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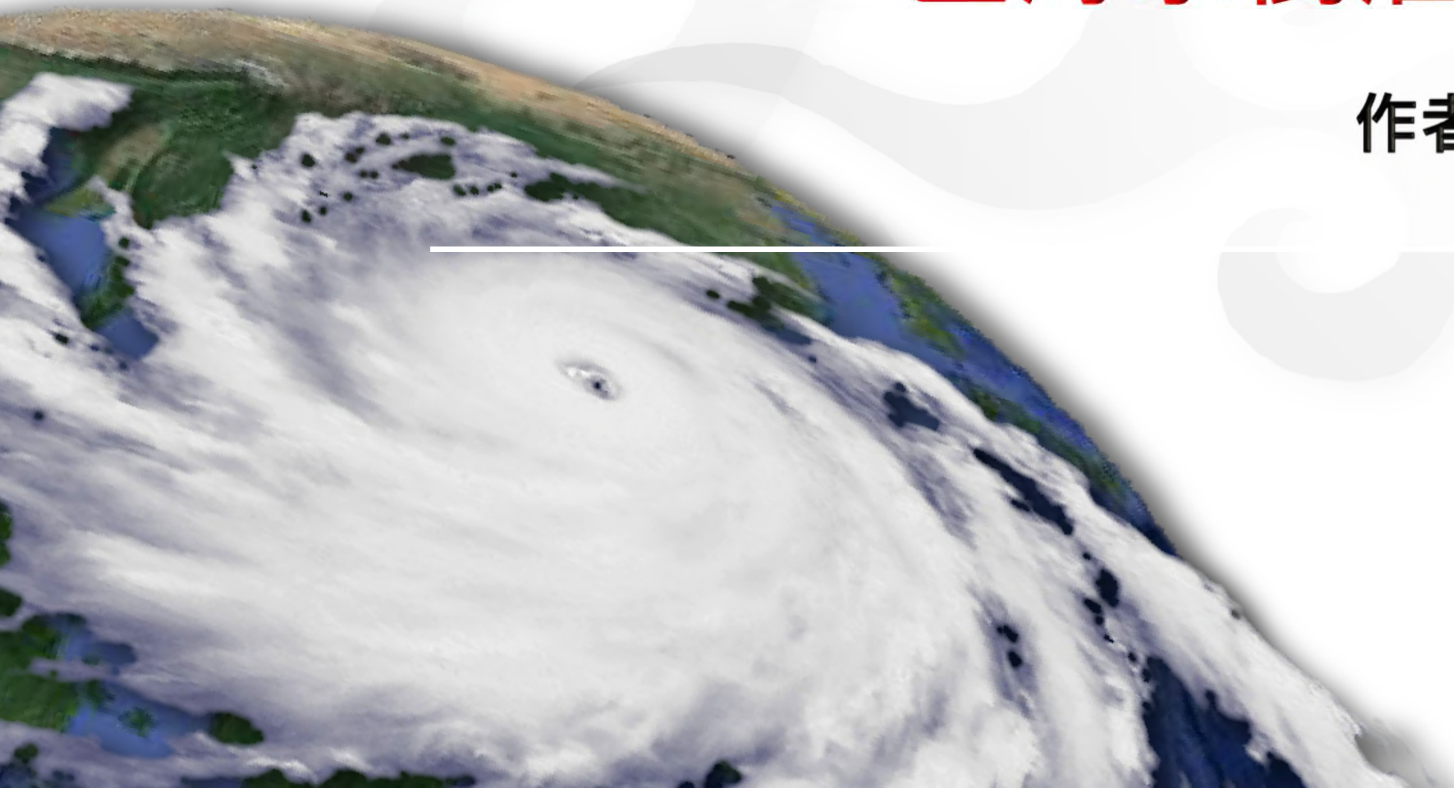
Central Weather Administration

2025年丹娜絲颱風引發臺灣西南地區海水倒灌事件之數值模擬研究

作者:楊天瑋、吳祚任、張哲瀚、葉宸豪
報告人 :楊天瑋

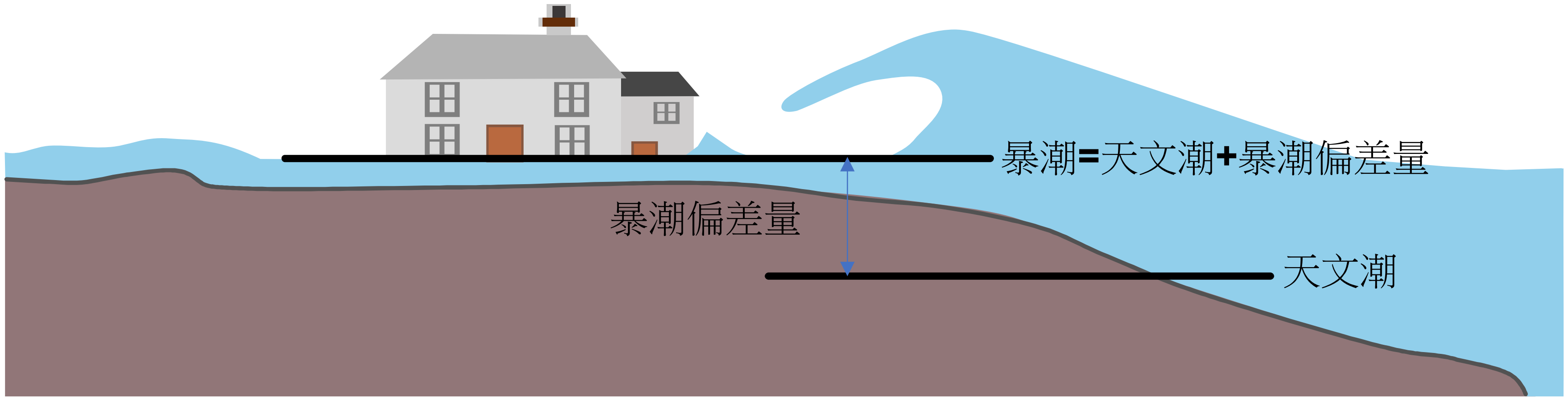


簡報大綱

- 暴潮模式介紹
- 丹娜絲颱風背景資訊
- 東石、將軍暴潮預報校驗
- 後續研究

暴潮定義

暴潮泛指溫帶氣旋或熱帶氣旋的低氣壓及強風共同導致海水面**上升**或**下降**的現象，在臺灣主要由颱風所造成，颱風的中心低氣壓會使海水面上升，中心氣壓每下降**1**百帕，海水面約上升**1**公分。而颱風強勁的風勢，會驅使岸邊的海水進一步上升或下降。颱風的中心低氣壓加上吹向陸地的風勢，會使海平面上升，進而導致海水倒灌或河川逕流無法順利流入大海



暴潮示意圖

Operational Storm Surge Forecast System in CWA, Taiwan (Cornell Multi-grid Coupled Tsunami Model – Storm Surge)

Nonlinear Shallow Water Equations on the Spherical Coordinate

$$\frac{\partial \eta}{\partial t} + \frac{1}{R\cos\varphi}\left\{\frac{\partial P}{\partial \psi} + \frac{\partial}{\partial \varphi}\left(\cos\varphi \cdot Q\right)\right\} = 0$$

$$\frac{\partial P}{\partial t} + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \psi}\left(\frac{P^2}{H}\right) + \frac{1}{R}\frac{\partial}{\partial \varphi}\left(\frac{PQ}{H}\right) + \frac{gH}{R\cos\varphi}\frac{\partial \eta}{\partial \psi} - fQ + F_\psi^b = -\frac{H}{\rho_w R\cos\varphi}\frac{\partial P_a}{\partial \psi} + \frac{F_\psi^s}{\rho_w}$$

$$\frac{\partial Q}{\partial t} + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \psi}\left(\frac{PQ}{H}\right) + \frac{1}{R}\frac{\partial}{\partial \varphi}\left(\frac{Q^2}{H}\right) + \frac{gH}{R}\frac{\partial \eta}{\partial \varphi} + fP + F_\varphi^b = -\frac{H}{\rho_w R}\frac{\partial P_a}{\partial \psi} + \frac{F_\varphi^s}{\rho_w}$$

- Solve shallow water equations on **both spherical and Cartesian coordinate systems**
- **Explicit leapfrog Finite Difference Method** for stable and high speed calculation
- **Multi/Nested-grid system** for multiple shallow water wave scales
- **Moving Boundary Scheme** for inundation
- **High-speed efficiency**

- **Moving Boundary Scheme**

Moving boundary scheme was also introduced in COMCOT to model the run-up and run-down. The instant "shoreline" is defined as the interface between a dry grid and wet grid and volume flux normal to the interface is assigned to zero.

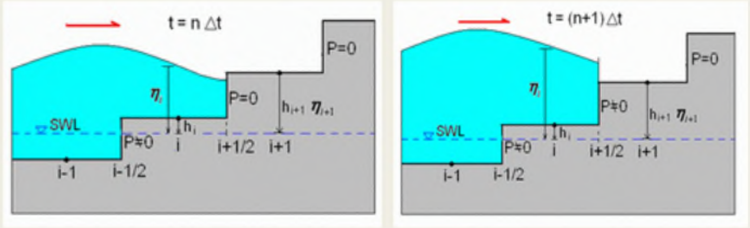


Fig.02 Moving Boundary Scheme

Meteorological Input : Idealized Wind Models

Holland Wind Model (1980)

$$P_a = P_c + (P_n - P_c)\exp\left[-\left(\frac{R_{max}}{r}\right)^B\right]$$

$$V_w = \sqrt{\frac{B(P_n - P_c)}{\rho_a}\left(\frac{R_{max}}{r}\right)^B \exp\left(-\left(\frac{R_{max}}{r}\right)^B\right) + \frac{r^2 f^2}{4}} - \frac{rf}{2}$$

$$B = 2 - \frac{P_c - 900}{160}$$

CWA Idealized Wind Models

$$P_a = P_c + (P_n - P_c)\exp\left[-\left(\frac{R_{max}}{r}\right)^B\right]$$

$$V_w = 2 \cdot V_{max} \cdot \frac{R_{max} \cdot r}{R_{max}^2 + r^2}$$

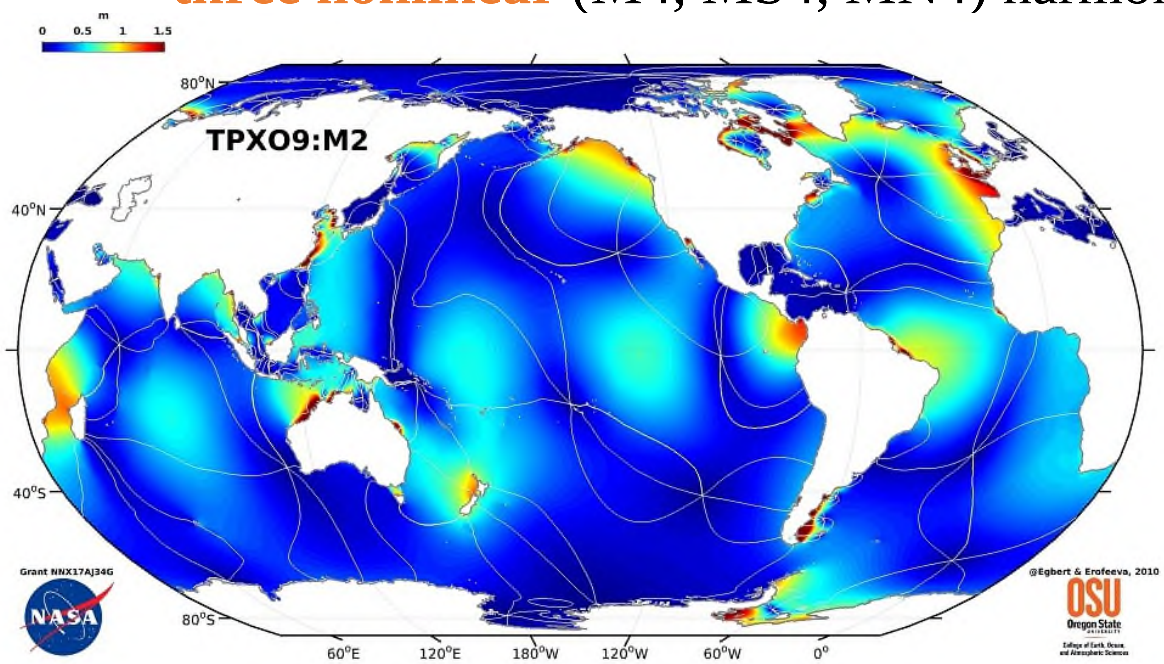
$$B = \frac{1}{P_n - P_c}\left(\frac{V_{max}}{5.375}\right)^2$$

$$R_{max} = \begin{cases} 42.6 - 0.86 \cdot (P_c - 990), & P_c \geq 990 \\ 51.0 - 0.84 \cdot (P_c - 980), & 980 \leq P_c < 990 \\ 58.4 - 0.74 \cdot (P_c - 970), & 970 \leq P_c < 980 \\ 63.0 - 0.46 \cdot (P_c - 960), & 960 \leq P_c < 970 \\ 70.0 - 0.234 \cdot (P_c - 930), & 930 \leq P_c < 960 \\ 80.0 - 0.167 \cdot (P_c - 870), & 870 \leq P_c < 930 \\ 80.0, & P_c < 870 \end{cases}$$

Rmax is empirically obtained from tropical cyclones from 1995 to 2015.

Tide Coupling with TPXO Model
(USA OSU TOPEX/POSEIDON Global Tidal Model)

TPXO9-atlas-v2 (Egbert & Erofeeva, 2002) applies a generalized inverse method by fitting the observation and **linear shallow water equations** in the **least square** sense (Egbert et al., 1994), and it provides **1/30-degree** resolution in the computational domain, with **ten linear primaries** (M2, S2, N2, K2, K1, O1, P1, Q1, S1, 2N2), **two long-period** (Mf, Mm), and **three nonlinear** (M4, MS4, MN4) harmonic constituents.



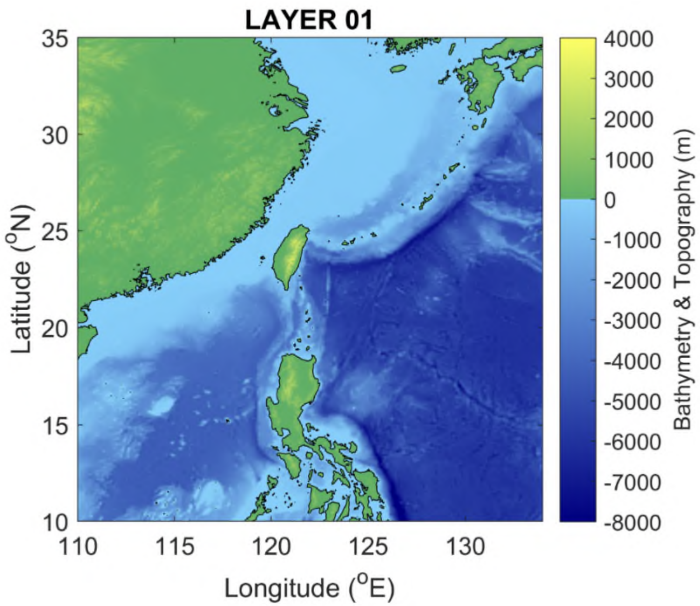
(https://www.tpxo.net/global)

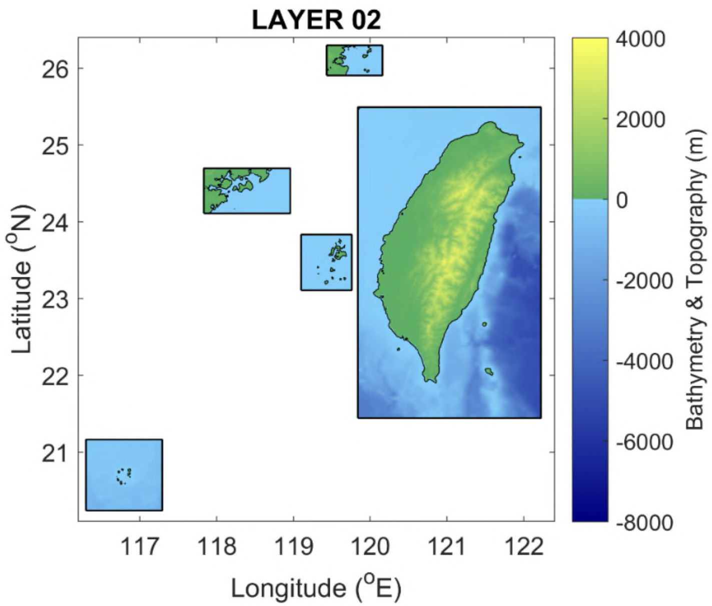
The partial tide component at time t for a constituent frequency ω at location x can be calculated by the following formula (Egbert & Erofeeva, 2002):

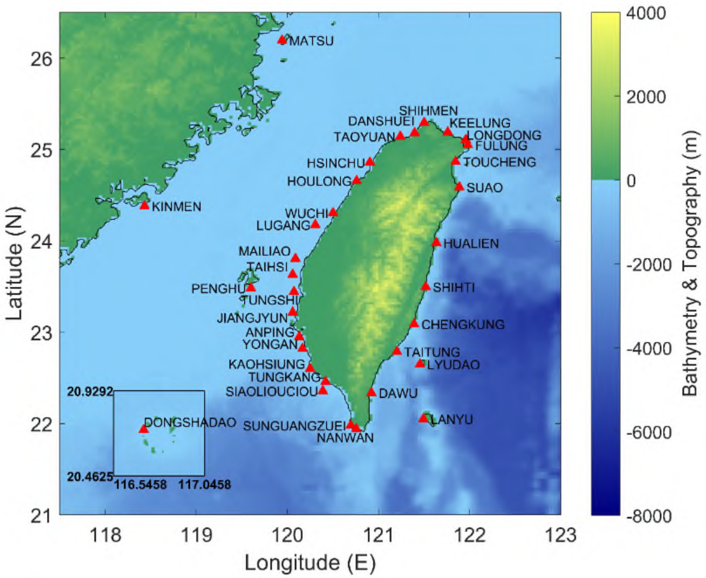
$$h(t,x) = pu(t,x) \cdot Re[h(x)\exp\{i[\omega(t-t0)+V0(t0)+ph(t,x)]\}]$$

where $V0(t0)$ is the astronomical argument for the constituent at time $t0$, $pu(t,x)$ and $ph(t,x)$ are nodal corrections. The amplitude will be $|h|$ and the phase will be $\operatorname{atan}\left(\frac{-Im(h)}{Re(h)}\right)$.

Numerical Sets for Current Forecast System



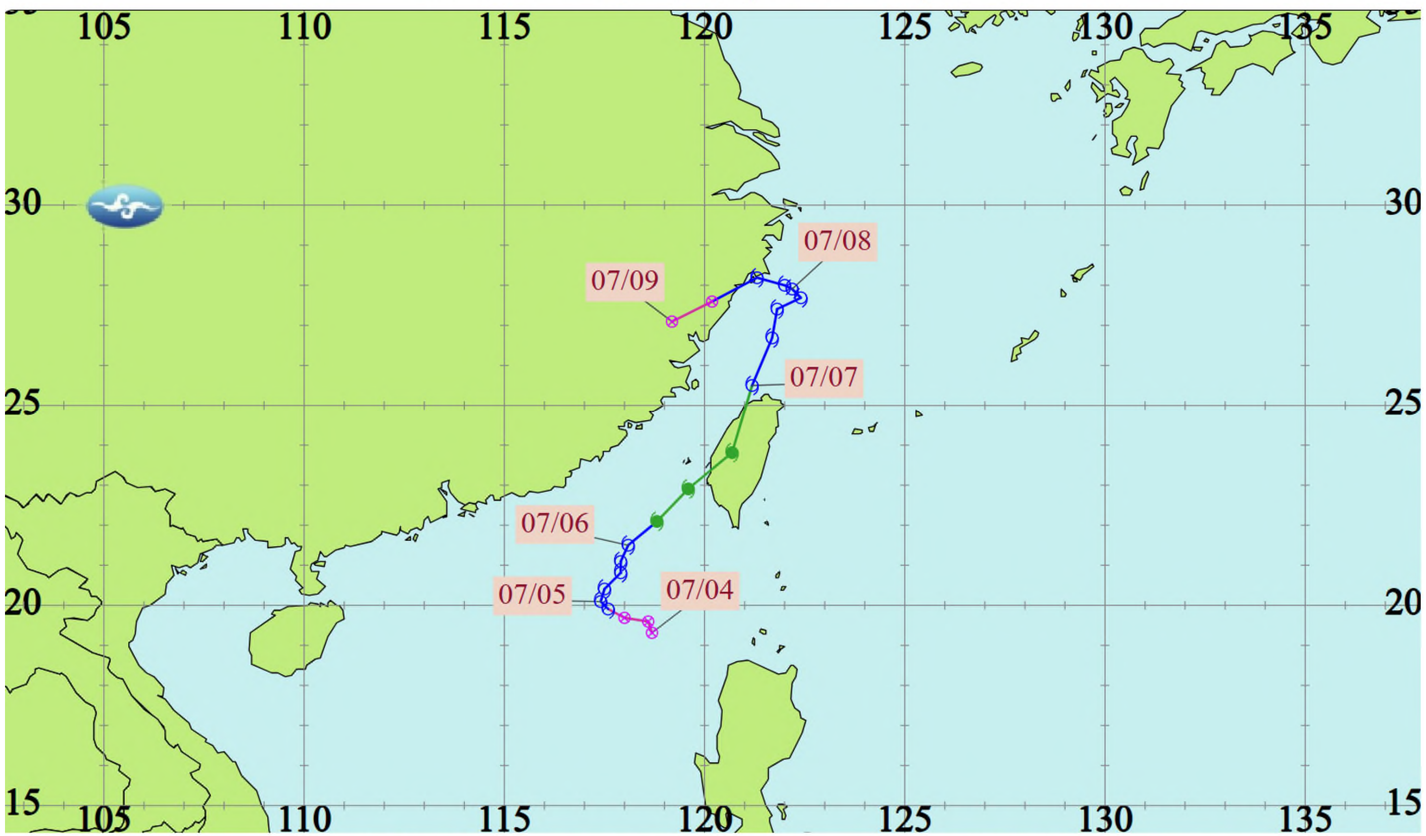




Layer ID	Domain	Array Size	Bathymetry Database	Resolution
LAYER-01	(110.00-134.00, 10.00-35.00)	361 * 376	ETOPO	4 arc-min
LAYER-02-A	(119.80-122.25, 21.40-25.50)	144 * 244	GEBCO	2.0 km
LAYER-02-B	(119.09-119.80, 23.05-23.89)	80 * 88	GEBCO	1.0 km
LAYER-02-C	(117.80-118.99, 24.09-24.70)	136 * 72	GEBCO	1.0 km
LAYER-02-D	(119.39-120.19, 25.84-26.35)	88 * 48	GEBCO	1.0 km
LAYER-02-E	(116.29-117.31, 20.19-21.23)	120*112	GEBCO	1.0 km

颱風路徑

202504 丹娜絲(DANAS)



強烈颱風(Vmax>=51.0m/s) 中度颱風(Vmax32.7-50.9m/s) 輕度颱風(Vmax17.2-32.6m/s) ⊗熱帶性低氣壓(Vmax<17.2m/s)

名稱	丹娜絲 (DANAS)
編號	202504
生成地點	117.6, 19.9
侵(近)臺日期	2025年 07月 06日
發布時間	海上 2025-07-05 08:30:00 陸上 2025-07-05 20:30:00
解除時間	陸上 2025-07-07 11:30:00 海上 2025-07-07 17:30:00
發布報數	20
最大強度	中度
近中心最大風速	40 (公尺/秒)
侵臺路徑分類	9
登陸地段	嘉義布袋

輿情

2025-07-15 【勁報記者于郁金/臺南報導】受到丹娜絲颱風襲擊，臺南市七股區出現嚴重災情，尤其是西寮里受創最為嚴重；當地不僅遭受強烈風害，還遭遇極端暴潮侵襲，導致大規模海水倒灌，村落嚴重淹水，災情雪上加霜；根據國立成功大學近海水文中心的協助水利署進行觀測與分析顯示，颱風侵襲當晚，臺南沿海地區出現近1公尺暴潮水位，屬於200年重現期等級極端事件，打破當地有紀錄以來觀測紀錄。

成大水利及海洋工程學系主任董東璟教授指出，這次極端暴潮並非單一因素所造成，而是多重機制共同疊加結果；首先，颱風中心低氣壓系統抬升海面水位，形成典型「氣壓型暴潮」；其次，颱風環流靠近岸邊時，產生接近16級強烈向岸風，觸發強烈「風揚效應」。

所謂風揚效應，指的是持續強風將大量海水推向岸邊，進一步抬高海平面水位；當風揚效應與低氣壓效應同時發生時，便會產生破壞力極強極端暴潮現象；本次風暴期間風揚效應強度遠超過以往經驗，導致海水倒灌範圍與深度均大幅超過過去颱風情形，而西寮里位於出海水道旁，海水灌入影響比其它地方顯著；值得慶幸的是，此次極端暴潮發生在6日晚間約22時前後，當時並非天文潮最高潮位時間，否則災害規模恐怕更為嚴重。

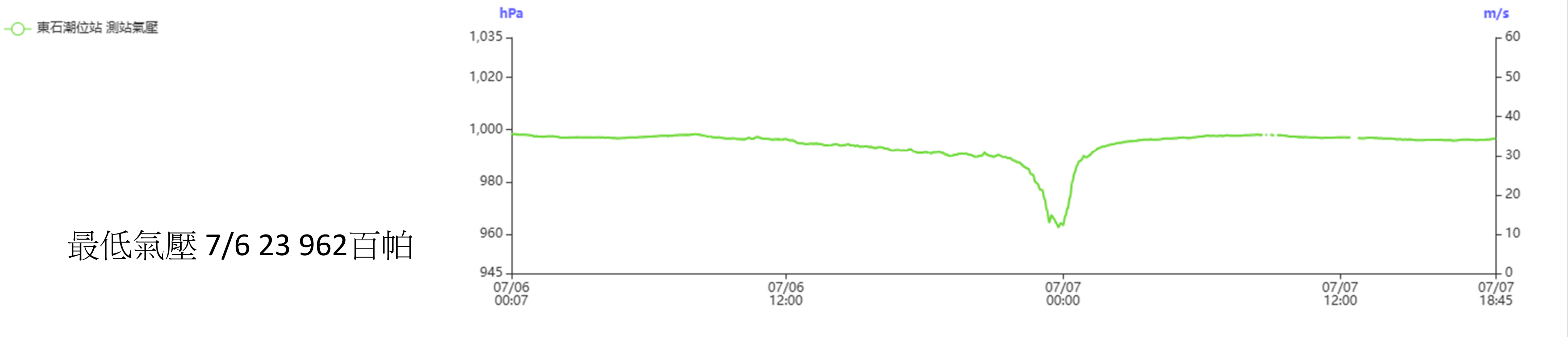
董東璟教授強調，低氣壓與風揚聯合作用下產生暴潮，是沿海低窪地區最致命淹水風險來源之一；西寮里此次慘重災情再次證明，在極端氣候背景下，風暴潮威脅絕不可輕忽；未來應亟需強化沿海防災體系，包括提升預警系統精度，以及進行防護設施整建與強化，降低類似災害重演風險。

極端暴潮

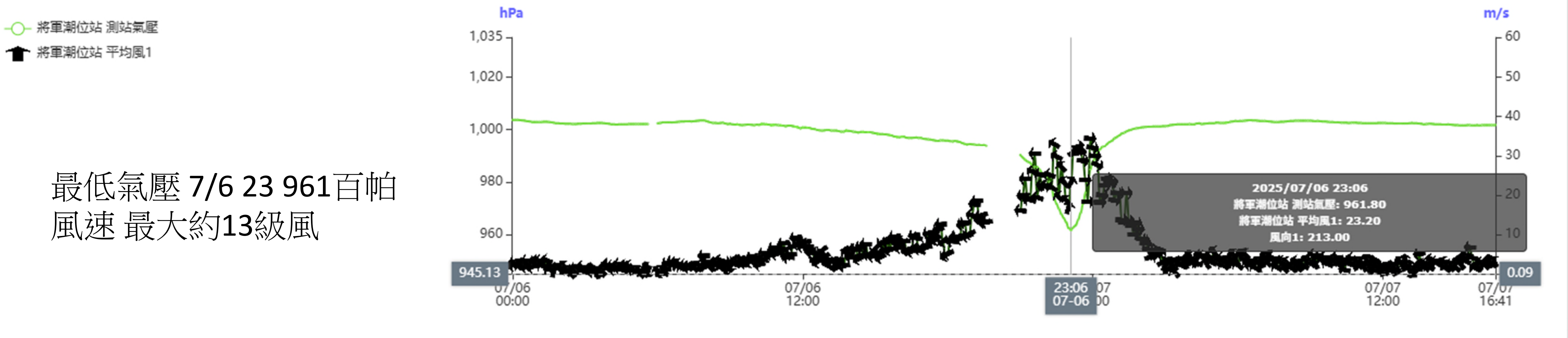
當日滿潮 7/6 20:00-21:00
暴潮最大 7/7 00:00-01:00

非天文潮最高潮位

潮位站風速壓力觀測資料



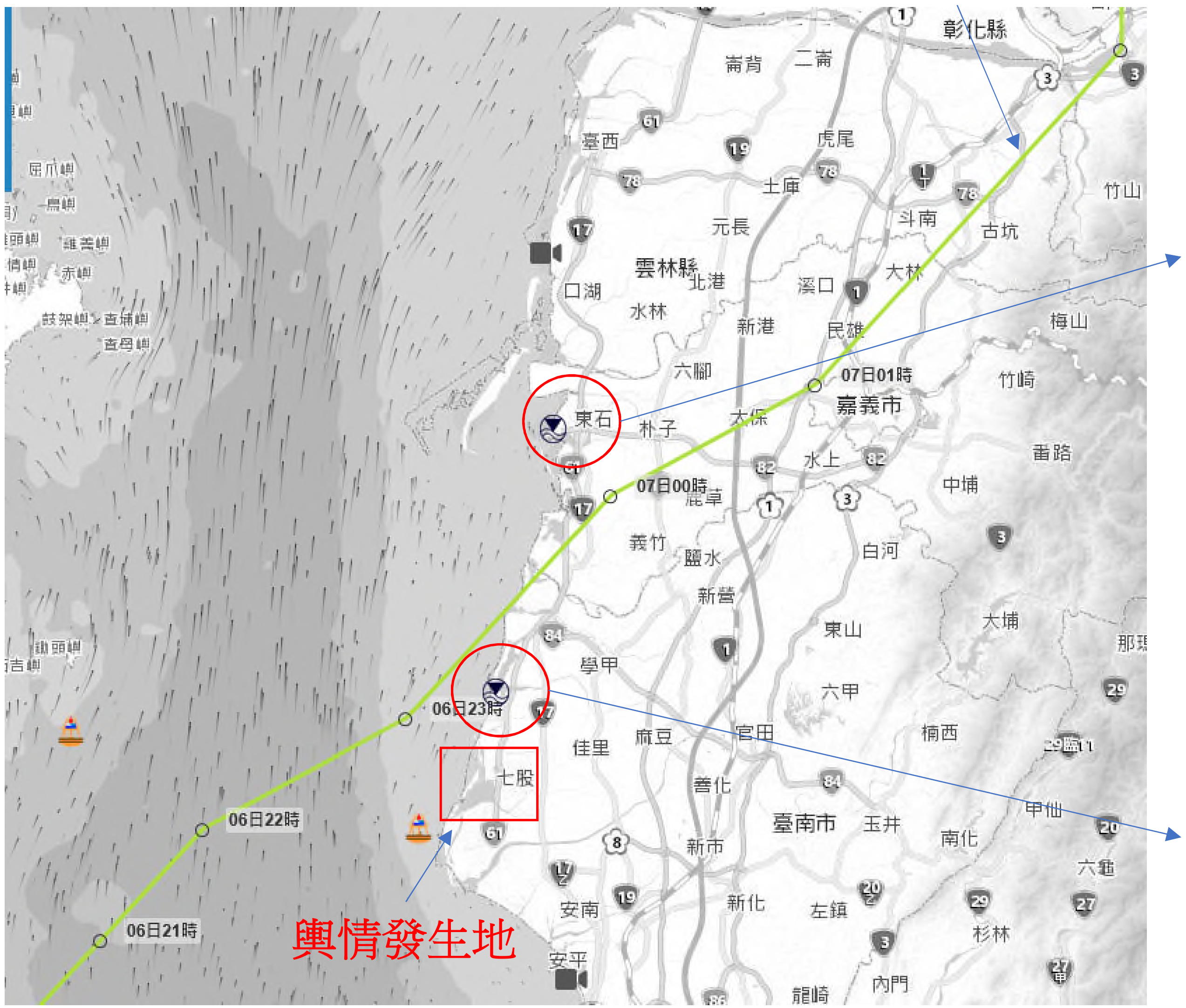
最低氣壓 7/6 23 962百帕



最低氣壓 7/6 23 961百帕
風速 最大約13級風

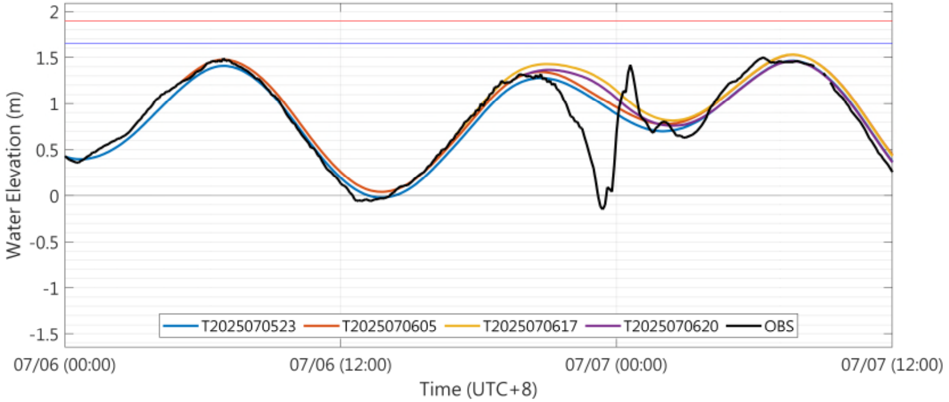
東石、將軍暴潮預報校驗

颱風路徑



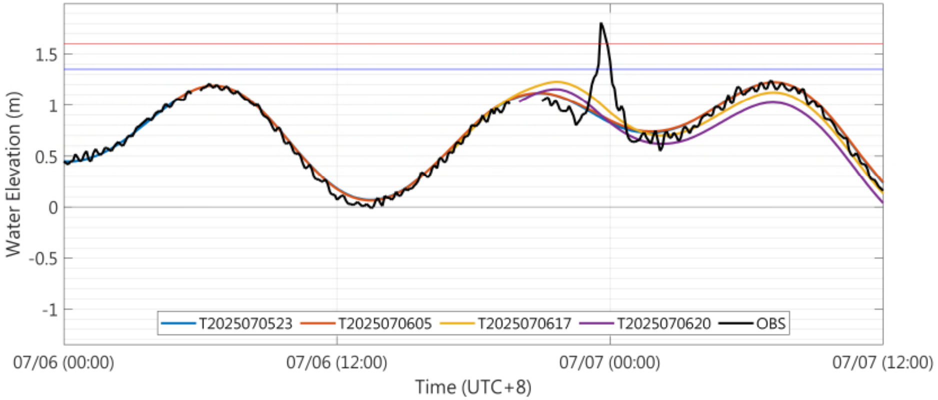
TUNGSHI (120.0, 23.5) in 2025 DANAS

Init. Time	RMSE	MAE	Corr.	Bias
2025070523	0.155	0.092	0.953	0.013
2025070605	0.183	0.121	0.953	0.098
2025070617	0.221	0.149	0.945	0.135
2025070620	0.187	0.112	0.946	0.066



JIANGJYUN (120.0, 23.2) in 2025 DANAS

Init. Time	RMSE	MAE	Corr.	Bias
2025070523	0.102	0.061	0.974	0.035
2025070605	0.111	0.076	0.972	0.053
2025070617	0.095	0.061	0.977	-0.005
2025070620	0.141	0.112	0.976	-0.101

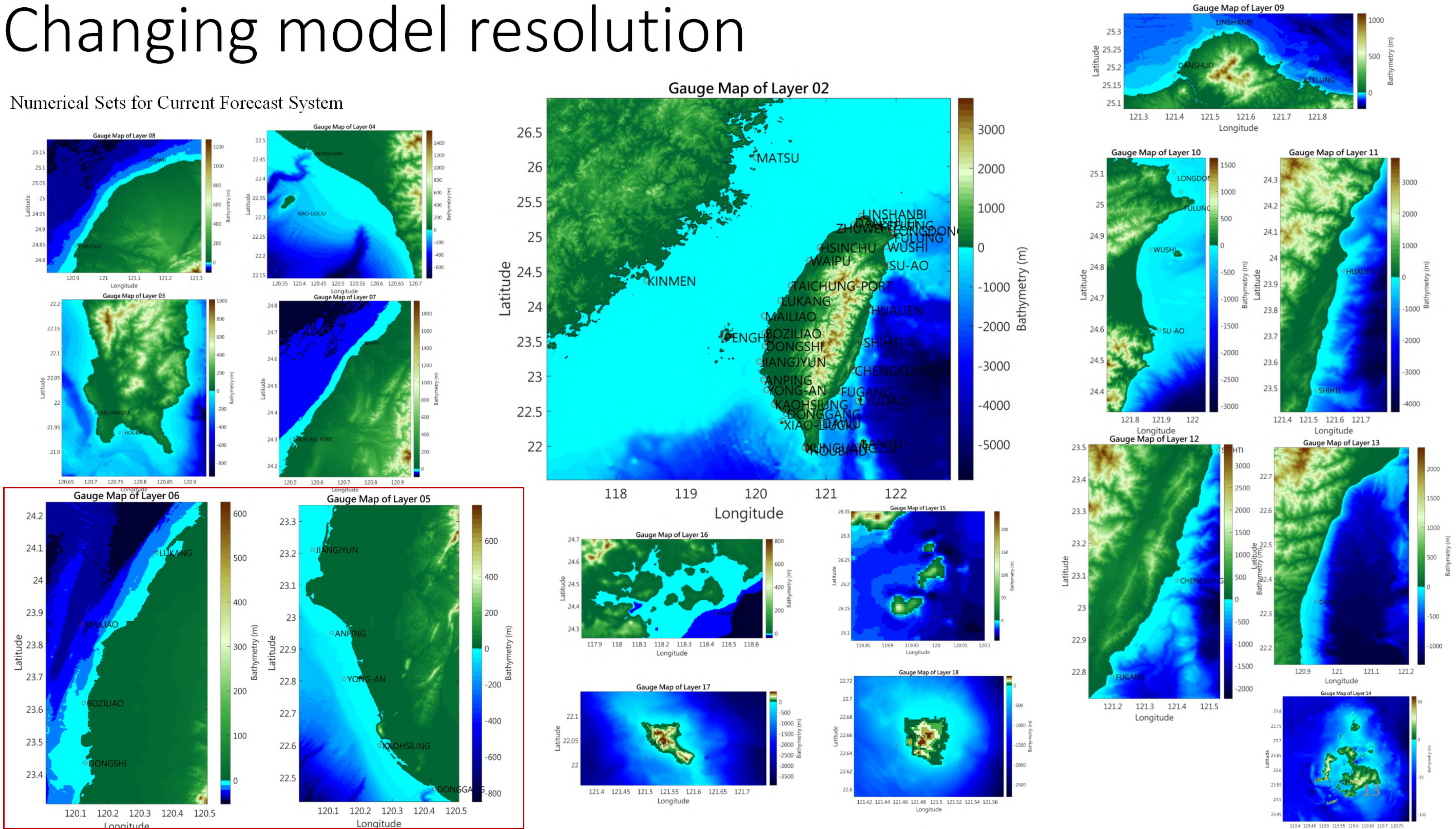


暴潮潮偏差排名表						
測站	最大潮位(mm)	最大潮位時間	最大暴潮偏差(mm)	最大暴潮偏差時間	颱風名稱	颱風強度
將軍潮位站	1810	2025/7/6 23:36	1354	2025/7/6 23:36	丹娜絲	中度
將軍潮位站	1494	2013/9/22 12:18	634	2013/9/22 8:30	天兔	強烈
將軍潮位站	1460	2024/10/31 21:42	492	2024/10/31 21:12	康芮	強烈
將軍潮位站	1530	2024/10/2 10:18	470	2024/10/2 17:24	山陀兒	強烈
將軍潮位站	1538	2023/7/28 6:12	470	2023/7/28 6:12	杜蘇芮	中度

潮位排名表				
測站	最大潮位(mm)	最大潮位時間	颱風名稱	颱風強度
將軍潮位站	1810	2025/7/6 23:36	丹娜絲	中度
將軍潮位站	1763	2023/8/31 10:18	蘇拉	強烈
將軍潮位站	1630	2024/7/25 13:18	凱米	強烈
將軍潮位站	1588	2023/9/2 11:54	海葵	中度
將軍潮位站	1538	2023/7/28 6:12	杜蘇芮	中度

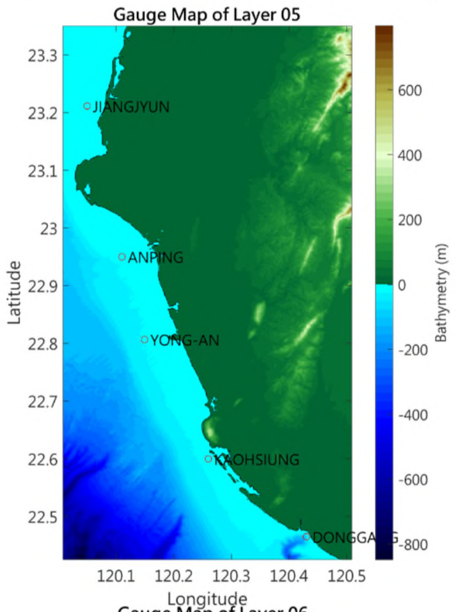
Changing model resolution

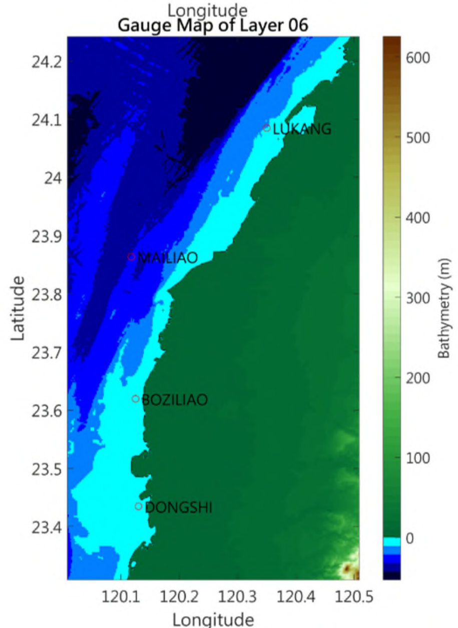
Numerical Sets for Current Forecast System



Changing model resolution

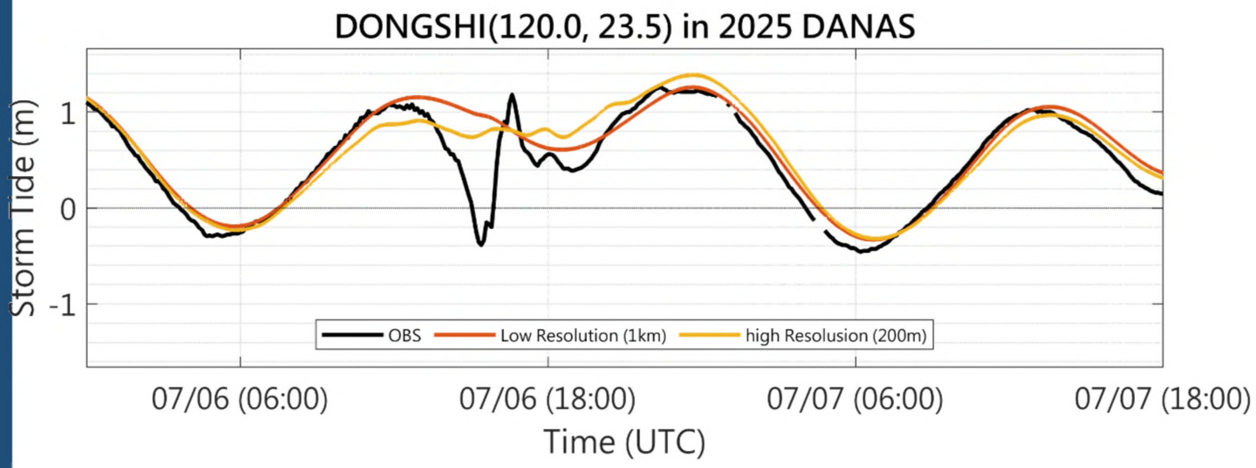
Numerical Sets for Current Forecast System

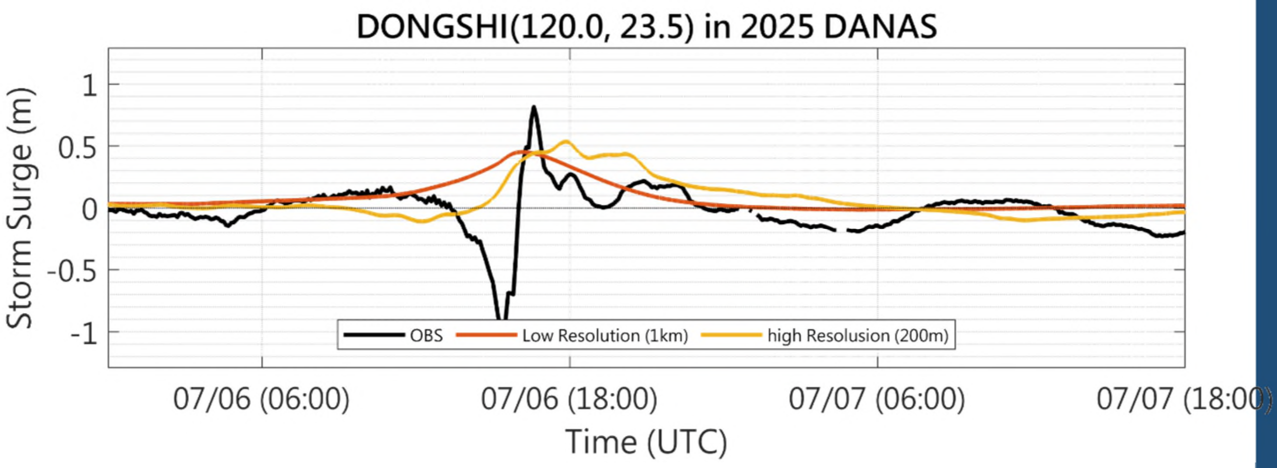


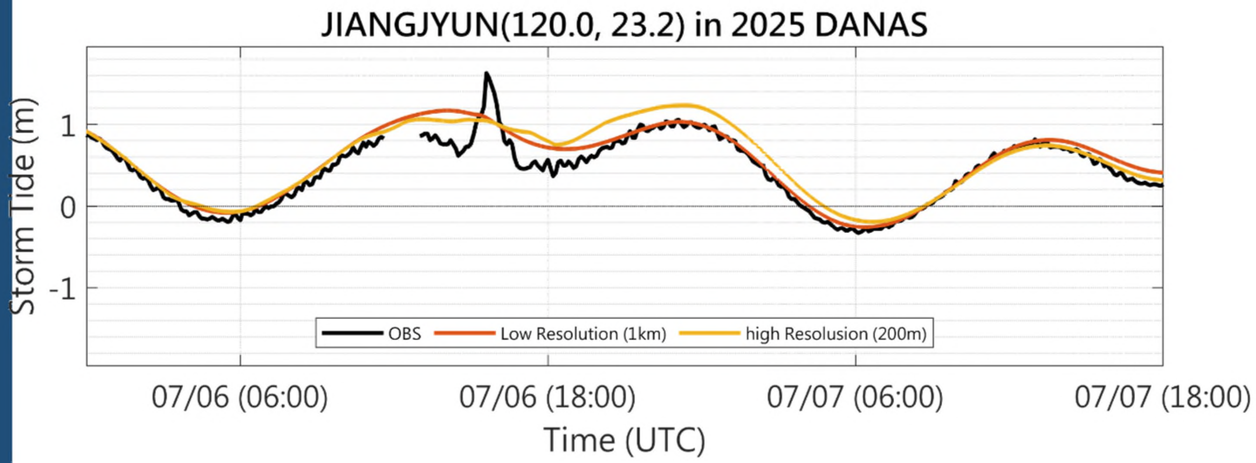


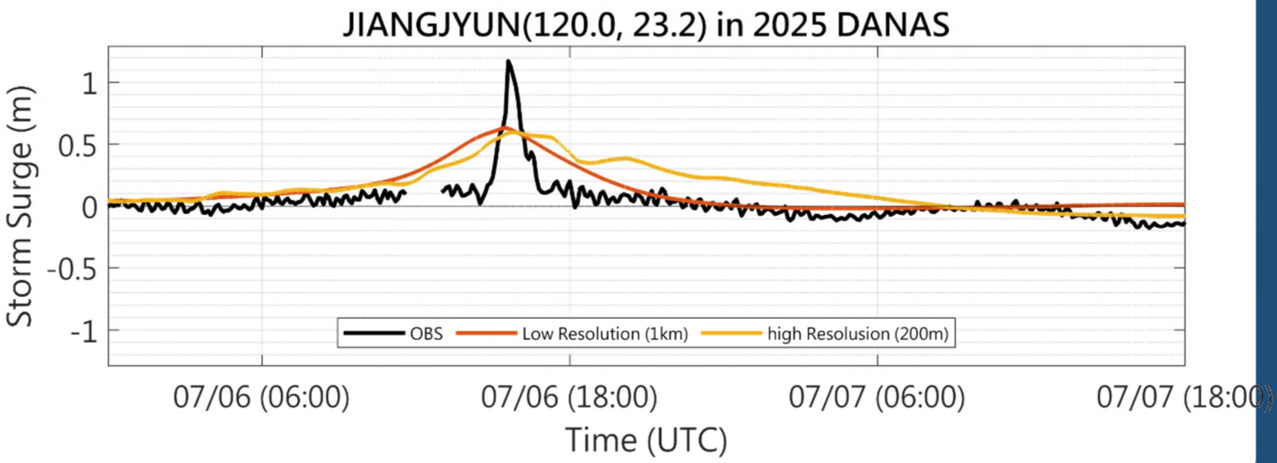
Layer ID	Domain	Array Size	Resolution
LAYER-01	(110.00-134.00, 10.00-35.00)	721 * 751	2 arc-min
LAYER-02	(117.02-122.78, 21.52-26.98)	692 * 656	1.0 km
LAYER-03	(120.64-112.93, 21.85-22.21)	140 * 172	200.0 m
LAYER-04	(120.32-120.72, 22.14-22.52)	192 * 184	200.0 m
LAYER-05	(120.01-120.51, 22.43-23.35)	240 * 444	200.0 m
LAYER-06	(120.01-120.51, 23.31-24.24)	240*448	200.0 m
LAYER-07	(120.46-120.95, 24.16-24.82)	236*316	200.0 m
LAYER-08	(120.82-121.32, 24.76-25.19)	240*208	200.0 m
LAYER-09	(121.26-121.90, 25.08-25.35)	308*128	200.0 m
LAYER-10	(121.73-122.04, 24.33-25.15)	152*392	200.0 m
LAYER-11	(121.39-121.80, 23.41-24.38)	196*468	200.0 m
LAYER-12	(121.13-121.53, 22.72-23.51)	196*380	200.0 m
LAYER-13	(120.82-121.21, 23.15-22.78)	188*304	200.0 m
LAYER-14	(119.36-119.79, 23.43-23.85)	208*204	200.0 m
LAYER-15	(119.83-120.10, 26.09-26.35)	66*64	200.0 m
LAYER-16	(117.84-118.65, 24.26-24.70)	194*106	200.0 m
LAYER-17	(121.37-121.75, 21.96-22.15)	184*92	200.0 m
LAYER-18	(121.41-121.57, 22.59-22.72)	80*64	200.0 m

提高解析度的結果


DONGSHI(120.0, 23.5) in 2025 DANAS
Storm Tide (m)
1
0
-1
OBS
Low Resolution (1km)
high Resolution (200m)
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
Time (UTC)


DONGSHI(120.0, 23.5) in 2025 DANAS
Storm Surge (m)
1
0.5
0
-0.5
-1
OBS
Low Resolution (1km)
high Resolution (200m)
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
Time (UTC)


JIANGJYUN(120.0, 23.2) in 2025 DANAS
Storm Tide (m)
1
0
-1
OBS
Low Resolution (1km)
high Resolution (200m)
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
Time (UTC)

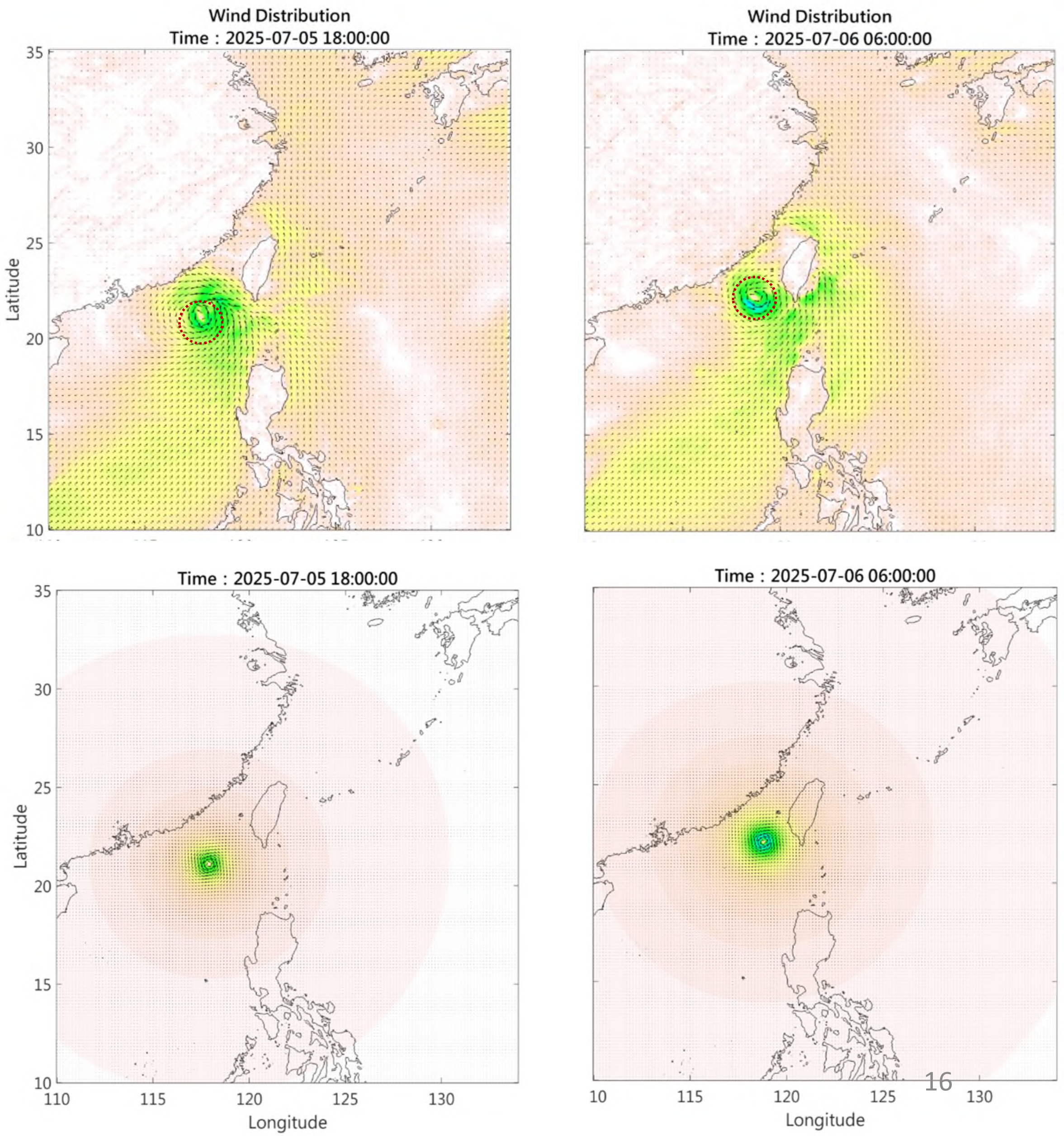

JIANGJYUN(120.0, 23.2) in 2025 DANAS
Storm Surge (m)
1
0.5
0
-0.5
-1
OBS
Low Resolution (1km)
high Resolution (200m)
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
Time (UTC)

Modifying wind field structure

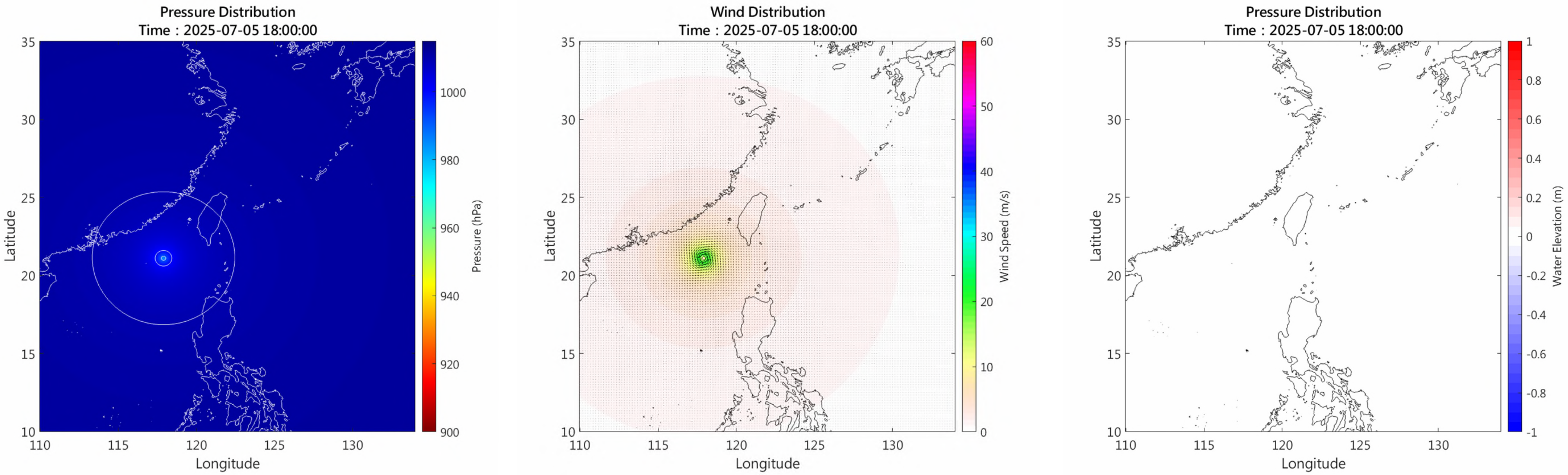
This storm surge event exhibited distinctive surge characteristics. As indicated by the previous results, merely increasing the model resolution provides limited improvement in resolving the surge signal.

Therefore, this study further investigates the idealized wind field. It was found that the maximum radius of gale winds in the idealized wind field differs from that in the TWRF simulation.

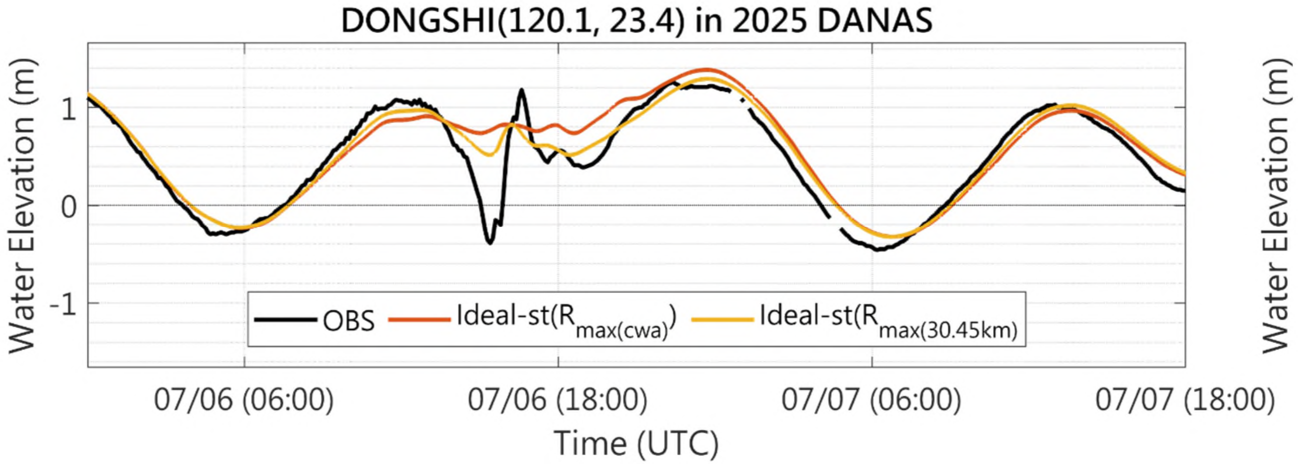
To address this discrepancy, we adjusted the value of the maximum radius of gale winds and modified the structural profile of the idealized wind field for simulation purposes.

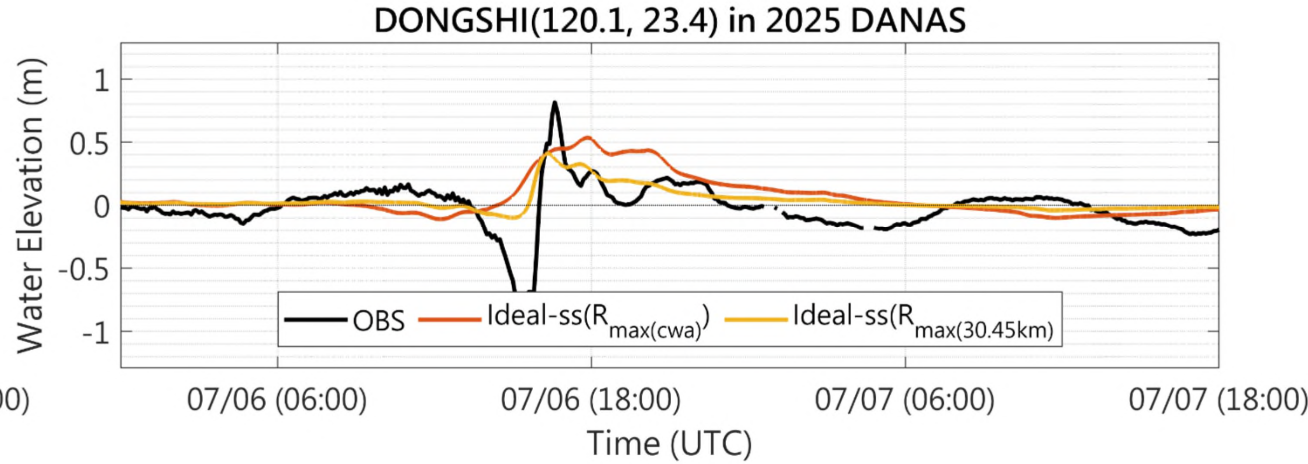


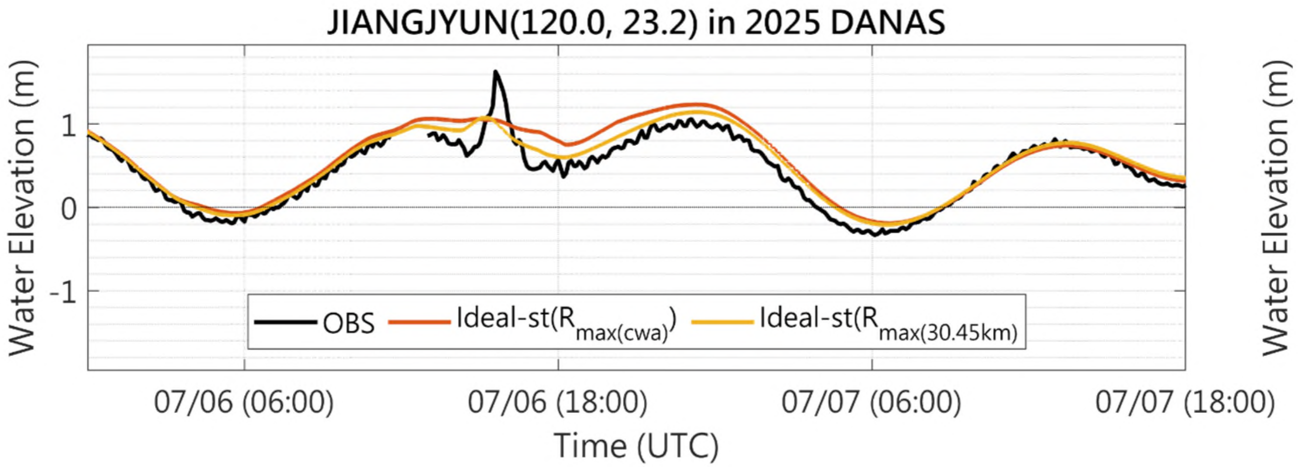
Modifying wind field structure

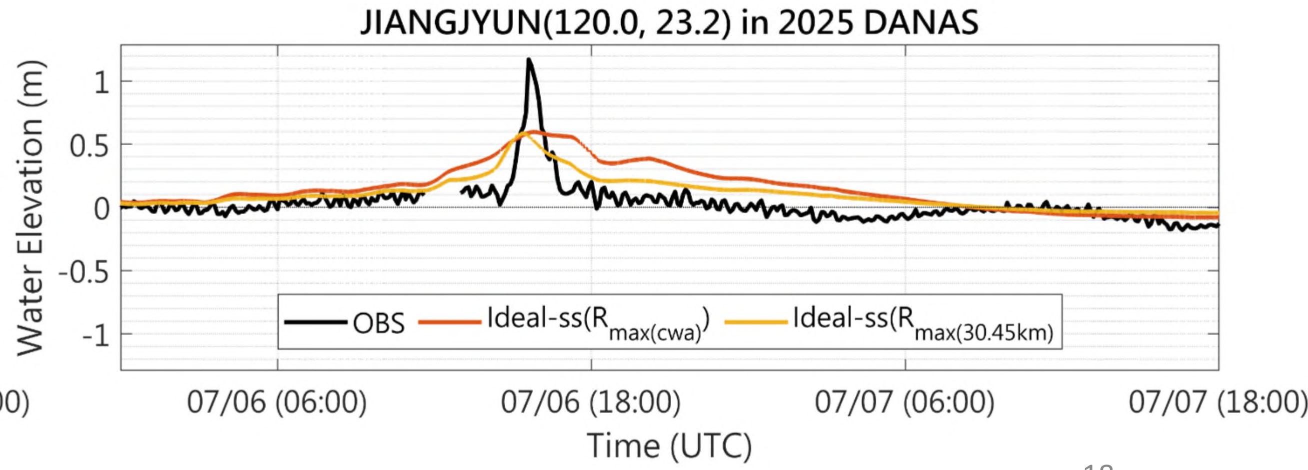


Modifying wind field structure





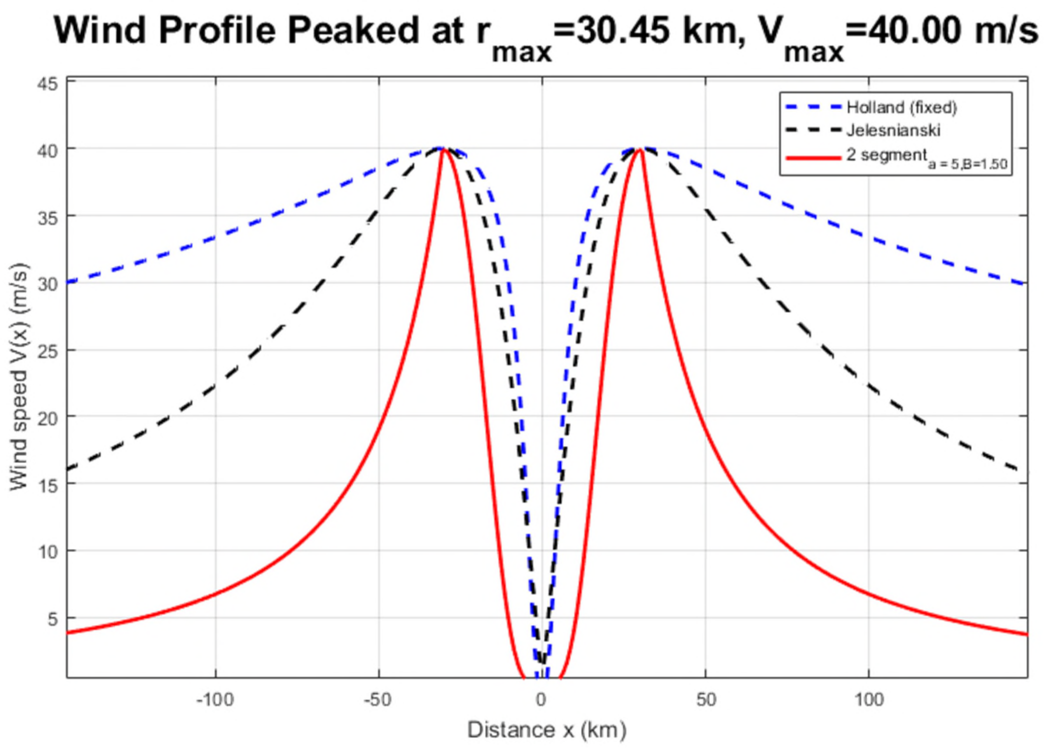




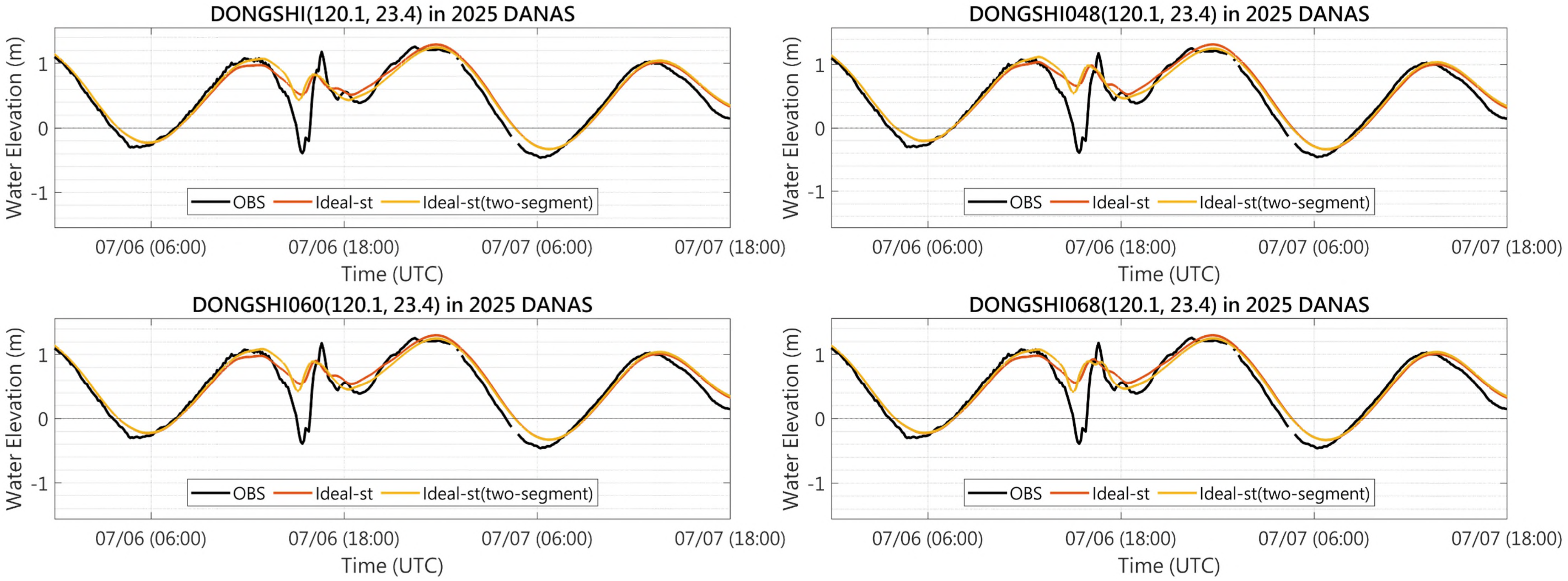
Other wind model (Ideal wind change)

- **Holland (1980)** $\rightarrow V_w = \sqrt{\frac{B(P_n-P_c)}{\rho_a}\left(\frac{R_{max}}{r}\right)^B \exp\left[-\left(\frac{R_{max}}{r}\right)^B\right] + \frac{r^2f^2}{2}} - \frac{rf}{2}$
- **Jelesnianski (1992)** $\rightarrow V_w = 2 \cdot V_{max} \cdot \frac{R_{max} \cdot r}{R_{max}^2 + r^2}$
- **Two-segment model** $\rightarrow V_w = \begin{cases} V_{max}\left(\frac{r}{r_{max}}\right)^{\alpha} exp[\alpha(1-\frac{r}{r_{max}})], 0 < r \le r_{max} \\ V_{max}\left(\frac{r}{r_{max}}\right)^{-\beta}, r > r_{max} \end{cases}$

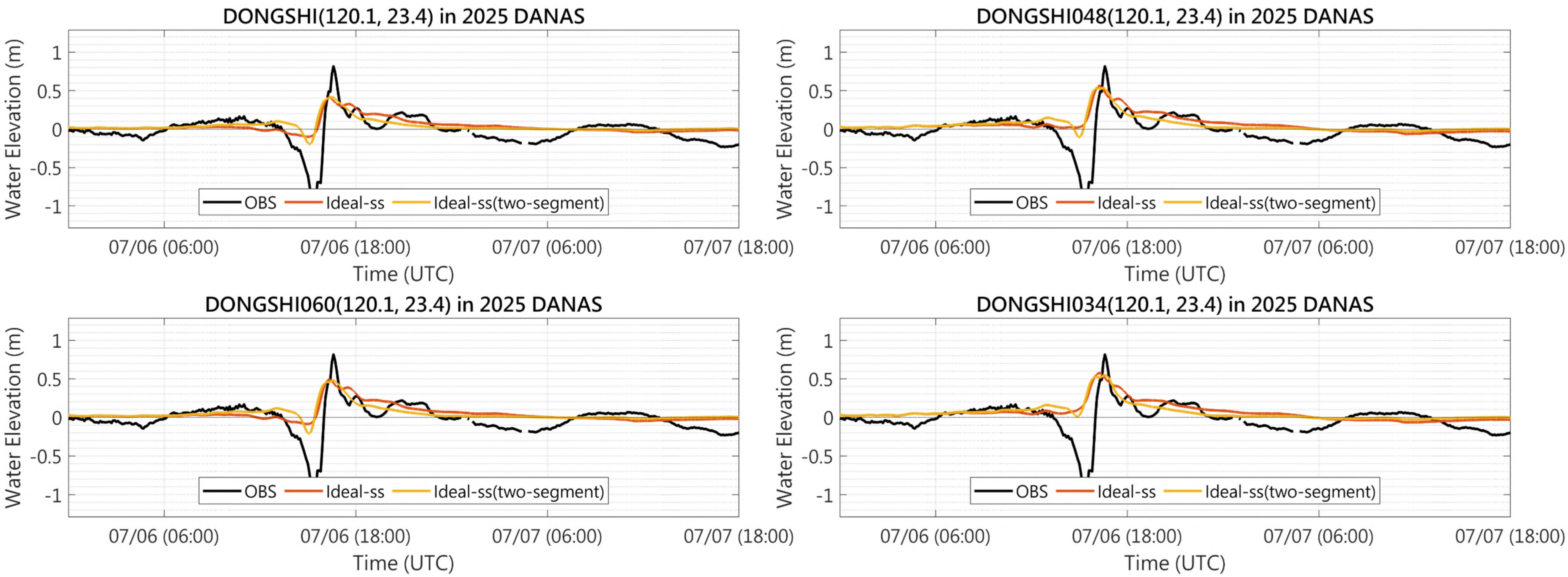
α: 內核陡度參數(>1 越尖) 、β外層衰減參數 (>0 越快衰減)



Other wind model (Ideal Wind Change)



Other wind model (Ideal Wind Change)



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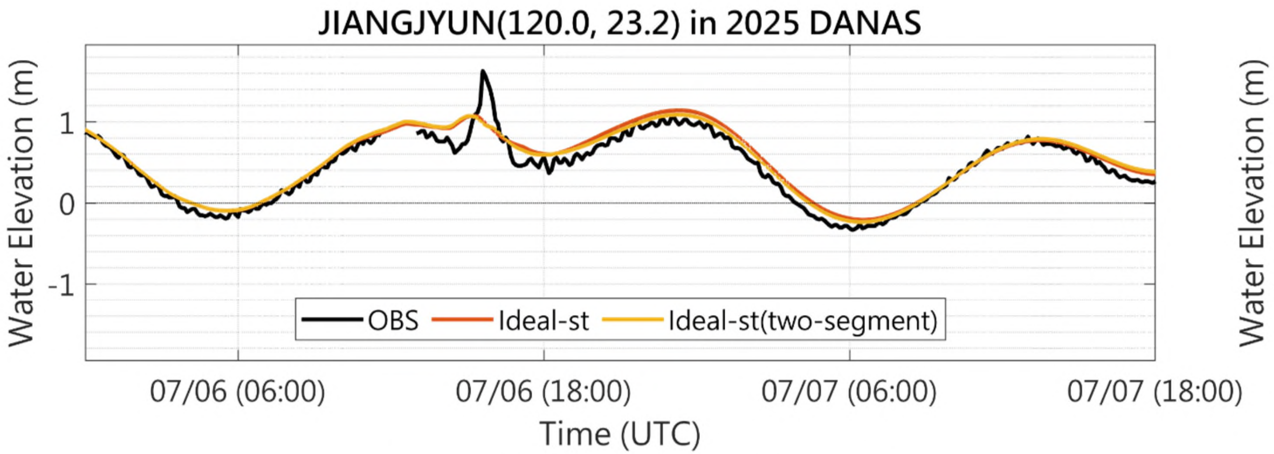
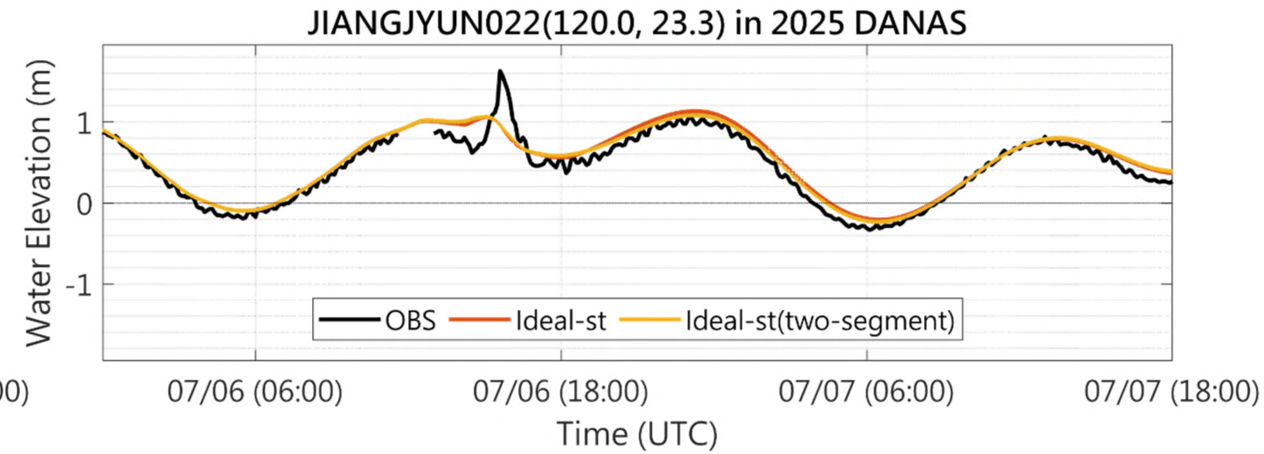
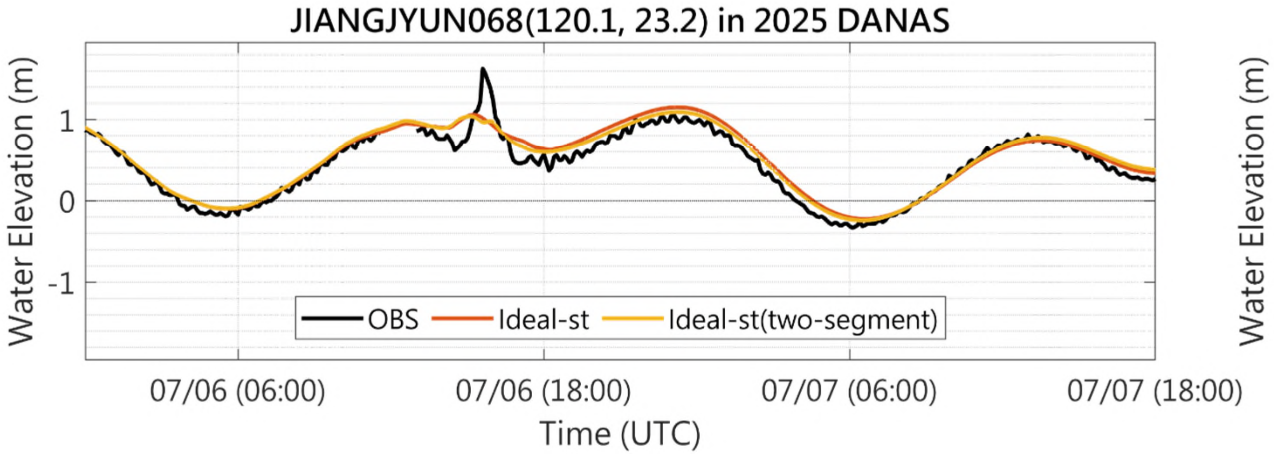
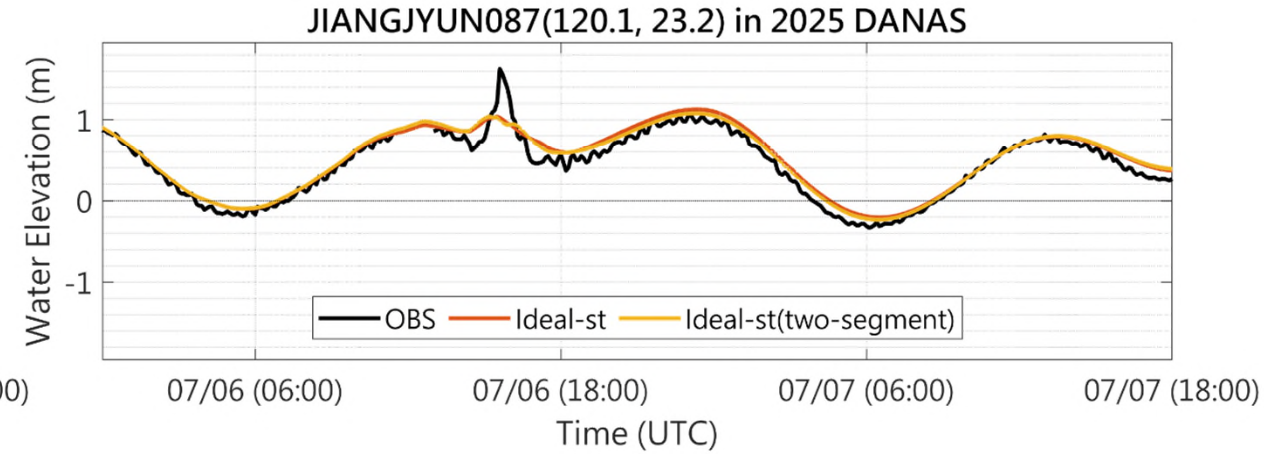
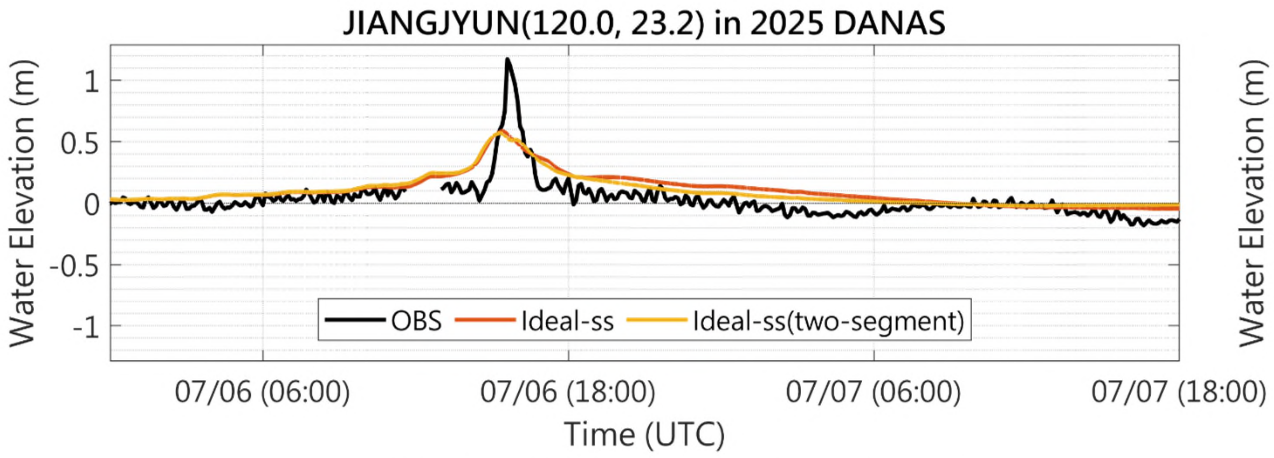


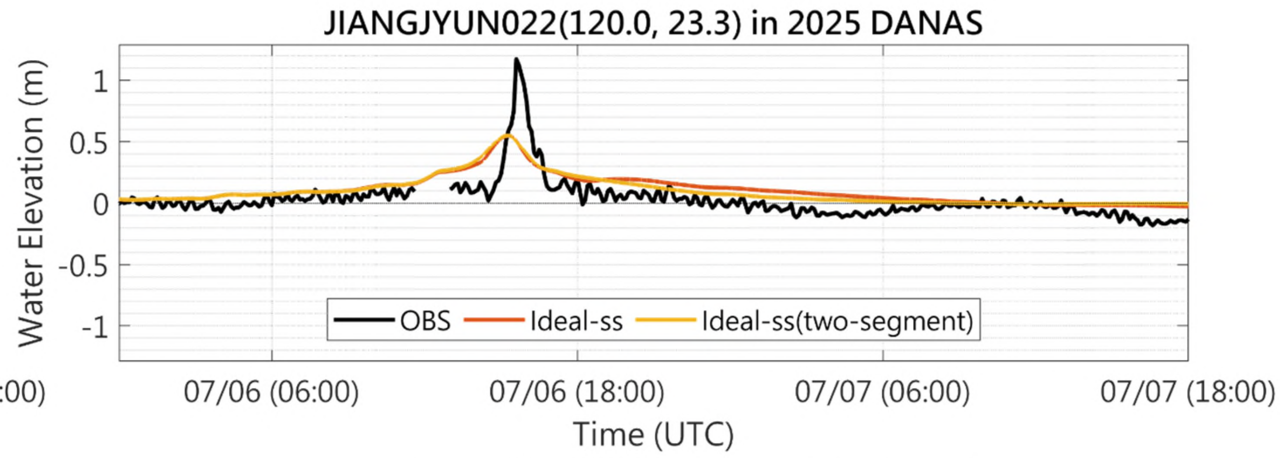


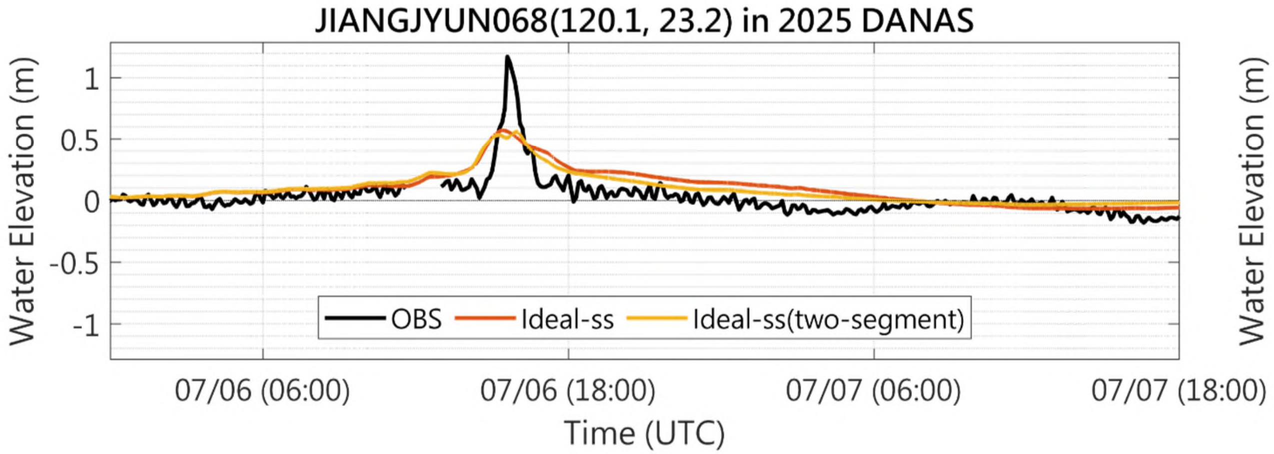


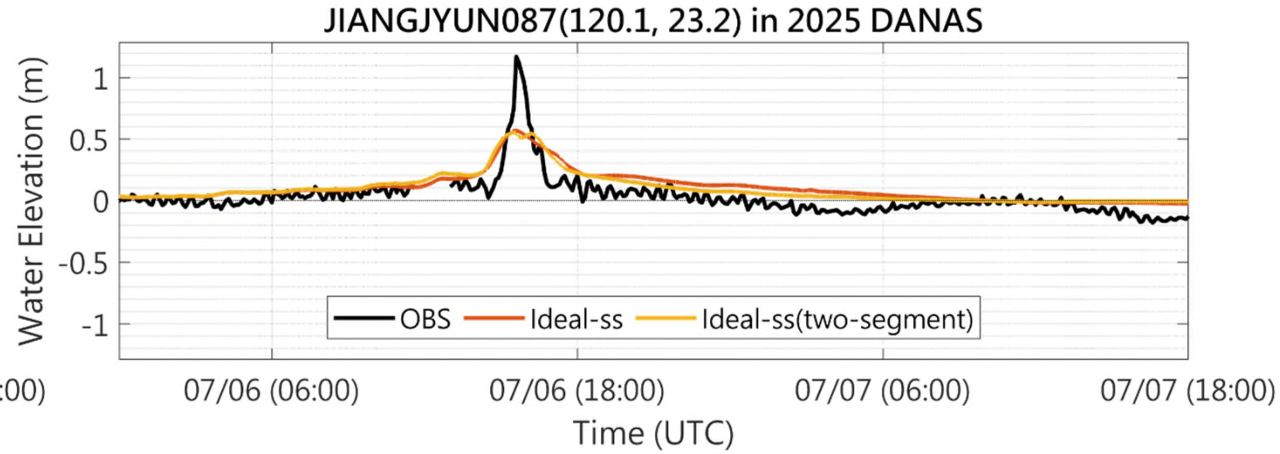


Other wind model (Ideal Wind Change)





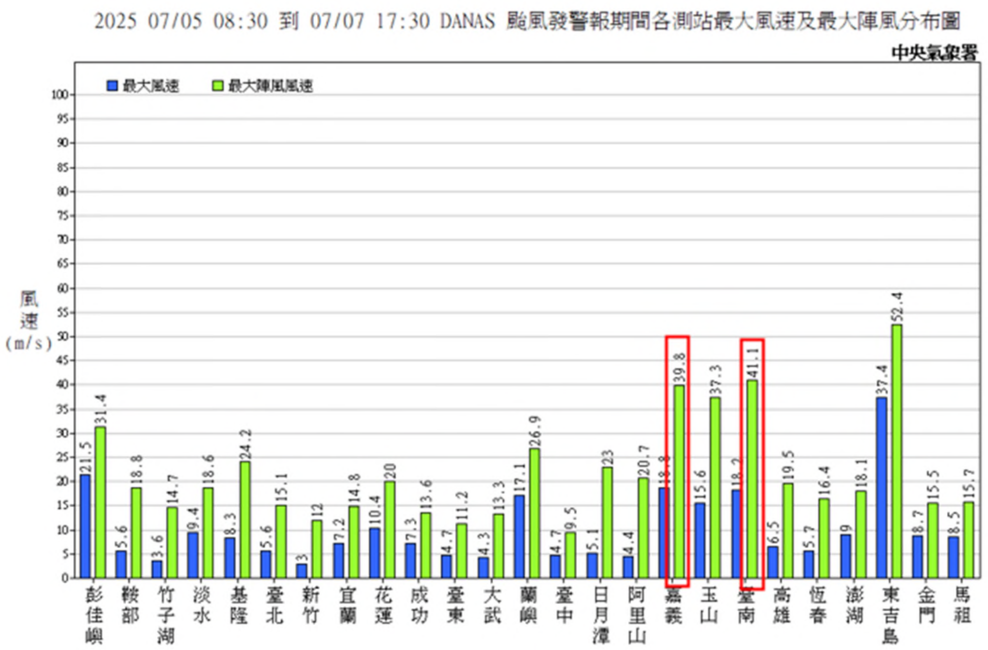




Varying wind speed magnitude

According to some reports, the automatic weather station in Kouhu, Yunlin recorded a maximum wind speed of 61.7 m/s. However, this extreme wind speed was not reflected in the available observational datasets. Therefore, we decided to adjust the wind speed magnitude to examine whether this change would affect the simulated storm surge levels.

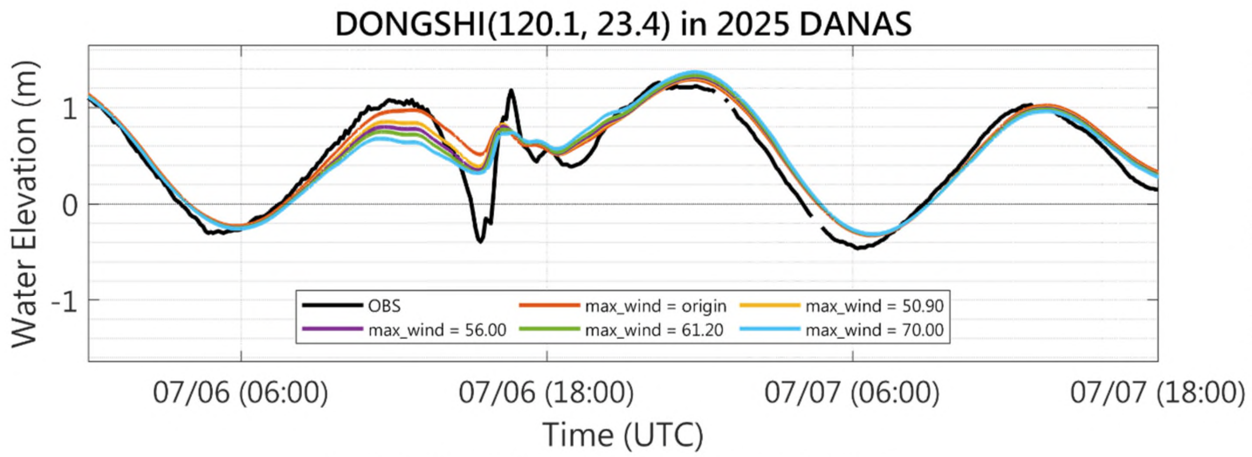
To analyze the sensitivity of storm surge simulations to wind speed, we systematically tested multiple wind speed scenarios and compared them with the original results.

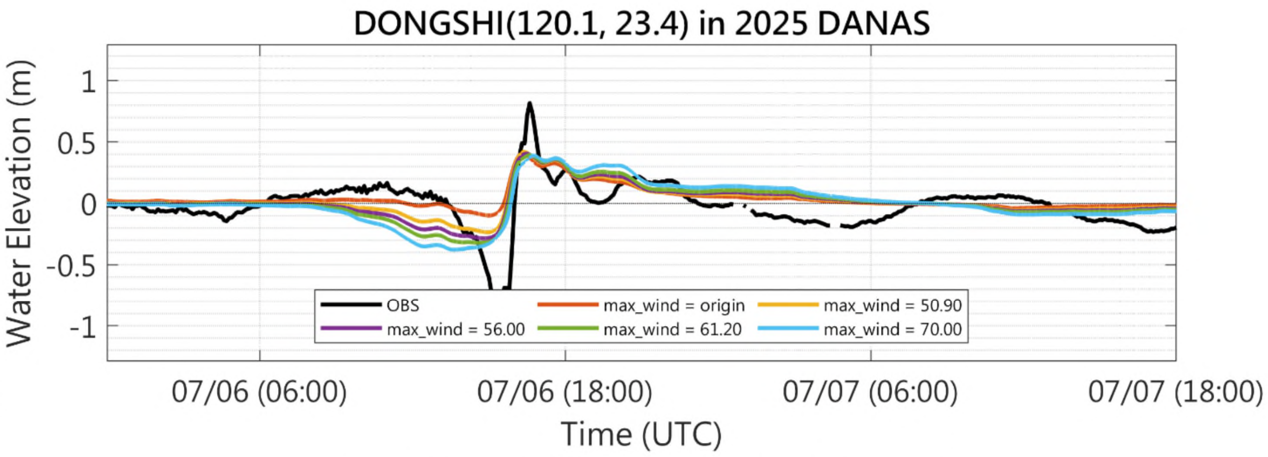


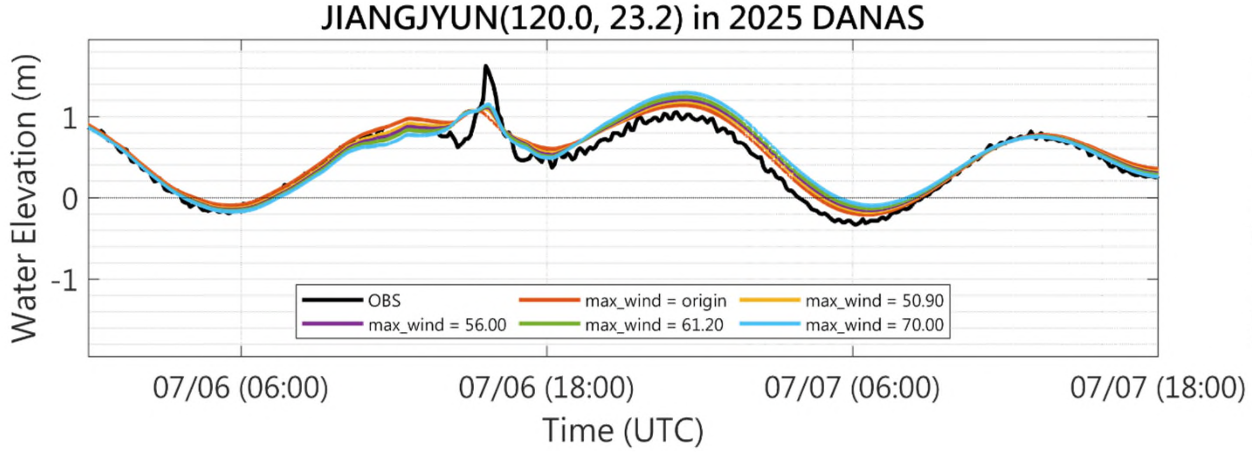
丹娜絲來勢洶洶，在雲林口湖鄉測得17級風、風速達每秒61.7公尺，但因是自動測站，不列入紀錄。就列入紀錄的人工站而言，台南站於6日晚間10時52分陣風達13級，風速為每秒41.1公尺，也是該站設站以來第3強的陣風。

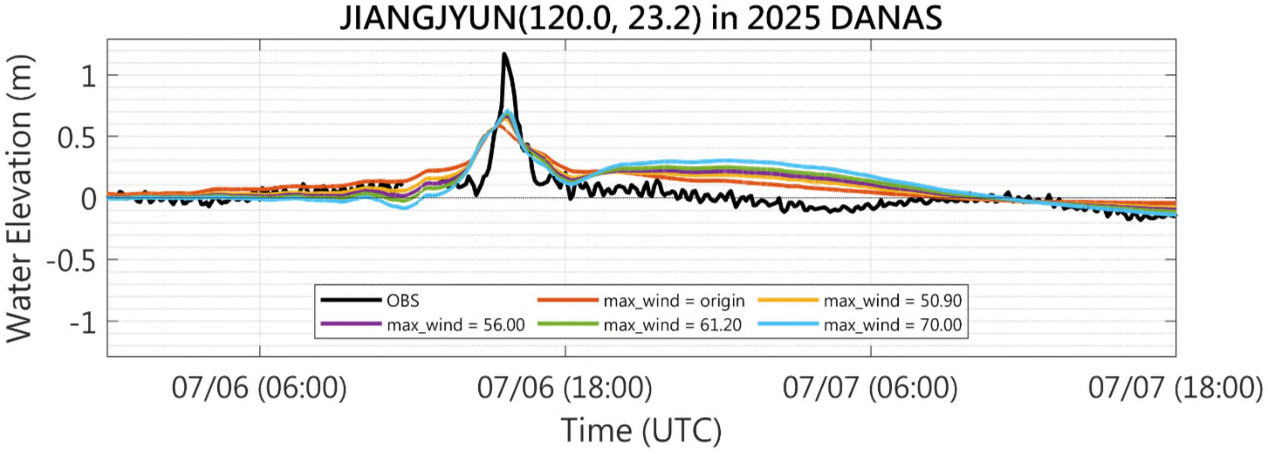
https://news.pts.org.tw/article/759699hi
https://www.taisounds.com/news/content/76/200195

Varying wind speed & fix $R_{max=30.45\ km}$



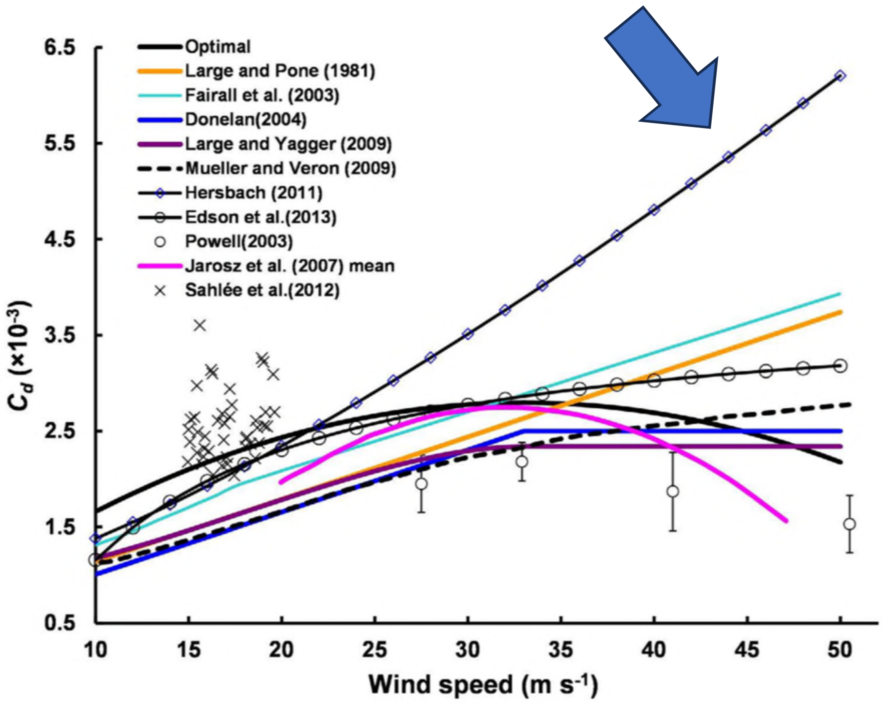




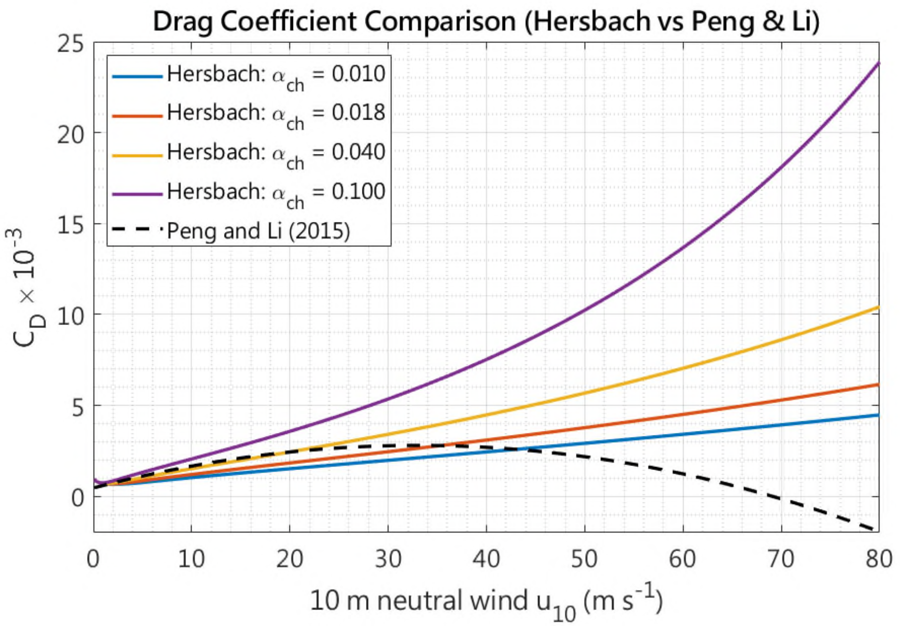


Change Drag Coefficient

The drag coefficient (CD) significantly influences the degree to which wind stress affects sea surface elevation. Most existing studies use CD values calibrated for deep-water conditions, which may not be applicable in nearshore environments. In this study, we adjusted the CD to a value more appropriate for coastal regions to better represent the wind-induced water level response near the shoreline.



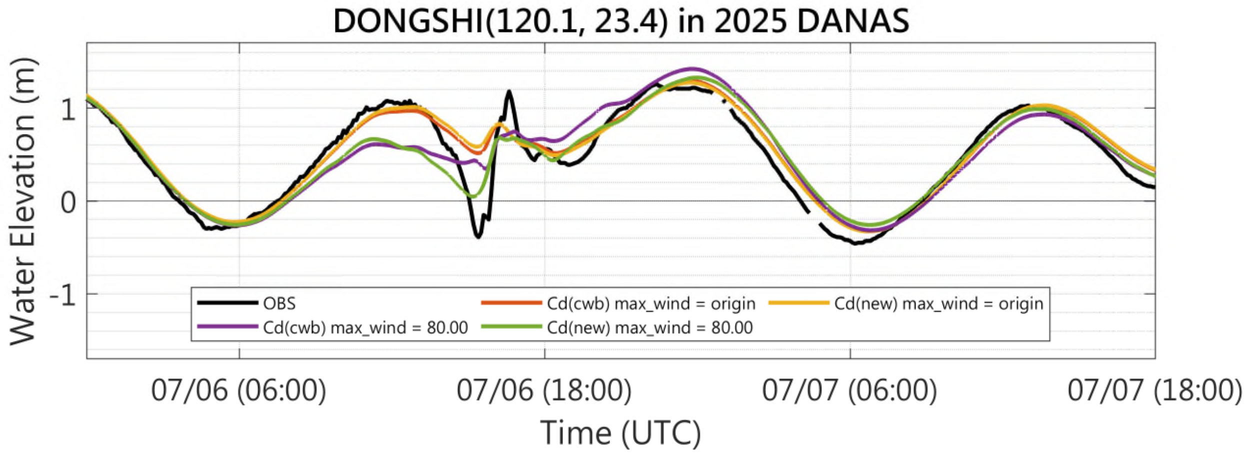
A parabolic model of drag coefficient for storm surge simulation in the South China Sea (Peng and Li, 2015)

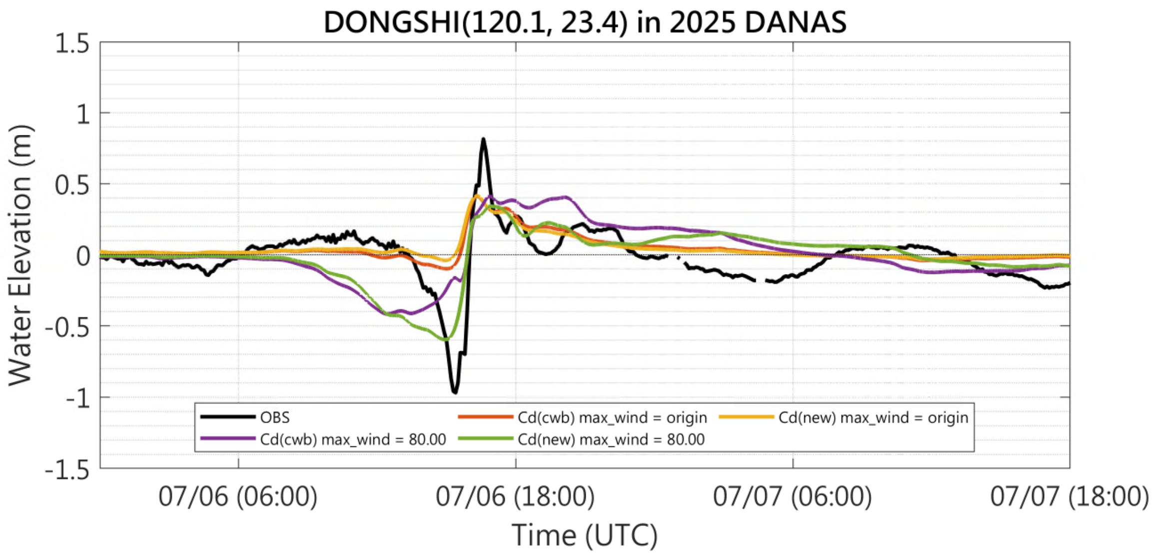


dash line：origin Cd value (Peng and Li, 2015)

solid line：new Cd value (Hersbach, 2011)

Compare


DONGSHI(120.1, 23.4) in 2025 DANAS
Water Elevation (m)
Time (UTC)
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
OBS
Cd(cwb) max_wind = origin
Cd(new) max_wind = origin
Cd(cwb) max_wind = 80.00
Cd(new) max_wind = 80.00


DONGSHI(120.1, 23.4) in 2025 DANAS
Water Elevation (m)
Time (UTC)
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
OBS
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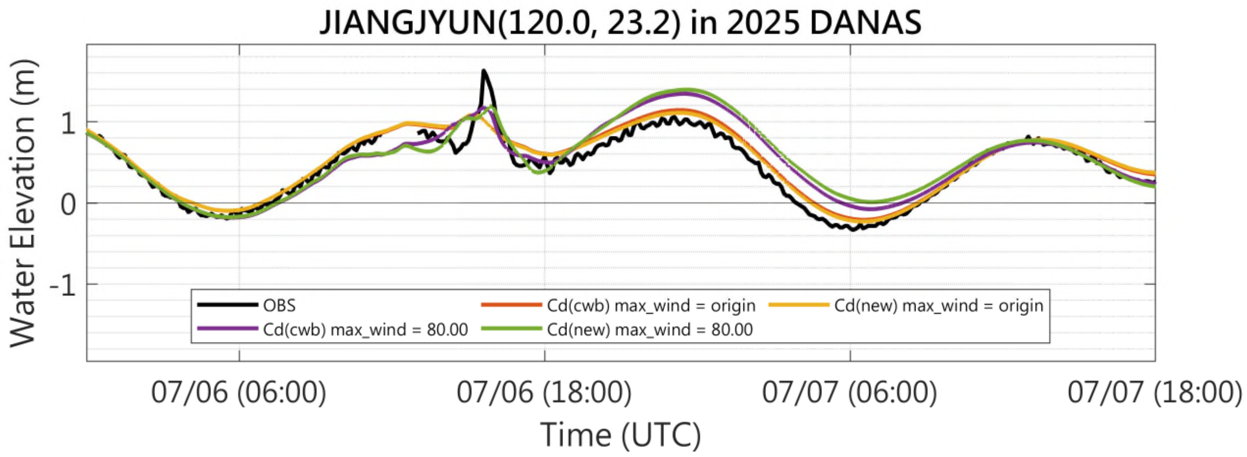
Cd(new) max_wind = 80.00


JIANGJYUN(120.0, 23.2) in 2025 DANAS
Water Elevation (m)
Time (UTC)
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
OBS
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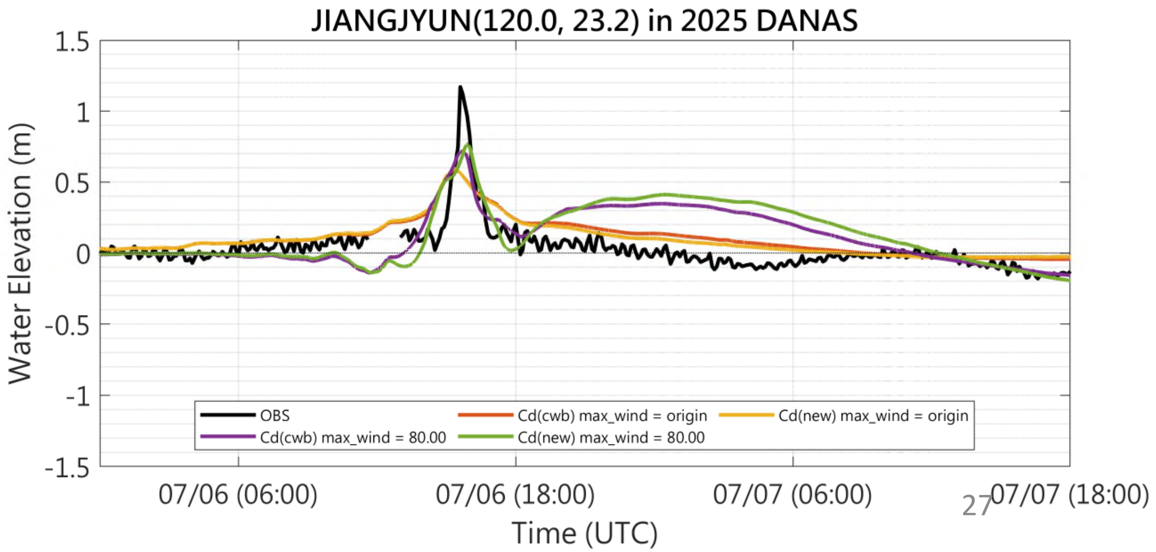
Cd(cwb) max_wind = 80.00
Cd(new) max_wind = 80.00


JIANGJYUN(120.0, 23.2) in 2025 DANAS
Water Elevation (m)
Time (UTC)
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
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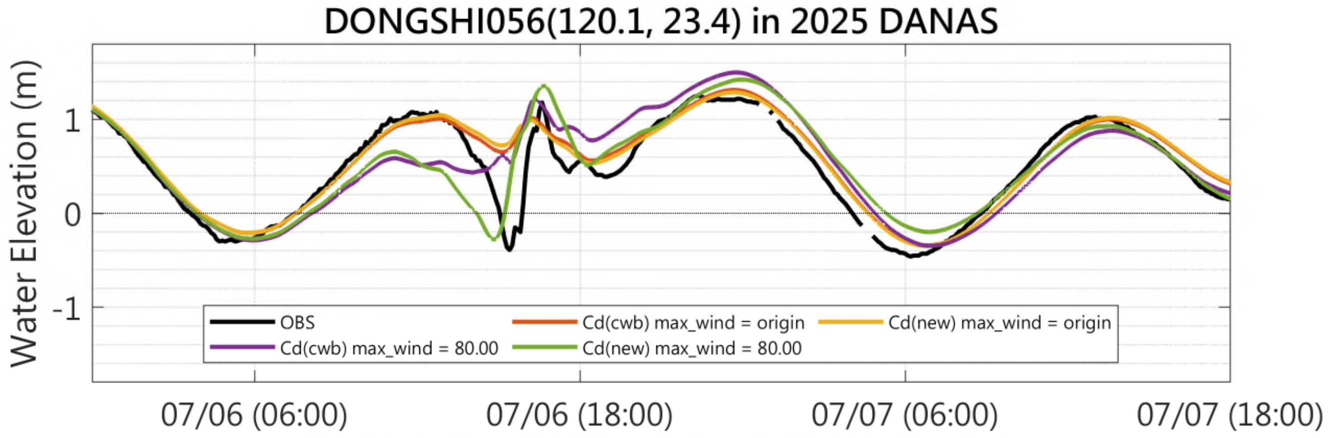
Cd(new) max_wind = 80.00


DONGSHI056(120.1, 23.4) in 2025 DANAS
Water Elevation (m)
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0
-1
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
OBS
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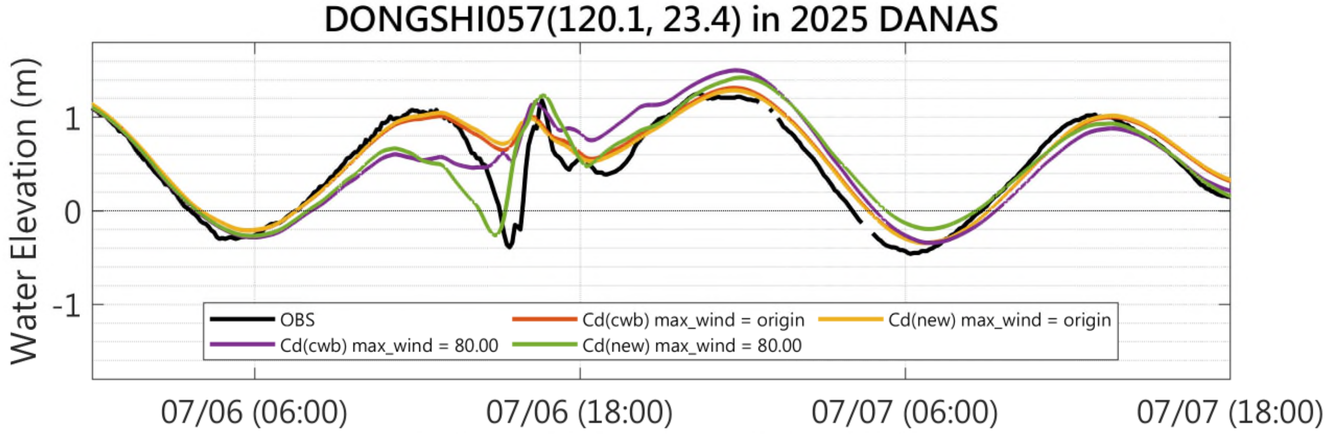
Cd(new) max_wind = 80.00


DONGSHI057(120.1, 23.4) in 2025 DANAS
Water Elevation (m)
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0
-1
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
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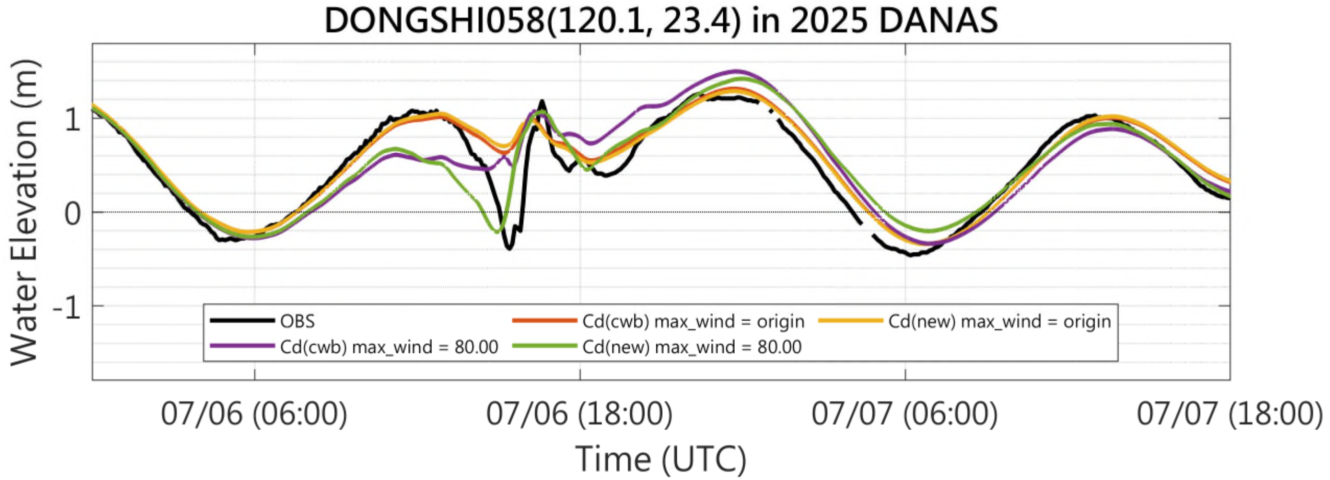
Cd(new) max_wind = 80.00


DONGSHI058(120.1, 23.4) in 2025 DANAS
Water Elevation (m)
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0
-1
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
Time (UTC)
OBS
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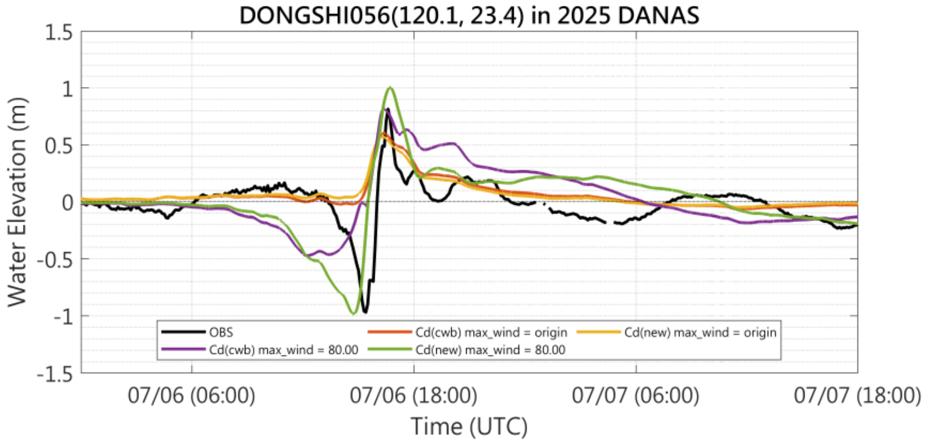
Cd(new) max_wind = origin
Cd(cwb) max_wind = 80.00
Cd(new) max_wind = 80.00


DONGSHI056(120.1, 23.4) in 2025 DANAS
Water Elevation (m)
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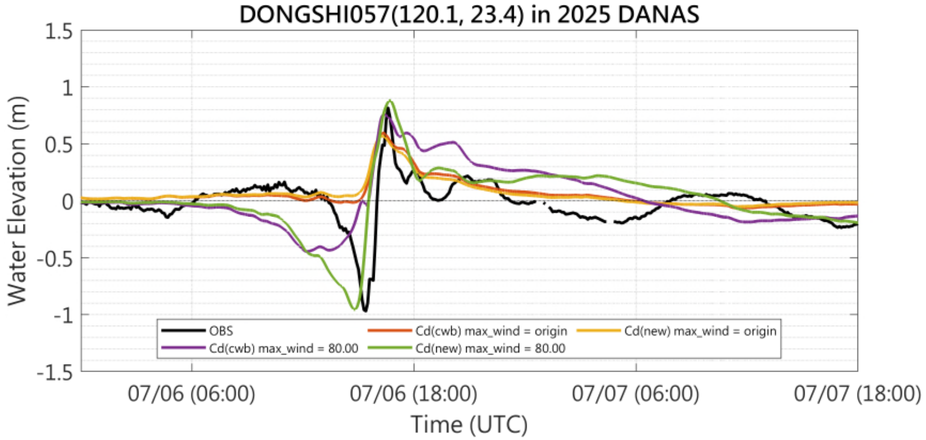
1
0.5
0
-0.5
-1
-1.5
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
Time (UTC)
OBS
Cd(cwb) max_wind = origin
Cd(new) max_wind = origin
Cd(cwb) max_wind = 80.00
Cd(new) max_wind = 80.00


DONGSHI057(120.1, 23.4) in 2025 DANAS
Water Elevation (m)
1.5
1
0.5
0
-0.5
-1
-1.5
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
Time (UTC)
OBS
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Cd(cwb) max_wind = 80.00
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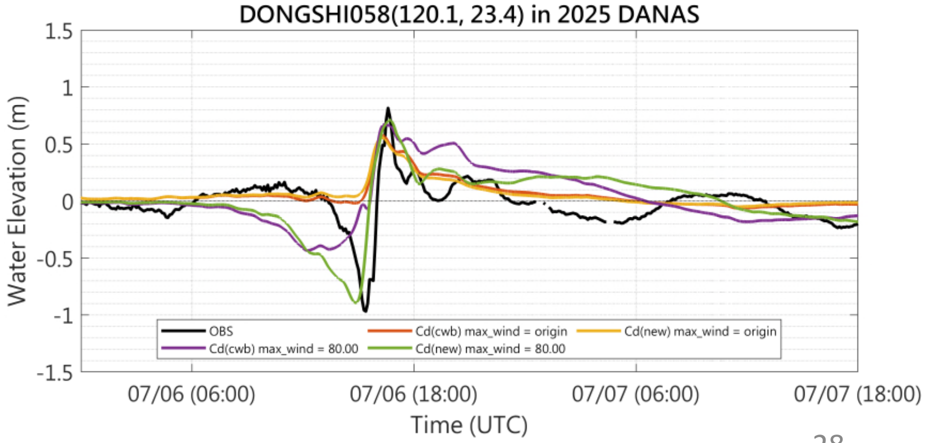
DONGSHI058(120.1, 23.4) in 2025 DANAS
Water Elevation (m)
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0.5
0
-0.5
-1
-1.5
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
Time (UTC)
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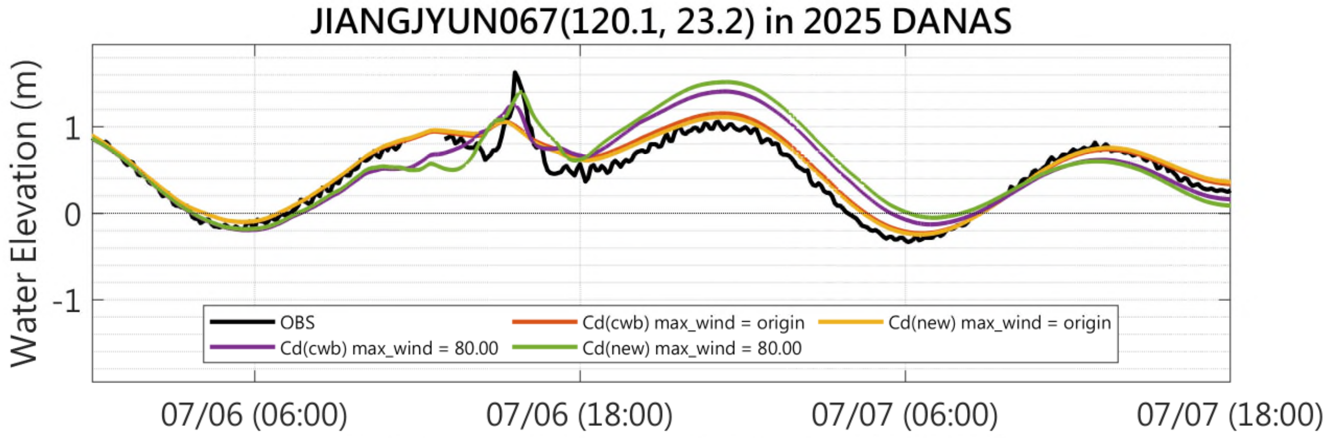
JIANGJYUN067(120.1, 23.2) in 2025 DANAS
Water Elevation (m)
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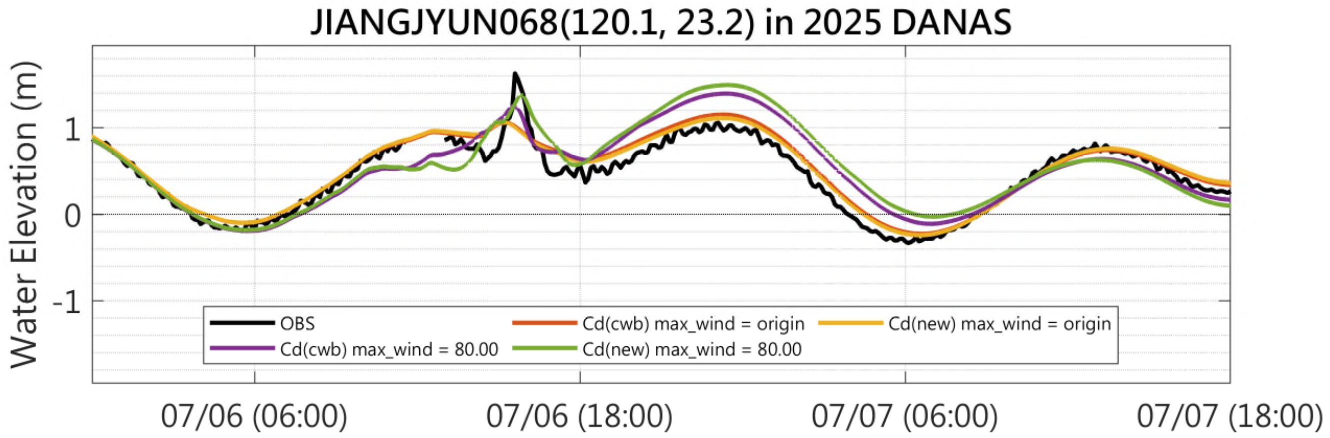
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)


JIANGJYUN068(120.1, 23.2) in 2025 DANAS
Water Elevation (m)
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-1
OBS
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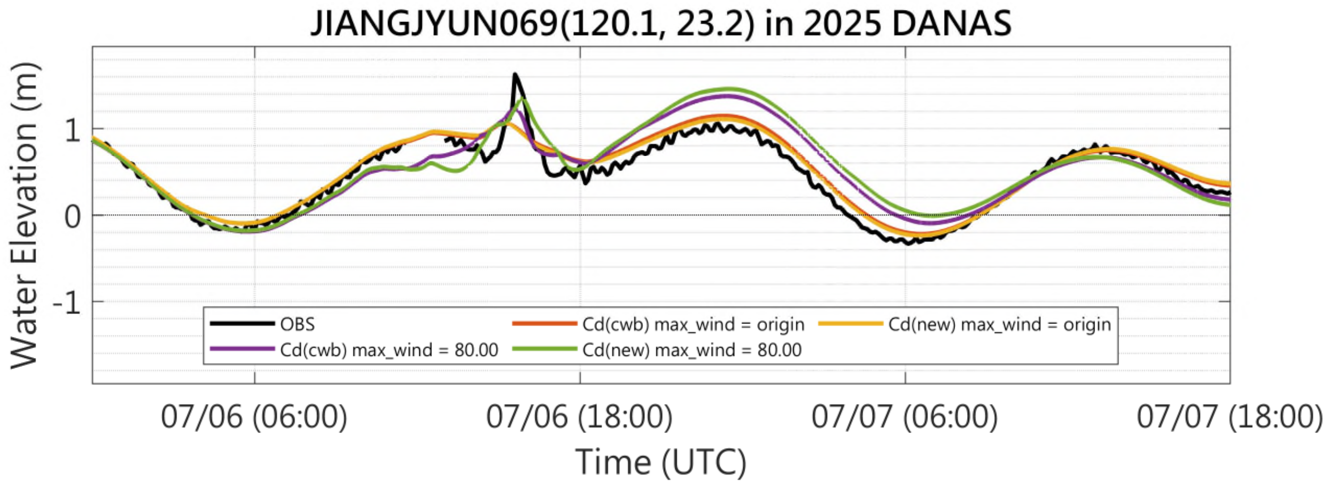
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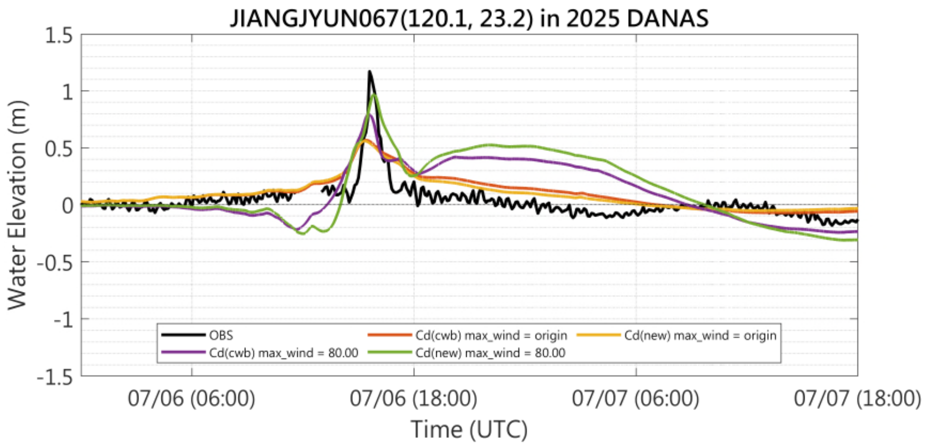
Time (UTC)


JIANGJYUN067(120.1, 23.2) in 2025 DANAS
Water Elevation (m)
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0
-0.5
-1
-1.5
OBS
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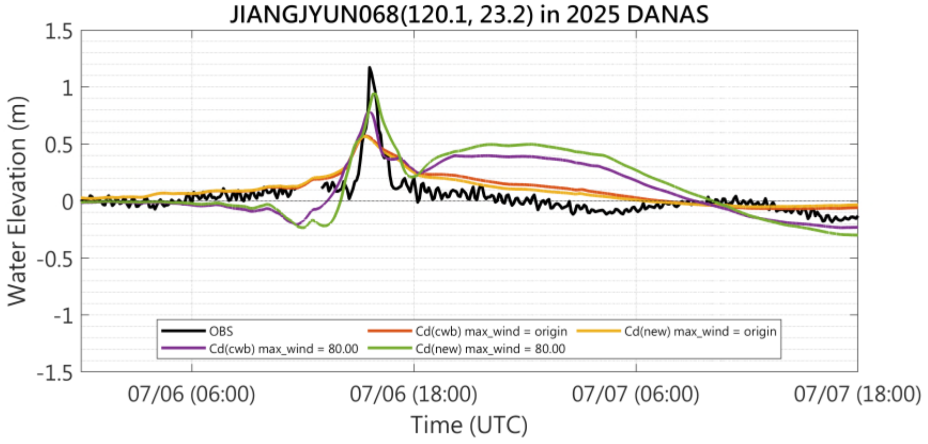
07/07 (18:00)
Time (UTC)


JIANGJYUN068(120.1, 23.2) in 2025 DANAS
Water Elevation (m)
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0
-0.5
-1
-1.5
OBS
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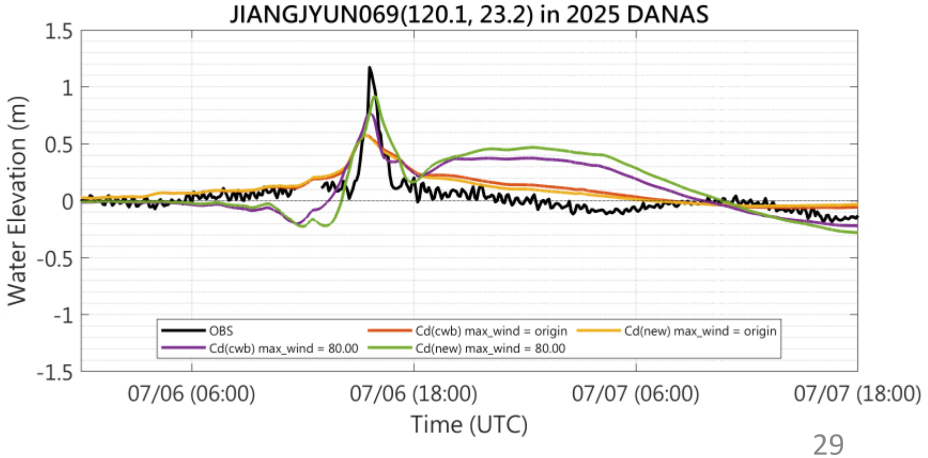
Time (UTC)


JIANGJYUN069(120.1, 23.2) in 2025 DANAS
Water Elevation (m)
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0
-0.5
-1
-1.5
OBS
Cd(cwb) max_wind = 80.00
Cd(cwb) max_wind = origin
Cd(new) max_wind = 80.00
Cd(new) max_wind = origin
07/06 (06:00)
07/06 (18:00)
07/07 (06:00)
07/07 (18:00)
Time (UTC)

Conclusion

地形解析度提升：提升地形解析度後，storm tide 結果呈現較細微的波動，但對潮位變化並無顯著影響。
固定暴風半徑與理想風場公式：固定最大風速半徑並採用新的理想風場公式後，模擬水位趨勢更接近觀測資料。
風速調整的影響：增加最大風速後，在東石站與將軍站的 storm tide 精準度略有提升，但最大風速的變動對暴潮訊號影響有限。
點位的調整:測站的調整，對暴潮的極值亦有影響。
Cd 參數調整：調整 Cd 後，可以明顯觀察到風速變化對整體水位提升的效果。

Thanks for your attention

Central Weather Administration