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The State of the Art and Science of Coastal Engineering

Estimation of bound and released infragravity waves based on wave observation and numerical simulation in shallow water

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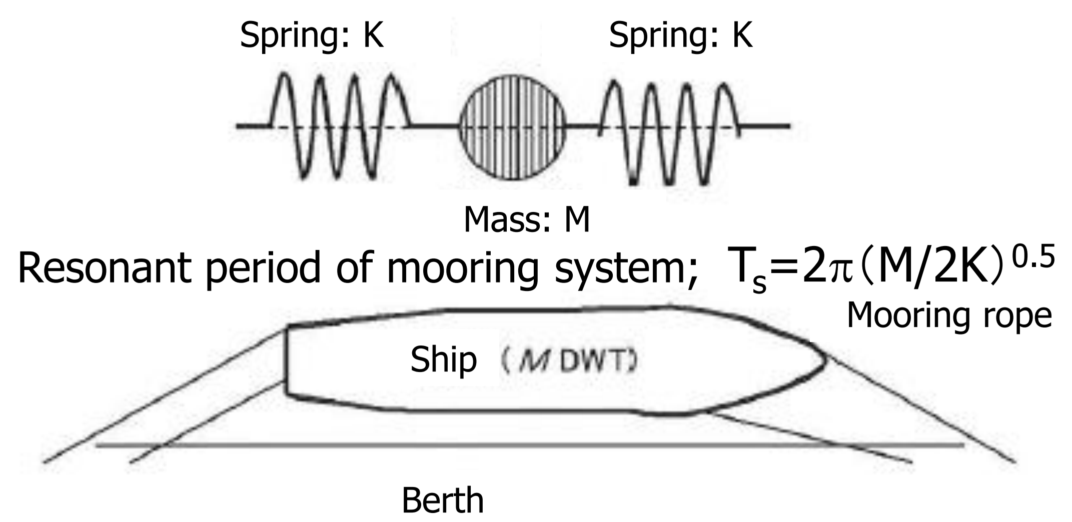
Motivation

Moored ship oscillation due to resonance of mooring system with infragravity waves



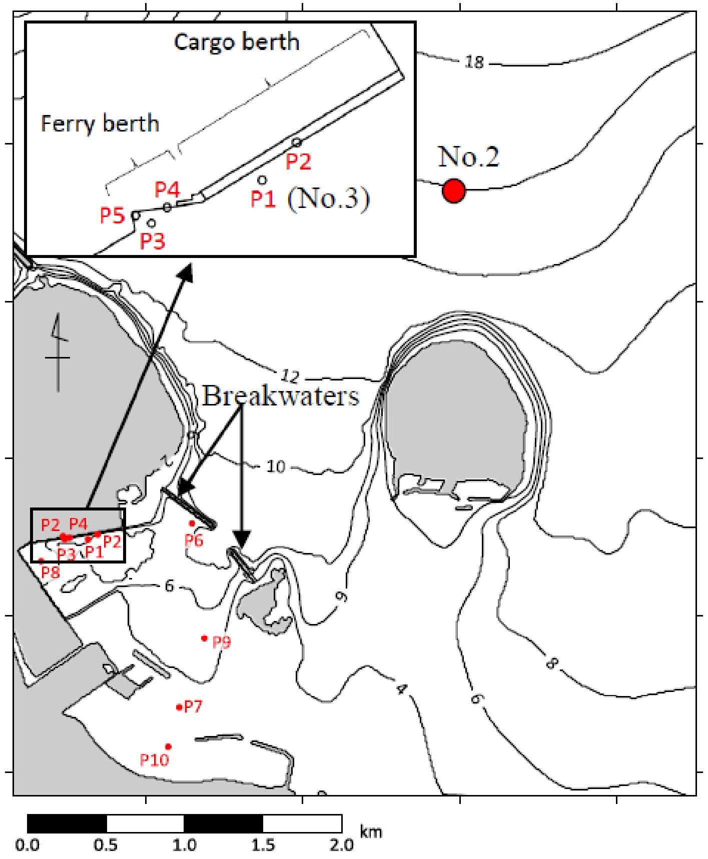
Contents

✓ <u>Introduction</u>
- Wave observation
- Standard spectrum

✓ <u>Bound infragravity waves in offshore</u>
- Estimation with observed wind waves
- Free long-period waves

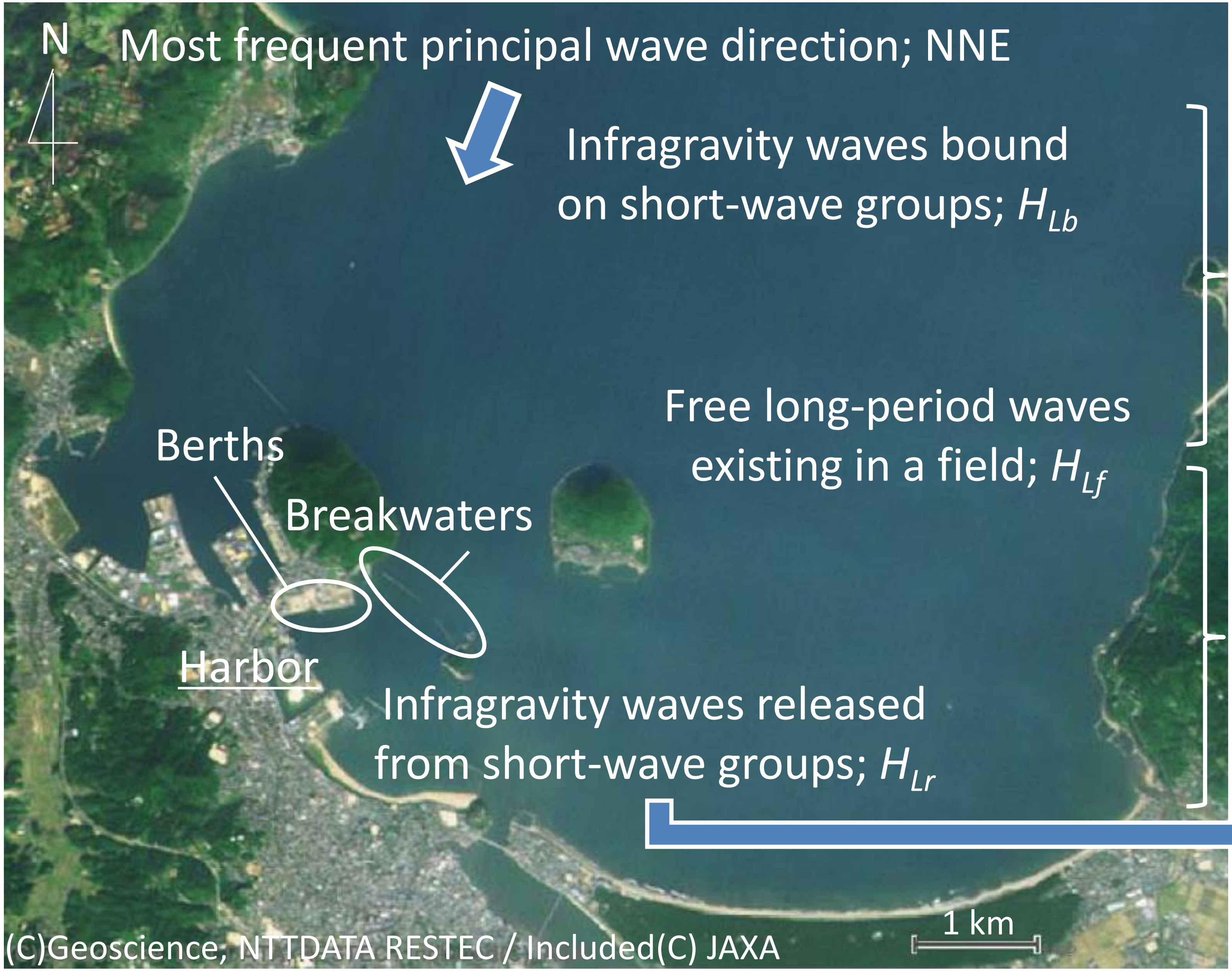
✓ <u>Released infragravity waves in harbor</u>
- Estimation using a Boussinesq model
- Evaluation with observed data

✓ <u>Conclusions</u>



Introduction

Location of the focused harbor



Observed infragravity waves may consist of …

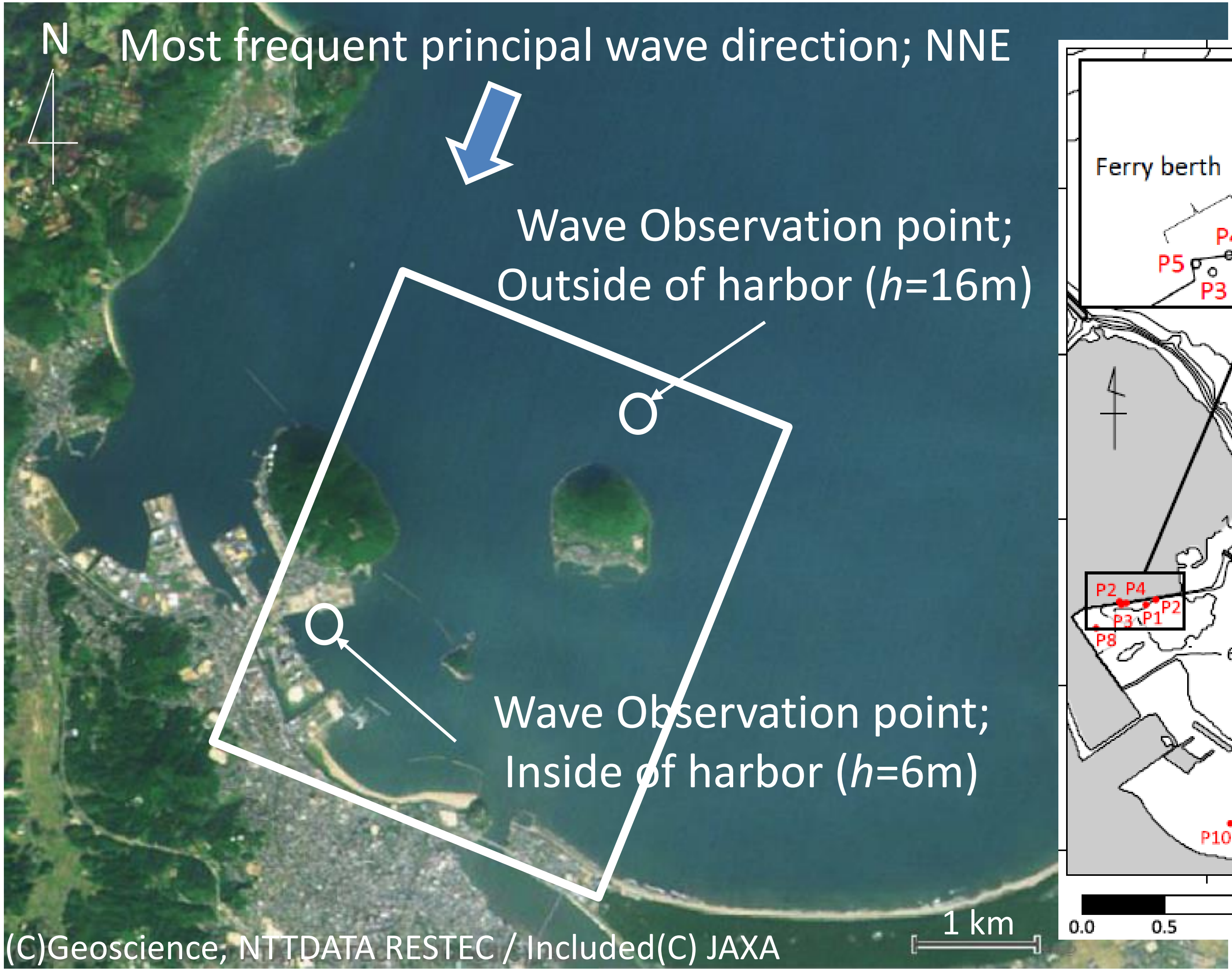
Outside of Harbor

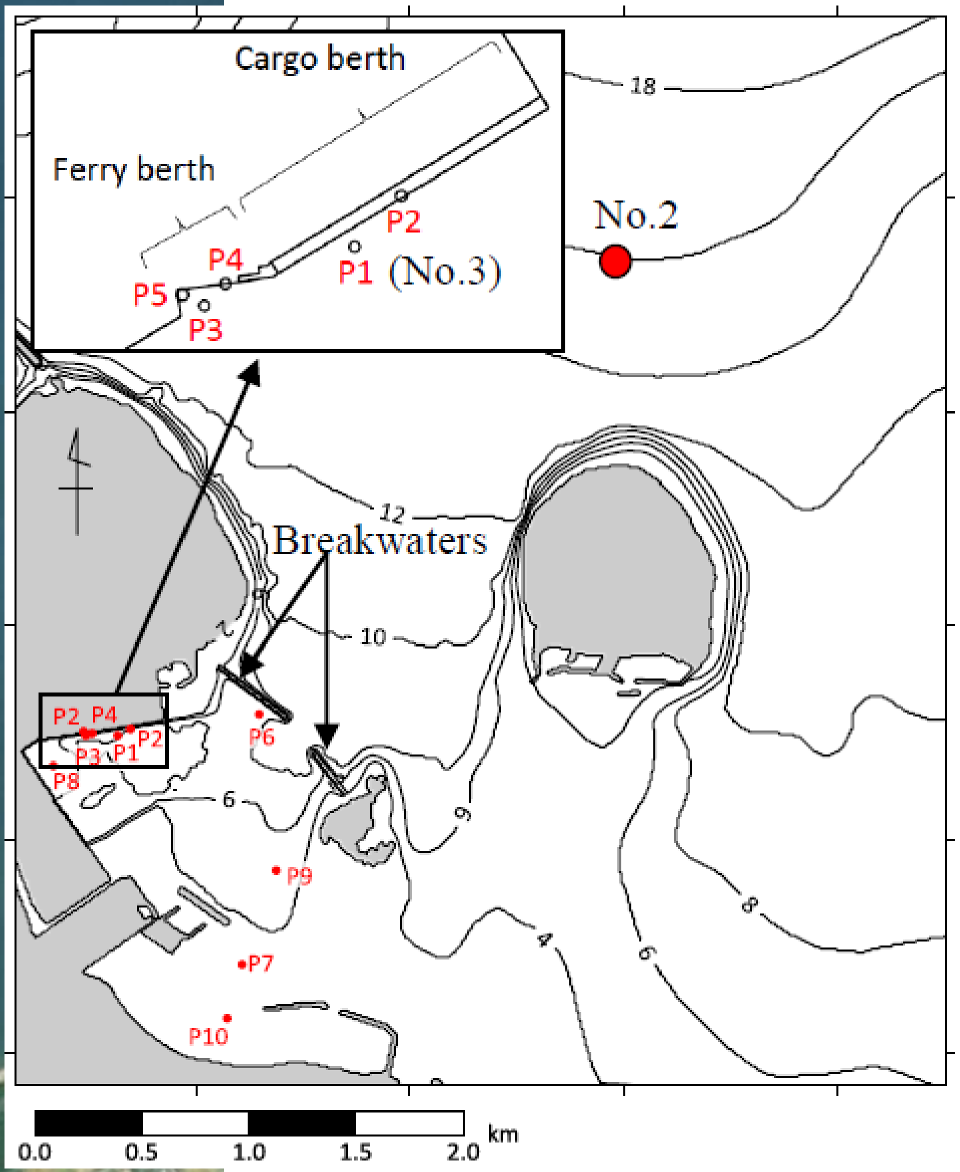
Inside of Harbor

Affecting to oscillation of a moored ship

Introduction

observation points for wind waves: H_S and infragravity waves: H_L

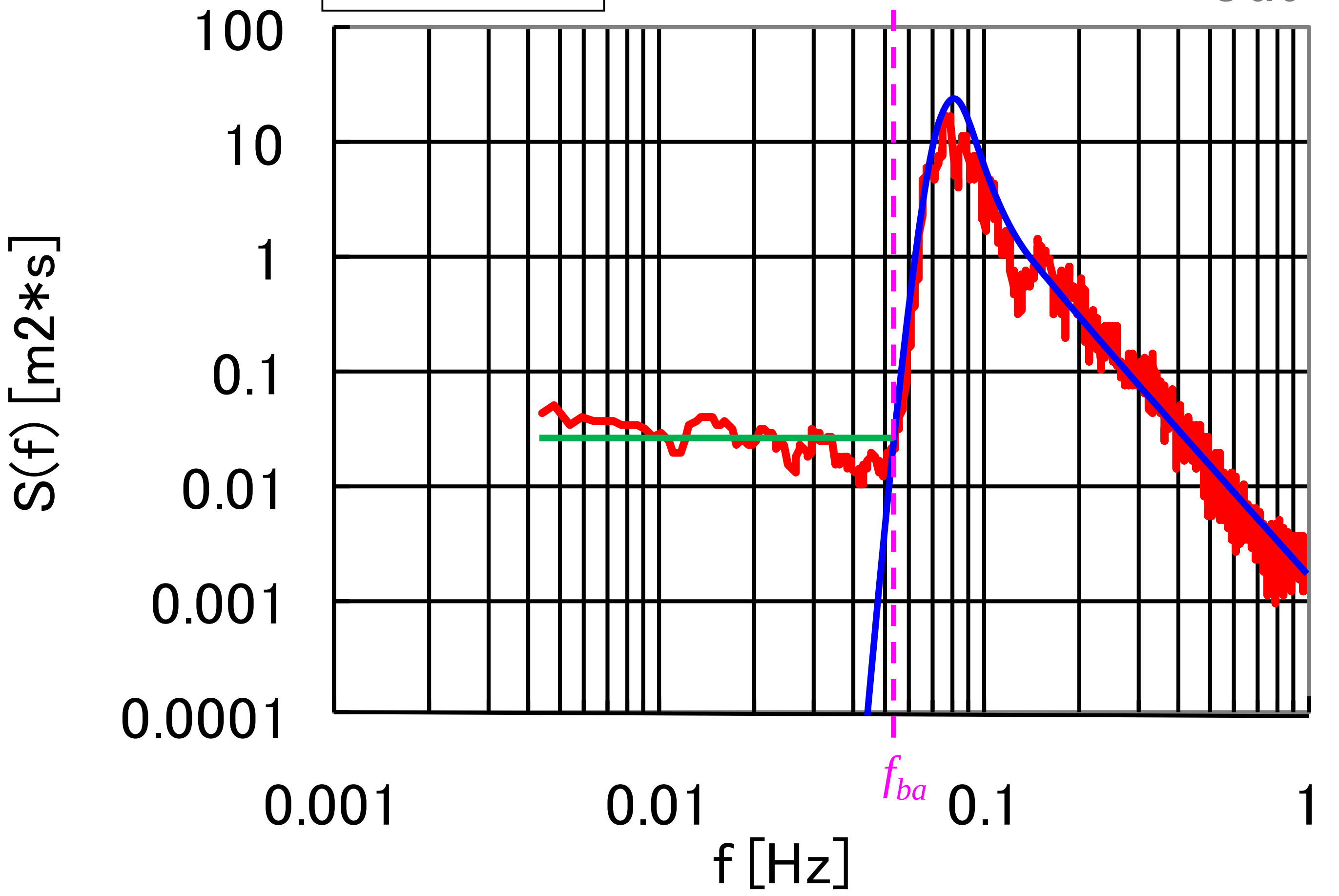




Standard spectrum for infragravity waves (Outside)

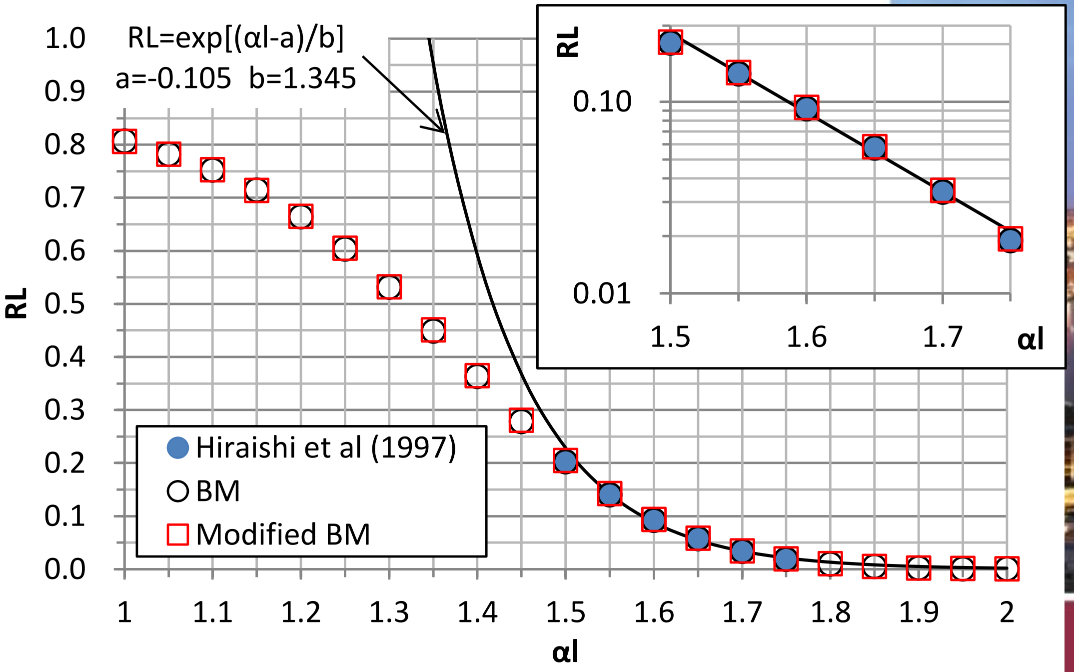
Hiraishi et al (1997): Standard spectrum for long period waves, Proc. Coastal Eng., JSCE, Vol.44, pp.246-250.

$f_{ba} = f_p / \alpha_l$ f_p: Peak frequency of wind wave



$$R_L = \sqrt{m_{0L}/m_0} = H_L/H_S$$

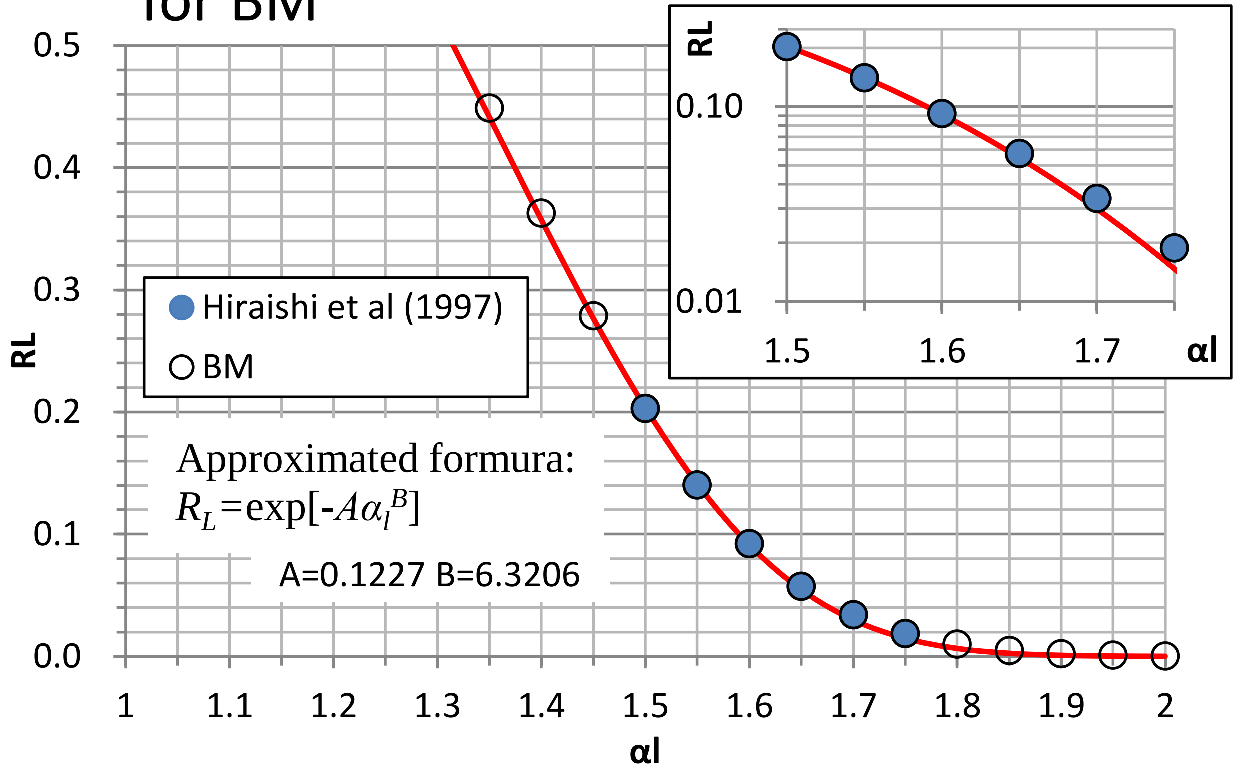
$$\begin{cases} m_0 = \int_0^\infty S(f)df \\ m_{0L} = \int_{f_0}^{f_{ba}} S(f)df \end{cases} \quad f_0 = 1/300\,[\text{Hz}]$$



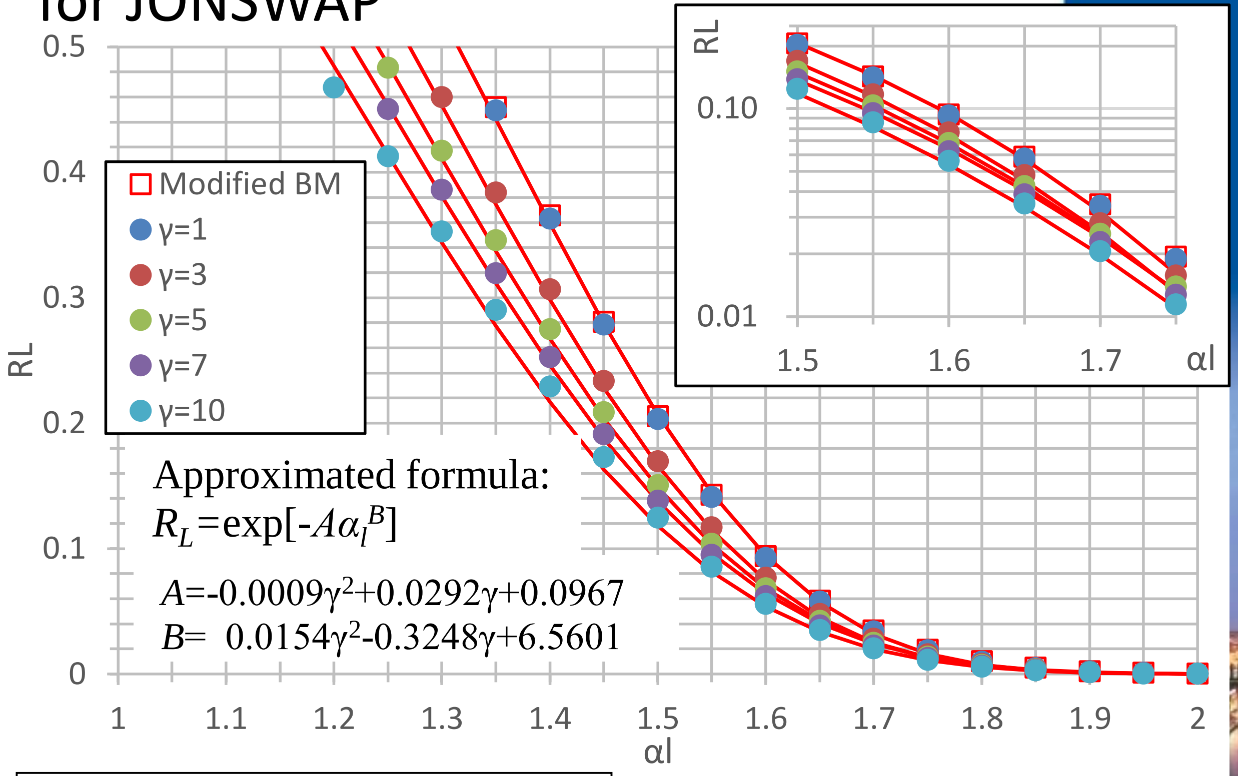
Standard spectrum for infragravity waves (Outside)

Newly proposed relational function between α_l and R_L for not only BM but JONSWAP

for BM



for JONSWAP



$$\alpha_l = \left[-(1/A)\ln R_L\right]^{(1/B)} \Leftrightarrow R_L = \exp\left[-A\alpha_l^{\,B}\right]$$

$$R_L = \sqrt{m_{0L}/m_0} = H_L/H_S$$

$$f_{ba} = f_p/\alpha_l$$

$$\begin{cases} A = 0.1227 \\ B = 6.3206 \end{cases}$$ for BM

$$\begin{cases} A = -0.0009\gamma^2 + 0.0292\gamma + 0.0967 \\ B = \quad 0.0154\gamma^2 - 0.3248\gamma + 6.5601 \end{cases}$$ for JONSWAP

(γ: peak parameter)

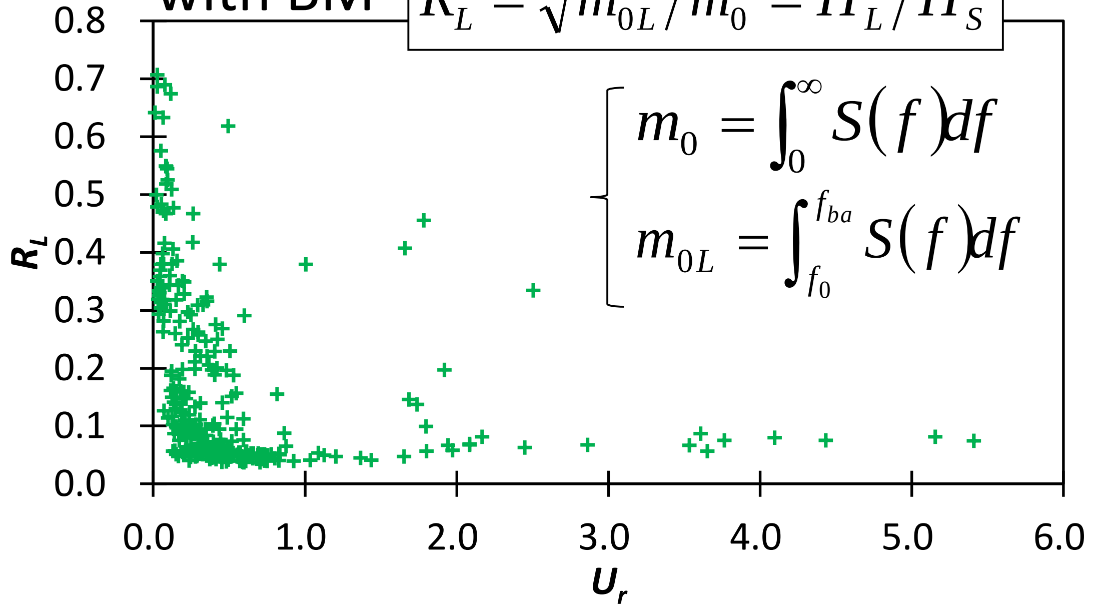
Estimation of infragravity waves bound on wave groups

Distribution of R_L calculated with BM or JONSWAP to waves (U_r) observed at Outside

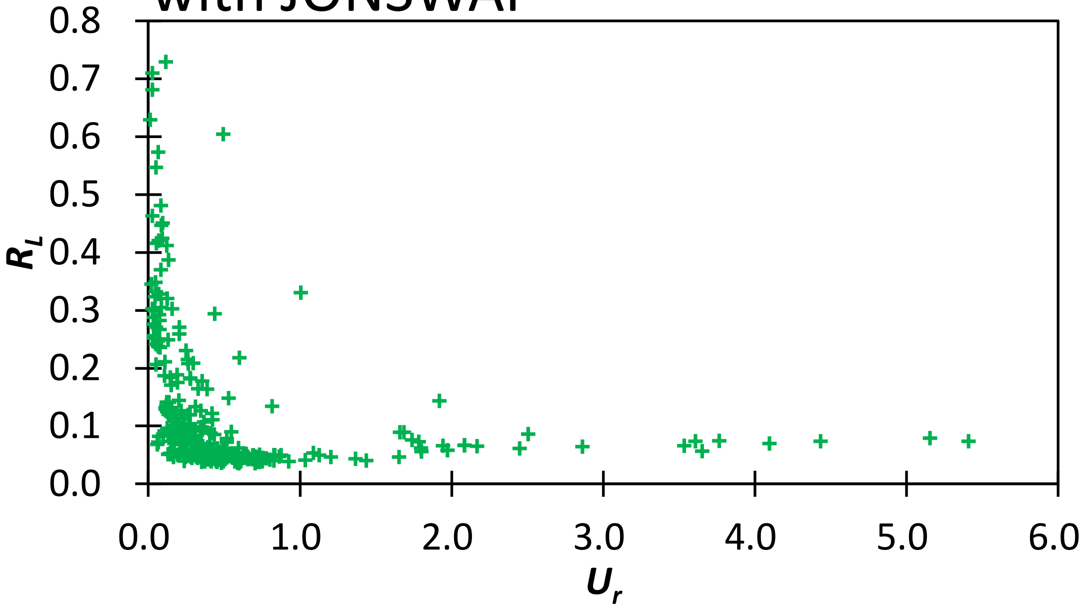
with BM

$$R_L = \sqrt{m_{0L}/m_0} = H_L/H_S$$

$$\begin{cases} m_0 = \int_0^{\infty} S(f)df \\ m_{0L} = \int_{f_0}^{f_{ba}} S(f)df \end{cases}$$



with JONSWAP



Ursell number: $U_r = H_S L_S{}^2 / h^3$

H_S: significant wave height
L_S: wave length for significant wave period
h : water depth at observation point

Each peak parameter of JS for observed wave spectrum is estimated by Mitsuyasu et al (1980)

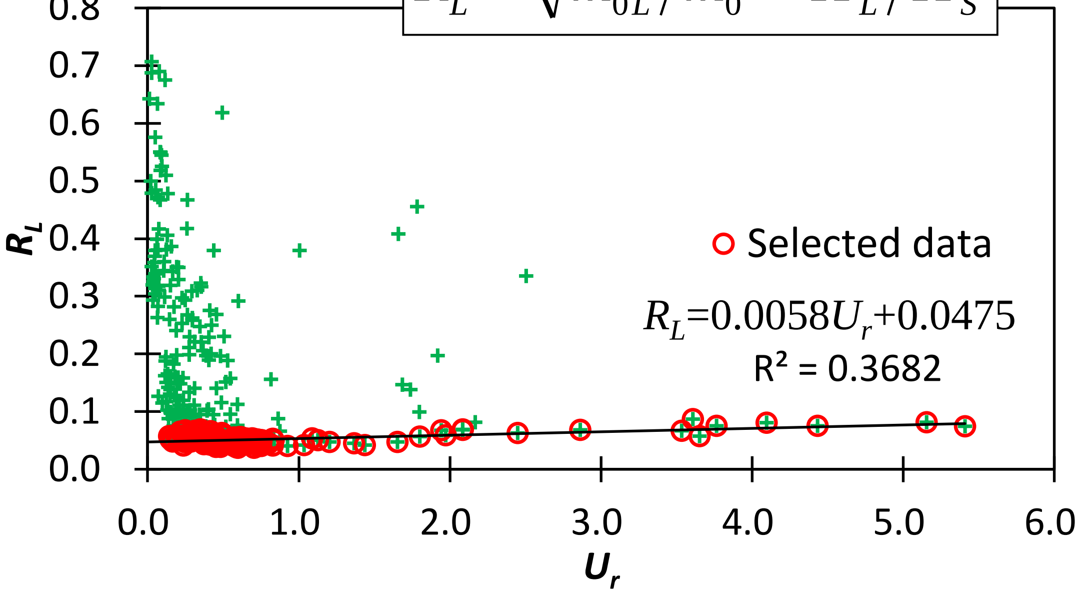
$$\gamma = S(f_p)(2\pi)^4 f_p{}^5 \exp(5/4)(\alpha_g g^2)^{-1}$$

$$\alpha_g = (0.65 f_p)^{-1} \int_{1.35 f_p}^{2 f_p} (2\pi)^4 f^5 g^{-2} \exp\left[\frac{5}{4}\left(\frac{f}{f_p}\right)^{-4}\right] S(f)df$$

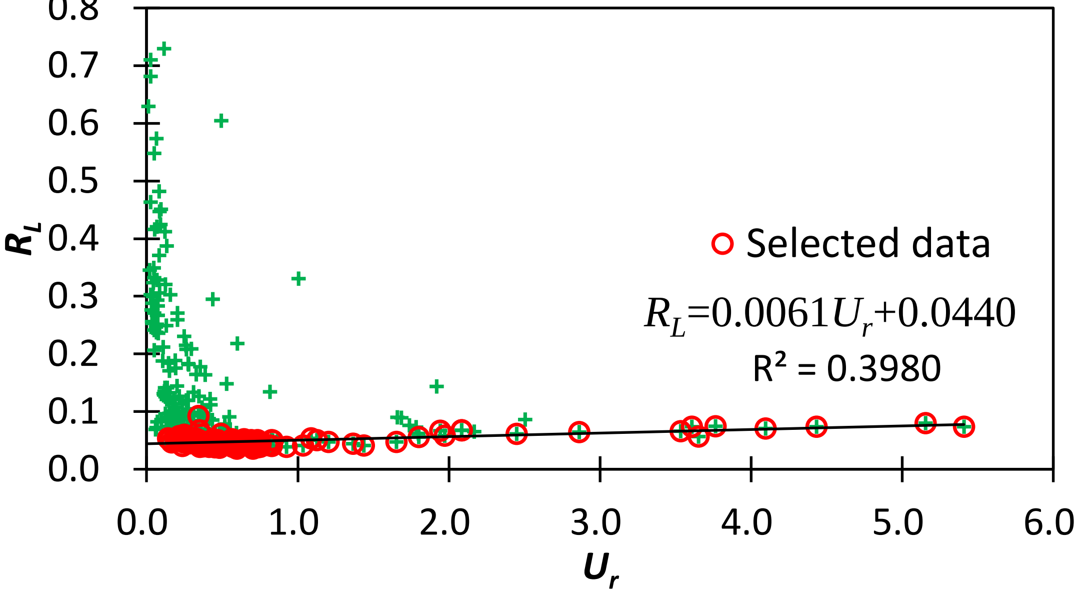
Estimation of infragravity waves bound on wave groups

Distribution of R_L calculated with BM or JONSWAP to waves (U_r) observed at Outside

with BM $R_L = \sqrt{m_{0L}/m_0} = H_L/H_S$



with JONSWAP



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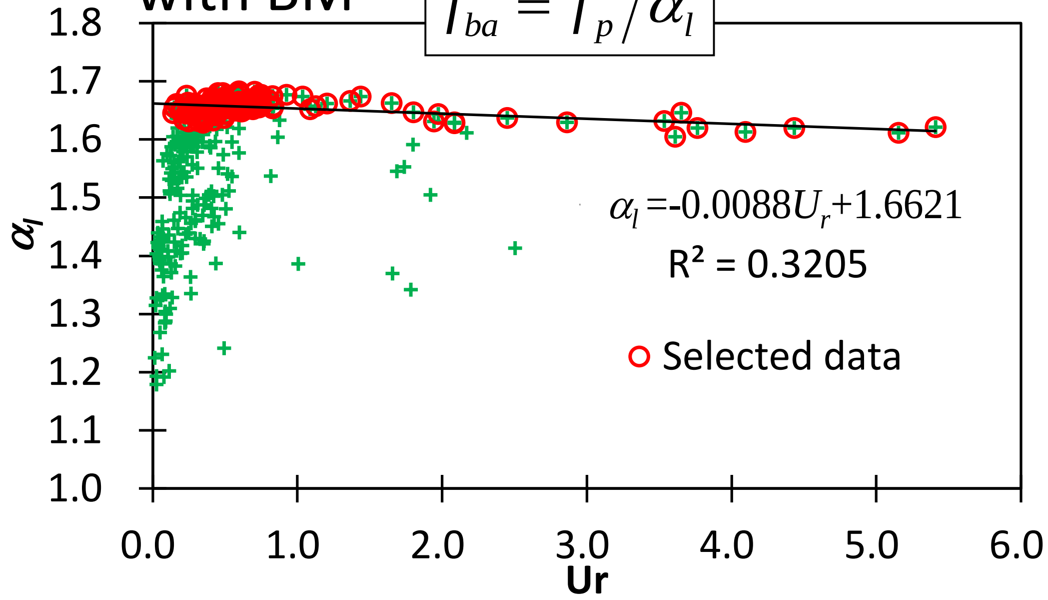
Selected data: the peak of wind wave spectrum is single in storm period.

Estimation of infragravity waves bound on wave groups

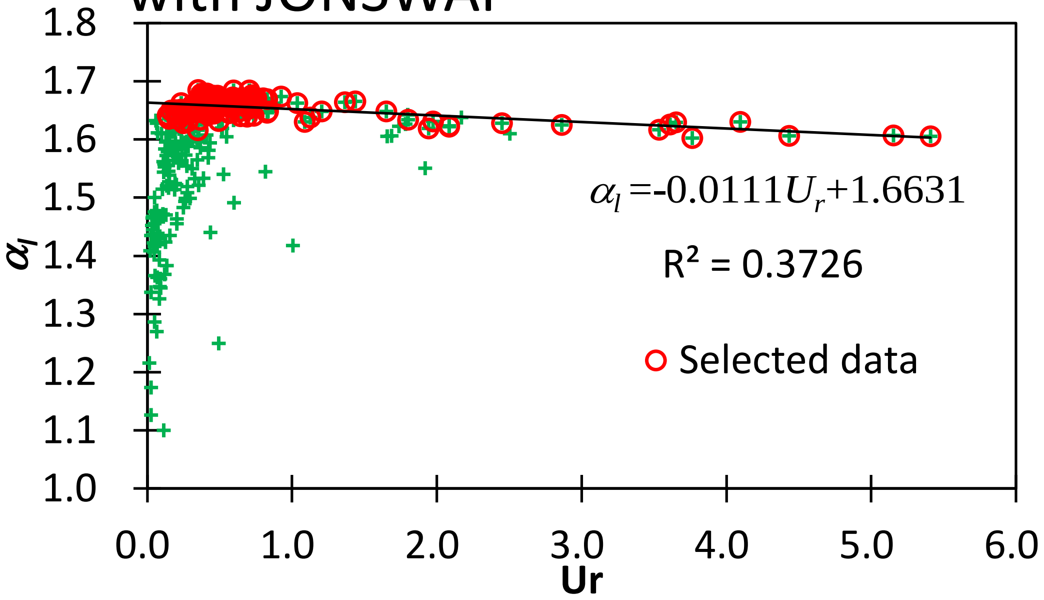
Distribution of α_l calculated with BM or JONSWAP to waves (U_r) observed at Outside

with BM

$$f_{ba} = f_p / \alpha_l$$



with JONSWAP



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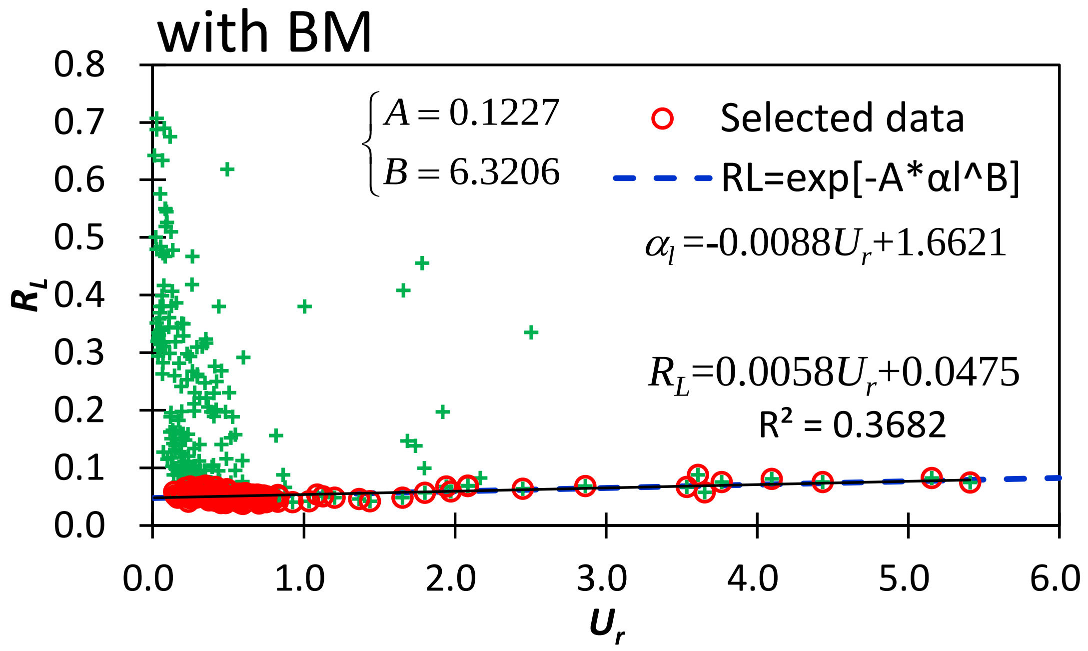
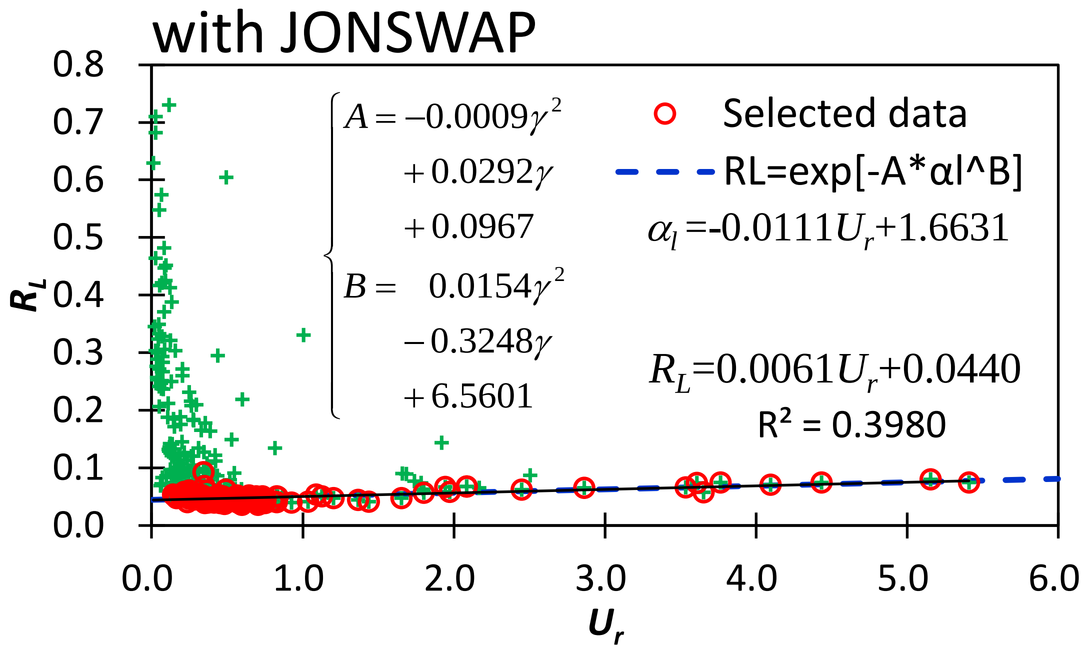
Estimation of infragravity waves bound on wave groups

Distribution of R_L calculated with BM or JONSWAP to waves (U_r) observed at Outside





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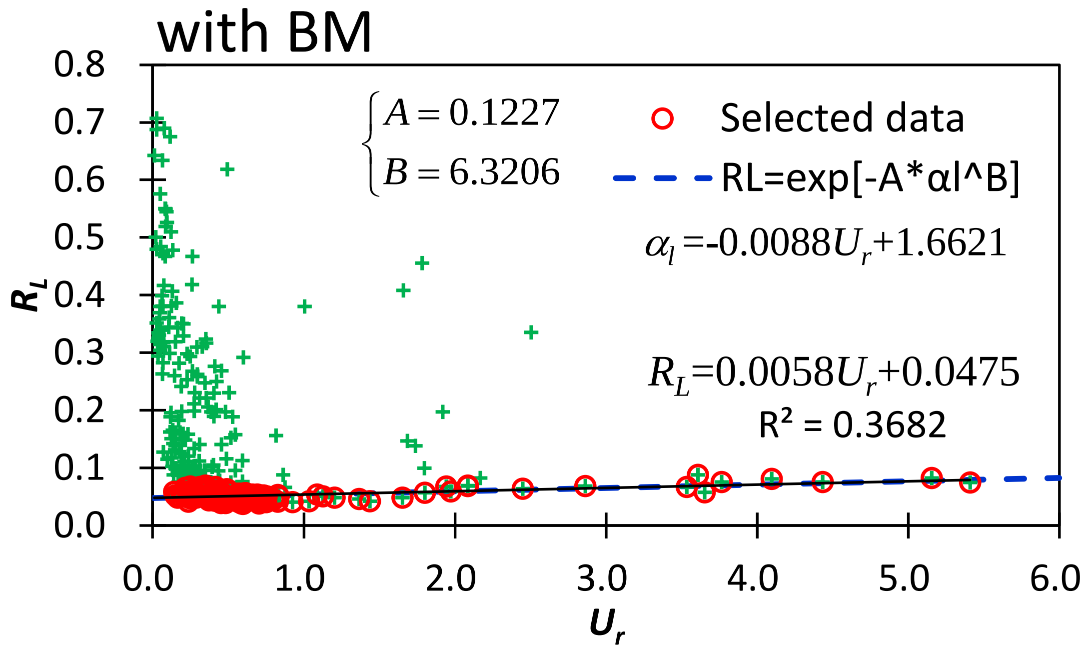
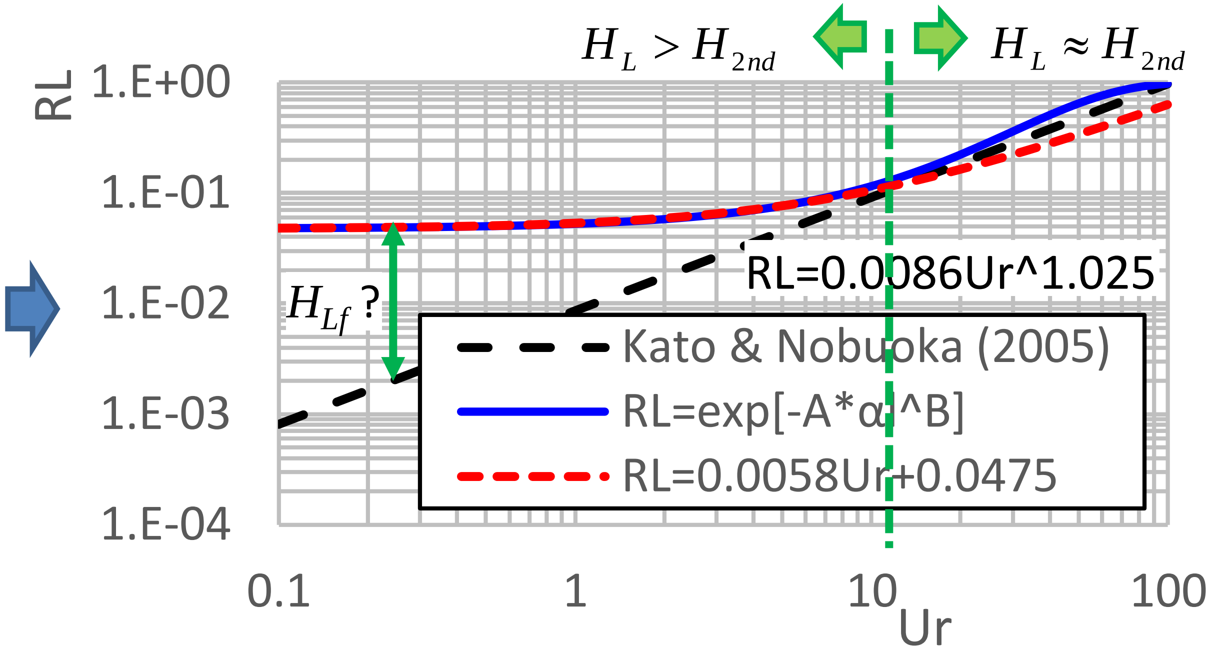
Estimation of infragravity waves bound on wave groups

Distribution of R_L calculated with BM or JONSWAP to waves (U_r) observed at Outside





Comparing to the relation between H_{2nd}/H_S and U_r

Ursell number: $U_r = H_S L_S{}^2 / h^3$

H_S: significant wave height

L_S: wave length for significant wave period

h : water depth at observation point

H_{2nd}: semi-theoretical second-order wave height for Modified BM (JS with γ=1) (Kato & Nobuoka, 2005)

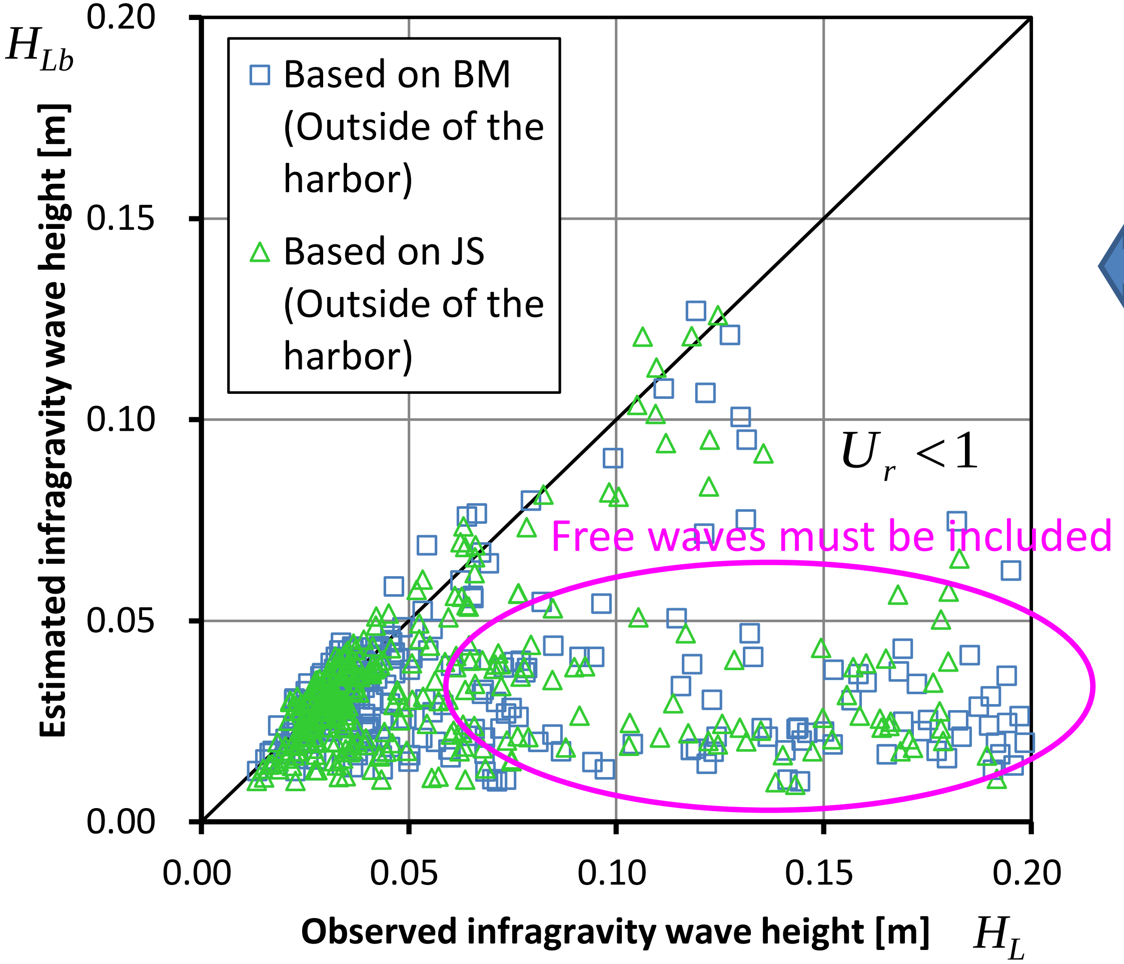
=> H_{Lb}: infragravity wave height bound on wave group

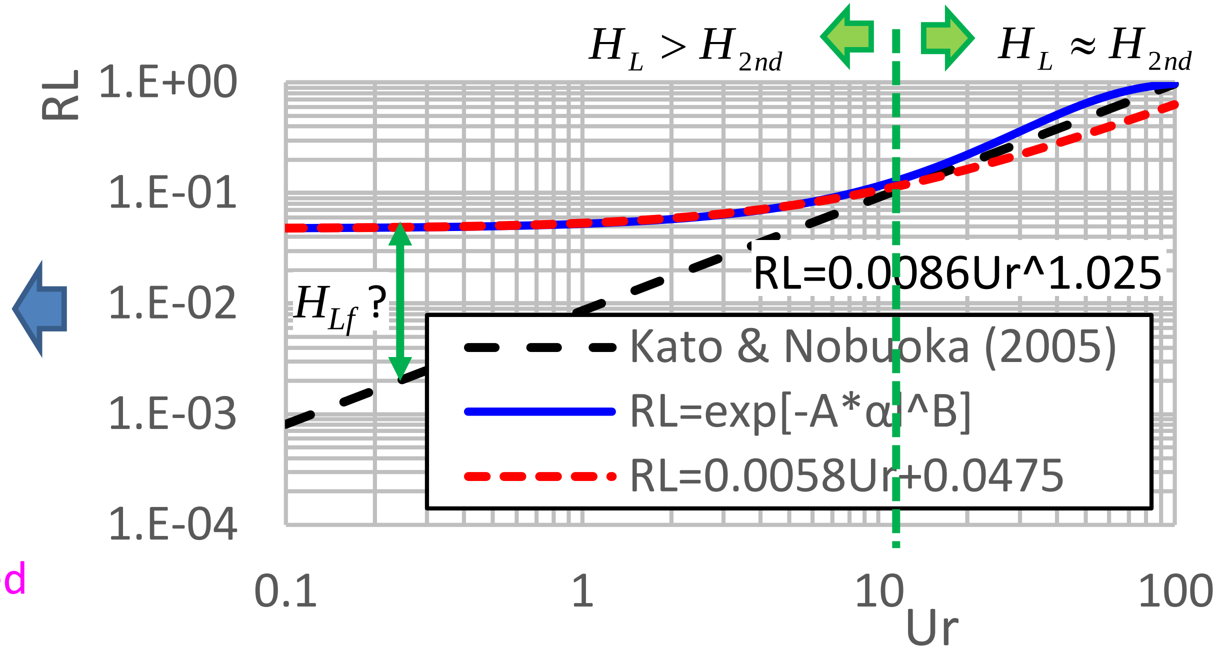
Free long wave height: $H_{Lf} = \sqrt{H_L{}^2 - H_{Lb}{}^2}$

Selected data: the peak of wind wave spectrum is single in storm period.

Estimation of free long-period waves existing in a field

Distribution of R_L calculated with BM or JONSWAP to waves (U_r) observed at Outside





Comparing to the relation between H_{2nd}/H_S and U_r

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=> H_{Lb}: infragravity wave height bound on wave group

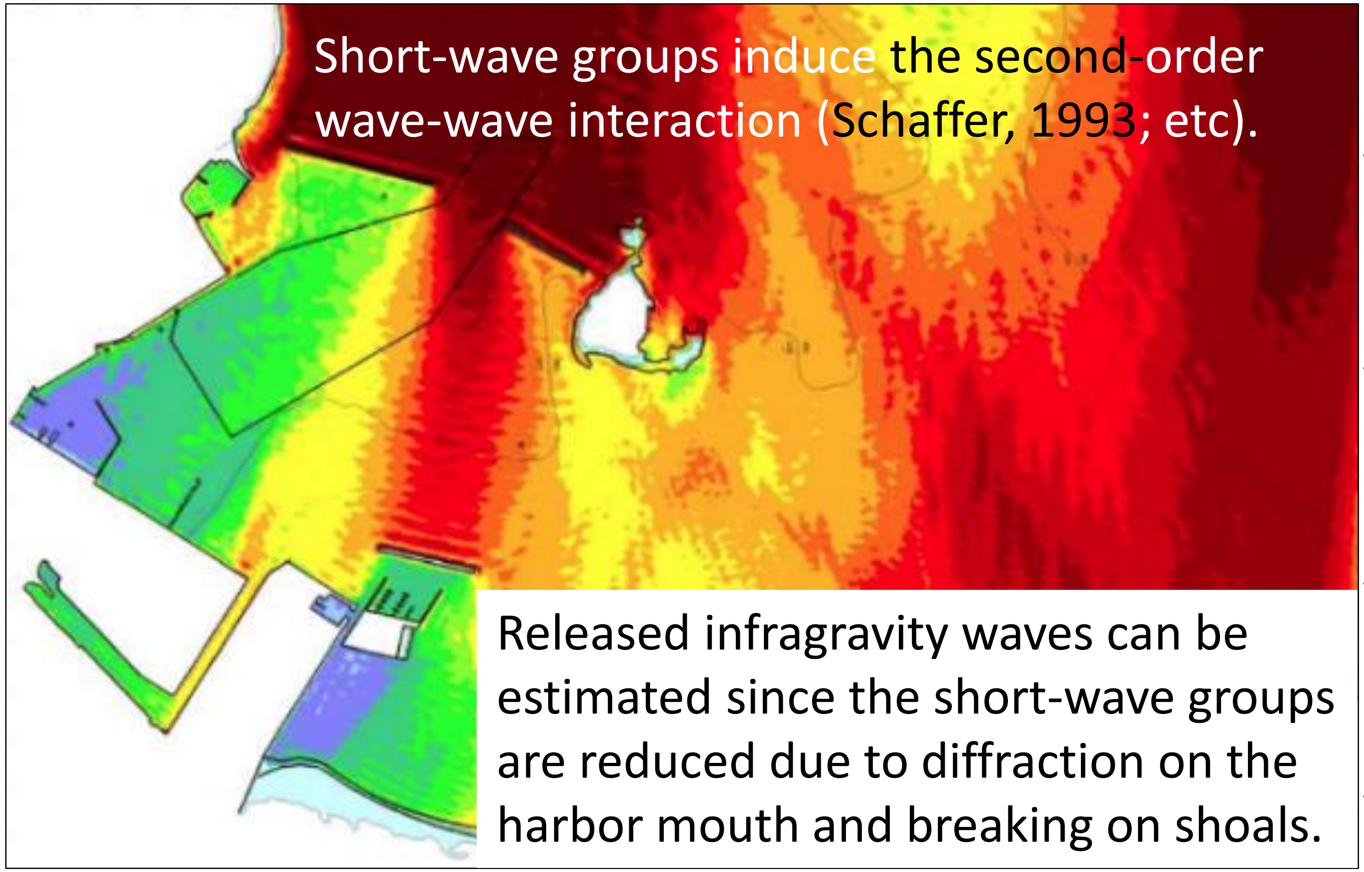
Free long wave height: $H_{Lf} = \sqrt{H_L^2 - H_{Lb}^2}$

Estimation of released waves from wave groups

Spatial distribution of H_S calculated by using a Boussinesq model for BM spectrum

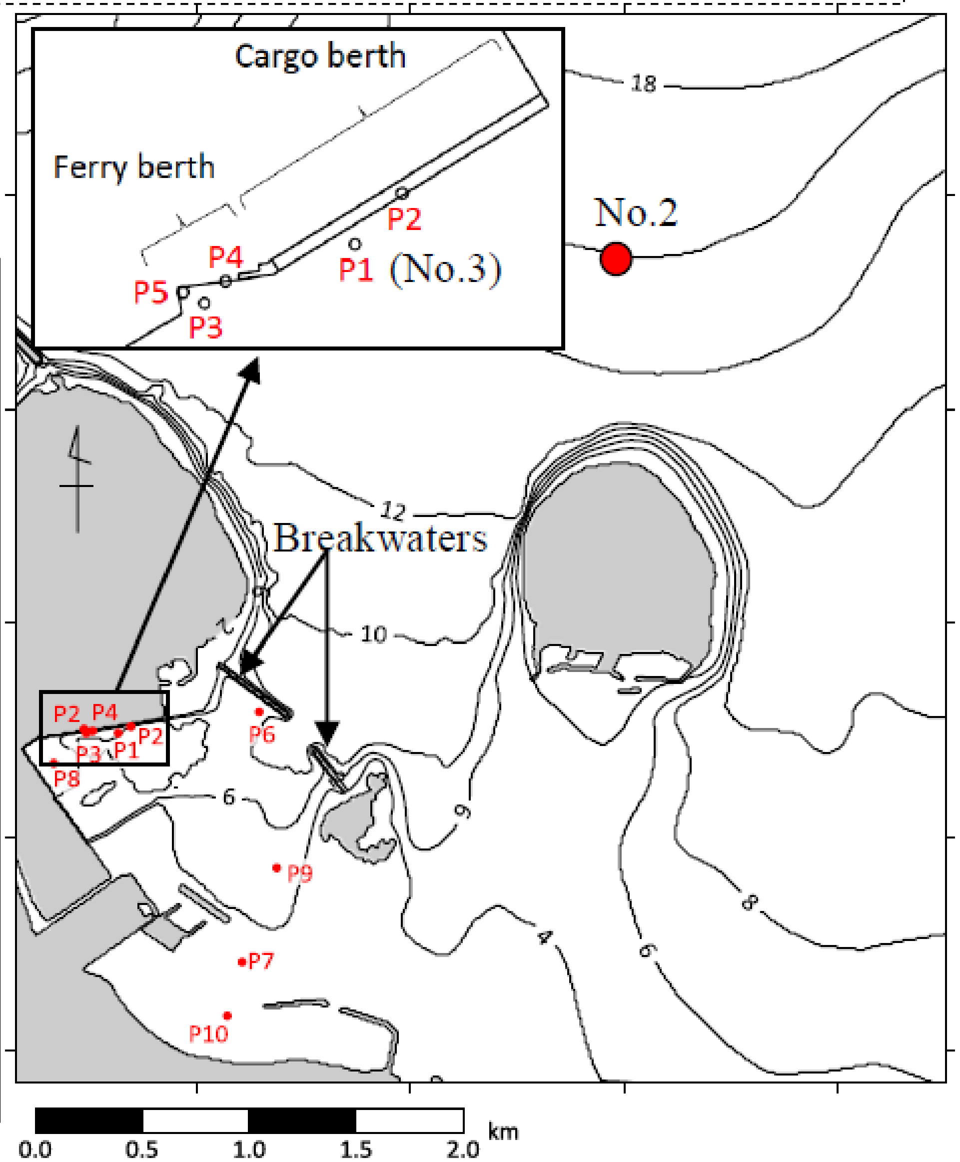
Ex) Wind wave: H_s=2.6m, T_s=12s, Principal direction: NNE and directional spreading parameter: S_{max}=75

NOWT-PARI (Hirayama and Hiraishi, 2005)



Short-wave groups induce the second-order wave-wave interaction (Schaffer, 1993; etc).

Released infragravity waves can be estimated since the short-wave groups are reduced due to diffraction on the harbor mouth and breaking on shoals.



Estimation of released waves from wave groups

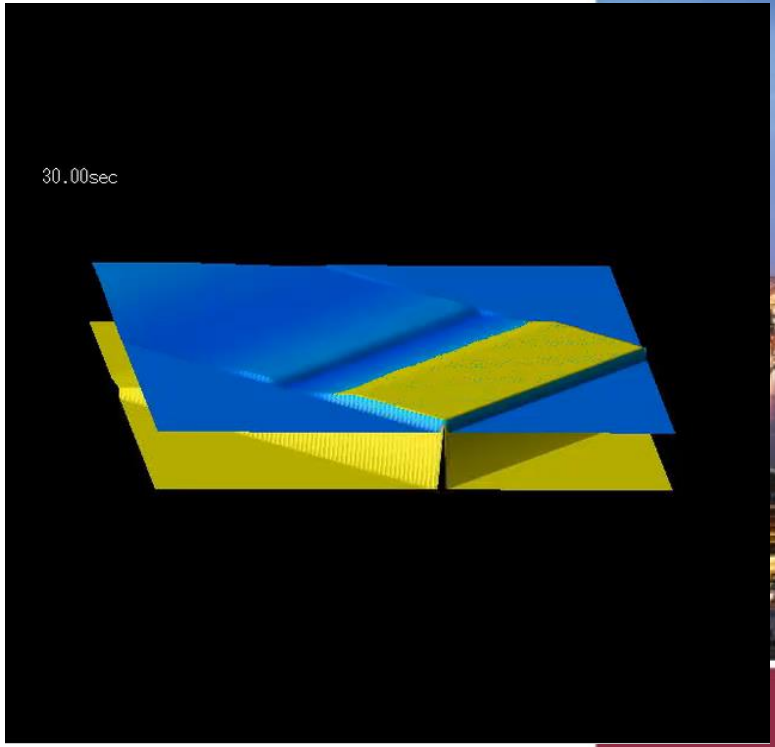
Applied Boussinesq model: NOWT-PARI Ver5.2 (Hirayama and Hiraishi, *Waves* 2005)

- Fundamental equation (Madsen & Sørensen, 1992)

$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left(\frac{P^2}{D}\right)+gD\frac{\partial \eta}{\partial x}-\nu_t\frac{\partial^2 P}{\partial x^2}=\left(B+\frac{1}{3}\right)h^2\frac{\partial^3 P}{\partial t\partial x^2}+\frac{h}{3}\frac{\partial h}{\partial x}\frac{\partial^2 P}{\partial x\partial t}+Bgh^3\frac{\partial^3 \eta}{\partial x^3}+2Bgh^2\frac{\partial h}{\partial x}\frac{\partial^2 \eta}{\partial x^2}$$

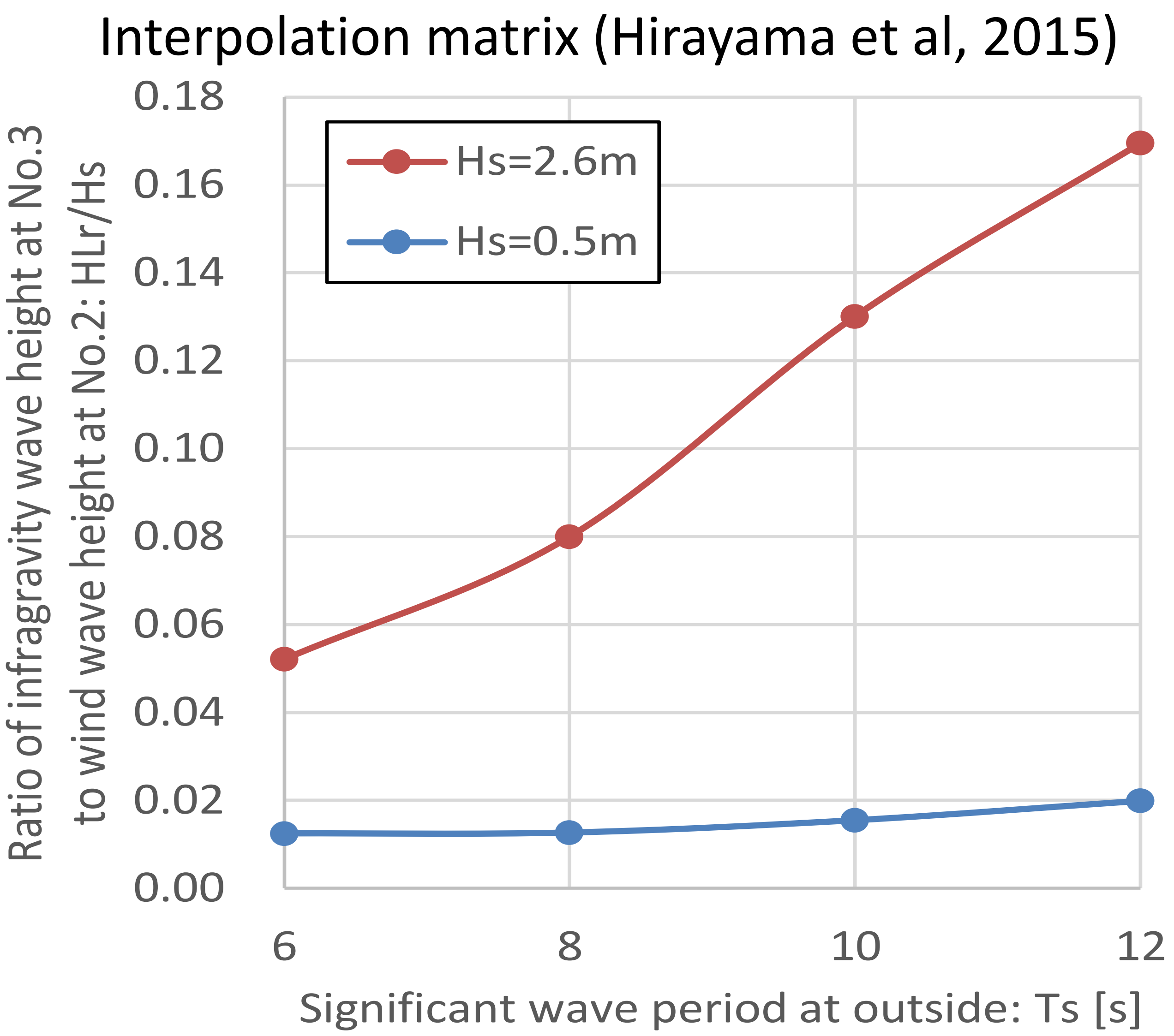
Momentum diffusion term due to breaking

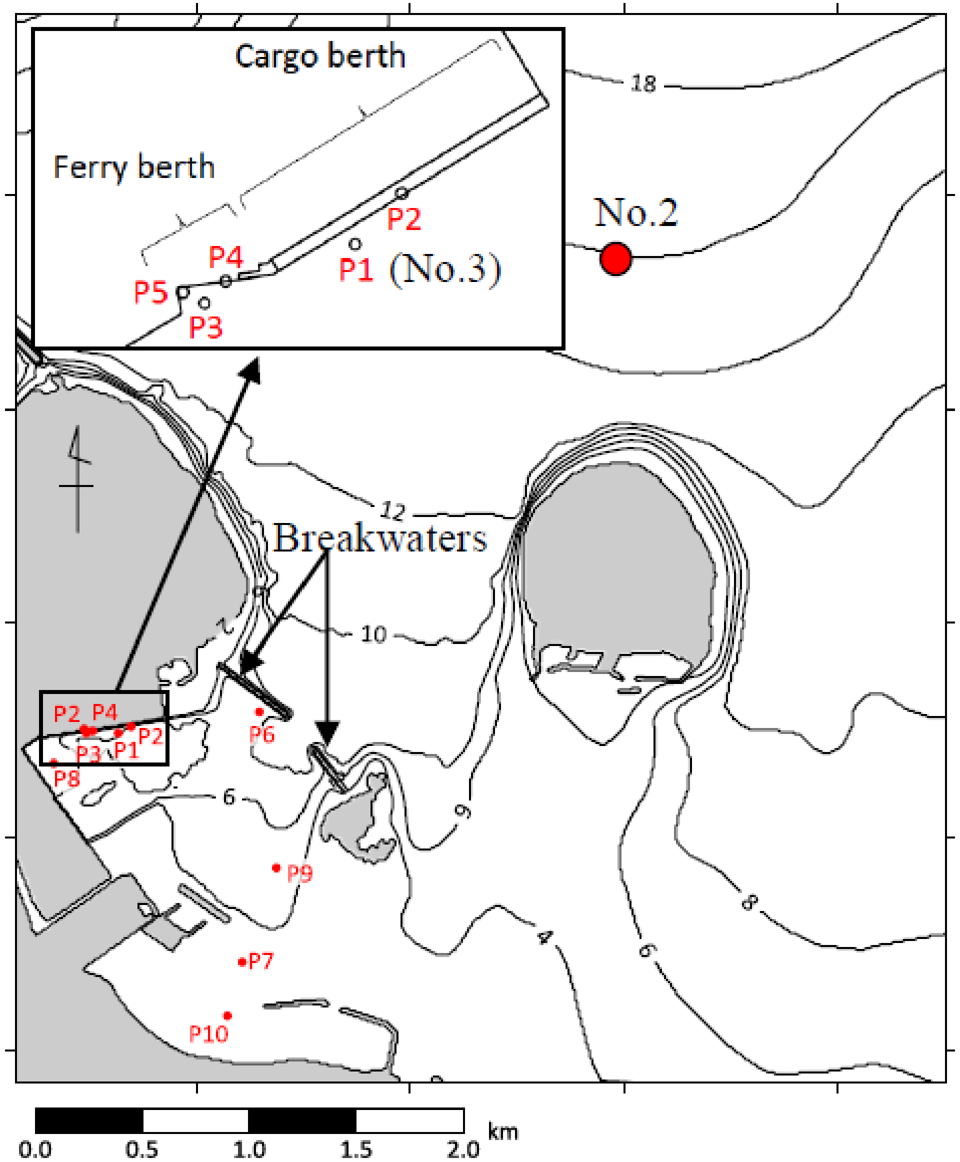
- Breaking model
  - Breaker index
    > Vertical water pressure gradient with BSQ approx.
  - Production of turbulence energy
    > Time dependent bore model
  - Wave attenuation
    > Eddy viscosity estimated by turbulence eq. model
- Runup model
  - Moving shoreline
    > Overtopping flux defined on board crested weir



Estimation of released waves from wave groups

Variation of ratios of H_{Lr} calculated in the harbor (No.3) to H_S generated in offshore (No.2)

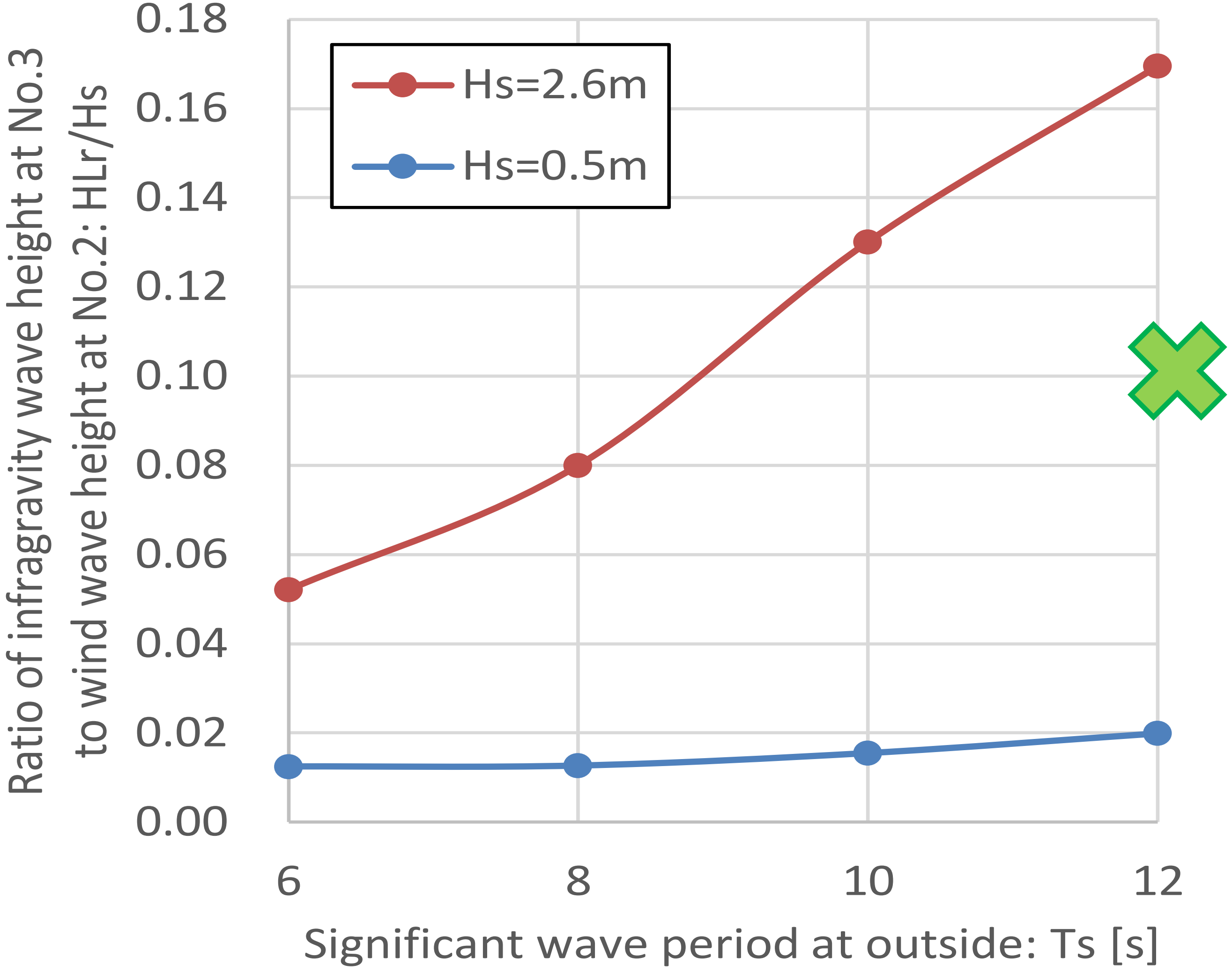


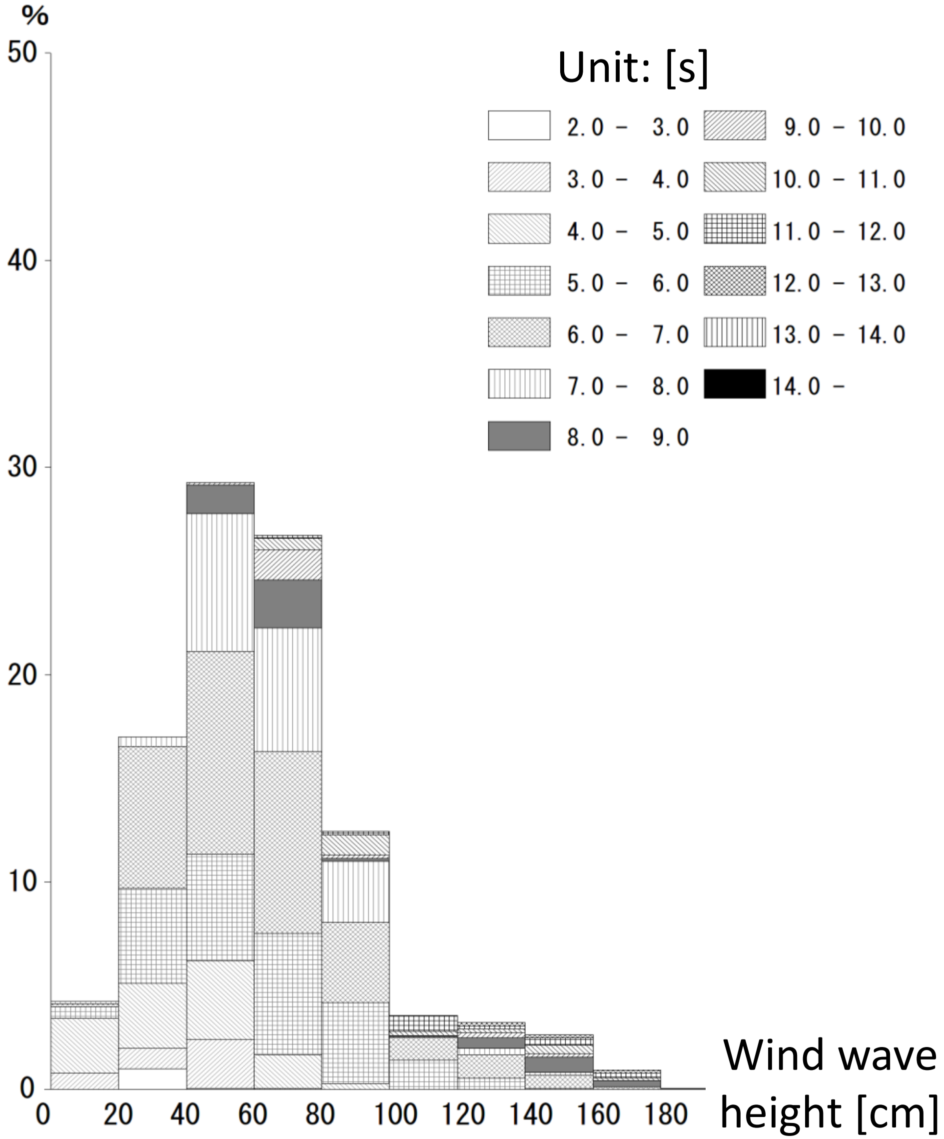


Estimation of released waves from wave groups

Variation of ratios of H_{Lr} calculated in the harbor (No.3) to H_S generated in offshore (No.2)

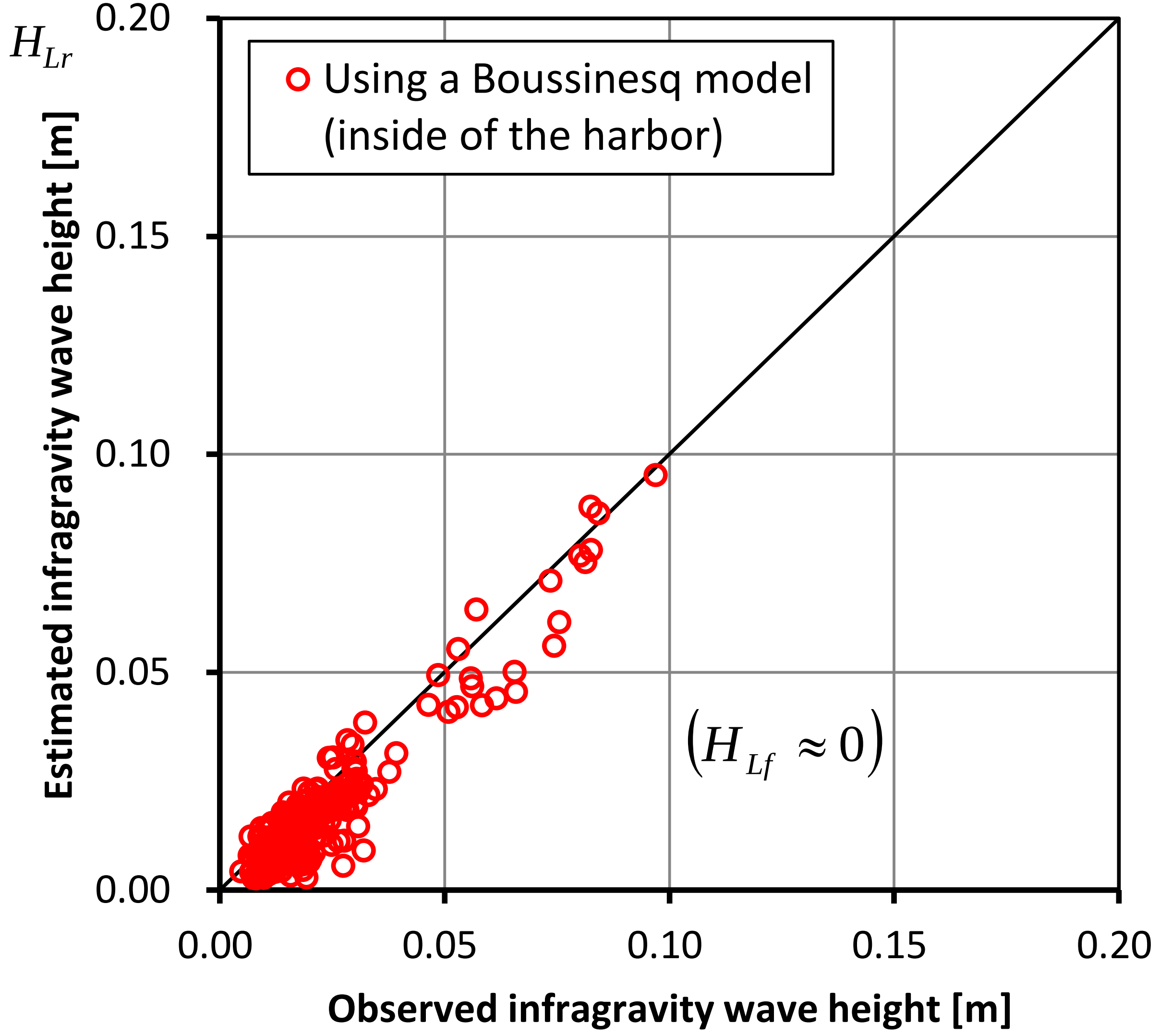
Interpolation matrix (Hirayama et al, 2015)

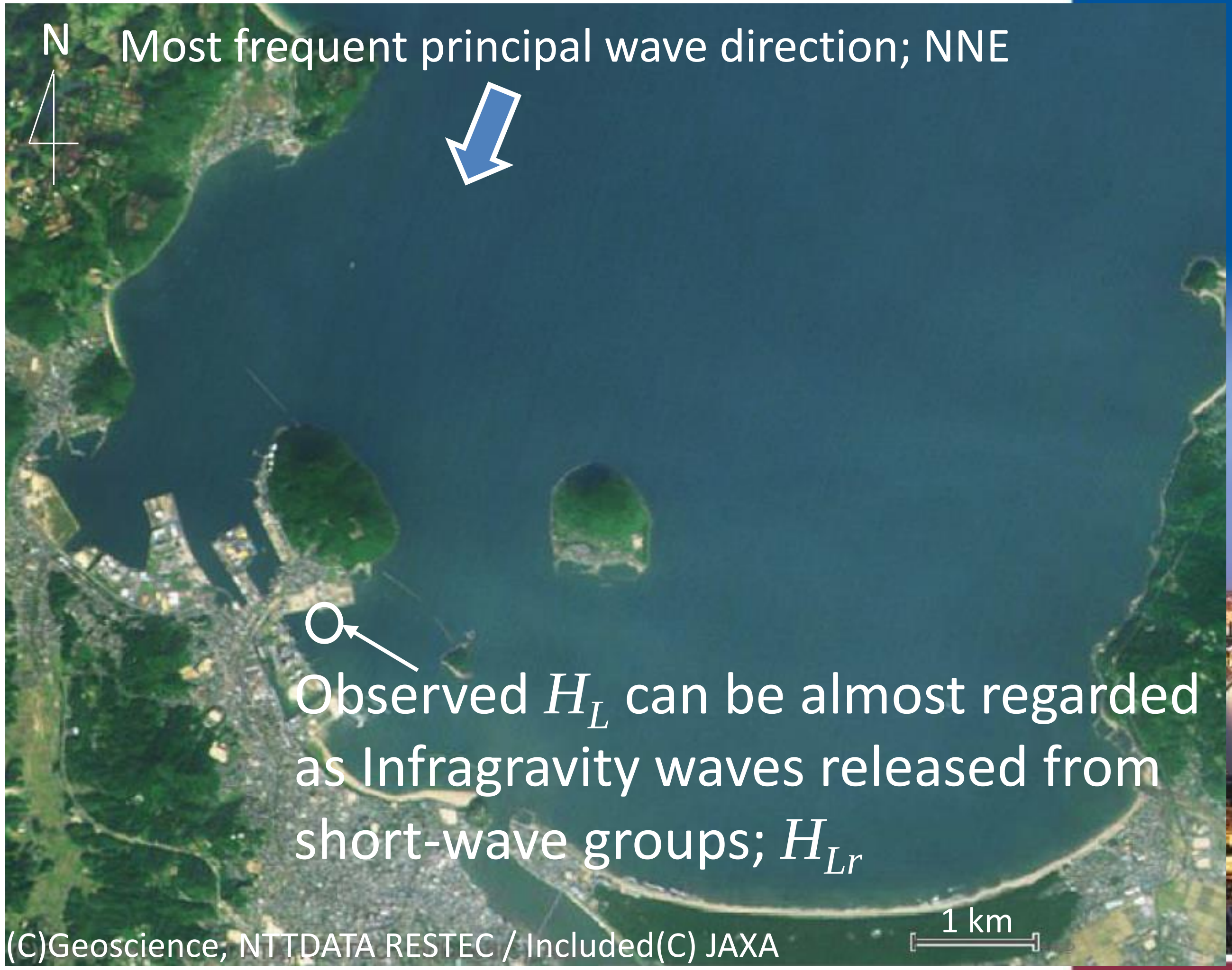




Estimation of released waves from wave groups

Evaluation of Distribution of H_{Lr} estimated with the matrix to H_L observed in the harbor (No.3)





Conclusions

- By using the newly proposed spectrum for infragravity waves, the height of offshore bound waves whose frequency are less than the boundary frequency can be estimated by the observed ratio of infragravity wave height to significant wave height while its Ursell number is greater.

- By using a Boussinesq model to calculate the reduction of short-wave groups at a harbor entrance, infragravity wave heights in a harbor can be estimated as released wave heights in case that free long-period waves rarely exist there.

- In a future work, the wave train which consists of both wind and infragravity waves will be generated from the standard spectrum, with considering distribution of their direction, in order to estimate infragravity waves those may include free long-period waves in a harbor.


Thank you for your attention