Wave Forecast and Wave Climate, Advances and Challenges

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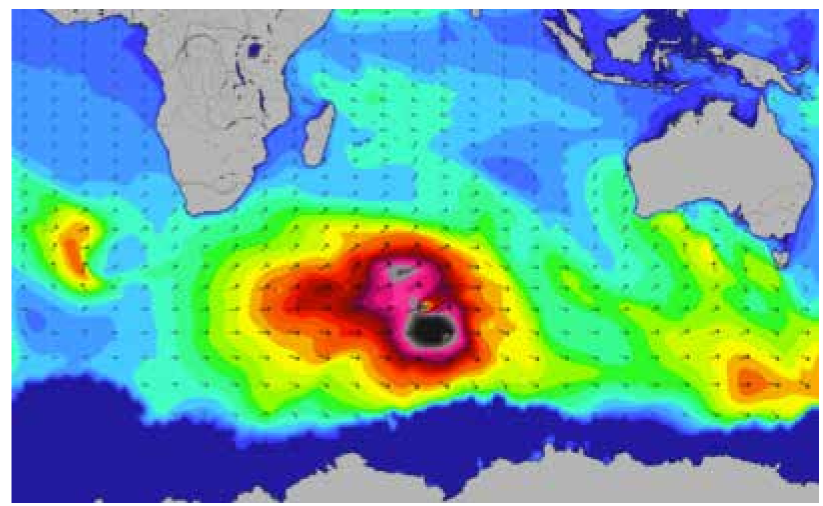
Wave Forecast, History and Significance

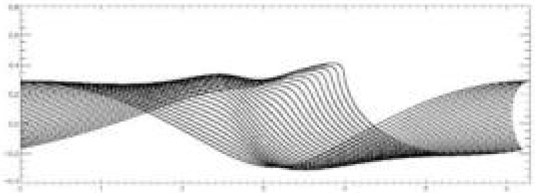
- 1st Generation models, WWII, primitive connection of wave height *H* with wind speed *U*
- *"Number of lives saved.. is reasonably assumed to be in the thousands over the course of the war" (Rogers et al., 2014)*
- 2nd Generation models, mid 60s, spectral, wind sea and swell separated, balance of input and dissipation
- 3rd Generation models, mid 80s, full physics (supposedly)

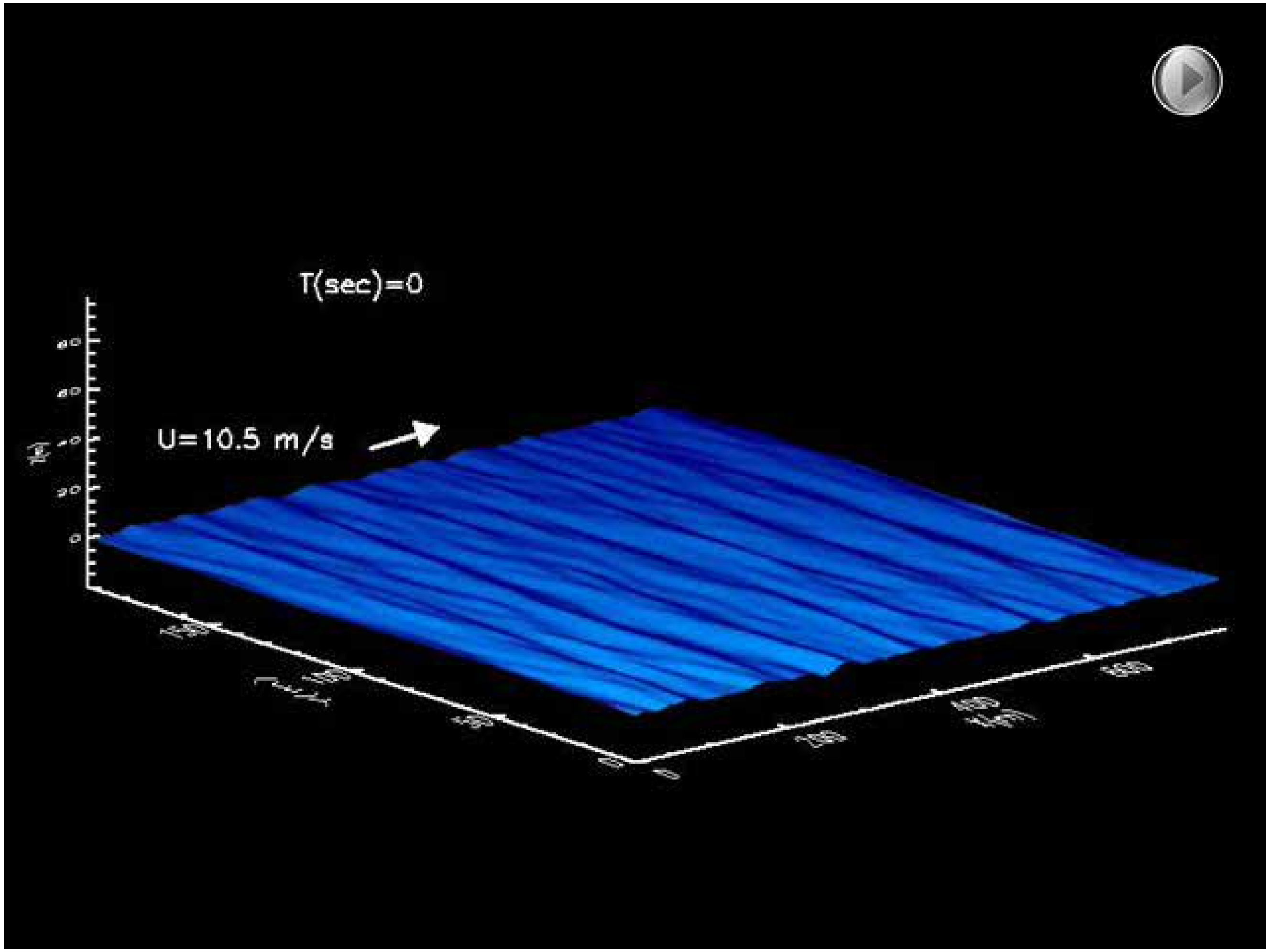
Ulluwatu swell, Bali



Henrique Rapizo: swells are normally delayed by one to one and a half days to the forecast

Fully nonlinear 3D potential wave modelling

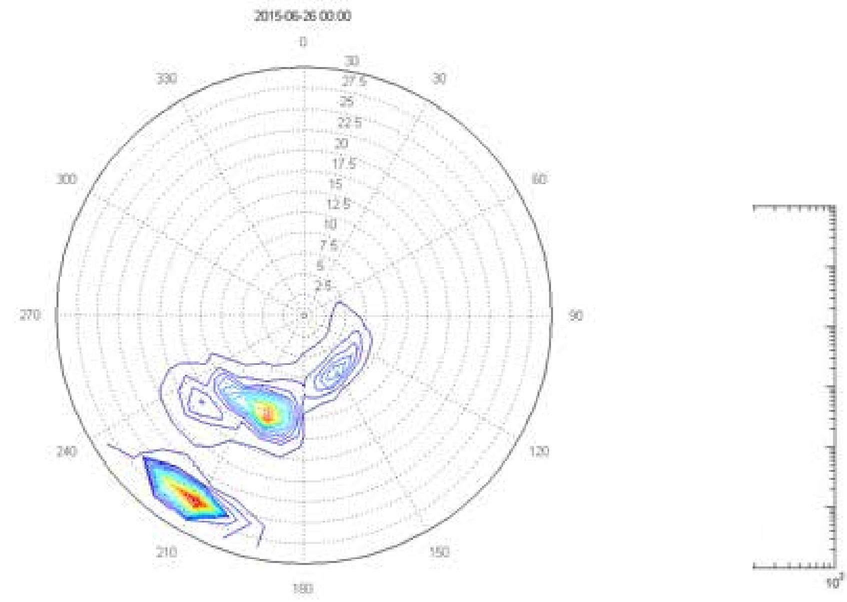




Chalikov & Babanin, OMAE 2013

Radiative Transfer
spectral models f

$$\frac{dE(k,f,q,x,t)}{dt} = S_{tot} = S_{in} + S$$



- Describes temporal and spatial evolution of the wave energy spectrum *E(k,f,q,t,x)*

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

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

Motivation

- physics (parameterisations of the source terms) was cursory
- had not been updated for some 20 years
- was not based on observations
- bulk calibration

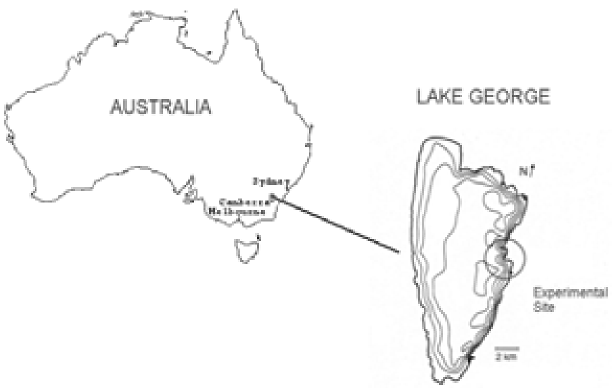
Requirements for the modern-date models:

- more accurate forecast/hindcast
- being used in the whole range of conditions, from swell to hurricanes
- coupling with weather, ocean circulation and climate models

Wind Input

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

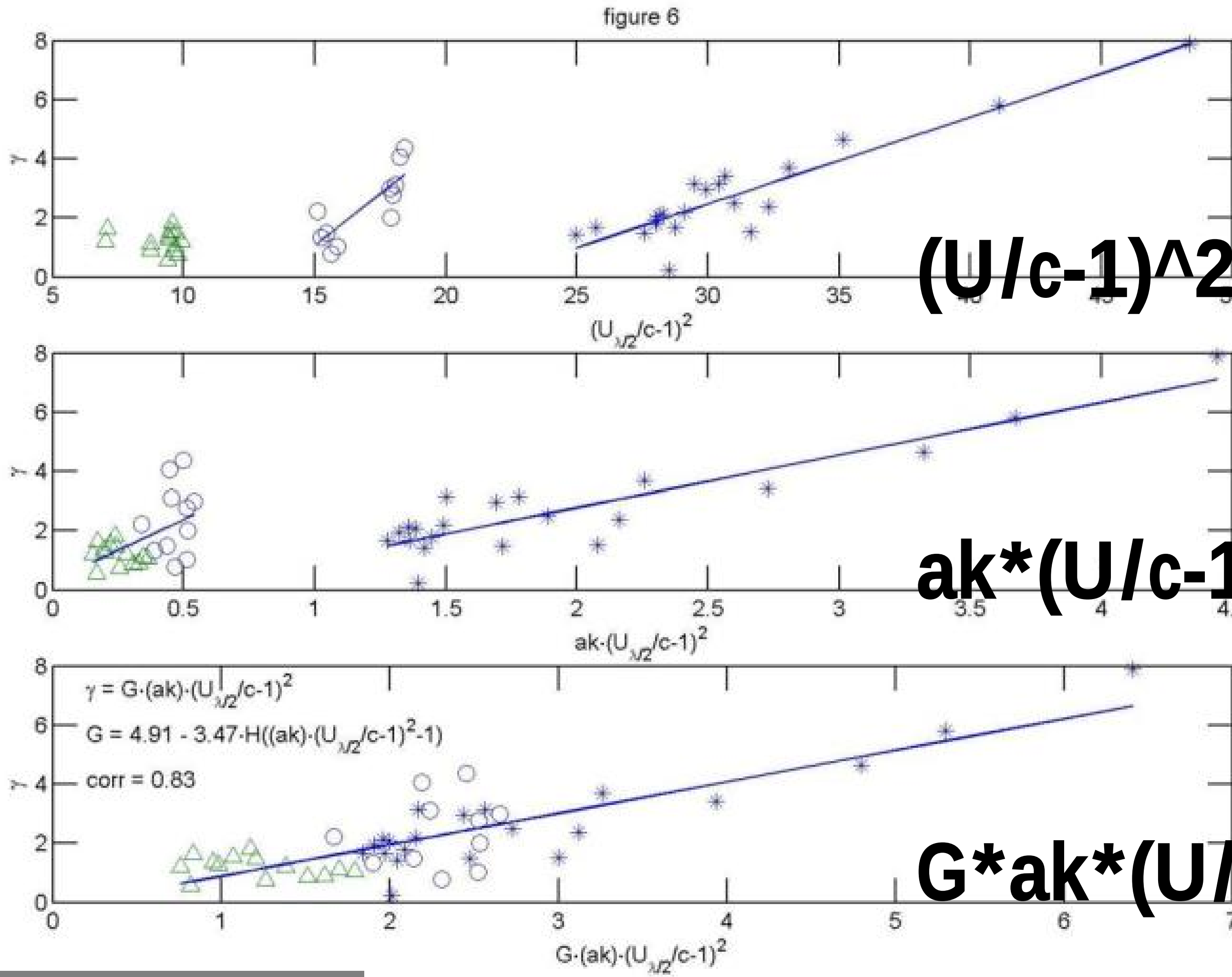
following the waves



Young et al., JAOT, 2005, Donelan et al., JAOT, 2005, JPO, 2006, Babanin et al., JPO, 2007

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

The parameterisation, growth rate γ



(U/c-1)^2

ak*(U/c-1)^2

G*ak*(U/c-1)^2

$$S_{in}(\omega) = \rho_a \omega g \gamma(\omega) E(\omega)$$

Breaking Dissipation S_{ds}

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

two passive acoustic methods to study spectral dissipation

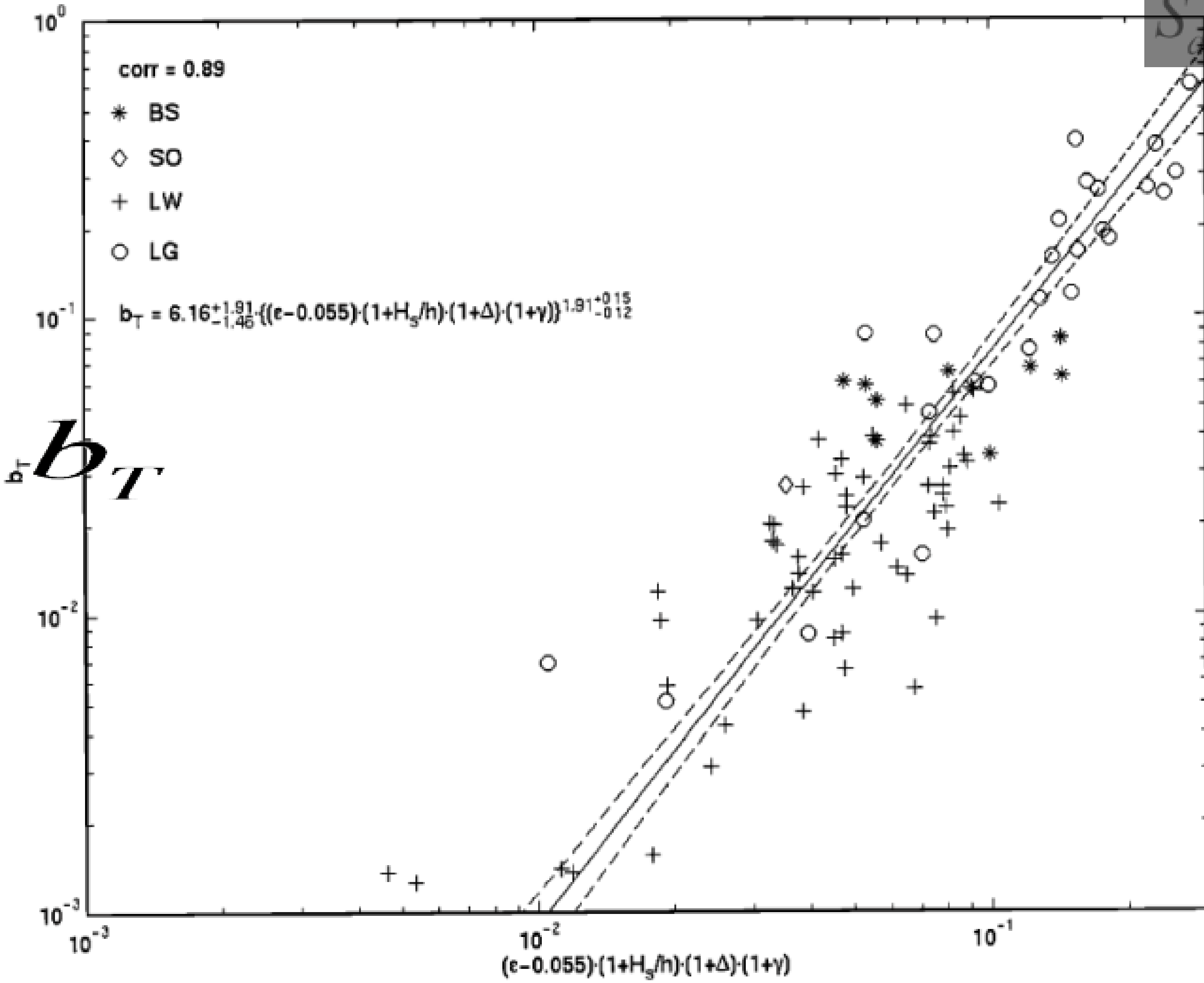
- segmenting a record into breaking and non-breaking segments
- using acoustic signatures of individual bubble-formation events

Babanin et al., 2001, 2007, 2010, Babanin & Young (2005), Manasseh et al. (2006), Young and Babanin (2006), Babanin & van der Westhuyusen, Babanin (2011)

Breaking probability dominant waves

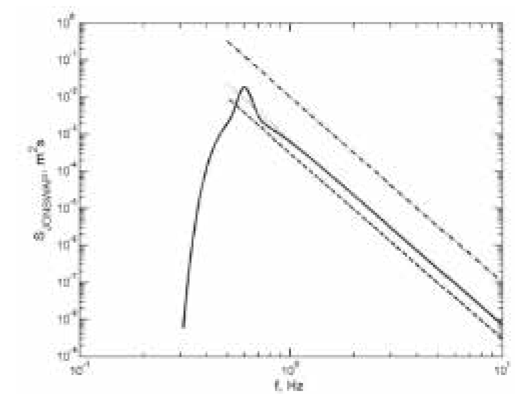
$$\frac{dE(k,f,q,x,t)}{dt} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

$$S_{ds}(\omega) = -\rho_a \omega g \gamma(\omega) E(\omega)$$



b_T

$\varepsilon - 0.055$



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

Whitecapping Dissipation S_{ds}

- 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

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

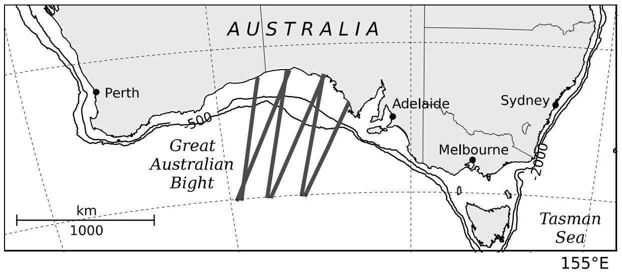
- dimensionless saturation threshold value of $\sqrt{\sigma_{thr}(f)} \approx 0.035$ should be used to obtain the dimensional spectral threshold $F_{thr}(f)$ at each frequency f

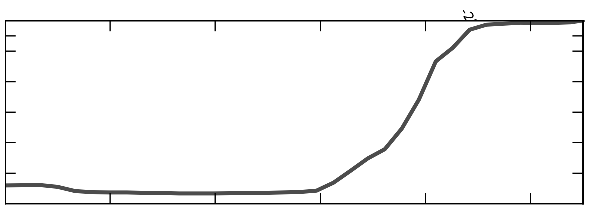
- dependence on the wind at strong wind forcing

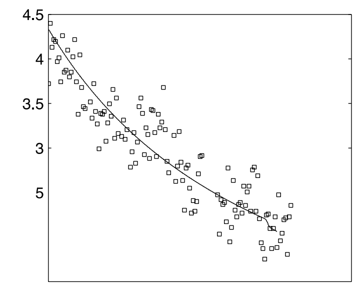
Swell attenuation

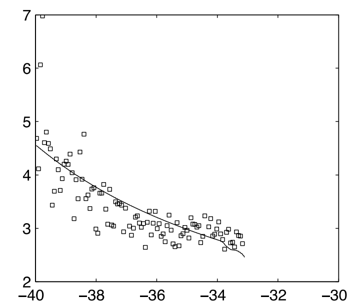
Young, Babanin, Zieger, JPO, 2013

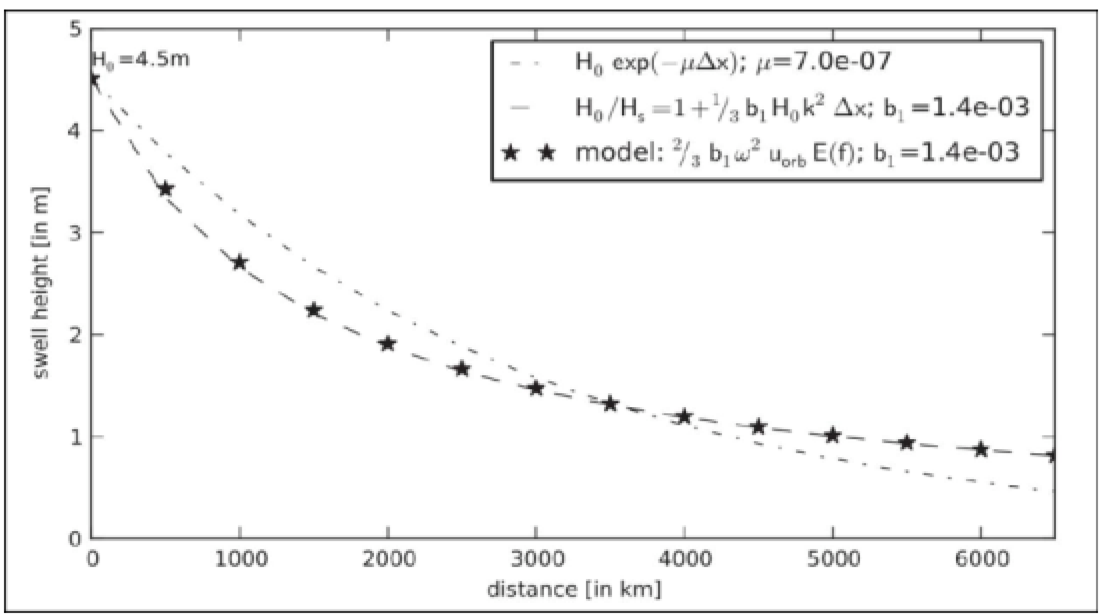
Swell attenuation

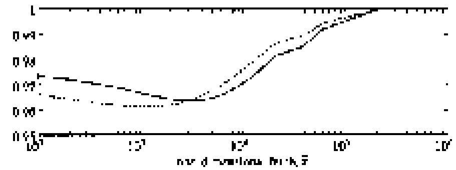












$$\frac{dE(k,f,\theta,x,t)}{dt} = S_{tot} = S_{in} + S_{ds} + S_{nl} + S_{bf}$$

The approach

- Traditional approach (ie. Komen et al. (1984)): reproduce known growth curves – i.e. model the balance of the source functions rather than the functions themselves
- Main constraint: integral wind momentum input must be equal to the total stress less viscous stress:

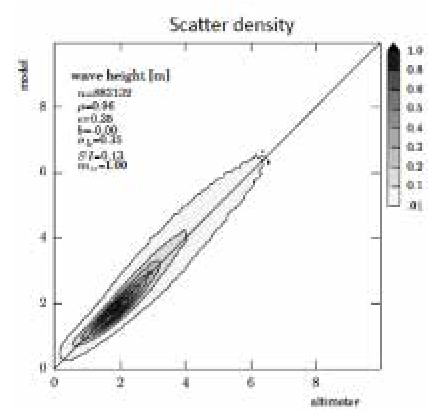
$$\int_0^{f_\infty} S_{in}^{\mu}(f)\,df = \int_0^{f_\infty} \frac{k}{\omega} S_{in}(f)\,df = \tau_w$$

- experimental dependences for total stress and viscous stress are used
- experimental dependences for ratio ot total input and total dissipation are used

$$\int_0^{f_\infty} S_{ds}(f)\,df \le \int_0^{f_\infty} S_{in}(f)\,df$$

TESTING, CALIBRATION, VALIDATIONS

Tropical Cyclone Yasi Eastern Australia

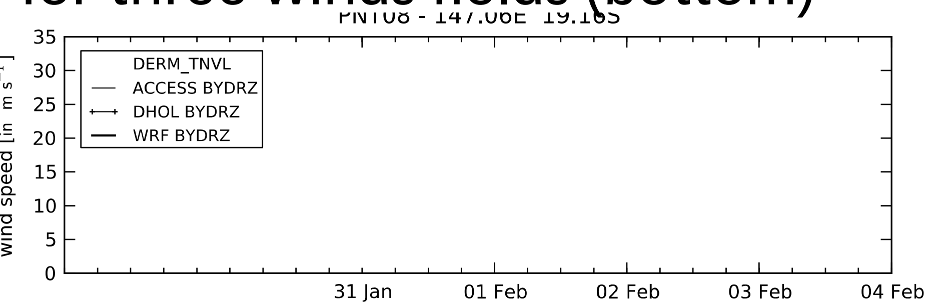


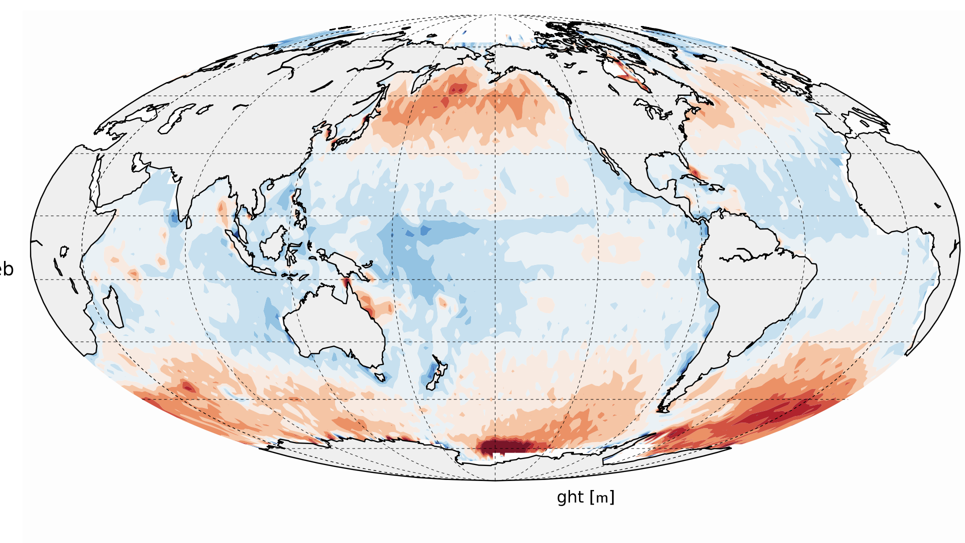
global hindcast

cyclone and altimeter tracks (top)

coastal measurements vs. model, for three winds fields (bottom)

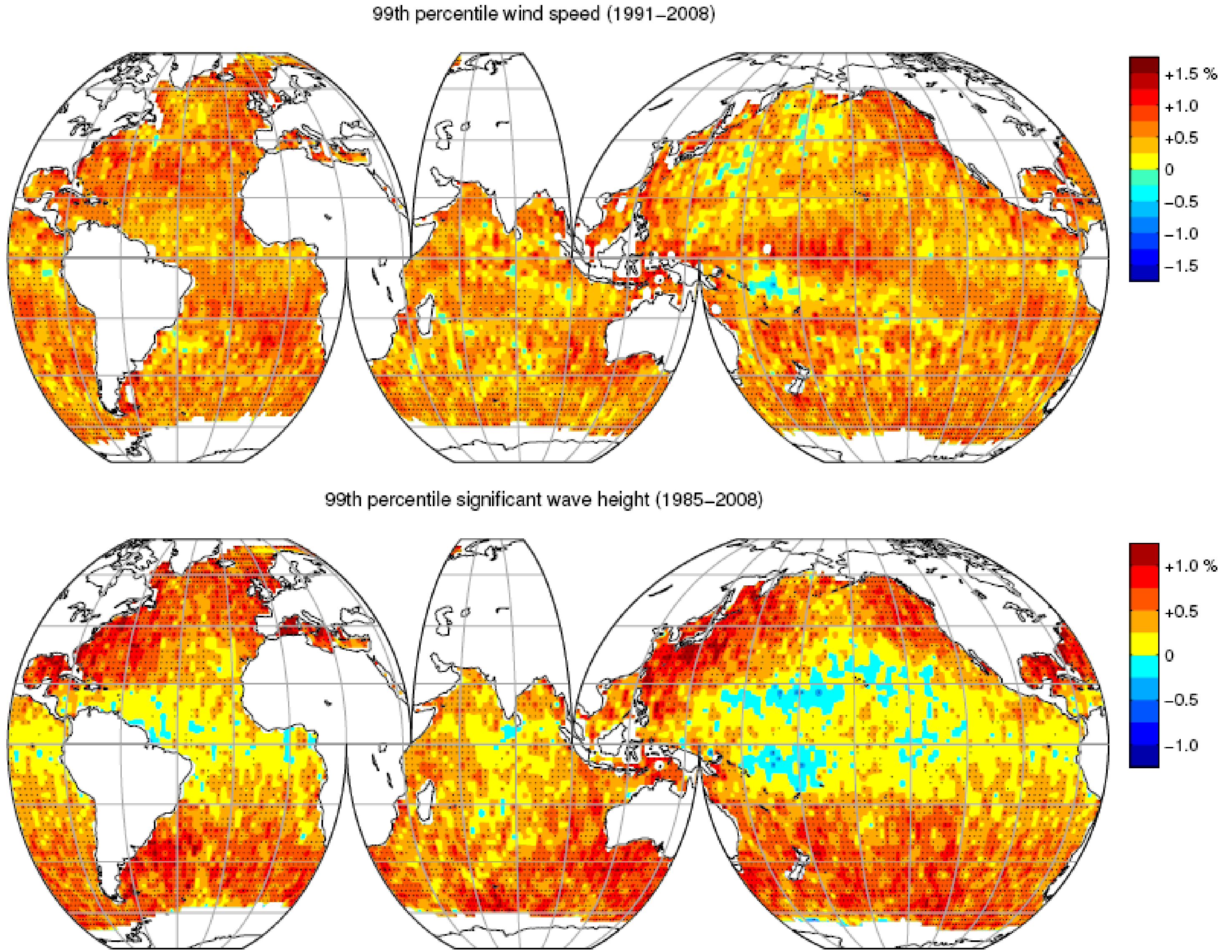
WAVEWATCH-III vs. altimeter 2006 (full year), wave height scatter plot (above), bias (below)





global and regional wave climate

- waves can serve as a climate indicator and also influence the atmospheric and oceanic climate



Young, Zieger and Babanin, *Science*, 2011

Other developments

- wave-bottom interaction routine (ready)
  - bottom sediment
  - ripple formation due to waves
- new non-linear interaction term (tested)
  - both resonant and quasi-resonant interactions
  - Stokes corrections
  - wave breaking
- wave-current interactions (in progress)
- wave-ice interactions

observation-based source terms

Released in WAVEWATCH-III (ST6) and SWAN

- *Wind input* (Donelan et al. 2006, Tsagareli et al. 2010)
- weakly nonlinear in terms of spectrum
- slows down at strong winds (drag saturation)
- constraint on the total input in terms of wind stress
- *Breaking dissipation* (Babanin & Young 2005, Rogers et al. 2012)
- threshold in terms of spectral density
- cumulative effect away from the spectral peak
- strongly nonlinear in terms of spectrum
- *Non-breaking (swell) dissipation* (Babanin 2011, Young et al. 2013)
- interaction of waves with water turbulence
- *Negative input* (adverse or oblique winds, Donelan 1999, unpublished Lake George observations)
- of principal significance for modelling waves in tropical cyclones
- *Physical constraints* (Babanin et al. 2010, Tsagareli et al. 2010)

Where to go?

Metrics missing

Requires a reasonable effort

- spectrum properties: α, γ, σ, f^{-4} to f^{-5} transition, *BFI*

Difficult to do

- fluxes: wind stress, radiation stress, partitioning of the dissipation between the water and air, extreme conditions

Very difficult to do

- directional distributions, both for the spectra and for the source terms

Wave Models Based on Full Physics

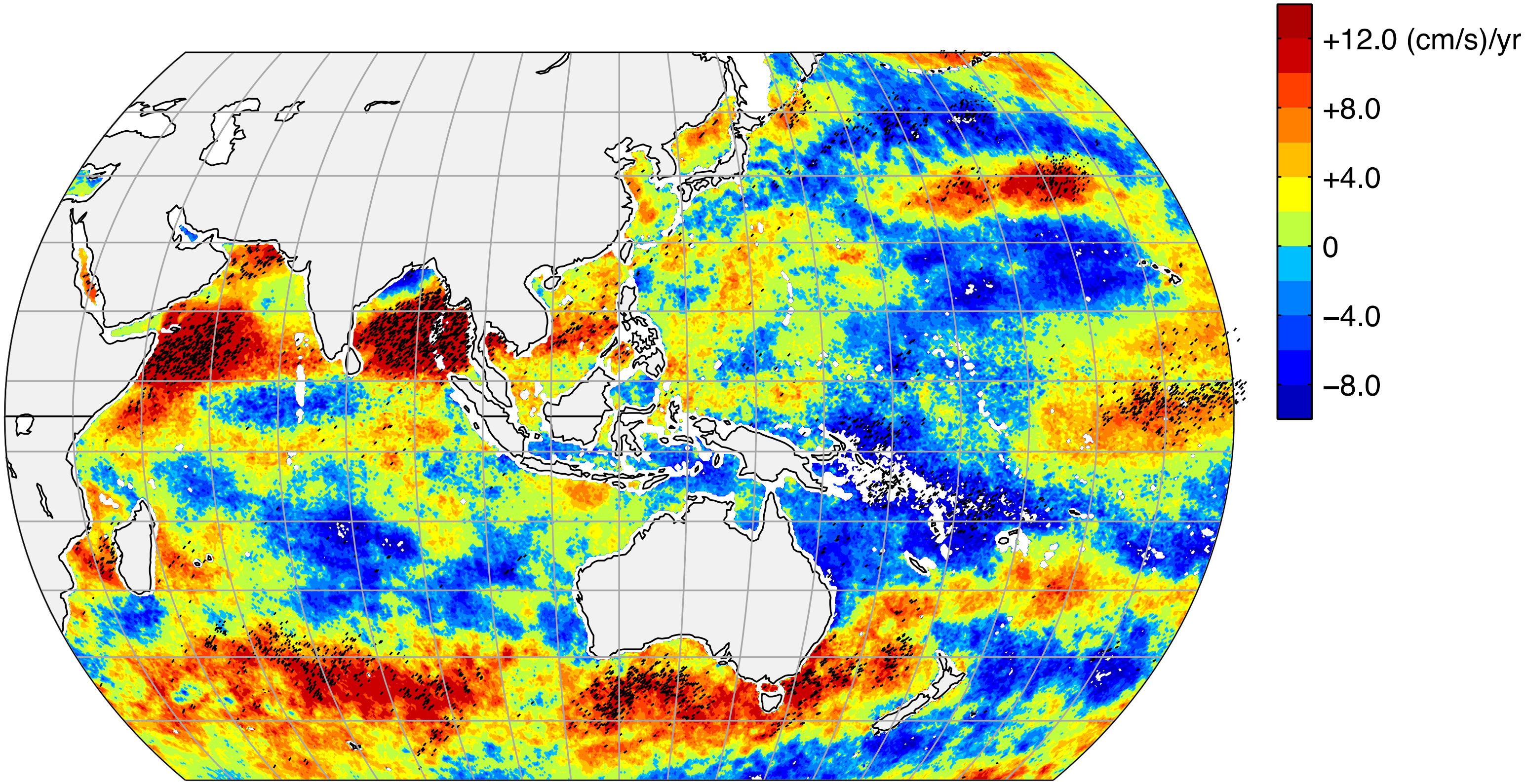
Can be used for

- prediction of adverse events (dangerous seas, freak waves, swells, breaking, steepness, PDF tail)
- outputting the fluxes
- coupling with extreme weather (hurricane) models
- coupling with atmospheric and oceanic modules of GCMs, atmospheric boundary layer, ocean circulation, climate

fourth generation models

wind trends, by SSM/I

mean wind speed (May 1991–2008)



Trend analysis (MK test) applied to monthly mean SSM/I (F10,F11,F13) wind and precipitation from 1991 to 2008. Hatching indicates significant changes (normcdf test [95% level]) and contour interval is 2.00 cm s^{-1} per year.

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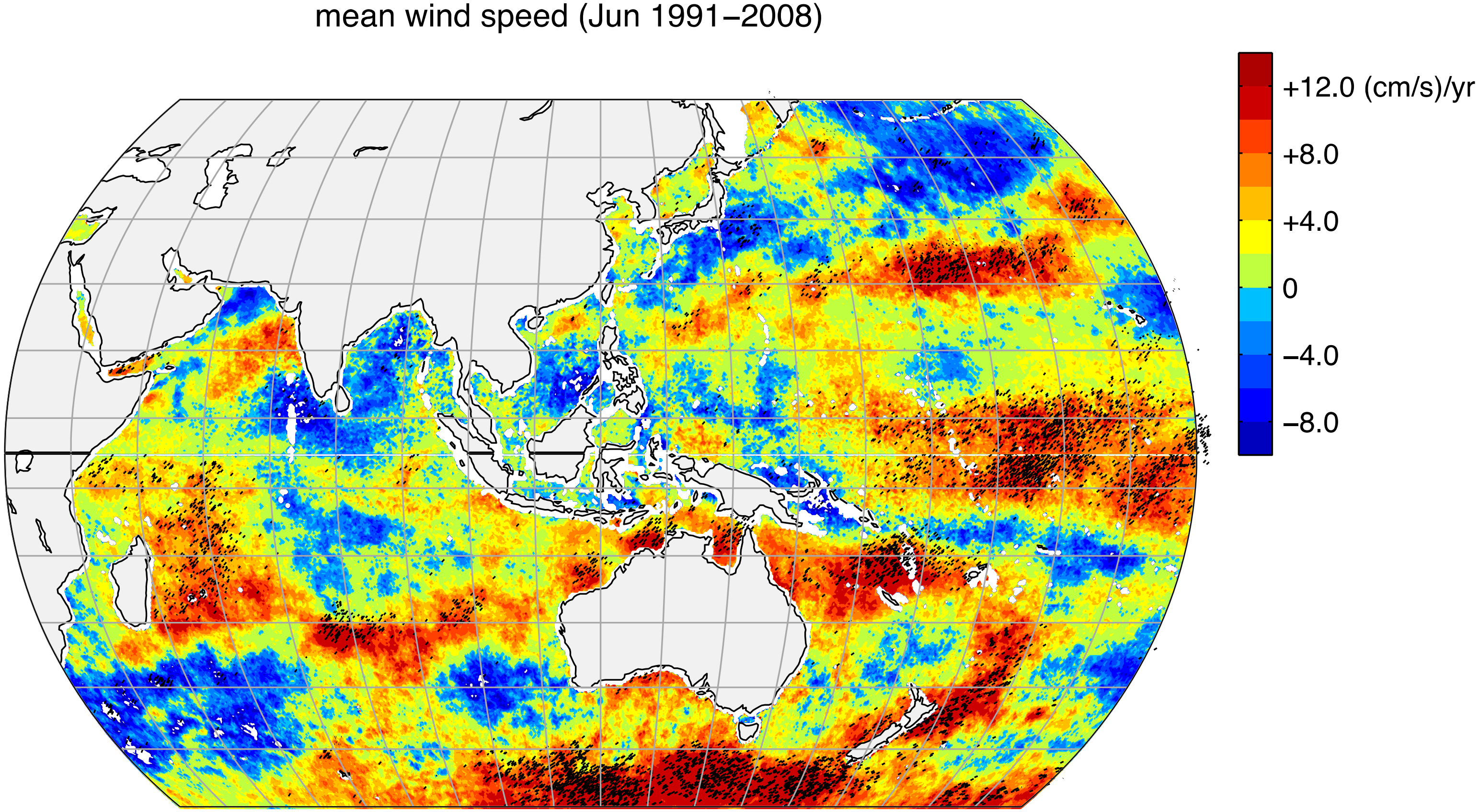

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