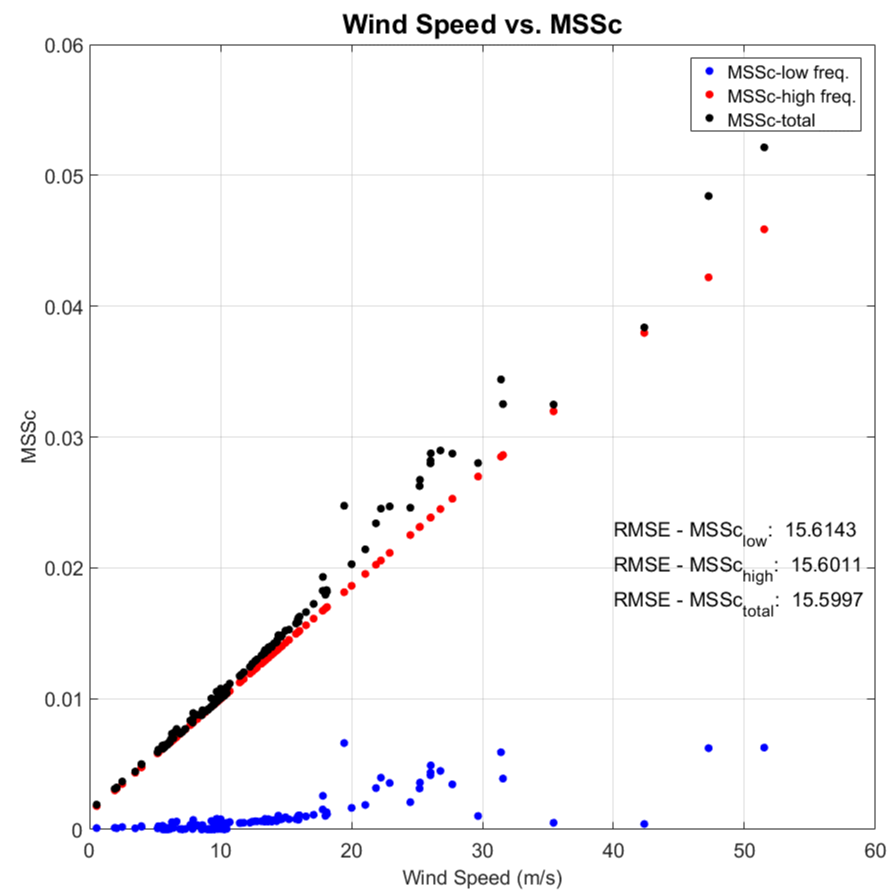


U10 @
(E 123.20, N24.45)
Input U10 (m/s)
Time(hour)
DDMA
×10^-12
Time(hour)
TES
×10^-13
Time(hour)
y = - 7e+12*x + 39
U10 - Input (m/s)
DDMA
×10^-12
y = - 1.3e+14*x + 42
U10 - Input (m/s)
TES
×10^-13



U10 by DDMA
U10 by TES
RMSE$_{DDMA}$: 3.4466(m/s)
RMSE$_{TES}$: 3.661(m/s)
Estimated U10 (m/s)
Input U10 (m/s)
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60


Wind Speed vs. MSSu
MSSu-low freq.
MSSu-high freq.
MSSu-total
RMSE - MSSu$_{low}$: 15.613
RMSE - MSSu$_{high}$: 15.6006
RMSE - MSSu$_{total}$: 15.5979
MSSu
Wind Speed (m/s)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
10
20
30
40
50
60


Wind Speed vs. MSSc
MSSc-low freq.
MSSc-high freq.
MSSc-total
RMSE - MSSc$_{low}$: 15.6143
RMSE - MSSc$_{high}$: 15.6011
RMSE - MSSc$_{total}$: 15.5997
MSSc
Wind Speed (m/s)
0.06
0.05
0.04
0.03
0.02
0.01
0
0
10
20
30
40
50
60

遙測數據不確定性評估

- 颱風風速估算不確定性來自(依據重要性):
  1. MSS vs. U10模型：**<u>2 %~14 %</u>** (for high wind, U10 > 30 m/s)
     - 受最大暴風半徑內颱風波浪的影響
  2. Noise level in DDM, from Path-loss, Antenna Gain, Thermal noise … : **<u>< 6 %</u>** when NSR=0.25 (DDMA better than TES, LES)
  3. Algorithm (CYGNSS method, due to DDM resolution): **<u><1 %</u>**

以上初估計值僅依據數值模擬結果。