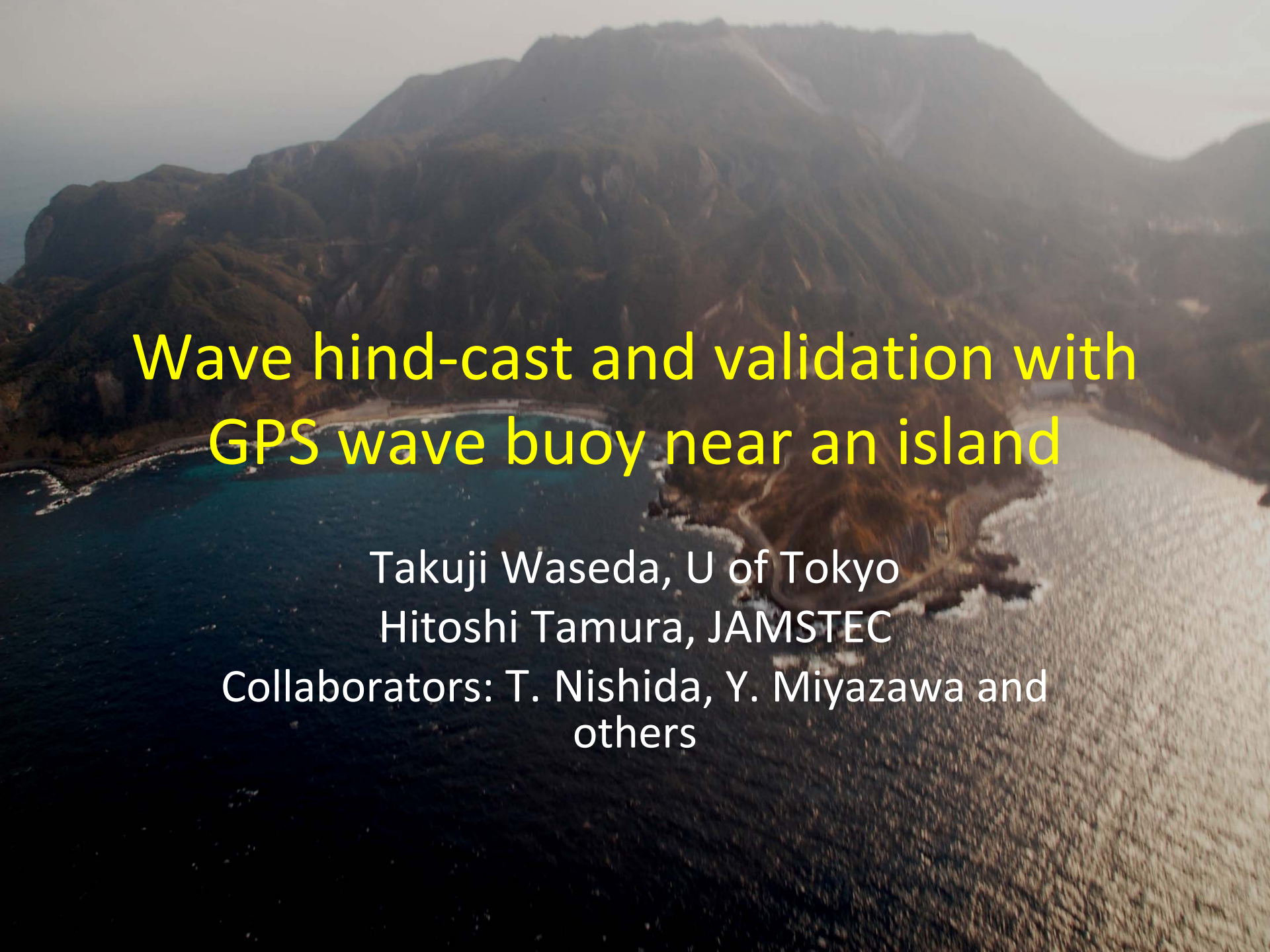


An aerial photograph of a rugged, mountainous island. The island features steep, forested slopes and a prominent peak. A small bay or cove is visible on the left side of the island, with a sandy beach and some buildings. The surrounding water is dark blue, and the sky is overcast. The text is overlaid on the image.

Wave hind-cast and validation with GPS wave buoy near an island

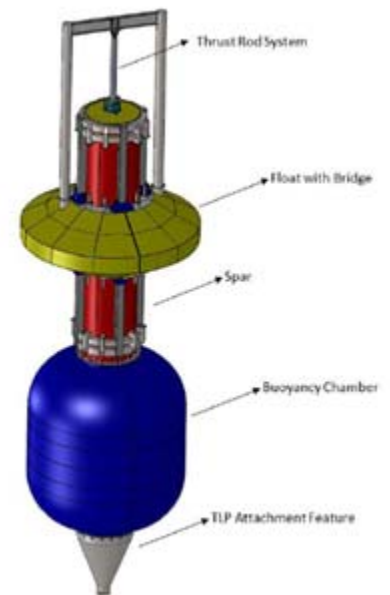
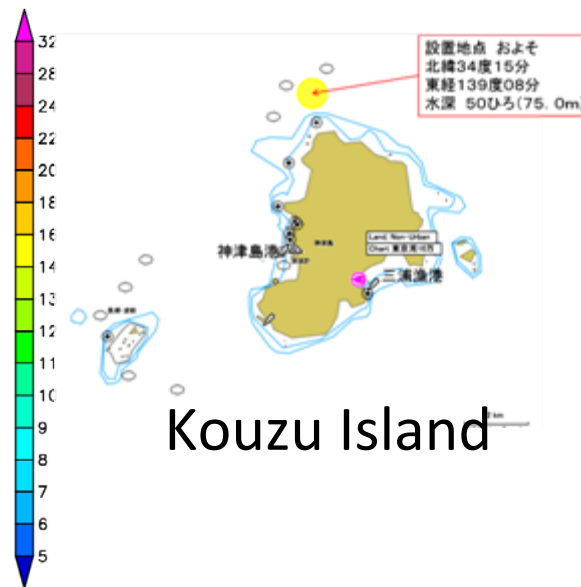
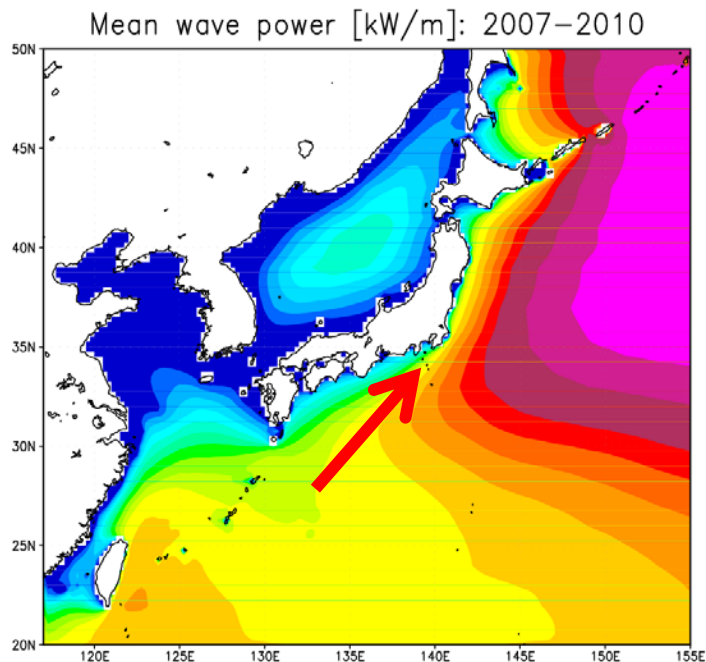
Takuji Waseda, U of Tokyo

Hitoshi Tamura, JAMSTEC

Collaborators: T. Nishida, Y. Miyazawa and
others

Background

- Wave Energy Utilization
 - Site selection
 - Resource evaluation
 - Estimating the Joint Probability Distribution of H_s and T
 - Providing met-ocean information to local people



OPT-MES
PowerBuoy-Japan model

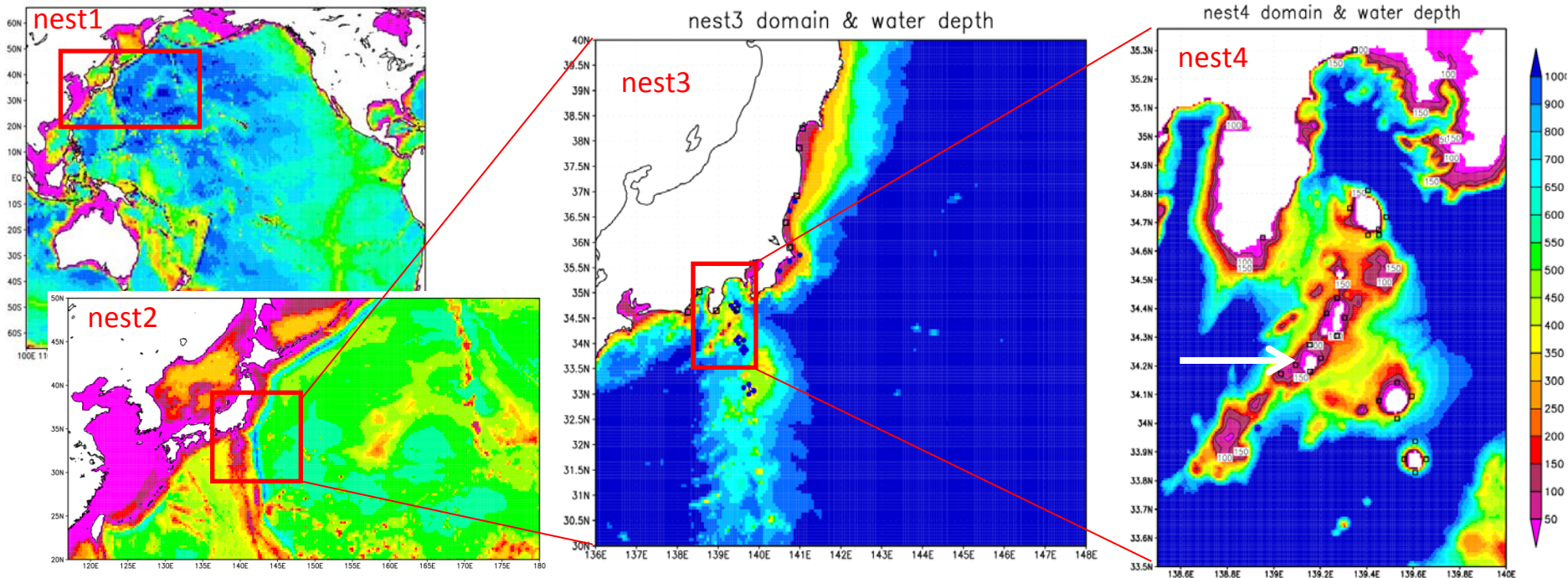
Methodology

- Nested wave hind-cast based on WAVEWATCH-IIITM $v\pi$
 - Long-term hindcast (5 years and 10 years)
 - Source terms (WAM4 + DIA)
 - Japan Meteorological Agency wind (MSM)
 - JCOPE2 ocean current ON/OFF
 - Short-term hindcast (1 month)
 - Source terms (TC + DIA)
 - Japan Meteorological Agency wind (MSM)
 - JCOPE-T ocean current and tide
- Validation with point-positioning GPS wave buoy
 - Based on a commercial product (Zenilite Buoy co.)
 - Software and platforms being developed under “freak wave” observation project

Summary

- Four-tier nested hind-cast wave model was developed based on WW3 and was validated against existing moored buoy network (NOWPHAS), drifting buoys of JMA and the original GPS wave measurement (at JKEO site)
- Based on the estimated wave power, a suitable site was selected and the GPS buoy was deployed at the Kouzu Island.
- Model performed well in winter time.
- The model failed considerably during the typhoon passage in fall. The bias of the NWP product was exaggerated by the island.
→ More work needs to be done.

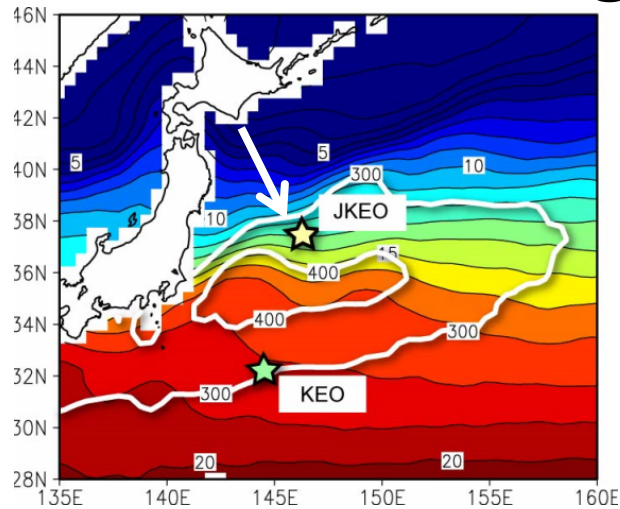
Nested Hindcast Model



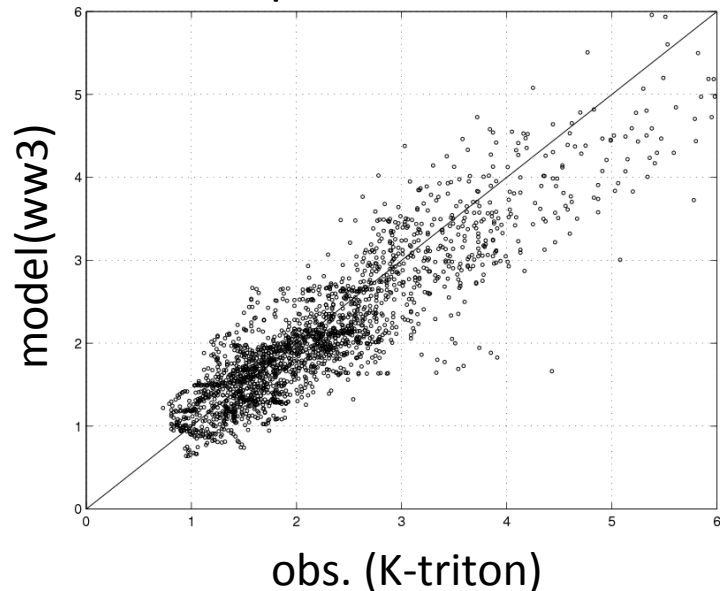
Models	domain	period	Grid size	Wind forcing
nest1 Pacific Model	100E-70W 66S-66N	11 Years 2000/1/1-2011/1/1	~100km (191x133)	NCEP/Reanalysis 100km, 6hourly
nest2 Japan Model	117-180E 20-50N	11 Years 2000/1/1-2011/1/1	~25km (255x123)	NCEP/Reanalysis 100km, 6hourly
nest3 South East J. M.	136-148E 30-40N	4.75 Years 2006/3/1-2011/1/1	~6.3km (195x163)	JMA/MSM 5km, 3hourly
nest4 Izu Islands Model	138.5-140E 33.5-35.375N	4.75 Years 2006/3/1-2011/1/1	~780m (195x243)	JMA/MSM 5km, 3hourly

Validation of Hs against offshore observation(nest3)

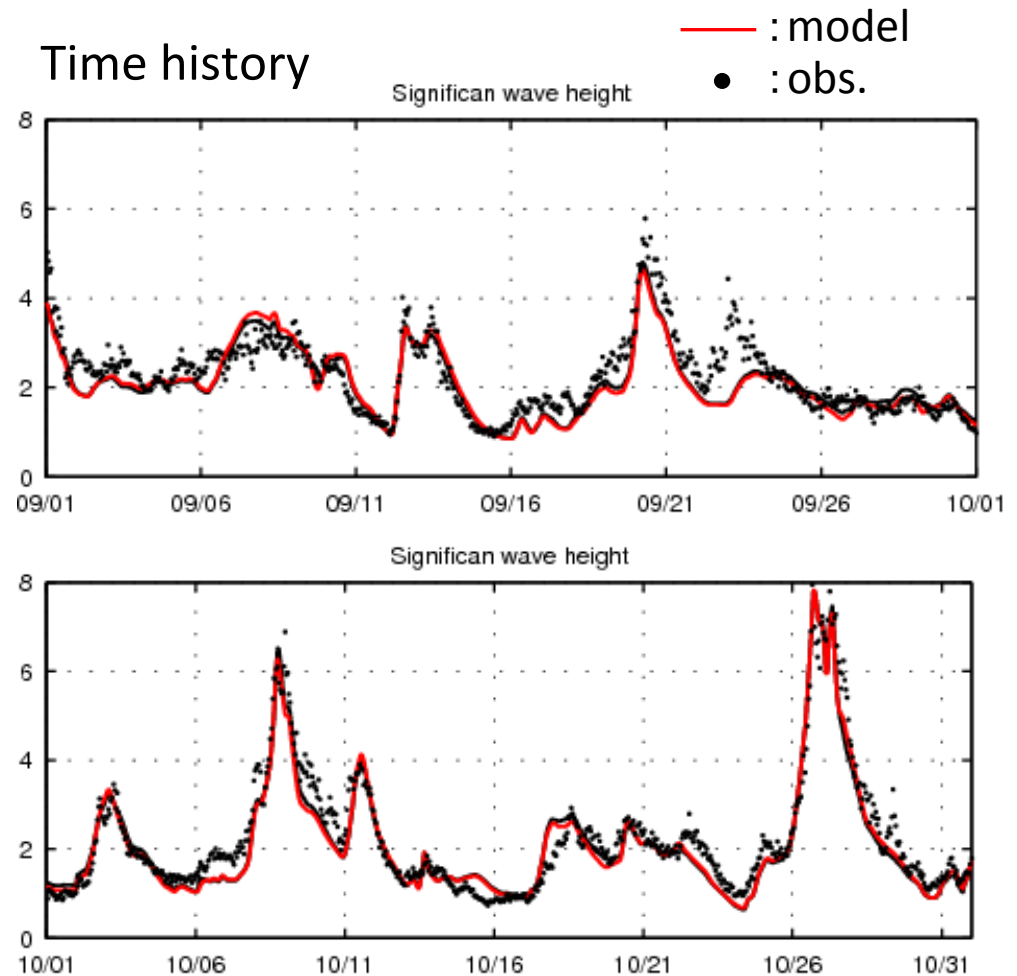
Obs. vs Model @ JKEO: from 2009 Aug to 2009 Nov



Scatter plot

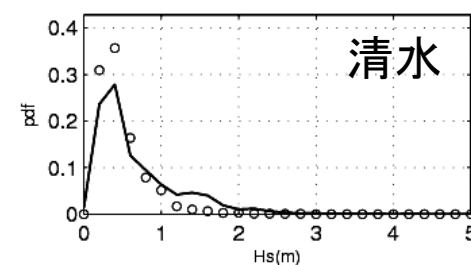
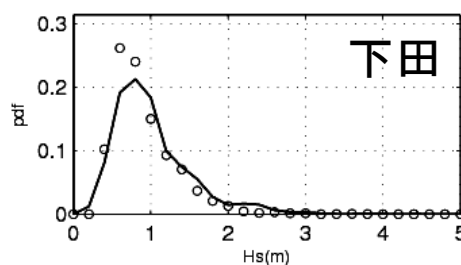
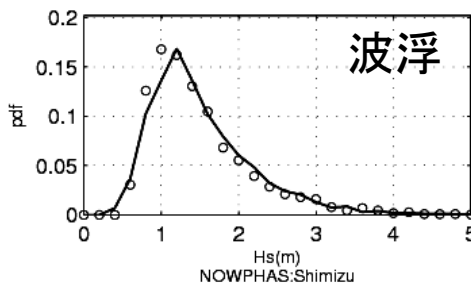
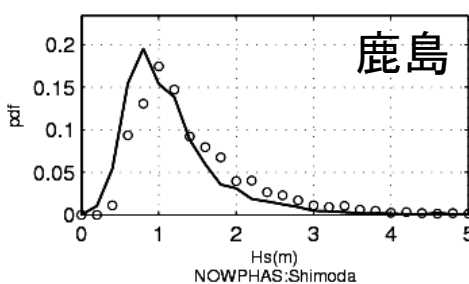
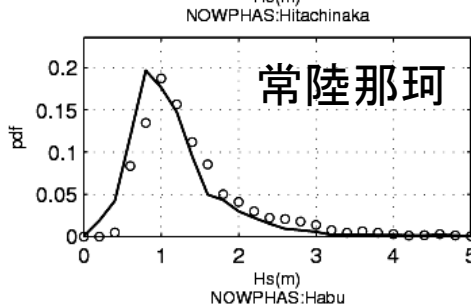
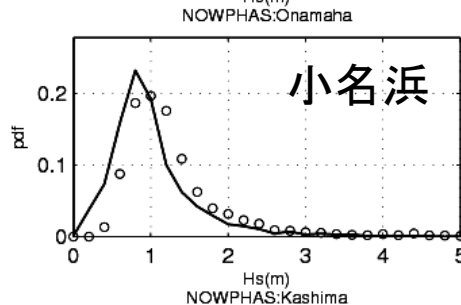
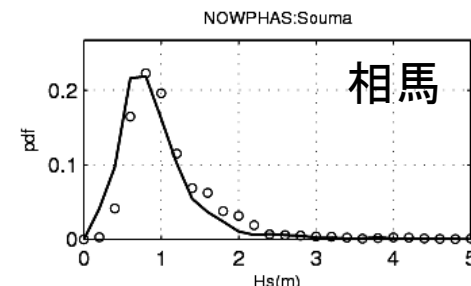
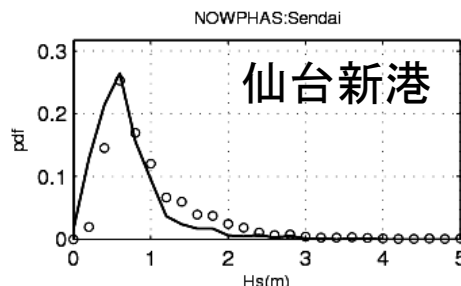


Time history



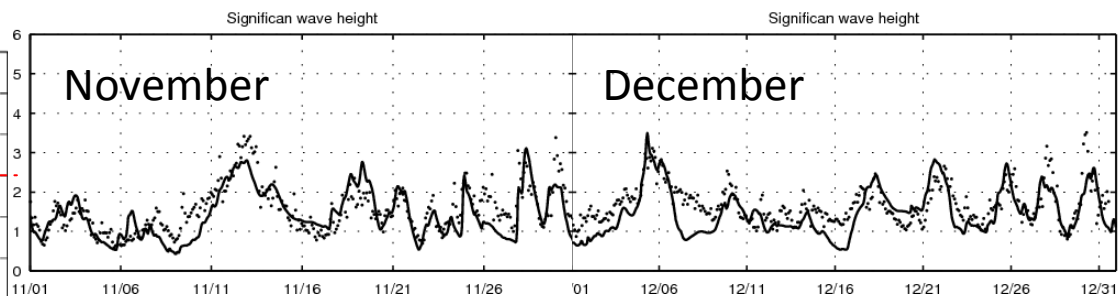
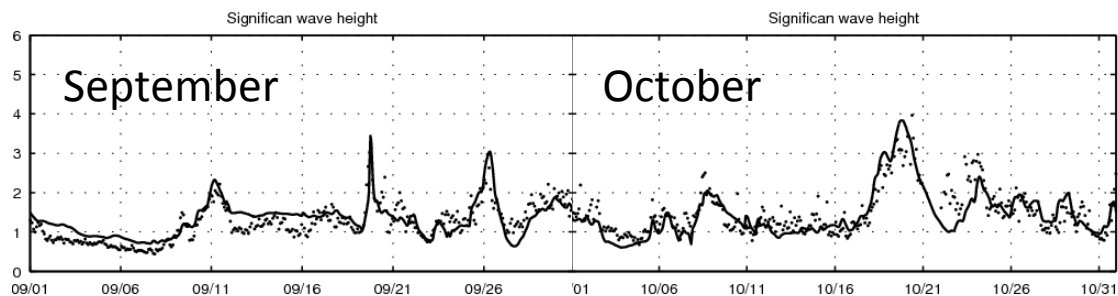
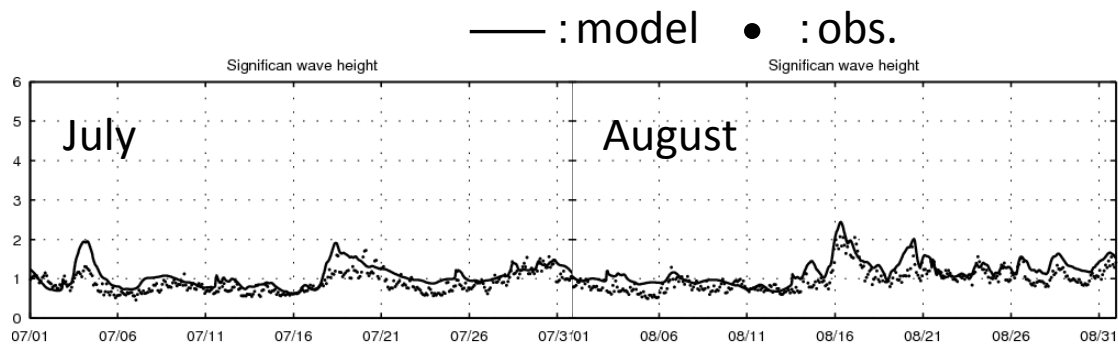
Validation of Hs against near-shore observations (nest3)

Comparison with NOWPHAS buoy network: Hs histogram

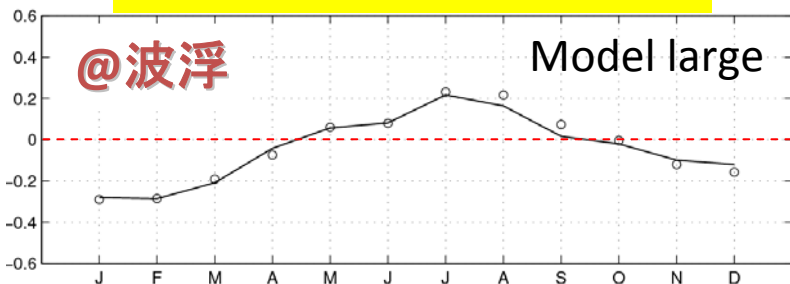


Validation of Hs against near-shore observations (nest3)

obs. (NOWPHAS) vs model (ww3)



$$(Hs(ww3) - Hs(obs))/Hs(obs)$$



2007-2009 monthly model bias

2008

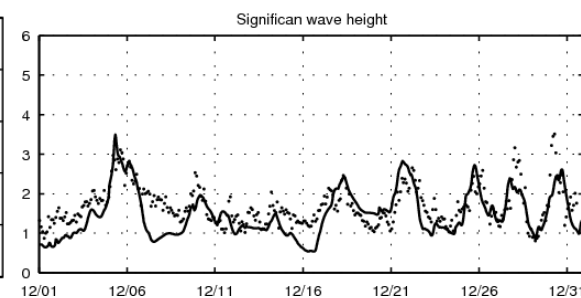
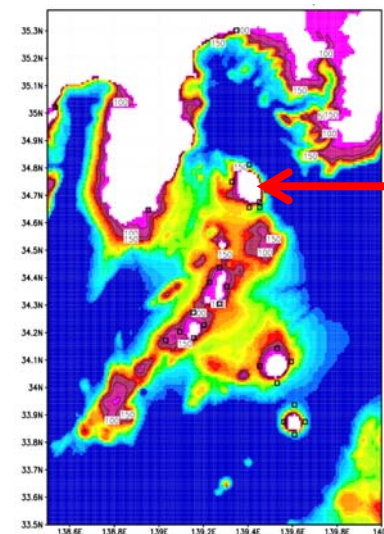
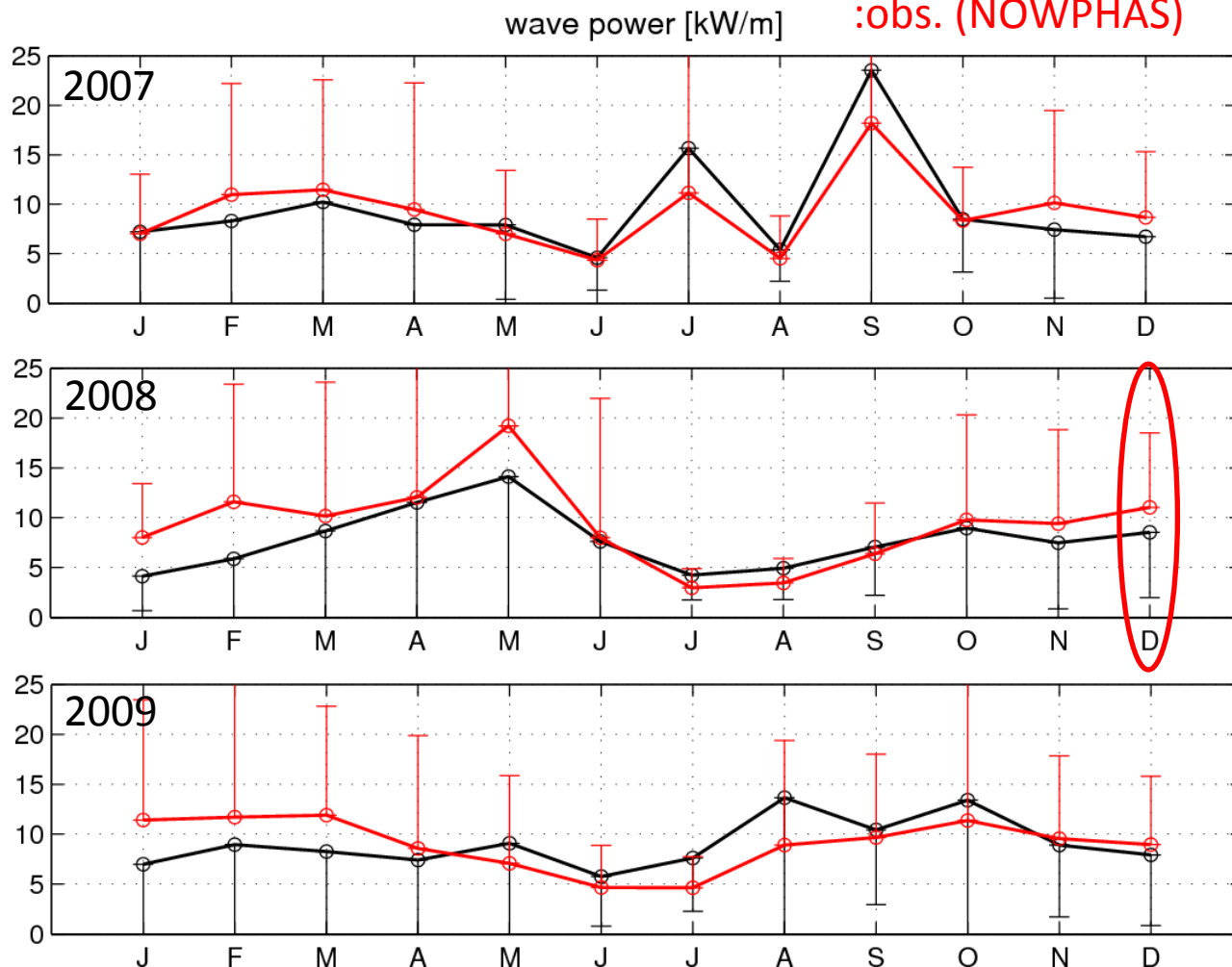
Validation of wave power estimation

Monthly wave power

(@波浮 Ooshima, nest3 model)

:model (ww3)

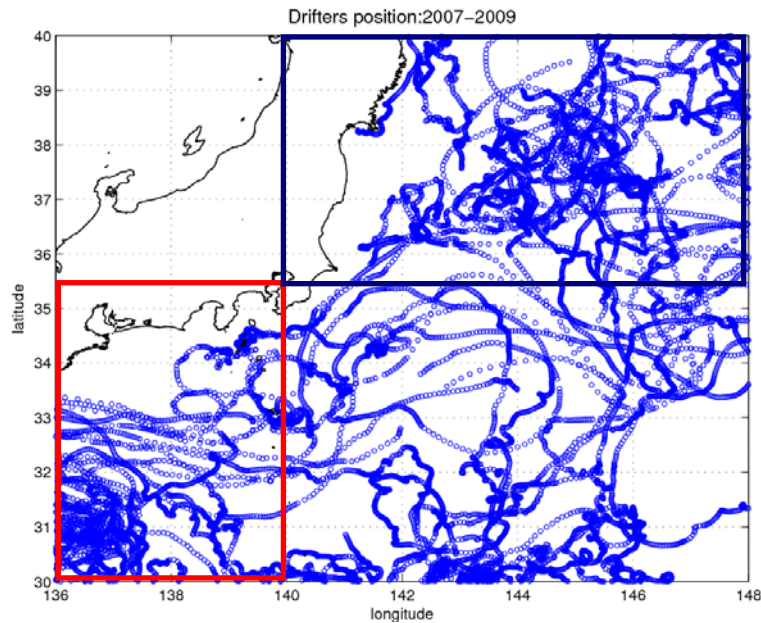
:obs. (NOWPHAS)



December 2008

$$P = \rho g \left(\frac{H_s}{4} \right)^2 \frac{1}{2} \left(\frac{g}{2\pi} \right) T_m$$

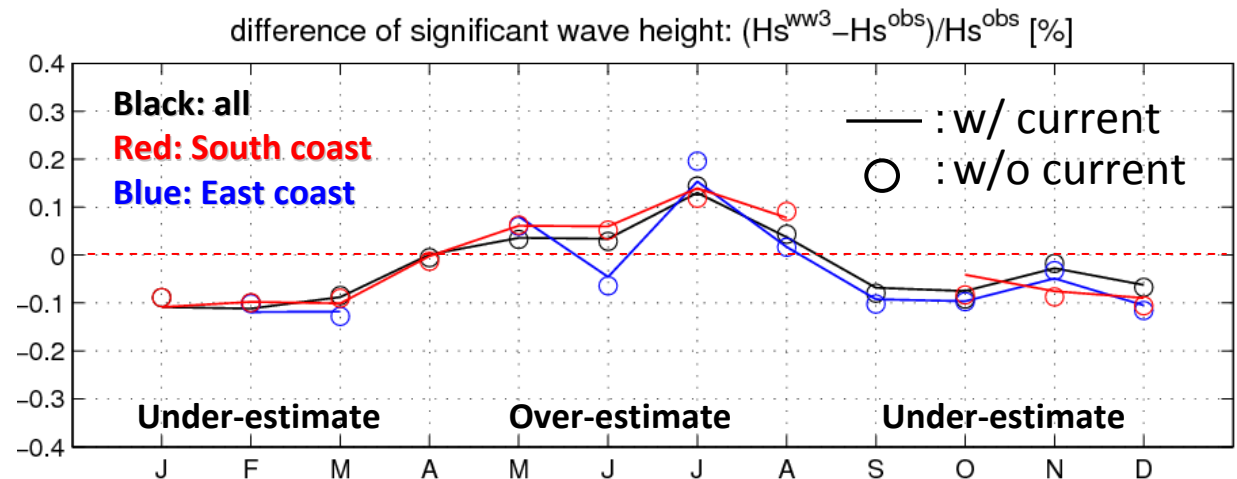
Sensitivity to ocean current



JMA drifting buoy vs wave model

$$\Delta \tilde{H}_s = \frac{1}{N} \sum_N (H_s^{ww3} - H_s^{obs}) / H_s^{obs}$$

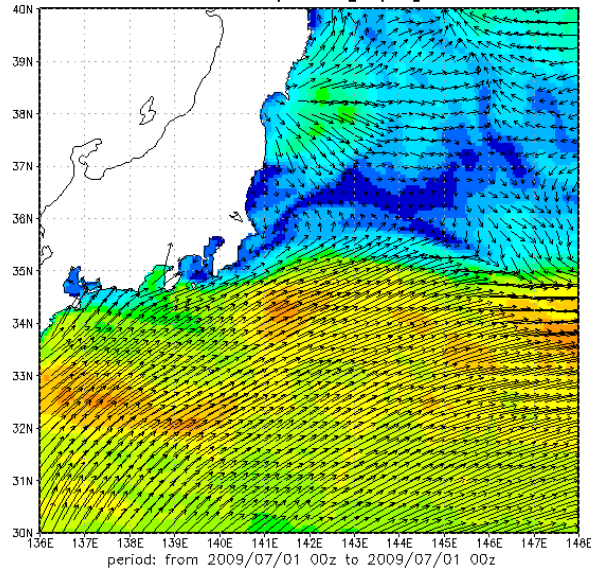
Current field:
JCOPE2 reanalysis
~1/10 degree, daily



Sensitivity to wind forcing

MSM wind at 2009/7/1

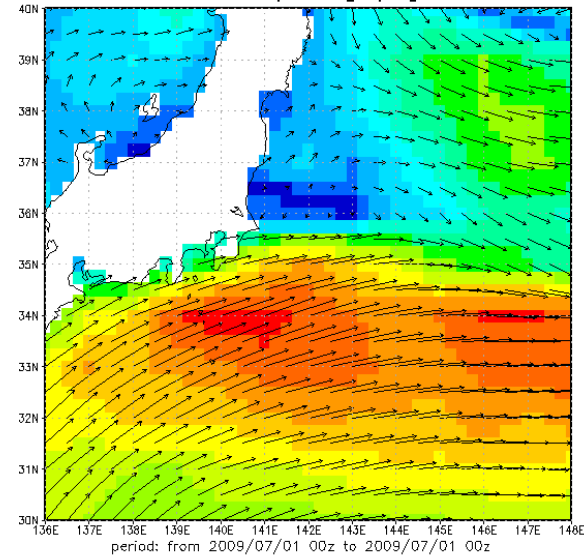
wind speed [m/s]



Wind

NOGAPS wind at 2009/7/1

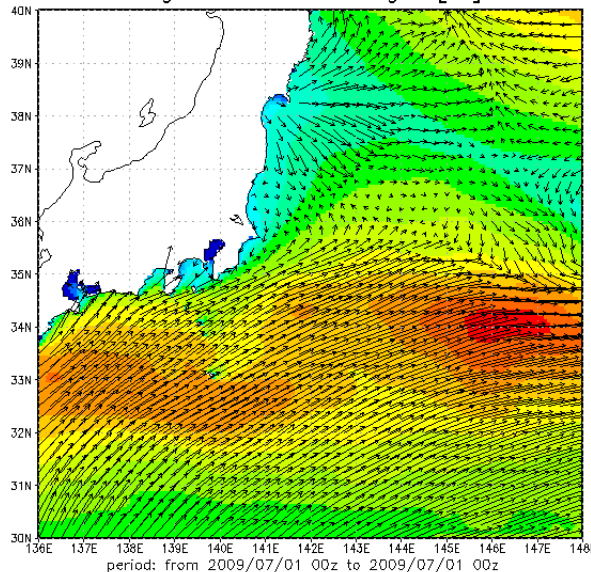
wind speed [m/s]



GRADS: COLA/IGES

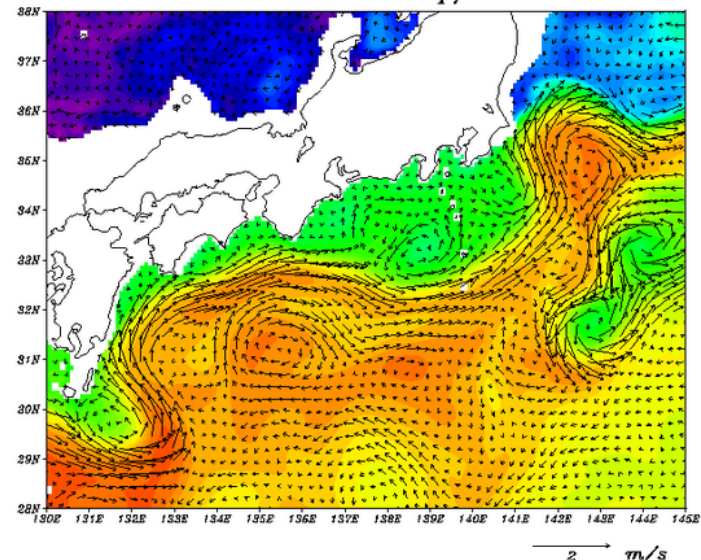
2009/07/05

significant wave height [m]



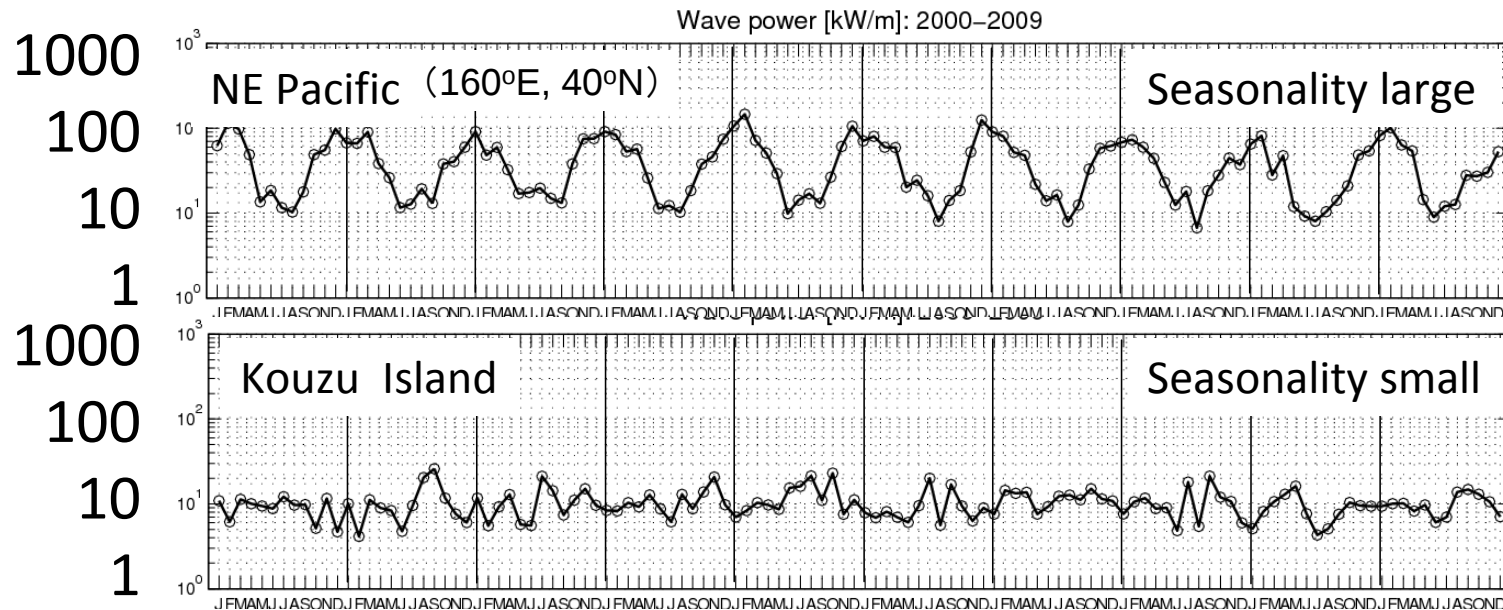
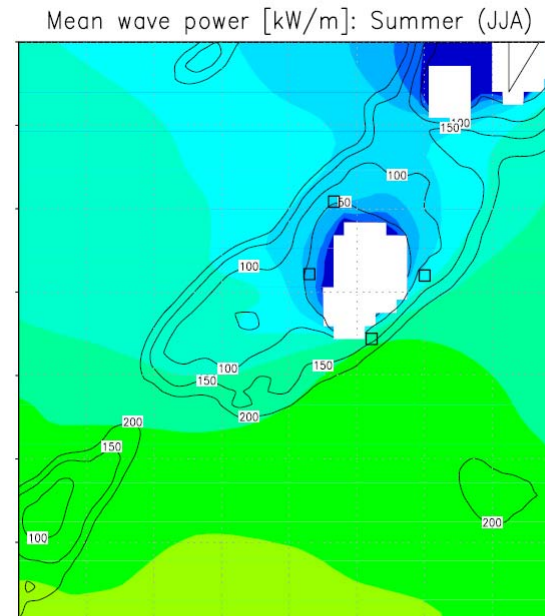
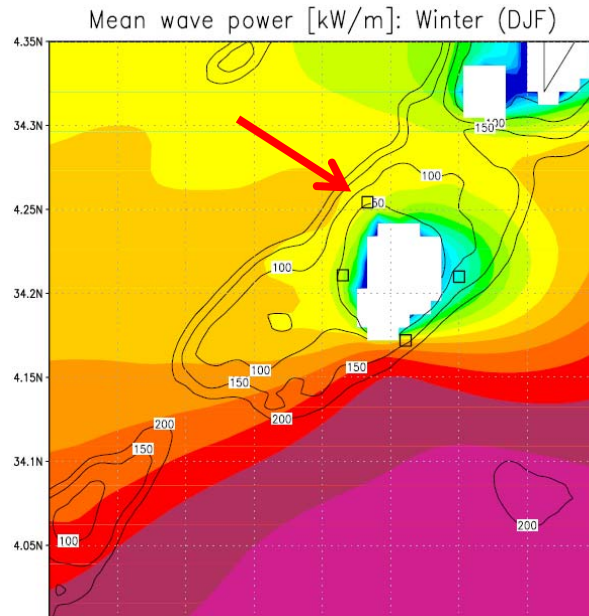
Significant
Wave
Height

JCOPE2 200m Temp/Current



2 m/s

Selected site (Kurone)



Year 10

GPS wave observation at the Kozu Island

- GPS: high-pass filtered XYZ time series (2.5 Hz, T 4-20 s, 0.1 m resolution)
2006: Zenilite Buoy • JMA (Open Ocean test, Off Shikoku)
2007: FRA (Kuroshio Long-term obs. 1 Yr, Komatsu et al.)
2008: MRI, JAMSTEC (Time series, East China Sea, Miyazawa et al.)
2009-2011: U-Tokyo • JAMSTEC (JKEO, Drifting buoy with wind sensor, moored buoy)

Hourly measurements (20-minute means)

- Longitude-Latitude, Air pressure and temperature, Water temperature

- Wave parameters

- [1/3, 1/10 significant, mean] height, period, direction
- Maximum wave height, period, direction
- Skewness, Kurtosis
- Number of waves in 20 minutes, erroneous waves

- Wind parameters

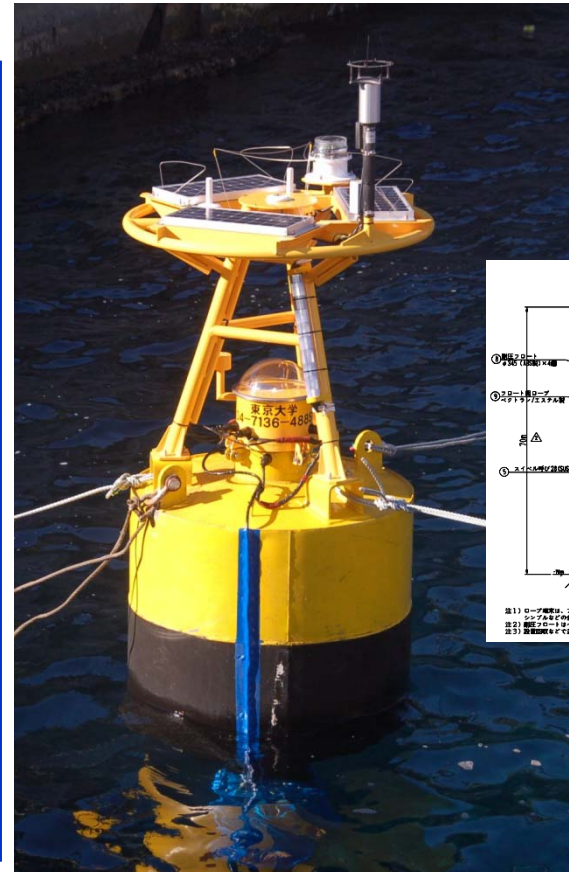
- Mean, maximum and variance of the NS, EW and Z wind vector components
- Correlations (mean of UV, VW, WU)

- System

- Board temperature, battery voltage, etc

Time-series by event

$$AI = H_{\max}/H_s > 2.0, H_s > 3.0\text{m}$$

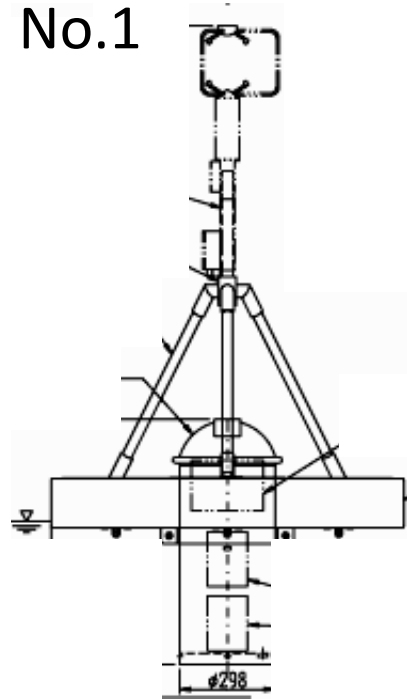


Observation platforms

- Drifting buoy

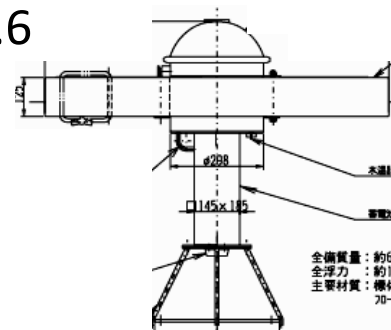
- Disk float at sea level to reduce Roll due to viscous effect (Katayama et al. 2007).
- No.1 with wind sensor
- No.3 & 6 improve stability

No.1



No.3

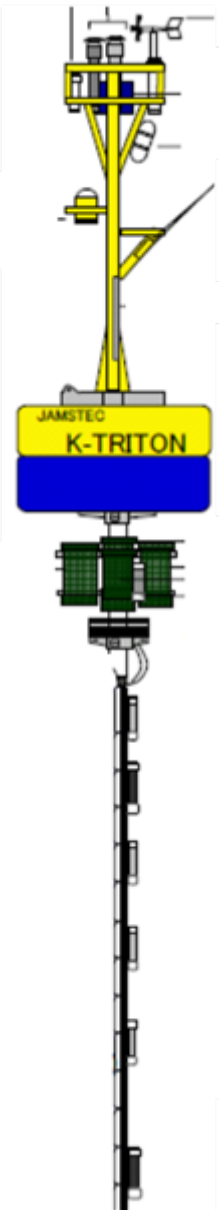
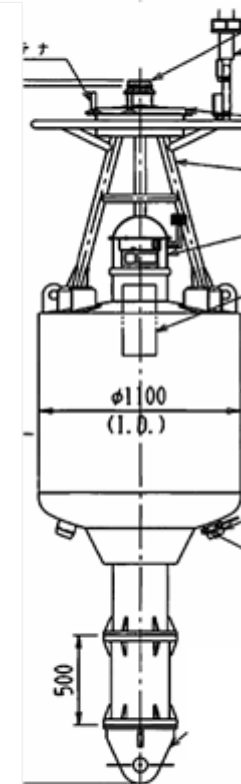
No.6



No.2

No.4

No.5



- Moored buoy

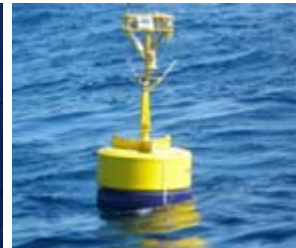
- Influence of cable
- Buoy response

Observation points

- JKEO (JAMSTEC Kuroshio Extension Observatory)
 - Depth 5400m, 38.1N, 146.4E, Slack mooring
- Hiratsuka observatory
 - Depth 20m, Ultra-sonic wave gauge, anemometer
- Kouzu Island
 - Depth 75m
- Kashiwa rooftop
 - Stationary



Google Earth



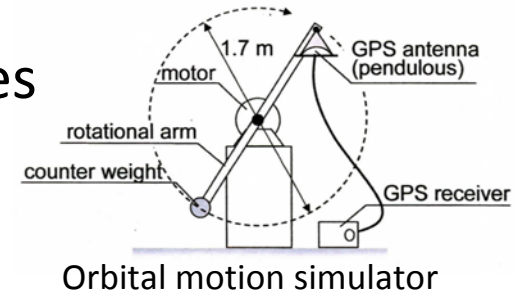
JAMSTEC

	Name	Location	Observation period	Status
No.1	Drifter No.1	Hiratsuka JKEO	2009/7/14–2009/8/10 2009/8/29–2009/9/2	Lost
No.2	K-TRITON No.1	JKEO	2009/8/30–(12/6) 2010/9/18	retrieved
No.3	Drifter No.2	Kashiwa Hiratsuka Mirai JKEO	2010/7/21–2010/8/11 2010/8/23–2010/12/21 2011/2/12–2011/2/23 2011/2/23–2011/2/26	Lost
No.4	K-TRITON No.2	Kashiwa Mirai JKEO	2010/11/5–2011/1/4 2010/2/12–2010/2/23 2011/2/23–(3/3) 2012/	failure data transmission to be retrieved
No.5	KOUZU	Nishi Chiba Kouzu harbor Kouzu Kouzu	2010/12/17–2010/12/24 2011/1/11–2011/1/23 2011/1/23–2011/3/4 2011/6/31 -	failure Retrieved deployed
No.6	Drifter No.3	Kashiwa Kouzu	2011/2/25–2011/3/2 2011/3/11–2011/4/30	retrieved to be deployed

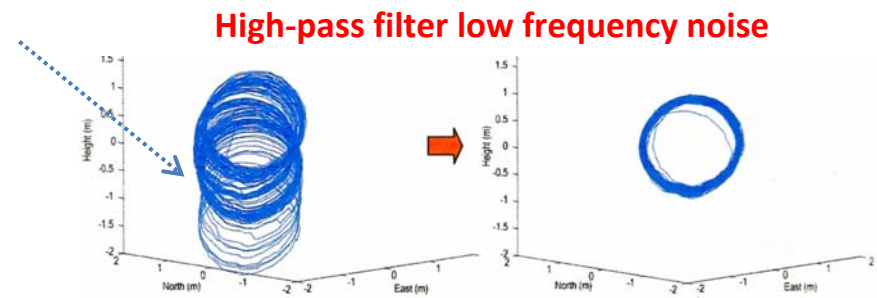


Principle of GPS wave sensing

- 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)
 - Noise due to change in number of satellites
 - Orbital motion simulator
 - Ocean testing off Shikoku Island



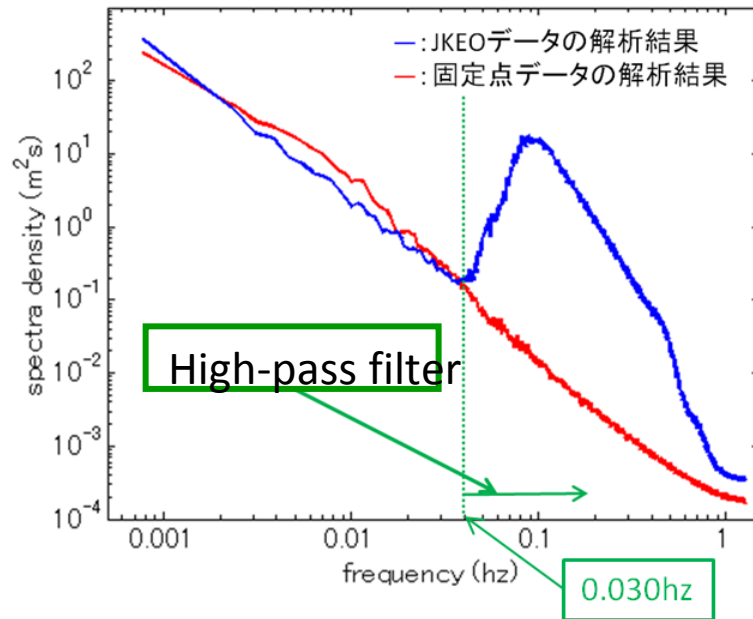
Error source	Range(1σ)	時定数
ephemeris	~3m	~1hr
Satellite clock	~3m	~5min
ionosphere	~9m	~10min
troposphere	~2m	~10min
multipath	~3m	~100sec
GPS receiver	~1m	white noise



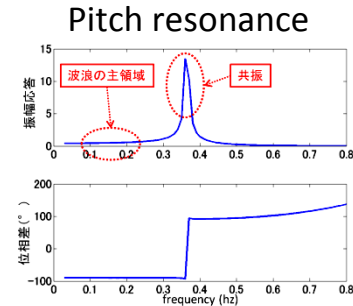
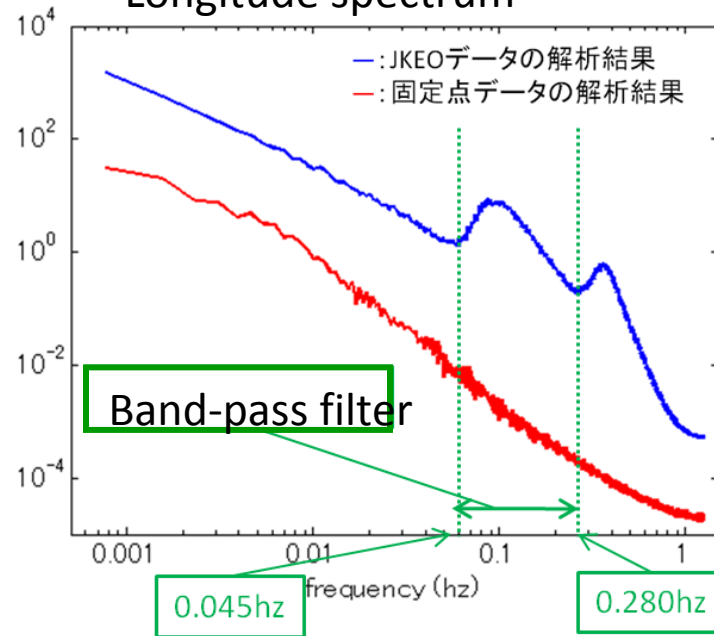
Parameter	Experiment result	True value
Wave height	167.5 cm	170 cm
Wave period	10.83 sec	11 sec
Wave direction	115.7 deg	114 deg

Short Summary of QC of GPS wave system (JKEO)

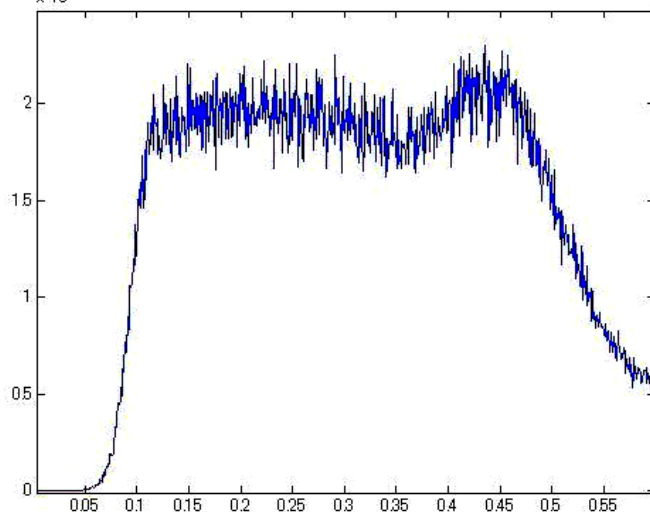
Heave spectrum



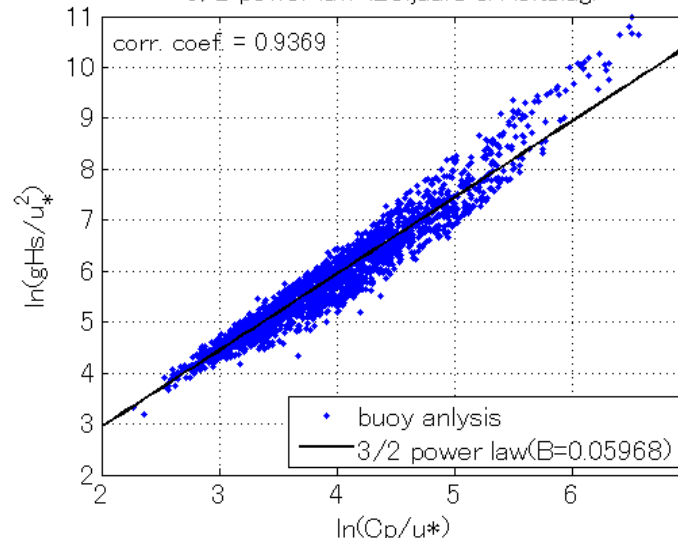
Longitude spectrum



Saturated spectrum $S(f)x f^4$



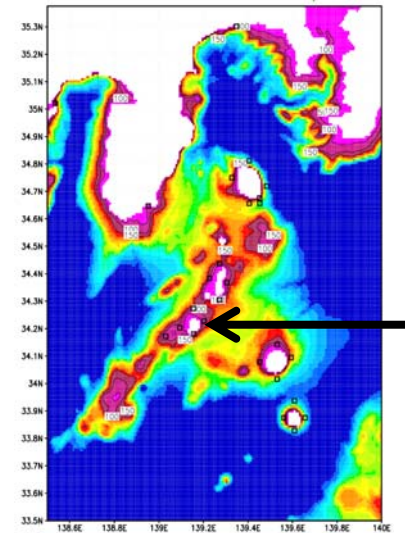
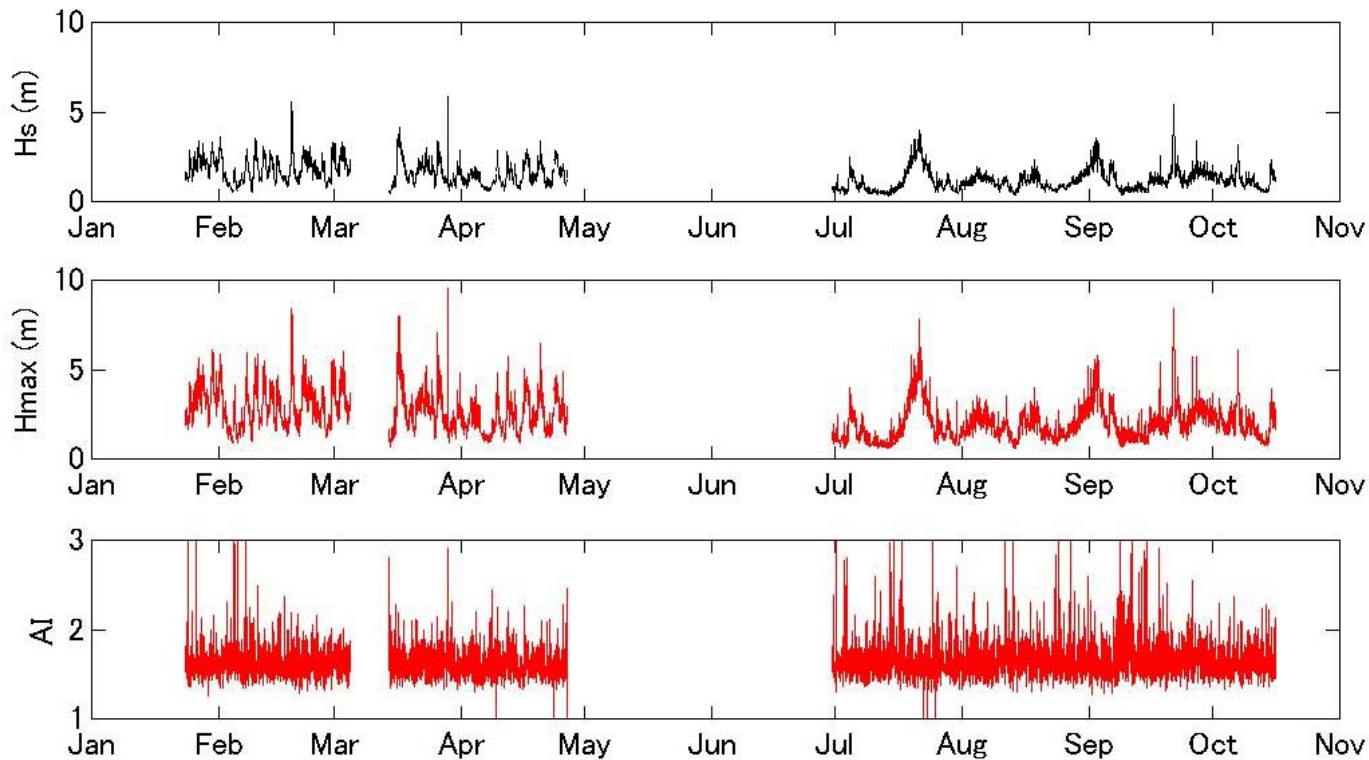
3/2 power law (Beljaars & Holtslag)



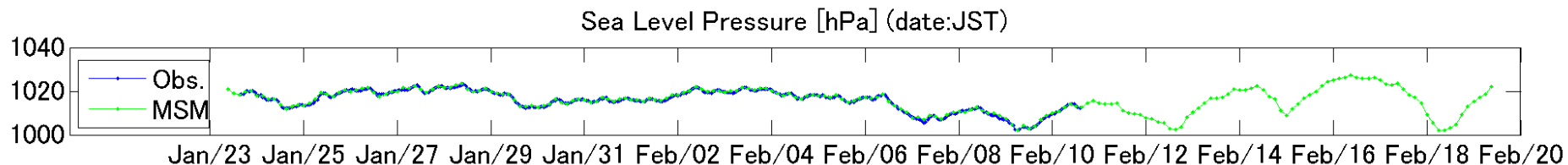
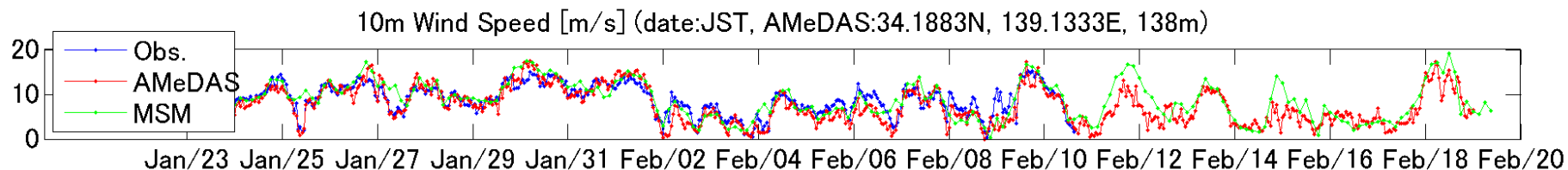
Toba 3/2 law

Details:
2011 ISOPE

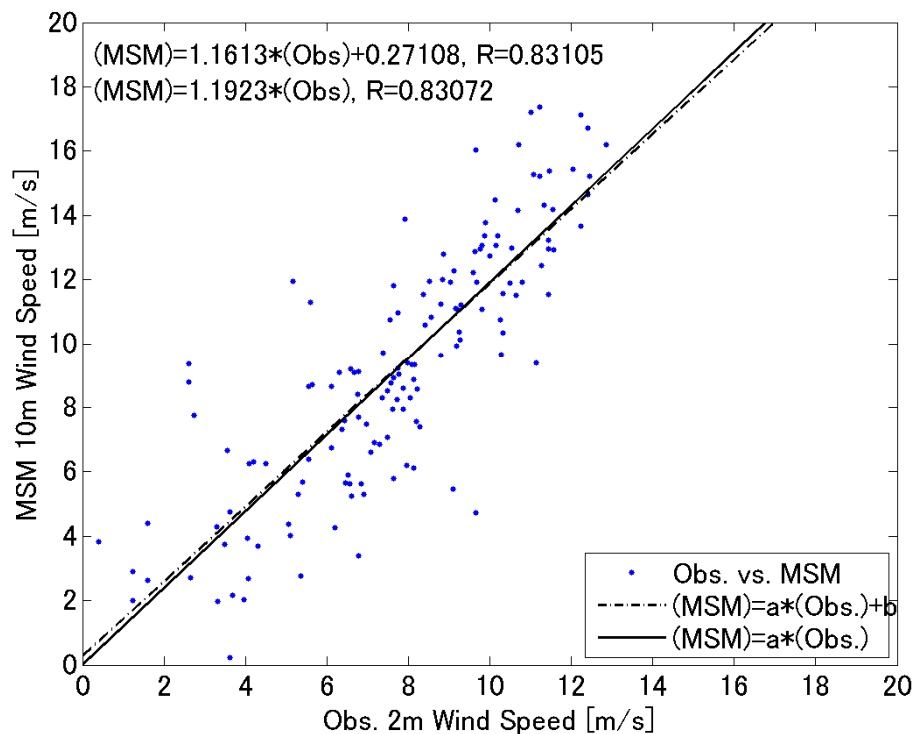
Overview of Kouzu Observation 2011



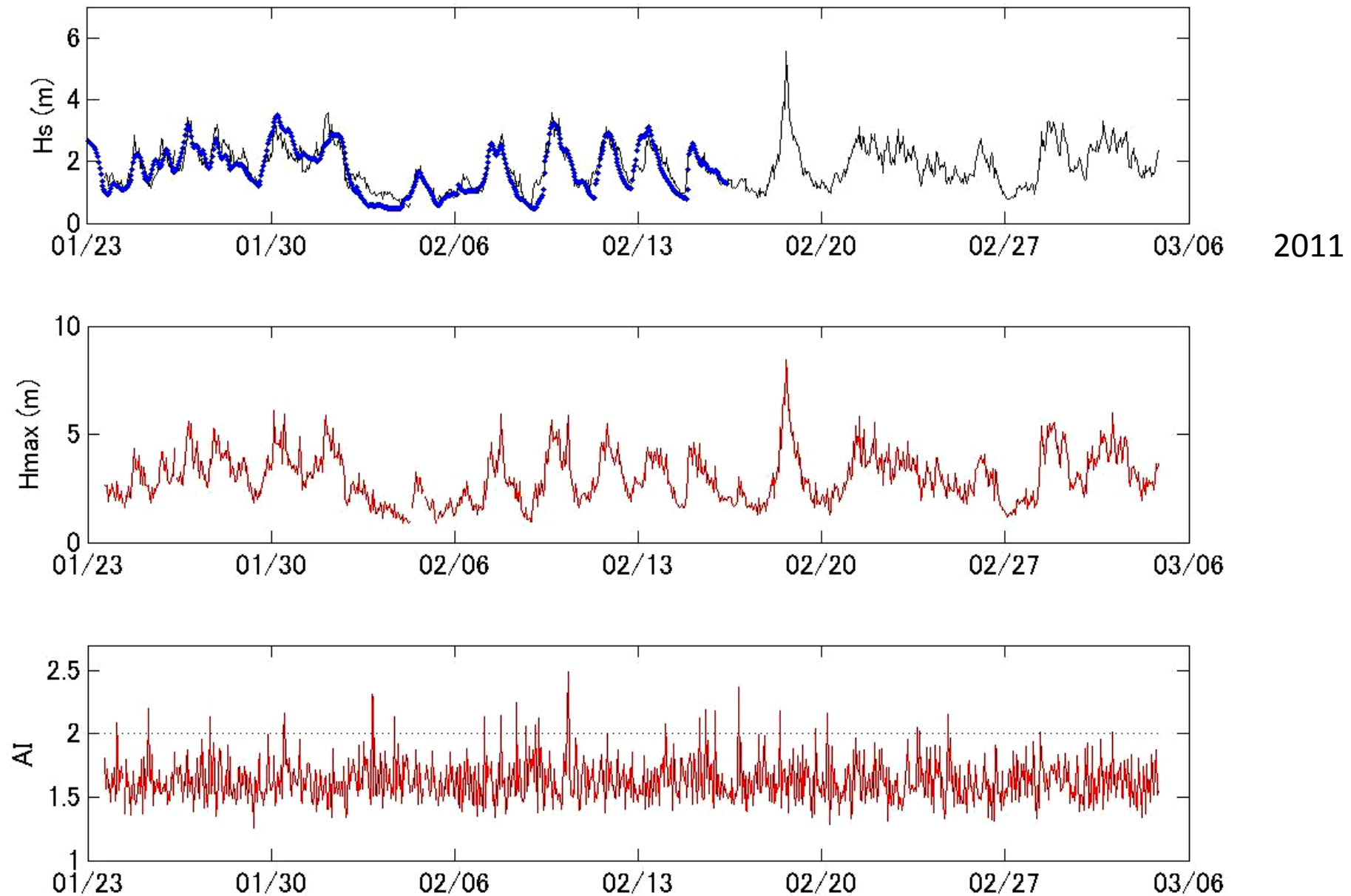
Validating the wind (buoy obs, land obs, NWP)



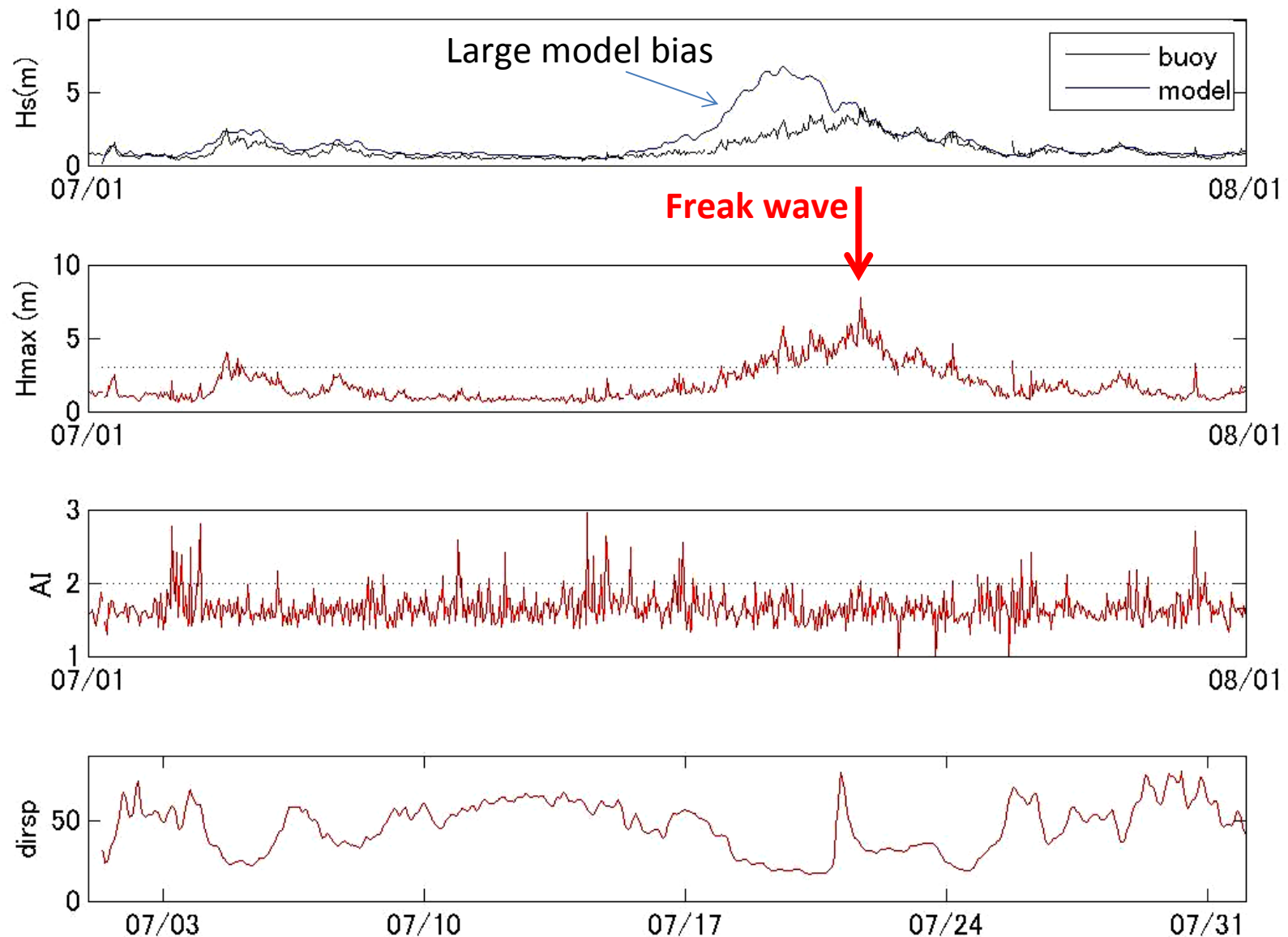
Buoy Wind (2m) x 1.2
Correlates well with
U10 from MSM (NWP)



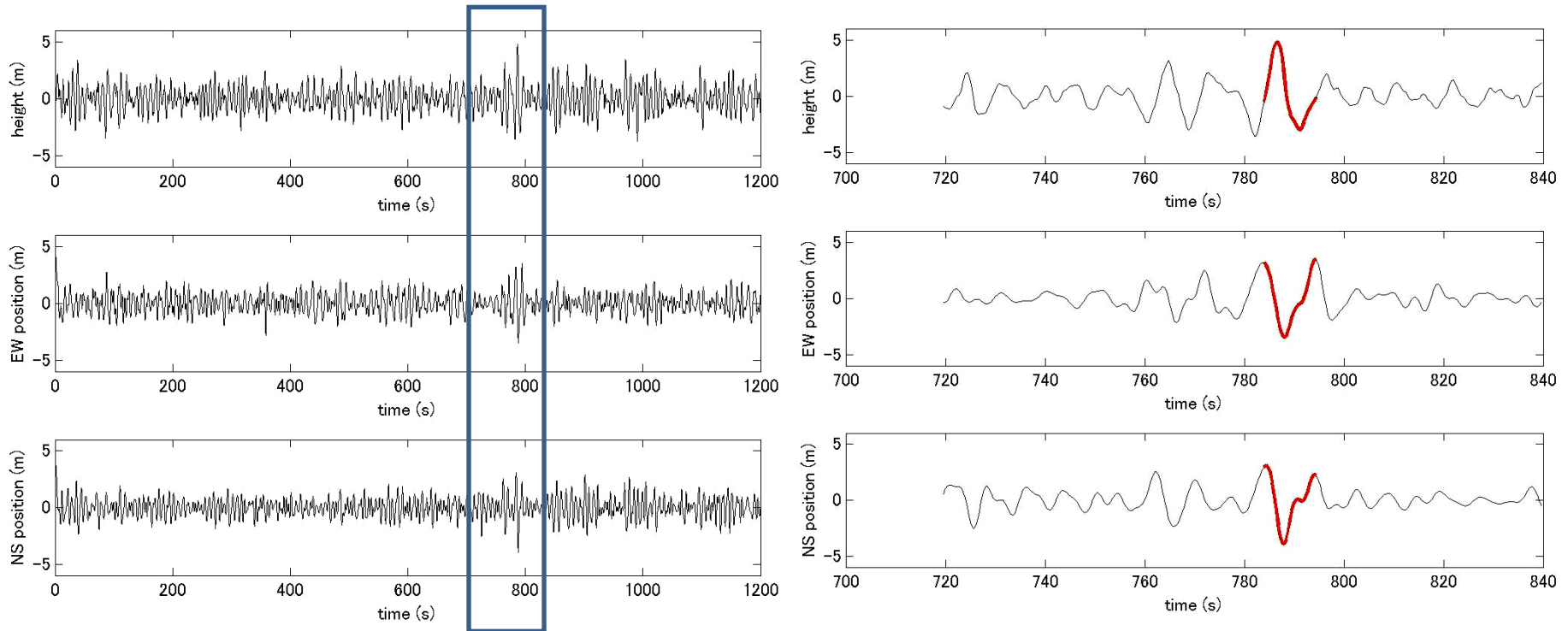
Validating the wave obs. at Kouzu (nest4) WAM4/DIA



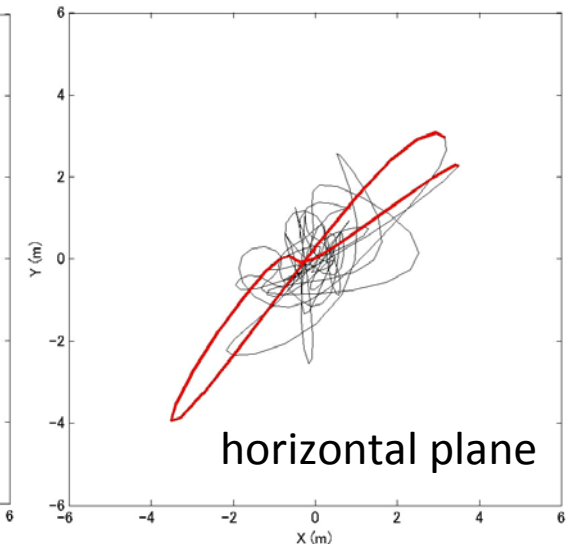
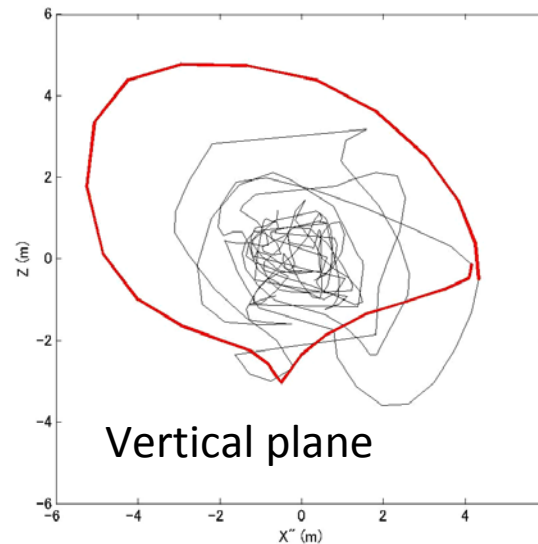
Observation during a strong typhoon



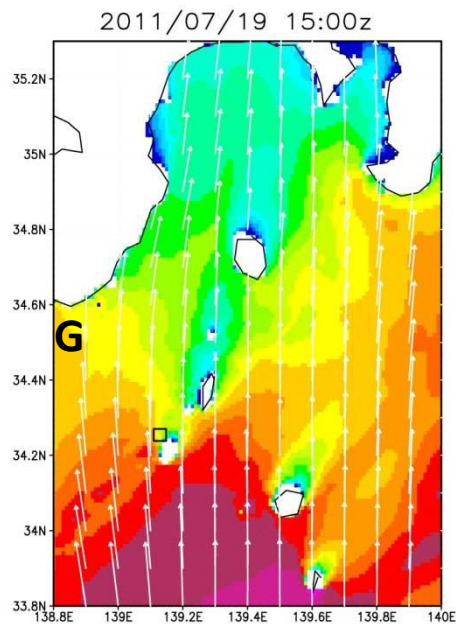
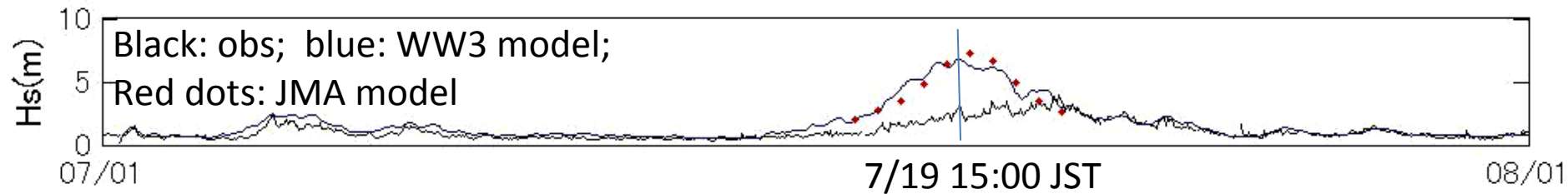
Observed largest freak wave (21-Jul-2011 8:00 UTC)



Freak wave
 $H_{max}=7.79$ m
 $H_s = 3.86$ m,
 $AI=2.01$

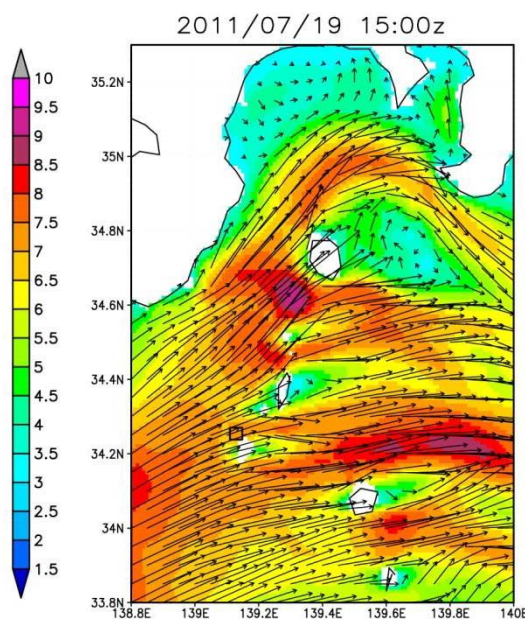


Island influence (at the model maximum Hs)



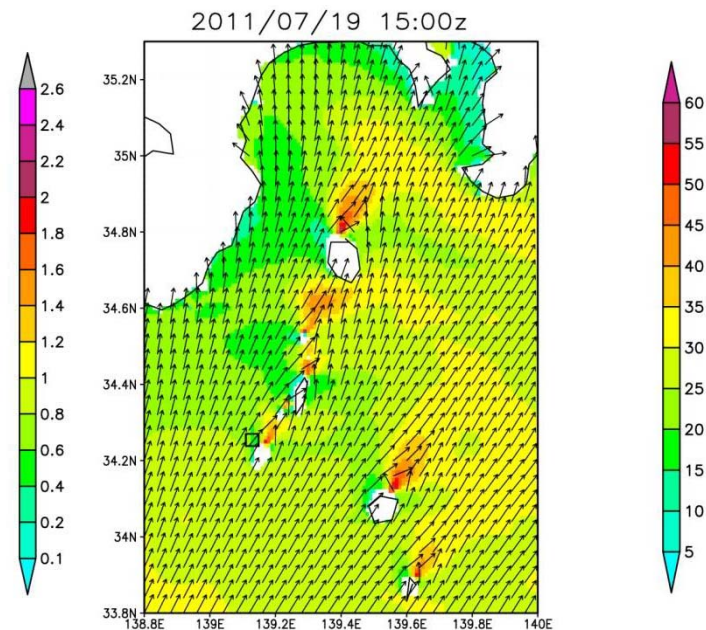
Contour: HS
Arrows: wind vector

Wind: MSM 5km res.



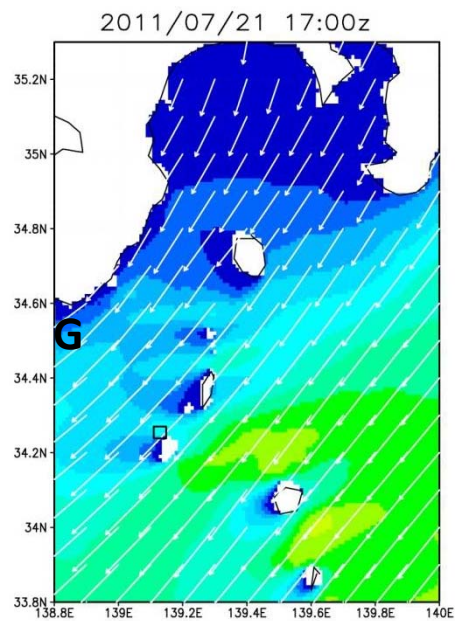
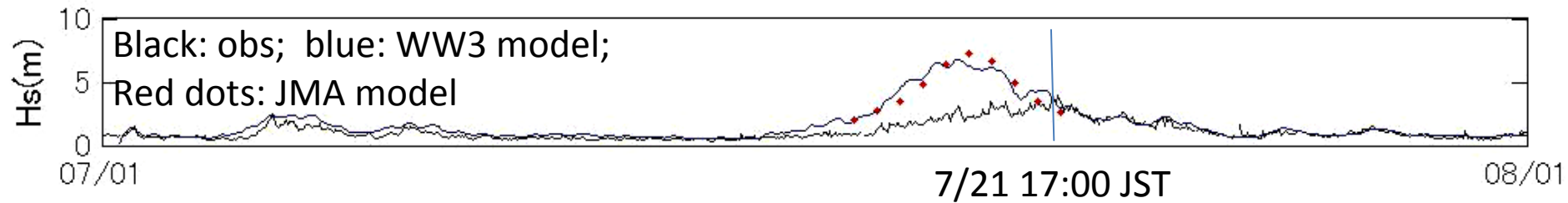
Contour: Current speed
Arrows: current vector

Current: JCOPE-T 3km res.



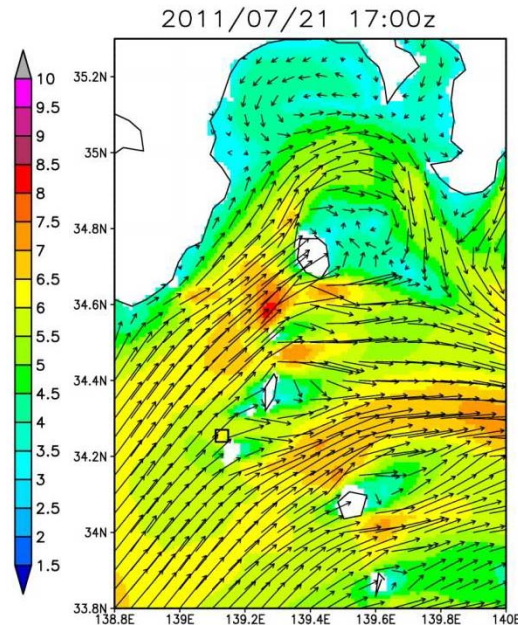
Contour: wave direction
Arrows: directional spread

Island influence (at the observed maximum Hs)



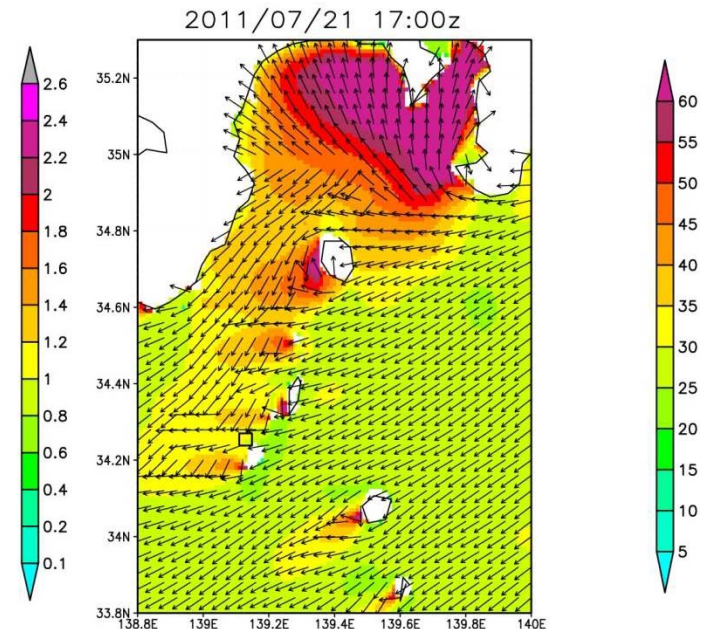
Contour: HS
Arrows: wind vector

Wind: MSM 5km res.



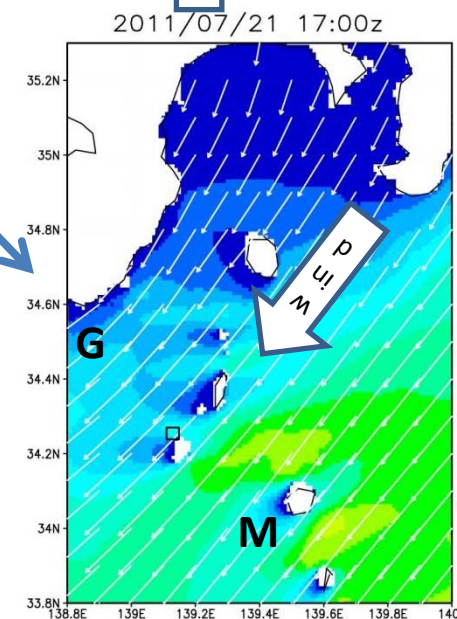
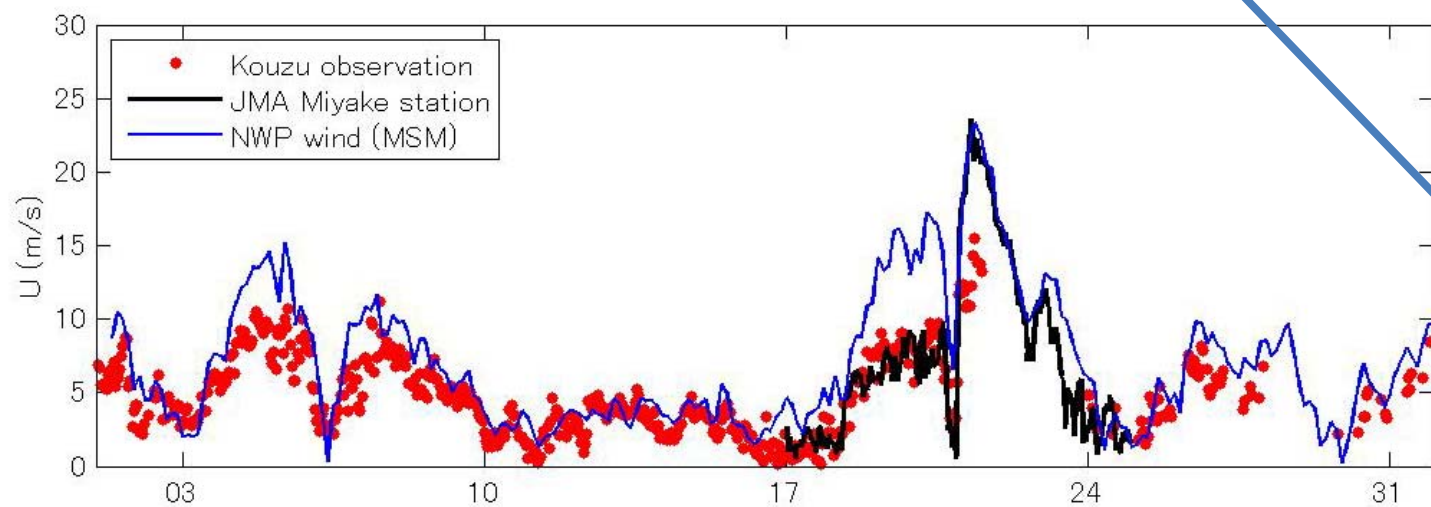
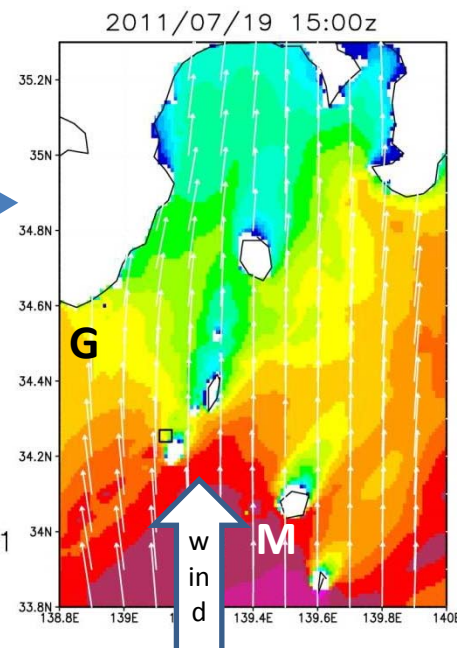
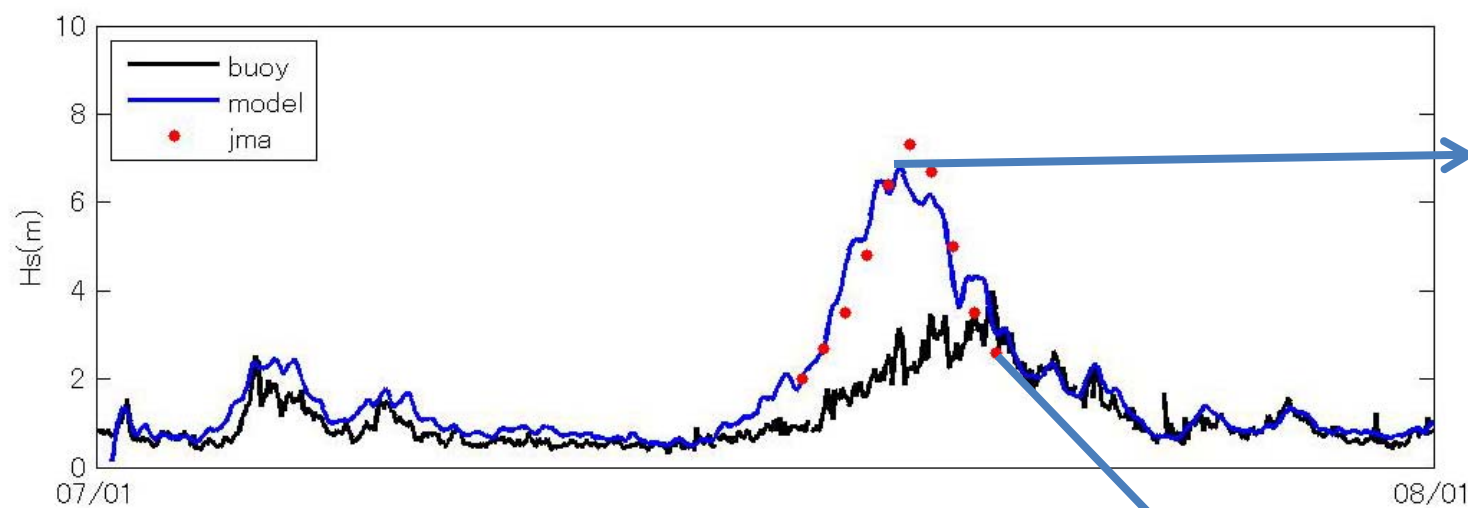
Contour: Current speed
Arrows: current vector

Current: JCOPE-T 3km res.



Contour: wave direction
Arrows: directional spread

Validating the wind

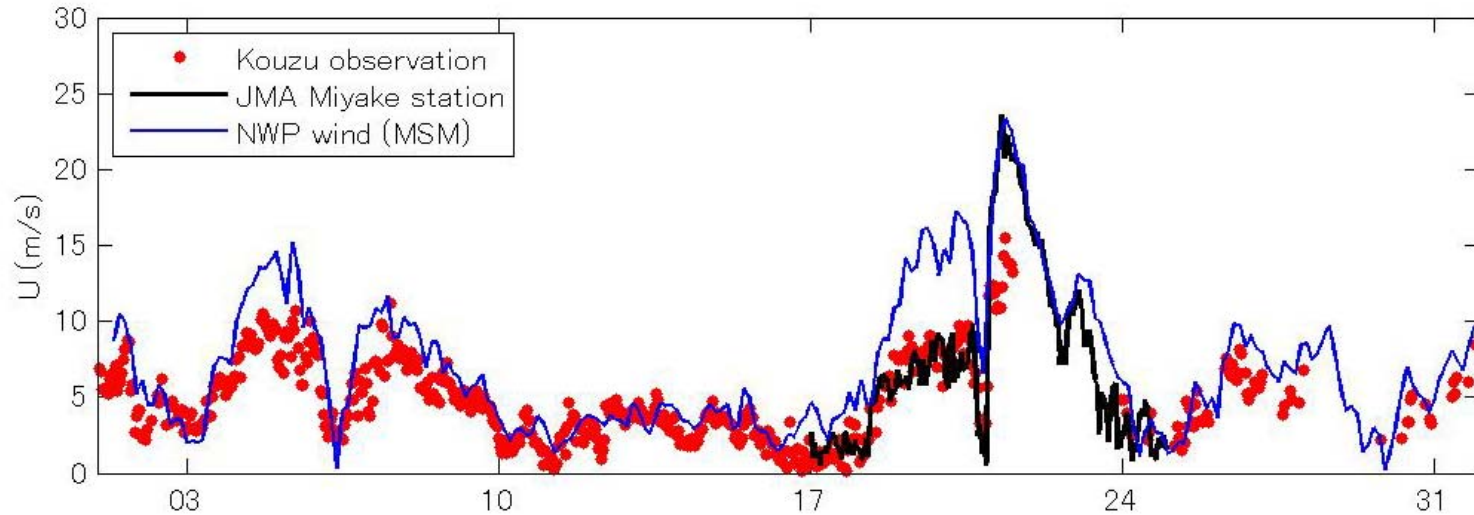


Concluding remarks

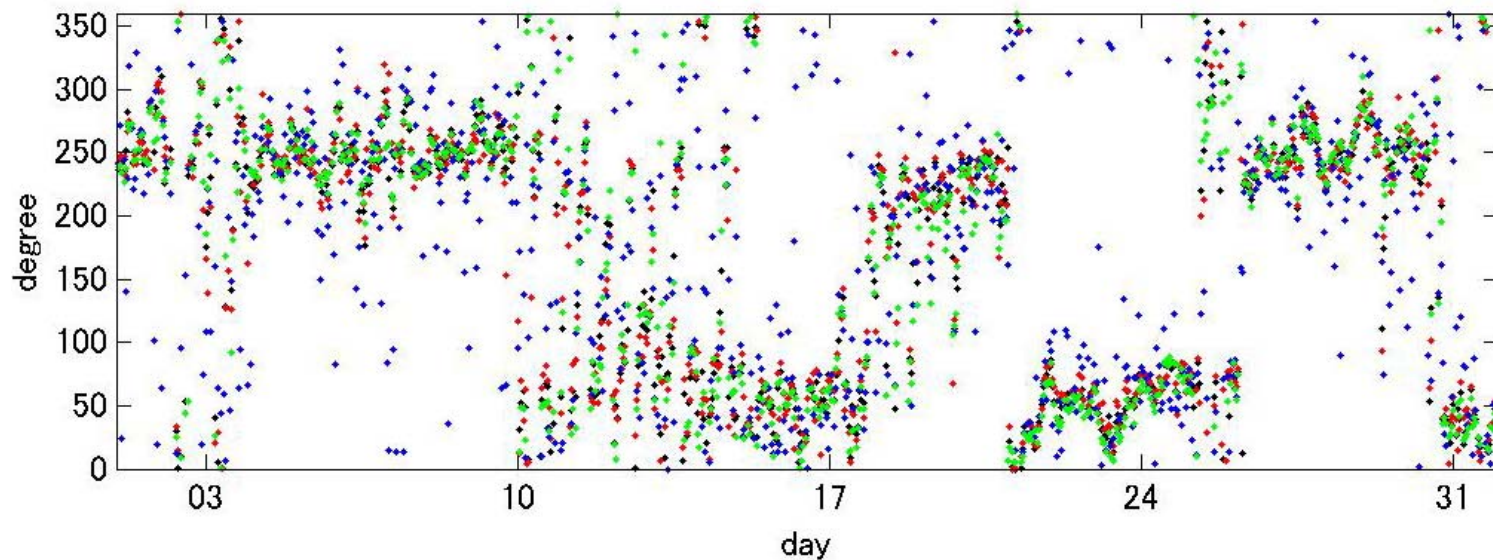
- Wave hindcast was utilized to select potential site for deploying wave energy converter
- In-situ measurement was conducted using mid-size buoy with GPS wave sensor and wind anemometer
- Good agreement between model and observation during winter time but fails largely during fall typhoon, likely due to wind bias
- Interaction of wave, wind, current and topography emphasizes the wind bias near an island and will be studied further

Wave direction

winds

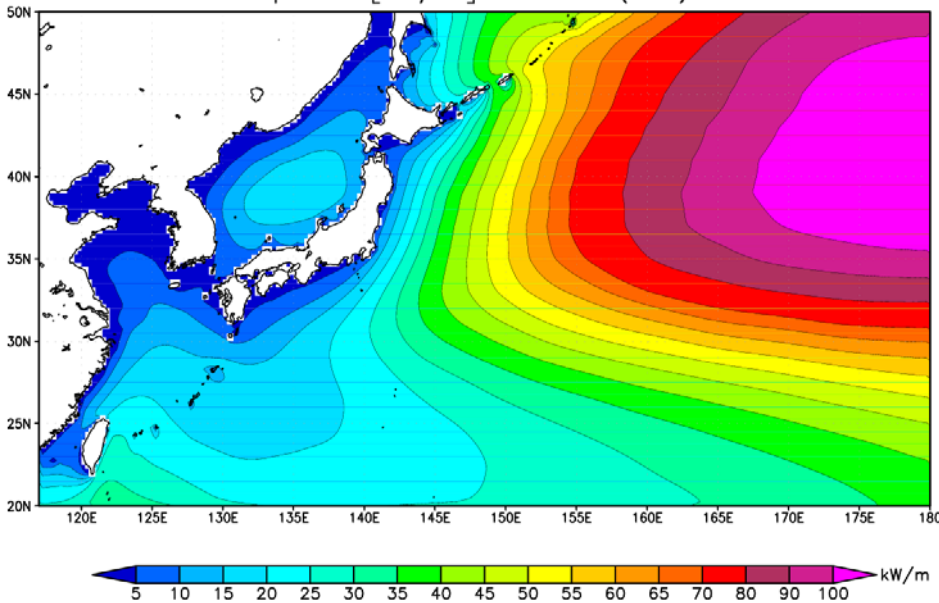


Observed wave direction

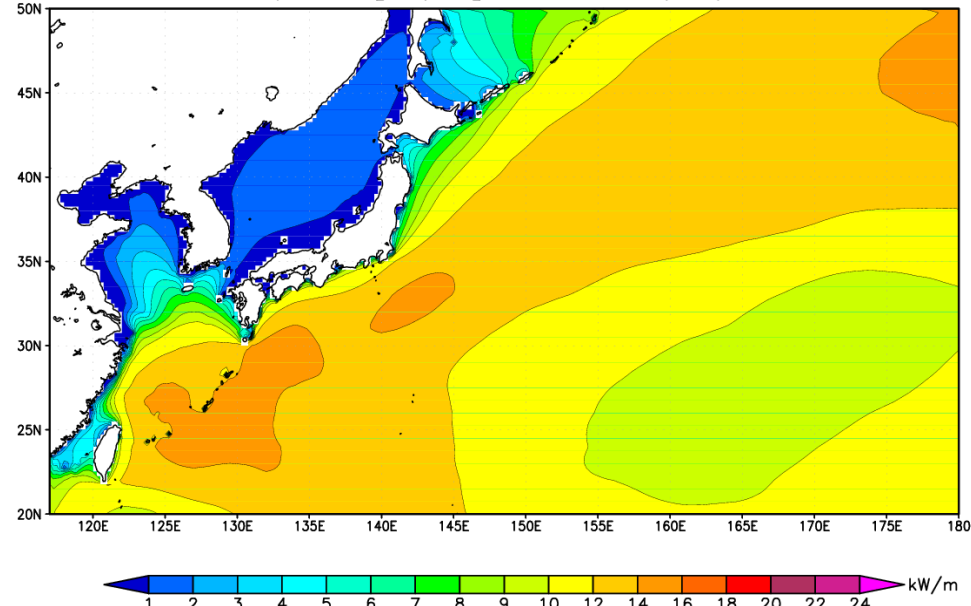


Seasonality of Wave Power

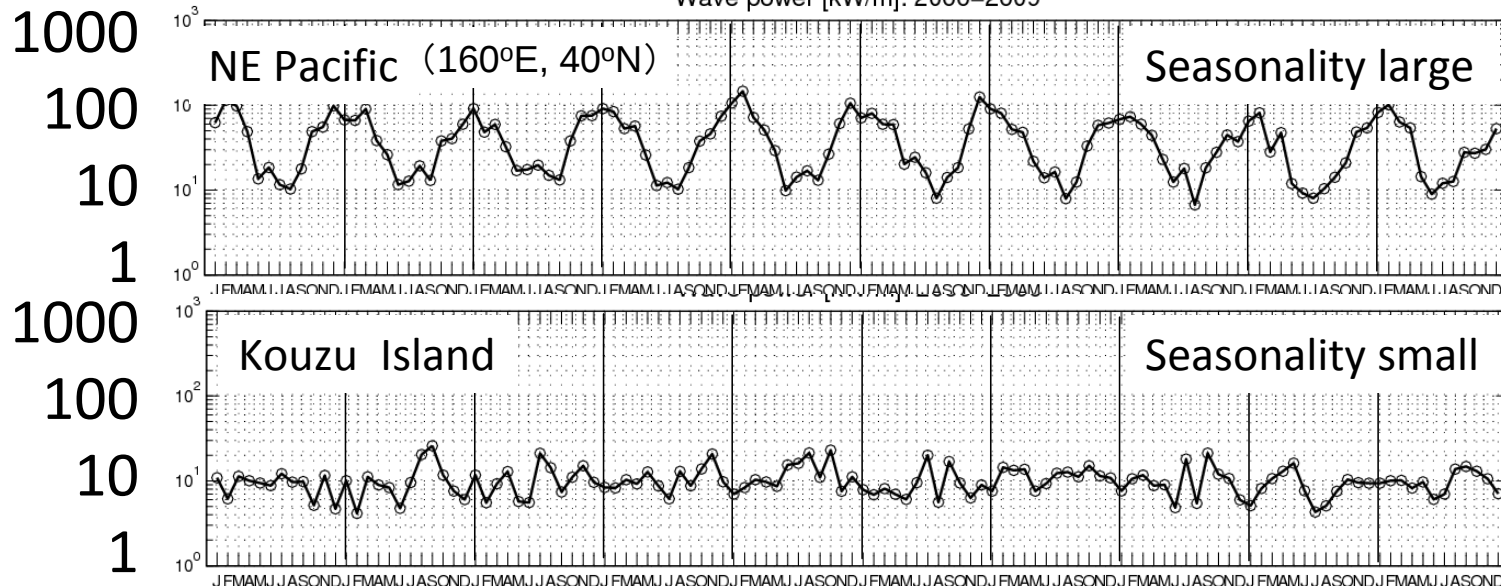
mean wave power [kW/m] : winter (DJF) 2000–2009



mean wave power [kW/m] : summer (JJA) 2000–2009



Wave power [kW/m]: 2000–2009



Year 10