ESCAP/WMO Typhoon Committee

ESCAP Economic and Social Commission for Asia and the Pacific

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"Advances in Tropical Cyclone Monitoring and Prediction for Impact Based Forecasting"

Coastal hazards and their risk analysis

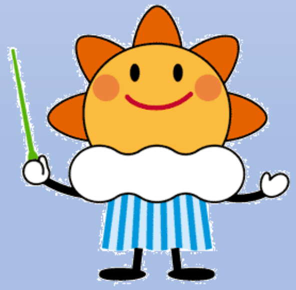
Nadao Kohno

The Third Laboratory,
Department of Applied Meteorology Research,
Meteorological Research Institute, JMA

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

Overview

- **Introduction**
  - **Impact-Based Forecast**
  - **Marine (storm surge) disasters**
  - **Risk of storm surges**
- **How to analyze marine hazard risks**
  - **Numerical Models / Systems**
  - **Product / Information for DRR**
  - **Educational aspect**
- **Further improvement perspectives**
  - **Monitoring (observations)**



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Impact-Based Forecast (IBF)

In IBF, following point are important:

1. Conversion from phenomena base forecast to real disaster risk

Typhoons (pressure, wind, rainfall, storm surge, etc)

-> possible hazards /damages (floods, landslide, coastal inundation…)

2. Downscaling

Detailed information indicating risk directly

Large scale general products -> small scale specific products

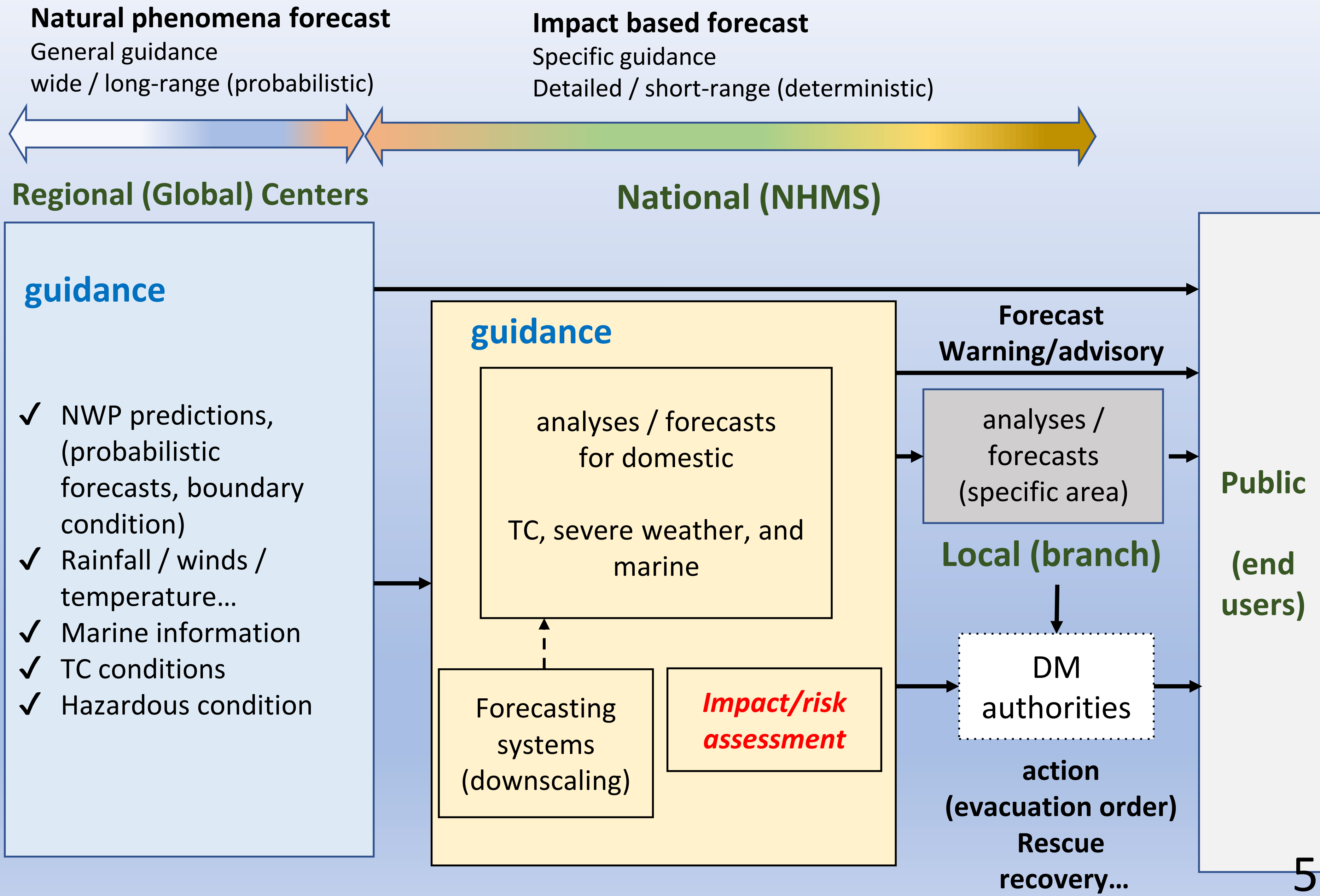
3. Reliability of the information

Detailed, but uncertainty is considered (probabilistic approach)

4. Indicating reactions

Indicating what actions are required, in facing the risks.

information flow image



Historical record of storm surges

Table 3. Top 10 Tropical Surge Levels in the Western North Pacific From 1880 to 2013[a]

Rank	Height (m)	Year	Storm Name	Maximum Surge Location
1	9.14[b,c]	1968	Didang	Narvacan Ilocos Sur, Philippines
2	8.0[b]	2013	Haiyan	Anibong, Eastern Visayas, Philippines
3	7.30[d]	1897	Typhoon of Samar/Leyte	Samar and Leyte, Philippines
4	7.00[b]	1912	Typhoon of Leyte/Cebu	Leyte and Cebu, Philippines
5	5.94[b]	1980	China Typhoon No. 8007	Nandu, Guangdong, China
6	5.02[b]	1956	China Typhoon No. 5612	Hanpu, China
7	4.60[d]	1984	Unnamed	Sarangani Island, Philippines
8	4.50[d]	1983	Unnamed	Near Infanta, Philippines
9	4.50[d]	1981	Rosita	South of Tinambac, Philippines
10	4.00[b]	2005	Damrey	Vietnam

[a]Compiled from the following sources: *Arafiles and Alcances* [1978], *PAGASA* [1987], *Henderson* [1988], *Bankoff* [2003], *Mai et al.* [2006], *Neumann et al.* [2012], and *Mas et al.* [2015].
[b]Storm surge.
[c]Considerable uncertainty for this observation.
[d]Storm tide.

Table 4. Top 10 Highest Northern Indian Ocean Tropical Surge Levels[a]

Rank	Height (m)	Year	Maximum Surge Location	Country
1	13.70[b]	1876	Precise location unknown	Bangladesh
2	12.00[c]	1737	Sundarbans	India
2	12.00[c]	1864	Calcutta and surroundings	India
4	9.60[b]	1966	Precise location unknown	Bangladesh
5	9.10[b]	1960	Precise location unknown	Bangladesh
5	9.10[b]	1963	Precise location unknown	Bangladesh
5	9.10[b]	1970	North of Chittagong	Bangladesh
8	8.80[b]	1961	Precise location unknown	Bangladesh
8	8.80[b]	1961	Precise location unknown	Bangladesh
8	8.80[b]	1967	Precise location unknown	Bangladesh

[a]From *Dube et al.* [1997].
[b]Storm tide.
[c]Storm surge.

Table 5. Top 10 Typhoon-Related Fatality Totals Along the Bay of Bengal[a]

Rank	Fatalities	Year	Location	Source
1	300,000	1737	India	*Dube et al.* [2008]
1	300,000	1970	Bangladesh	*Dube et al.* [2008]
3	200,000	1876	Bangladesh	*Dube et al.* [2008]
4	175,000	1897	Bangladesh	*Dube et al.* [2008]
5	146,000	2008	Myanmar	*Fritz et al.* [2010b]
6	140,000	1991	Bangladesh	*Dube et al.* [2008]
7	50,000	1833	India	*Dube et al.* [2008]
7	50,000	1864	India	*Dube et al.* [2008]
9	40,000	1822	Bangladesh	*Dube et al.* [2008]
10	19,279	1965	Bangladesh	*Dube et al.* [2008]

[a]From *Dube et al.* [2008] and *Fritz et al.* [2009].

Needham et al (2015)

Recent major storm surge cases generated by TCs

Year	Areas	Cause (TC name)	Economic losses* (billion)	fatalities*	Typical storm surge (m)
2005	United States	Katrina	$108	1,833	4-7
2007	South Indian Ocean	Sidr	$1.7	~15,000	3-6
2008	South Indian Ocean	Nargis	$10	138,366	3-5
2012	United States	Sandy	$68	148 + 138	3-4
2013	Western North Pacific	Haiyan	$2.86	~7,400	5-7
2016	South Pacific	Winston	$1.4	44	3
			$148.8	89	3
			$59.5	97	3
			$107.1	2,981	2.7
			>$13	21	2-3.5
			$3.77	52+82	2-3.5
2018	South Indian Ocean	Idai	$2.2	1,593	4.4
2018	South Pacific	Gita	$0.22	1+1	1-3
2018	United States	Flo[illegible]ce	$27.8	53	3.4
		Micha[illegible]	$29.0	49	4.3
2020	North Indian Ocean	Amphan	$13.7	128	5
2020	South Pacific	Harold	$0.123	31	4
2020	United States	Laura	$26.0	42	5.2
2021	Western North Pacific	In-Fa	>$1	6	3
2021	Western North Pacific	Rai	$1.02	410	2-3
2021	South Indian Ocean	Eloise	$0.01	27	2-3.5
2021	United States	Ida	$78.7	96	3.7-4.3

- Total deaths (not only deaths from storm surge).

U.S. economic losses referenced from: https://www.ncei.noaa.gov/ . For U.S., fatalities and storm surge are specific to U.S. and referenced from NHC Tropical Cyclone Reports: https://www.nhc.noaa.gov/data/tcr/index.php

Storm surges…

They are capable of causing significant disasters:

- ✓ killing more than thousands of people at once
- ✓ damaging infrastructure critically.

Studies have shown that nearly half of direct fatalities in US are attributed to storm surge (Rappaport 2014).

While storm surges have devastated many parts of the world, the death toll is remarkably decreased in recent cases (< 100) although economic losses are sometimes huge.

This would be partly come from improved warning services on coastal hazards.

Storm surge is one of the key hazards associated with tropical cyclones, although severe storm surge disaster does not happen so frequently.

Definition of storm surges

- Abnormal rise of sea level caused by meteorological phenomena (typhoons, hurricanes, cyclones, extra-tropical cyclones).
- Sea level changes are caused by strong winds and pressure depressions.
- From a hydro-dynamical point of view, storm surges are classified to **external gravity waves**, especially shallow water waves (long waves) as their large horizontal scale, as well as tsunamis.

Technical terms of storm surges

- **Storm surge**

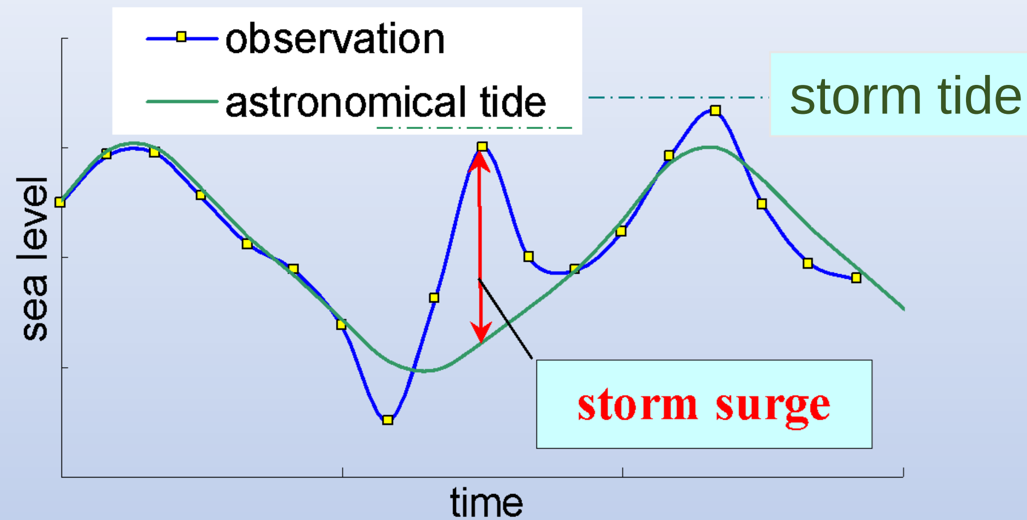
  Sea level anomaly from (estimated) astronomical tide.

  Storm surges are used for indicating magnitude of phenomena.

- **Storm tide**

  Sea level with astronomical tides.

  Storm tides are used for indicating risk of disasters.



note1

In using storm tide, it is important to be aware of the base water level, such as Mean Sea Level (MSL), Chart Datum Level (CDL) etc.

Note2

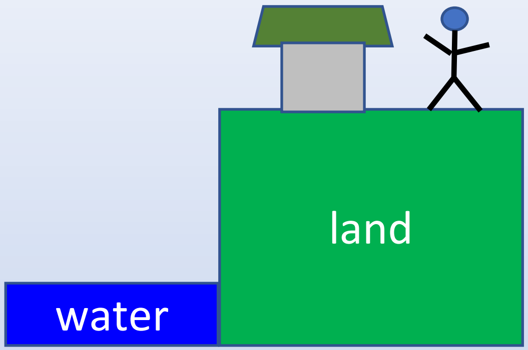
Recently "**Total Water Levels (TWL)**" is also used to express more comprehensive values.

Strictly speaking, storm surges are defined as

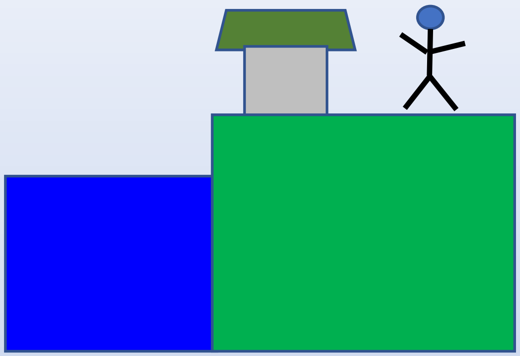
anomaly (= observed water level - astronomical tide).

However, the term "storm surge" is widely used for just expressing the phenomenon itself.

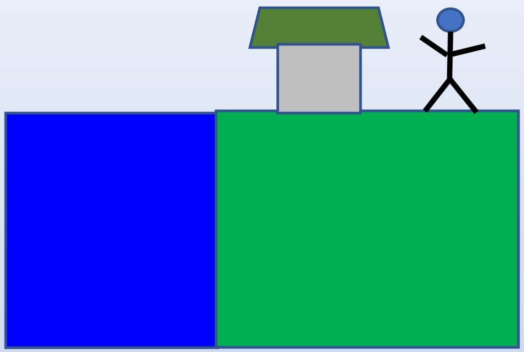
Risk of Storm Surges



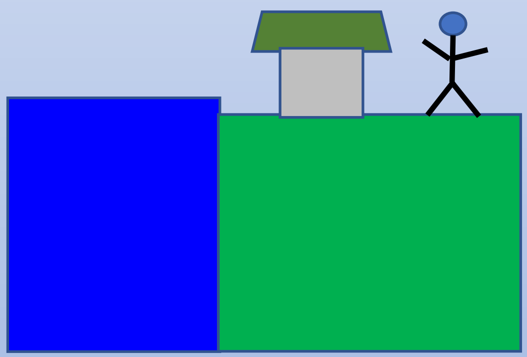
(definitely) Safe



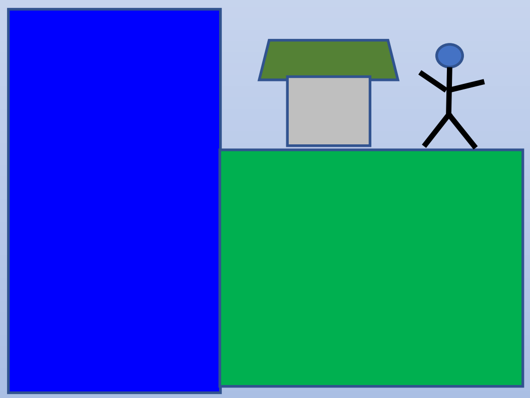
Safe



(still) Safe



danger

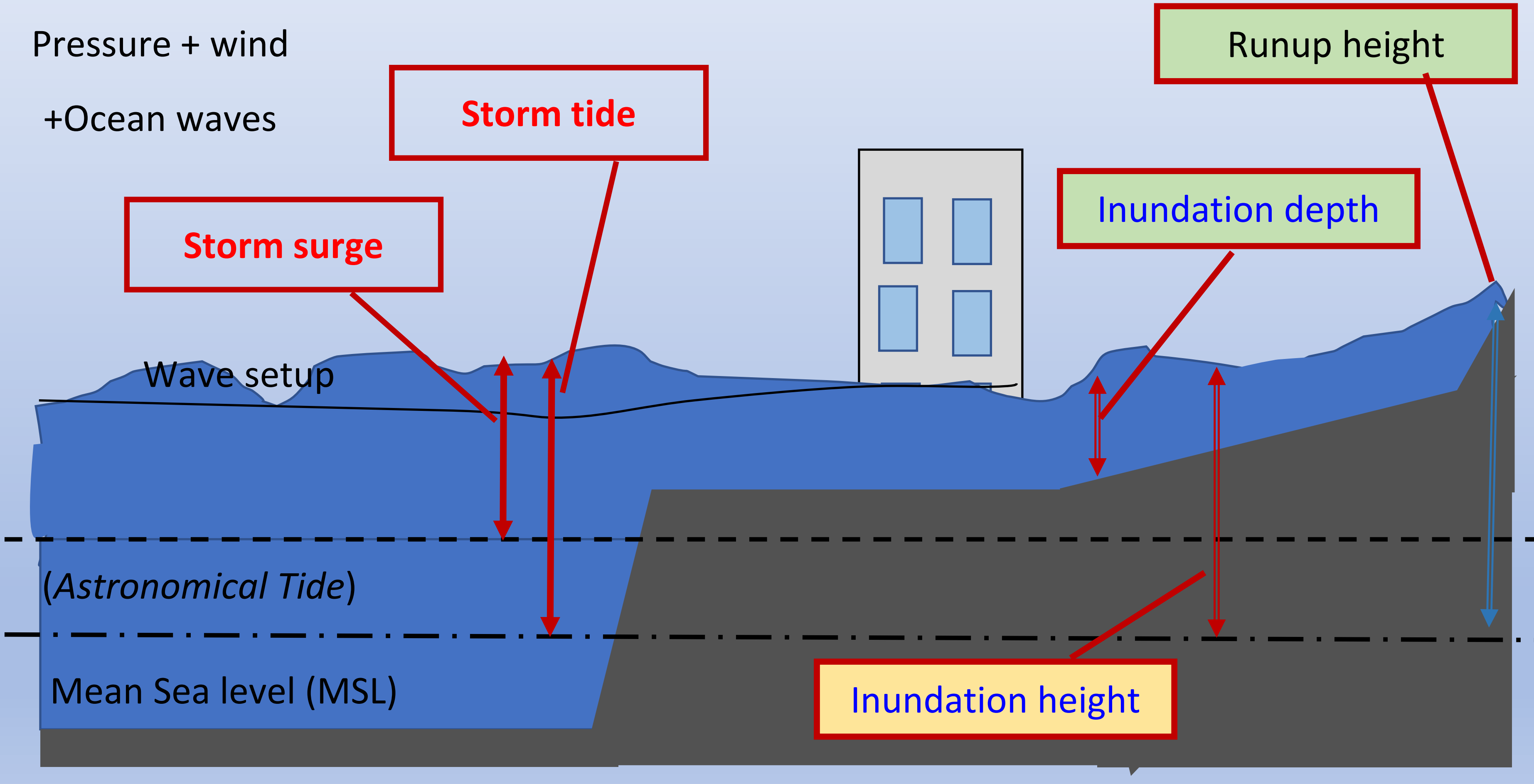


Very danger

Risk of storm surges is decided by the difference

Between water level and land height.

Terms related with storm surge and inundation



Mechanism of storm surges

1. Inverse barometer effect

1hPa pressure decrease ≒ 1cm surge

$$\eta_p = \frac{\Delta P}{\rho g}$$

2. Wind setup

surge

$\propto \tau_s (V^2)$ (*wind stress*: *square of wind speed*)

$\propto L$ (*horizontal scale of wind*: *fetch*)

$\propto 1/h$ (inverse of water depth)

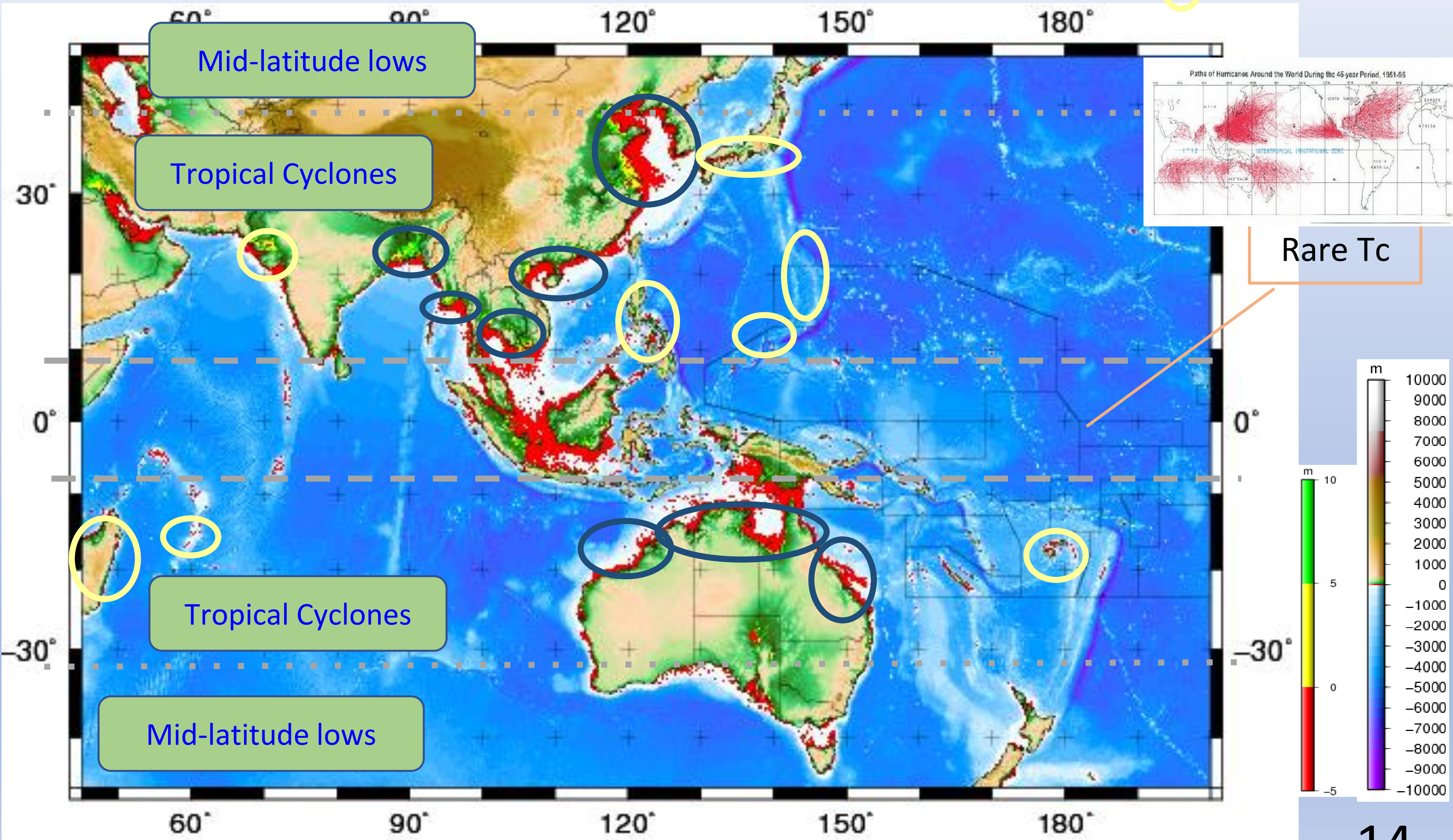
$$\eta_w = \frac{3}{2} \frac{\tau_s L}{\rho g h}$$

Geographic condition

Sea Bathymetry(GEBCO 30seconds)

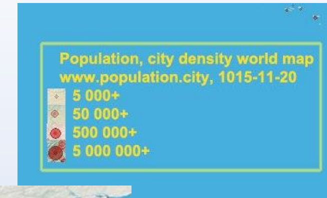
The area vulnerable to storm surge

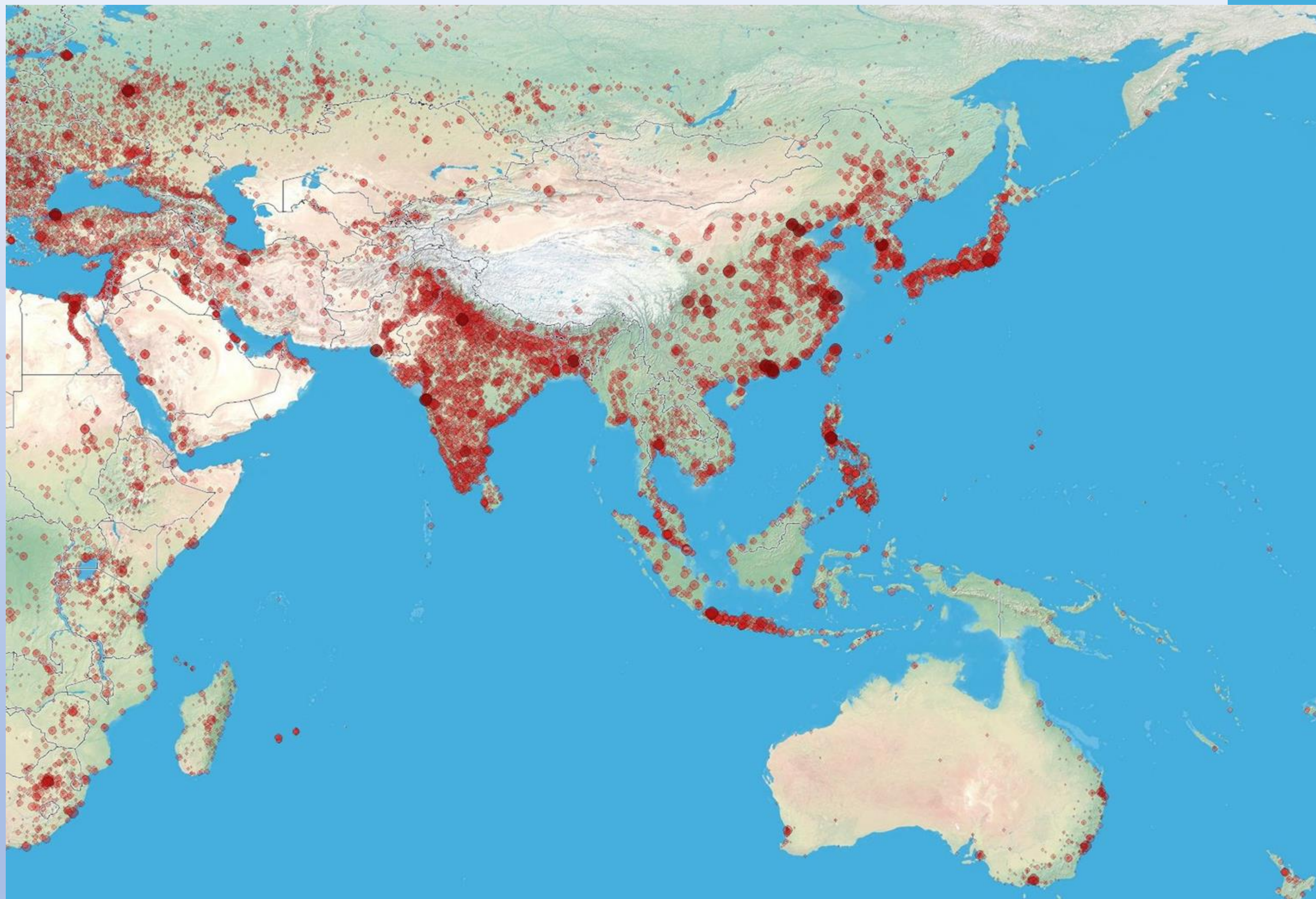
large storm surge



Contours are drawn in every 50m.

Population

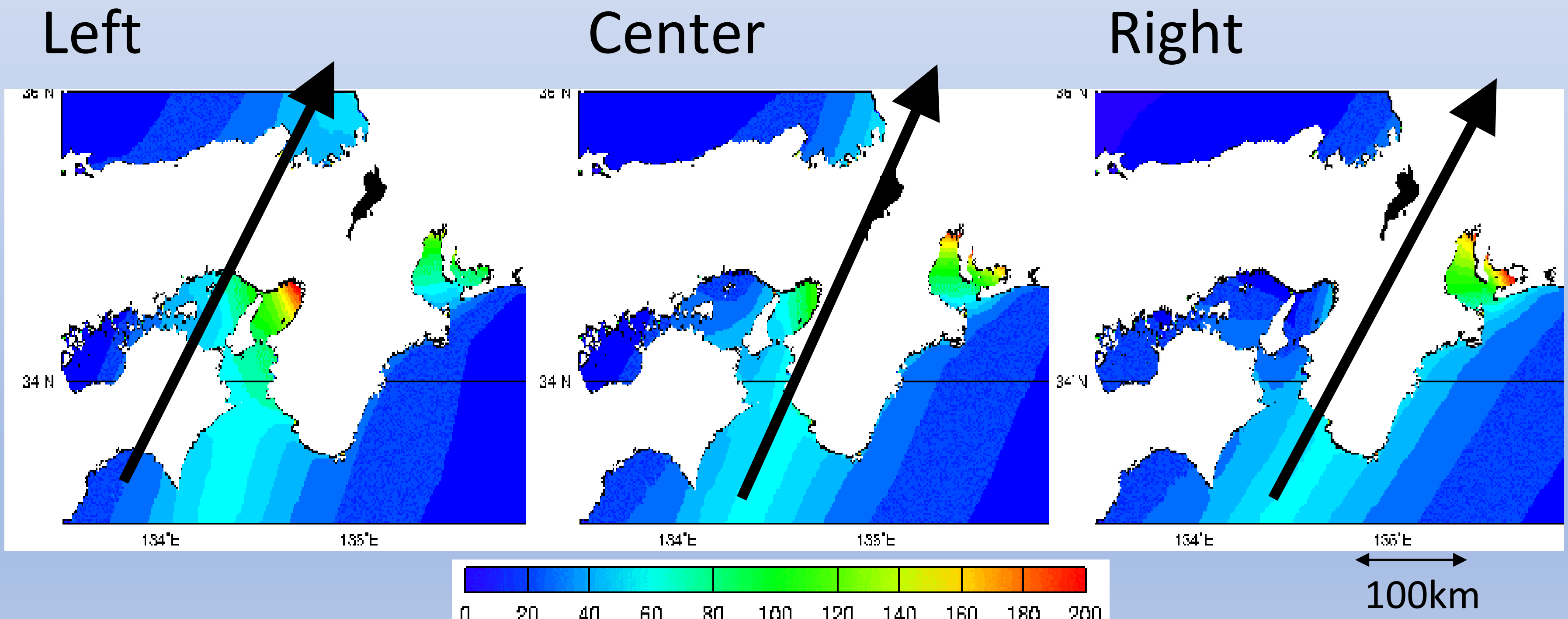




Recently many people come to live in low flat coasts.
Urbanization is one of main cause of heavy damage by storm surges.

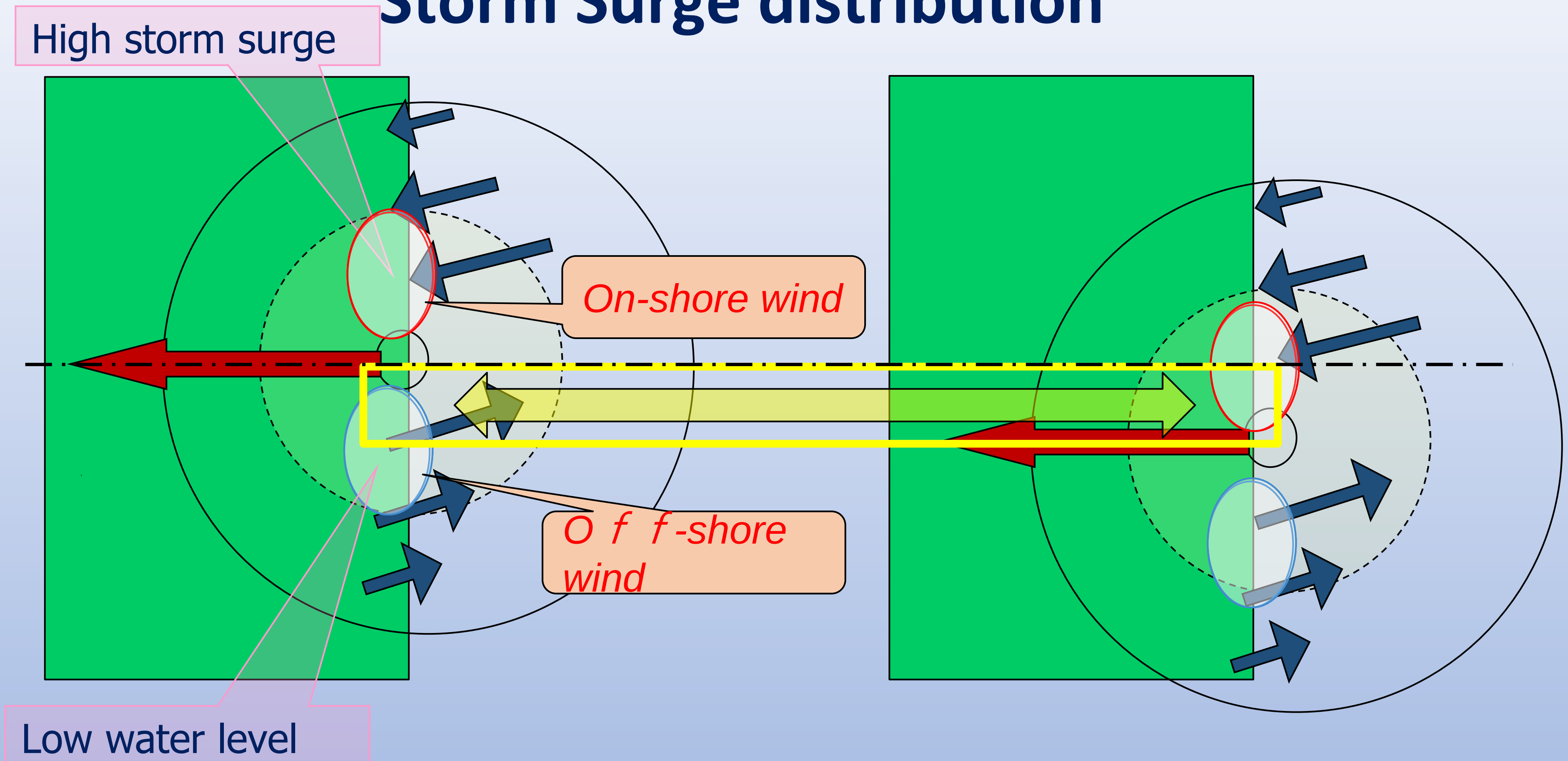
Influence of typhoon track

Storm surges strongly depend on typhoon tracks.
Considering of track forecast errors, ***probabilistic approach*** would be practical.



maximum storm surge [cm]

Storm Surge distribution



: storm wind area

: moving direction of TC

: winds

high storm surge area critically depends on

TC tracks (landfall point).

Influence of Astronomical Tides

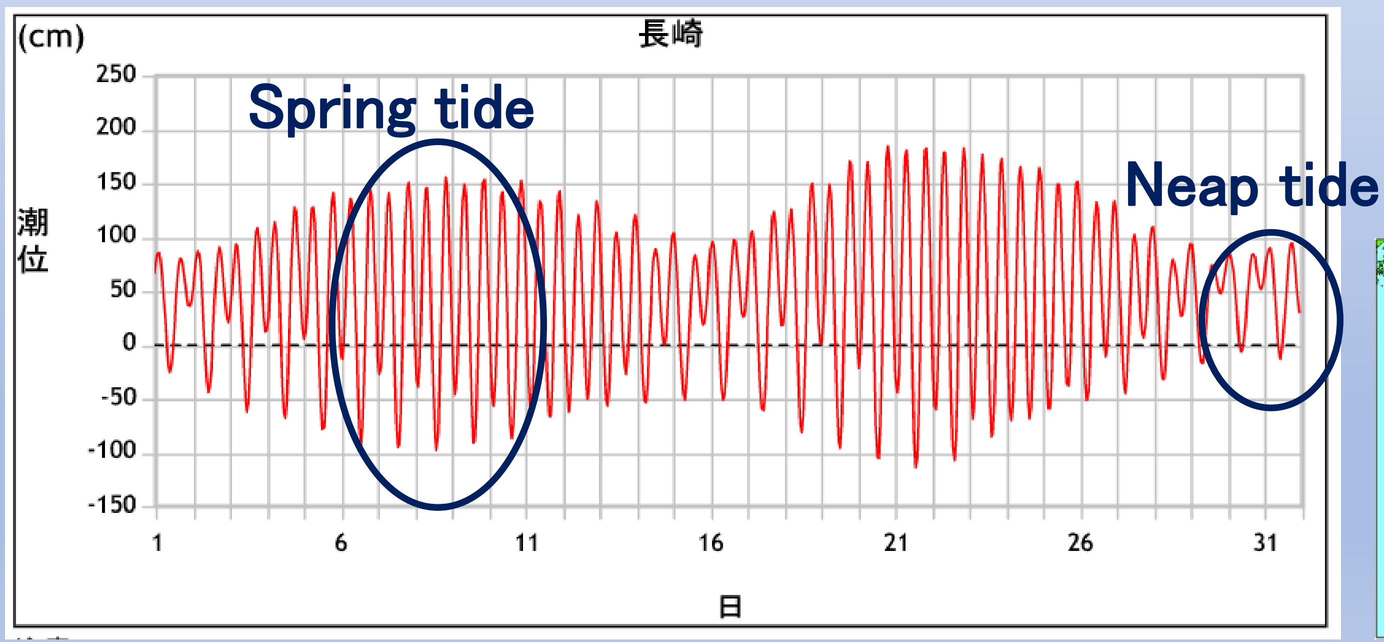
- Storm tide = astronomical tide + storm surge

situation of astronomical tide:

high tide ⇔ low tide

spring tide ⇔ neap tide

When would the situation be dangerous?

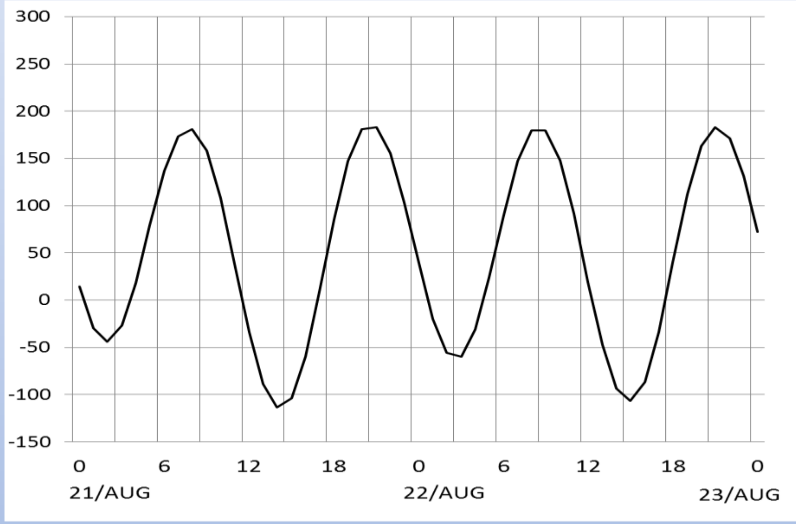


(Tides at Nagasaki in August, 2013)

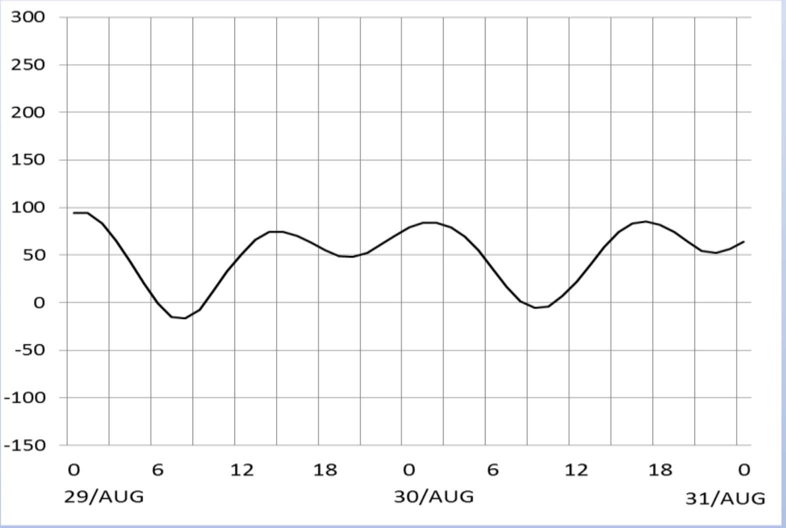
Astronomical Tides

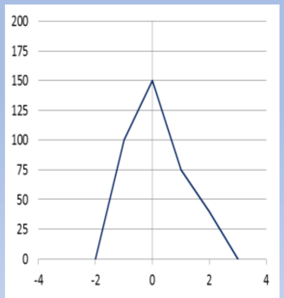
Assume that a typhoon hit and generated maximum storm surge of 1.5 m, in spring tide or neap tide.

spring tide



neap tide





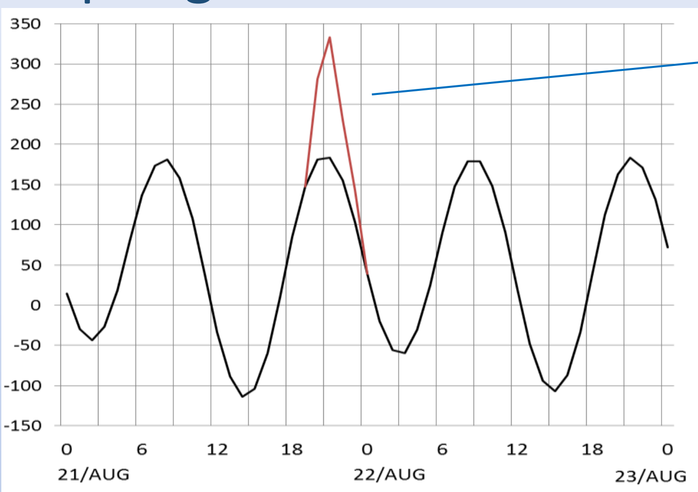
Storm surge

Storm tides

High tide + surge

Low tide + surge

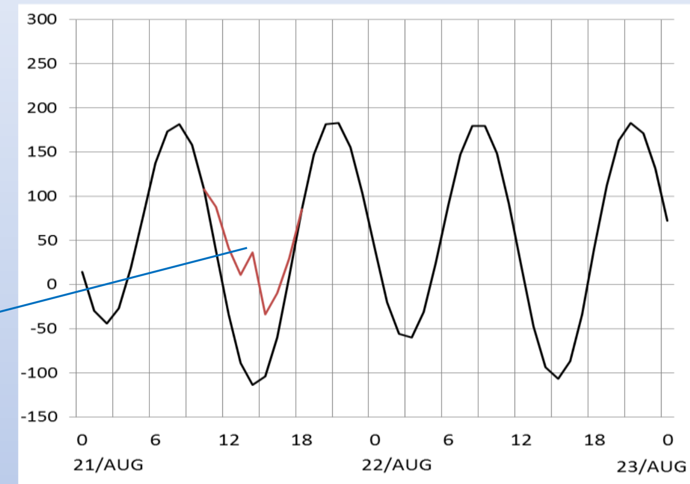
In spring tide



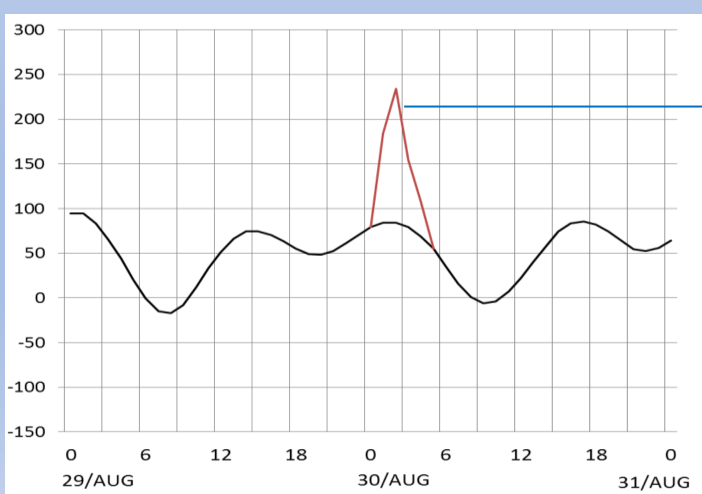
Tide : 1.8m
Storm Surge : 1.5m
Storm tide : **3.3m**

≫

Tide : -1.1m
Storm Surge : 1.5m
Storm tide : **0.4m**



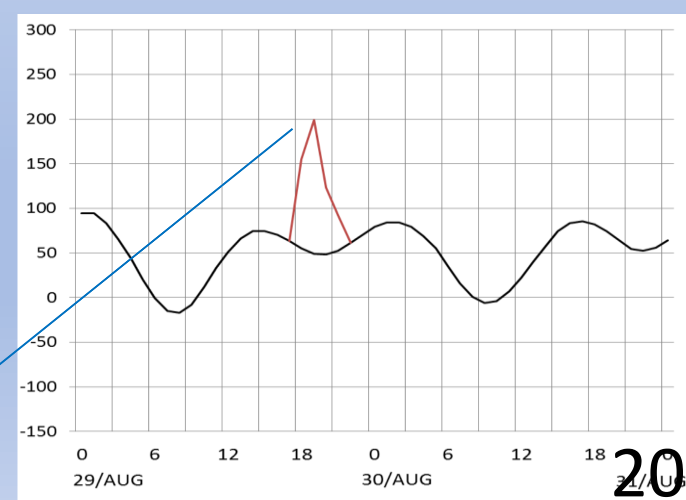
In neap tide



Tide : 0.8m
Storm Surge : 1.5m
Storm tide : **2.3m**

≈

Tide : 0.5m
Storm Surge : 1.5m
Storm tide : **2.0m**



Tide + surge

- Strictly speaking, surge and tide are not separable and can not add linearly.
- However if tidal motion is small compared with surge, which is common in the case by tropical cyclones, the linear addition of storm surge and tide gives good estimation.

Wave setup

There are points where storm surge forecasts tend to be under-estimated.

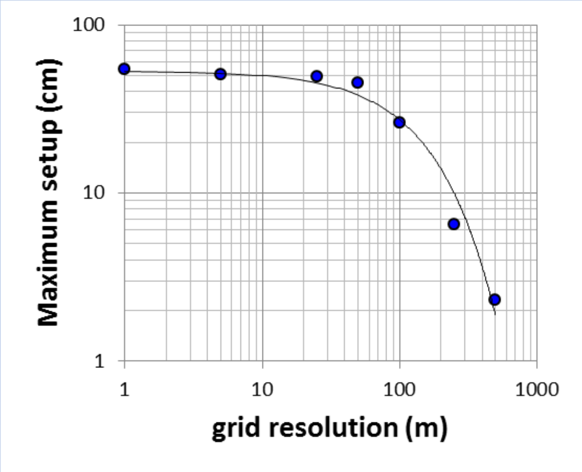
Some of these points are likely to be influenced by the ocean waves (wave setup).

When wave setup becomes predominant?

- High waves hit to the coast
- Water depth quickly becomes shallow near the beach

wave setup ~ 0.1 – 0.2 Hw

Hw: significant wave heights



The mechanism was explained by Longuet-Higgins and Stewart (1962).

However, the effect is not included in the operational forecast models, because it needs very high resolution (about 50 m) wave calculation for accurate wave setup values.

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Flow of storm surge information

TC conditions Analysis/ forecast	→	Storm surge forecast Risk assessment	→	Information Warning/advisory

We need to consider the following matters in each step!

- ✓ *Accurate analysis?*
- ✓ *Reliable forecast?*
- ✓ *Detailed contents?*

- ✓ *Accurate model?*
- ✓ *Detailed conditions can be resolved?*
- ✓ *Necessary factors are included?*
- ✓ *Operationally useful? (fast, sturdy)*
- ✓ *Can we deal with TC forecast errors? (Ensemble prediction)*

- ✓ *Clear meaning?*
- ✓ *Practically efficient?*
- ✓ *Instructive?*

Storm surge models

- There are many storm surge models used in NMHSs.

  SLOSH, IIT-D, JMA-MRI

- Moreover, what are commonly called “community ocean models” have become increasingly popular and widespread in the last decade.

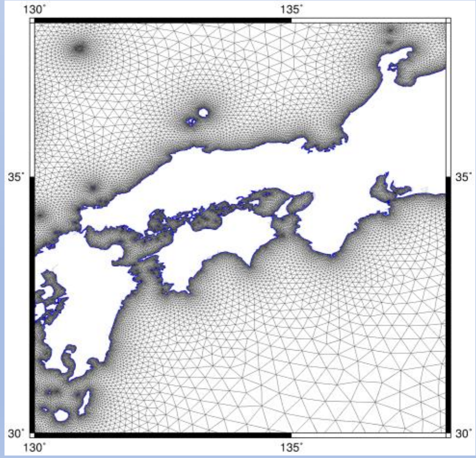
  POM, ROMS, NEMO

- Most of those models are regular-mesh finite difference models (Dube et al., 2009).
- Recently, unstructured numerical storm surge models have been used too, especially in research communities.

  ADCIRC, FVCOM, Delft3D, SELFE

India (INCOIS) operates the Advanced Circulation (ADCIRC) model for the real-time forecasting of storm surge and inundation extents along the Indian coasts.

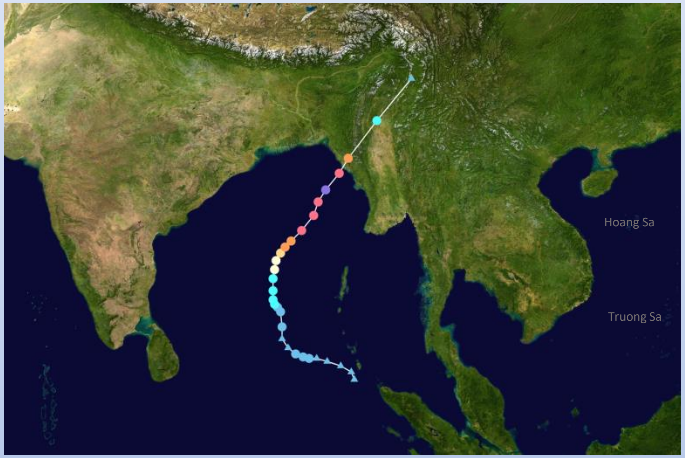
JMA also launched new unstructured storm surge model in August 2022.



An illustration of the grid mesh configuration

A case of storm surge forecast

ESCS(Extremely Severe Cyclonic Storm) Mocha



9/May: a TC was formed in North Indian Ocean
11/May: upgraded to Cyclone Mocha
14/May: made landfall Sittwe, Maynmar at 07 UTC

Maximum wind: 70m/s
Minimum Pc: 931hPa

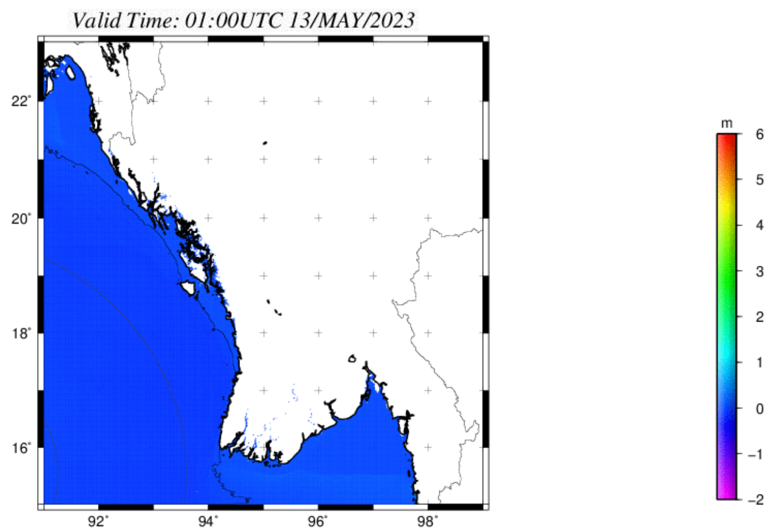
Dead ~100
Storm surges ~2m

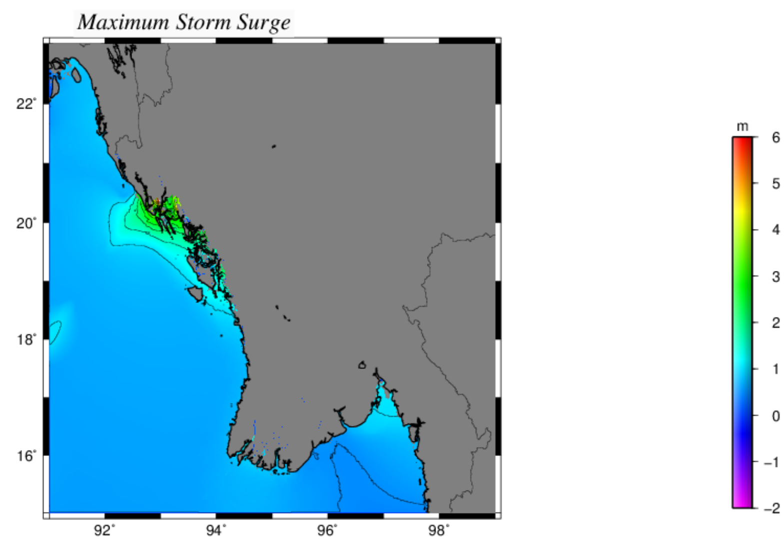
Model: Storm surge forecasting system (in development) at DMH, Myanmar
(JMA storm surge model + FES2014)

Initial: 00UTC 13/May
TC condition: Official forecast of DMH.

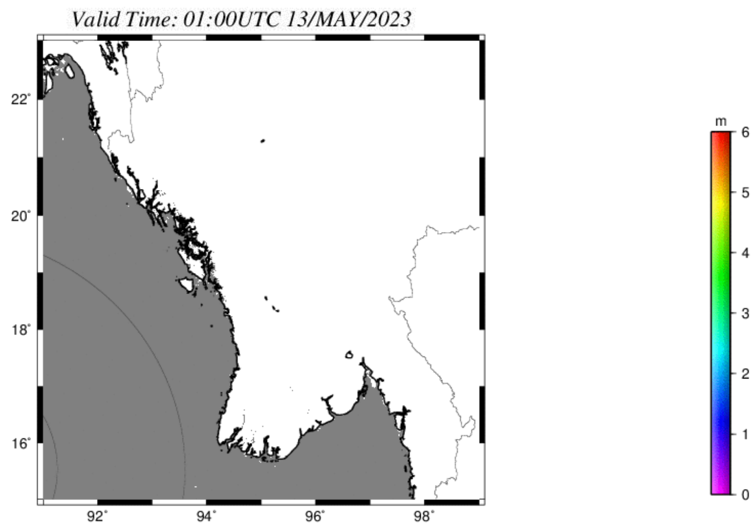
Calculated results

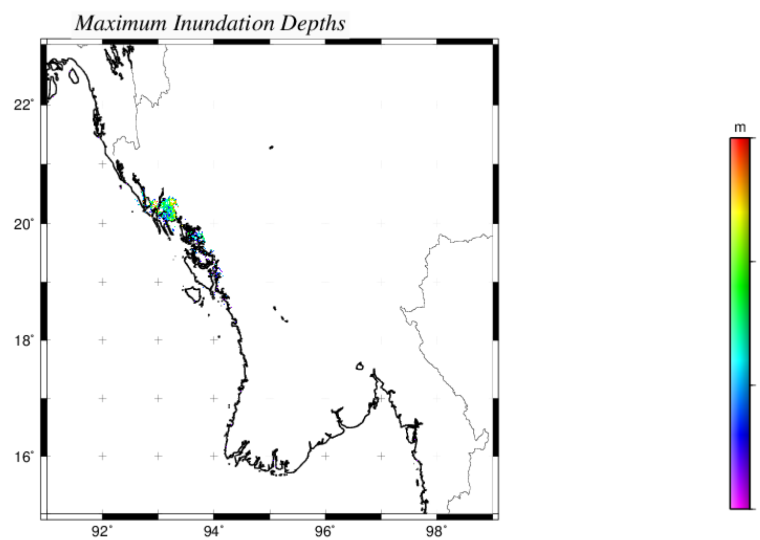
Water level (Storm tide)





Inundation heights





Coupled models

Ocean wave models are also available and a recent trend is to develop a surge - (tide) - wave coupled system.

- SELFE + Wind Wave Model II (WWM-II) (Roland et al., 2012)
- ADCIRC + SWAN Dietrich et al. (2012)
- FVCOPM + SWAVE (Qi et al., 2008)

The results were very reasonable in terms of both storm surge and wave prediction. Wave setup is a rather small scale phenomenon but such a high resolution (~ 50m) models have the ability to simulate the effect accurately.

The problem is that wave models need much computational resources than storm surge model, and such coupled models are not handy.

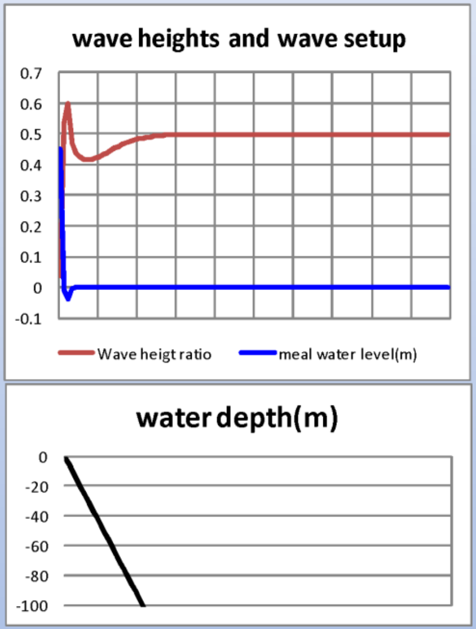
Wave setup

There are several approaches for wave setup estimation in operational work.

- A simple wave setup model (JMA)

  Kohno and Chikasawa (2013, 2015)

  based on Goda (1975)



- Simple formula (BoM)

  O'Grady et al. (2015)

$$\bar{\eta} = 0.29(0.8)H_0[0.34S^{\frac{1}{7}}]\left(\frac{H_0}{L_0}\right)^{-\frac{1}{4}}$$

- Coupling with a handy second generation wave model (NCEP)

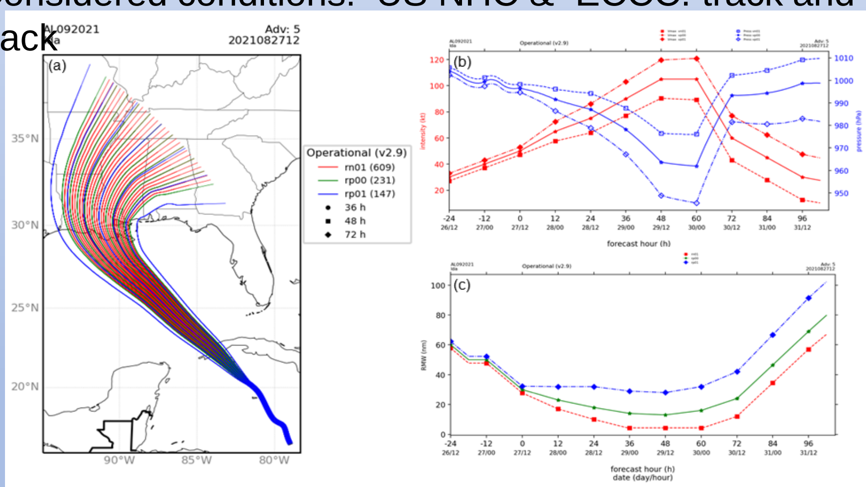
  Westhuysen et al. (2015)

Cooperate with forecast uncertainty

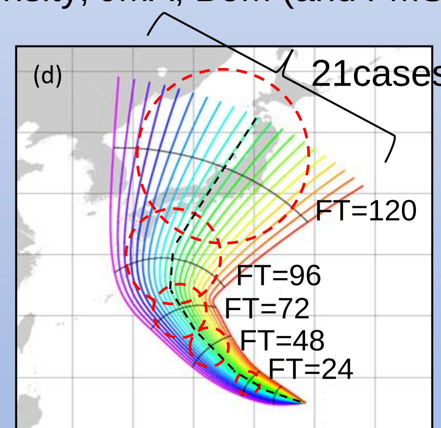
Storm surges are strongly dependent on the landfall location / intensity of TCs. Therefore, accurate TC forecasts is essential, but it is impossible to remove forecast errors in real.

- Probabilistic (or multi-scenario) forecasts rather than deterministic is introduced in regions (US NHC, JMA, BoM and MSC. planned: FMS and IMD)

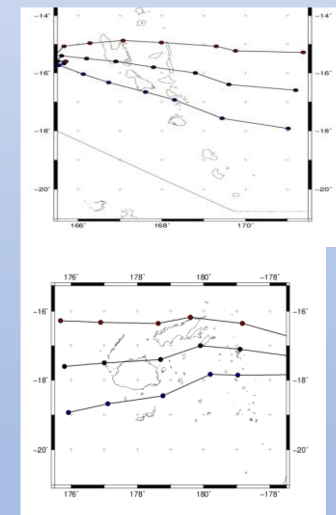
Considered conditions: US NHC & ECCC: track and intensity, JMA, BoM (and FMS): track



An example of (a) the distribution of P-Surge ensemble track members, the three members of (b) intensity, and (c) size of NHC.



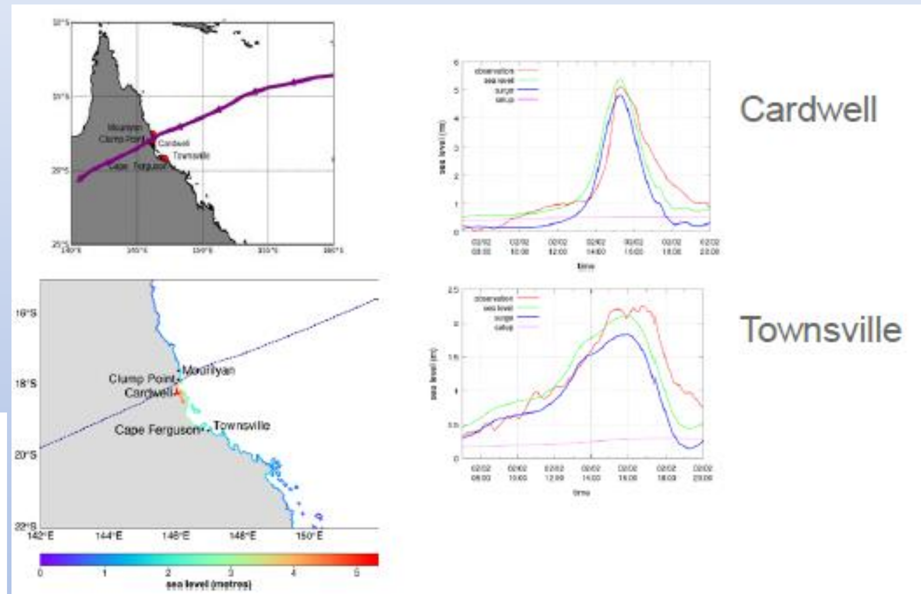
(d) the 21-track ensemble produced by JMA



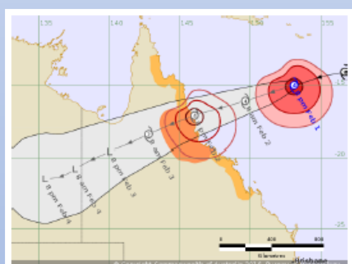
Planned multi-scenario cases at FMS

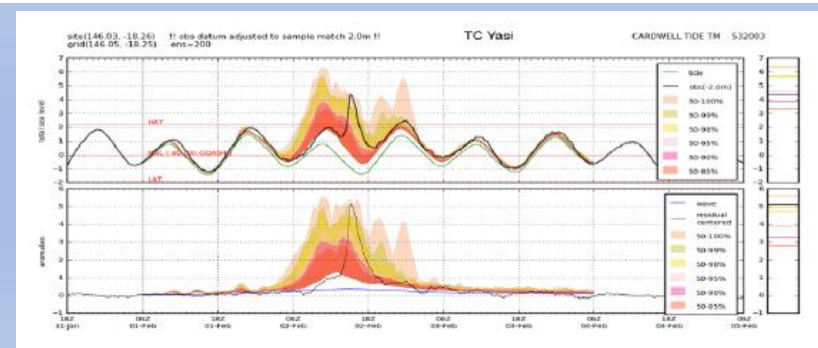
Storm surge Ensemble Forecast (BoM)

- ✓ Base: BoM Official forecast track
- ✓ Derive ensemble of tracks (DeMaria et al., 2009)
- ✓ 200 ensemble members
  Randomly chosen from 1000 possible track



TC Yasi in 2011

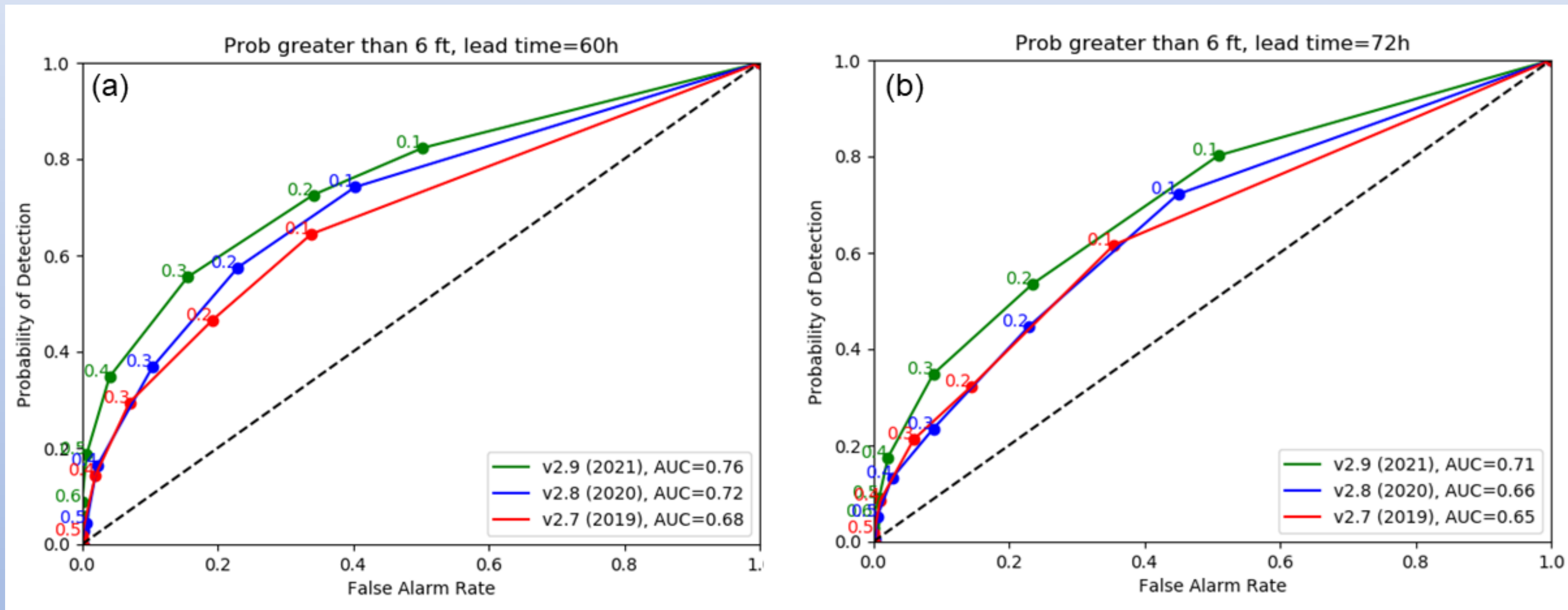




Greenslade et al.(2017)

Effectiveness of probabilistic forecast

Probabilistic guidance may then be used to aid in the dissemination of coastal hazard products and guide storm surge warnings/alerts



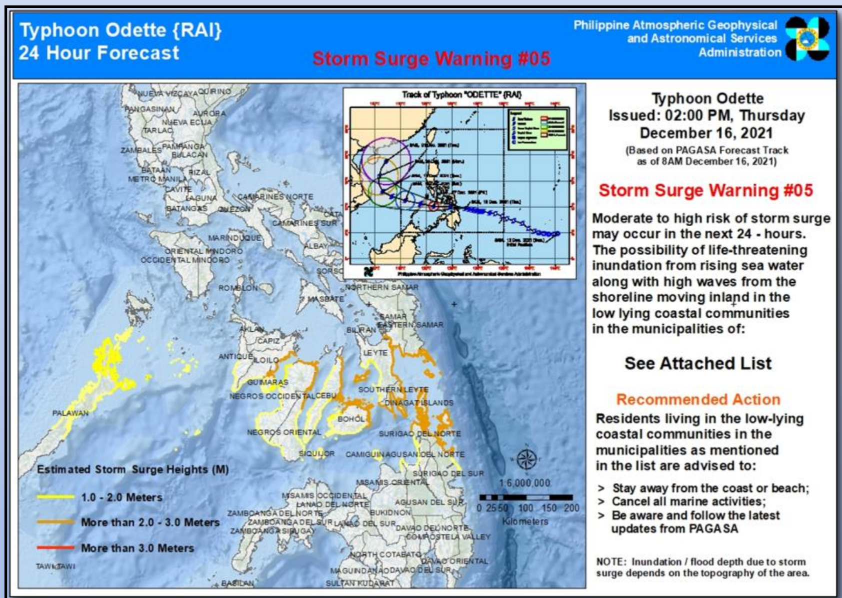
Relative operating characteristic (ROC) curves for probability thresholds exceeding 6 ft NAVD88 for (a) 60 h prior to landfall and (b) 72 h prior to landfall for P-Surge (NHC). These ROC curves determine whether or not the forecast exceedances can discriminate between events and non-events and therefore quantify the skill of a probabilistic model a specific lead times.

(IWTC-10 report)

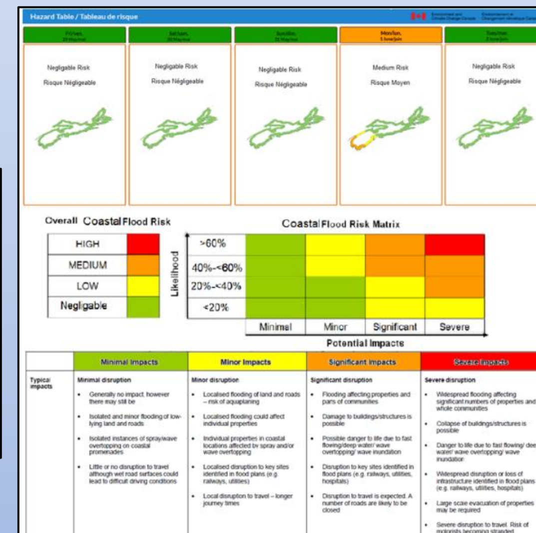
Information on area of coastal hazard

NHMSs have been indicating coastal hazard risk with map images.

Philippine Atmospheric Geophysical and Astronomical Service Administration (PAGASA) and Meteorological Service of Canada (MSC) issue maps indicating areas where coastal hazard is feared.



Risk maps of Storm Surge Warning issued from PAGASA

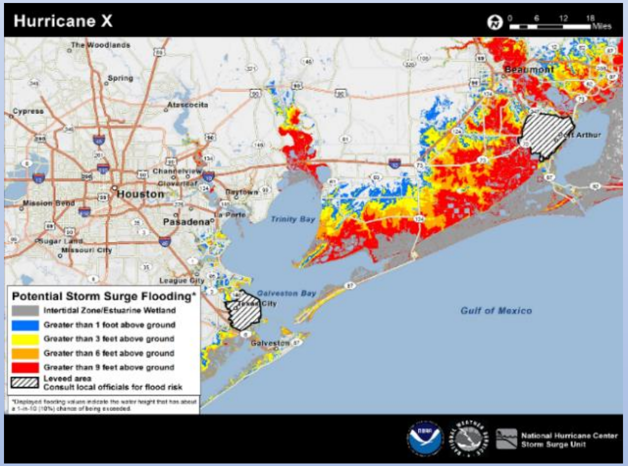


Coastal Flooding Risk issued from MSC
24-hour forecast (left) and 5 day outlook (right)

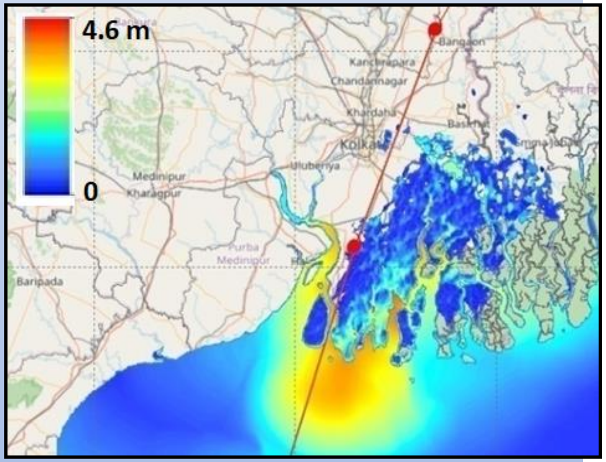
※Storm Surge(=total water level): surge (anomaly) + astronomical tide + wave setup

Inundation risk maps

Storm surge is an unfamiliar phenomenon and many people do not perceive the risk easily. Recently, the information issued from NHMSs have been shifting to indicate real risk, considering total water levels for evaluating inundation risks. US NHC and IMD (INCOIS) issue inundation risk maps (real time hazard maps).



An example of the Potential Storm Surge Flooding Map. Represents the storm surge heights at the 10% probability of exceedance (NHC)

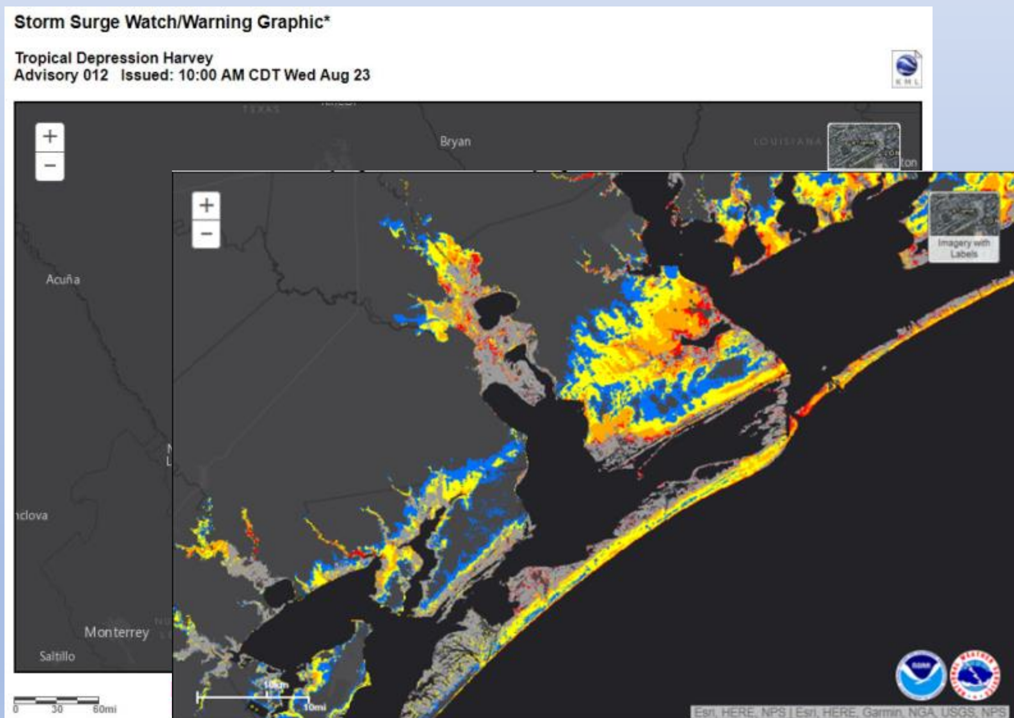


Forecasted storm surges and inundation heights due to Cyclone Amphan in May 2020 (IMD).

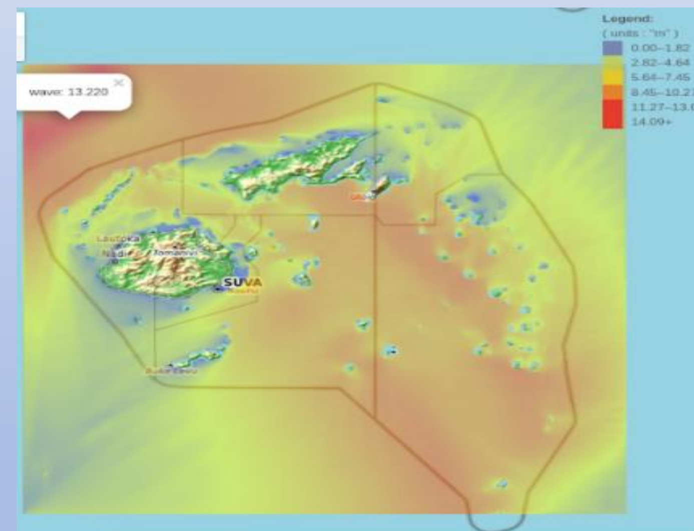
Detailed inundation heights (m) analyzed by the prototype system of the Strategic Innovation Promotion (SIP) Program of Japan

Visualization of inundation risk

In visualizing inundation risk, several Met. Services issues the graphical images by utilizing GIS tools.



US NWS



FMS

Concern on inundation risk maps

- It is necessary many factors to create inundation risk maps.
- It means errors at each factor will be accumulated to the final products.
- However, it is difficult to modify such highly integrated products by evaluation those possible errors.
- Therefore, providers need to verify the reliability of those products well.

Explanation on Coastal Hazard Impact

Recently, possible coastal impacts are come to be informed to public with concrete disasters and adequate actions.

PAGASA issues impact and necessary actions in table form.

REPUBLIC OF THE PHILIPPINES
Department of Science and Technology
Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)
Science Garden, Agham Road, Diliman, Quezon City 1100

STORM SURGE INFORMATION
STORM SURGE: WARNING #05
FOR: TYPHOON "ODETTE" (RAI)
ISSUED AT 2PM, 16 December 2021
(Valid until the next storm surge information to be issued at 5PM today)
(Analysis is based on PAGASA Forecast as of 8AM, 16 December 2021)

SS Height	Provinces	Low Lying Coastal Areas in the Municipalities of:	IMPACTS	ADVICE/Actions to Take
More than 2.0 – 3.0 meters	Eastern Samar	Guiuan Balangiga Giporlos Lawaan Mercedes Quinapondan Salcedo	• Moderate to significant damage to communities, coastal/marine infrastructures and disruption to all marine related activities • Moderate to significant erosion to beaches • Possible flooding due to storm surge	• Evacuation is advised to those living in low lying coastal areas • All marine activities must be cancelled • Public is advised to follow all the latest updates on tropical cyclone bulletins and storm surge warning from PAGASA
	Leyte	Abuyog Dulag Macarthur Mayorga Palo Tacloban City Tanauan Tolosa Javier		
	Southern Leyte	Silago City of Maasin Anahawan Hinundayan San Juan (Cabalian) Sogod Tomas Oppus Hinunangan Libagon Liloan St. Bernard San Francisco San Ricardo Macrohon Padre Burgos Malitbog Pintuyan Limasawa Bontoc		
	Surigao del Sur	Carrascal Cantilan Madrid Cortes Lanuza		
	Surigao del Norte	Bacuag Gigaquit Placer Burgos San Isidro		

"tracking the sky... helping the country"

Postal Address: P.O. Box 3278 Manila Tel No. (63-2) 929-4865, 922-1992 (w/Fax) & 434-9040

More than 2.0 – 3.0 meters		Mercedes Quinapondan Salcedo	• Moderate to significant damage to communities, coastal/marine infrastructures and disruption to all marine related activities • Moderate to significant erosion to beaches • Possible flooding due to storm surge	• Evacuation is advised to those living in low lying coastal areas • All marine activities must be cancelled • Public is advised to follow all the latest updates on tropical cyclone bulletins and storm surge warning from PAGASA
	Leyte	Abuyog Dulag Macarthur Mayorga Palo Tacloban City Tanauan Tolosa Javier		
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	Surigao del	Carrascal Cantilan Madrid		

Explanation on Coastal Hazard Impact

MSC created *Coastal Flood Risk Index* to show an impact and risk-based analysis.

Proposed Wave Level	Level/ tier/ Category	Possible Disruption Time	Impact		Suggested Response (Call to Action)
			Receptor	Possible Consequence	
<HAT	**negligable**	NA	NA	none expected	NA
>HAT	**Minimal**	Minutes to hours	Damage to infrastructure or property	inconvenience or nuisance flooding	personal property in low lying areas needs to be moved or it may get wet
			Disruption to travel	inconvenience or nuisance flooding	be aware of possibly wet nearshore roads
			Danger to life	individuals close to the coast maybe caught off guard by the rapid approach of unexpectedly larger waves or stronger currents	be aware of higher than usual water levels, waves or stronger currents
lowest infrastructure	**Minor**	Hours to days	Damage to infrastructure or property	water over banks and in yards or in campgrounds	personal property in low lying areas needs to be moved or may get damaged or destroyed
				damage to wharfs, boat houses and fishing stages. No significant flooding to main floors of residential buildings.	
				Individual properties in coastal locations affected by spray and/or wave overtopping or slightly flooded basements or sewage backup	be prepared for the possibility of minor flooding of basements, elevate or relovate property to main floor
			Disruption to travel	little or no disruption to travel although wet road surfaces could lead to difficult driving conditions	be prepared for possible longer journey times
				water on bike paths	
			Danger to life	individuals close to the coast maybe caught off guard by the rapid approach of unexpectedly larger waves or stronger currents	be prepared for higher than usual water levels, waves or stronger currents
lowest infrustructure + 20 or 30 cm (TBD)	**Significant / Major**	Days to months	Damage to infrastructure or property	Main floor flooding affecting properties and parts of communities	Disruption to key sites identified in flood plans (e.g. railways, utilities)
				Damage to buildings/structures is possible.	
			Disruption to travel	Disruption to travel is expected.	A number of roads should be closed.
				water over the road is deep enough to make driving unsafe	
			Danger to life	Possible danger to life due to fast flowing/deep water/wave overtopping/wave inundation.	Evacuation will be possible or access restricted for the most vulnerable shoreline and coastal areas.
lowest critical infrustructure	**Severe / Extreme / Critical**	Months to years	Damage to infrastructure or property	Widespread flooding affecting significant number of properties and whole communities	Widespread disruption or loss of infrastructure identified in flood plans (e.g. railways, utilities, hospitals)
				Collapse of building/structures is possible	
				multiple homes are flooded or moved off foundations	
			Disruption to travel	Many cars will likely be submerged or washed away.	Several sections of roads and escape routes should be closed.
				Several sections of nearshore roads and escape routes will be impassable and a few could be washed out.	
			Danger to life	Danger to life due to fast flowing / deep water / wave overtopping/ wave inundation	Large scale evacuation may be required

proposed water level and impact tier [as of Aug 1, 2022]

Information based on requirement

Alerting the public (via Storm Surge Warnings) and providing impact-based information is necessary to mitigate loss of life and property. Regions have utilized a variety of alerting protocols to disseminate information more effectively, based on requirement of disaster authorities.

5-day perspective (probability of warning)

Miyakojima: Probability of warnings

Issued at 05:00 JST, 12 Sep. 2022

Okinawa: Miyakojima Region		09/12			09/13		09/14	09/15	09/16
		06-12	12-18	18-24	00-06	06-24			
Heavy Rain	Probability of warnings	[Mid]		[Mid]		[Mid]	[Mid]	-	-
	Maximum hourly	20	30	30	30	30			
	Maximum 3-hour	40	60	60	60	60			
	Maximum 24-hour				100～150				
Storm	Probability of warnings	[High]		[High]		[High]	[Mid]	-	-
	Maximum wind speed	30	35	35	35	30			
High Wave	Probability of warnings	[High]		[High]		[High]	[Mid]	-	-
	Wave height	9	10	10	10	10			
Storm Surge	Probability of warnings	-		[Mid]		[Mid]	[Mid]	-	-

[High] [Mid]

The probability of warning for hazards over a 5-day period produced by JMA. The probability of storm surge warning is indicated qualitatively by "high" or "middle".

Specific storm surge guidance for local government

BoM basically provides 'worst case scenario' storm tide, which is determined with worst case scenario storm surge + high tide.

In Queensland and the Northern Territory, guidance with "most likely" scenario is also provided to emergency managers, for interpretating error range.

What is inundation?

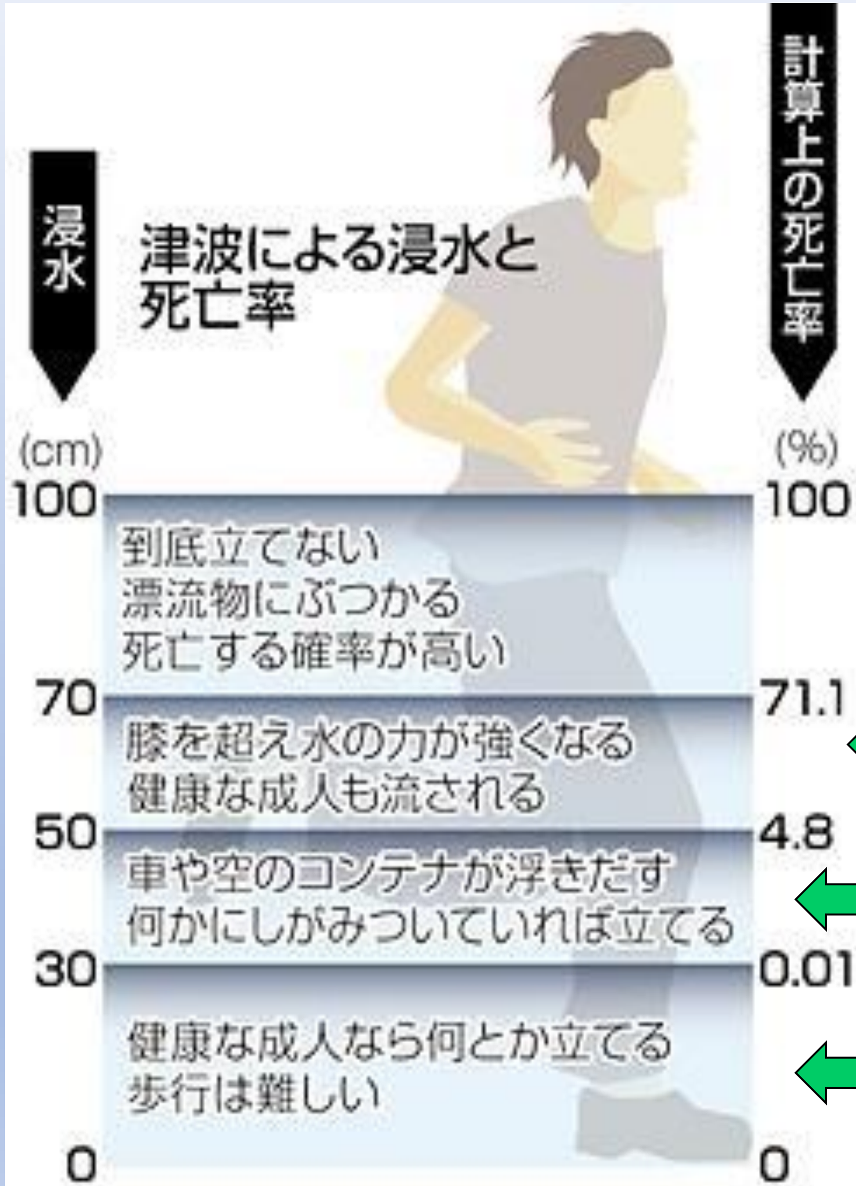
- Inundation can be caused by
  - Storm surges
  - Waves (swell)
  - Astronomical tides
  - River (floods)

- It is important to understand the exact cause. It is desirable to avoid using customary words, such as king tide (or just using surge for all phenomena).

- However, public people basically do not care the inundation mechanism, only its risk to them is interested.

Dangerous Inundation

Inundation Depth



Estimated Death rate

A poster for tsunami inundation risk (Japan Cabinet Office)

Impossible to stand
Floating obstacles hit
High possibility of death

Sturdy people will be washed down with strong water flow (higher than knees)

Cars / empty containers start floating.
Can not stand without clinging to something.

Only healthy adults can keep standing, but are hard to walk.

How to keep memories on storm surge diesters

「天災は忘れた頃にやってくる」

"A natural disaster strikes when people lose their memory of the previous one."

Torahiko Terada (寺田寅彦, 1878 – 1935)

a Japanese physicist and author

Rare happening might make people forget memory and become regardless of risk.

Education to public is indispensable!

Overview

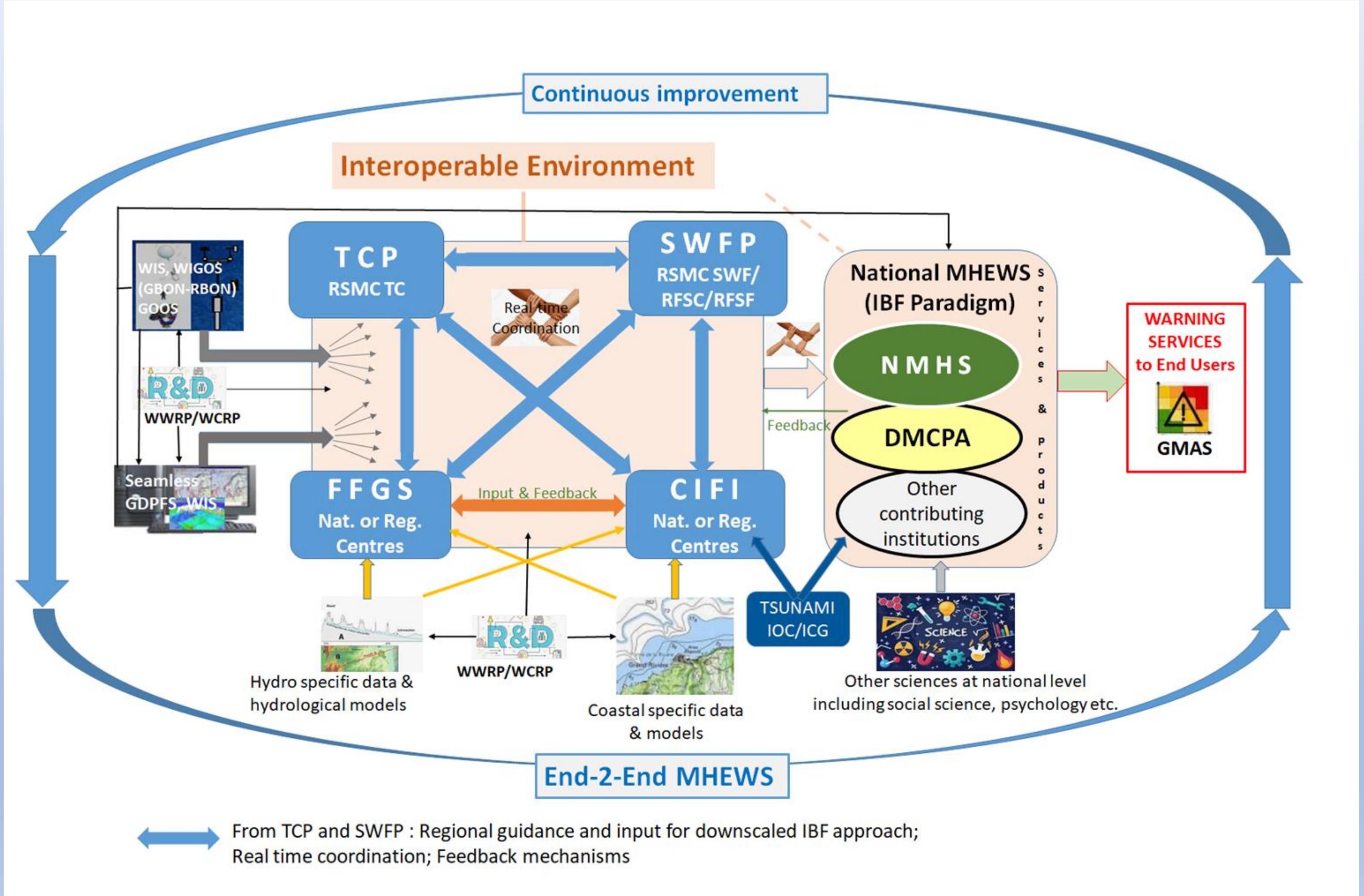
- Introduction
  - Impact-Based Forecast
  - Marine (storm surge) disasters
  - Risk of storm surges
- How to analyze marine hazard risks
  - Numerical Models / Systems
  - Product / Information for DRR
  - Educational aspect
- **Further improvement perspectives**
  - **Regional framework**
  - **Monitoring (observations)**

WMO Coastal Inundation Forecast Initiative (CIFI)

- The Coastal Inundation Forecasting Demonstration Project (CIFDP) was initiated by WMO in 2009 to provide an **example of cooperative work** as a strategy for building **improved operational forecast and warning capability for coastal inundation from combined extreme waves, surges and river flooding events**.
- The 18th World Meteorological Congress, through Resolutions 15 and 29, decided to remove the "demonstration" tag from the project and endorsed the **Coastal Inundation Forecasting Initiative (CIFI)** to ensure the continued development, **Flood Forecast Guidance System (FFGS**) and **Severe weather Forecast Programme (SWFP)** as individual initiatives within the context of an MHEWS environment with integrated coastal, flooding and severe weather capabilities for the WMO, and to support the implementation of the three individual initiatives (CIFI, FFGS and SWFP) for the benefit of Members.
- CIFI is led by the Standing Committee on Marine Meteorology and Oceanography (SC-MMO) in collaboration with the Standing Committee on Hydrology (SC-HYD). Secretariat support is provide by the Marine Services Division (MSD) and the Hydrology and Water Resources Services Division (HWRD).

Guidelines on Implementation of a Coastal Inundation Forecasting-Early Warning System
(https://library.wmo.int/doc_num.php?explnum_id=11335)

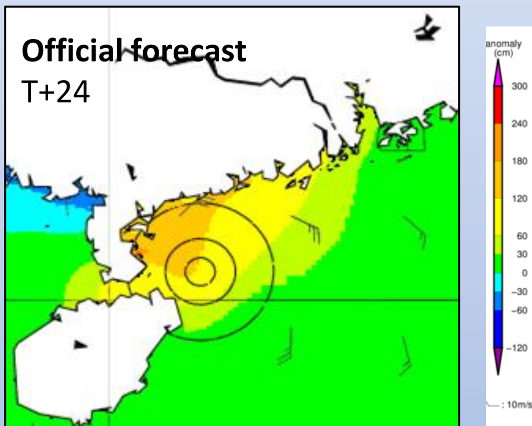
Multi-Hazard Early Warning System Interoperable Environment (MIE)

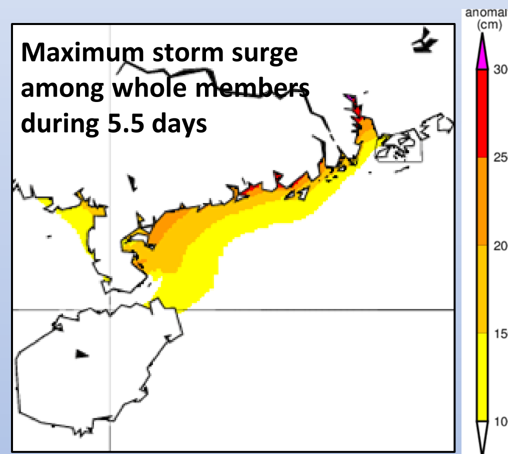


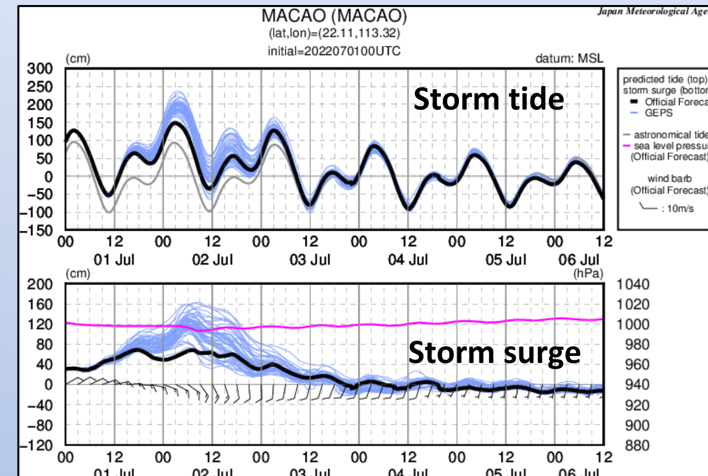
WMO Storm Surge Watch Scheme (SSWS)

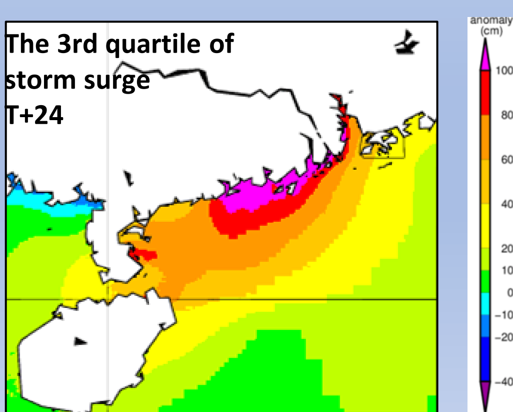
Real-time storm surge information for Typhoon Committee Members issued from the RSMC Tokyo.

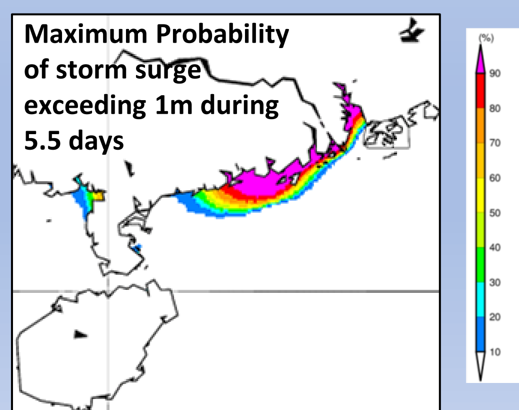
Example of the products
TY Chaba (1 Jul. 2022 00UTC Initial)

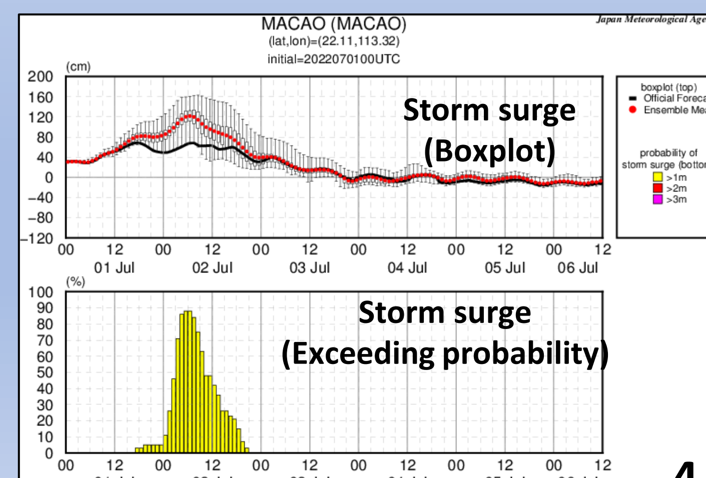








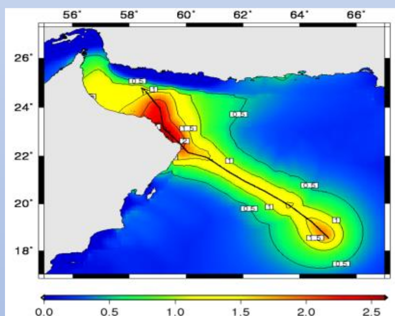


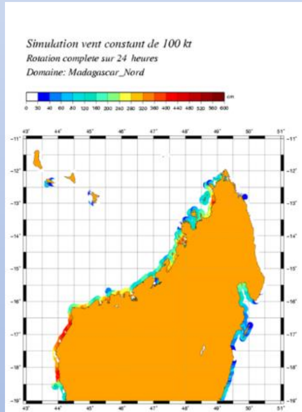


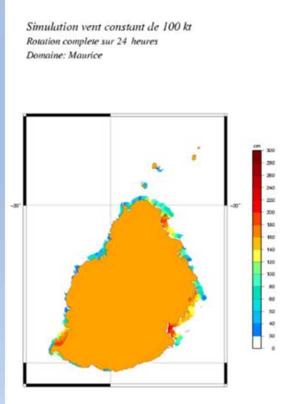
SSWS in the world

SSWS actions are taken in most regions:

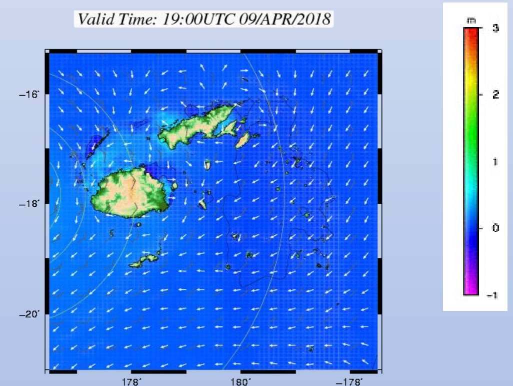
- ✓ RSMC New Delhi (2009-): Maximum storm surge maps
- ✓ RSMC Tokyo (2011-): Storm surge predictions
- ✓ RSMC Miami (planned in 2015, on going): Inundation risk map
- ✓ RSMC La Reunion (2013-2014): Cyclone surge atlas etc
- ✓ RSMC Nadi (2019-): Storm surge predictions

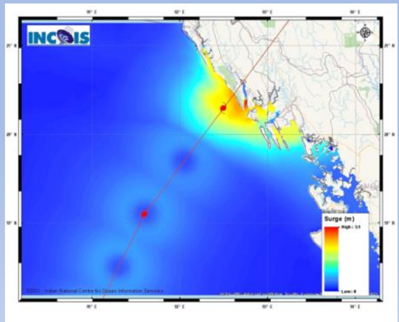


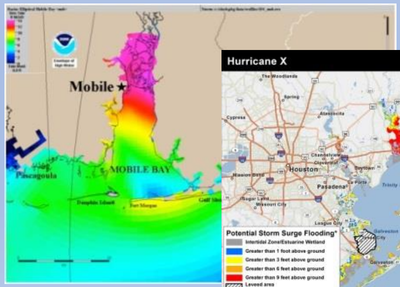


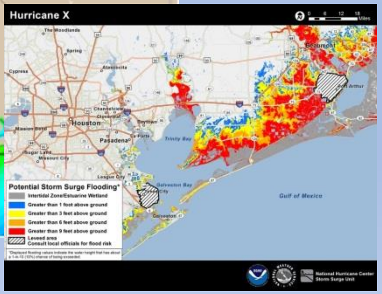


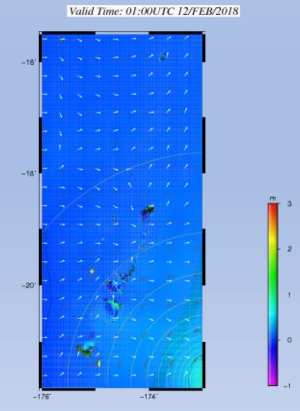
TC KENI

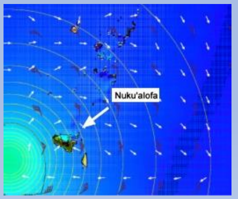






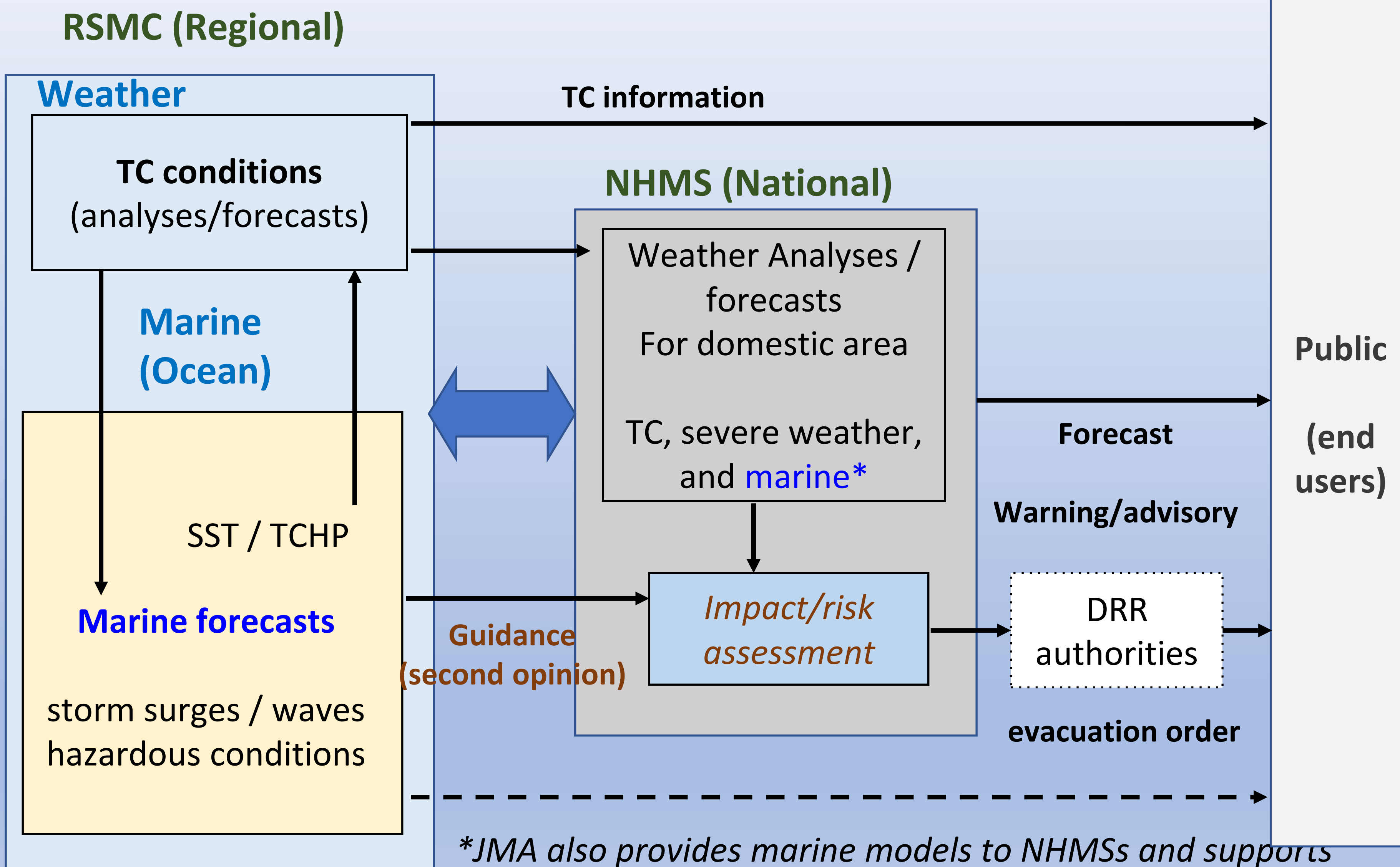






TC GITA

Marine information flow

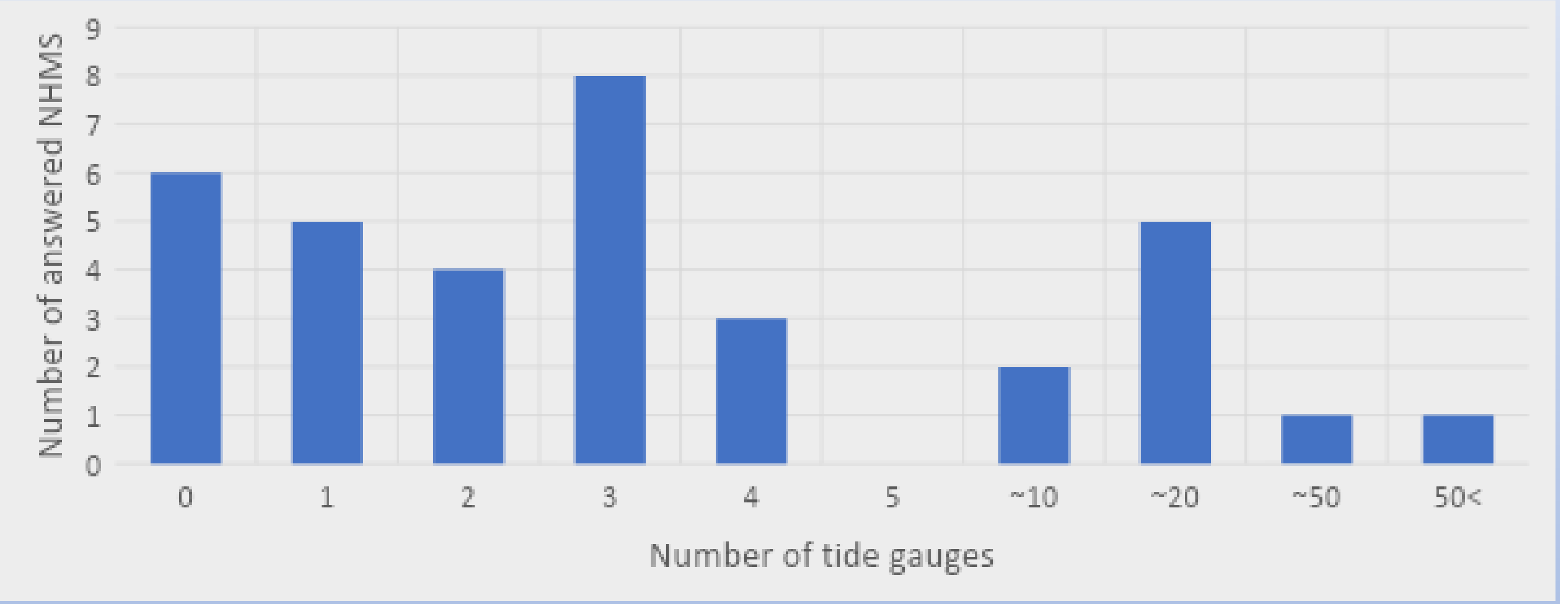


*JMA also provides marine models to NHMSs and supports their own operations, if requested.

Tide observations

Number of tide stations available at NMHSs

Results of survey on operational storm surge forecast, conducted for IWTC-9 (2018)



Although some NHMSs can refer many tide observed data, most NHMSs have only five or less tide gauges.

The small number of tide gauges leads to insufficient monitoring / verification, and more tide gauges would be encouraged.

Wave / Tide observation

Waves

Ships

Buoys

Drifting

Mooring

Coastal recorders

Radar

USW

ADCP

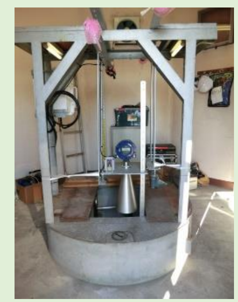
Satellites

Jason-3
(NOAA / EUMETSAT)

SARAL
(CNES / ISRO)

Tides

There are many kinds of types for tide gauges,
but they are in-situ observations.
(No remote-sensing)
Local observation is crucial!



Summary

- ✓ Recently storm surge information is shifting to integrated marine hazard information, and the products on their risks become available in the world.
- ✓ It is useful to issue risk information like coastal inundation or IBF, since marine phenomena is not so familiar with general public.
- ✓ Marine forecasting systems have now ability of simulating reasonable phenomena, which can be converted to specific risks. Graphical tools such as GIS support visualization.
- ✓ For effective IBF, improvement of all of related matters, not only forecasting systems, including framework of information flow from regional to end users.
- ✓ It is also important to raise public awareness so that they can correctly understand information issued.

Any Questions?

The JMA Mascot “*Harerun*”

(The word “hare” means fine weather in Japanese.)