Wave frequency estimation under low-wind conditions

XiFeng Wang
（Interdisciplinary graduate school of engineering sciences　Kyushu University）
(wangxf@riam.kyushu-u.ac.jp)

Kaoru Ichikawa
（Research Institute for Applied Mechanics　Kyushu University）
(ichikawa@riam.kyushu-u.ac.jp)

1. Introduction

Recent researches have proved the possibility of retrieving wave periods from altimeter normalized radar cross section (σ_0) and significant wave height (H_s), but all of the algorithms lost its precision in low wind speed condition.

We noted that buoy observations, always treated as "sea truth", ignorded the high frequency portion of waves which significantly affects σ_0 of altimeters. These discrepancy of observations would affect wave period retrieval.

2. Data

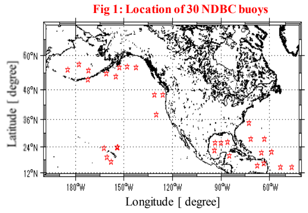
Altimeter data: Jason2 GDR, 2008 ~ 2014

Buoy data: National Data Buoy Center (NDBC)

Collocation criteria: 50km & 30min

Number of collocated data: 4196

Fig 1: Location of 30 NDBC buoys



3. Rationale of wave period retrieval from altimeters

From buoy wave measurements S(f):

$H_s = 4\sqrt{m_0}$　　$S(f)$: frequency spqctrum

$\boldsymbol{T_z = (\frac{m_0}{m_2})^{0.5}}$　　$m_n = \int f^n S(f) df$

(mean zero-crossing wave period)

Altimeter measurements

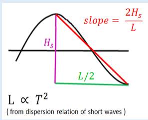
$\sigma^0 = 10 lg\sigma_0$
σ_0: normalized radar cross section
$|R(0)|^2$: Fresnel reflection coefficient
MSS: mean square slope

σ_0　　SWH

$$\sigma^0 = \frac{|R(0)|^2}{MSS}$$

$$MSS = \frac{16\pi^4}{g^2} m_4$$

$H_s = 4\sqrt{m_0}$

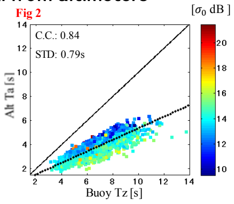


$L \propto T^2$
(from dispersion relation of short waves)

$$Ta = \left(\frac{m_0}{m_4}\right)^{0.25} = \frac{\pi}{\sqrt{g|R(0)|}} \cdot (Hs^2\sigma_0)^{0.25}$$

(Gommenginger, Srokosz and Challenor, 2003; Caires, 2005)

Fig 2



Alt Ta vs Buoy Tz

not good linear relationship compared to Fig3

(Buoy Tz vs Buoy Ta)

Alt SWH and Buoy SWH: good agreement (Fig 4)

Fig 3

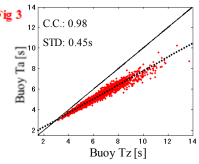
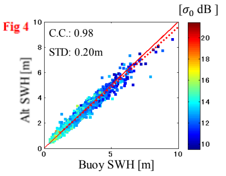
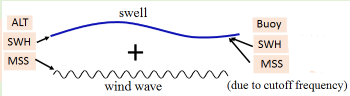


Fig 4



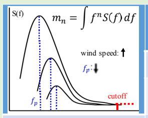
Due to discrepancy of MSS(alt) and MSS(buoy) ?



Discrepancy of altimeter and buoy measurements

Buoy: NDBC buoys have upper cutoff frequency 0.485Hz ($L \approx 6.6m$) due to buoy size et al.

Altimeter: dominated by waves whose lengths is longer than 3 times of incident wavelength ($L \approx 6cm$)



	SWH (m_0)		MSS (m_4)	
	mainly longer wave		mainly short wave	
	ALT	Buoy	ALT	Buoy
Low σ_0 (high wind)	wind wave	wind wave	wind wave	wind wave
High σ_0 (low wind)	swell	swell	wind wave	swell (due to cutoff)

Under high σ_0 conditions, mss depend on short waves overlapped on swell, but MSS measured by buoys have no sensitivity to short waves and dominated by swell

4. Estimation of missing high frequency spectrum for buoys

Estimation of **missing MSS for high frequency** spectrum of buoys with wind wave equilibrium spectrum and saturation spectrum　(Hwang, 2001)

$$MSS = \int_{k_l}^{k_1} bu_* g^{-0.5} k^{-0.5} dk + \int_{k_1}^{k_u} Bk^{-1} dk$$

u_*: friction velocity, $u_* = \sqrt{C_d} u$

u: wind speed, C_d: drag coefficient

$k_l = \max[0.95, k_p] rad \cdot m^{-1}$
[for 6.6m limit]

$k_u = 100 rad \cdot m^{-1}$
[for 6cm limit]

$k_p = \frac{g}{u^2}$ peak wavenumber

$k_1 = \left(\frac{B}{b}\right)^2 \frac{1}{C_d} k_p$, separation wavenumber

b = 5.2×10^-2^, B = 4.6×10^-3^

g: gravational accelerration

Fig 5

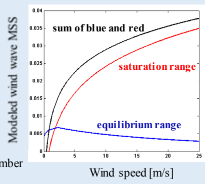
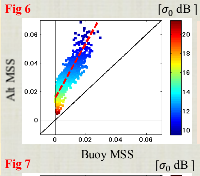


Fig 6



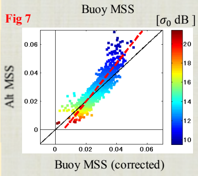
Alt MSS vs Buoy MSS

due to cut off frequency, buoy mss always less than altimeter mss

Buoy MSS $= \frac{16\pi^4}{g^2} m_4$,　$m_4 = \int f^4 S(f) df$

4th moment of wave frequency spectrum

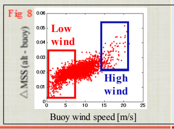
Fig 7



Alt MSS vs Buoy MSS (corrected)

missing MSS is well corrected

though high wind is underestimated



△MSS (Alt - Buoy) VS Buoy wind speed

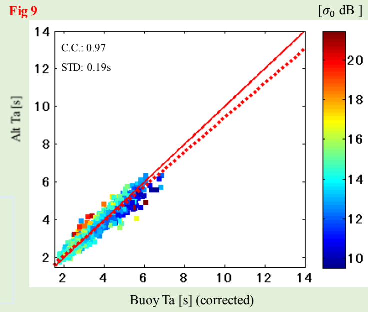
Low wind : good agreement with saturation spectrum showed in Fig 5

High wind : both equilibrium spectrum and saturation spectrum can not explain the rapidly increase with wind speed

Alt Ta vs Buoy Ta (corrected)

compared to Fig 2, good agreement even in low wind conditions

Fig 9

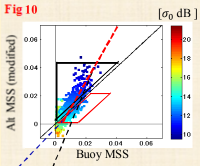


5. Discussion

Conversely, can we modify altimeter MSS to fit practical buoy observations?

Assumption: MSS(swell) = MSS(alt) – MSS(wind wave)

Fig 10

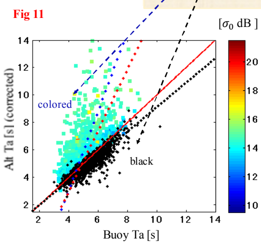


Alt MSS (modified) vs Buoy MSS

low wind : modified MSS sometimes becomes negative, i.e., overcorrected (not used in futher analysis)

high wind: modified Alt MSS > Buoy MSS, i.e., undercorrected

Fig 11



Alt Ta (modified) vs Buoy Ta

C.C.:
black: 0.88, colored: 0.57, all data: 0.52

STD:
black: 0.40 colored: 1.31, all data: 1.15s

For high wind conditions (black points), slightly better agreement w.r.t. Fig 2. For low wind conditions (colored points), Ta differences are large. Probably, because MSS (m4) is so small that $T_a = (\frac{m_0}{m_4})^{0.25}$ is sensitive to SWH (m0)

6. Conclusion

Due to **cutoff frequency**, buoy measurements **miss high frequency** information of waves, which is necessary in MSS estimation. Through estimation of missing MSS for high-frequency portion of the wave spectrum using buoy wind speed, we found that :

1) corrected buoy Ta shows **good agreement** with altimeter Ta **even under low wind conditions** (Fig 9).

2) modification of altimetry MSS to fit buoy observations seems difficult, especially in low wind conditions.

Reference:

Caires, S., Journal of Geophysical Reseach, Vol. 110, C02003, 2005

Gommenginger, C.P., Srokosz, M.A. and Challenor P. G., Geophysical Research Letters, Vol. 30, no. 22, 2150, 2003

Hwang, P.A. and Wang, D.W., Journal of Physical Oceanography, Vol, 33, pp: 1346-1360, 2001