HIGHLY RESOLVED DIRECTIONAL PROPERTIES OF WIND WAVES AND SWELL WITH VARIOUS SCALES

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- Estimation of directional spectrum with Bayesian inversion
- Results:
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Wave Observation by MLIT

- Observation plan designed by MLIT

  (**M**inistry of **L**and, **I**nfrastructure and **T**ourism)

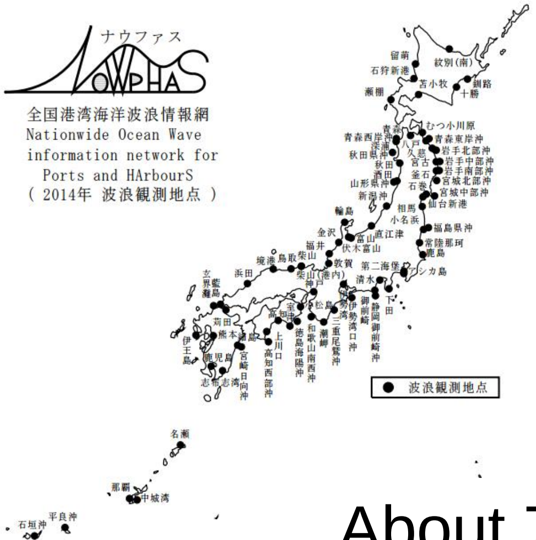
- Started with pressure gauges in 70's

- Two major type instruments at present

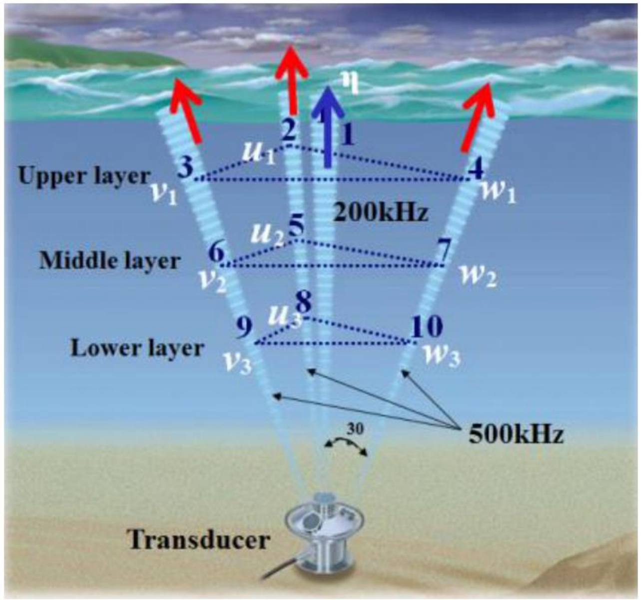
  Buoy type: GPS sensor on mooring buoy

  bottom installed type: Wave-ADCP, USW, pressure gauge

GPS-buoy



About 70 site



Wave-ADCP

<u>Aim of Wave Observation and Its Applications in Japan</u>

Wave statics(height, period, direction) in various scales are used for coastal design, coastal operation, etc.

- **<u>High sea</u>**（wave height > 8m） -> Sampling of reference data for design use

- **<u>Moderate sea</u>**（ wave height < 1m） -> Monitoring of tranquility for marine activities

- **<u>All time</u>**(from low to high) -> validation of model prediction using wave forcing, e.g., shoreline change, wave climate, etc.

-> These aims requests instruments for moderate sea to high sea

Observation from Moderate Sea to High Sea

・Bottom installed type is desirable for its high durability to high sea state

<- wave staff on sea surface can be troubled easily by high waves

・Array instruments is required for directional information

<- directional info is obtained through directional spectrum

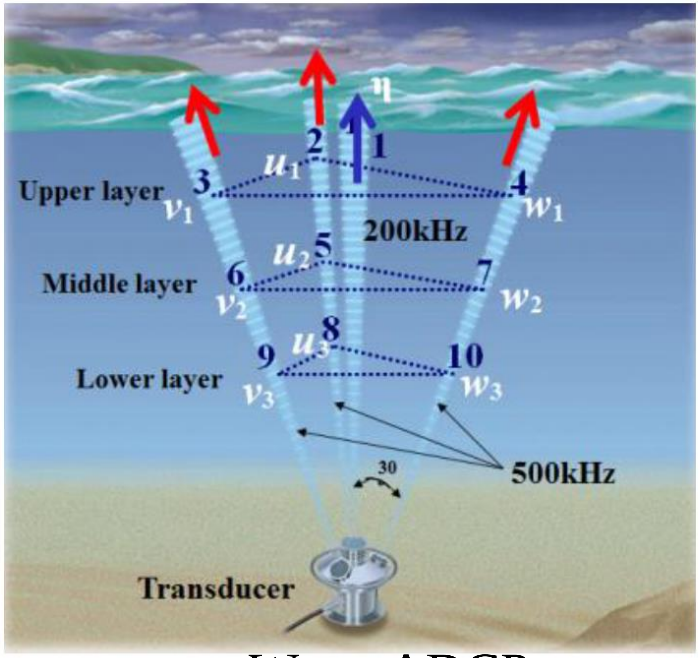
Wave-ADCP meets these requests

・function：

-vertical ultra sonic wave -> surface displacement

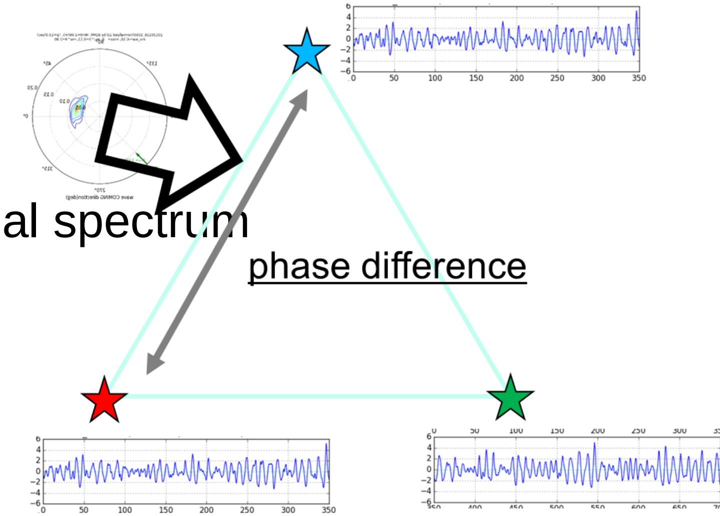
-along beam back scattering -> current profile

・ Array observation with single instrument



Wave-ADCP

Inversion of Directional Spectrum



▪Discretized Integral equation for inversion of directional spectrum

$$\boldsymbol{d} = \boldsymbol{G} \cdot \boldsymbol{m}$$

$\boldsymbol{d}$: ovservational data vector(phase difference)

$\boldsymbol{G}$: model matrix(transfer function)

$\boldsymbol{m}$: directional spectrum

Simple solution by Least Square Method :

$$\boldsymbol{m}^* = \boldsymbol{G}^{-1} \cdot \boldsymbol{d}$$

Problems in simple inversion method

▪Low resolution due to $\boldsymbol{G}$, which is transfer function of Doppler velocity

▪Observational noise in $\boldsymbol{d}$ make estimator unstable

▪Increasing size of $\boldsymbol{d}$ give Collinearity

} Ill-Posed problem

Bayesian Inversion of Directional Spectrum

・Bayesian Inversion enables smoothing based on prior berief

・Introduction of smoothing by Bayesian inference (Hashimoto, 1987)

−smoothing by minimizing second difference on directional spectrum

Hyper parameter u, which controls contribution of prior distribution,

is determined by ABIC(Akaike Bayesian Information Criteria) **automatically**

$$R(\mathbf{m}) = |\mathbf{d} - \mathbf{G} \cdot \mathbf{m}|^2 + u^2|\mathbf{L} \cdot \mathbf{m}|^2 -> min$$

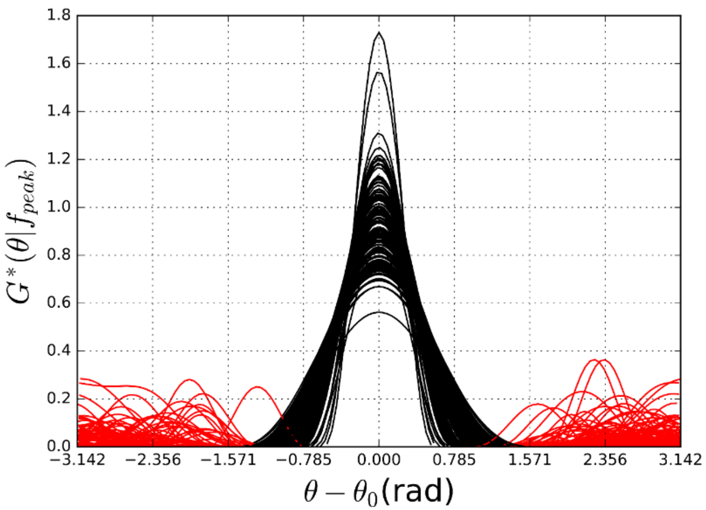
penalty term for smoothing(varying with u)

$u \rightarrow 0$: solution by Least Square Method

$u \rightarrow \infty$: uniform directional spectrum(NO contribution of observed data)

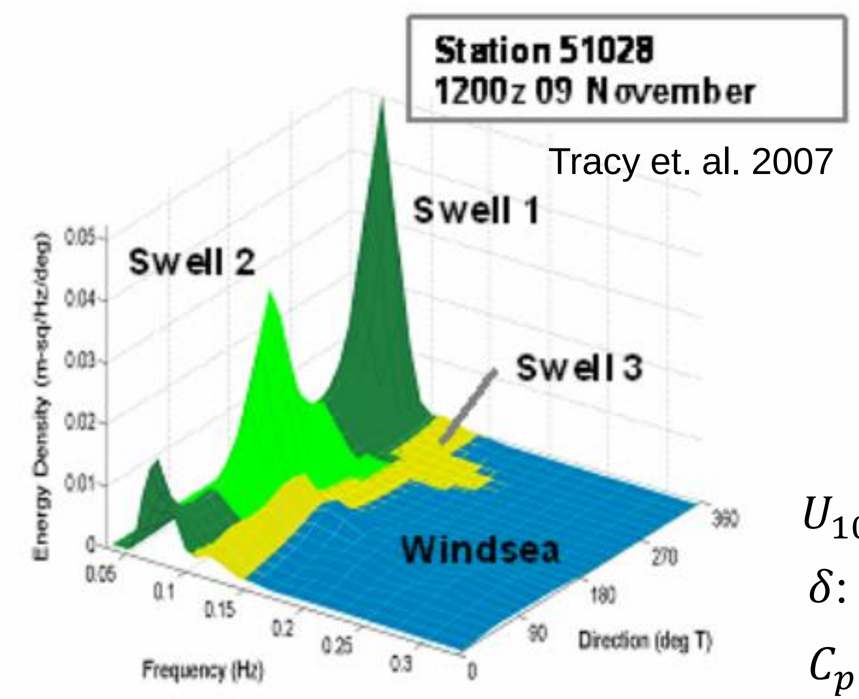
Partitioning and Identification of Several Wave Systems

Major peak + Minor peaks



- Observed directional spectrum can show several peaks
  - -Detailed analysis for each peaks is required

- WITS(**W**ave **I**dentification and **T**racking **S**ystem) by Hanson et al. 2001
  - -peak detection by **Water Shedding Algorithm**
  - -merging several peaks close to each other
  - -rejecting apparent peaks with small energy



Tracy et. al. 2007

- calculate wave statics for each peaks
  - -height, period, direction

- Identification for windsea and swell by inverse wave age, $|U_{10} \cos \delta| / C_p$

U_{10}: 10m-above local wind(m/s)

δ: Directional difference between wave and wave(rad)

C_p: Phase speed at spectral peak(m/s)

Data Processing

▪site：

Akita（Japan sea, windsea is dominant in winter）

Hachinohe（Pacific ocean, swell is dominant in summer）

▪analysis method: directional spectrum by Bayesian inversion

▪criteria to reject marginal data for detailed analysis：

H_{m0}(m) : 0.5 ~ 6.0

T_p(s) : 4.0 ~

reject counter swell

$|D_{wind} - D_{\mathrm{wave}}|$ (deg): < 45.

reject transient wave

ΔU_{10} (m/s) : < 5.0

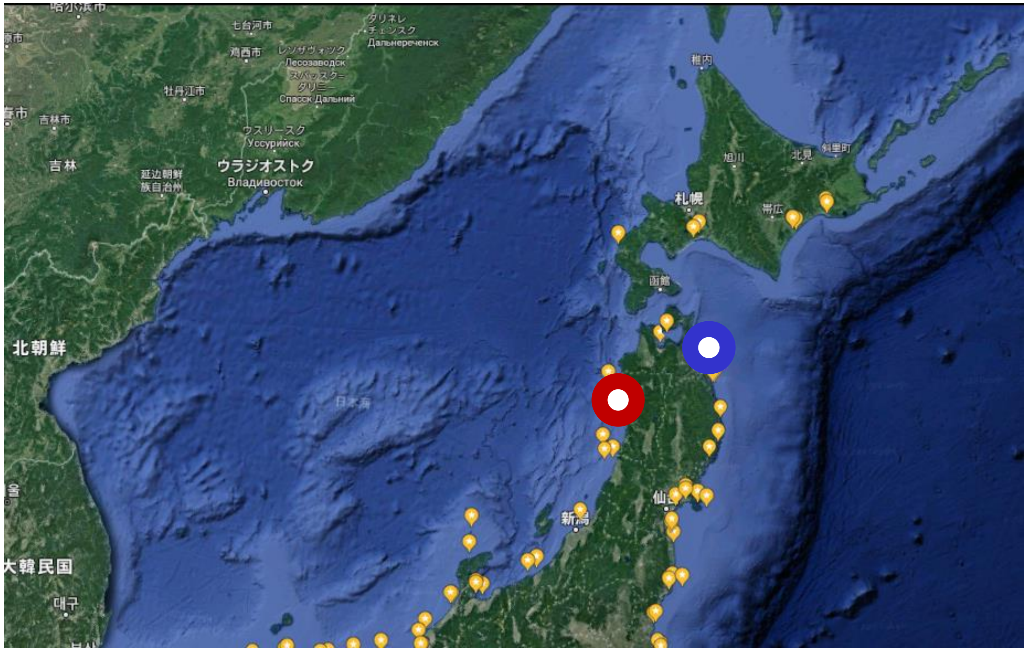
ΔD_{wave} (deg) : < 30.

ΔD_{wind} (deg) : < 30.

separating windsea and swell

Windsea: U_{10}/C_p(-): **1.0 ~**

Swell: U_{10}/C_p(-): **0.1 ~ 0.5**



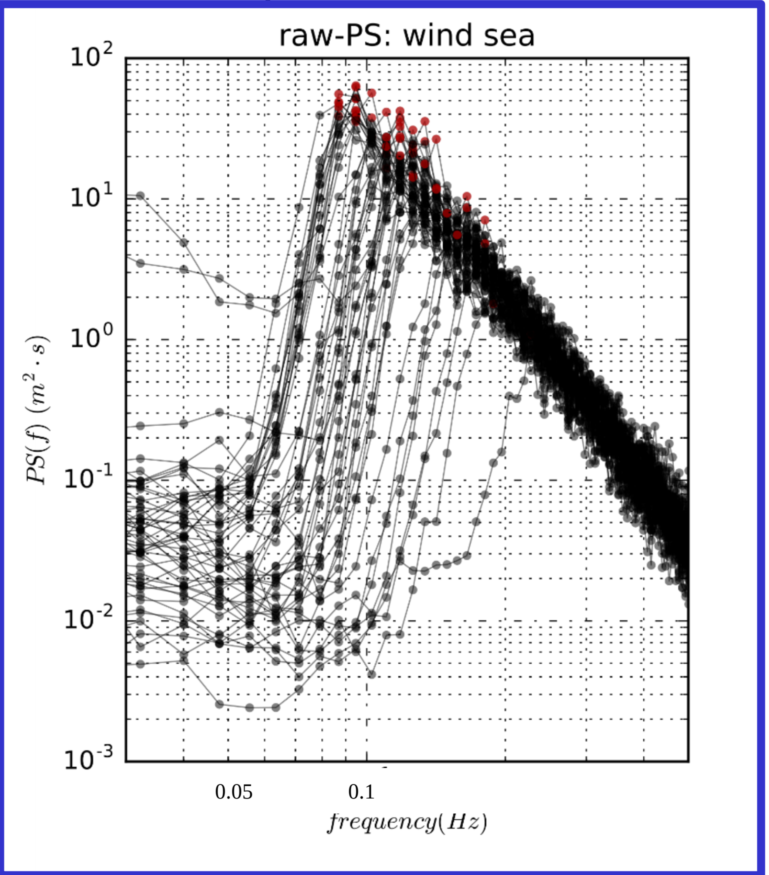
Summary of samples

wind sea(**50**/26280)

H_{m0}(m) : 0.62 ~ 5.21

T_p(s) : 4.4 ~ 11.5

U_{10}/C_p(-): 0.93 ~ 1.69

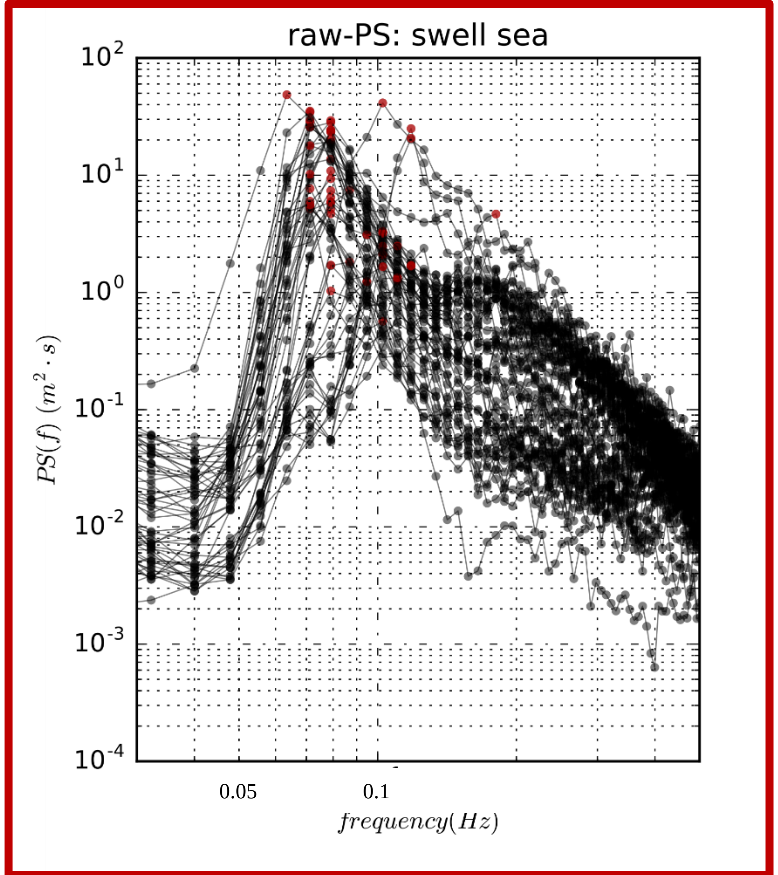


swell sea(**53**/26280)

H_{m0}(m) : 0.50 ~ 4.18

T_p(s) : 5.8 ~ 15.8

U_{10}/C_p(-): 0.16 ~ 0.50



Results: validation on Power Law

- The 3/2 power of law for wind wave
  - Non-dimensional wave height and period

$$H^* \sim {T^*}^{3/2}$$

$$H^* = gH_{m0}/|U_{10}\cos\delta|^2$$
$$T^* = gT_p/|U_{10}\cos\delta|$$

U_{10}: 10m-above local wind(m/s)

δ: Directional difference between wave and wave(rad)

- Validation with samples with various scales, including moderate sea to high sea

- Does swell also conform the 3/2 power of law ?

Suzuki(2011)

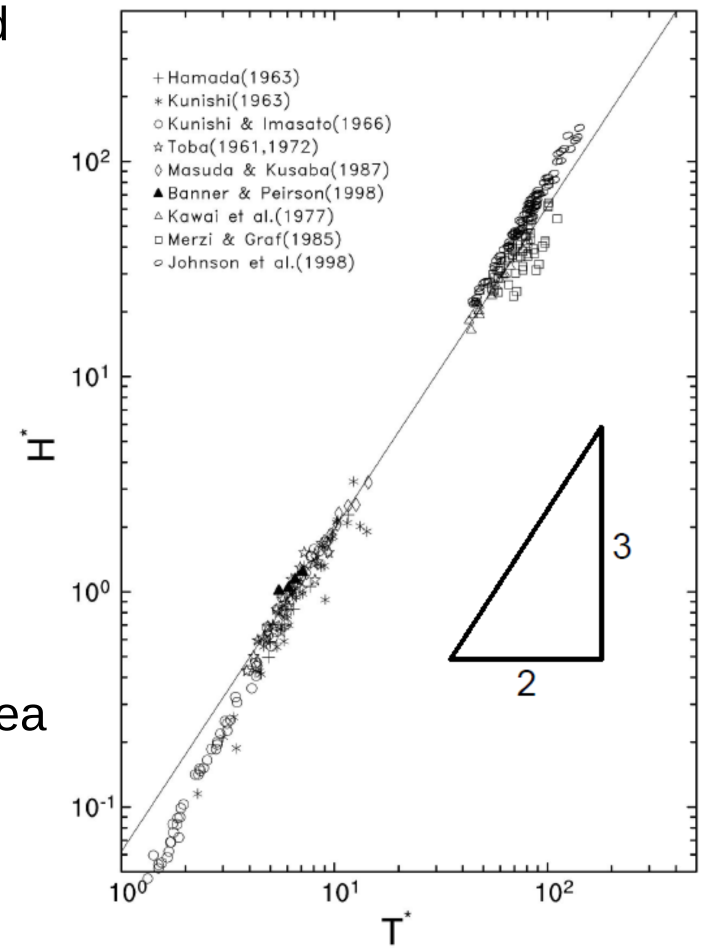


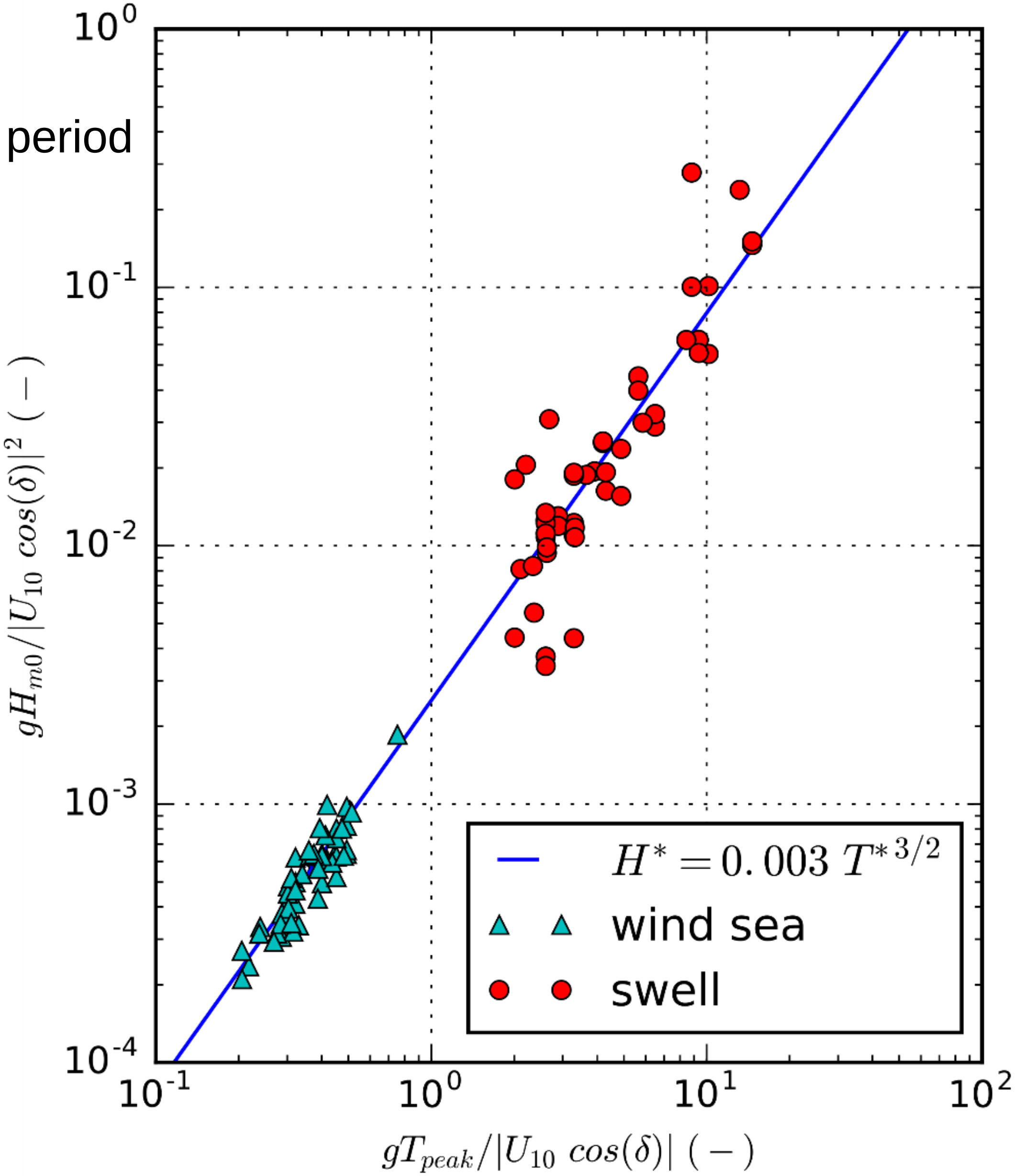
Fig.5 The relation between non dimensional wave height H^* and period T^*. The 3/2 power law (Toba, 1972) is plotted as a thin line.

Results: Validation for 3/2 Power of Law

- Relationship between
  Non-dimensional wave height and period

- Windsea shows
  - good agreement with $H^* \sim T^{*3/2}$

- Swell shows unclear relationship
  - scattered around $H^* \sim T^{*2}$?



Results: Wave Steepness and Directional Spreading

- Investigation about determinant for directional properties

$\overline{\sigma_\theta(f)}$: frequency-mean directional spreading

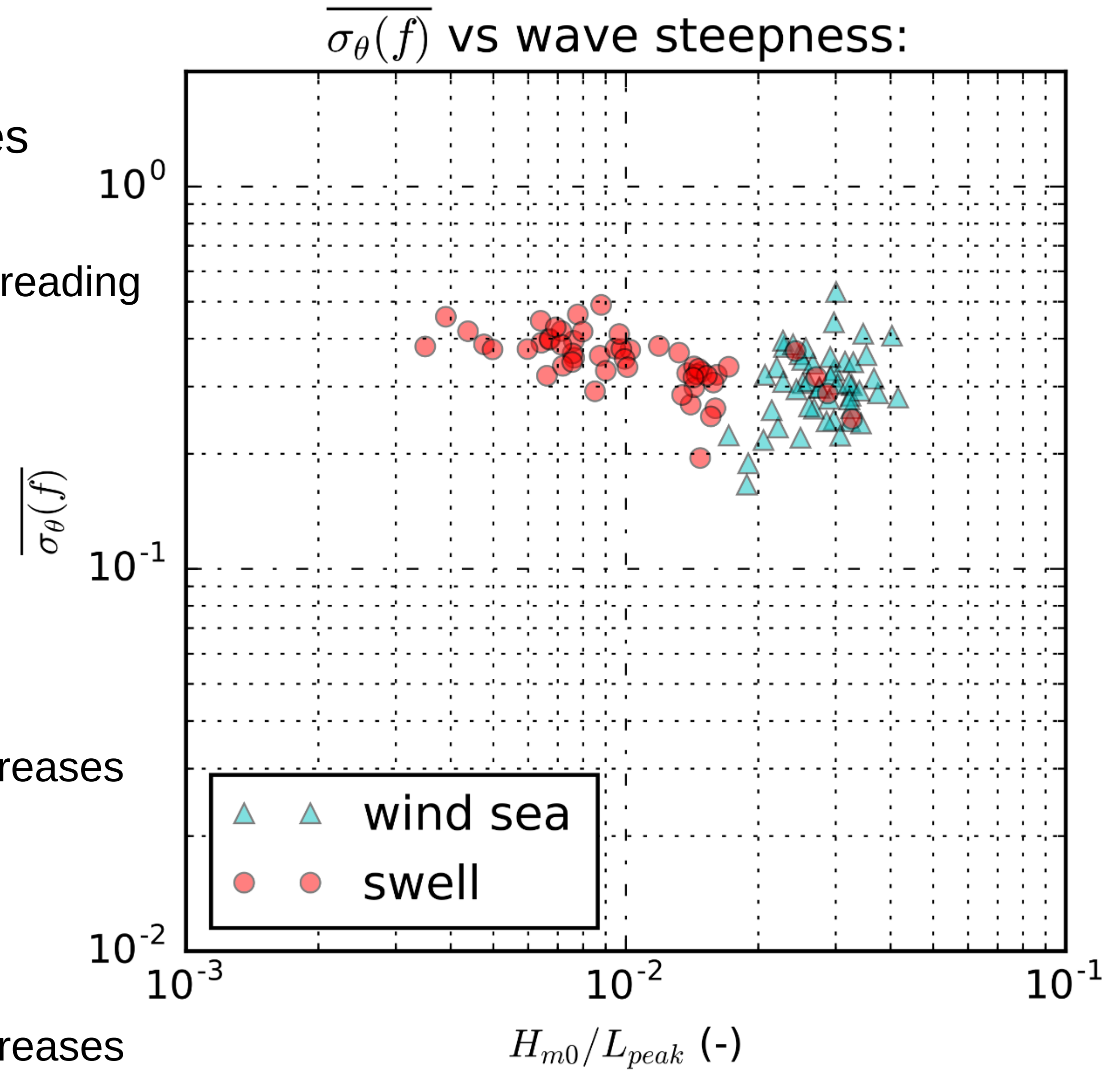
H_{m0}/L_p: wave steepness

Windsea:

$\overline{\sigma_\theta(f)}$ increases with H_{m0}/L_p,
directional spectrum becomes broad as wave steepness increases

Swell:

$\overline{\sigma_\theta(f)}$ decreases with H_{m0}/L_p,
directional spectrum becomes narrow as wave steepness increases



$\sigma_\theta(f)$: circular root mean square spreading, $\sigma_\theta(f) = \sqrt{2(1 - m_1(f))}$

$m_1(f) = \sqrt{a_1(f)^2 + b_1(f)^2}$, $a_1(f) = \int cos(\theta) G(\theta | f) d\theta$, $b_1(f) = \int sin(\theta) G(\theta | f) d\theta$

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directional spectrum becomes **broad** as wave steepness **increases**

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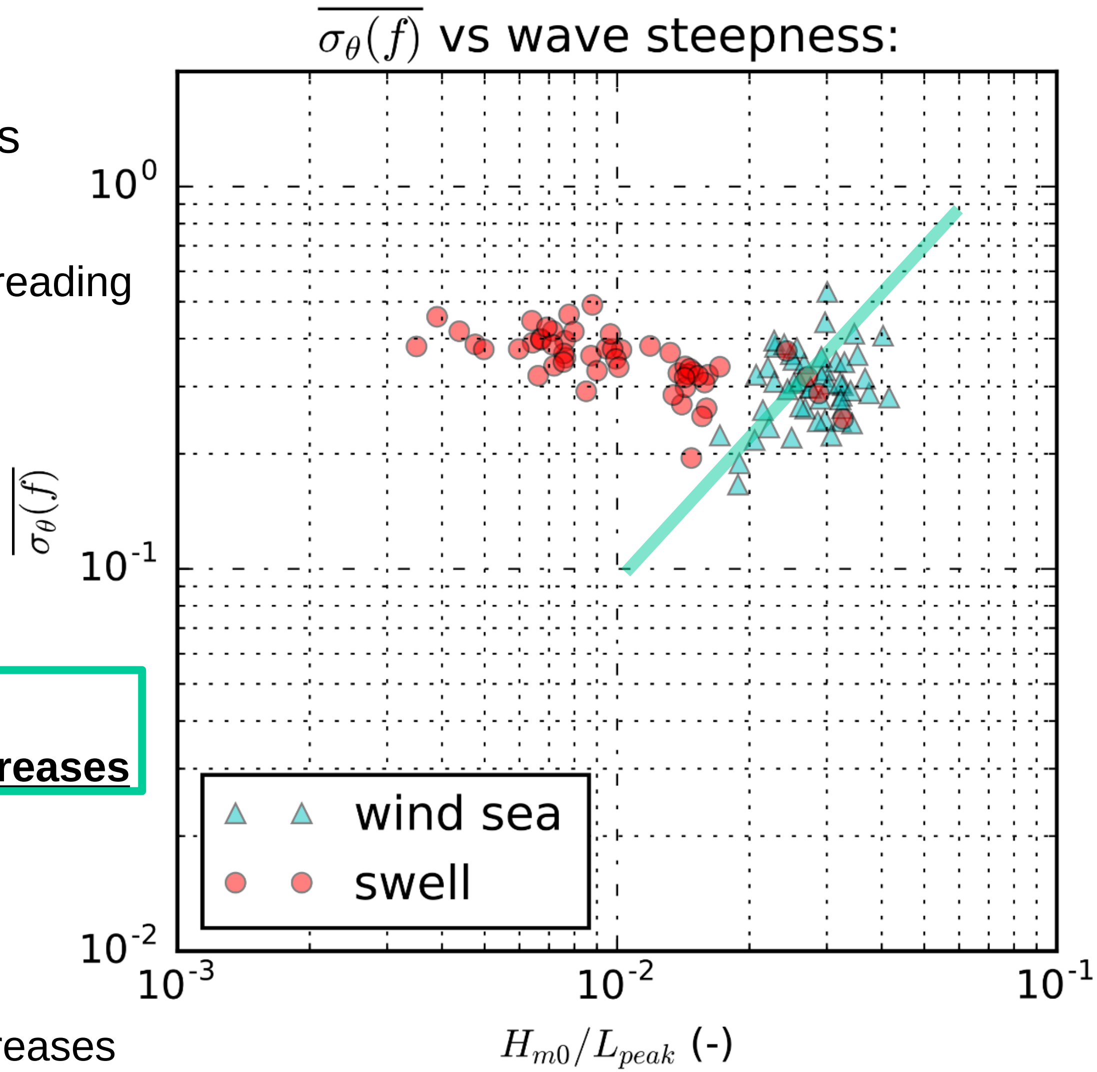

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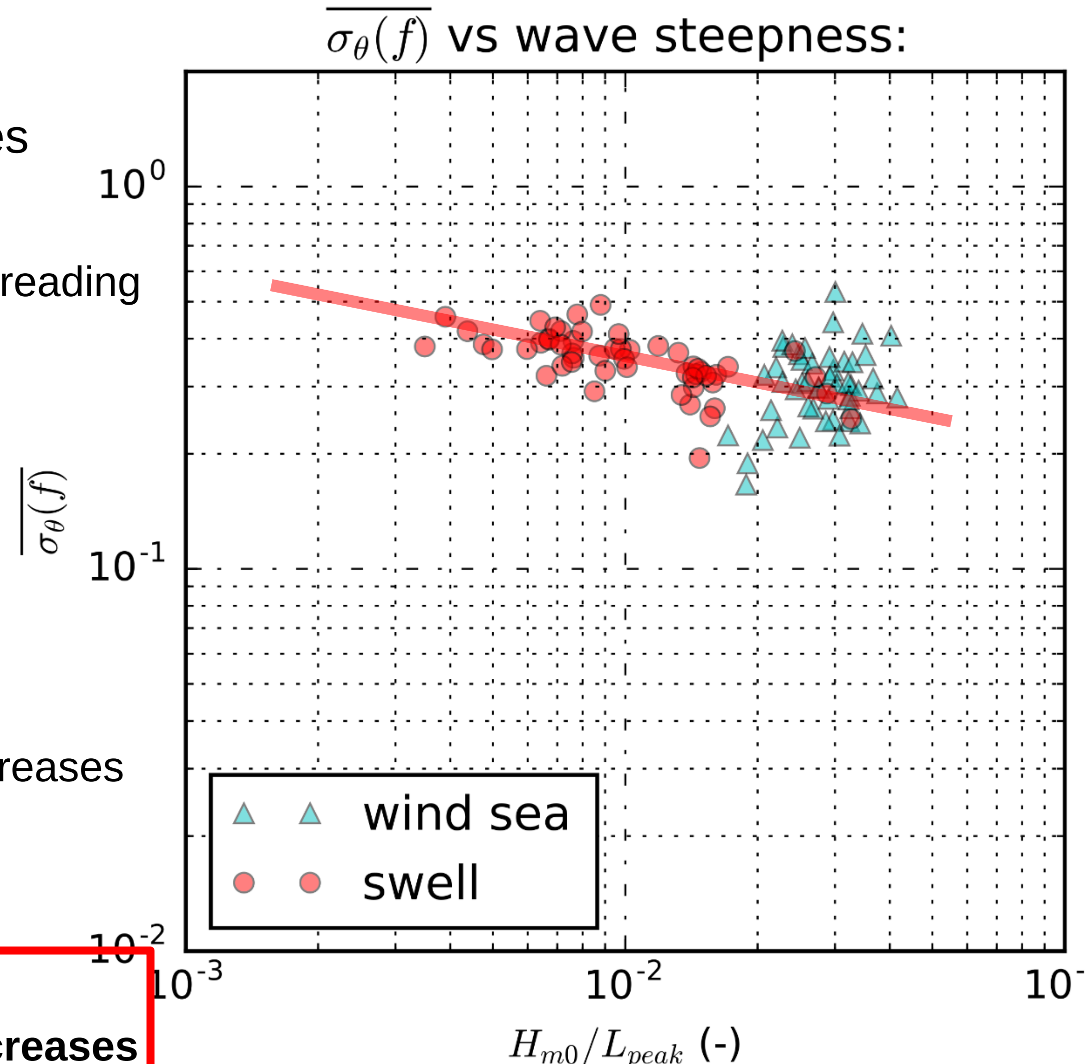

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directional spectrum becomes **narrow** as wave steepness **increases**

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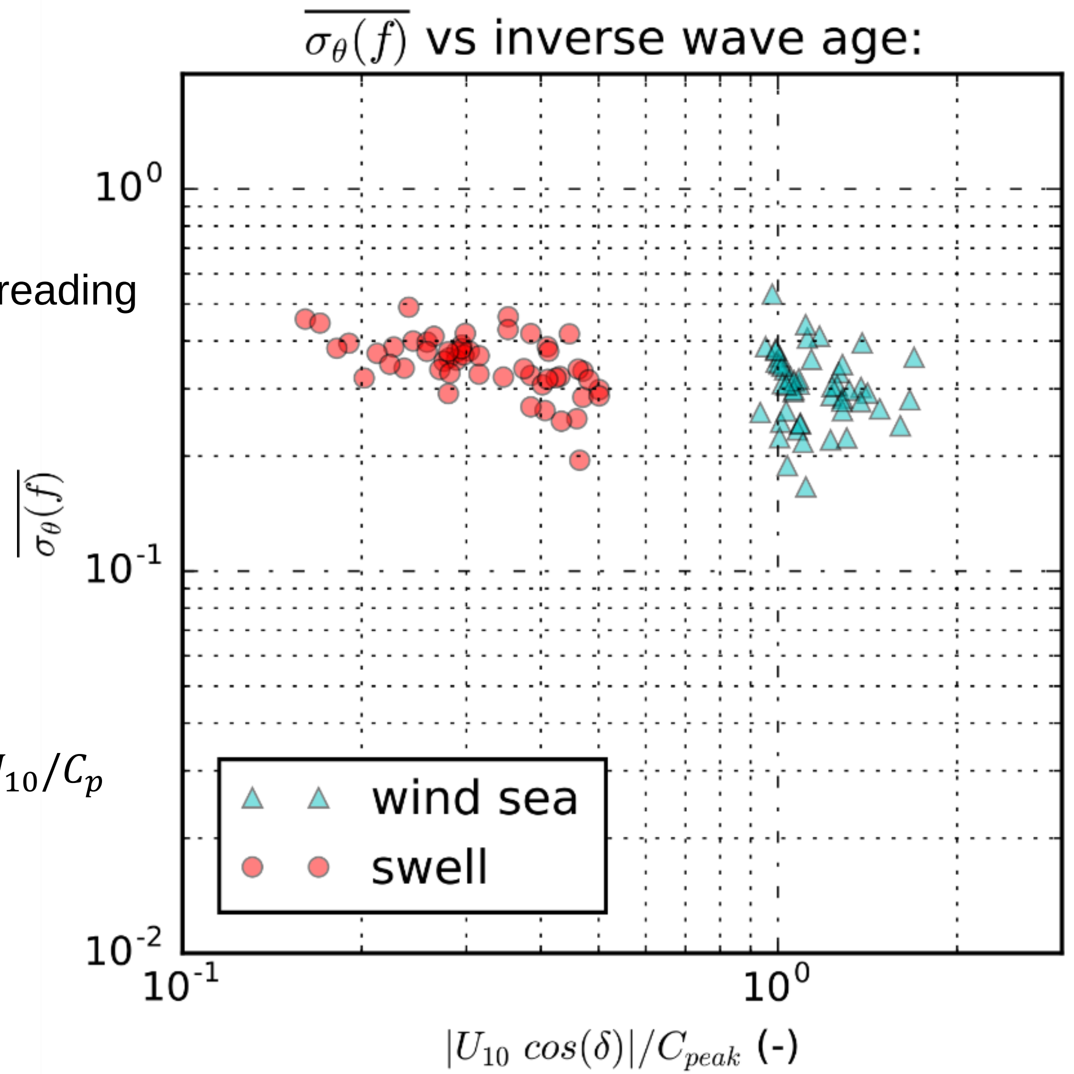
Results: Inverse Wave Age and Directional Spreading

▪Investigation about determinant for directional properties

$\overline{\sigma_\theta(f)}$: frequency-mean directional spreading

U_{10}/C_p: Inverse wave age



Windsea:

Concentrating in narrow range of U_{10}/C_p

Difficult to interpret clear dependency between $\overline{\sigma_\theta(f)}$ and U_{10}/C_p

Swell:

$\overline{\sigma_\theta(f)}$ decreases with U_{10}/C_p, directional spectrum becomes narrow as inverse wave age increases

Results: Inverse Wave Age and Directional Spreading

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U_{10}/C_p: Inverse wave age

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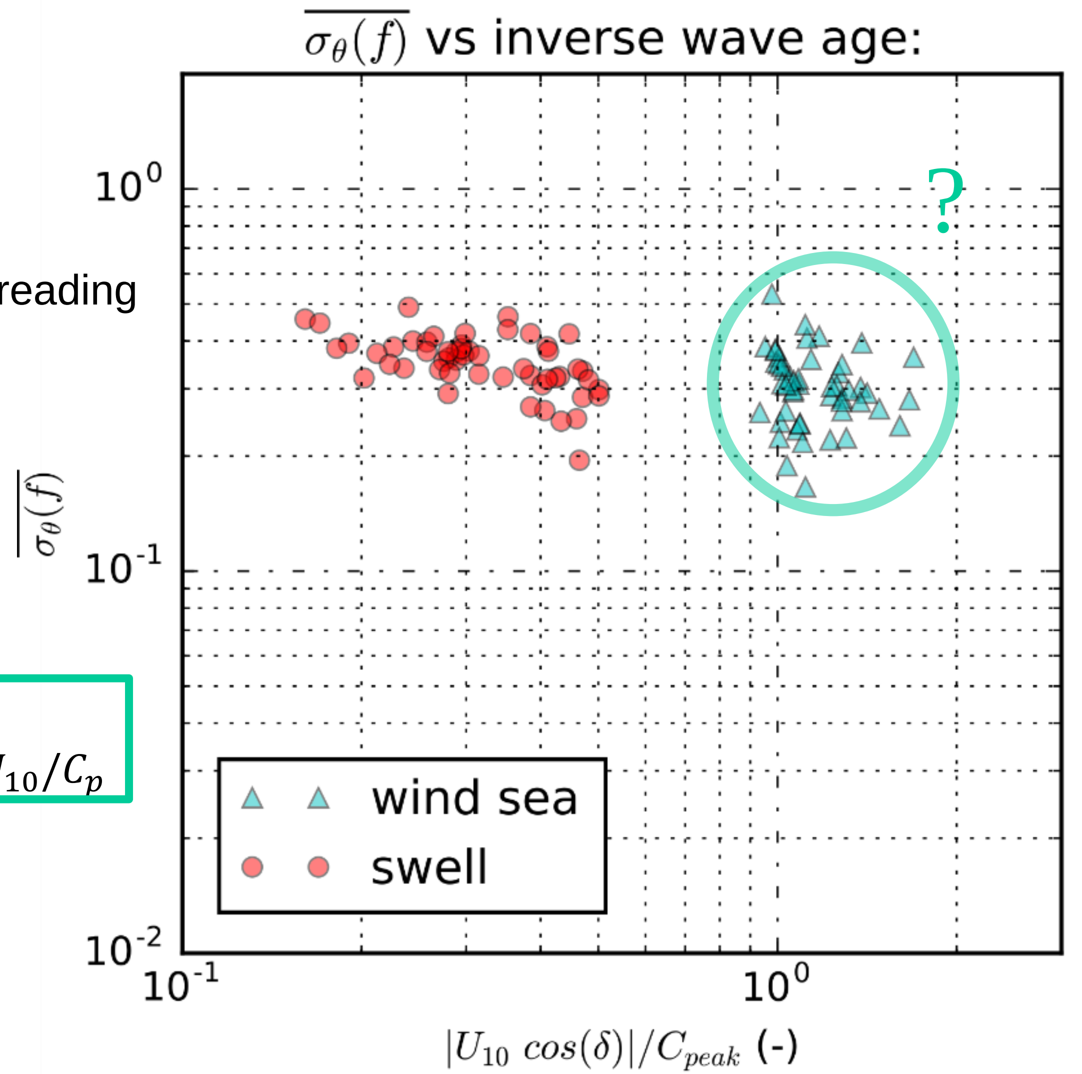

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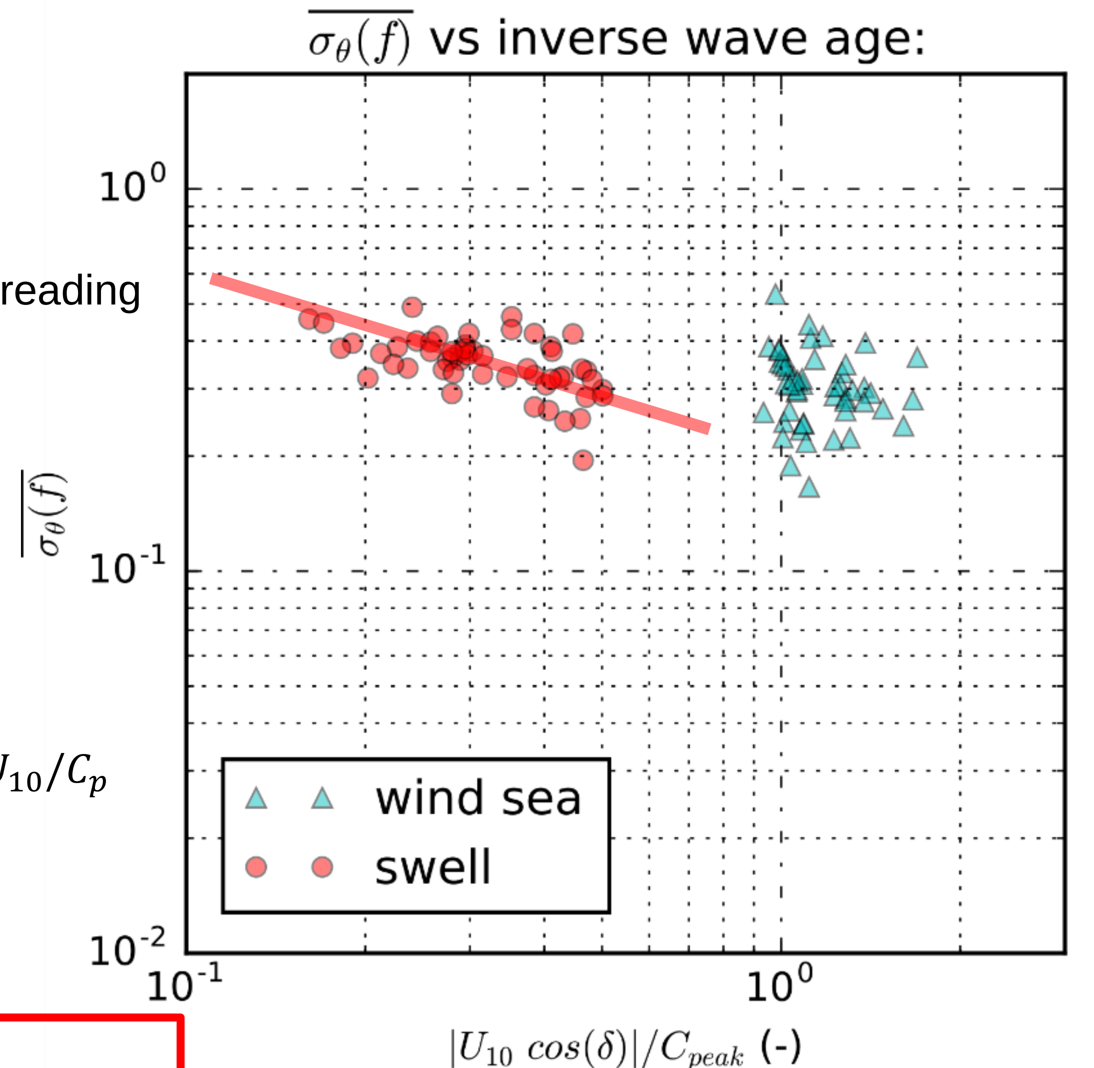

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Discussions and Conclusions

・Non-dimensional wave statics is **limited in narrow range** in this field observations

-Contrary to the previous study, ONLY the field data was investigated

・Wave steepness is **insufficient for separating windsea and swell**

-Wave steepness of wind wave and swell can be overlapped

・Directional property of dependency on wave statics is different in windsea and swell

windsea: directional spectrum becomes broad as wave steepness increases

-Consistent with previous study, proposed by Goda et al. 1973

Swell: directional spectrum becomes narrow as wave steepness increases

-Swell show the property contrary to windsea

Future Works

・Validation of theories in the previous study with data in various scales

-Focused in design use, research for extreme wave events, etc.

・Improvement on inversion method of directional spectrum

-Result of inversion is NOT always perfect under too calm or severe sea state

・ Improvement on data processing before inversion

-In-situ data contains various type noise: spike, drift, jump, etc.

-Careful processing including visual inspection is available for reliable analysis

-Automated process to reject or modify such marginal data
is required for analyzing much data efficiently