Disaster Mitigation Workshop
APAN 44 at Dalian, China

Demonstration of Tsunami and Storm Surge Modeling

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Tsunami Disaster

http://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/9563/Can-Acoustic-Waves-Act-as-Tsunami-Detectors.aspx

http://www.newstatesman.com/culture/books/2017/08/ghosts-tsunami-what-disaster-japan-left-behind

COMCOT Tsunami Model

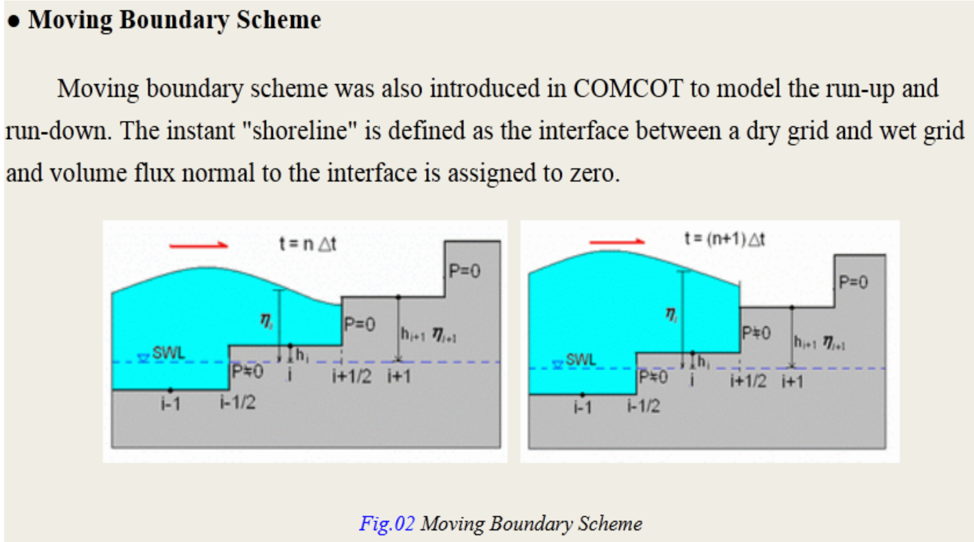
COrnell Multi-grid Coupled Tsunami Model

Solve nonlinear shallow water equation directly

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

$$\frac{\partial P}{\partial t} + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \psi}\left(\frac{P^2}{H}\right) + \frac{1}{R}\frac{\partial}{\partial \varphi}\left(\frac{PQ}{H}\right) + \frac{gH}{R\cos\varphi}\frac{\partial \eta}{\partial \psi} - f \cdot Q + F_{\psi}^{b} = 0$$

$$\frac{\partial Q}{\partial t} + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \psi}\left(\frac{PQ}{H}\right) + \frac{1}{R}\frac{\partial}{\partial \varphi}\left(\frac{Q^2}{H}\right) + \frac{gH}{R}\frac{\partial \eta}{\partial \varphi} + f \cdot P + F_{\varphi}^{b} = 0$$



- **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

- Solve nonlinear shallow water equations on both spherical and Cartesian coordinates.
- 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 of OpenMp parallel computation.

COMCOT has been used on many scientific papers

At least 26 SCI papers were published during 2001 to 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

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

（To be continued）

Supporting Tool with COMCOT Tsunami Model

- Fortran Compiler: ifort
- Data Processing: MATLAB/Octave
- Figure Plotting: MATLAB/Octave

Intel® Fortran Compiler

MathWorks®

GNU Octave

1. Demonstration of 2004 Sumatra Tsunami

Tsunami Source Reconstruction of 2004 Sumatra Tsunami

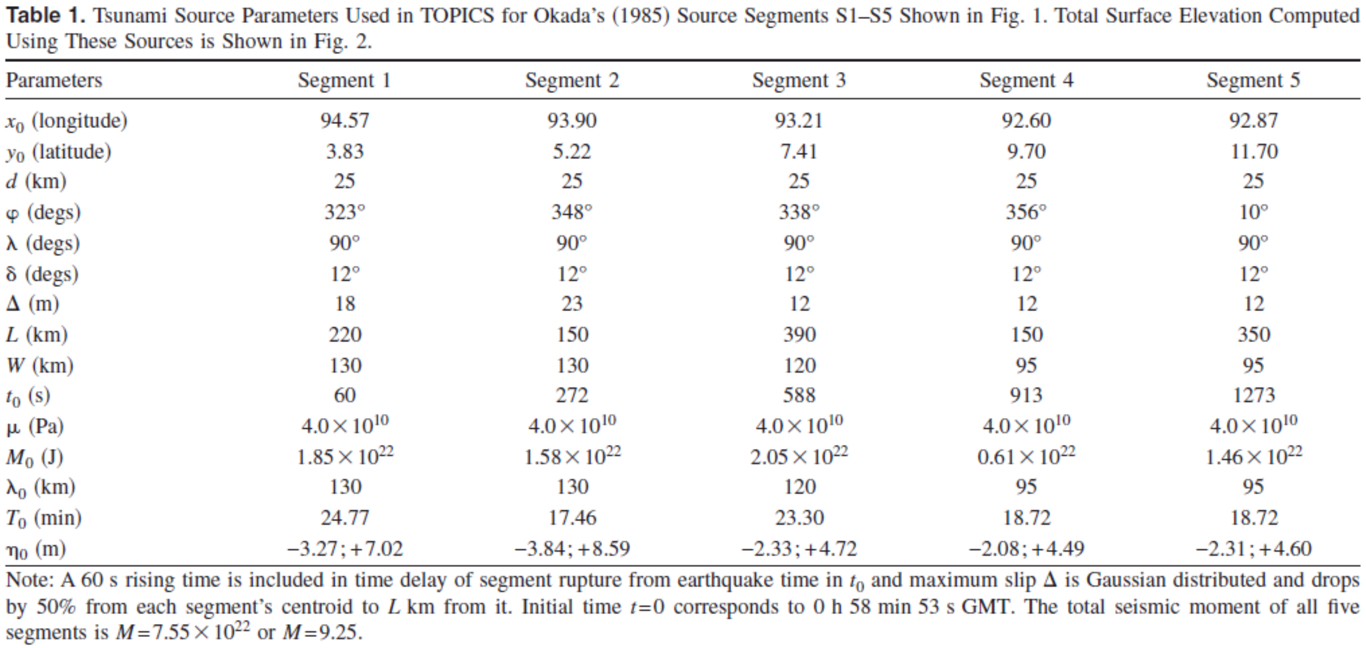
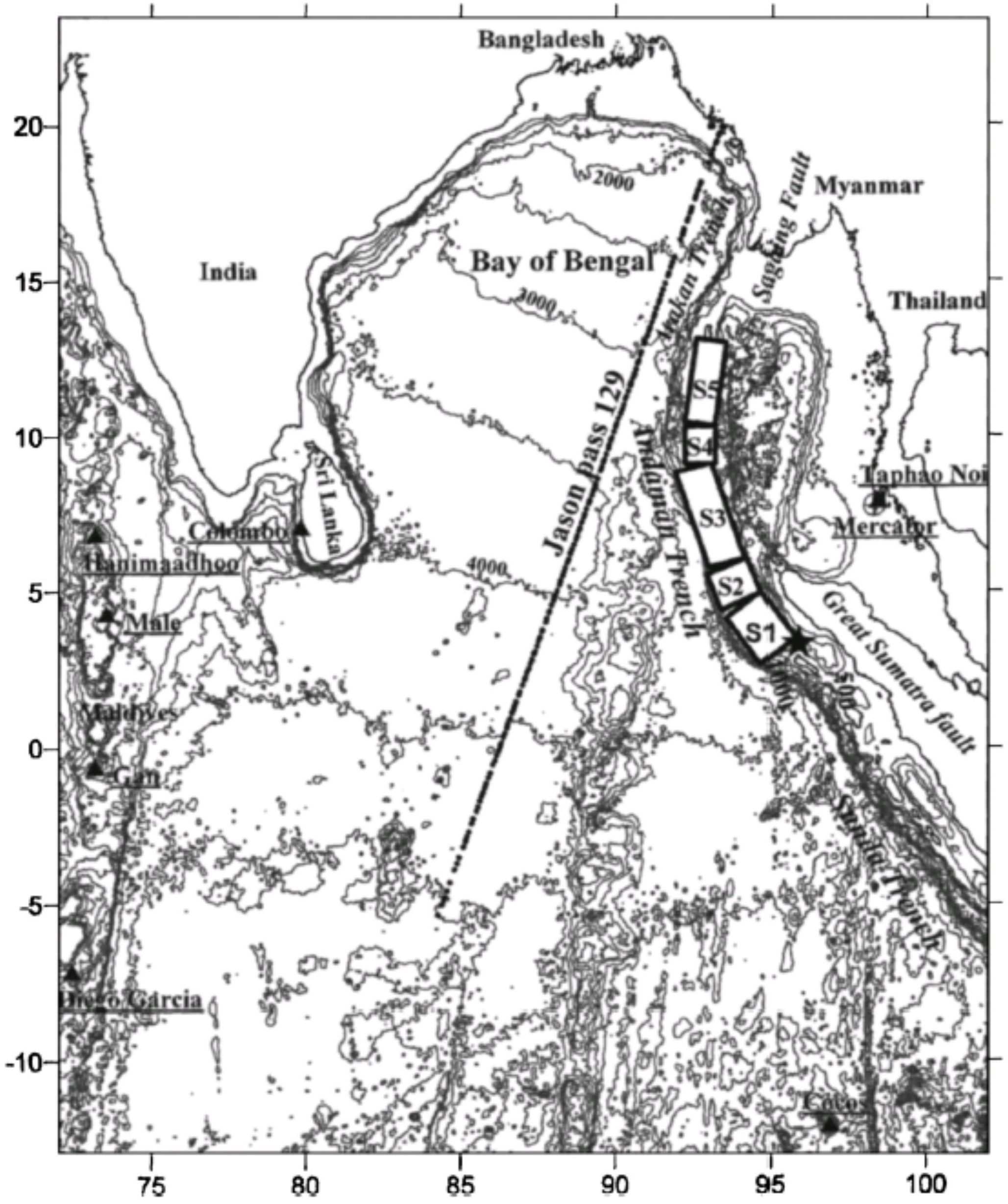


Table 1. Tsunami Source Parameters Used in TOPICS for Okada's (1985) Source Segments S1–S5 Shown in Fig. 1. Total Surface Elevation Computed Using These Sources is Shown in Fig. 2.

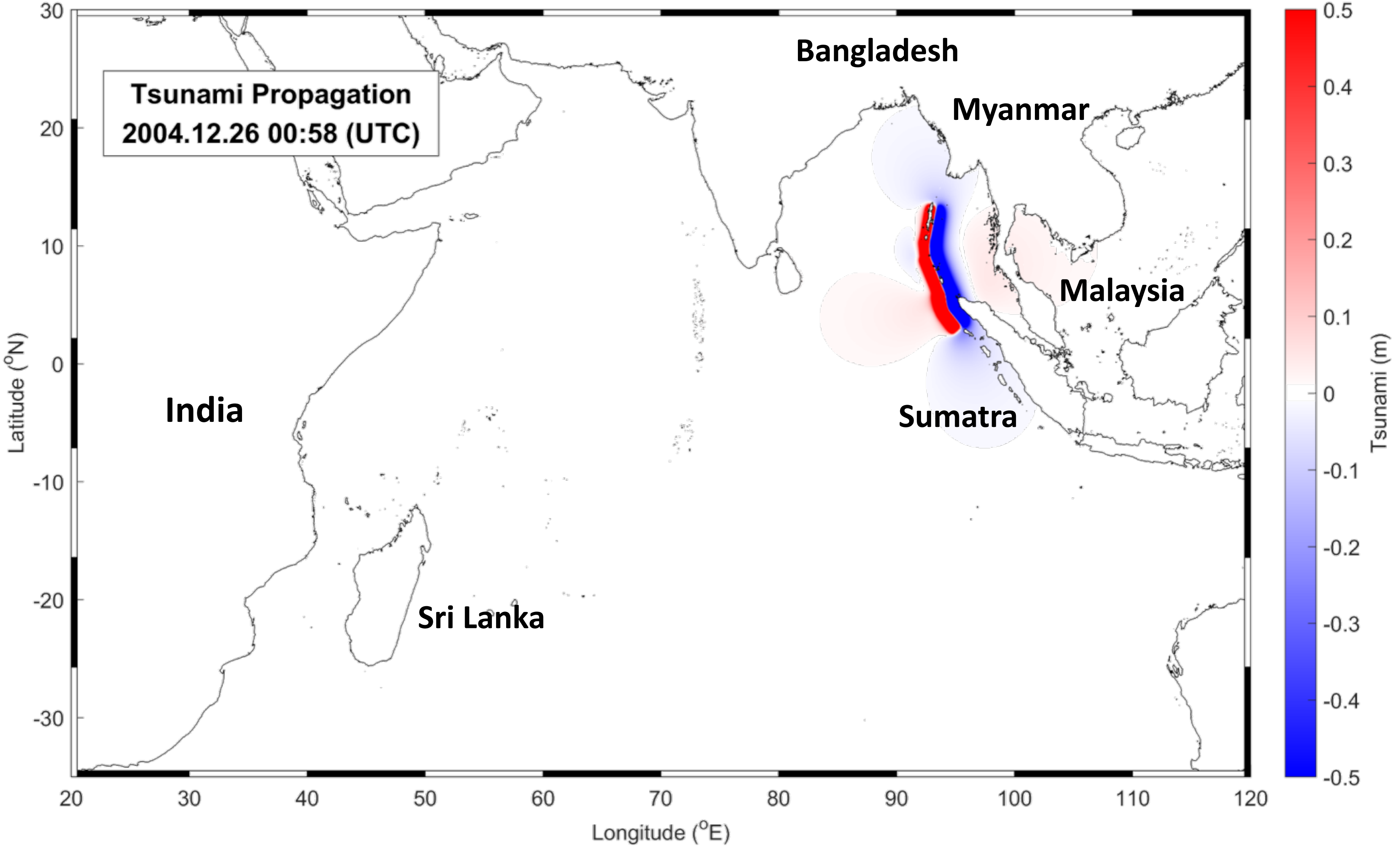
Parameters	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
x_0 (longitude)	94.57	93.90	93.21	92.60	92.87
y_0 (latitude)	3.83	5.22	7.41	9.70	11.70
d (km)	25	25	25	25	25
φ (degs)	323°	348°	338°	356°	10°
λ (degs)	90°	90°	90°	90°	90°
δ (degs)	12°	12°	12°	12°	12°
Δ (m)	18	23	12	12	12
L (km)	220	150	390	150	350
W (km)	130	130	120	95	95
t_0 (s)	60	272	588	913	1273
μ (Pa)	4.0×10^{10}	4.0×10^{10}	4.0×10^{10}	4.0×10^{10}	4.0×10^{10}
M_0 (J)	1.85×10^{22}	1.58×10^{22}	2.05×10^{22}	0.61×10^{22}	1.46×10^{22}
λ_0 (km)	130	130	120	95	95
T_0 (min)	24.77	17.46	23.30	18.72	18.72
η_0 (m)	−3.27; +7.02	−3.84; +8.59	−2.33; +4.72	−2.08; +4.49	−2.31; +4.60

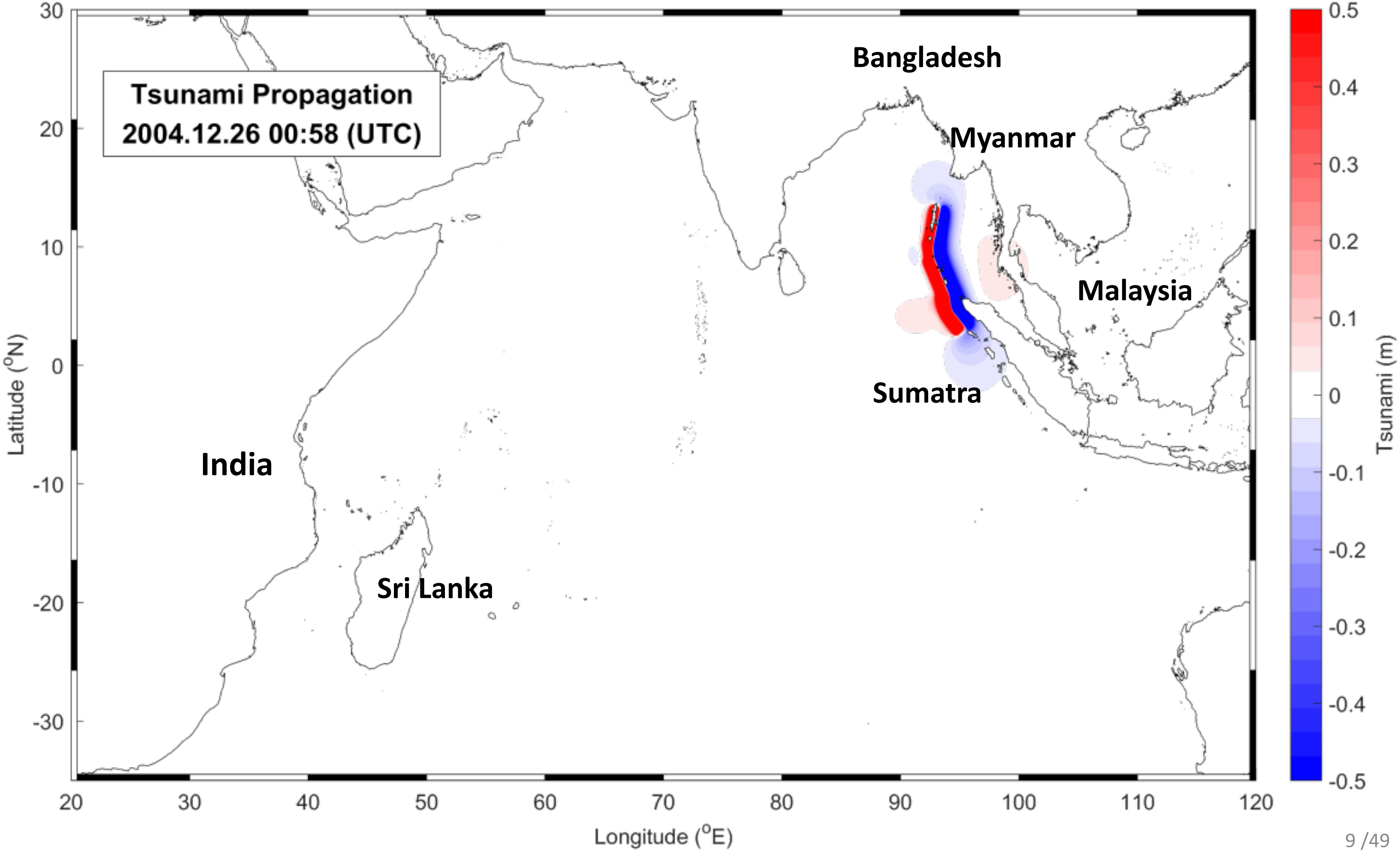
Note: A 60 s rising time is included in time delay of segment rupture from earthquake time in t_0 and maximum slip Δ is Gaussian distributed and drops by 50% from each segment's centroid to L km from it. Initial time $t=0$ corresponds to 0 h 58 min 53 s GMT. The total seismic moment of all five segments is $M=7.55\times10^{22}$ or $M=9.25$.



Source Constraints and Model Simulation of the December 26, 2004, Indian Ocean Tsunami (Grilli et al., 2007)

Initial Tsunami Wave Height of 2004 Sumatra Tsunami




Tsunami Propagation
2004.12.26 00:58 (UTC)
Bangladesh
Myanmar
Malaysia
Sumatra
India
Sri Lanka
30
20
10
0
-10
-20
-30
Latitude (°N)
20
30
40
50
60
70
80
90
100
110
120
Longitude (°E)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Tsunami (m)

2. Demonstration of 2011 Japan Tsunami

Tsunami Source Reconstruction of 2011 Japan Tsunami

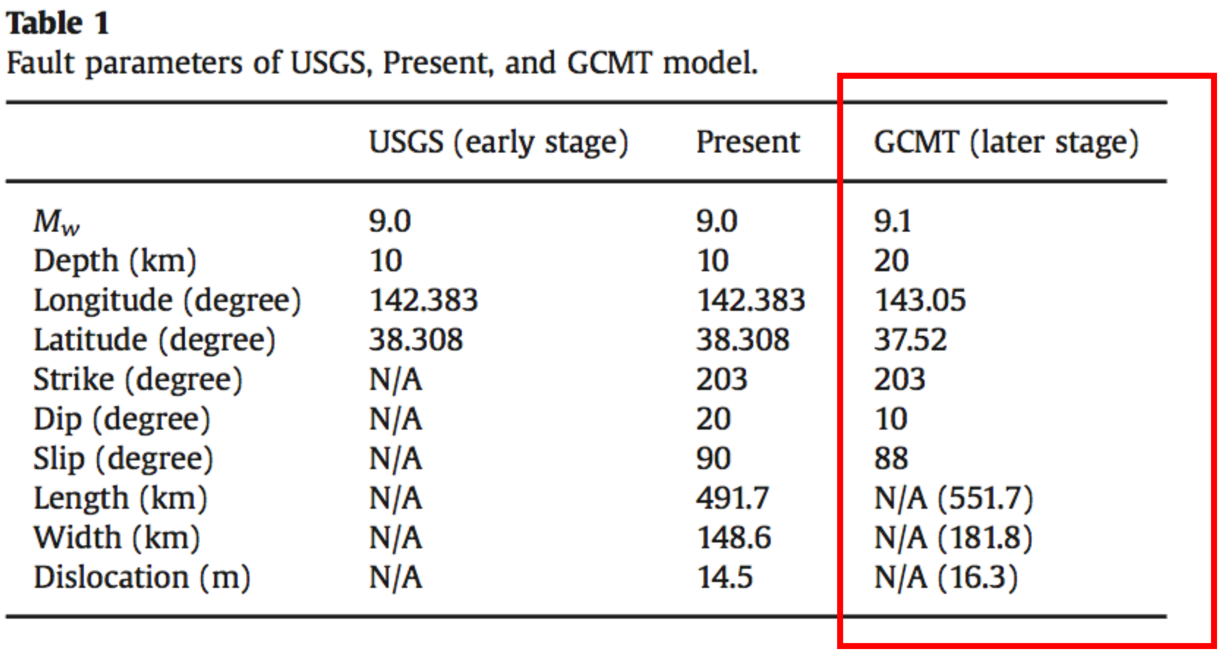
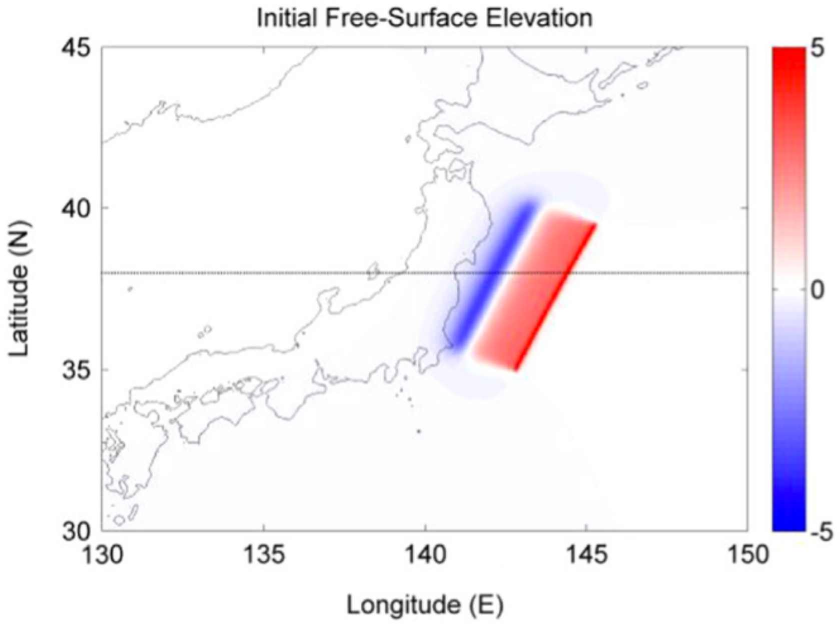
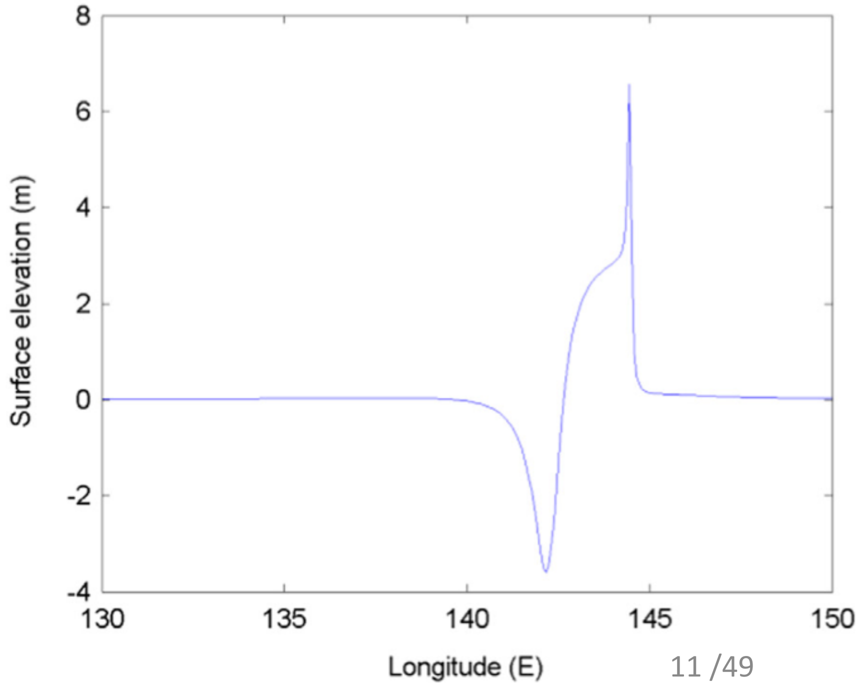


Table 1
Fault parameters of USGS, Present, and GCMT model.

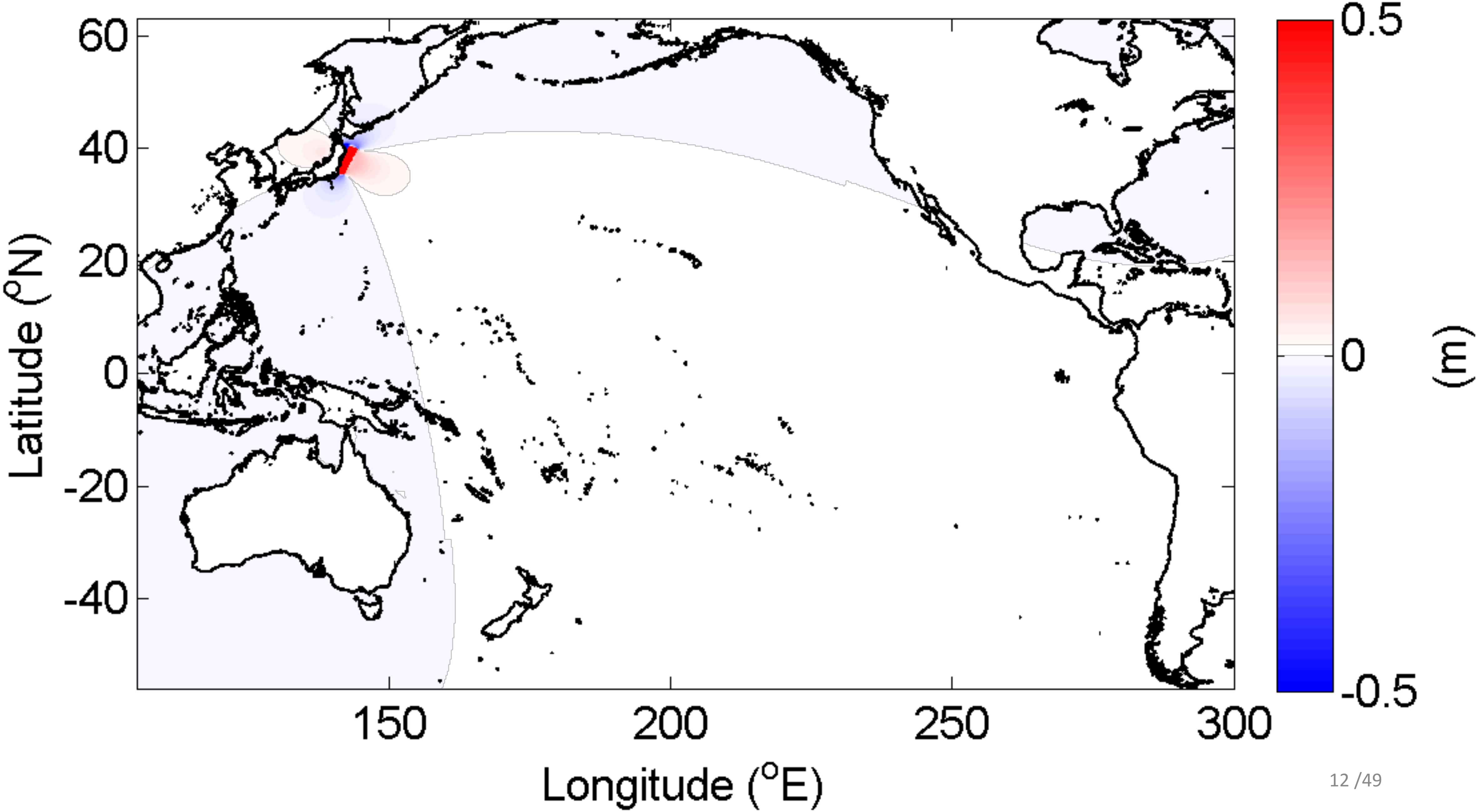
	USGS (early stage)	Present	GCMT (later stage)
M_w	9.0	9.0	9.1
Depth (km)	10	10	20
Longitude (degree)	142.383	142.383	143.05
Latitude (degree)	38.308	38.308	37.52
Strike (degree)	N/A	203	203
Dip (degree)	N/A	20	10
Slip (degree)	N/A	90	88
Length (km)	N/A	491.7	N/A (551.7)
Width (km)	N/A	148.6	N/A (181.8)
Dislocation (m)	N/A	14.5	N/A (16.3)

Development of a tsunami early warning system for the South China Sea (Lin et al., 2015)

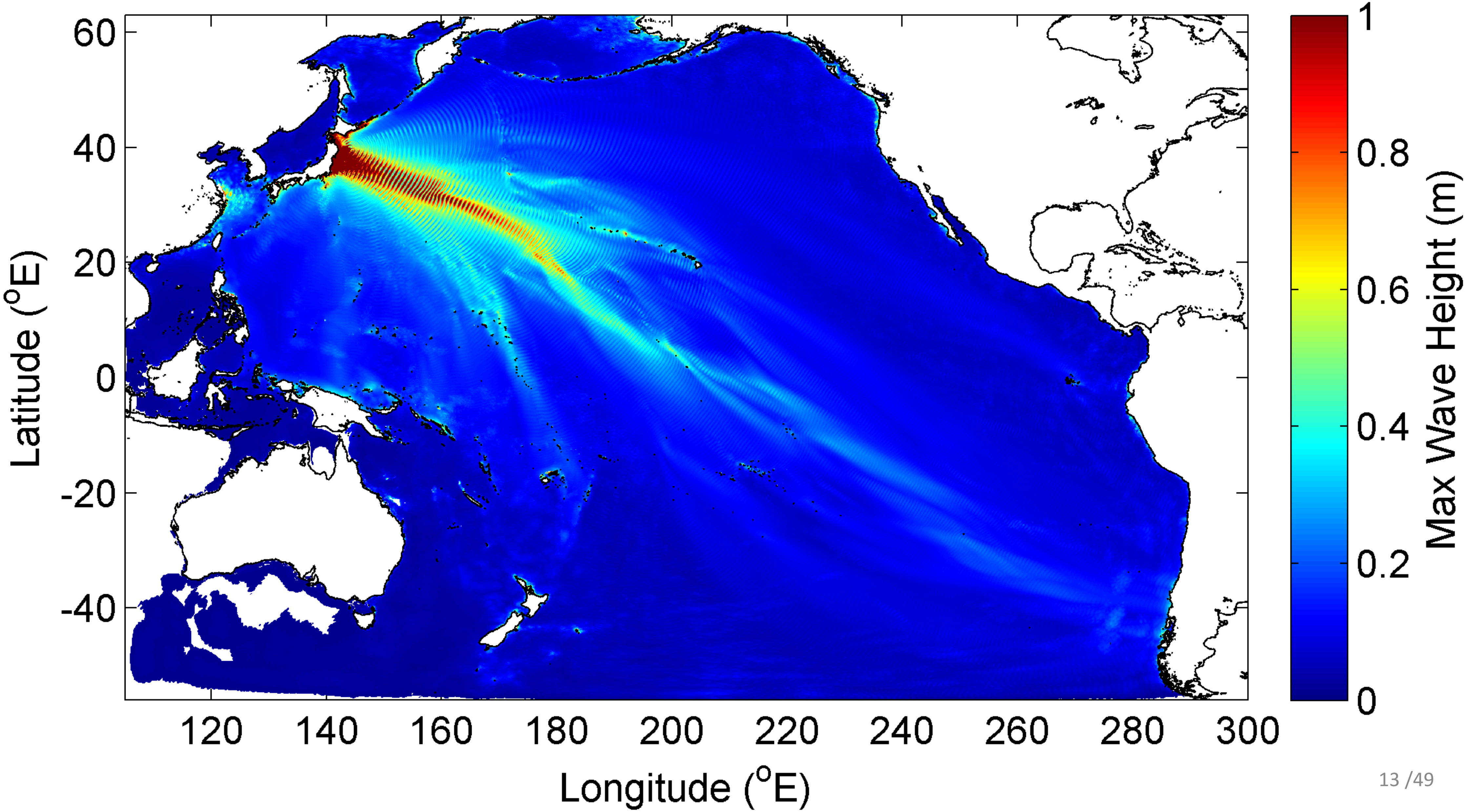




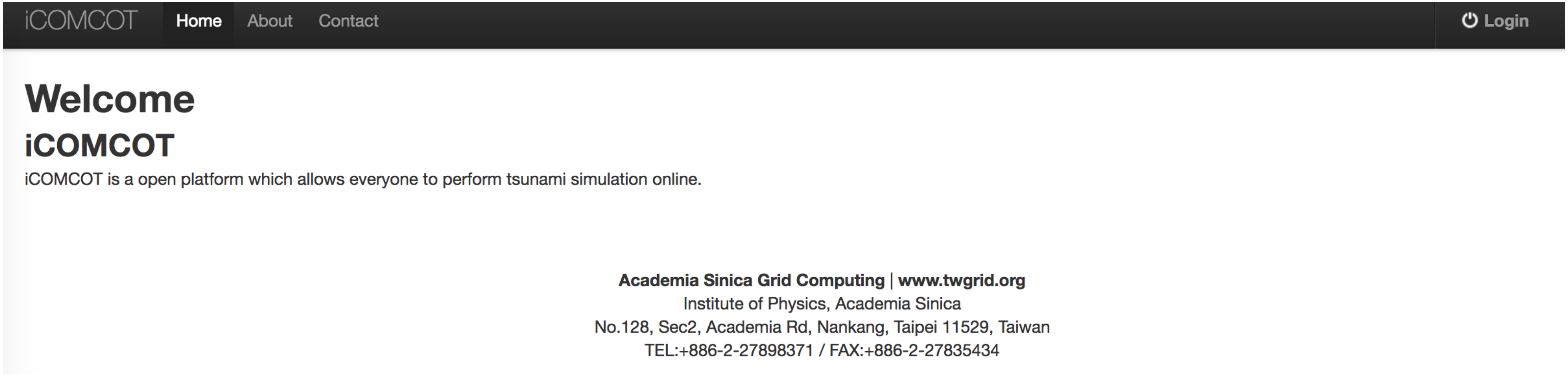
2011/03/11 05:47:33 (UTC+0)



Maximum Tsunami Wave Height of 2011 Japan Tsunami



iCOMCOT Cloud Computing Service at ASGC



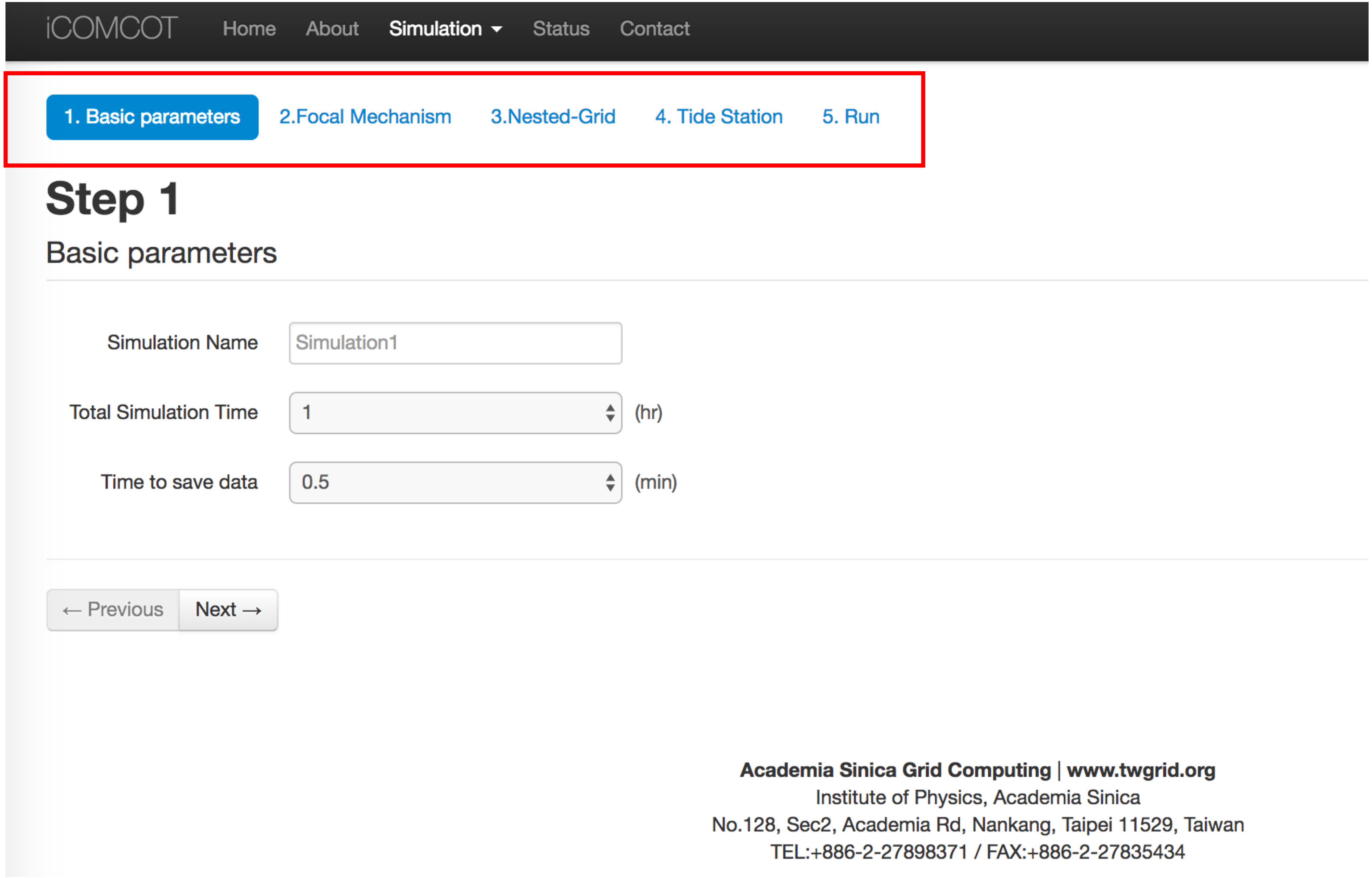
Welcome

iCOMCOT

iCOMCOT is a open platform which allows everyone to perform tsunami simulation online.

Academia Sinica Grid Computing | **www.twgrid.org**
Institute of Physics, Academia Sinica
No.128, Sec2, Academia Rd, Nankang, Taipei 11529, Taiwan
TEL:+886-2-27898371 / FAX:+886-2-27835434

iCOMCOT (https://icomcot.twgrid.org/index.html)



Step 1

Basic parameters

Simulation Name: Simulation1

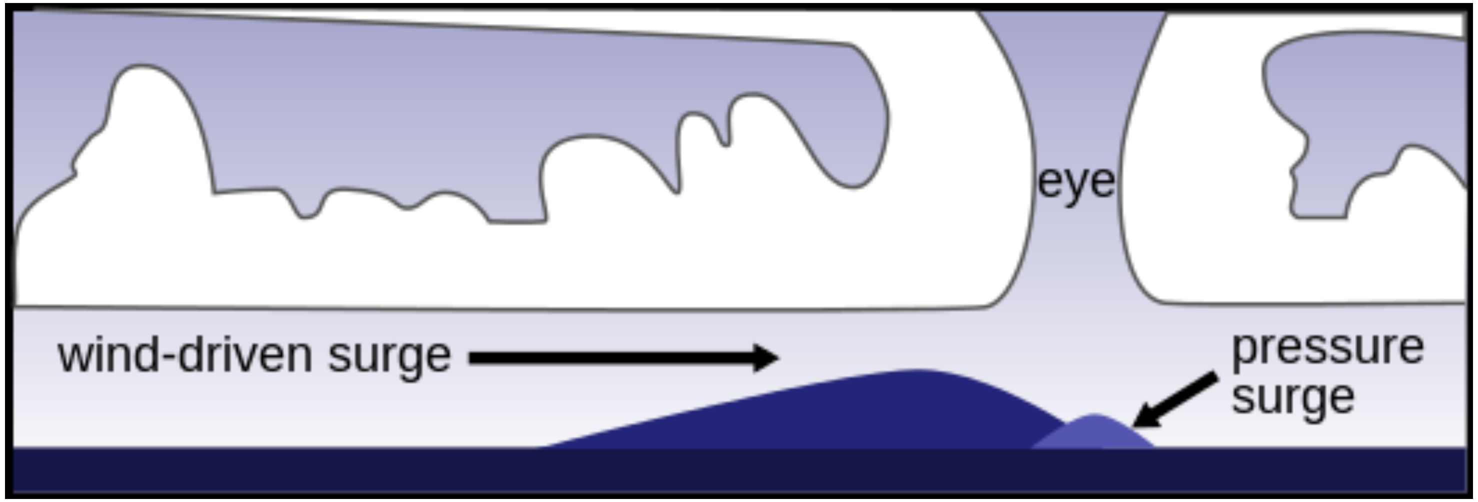
Total Simulation Time: 1 (hr)

Time to save data: 0.5 (min)

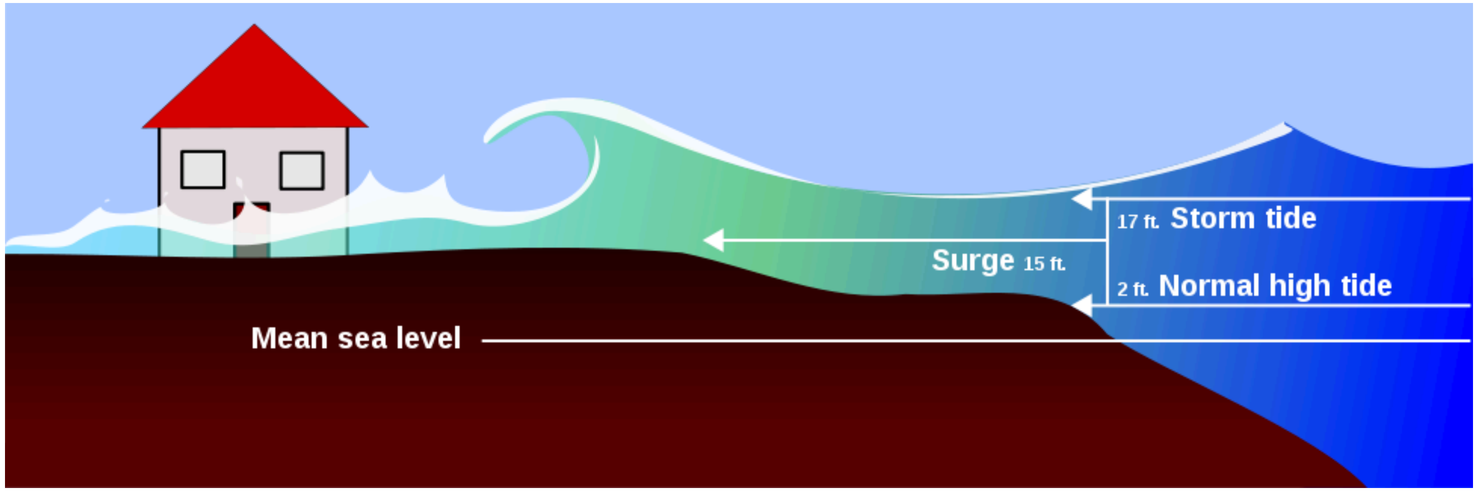
Academia Sinica Grid Computing | **www.twgrid.org**
Institute of Physics, Academia Sinica
No.128, Sec2, Academia Rd, Nankang, Taipei 11529, Taiwan
TEL:+886-2-27898371 / FAX:+886-2-27835434

Storm Surge Modeling

STORM SURGE



Sea Surface induced by typhoons (Wiki)



Tidal Effect with Storm Surges (Wiki)

- Storm surge is a coastal flood of rising water commonly associated with low pressure weather systems :
  - ✓ **Tropical cyclones**
  - ✓ **Storms**
  - ✓ **Typhoons**
  - ✓ **Hurricanes**

- The two main meteorological factors contributing to a storm surge are:
  - ✓ **Pressure gradient**
  - ✓ **Wind shear stress**

Inundation induced by Storm Surges

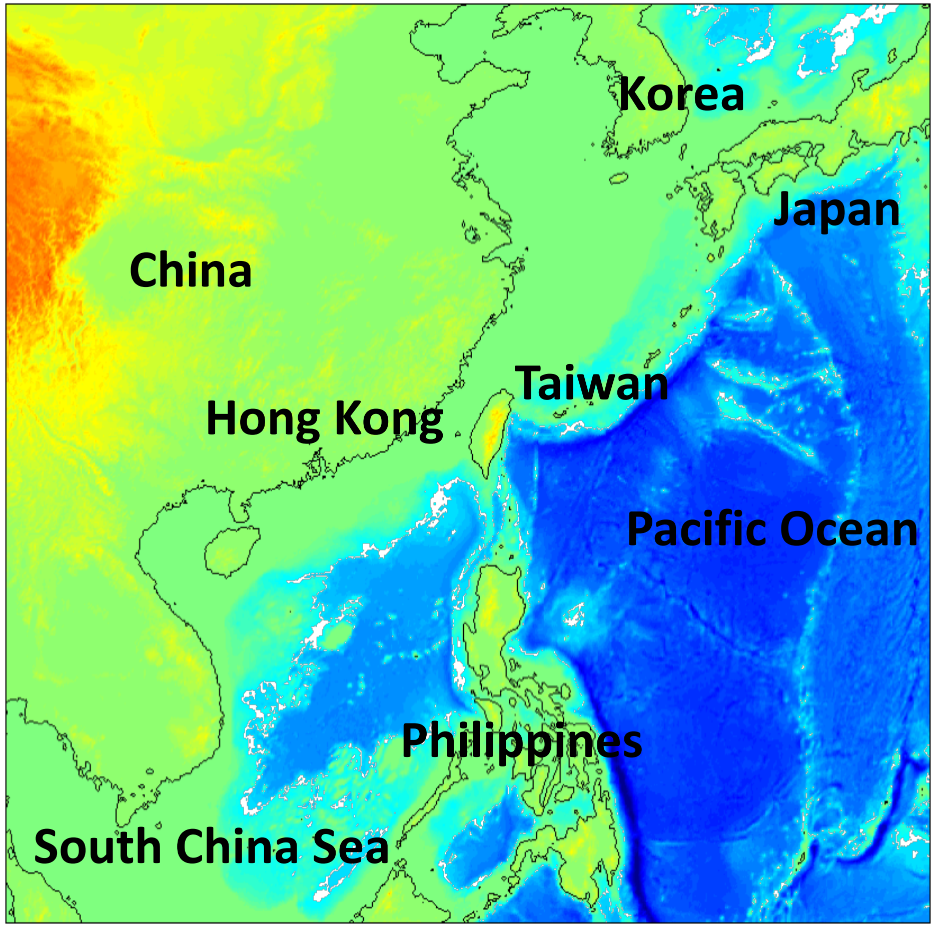
- *Destroy of homes and business*
- *Potential threat of coastal communities*
- *Damages of roads and bridges*

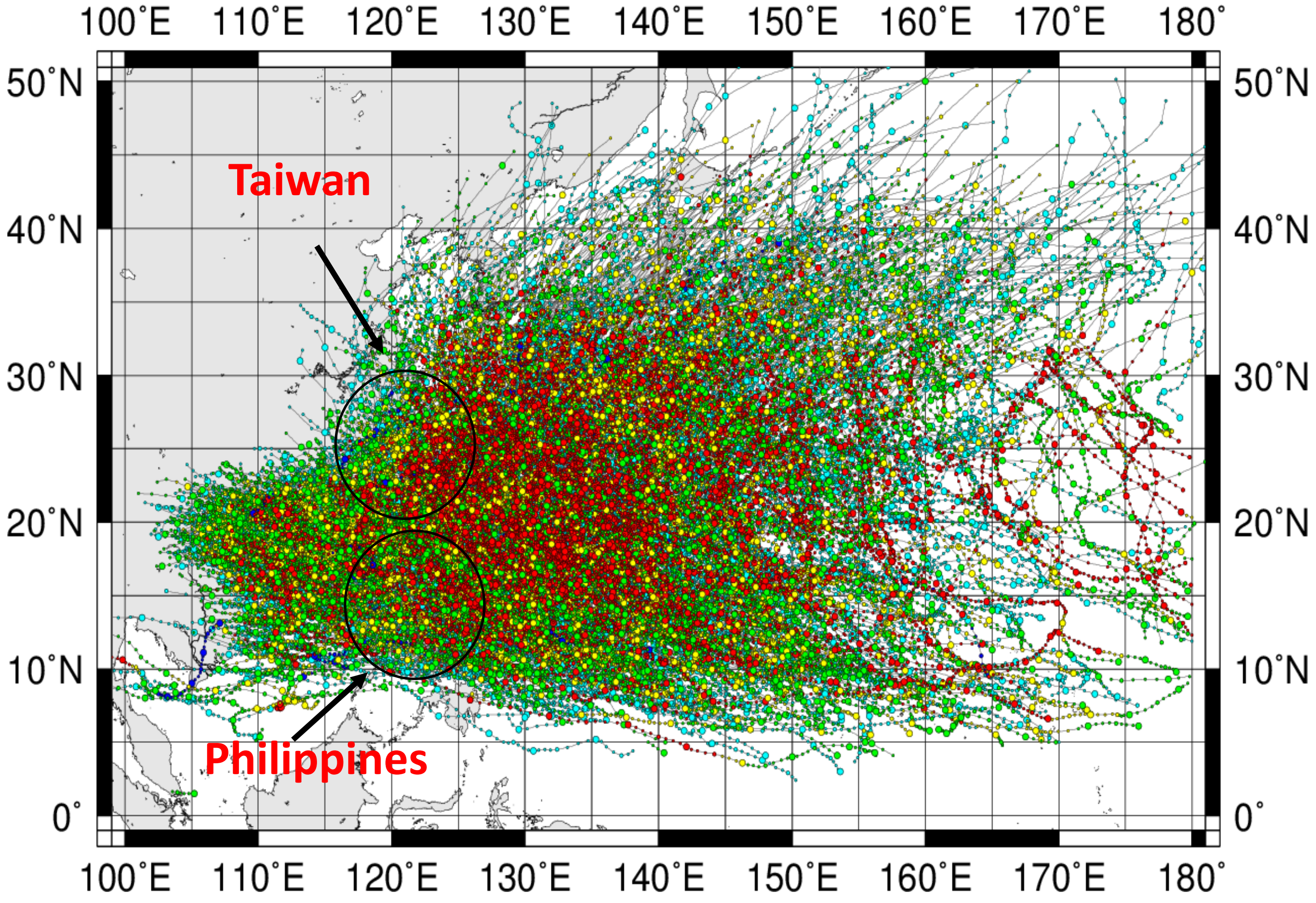
Views of inundated areas in New Orleans following breaking of the levees surrounding the city as the result of storm surge from Hurricane Katrina - 2005

Inundation induced by 2005 Hurricane Katrina. (http://www.stormsurge.noaa.gov/)

Flooded by storm surge of Hurricane Katrina (2005) in the northwest New Orleans.

Tropical Cyclones in East Asia





Tracks of all tropical cyclones in the northwestern Pacific Ocean between 1951 and 2014.

COMCOT-SURGE Model

(**CO**rnell **M**ulti-grid **CO**upled **T**sunami Model – Storm Surge)

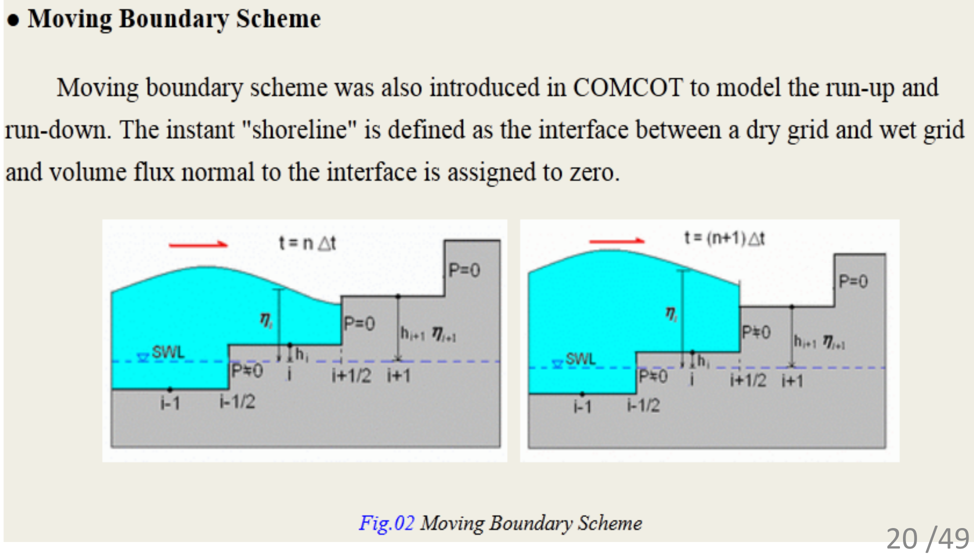
Nonlinear Shallow Water Equations on the Spherical Coordinate

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

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

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

- Solve nonlinear shallow water equations on **both spherical and Cartesian coordinates.**
- **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

Supporting Tool with COMCOT-SURGE Model

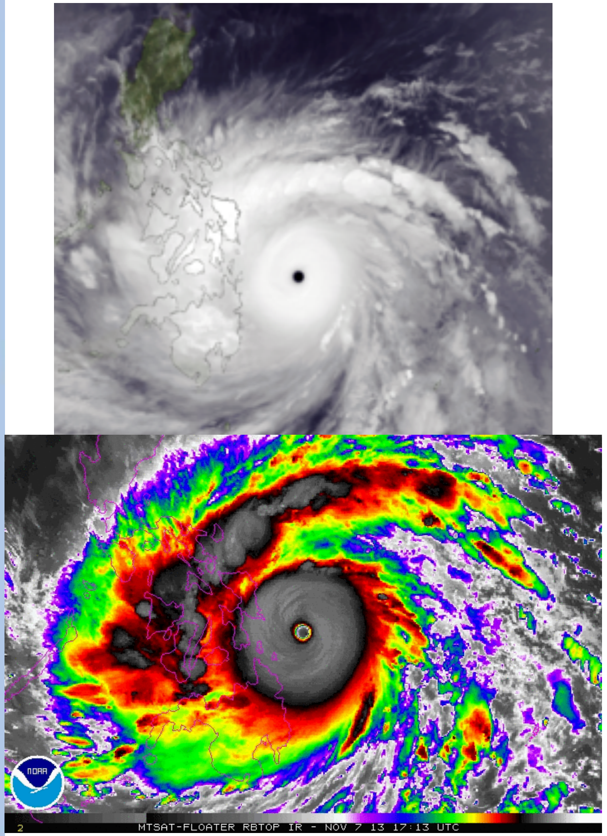
- Fortran Compiler: ifort
- Data Processing: MATLAB/Octave
- Figure Plotting: MATLAB/Octave

Intel® Fortran Compiler

MathWorks®

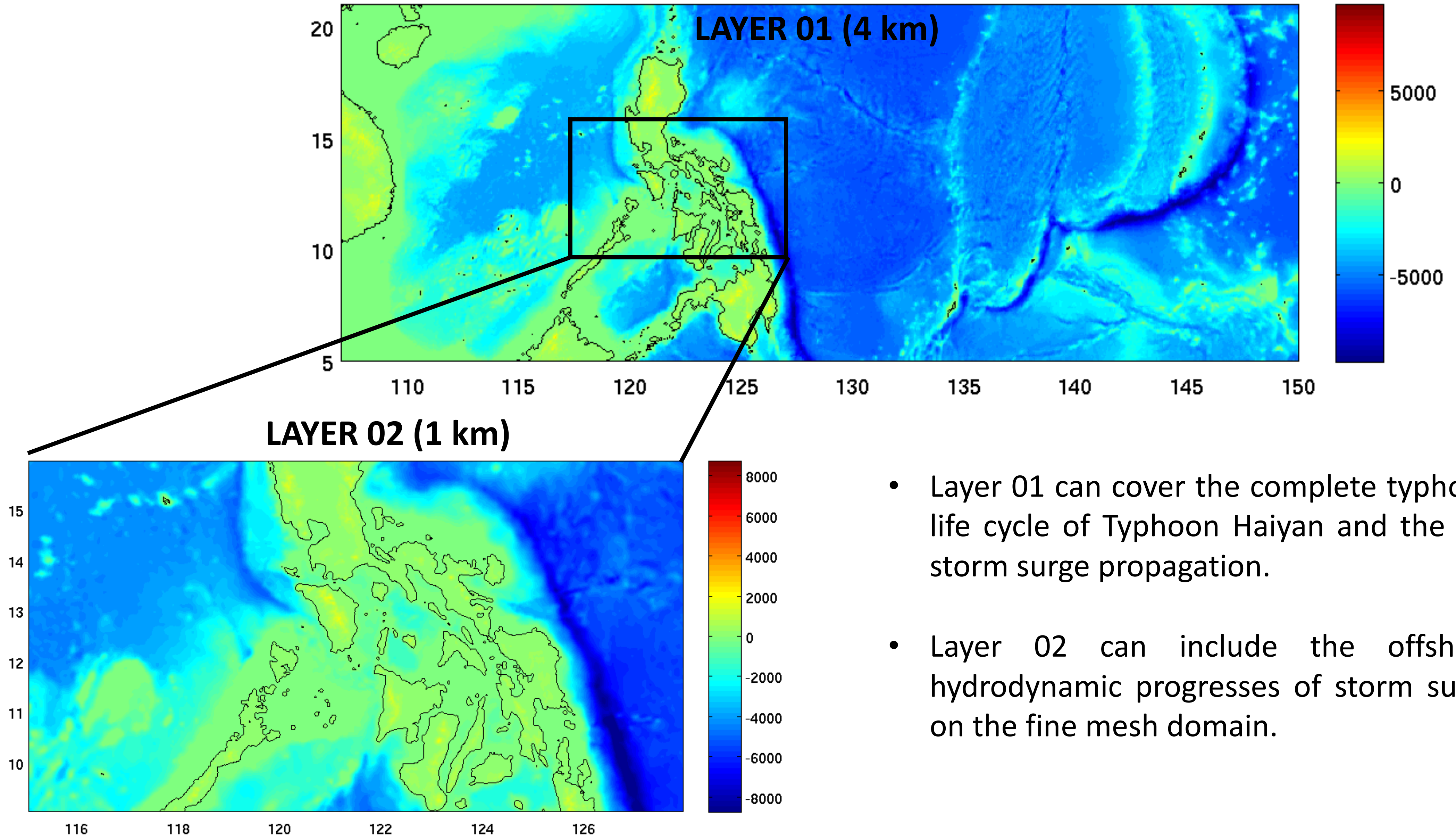
GNU Octave

1. The Case Study of 2013 Typhoon Haiyan



Source: Hong Kong Observatory

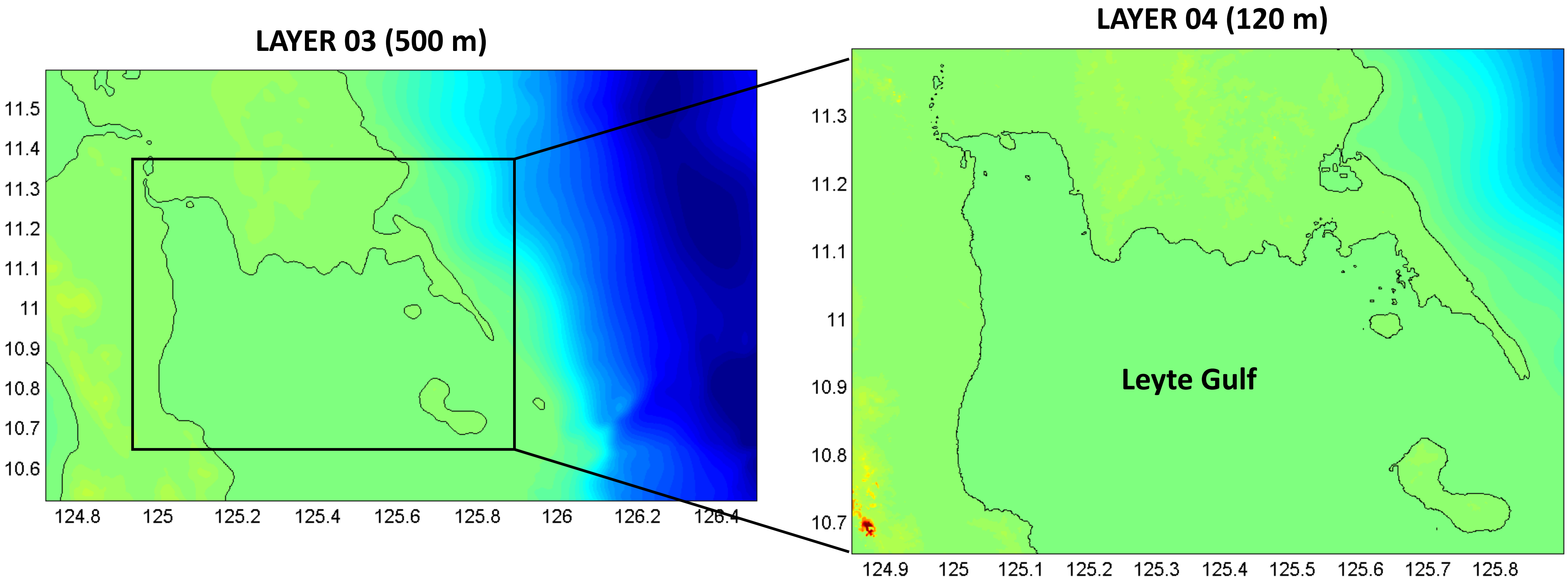
Four-Level Nested Computational Domain



- Layer 01 can cover the complete typhoon life cycle of Typhoon Haiyan and the full storm surge propagation.
- Layer 02 can include the offshore hydrodynamic progresses of storm surge on the fine mesh domain.

Near-shore Computational Domain

Layer 03 (500 m)/ Layer 04 (120 m)

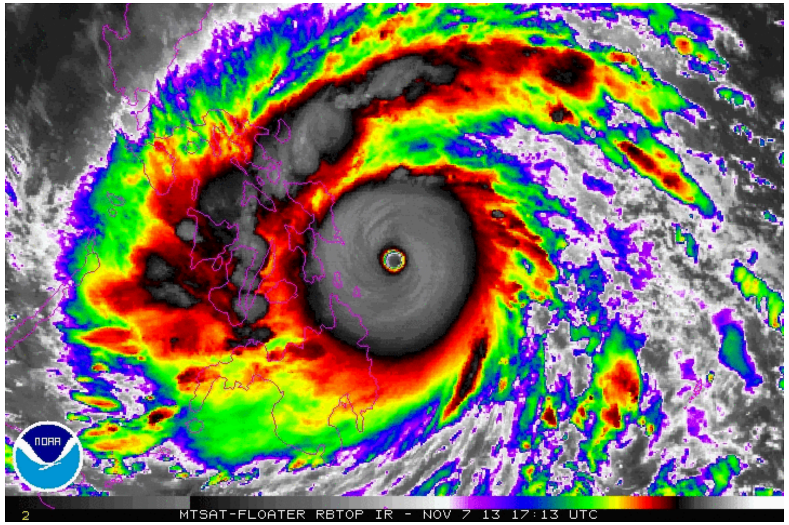


LAYER 03 (500 m)

LAYER 04 (120 m)

The computational domain of Layer 03 and Layer 04 could cover the storm surge propagations in offshore and nearshore regions.

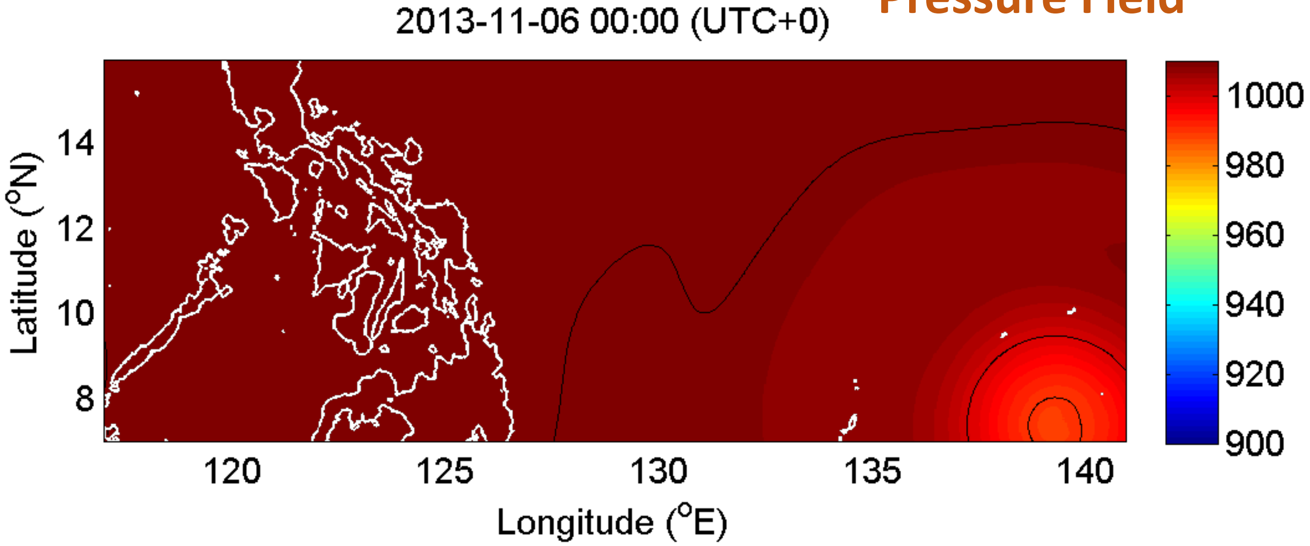
Combine with the Atmospheric WRF Model



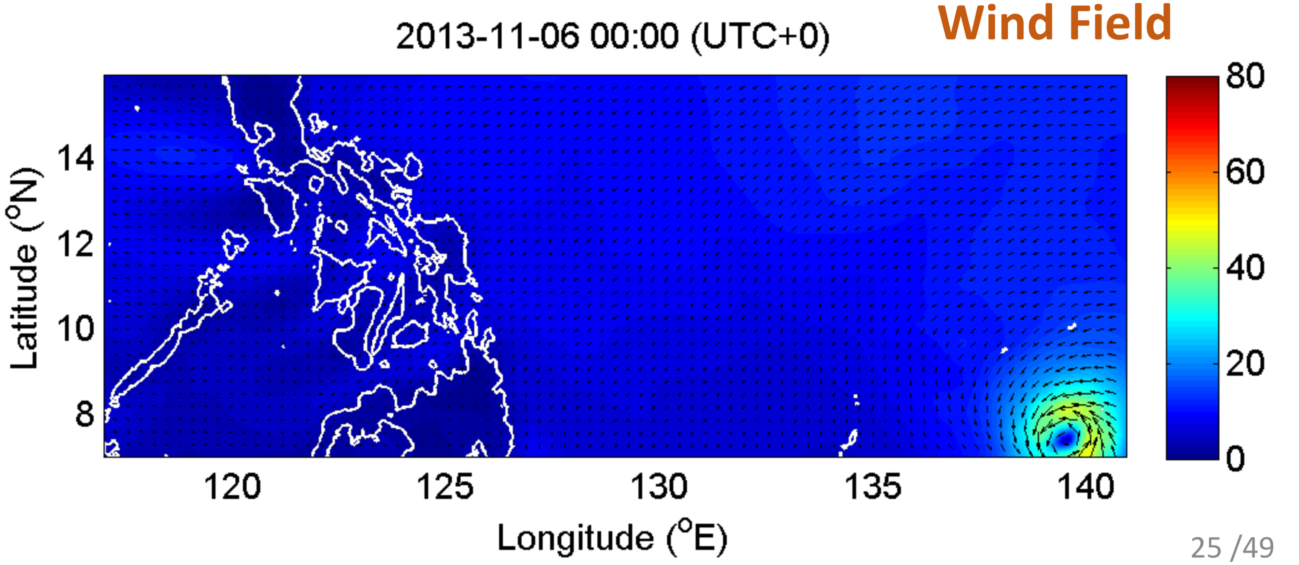
- *Asymmetric effect*
- *Topographic effect*
- *Hydrodynamic Pressure*

The WRF simulations are provided by Prof. Chuan-Yao Lin, AAR Modeling Laboratory (Sinica).

Pressure Field

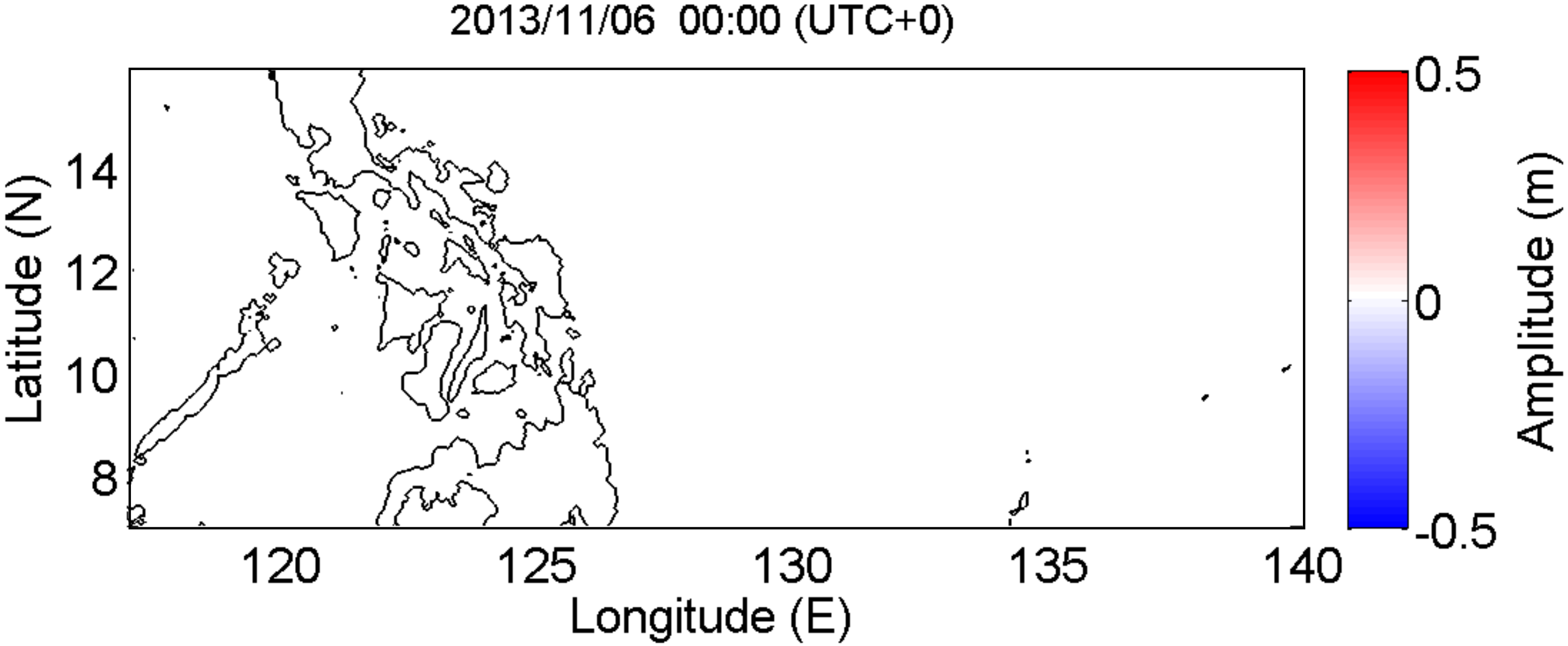

2013-11-06 00:00 (UTC+0)

Wind Field


2013-11-06 00:00 (UTC+0)

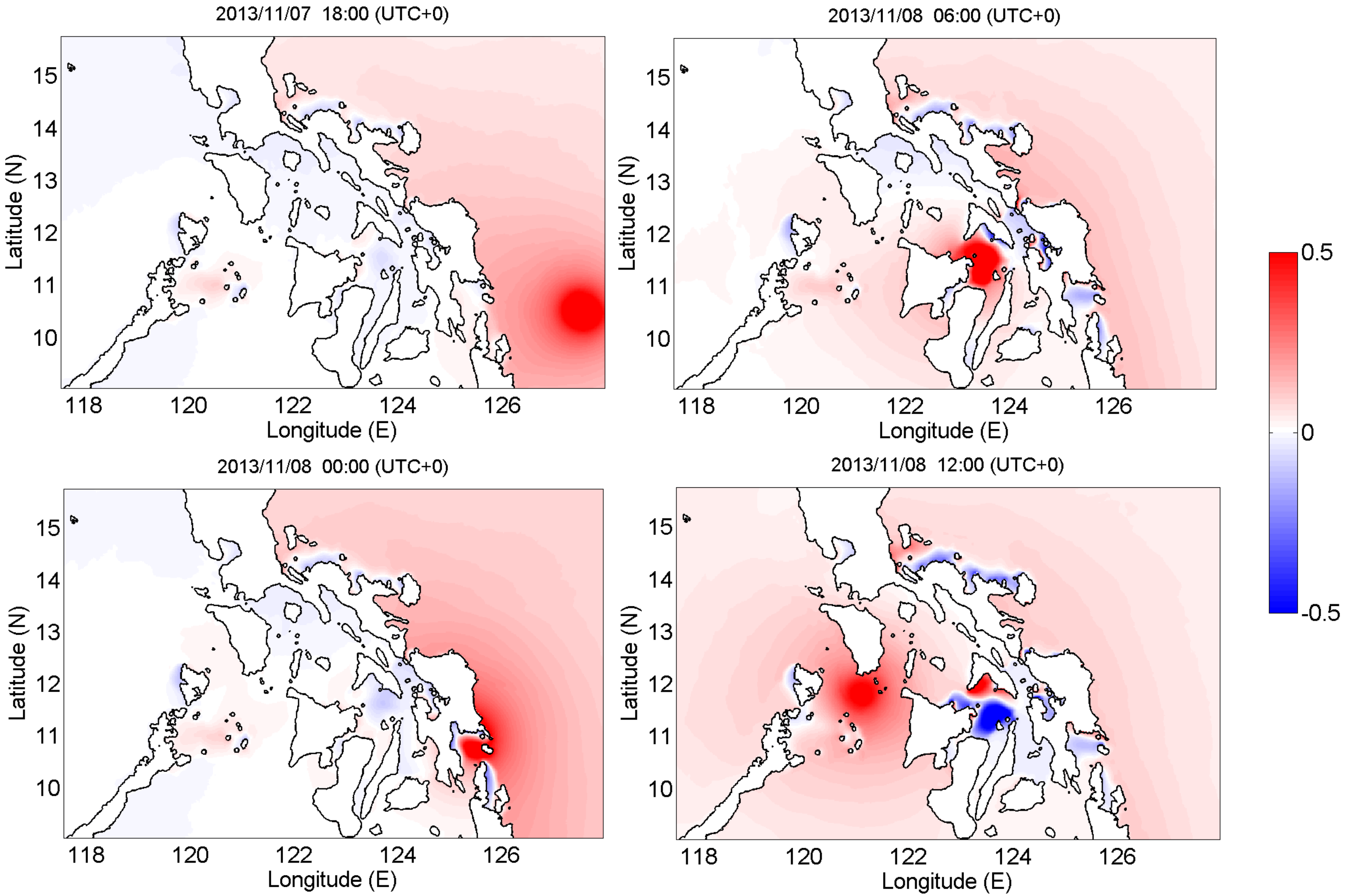
Storm Surges Induced by Typhoon Haiyan

2013.11.06 00:00 – 2013.11.09 00:00 (UTC+0)

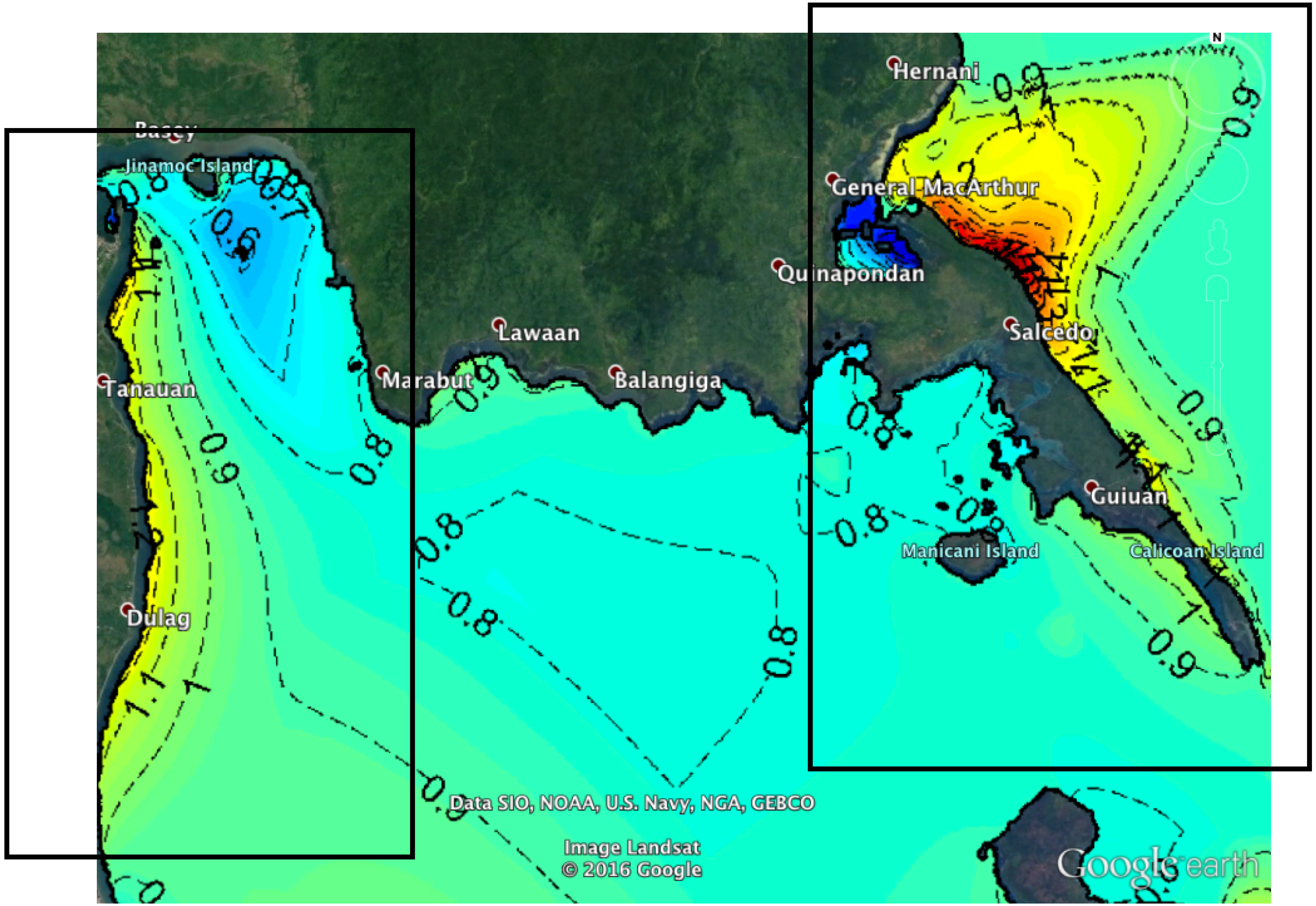


Large computational domain to cover the complete storm surge propagation induced by Typhoon Haiyan with Coriolis effect.

Snapshots of Storm Surges in the Philippines



Maximum Simulated Storm Tides at Leyte Gulf



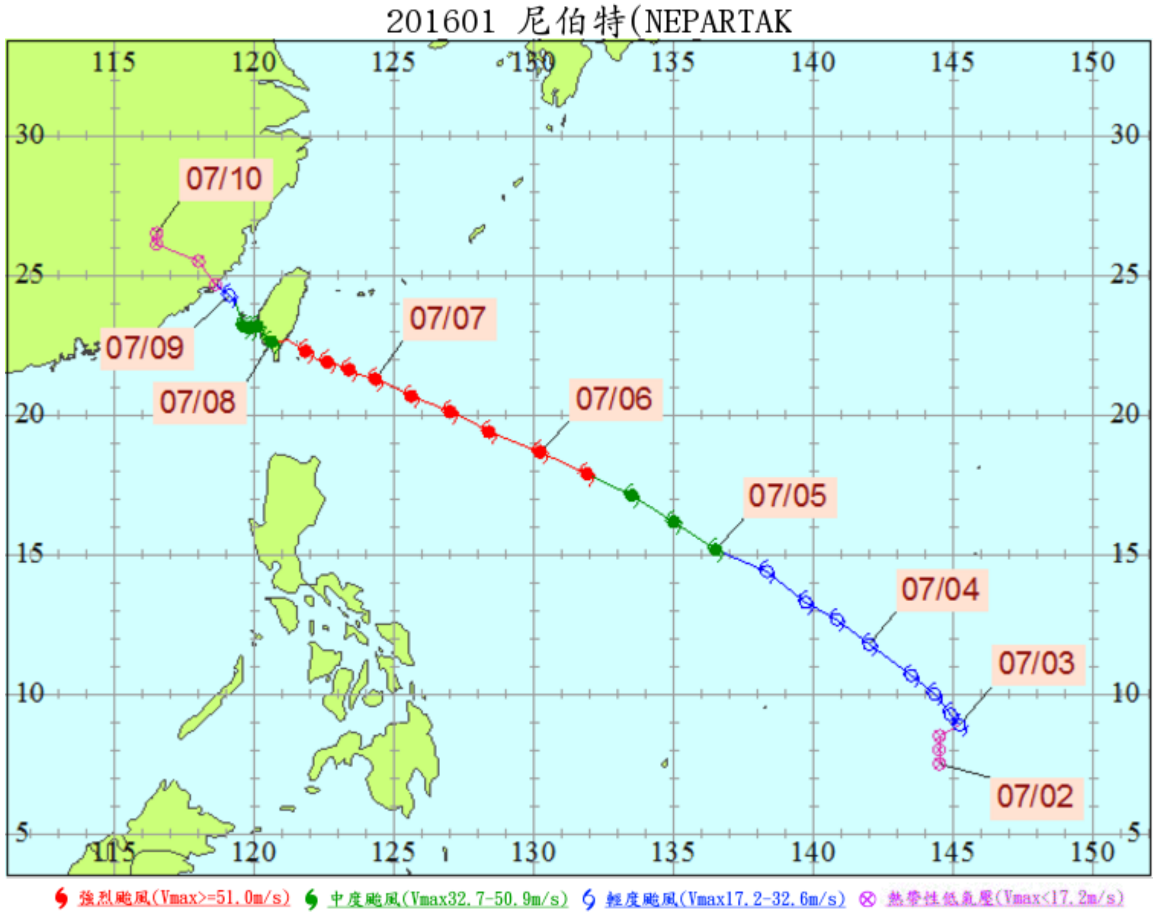
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Image Landsat
© 2016 Google

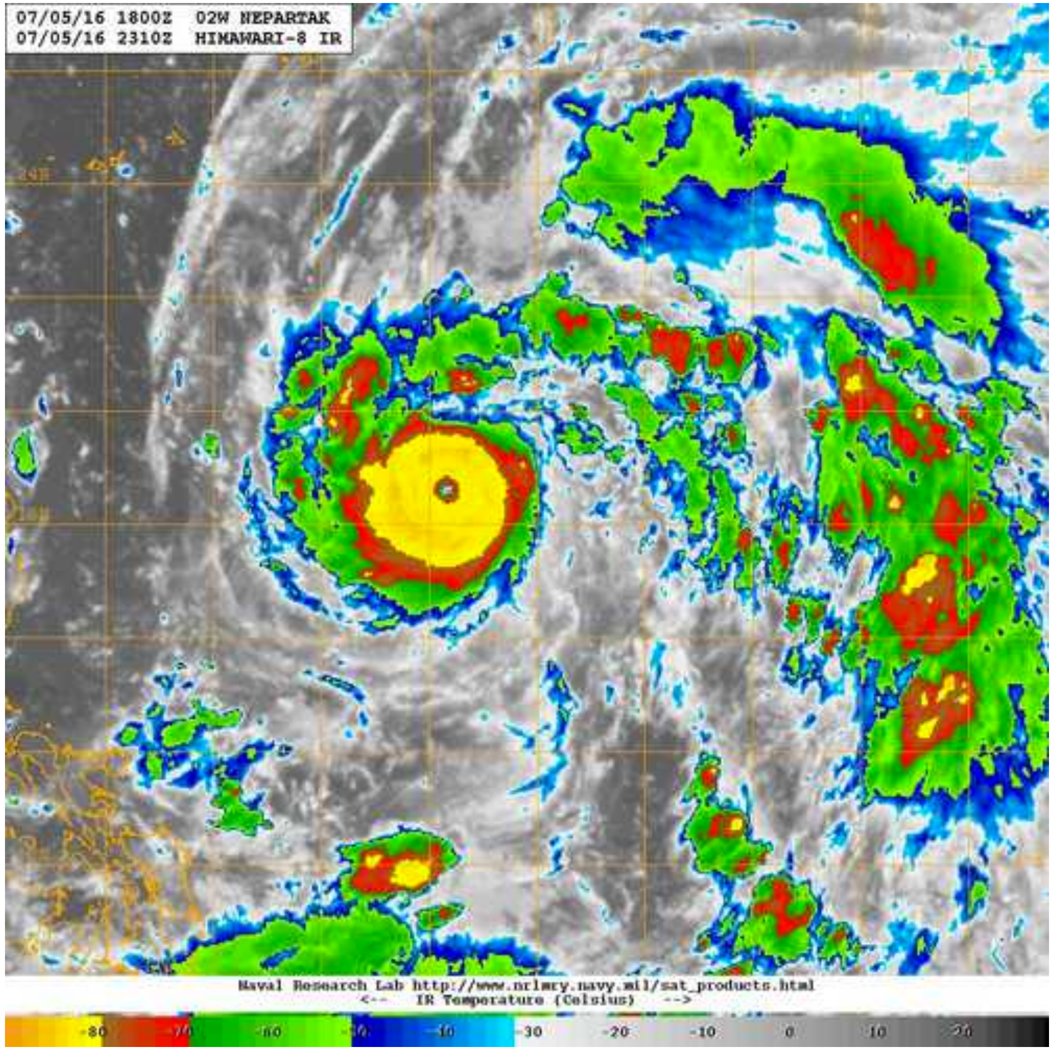
2. Demonstration of Operational Storm Surge Prediction in Taiwan

2016 Catogory-5 Typhoon Nepartak in Taiwan

Our COMCOT storm surge model has been to the official operational system at CWB, Taiwan since Typhoon Nepartak.



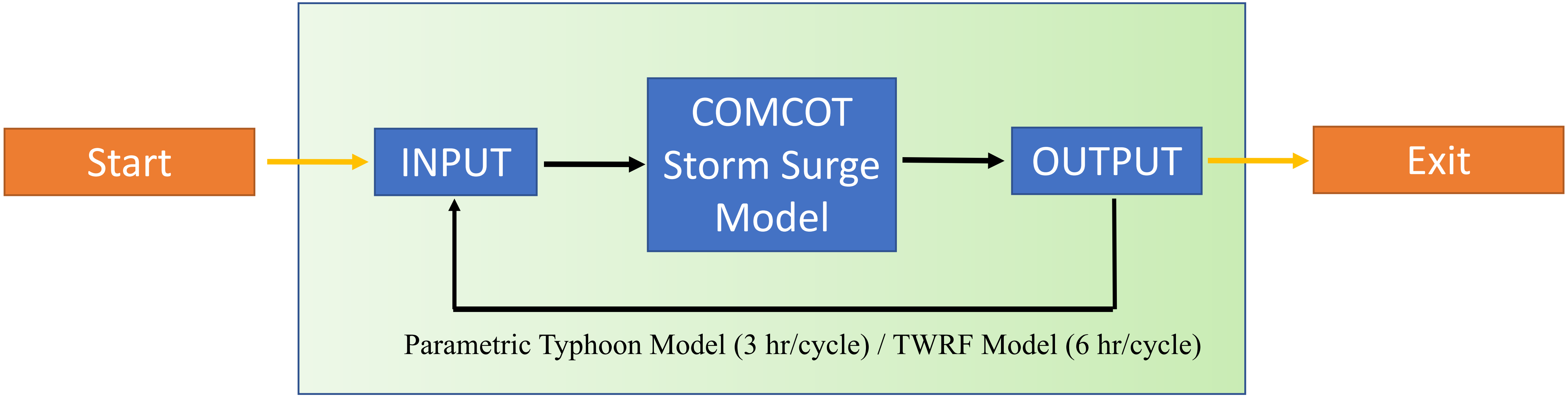
The track of Typhoon Nepartak (CWB, Taiwan)



U.S Naval Research Laboratory

Storm Surge Operational Task

Our COMCOT storm surge model has been the official operational system at the Central Weather Bureau (CWB) from 2016.



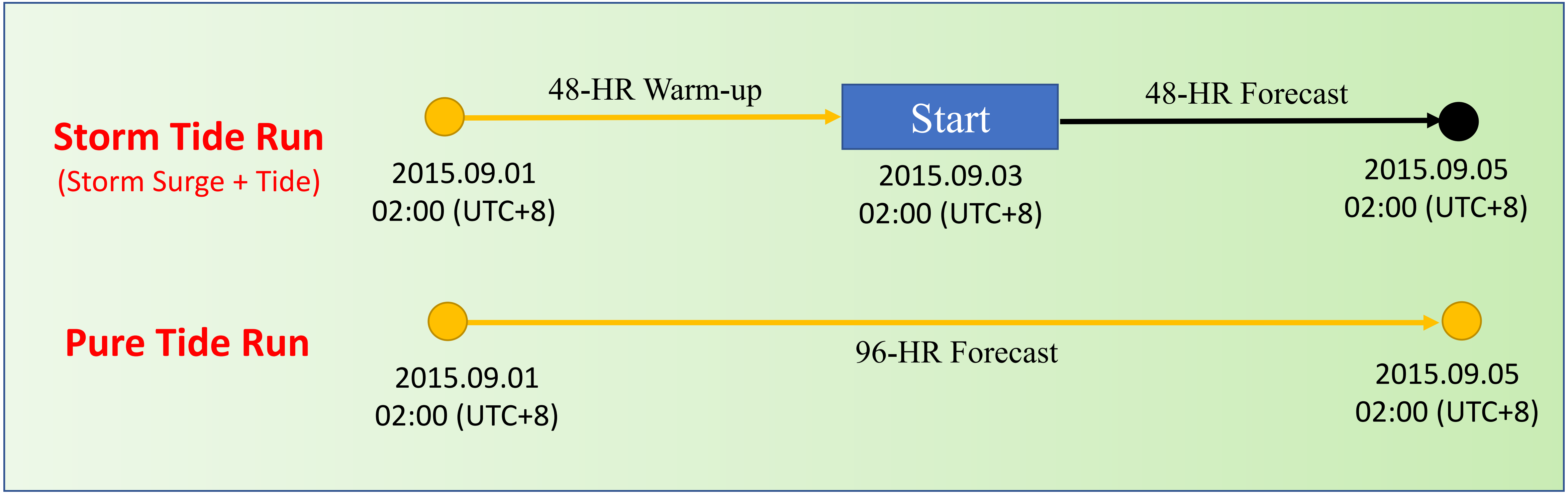
INPUT

- Meteorological Force: Parametric Typhoon Model or TWRF Model.
- Tidal Boundary Condition: TPXO 7.1 model.

OUTPUT

- 48-HR Time Series for Storm Tide and Pure Tide at 34 specified locations.
- 2-dimensional model product.

Schematic Diagram for Storm Tide Run and Pure Tide Run



Storm Tide Run

(Storm Surge + Tide)

2015.09.01
02:00 (UTC+8)

48-HR Warm-up

Start

2015.09.03
02:00 (UTC+8)

48-HR Forecast

2015.09.05
02:00 (UTC+8)

Pure Tide Run

2015.09.01
02:00 (UTC+8)

96-HR Forecast

2015.09.05
02:00 (UTC+8)

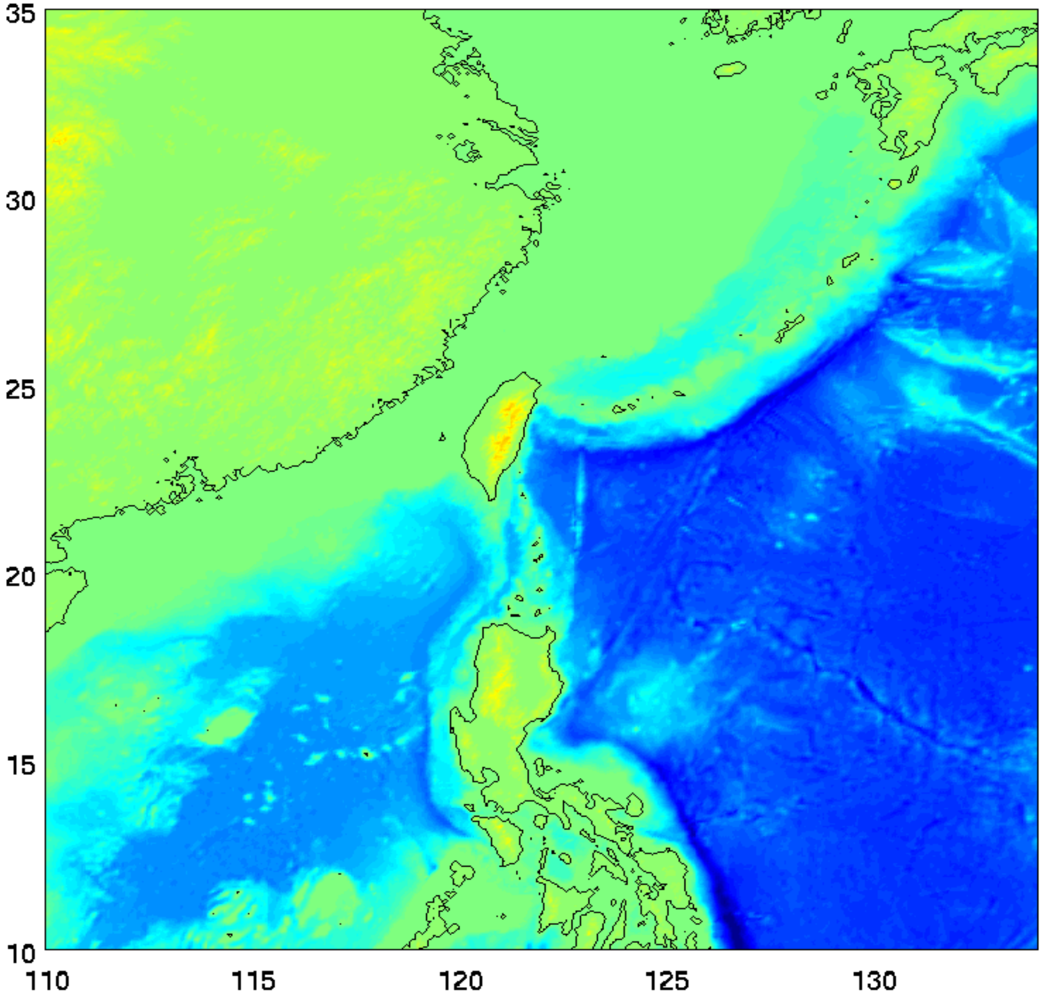
1. Every forecasting includes two 96-HR computations, and one for storm tide (storm surge + tide) run and another for pure tide run.

2. There are 48-HR warm-up and 48-HR forecast at each storm tide run.

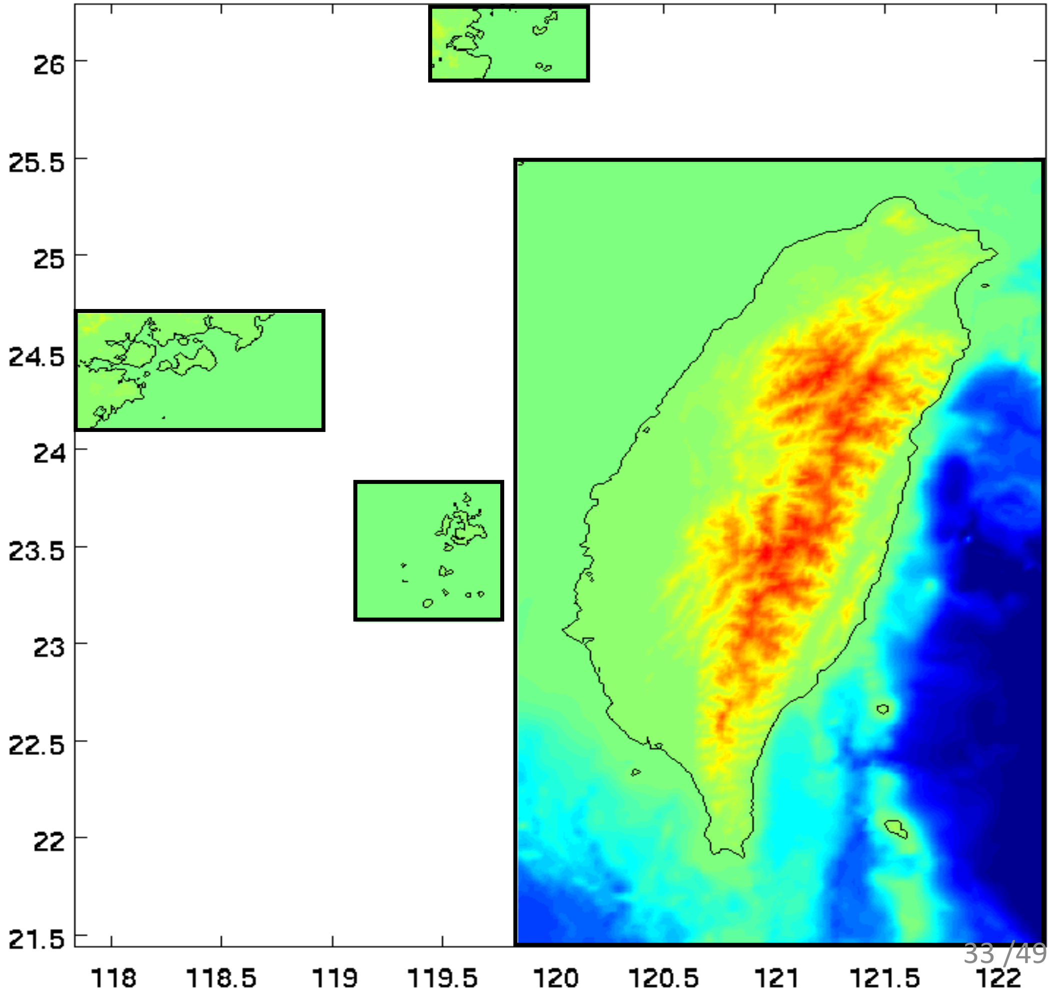
Two-level Nested-grid Domain for Operational Task

Layer 01 (8 km)/Layer 02 (2 km)

LAYER 01 (Deep-water Regions)



LAYER 02 (Offshore Regions)

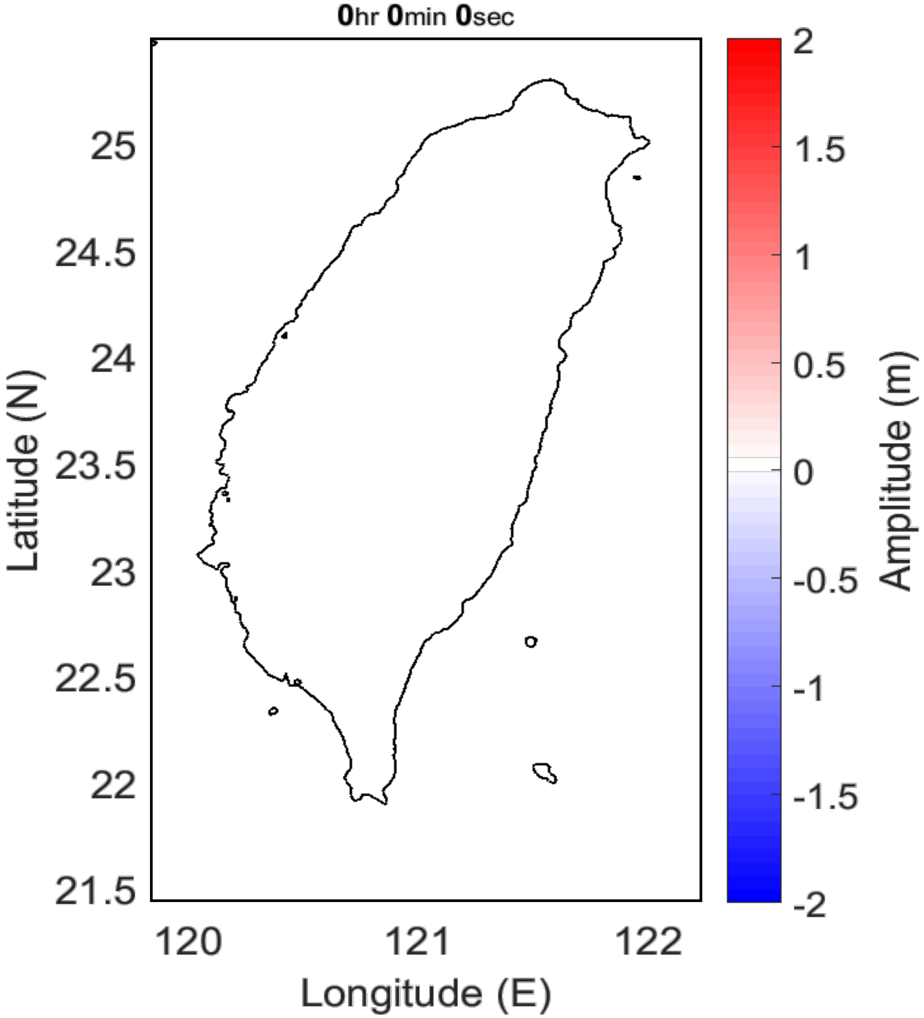


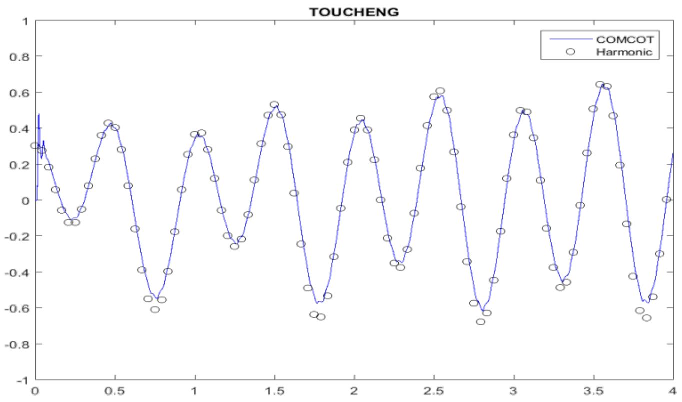
Grid Information of Two-Level Nested Domains

Layer ID	Domain	Array Size	Grid Number	Bathymetry Database
LAYER-01	(110.00-134.00, 10.00-35.00)	361 * 376	135,736	ETOPO 1
LAYER-02-A	(119.80-122.25, 21.40-25.50)	144 * 244	35,136	GEBCO
LAYER-02-B	(119.09-119.80, 23.05-23.89)	80 * 88	7,040	GEBCO
LAYER-02-C	(117.80-118.99, 24.09-24.70)	136 * 72	9,792	GEBCO
LAYER-02-D	(119.39-120.19, 25.84-26.35)	88 * 48	4,224	GEBCO

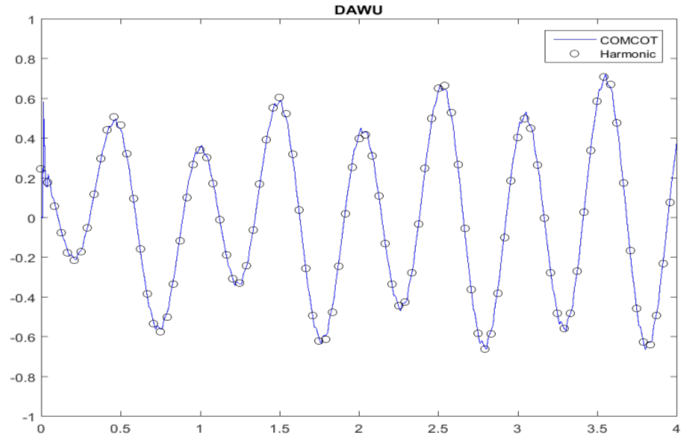
Tide Validation of COMCOT-SURGE Model

(2016.09.11 00:00 – 2016.09.15 00:00)

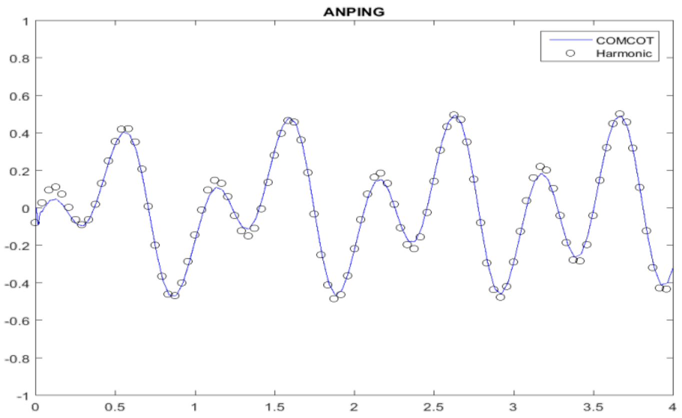




Toucheng
頭城

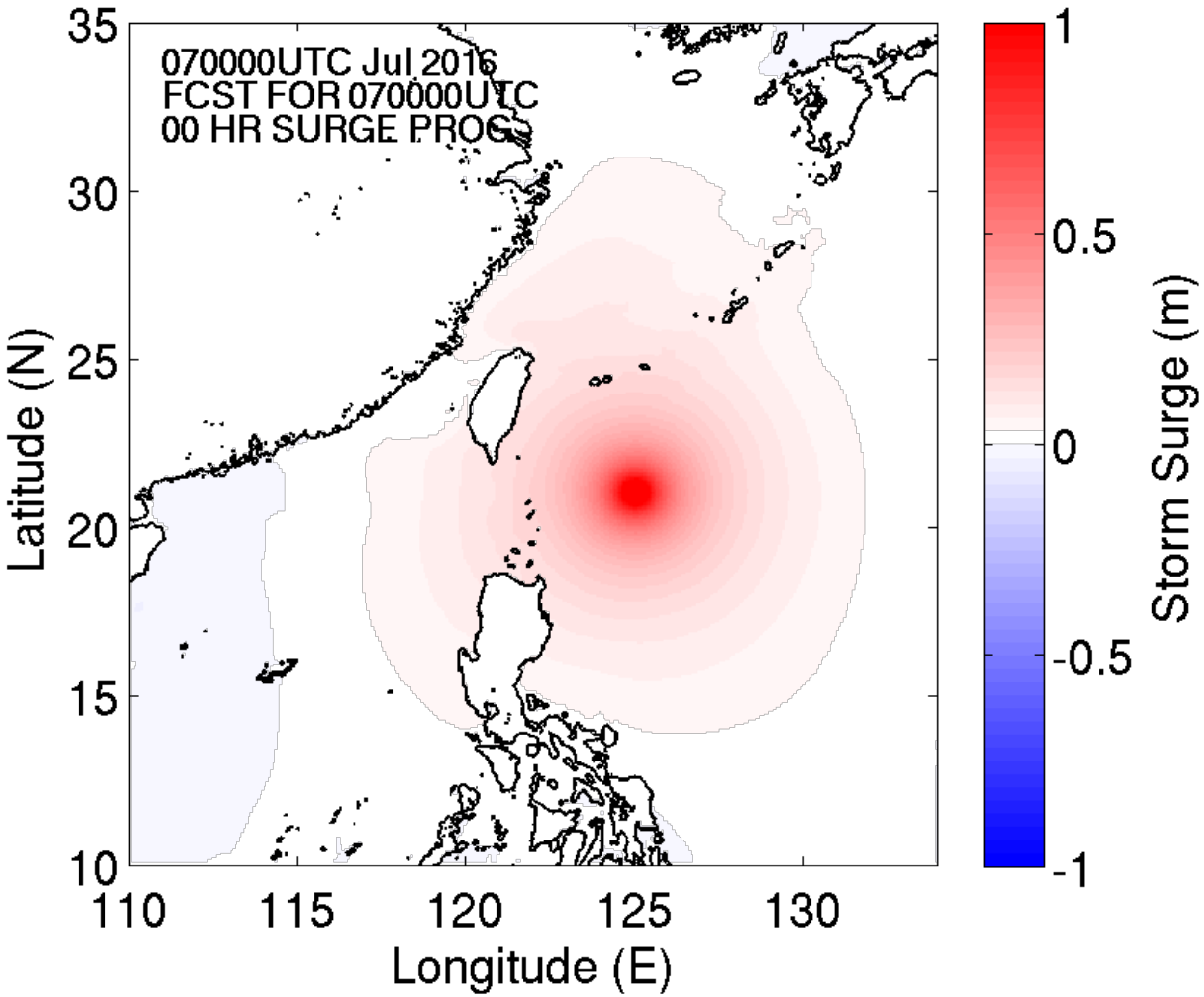


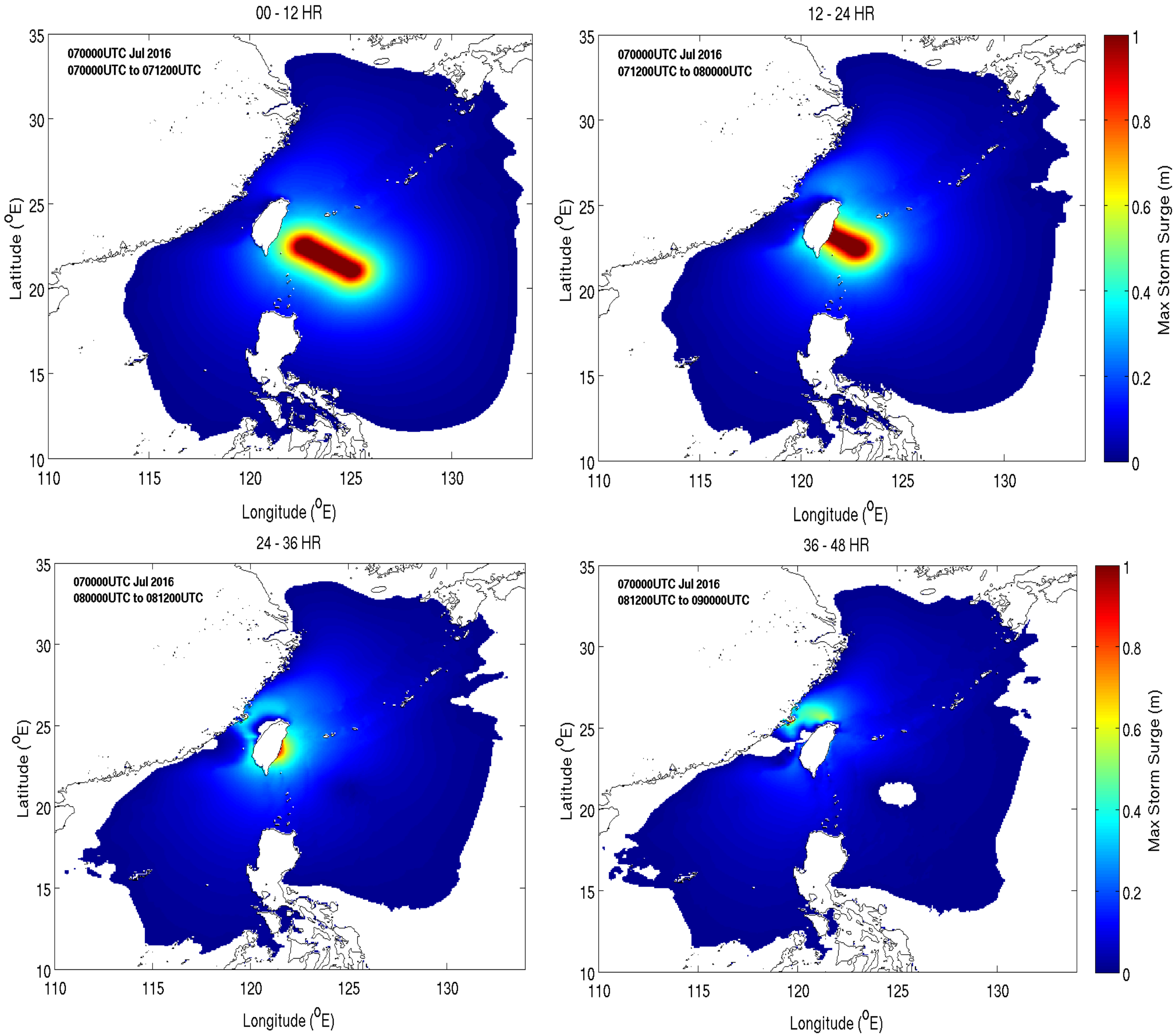
Dawu
大武



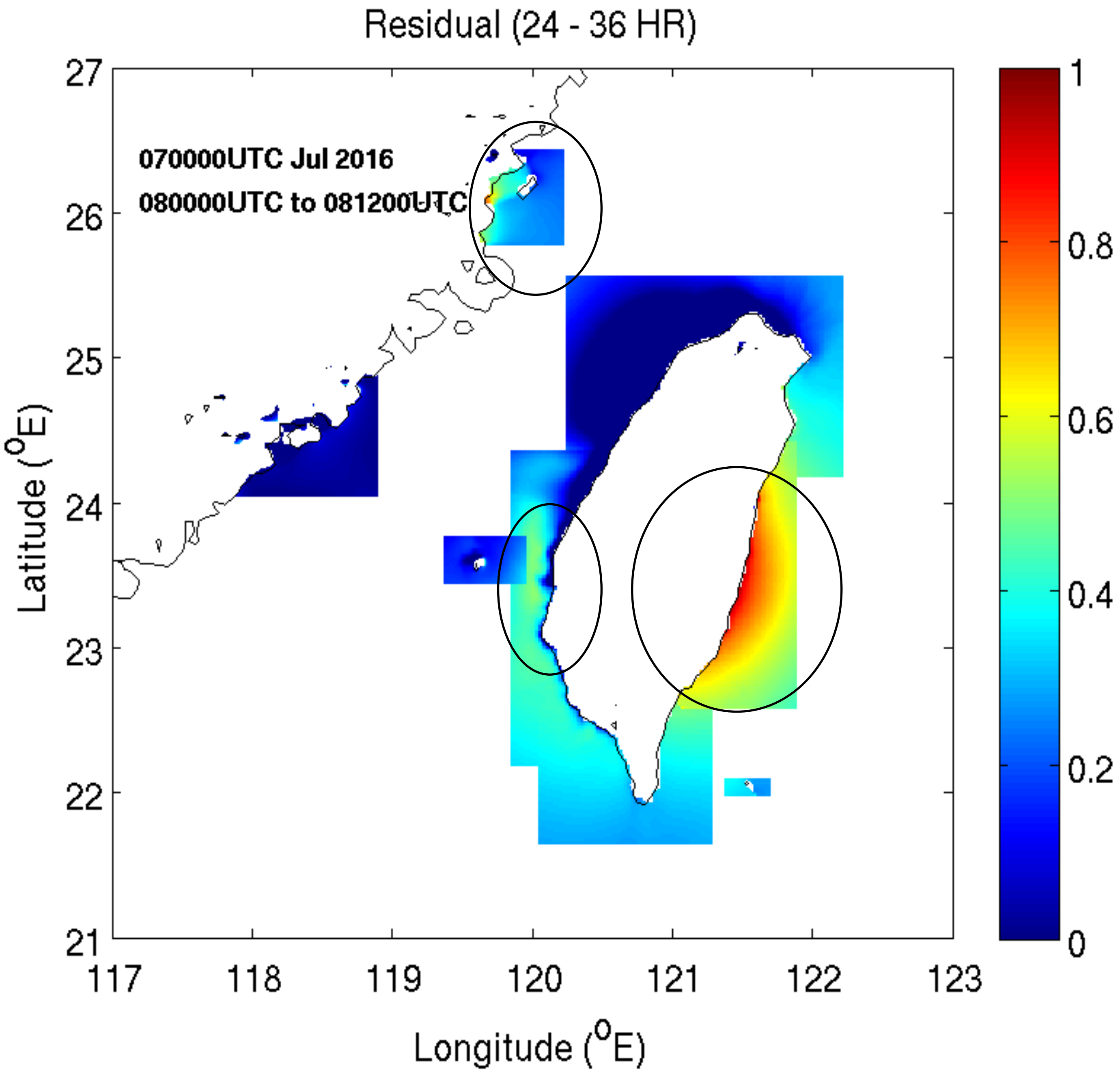
Anping
安平

Storm Surges Induced by Typhoon Nepartak





Storm surges could be calculated for 2-day predictions and only spends 1.0 hr on a PC-level computational resources.



Surge and Wave in Taiwan
(http://news.rthk.hk/rthk/ch/component/k2/1271353-20160708.htm)

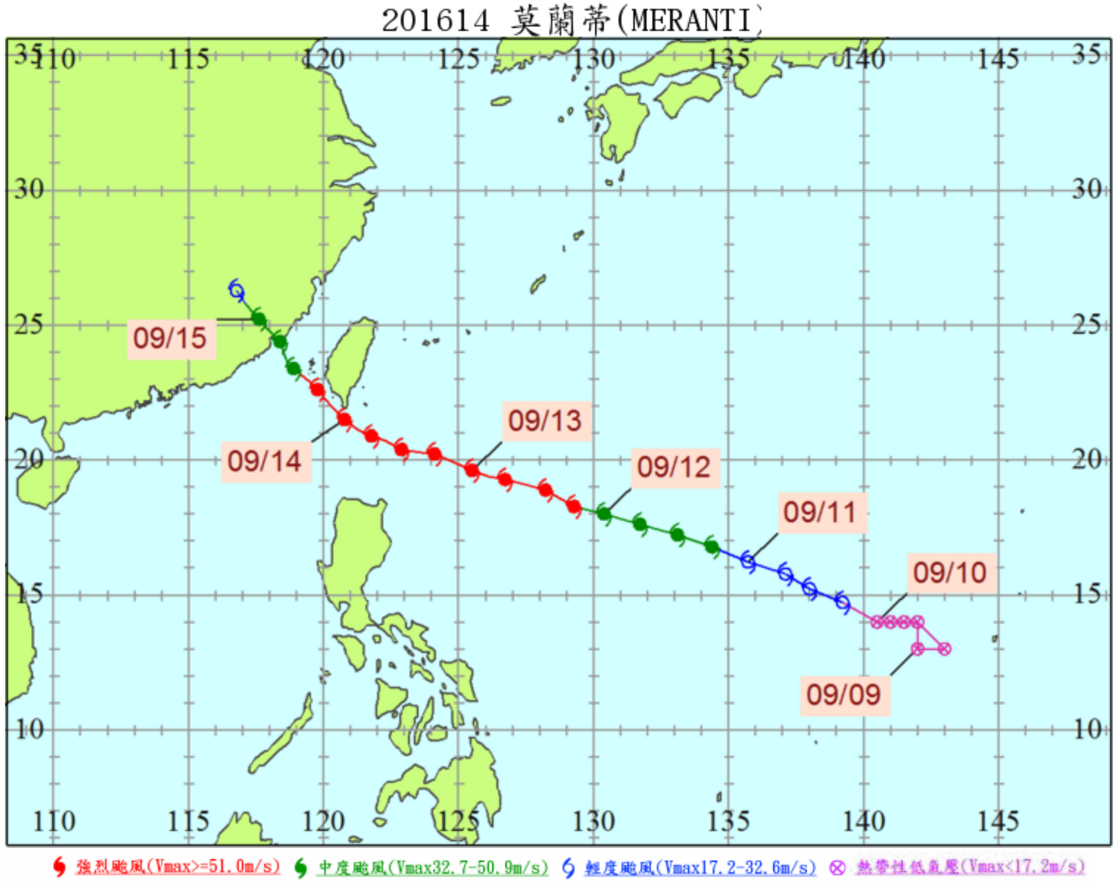
People live in these areas need to pay attention to the storm surge inundation.

3. 2016 Severe Typhoon Meranti

Typhoon Meranti was one of the most intense tropical cyclones on record. Impacting the Batanes in the Philippines, Taiwan, as well as Fujian, China in September 2016.

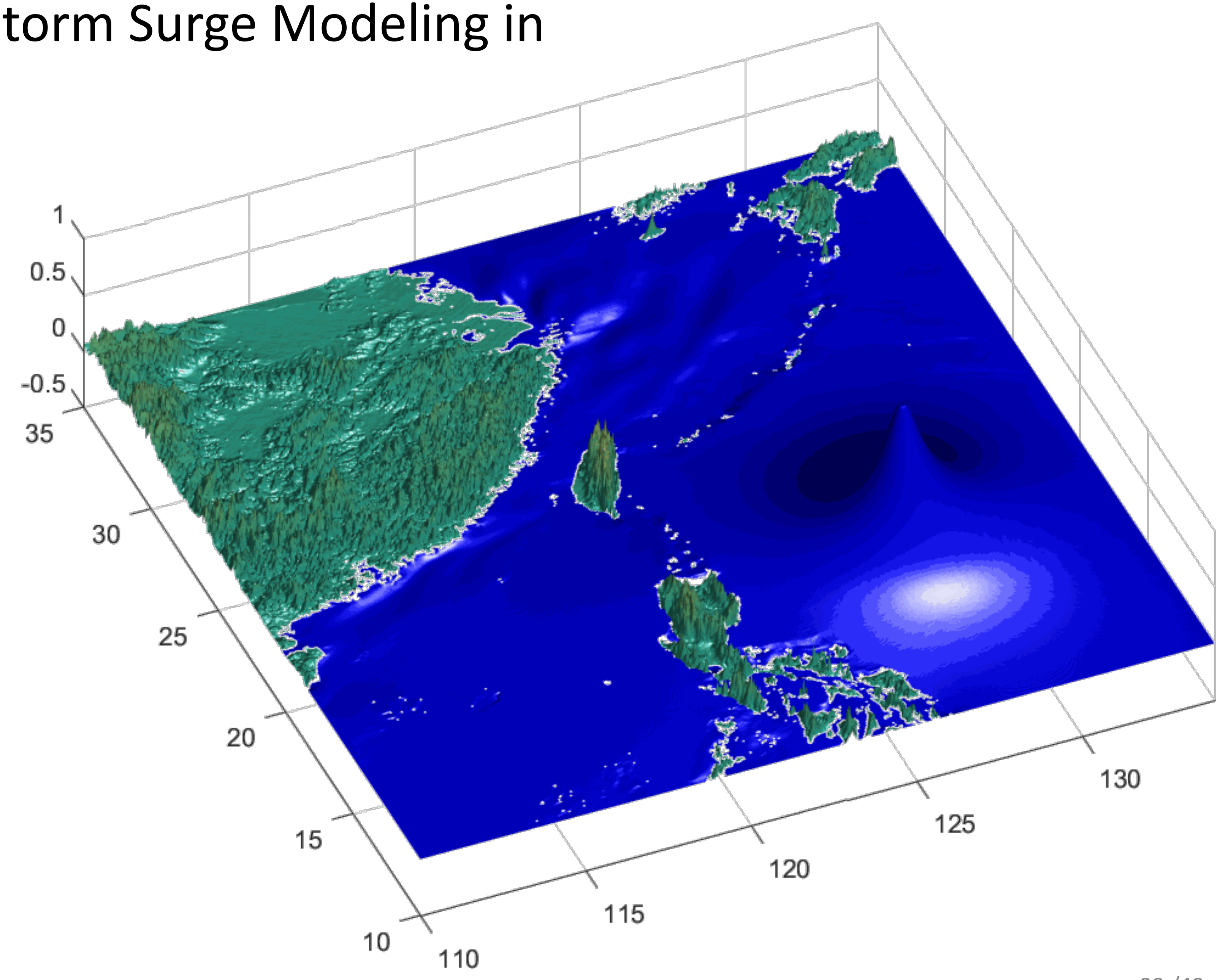
Best-track parameters of Typhoon Meranti

年	月	日	時	中心位置 (經/緯)		中心氣壓 (Pa)	七級風半徑 (km)	近中心最大風速 (m/s)
2016	9	12	00	130.4	18.0	940	180	45
2016	9	12	06	129.3	18.3	925	200	51
2016	9	12	12	128.2	18.9	910	200	55
2016	9	12	18	126.7	19.3	905	200	58
2016	9	13	00	125.5	19.6	905	200	58
2016	9	13	06	124.1	20.2	905	200	58
2016	9	13	12	122.9	20.4	900	220	60
2016	9	13	18	121.8	20.9	905	220	58
2016	9	14	00	120.8	21.5	905	220	58
2016	9	14	06	119.8	22.6	925	200	51
2016	9	14	12	118.9	23.4	930	200	48
2016	9	14	18	118.4	24.4	950	180	40
2016	9	15	00	117.6	25.2	970	150	33



莫蘭蒂路徑圖

3-D Demonstration of Storm Surge Modeling in Deep-water Regions

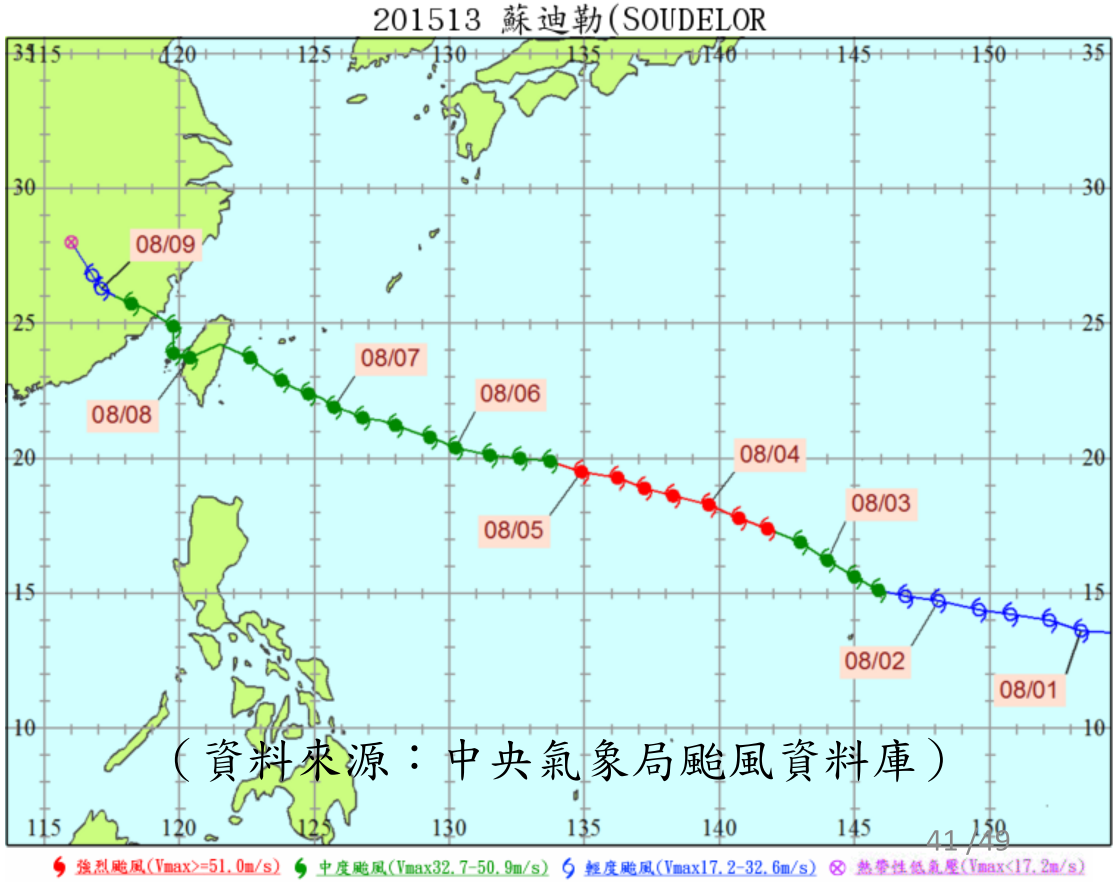


3. Demonstration of
High-Resolution Storm Surge Inundation Calculation in Taiwan

Typhoon Soudelor in 2015

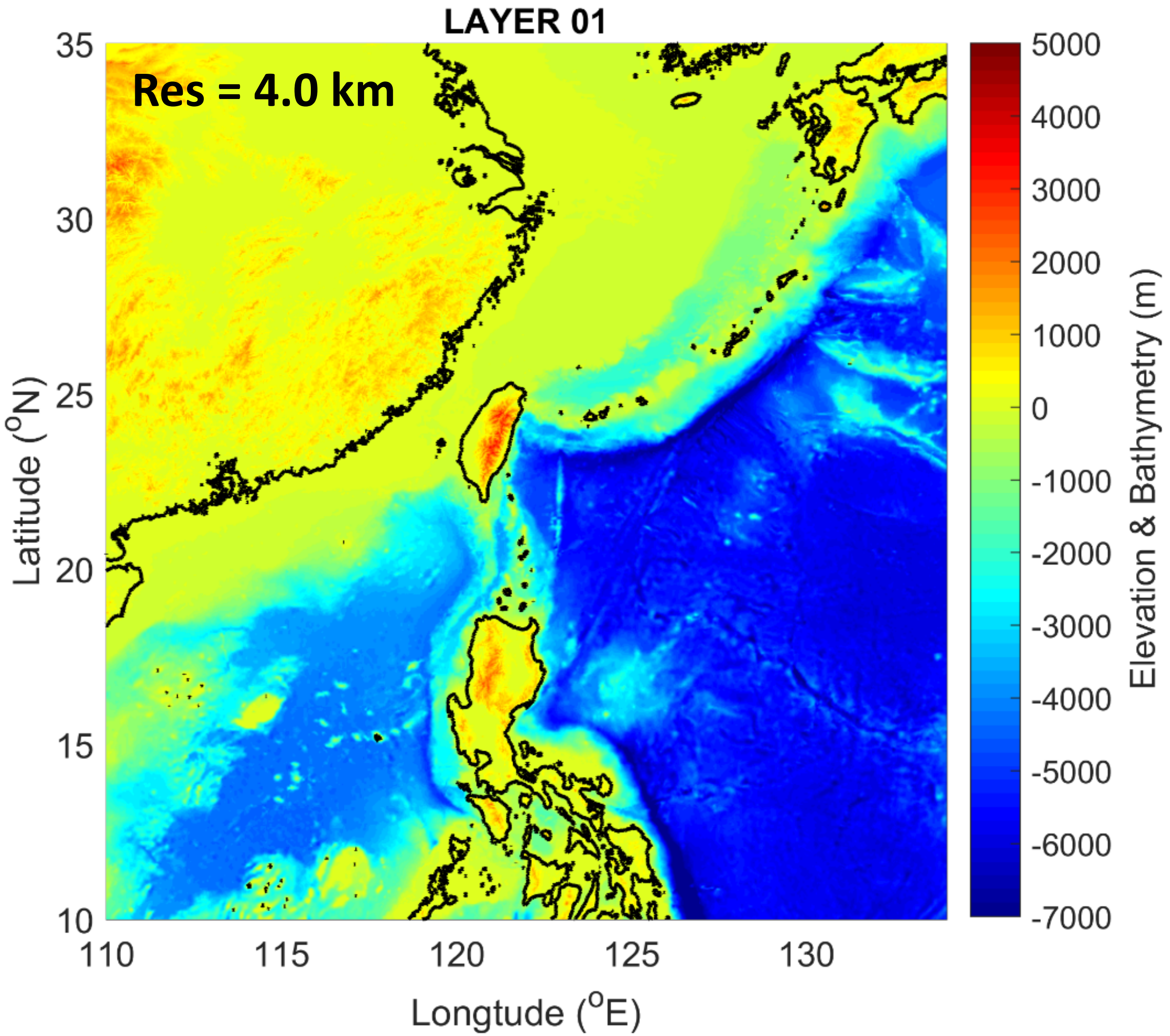
- Typhoon Soudelor was the strongest typhoon in Western North Pacific regions at 2015. According to the brief analysis, more than 4,000 thousands families lost their electricity during typhoon period and accumulative rainfall is more than 1,000 mm.
- Because of the destructive damages, economic loss and human casualties at Mariana Islands, Taiwan, and China, the name “Soudelor” was removed from the list of typhoon names and would not be used forever.

The flood in low-lying region at Ilan because of Typhoon Soudelor. (中央社記者沈如峰宜蘭縣)



（資料來源：中央氣象局颱風資料庫）

Nested-Grid Computational Domain (1) –
Open Ocean and Offshore Region

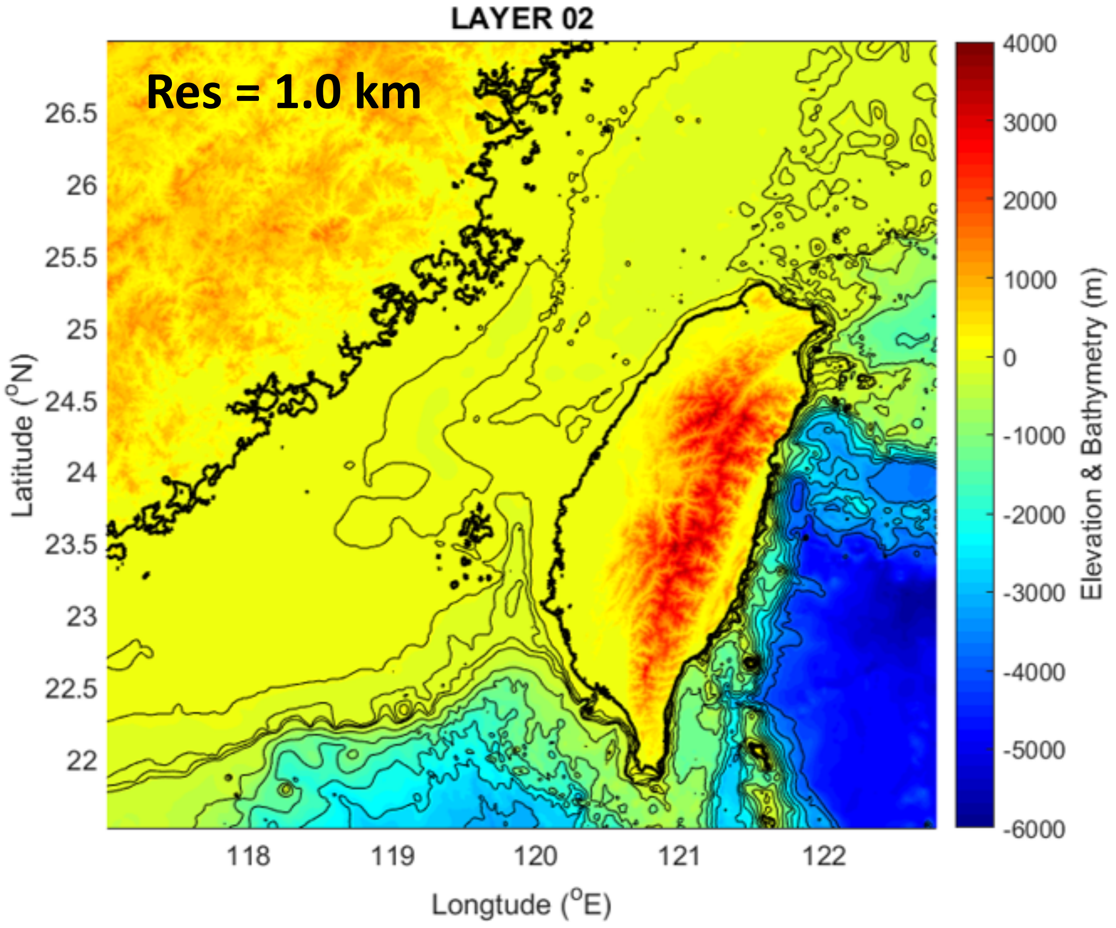


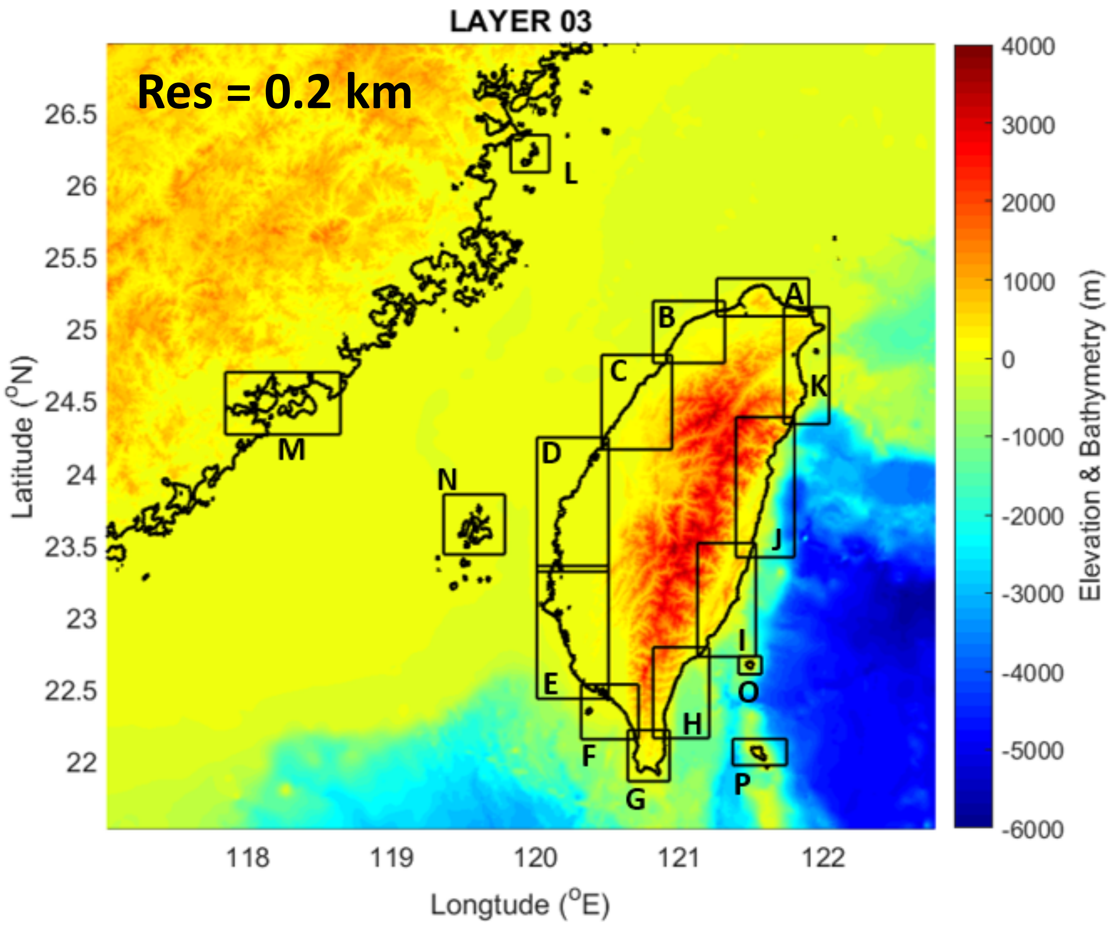
Layer 01 is adopted to cover the complete typhoons' life cycle and full storm surge propagations.

採用大尺度之球座標系統計算域，涵蓋颱風生命週期以及完整的風暴潮傳遞歷程。

Nested-Grid Computational Domain (2) -

Near-Shore and Coastal Region

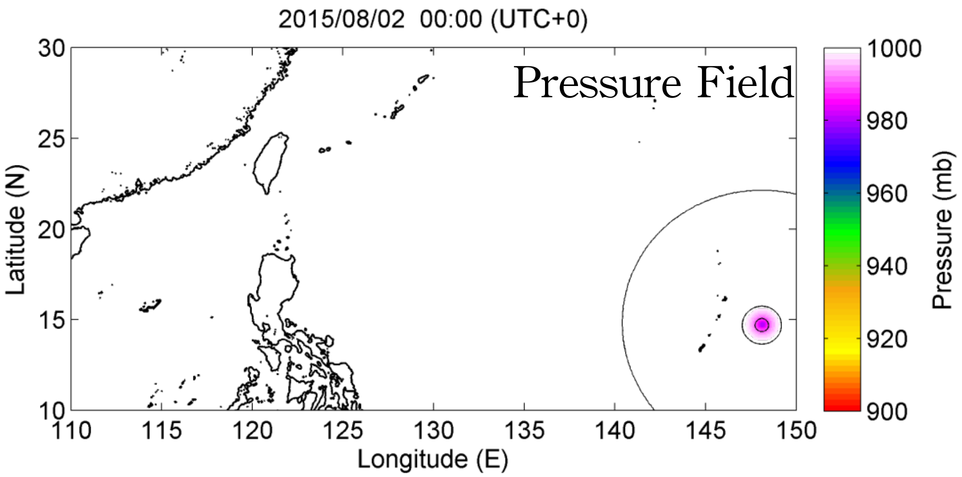


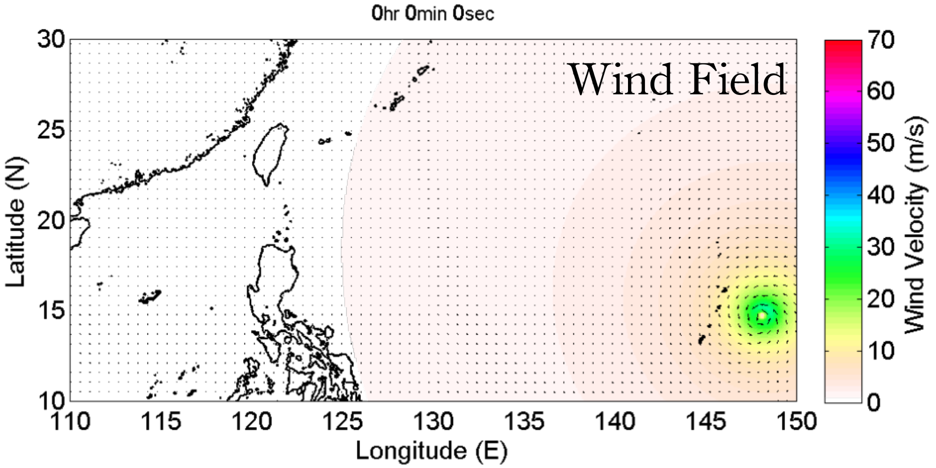


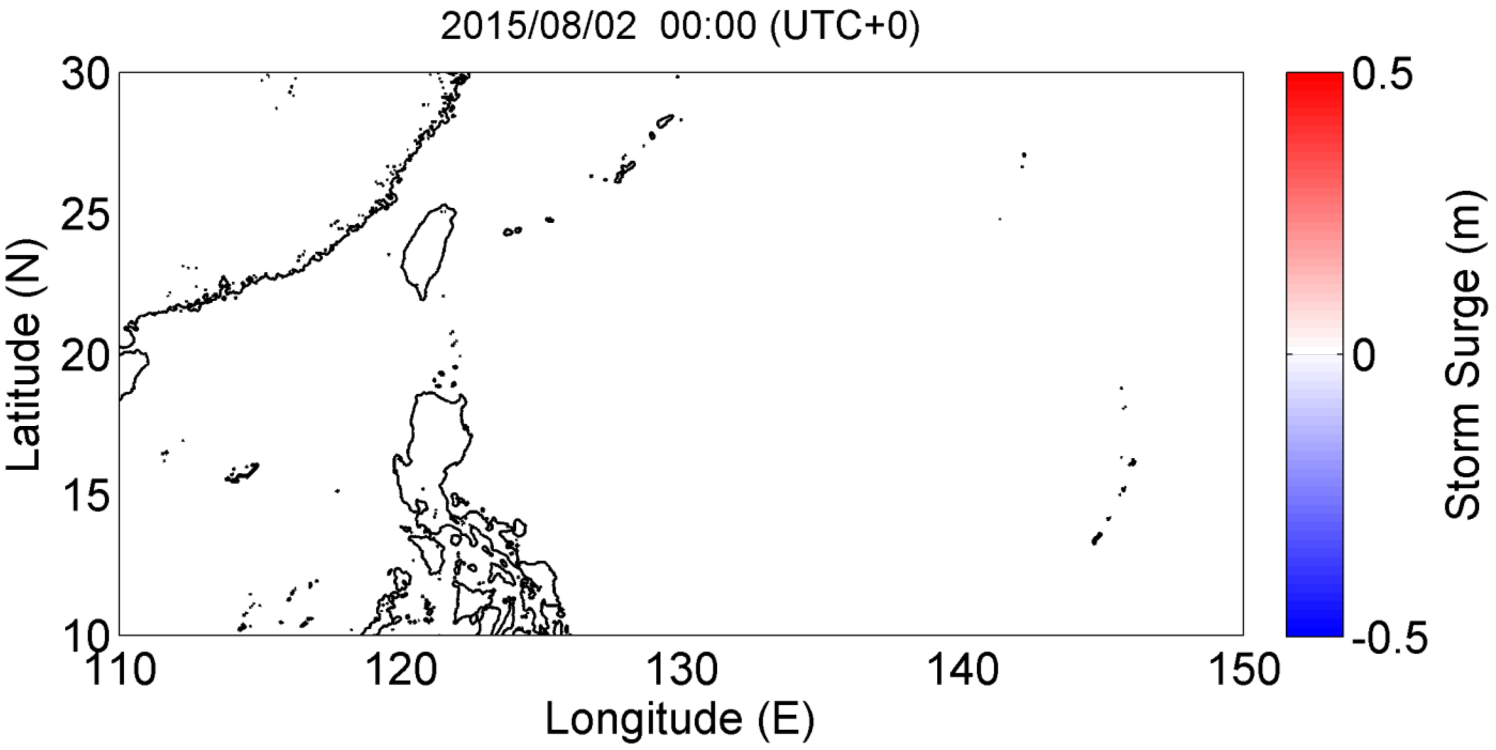
Layer 02 and Layer 03 are adopted to calculate nonlinear shallow water equations with tidal effect, bottom effects, and Coriolis effect, and evaluate inundation area in the resolution of 200 meters.

Large-Scale Storm Surge Simulation on Spherical Coordinate System

2015.08.02 00:00 – 2015.08.09 06:00 (UTC)

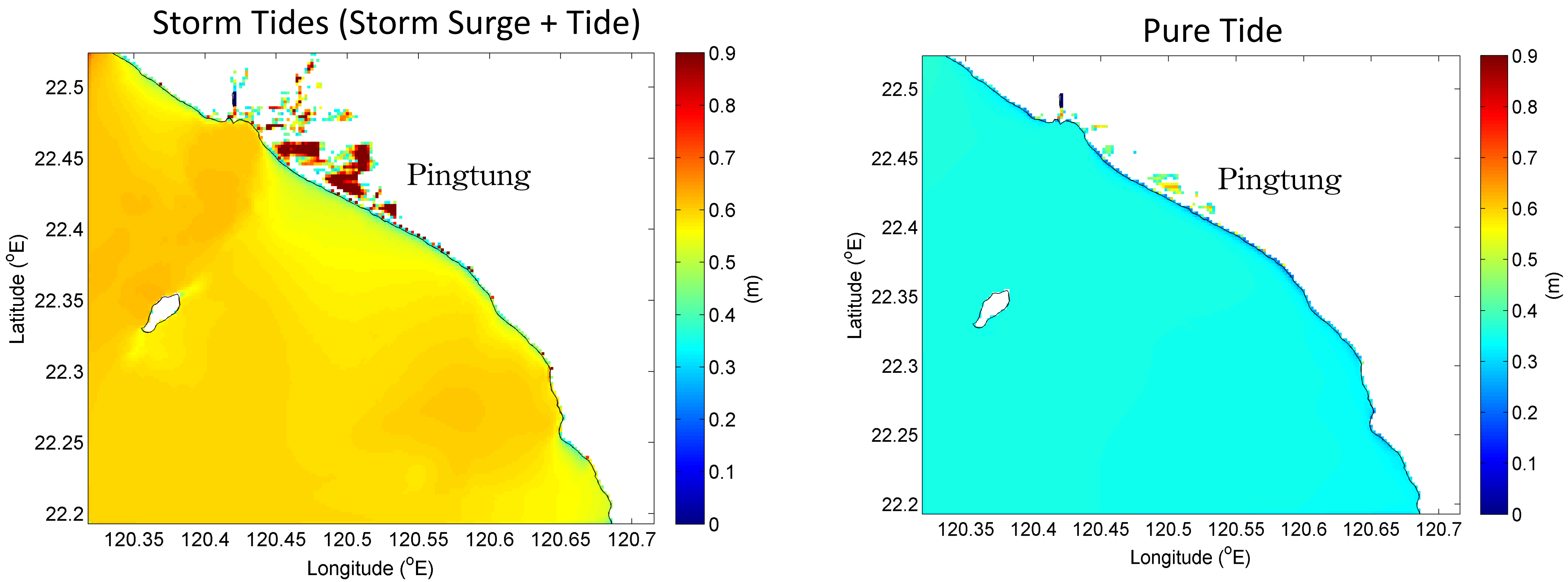






The large computational domain is adopted to simulate the complete storm surge propagation on spherical coordinate system.

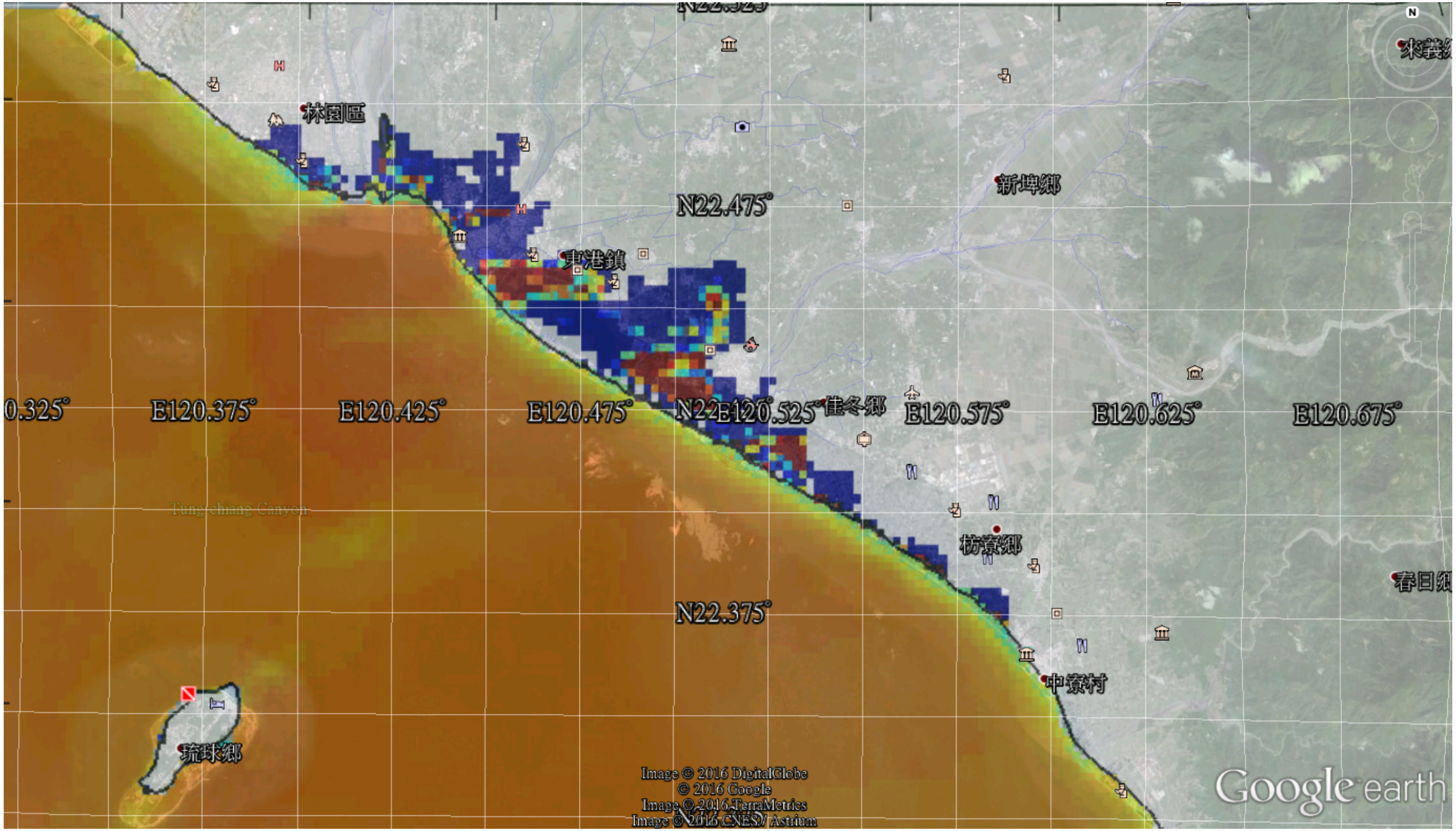
Coastal Inundation Calculation


Storm Tides (Storm Surge + Tide)

Pure Tide

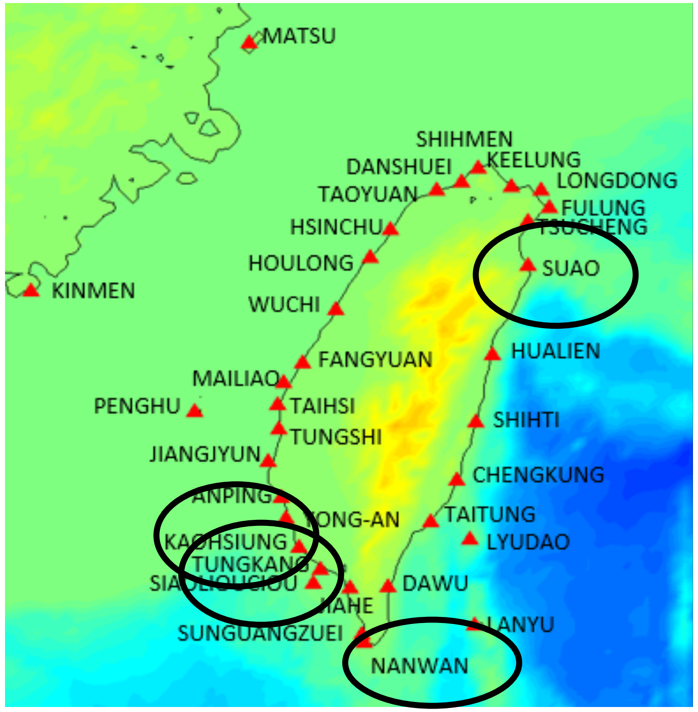
Our COMCOT storm surge model could also calculation the inundation area with nonlinear shallow water equations which considers nonlinear effects, bottom effects, and Coriolis effects inside.

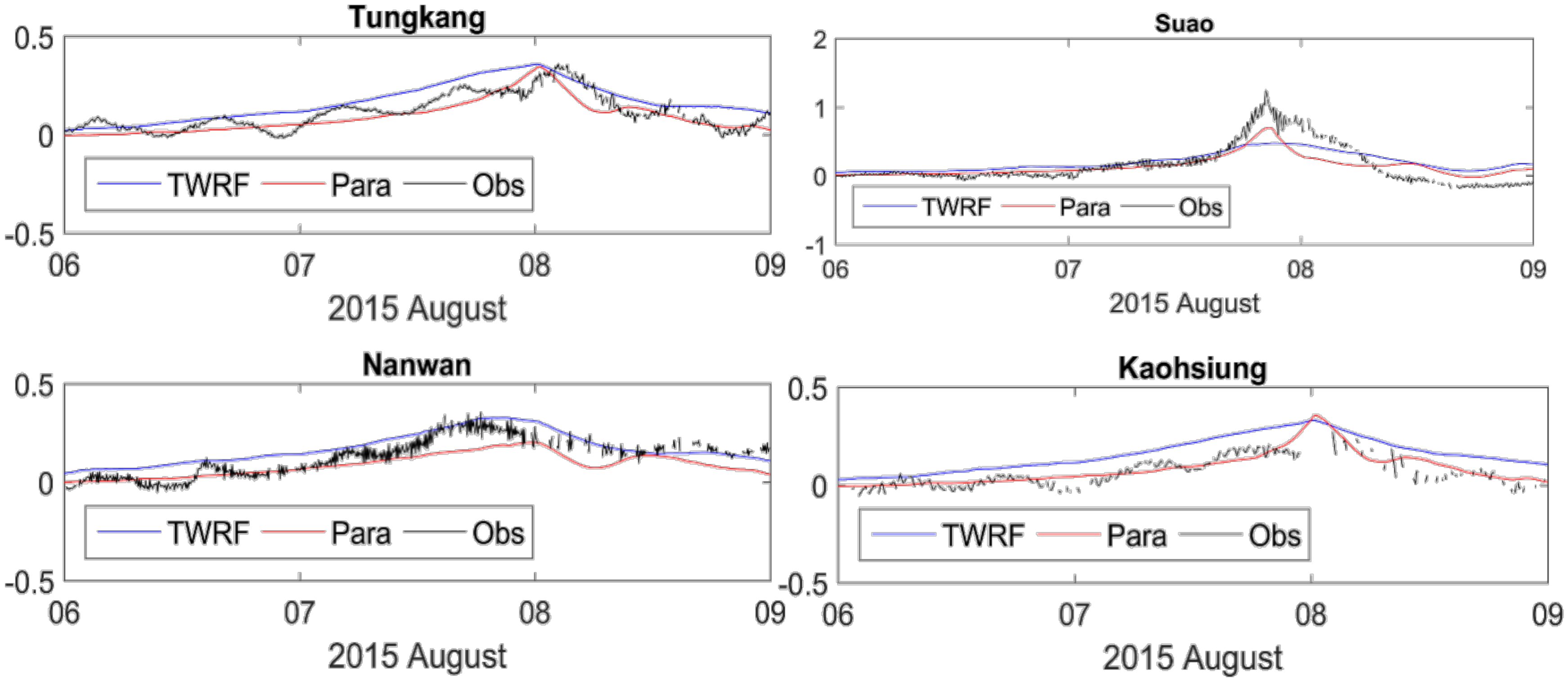
Combine with GIS Google Earth Software



Comparison with Observed Data

2015.08.06 00:00 -2015.08.09 06:00 (UTC)





The tide observed data are provided by our CWB in Taiwan.

Conclusion

- Demonstration of Tsunami Modeling
  - 2004 Sumatra Tsunami
  - 2011 Japan Tsunami

- Demonstration of Storm Surge Modeling
  - 2013 Typhoon Haiyan (Philippines)
  - 2015 Typhoon Soudelor (Taiwan)
  - 2016 Typhoon Netpark (Taiwan)
  - 2016 Typhoon Meranti (Taiwan)

- iCOMCOT – Cloud Tsunami Modeling Service

- iSurge – Coming soon

Welcome for Discussion!

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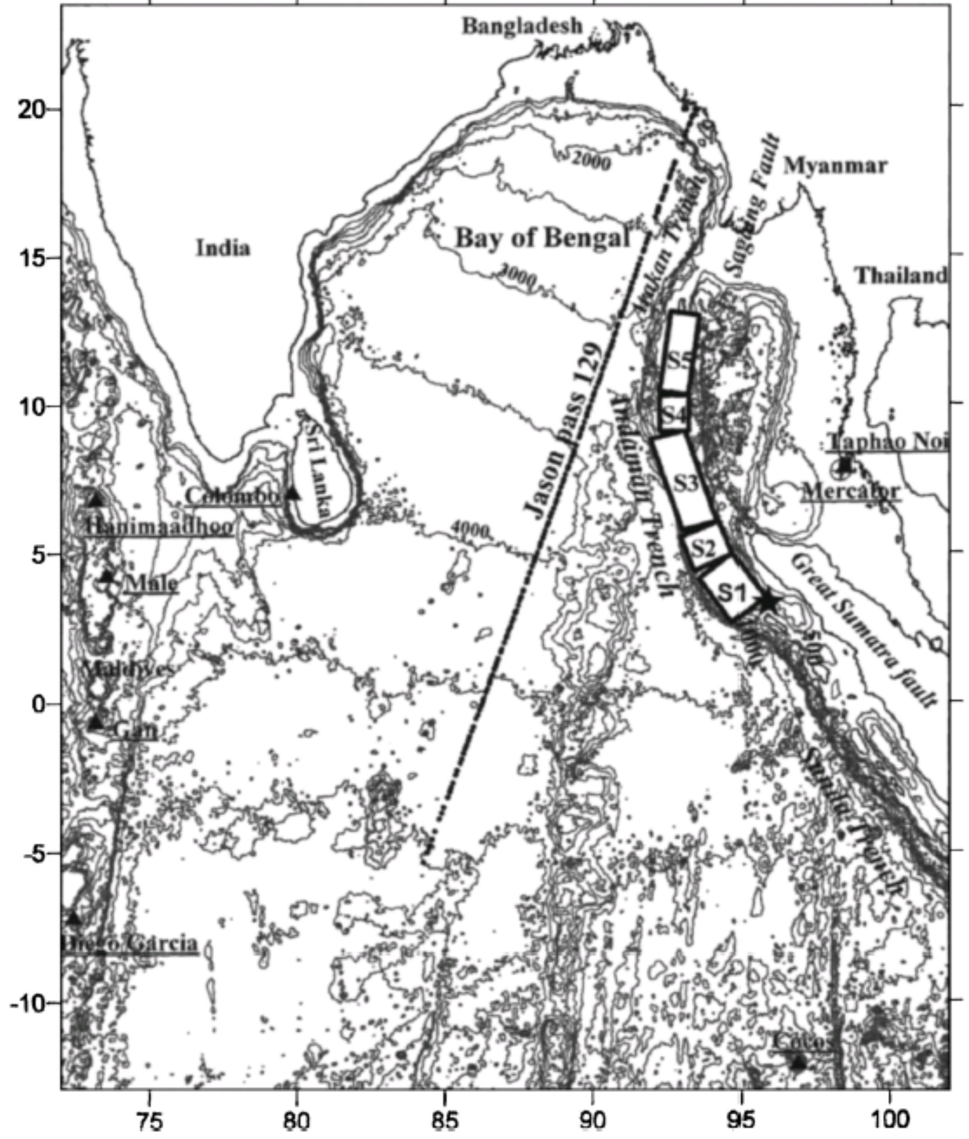
ASGC, Sinica, Taiwan

Source Constraints and Model Simulation of the December 26, 2004, Indian Ocean Tsunami

Stéphan T. Grilli; Mansour Ioualalen; Jack Asavanant; Fengyan Shi; James T. Kirby; and Philip Watts



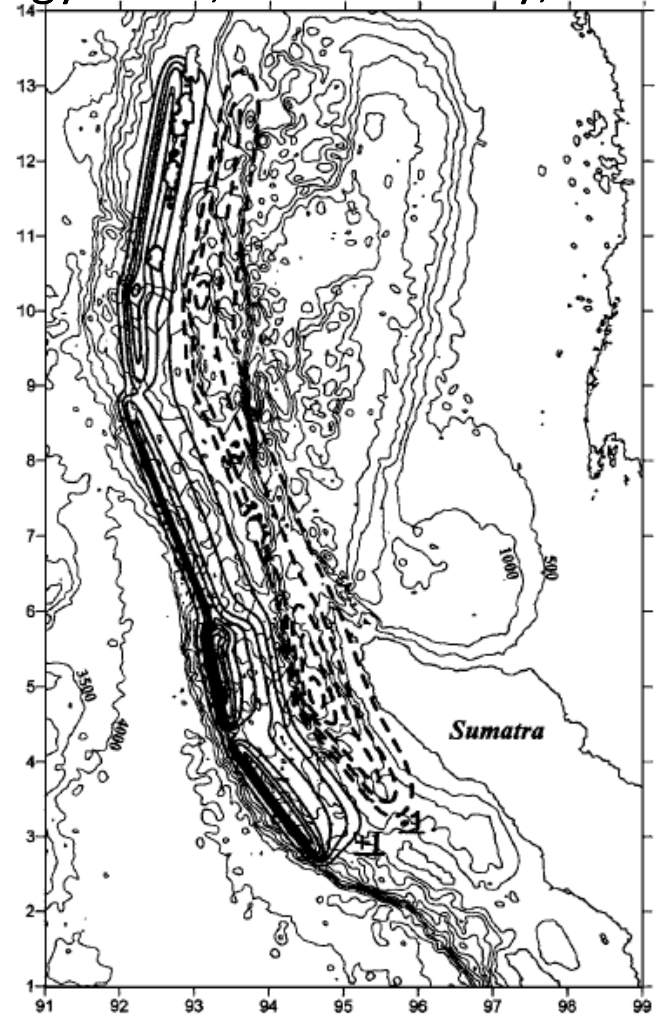


Fig. 2. Total tsunami source elevation computed for combination of five Okada sources, with parameters listed in Table 1. Thick (—) lines indicate uplift and (- - - -) subsidence, contoured every 1 m; thin (—) lines show bathymetric contours every 500 m.

Source Parameters (Grilli et al., 2007)

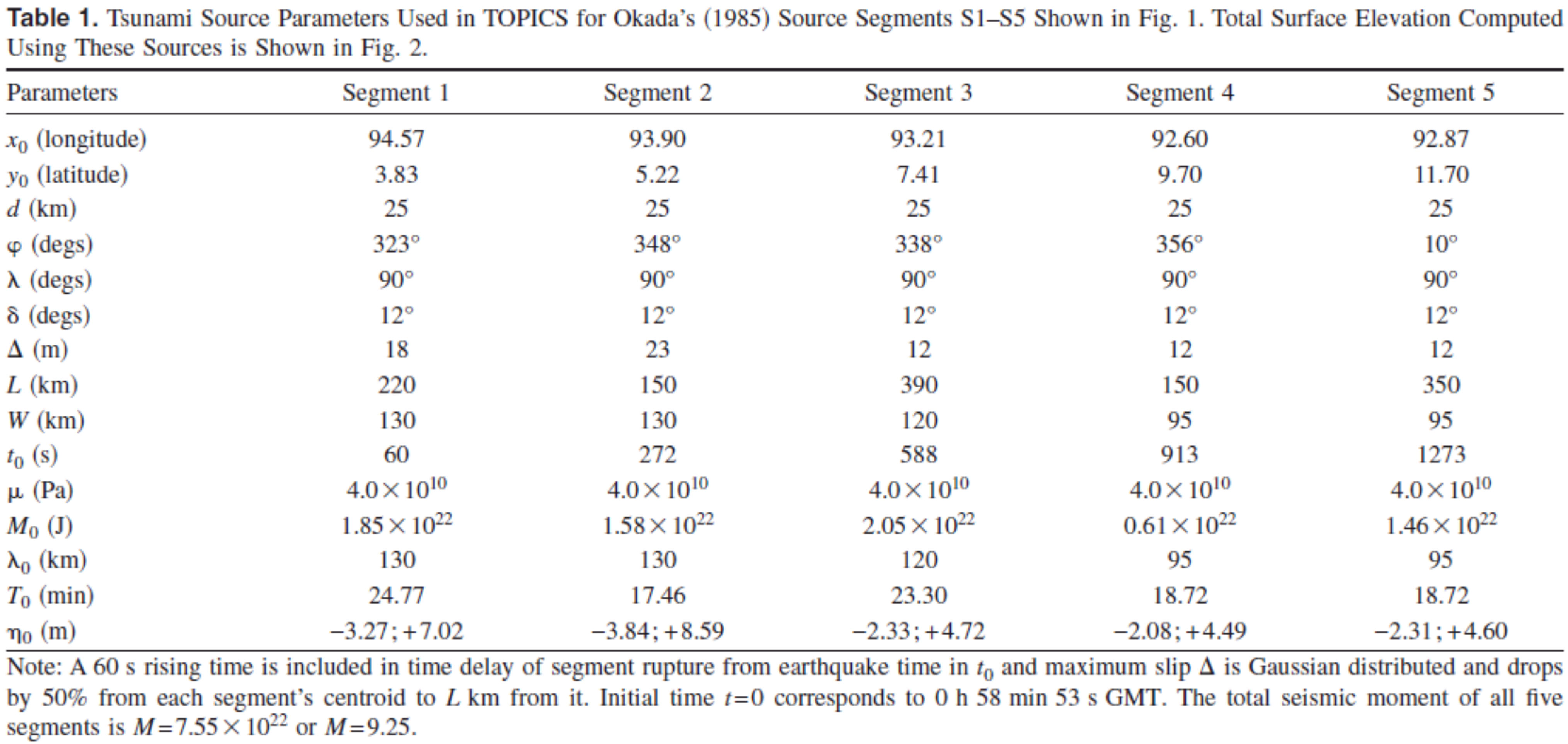


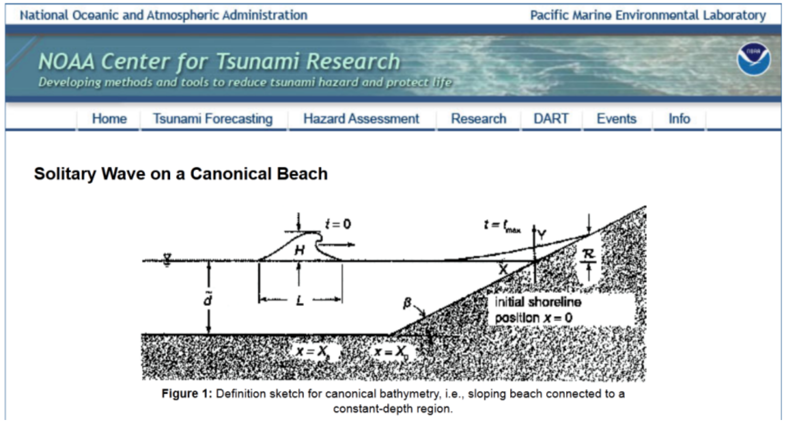
Table 1. Tsunami Source Parameters Used in TOPICS for Okada's (1985) Source Segments S1–S5 Shown in Fig. 1. Total Surface Elevation Computed Using These Sources is Shown in Fig. 2.

Parameters	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
x_0 (longitude)	94.57	93.90	93.21	92.60	92.87
y_0 (latitude)	3.83	5.22	7.41	9.70	11.70
d (km)	25	25	25	25	25
φ (degs)	323°	348°	338°	356°	10°
λ (degs)	90°	90°	90°	90°	90°
δ (degs)	12°	12°	12°	12°	12°
Δ (m)	18	23	12	12	12
L (km)	220	150	390	150	350
W (km)	130	130	120	95	95
t_0 (s)	60	272	588	913	1273
μ (Pa)	4.0×10^{10}	4.0×10^{10}	4.0×10^{10}	4.0×10^{10}	4.0×10^{10}
M_0 (J)	1.85×10^{22}	1.58×10^{22}	2.05×10^{22}	0.61×10^{22}	1.46×10^{22}
λ_0 (km)	130	130	120	95	95
T_0 (min)	24.77	17.46	23.30	18.72	18.72
η_0 (m)	$-3.27;+7.02$	$-3.84;+8.59$	$-2.33;+4.72$	$-2.08;+4.49$	$-2.31;+4.60$

Note: A 60 s rising time is included in time delay of segment rupture from earthquake time in t_0 and maximum slip Δ is Gaussian distributed and drops by 50% from each segment's centroid to L km from it. Initial time $t=0$ corresponds to 0 h 58 min 53 s GMT. The total seismic moment of all five segments is $M=7.55\times10^{22}$ or $M=9.25$.

(1). NOAA Benchmark Problem Validation

Compare with the Solitary Wave Run-up Experiments (Synolakis, 1986 and 1987).



National Oceanic and Atmospheric Administration Pacific Marine Environmental Laboratory

NOAA Center for Tsunami Research

Developing methods and tools to reduce tsunami hazard and protect life

Home | Tsunami Forecasting | Hazard Assessment | Research | DART | Events | Info

Solitary Wave on a Canonical Beach

Figure 1: Definition sketch for canonical bathymetry, i.e., sloping beach connected to a constant-depth region.

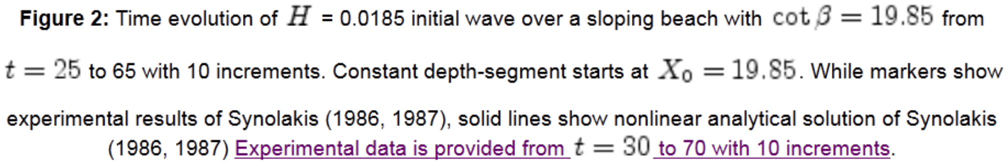
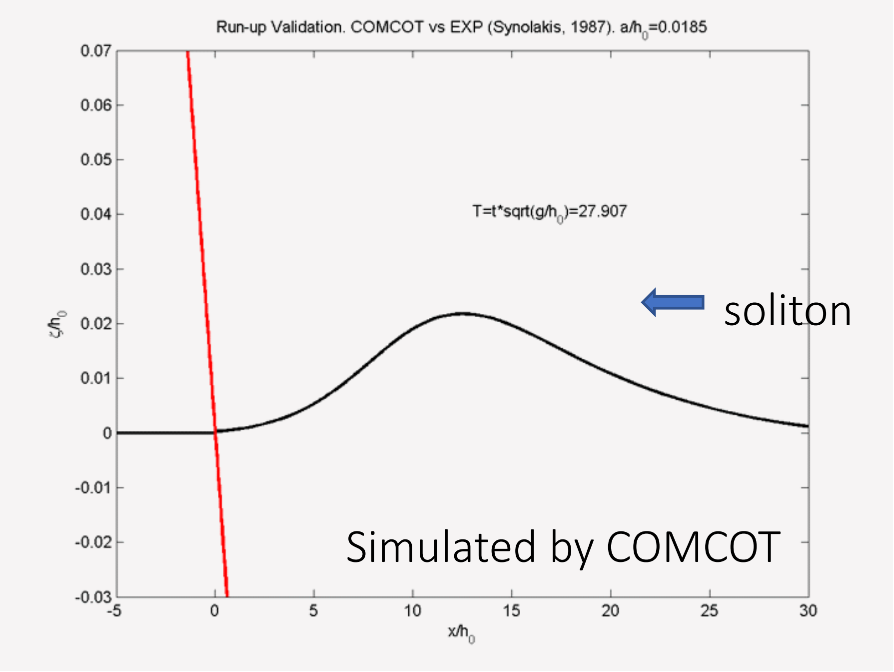


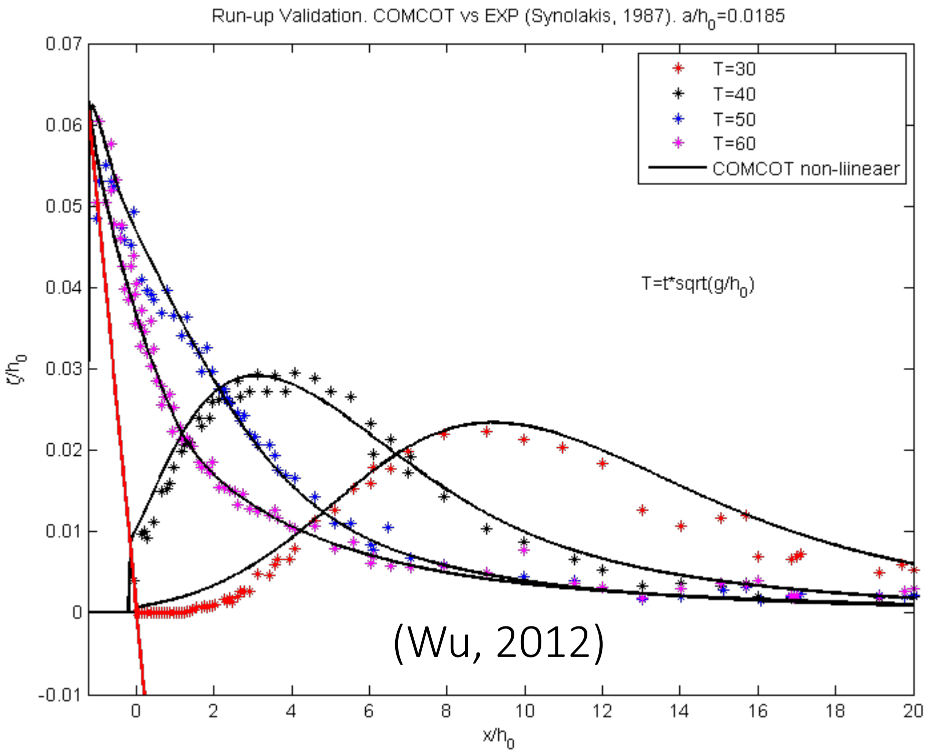
Figure 2: Time evolution of H = 0.0185 initial wave over a sloping beach with $\cot\beta = 19.85$ from $t = 25$ to 65 with 10 increments. Constant depth-segment starts at $X_0 = 19.85$. While markers show experimental results of Synolakis (1986, 1987), solid lines show nonlinear analytical solution of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

(from NOAA Official Website)



soliton

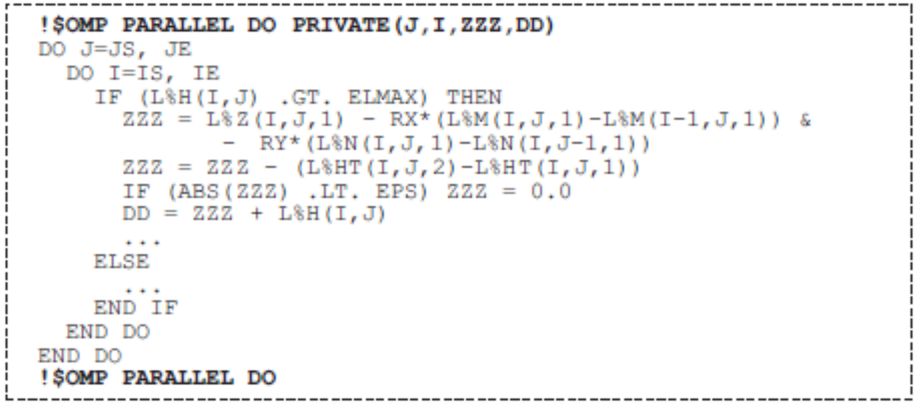
Simulated by COMCOT



(Wu, 2012)

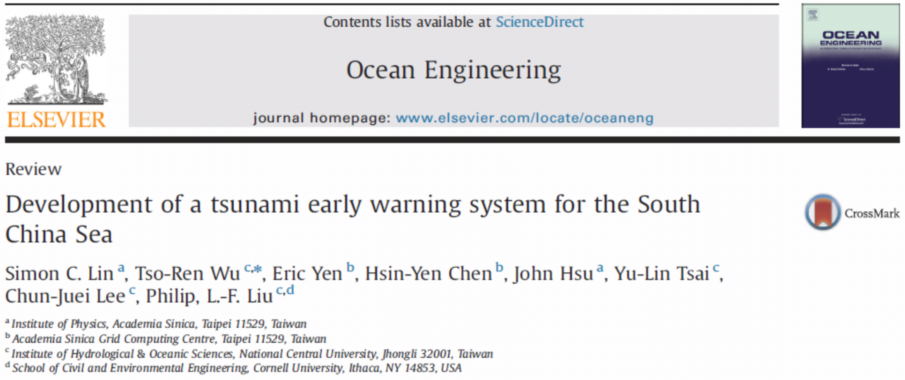
(2). High-speed Calculation

CWB COMCOT-Surge Model can finish 48 hrs forecast in 30 mins and be used for the operational system.



```
!$OMP PARALLEL DO PRIVATE(J,I,ZZZ,DD)
DO J=JS, JE
  DO I=IS, IE
    IF (L%H(I,J) .GT. ELMAX) THEN
      ZZZ = L%Z(I,J,1) - RX*(L%M(I,J,1)-L%M(I-1,J,1)) &
             -  RY*(L%N(I,J,1)-L%N(I,J-1,1))
      ZZZ = ZZZ - (L%HT(I,J,2)-L%HT(I,J,1))
      IF (ABS(ZZZ) .LT. EPS) ZZZ = 0.0
      DD = ZZZ + L%H(I,J)
      ...
    ELSE
      ...
    END IF
  END DO
END DO
!$OMP PARALLEL DO
```

Parallel Computing on Multi Cores.



Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/oceaneng

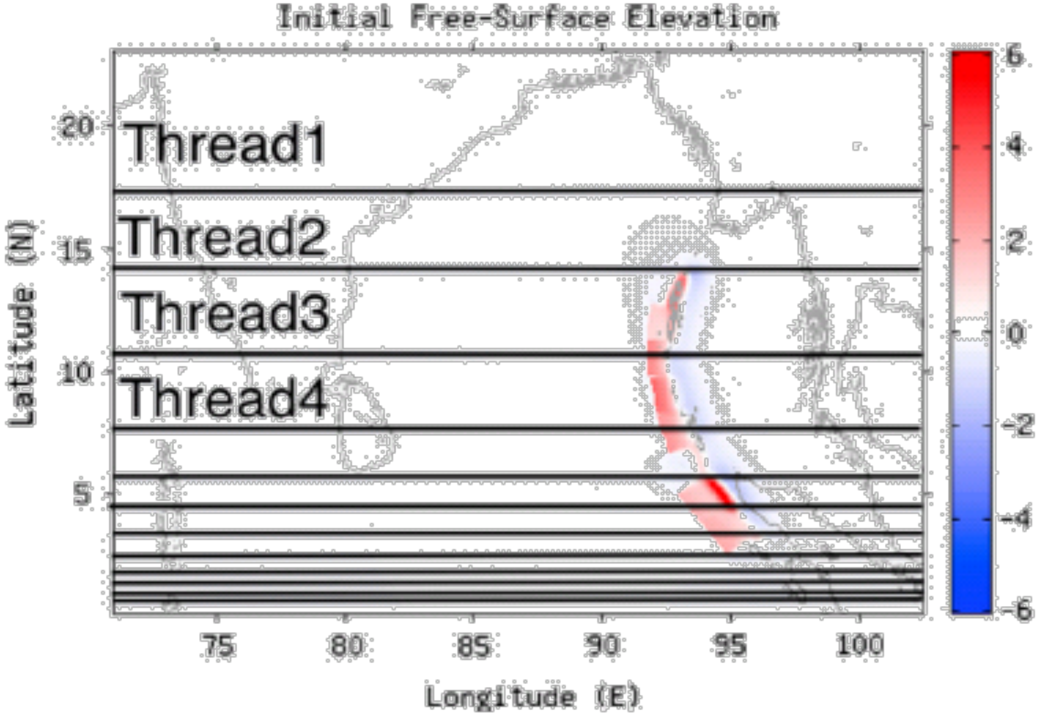
Review

Development of a tsunami early warning system for the South China Sea

Simon C. Lin [a], Tso-Ren Wu [c,*], Eric Yen [b], Hsin-Yen Chen [b], John Hsu [a], Yu-Lin Tsai [c], Chun-Juei Lee [c], Philip, L.-F. Liu [c,d]

[a] Institute of Physics, Academia Sinica, Taipei 11529, Taiwan
[b] Academia Sinica Grid Computing Centre, Taipei 11529, Taiwan
[c] Institute of Hydrological & Oceanic Sciences, National Central University, Jhongli 32001, Taiwan
[d] School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853, USA

*The results has been published on Ocean Engineering (**Simon C. Lin** et al., 2015).*



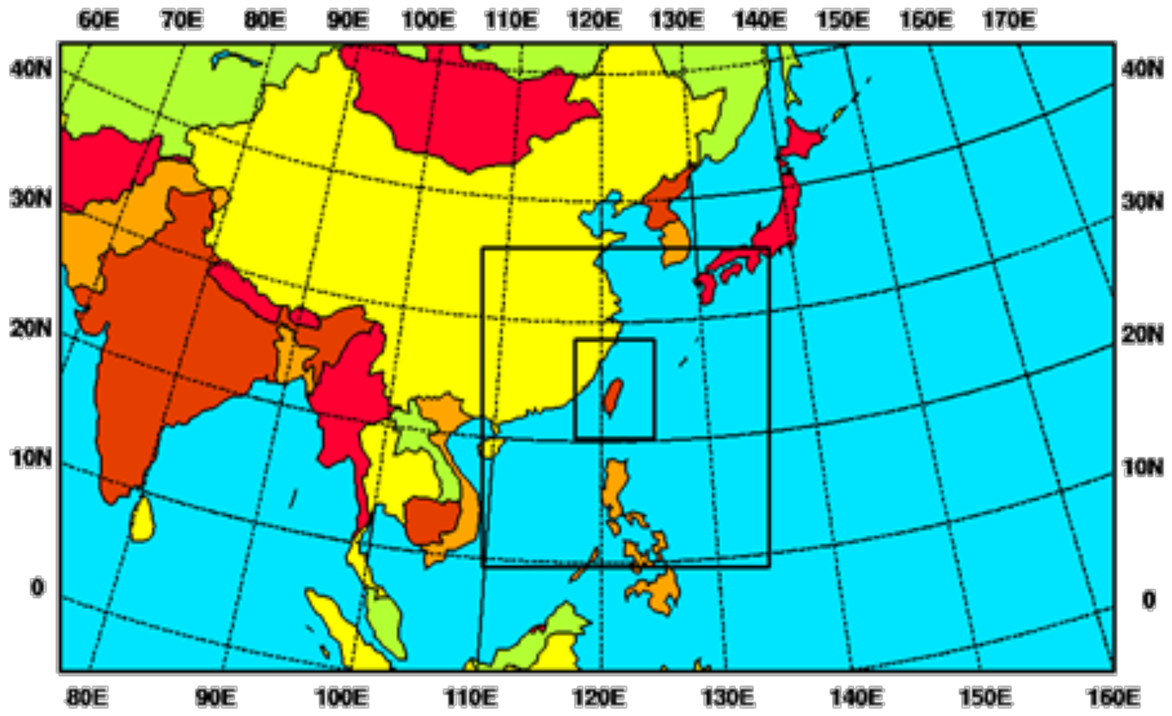
Dynamic resources sharing.

(3). Combine with the Atmospheric Model

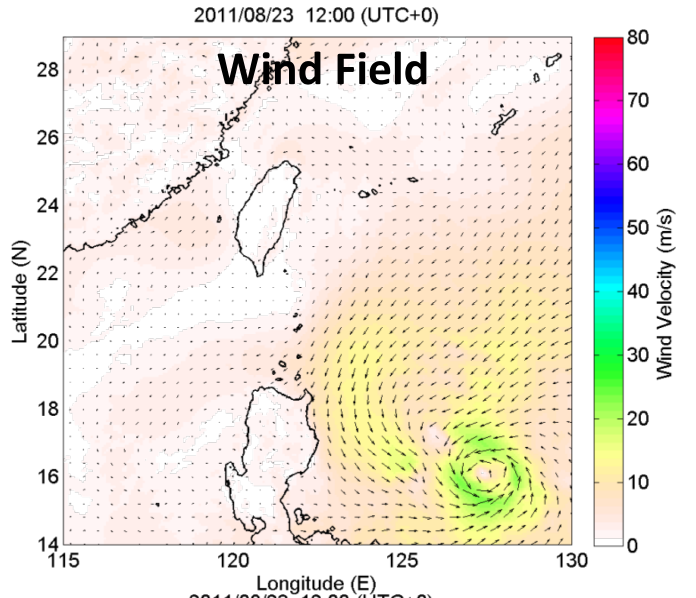
WRF/TWRF (Weather Research and Forecasting Model)

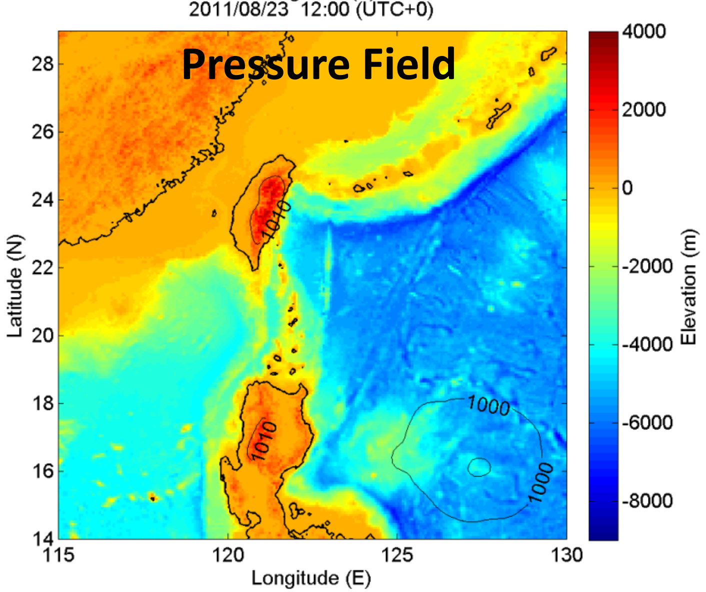
- TWRF model is an atmospheric model adopted for operational forecasts by Central Weather Bureau in Taiwan.

- The TWRF model will start its simulation per 6 hours in a day at 00, 06, 12 and 18 UTC time respectively.



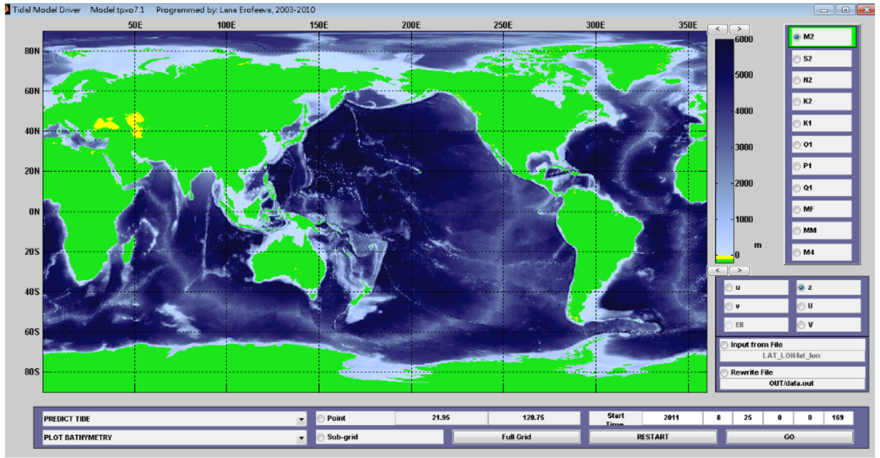
WRF Computational Domain (CWB)



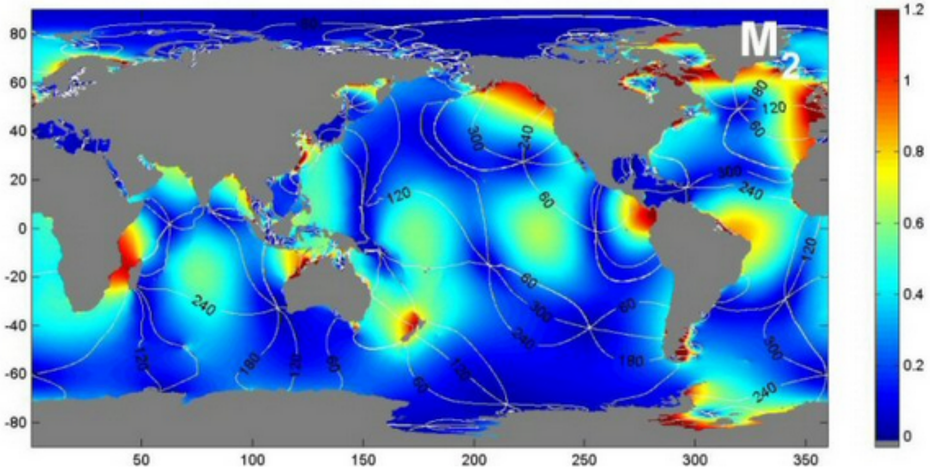


(4). Combine with Global Tide Model

(USA OSU TOPEX/POSEIDON Global Tidal Model)

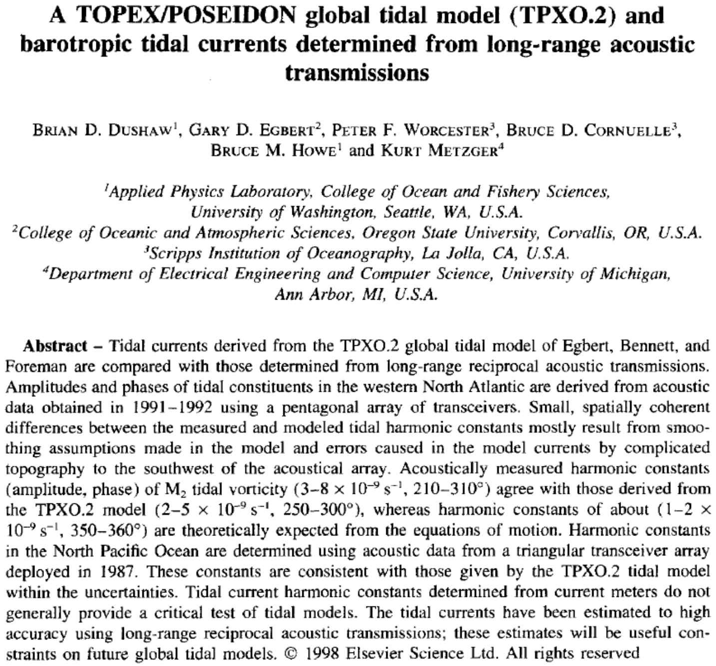


User Interface of TPXO



TPXO can provide tidal information, like M2.

The tides are provided as complex amplitudes of earth-relative sea-surface elevation for eight primary (M2, S2, N2, K2, K1, O1, P1, Q1), two long period (Mf,Mm) and 3 non-linear (M4, MS4, MN4) harmonic constituents.



A TOPEX/POSEIDON global tidal model (TPXO.2) and barotropic tidal currents determined from long-range acoustic transmissions

Brian D. Dushaw[1], Gary D. Egbert[2], Peter F. Worcester[3], Bruce D. Cornuelle[3],
Bruce M. Howe[1] and Kurt Metzger[4]

[1]*Applied Physics Laboratory, College of Ocean and Fishery Sciences,*
University of Washington, Seattle, WA, U.S.A.
[2]*College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, U.S.A.*
[3]*Scripps Institution of Oceanography, La Jolla, CA, U.S.A.*
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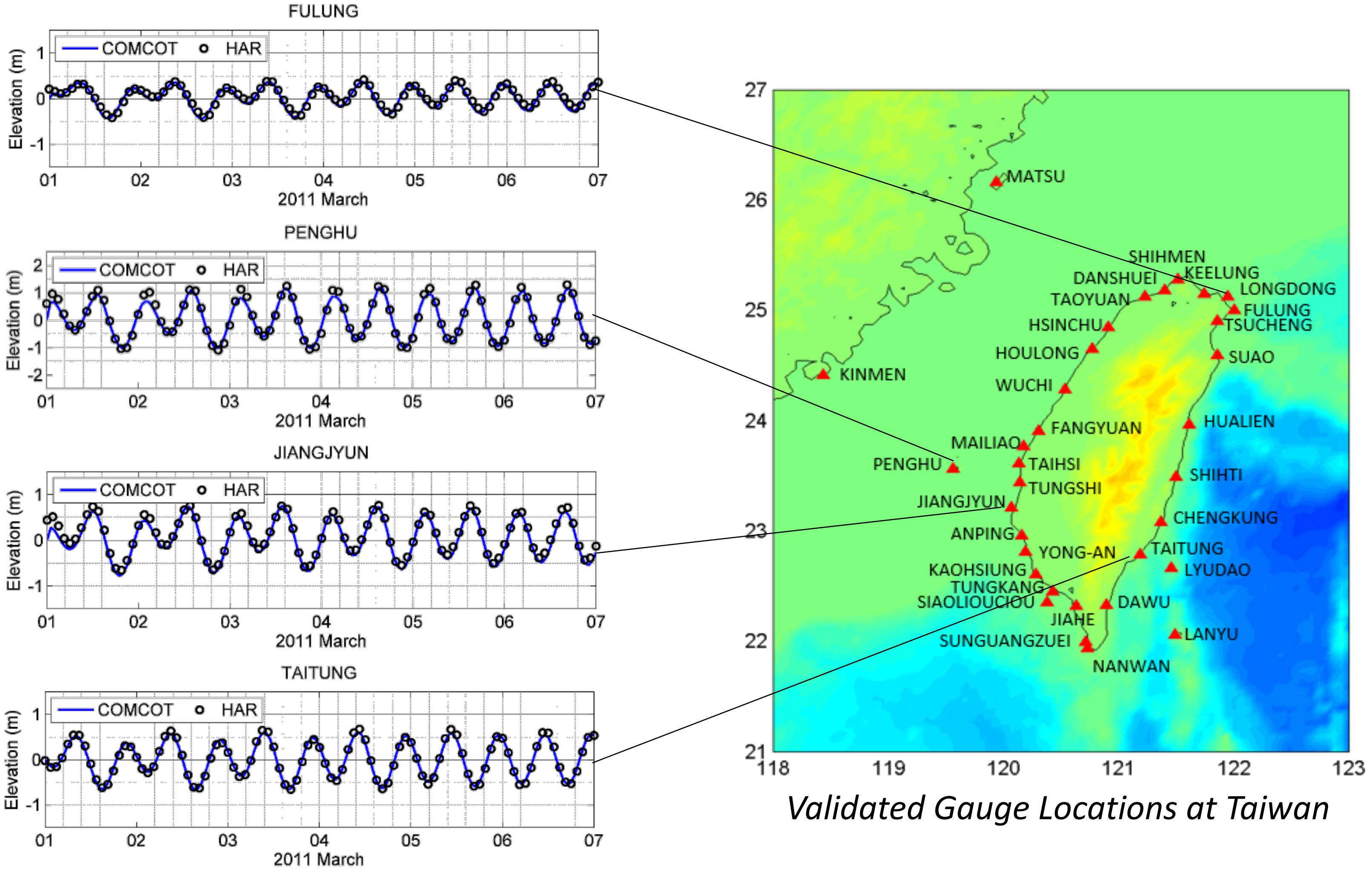
Ann Arbor, MI, U.S.A.

Abstract – Tidal currents derived from the TPXO.2 global tidal model of Egbert, Bennett, and Foreman are compared with those determined from long-range reciprocal acoustic transmissions. Amplitudes and phases of tidal constituents in the western North Atlantic are derived from acoustic data obtained in 1991–1992 using a pentagonal array of transceivers. Small, spatially coherent differences between the measured and modeled tidal harmonic constants mostly result from smoothing assumptions made in the model and errors caused in the model currents by complicated topography to the southwest of the acoustical array. Acoustically measured harmonic constants (amplitude, phase) of M_2 tidal vorticity ($3\text{–}8 \times 10^{-9}\ s^{-1}$, 210–310°) agree with those derived from the TPXO.2 model ($2\text{–}5 \times 10^{-9}\ s^{-1}$, 250–300°), whereas harmonic constants of about ($1\text{–}2 \times 10^{-9}\ s^{-1}$, 350–360°) are theoretically expected from the equations of motion. Harmonic constants in the North Pacific Ocean are determined using acoustic data from a triangular transceiver array deployed in 1987. These constants are consistent with those given by the TPXO.2 tidal model within the uncertainties. Tidal current harmonic constants determined from current meters do not generally provide a critical test of tidal models. The tidal currents have been estimated to high accuracy using long-range reciprocal acoustic transmissions; these estimates will be useful constraints on future global tidal models. © 1998 Elsevier Science Ltd. All rights reserved

(Dushaw et al., 1997)

(5). High-Accuracy Tide Simulation

The bias is smaller than 0.1 m and RMSE is smaller than 0.4 m.



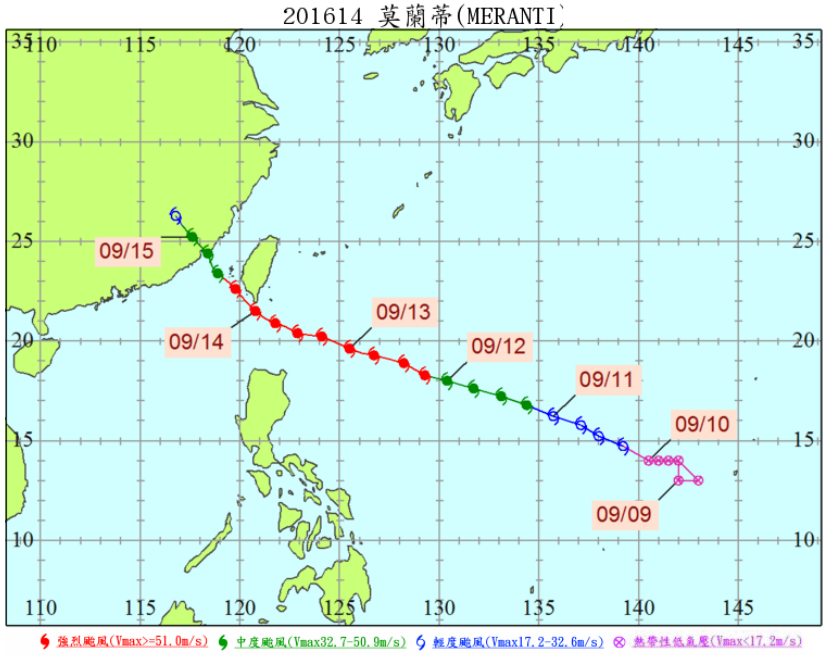
Validated Gauge Locations at Taiwan

The observed data and harmonic data are provided by CWB (Taiwan).

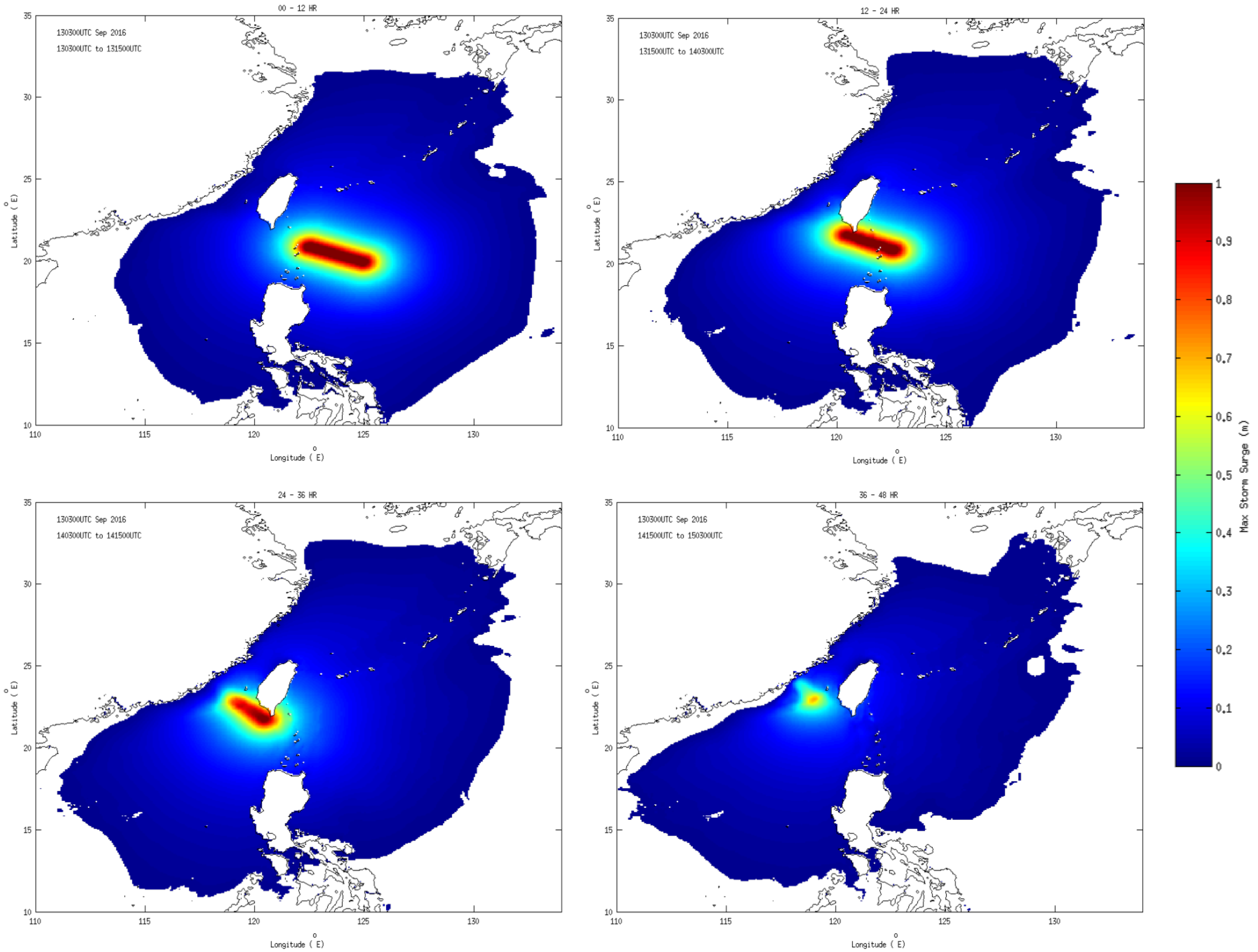
Forecast Product (1)
Maximum Storm Surge

2016年莫蘭蒂颱風

颱風警報單時間：2016031308



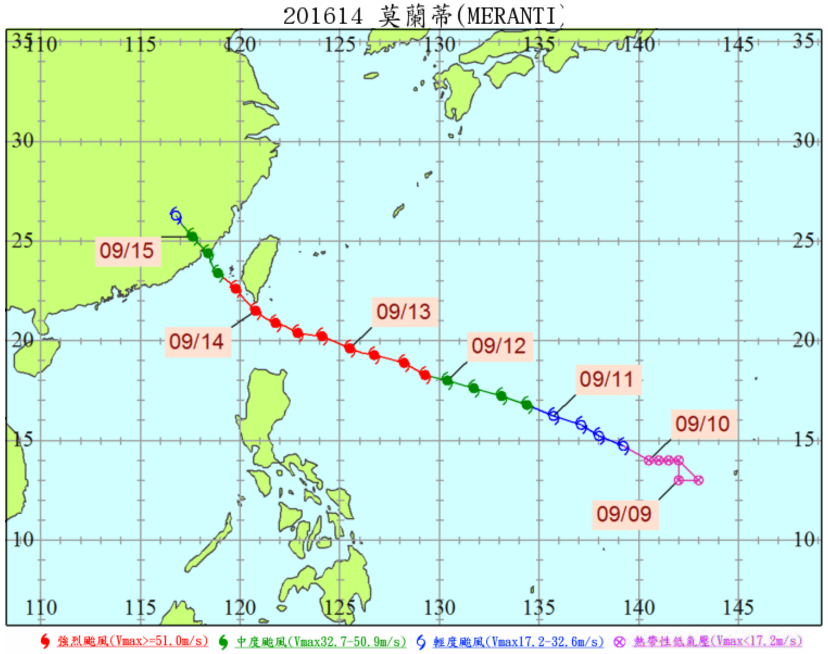
(颱風資料庫提供)



Forecast Product (2) Maximum Storm Tides

2016年莫蘭蒂颱風

颱風警報單時間：2016031308



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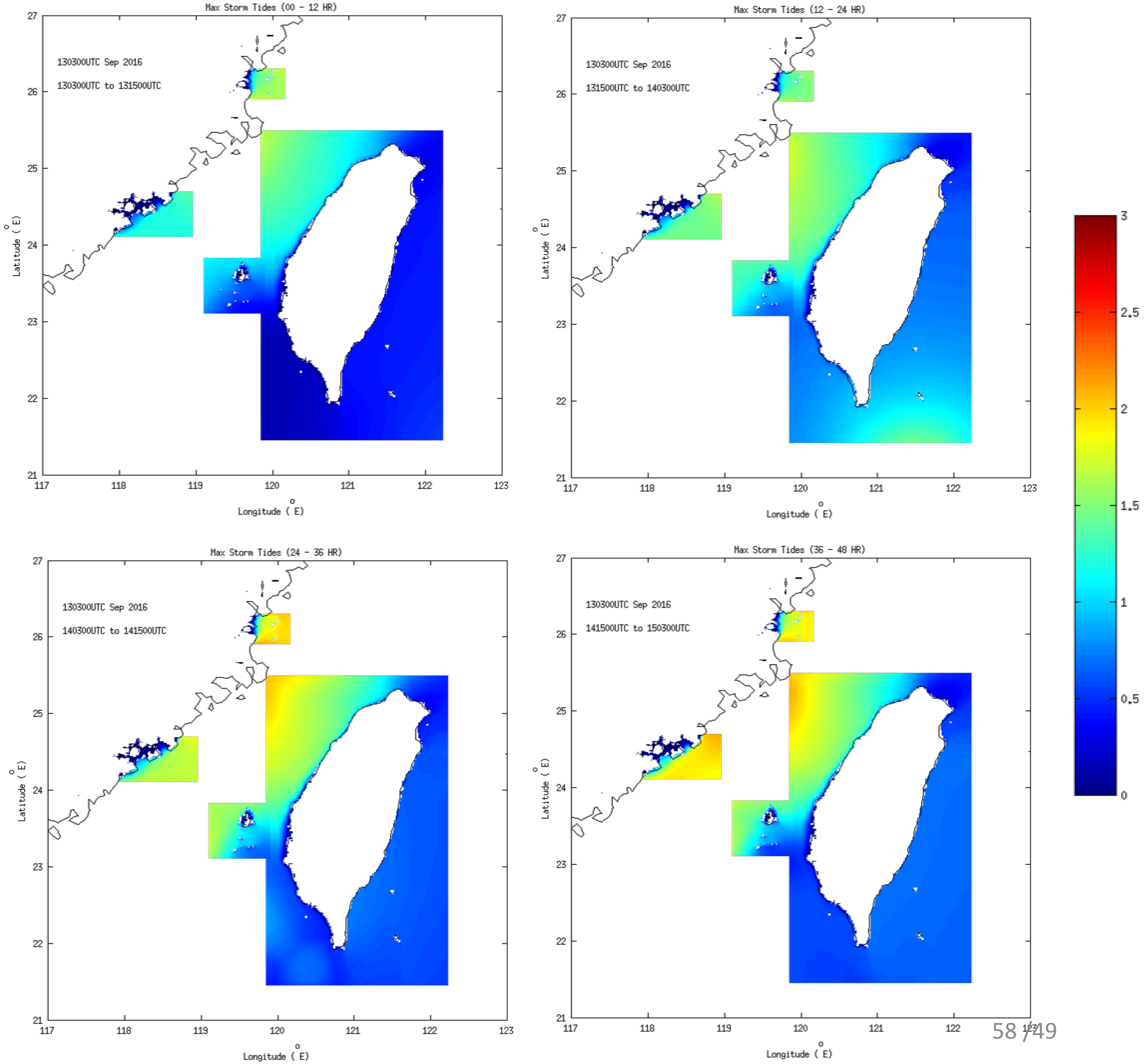
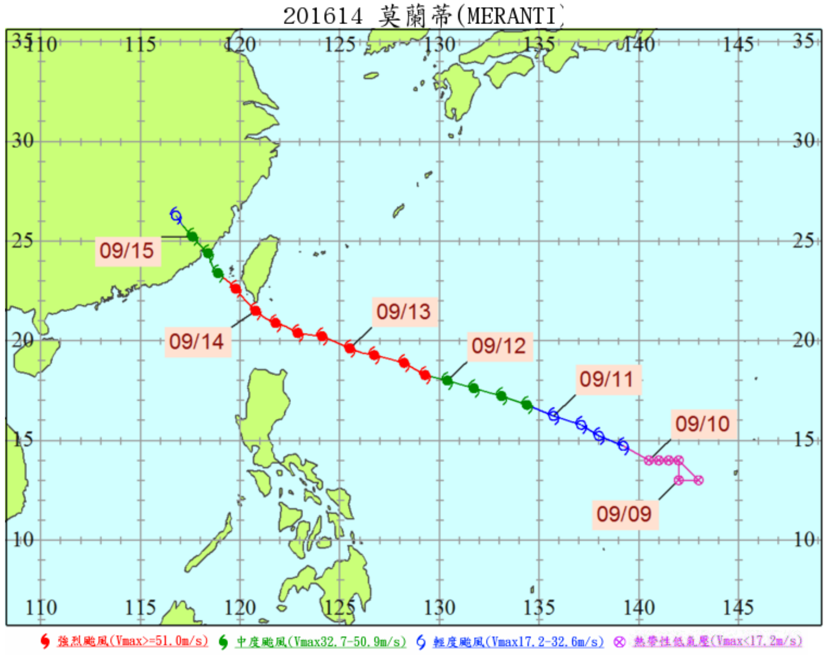


Forecast Product (3) Maximum Tides

2016年莫蘭蒂颱風

颱風警報單時間：2016031308



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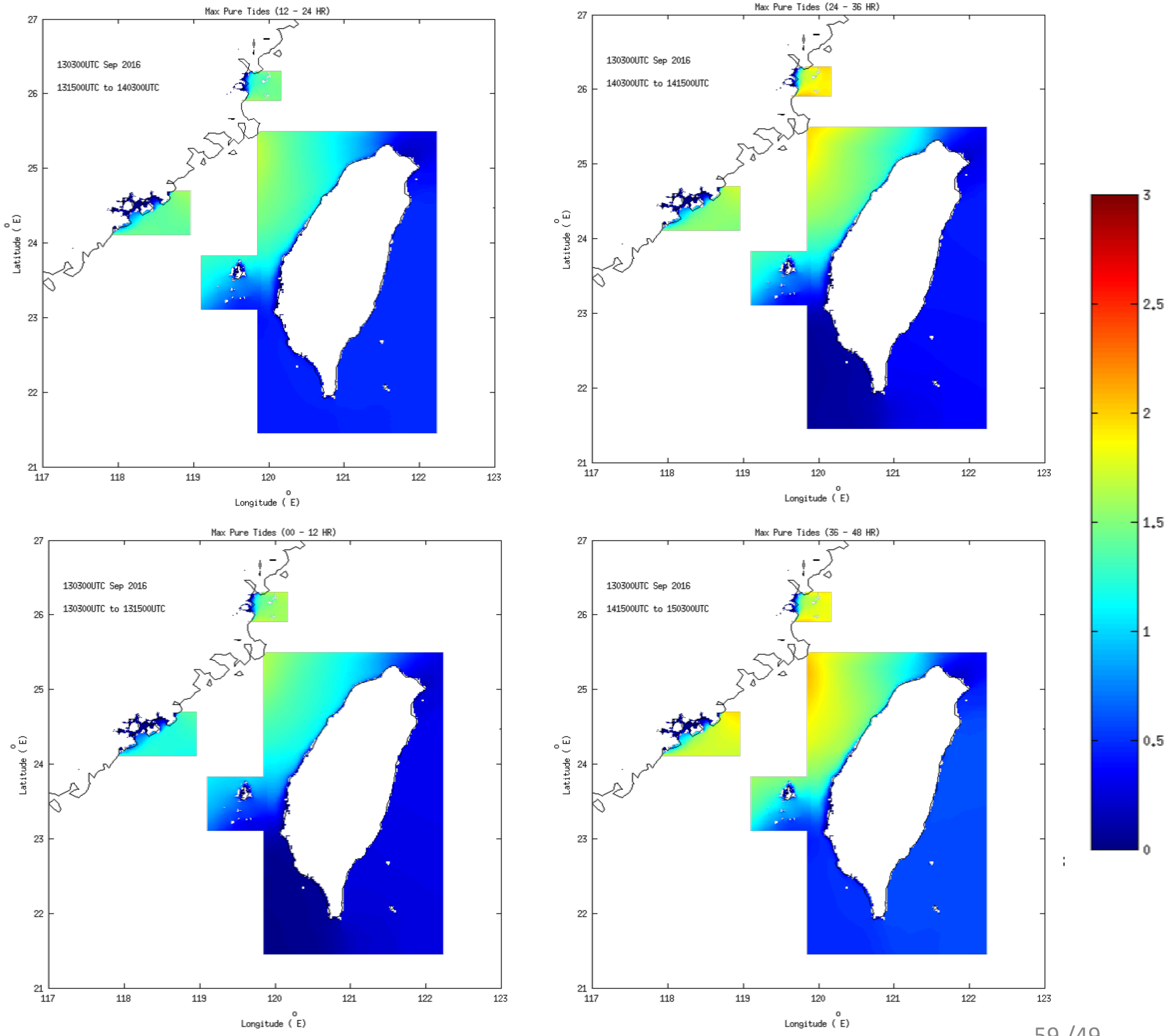


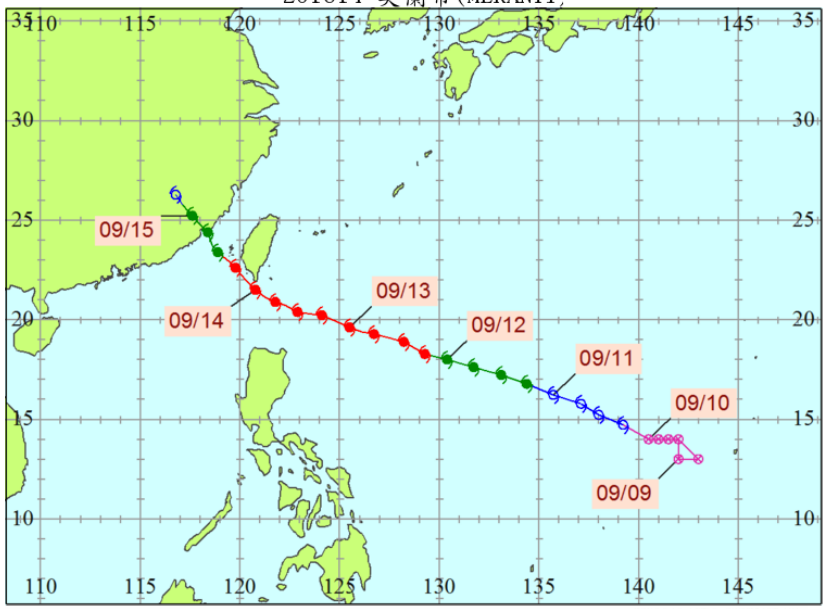
Forecast Product (4)

Maximum Storm Tides – Maximum Tides

2016年莫蘭蒂颱風

颱風警報單時間：2016031308

201614 莫蘭蒂(MERANTI)



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)

(颱風資料庫提供)