Global Supply Chain Forum
(Bridgetown, Barbados, 21–24 May 2024)

Parallel Session A7

Climate change adaptation, resilience-building and disaster risk reduction for ports

23 May 2024

Key insights from port adaptation in practice

Presentation by

Miguel Esteban
Professor, Department of Civil and Environmental Engineering
Waseda University

Global Supply Chain
Forum
Barbados
21–24 May 2024

Climate Change Adaptation, Resilience-Building and DRR for Ports

Miguel Esteban
Professor
Waseda University, Tokyo, Japan

UNITED NATIONS
UNCTAD

WASEDA UNIVERSITY

Motivation for this research

- **Everybody talks about climate changes, its effects, etc.**
- **However, very little work has been done on climate change and ports**
- **Need to try to understand how much climate change is going to cost to ports**

WASEDA UNIVERSITY

My Objective Today

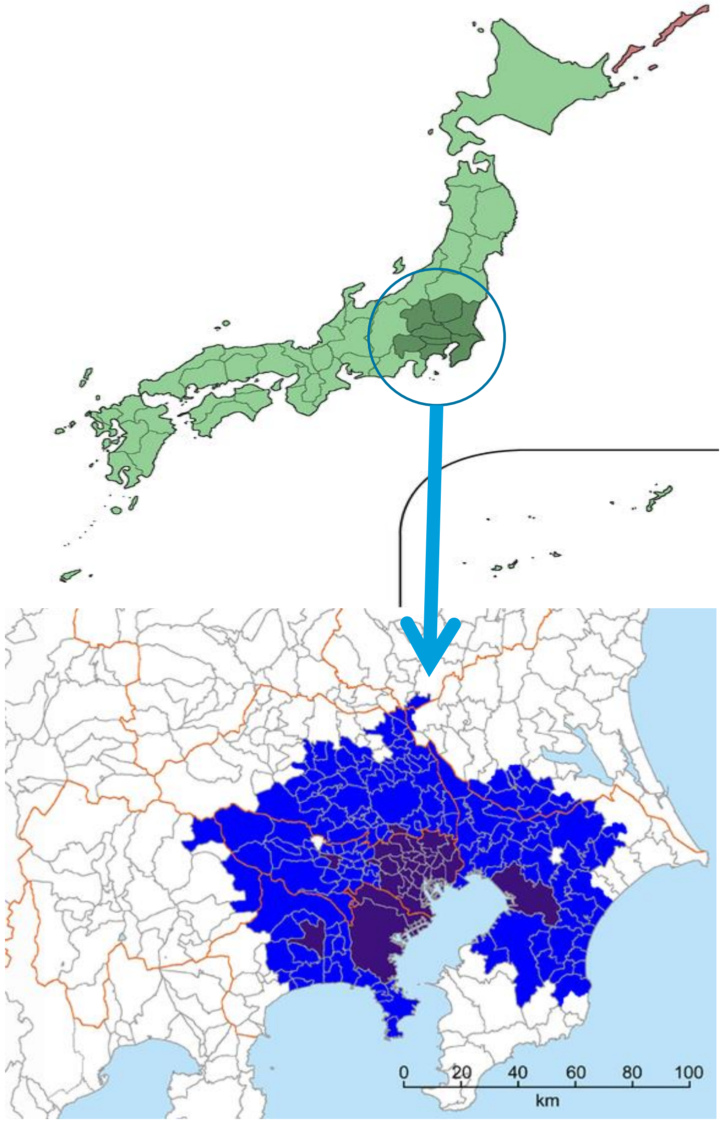
- **There are many major challenges facing port construction in the future in the light of climate change**

- **Sea level rise**
  - **Raise ground level**
  - **Reinforce breakwaters**

- **Increase in typhoon intensity**
  - **Port operation (downtime)**
  - **Reinforce breakwaters**

Greater Tokyo and the Ports around Tokyo Bay

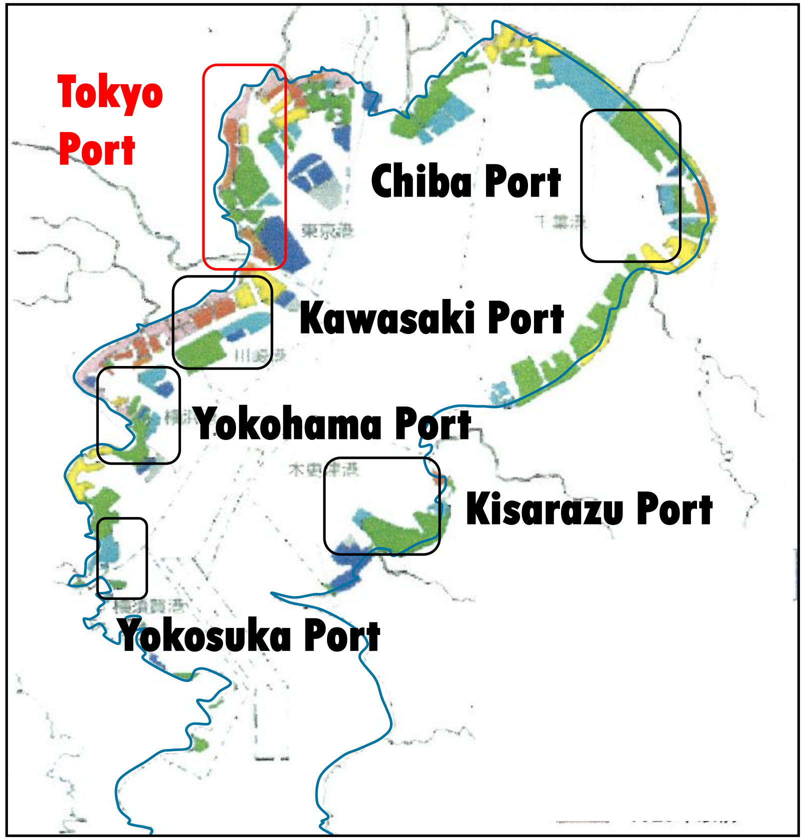
Greater Tokyo Area



- A 2007 UN estimate puts the population at **35,676,000** (world's most populous metropolitan area).
- Area of 13,500 km² , population density 2,642 person/km² - twice that of Bangladesh
- **Largest metropolitan economy in the world**, with a total GDP (nominal) of approximately US$1.9 trillion (¥165 trillion) in 2008 (it would be the world's 9th biggest economy*)

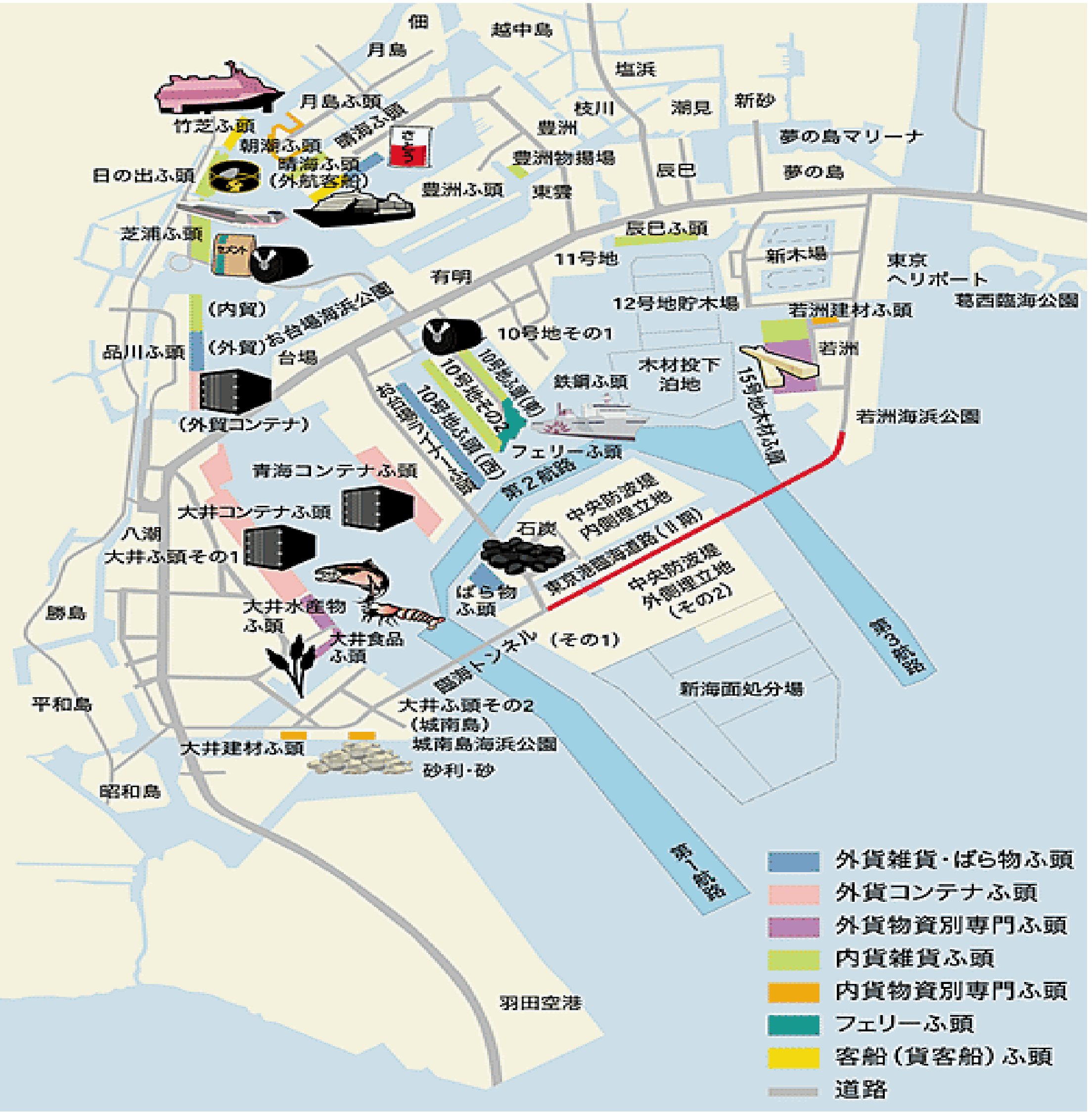
*ahead of Russia or Spain (GDP of Italy in 2011: US$2.1 trillion, India, 1.89 trillion, Russia: 1.85 trillion)

Tokyo Bay Ports



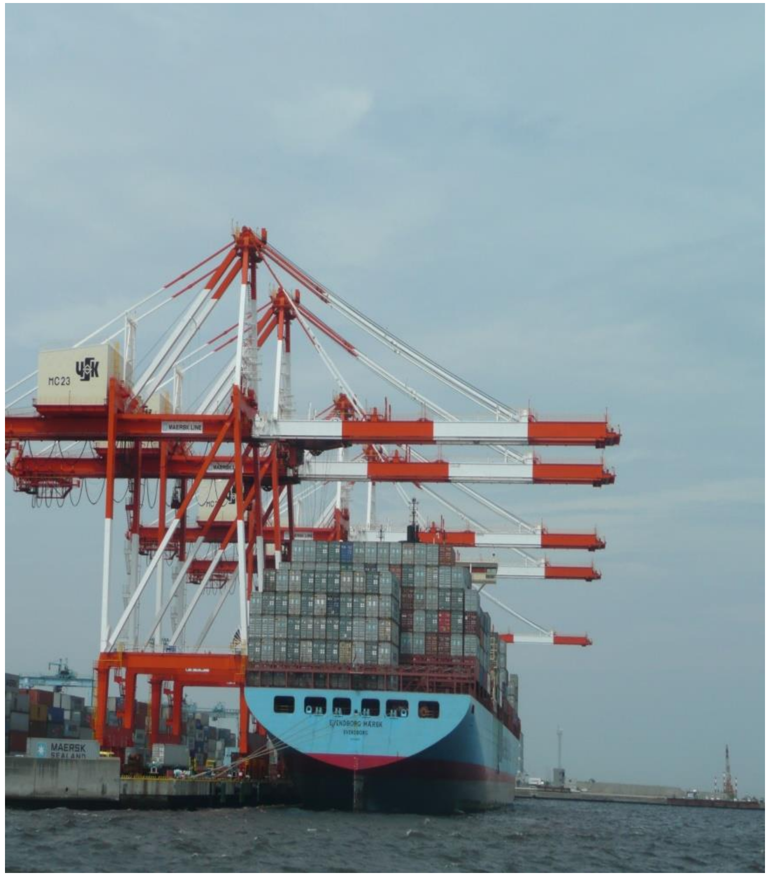
- A **number of major ports** located around the bay
- Yokohama was first international port in the area, in 19th century
- Almost the entire Bay circumference is **reclaimed land** now, with large areas dedicated to **port** installations

Port of Tokyo

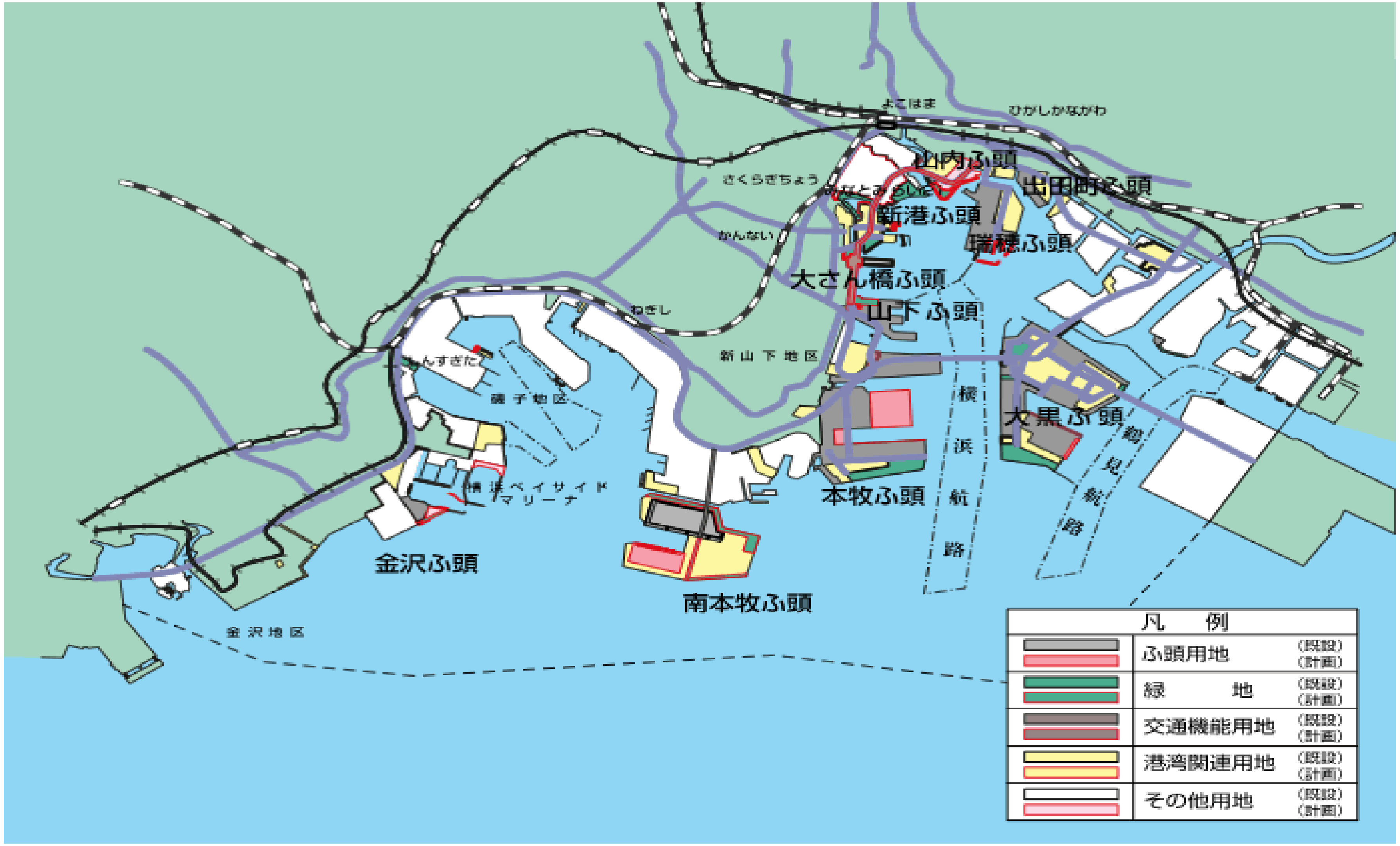


- One of the largest Japanese ports
- One of the largest ports in the Pacific Ocean basin
- Annual traffic capacity of around 100 million tonnes of cargo and 4,500,000 TEU's.
- 30,000 employees
- More than 32,000 ships every year.

Port of Yokohama (I)

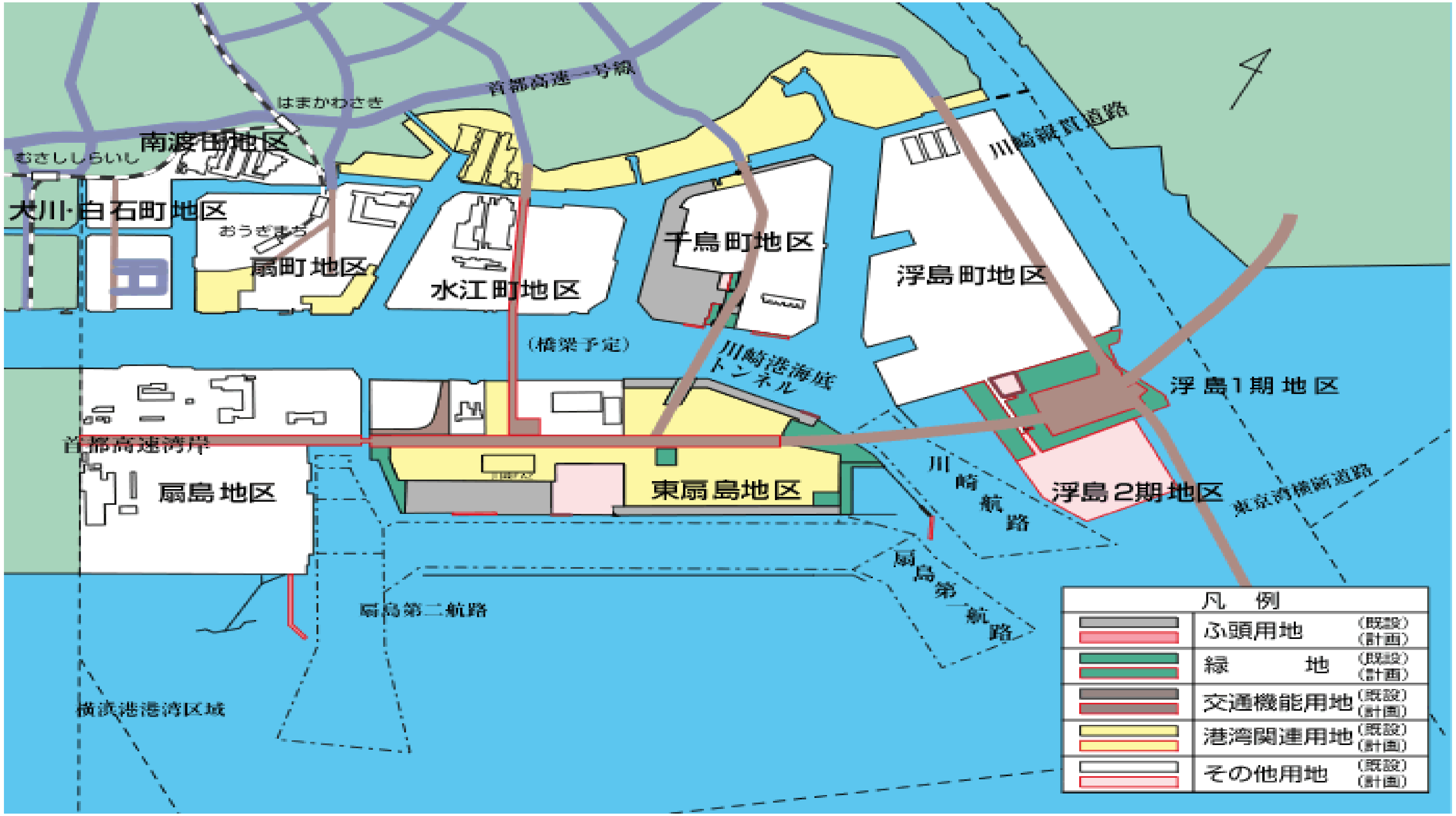


Port of Yokohama (II)



横浜港案内より

Port of Kawasaki



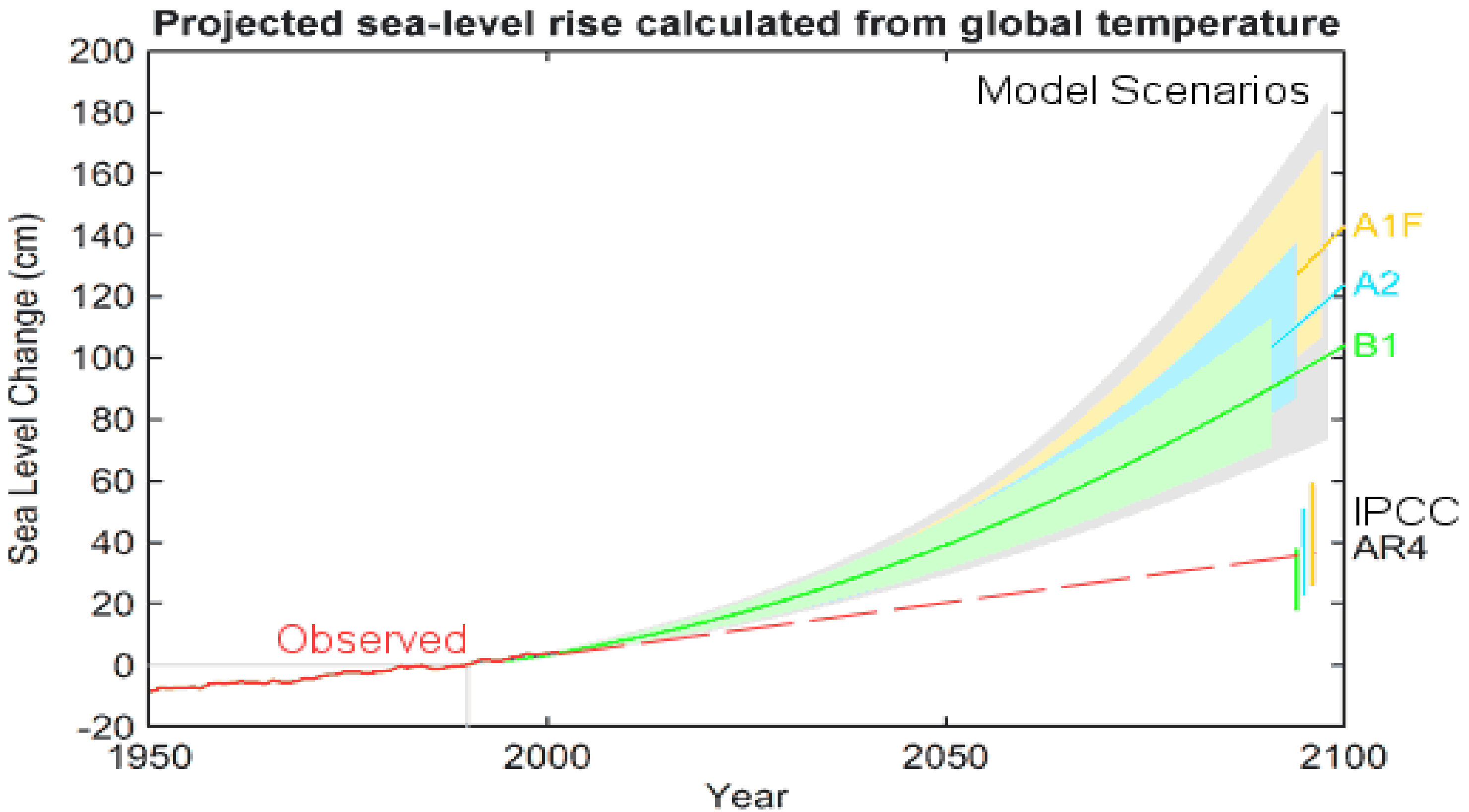
川崎港案内より

WASEDA UNIVERSITY

Sea Level Rise and Port Levels

The Science Behind Sea Level Rise (II)

- **Vermeer and Rahmstorf (2009), argue that sea level rise could be in the range of 0.81 to 1.79m by 2100**



WASEDA UNIVERSITY

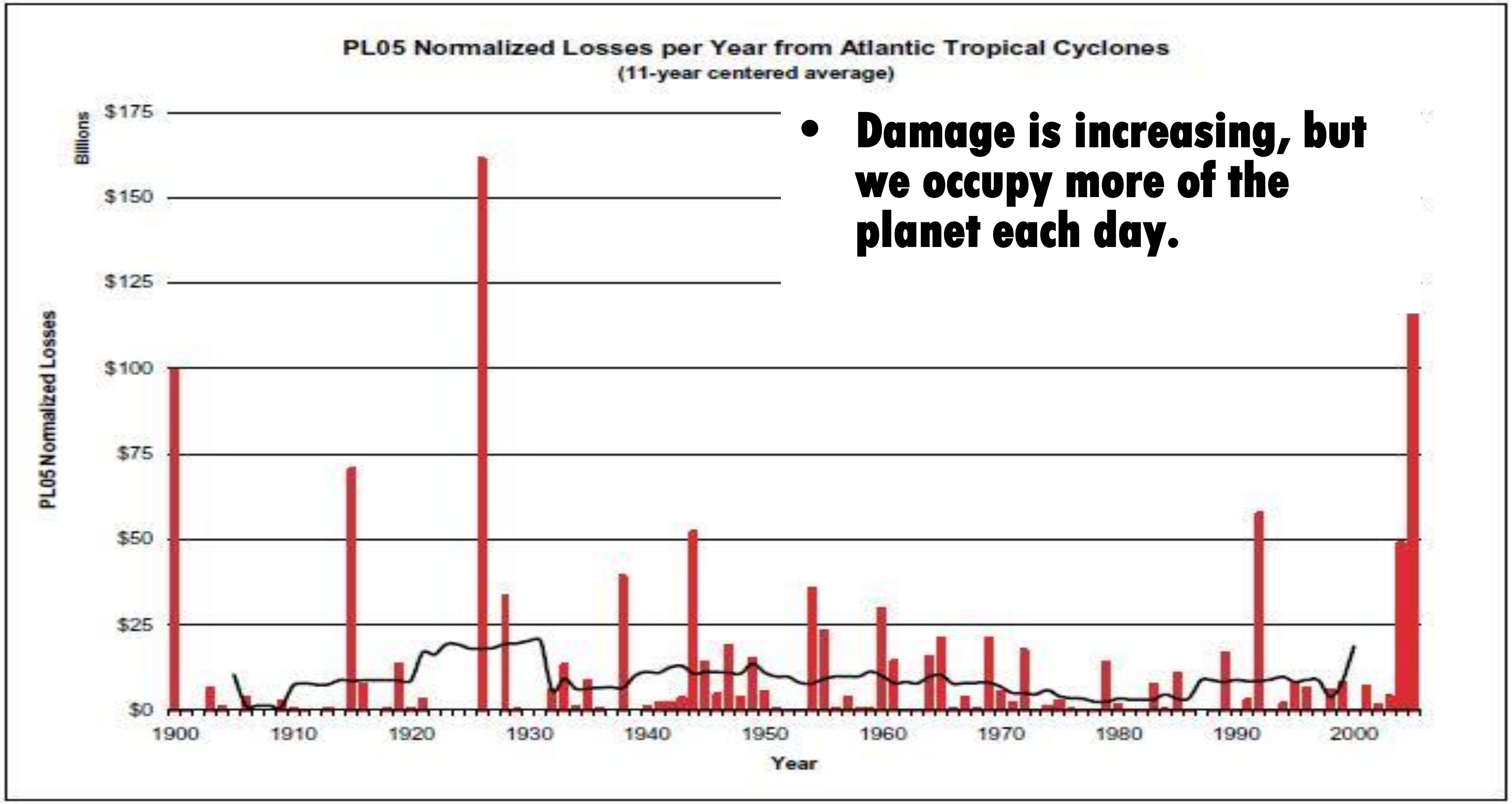
Climate Change and Tropical Cyclones

WASEDA UNIVERSITY

Changing Weather Patterns

- Tropical cyclones are amongst the most dangerous weather systems for breakwaters
- One of the fears of global warming is that it could result in an increase in the frequency and intensity of tropical cyclones due to the warming of sea temperature (Knutson et al., 2010)
- However, it is difficult to conclude so far that any event has been influenced by climate change!

Knowledge about future and typhoons



- **Damage is increasing, but we occupy more of the planet each day.**

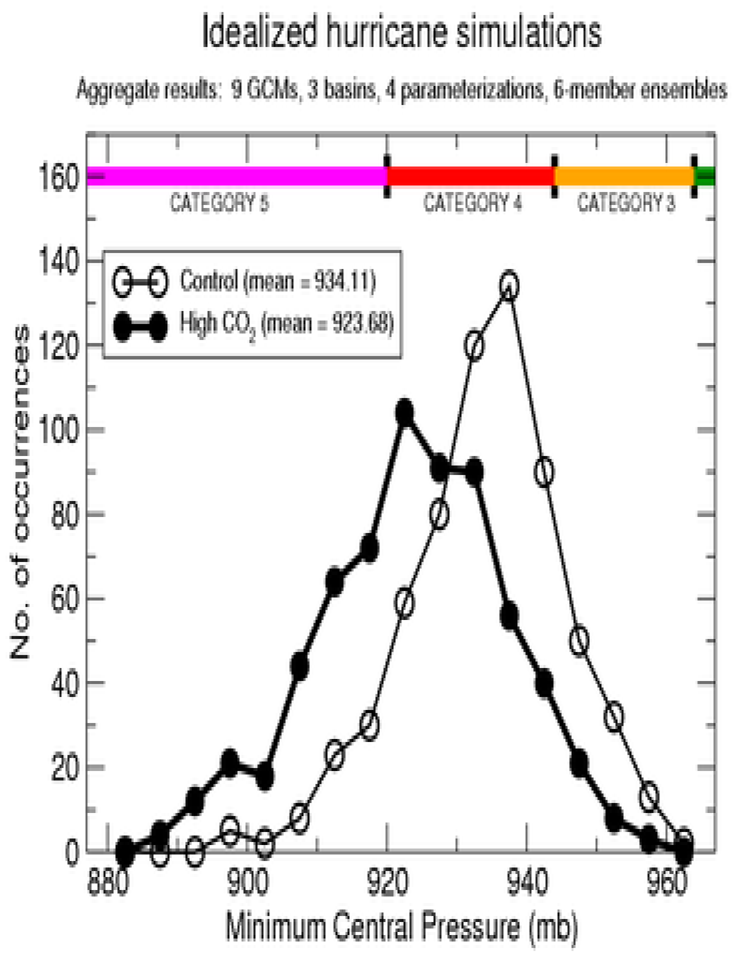
- **Pielke et al. (2006) "*Normalised Hurricane Damage in the United States, 1900-2005*"**

Knowledge about future and typhoons (III)

- **Typhoon formation is influenced by surface sea water temperature (0.7 degree increase during the 20th century)**

- **Simulations by Knutson and Tuleya (2004).**

- **Knutson et al. (2010) "Some increase in the mean maximum wind speed of tropical cyclones is likely (+2 to +11% globally) with projected twenty-first-century warming"**

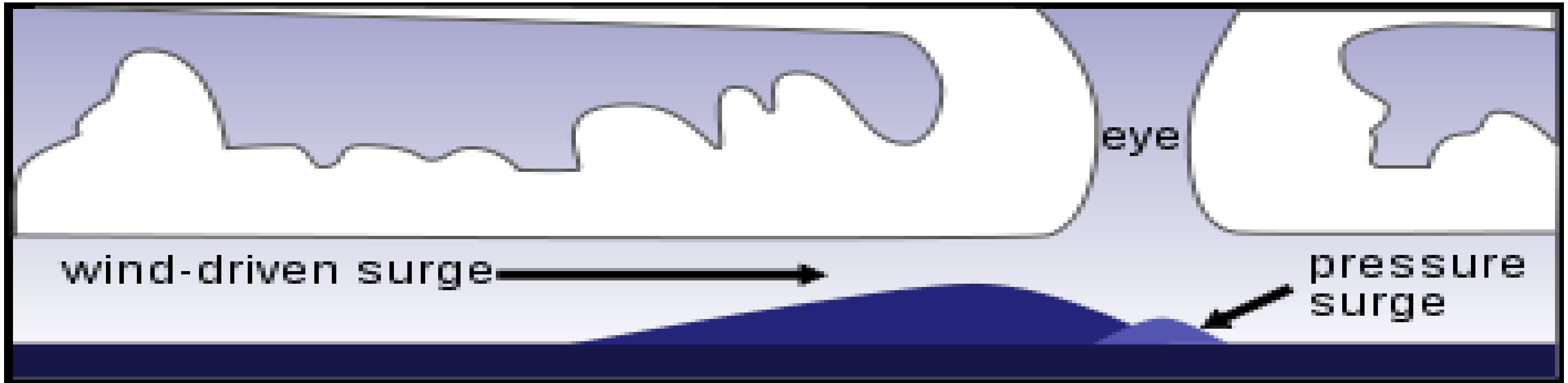


Increased flooding due to Storm Surges

- Storm Surge: During the passage of a tropical cyclone sea level goes up due to the drop in atmospheric pressure and wind forcing

- This can lead to flooding of coastal areas (Katrina in the US, Nargis in Myanmar, etc)

- This effect could increase in the future, and combined with sea level rise could exacerbate flooding potential

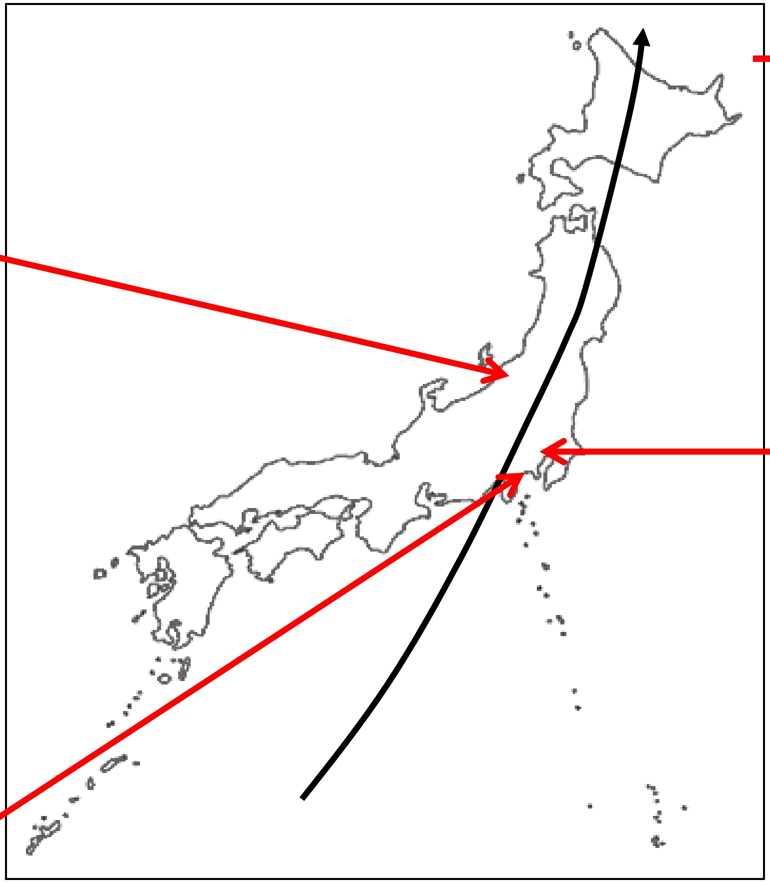


Effect of Climate Change on 1 in 100 year typhoon in Tokyo Bay

TARGET TYPHOON

(Broken river banks at Kounan, Niigata)

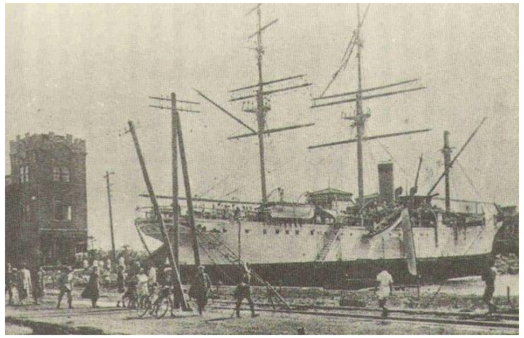
(Broken station at Hatano, Kanagawa)



<u>Taisho 6th year (1917) typhoon</u>

<u>30th September - 1st October</u>

(Ministry of transport, 2000)

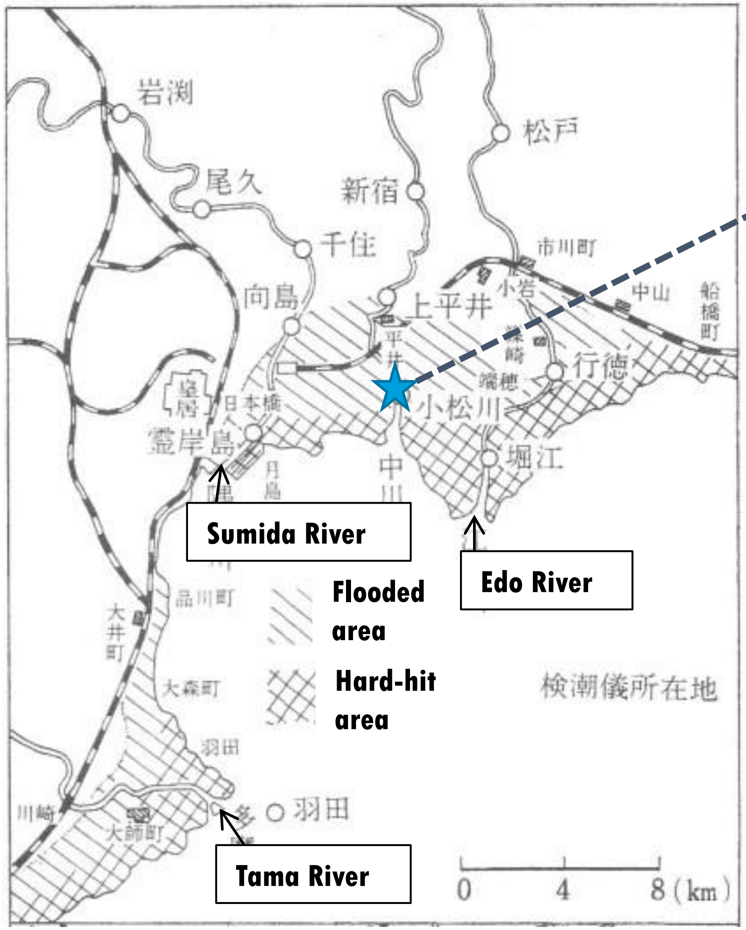


(Broken ship at Koutouku, Tokyo)

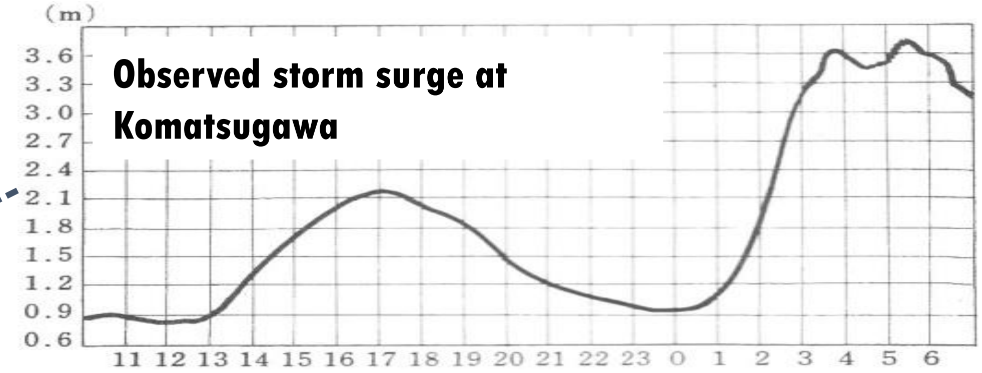
(Broken river banks at Otsuka, Tokyo)

(Broken house at Tsukishima, Tokyo)

Taisho 6th year (1917) typhoon Damage (Worst storm in 100 years)



(Flooded and hard-hit areas by Taisho typhoon)



Dead or missing	1,324
Wounded	2,022
Completely destroyed houses	36,459
Half destroyed houses	21,274
Houses washed away	2,442
Flooded houses	302,917
Flooded area	215km² (in Tokyo)

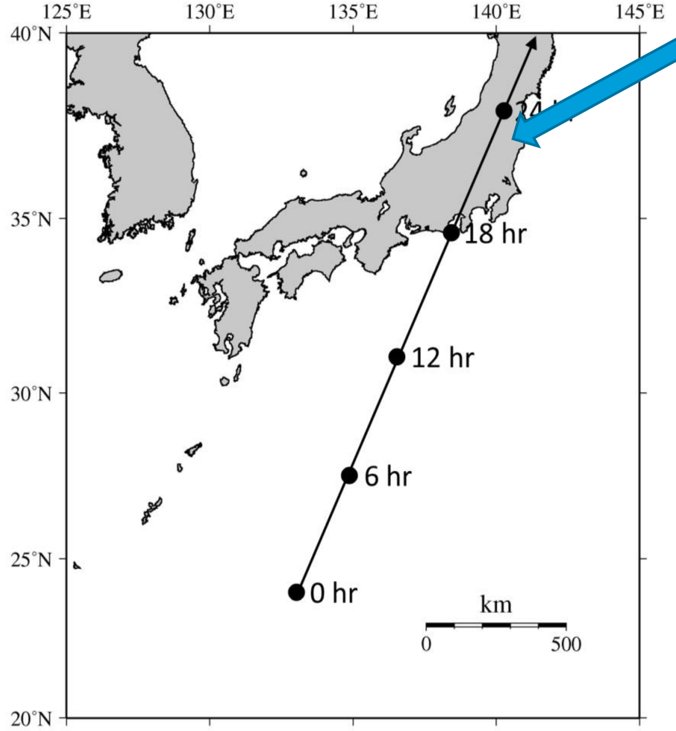
<Miyazaki, 2003,"Study of storm surge">

Calculate the storm surge height

Target typhoon

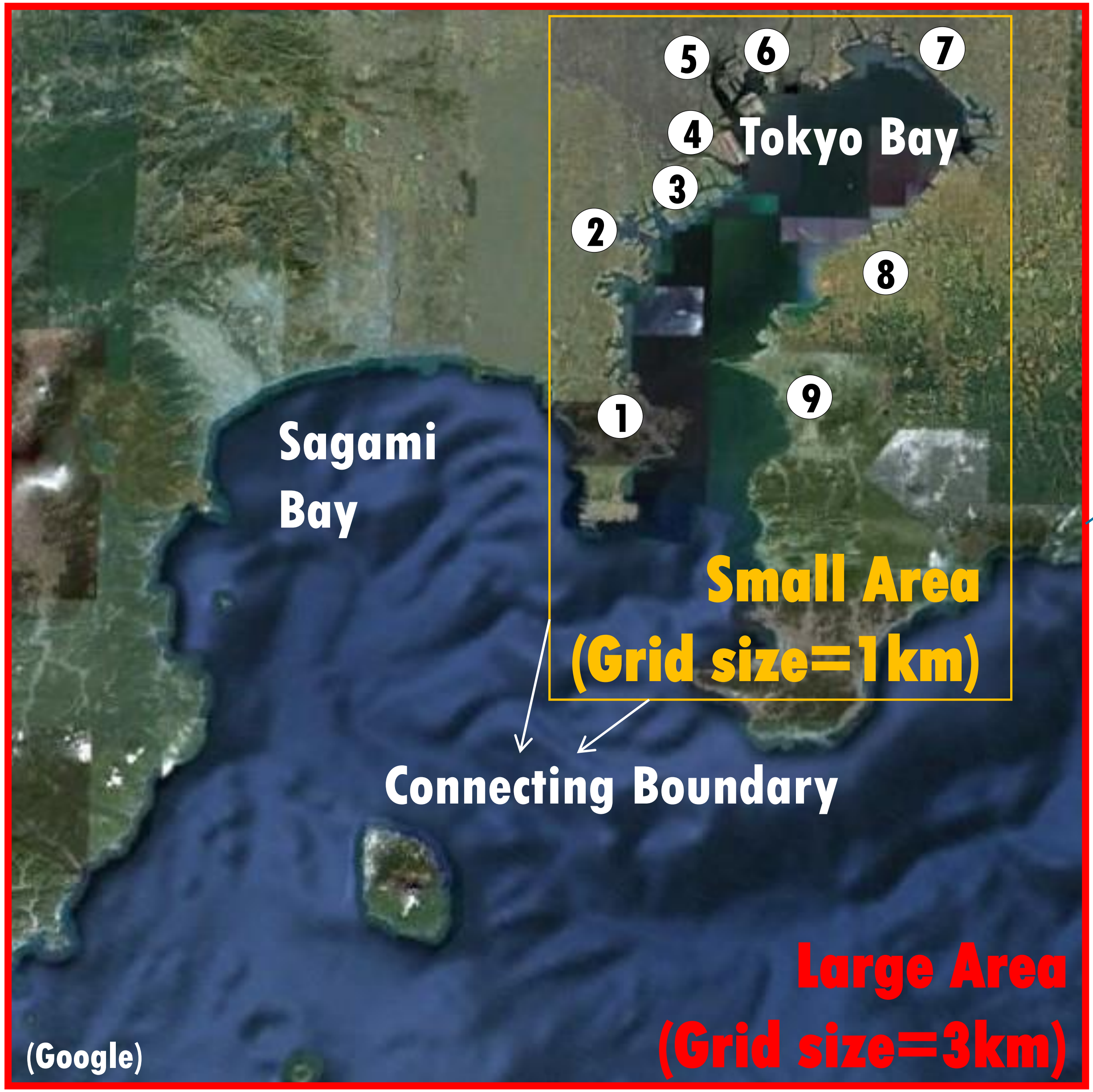
(Taisho 6th typhoon

— The worst typhoon to affect to Tokyo Bay in 100 years)



Target area

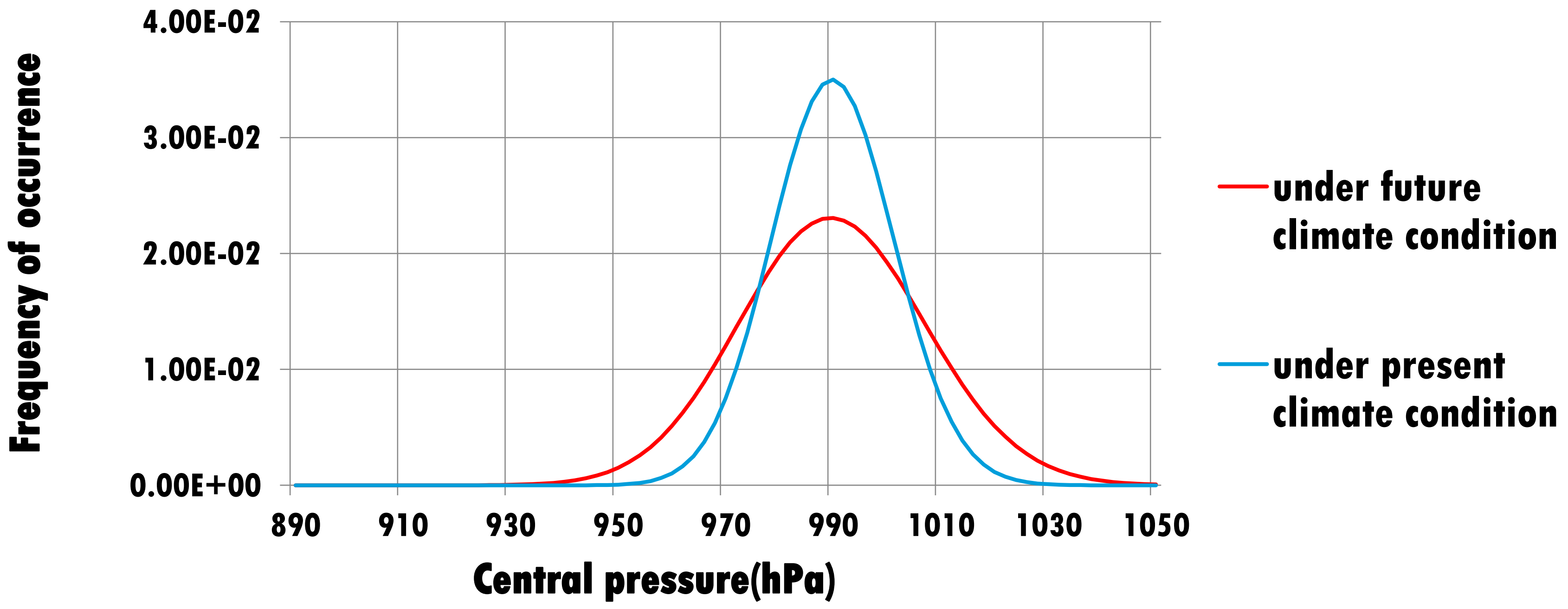
TARGET AREA



The simulation uses
a **nesting approach**

No	Place	Prefecture
1	Yokosuka	Kanagawa
2	Yokohama	
3	Kawasaki	
4	Samezu	Tokyo
5	Shibaura	
6	Toyosu	
7	Funabashi	Chiba
8	Sodegaura	
9	Futtsu	

Calculate the central typhoon pressure (from Yasuda et al., 2010)



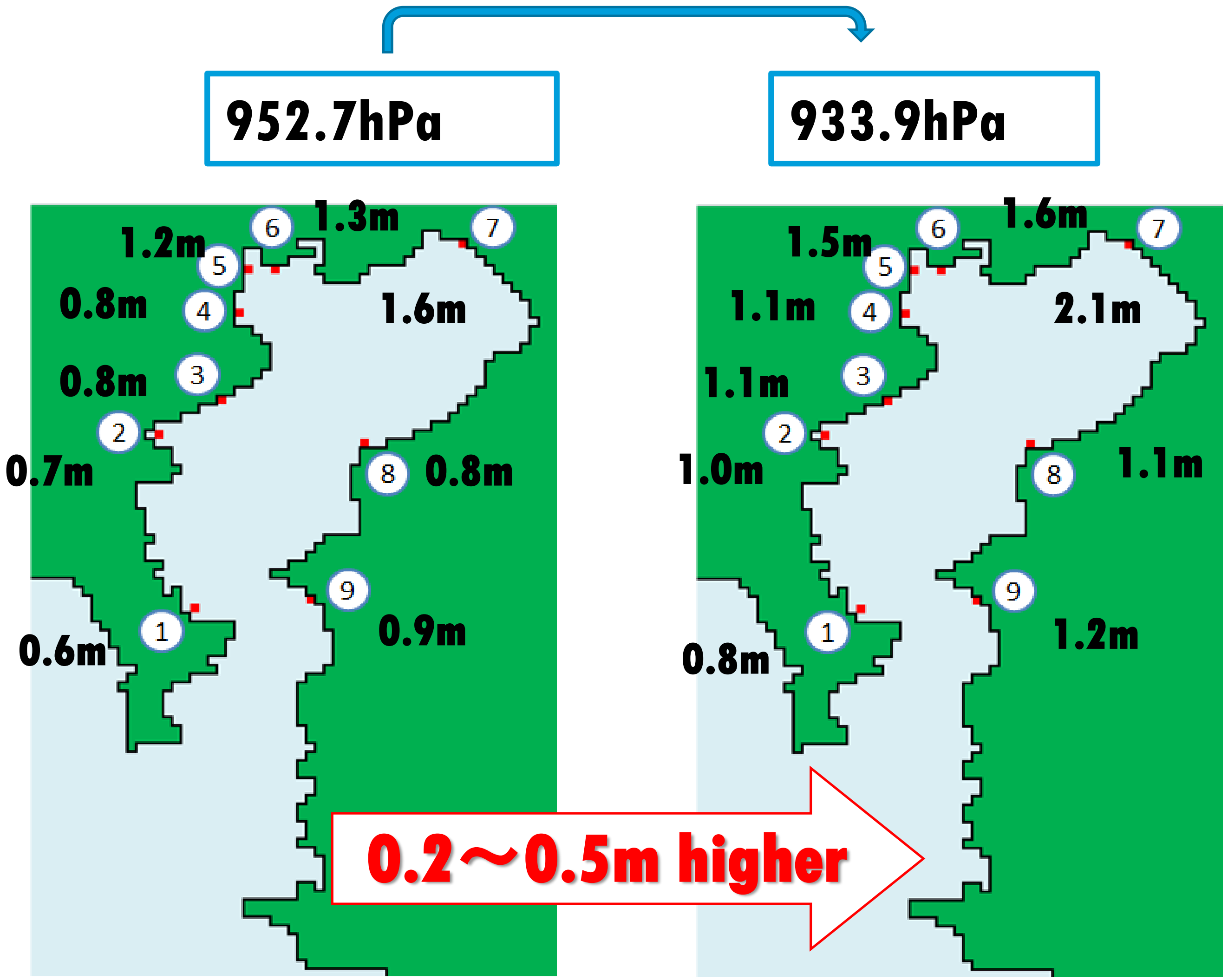
Compare the frequency of occurrence…

⇨

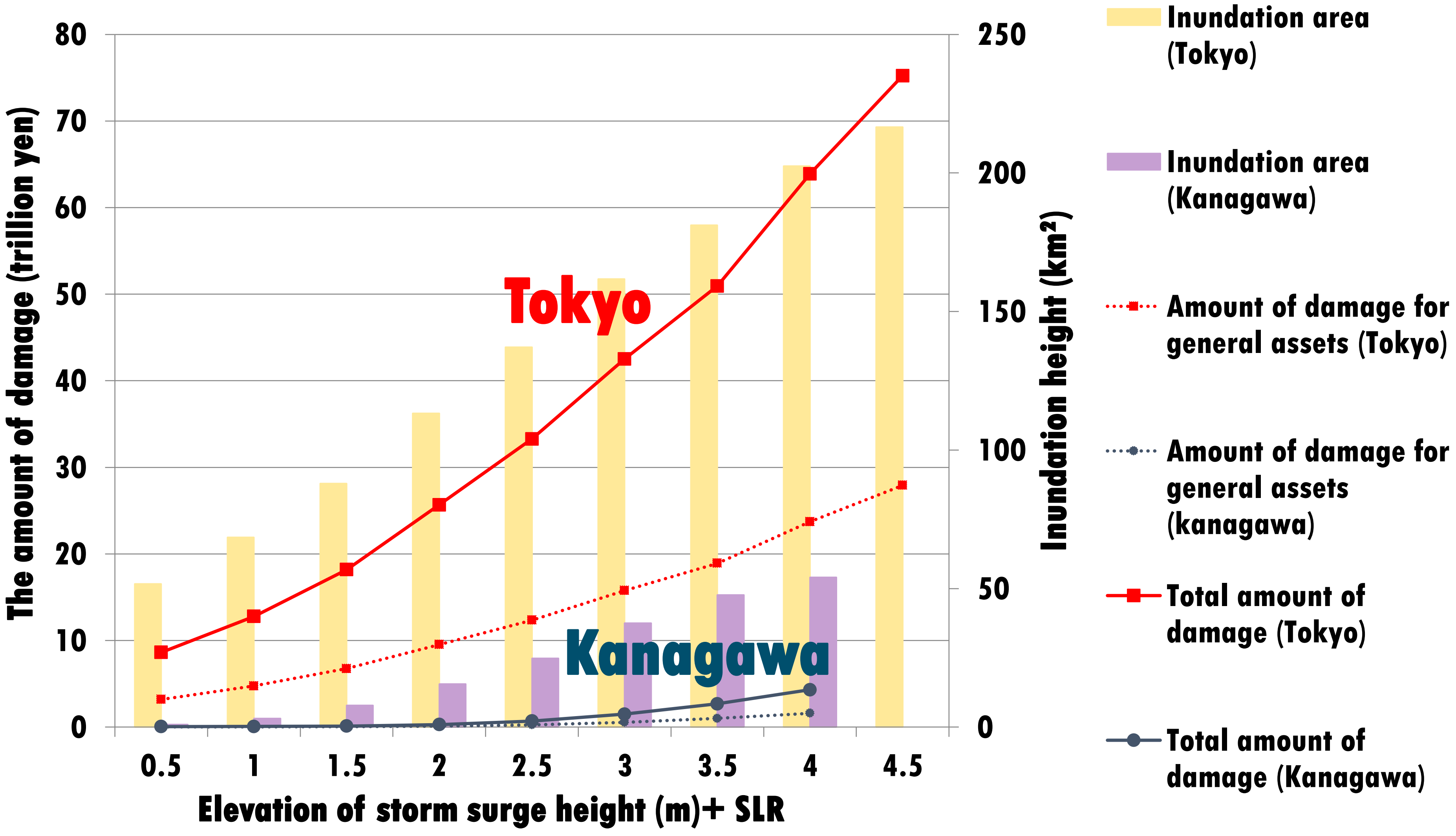
Historical Central Pressure of Taisho 6th typhoon	952.7 hPa
Computational Central Pressure	933.9 hPa

Change in storm surge level

Change the central pressure

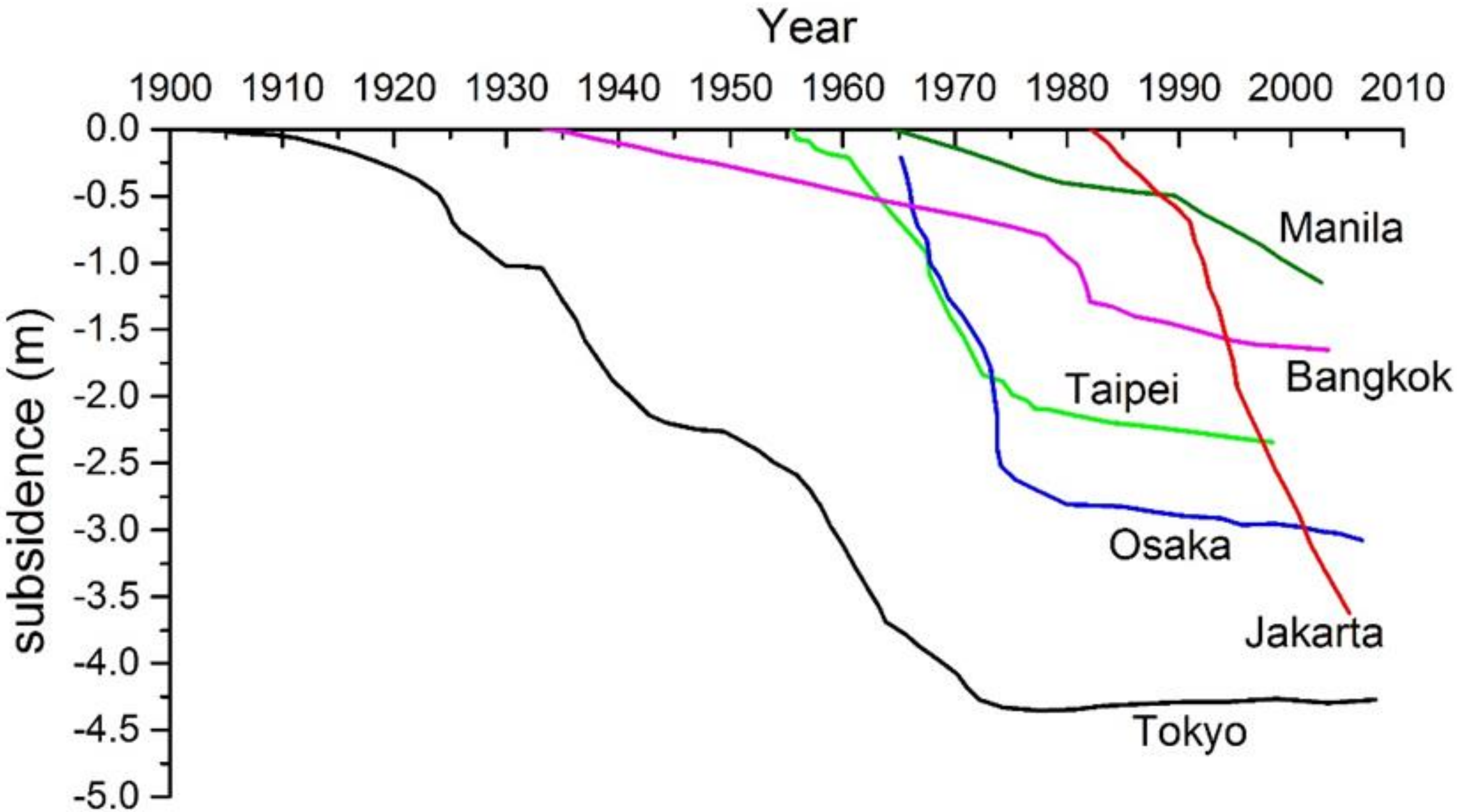


Inundation area and economic damage



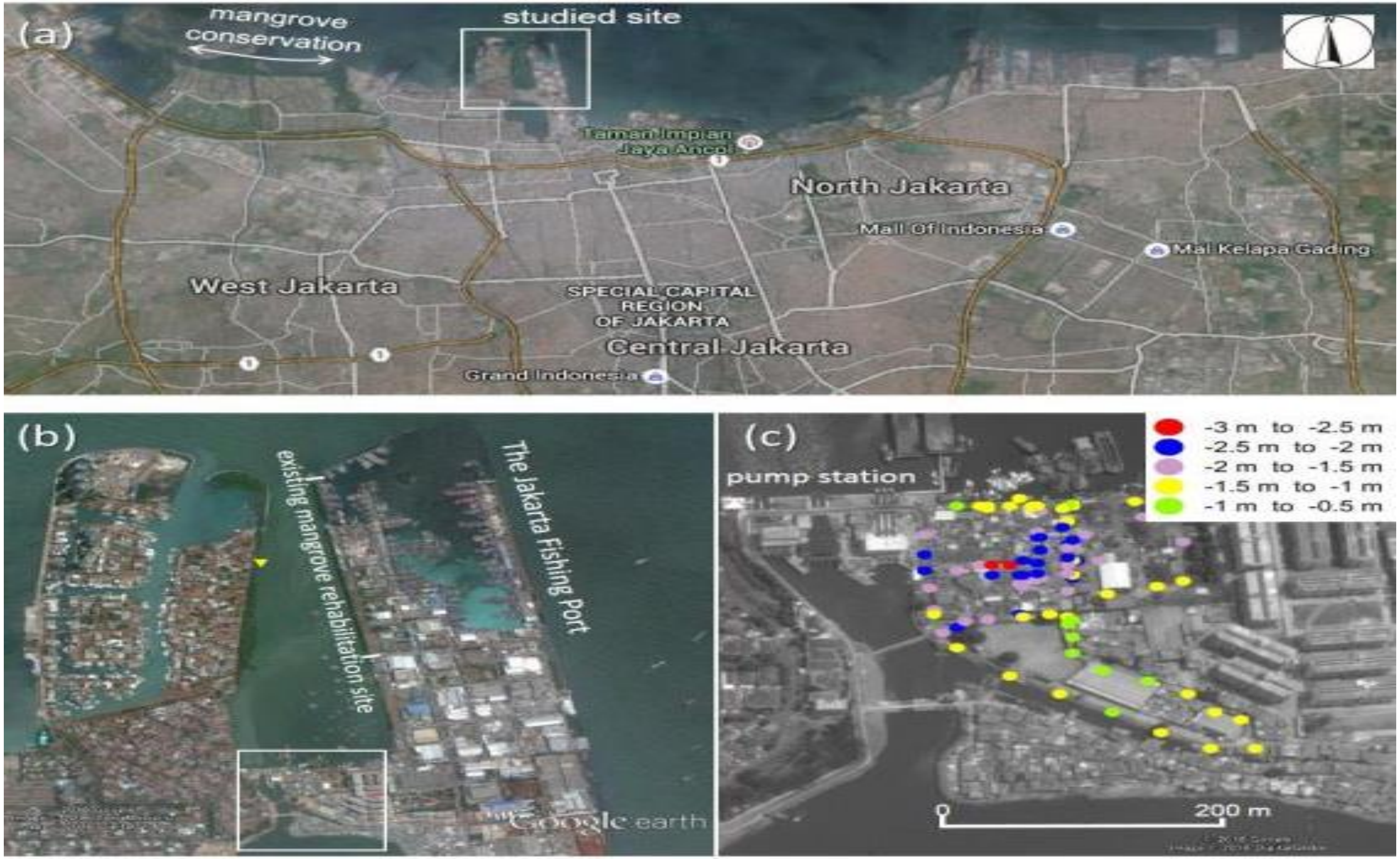
Learning from ports in Jakarta

Reason: Groundwater Extraction (currently ~0.1-0.2 m* subsidence/year)



***No, this is not a typo, it really is 20cm per year!*

Study site: Coastal Jakarta (-0.5 to -3m below sea level)



Sunda Kelapa Port (I)

Sunda Kelapa Port (II)

Sunda Kelapa Port (III)

-Oldest in Jakarta

-52 ha of land area

-~7-10cm subsidence per year

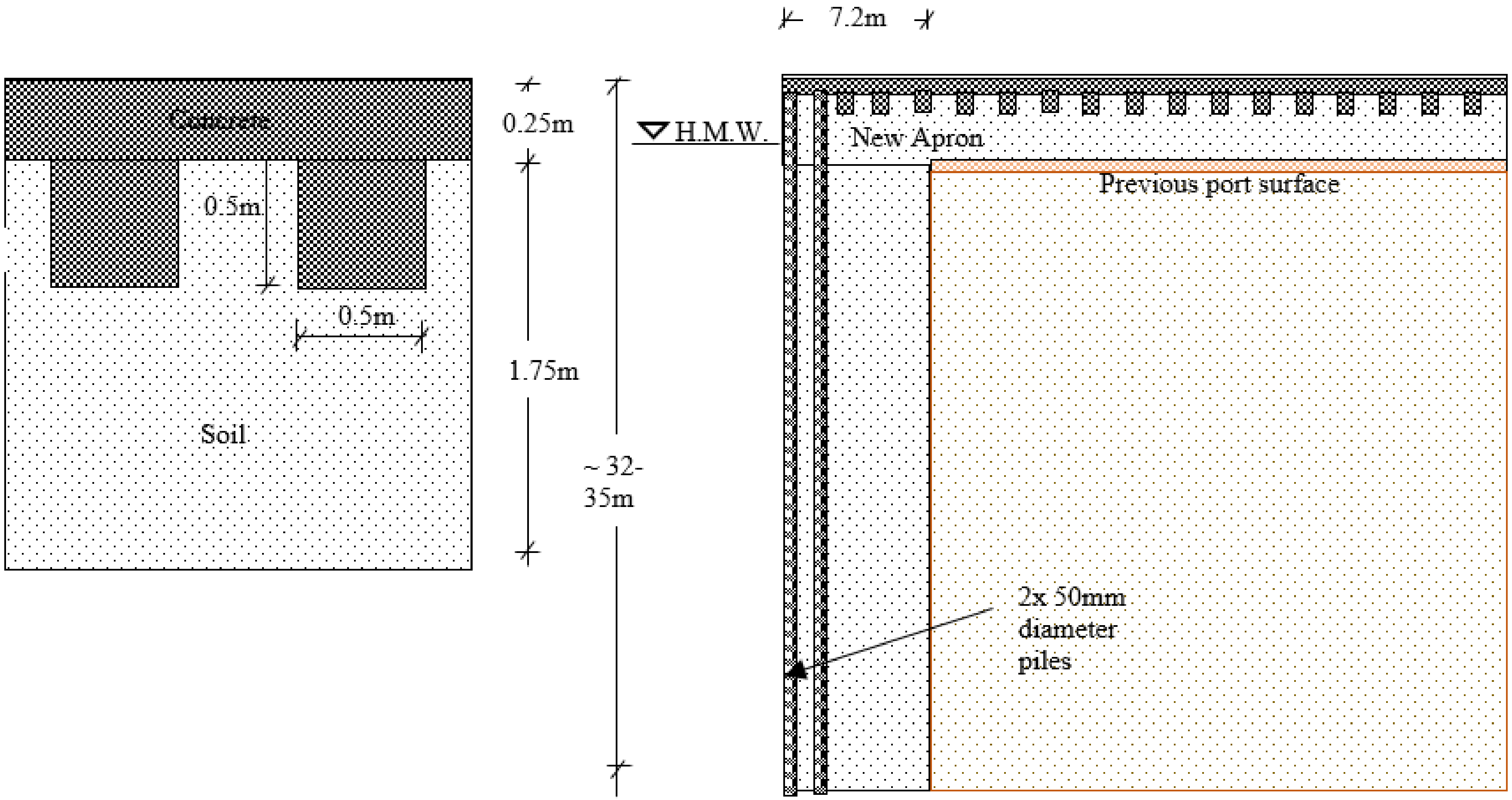
-20% of their annual income spent on adaptation

-Section by section the port elevates its wharfs (depending on the year)

-Adaptation measures do not consider earthquakes (Jakarta has low tsunami risk)

Adapting to land subsidence (I)

Countermeasures: piles 7.2m to the water side, piled soil on top of old surface, placed concrete.
Cost: Ground raising ~**100USD/m²** **Piling, 4,000 USD/m run**



Adapting to land subsidence (II)

Barriers to Adaptation

-The port believes there is no limit to how far up they can go using the technology they are using

-If their costs increase they will simply increase tariffs. It is a heritage port, and there are plans to consolidate all passenger transit there

-The government will ultimately have to pay

-Might be increasingly difficult for water to drain to sea (solved through pumps etc)

Sea Level Rise	Technological Limits	Cost-Benefit Limits	Financial Barriers	Social Conflict Barriers
+ 0.5m				
+ 0.51 - **1.0m**				
+ 1.01 - **2.0m**				
+ 2.01 - **4.0m**				
+ 4.01 - **8.0m**				

PPS Nizam Zahman Port (I)

PPS Nizam Zahman Port(II)

PPS Nizam Zahman Port (III)

-Founded in 1984, largest fishing port in Indonesia

-52 ha of land area

-~7-12cm subsidence per year

-Port was raised in 2002 and then in 2012 (last time by +1.4m)

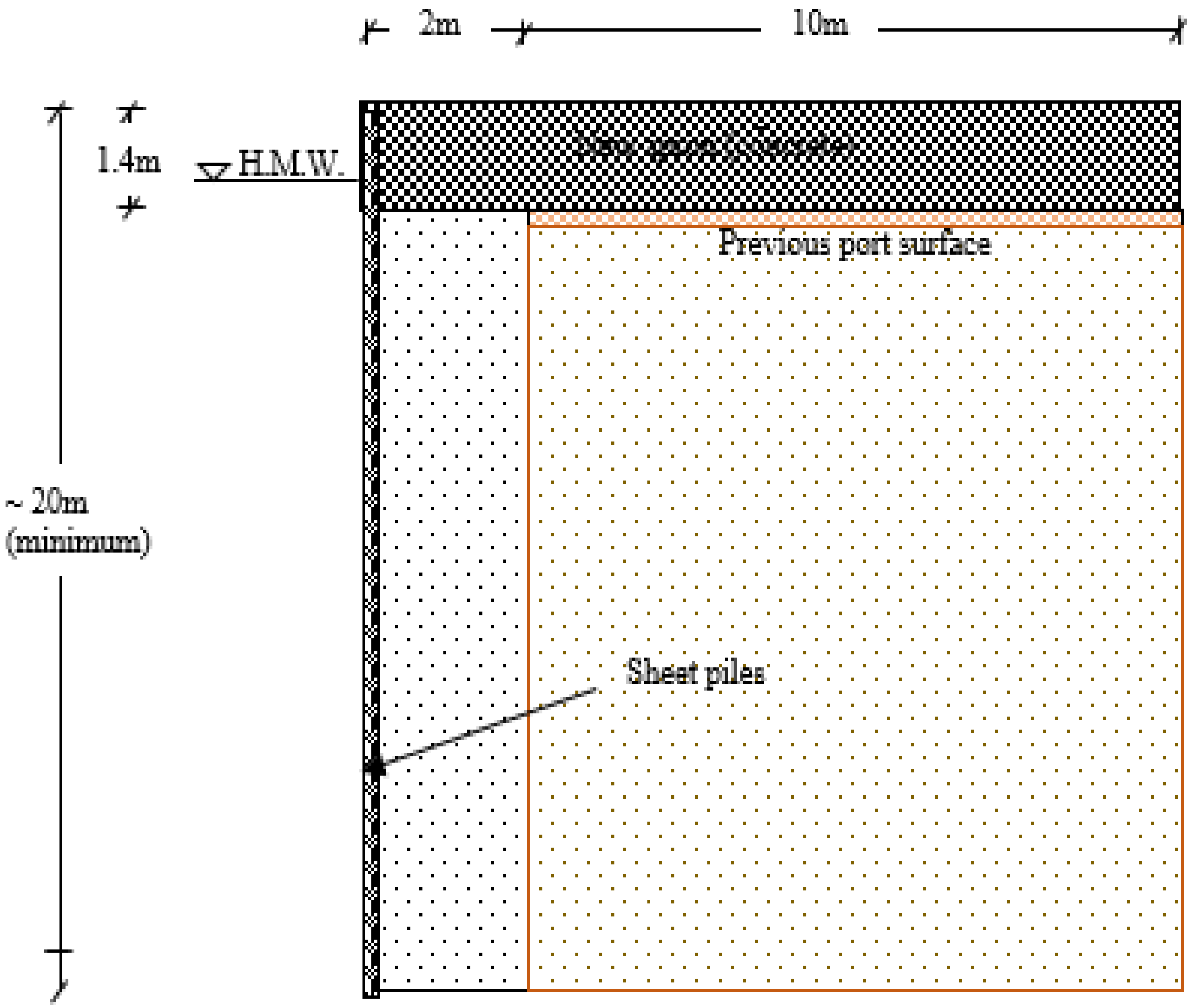
-Raising is done sequentially, first one part of the port, then the others

-Funding for raising was provided by JICA

Adapting to land subsidence (I)

-Port was raised by using sheet piles 2.0m from edge of old port, and then pouring 1.4m of concrete on top of existing port structure

-Thinking of moving to floating port?



Barriers to Adaptation

-The port believes there is no limit to how far up they can go using the technology they are using

-However, might be cost-effective to move to a floating port

-The government will ultimately have to pay (giving multiplier effects to economy)

-Nearby communities are happy to know that the ports are being raised.

<table>
<tr><th>Sea Level Rise</th><th>Technological Limits</th><th>Cost-Benefit Limits</th><th>Financial Barriers</th><th>Social Conflict Barriers</th></tr>
<tr><td>+ 0.5m</td><td></td><td rowspan="5">Floating port better?</td><td></td><td></td></tr>
<tr><td>+ 0.51 - 1.0m</td><td></td><td></td><td></td></tr>
<tr><td>+ 1.01 - 2.0m</td><td></td><td></td><td></td></tr>
<tr><td>+ 2.01 - 4.0m</td><td></td><td></td><td></td></tr>
<tr><td>+ 4.01 - 8.0m</td><td></td><td></td><td></td></tr>
</table>

Muara Angke Port (I)

Muara Angke Port (II)

-Fishing port

-Founded in 1977

-64 ha of land area

-~7cm subsidence per year (Water Resource Agency of Indonesia)

-Port was raised three times (2006, 2011 and 2014, about 40-50cm each time)

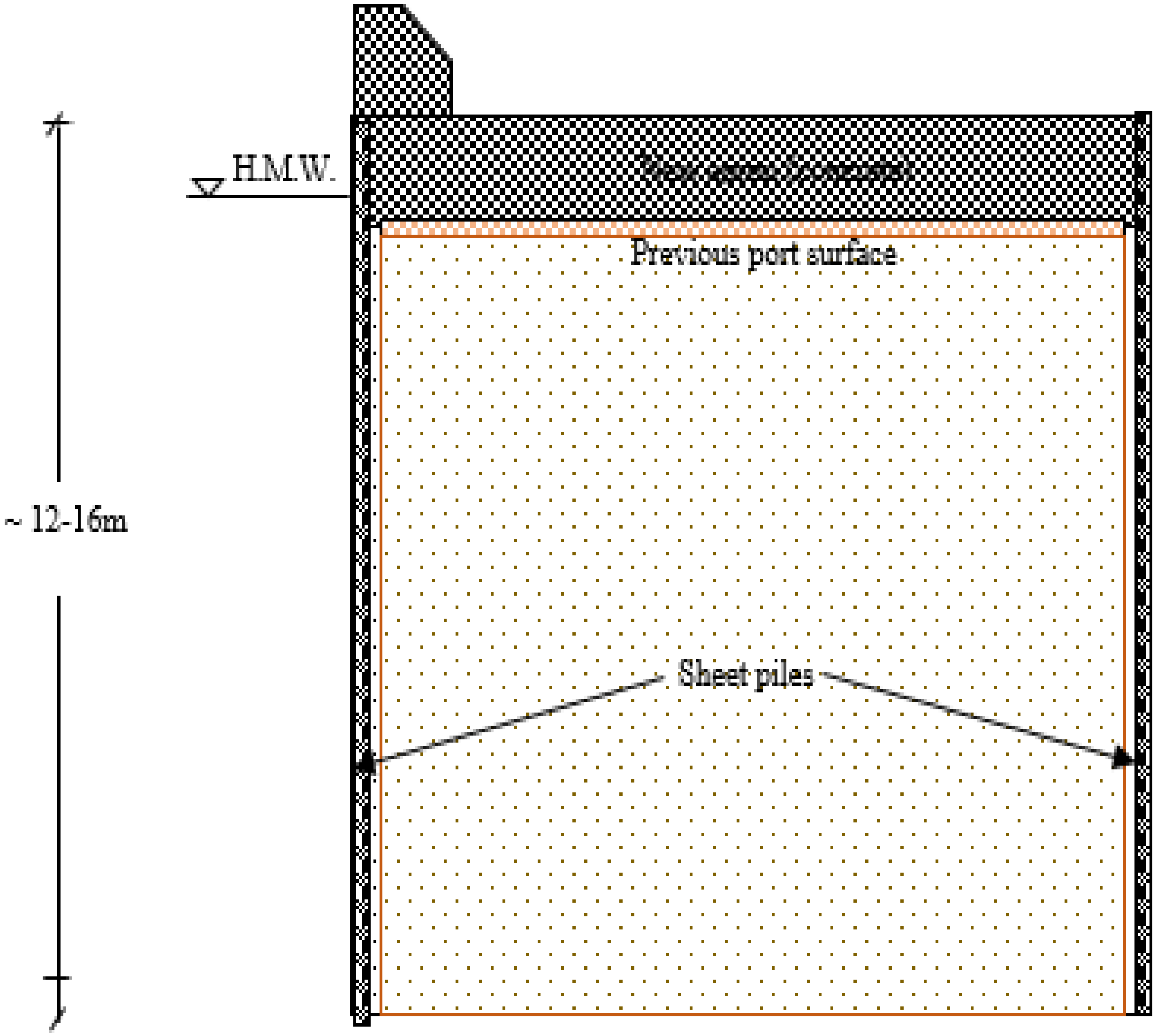
-Breakwaters also being submerged by the subsiding land

Muara Angke Port (III)

Muara Angke Port (I)

-Port was raised by using sheet piles right at the edge, and then pouring 0.4-0.5m of concrete on top of existing port structure

-Thinking of moving to floating port?



Barriers to Adaptation

-They can only raise port another 2-3 times before they reach limit of sheet piles. Then they have to move to something else (maybe deeper piles), or maybe floating ports (they are already experimenting with this)

-This will affect the cost of raising the ports (cost-benefit issues), but ultimately the government will have to pay.

-They noted how fishermen are not happy for ports to be elevated by too much each time, given that it is difficult to access ships.

Sea Level Rise	Technological Limits	Cost-Benefit Limits	Financial Barriers	Social Conflict Barriers
+ 0.5m				
+ 0.51 - **1.0m**	Sheet piling limit			
+ 1.01 - **2.0m**	Piles? Floating port			
+ 2.01 - **4.0m**	Piles? Floating port			
+ 4.01 - **8.0m**	Piles? Floating port			

Adapting to land subsidence (II)

Tohoku and Land Subsidence (0.5 to 1m subsidence)

WASEDA UNIVERSITY

Raising of Port Levels (I)

Raising of Port Levels (II)

Ishinomaki Port

Ishinomaki Port (II)

-Industrial port

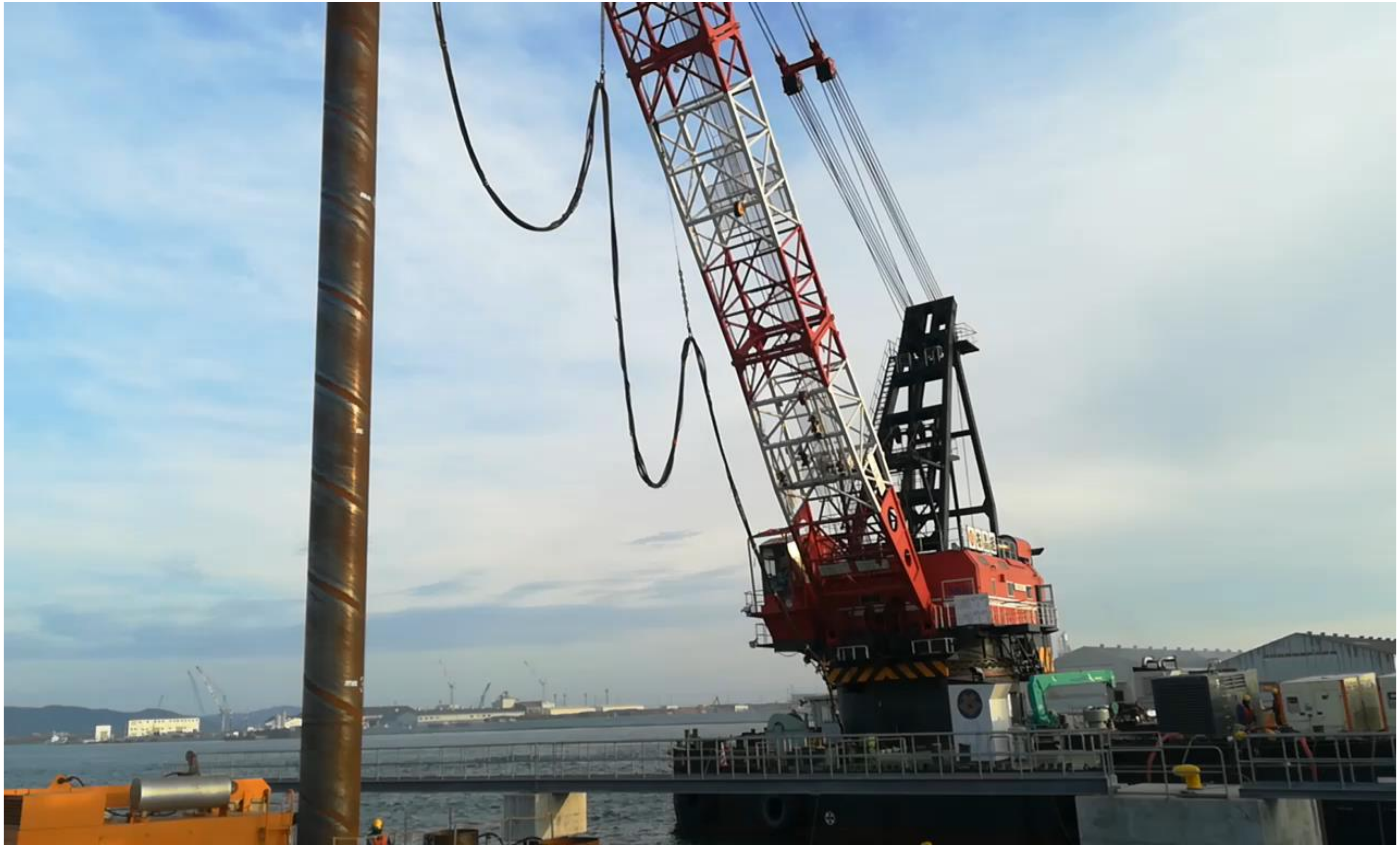
-Approx. 1.0m land subsidence as consequence of 2011 earthquake

-Design considerations are dominated by tsunami hazard in the area

-Earthquake countermeasures are very important (and costly).

-4,000 USD to elevate 1m^2 of port by one metre

Ishinomaki Port Raising of Port Levels (II)



Barriers to Adaptation

-No technological limits, though re-design would be necessary to adapt the design (new piles?) if going above an extra 1m of raise. Raixing ground by another half a metre would be maybe x10 more expensive, and a further metre could be x100 more expensive (earthquake measures)

-No cost-benefit assessments were conducted, but government would ultimately spend the money. However, over 4m would be make no sense from cost-benefit point of view.

-After 4.0m local residents might be happier to retreat

Sea Level Rise	Technological Limits	Cost-Benefit Limits	Financial Barriers	Social Conflict Barriers
+ 0.5m				
+ 0.51 - **1.0m**				
+ 1.01 - **2.0m**				
+ 2.01 - **4.0m**				
+ 4.01 - **8.0m**				

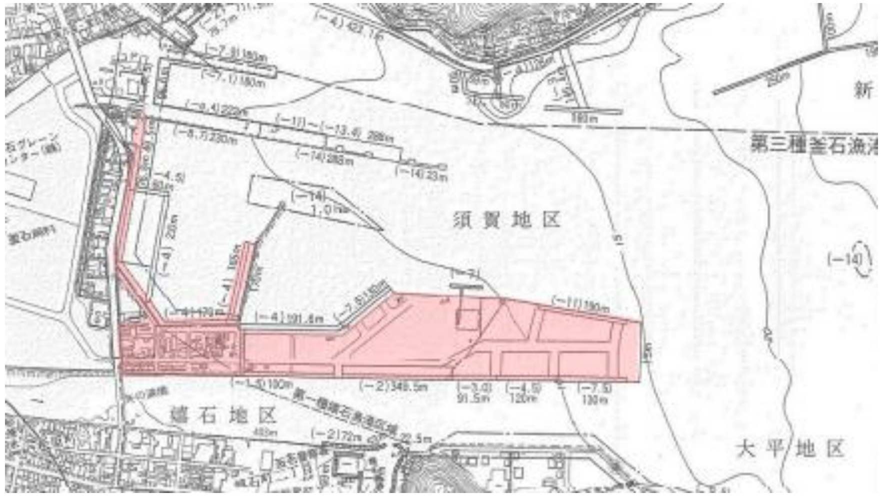
Kamaishi Port (I)

-Industrial port

-Approx. 1.0m land subsidence as consequence of 2011 earthquake

-Design considerations are dominated by tsunami hazard in the area

-360 USD to elevate 1m^2 of port by one metre (looks like unit rates only)



Summary of costs so far?

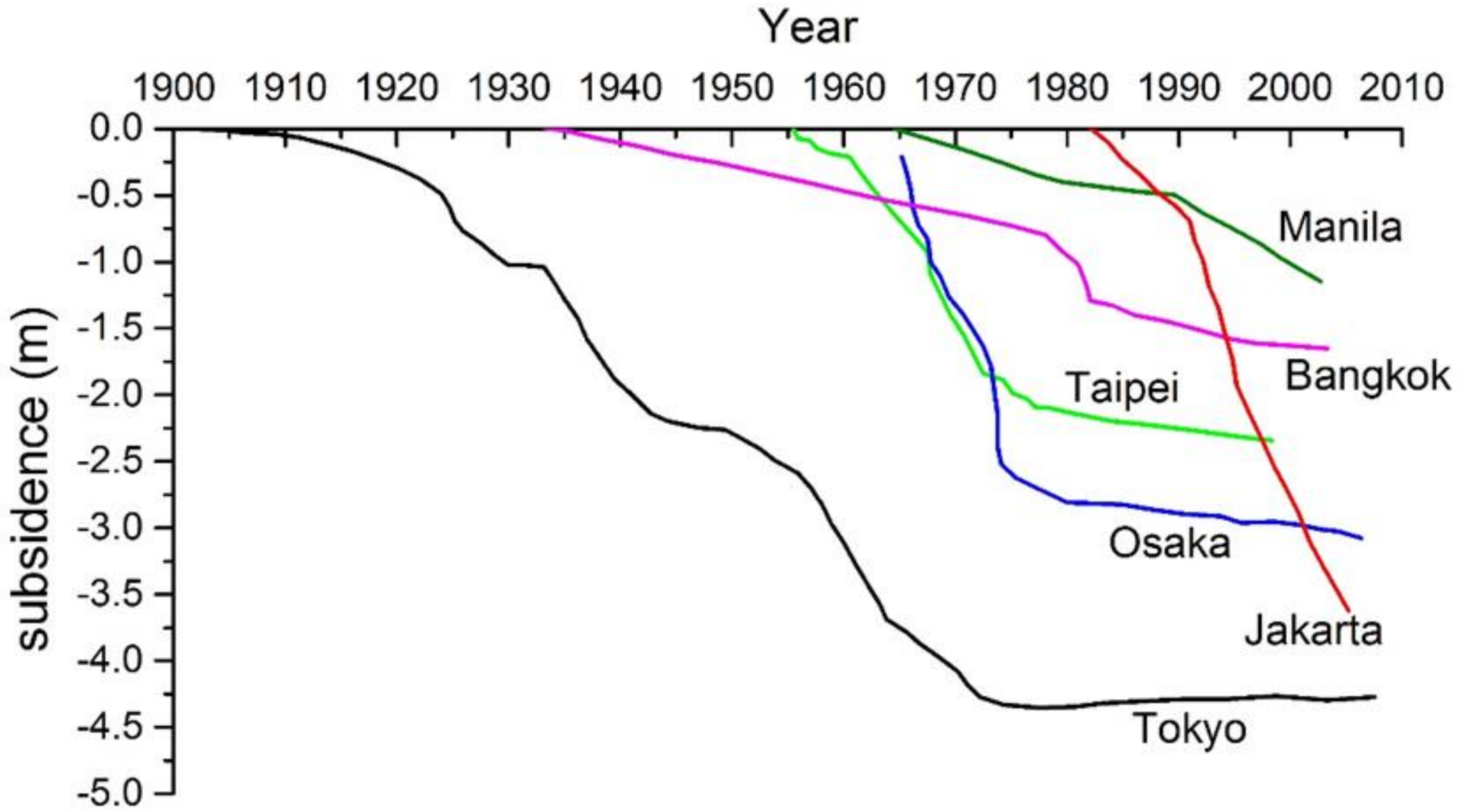
-Seems there is some disparity in costs

- Developing vs developed country
- Earthquake countermeasures
- Cost of materials to raise, vs inclusion of piling etc

Source	Cost/m^2 for 1 m raise	Notes
Kamaishi Port	360 USD	Does it include piling?
Ministry of Land, Infrastructure, Transport and Tourism	80 USD	Unit rates only. Hoshino et al. (2013)
Ishinomaki Port	4000 USD	Includes piling (for next 1m cost would be x 10!)
Sunda Kelapa	100 USD (+4000 USD/m run)	4000 USD/m run for piling, 100 USD/m^2 for ground elevation

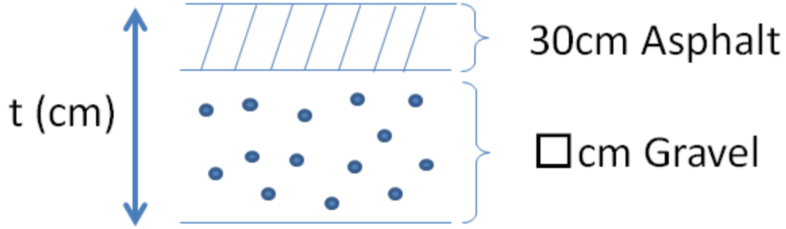
Cost of adaptation to Tokyo

Reason: Groundwater Extraction (currently ~0.1-0.2 m* subsidence/year)



***No, this is not a typo, it really is 20cm per year!**

The Cost to Port Areas: Raising the ground level outside the levees



Unit cost Ministry of Land, Infrastructure, Transport and Tourism (2008)

Asphalt (30cm height)	**5,194 yen/m²**
Gravel (30cm height)	**296 yen/m²**

	Tokyo	Kawasaki	Yokohama
Area	11.9 km²	17.6 km²	8.5 km²
Height (T.P.)	4.5 m	4.0 m	3.9 m
Cost (Unit: bn yen)	19.5	67.7	34.5

Discussion regarding costs

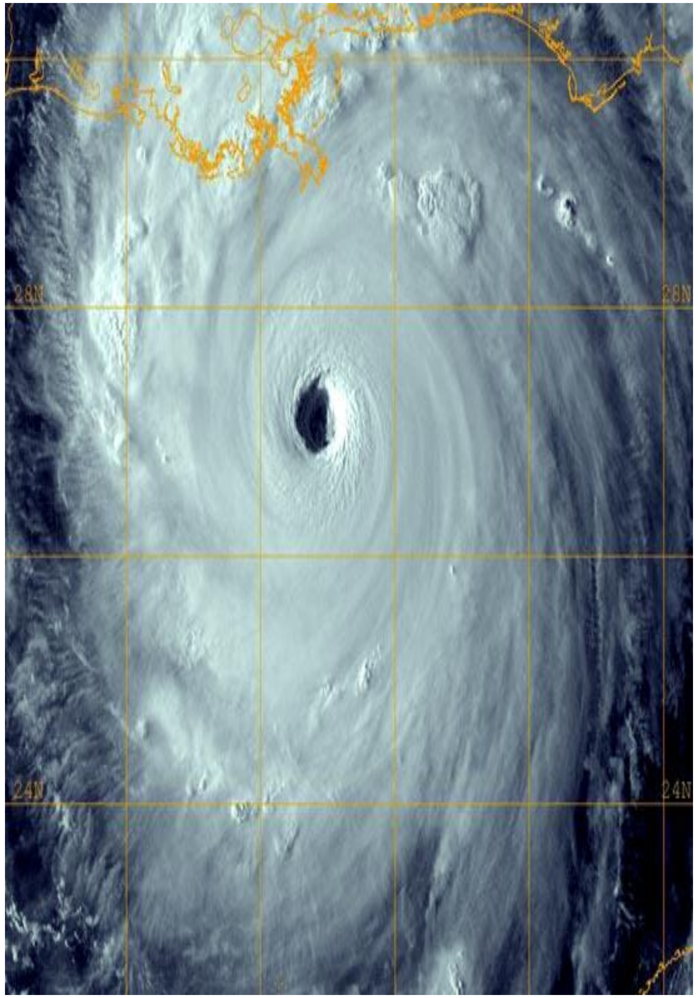
		Elevating Port Areas (Unit: 億円 i.e. 100,000,000 yen)
Tokyo	Tokyo port	195.11
Kanagawa	Kawasaki port	677.97
	Yokohama port	345.24

	Cost: 億円	% Tokyo GDP
Tokyo	195	0.01%
Kanagawa	1023	0.062

- Nominal GDP Tokyo= 165 trillion yen
- Total Damage worst case scenario = 80 trillion yen (48% GDP)
- Total cost of all adaptation= 0.389 trillion yen (0.2% GDP)

Port Downtime

Port Downtime

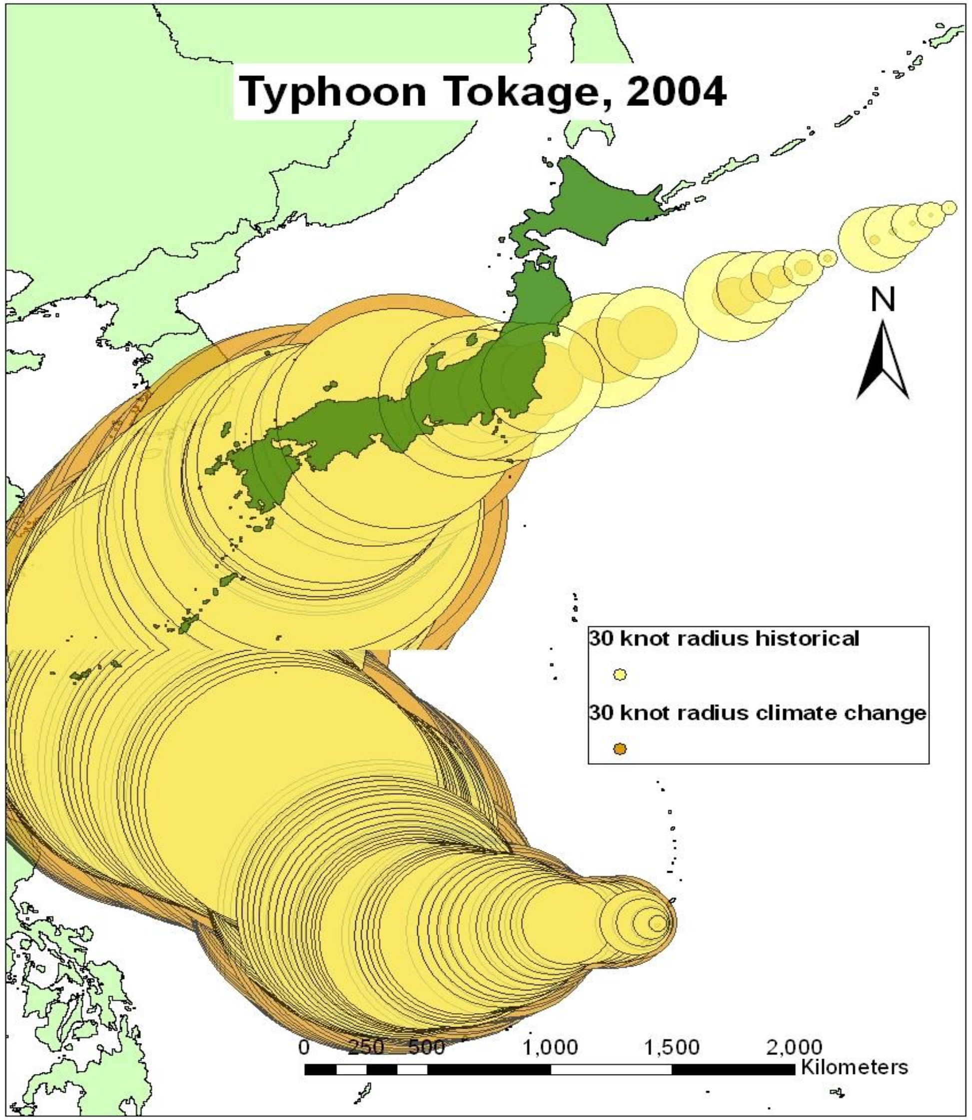


- **Ports have to close when wind speed is too high, as it interferes with crane operations, etc**

- **Assumed that knots port operation will stop when wind speed is over 30 knots**

- **Note that while it might be possible to work a bit longer, there is also the issue of preparations for typhoon, etc.**

Increase in Port Downtime (I)

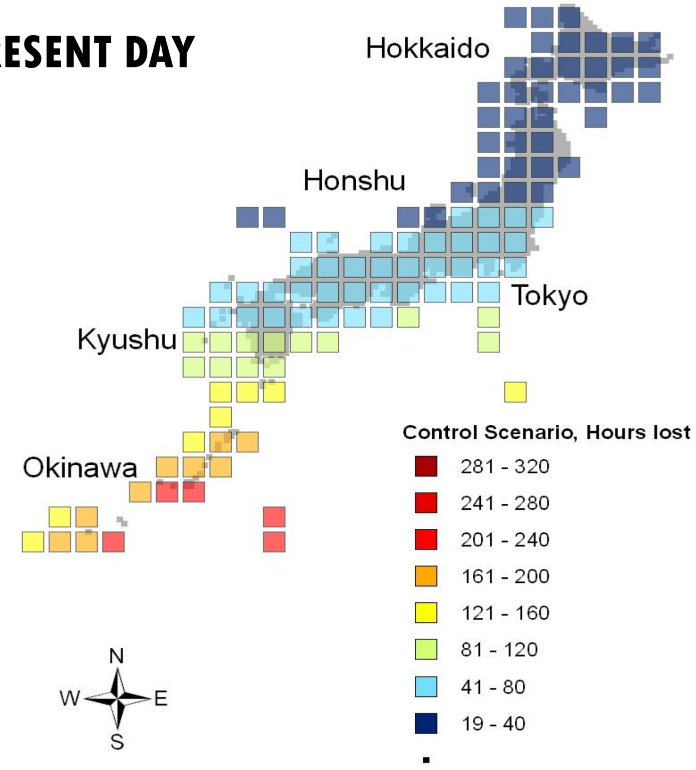


- **If typhoons get stronger, they also get bigger**
- **We assumed that ports have to stop operating when <u>winds re higher than 30 knots</u>**
- **Carried out a Monte Carlo simulation of how many hours a port is likely to stay closed in future**

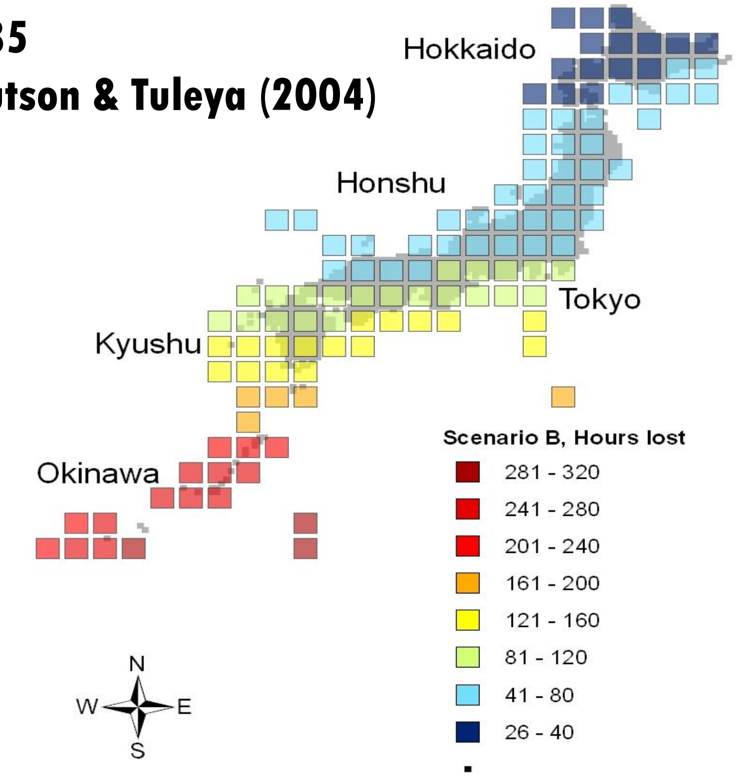
Increase in Port Downtime (II)

- **All Japan will be affected by 30 knot winds for longer periods in 2085**

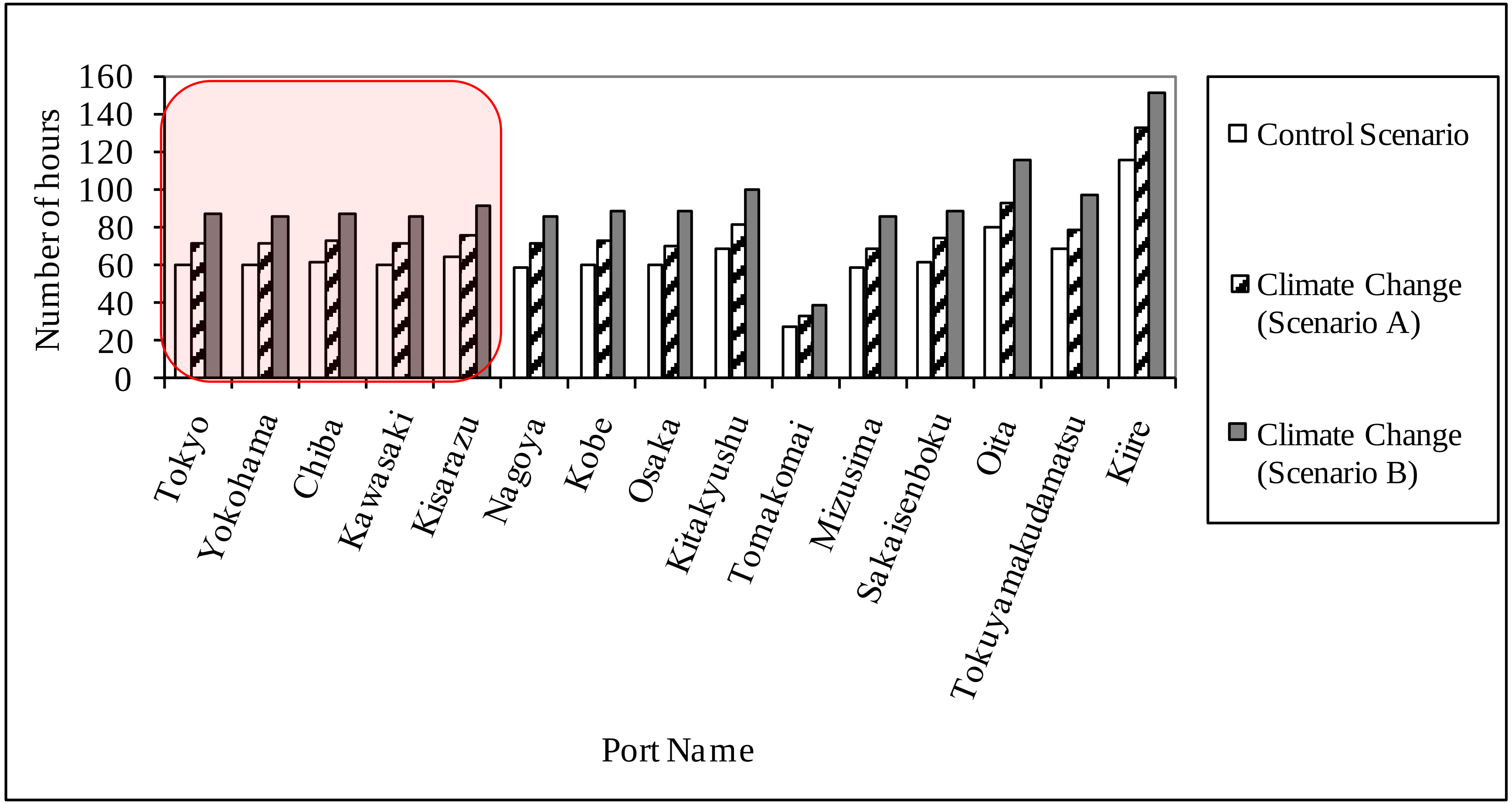
PRESENT DAY



2085
Knutson & Tuleya (2004)

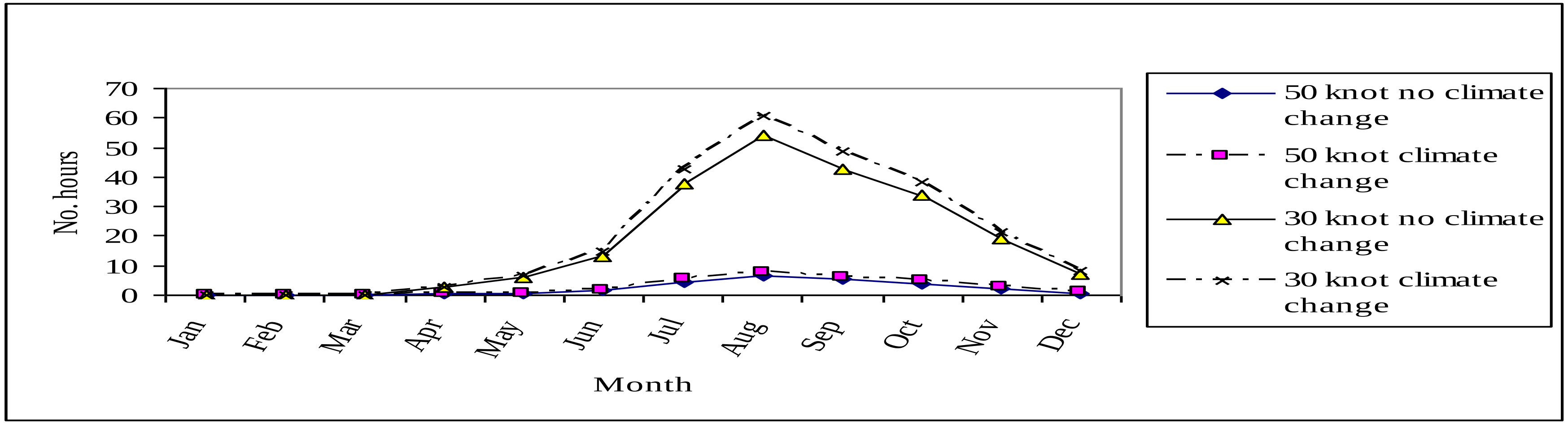


Increase in Port Downtime (III)

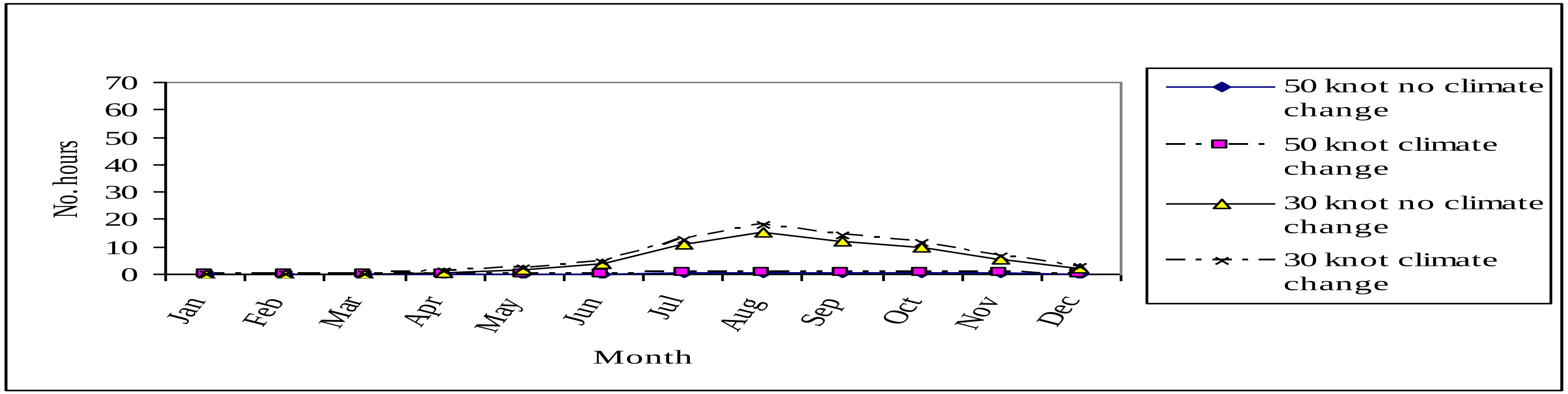


Expected hours that selected Japanese ports are affected by 30 knot winds for the control and climate change scenarios.

Increase in Port Downtime (IV)



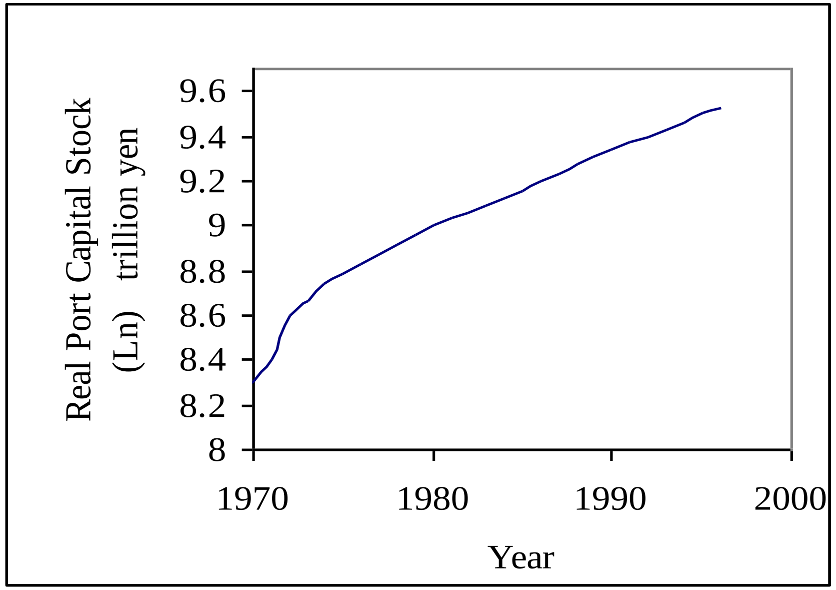
Expected hours that the **Port of Naha** will be affected by various winds for the control and climate change events for each month of the year. (Scenario A)



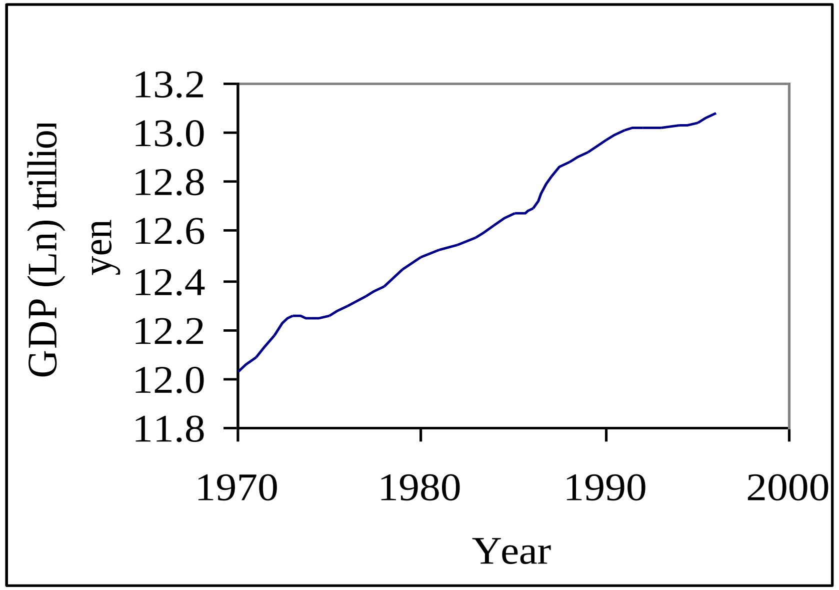
Expected hours that the **Port of Yokohama** will be affected by various winds for the control and climate change events for each month of the year. (Scenario A)

Relation between GDP and RPCS

- **Direct correlation between the natural logarithm of the Real Port Capital Stock (*RPCS*) and the growth in Japanese GDP (Kawakami and Doi 2004).**



Growth in *RPCS* in Japan, 1990 Prices in trillion yen (Ln)



Growth in GDP in Japan, 1990 Prices in trillion yen (Ln)

Extra required *RPCS* due to climate change (I)

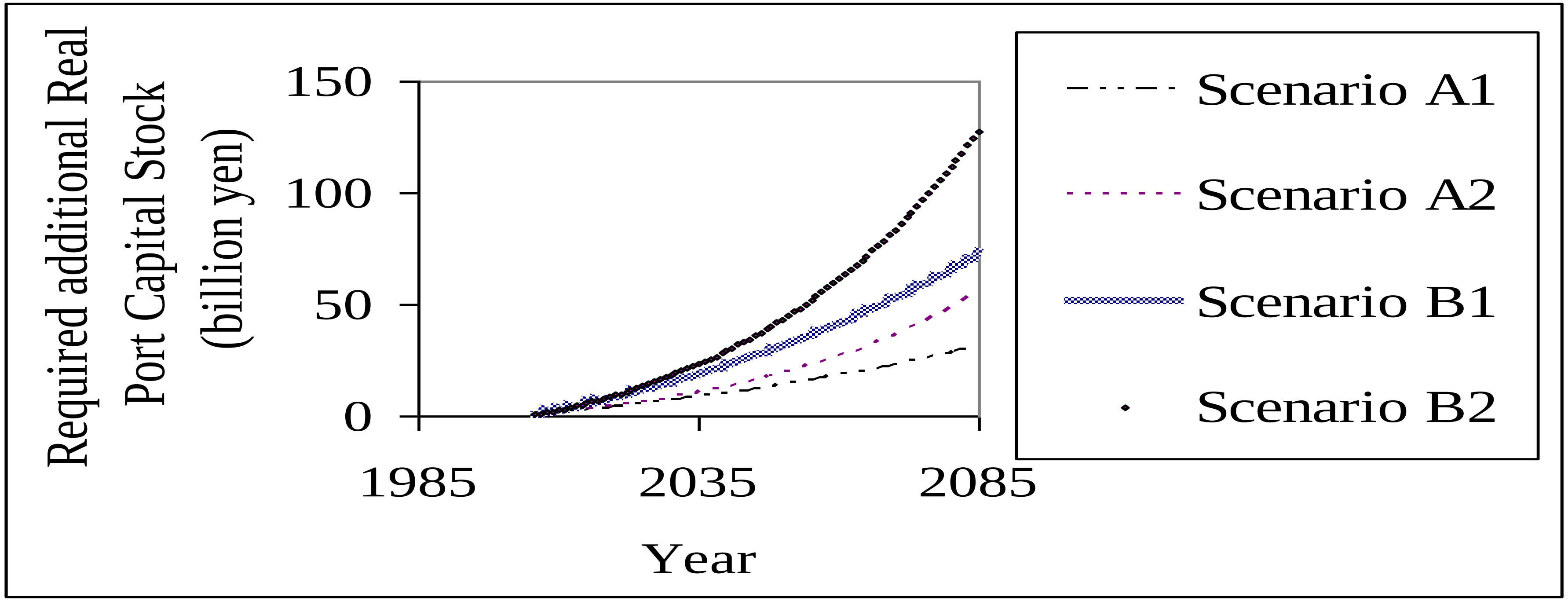
- **If port downtime increases, then port capacities must also be higher to deal with the bottlenecks created by this**

- **Using the relationships in the previous slide calculated what would be the extra investment needed**

- **i.e. ports will need to be bigger in the future to deal with increased uncertainty**

Extra required *RPCS* due to climate change (II)

- **4 Scenarios, depending on rate of economic growth (1 or 2%) and the relationship between maximum wind speed and typhoon area**
- **30.6 and 127.9 billion additional Yen required to be invested by the year 2085**
- **Failure to spend this money could reduce GDP by between 1.5 and 3.4% by 2085.**



Conclusions

- Stronger tropical cyclones and sea level rise could lead to the inundation of many port areas
- These port areas should be elevated in the future to cope with these effects
- Breakwaters and other infrastructure should also be strenghthened
- Stronger tropical cyclones will also lead to increased downtime and bottlenecks in supply systems, unless extra port capacity is added
- Otherwise, loses could be substantial, not only for ports but major population centres around them

Global Supply Chain Forum
Barbados 21–24 May 2024

Thank you for your attention

Plus just in case here goes my email:

esteban.fagan@gmail.com

UNITED NATIONS
UNCTAD