Ad Hoc Expert Meeting on

Climate Change Impacts and Adaptation: A Challenge for Global Ports

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Climate Change and its Effects on Ports: Increase in Downtime and Infrastructure Requirements

Presentation by

Prof. Miguel Esteban
Assistant Professor
Waseda University, Tokyo

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“Climate Change and its Effects on Ports: Increase in Downtime and Infrastructure Requirements”

Miguel Esteban

Assistant Professor, Waseda University (Japan)

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Acknowledgments

- The work presented today is a summary of work done in collaboration with other people: Hiroshi Takagi, Tomoya Shibayama, Sayaka Hoshino, Christian Webersik, amongst others

- I got good feedback at the Coastal Structures Conference a few weeks ago (V. Tsimopoulou, J. R. Headland, W. Allsop, I. Losada, etc)

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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

My Objective Today (I)

- I want to introduce what I see are the **major challenges** facing the 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

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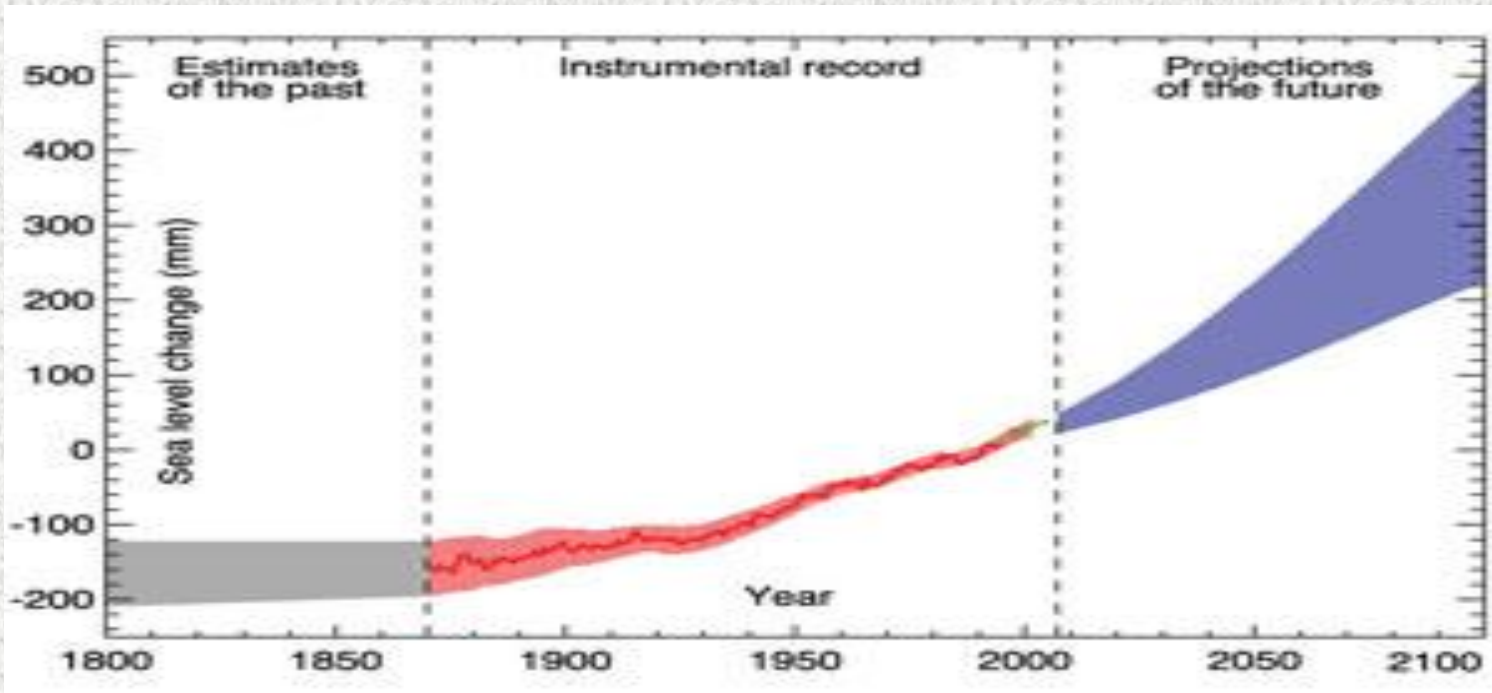
My Objective Today (II)

- <u>I have been asked to leave the differential equations out</u>
- Today I will present **ONLY** results and some thoughts
- If you want to read the methodologies, etc, please refer to the papers in the handout
  - Note that these are by me, my student, and some other researchers.

Sea Level Rise and Port Levels

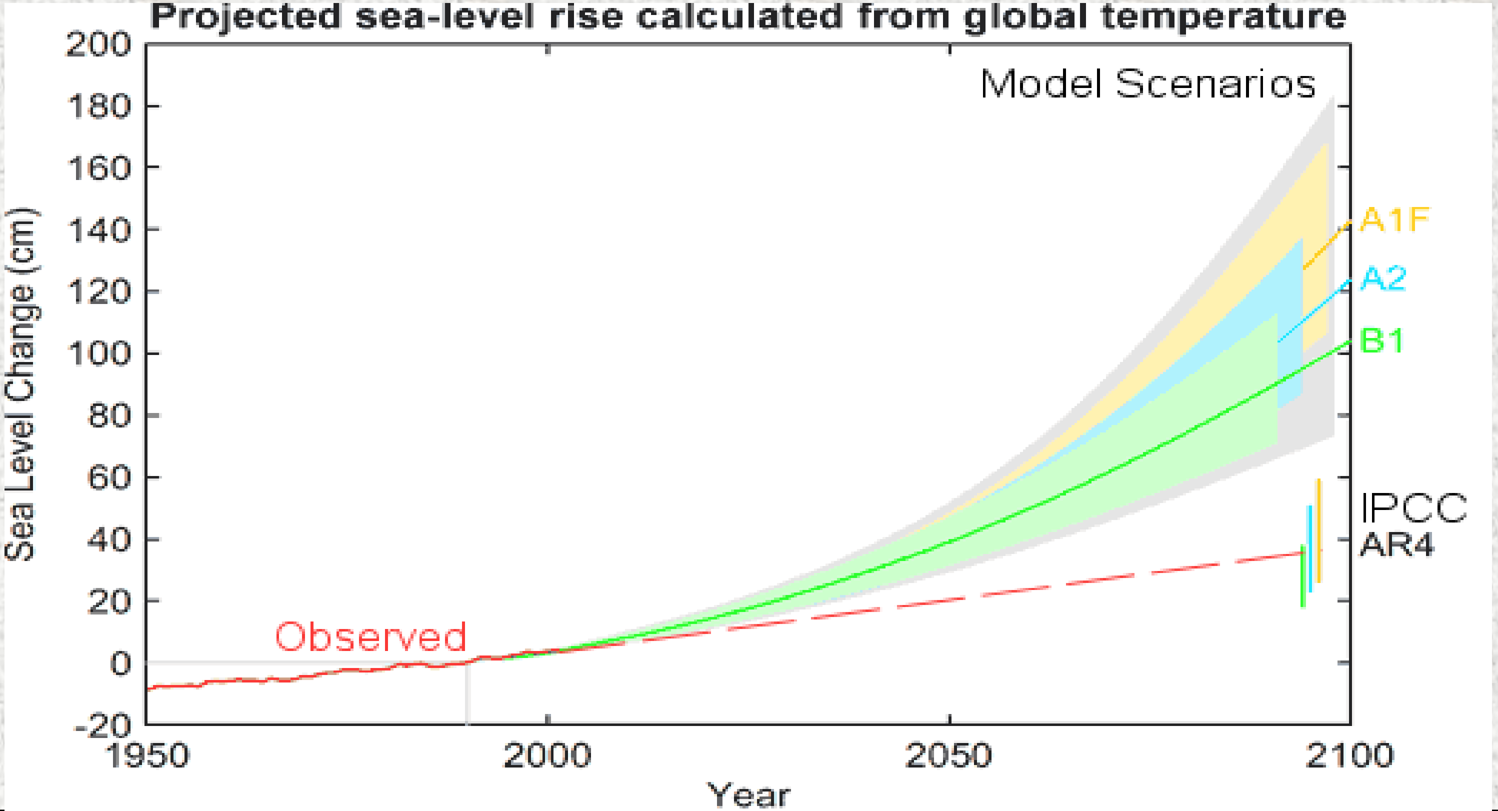
The Science Behind Sea Level Rise

- **IPCC projections show that by the end of the 21st century sea level could be between 0.18 and 0.59m higher than at present**



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**



Climate Change, Changing Weather and Waves

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Current Philosophy Behind Breakwater Construction

Traditional breakwater design assumes that:

- **Sea level does not change**
- **Future weather patterns will be the same as historical weather (i.e. by studying past weather we can obtain future return periods for a given design wave height)**

It appears that both of these assumptions might be incorrect in the future

Note: some people nowadays have realized this, others have not!!! Particularly in the Netherlands they seem fairly advanced, in other places not so much…

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Changing Weather Patterns

- **Tropical cyclones are amongst the most dangerous weather systems for breakwaters**

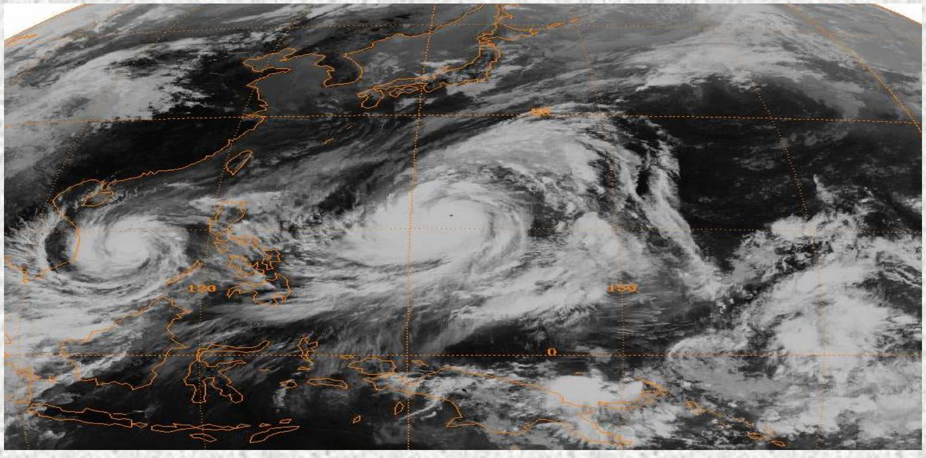
- **One of the fears of global warming is that it could result in an increase in the frequency and intensity of tropical cyclones due to the warming of sea temperature (Knutson et al., 2010)**

Knowledge about future and typhoons (I)

- **IPCC States that there is a general agreement that tropical cyclones are likely to increase in intensity, there is yet no consensus on the future frequency of these events.**

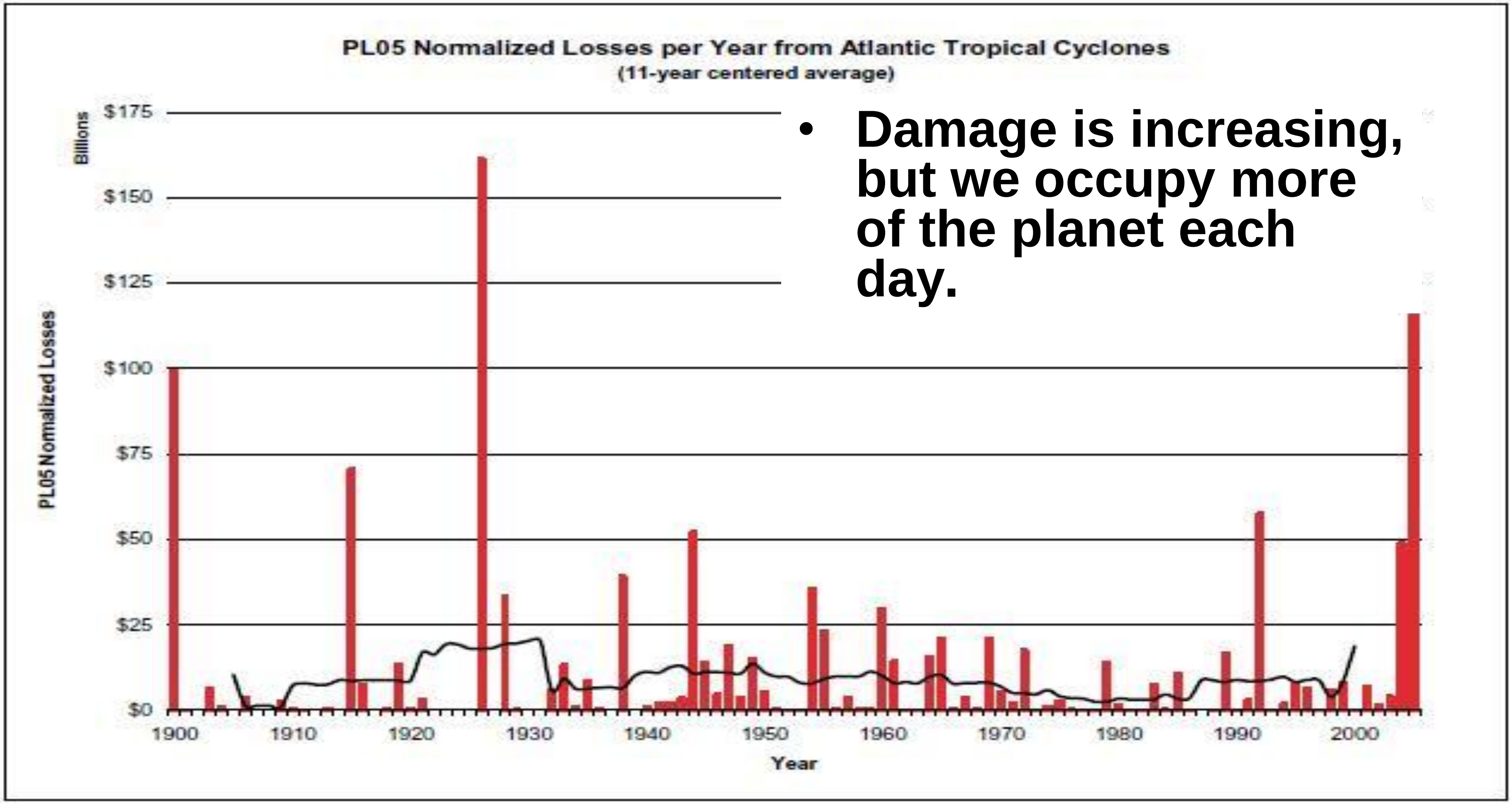
- **Typhoons are believed to have a 30-40 year cycle**

- **Strongest typhoons in Western Pacific history**
- Tip 870 mbar 1979
- Gary 872 mbar 1992
- Ivan 872 mbar 1997
- Joan 872 mbar 1997
- Keith 872 mbar 1997
- Zeb 872 mbar 1998
- June 875 mbar 1975
- Ida 877 mbar 1958
- Nora 877 mbar 1973
- Rita 878 mbar 1978
- Yvette 878 mbar 1992
- Damrey 878 mbar 2000



- **CANNOT SAY ANY EVENT UP TO NOW HAS BEEN INFLUENCED BY CLIMATE CHANGE**

Knowledge about future and typhoons (II)

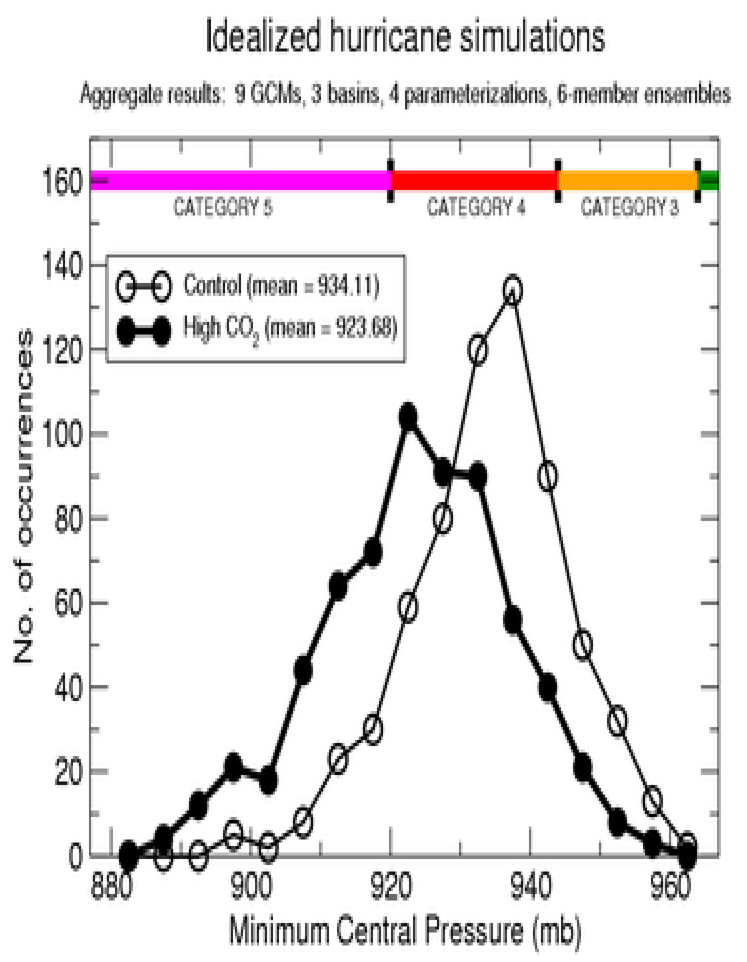


- **Damage is increasing, but we occupy more of the planet each day.**

- **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"**



Changing Weather and Waves

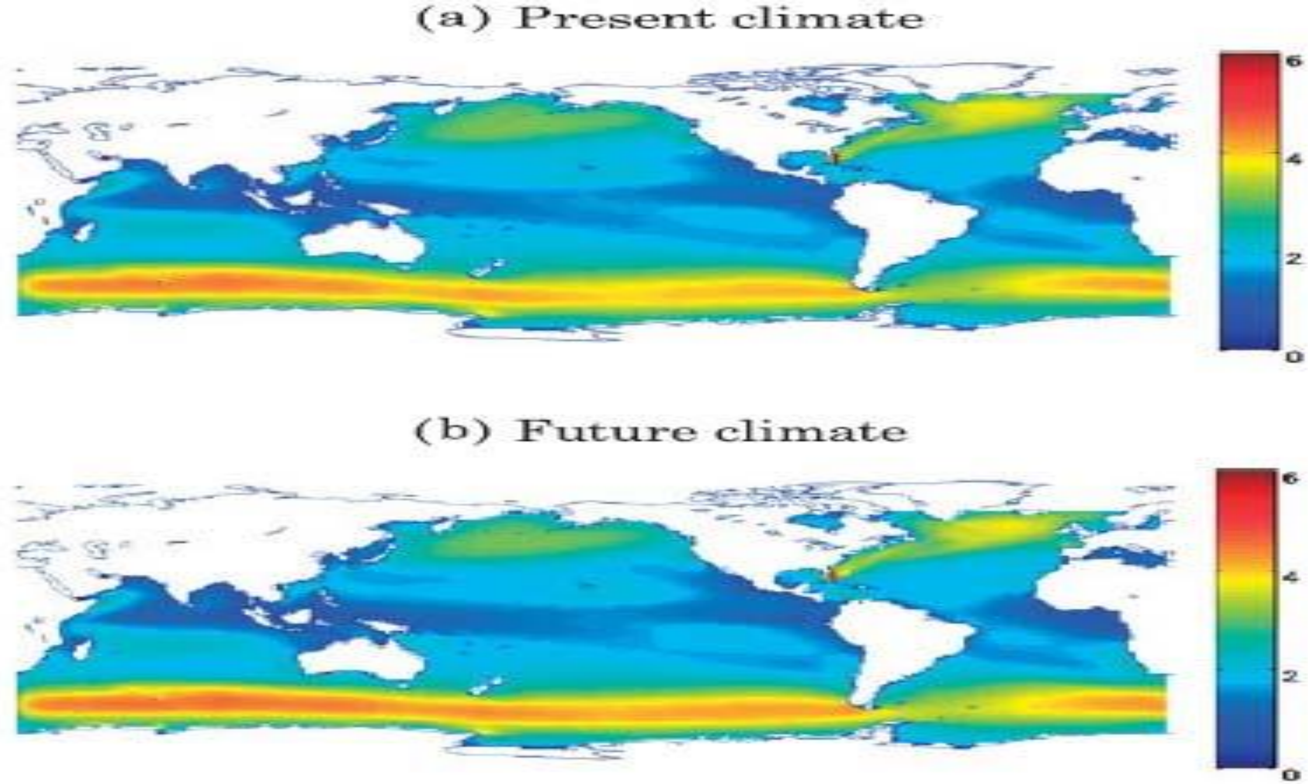


Figure 2. Period averaged $\overline{H}_s$

- **Mori, Yasuda, Mase et al. (2010) analysed the annual averaged and extreme sea surface winds and waves throughout the world as a consequence of climate change**

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Changing Weather and Waves

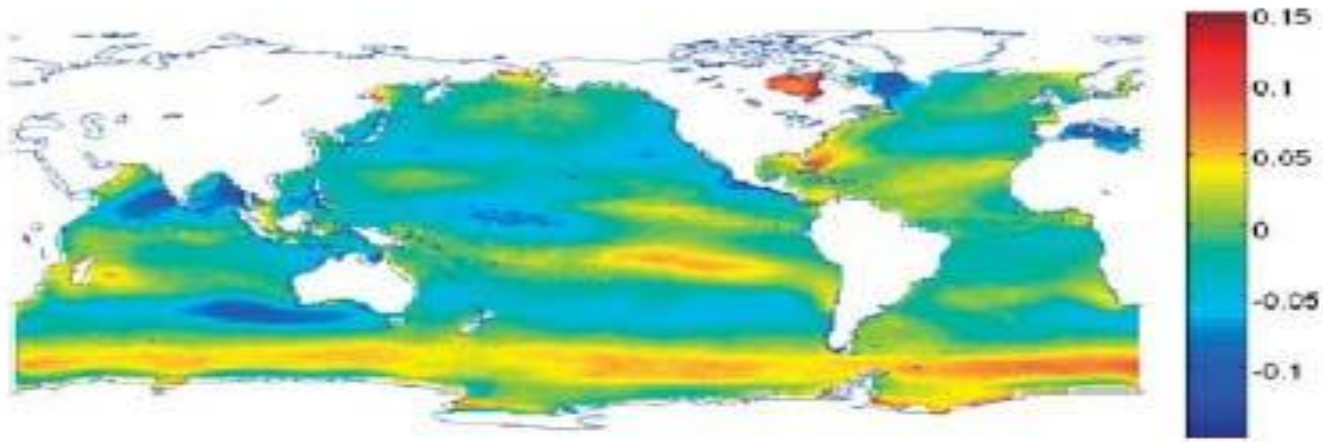


Figure 3. Difference of $\overline{H}_s$ between future minus present climate normalized by present climate

- **Clear regional dependences of both annual average and also extreme wave height changes from present to future climates**

- **Wave heights in the future will increase at both middle latitudes and also in the Antarctic Ocean, with a decrease at the equator.**

Implications for Breakwater Construction

Can Breakwaters in the Future be Designed in the Same Way?

- **Currently we use the significant wave height (*H_s*) as the main design parameter.**
- **However to obtain the design *H_s* we use historical data**
- **But in the future the weather will change!!!**
- **So, can we use computers to predict what will *H_s* be like in the future?**

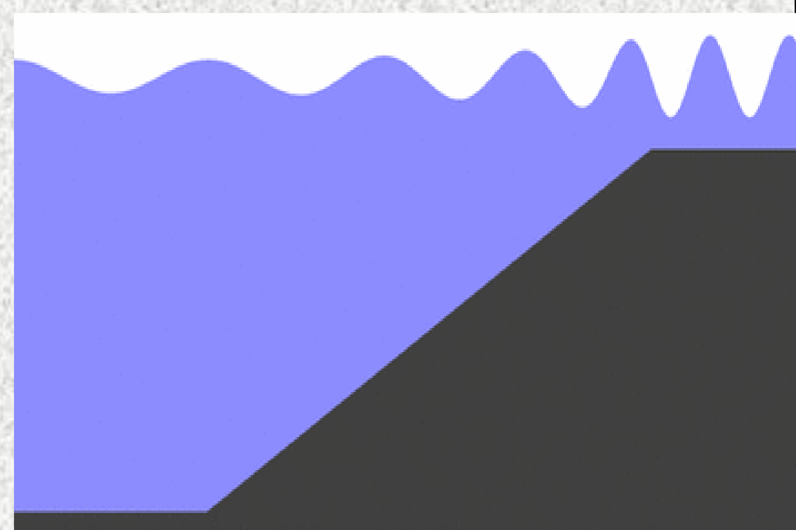
The Use of Computers to Predict Climate Change

Wave Uncertainty

- Changes in wind patterns
- Changes in tropical cyclone patterns

- Wave breaking is key concept for breakwater design!!. This depends in water depth
- If water depth increases (sea level rise), pattern of breaking will change.

- This can make many breakwaters vulnerable!!!



Design According to Limiting Breaker Height (H_b)

- **Uncertainty about what the future H_s should be**

- **Limiting Breaker Height (H_b) gives us the maximum wave that is possible at a structure for a given water depth (i.e. H_b will take the place of H_s)**

- **Goda (1985)**

$$H_b = 0.17 L_0 \left\{1 - exp\left[-1.5 \frac{\pi h}{L_0}\left(1 + 15 tan^{4/3} \alpha\right)\right]\right\}$$

in which h is the water depth at the breakwater, L_0 is the deep water wave length and α is the slope of the sea bottom.

Implications For Breakwater Cost

- **In the next few slides the implications of climate change on the cost of rubble mound breakwaters will be outlined**

- **Note: Designing with H_b is more expensive!!!**

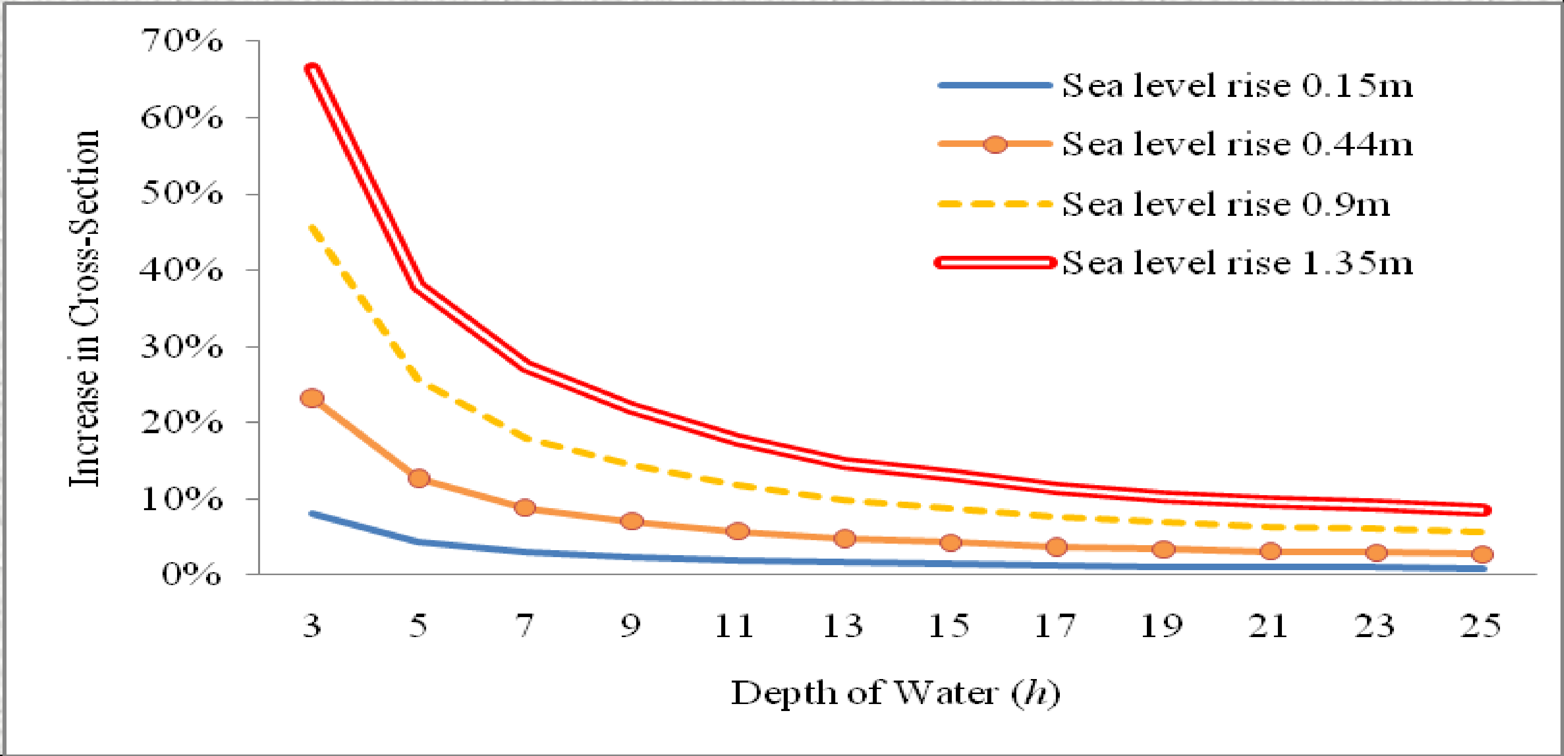
- **Methodology**
  - **Use the Limiting Breakwater Height as the Design Wave**
  - **Use Van der Meer (1987) for armour design**
  - **Use Van der Meer (1993) for run-up**
  - **Take into account various sea-level rise scenarios**

Average Total Increase in Cost

- **Important to know what is the total final increase in cost of the breakwater**
- **In order to give non-coastal engineers a feel of the magnitude of the problem the average increase in cross-sectional of all the sections at a given depth of water is calculated**
- **NOTE: This is to provide a FEEL of the magnitude of the problem (did not include actual cost)**

Average Total Increase in Cross-Sectional Area

- **Effect is quite important for shallow breakwaters, though of course deeper breakwaters are much more expensive so financially has a bigger impact**



Yes, but is it worth over-designing now a breakwater?

- **Typically breakwaters are designed with 30 or 50 years design lives**
- **However generally people expect that they might have to repair them**
- **It might be cheaper to use current methods and then reinforce in future, depending on what discount rate you are using (Headland, 2011)**

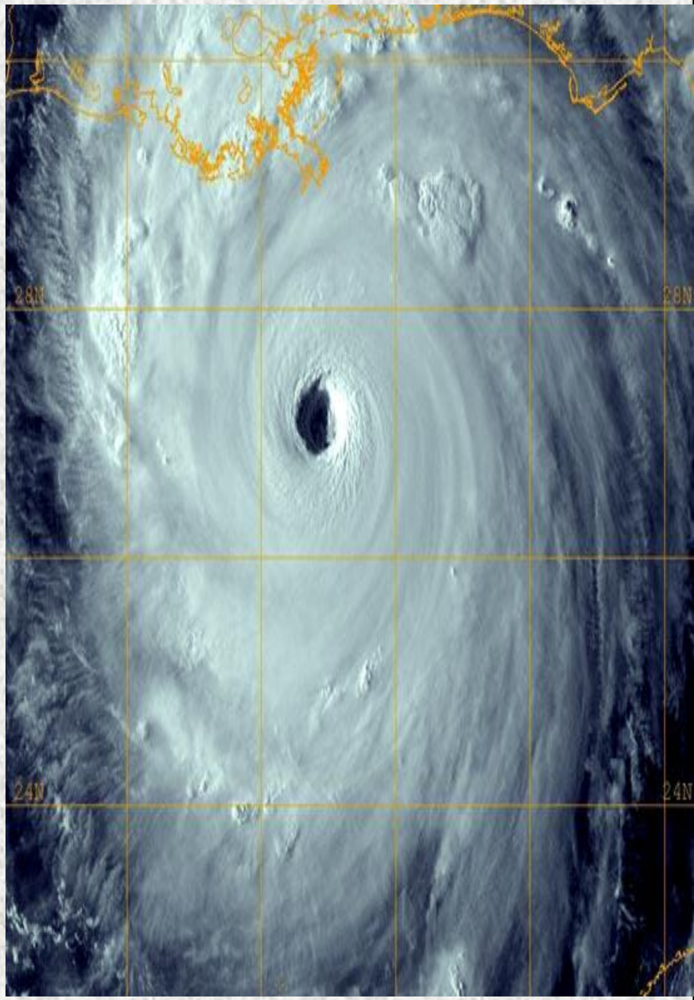
Port Downtime

Port Downtime

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

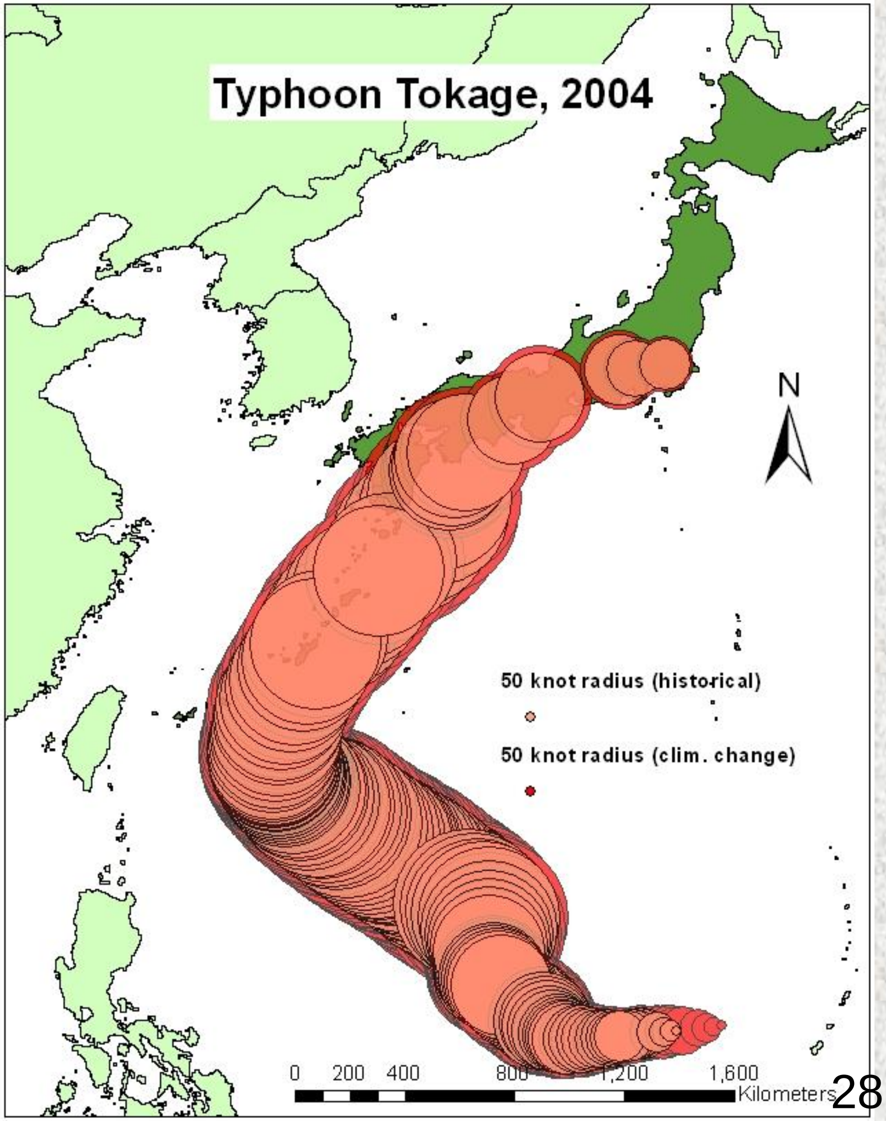
- **Assumed that knots port operation will stop when wind speed is over 30 knots**

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



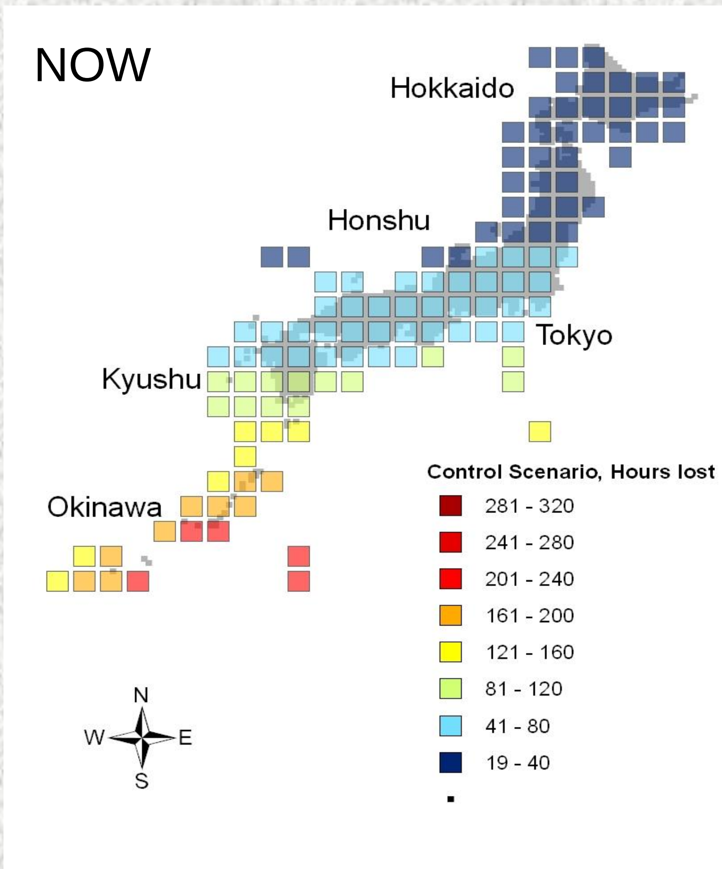
Increase in Port Downtime (I)

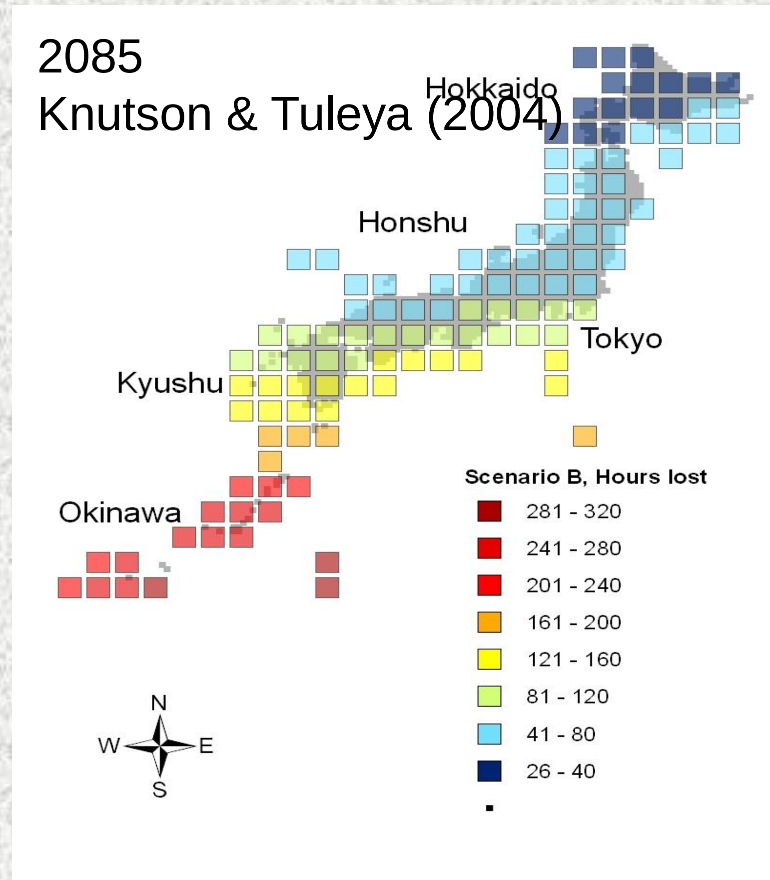
- **If typhoons get stronger, they also get bigger**
- **Carried out a Monte Carlo simulation of how many hours a port is likely to stay closed due to <u>winds higher than 30 knots</u>**



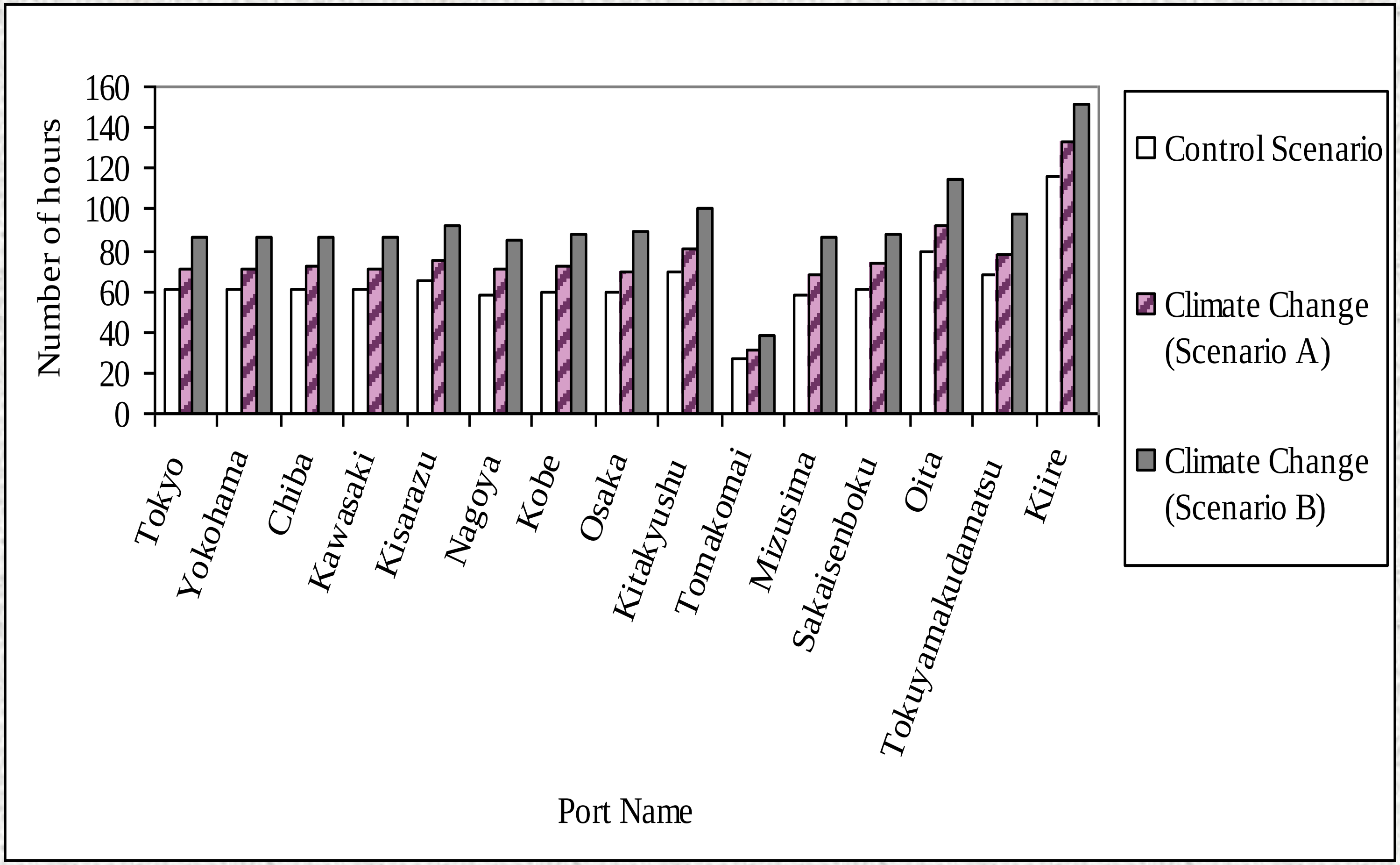
Increase in Port Downtime (II)

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



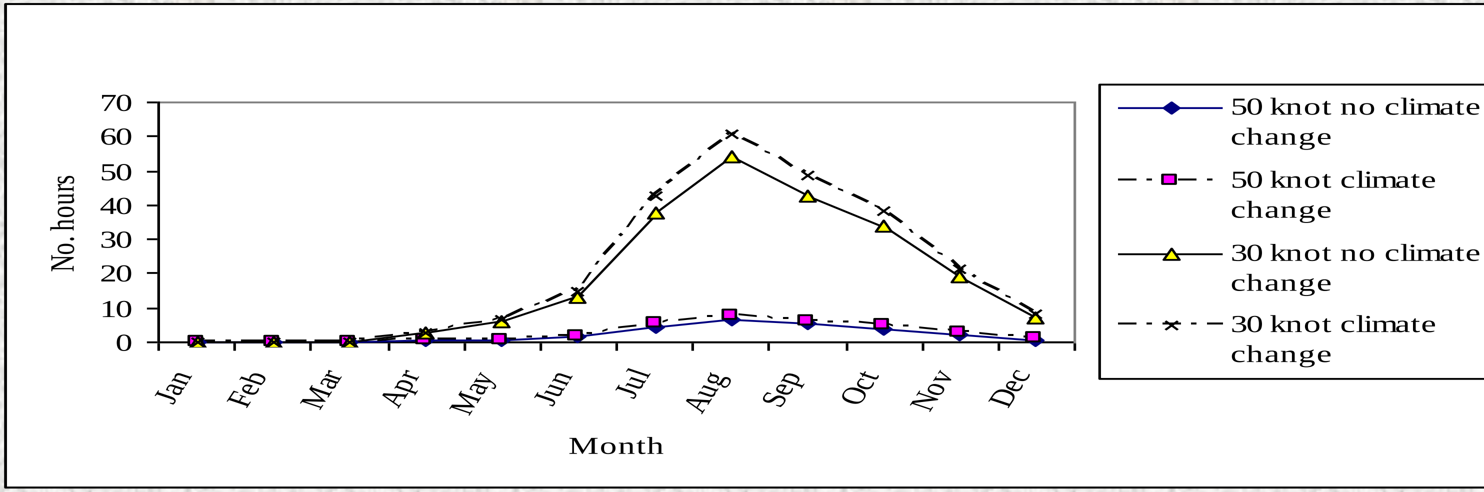


Increase in Port Downtime (III)

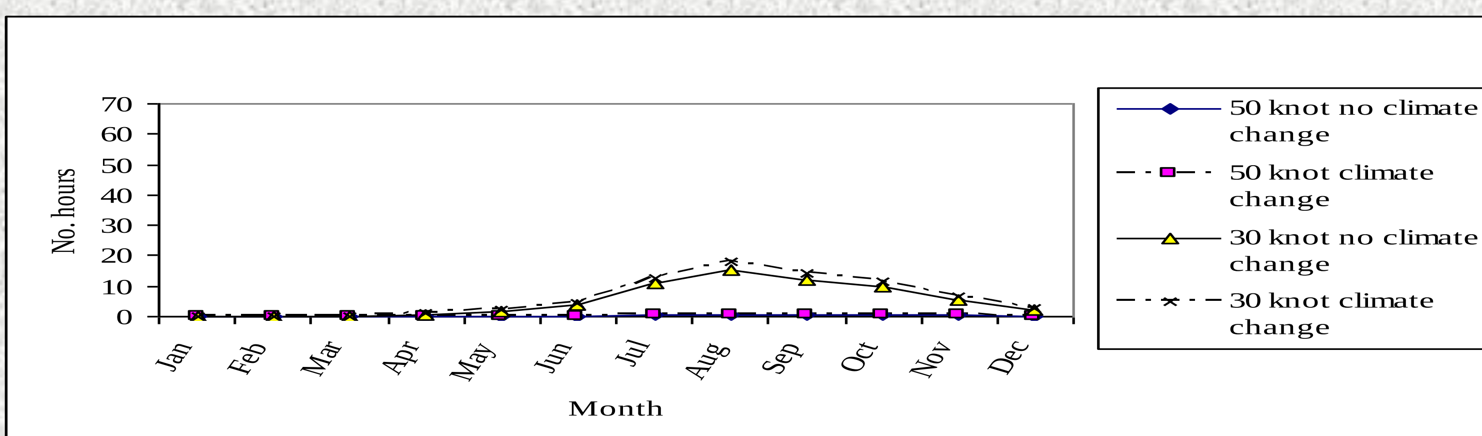


Expected hours that selected Japanese ports are affected by 30 knot winds for the control and climate change scenarios.

Increase in Port Downtime (IV)



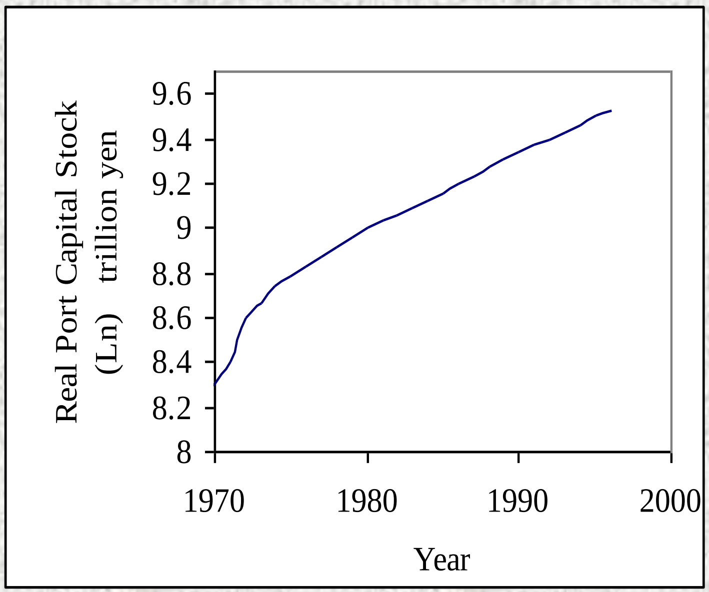
Expected hours that the Port of Naha will be affected by various winds for the control and climate change events for each month of the year. (Scenario A)



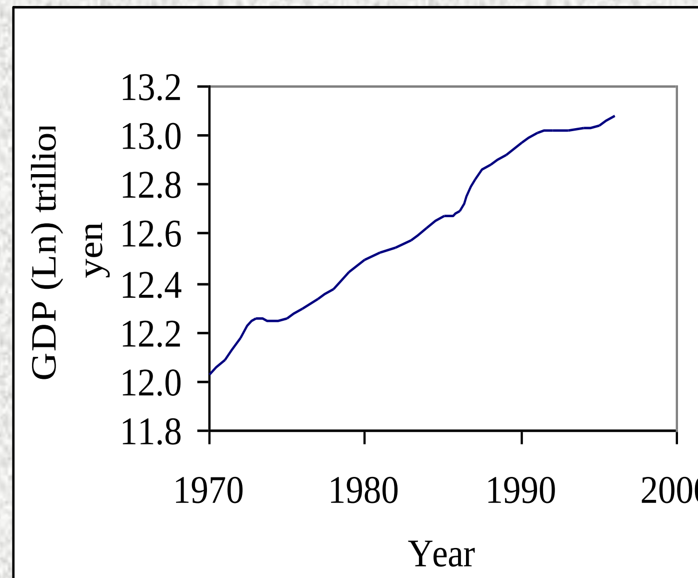
Expected hours that the Port of Yokohama will be affected by various winds for the control and climate change events for each month of the year. (Scenario A)

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)



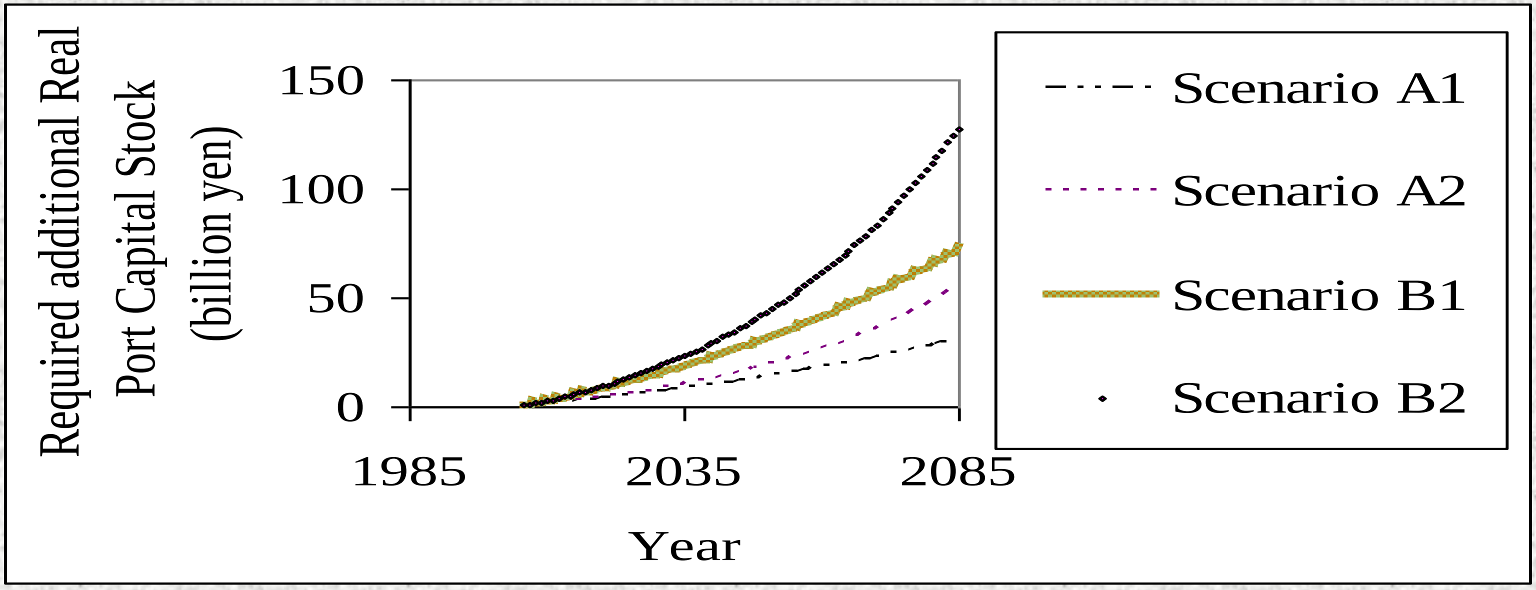
Growth in GDP in Japan, 1990 Prices in trillion yen (Ln)

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.



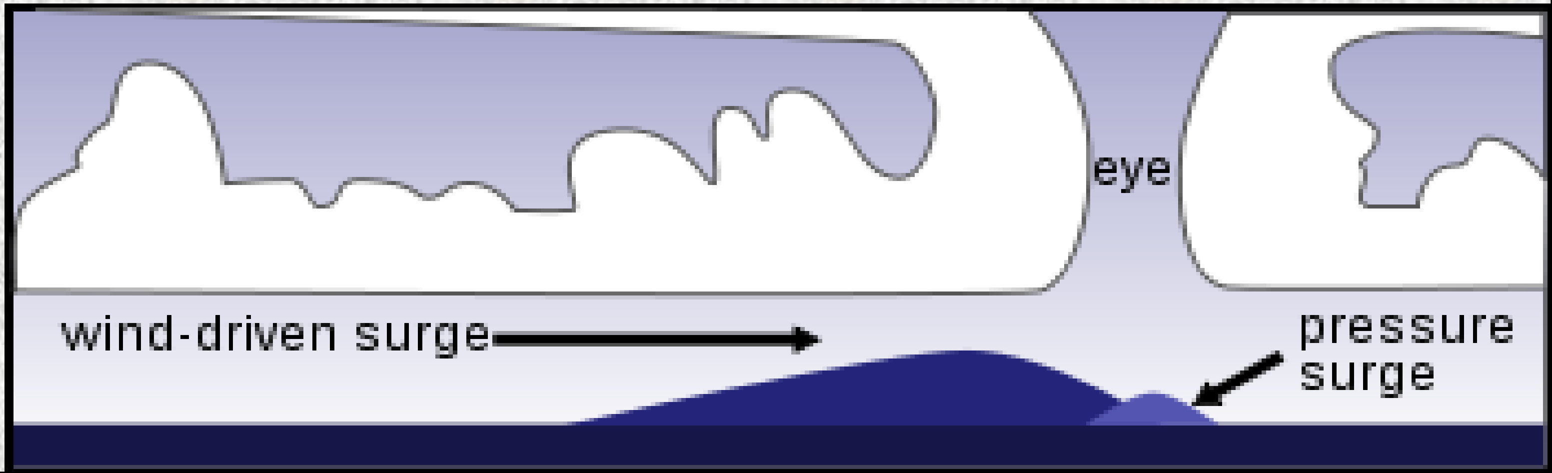
Port Flooding due to Storm Surges

Increased flooding due to Storm Surges

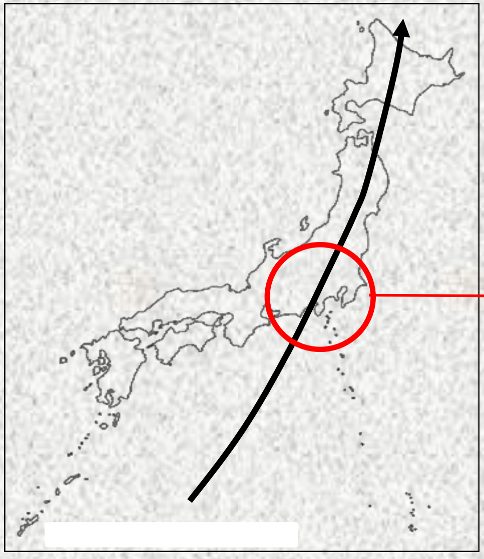
- Storm Surge: During the passage of a tropical cyclone sea level goes up due to the drop in atmospheric pressure and wind forcing

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

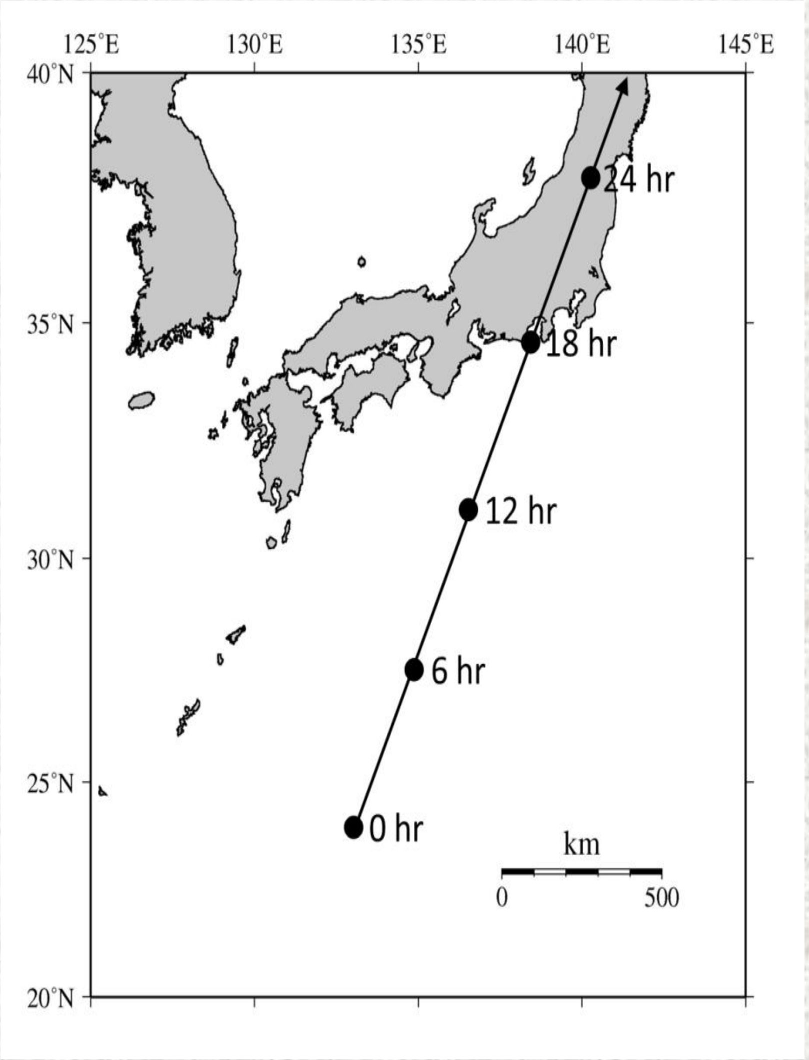
- This effect could increase in the future, and combined with sea level rise could exacerbate flooding potential



Taisho 6th year (1917) typhoon Typhoon Course



Recorded course
(Ministry of transport, 2000)



The lowest pressure of the typhoon was said to be 952.7hPa according to Miyazaki (2003)

Coastal Defences

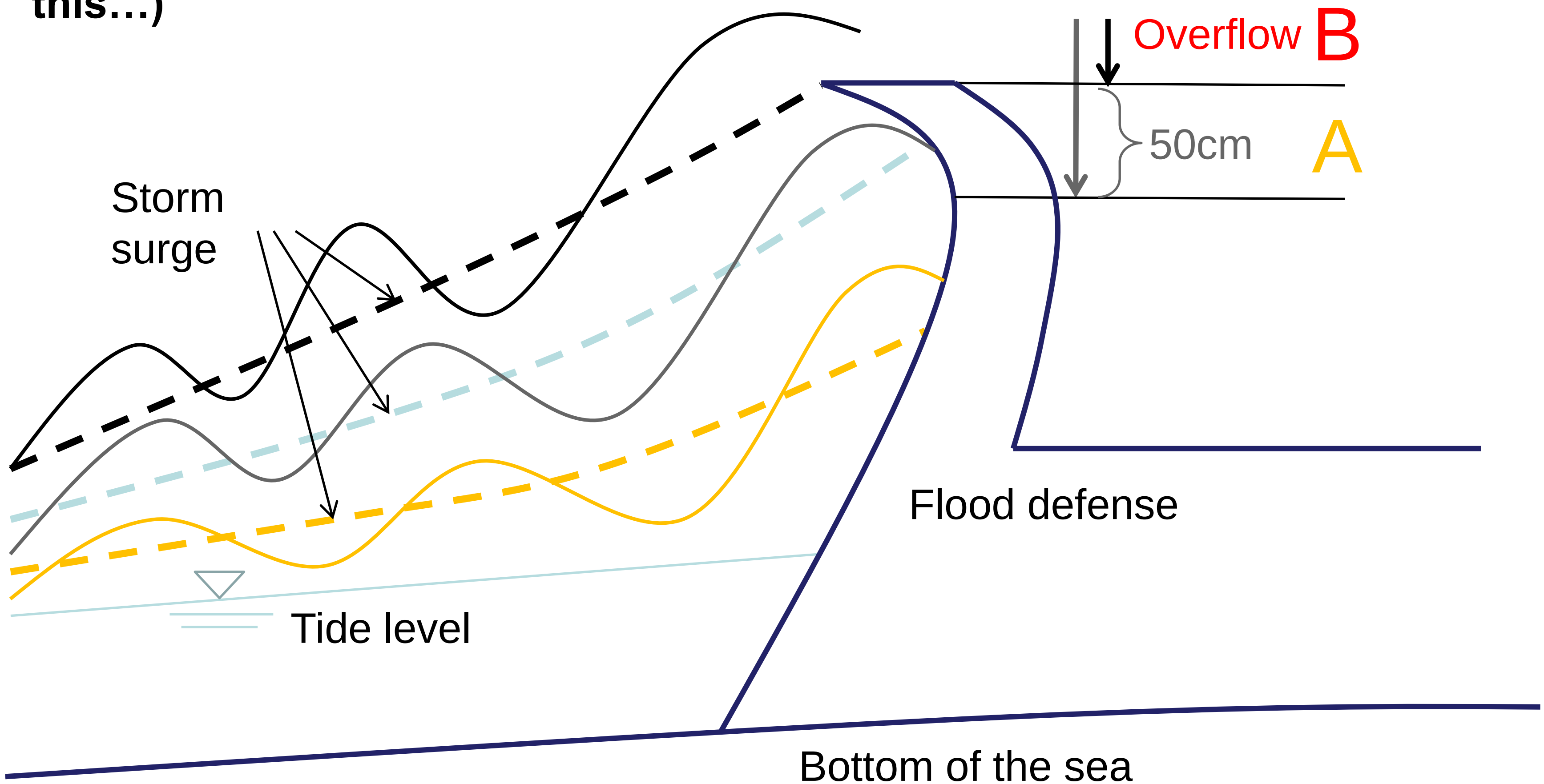
- **Note:**

  On top of storm surges you also get the effect of waves!!!

  (cannot show you this yet, I have a student working on this…)

A the probability the storm surge will reach a level of **at least 50cm below** the top of the flood defense

B the probability of the storm surge **overflowing** the flood defense



Probability (%) that storm surge height becomes higher than case A or B of defenses

- **Note:**
- **Scenario I is for a 14% decrease in mean central typhoon pressure**
- **Scenario II is for 21% decrease (Knutson et al., 2010)**

Scenario	Scenario Ⅰ		Scenario Ⅱ	
Level of Storm Surge Height	**A**	**B**	**A**	**B**
Yokosuka	95	0	95	6.7
Yokohama	58	0	80	0
Kawasaki	64	0	80	0
Samezu	0	0	0	0
Shibaura	0	0	0	0
Toyosu	0	0	0	0
Funabashi	0	0	0	0
Sodagaura	0	0	0	0
Futtsu	81	0	95	0

Sea level rise 28cm

Probability (%) that storm surge height becomes higher than case A or B of defenses

- **Note:**
- **Scenario I is for a 14% decrease in mean central typhoon pressure**
- **Scenario II is for 21% decrease (Knutson et al., 2010)**

Sea level rise 59cm

Scenario	Scenario Ⅰ		Scenario Ⅱ	
Level of Storm Surge Height	**A**	**B**	**A**	**B**
Yokosuka	100	**64**	100	**80**
Yokohama	100	0	100	**58**
Kawasaki	100	0	100	**80**
Samezu	0	0	0	0
Shibaura	0	0	8	0
Toyosu	0	0	0	0
Funabashi	0	0	0	0
Sodagaura	63	0	64	0
Futtsu	100	**64**	100	**80**

Conclusions (I)

- **Stronger tropical cyclones and changing wave patterns will often require the strengthening of breakwaters and other sea defenses.**

- **Stronger tropical cyclones could also lead to higher storm surges**

- **In the future practicing engineers will have to re-think the way that breakwaters are designed**

Conclusions (II)

- **Port Downtime will increase as a consequence of stronger tropical cyclones, potentially creating bottlenecks in supply chains**

- **There will be a need to adapt port infrastructure to increases in sea level, which could potentially mean raising the level of port infrastructure in many areas**

Thank you…

Questions?

Plus just in case here goes my email:

esteban.fagan@gmail.com