Session 2 Presentation - A New Generation of Spectral Wave Models

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A New Generation of Spectral Wave Models

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Overview

• Historical Perspective on Spectral Models
• First-, Second- and Third-Generation Models
• Stated Expectations
• Today’s State of the Art
• 3G Problems: Deep
• Future Directions and Needed Objectivity in Testing
1950-1970 First-Generation

• Spectral models were just beginning to replace parametric models:

**ON THE GROWTH OF THE SPECTRUM OF A WIND GENERATED SEA ACCORDING TO A MODIFIED MILES-PHILLIPS MECHANISM**

by

Tokujiro Inoue
1G Motivation

- Spectra can represent waves in nature MUCH BETTER then wave parameters
- The paradigm for physics was that spectra had a shape controlled by high-frequency breaking $F(k) \propto \alpha k^{-3}$ in deep water $E(f) \propto ag^2 f^{-5}$
- Pierson Moskowowitz spectrum formed an upper limit for wave growth (?)
- Only source was a modified Miles-Phillips wind input $\frac{\partial E(f, \theta)}{\partial t} = A(f, \theta) + BE(f, \theta)$
Spectra not realistic

Fig. 3(a)  Spectral growth with respect to duration.
2G Motivation

✓ Theoretical work confirmed the existence and important of resonant wave interactions

▪ The paradigm for physics was retained that spectra had a shape controlled by high-frequency breaking

\[ E(f) = a g^2 f^{-5} \]

▪ Pierson Moskowitz spectrum transitioned to JONSWAP spectrum

✓ A source was added to Miles-Phillips wind input

\[ \frac{\partial E(f, \theta)}{\partial t} = A(f, \theta) + BE(f, \theta) + S_{nl}(f, \theta) \]

✓ 1G could not reproduce spectral shape and both fetch and duration growth 2G could
JONSWAP spectra

- Spectra had a very pronounced overshoot at the spectral peak
- The equilibrium range was not a constant = not controlled by breaking
3G Motivation

- Wave spectra had to be free to obtained its natural shape unconstrained by parameters
- The paradigm for physics did not address Snl energy flux paradigm $E(f) \propto \beta g f^{-4}$
- Basic spectrum retained the JONSWAP form
- Detailed balance source was added to Miles-Phillips wind input
  \[
  \frac{\partial E(f, \theta)}{\partial t} = A(f, \theta) + BE(f, \theta) + S_{nl}(f, \theta)
  \]
- 2G could not reproduce spectral shape and needed frequent retuning
The WAMDI Group (1988) argued strongly that the number of degrees of freedom in $S_{nl}$ had to be equal to the “number of degrees of freedom in the spectrum” to allow spectra to evolve with no shape restriction.

Why did we need to increase the computational requirements by two orders of magnitude?

A second stated expectation was the ability to develop a model that would not need local recalibration. Unfortunately, for over 30 years, 3G models continue to be retuned by different operational groups and still do not capture even integral properties of angular spreading (Stopa et al. 2016)
Why: The Discrete Interaction Approximation (DIA)

• The DIA chose to use only 4 points in the space that was later found to need more than 2000 to represent (Resio and Perrie, 1991: JFM)

• And used an incorrect closure term that does not produce an appropriate constant flux behavior!!
Two Classic Spectral Forms Have Been Developed

- Equilibrium range dominated by resonant nonlinear interactions (Zacharov and Filonenko, 1966)
  \[ F(k) \propto \beta g^{1/2} k^{-5/2} \text{ in deep water} \]
  \[ E(f) \propto \beta g f^{-4} \]

- Equilibrium range Dominated by wave breaking –
  \[ F(k) \propto \alpha k^{-3} \text{ in deep water} \]
  \[ E(f) \propto a g f^{-5} \]

- Compensated spectral forms:
  \[ S_{nl} \rightarrow \beta' = \hat{F}(k)k^{-5/2} \]
  \[ S_d \rightarrow \alpha = \hat{F}(k)k^{-3} \]
Momentum Transfer

- Turbulent transfers from and pressure perturbations in the atmosphere force motions in the water column.

- It is straightforward to show that momentum transfer per unit area is given by:
  \[ \tau \frac{u^2}{g} \] where \( g \) is gravity and \( u \) is wind speed.

- This means that energy transfer rate into waves is expected to be related:
  \[ \Gamma_E \rightarrow \tau_M c \] rather than \[ \Gamma_E \rightarrow \tau_M u \]
Four-wave “resonant” interactions have a rich theoretical foundation: Hasselmann, 1961; Zakharov. 1966

An interesting test of the behavior of the fluxes is the idea that in the range of constant fluxes – in other words the constant \( \beta \) in the flux based system should be a constant which depends on the total energy coming into the spectrum from lower frequencies (assuming no energy in added into the equilibrium range)

\[
\Gamma_E \rightarrow \frac{u^3}{g} \quad (\beta \text{ linear with } u)
\]

\[
\text{Current 3G models use this paradigm}
\]

\[
or
\]

\[
\Gamma_E = \frac{u^2c}{g} \quad (\beta \text{ linear with } (u^2c)^{1/3})
\]
Toba, Belcher and others have postulated that $\beta$ is linearly proportional to wind speed. This clearly does not work for multiple data sets.

This graph shows the importance of multiple data sets!
Resio et al. (2004) showed that spectral energy levels could be scaled consistently. This form represents a constant momentum fraction entering the wave field near the spectral peak.

\[ r^2 = 0.939 \]
But this is part of a larger pattern showing that both $k^{-5/2}$ and $k^{-3}$ ranges co-exist in spectra around the world.

What does this mean in terms of the dominant source terms in these regions of the spectrum in coastal areas?

Transition to a breaking form?
Does the DIA return the spectrum to the observed equilibrium form?

Ardag and Resio, accepted with revisions
Even With zero energy added!

Ardag and Resio, accepted with revisions
Does it produce adequate long term evolution of the peak?

Ardag and Resio, accepted with revisions
A Next-Generation of Model

- An accurate evolutionary solution compared to the full integral solution
- New Source Terms that match our understanding of the physics today
- Objective testing in a range of scenarios
- Faster run time
- Maintenance of an easy-to-use, efficient, open-source version for open-source testing
How do we move to more accurate and faster?

• Think Digital (audio, video, cameras, etc.)

• Stochastic digital solutions replace analogue solutions

• The number of degree of freedom in the digital representation have to show their ability to resolve the solution accurately – which is determined by operator/user requirements
Why has development stagnated?

• Modelers are now in charge of all testing and evaluation of test performance.

• They do not focus on
  – Detailed balance (now incorrect)
  – Spectral shape (now incorrect)
  – Momentum transfers in coupled models (now incorrect)

• Instead the model continues to focus on “holistic” performance via parameter adjustment for matching integrated parameters

• Little event focus in comparisons

Re-tuning is “continual” and locally based
Do we need more comparisons of this type??

Normalized percentage bias of swell and wind se partitioned quantities in different regions (from Stopa et al., 2016).
Or of this type??
Or Would you rather see…

- Time series of TC comparisons (H,T,θ)
- Time series of Swell spectra arrival
- Comparisons of predicted and modeled maxima in TCs and ECs
- Time series and summary statistics of systems near the coast of operational ranges
- ETC.
Conclusions

• Motivations for transitions to 1G and 2G models were successfully met – objective metrics and specific, careful testing by objective operators was key
• Motivations for transition to 3G model have not been successfully met
• It is time to begin developing some specific operational metrics and careful testing protocols for what is needed?
• AND to execute these comparisons in an accessible and objective manner
QUESTIONS