103年度天氣分析與預報研討會

風暴潮速算模式之開發暨
1845年雲林口湖風暴潮事件之初步研究

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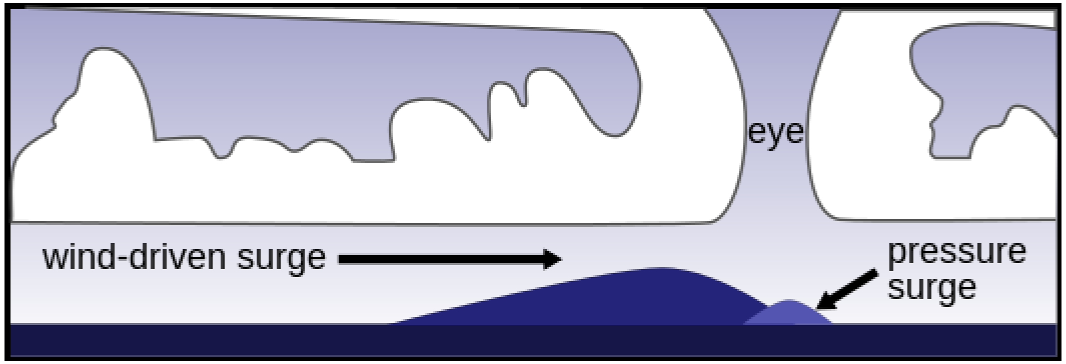
- 2005年8月，卡崔娜颶風在美國佛羅里達州登陸，整個密西西比州的死亡人數至少為218人，紐奧良市甚至出現了無政府狀態的混亂局面。
- 2013年11月，海燕颱風 (Typhoon Haiyan)，為西北太平洋最三強烈之颱風，據沿海居民表示至少有5公尺之風暴潮潮高，官方確認超過6萬人喪生。

海燕颱風－如同海嘯一般重創菲律賓


紐奧良被海水淹沒 (wiki)

什麼是風暴潮 (Storm Surge)？

受颱風壓力梯度和風剪力作用，致使海平面上升，造成沿海地區溢淹和海水倒灌等災害，泛稱為風暴潮。凡颱風盛行區域均受其害，在中國大陸沿岸、台灣、歐洲北海、美國東海岸和西北太平洋等地區影響甚深。



Wiki

海水倒灌 – 台灣彰化

1845年雲林口湖-萬善同歸

The Development of Storm Surge Model

- Wu (1984) established a model from the Taiwan Strait to southeast of China, but the domain was limited to the continental shelf of China.
- Jelesnianski et al. (1992) established a storm surge model named **SLOSH** (Sea, Lake, and Overland Surges from Hurricanes) for NOAA, which adopts the moving boundary scheme to evaluate surge inundation in Cartesian and polar coordinates.
- Flater (1994) developed a geographical storm surge prediction model, **CS3**, based on depth-averaged equations for the Northern Bay of Bengal and applied it to the 1991 event.
- Westerink et al. (2008) used a depth-integrated storm surge model with unstructured grid, **ADCIRC** (ADvanced CIRCulation), and applied in Southern Louisiana.
- Sheng et al. (2010) developed a three-dimensional model, **CH3D-SSMS**, coupled with the wave model to study effects of waves on storm surge, currents, and inundation in the Outer Banks and Chesapeake Bay during Hurricane Isabel in 2003.
- Phadke et al. (2003) used the **WAM** model to simulate the wave height caused by Hurricane Iniki without surge inundation.
- Weisberg and Zheng (2006) used three-dimensional model named **FVCOM** (Finite-volume coastal ocean model) to simulate the storm surge for Tampa Bay.
- Ou et al. (2008) used the **POM** (Princeton Ocean Model) with finite element depth-averaged model to predict the surge height in Taiwan.

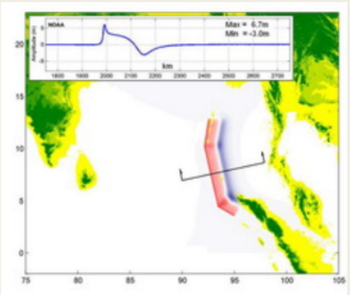
A good storm surge model requires:

- A spherical coordinate system with a large computational domain.
- Calculating inundation area with high-resolution topographic data.
- High-speed efficiency for the warning system.
- Widely validated and open source.

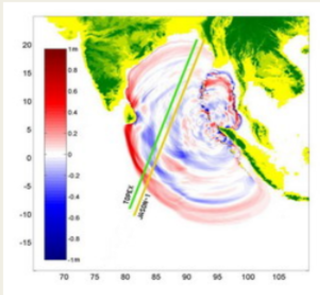
Introduction of COMCOT

(Cornell Multi-grid Coupled of Tsunami Model)

COMCOT: A Tsunami Modeling Package



Tsunami Generation



Tsunami Propagation

COMCOT (Cornell Multi-grid Coupled Tsunami Model) is a tsunami modeling package, capable of simulating the entire lifespan of a tsunami, from its generation, propagation and runup/rundown in coastal regions.

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

• Governing Equations

COMCOT was developed based on Shallow Water Equations (SWE) in Spherical Coordinates (*Eq.01*) and Cartesian Coordinates (*Eq.02*). In the equations, ζ denotes free surface elevation; P and Q are volume flux in x and y direction ($P=hu$, $Q=hv$); φ and ψ stand for longitude and latitude, respectively.

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

$$\frac{\partial P}{\partial t} + \frac{gh}{R\cos\varphi}\frac{\partial \zeta}{\partial \psi} - fQ = 0$$

$$\frac{\partial Q}{\partial t} + \frac{gh}{R}\frac{\partial \zeta}{\partial \varphi} + fP = 0$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0$$

$$\frac{\partial P}{\partial t} + \frac{\partial}{\partial x}\left(\frac{P^2}{H}\right) + \frac{\partial}{\partial y}\left(\frac{PQ}{H}\right) + gH\frac{\partial \zeta}{\partial x} + \frac{\tau_x H}{\rho} = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{PQ}{H}\right) + \frac{\partial}{\partial y}\left(\frac{Q^2}{H}\right) + gH\frac{\partial \zeta}{\partial y} + \frac{\tau_y H}{\rho} = 0$$

Eq.01 SWE in Spherical Coord. *Eq.02 SWE in Cartesian Coord.*

• 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.

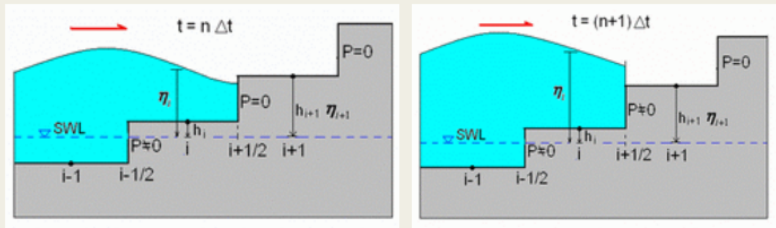


Fig.02 Moving Boundary Scheme

(2). COMCOT has been used on many scientific papers

At least 26 SCI papers were published during 2001~2011

(Including Science)

1. Title: Long waves through emergent coastal vegetation
Author(s): Mei Chiang C.; Chan I-Chi; Liu Philip L. -F.; et al.
Source: JOURNAL OF FLUID MECHANICS Volume: 687 Pages: 461-491 DOI: 10.1017/jfm.2011.373 Published: NOV 2011

2. Title: Insights on the 2009 South Pacific tsunami in Samoa and Tonga from field surveys and numerical simulations
Author(s): Fritz Hermann M.; Borrero Jose C.; Synolakis Costas E.; et al.
Source: EARTH-SCIENCE REVIEWS Volume: 107 Issue: 1-2 Special Issue: SI Pages: 66-75 DOI: 10.1016/j.earscirev.2011.03.004 Published: JUL 2011

3. Title: Solid landslide generated waves
Author(s): Wang Yang; Liu Philip L. -F.; Mei Chiang C.
Source: JOURNAL OF FLUID MECHANICS Volume: 675 Pages: 529-539 DOI: 10.1017/S0022112011000681 Published: MAY 2011

4. Title: An explicit finite difference model for simulating weakly nonlinear and weakly dispersive waves over slowly varying water depth
Author(s): Wang Xiaoming; Liu Philip L-F
Source: COASTAL ENGINEERING Volume: 58 Issue: 2 Pages: 173-183 DOI: 10.1016/j.coastaleng.2010.09.008 Published: FEB 2011

5. Title: Field Survey of the Samoa Tsunami of 29 September 2009
Author(s): Okal Emile A.; Fritz Hermann M.; Synolakis Costas E.; et al.
Source: SEISMOLOGICAL RESEARCH LETTERS Volume: 81 Issue: 4 Pages: 577-591 DOI: 10.1785/gssrl.81.4.577 Published: JUL-AUG 2010

6. Title: Impact of a 1755-like tsunami in Huelva, Spain
Author(s): Lima V. V.; Miranda J. M.; Baptista M. A.; et al.
Source: NATURAL HAZARDS AND EARTH SYSTEM SCIENCES Volume: 10 Issue: 1 Pages: 139-148 Published: 2010

7. Title: An insitu borescopic quantitative imaging profiler for the measurement of high concentration sediment velocity
Author(s): Cowen Edwin A.; Dudley Russell D.; Liao Qian; et al.
Source: EXPERIMENTS IN FLUIDS Volume: 49 Issue: 1 Special Issue: SI Pages: 77-88 DOI: 10.1007/s00348-009-0801-8 Published: JUL 2010

8. Title: Tsunami hazard from the subduction megathrust of the South China Sea: Part I. Source characterization and the resulting tsunami
Author(s): Megawati Kusnowidjaja; Shaw Felicia; Sieh Kerry; et al.
Source: JOURNAL OF ASIAN EARTH SCIENCES Volume: 36 Issue: 1 Pages: 13-20 DOI: 10.1016/j.jseaes.2008.11.012 Published: SEP 4 2009

9. Title: Simulation of Andaman 2004 tsunami for assessing impact on Malaysia
Author(s): Koh Hock Lye; Teh Su Yean; Liu Philip Li-Fan; et al.
Source: JOURNAL OF ASIAN EARTH SCIENCES Volume: 36 Issue: 1 Pages: 74-83 DOI: 10.1016/j.jseaes.2008.09.008 Published: SEP 4 2009
Times Cited: 0 (from Web of Science)

10. Title: Modeling tsunami hazards from Manila trench to Taiwan
Author(s): Wu Tso-Ren; Huang Hui-Chuan
Source: JOURNAL OF ASIAN EARTH SCIENCES Volume: 36 Issue: 1 Pages: 21-28 DOI: 10.1016/j.jseaes.2008.12.006 Published: SEP 4 2009
Times Cited: 0 (from Web of Science)

11. Title: Tsunami hazard and early warning system in South China Sea
Author(s): Liu Philip L. -F.; Wang Xiaoming; Salisbury Andrew J.
Source: JOURNAL OF ASIAN EARTH SCIENCES Volume: 36 Issue: 1 Pages: 2-12 DOI: 10.1016/j.jseaes.2008.12.010 Published: SEP 4 2009

（To be continued）

12. Title: Analytical and numerical simulation of tsunami mitigation by mangroves in Penang, Malaysia
Author(s): Teh Su Yean; Koh Hock Lye; Liu Philip Li-Fan; et al.
Source: JOURNAL OF ASIAN EARTH SCIENCES Volume: 36 Issue: 1 Pages: 38-46 DOI: 10.1016/j.jseaes.2008.09.007 Published: SEP 4 2009

13. Title: Simulation of Andaman 2004 tsunami for assessing impact on Malaysia
Author(s): Koh Hock Lye; Teh Su Yean; Liu Philip Li-Fan; et al.
Source: JOURNAL OF ASIAN EARTH SCIENCES Volume: 36 Issue: 1 Pages: 74-83 DOI: 10.1016/j.jseaes.2008.09.008 Published: SEP 4 2009

14. Title: SPECIAL ISSUE Tsunamis in Asia Preface
Author(s): Liu Philip L. -F.; Huang Bor-Shouh
Source: JOURNAL OF ASIAN EARTH SCIENCES Volume: 36 Issue: 1 Pages: 1-1 DOI: 10.1016/j.jseaes.2009.05.001 Published: SEP 4 2009

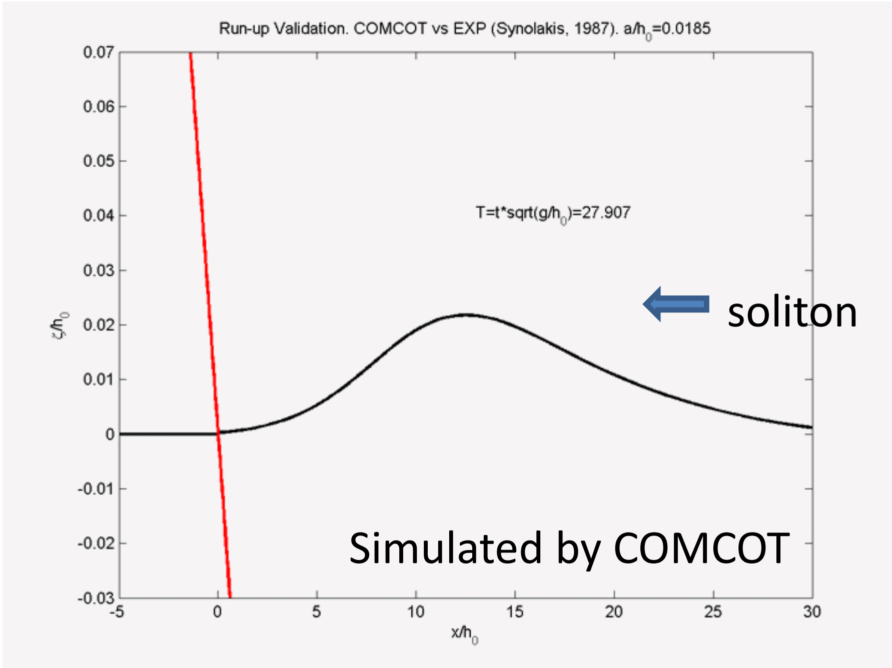
15. Title: INDIAN OCEAN TSUNAMI ON 26 DECEMBER 2004: NUMERICAL MODELING OF INUNDATION IN THREE CITIES ON THE SOUTH COAST OF SRI LANKA
Author(s): Wijetunge J. J.; Wang Xiaoming; Liu Philip L. -F.
Source: JOURNAL OF EARTHQUAKE AND TSUNAMI Volume: 2 Issue: 2 Pages: 133-155 Published: JUN 2008

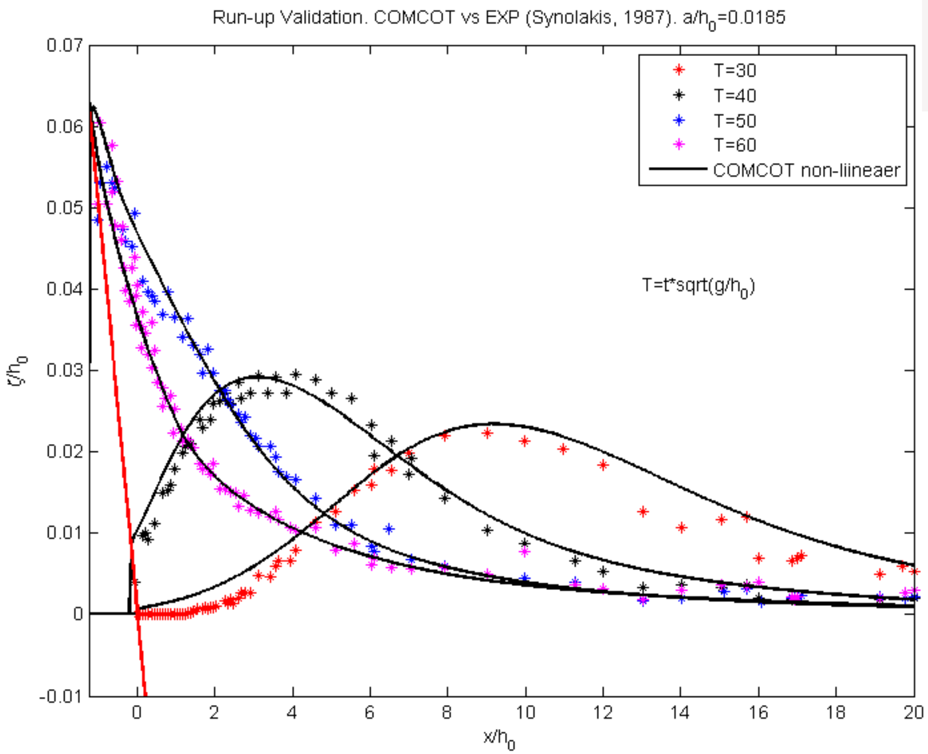
16. Title: TSUNAMI SOURCE REGION PARAMETER IDENTIFICATION AND TSUNAMI FORECASTING
Author(s): Liu Philip L. -F.; Wang Xiaoming
Source: JOURNAL OF EARTHQUAKE AND TSUNAMI Volume: 2 Issue: 2 Pages: 87-106 Published: JUN 2008

17. Title: Bottom friction and its effects on periodic long wave propagation
Author(s): Orfila A.; Simarro G.; Liu P. L. F.
Source: COASTAL ENGINEERING Volume: 54 Issue: 11 Pages: 856-864 DOI: 10.1016/j.coastalene.2007.05.013 Published: NOV 2007

(3). COMCOT has been widely validated:

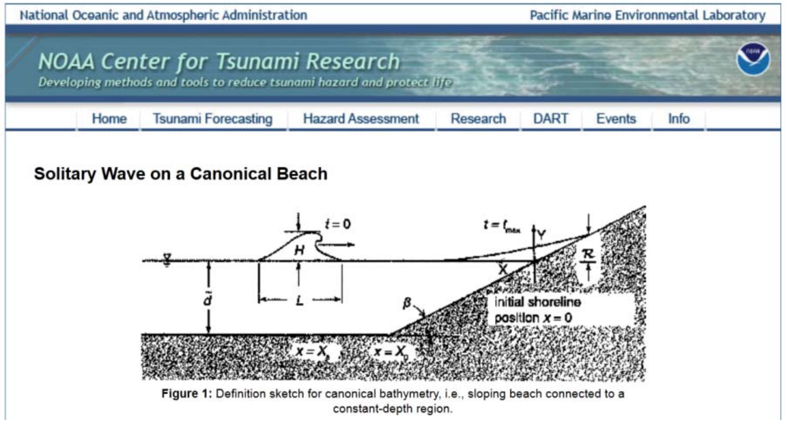
Synolakis solitary wave runup (1986, 1987).





(Wu, 2012)

Figure 2: Time evolution of H = 0.0185 initial wave over a sloping beach with $\cot\beta = 19.85$ from $t = 25$ to 65 with 10 increments. Constant depth-segment starts at $X_0 = 19.85$. While markers show experimental results of Synolakis (1986, 1987), solid lines show nonlinear analytical solution of Synolakis (1986, 1987) Experimental data is provided from $t = 30$ to 70 with 10 increments.



(NOAA)

Transfer COMCOT into a Storm Surge Model

Pressure gradient and wind shear stress were added to the shallow water equation.

Governing Equations in Spherical Coordinate

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

Wind shear stress

$$F^s = \rho_a C_d \left|\overrightarrow{V_w}\right| \overrightarrow{V_w}$$

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

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

Pressure gradient

η : free surface elevation

h : still water depth

R: earth radius

ψ, φ : longitude and latitude of the earth

P, Q : volume fluxes in longitude and latitude

Pa : atmospheric pressure

f : Coriolis parameter

ρ : density of water

F_ψ^s, F_φ^s : surface wind shear stress

C_d : Drag coefficient

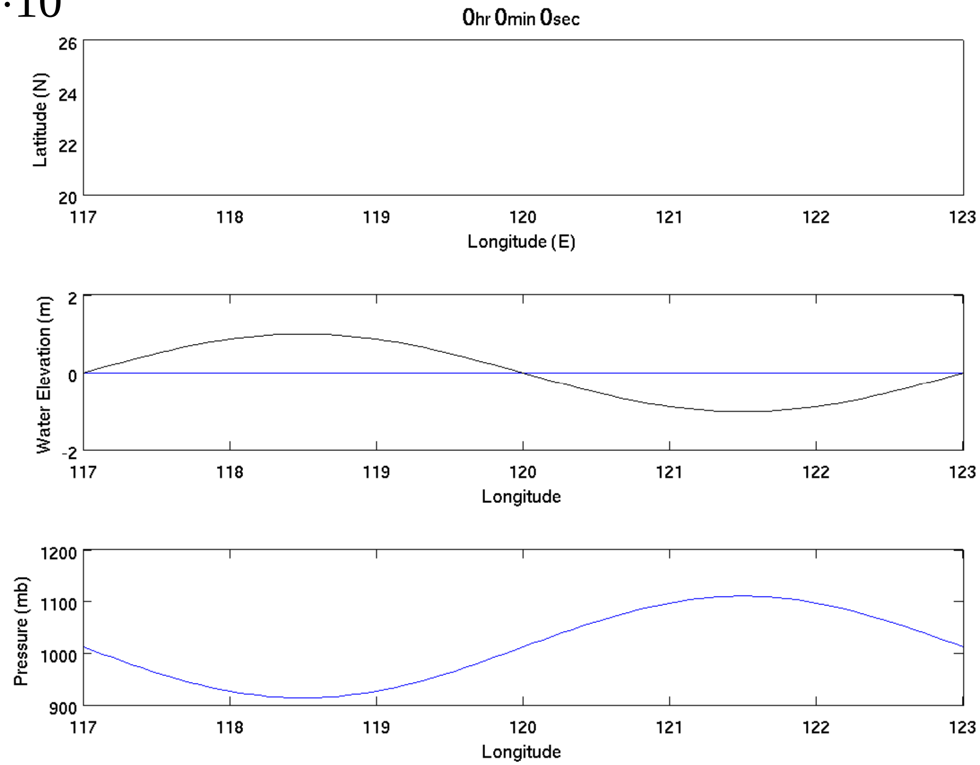
Validation with Pressure Gradient

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

$$\frac{\partial P}{\partial t}+\frac{gH}{R\cos\varphi}\frac{\partial\eta}{\partial\psi}=-\frac{H}{\rho_w R\cos\psi}\frac{\partial P_a}{\partial\psi}$$

$$P_a=-9800\cdot\sin\left[\frac{2\cdot\pi(\psi-\psi_1)}{\psi_2-\psi_1}\right]+1013.25\cdot10^2$$

$$\partial\eta=-\frac{\partial P_a}{g\rho_w}=\sin\left[\frac{2\cdot\pi(\psi-\psi_1)}{\psi_2-\psi_1}\right]$$

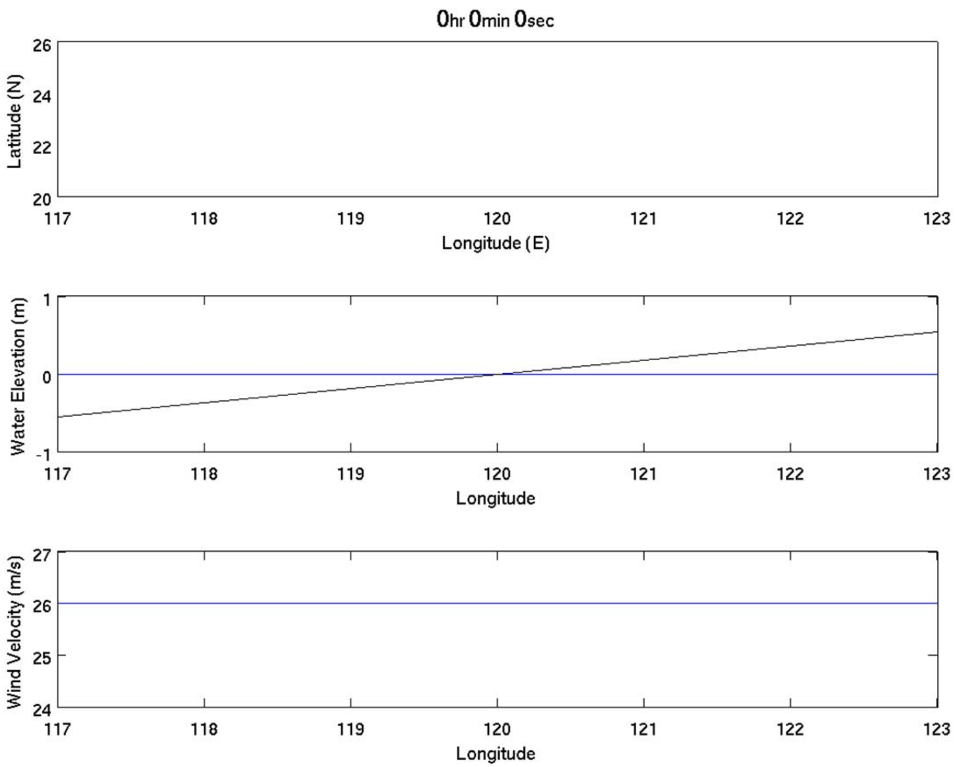


數值預測之水位面持續上下擾動，最終收斂於解析解。初始擾動為數值模擬之正常情況，此代表水面受壓力梯度作用後，漸漸達到穩態（steady state）之情況。

Validation with Wind Shear Stress

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

$$\rightarrow\quad \frac{\partial P}{\partial t}+\frac{gH}{R\cos\varphi}\frac{\partial\eta}{\partial\psi}=\frac{F_\psi^s}{\rho_w}$$



$$\overrightarrow{V_w}=26\,(m/s) \qquad F_\psi^s=\rho_a C_d\left|\overrightarrow{V_w}\right|\overrightarrow{V_w}$$

$$\partial\eta=\rho_a C_d\left|\overrightarrow{V_w}\right|\overrightarrow{V_w}\cdot\frac{R\cdot\cos\varphi\cdot\partial\psi}{\rho_w\cdot gH}$$

$$=1.0992\,(\mathrm{m})$$

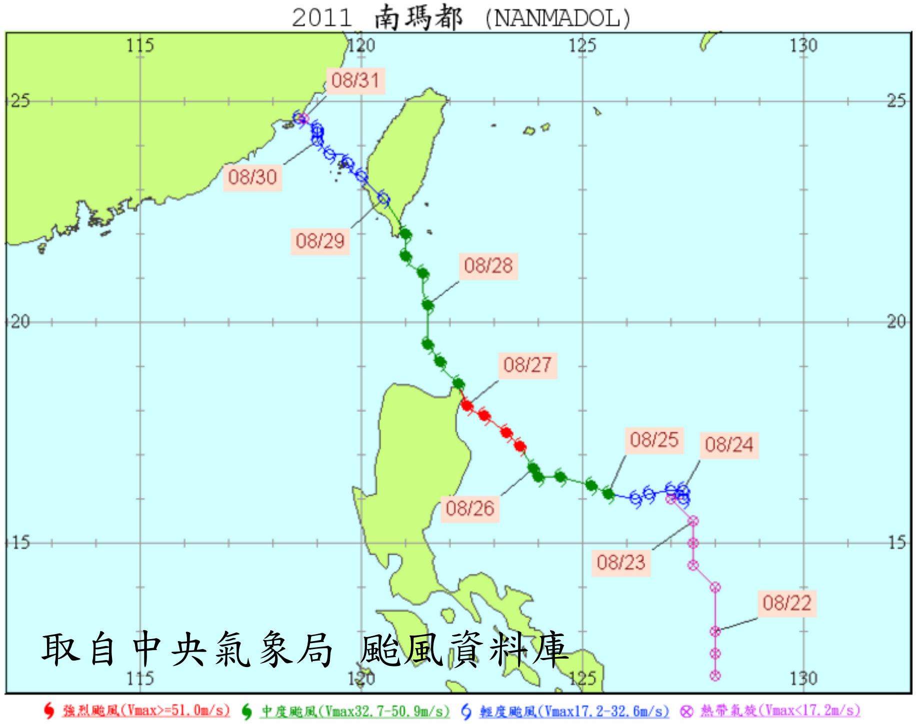
數值預測之水位面持續上下擾動，最終收斂於解析解附近。擾動為數值模擬之正常情況，此代表水面受風剪力作用後，漸漸達到穩態（steady state）之情況。

Case Study of 2011 Typhoon Nanmadol

- 南瑪都 (Nanmadol)颱風，國際颱風編號：1111，生命週期由2011年8月21日至2011年8月31日，為一強烈颱風，第4類侵臺路徑，颱風中心於29日4時20分左右由臺東縣大武附近登陸，13時左右在臺南附近出海，進入臺灣海峽，緩慢向西北移動，31日8時於臺灣海峽減弱為熱帶性低氣壓。

- 南瑪都颱風影響臺灣期間，造成彰化縣西塭仔漁港海水倒灌，海水溢堤進入附近商店街，水深及膝，沿海居民財產受到損害。

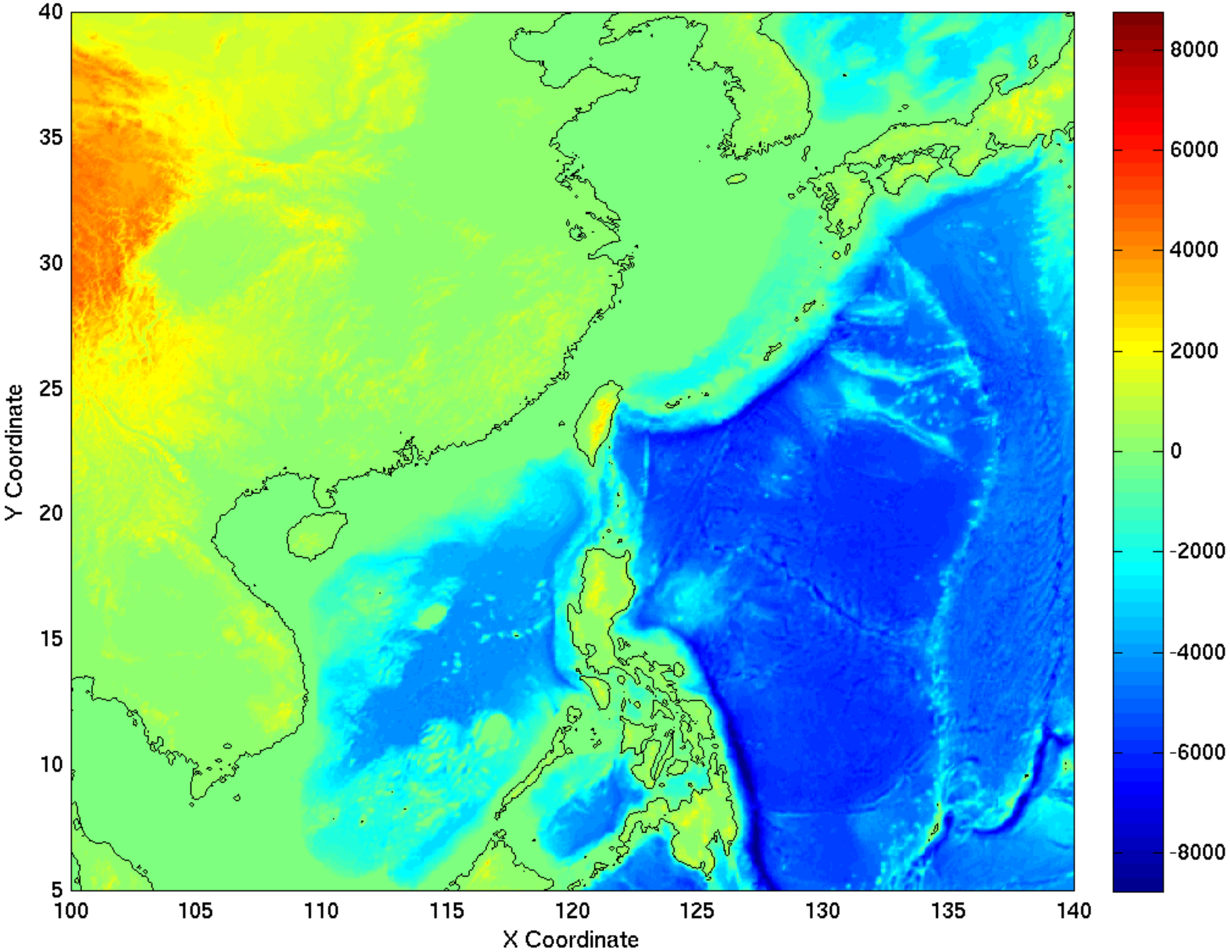
海水倒灌 – 台灣彰化



取自中央氣象局 颱風資料庫

地形與網格設定

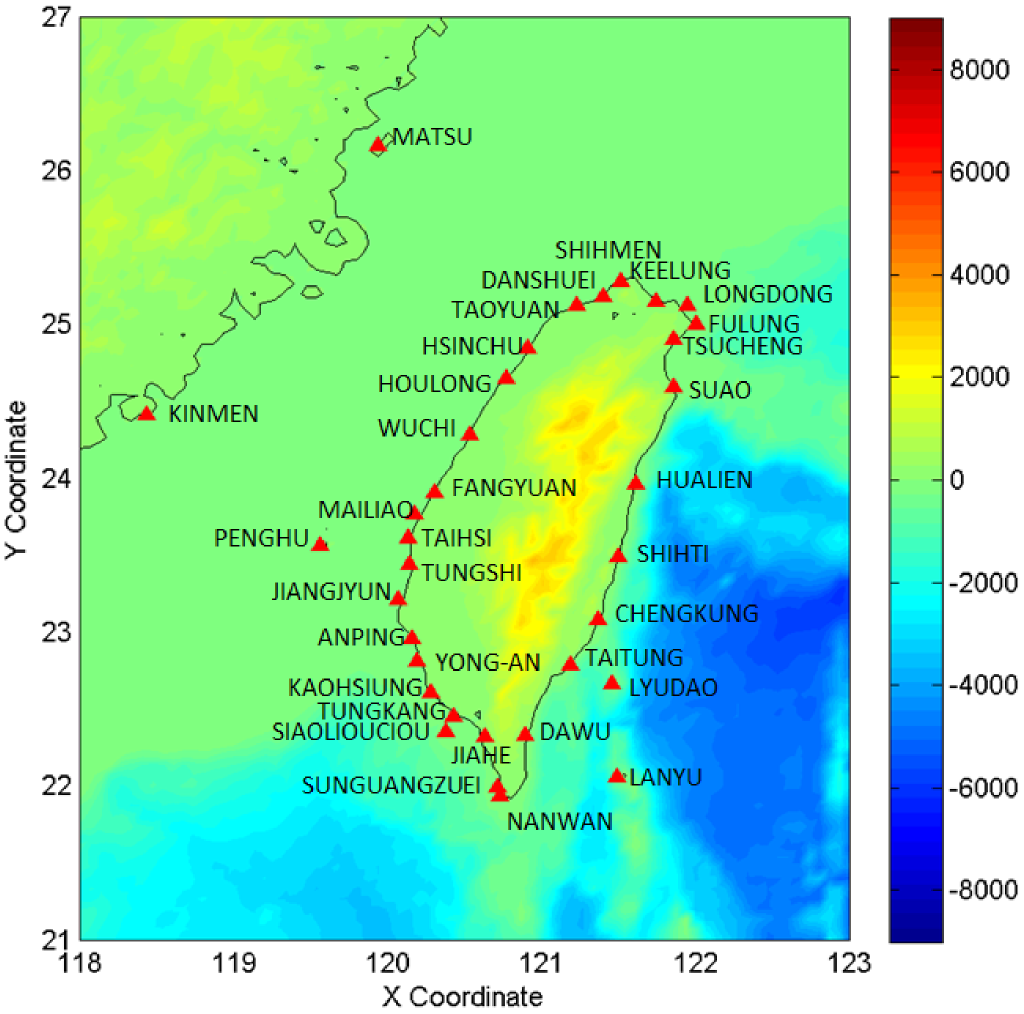
- 為涵蓋颱風完整生命週期，因此選用大範圍之計算域。
- 在此模擬區域中，台灣東部地帶為太平洋海域，水深較深，平均深度約為5000 公尺，西部介於中國大陸與台灣之間的台灣海峽為近岸地區，水深較淺，平均水深約在80 公尺左右。
- 地形資料取自ETOPO4，網格間距為四弧分。



Computational Domain

數值潮位計設置

測站名稱	經度座標	緯度座標
SHIHTI	121.50	23.49
CHENGKUNG	121.37	23.08
TAITUNG	121.19	22.79
DAWU	120.89	22.33
LYUDAO	121.46	22.66
LANYU	121.49	22.06
SHIHMEN	121.51	25.28
DANSHUEI	121.40	25.18
TAOYUAN	121.23	25.12
HSINCHU	120.91	24.85
HOULONG	120.77	24.65
WUCHI	120.53	24.28
FANGYUAN	120.30	23.91
MAILIAO	120.17	23.77
TAIHSI	120.13	23.61
TUNGSHI	120.14	23.44
JIANGJYUN	120.07	23.21
ANPING	120.16	22.96
YONG-AN	120.19	22.81
KAOHSIUNG	120.28	22.61
TUNGKANG	120.43	22.45
JIAHE	120.63	22.32
SUNGUANGZUEI	120.71	21.99
NANWAN	120.73	21.94
SIAOLIOUCIOU	120.38	22.35
PENGHU	119.56	23.56
KINMEN	118.43	24.41
MATSU	119.94	26.16



依照氣象局實際測站於風暴潮模式中加入34個數值潮位計，進行模式校驗。

Parametric Model

Holland Model (1980)

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

$$V_w = \sqrt{\frac{B(P_n - P_c)}{\rho_a}\left(\frac{R_{\max}}{r}\right)^B \exp\left[-\left(\frac{R_{\max}}{r}\right)^B\right] + \frac{r^2 f^2}{4}} - \frac{rf}{2} \qquad B = 2 - \frac{P_c - 900}{160}$$

CWB Model

$$P_a = P_c + (P_n - P_c)\exp[-(\frac{\mathrm{R}_{\max}}{r})^B]$$

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

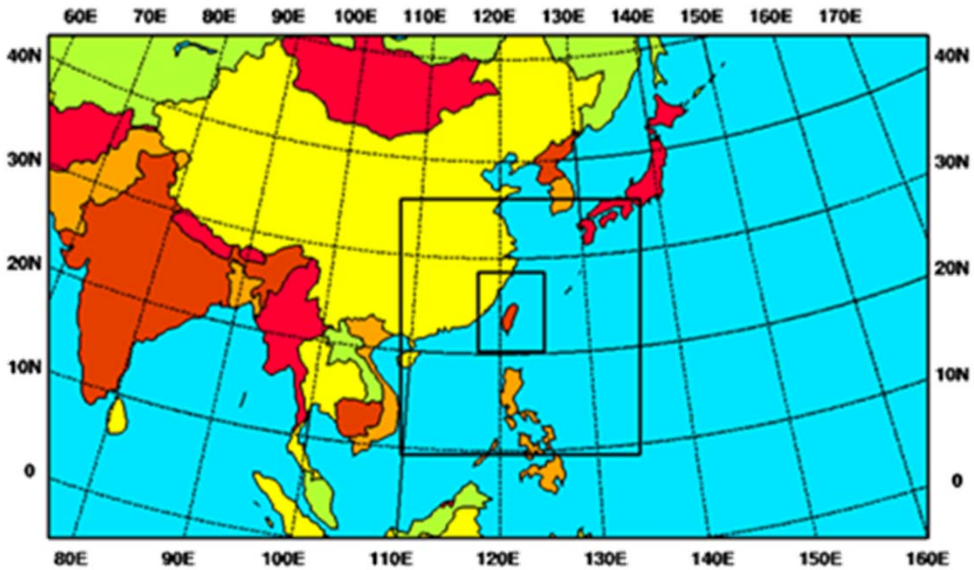
$$B = \frac{1}{P_n - P_c}(\frac{V_{\max}}{5.375})^2$$

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

大氣模式耦合

TWRF（Typhoon Weather Research and Forecasting Model）

- TWRF模式目前為氣象局所使用之大氣模式之一，其投影系統為藍伯特投影 (Lambert)。
- 模式之預報作業每日執行四次，分別為每日之00 UTC 、06 UTC 、12 UTC和18 UTC 。
- 第一層巢狀網格之模式初始場來自美國NCEP GFS的全球預報系統，而第二層和第三層巢狀網格之模式初始場由第一層巢狀網格內插。

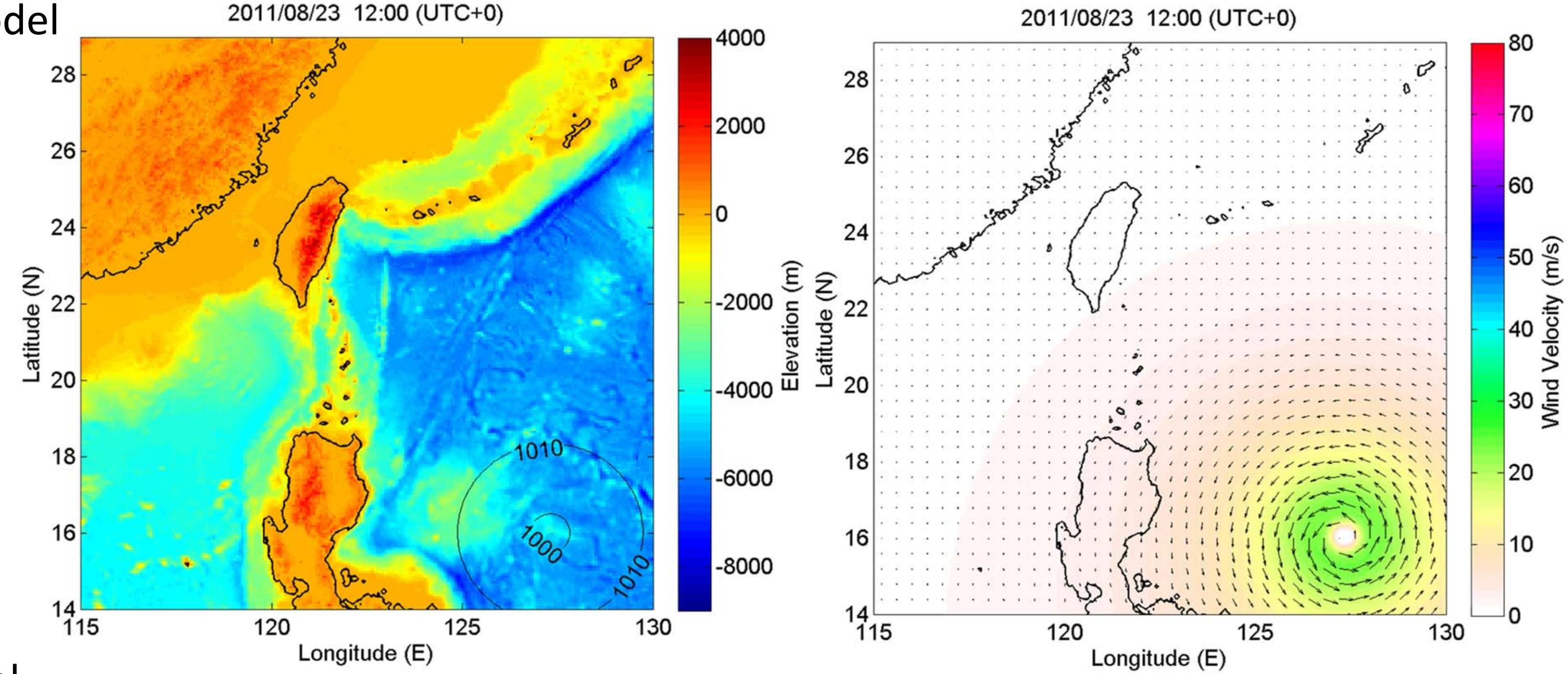


計算域 (CWB)

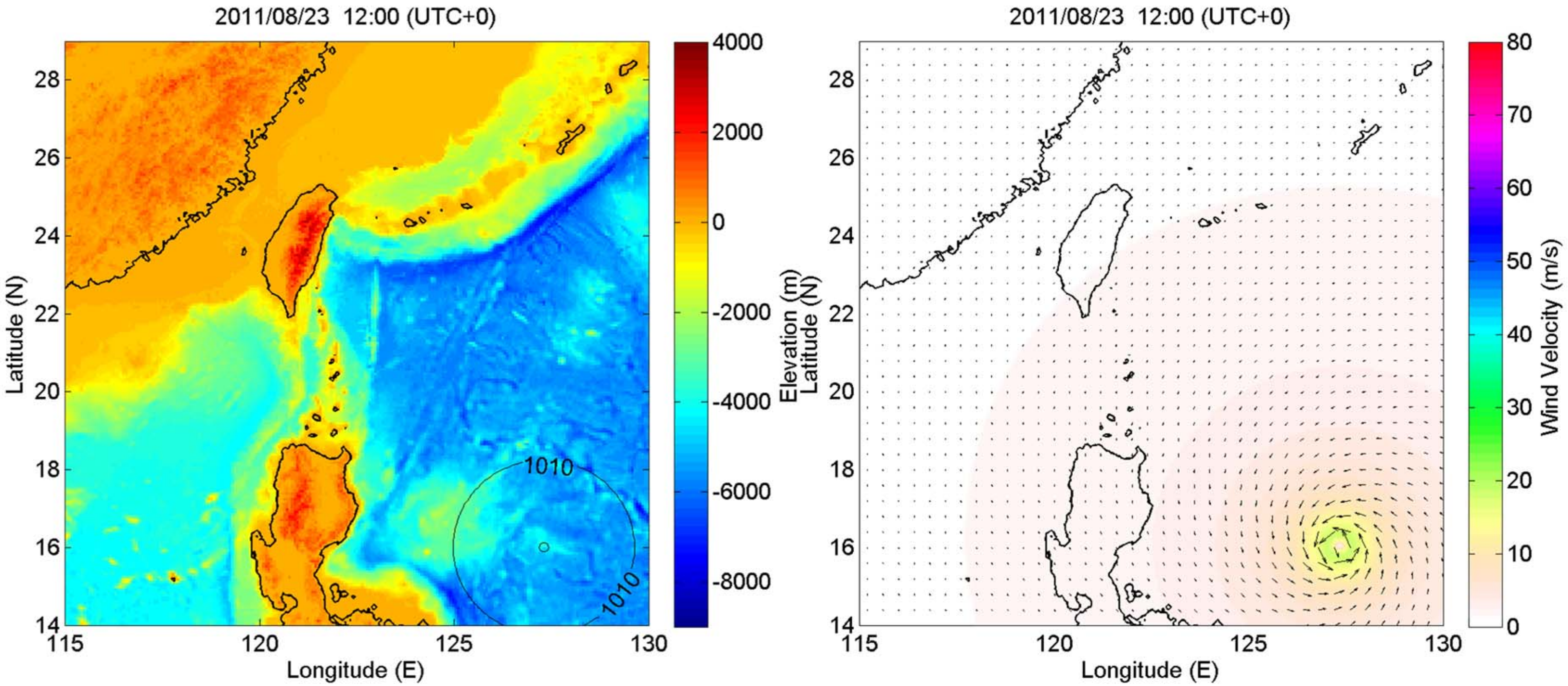
巢狀網格設定 (CWB)

	Domain 1	Domain 2	Domain 3
投影法	Lambert		
網格解析度(km)	45 km	15 km	5 km
X方向格點數	221	181	151
Y方向格點數	127	193	181
中心經度	118.59	122.27	121.07
中心緯度	27.07	22.87	24.28

Holland Model



CWB Model

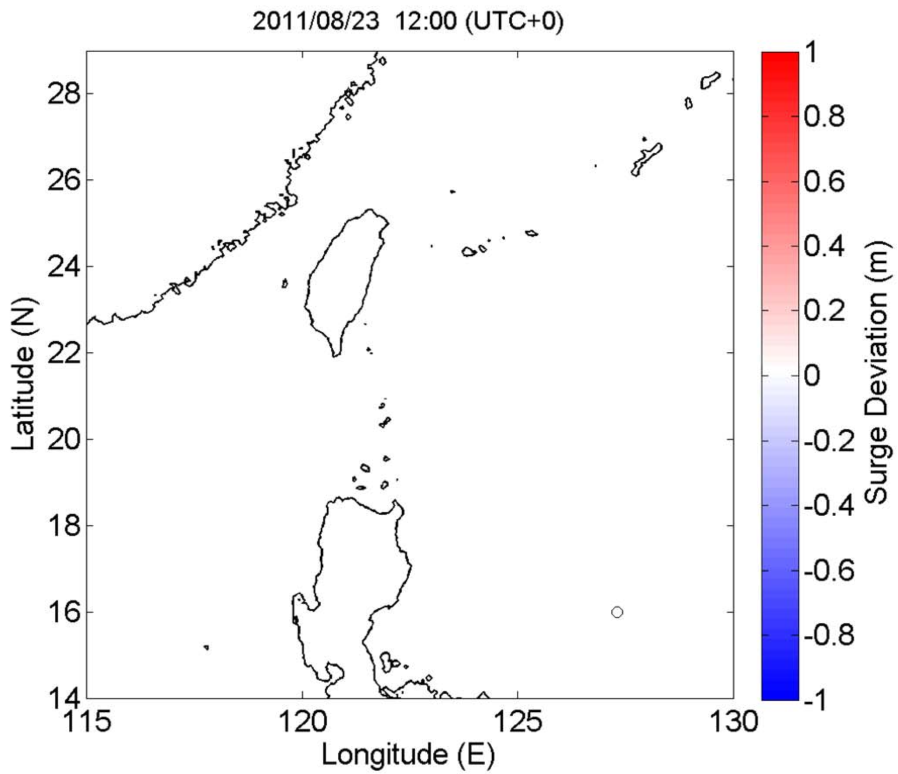


Surge Deviation of 2011 Typhoon Nanmadol

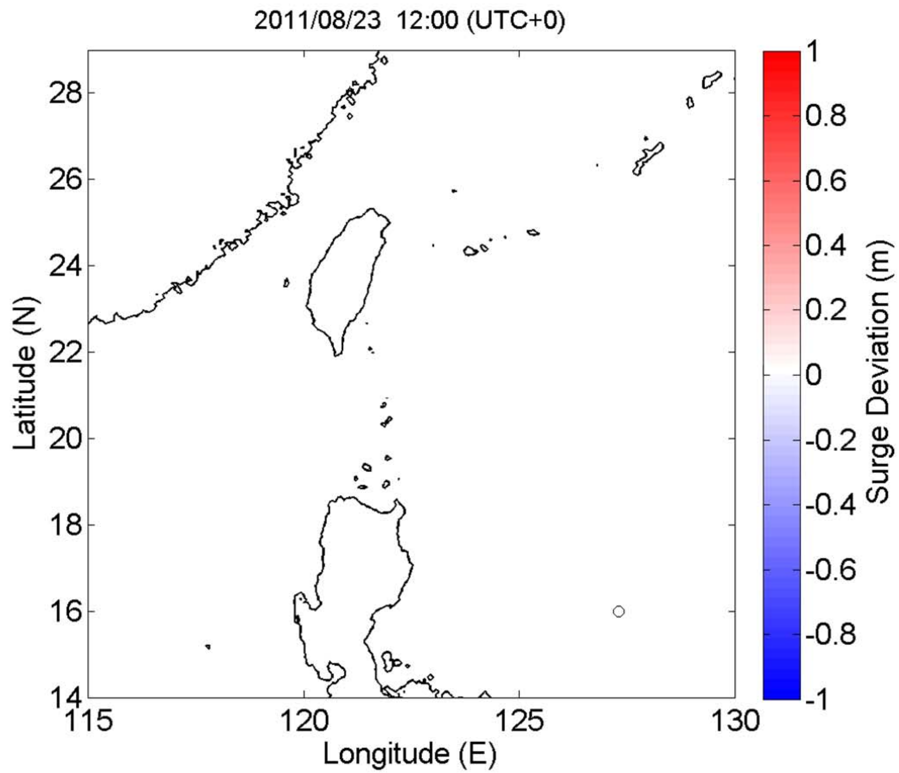
2011.08.23 12:00 – 2011.08.30 18:00 (UTC+0)

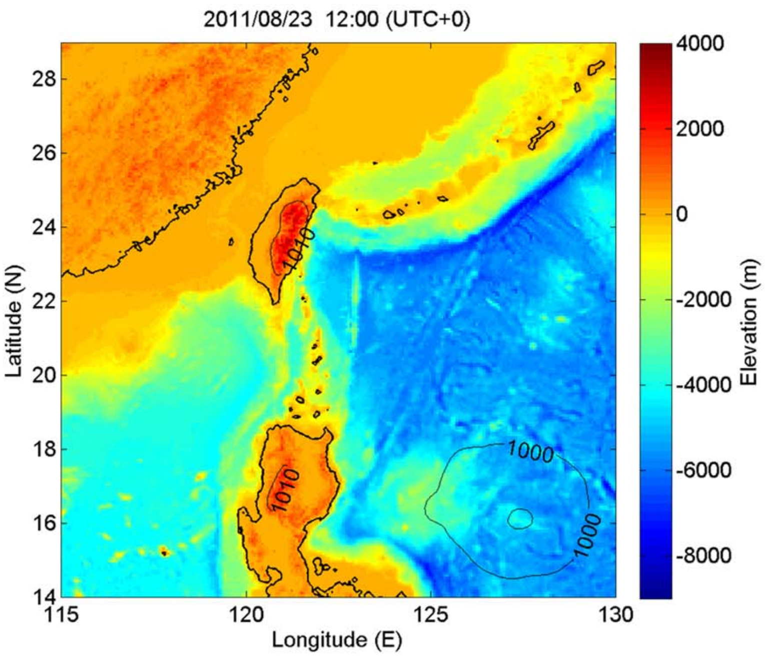
Total Time : 626400 sec (~7 days)
Time Step : 4 sec
Resolution : 4 arc-min

Holland Model



CWB Model

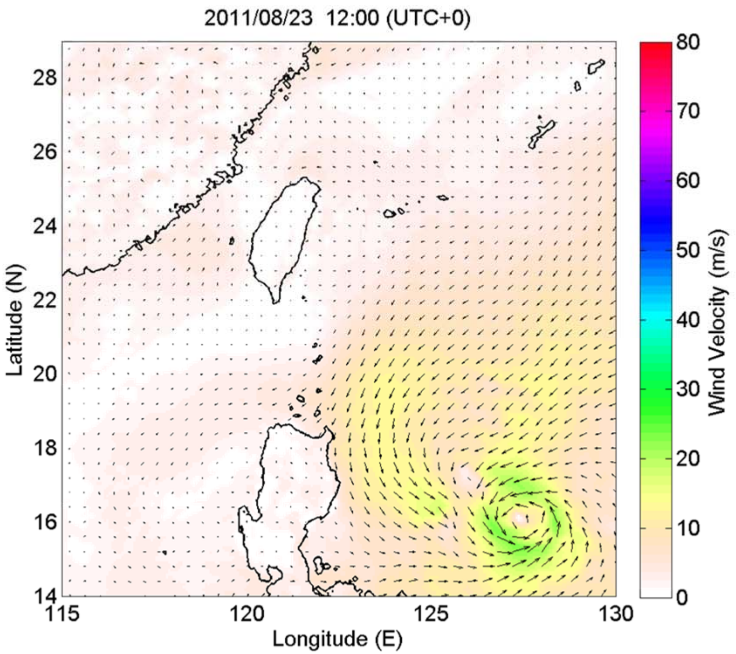


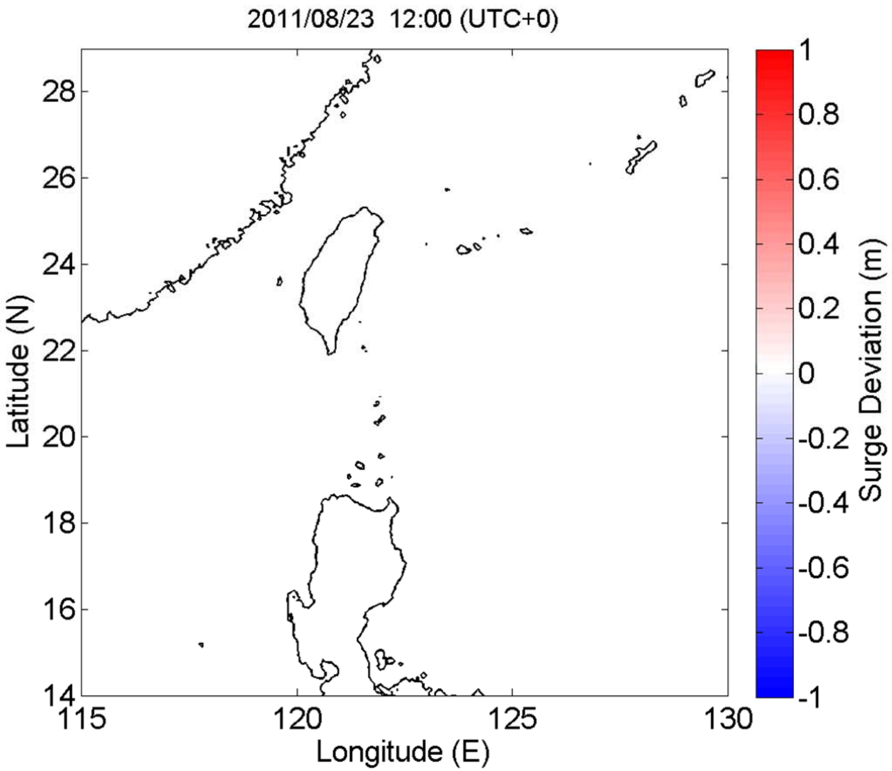


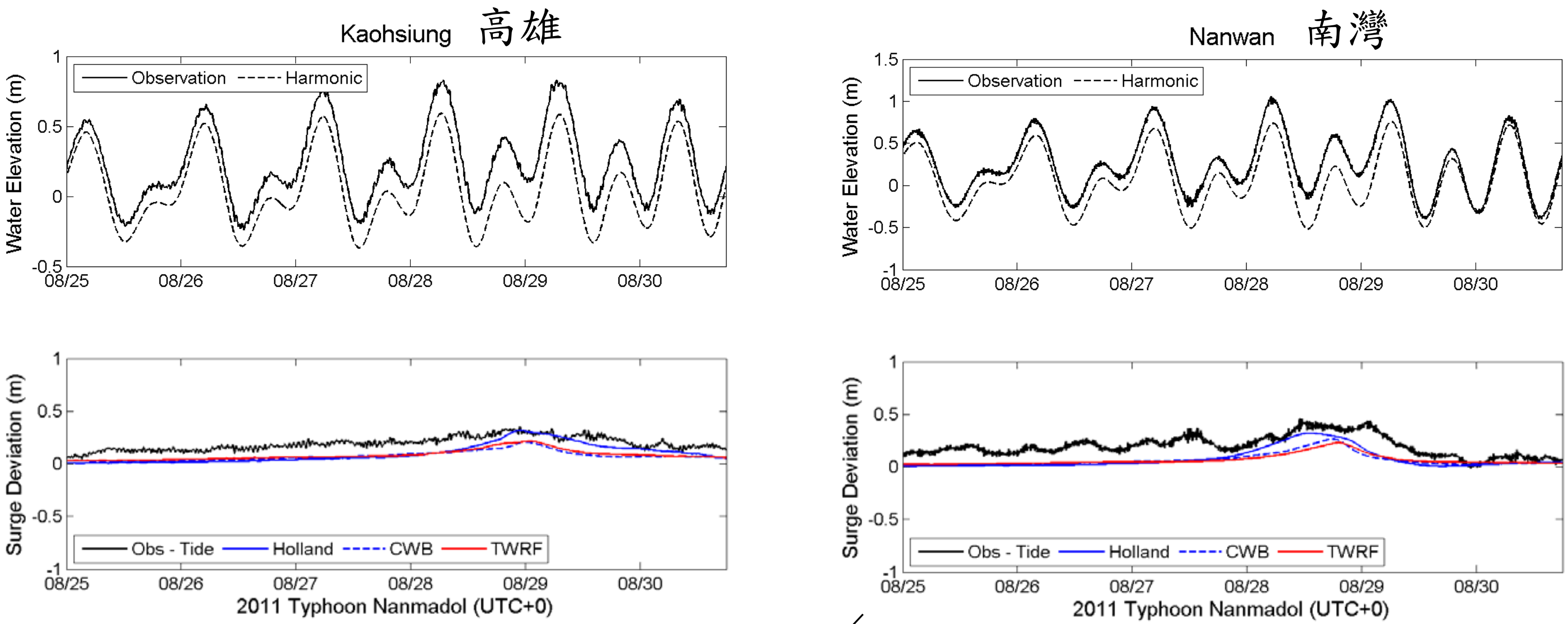
2011 Typhoon Nanmadol Coupled with TWRF

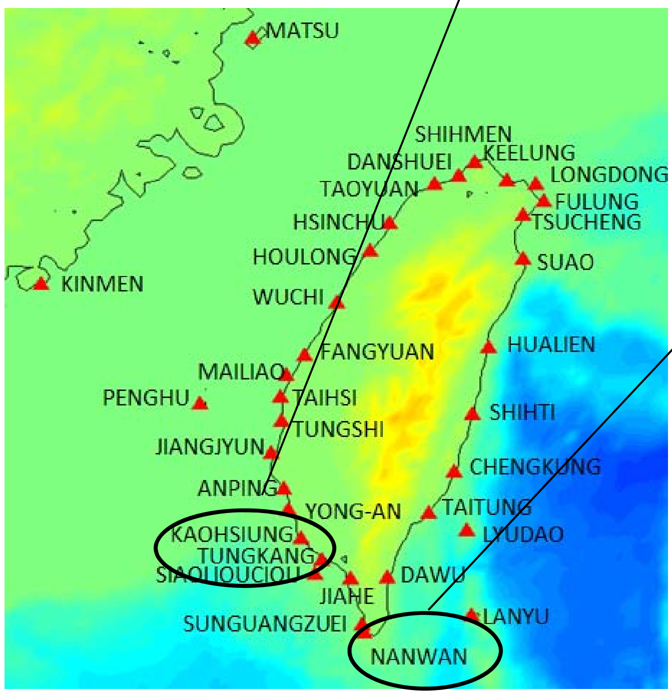
2011.08.23 12:00 – 2011.08.30 18:00 (UTC+0)

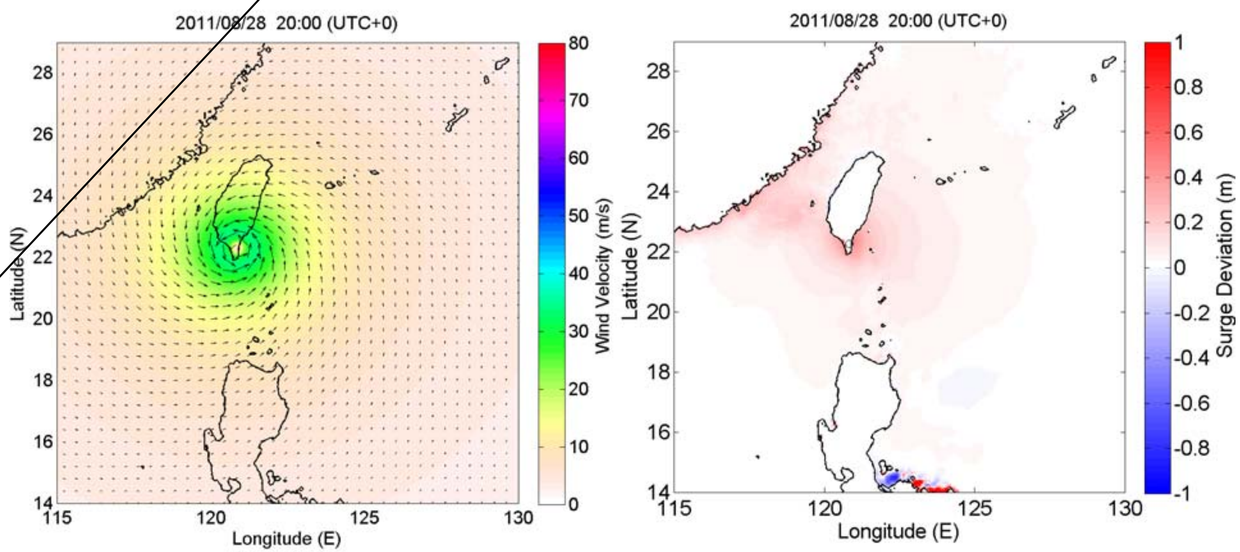
Total Time : 626400 sec (~7 days)
Time Step : 4 sec
Resolution : 4 arc-min



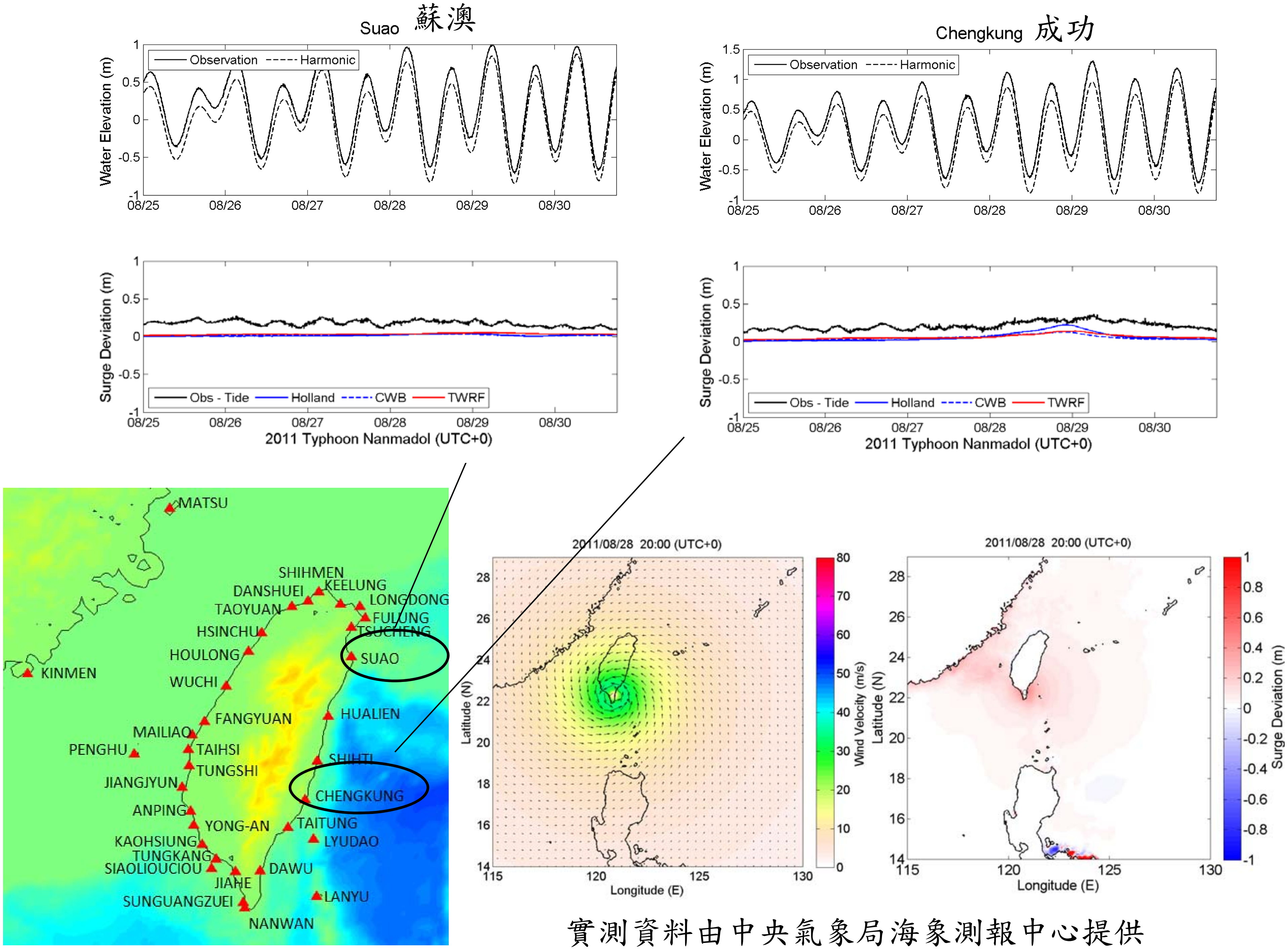




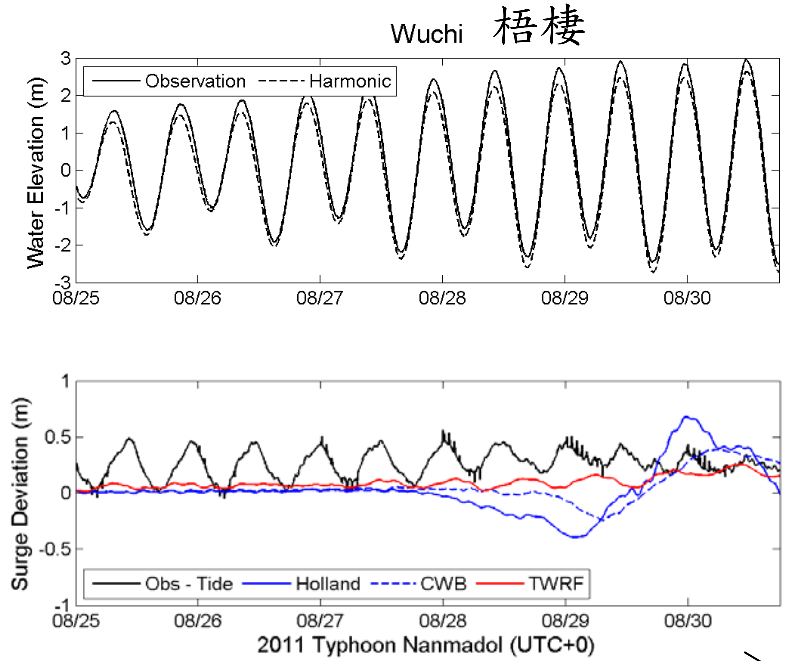


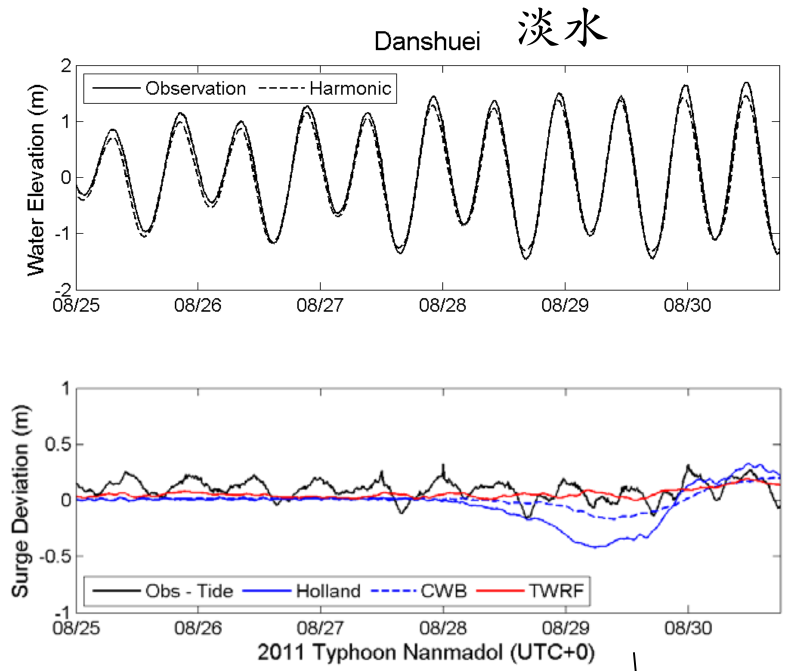


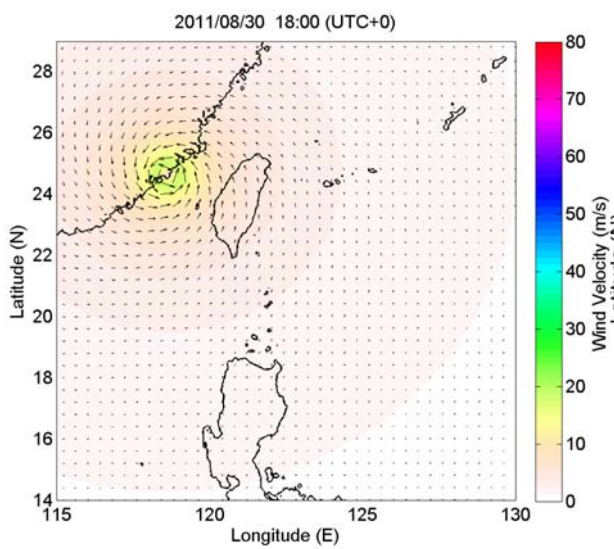
實測資料由中央氣象局海象測報中心提供

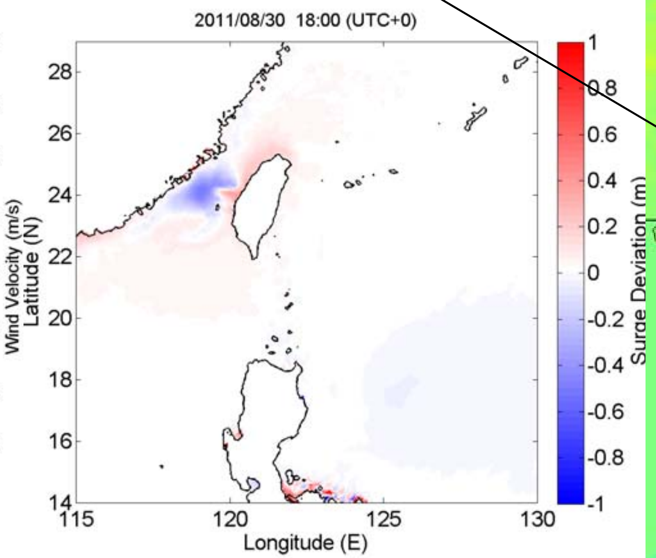


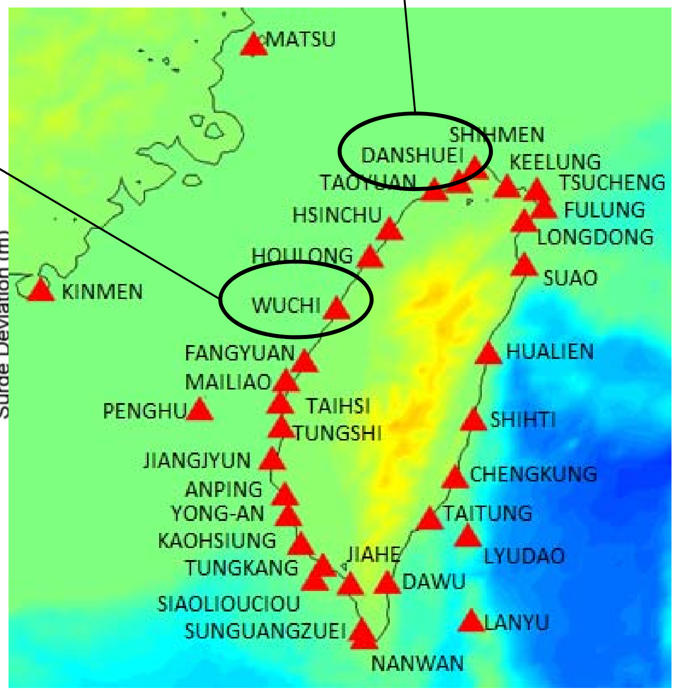
實測資料由中央氣象局海象測報中心提供











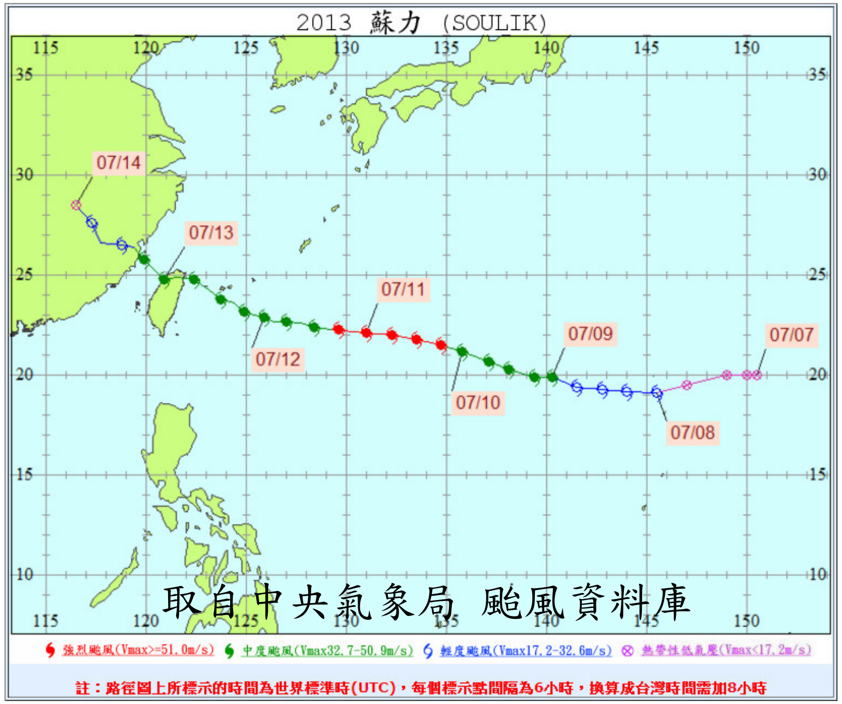
實測資料由中央氣象局海象測報中心提供

Case Study of 2013 Typhoon Soulik

- 颱風蘇力（Typhoon Soulik）於2013年7月7日轉為熱帶性低氣壓，持續增強其威力，一直到7月9日變為中度颱風，於當天下午5時升格為強烈颱風；蘇力颱風7月13日上午於臺灣新北市三貂角登陸，颱風結構遭地形破壞，強度減弱，7月13日下午從新竹出海離開臺灣，為第2類侵臺路徑。

- 蘇力颱風造成臺灣7月13日全臺停班停課，出現12級之強風，同時造成新北市嚴重海水倒灌，野柳地質公園以及野柳海洋世界因設施遭海水破壞被迫關閉園區進行維修。

基隆－滿潮後海水倒灌（東森新聞）



取自中央氣象局 颱風資料庫

Simulation of 2013 Typhoon Soulik

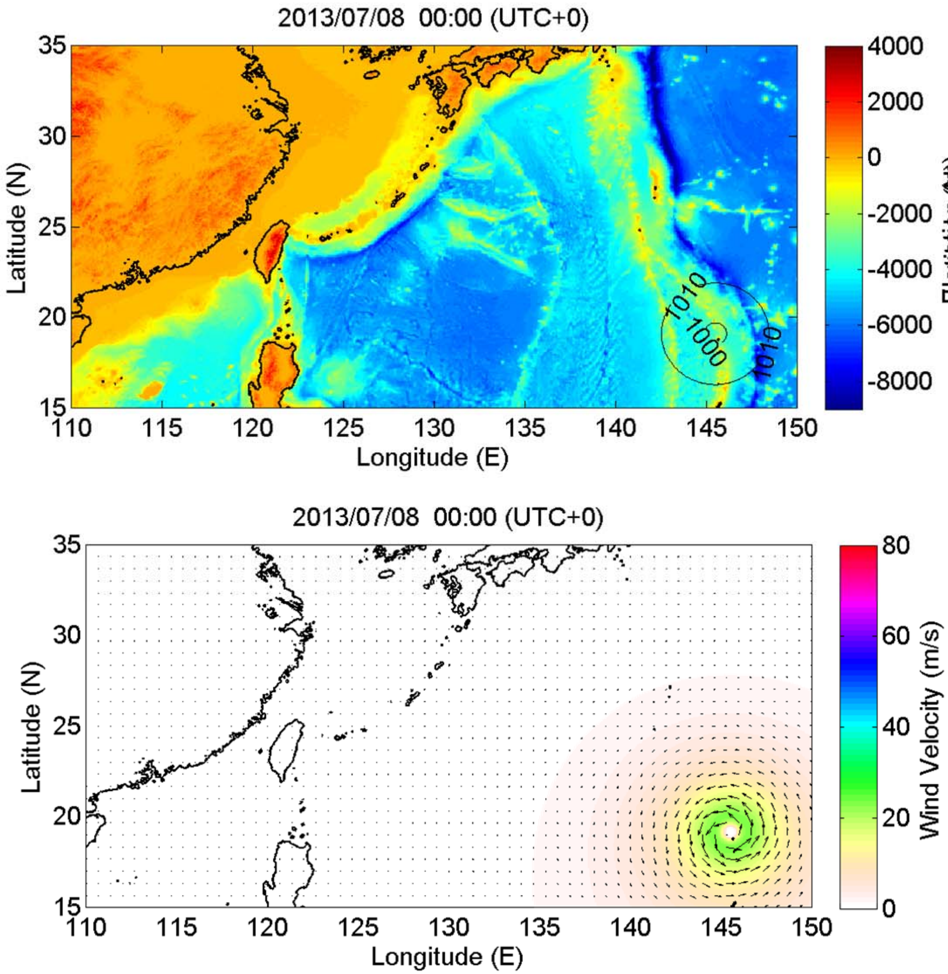
2013.07.08 00:00 – 2013.07.13 18:00 (UTC+0)

Total Time :496800 sec (~6 days)

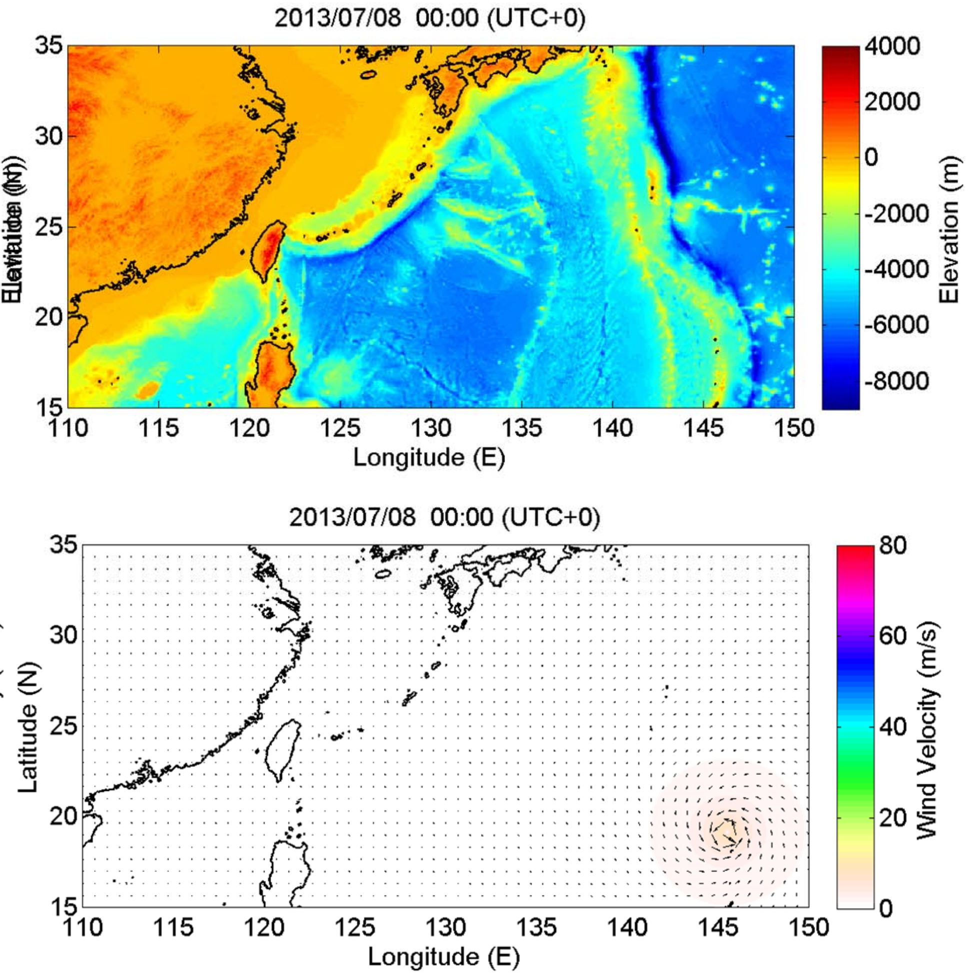
Time Step : 4 sec

Resolution : 4 arc-min

Holland Model

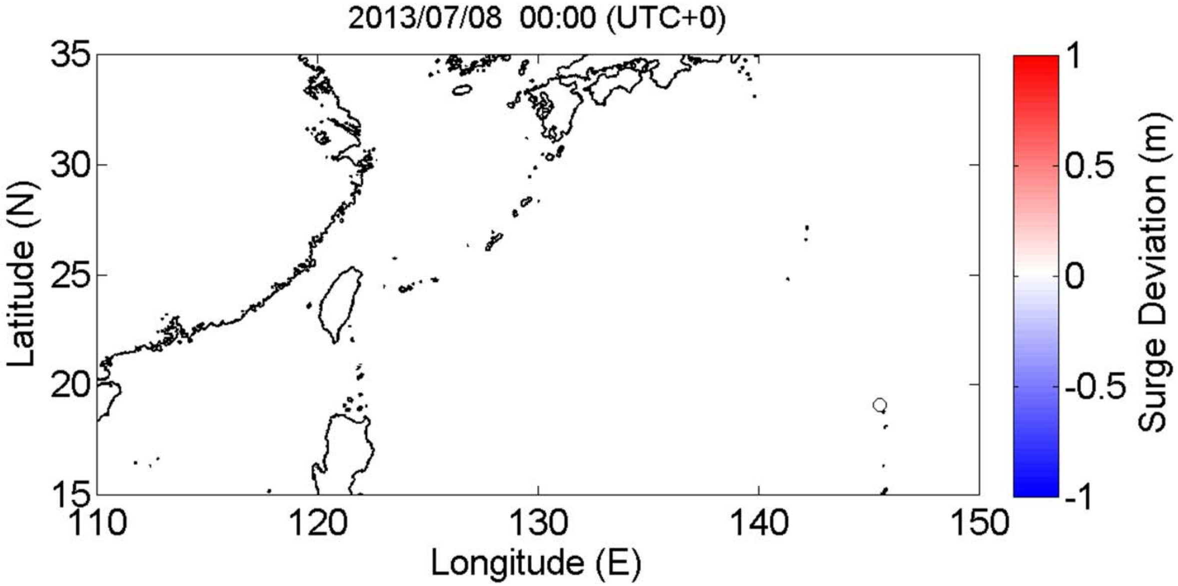


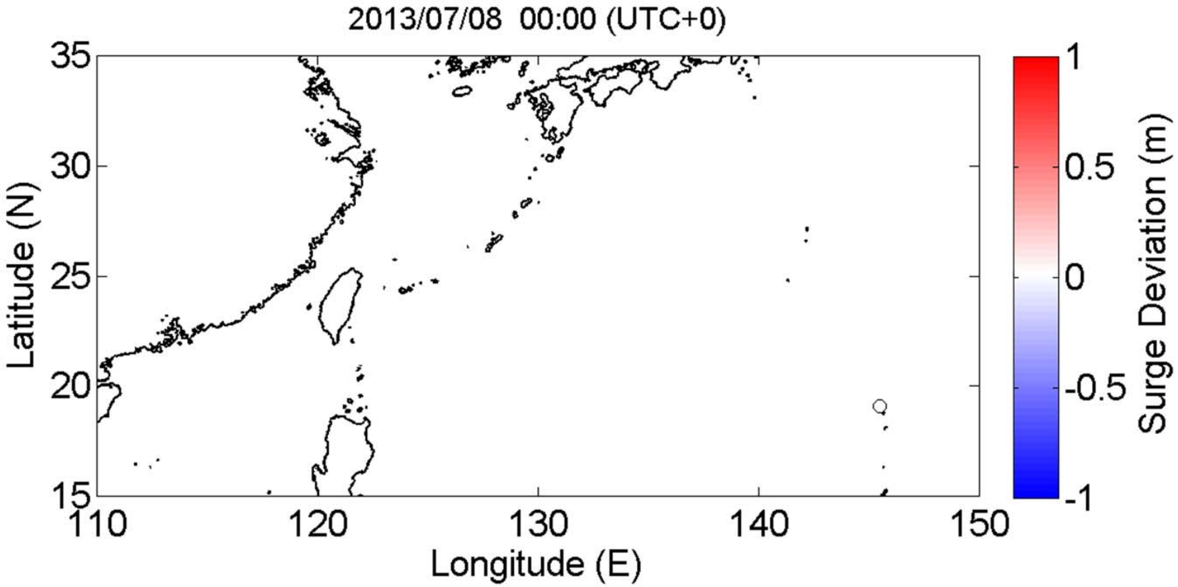
CWB Model



Surge Deviation of 2013 Typhoon Soulik

2013.07.08 00:00 – 2013.07.13 18:00 (UTC+0)





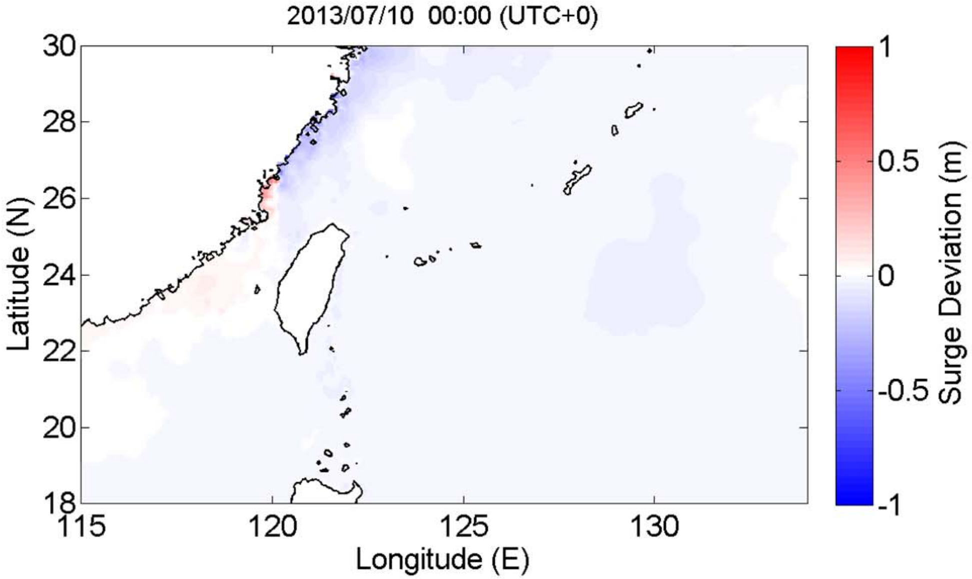
2013 Typhoon Soulik Coupled with TWRF

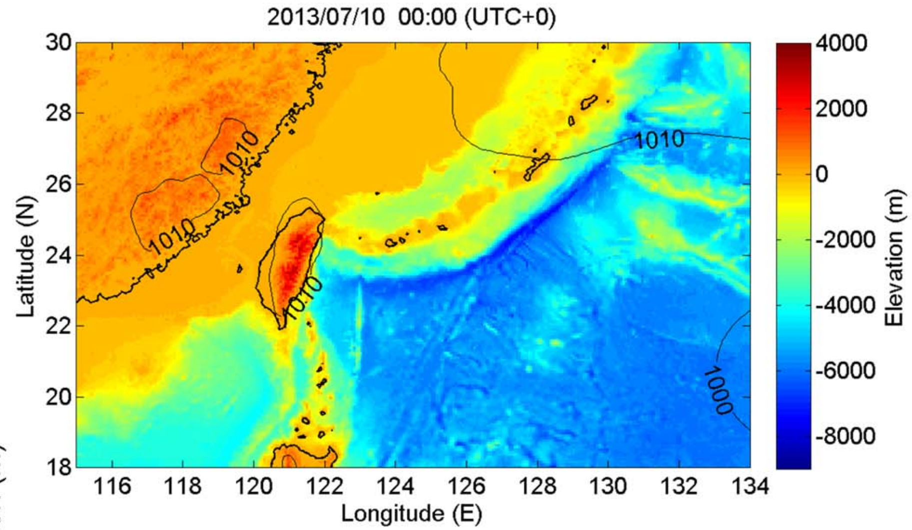
2013.07.05 00:00 – 2013.07.16 18:00 (UTC+0)

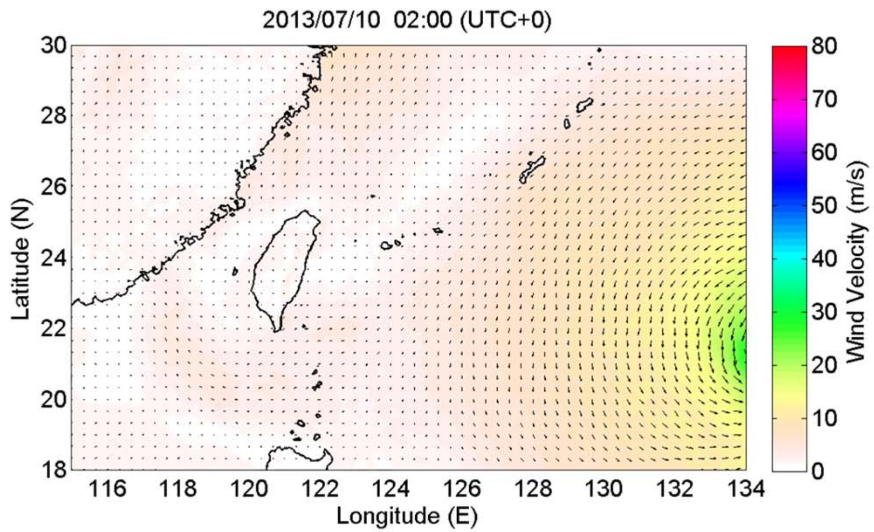
Total Time :1015200 sec(~12 days)

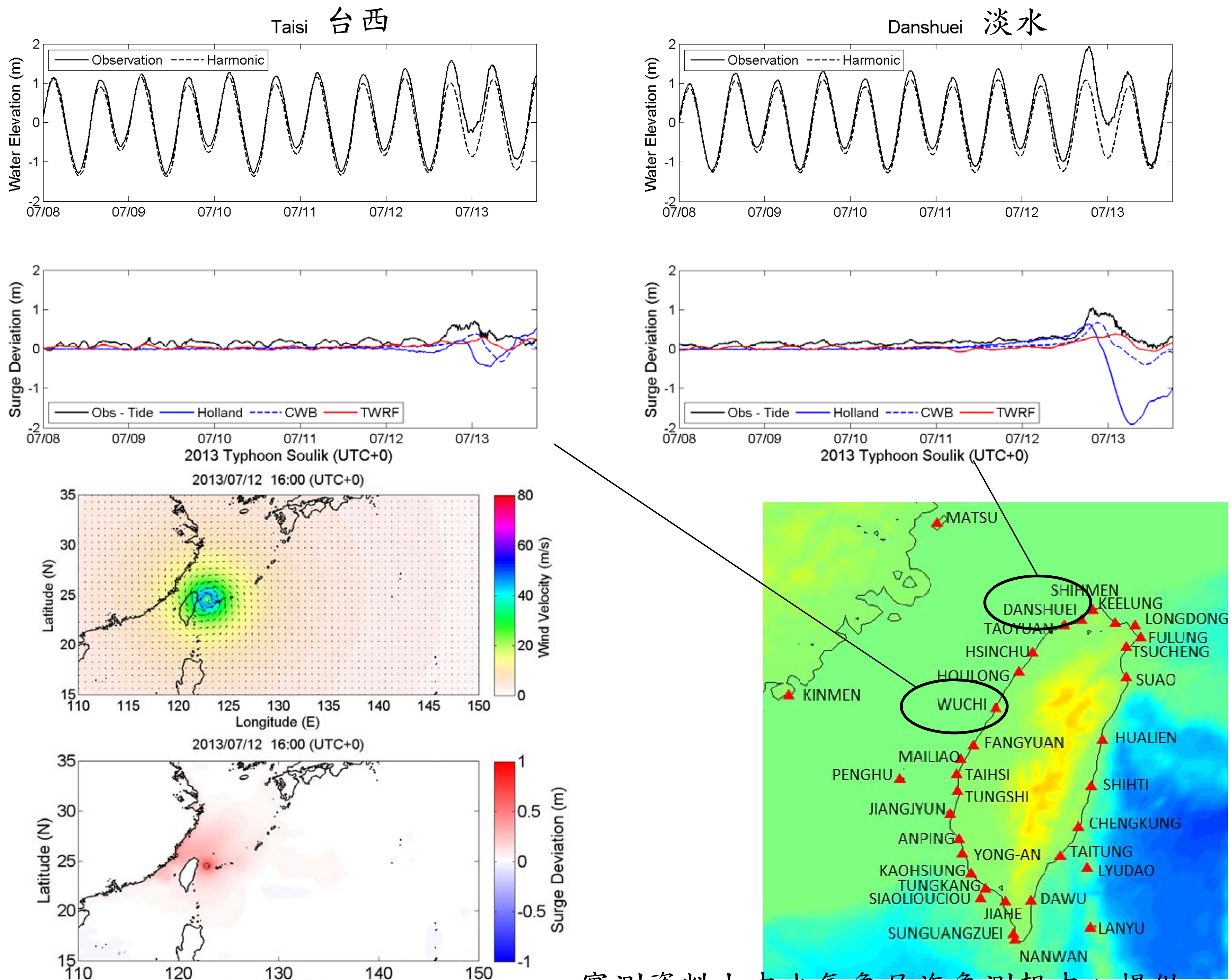
Time Step : 4 sec

Resolution : 4 arc-min

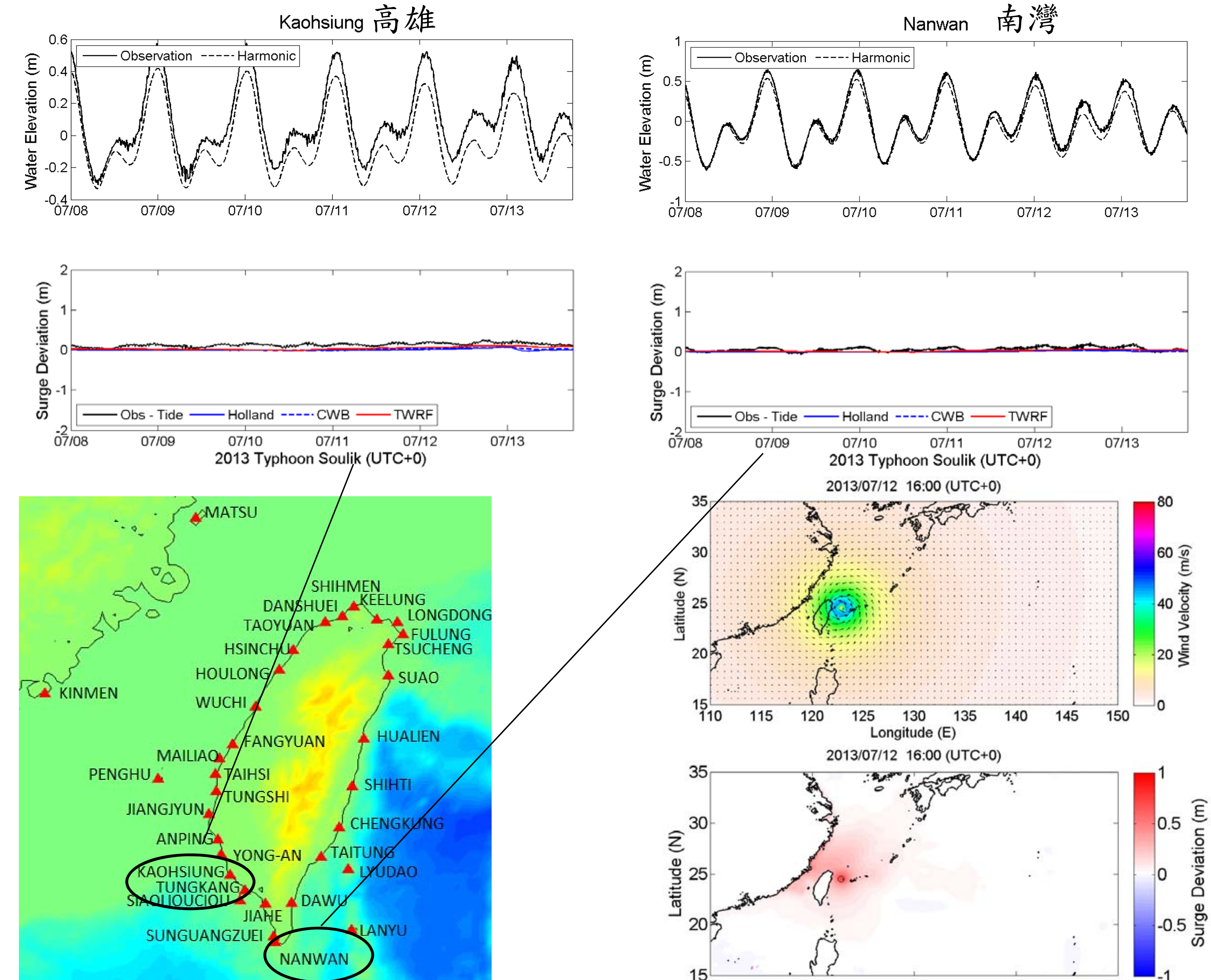




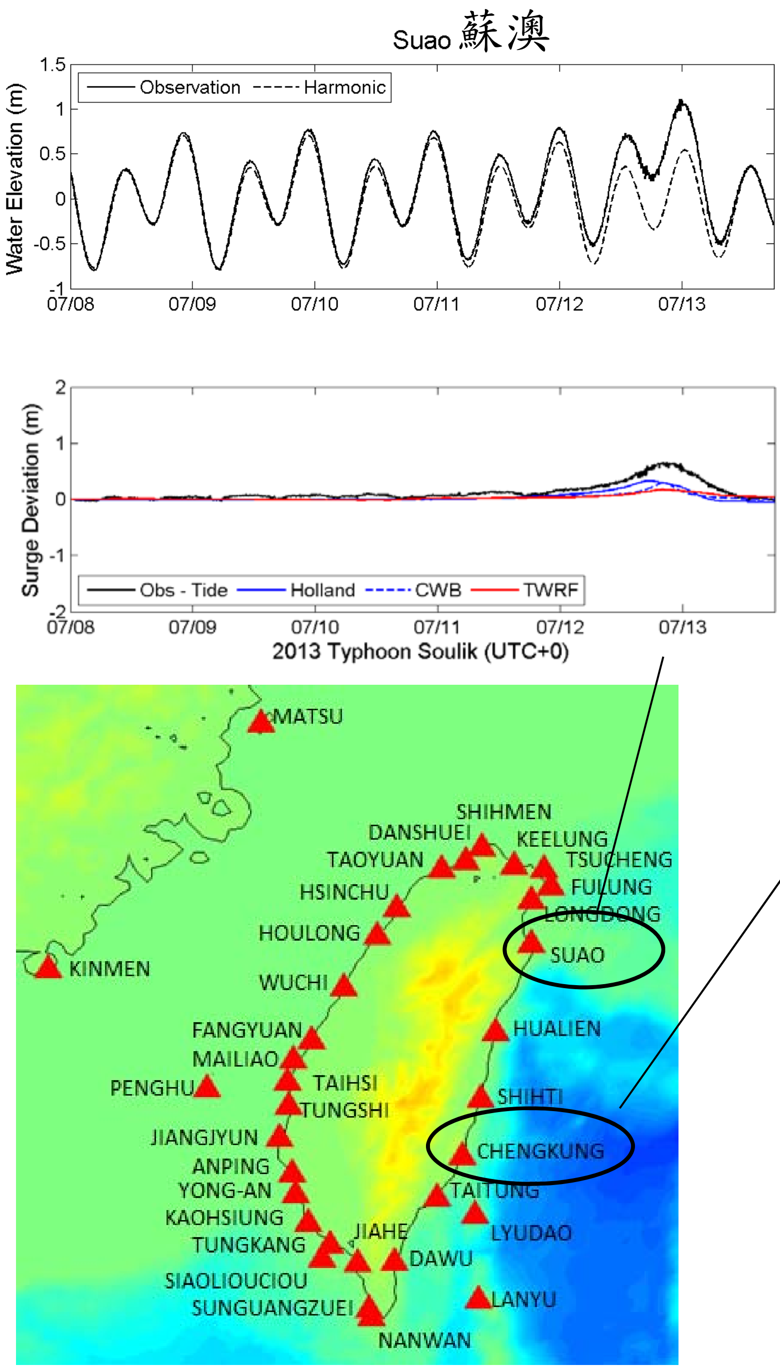


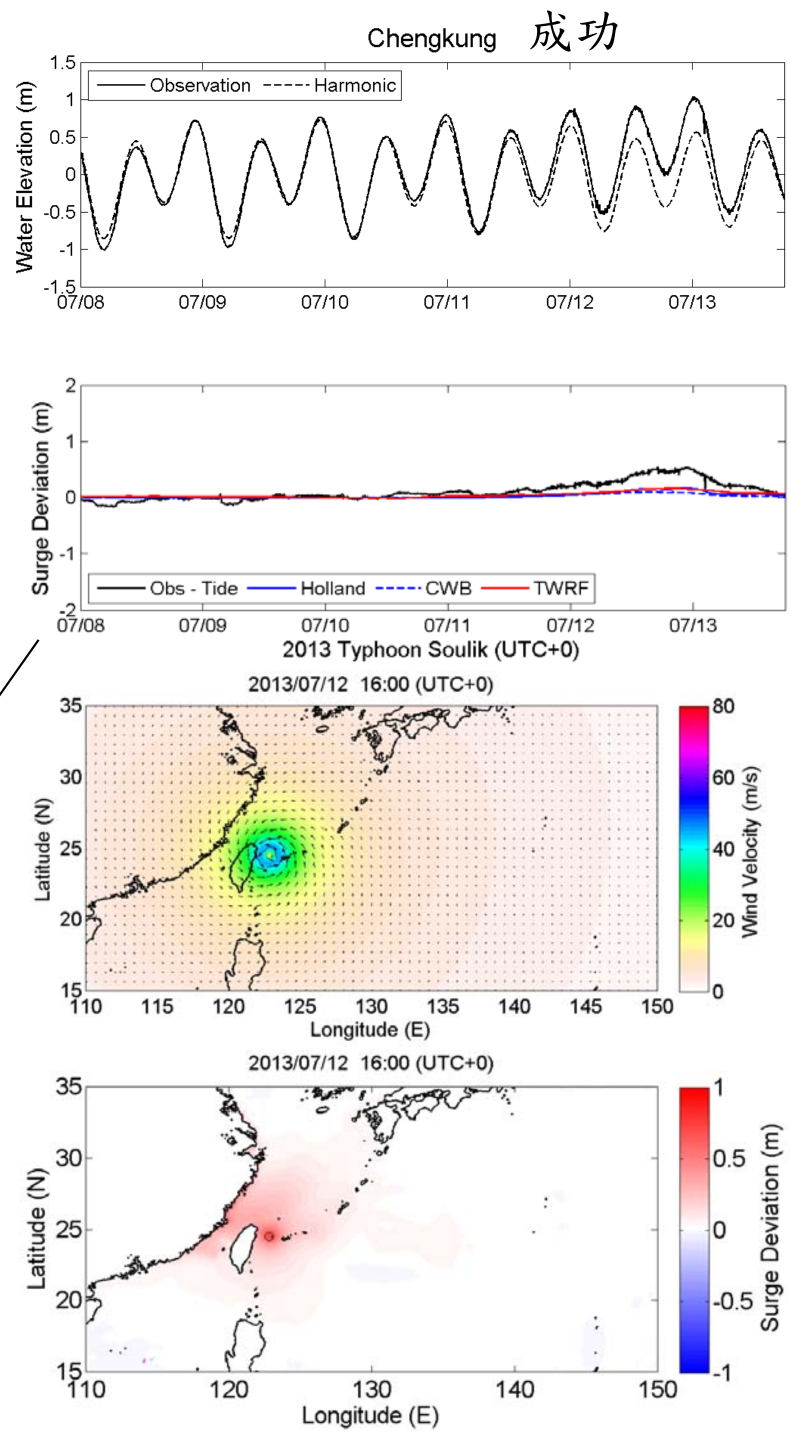


實測資料由中央氣象局海象測報中心提供



實測資料由中央氣象局海象測報中心提供





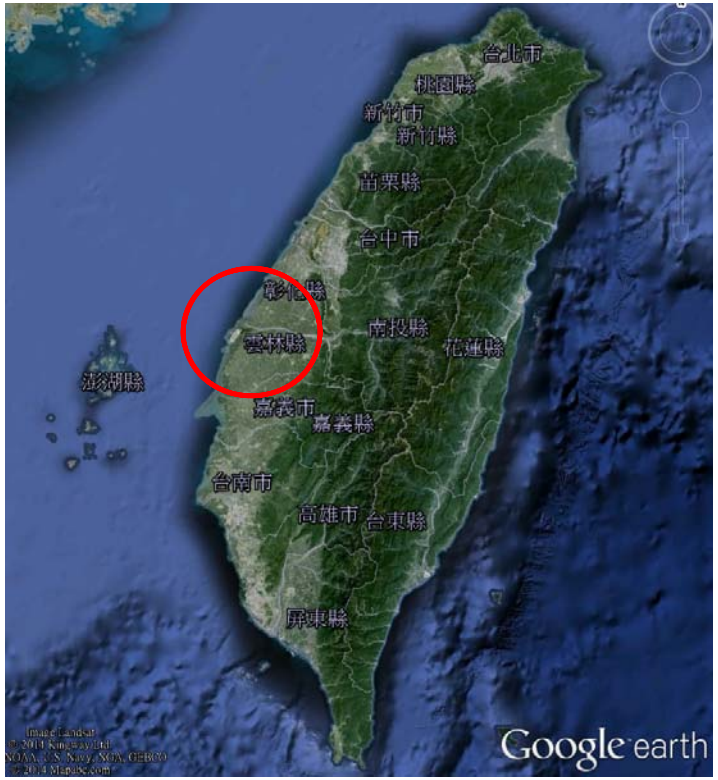
實測資料由中央氣象局海象測報中心提供

1845年雲林口湖風暴潮事件介紹

- 西元1845年（清道光25年）農曆6月7日，連宵大雨，颶風由西南捲向東北，引起海水倒灌，海浪吞沒之沿海九座村莊，分別為下湖街、新港莊、箔仔寮、蚶仔寮、竹苗寮、蝦仔寮、竹達寮等，其中又以竹苗寮、蝦仔寮（今湖口村南、北港溪畔）以及竹達寮（今廣溝厝西南處）等地區災情最為嚴重，俱沒入海中，無一倖存。
- 影響區域遍及雲林沿海一帶，罹難屍首不計其數，最後由朝廷派出官兵前來掩埋，道光皇帝為憐恤百姓，敕封為「萬善同歸」，倖存下來之民眾為告祭先祖，因而有雲林口湖牽水狀告慰冤魂之科教儀式。

（李豐楙，1996；曾人口，1978）

臺灣府輿圖纂要－嘉義縣輿圖

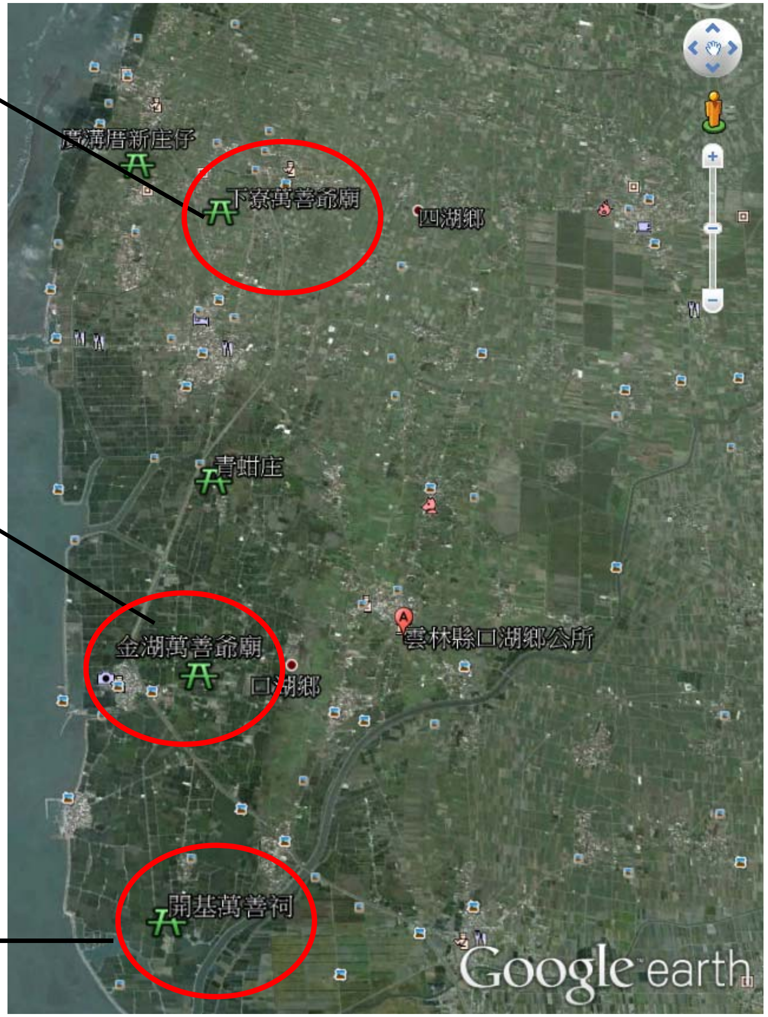


雲林縣位置

雲林口湖野外調查

時間：2014.04.29 – 2014.04.30

感謝李俊叡、李宇弘、李珮瑜同學協助



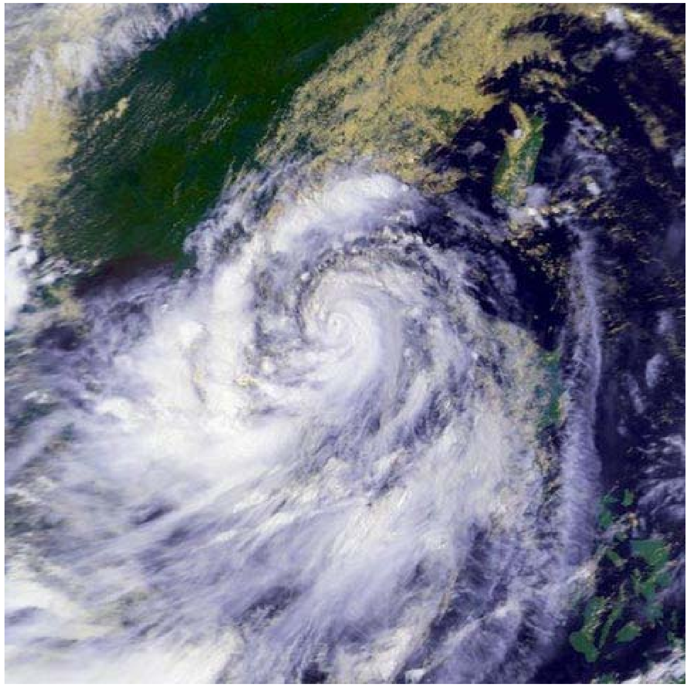
萬善同歸遺址

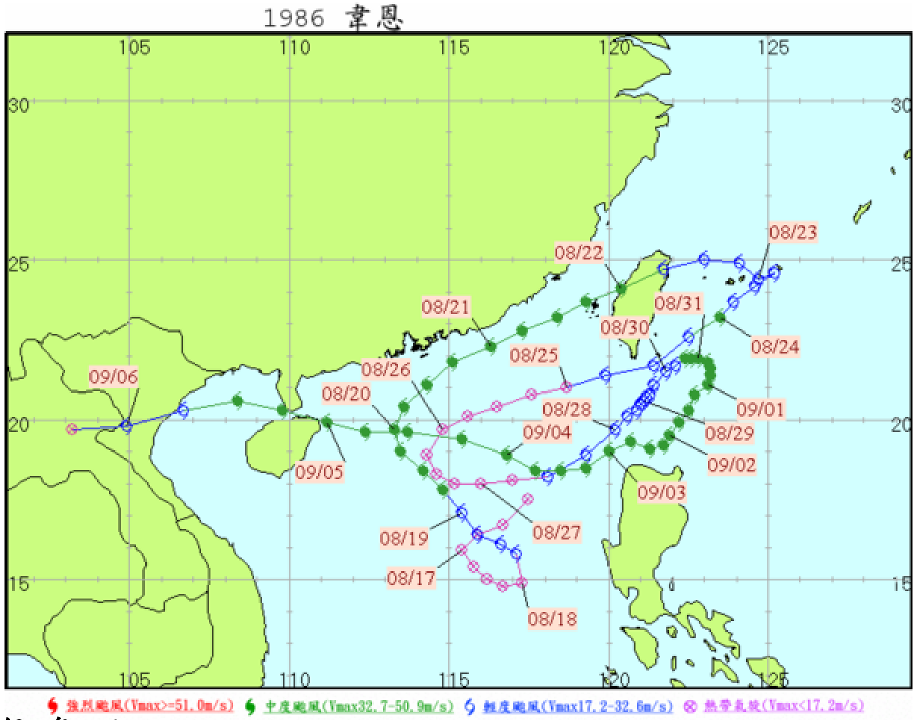
民間傳說及習俗

Case Study of 1986 Typhoon Wayne

- 以現代科學知識檢閱歷史資料並進行分析，颱風極有可能從中部地區登陸臺灣，緊接著朝東北方向前進，1986年韋恩颱風（Typhoon Wayne）路徑可能類似於此1845年之歷史颱風情況 （王志文，2002 ） 。

- 韋恩颱風創造了許多臺灣氣象史上之特別記錄，例如，第一個從臺灣西部登陸和颱風生命週期最長等現象，甚至一度轉為熱帶性低氣壓，最後卻再度發展為颱風之奇特情況，因此，與1991年耐特颱風、2001年納莉颱風、2012年天秤颱風，合稱為臺灣颱風史上之「四大怪颱」。





取自中央氣象局

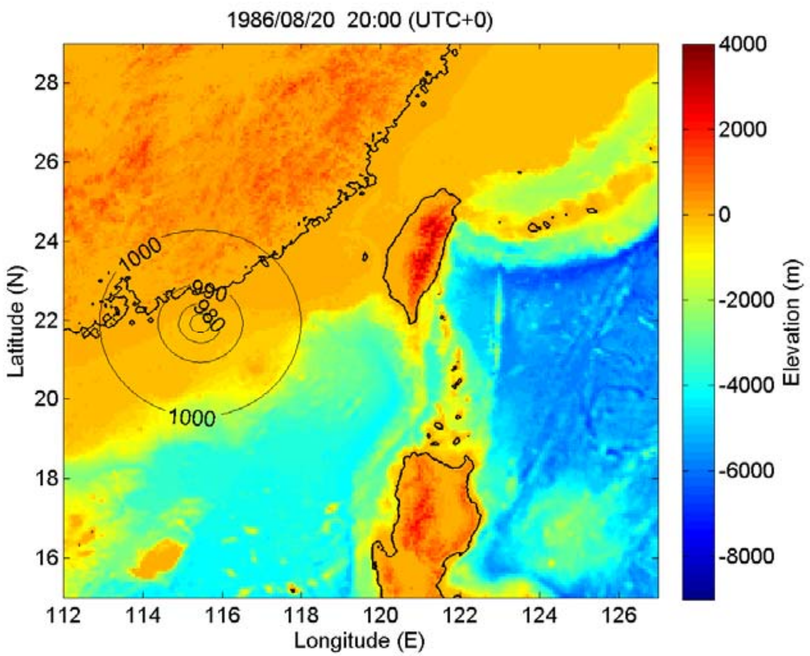
Simulation of 1986 Typhoon Wayne

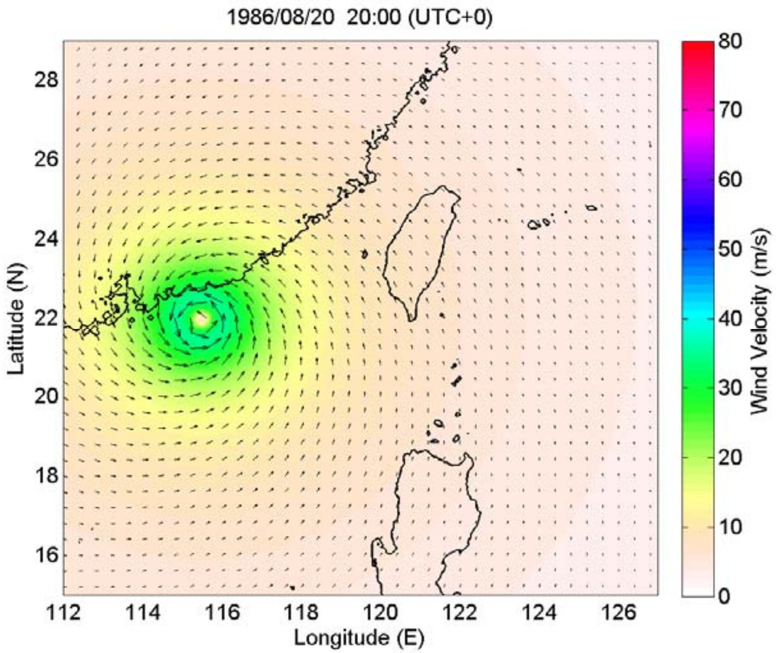
1986.08.20 20:00 – 1986.09.02 23:00 (UTC+0)

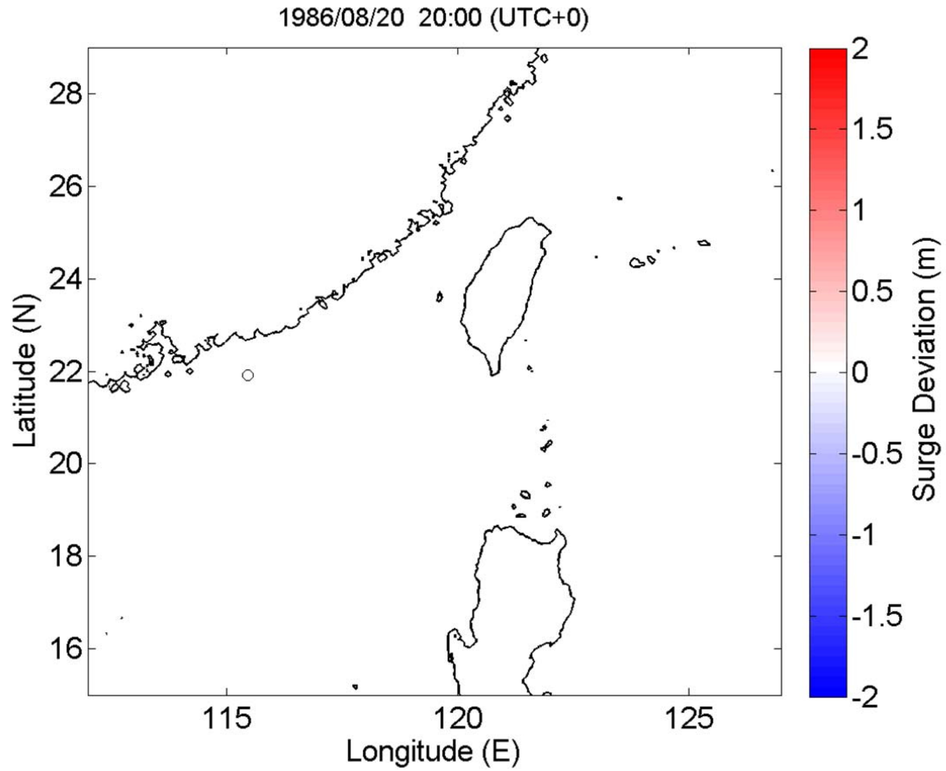
Total Time :1134000 sec (~13 days)

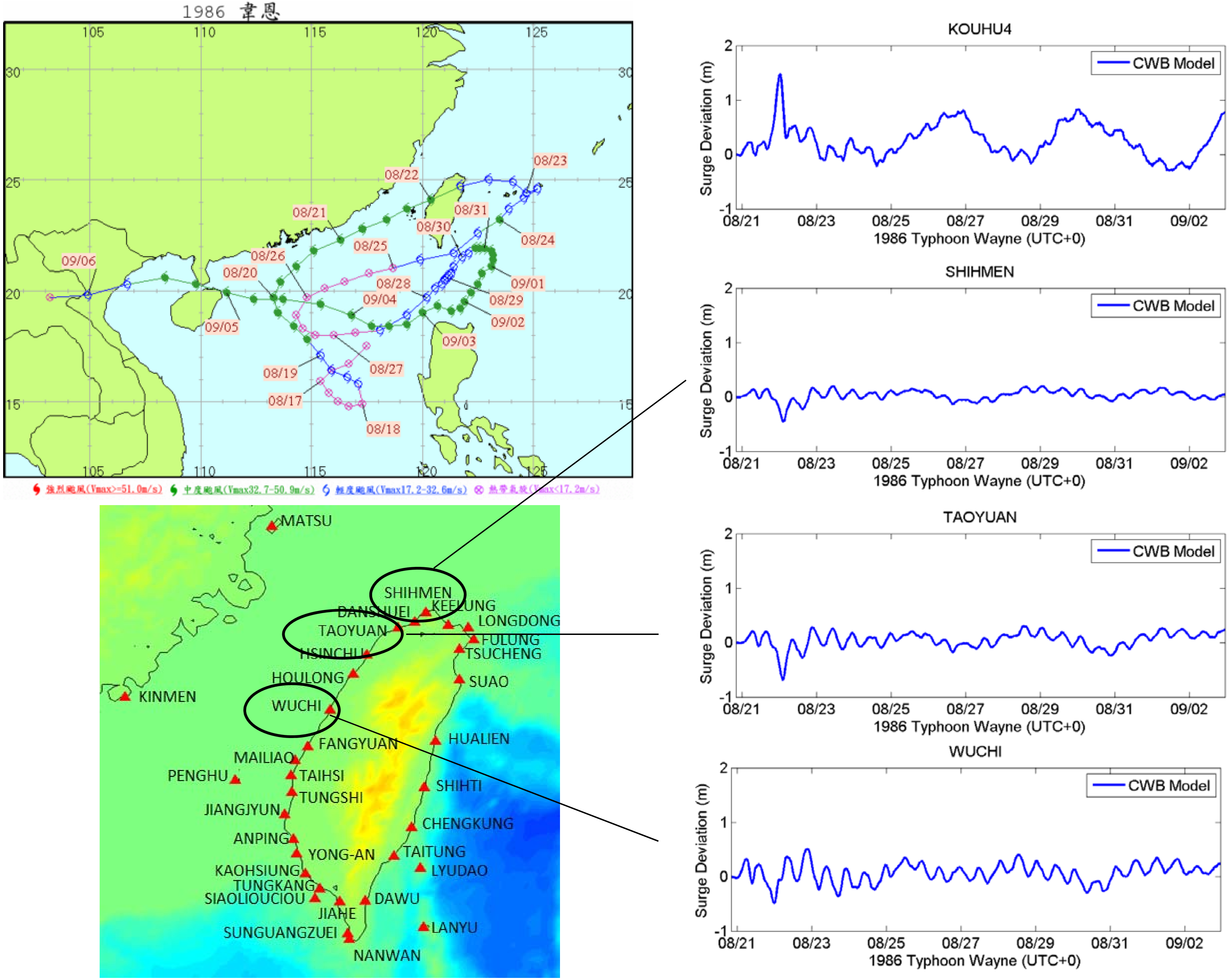
Time Step : 4 sec

Resolution : 4 arc-min








1986 韋恩
105
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MATSU
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TAOYUAN
FULUNG
HSINCHU
TSUCHENG
HOULONG
SUAO
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WUCHI
HUALIEN
FANGYUAN
MAILIAO
PENGHU
TAIHSI
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TUNGSHI
JIANGJYUN
CHENGKUNG
ANPING
YONG-AN
TAITUNG
KAOHSIUNG
LYUDAO
TUNGKANG
SIAOLIOUCIOU
DAWU
JIAHE
LANYU
SUNGUANGZUEI
NANWAN
KOUHU4
SHIHMEN
TAOYUAN
WUCHI
CWB Model
Surge Deviation (m)
1986 Typhoon Wayne (UTC+0)
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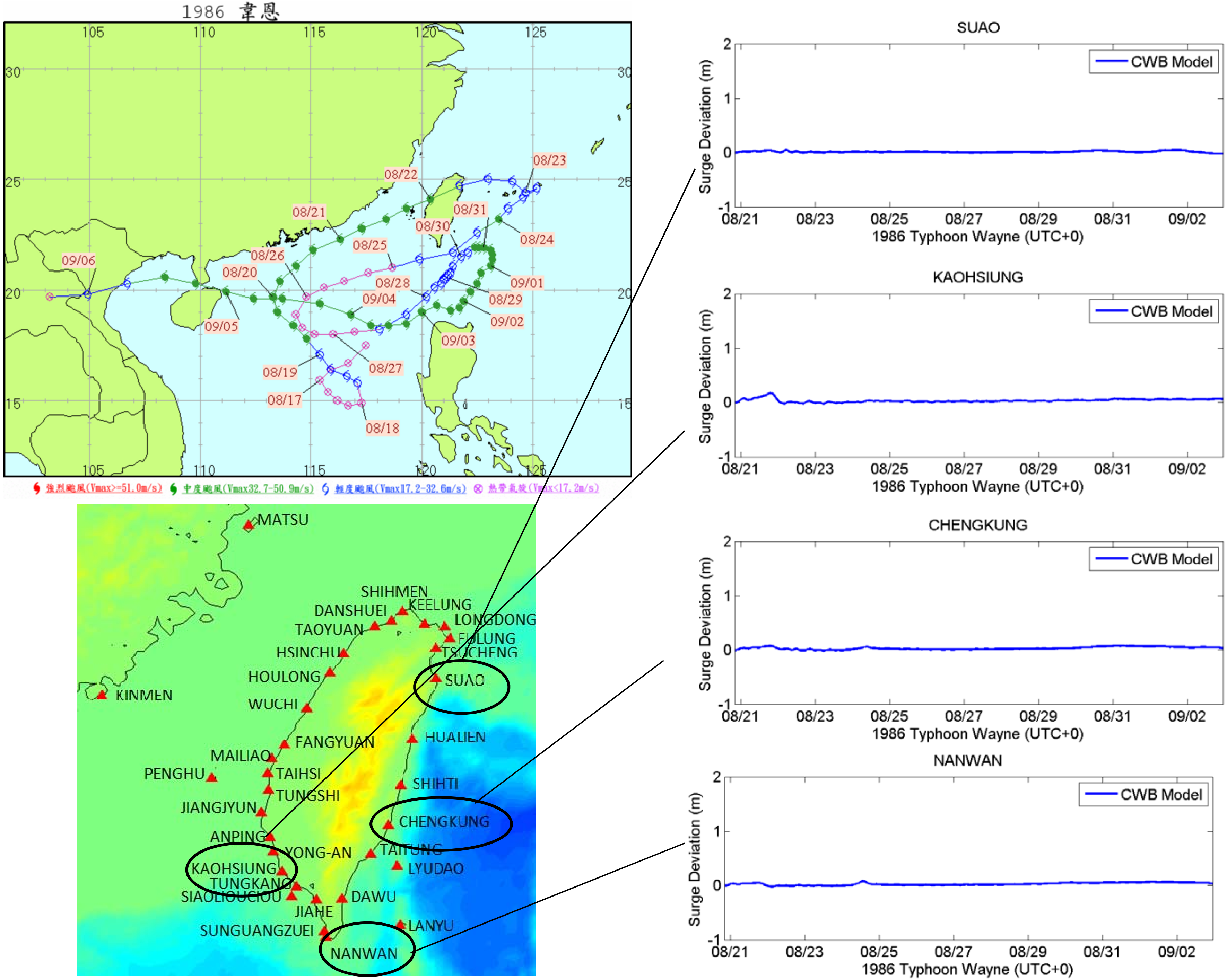

1986 韋恩
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08/27
08/17
08/18
強烈颱風(Vmax>=51.0m/s)
中度颱風(Vmax32.7-50.9m/s)
輕度颱風(Vmax17.2-32.6m/s)
熱帶低壓(Vmax<17.2m/s)
MATSU
SHIHMEN
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KEELUNG
TAOYUAN
LONGDONG
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HSINCHU
TSUCHENG
HOULONG
SUAO
KINMEN
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FANGYUAN
HUALIEN
MAILIAO
PENGHU
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CHENGKUNG
ANPING
YONG-AN
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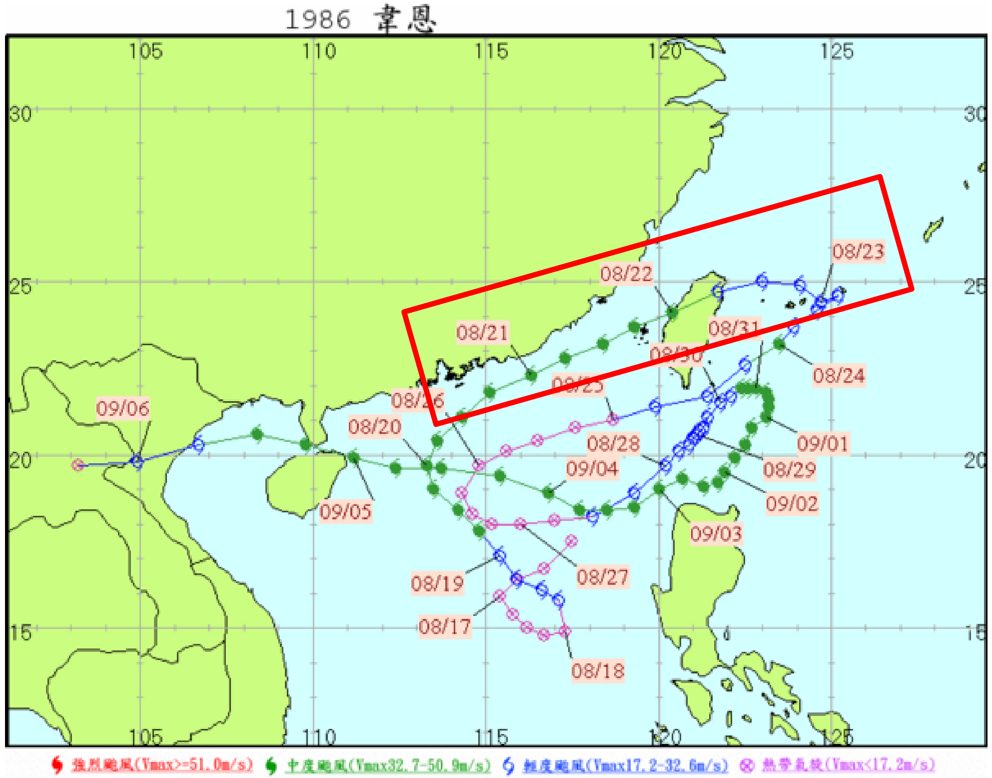
KAOHSIUNG
LYUDAO
TUNGKANG
SIAOLIOUCIOU
DAWU
JIAHE
LANYU
SUNGUANGZUEI
NANWAN
SUAO
KAOHSIUNG
CHENGKUNG
NANWAN
CWB Model
Surge Deviation (m)
1986 Typhoon Wayne (UTC+0)
08/21
08/23
08/25
08/27
08/29
08/31
09/02

Scenario Analysis

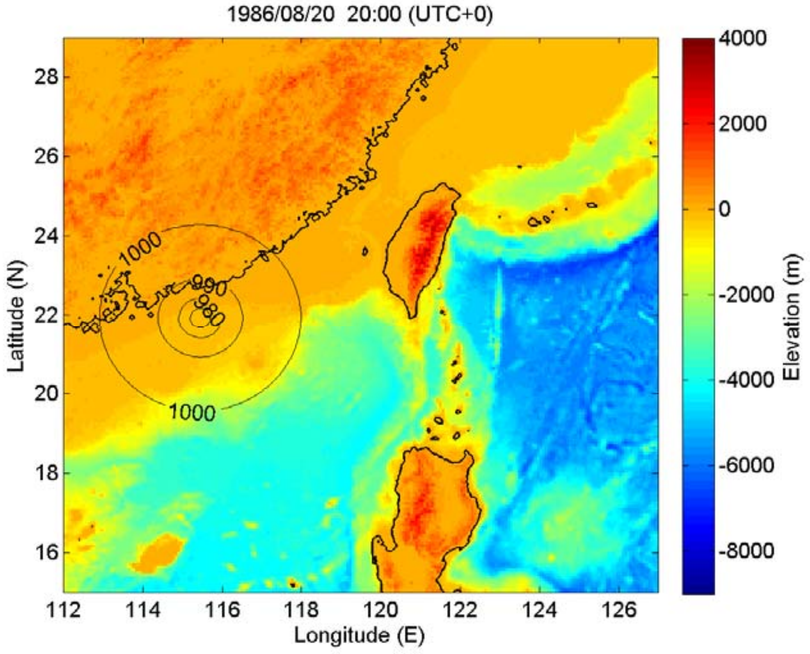
- 全球氣候變遷之暖化現象，可能導致未來強烈颱風等極端事件產生，甫以海平面上升，將使得風暴潮危害加遽。
- 比照2013年颱風海燕颱風（Typhoon Haiyan），假設颱風中心壓力漸增為895 mb，七級風半徑漸增為300 km，最大風速漸增為87.5 m/s，為一強烈颱風，並且於8月22日登陸臺灣之時，颱風威力達到最強；通過臺灣後，受到地形影響破壞其架構，因此8月22日至8月23日颱風威力漸漸下降。

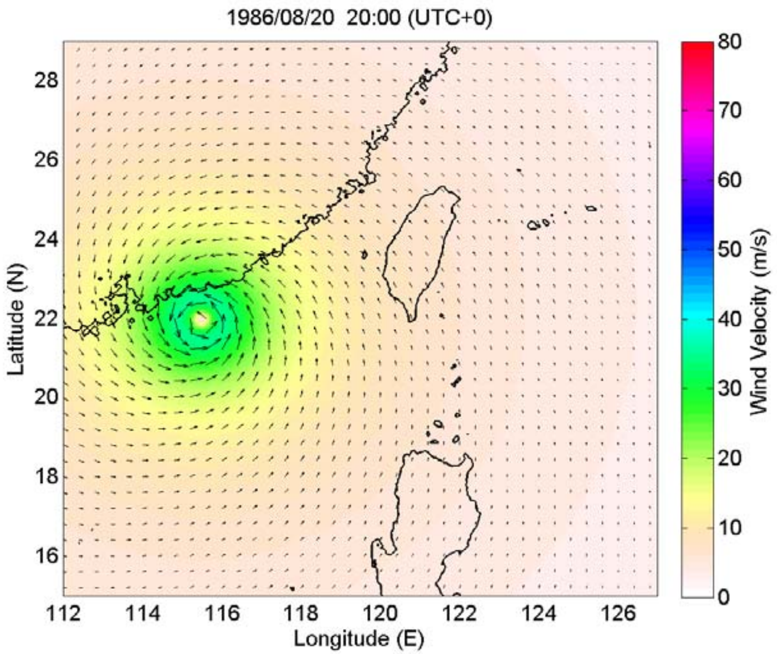


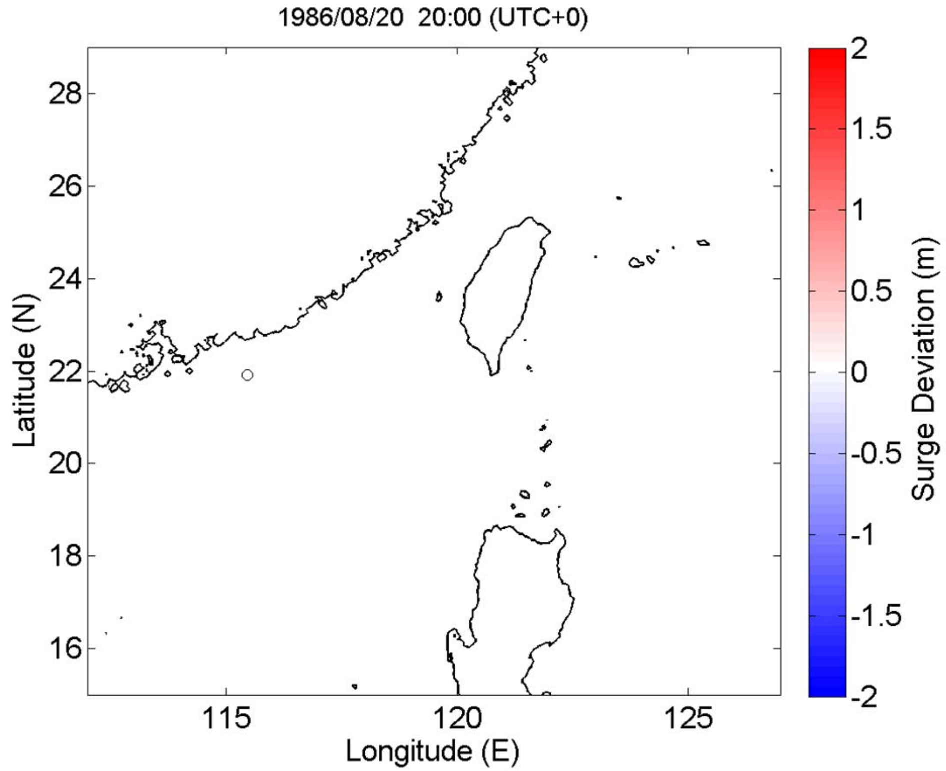
Simulation of the Scenario

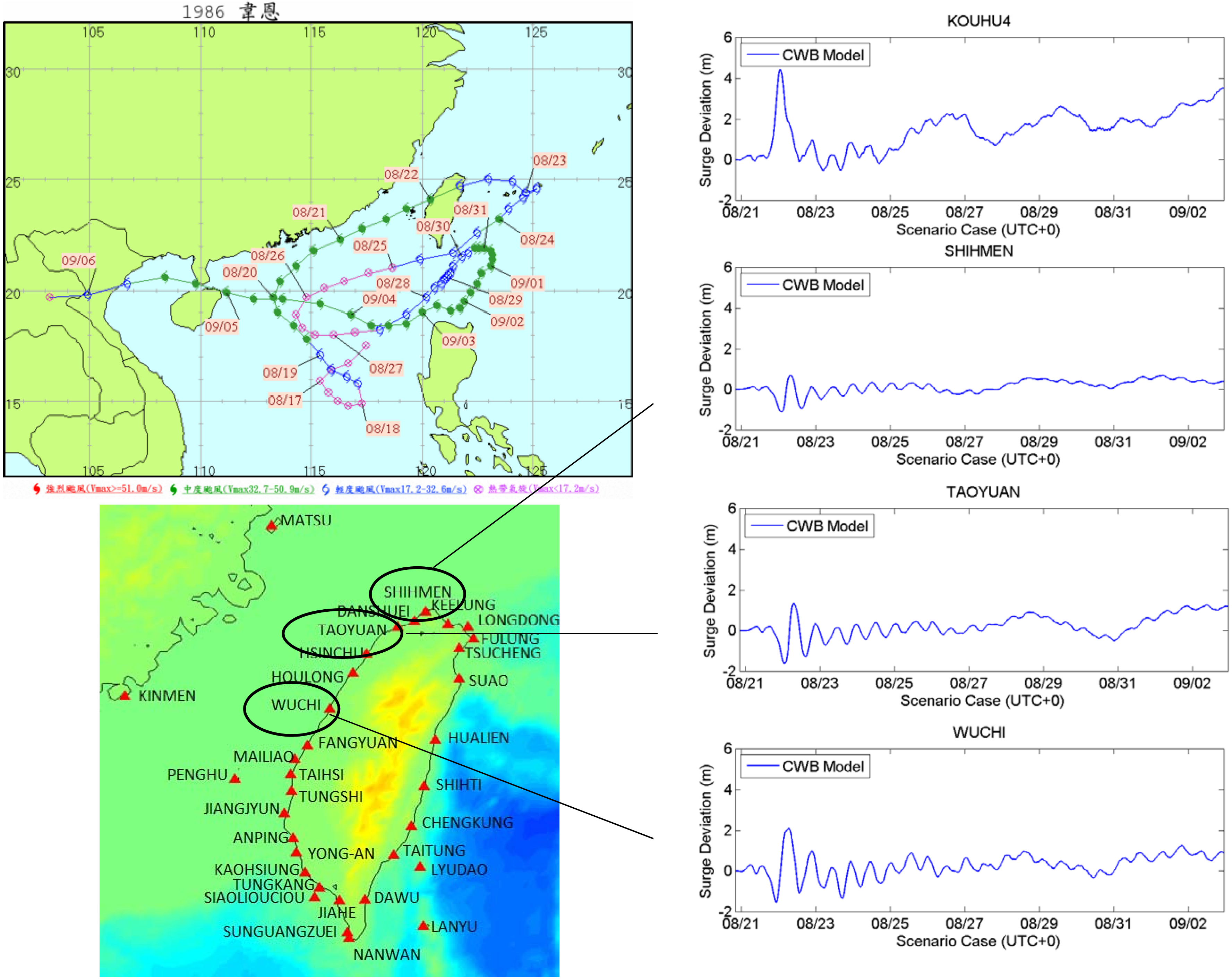
1986.08.20 20:00 – 1986.09.02 23:00 (UTC+0)

Total Time :1134000 sec (~13 days)
Time Step : 4 sec
Resolution : 4 arc-min









1986 韋恩
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MAILIAO
PENGHU
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SHIHTI
JIANGJYUN
CHENGKUNG
ANPING
YONG-AN
TAITUNG
KAOHSIUNG
LYUDAO
TUNGKANG
SIAOLIOUCIOU
DAWU
JIAHE
SUNGUANGZUEI
LANYU
NANWAN
KOUHU4
SHIHMEN
TAOYUAN
WUCHI
CWB Model
Surge Deviation (m)
Scenario Case (UTC+0)
08/21
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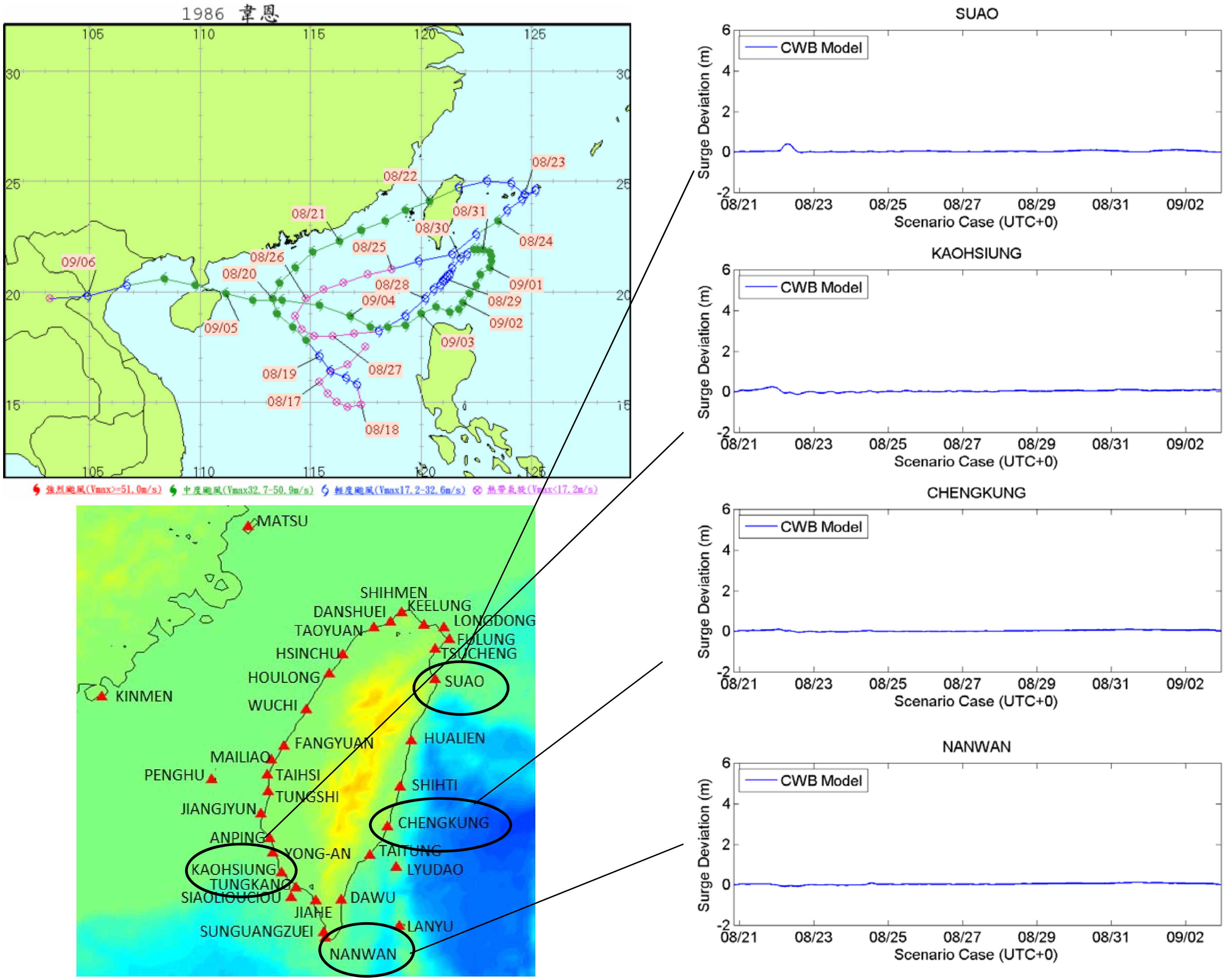
08/31
09/02



1986 韋恩
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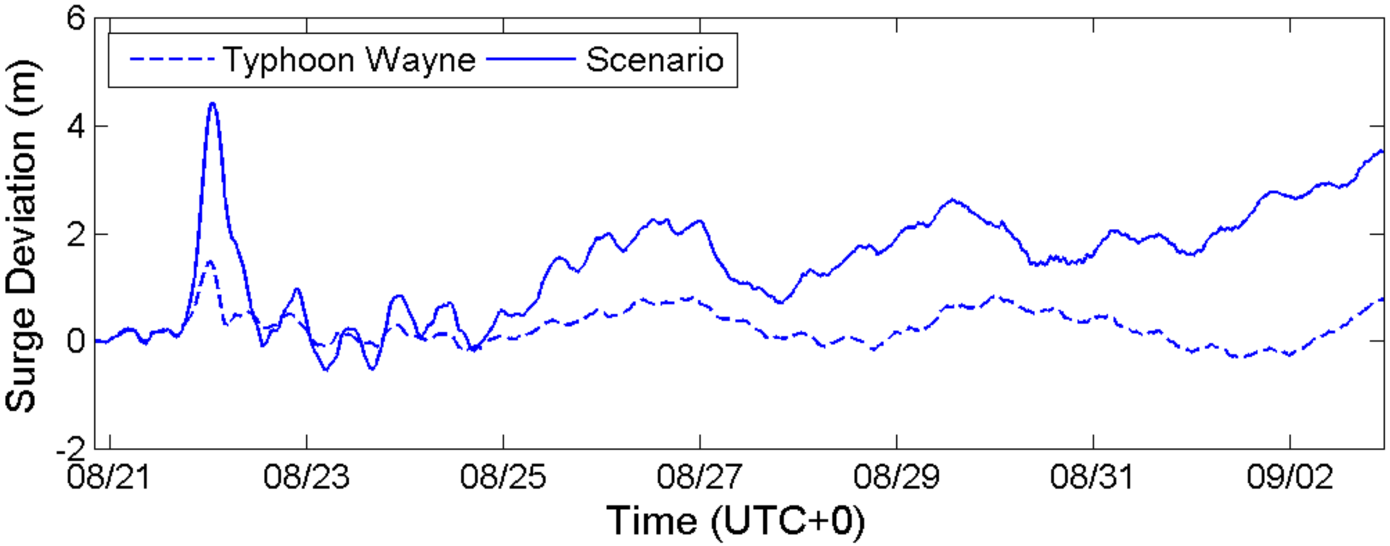
FANGYUAN
HUALIEN
MAILIAO
TAIHSI
TUNGSHI
SHIHTI
JIANGJYUN
ANPING
CHENGKUNG
YONG-AN
TAITUNG
KAOHSIUNG
LYUDAO
TUNGKANG
SIAOLIOUCIOU
DAWU
JIAHE
LANYU
SUNGUANGZUEI
NANWAN
SUAO
KAOHSIUNG
CHENGKUNG
NANWAN
CWB Model
Surge Deviation (m)
Scenario Case (UTC+0)
08/21
08/23
08/25
08/27
08/29
08/31
09/02

Comparison between 1986 Typhoon Wayne and Scenario

1986.08.20 20:00 – 1986.09.02 23:00 (UTC+0)



Model Efficiency

Case	Holland	CWB	TWRF
Nanmadol	52 min 135,736 grids, 7days	51 min 135,736 grids 7days	42 min 135,736 grids, 7days
Soulik	55 min 180,901 grids, 6days	54 min 180,901 grids, 6days	59 min 135,736 grids, 12days
Wayne	N/A	92 min 135,736 grids, 13days	N/A
Scenario	N/A	93 min 135,736 grids, 13days	N/A

Intel 5 750, 2.67 GHz with 4 cores

海嘯科學研究室 工作站

Conclusion (1)

- 本研究使用廣為學界所認可之開放原始碼之非線性淺水波海嘯模式COMCOT（Cornell Multi-grid Coupled of Tsunami Model），加入颱風氣象力，使其具備計算風暴潮傳遞之能力，並且建立風暴潮速算系統，可於半小時內完成未來48小時之風暴潮模擬，以供預警之用。

- 本研究開發之COMCOT風暴潮模式分別於壓力梯度以及風剪力之假想環境下，與解析解進行驗證，並且有良好之驗證成果，結果顯示長時間作用下，數值答案會達到穩態（Steady-state），符合解析解之答案。

- 本研究選用2011年南瑪都颱風和2013年蘇力颱風進行模式驗證，同時耦合參數化大氣模式Holland Model、CWB Model以及TWRF大氣模式之颱風氣象力，完整包涵颱風生命週期計算其暴潮傳遞，並且和氣象局提供之實測資料進行比對，皆有良好之比對成果，其中以CWB Model代入所模擬之結果最佳。

Conclusion (2)

- 以1986年韋恩颱風作為還原1845年雲林口湖風暴潮事件之參考案例，韋恩颱風為臺灣近代史上第一個直接由臺灣西部登陸之颱風，登陸時強度僅為中度颱風，卻造成中部地區嚴重之海水倒灌。本研究數值模式計算出之答案，於雲林口湖一帶之暴潮偏差遠大於臺灣沿海其他地區。

- 以2013年海燕颱風參數代入1986年韋恩颱風之真實路徑，計算氣候變遷情況下，強烈颱風等極端事件於臺灣造成之風暴潮影響；模式計算結果於雲林口湖地區有4公尺以上之暴潮偏差，若未來發生類似路徑之強烈颱風情況，中部地區如梧棲、芳苑和麥寮等地應嚴防海水倒灌之災情。

Future Work

- 針對氣象局9種侵臺颱風路徑和特殊路徑進行模擬與研究，分析不同路徑對於臺灣雲林口湖以及沿海其他地區之風暴潮水位敏感度，並考慮端端事件下之強烈颱風對於臺灣可能造成之風暴潮災害。

- 耦合COMCOT多重網格海嘯模式之巢狀網格功能，計算高解析度地形之近岸風暴潮傳遞以及溯上情況，同時以移動邊界法推算暴潮溢淹範圍。

- 將風暴潮模式耦合天文潮，使模式中考慮潮汐傳遞。

謝謝各位

歡迎提問

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Institute of Hydrological and Oceanic Sciences