ESCAP/WMO Typhoon Committee

ESCAP/WMO Typhoon Committee
Roving Seminar 2016
Ha noi, Viet Nam, 15-17 / Nov / 2016

Storm surge forecast and outline of RSMC Tokyo products

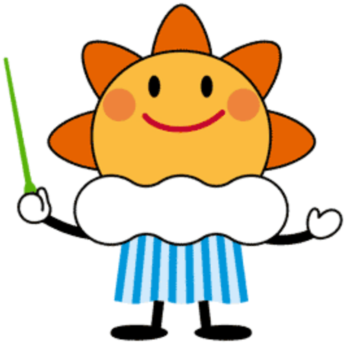
Nadao Kohno

Office of Marine Prediction,
Global Environment and Marine Department, JMA

nkono@met.kishou.go.jp; nkohno@mri-jma.go.jp

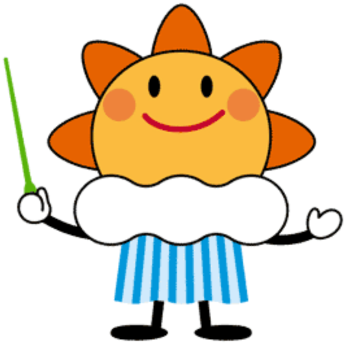
Contents

- Storm surge forecast
- Storm Surge Watch Scheme (SSWS)
- Products of RSMC Tokyo



Contents

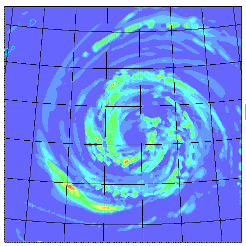
- Storm surge forecast
- Storm Surge Watch Scheme (SSWS)
- Products of RSMC Tokyo



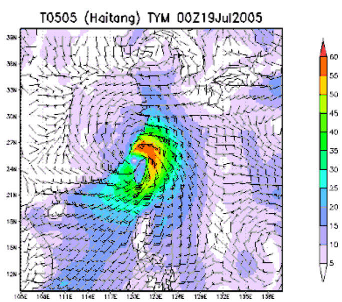
Accurate storm surge prediction

Input

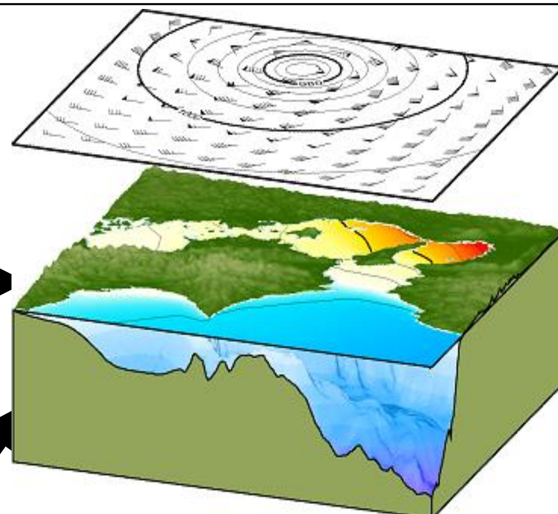
tropical cyclone information



NWP GPVs



Storm surge model

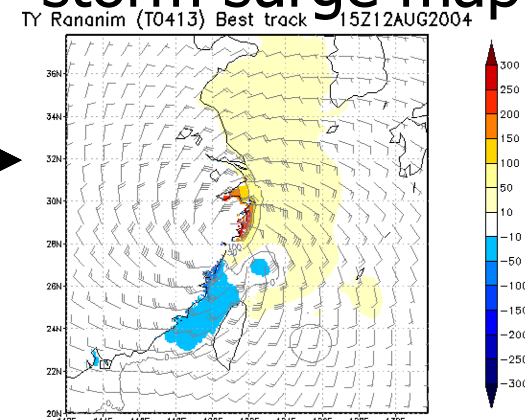


bathymetry

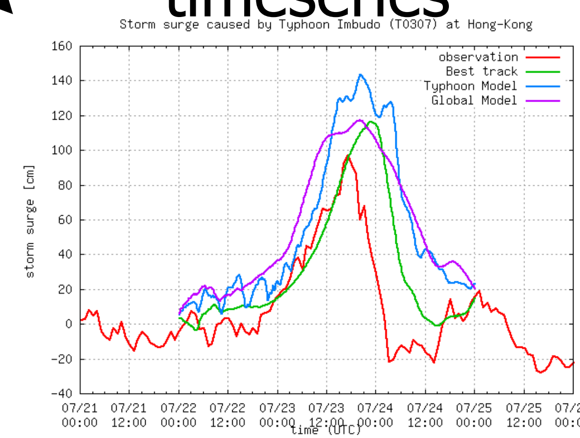
- based on two-dimensional shallow water equations

products

storm surge map



timeseries



If you are interested in using a storm surge model,
please contact with the Office of Marine Prediction, JMA

Model numerics of storm surge model

Non divergent Navier–Stokes equation without viscosity. Coriolis force and gravity are included.

Equations of motion

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - fv = -\frac{1}{\rho_0}\frac{\partial P}{\partial x} + \frac{1}{\rho_0}\frac{\partial \tau_x}{\partial z}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + fu = -\frac{1}{\rho_0}\frac{\partial P}{\partial y} + \frac{1}{\rho_0}\frac{\partial \tau_y}{\partial z}$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho_0}\frac{\partial P}{\partial z} - g$$

Continuity equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

(x, y), z: horizontal / vertical directions (u, v), w: velocity components
P: pressure, ρ_0: density, τ:stress, f : Coriolis parameter, g: gravitational acceleration.

Simplification

For simplicity, the mass fluxes are expressed in horizontal 2-dimensional (2D) layer, vertically integrated.

In Cartesian Coordinates :

Inverse Barometer effect

Equations of motion

$$
\begin{cases}
\dfrac{\partial Du}{\partial t} + \dfrac{\partial Du^2}{\partial x} + \dfrac{\partial Duv}{\partial y} = -\dfrac{1}{\rho_w g} D \dfrac{\partial(\varsigma - \varsigma_0)}{\partial x} - \dfrac{1}{\rho_w}(\tau_{ax} - \tau_{bx}) + fDv \\
\dfrac{\partial Dv}{\partial t} + \dfrac{\partial Duv}{\partial x} + \dfrac{\partial Dv^2}{\partial y} = -\dfrac{1}{\rho_w g} D \dfrac{\partial(\varsigma - \varsigma_0)}{\partial y} - \dfrac{1}{\rho_w}(\tau_{ay} - \tau_{by}) - fDu
\end{cases}
$$

Continuity equation

Storm surge

Wind setup

$$
\frac{\partial \varsigma}{\partial t} + \frac{\partial Du}{\partial x} + \frac{\partial Dv}{\partial y} = 0
$$

$$
D(x, y, t) = H(x, y) + \varsigma(x, y, t)
$$

$\mathbf{x} = (x, y)$: horizontal position, $\mathbf{U} = (u, v)$: current velocity,

ζ: height deviation, ζ_0 : balance level with surface pressure,

ρ_w: sea water density, f: Coriolis parameter, g: gravitational acceleration,

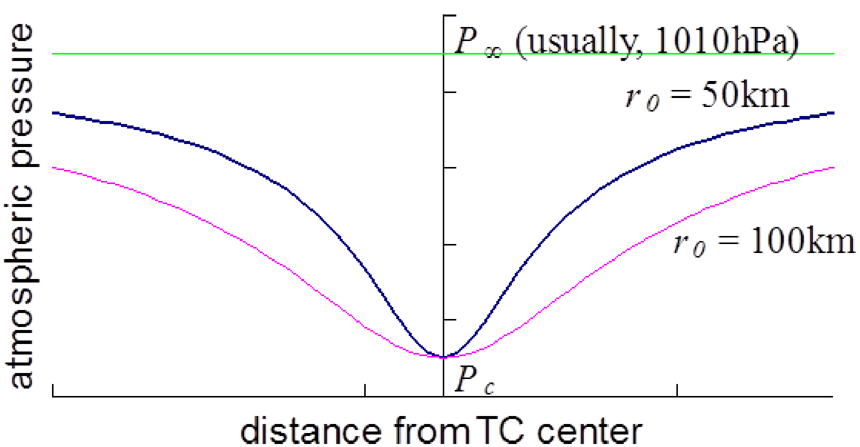
$\boldsymbol{\tau}_\mathbf{a} = (\tau_{ax}, \tau_{ay})$: surface stress, and $\boldsymbol{\tau}_\mathbf{b} = (\tau_{bx}, \tau_{by})$ bottom stress

Typhoon forcing

- Pressure
  - Fujita's formula

$$P(r) = P_\infty - \frac{P_\infty - P_c}{\sqrt{1 + (r/r_0)^2}}$$

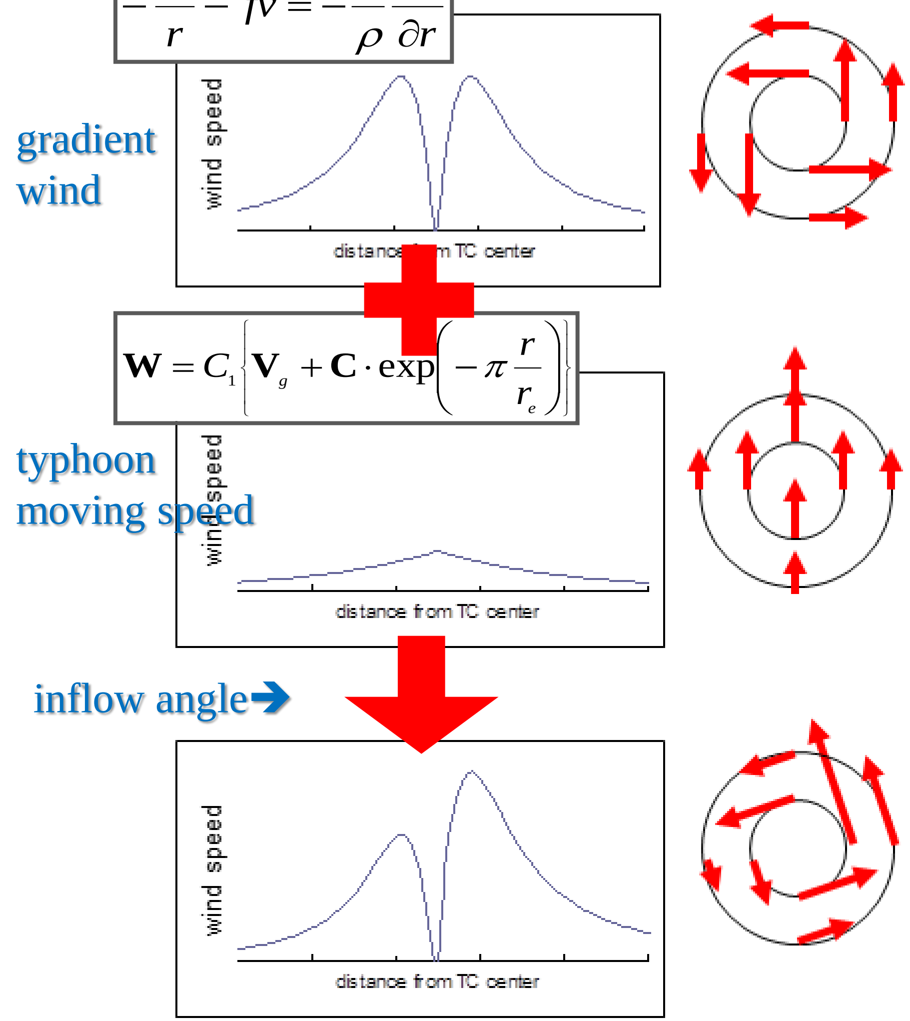
- r_0 decides sharpness of pressure distribution.
- r_0 is calculated from 30 and 50 knot radius.



- Wind

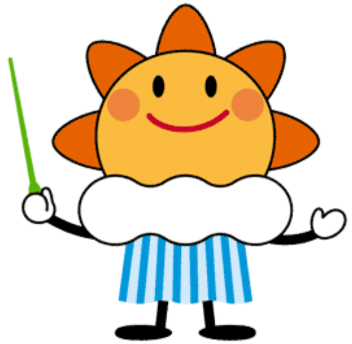
$$-\frac{v^2}{r} - fv = -\frac{1}{\rho}\frac{\partial P}{\partial r}$$

$$\mathbf{W} = C_1\left\{\mathbf{V}_g + \mathbf{C}\cdot\exp\left(-\pi\frac{r}{r_e}\right)\right\}$$



Contents

- Storm surge forecast
- Storm Surge Watch Scheme (SSWS)
- Products of RSMC Tokyo



WMO Storm Surge Watch Scheme (SSWS)

History

2008.5 Storm surge disasters by Nargis

(Major storm surge disasters successively happened…)

2008.6 60th WMO Executive Council (Geneva, 2008.6)

Requested WMO/SG to facilitate development of Storm Surge Watch Scheme (SSWS).

2008.12 14th Regional Association II (Tashkent)

Requested RSMC to consider participation in a Regional Storm Surge Watch Scheme, and to develop a proposal for consideration by the ESCAP/WMO Typhoon Committee and the Association.

2009.1 41st Typhoon Committee (Chiang Mai)

Approved WGM recommendation to authorize WGM/RSMC Tokyo to conduct a survey on the present status of Members in using storm surge models and to develop a future plan for the establishment of a Regional Storm Surge Watch Scheme suitable for the TC region.

Planned to establish a Regional Storm Surge Watch Scheme suitable for the TC region.

2010.1 42nd Typhoon Committee (Singapore)

Approved WGM recommendation to produce the storm surge distribution map and report the evaluation in 43rd session.

(System development started in JMA)

Progress

2011.6 RSMC Tokyo started operation to provide storm surge distribution maps.

2012.6 RSMC Tokyo started to provide storm surge time series charts at one point for each TC Member.

2013.6 RSMC Tokyo extended forecasting region.

2016.1 RSMC Tokyo began running storm surge model daily (experimental mode).

2016.6 RSMC Tokyo began operating multi-scenario prediction system.

2016.8 RSMC Tokyo began issuing wave ensemble forecasts.

Operation chart of SSWS

JMA NWP routine

JMA Official forecast

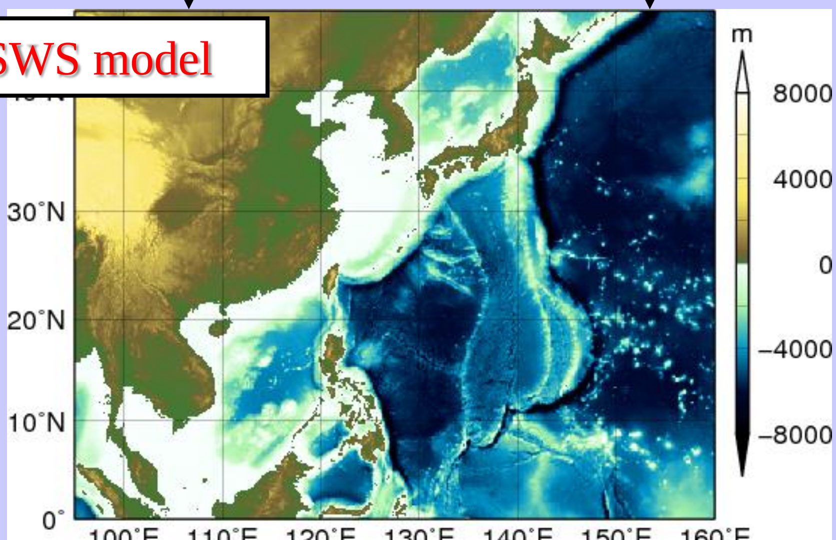
GSM
(sea level pressure, wind, etc.)

TC information
(central pressure, wind etc.)

GPV

Bogus

SSWS model



GPV

Bogus

TEPS
(25 members)
(sea level pressure, wind, typhoon track)

predicted typhoon track

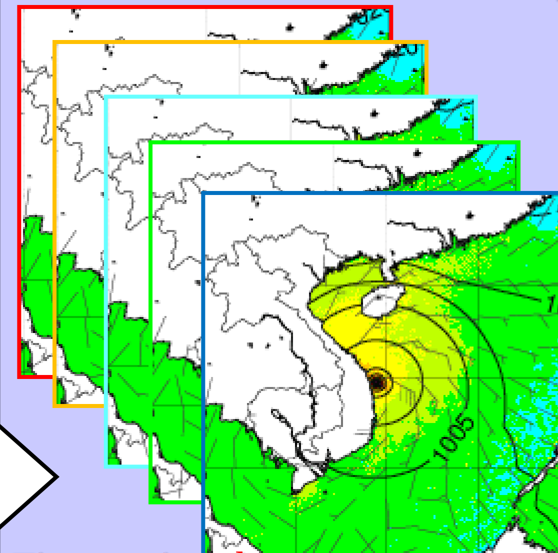
Cluster analysis
(select 5 members)

typhoon location

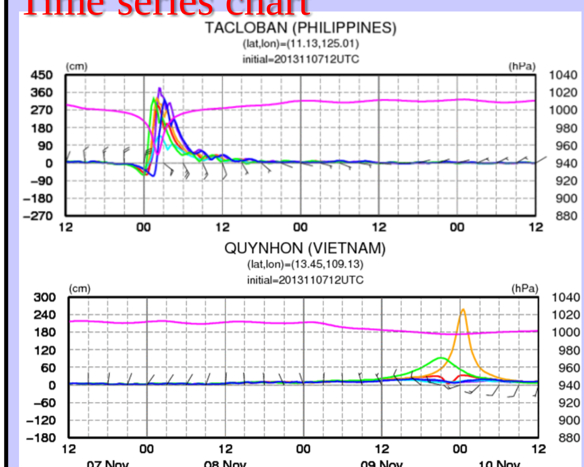
TC information
(central pressure, wind etc.)

Products

Storm surge distribution map

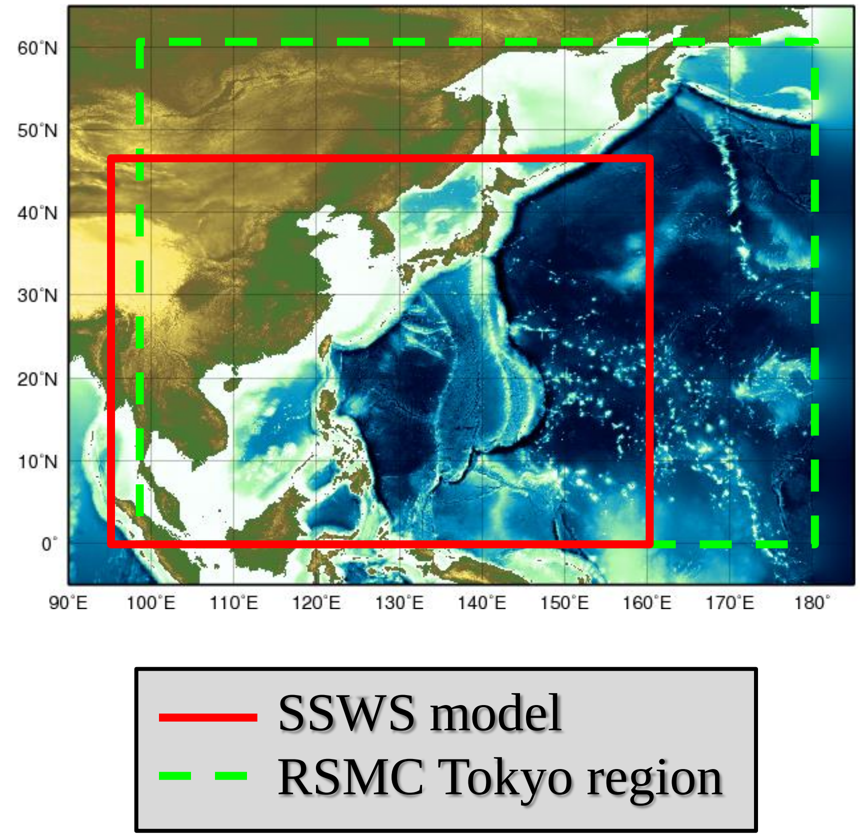


Time series chart



Outline of the model

	SSWS model
Model	2-dimensional linearized model
Grid	Lat-Lon, staggered grid (Arakawa C-Grid)
Region	0 – 46°N, 95°E – 160°E
Resolution	2’ x 2’, 1951 x 1381 (~3.7km)
Time step	8-seconds
Forecast time	72-hours
Cycle	4 / day (every 6-hours)
Initial time	00, 06, 12, 18 UTC
Member	no-typhoon case: 1 member (model GPV) typhoon case: 6 member (model GPV + bogus (center))
Model GPV forcing	GSM (0.25° x 0.2°) TEPS (0.5625° x 0.5625°)
Typhoon forcing (bogus)	Pressure: Fujita’s formula Inflow angle: 30° Moving velocity for asymmetry



GSM: JMA Global Spectral Model
TEPS: JMA Typhoon Ensemble Prediction system

Inundation, ocean wave and river water are not included.

Cluster analysis

- Cluster analysis (K-means method) is adopted to select representative 5 members from TEPS 25 members.

Cluster analysis

K-means method

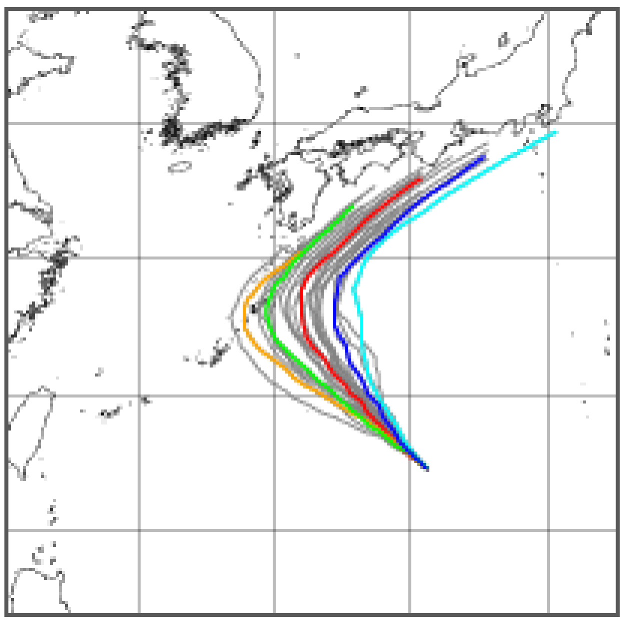
(N=25, K=5)

Center of typhoon:

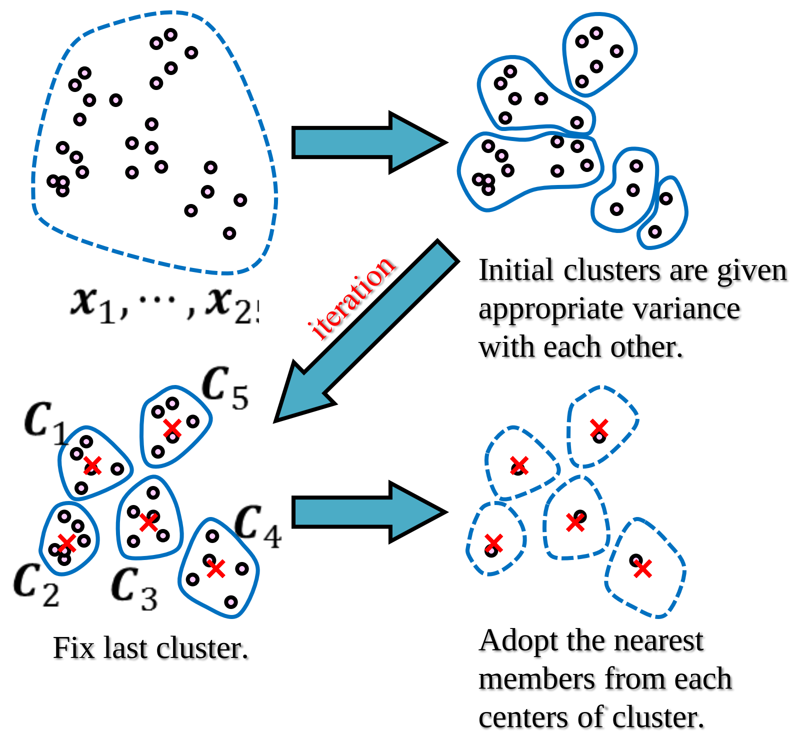
$$\boldsymbol{x}_i = (lat_i, lon_i), (i = 1, \cdots, N)$$

Center of cluster:

$$\boldsymbol{c}_k = \frac{1}{N_k} \sum \boldsymbol{x}_i, (k = 1, \cdots, K)$$

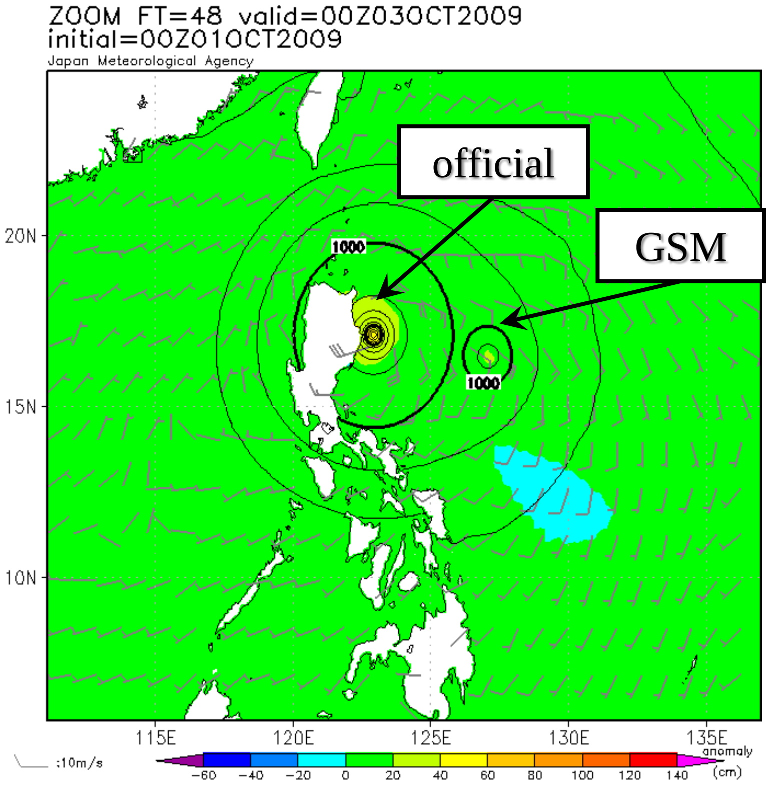


Ex.) T1418
grey: TEPS 25 member
color: selected 5 member



Imaginary twin center

If GSM predicted considerably different course from the official one, two peaks might appear.

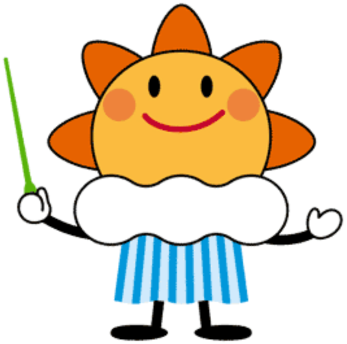


Ex.) T0917 (Typhoon "Parma")
Colors show storm surge (cm), contours show surface pressure (hPa), barbs show surface wind. Initial time is 00UTC, 01Oct.2009.

In multi-scenario, two peaks never appear because it just refers each typhoon course predicted by TEPS.

Contents

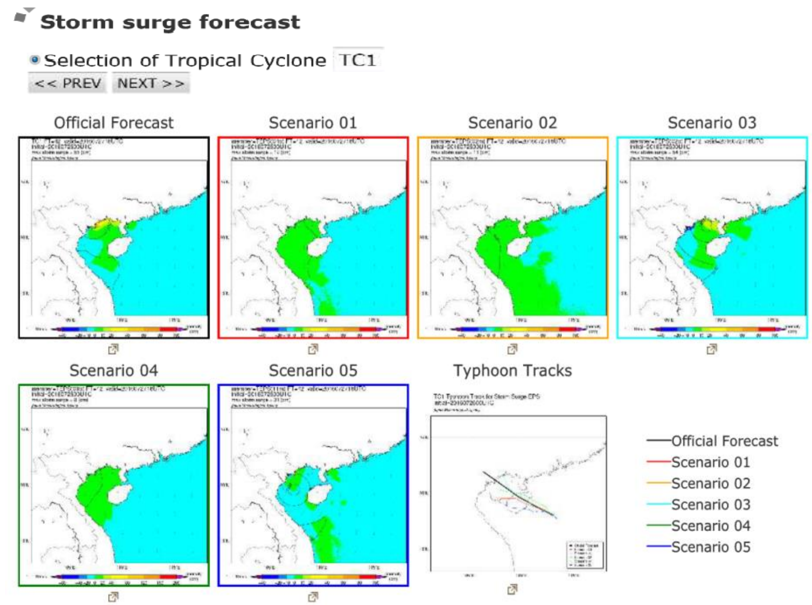
- Storm surge forecast
- Storm Surge Watch Scheme (SSWS)
- Products of RSMC Tokyo



Numerical Typhoon Prediction Website

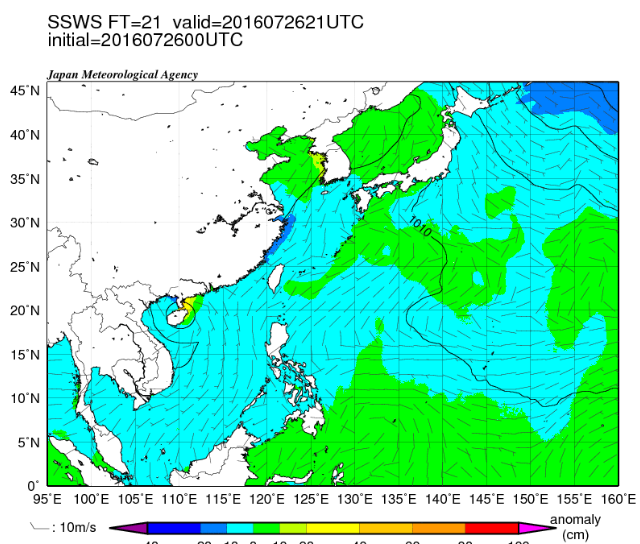
RSMC Tokyo provides storm surge prediction information to the TC members via JMA Numerical Typhoon Prediction (NTP) Website.

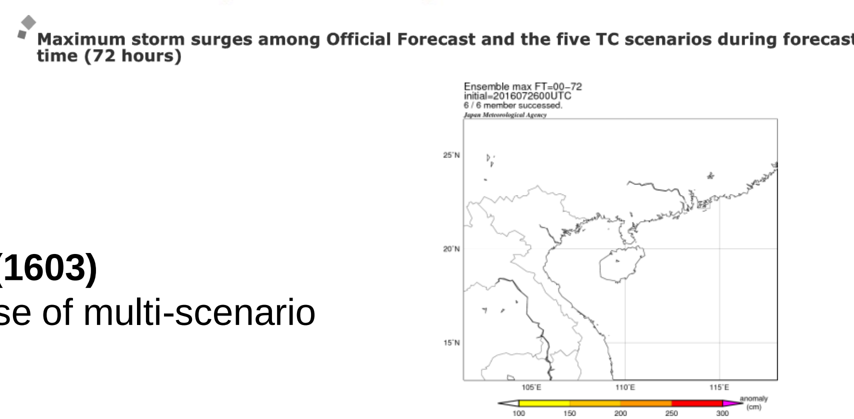
https://tynwp-web.kishou.go.jp/ (account authentication)



Storm surge distribution maps

- Whole domain maps (with official forecast)
- Enlarged maps around a typhoon for each scenario
- Max storm surge among all members during forecast time

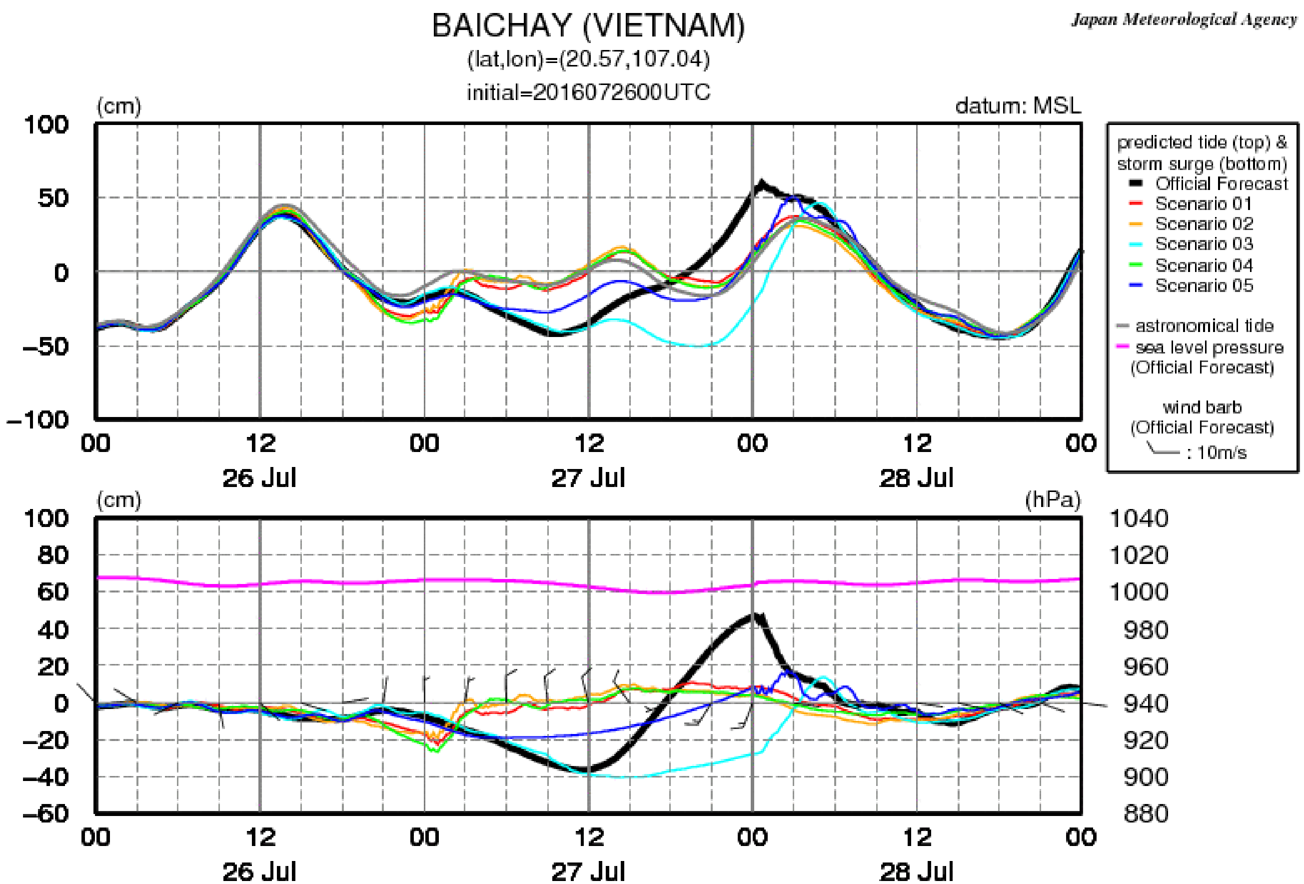




Ty Mirinae(1603)
The first case of multi-scenario prediction

Numerical Typhoon Prediction Website

- Time series charts at selected stations (2012.6~).
- Revised the form for multi-scenario prediction



Predicted storm surges / tides of each scenario

astronomical tides

sea level pressures and winds (of official forecast case)

Time series chart stations

Country	Num. of stations	Location of Station
Hong Kong (China)	6	Cheung Chau, Ko Lau Wan, Ma Wan, Quarry Bay, Shek Pik, Tai Miu Wan, Tai Po Kau, Tsim Bei Tsui, Waglan Island
Macao (China)	1	Macao
Malaysia	17	Johor Baharu, Kuantan, Tioman, Sedili, Kukup, Getting, Tawau, Kota Kinabalu, Bintulu, Miri, Sandakan, Kelang, Keling, Langkawi, Lumut, Penang, Cendering
Republic of Korea	11	Boryeong, Busan, Incheon, Jeju, Mokpo, Sokcho, Gunsan, Seogwipo, Tongyeong, Pohang, Uljin (Hupo)
The Philippines	9	Manila South Harbor, Cebu Port, Legaspi Port, SanFernando Harbor, SanVicente Port, Batangas Port, Curimao Port, Subic Bay, Mariveles Harbor, Tacloban
Thailand	2	Hua Hin, Chum Phon
Guam (USA)	1	Guam
Viet Nam	20	Cua Ong, Bai Chay, Hon Dau, Van Ly, Sam Son, Nghi Son, Hon Ngu, Vung Ang, Cua Gianh, Cua Viet, Thuan An, Son Tra, Hoi An, Dung Quat, Quy Nhon, Nha Trang, Phan Thiet, Vung Tau, Sai Gon, Dinh An

Current: 68 stations

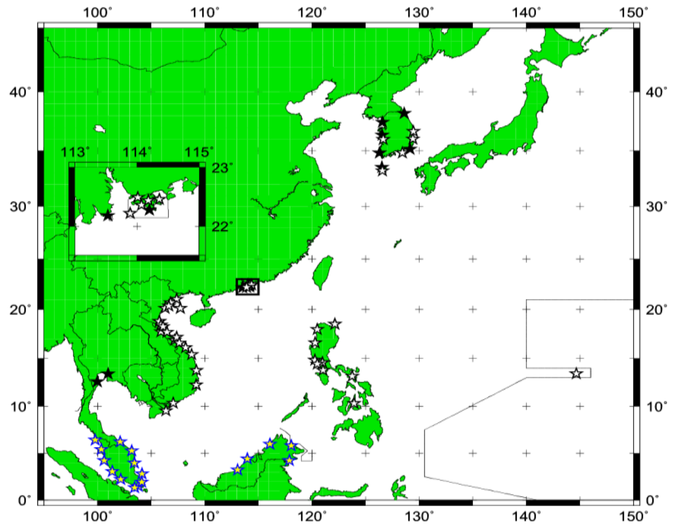
stations will further increase upon request from TC Members

Location of stations →

★ : −2013

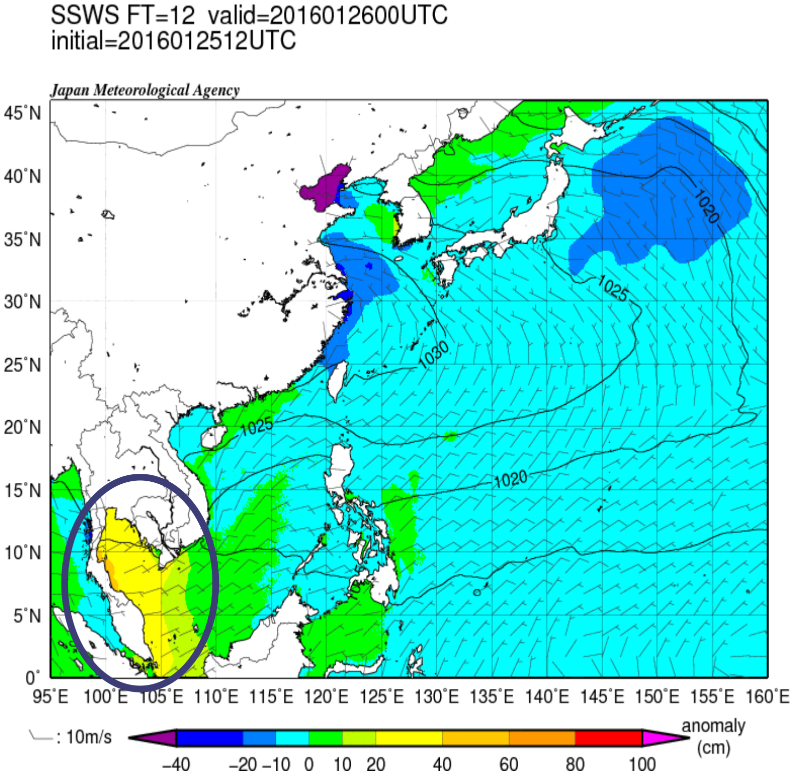
☆ : added in 2014

☆ : added in Jan. 2016



Daily run of storm surge model

JMA also began to run the storm surge model daily on an experimental basis on 28 Jan 2016, to support the provision of predictions for storm surges generated by monsoon winds or extra-tropical cyclones as well as typhoons.

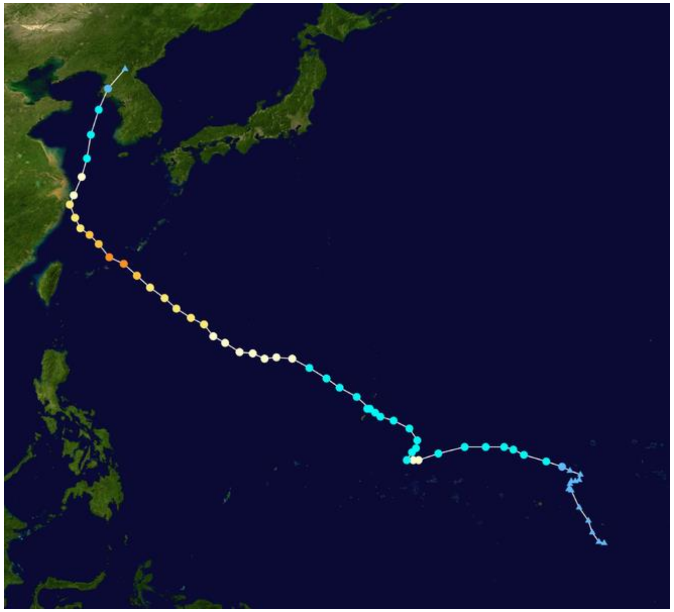


Coast of Malaysia

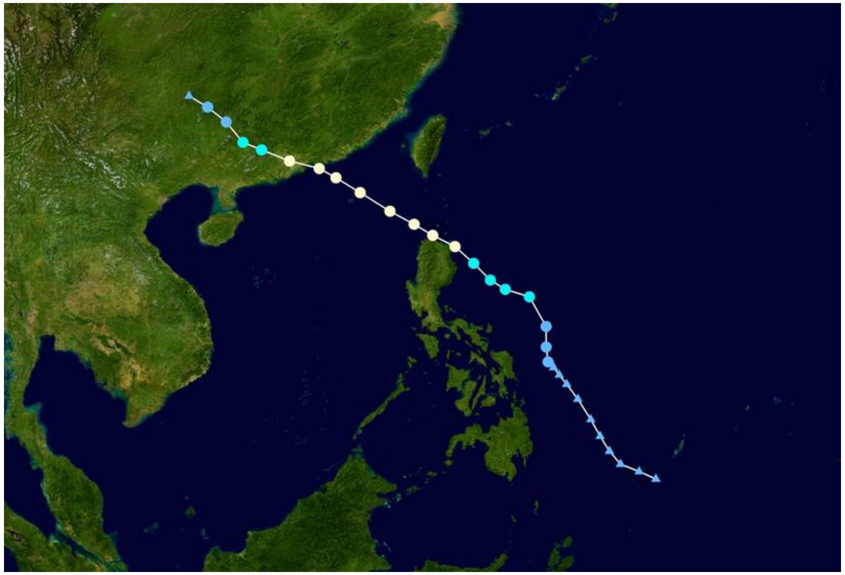
Example of storm surges generated by monsoon wind

SSWS product cases

- Typhoon Chan-hom (1509)
- Typhoon Nida (1604)



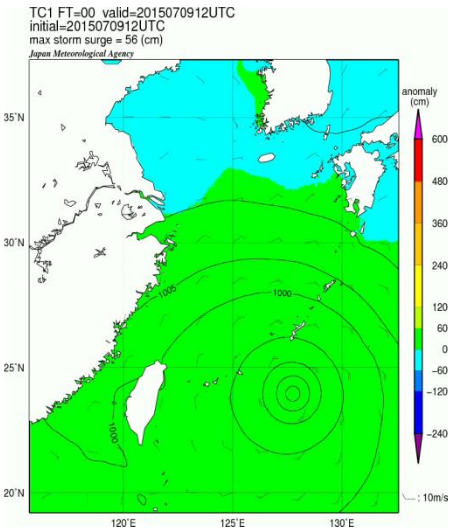
Ty Chan-hom



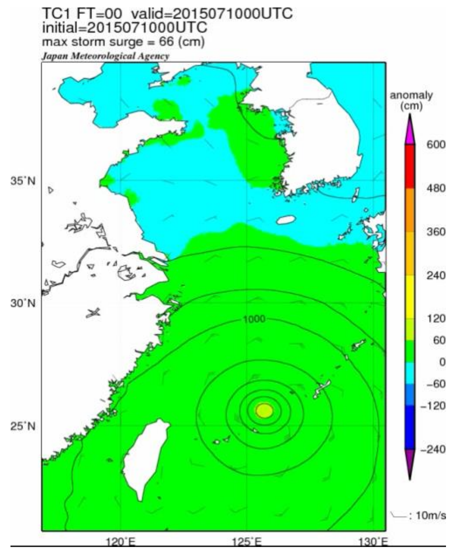
Ty Nida

Storm surges by Typhoon Chang-hom

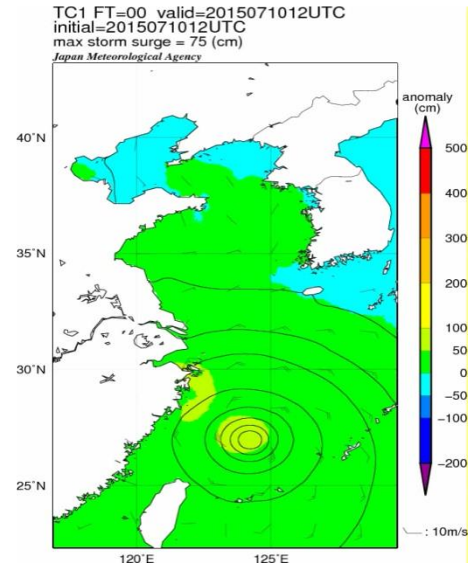
Initial: 12UTC 09/JUL



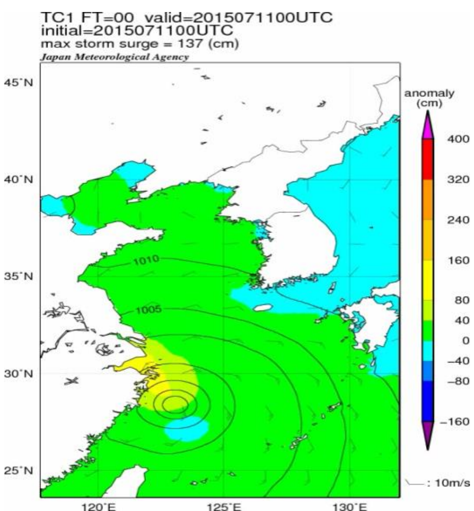
Initial: 00UTC 10/JUL



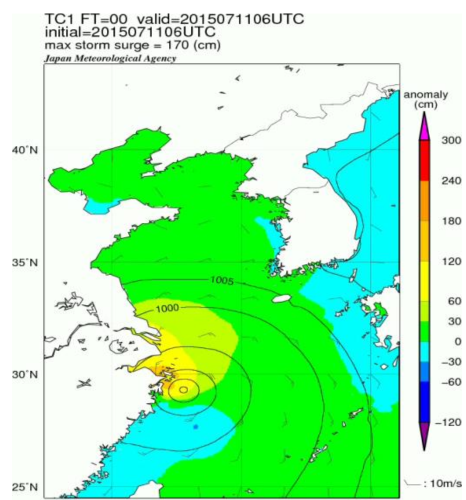
Initial: 12UTC 10/JUL



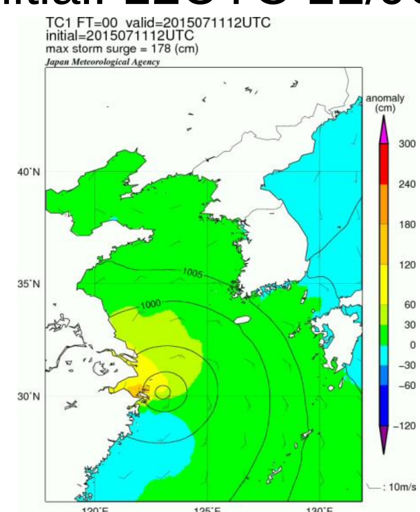
Initial: 00UTC 11/JUL



Initial: 06UTC 11/JUL

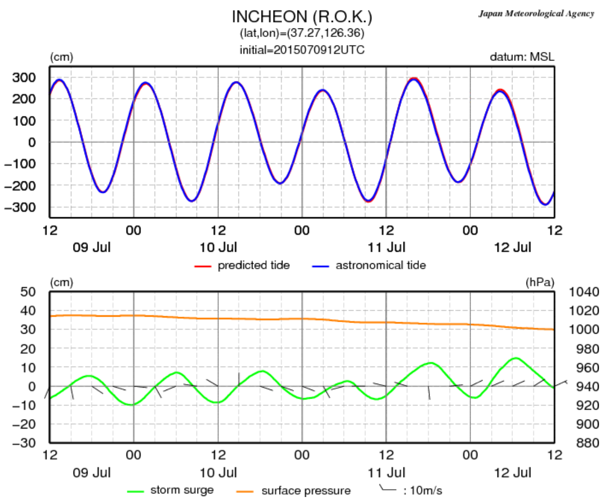


Initial: 12UTC 11/JUL

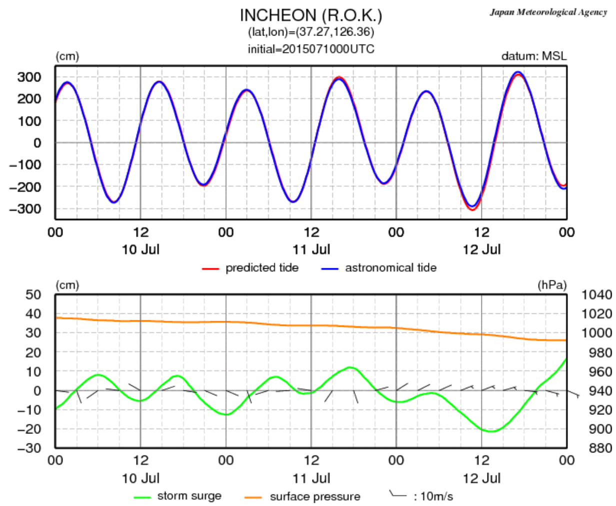


Storm surges by Typhoon Chang-hom

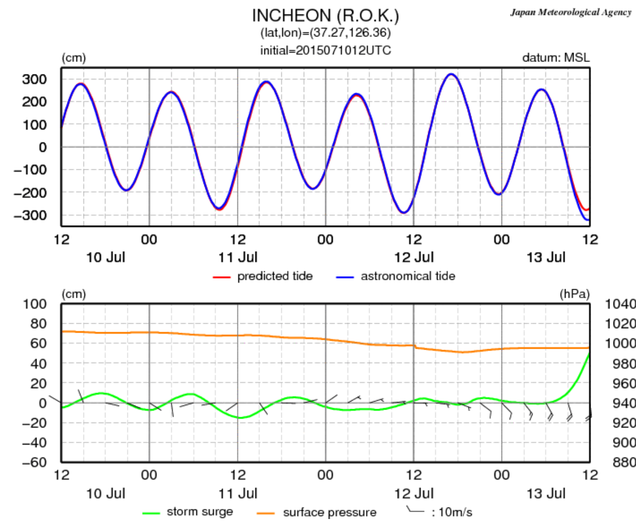
Initial: 12UTC 09/JUL



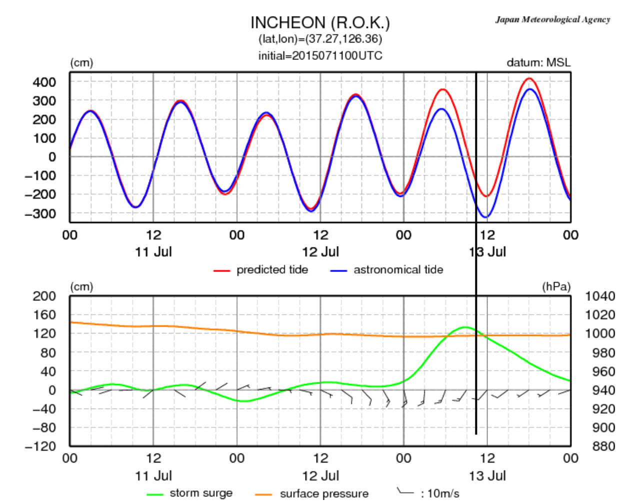
Initial: 00UTC 10/JUL



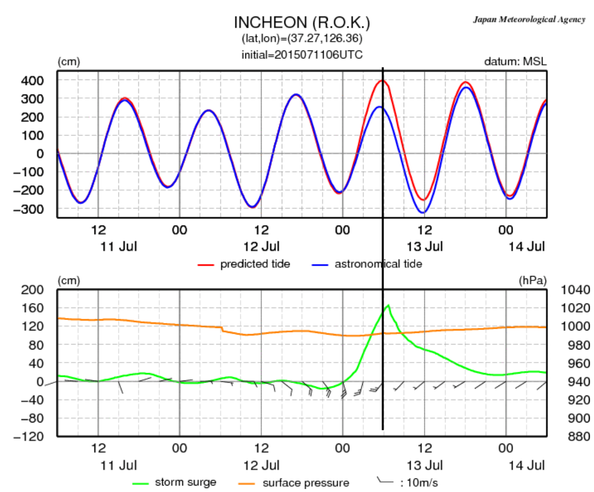
Initial: 12UTC 10/JUL



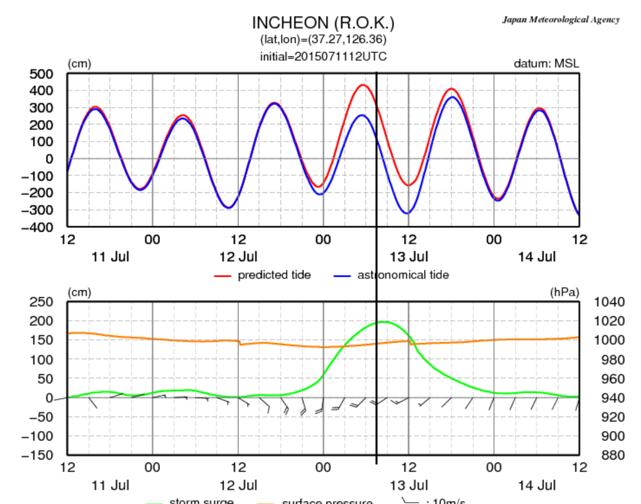
Initial: 00UTC 11/JUL



Initial: 06UTC 11/JUL



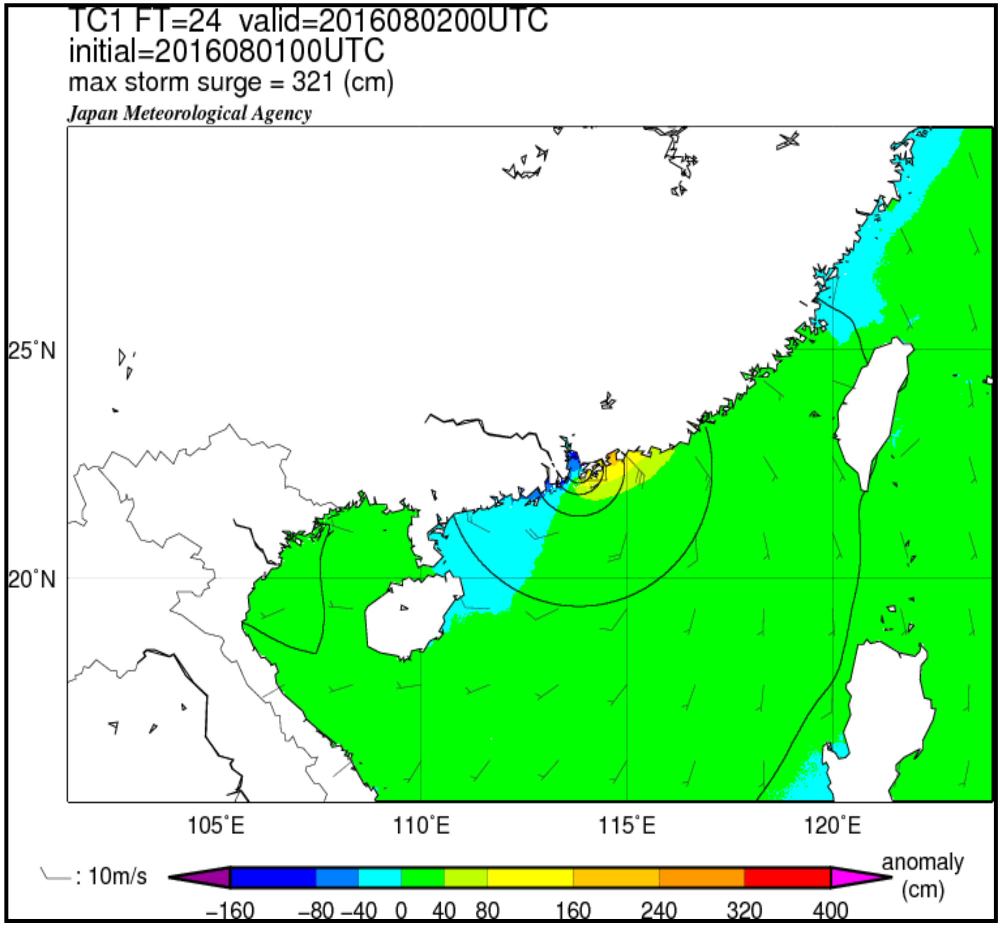
Initial: 12UTC 11/JUL

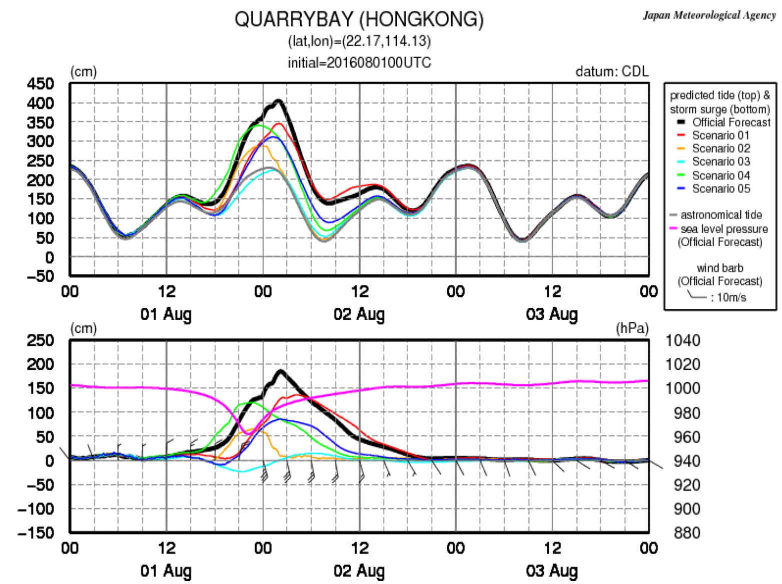


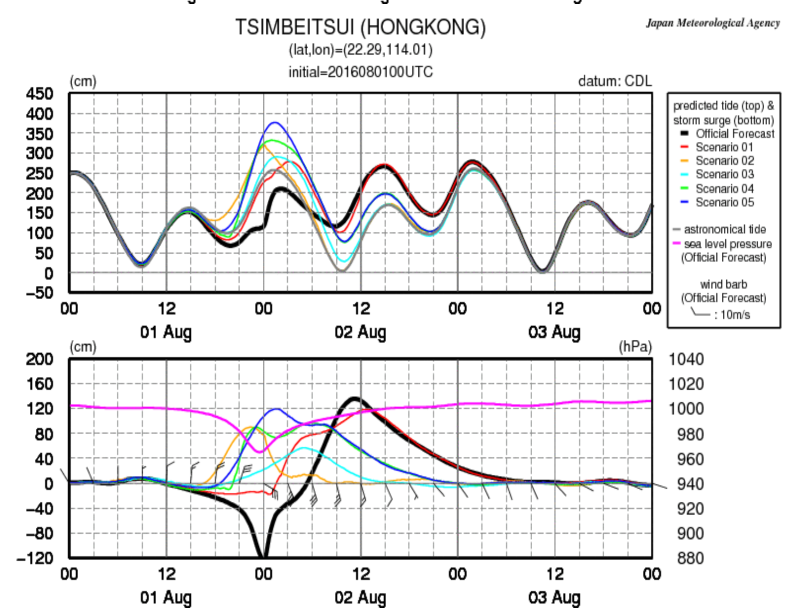
Storm surges by Typhoon Nida

Initial: 00UTC on 1/Aug/2016

Official forecast was the worst scenario!

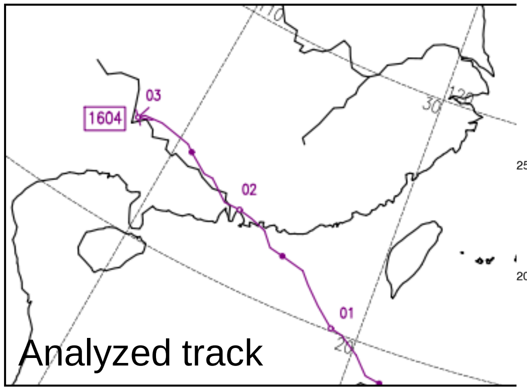


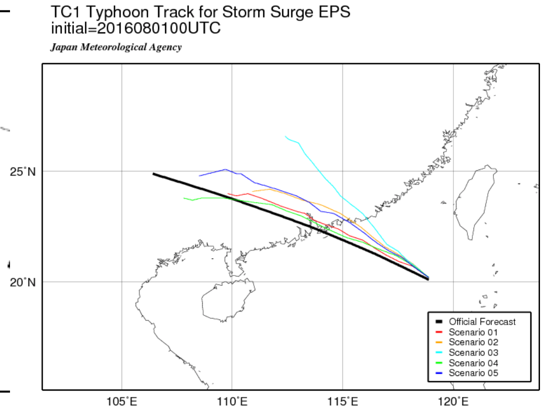


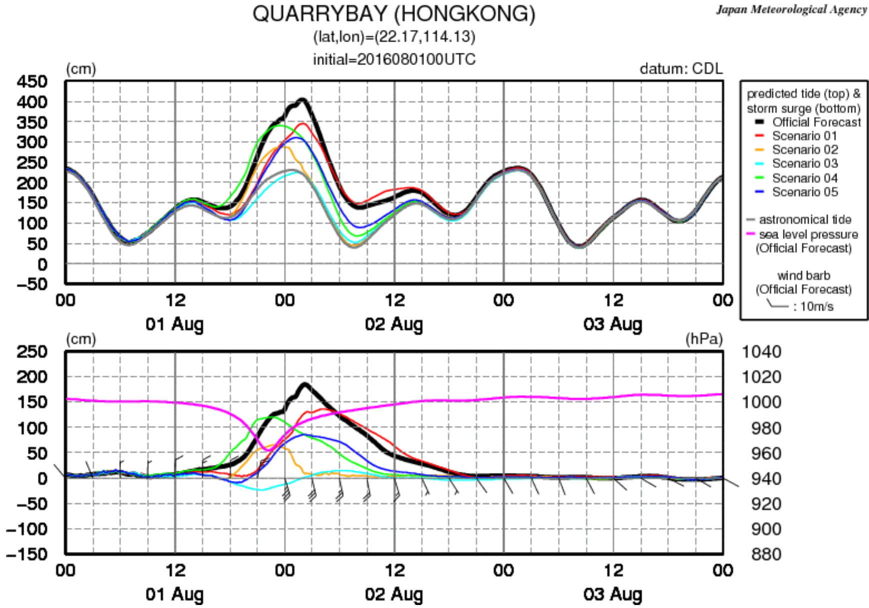


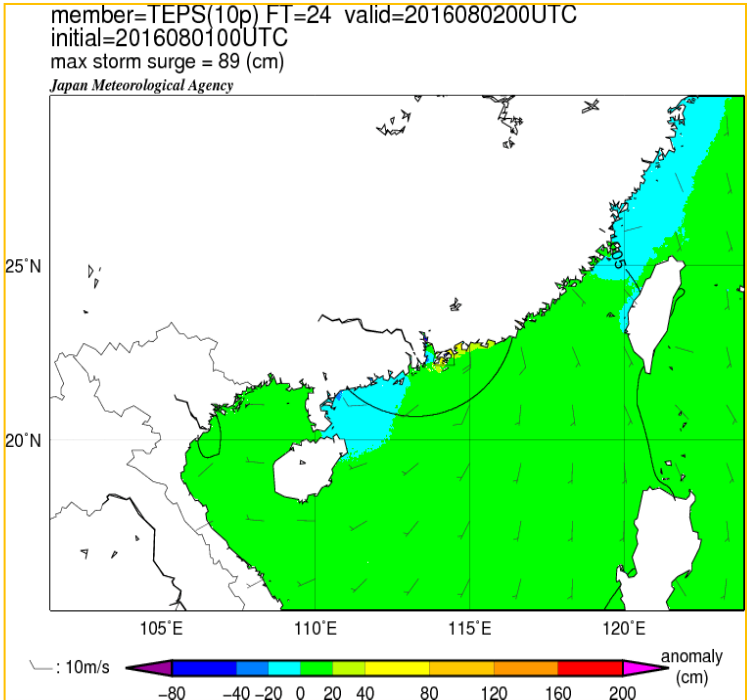
Storm surges by Typhoon Nida

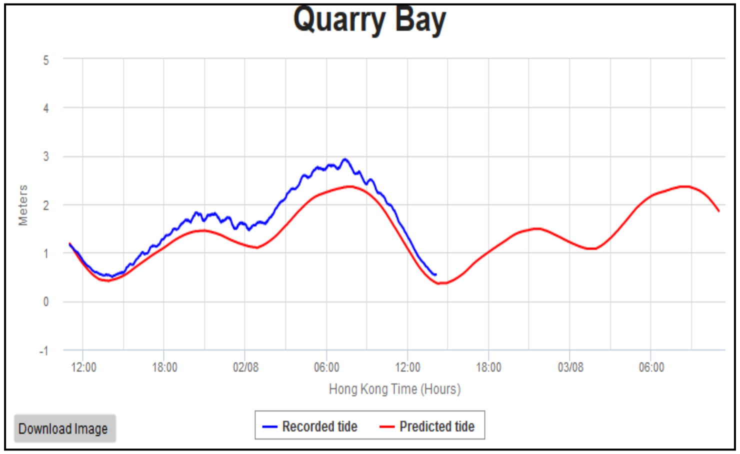
Typhoon took the course similar to scenario 2







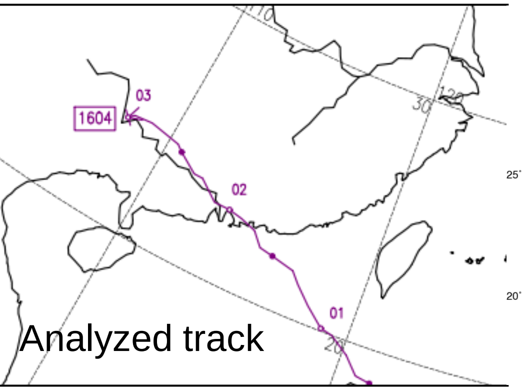


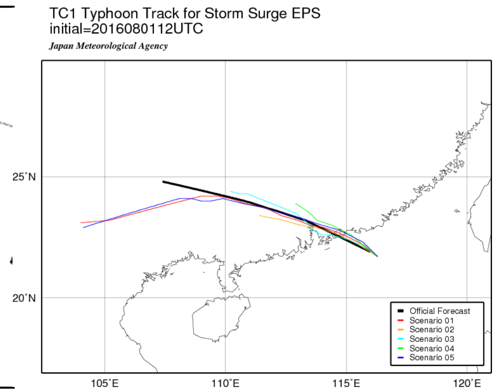


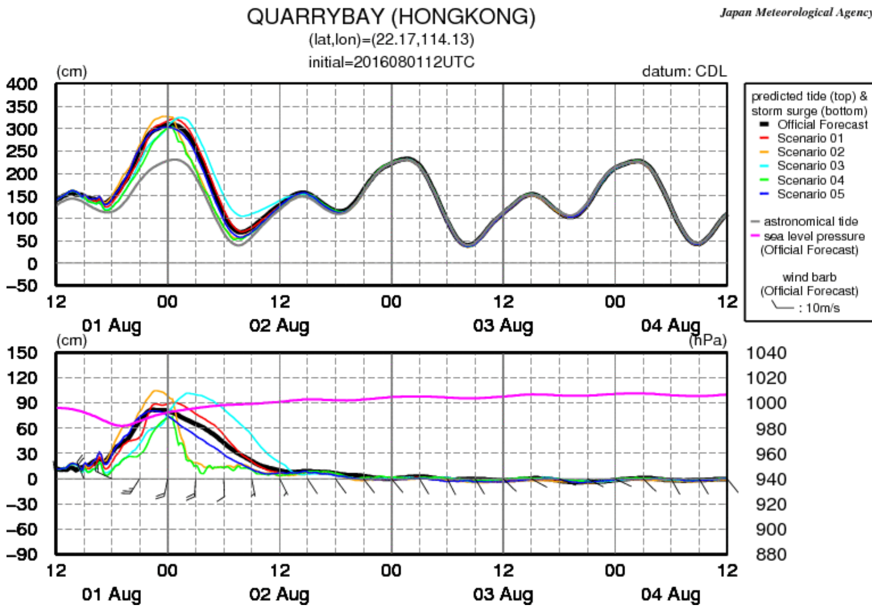
Blue: observed tide, Red: astronomical tide
(Hong Kong Observatory)

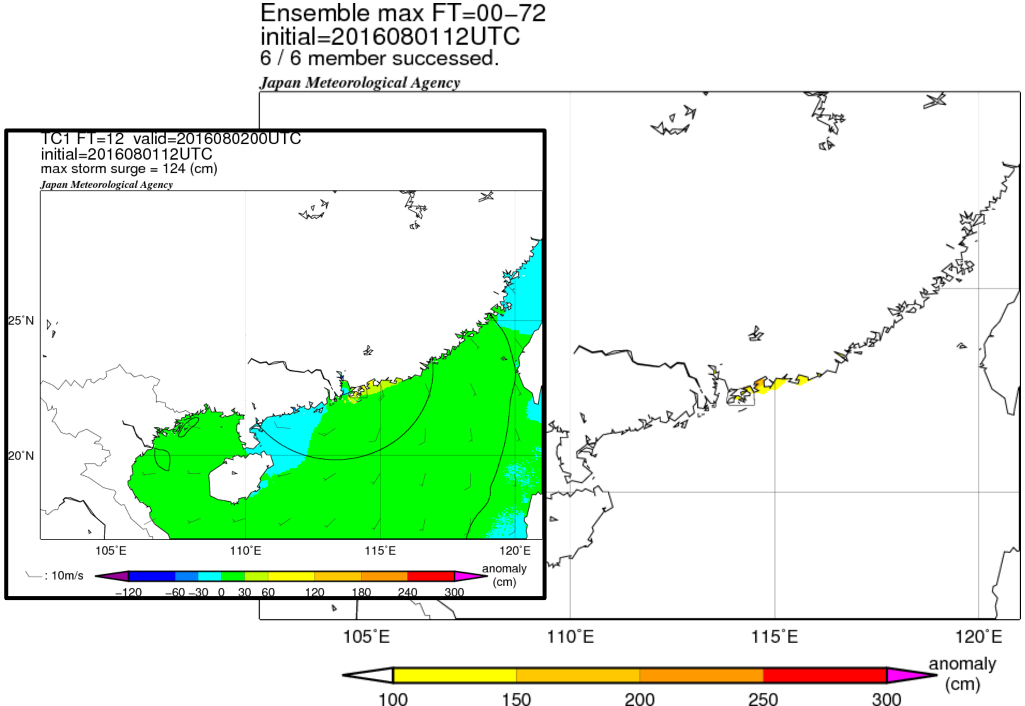
Storm surges by Typhoon Nida

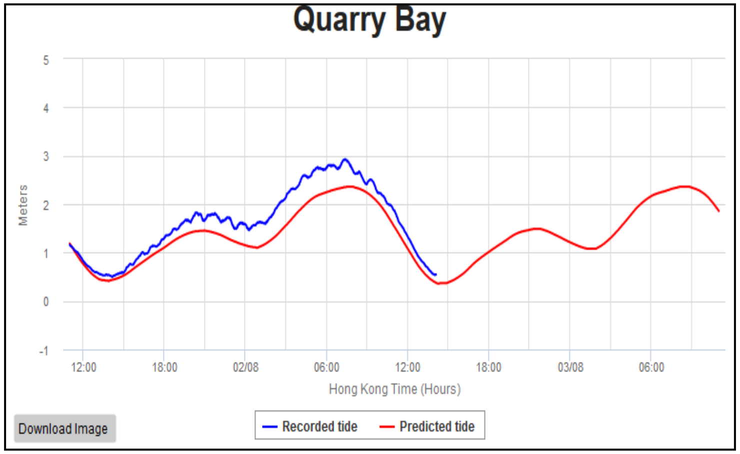
Initial: 12UTC on 1/Aug/2016







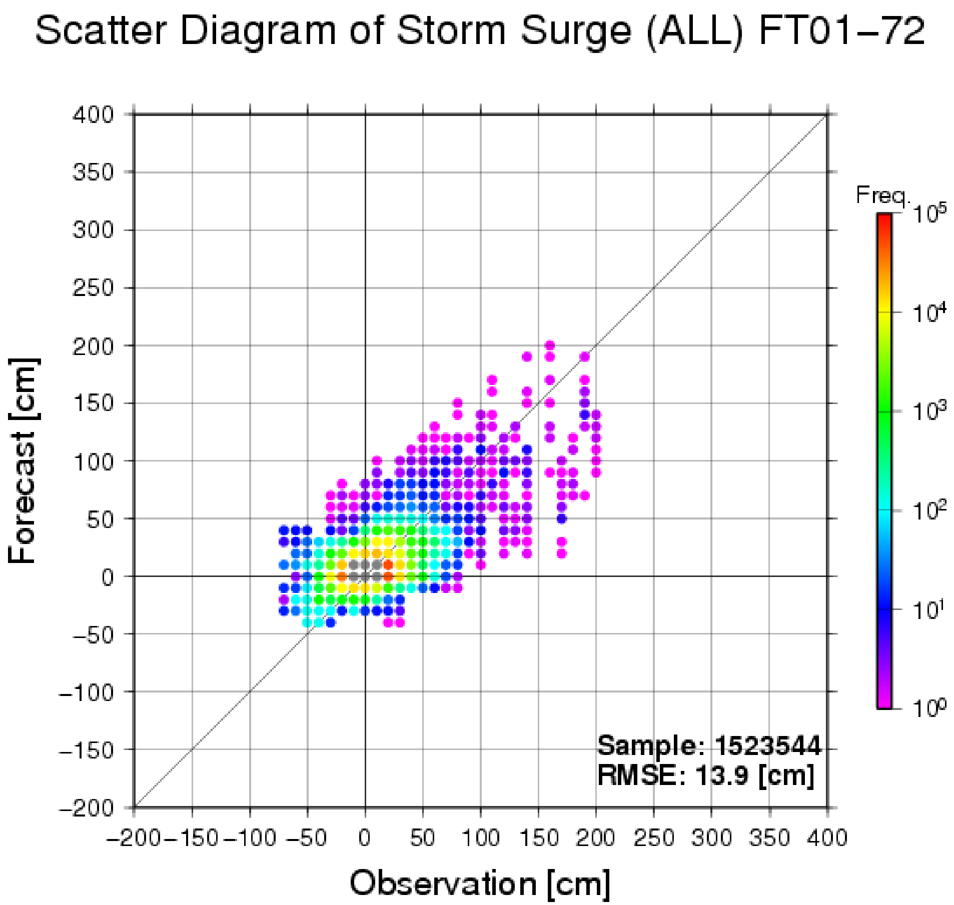




Blue: observed tide, Red: astronomical tide (Hong Kong Observatory)

Scatter diagram (Prediction vs. Observation)

Atmospheric forcing: GSM analysis and best track



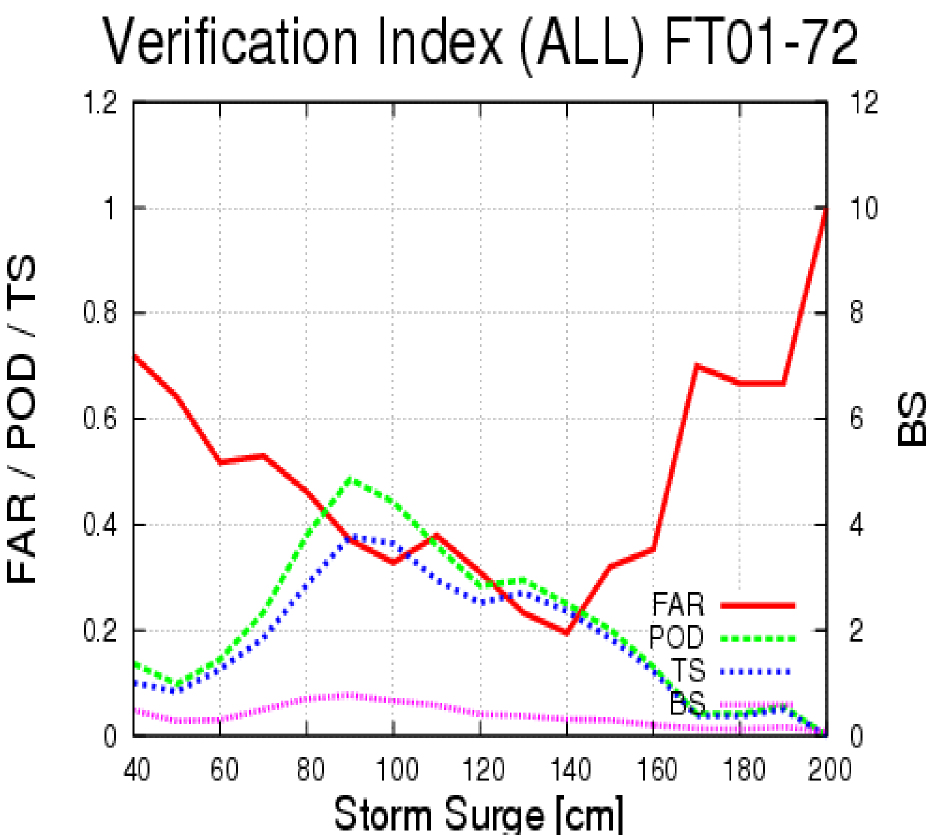
Scatter diagram of predicted storm surges against observed values

The statistical period:
Sep/2007 to Dec/2010.

The used stations:
Quarry Bay (Hong Kong, China)
Macao (Macao, China)
Manila South Harbor (Philippines)
Mariveles Harbor (Philippines)
Tanjong Pagar (Singapore)
Huahin (Thailand)

Verification scores

The scores indicate that the SSWS model tends to overestimate in general, but to underestimate large storm surges.



- **Bias Score (0≤BS<∞, perfect: 1)**

$$BS = \frac{(Hits) + (False\ alarms)}{(Hits) + (Misses)} \quad (A1)$$

- **Probability Of Detection (0≤POD≤1, perfect: 1)**

$$POD = \frac{(Hits)}{(Hits) + (Misses)} \quad (A2)$$

- **False Alarm Ratio (0≤FAR≤1, perfect: 0)**

$$FAR = \frac{(False\ alarms)}{(Hits) + (False\ alarms)} \quad (A3)$$

- **Threat Score (0≤TS≤1, perfect: 1)**

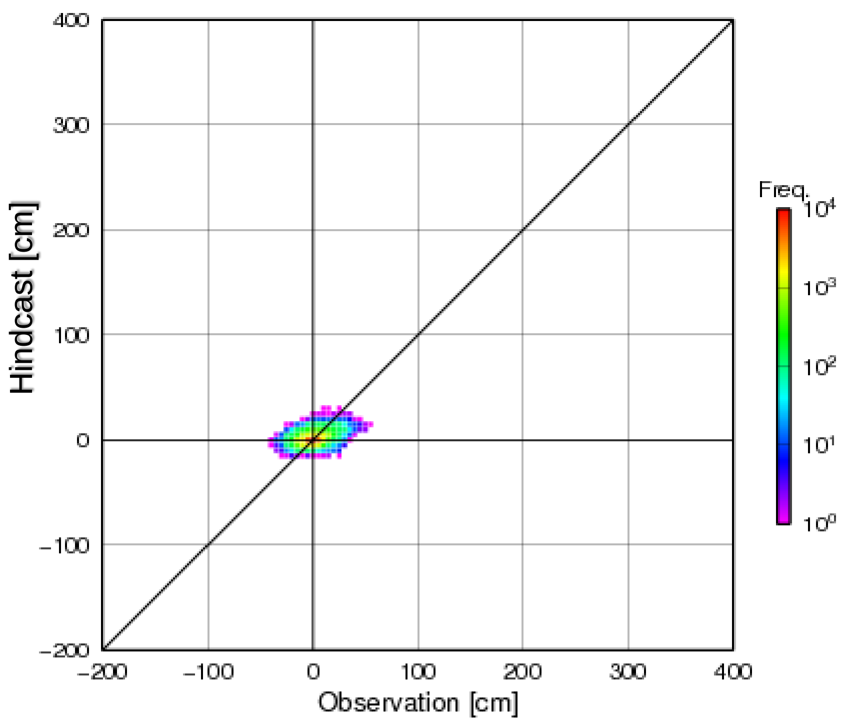
$$TS = \frac{(Hits)}{(Hits) + (False\ alarms) + (Misses)} \quad (A4)$$

Contingency table

		Observed	
		Yes	No
Forecast	Yes	Hits	False alarms
	No	Misses	Correct negatives

Verification (annual report)

- RSMC Tokyo is going to start issuing annually providing “verification report” from 2016.
  - For stations in which fast delivery observation data (last year) is available



Scatter diagram of predicted storm surges against observed values

The statistical period:
Jan – Dec, 2015.

The stations:
Quarry Bay (Hong Kong, China)
Langkawi (Malaysia)
Manila South Harbor (Philippines)
Legaspi Port (Philippines)
Subic Bay (Philippines)
Apra Harbor (U.S.A.)
Qui Nhon (Viet Nam)
Vung Tau (Viet Nam)

Numerical Typhoon Prediction Website

- JMA started to operationally run a Wave Ensemble Prediction System (WENS) on 8 June 2016.
- The product became available at the NTP website on 27 August.

Global WENS

model type	MRI-III
calculation area	global area 75° S〜75° N 180° W〜180° E
grids	289 × 113
grid interval	1.25° × 1.25°
wave spectrum components	900 components 25 in frequency 36 in direction
forcing	GSM EPS (27 members, 6 hourly)
forecast time (12UTC)	264 hours

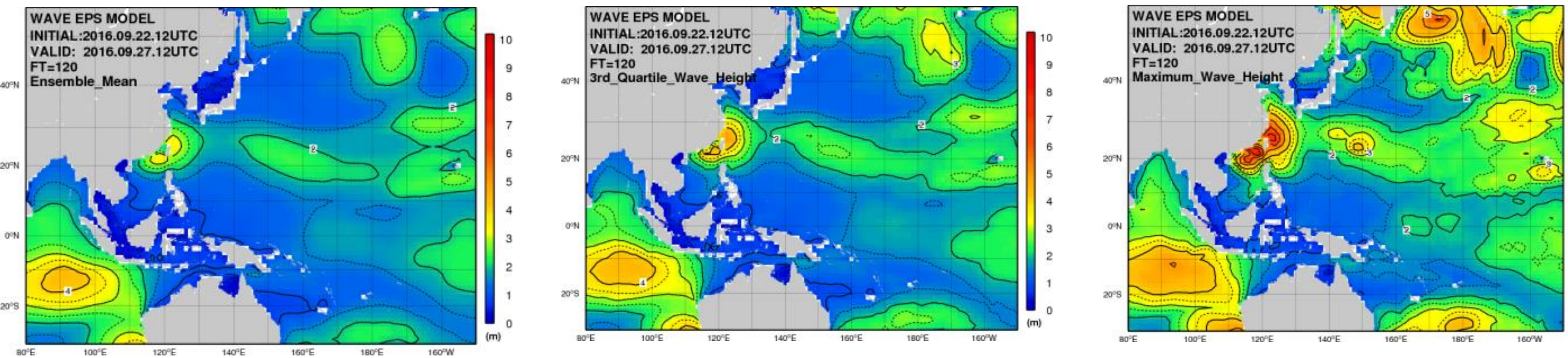
Wave height products

- **Daily horizontal maps up to 11 days**
  - (ensemble) mean wave height
  - maximum wave height (of ensemble members)
  - 3rd quantile wave height (of ensemble members)
  - probability of wave height exceeding 2, 3, 4, 5, 6 m
  - Ensemble spread
- **Stochastic values at stations**
  - Box plot
  - probability of wave height exceeding 3 and 6 m

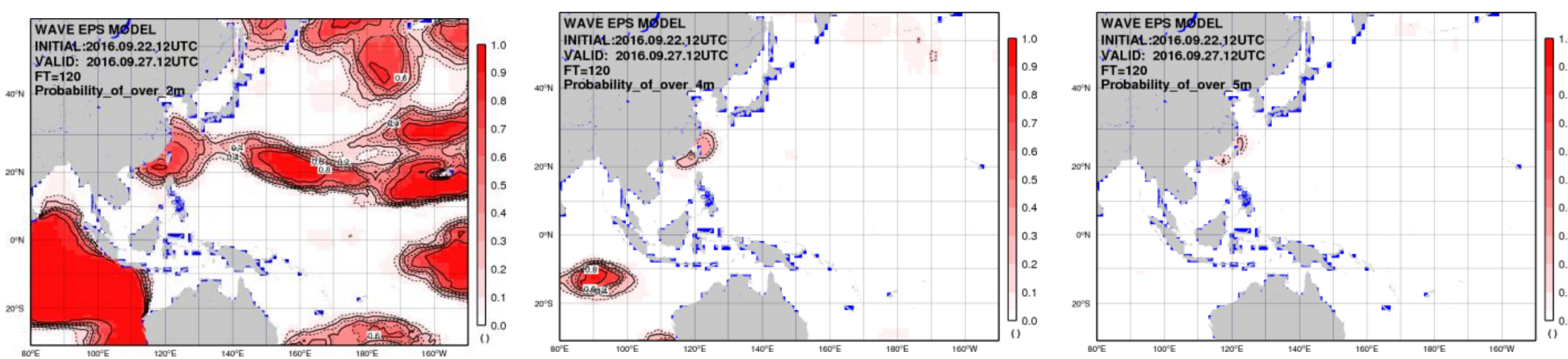
Wave Products

Product Samples (Results of 120 hours forecast at12UTC on Sep/22/2016)

Stochastic horizontal maps



Mean (left), 3rd quantile (center) and maximum(right) wave height

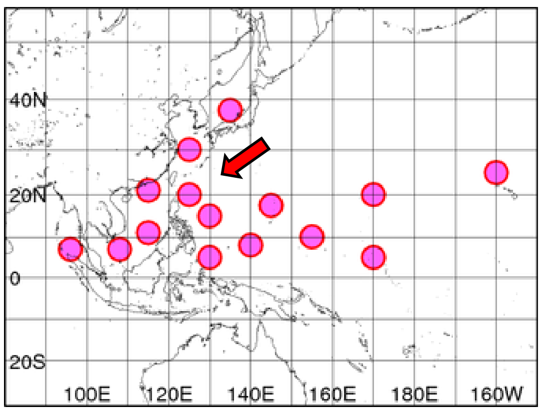


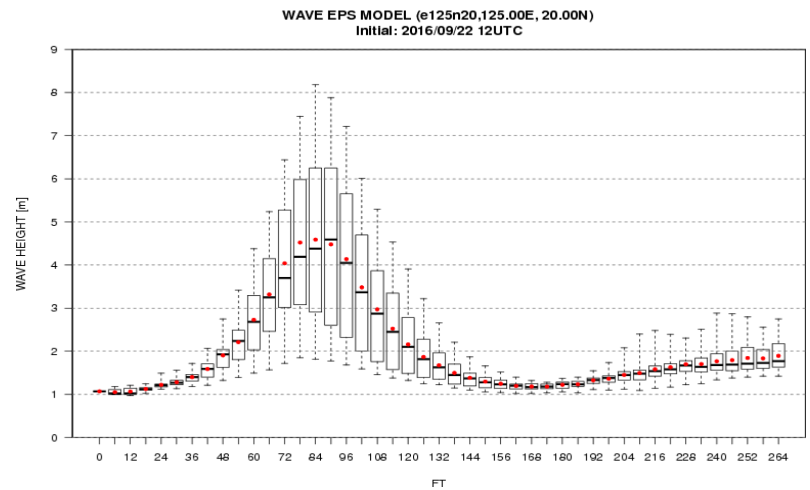
Probability of Hw_sig > 2m (left), 4m (center) and 5m (right)

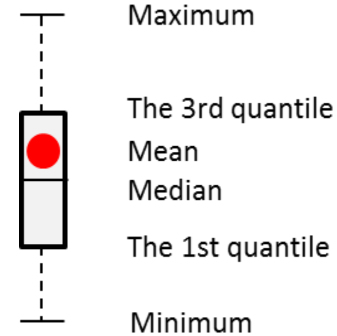
Wave Ensemble Prediction System

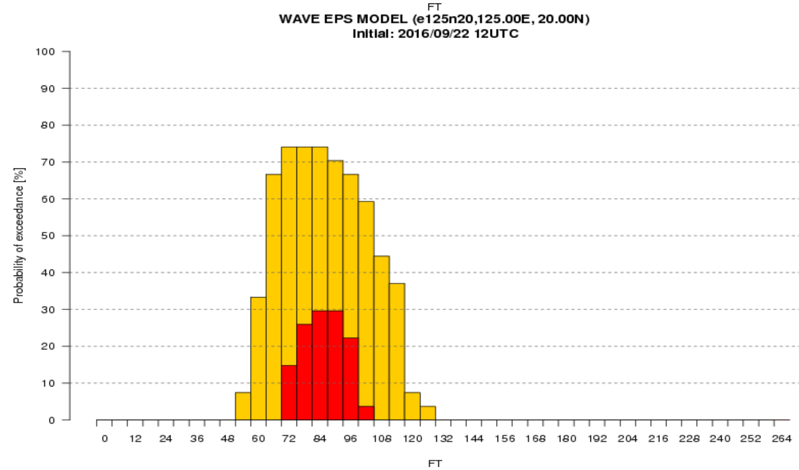
Product Samples (Results of 12UTC initial on Sep/22/2016)

Stochastic values at stations









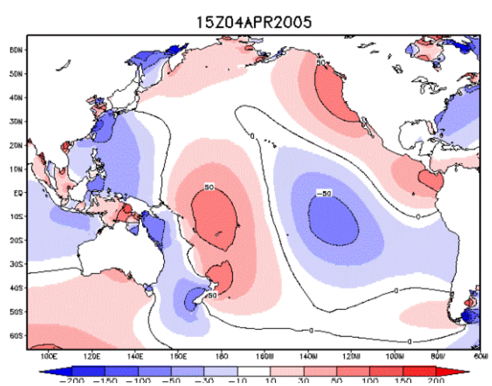
Probability
Yellow: Hw > 3m
Red: Hw > 6m

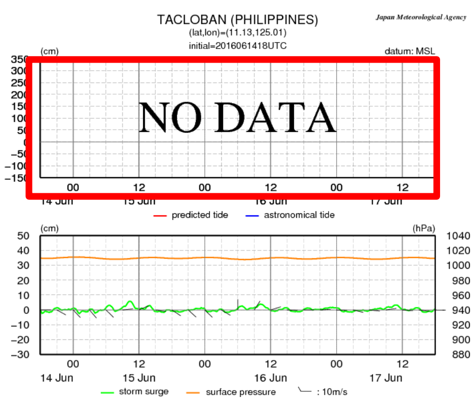
Box plot (upper) and Exceeding probability (lower)

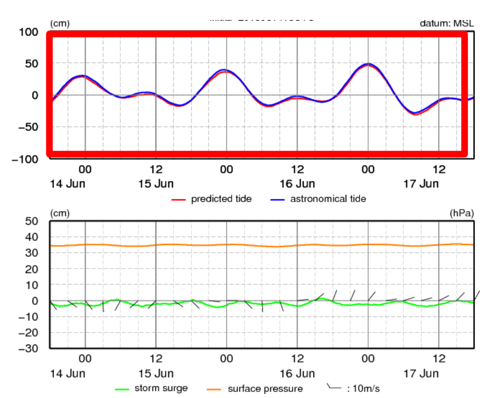
Plans (next year)

- JMA considering of refer astronomical tide estimated by a ocean tide model such as OTIS (OSU Tidal Inversion Software).
- The estimated astronomical tides can be used to express storm tide in time series charts, where only storm surges is plotted now (17 stations).

The estimated tide can be used to plot storm tide level, although it will less accurate than the estimated values from observed data. (Therefore we still encourage the TC members to provide tide observations.)







Plans in a few years ※

- JMA is going to upgrade the storm surge model to non-structural high resolution model.
- The model will be extended so that cover most responsible area
- The number of multi-scenario prediction will be increased, using whole members of EPS.
- The forecast hour will be extended to 5 days (120 hours), after 5-day forecast becomes available.

※ *JMA super computer system (NAPS) is scheduled to be replaced to a new one in June 2018, and any model update will be suspended in the current system in early 2017.*

Any Questions?

The JMA Mascot "*Harerun*"

(The word "hare" means fine weather in Japanese.)