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)

JKEO & NKEO GPS buoy observation

Diameter 2.0 m

K-TRITON
JAMSTEC

JKEO & NKEO GPS buoy observation

Diameter 2.0 m

K-TRITON
JAMSTEC
Buoy Tracking Velocimetry

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)

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

Kiyomatsu presentation B4
Orbital speed of non-breaking waves in a group

Quality Control

\[ KC > 40 \]

\[ KC \equiv \frac{U_{\text{max}} T_{\text{max}}}{D} \]

D: diameter of buoy

average \( (ak_s) \) = 0.079
average \( (H_s) \) = 4.9 m
average \( (ak_{\text{max}}) \) = 0.14
average \( (H_{\text{max}}) \) = 8.1 m
average \( (T_{\text{max}}) \) = 11.2 s
Degree of Nonlinearity (DON)

- Non-breaking modulational wave train
- Modulational wave train with breaking

Dysthe’s Eqn. curve corresponds to:

\[
DON \equiv \frac{U_{\max}}{C_p} \sim 1
\]

i.e.

\[
U(x, t) = A(x, t)k_pC_p
\]

Physical experiments:

- DON > 1
- Narrow-band approx. fails

UTokyo Experimental result:

- Red: breaking
- Black: non-breaking
HORIZONTAL PARTICLE VELOCITY ESTIMATE FROM SOFS OBSERVATION IN THE SOUTHERN OCEAN
SOFS wave observation (Rapizo et al. 2015)

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

Diameter 2.7 m
Orbital speed of non-breaking waves in a group

\[ KC > 40 \]

**DON > 1**

failure of narrow band & weakly nonlinear approx.

**SOFS**

**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

Pacific 0.6 x 0.75 deg (1/3)
60km

Offshore 0.2 x 0.25 deg (1/4)
20km

Japan 0.05 x 0.0625 deg (1/5)
5km

Coastal 0.01 x 0.0125 deg
1km

1800 sec

900 sec

450 sec

225 sec

Nested offshore layer

Nested Japan layers

JCOPE-T Region

P01

O01

J01

J02

J03

J04

J05

C01

C06

C07

C11

C12

C17

C18

C24

C23

13
JKEO Hs comparison

Dots: observation
Green: TodaiWW3
Red: WW3_ODYN

\[ H_s(\text{TodaiWW3}) \]

\[ c.c. = 0.94 \]
NKEO Hs comparison

Dots: observation
Black: TodaiWW3
Red: WW3_ODYN

TodaiWW3 & observation correlation: 0.92

\[ \text{Hs(TodaiWW3)} \]

\[ \text{obs} \]

\[ \text{WW3(NEDO)} \]

\[ \text{WW3(Koji)} \]

\[ H_s(\text{model}) = 0.89396 \times H_s(\text{obs}) \]

\[ \text{c.c.} = 0.92 \]
JKEO $Q_p$ and $\sigma_\theta$ comparison

$Q_p(TodaiWW3)$ vs. $\sigma_\theta(TodaiWW3)$

Correlation Coefficients:
- $Q_p$: c.c. = 0.48
- $\sigma_\theta$: c.c. = 0.71
NKEO $Q_p$ and $\sigma_\theta$ comparison

$Q_p$ comparison:
- Toda WW3
- Iwate WW3
- NKEO obs

$\sigma_\theta$ comparison:
- Toda WW3
- Iwate WW3
- NKEO obs

Correlation Coefficient:
- $c.c. = 0.57$
- $c.c. = 0.77$

Graphs showing the comparison of $Q_p$ and $\sigma_\theta$ with observed data.
DEPENDENCE OF ORBITAL VELOCITY ON SPECTRAL GEOMETRY
Orbital velocity and frequency bandwidth

NKEO & JKEO

Note: KC>20

\[ Q_p = 2m_0^{-2} \int_0^\infty \sigma \left[ \int_0^{2\pi} F(\sigma, \theta) d\theta \right]^2 d\sigma \]
Orbital velocity and directional spreading
NKEO & JKEO

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

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

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

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
\[ \cos^N \frac{\theta}{2}; \quad N = 2 \sim 1000 \]

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

\[ \sigma_\theta \]

\[ U_{\max} / C_p \]

\[ DONT \equiv \frac{U_{\max}}{C_p} / ak_{\max} \sim \text{const} \]

JKEO/NKEO obs.
Orbital velocity and directional spreading

SOFS

\[ DON \equiv \frac{U_{\text{max}}}{C_p} \sim \text{const} \]

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

\[ v(t) = v(0) + \int_0^t a(t') \, dt' \]

Constant drift speed is unknown

Cutoff 20 s
Ideal High-pass filter

EW

NS

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

\[ S(f) \times f^4 \]

JKEO spectrum

SOFS spectrum

SOFS saturation spectrum

JKEO 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
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 \( \frac{U_{\text{max}} / C_p / a k_{\text{max}}}{a} \) 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)

Tier 1 (1 degree)
JMA/GSM

Tier 2 (1/10 degree)
JMA/MSM

WAVEWATCHIII™

Sin, Sds: Tolman-Chalikov, Snl: DIA

Wind: GSM (Pacific) → MSM (Japan)

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

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

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

\[ a = \int_0^{2\pi} \int_0^\infty \cos(\theta) F(\sigma, \theta) d\sigma d\theta \]
Estimation of velocity & position from accelerometer

Position estimate from MRU without any filter

![Graph showing zonal and meridional position over time.](image)