Spectral Dissipation Term for Wave Forecast Models, Experimental Study

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Whitecapping Dissipation S_{ds}

$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

- S_{ds} is traditionally regarded as a tuning knob
- recent experimental advances brought much more certainty into physics of whitecapping dissipation
- Threshold behaviour in terms of the wave spectrum: $S_{ds} \sim (F - F_{thr})^n$
- Two-phase behaviour: dissipation at smaller scales depends on breaking/modulation at larger scales

$$S_{ds}(f) = a \cdot f\,(F(f) - F_{thr}(f))\,A(f) + b\int_{f_p}^{f}(F(g) - F_{thr}(g))\,A(g)\,dg$$

- At high wind speeds, dissipation depends on the wind
- At high frequencies (cumulative term dominates), turbulent viscosity is more significant than breaking dissipation
- At low spectral densities (below the threshold), dissipation may persist without breaking, but has to be described by separate terms

Little if any new experimental knowledge implemented in the models

White Cap Dissipation S_{ds}

$$\frac{dE(k, f, \theta, x, t)}{dt} = S_{in} + S_{ds} + S_{nl}$$

passive acoustic methods have a potential advantage

+ instrumentation is cheap, robust and easy to maintain

+ hydrophones are deployed below the surface and escape distructive power of breaking waves

+ can be operated on long-term or regular basis

two passive acoustic methods to study spectral dissipation
- segmenting a record into breaking and non-breaking segments
- using acoustic signatures of individual bubble-formation events

the photo is curtesy of Fabrice Ardhuine, France

- are we prepared to describe the surface like this?
- the description is necessary if we want to forecast the waves

Radiative Transfer Equation

$$\frac{dE(k, f, \theta, x, t)}{dt} = S_{tot} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

- Represents the temporal and spatial evolution of the wave energy spectrum E(k,f,θ)

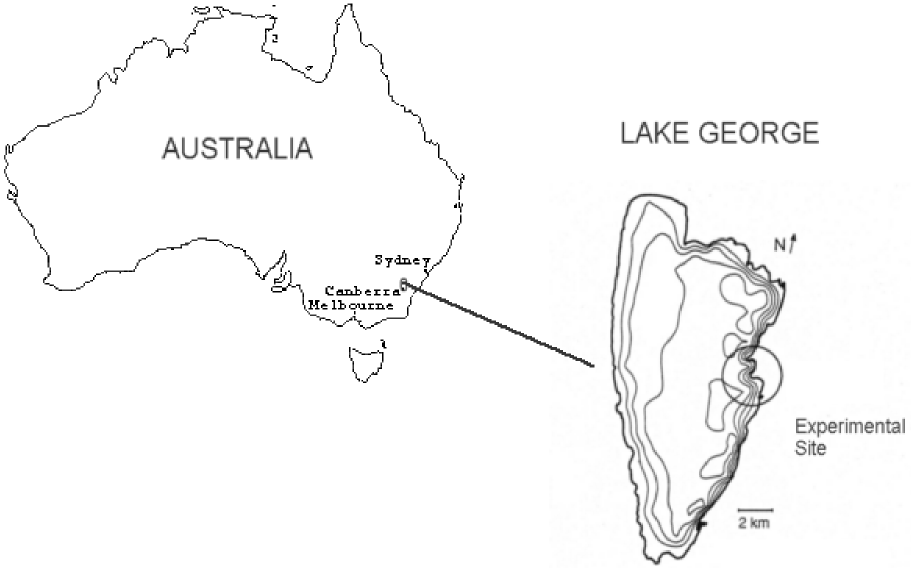
S_{tot} – all physical processes which affect the energy transfer
S_{in} – energy input from the wind
S_{ds} – dissipation due to wave breaking
S_{nl} – nonlinear interaction between spectral components
S_{bf} – dissipation due to interaction with the bottom

$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

Lake George - Canberra

20 km x 10km

- uniform finite water depth (0.3m - 2.2m)
- steep waves $f_p > 0.3\ Hz$
- strongly forced waves $1 < U/c_p < 8$



$$\frac{dE(k, f, \theta, x, t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

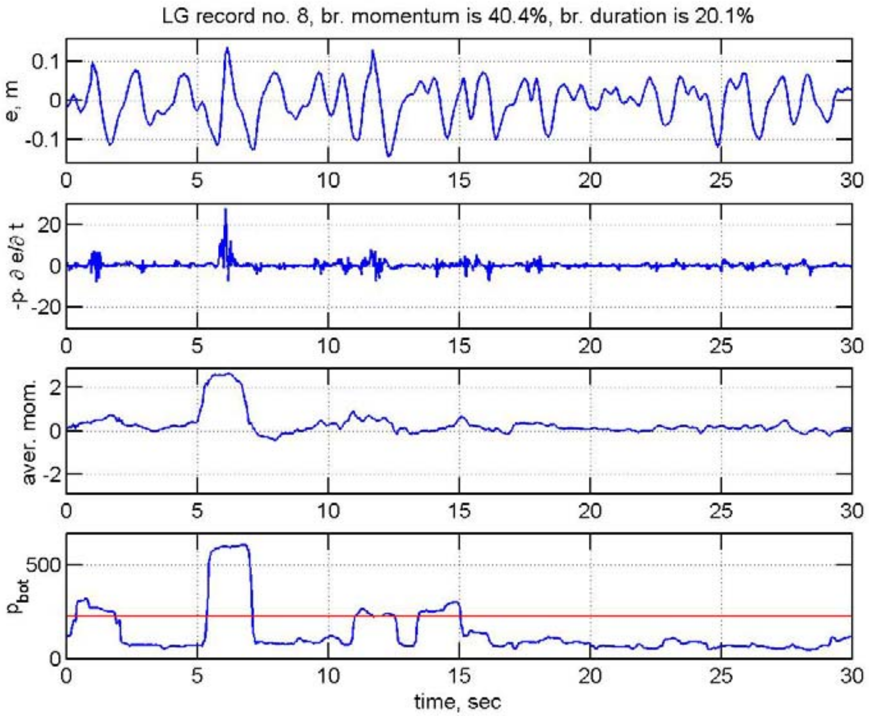
Instrumentation

S_{wc} - *White-cap dissipation*

- 3 Acoustic Doppler Current Meters
- Doppler spatial current profiler
- Hydrophone
- Video images
- Manual tagging

recording the breaking

$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$



passive acoustic methods have a potential advantage

+ instrumentation is cheap, robust and easy to maintain

+ hydrophones are deployed below the surface and escape destructive power of breaking waves

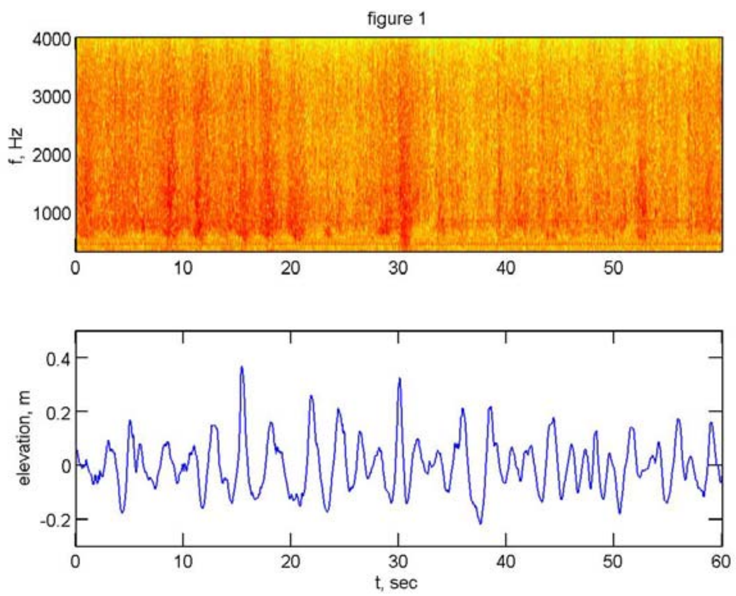
+ can be operated on long-term or regular basis

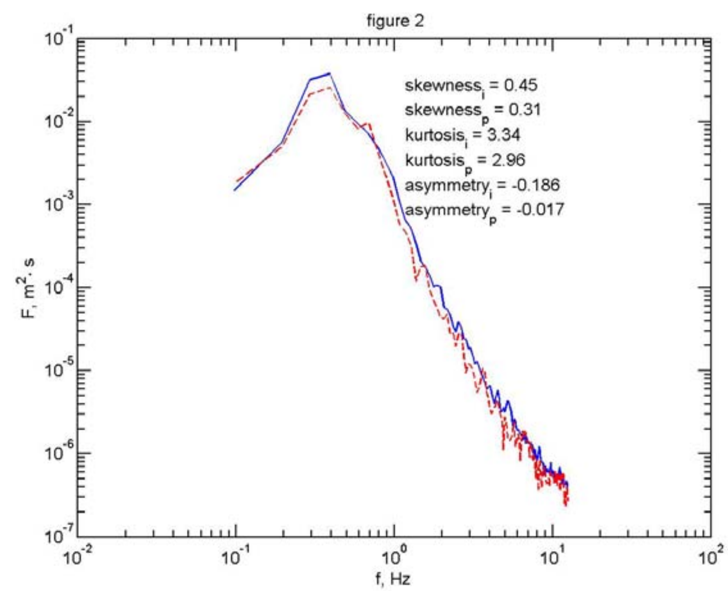
S_{ds} Spectrogram method

$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

Segmenting the record

- **50% breaking rate**
- **trains of dozens of breaking waves followed by dozens of non-breaking waves**
- **stationary, fully-developed, constant depth case**
- **U_{10} = 20 m/s, f_p = 0.4 Hz**
- **succession of breaking waves considered a train of incipient breakers**
- **succession of non-breaking waves considered a train of broken waves**
- **segments are from half a minute to a few minutes long**





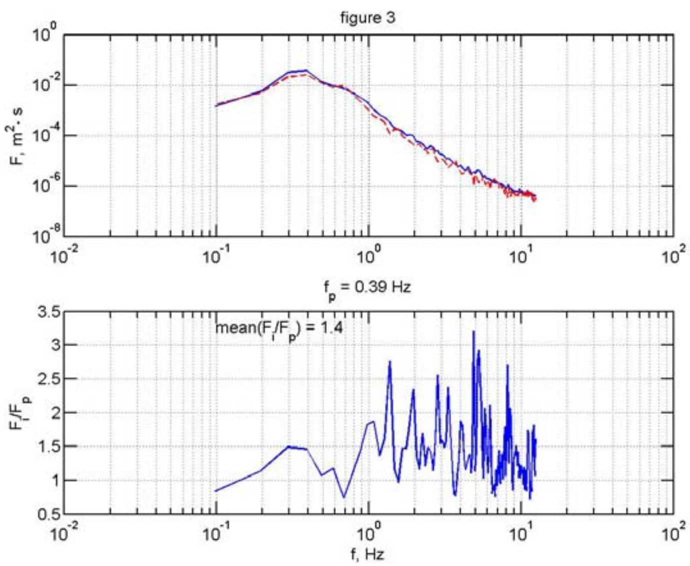
S_{ds} Spectrogram method

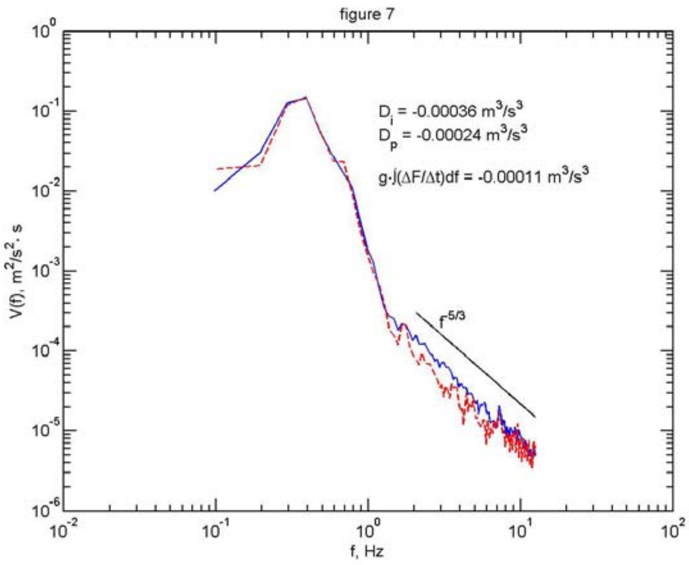
$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

Cumulative effect

$$S_{ds}(f) = \Delta F(f)/\Delta t$$

$$\int_f S_{ds} df = D_i - D_p = \int_f (\Delta F(f)/\Delta t) df$$



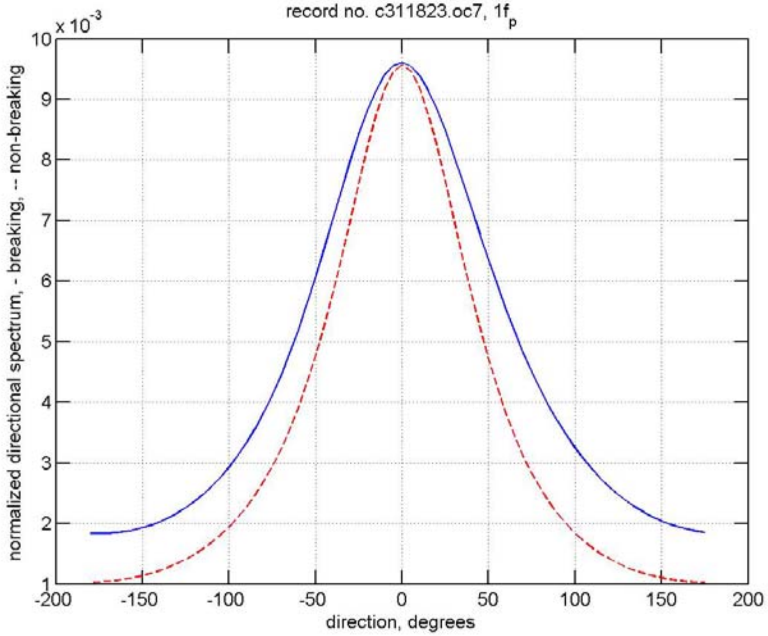


Young & Babanin, JPO, 2006

S_{ds} Spectrogram method

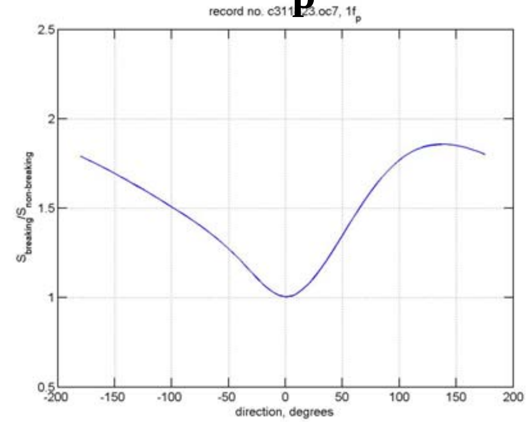
$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

Directional dissipation

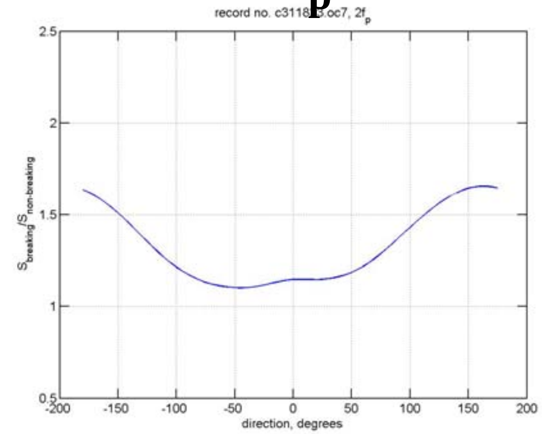


f_p

f_p



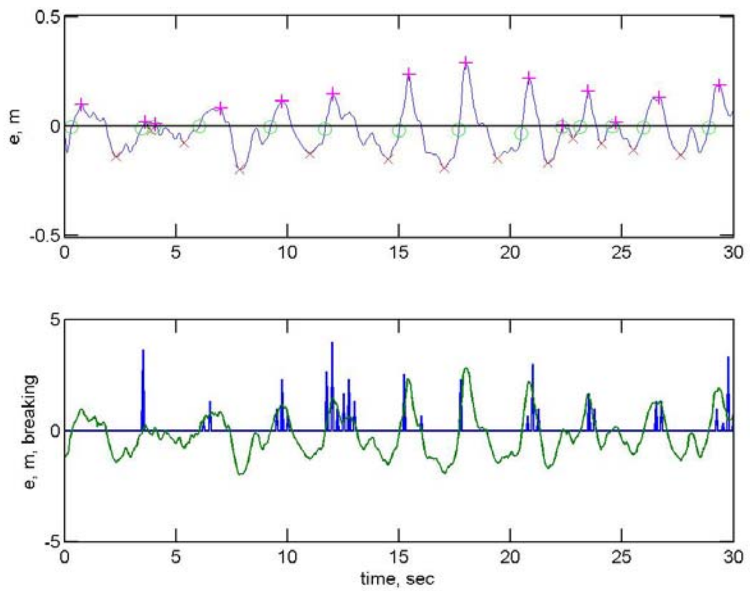
$2f_p$

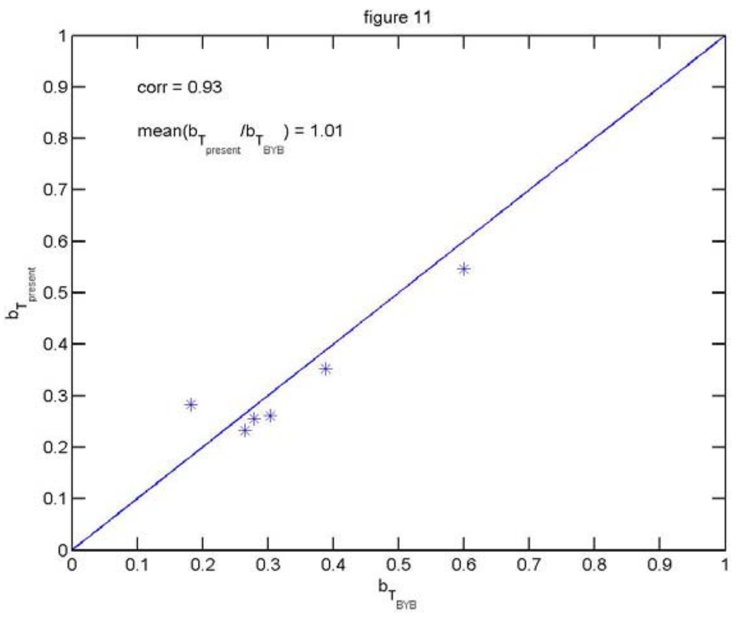


S_{ds} Bubble-detection method

$$\frac{dE(k, f, \theta, x, t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

- individual bubbles oscillate volumetrically: $\omega_0 \sim 1/R$
- bubbles passively emit sound at the natural frequency when formed or collapse
- individual bubbles ring at frequencies 0.5-10 kHz
- ringing lasts 10-20 cycles
- what humans perceive as a continuous noise is many discrete events
- sufficiently short time window triggered on a signal peak contains information about the bubble
- appropriately thresholded acoustic data generates statistic in time on number of bubbles and bubble size

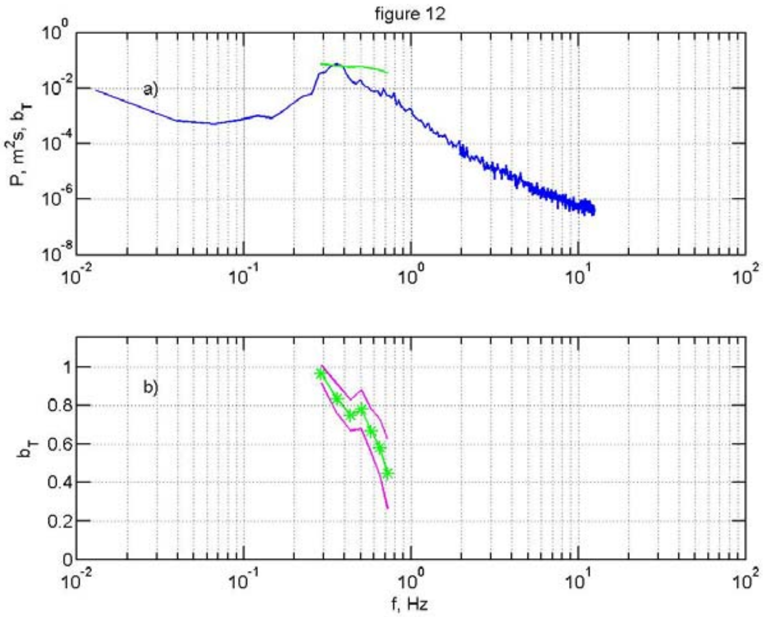


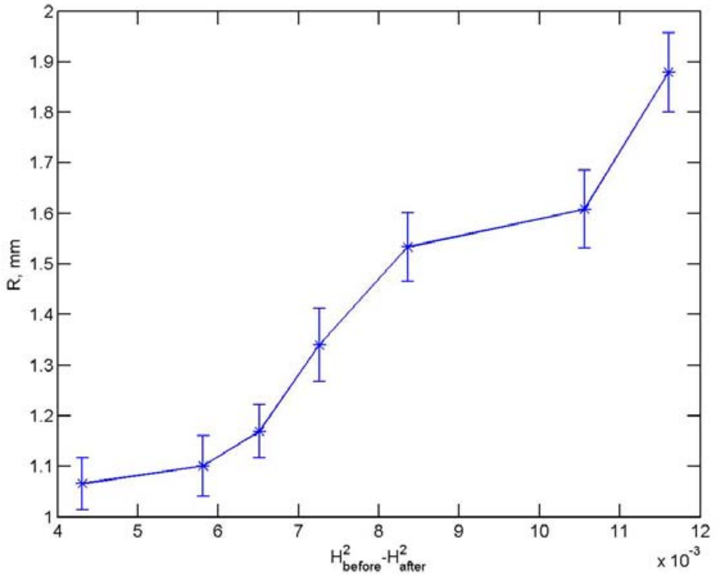


$\mathbf{S_{ds}}$ Bubble-detection method

$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

Frequency distributions of breaking probability
Breaking severity





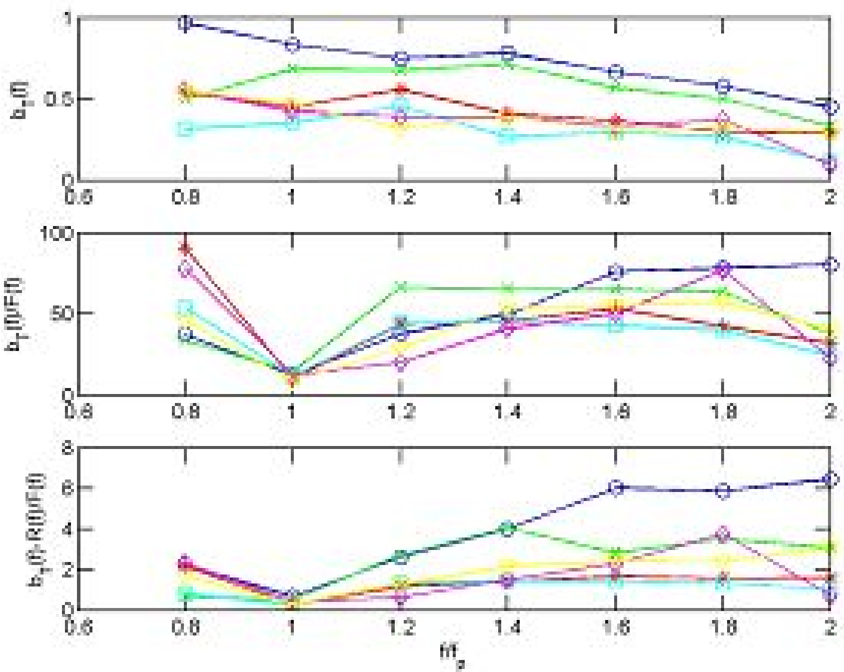
Manasseh et al., JTec, 2006

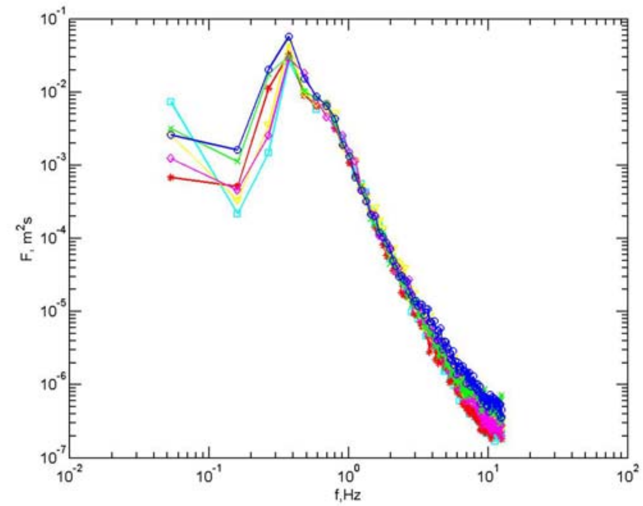
S_{ds} Bubble-detection method

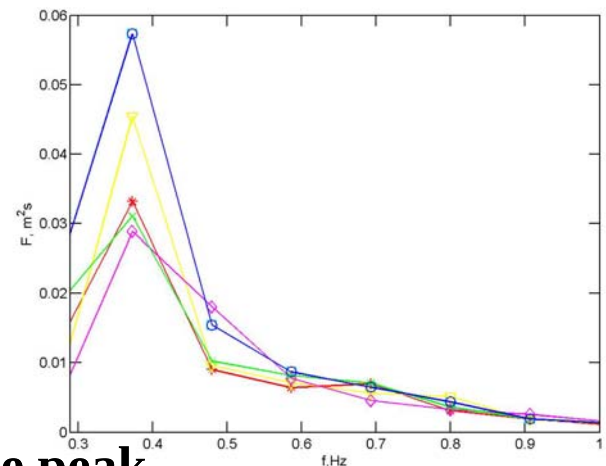
$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

Cumulative effect

Dependence on the wind







➢ **two-phase behaviour of spectral dissipation:**

- linear dependence of S_{ds} on the spectrum at the peak

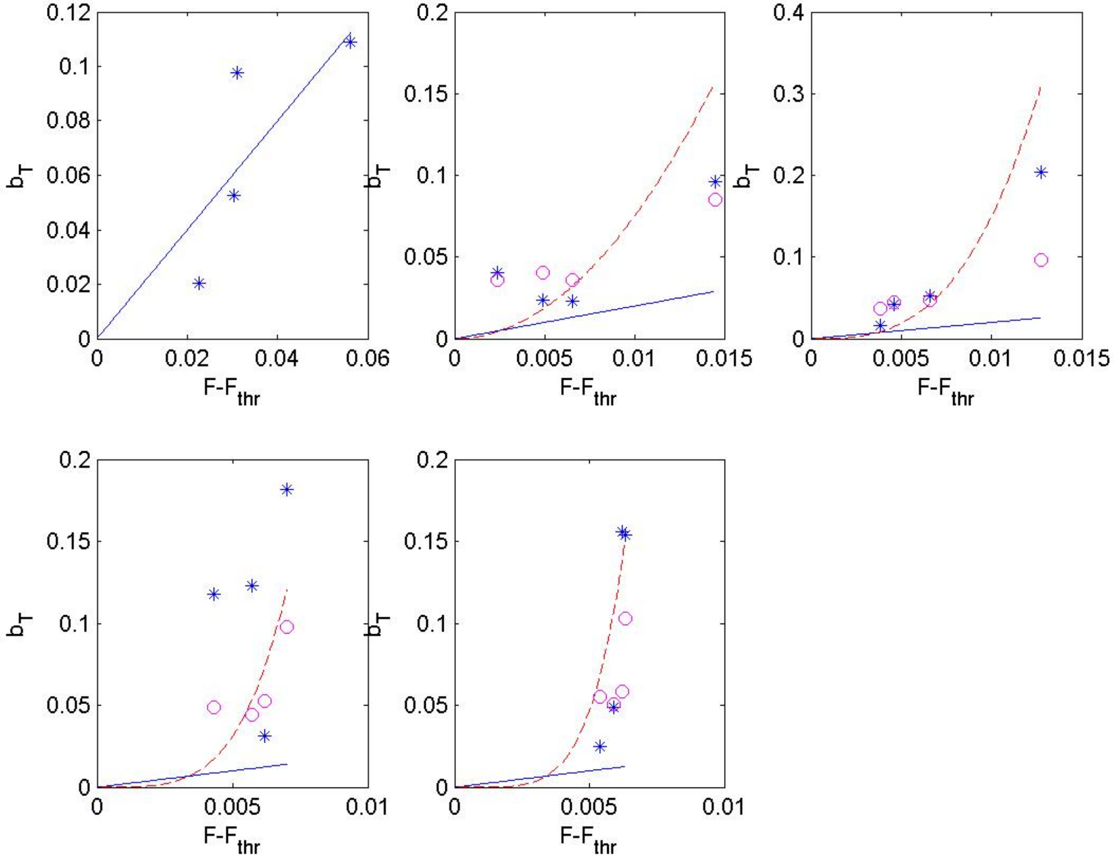
- cumulative effect at smaller scales

➢ **b_T depends on the wind for $U_{10} > 14$ m/s**

S_{ds} Bubble-detection method

$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

Frequency distributions of breaking probability

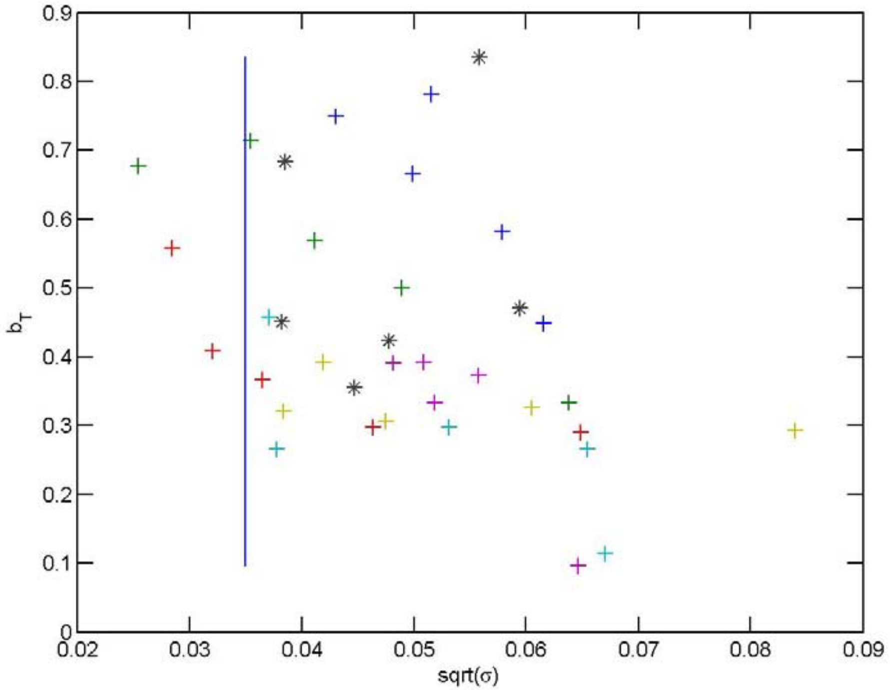


Breaking probabilities (from left to right) for frequencies of f_p, *1.2* f_p, *1.4* f_p, *1.6* f_p, 1.8 f_p in the $\pm 0.1 f_p$ *frequency range. Solid line in all plots identifies the linear dependence obtained in the first panel. Dashed lines, from left to right, are* $b_T \sim (F - F_{thr})^2$, $b_T \sim (F - F_{thr})^3$, $b_T \sim (F - F_{thr})^4$, $b_T \sim (F - F_{thr})^5$.

Whitecapping dissipation S$_{ds}$

$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

Saturation threshold



$$\sigma_{Phillips}(f) = \frac{(2\pi)^4 f^5 F(f)}{2g^2}$$

$$\sigma(f) = \sigma_{Phillips}(f) A(f)$$

$$F_{thr} = \frac{2g^2}{(2\pi)^4} \frac{\sigma_{thr}}{A(f) f^5}$$

$$\sqrt{\sigma_{thr}(f)} = const = 0.035$$

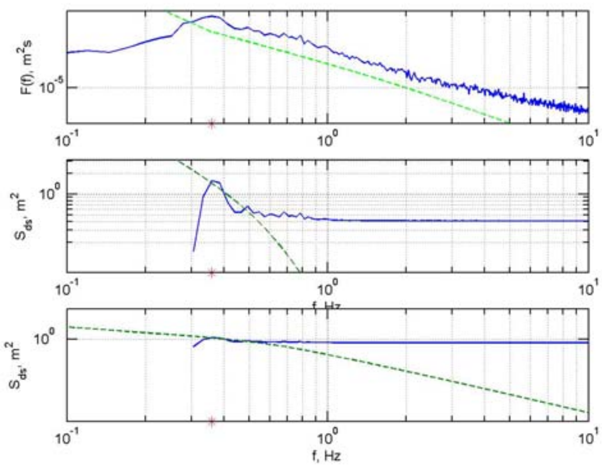
$$S_{ds}(f) = -a_1 \rho_w g f ((F(f) - F_{thr}(f)) A(f)) - a_2 \rho_w g \int_{f_p}^{f} ((F(q) - F_{thr}(q)) A(q)) dq$$

Dissipation S_{ds}

$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

➢ The induced dissipation can be caused by forced breaking of shorter waves due to the dominant breaking/modulation, or by enhanced turbulent viscosity due to the dominant breaking, or both.

➢ comparing with the Melville & Matusov dissipation based on distributions of the breaking crests



➢ importance of the turbulent viscosity contribution to the cumulative dissipation is evident

$$S_{ds}(f) = a \cdot f((F(f) - F_{thr}(f))A(f))^n + b\int_{f_p}^{f}(F(g) - F_{thr}(g))A(g)dg$$

Whitecapping Dissipation S_{ds}

$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

• spectral dissipation was approached by two independent means based on passive acoustic methods

• if the wave energy dissipation at each frequency were due to whitecapping only, it should be a function of the excess of the spectral density above a dimensionless threshold spectral level, below which no breaking occurs at this frequency. This was found to be the case around the wave spectral peak (dominant breaking)

• dissipation at a particular frequency above the peak demonstrates a cumulative effect, depending on the rates of spectral dissipation at lower frequencies

$$S_{ds}(f) = a \cdot f((F(f) - F_{thr}(f))A(f))^n + b\int_{f_p}^{f}(F(g) - F_{thr}(g))A(g)dg$$

• dimensionless saturation threshold value of $\sqrt{\sigma_{thr}(f)} = 0.022 - 0.035$

should be used to obtain the dimensional spectral threshold $F_{thr}(f)$ at each frequency f

• comparisons indicate that the turbulent viscosity becomes significant when the cumulative term dominates