14TH INTERNATIONAL WORKSHOP ON WAVE HINDCASTING
AND FORECASTING/5th COASTAL HAZARDS SYMPOSIUM
Key West, Florida, USA, Nov 8-13, 2015

Observed orbital velocity of extreme waves and directional spectrum

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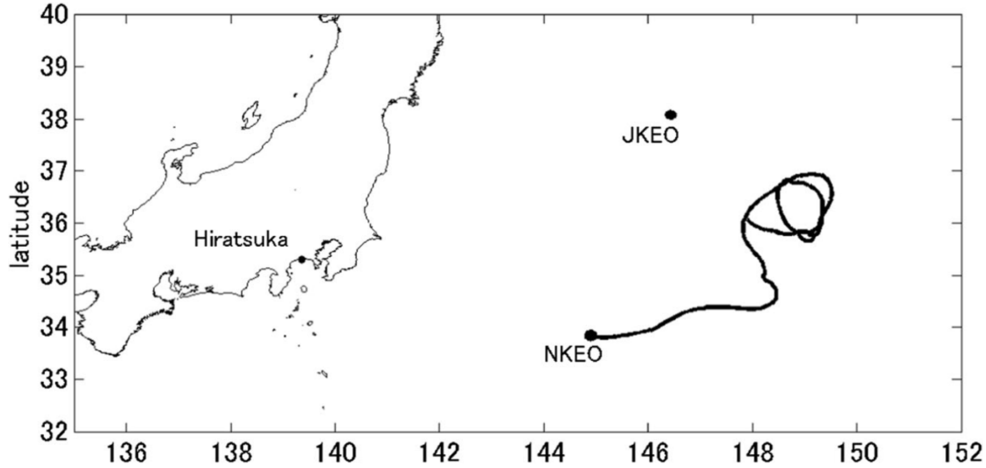
Outline

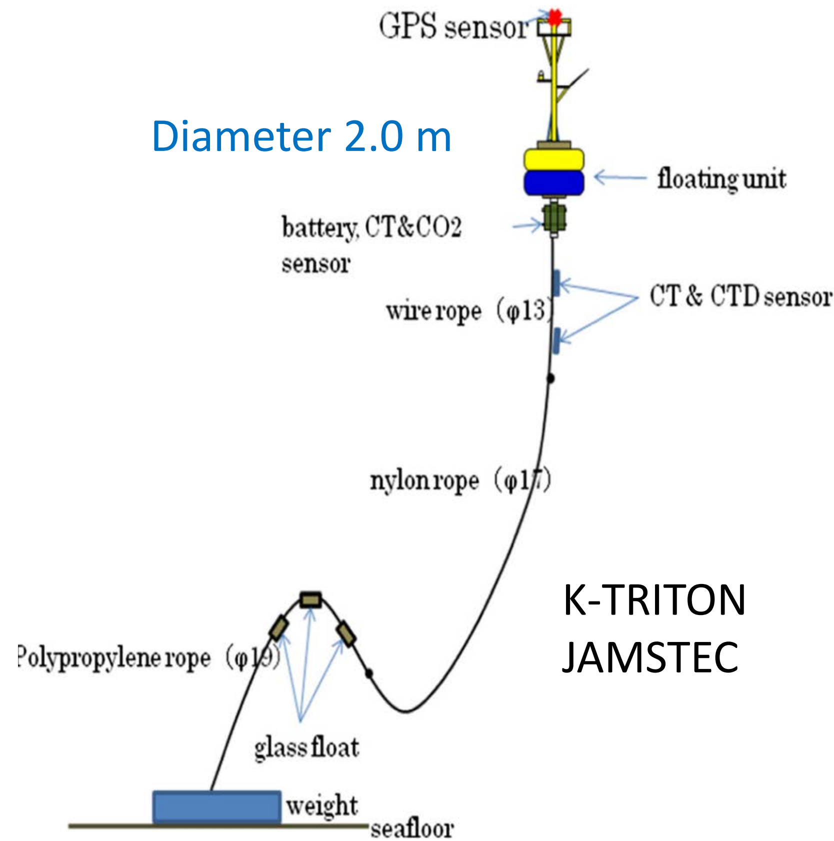
- Observed horizontal particle velocity from tethered buoy near Japan (13th IWWHF)
- Horizontal particle velocity estimate from SOFS observation in the southern ocean
- Directional spectral estimate from tethered buoy
- Dependence of orbital velocity on spectral geometry
- Preliminary results from HOSM simulation
- Comparison of GPS wave measurement and accelerometer wave measurement

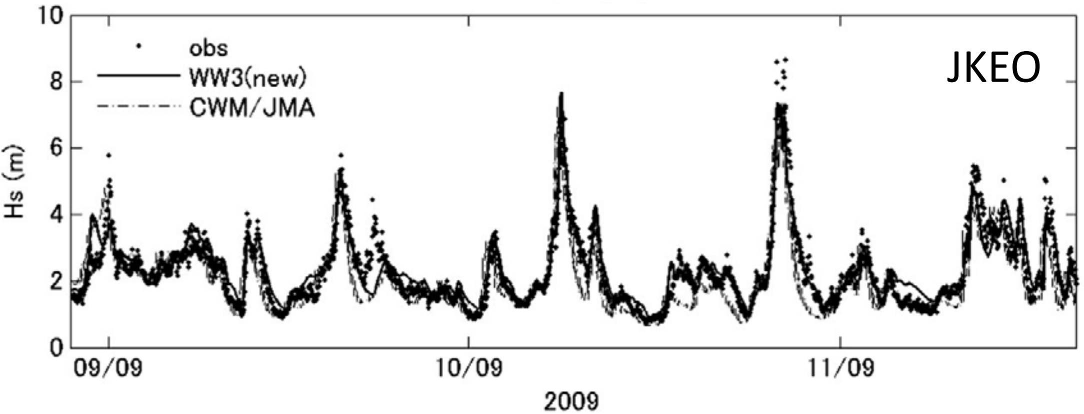
OBSERVED HORIZONTAL PARTICLE VELOCITY FROM TETHERED BUOY NEAR JAPAN (13TH IWWHF & ODYN2014)

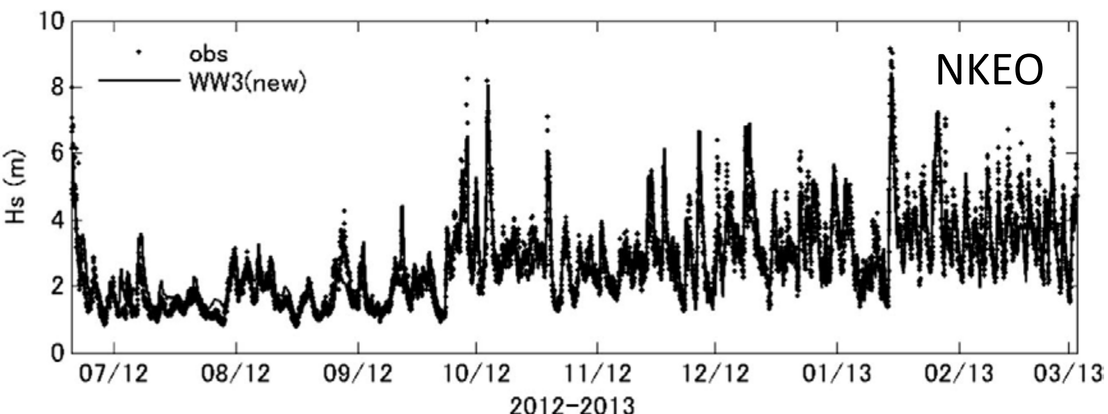
WASEDA, T., et al. Deep water observations of extreme waves with moored and free GPS buoys. *Ocean Dynamics*, 2014, 64.9: 1269-1280.

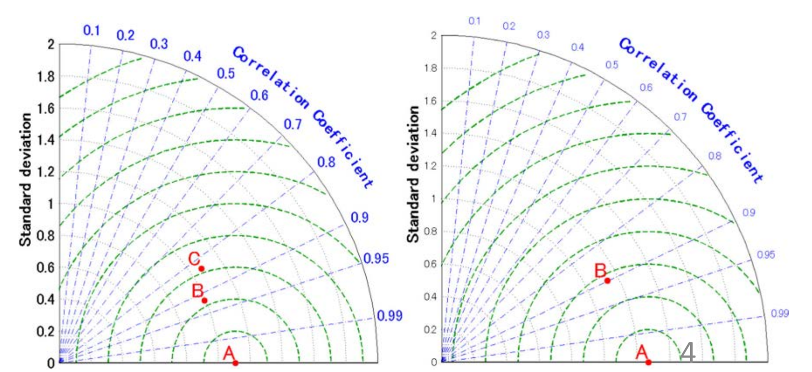
JKEO & NKEO GPS buoy observation



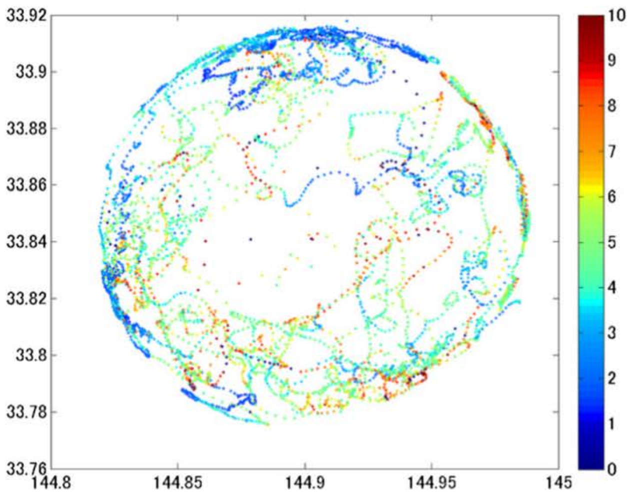


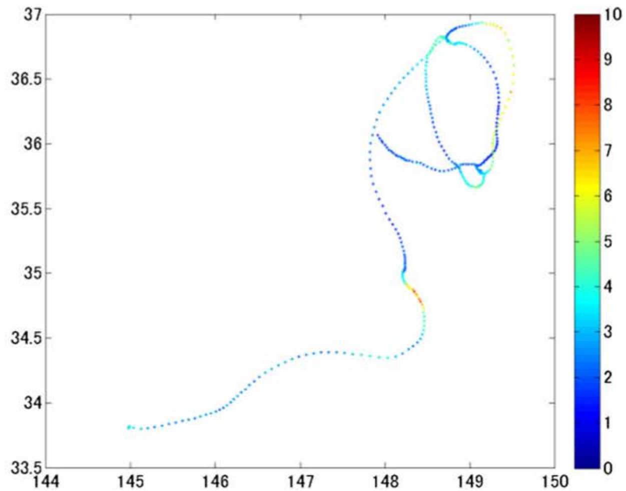






Buoy Tracking Velocimetry





Largest wave in each record

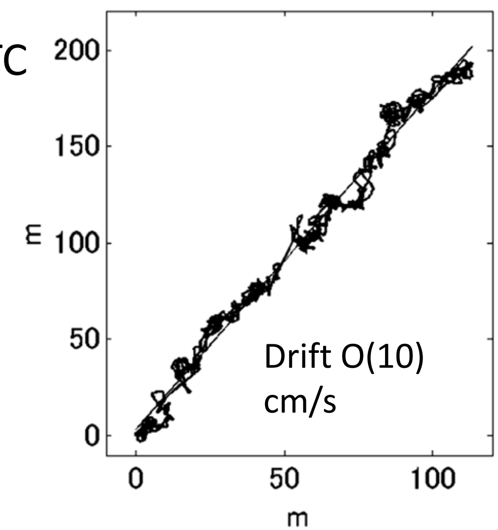
2012.10.4 1AM UTC

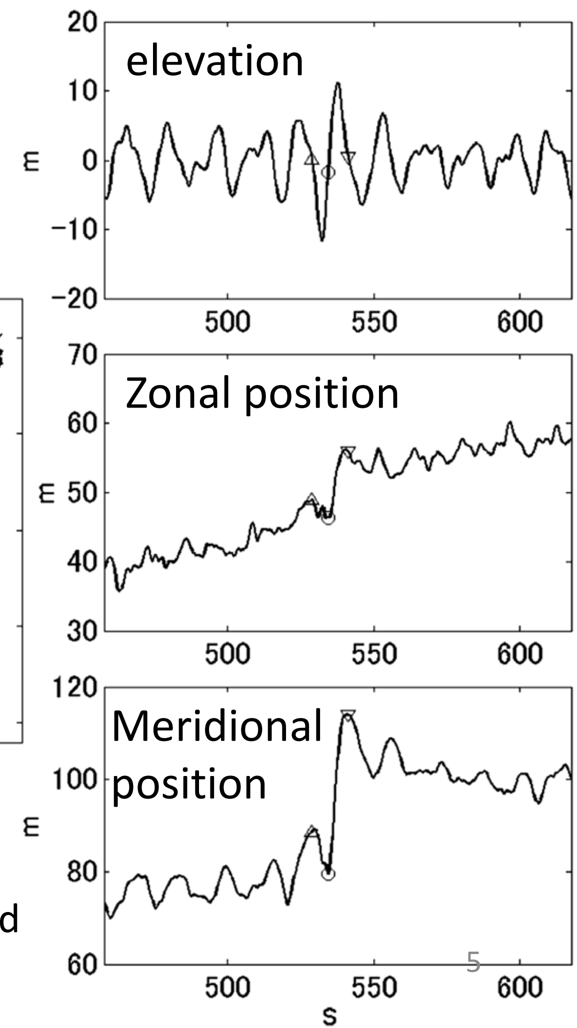
Hmax=22.8 m

Cp=23.7 m/s

Umax=11.7 m/s

Umax/Cp=0.49





Point-positioning GPS wave sensor
Wave sensing with point-positioning GPS (JAXA: Yamaguchi et al, 2005); High-pass filter: distinct frequency bands of wave and GPS noise spectrum (Harigae et al. 2005)

Kiyomatsu presentation B4

NOTE: High-pass filter is not applied for the horizontal position

Orbital speed of non-breaking waves in a group

Quality Control

$KC > 40$

$$KC \equiv \frac{U_{\max} T_{\max}}{D}$$

D:diameter of buoy

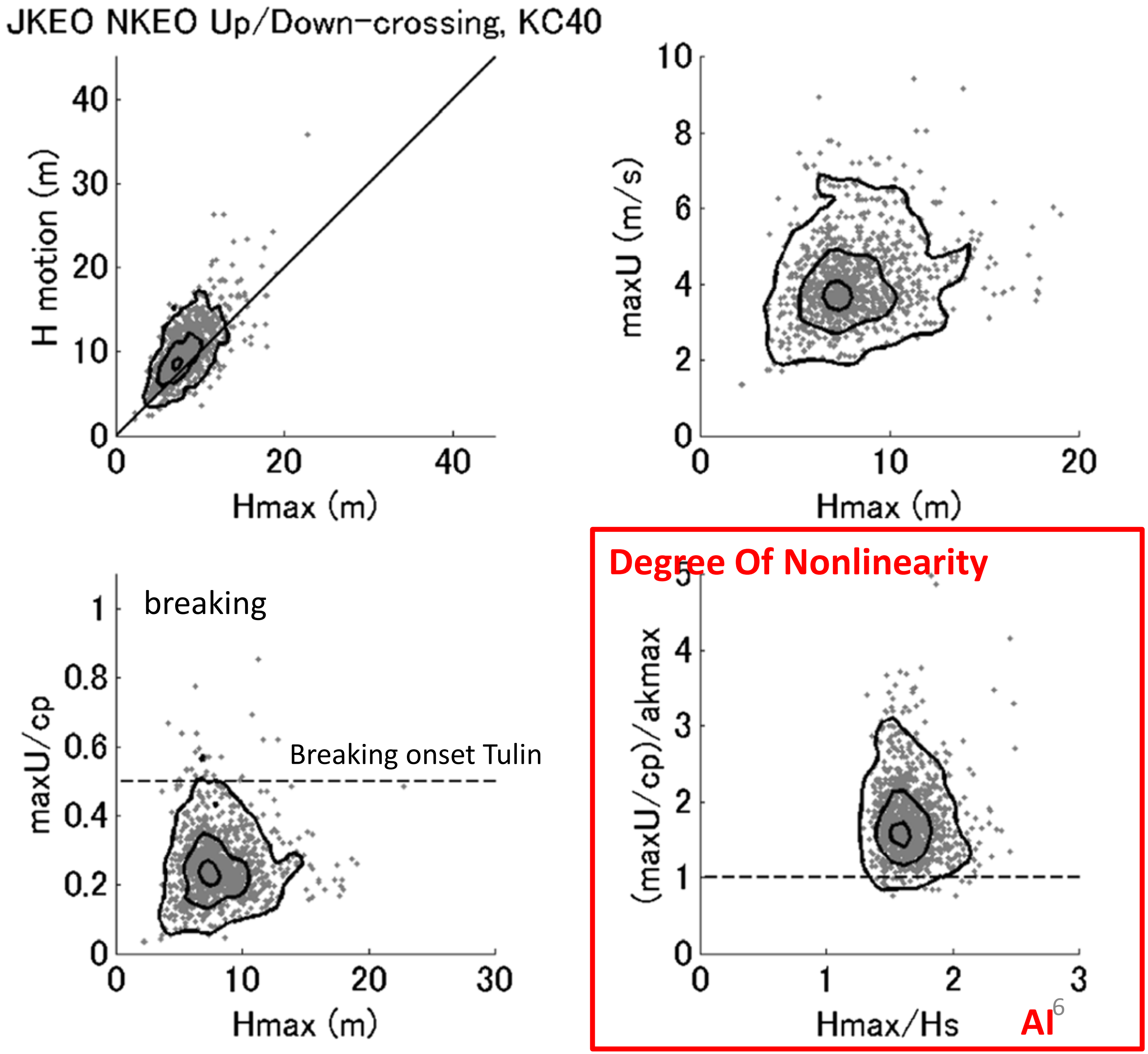
$\text{average}(ak_s) = 0.079$

$\text{average}(H_s) = 4.9\ \text{m}$

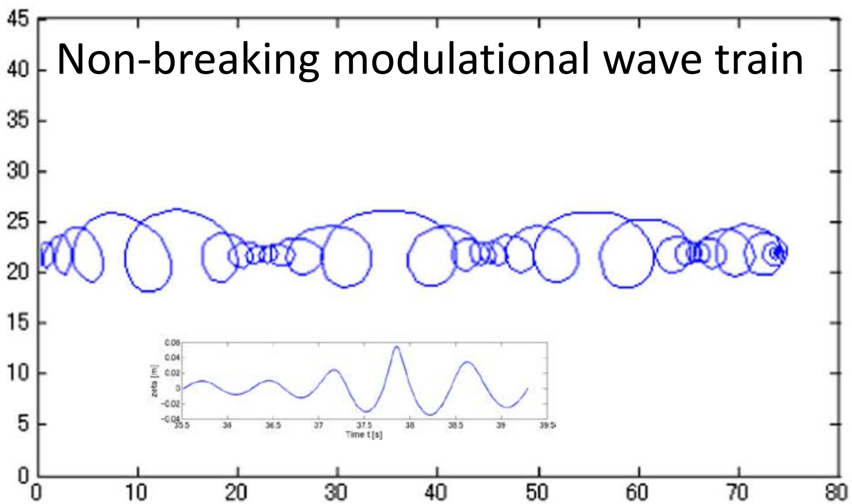
$\text{average}(ak_{\max}) = 0.14$

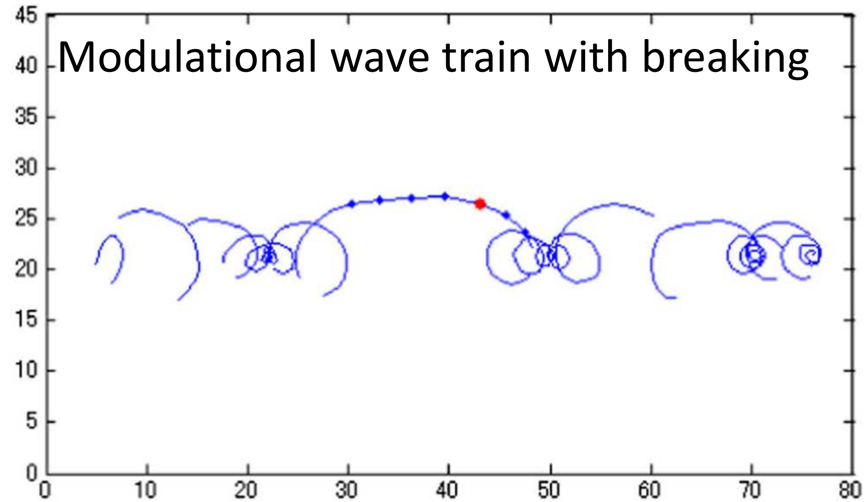
$\text{average}(H_{\max}) = 8.1\ \text{m}$

$\text{average}(T_{\max}) = 11.2\ \text{s}$

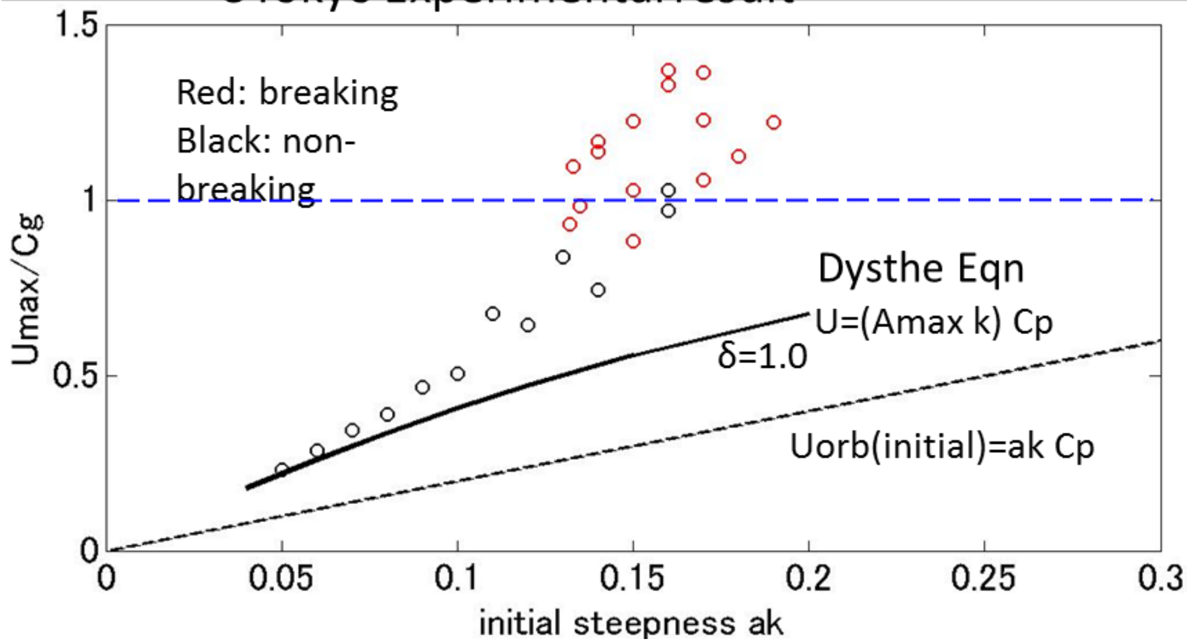


Degree of Nonlinearity (DON)





UTokyo Experimental result



Dysthe's Eqn. curve corresponds to:

Degree Of Nonlinearity

$$DON \equiv \frac{\frac{U_{max}}{C_p}}{ak_{max}} \sim 1$$

i.e. $U(x,t) = A(x,t)k_pC_p$

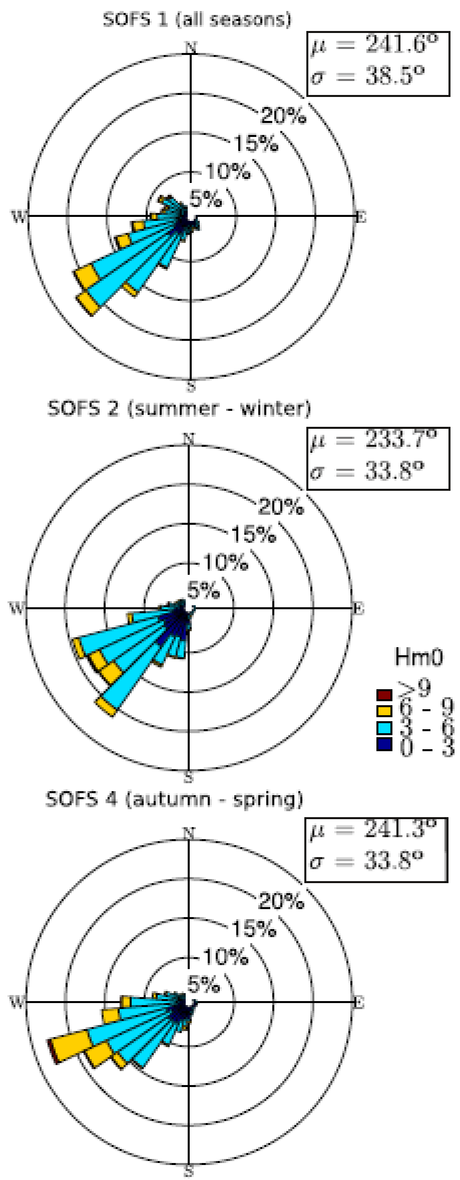
Physical experiments:

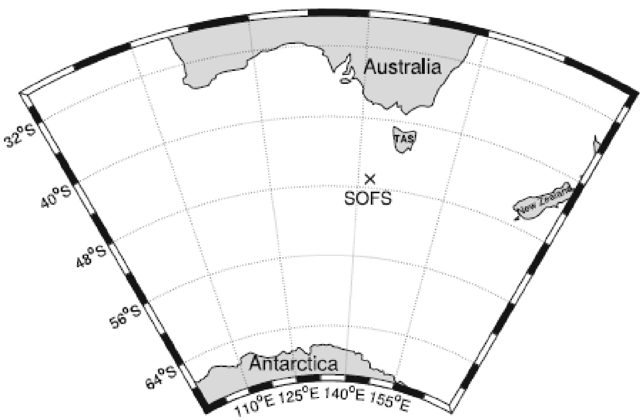
$$DON > 1$$

Narrow-band approx. fails

HORIZONTAL PARTICLE VELOCITY ESTIMATE FROM SOFS OBSERVATION IN THE SOUTHERN OCEAN

SOFS wave observation (Rapizo et al. 2015)





Diameter 2.7 m

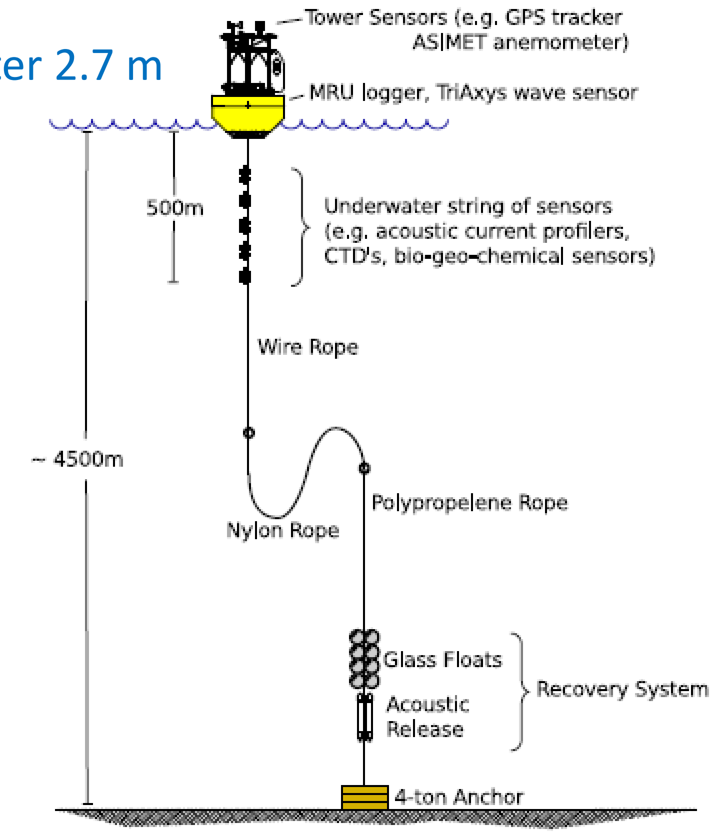
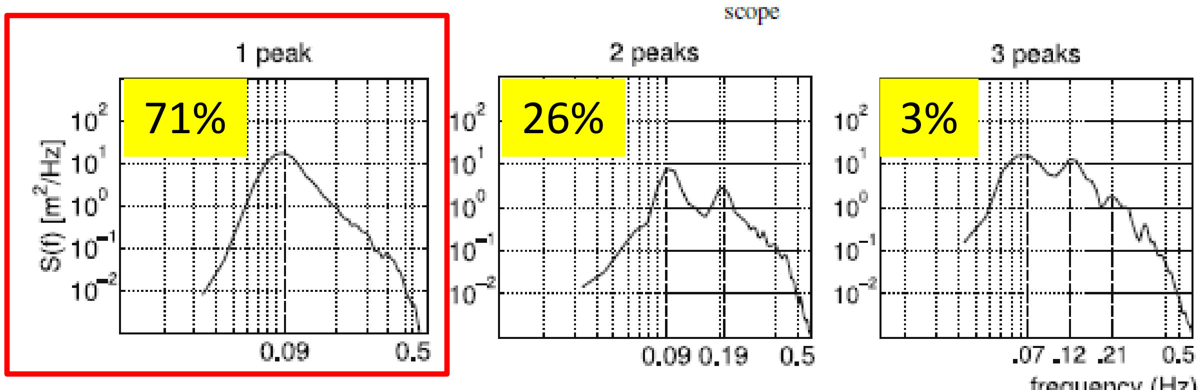


Fig. 2 Schematic of the slack–mooring system and location of instruments of the SOFS. Adapted from the CSIRO Fourth Deployment scope

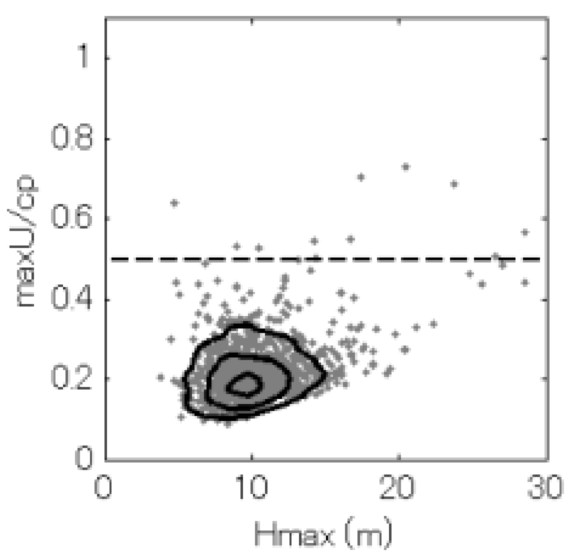
SOFS1: 2010.4-2011.2
SOFS2: 2011.12-2012.7
SOFS4: 2013.4-2013.9

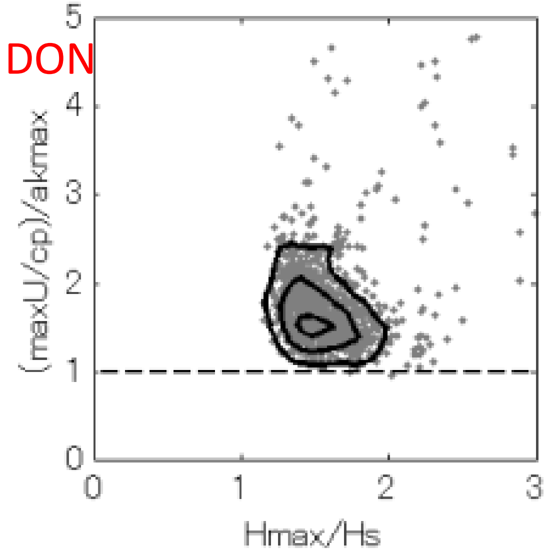


Orbital speed of non-breaking waves in a group

$KC > 40$

SOFS

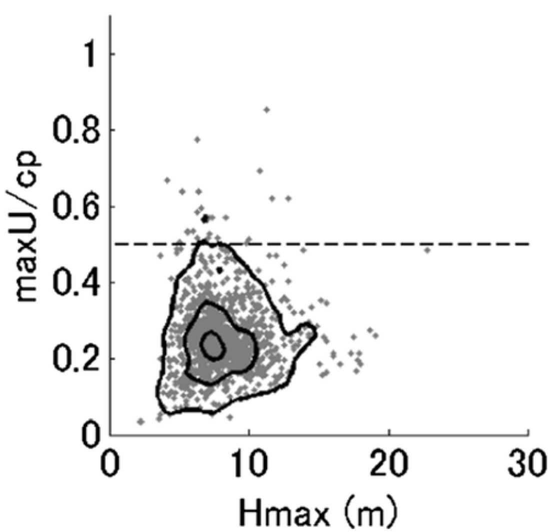


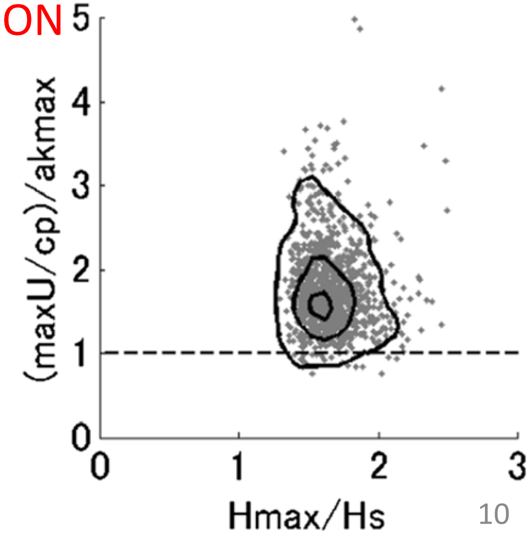


$DON > 1$

failure of narrow band
& weakly nonlinear approx.

JKEO/NKEO



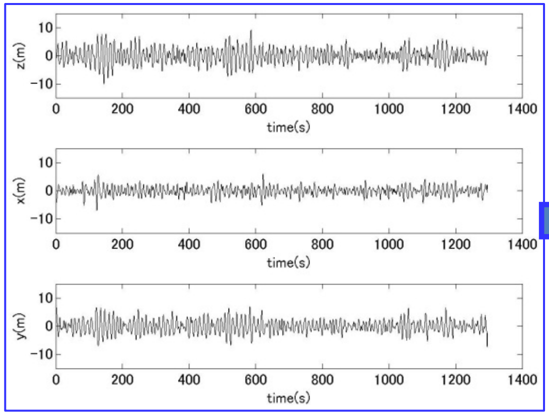


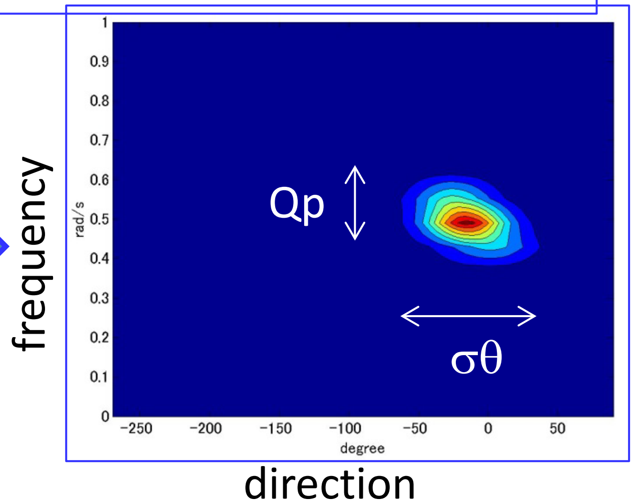
DIRECTIONAL SPECTRAL ESTIMATE FROM TETHERED BUOY

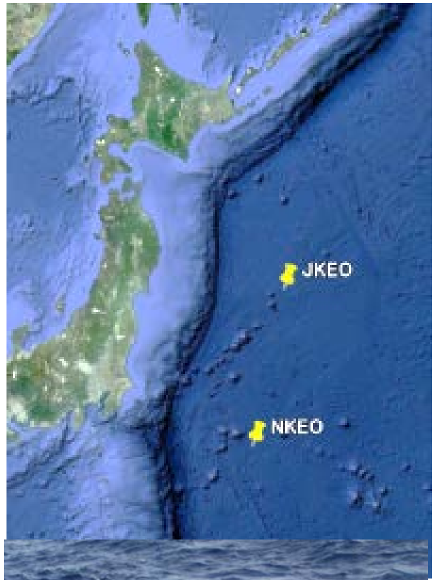
Comparison of wave models, and JKEO and NKEO K-TRITON buoy observations

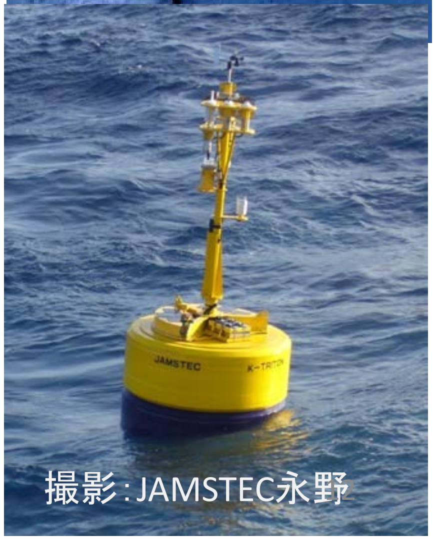
- Observational data (GPS wave sensor)
  - JKEO (2009/9-2009/11)
  - NKEO (2012-2013)
- TodaiWW3-Japan5km

Directional spectrum is estimated from the observation by Extended Maximum Entropy Method





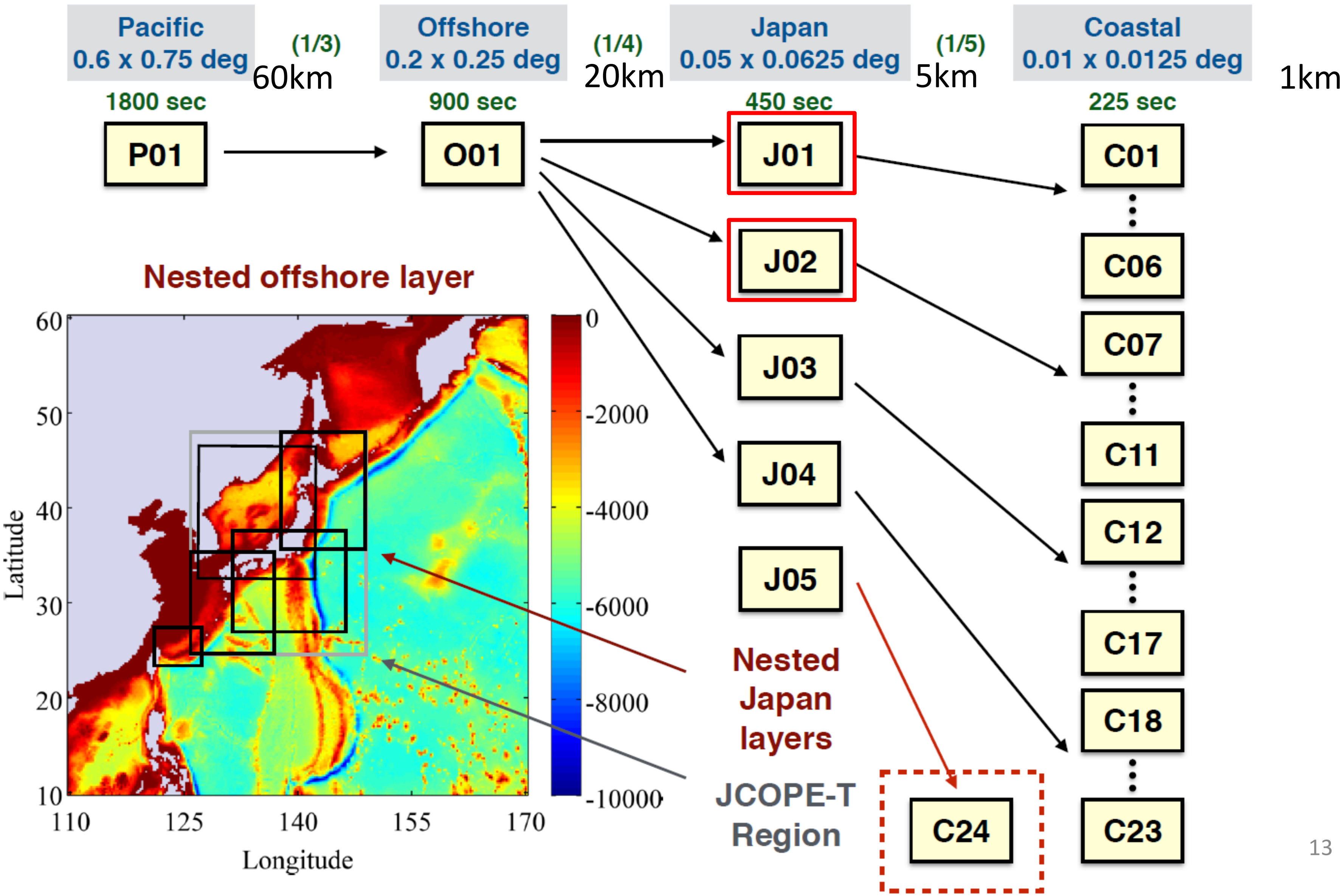




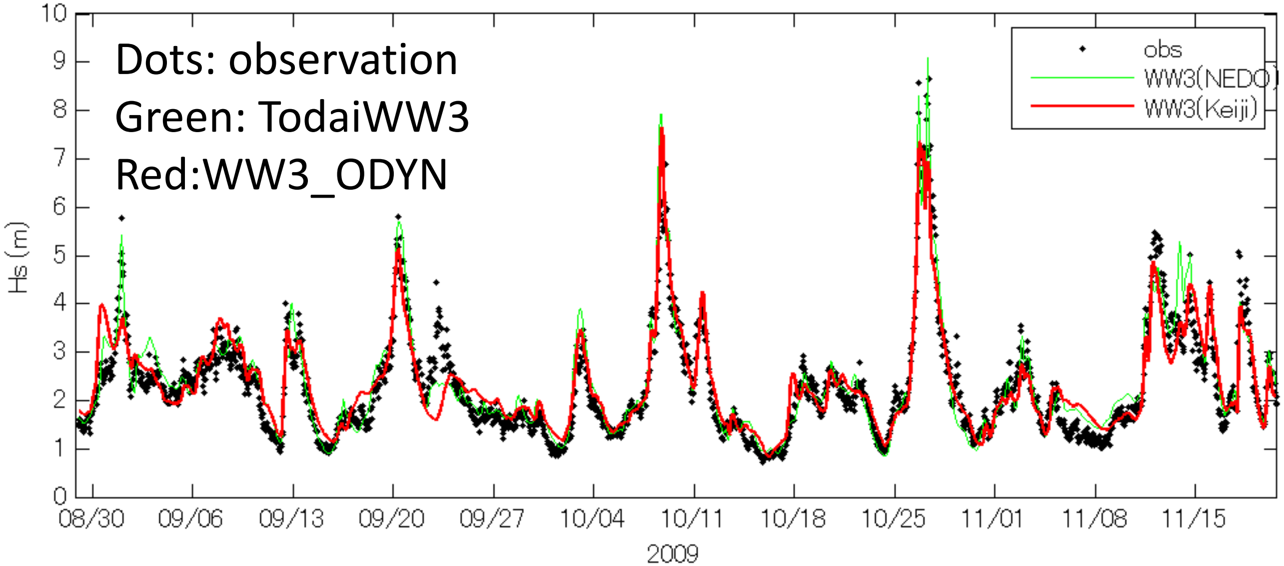
TodaiWW3-Japan5km (1994-2014)

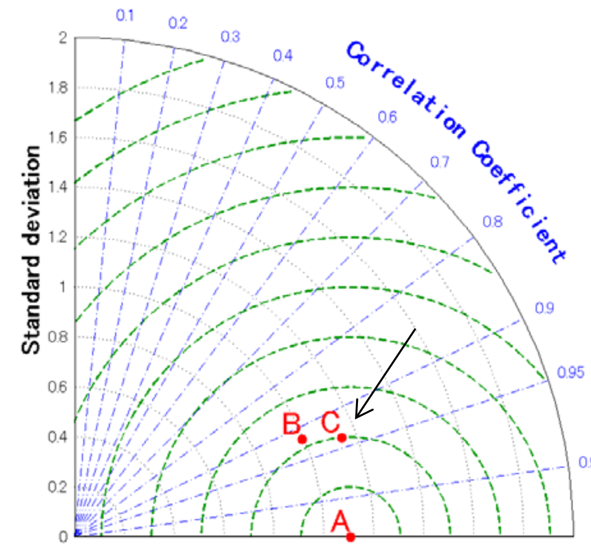
NCEP/CFSR Wind

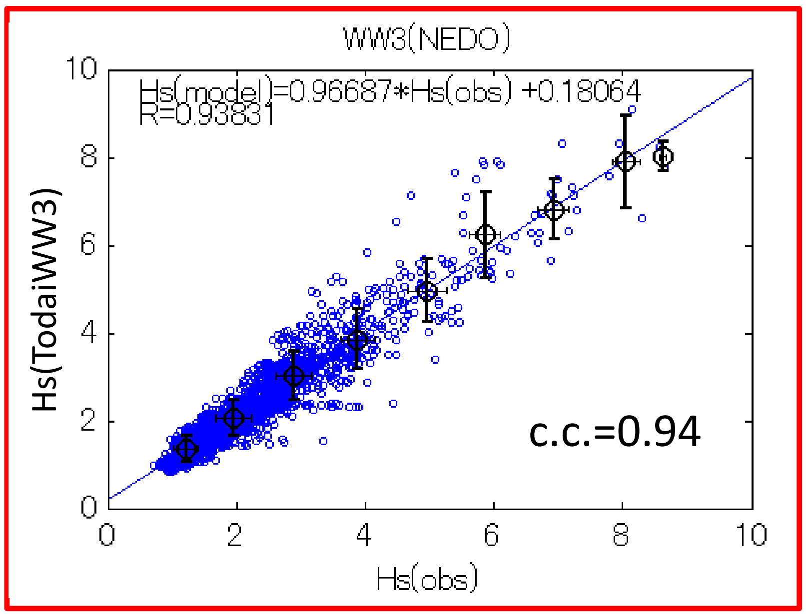
Webb presentation on 11/11 L4

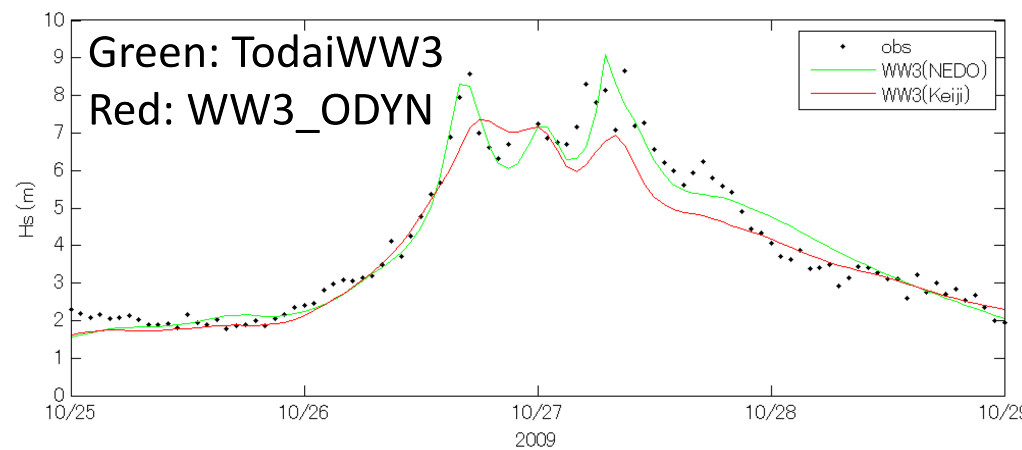


JKEO Hs comparison

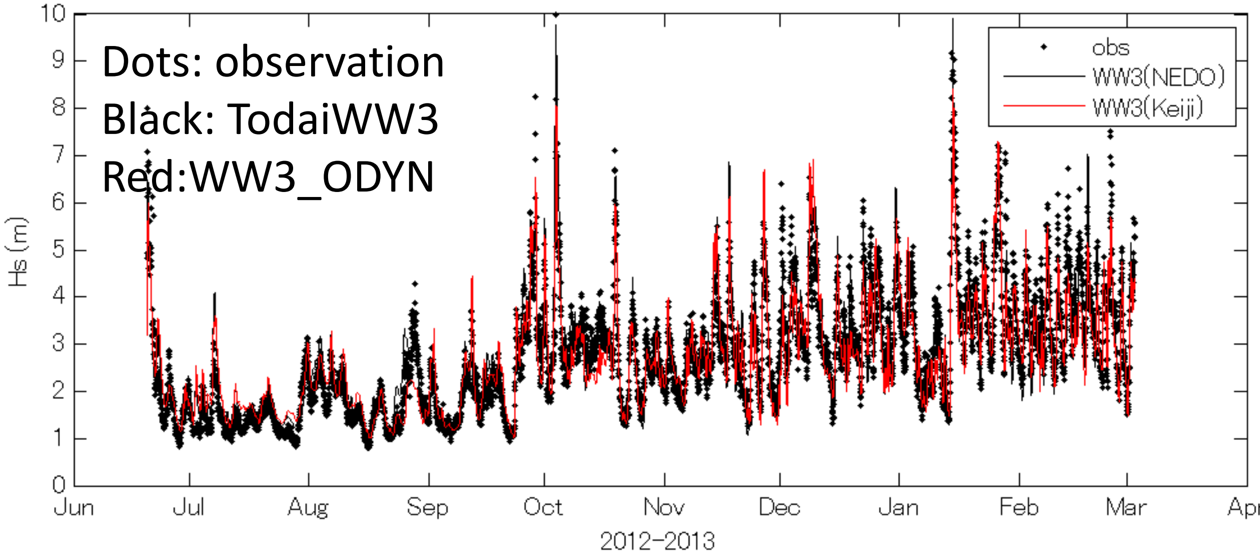






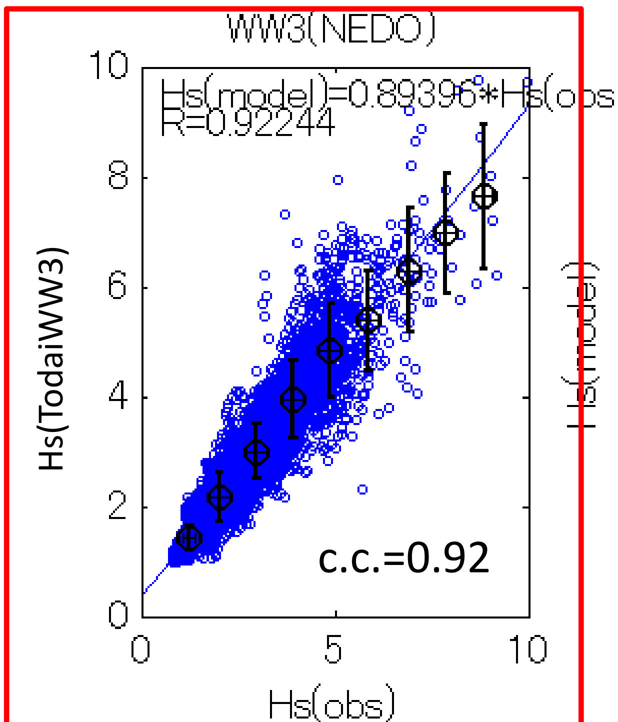


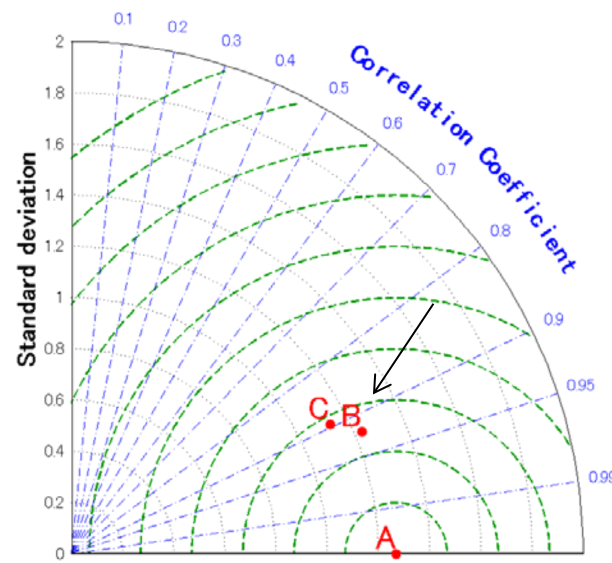
NKEO Hs comparison



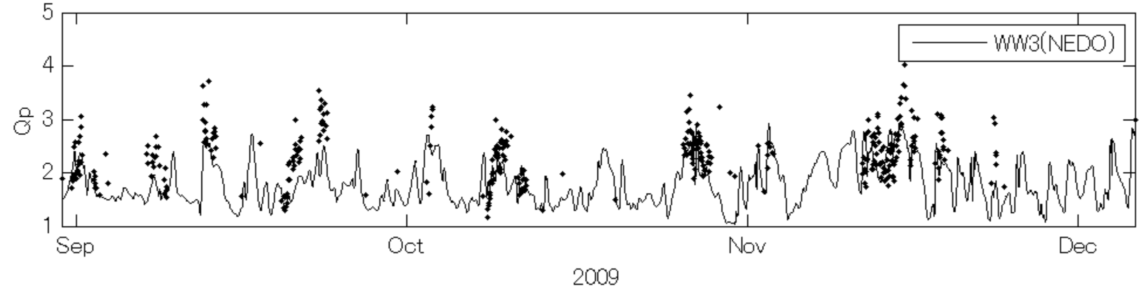
Black: TodaiWW3

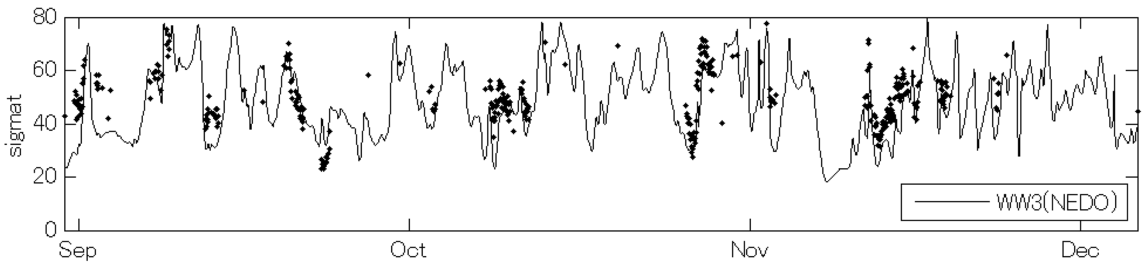
TodaiWW3 & observation correlation: 0.92



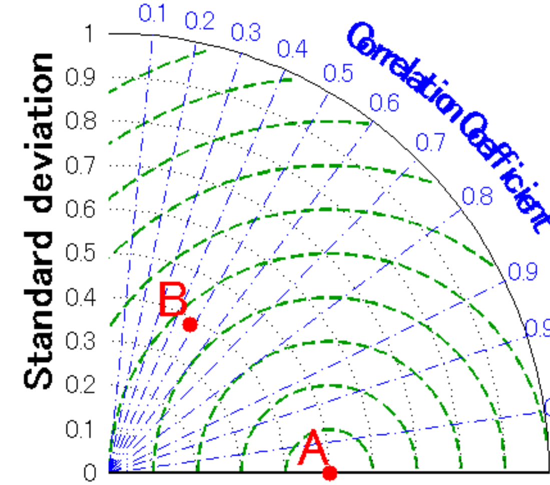


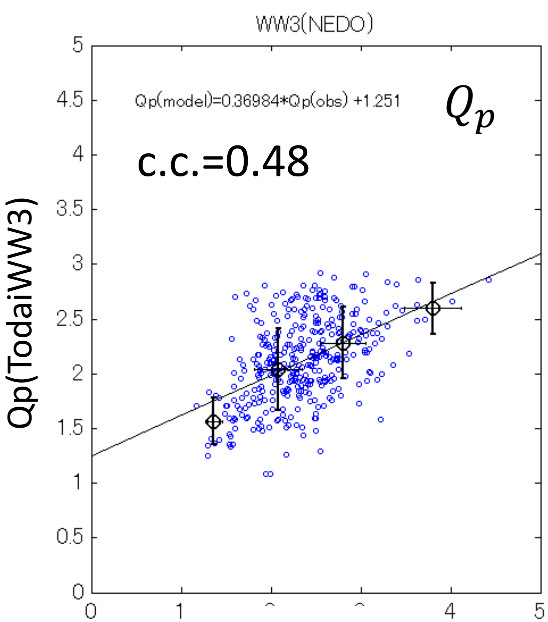
JKEO Q_p and σ_θ comparison





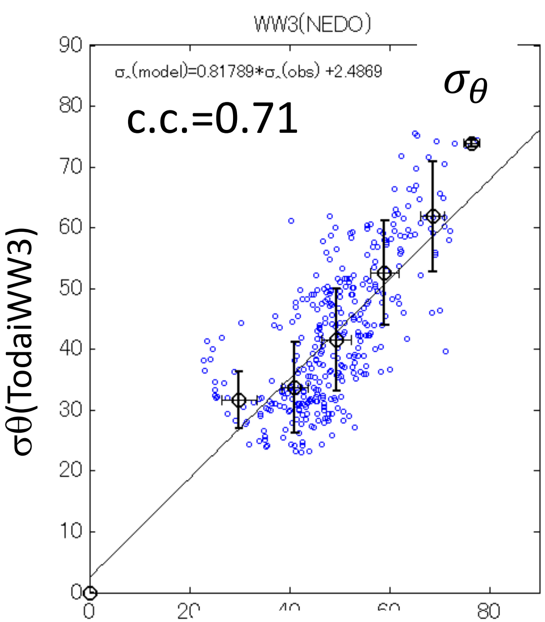
Q_p





Q_p

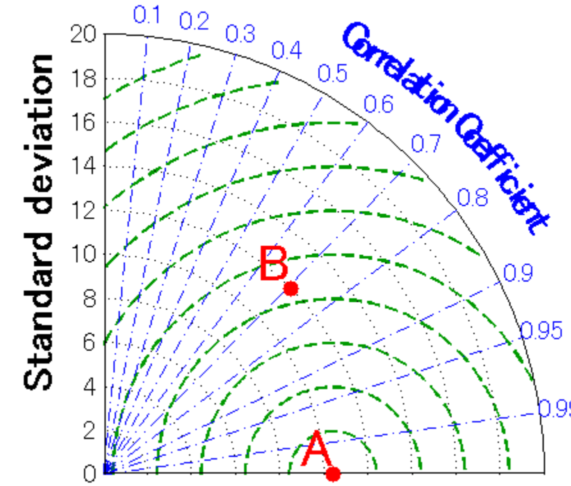
Q_p(obs)



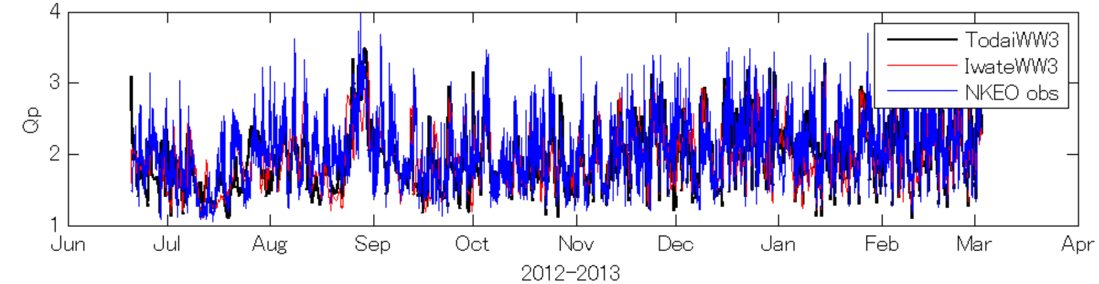
σ_θ

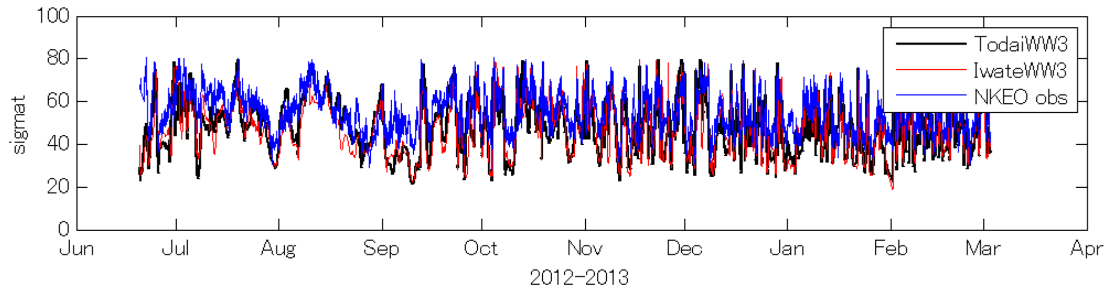
$\sigma_\theta(obs)$

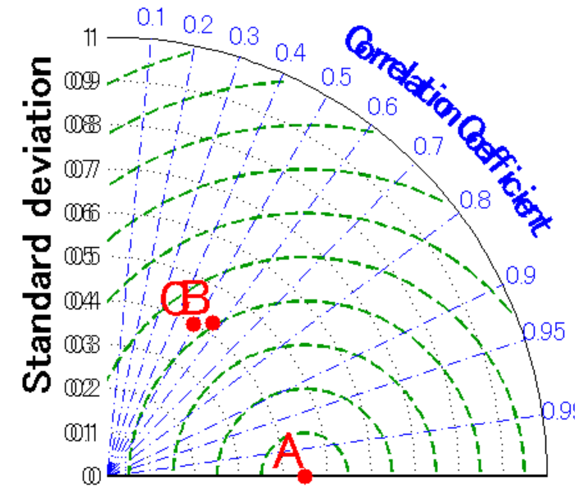
σ_θ

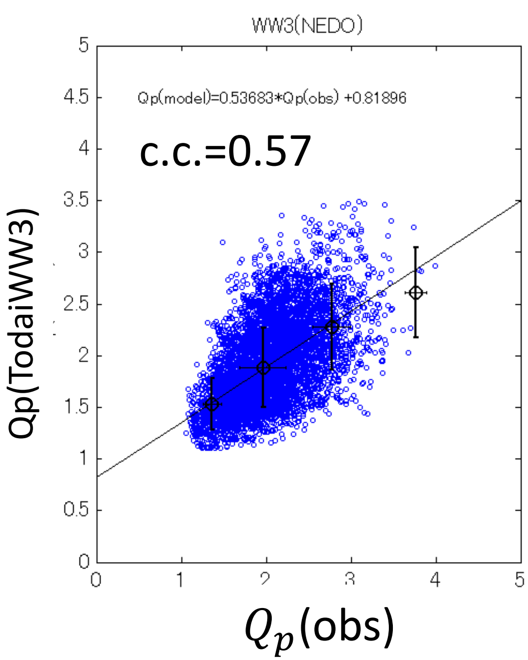


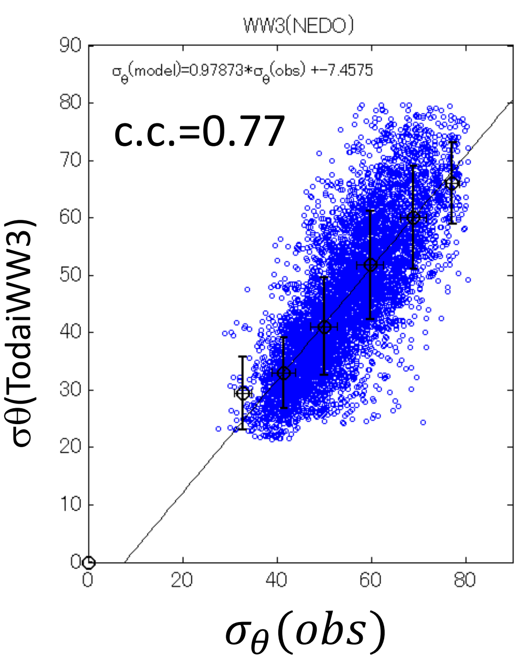
NKEO Q_p and σ_θ comparison

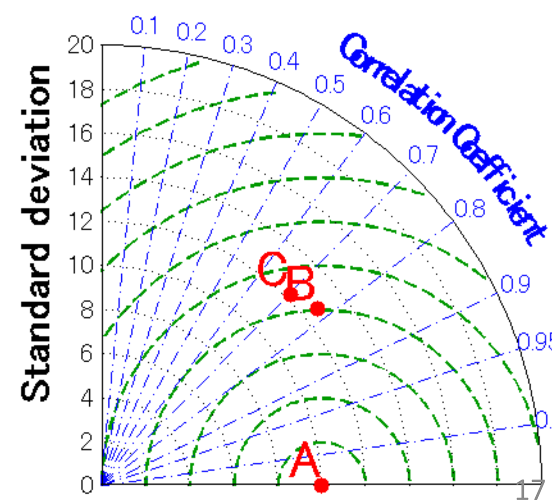






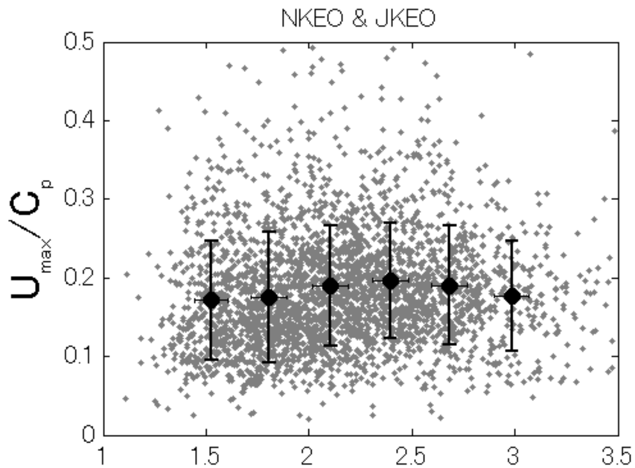




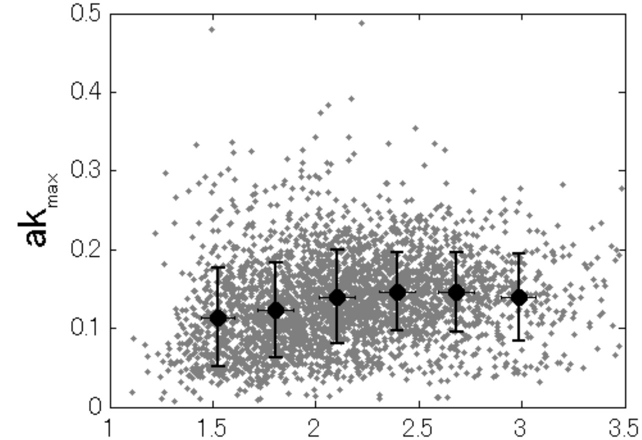


DEPENDENCE OF ORBITAL VELOCITY ON SPECTRAL GEOMETRY

Orbital velocity and frequency bandwidth NKEO & JKEO

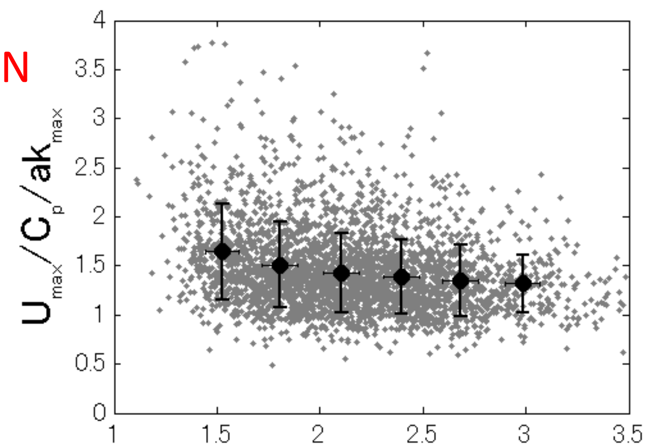


broad Qp narrow



broad Qp narrow

DON

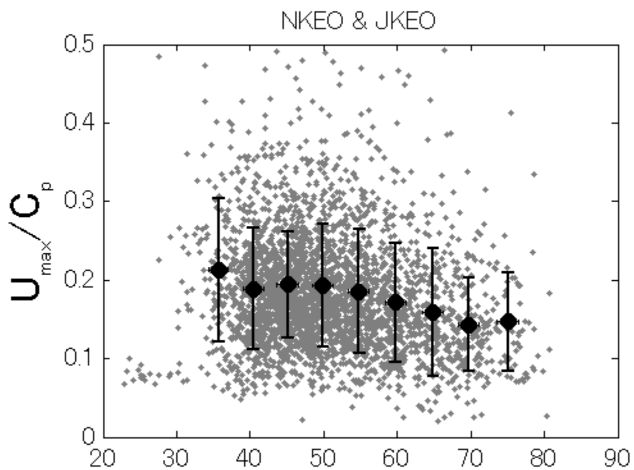


broad Qp narrow

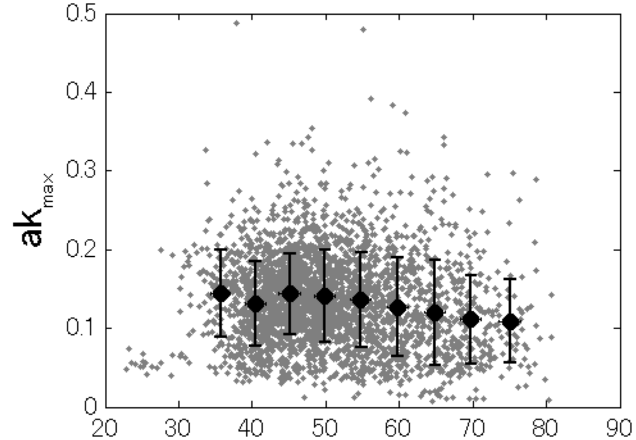
$$Q_p = 2m_0^{-2}\int_0^{\infty}\sigma\left[\int_0^{2\pi}F(\sigma,\theta)d\theta\right]^2 d\sigma$$

Note: KC>20

Orbital velocity and directional spreading NKEO & JKEO

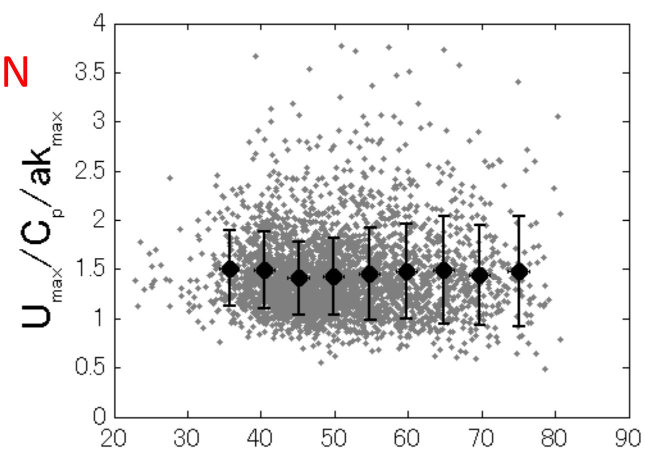


narrow σ_θ broad



narrow σ_θ broad

DON



narrow σ_θ broad

$$\sigma_\theta = \left[2\left\{ 1 - \left(\frac{p^2 + q^2}{m_0{}^2} \right)^{\frac{1}{2}} \right\} \right]^{\frac{1}{2}}$$

$$p = \iint \cos\theta F(\sigma,\theta)\, d\sigma d\theta$$

$$q = \iint \sin\theta F(\sigma,\theta)\, d\sigma d\theta$$

Note: KC>20

PRELIMINARY RESULTS FROM HOSM SIMULATION

HOSM simulation of directional wave field

Higher Order Spectral Method
(HOSM Dommermuth & Yue 1987; West et al. 1987).

JONSWAP spectrum

$\gamma = 3.3$

$ak = 0.5\,H_s k_p = 0.11$

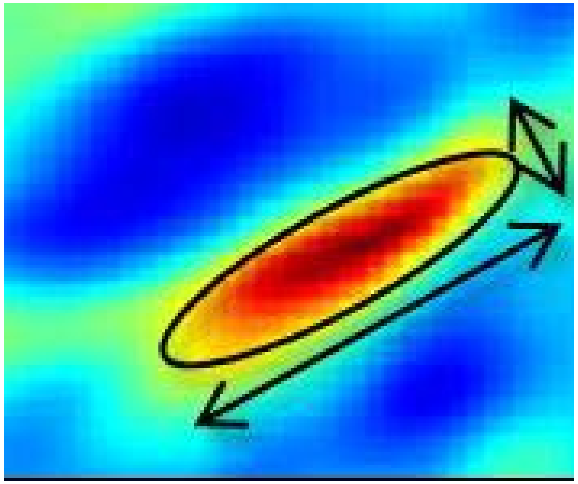
Directional distribution

$\cos^N \dfrac{\theta}{2};\ \ N = 2\sim1000$

$50\,T_p \times 10\ \ ensembles$

$512(10\,\lambda_p) \times 512(20\,\lambda_p)$

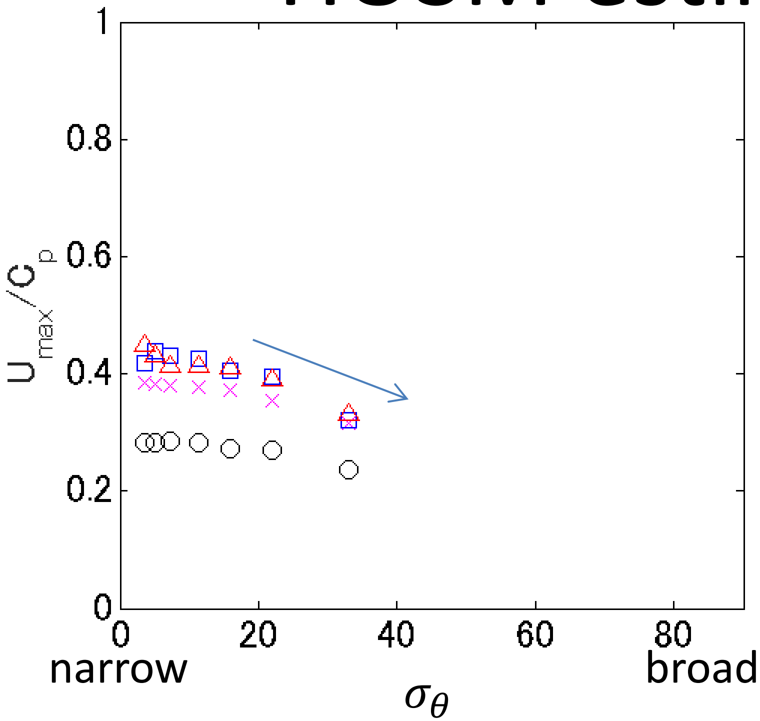
Order of Nonlinearity
M=1 (linear)
M=2,3,5

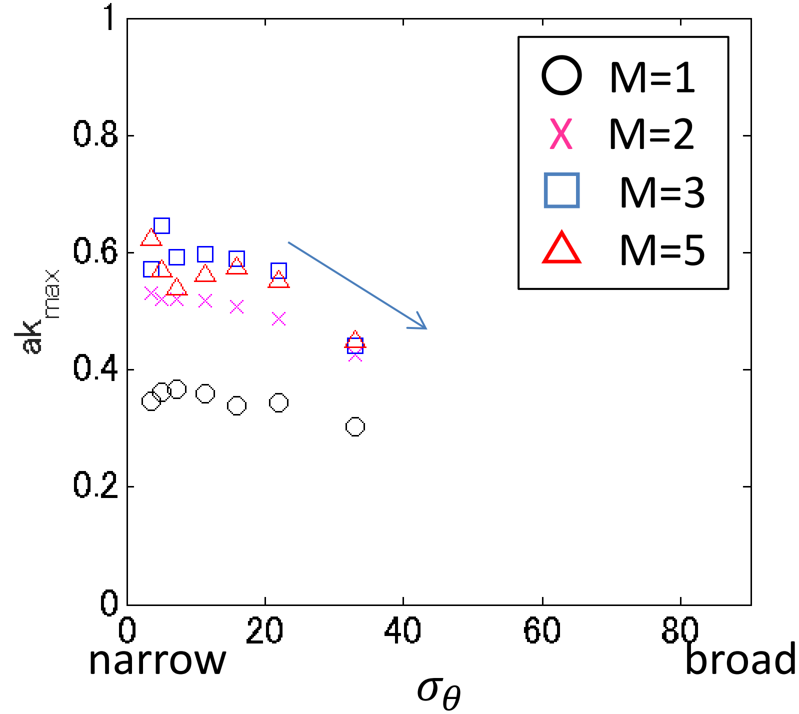


Detecting maximum wave in a group
Determine shape parameters
Estimate local steepness
Estimate orbital velocity

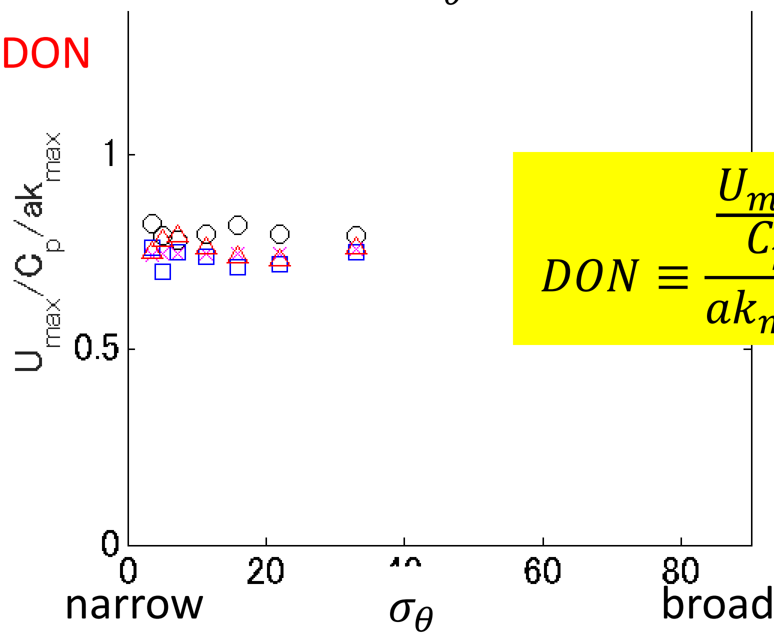
Fujimoto & Waseda 2014 WISE

HOSM estimation of DON



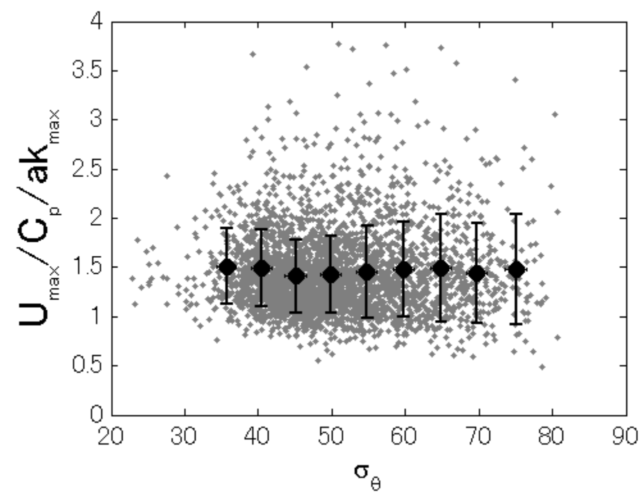


DON

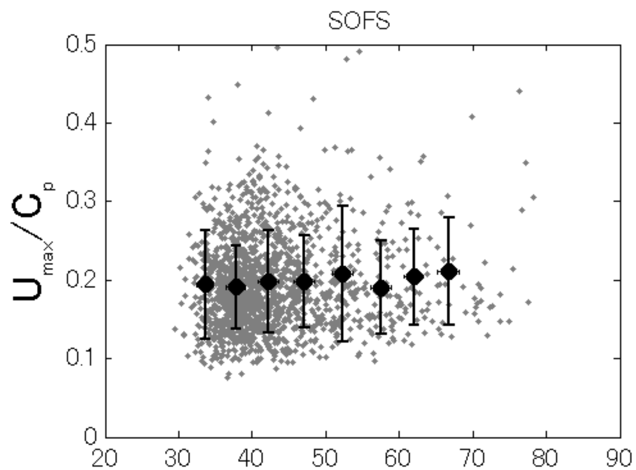


$$DON \equiv \frac{\frac{U_{max}}{C_p}}{ak_{max}} \sim const$$

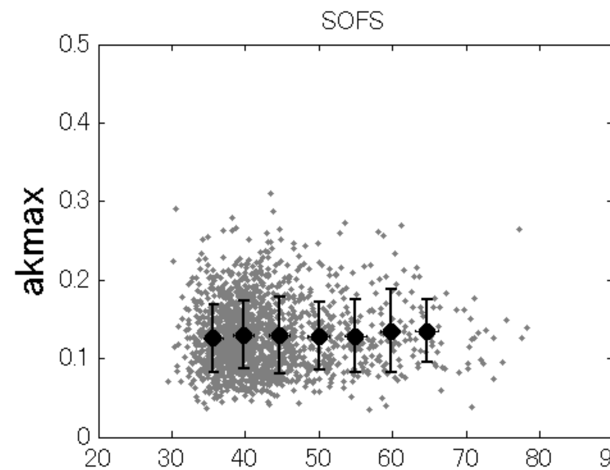
JKEO/NKEO obs.



Orbital velocity and directional spreading SOFS

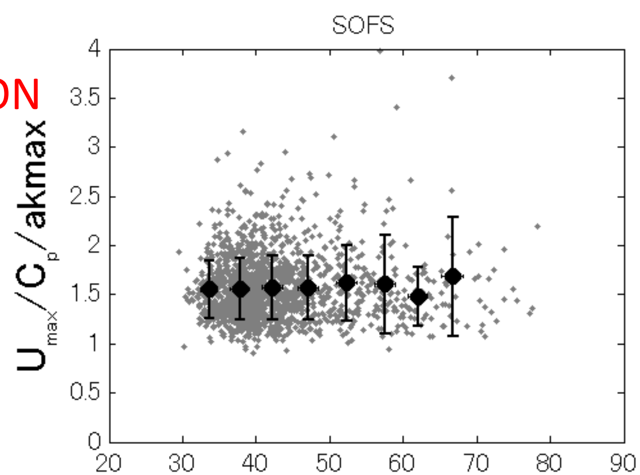


narrow σ_θ broad



narrow σ_θ broad

DON



narrow σ_θ broad

$$DON \equiv \frac{\frac{U_{max}}{C_p}}{ak_{max}} \sim const$$

Note: KC>30

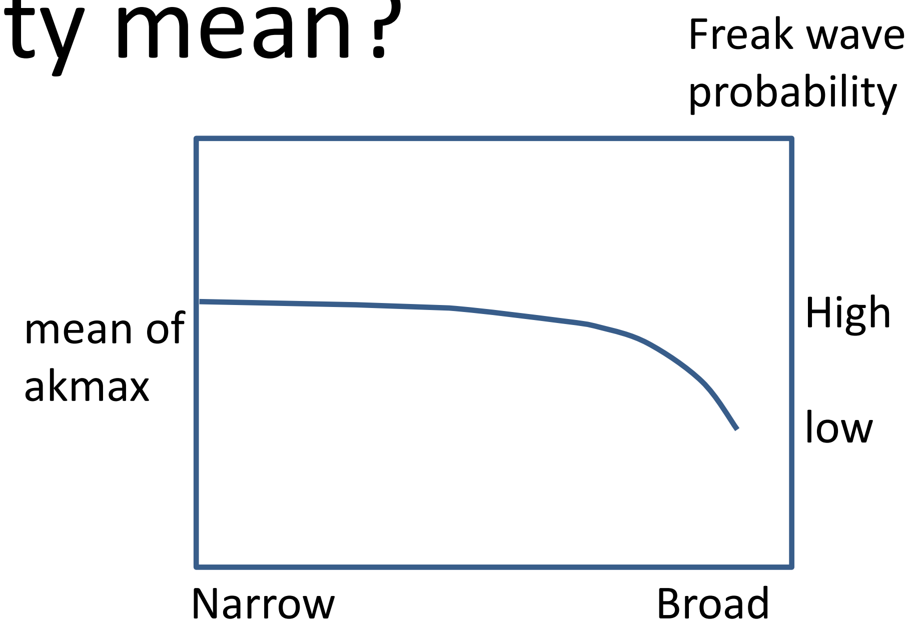
What does a constant Degree of Nonlinearity mean?

Lessons from freak wave research:

- Occurrence probability of large amplitude waves is enhanced when spectrum narrows

Conjecture:

- For broader spectrum, the mean of the observed extreme wave steepness lowers



From the HOSM simulation:

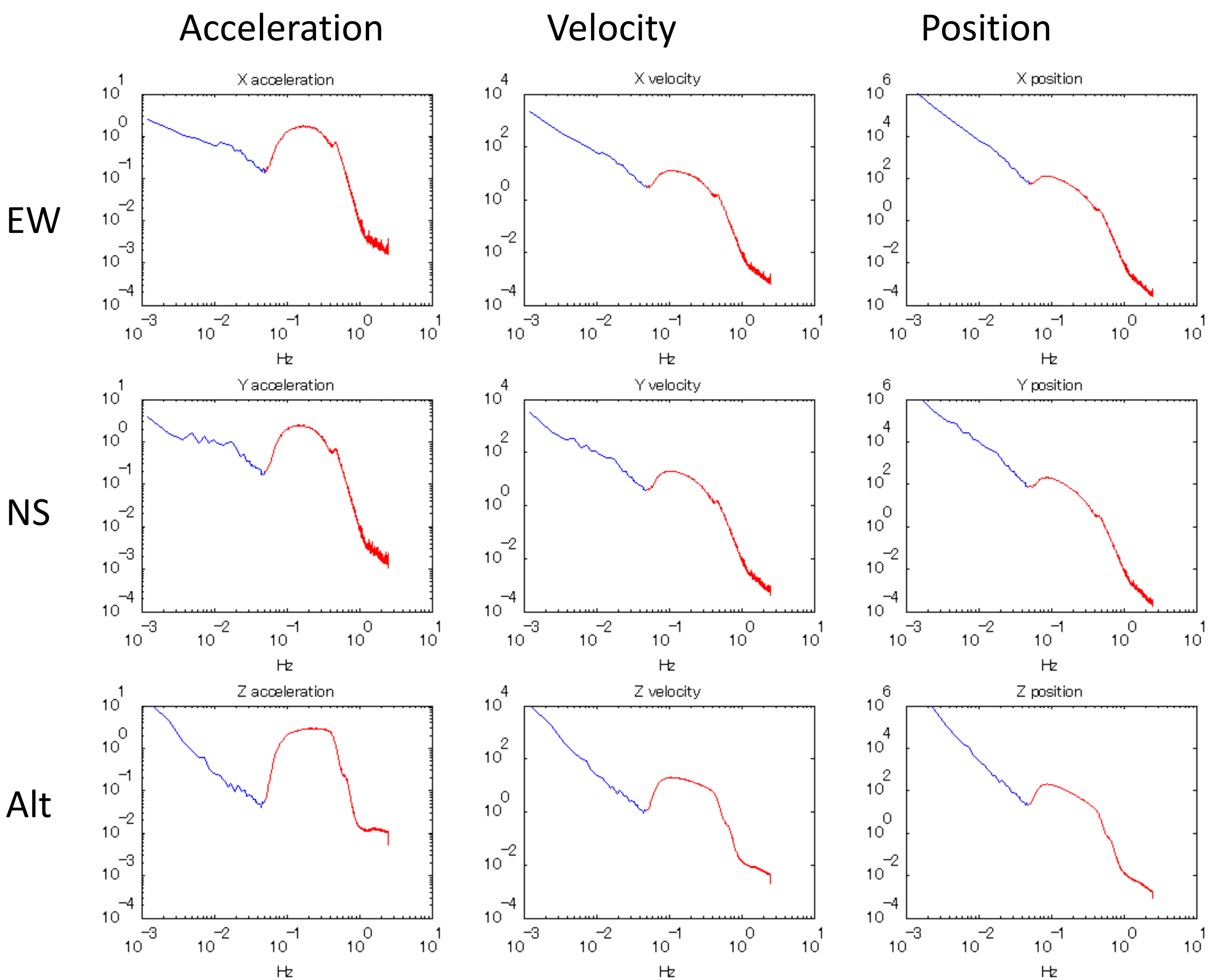
- Local steepness determines the DON, and not the spectral geometry

Speculation:

- Structure of coherent wave group in random directional wave field does not depend on spectral geometry

COMPARISON OF GPS WAVE MEASUREMENT AND ACCELEROMETER WAVE MEASUREMENT

Estimating velocity from acceleration

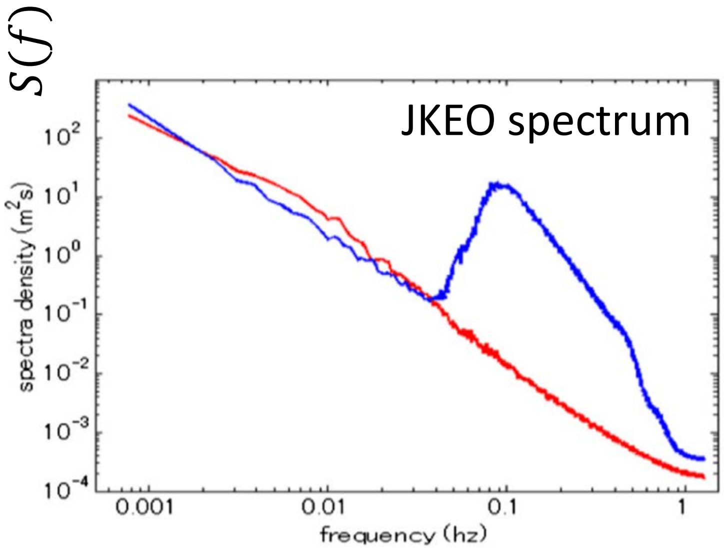


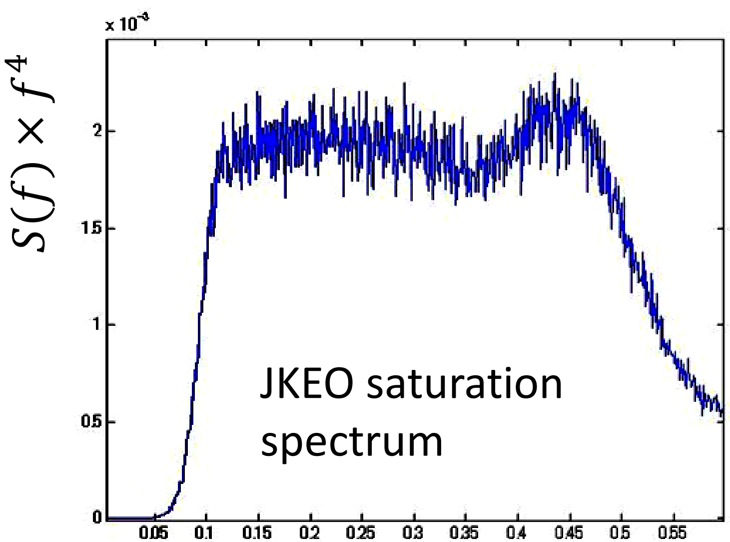
Cutoff 20 s
Ideal High-pass filter

$$v(t)=\cancel{v(0)}+\int_0^t a(t')\,dt'$$

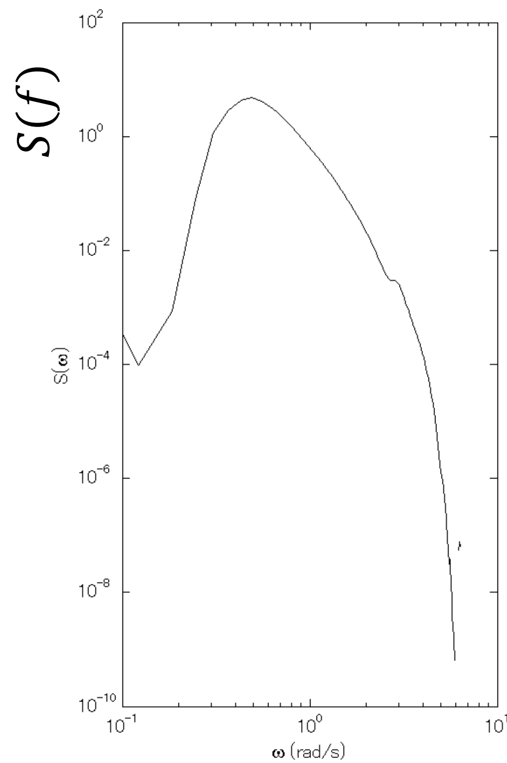
Constant drift speed is unknown

Difference in the spectral shape of elevation; GPS wave sensor and accelerometer (MRU)

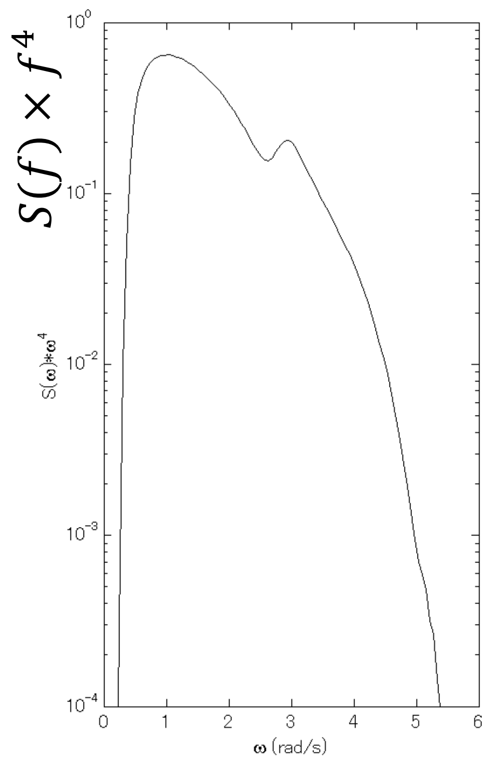




SOFS spectrum



SOFS saturation spectrum



SOFS Observation   2015.3-2016.3

IN2015_V01 “Integrated Monitoring Observing System Time Series automated moorings for climate and carbon cycle studies southwest of Tasmania”

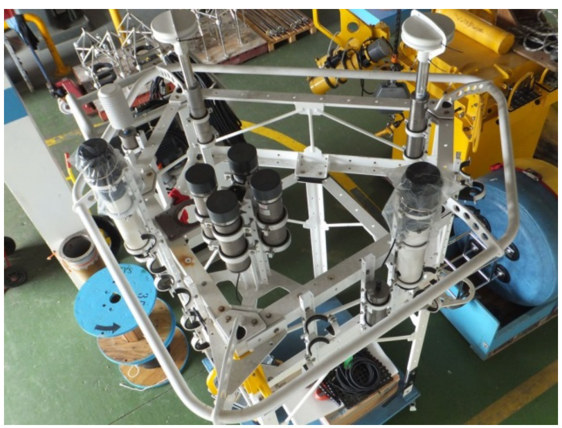
PI: Prof Tom Trull (ACE CRC)

March 22 – April 1 (10 days cruise)

Simultaneous observation of GPS and accelerometer

- MRU 10 minutes every hour
- TriAXYS 20 minutes every two hours
- GPS 20 minutes every two hours

In collaboration w. Peter Jansen, Eric Schulz



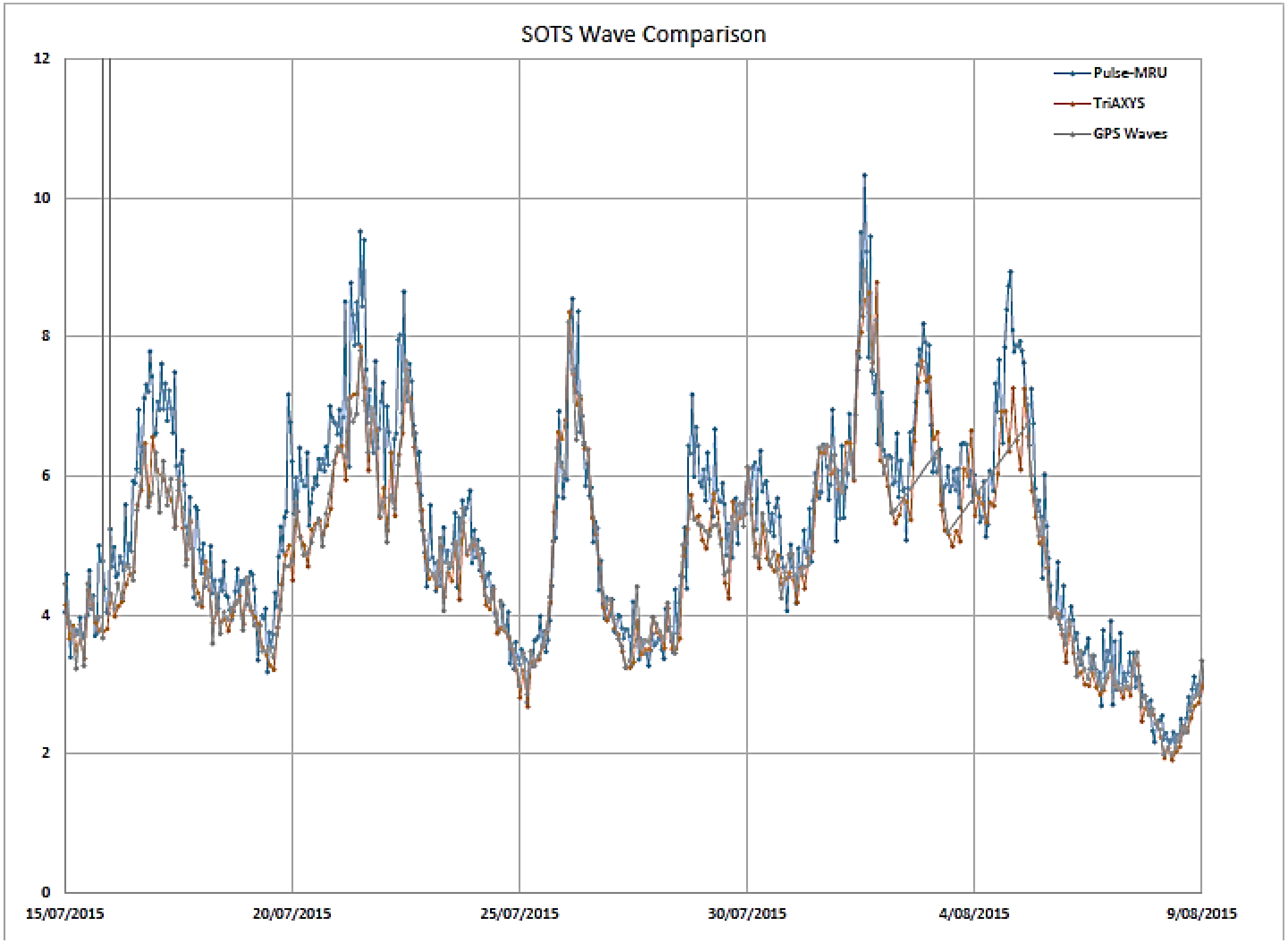
Electronics well

GPS wave sensor

Antenna enclosure

Battery pack

Preliminary comparison of wave heights from TriAxys, MRU and GPS



Summary

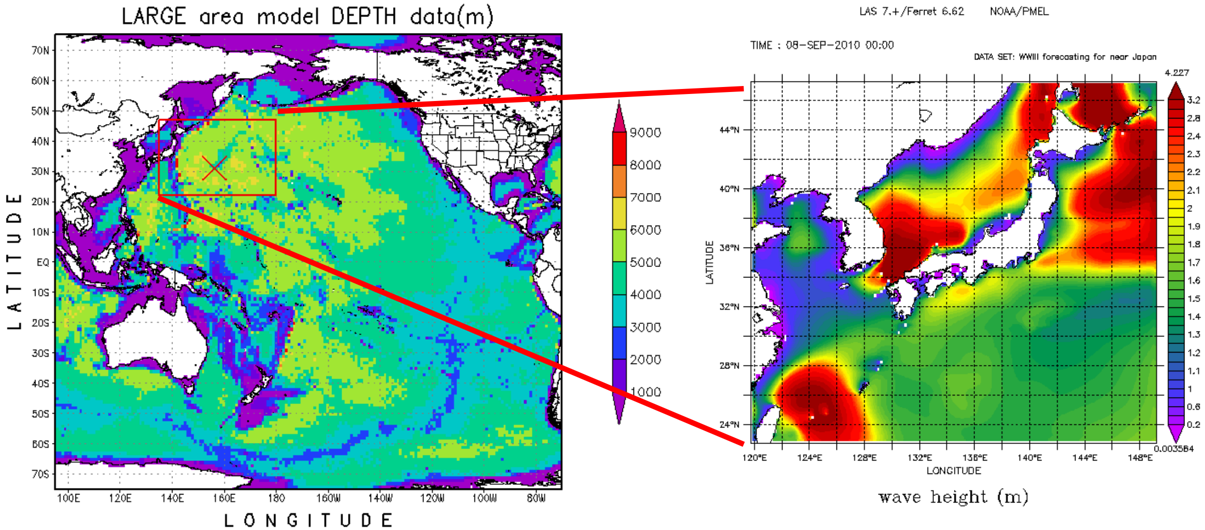
- Orbital velocity of the extreme waves were estimated from the motion of the moored buoy
- The orbital velocity and the steepness of the extreme waves tended to decrease as the spectrum broadened
- The degree of nonlinearity ($U_{max}/C_p/ak_{max}$) showed statistically insignificant dependence on the spectral parameters
- *Therefore, it is speculated that the structure of coherent wave group that forms in directional wave field may have some universal features, except for the crest length*

Iwate model (2007.12-2013)

WAVEWATCHIII™

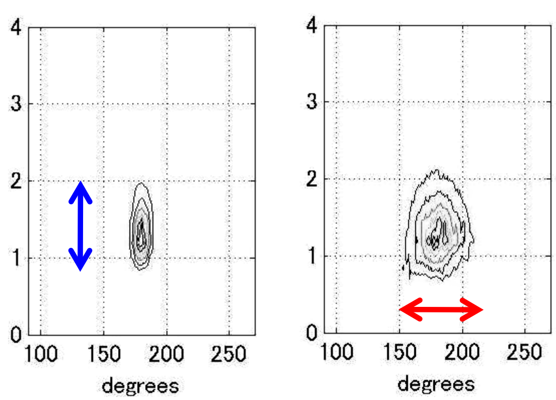
Sin, Sds: Tolman-Chalikov, Snl: DIA

Wind： GSM（Pacific）→MSM（Japan）



Tier 1 (1 degree)
JMA/GSM

Tier 2 (1/10 degree)
JMA/MSM



$$Q_p = 2m_0^{-2}\int_0^{\infty}\sigma\left[\int_0^{2\pi}F(\sigma,\theta)d\theta\right]^2 d\sigma$$

$$m_0 = \int_0^{2\pi}\int_0^{\infty}F(\sigma,\theta)d\sigma d\theta$$

$$\sigma_\theta = \left[2\left\{1-\left(\frac{a^2+b^2}{E^2}\right)^{\frac{1}{2}}\right\}\right]^{\frac{1}{2}}$$

$$a = \int_0^{2\pi}\int_0^{\infty}\cos(\theta)F(\sigma,\theta)d\sigma d\theta$$

Estimation of velocity & position from accelerometer

Position estimate from MRU without any filter