ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

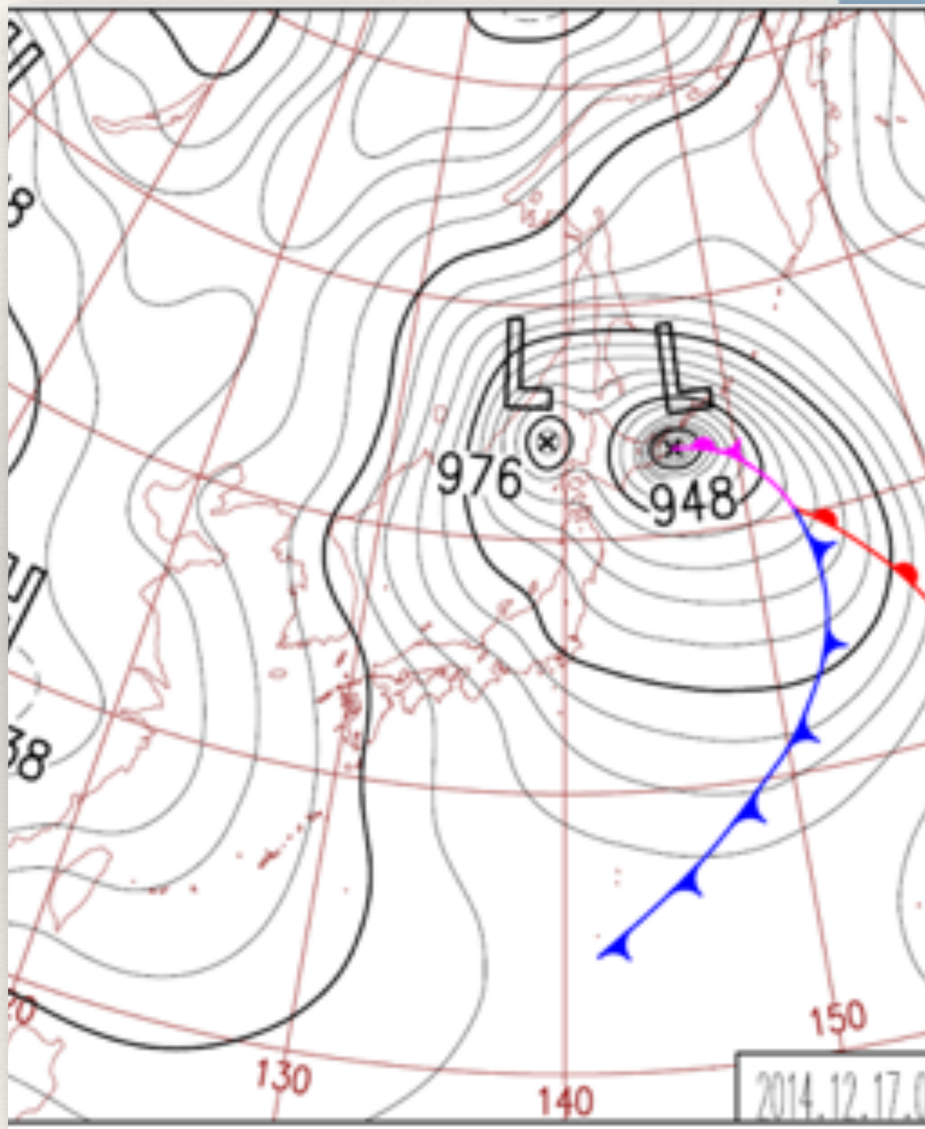
Hindcasting of surge and wave on Hokkaido coasts by a winter low pressure system using surge-wave coupled sea bottom and surface stresses in SuWAT

Sooyoul Kim; Tottori University
K., Kumagai, D., Tsujio and T., Tsuji; Pacific Consultants Co. Ltd.
Hajime Mase; Kyoto University



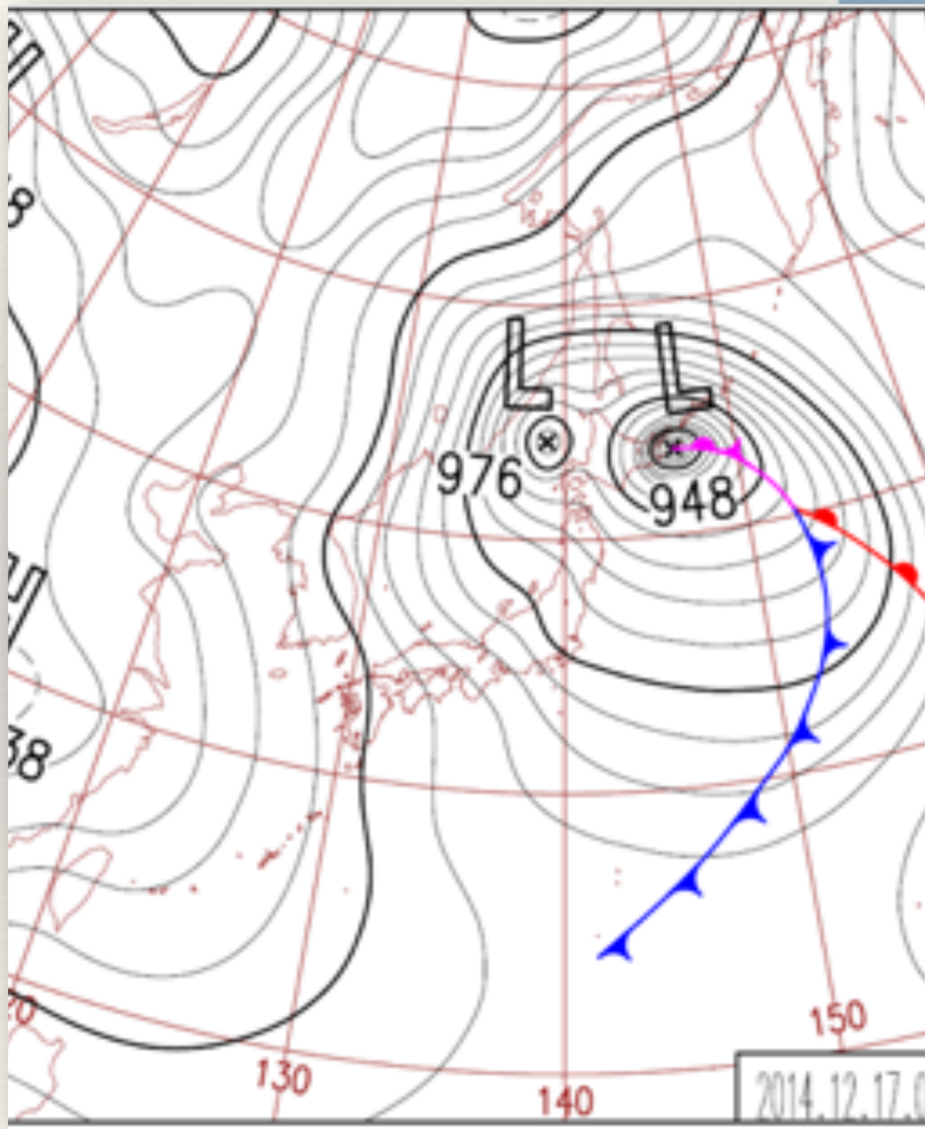

Background

- A Winter Low Pressure System (or Extratropical Cyclones) (WLPS): similar impacts to a typhoon.
- A WLPS In Hokkaido, Japan
  - 16-17 December 2014
  - 1.75 m high surge level
  - vast areas of flooding on the Kushiro coast
  - coastal facilities broken
  - New record-break surge level due to WLPS since record-break level of 0.9 m in 1994

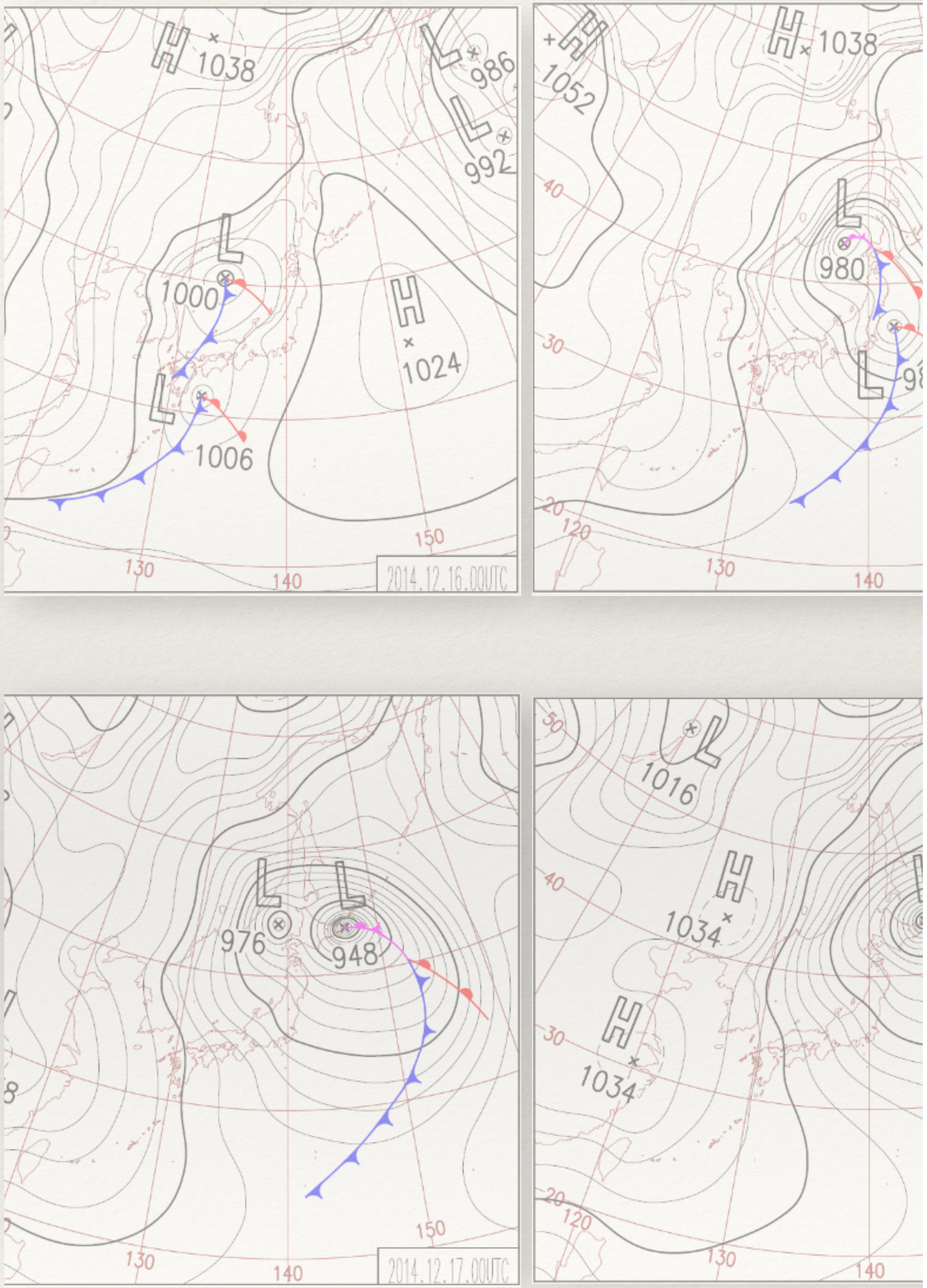


Purpose

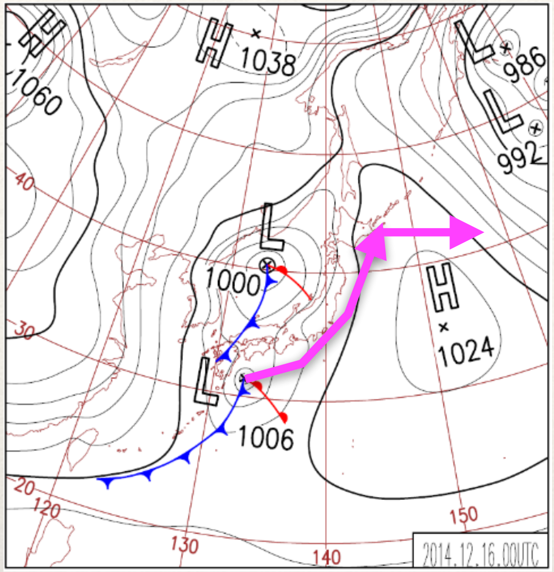
- Understanding the WLPS event in 2014
- Understanding surges and waves due to WLPS 2014
  - Hindcast: surges and waves
  - using a coupled model of surge, wave and tide
    - no consideration: tide

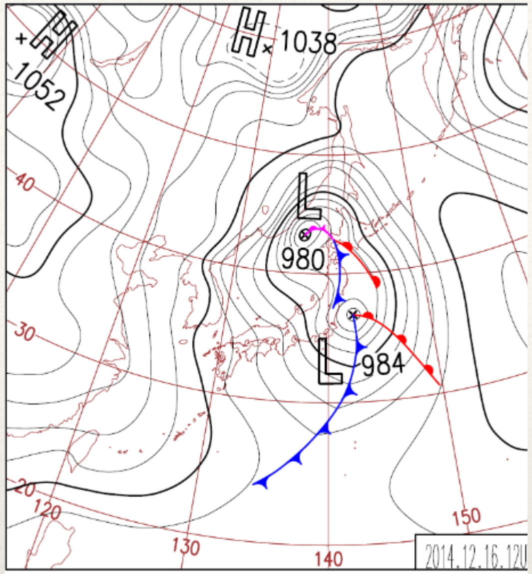


Winter Low Pressure System 2014



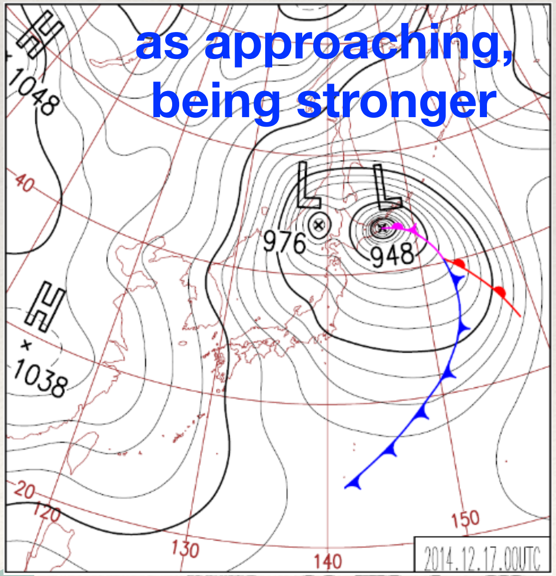
WLPS in Dec. 2014 vs Feb. 1994

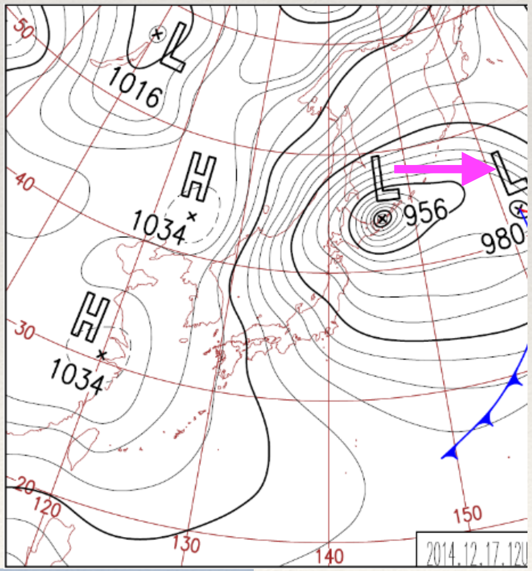




9:00, 16th Dec. in JST

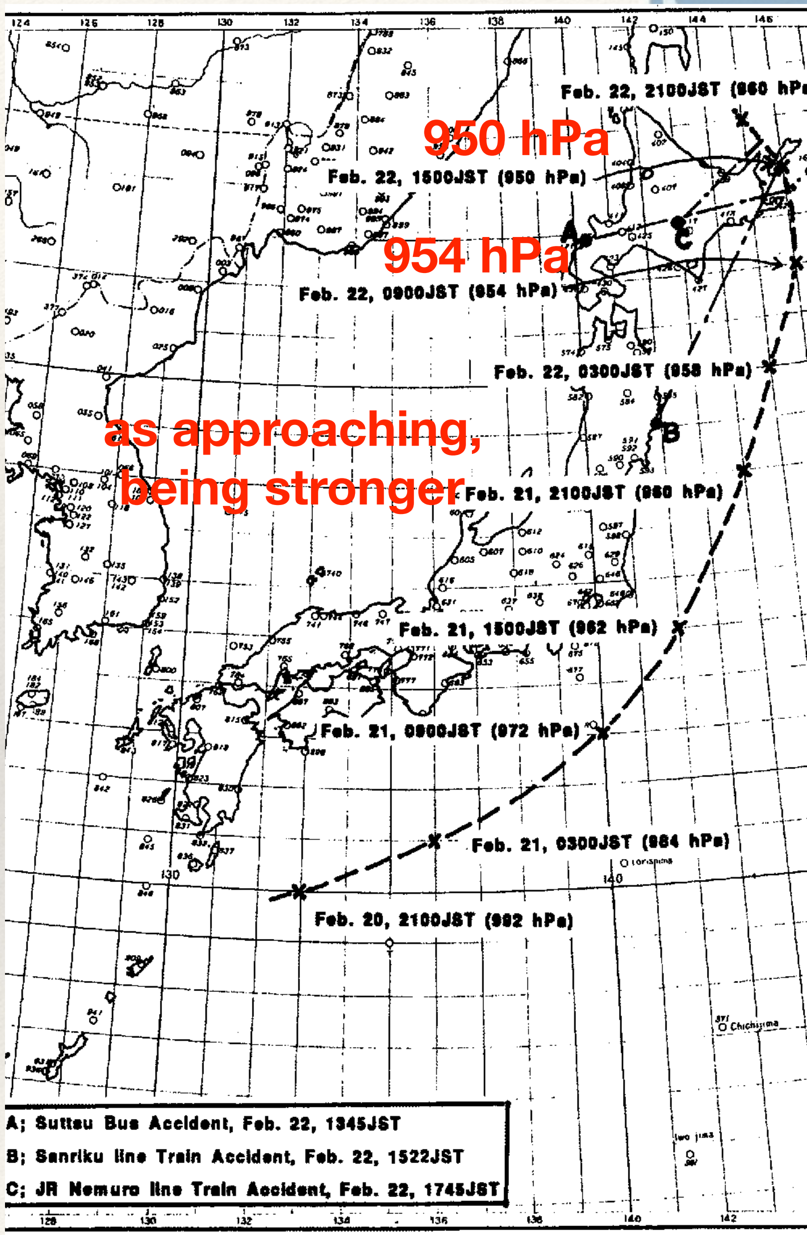
21:00, 16th Dec.





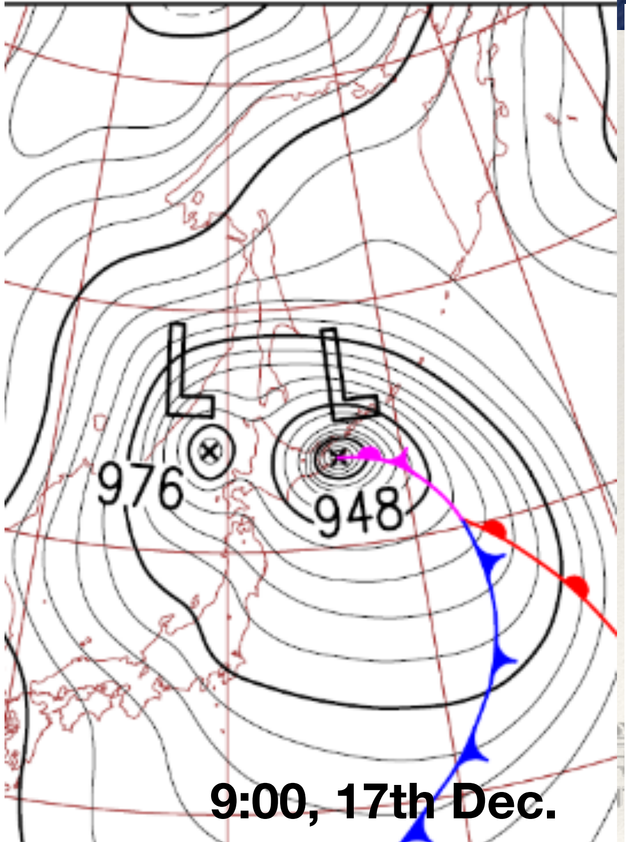
9:00, 17th Dec.

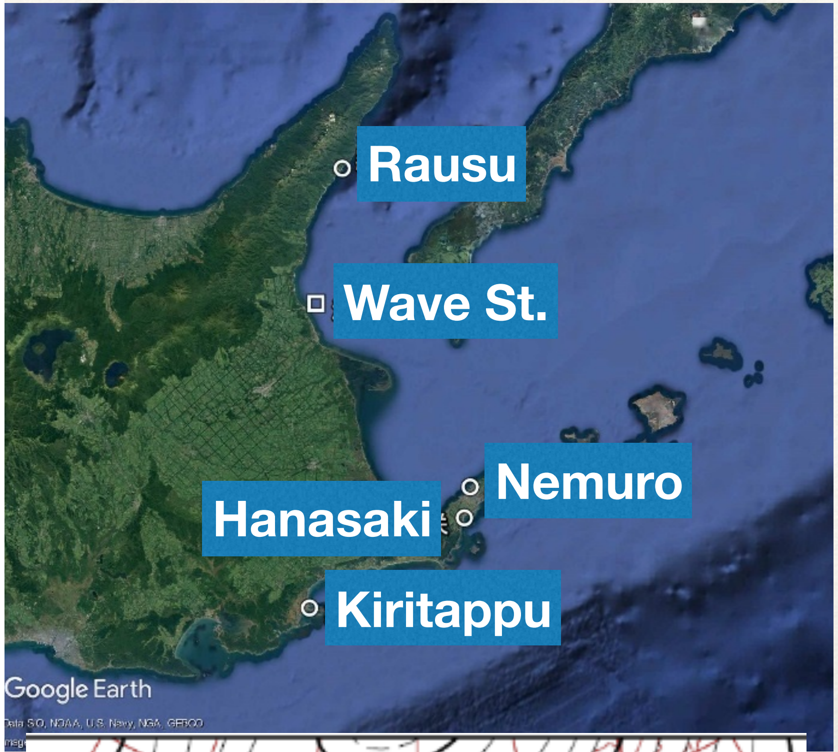
21:00, 17th Dec.

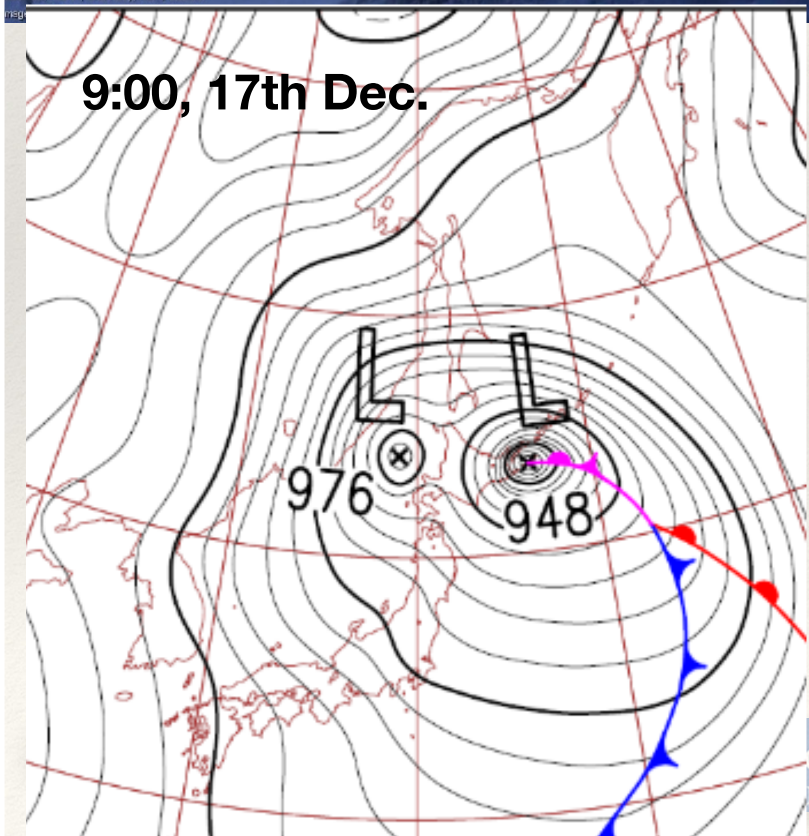


鳥取大学 Tottori University
京都大学 KYOTO UNIVERSITY
Pacific Consultants
ICCE

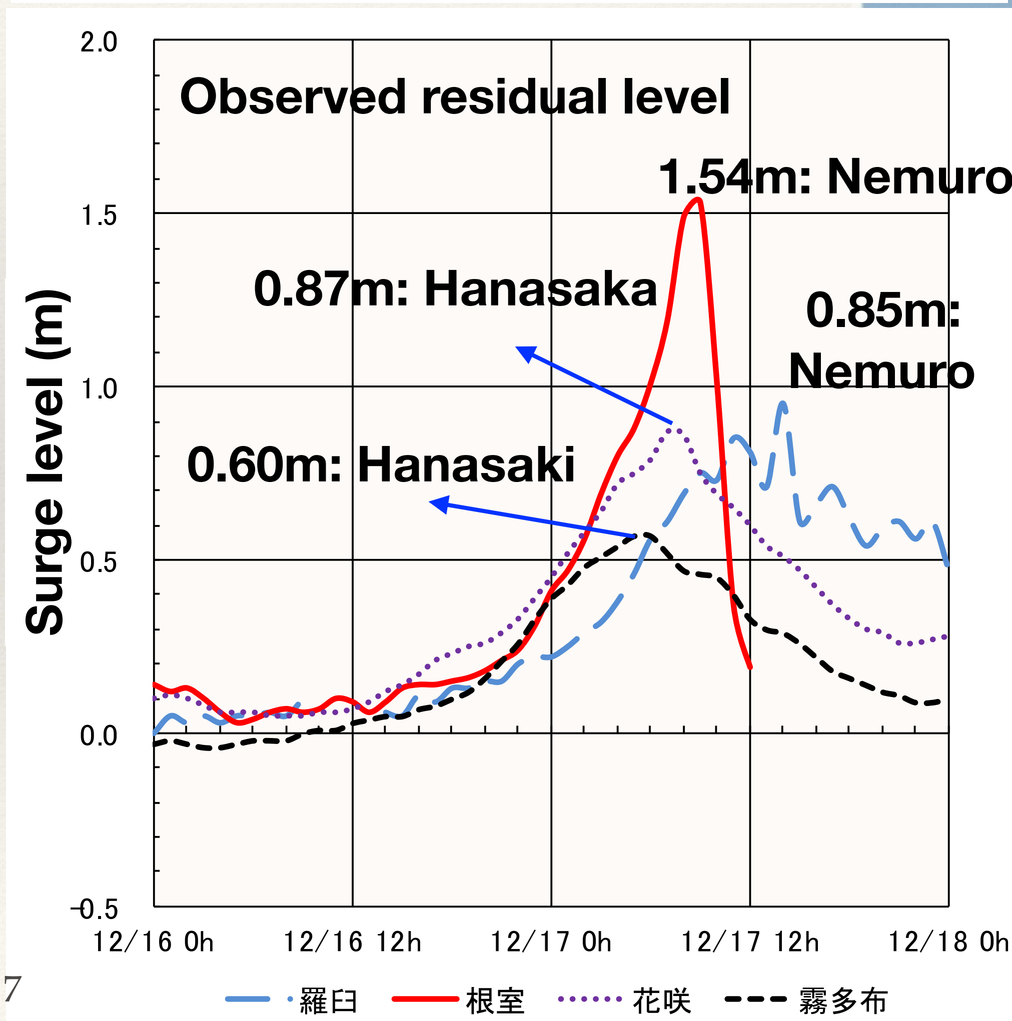
Observed wind and sea level pressure in Nemuro

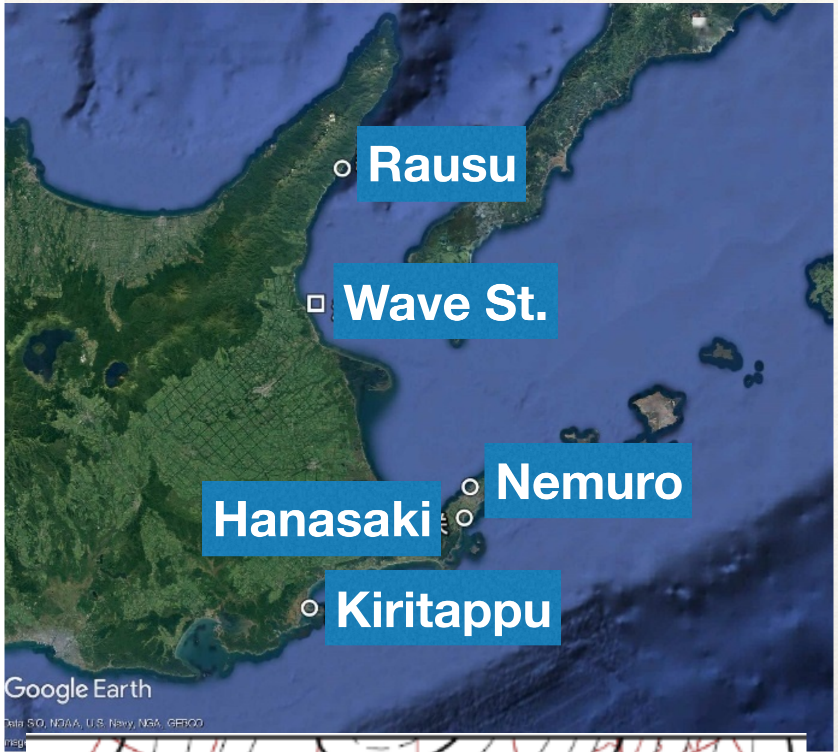


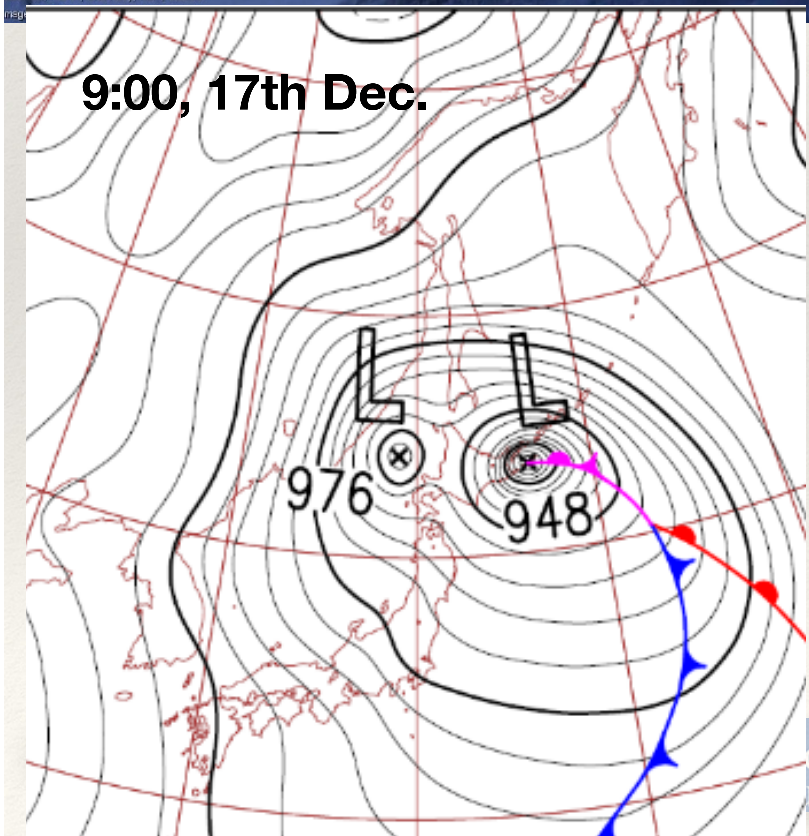

Rausu
Wave St.
Nemuro
Hanasaki
Kiritappu
Google Earth


9:00, 17th Dec.
976
948

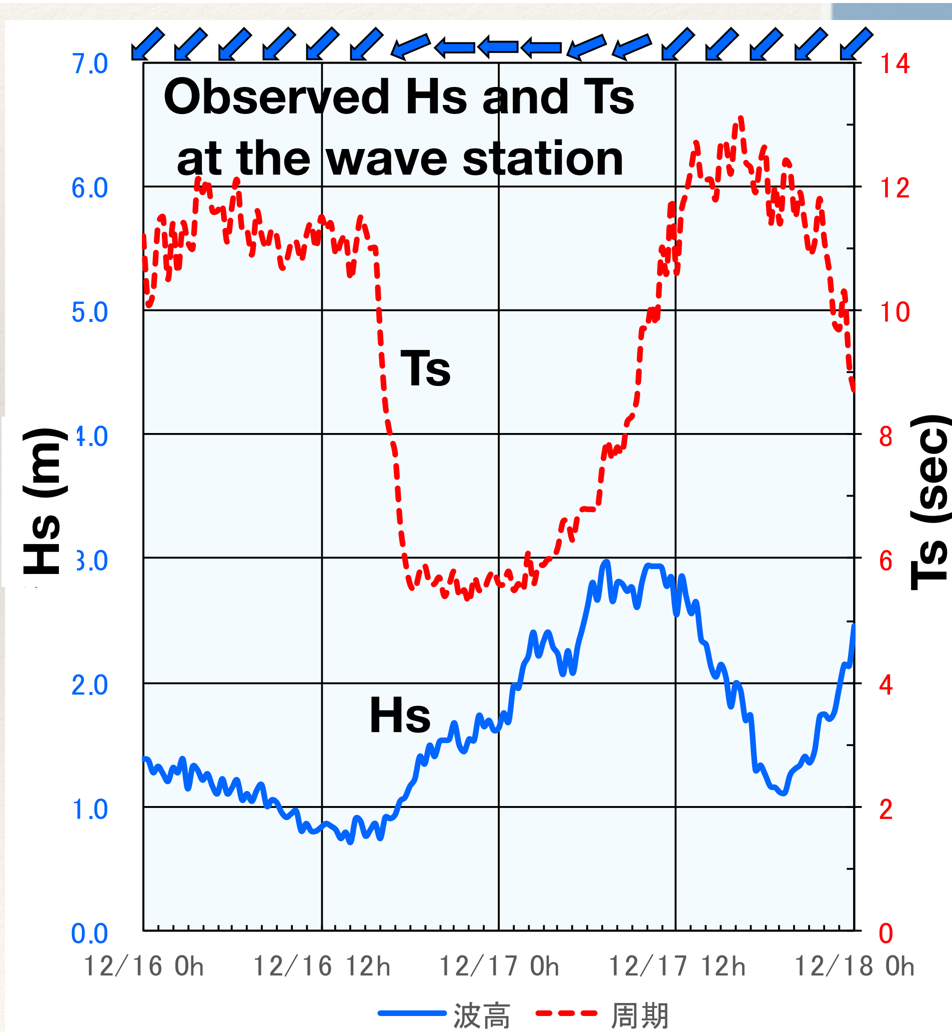

30.0
25.0
20.0
15.0
10.0
5.0
0.0
1040
1020
1000
980
960
940
920
風速(m/s)
気圧(hPa)
12/16 0h
12/16 12h
12/17 0h
12/17 12h
12/18 0h
平均風速
海面気圧


Observed residual level
1.54m: Nemuro
0.87m: Hanasaka
0.85m: Nemuro
0.60m: Hanasaki
Surge level (m)
2.0
1.5
1.0
0.5
0.0
-0.5
12/16 0h
12/16 12h
12/17 0h
12/17 12h
12/18 0h
羅臼
根室
花咲
霧多布


Rausu
Wave St.
Nemuro
Hanasaki
Kiritappu
Google Earth

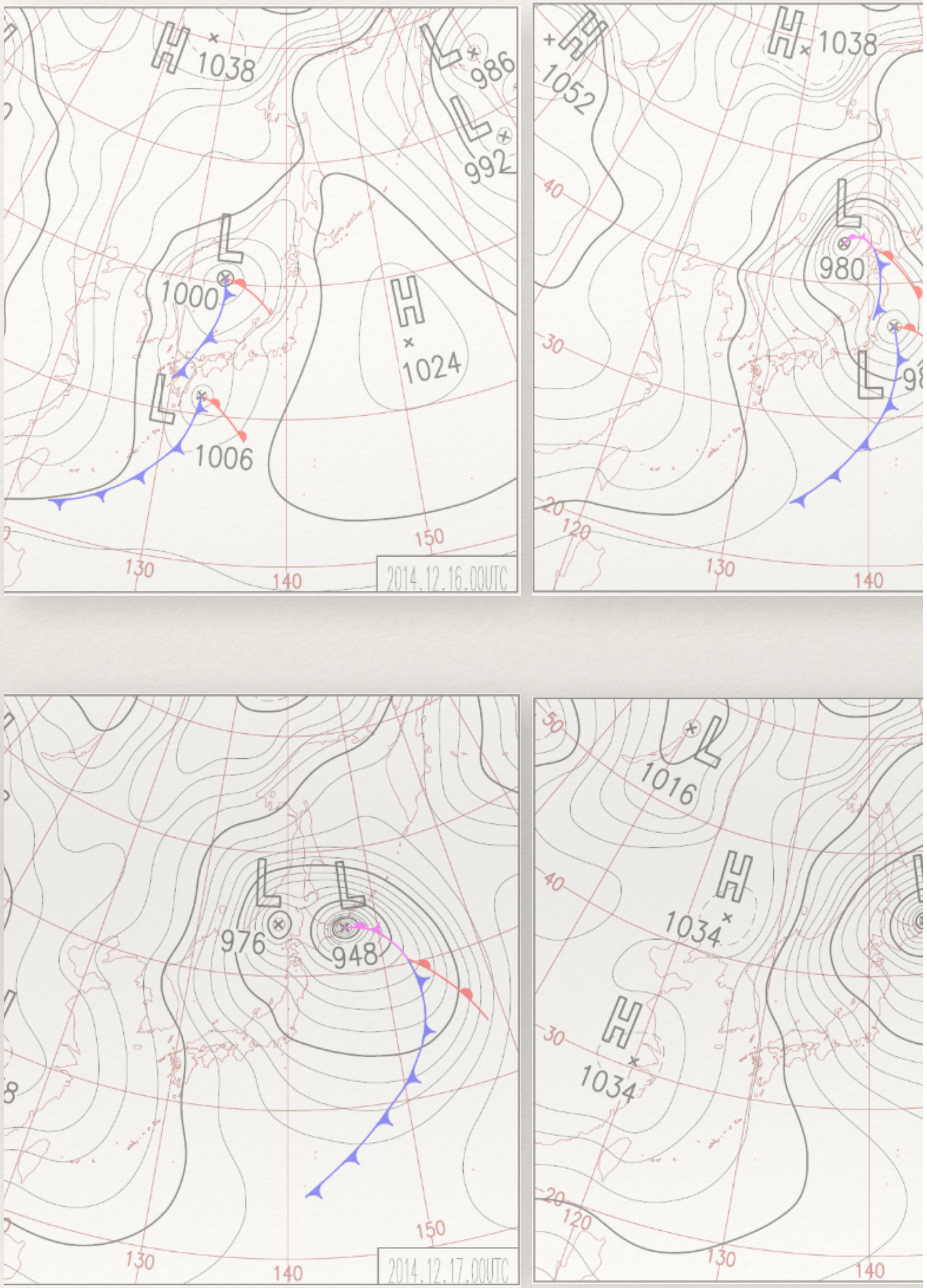

9:00, 17th Dec.
L
L
976
948


30.0
25.0
20.0
15.0
10.0
5.0
0.0
1040
1020
1000
980
960
940
920
風速(m/s)
気圧(hPa)
12/16 0h
12/16 12h
12/17 0h
12/17 12h
12/18 0h
平均風速
海面気圧


Observed Hs and Ts
at the wave station
Ts
Hs
Hs (m)
Ts (sec)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
14
12
10
8
6
4
2
0
12/16 0h
12/16 12h
12/17 0h
12/17 12h
12/18 0h
波高
周期

Hindcasting surges and waves

- The coupled model of surge, wave and tide; SuWAT
- Wave dependent drag coefficient capped at specific wind speeds
- wave-current interaction-induced bottom stress



The drag coefficient, C_d, in sea surface layer

- Wave growth term in SWAN

$$S_{\text{in}}(\sigma,\theta) = A + BE(\sigma,\theta)$$

  - A: the linear wave growth term
  - BE: the exponential wave growth term

The drag coefficient, C_d, in sea surface layer

- Wave growth term in SWAN

$$S_{in}(\sigma,\theta) = A + BE(\sigma,\theta)$$

  - A: the linear wave growth term
  - BE: the exponential wave growth term
- Cd in the linear wave growth term
  - Transfer U10 to U* — the friction velocity ($u_*^2 = C_D U_{10}^2$)
  - Wu (1982):

$$C_D = \begin{cases} 1.2875 \times 10^{-3} & \text{for } U_{10} < 7.5\text{m/s} \\ (0.8 + 0.065 U_{10}) \times 10^{-3} & \text{for } U_{10} > 7.5\text{m/s} \end{cases}$$

Zijlema et al (2012):

$$C_D = (0.55 + 2.97\tilde{U} - 1.49\tilde{U}^2) \times 10^{-3}$$

The drag coefficient, C_d, in sea surface layer

- Wave growth term in SWAN

$$S_{in}(\sigma,\theta) = A + BE(\sigma,\theta)$$

  - BE: the exponential wave growth term

- Janssen's wave dependent Cd in the exponential wave growth term (1991) and following Mastenbroek et al.(1993) accounting for sea state
  - Wind profile: $U(z) = \frac{u_*}{\kappa}\ln\left(\frac{z+z_e+z_0}{z_e}\right)$ Turbulent stress $\tau_t = \rho_a(\kappa z)^2\left(\frac{\partial U}{\partial z}\right)^2$
  - Effective roughness: $z_e = \frac{z_0}{\sqrt{1-\tau_w/\tau}}$
  - Wind speed-capped Wave dependent Cd

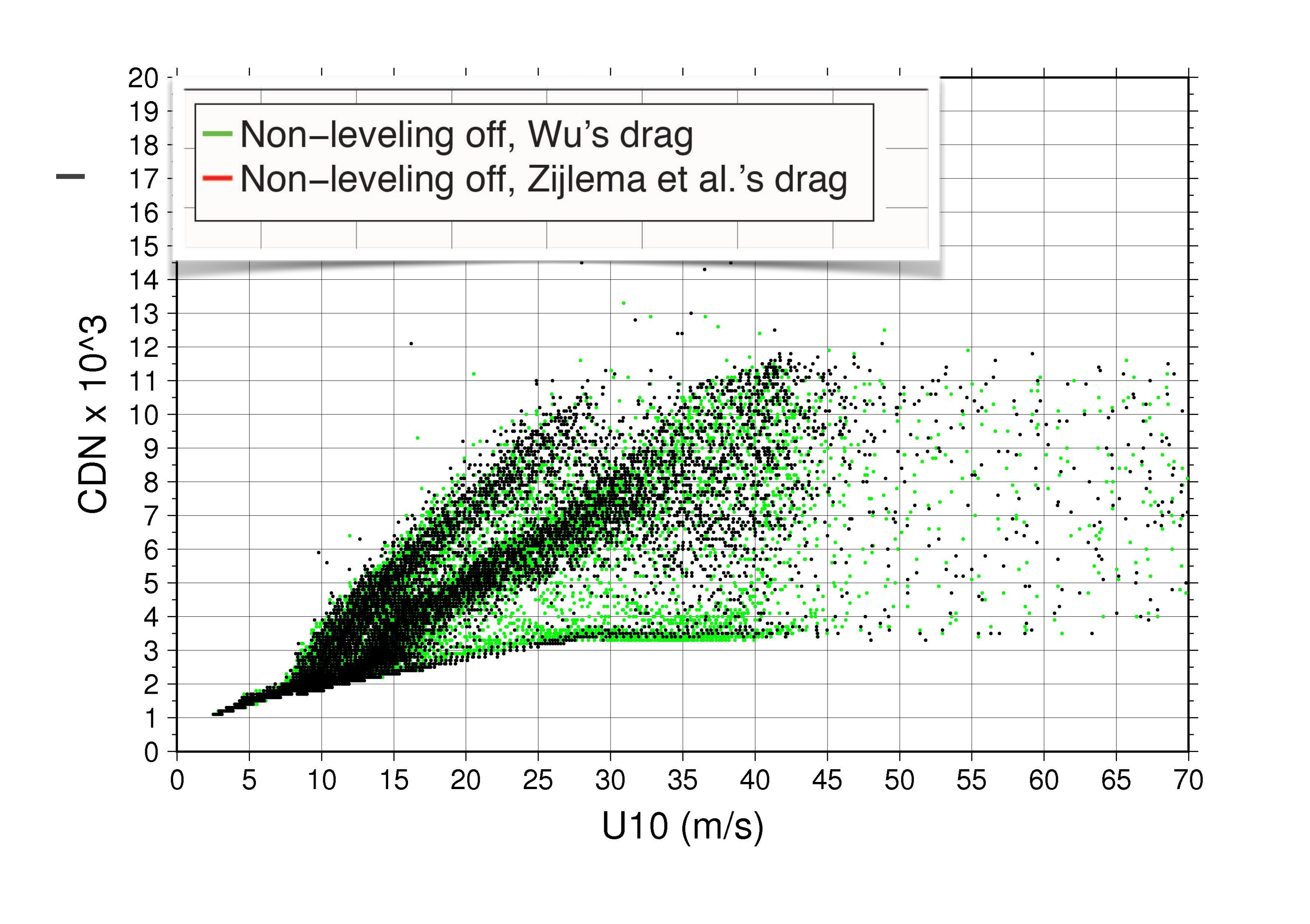
$$C_D = u_*^2/U(z)^2 = \left[\kappa/\ln\left(\frac{z+z_e-z_0}{z_e}\right)\right]^2 \rightarrow \tau_s = \rho_a C_D \vec{U}_{10}|\vec{U}_{10}|$$

鳥取大学 Tottori University

京都大学 KYOTO UNIVERSITY

Pacific Consultants

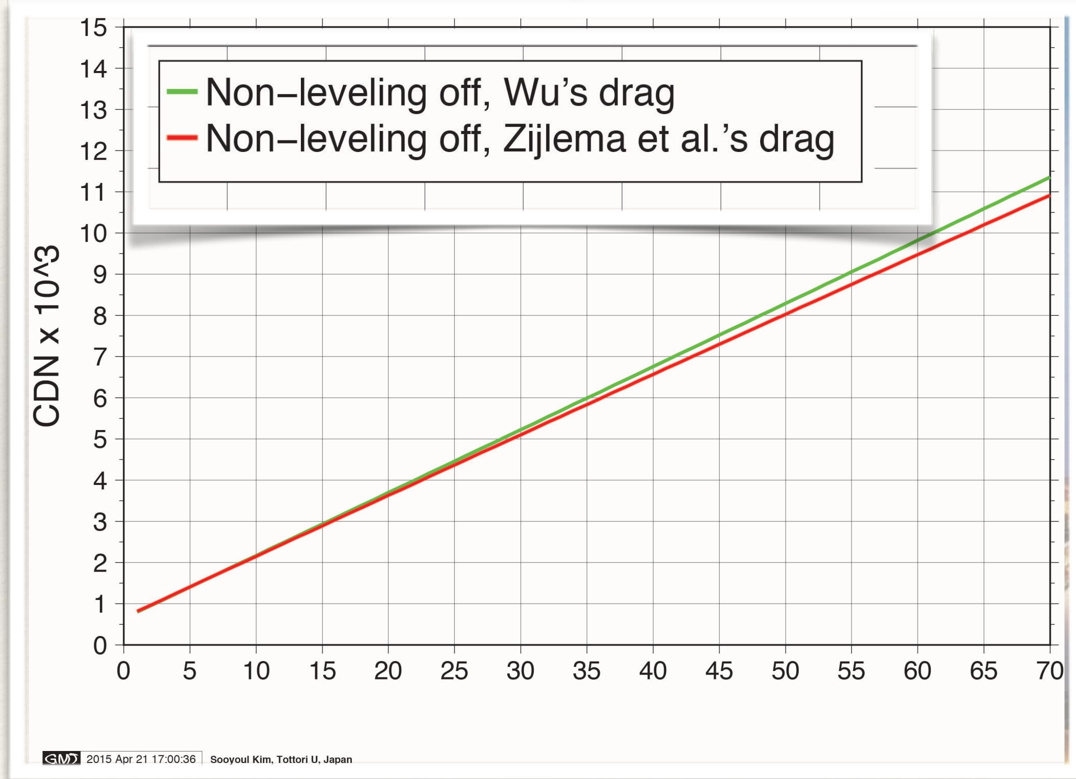
Estimated wave dependent C_d without levelling off due to Typhoon Hainan 2013



The best-fitted wave dependent C_d to the 2nd-order polynomial due to Typhoon Hainan 2013

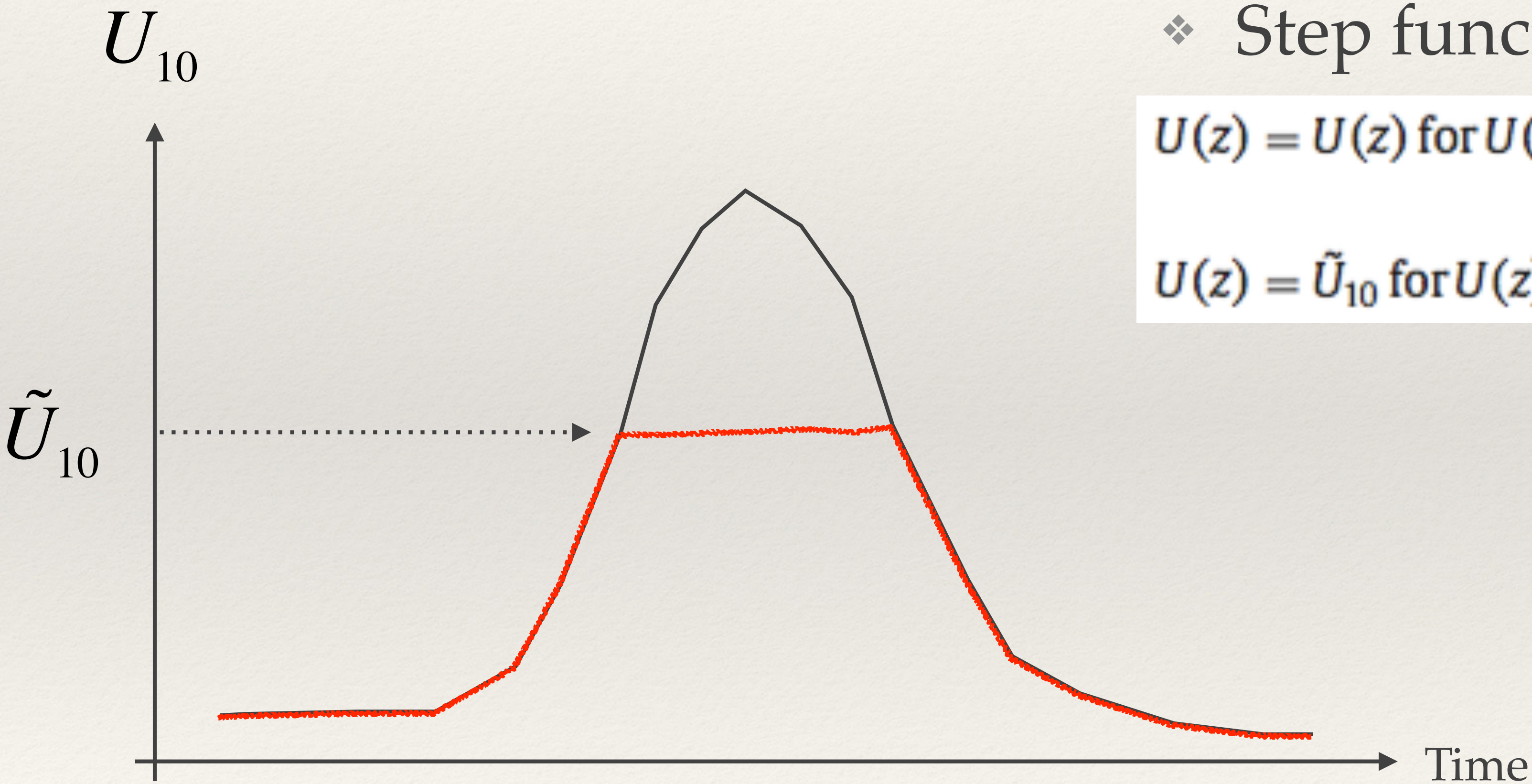
Kim et al., 2015 *Ocean modelling*

- Threshold for a levelling off based on measurements
  - 33 *m/s* : Powell et al. (2003)
  - 30-40 *m/s* : Donelan et al. (2004)
  - 22-23 *m/s* : Black et al. (2007)



Levelling Wave dependent Cd off in the exponential term due to Typhoon Hainan 2013

- Wind profiles only in the exponential term



- Step functions

$$U(z) = U(z) \text{ for } U(z) < \tilde{U}_{10}$$

$$U(z) = \tilde{U}_{10} \text{ for } U(z) \geq \tilde{U}_{10}$$

Levelling off in the exponential term

- Levelling off the wave dependent Cd in the exponential wave growth term
  - Step functions

$$U(z) = U(z) \text{ for } U(z) < \tilde{U}_{10}$$

$$U(z) = \tilde{U}_{10} \text{ for } U(z) \geq \tilde{U}_{10}$$

  - Wind profile

$$U(z) = \frac{u_*}{k} \ln\left(\frac{z + z_e + z_0}{z_e}\right), \text{ if } U(z) < \tilde{U}(z)$$

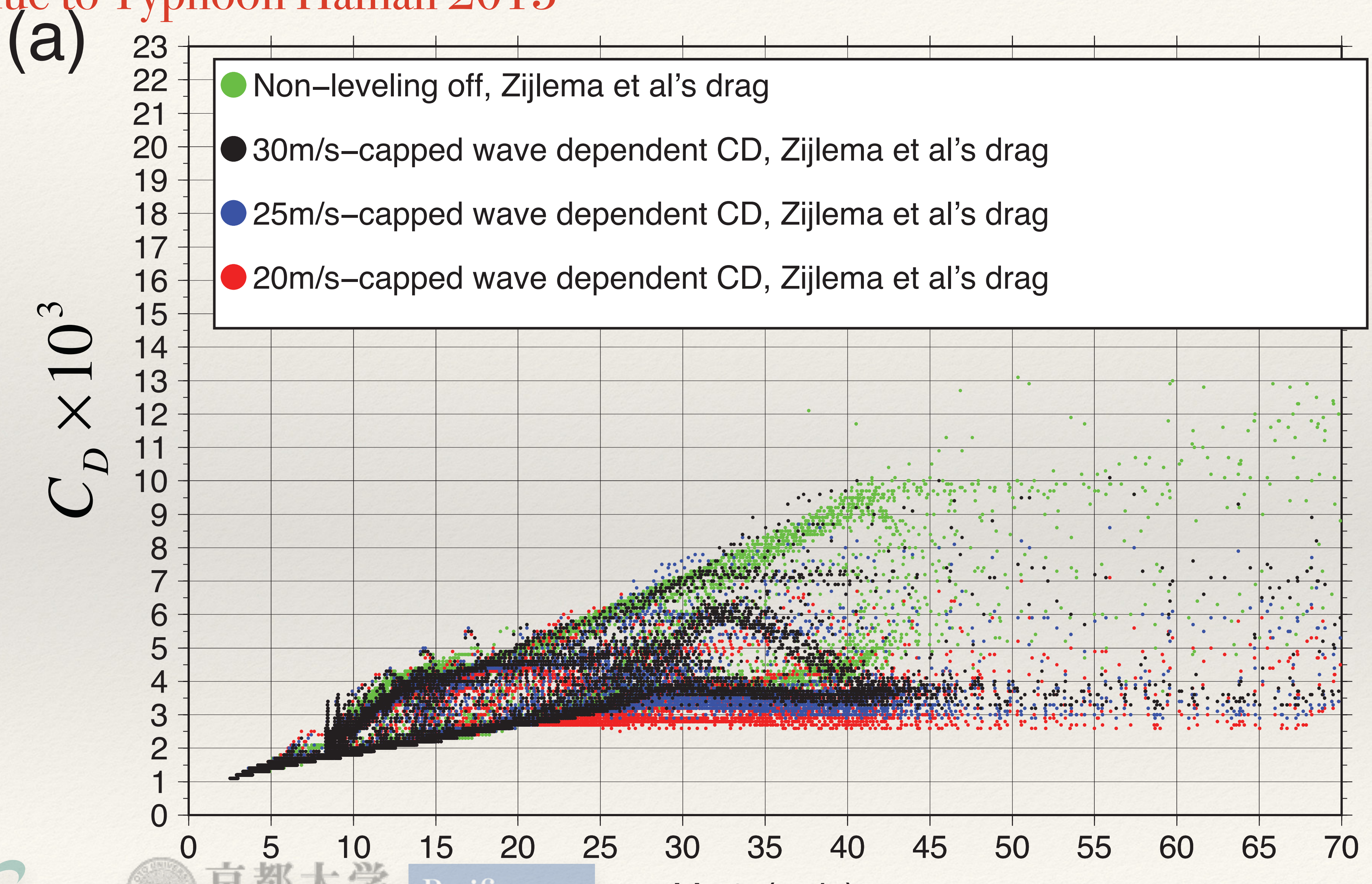
$$\tilde{U}(z) = \frac{u_*}{k} \ln\left(\frac{z + z_e + z_0}{z_e}\right), \text{ if } U(z) \geq \tilde{U}(z)$$

  - Wind speed-capped Wave dependent Cd

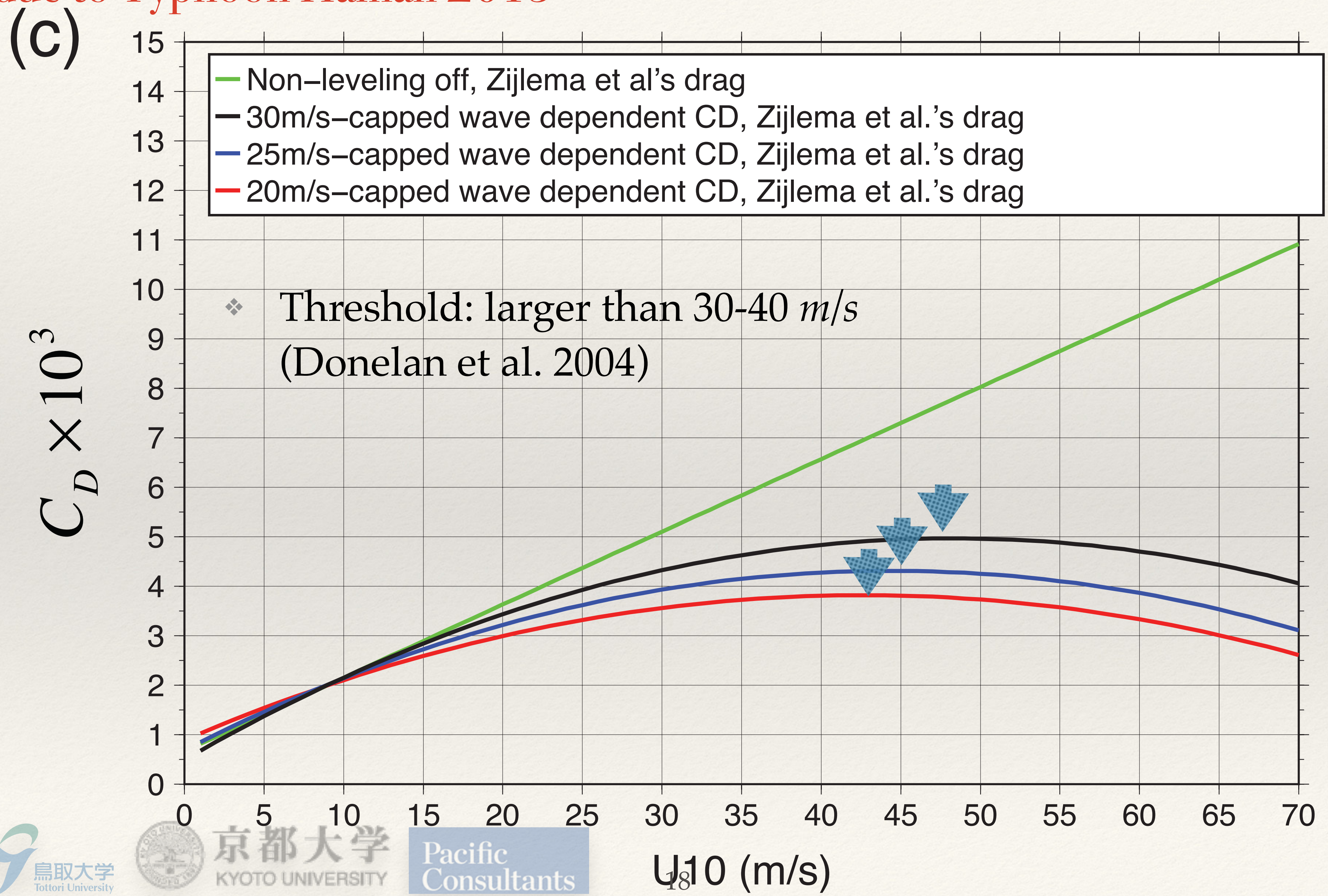
$$C_d = u_*^2 / U(z)^2 = \kappa / \ln\left(\frac{z + z_e + z_0}{z_e}\right), \text{ if } U(z) < \tilde{U}(z)$$

$$C_d = u_*^2 / \tilde{U}(z)^2 = \kappa / \ln\left(\frac{z + z_e + z_0}{z_e}\right), \text{ if } U(z) \geq \tilde{U}(z)$$

Scattered wave dependent C_d with levelling off due to Typhoon Hainan 2013



The best-fitted wave dependent *Cd* to the 2nd-order polynomial due to Typhoon Hainan 2013



- Threshold: larger than 30-40 *m/s* (Donelan et al. 2004)

鳥取大学 Tottori University · 京都大学 KYOTO UNIVERSITY · Pacific Consultants

The wave&current interaction-induced bottom drag, f_c

- Conventional method
  - Manning number, *n*,

$$\tau_b = \rho_w g n^2 \frac{\vec{Q}|\vec{Q}|}{h^{7/3}} \quad \xrightarrow{f_c = 8 \times \frac{gn^2}{h^{1/3}}} \quad \tau_b = \rho_w \frac{f_c}{8} \frac{\vec{Q}|\vec{Q}|}{h^2}$$

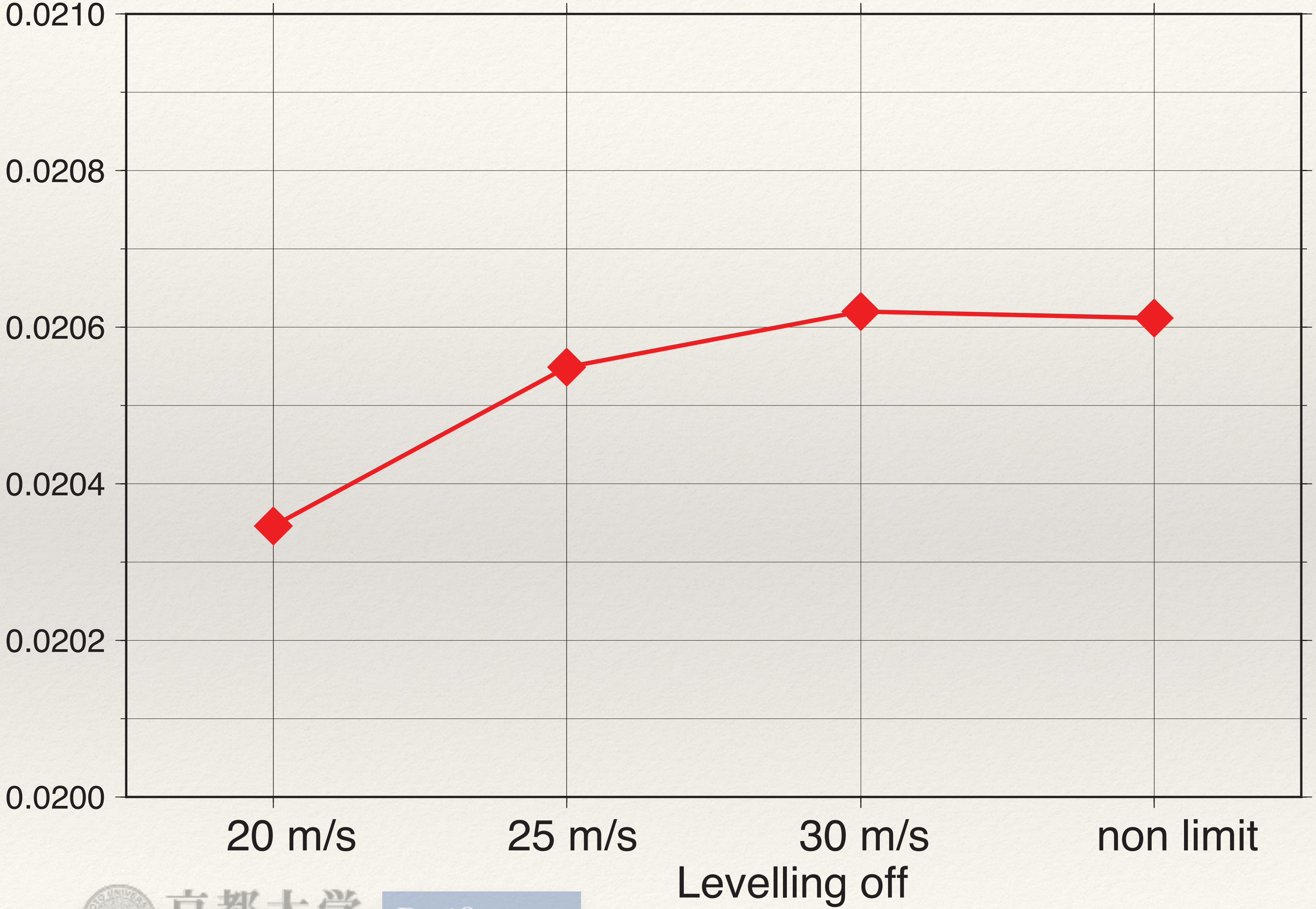
- *Signell et al., 1990 & Davies and Lawrence, 1995*

$$k_{bc} = k_b \left[C_1 \frac{U_{*cw} A_b}{U_w k_b} \right]^{\beta} \qquad f_c = 2 \left[\frac{K}{\ln(30 z_r / k_{bc})} \right]^2$$

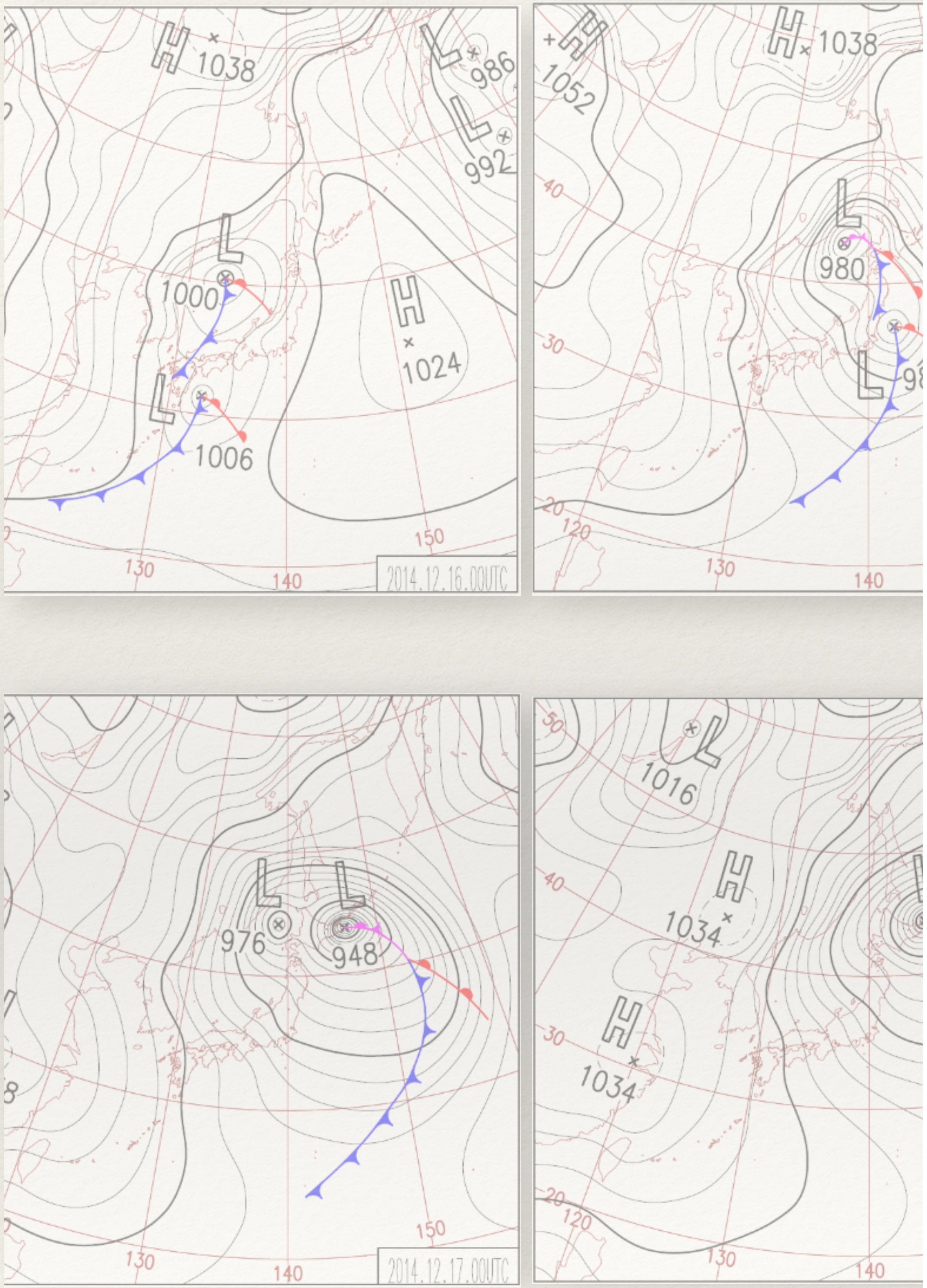
ICCE 2018

鳥取大学 Tottori University 京都大学 KYOTO UNIVERSITY Pacific Consultants

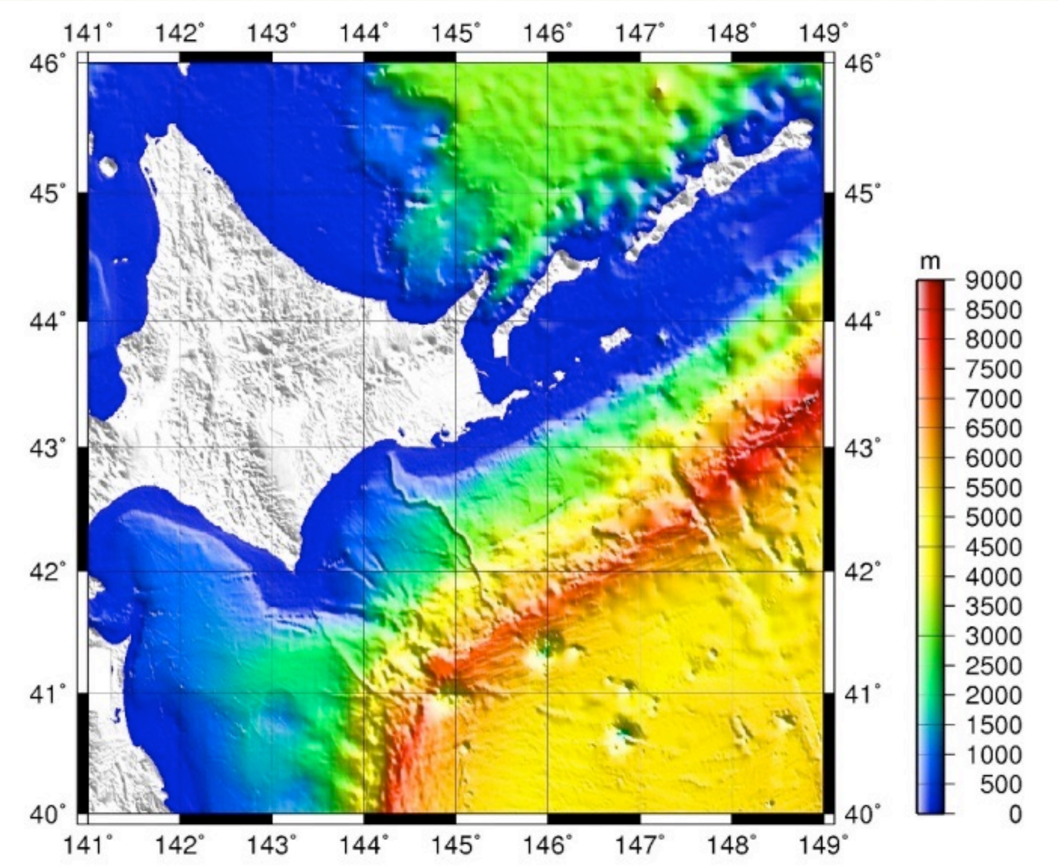
Averaged Manning Number converted from f_c due to Typhoon Haiyan 2013



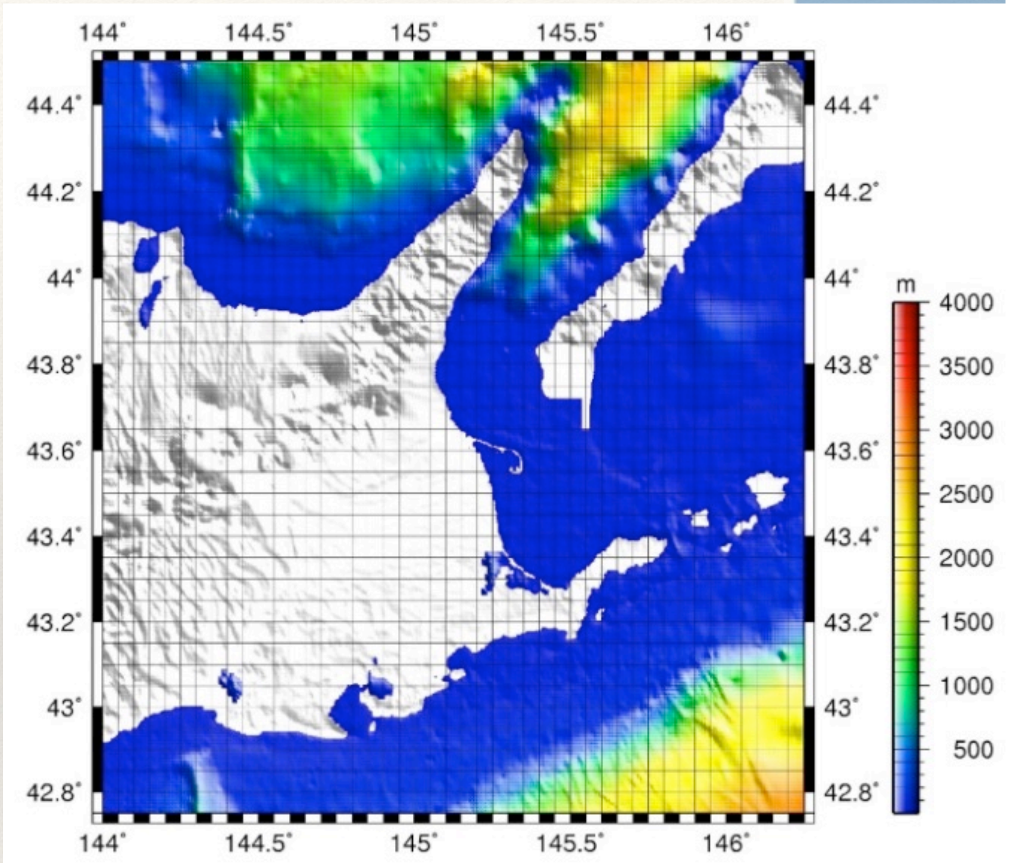
Cal. Conditions



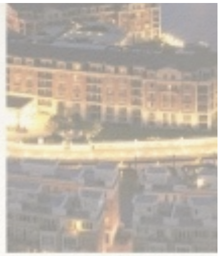
Calculation domains



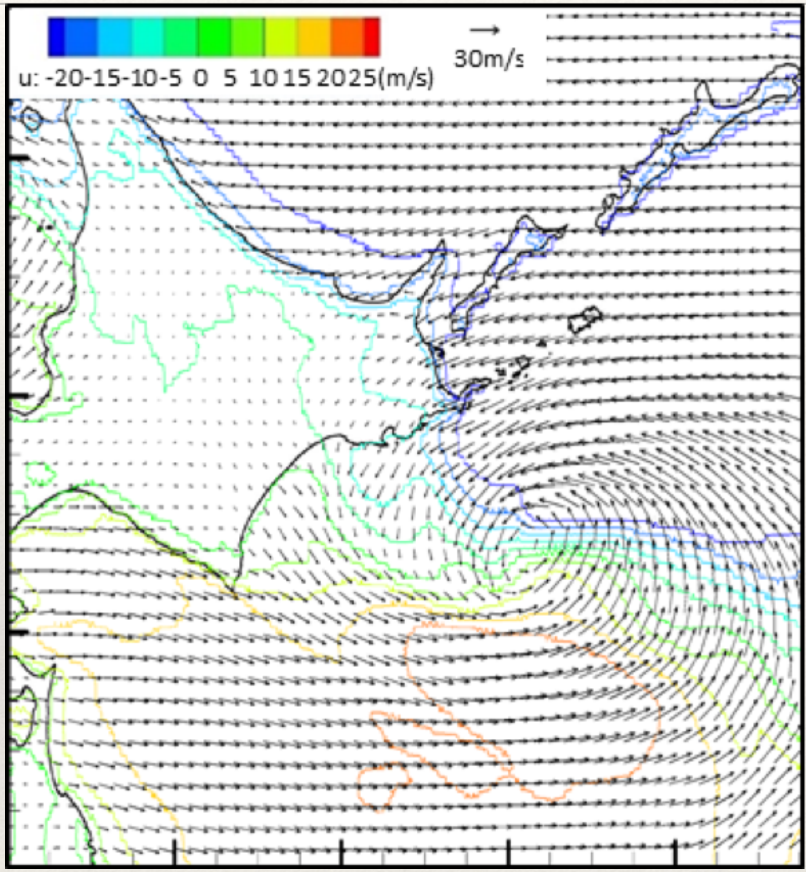
Grid size: 677 m x 927 m



Grid size: 226 m x 309 m

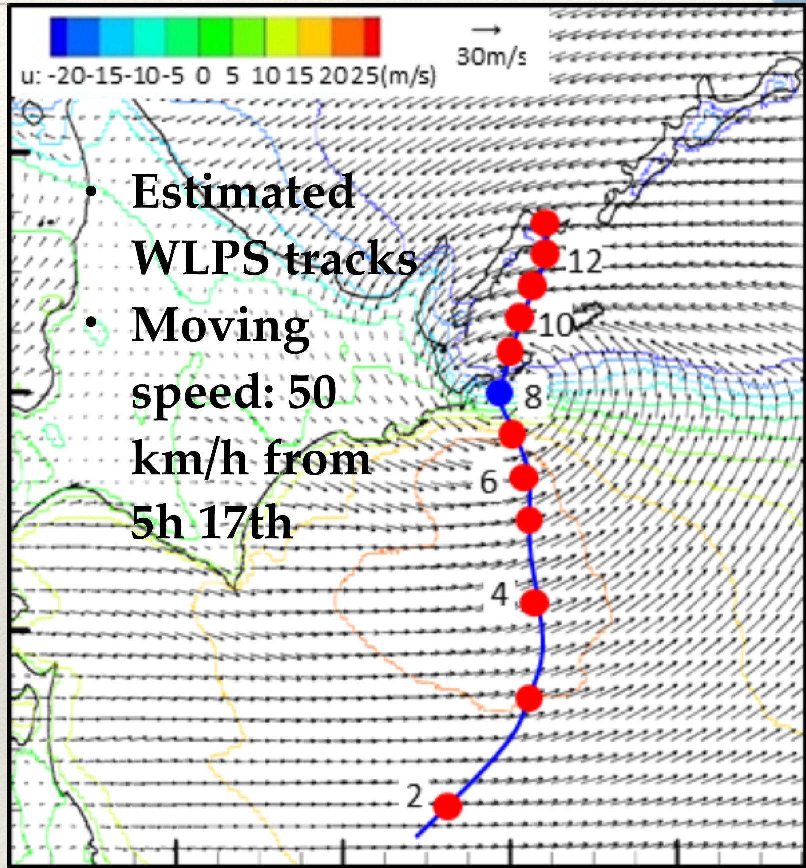


Wind and pressure fields by JMA



5:00 17th Dec.

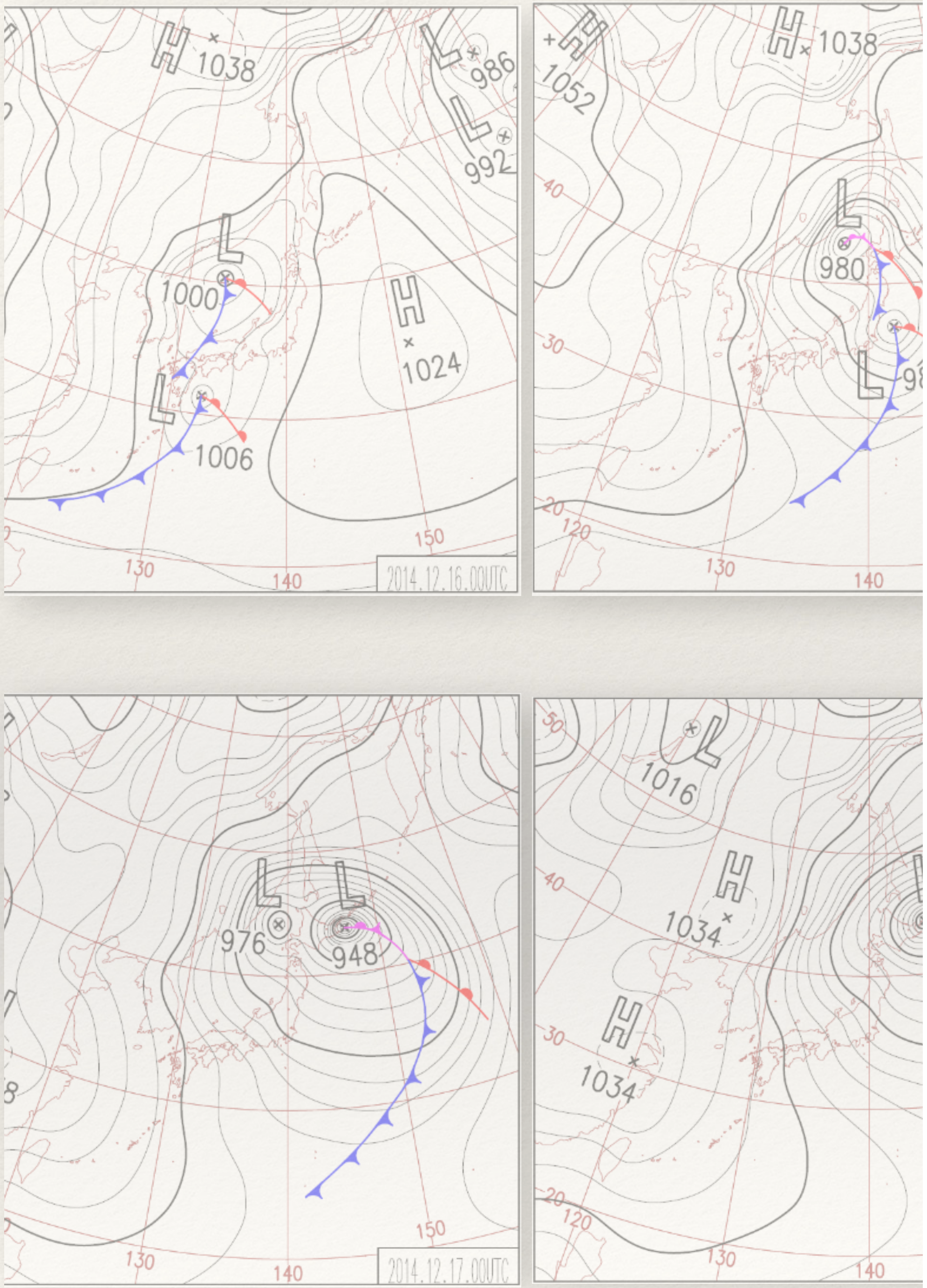
- Max. Wind speed: 30.7 m/s



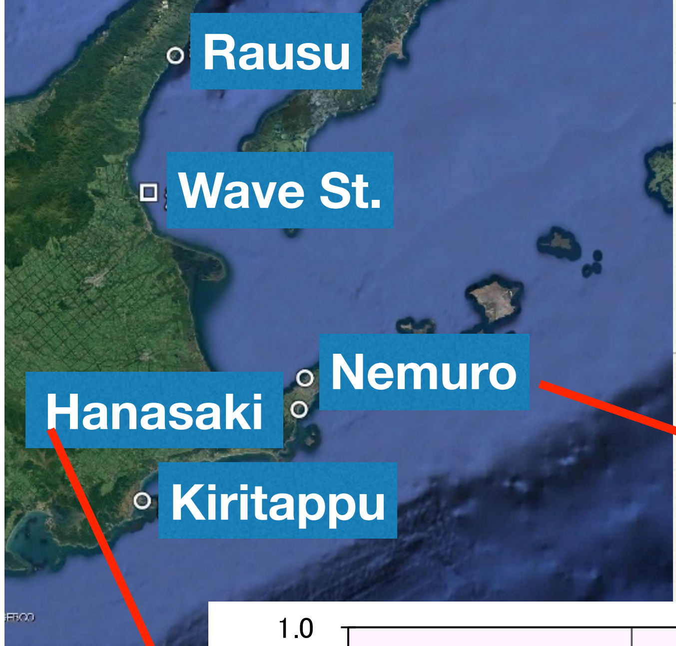
8:00 17th Dec.

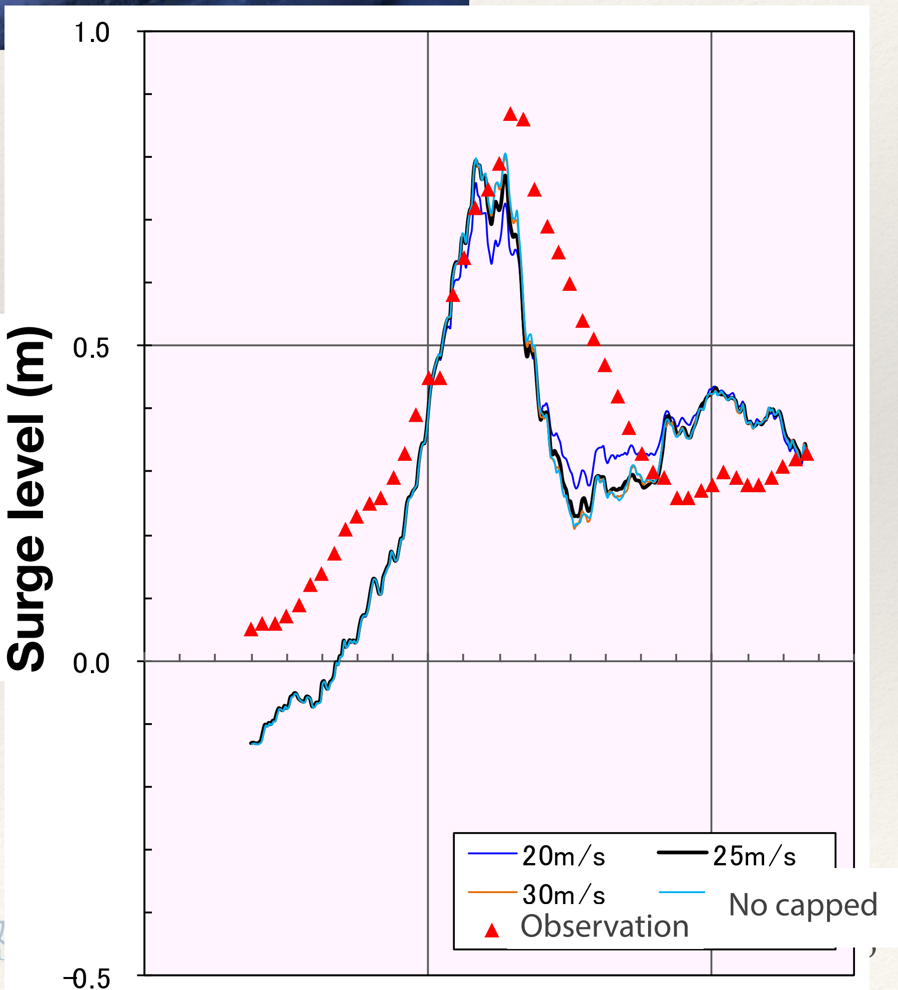
- The wind and pressure field
  - when the minimum drop of pressure is observed in Nemuro.

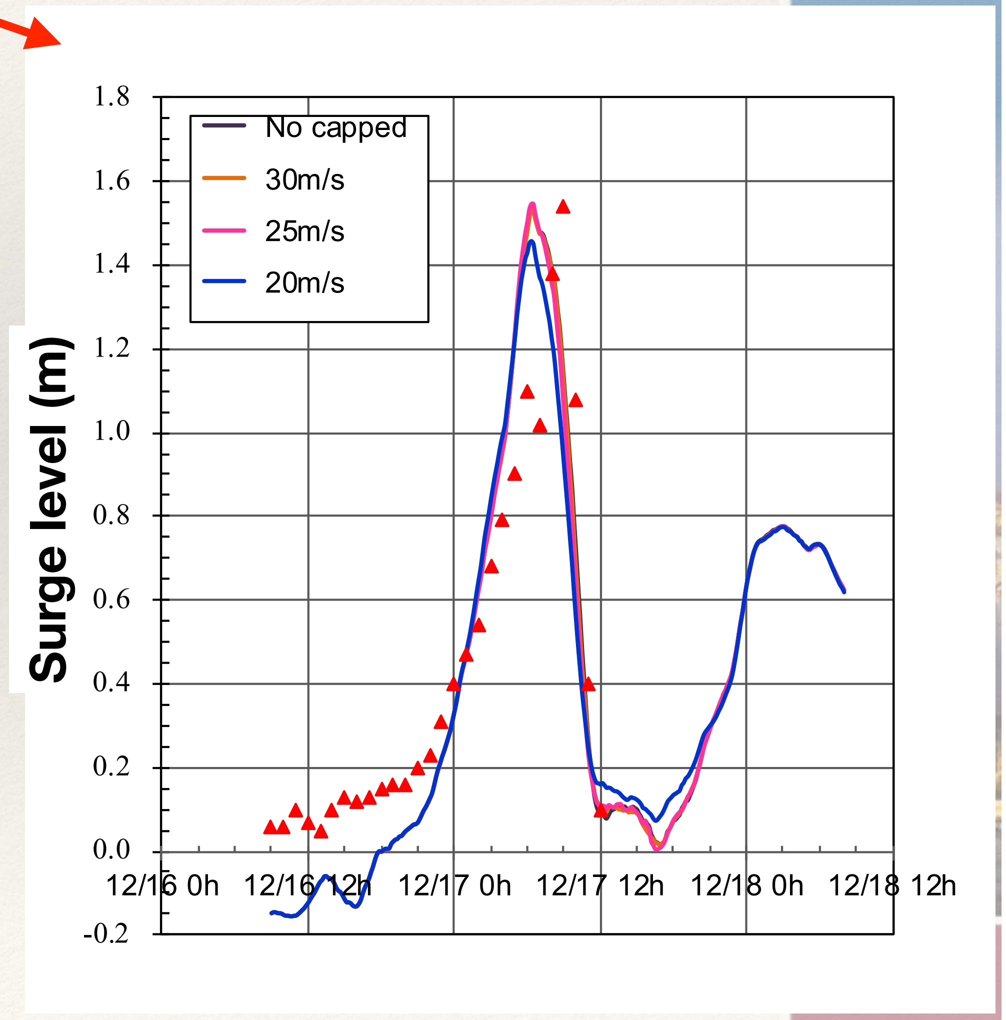
Results


H 1038
L 986
L 992
L 1000
L 1006
H 1024
2014.12.16.00UTC
H 1052
H 1038
L 980
L 976
L 948
2014.12.17.00UTC
L 1016
H 1034
H 1034

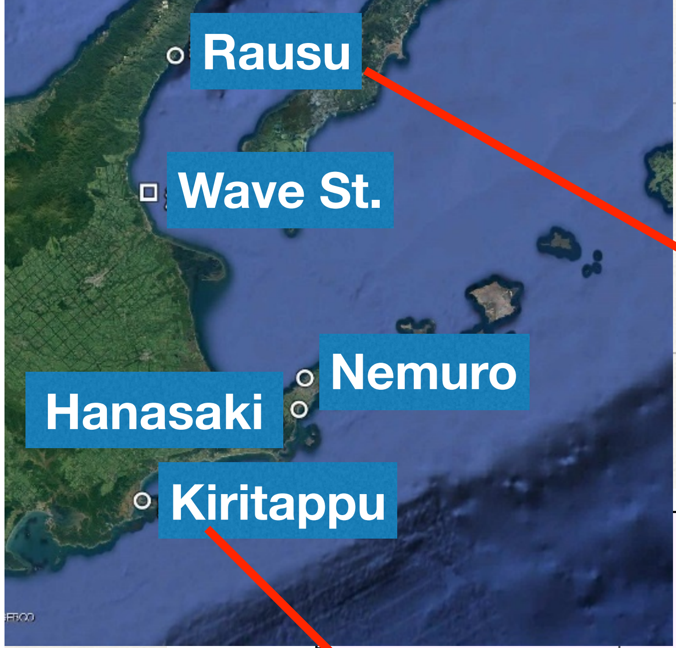
Results: Surge levels

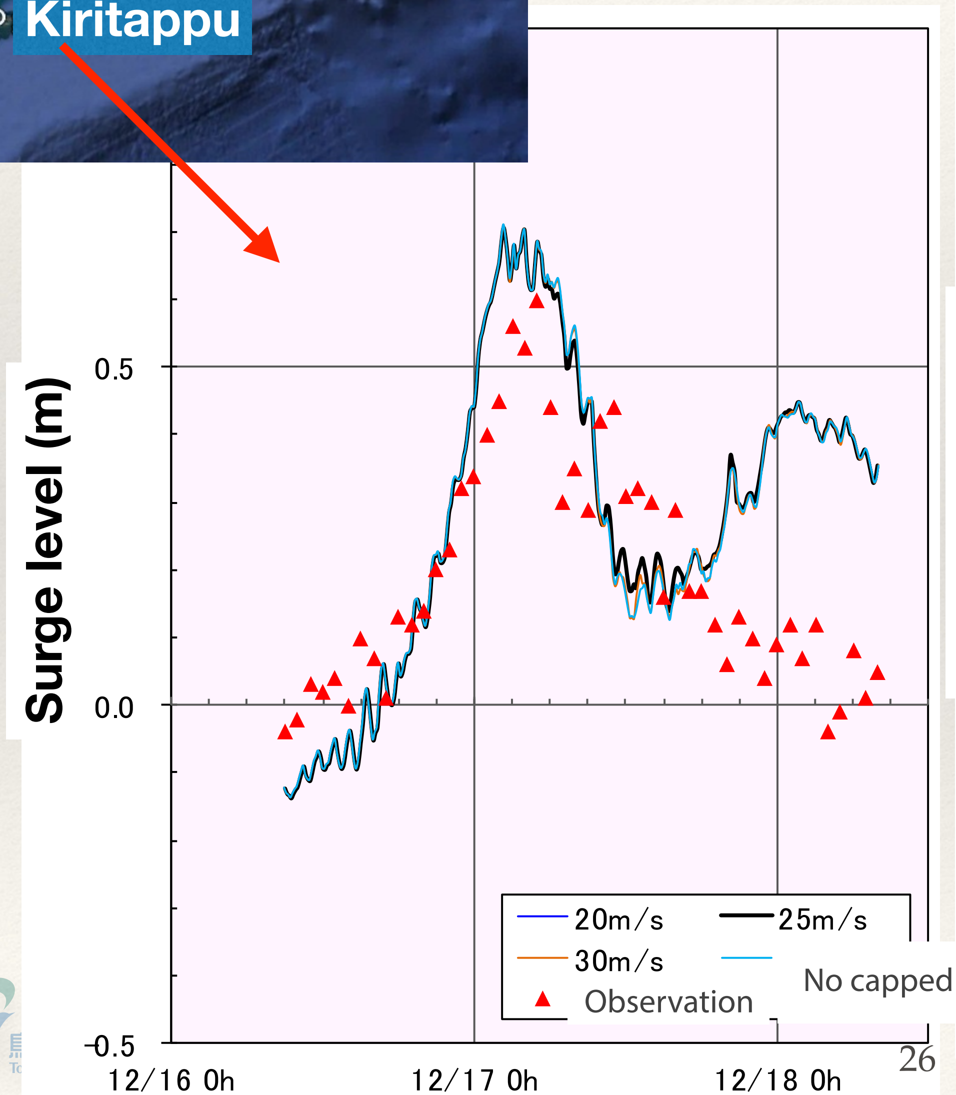


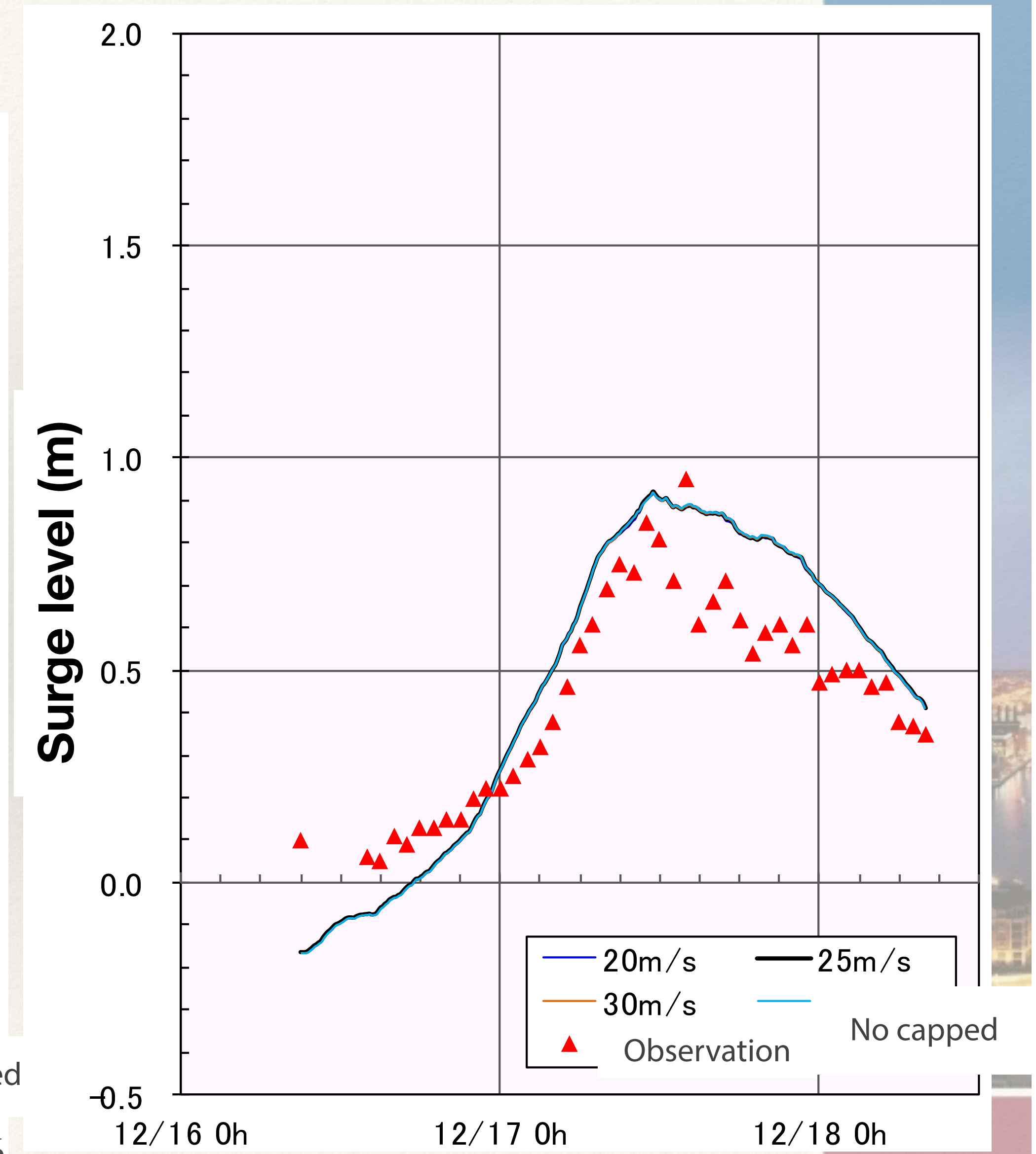




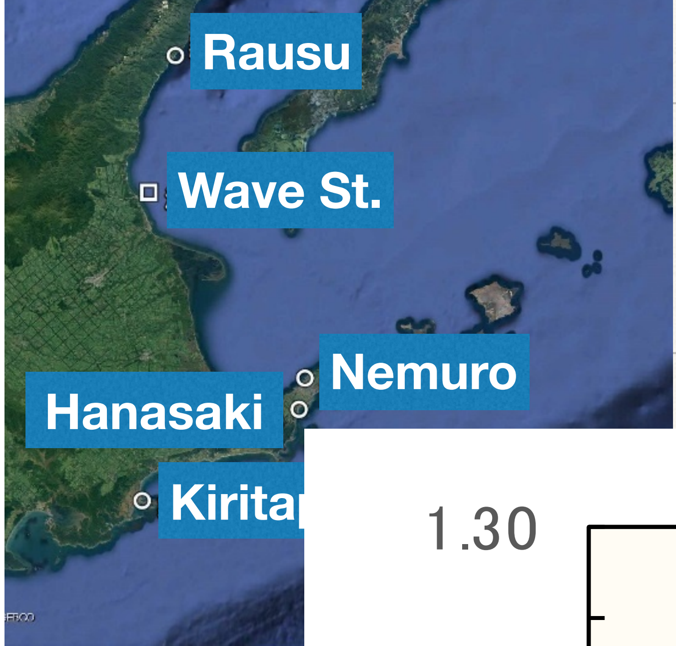
Results: Surge levels

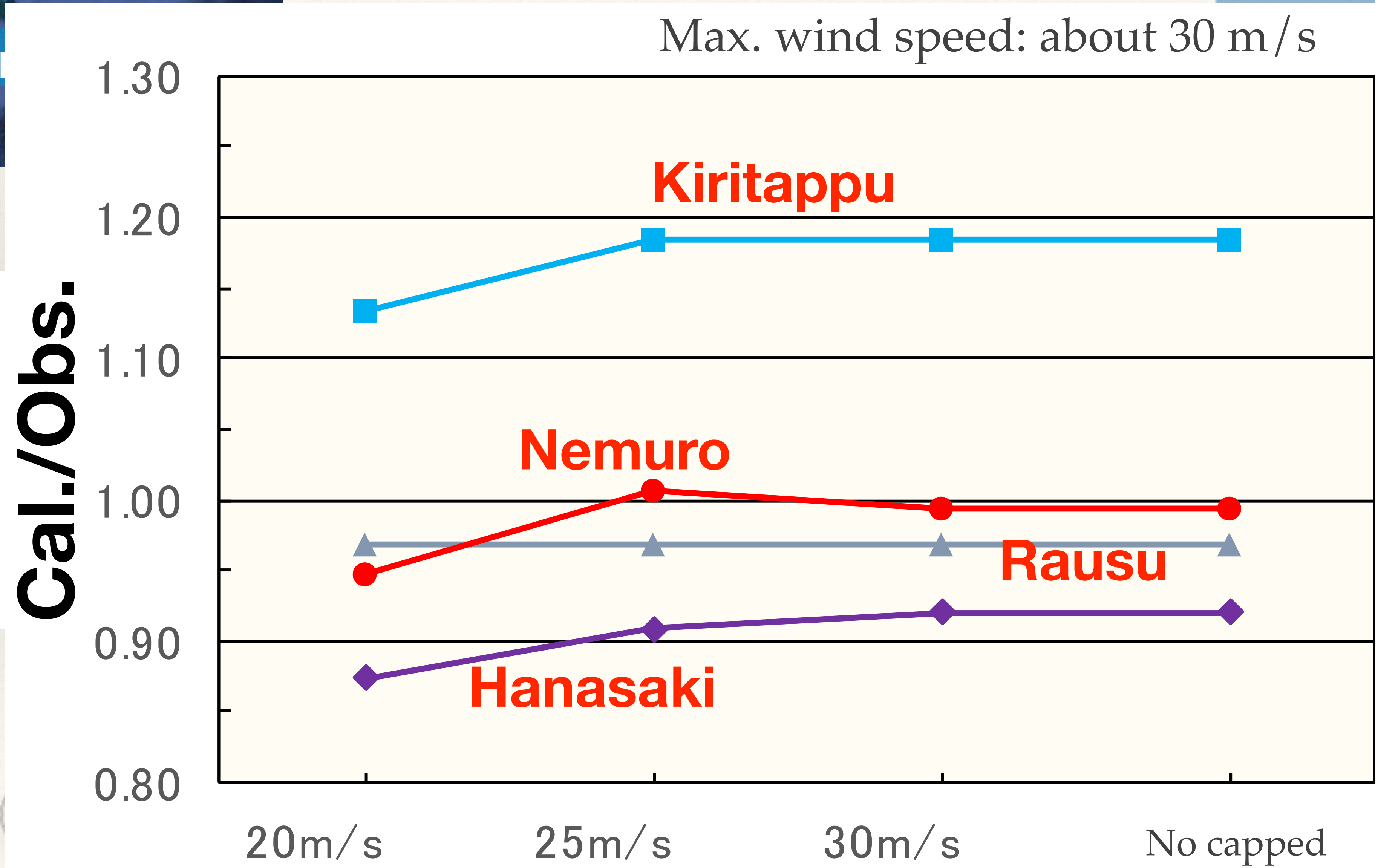




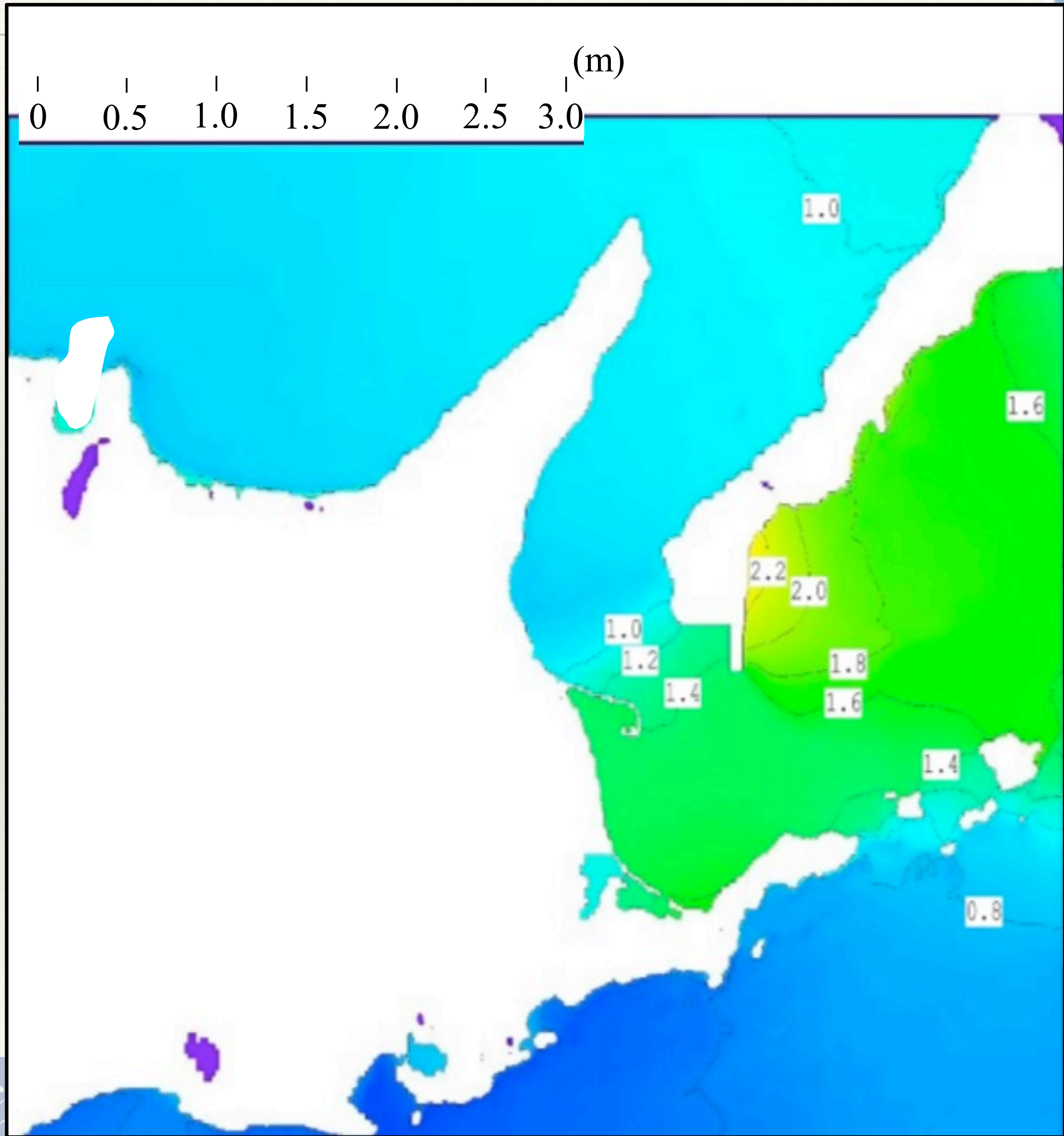


Ratio of cal. / Obs. for Max. level

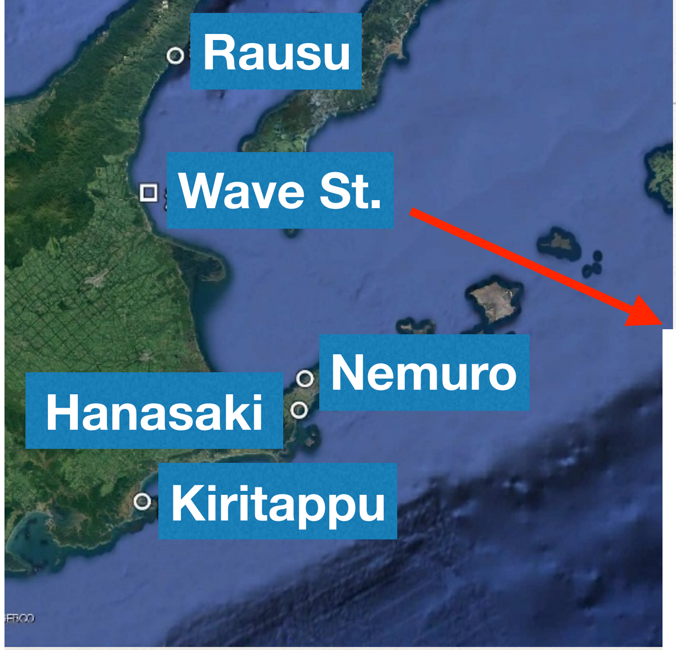


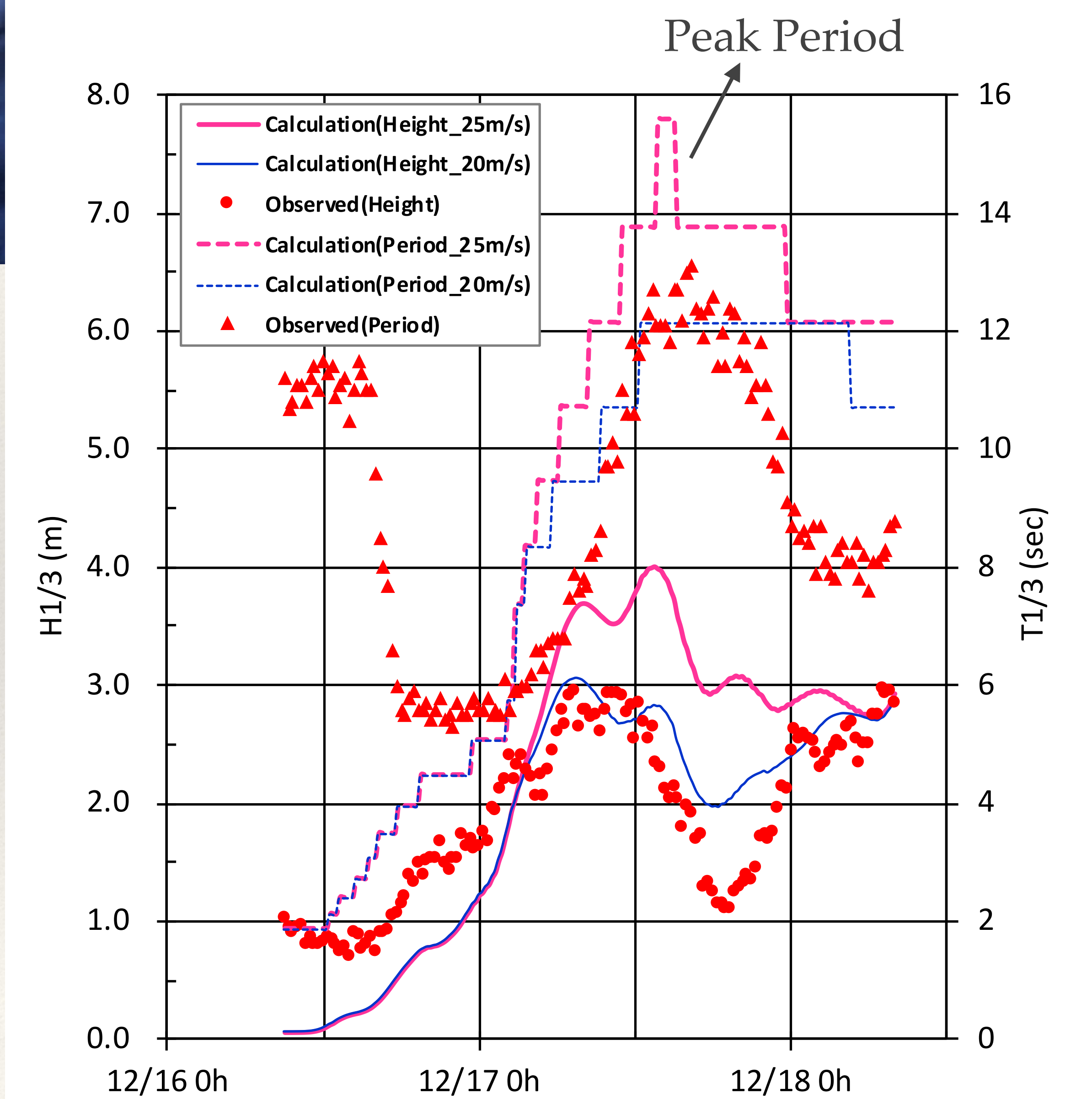


Results: Max. surge levels (25 m/s capped)

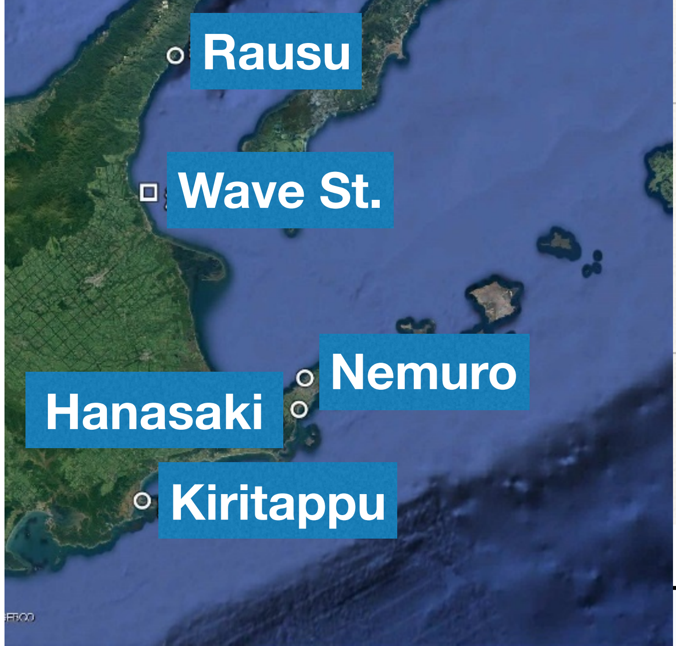


Results: Waves

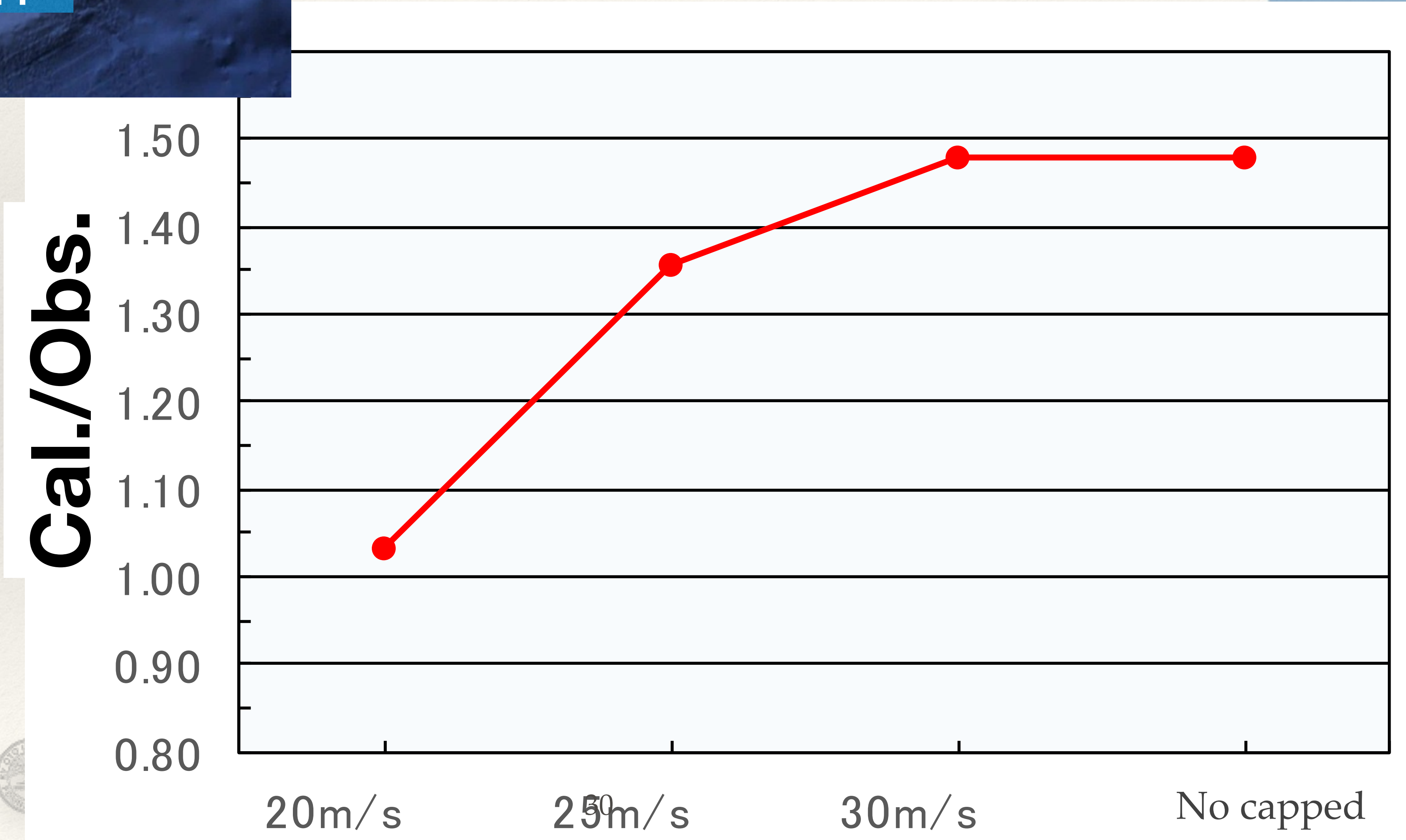




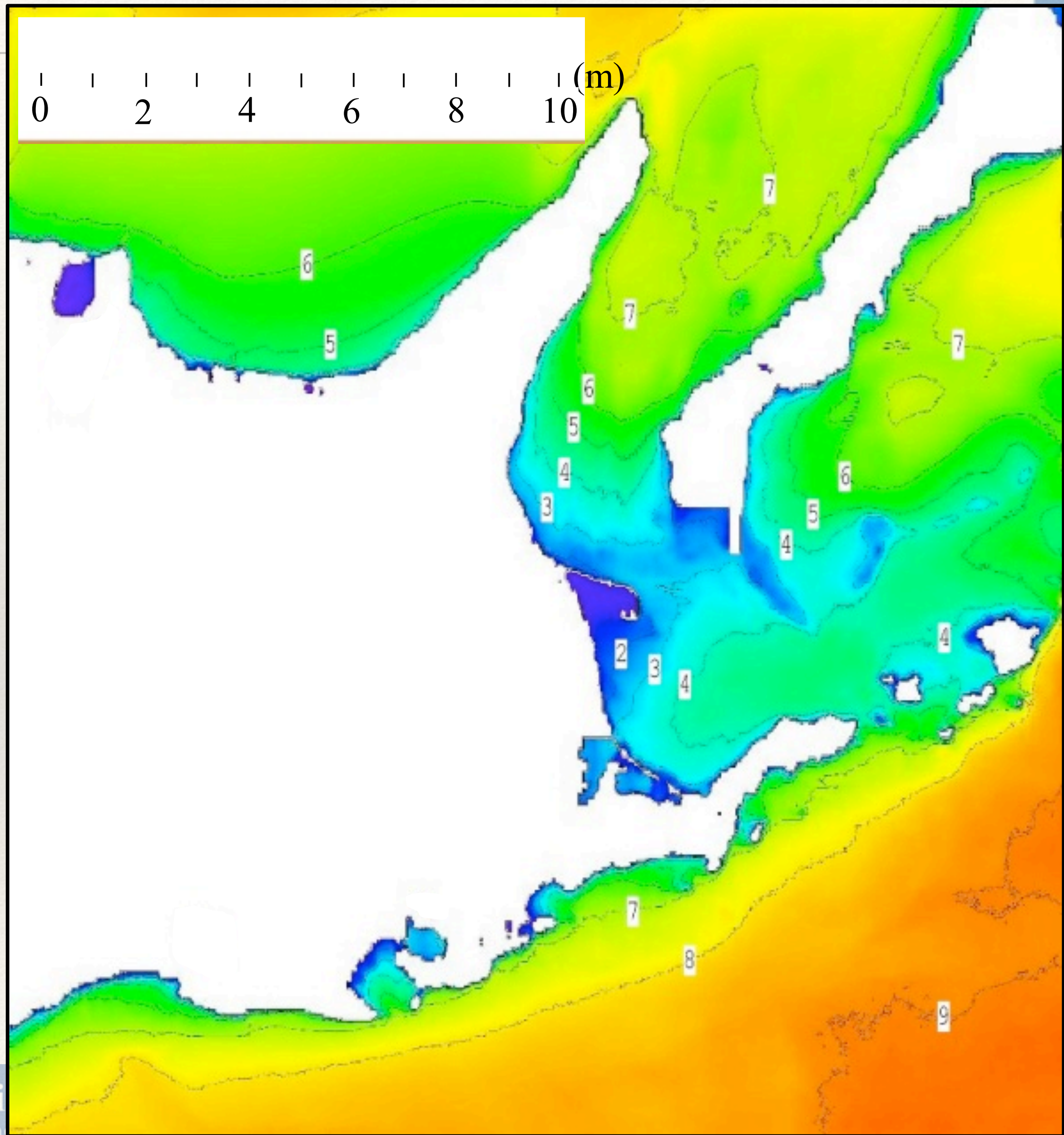
Ratio of cal. / Obs. for Max. Hs



Max. wind speed: about 30 m/s



Results: Max. Hs (20 m/s capped)



Summaries

- Winter Low Pressure System (WLPS) 2014 induced the record-break surge level in Hokkaido.
- A series of surge and wave coupled simulations was conducted by using the coupled model of SuWAT
  - wind speed capped wave dependent drag coef.
  - wave-current interaction-induced bottom drag coef.
- Leveling off at 20 m/s was best for waves at one station
- Leveling off at 25 m/s was best for surges at 4 station
- Discrepancy of the specific wind speed for the leveling off has to be investigated.
  - tides?
  - more observed wave data?
  - stronger typhoons/hurricanes?

Questions or comments ?

Thank you very much