# The Details of Detailed Balance

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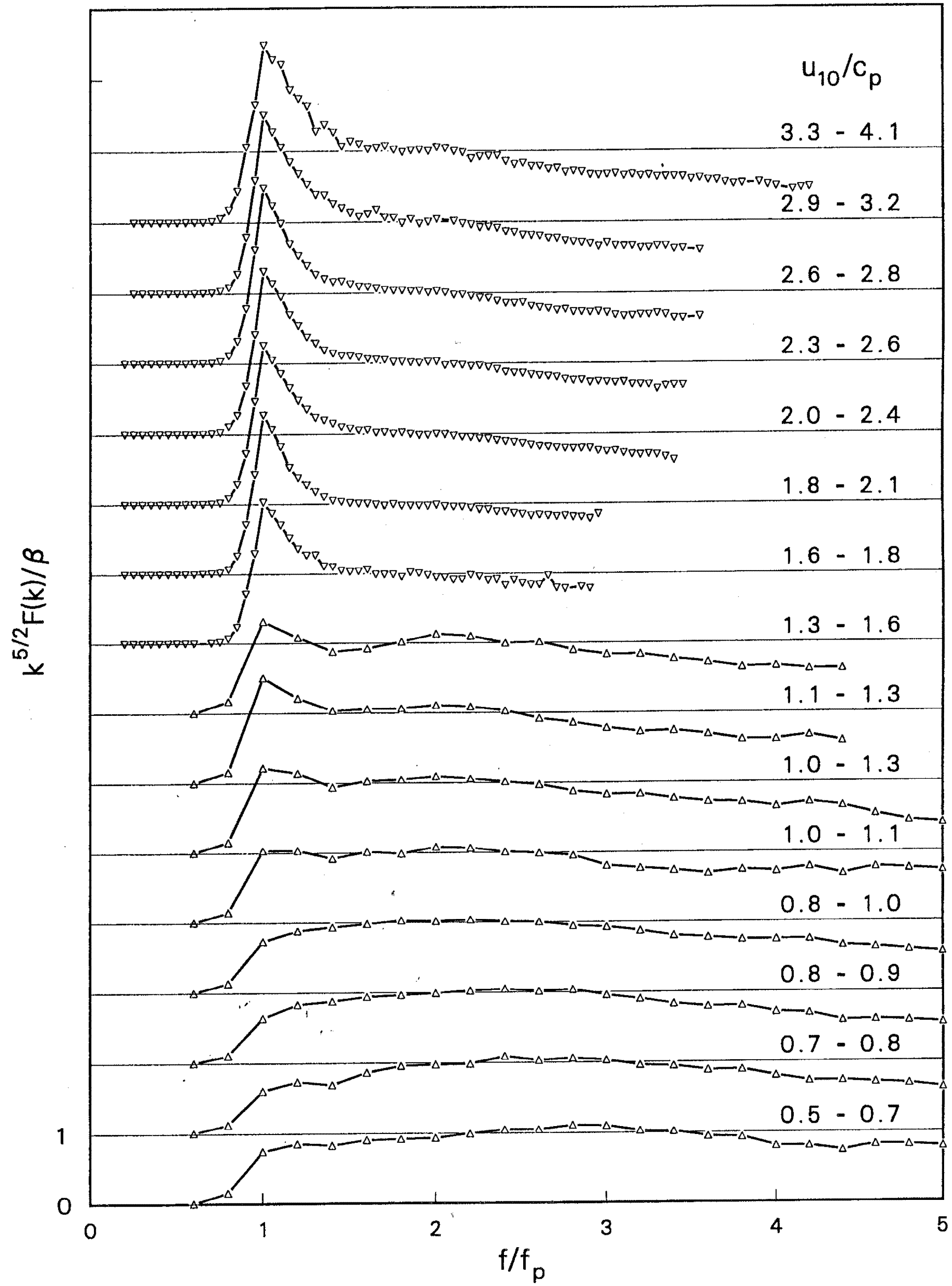
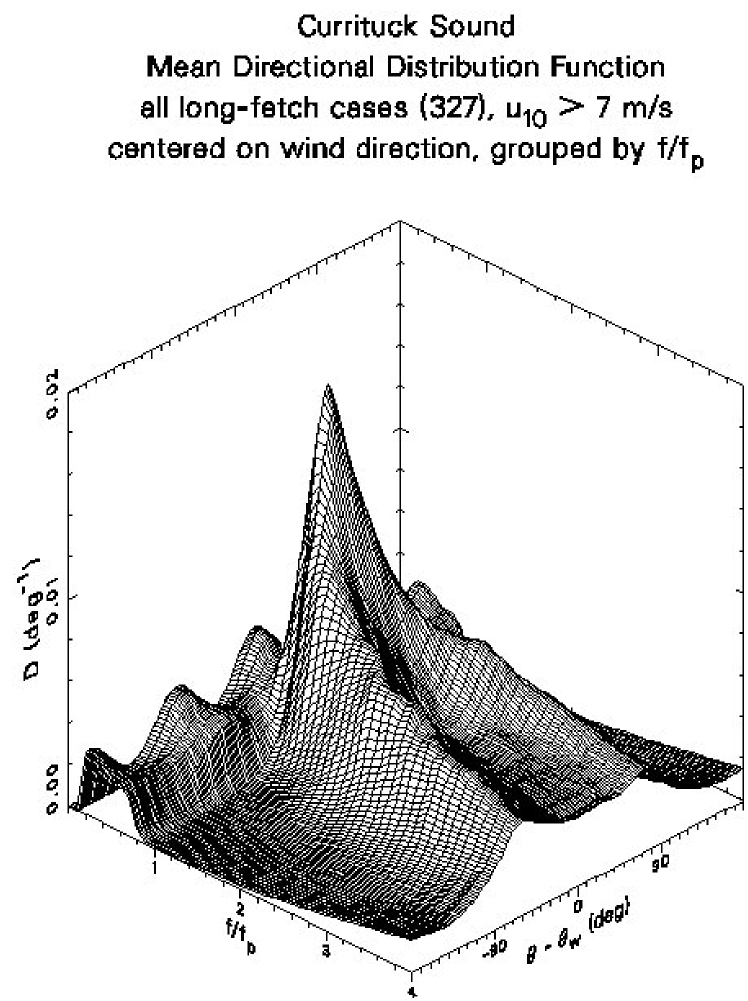
# MOTIVATION

- Spectral shape provides critical information for understanding source term balance in wind wave spectra
- Our focus on wave models has been to compare to integrated spectral parameters –
  - which we have been doing reasonably well since the 1960s
  - but maybe not in all situations



# MOTIVATION

**In 1985, Hasselmann *et al.* created a new class of wave model – the third generation wave model. Its primary difference from previous models was that it solved all of the source terms, including the Snl source term with the same number of dof as in the directional spectrum:**

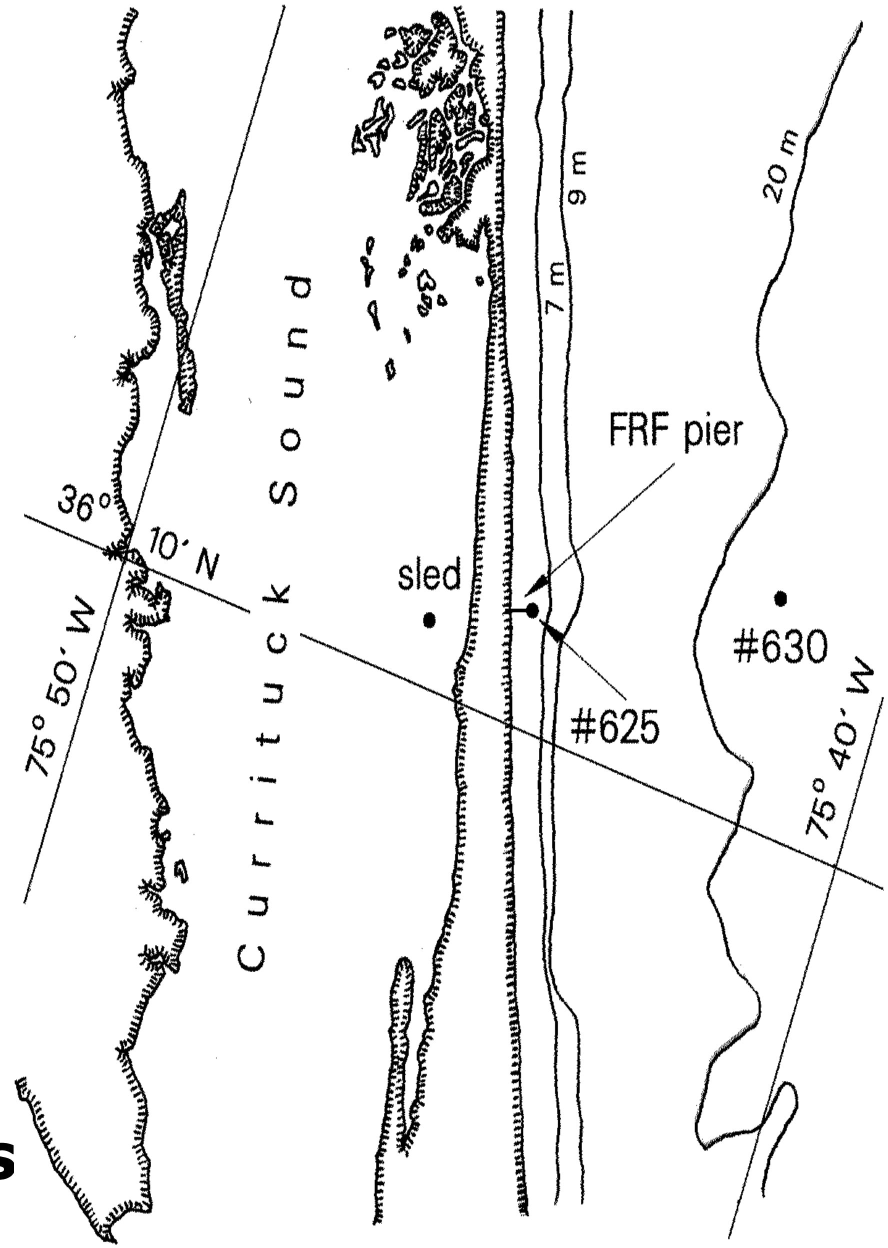



**Ideally no constraints would lead to better physics in complex situations.**

# MOTIVATION

**Today we focus on comparisons of only Hs and Tp, and mean direction, and keep adjusting terms to improve the fits to global data sets.**

**This may work fine for some operational purposed but will likely not suffice for either extremes (Hs >20m?) or complex generation situations or for coastal areas**



# MOTIVATION

**SO: Although today's models can reproduce good Q-Q agreement in many open ocean situations we are not quite (ITWS) there yet.**

**We need to adopt an approach that puts sustained effort into improved physics - as well as – into improved operational products.**

**If we want to advance 3G modeling we need to improve the details of detailed balance models!**

**Engineering Approach**

**Spectral Shape**

**Research Approach**

**Hs, Tp, θ**

**E(f, θ)**

# Conclusions:

- Modern 3-G models do not capture key attributes of directional spectra
- Dissipation and wind input are overemphasized relative to Snl
- Momentum fluxes are not constant through the equilibrium range in spectra with constant directional spread
- But are constant for realistic directional spreading
- New wind input, dissipation and SNL
- terms are needed
- It is critical to include detailed balance comparisons for detailed balance models

# Spectral shape characteristics that have been found to be relatively universal

- Spectral shape in equilibrium range
- Energy level in equilibrium range
- Spectral peakedness
- Directional distribution – including bimodality
- Temporal vs. Spatial wave growth rates

**Phillips, 1958** $E(f) \sim \alpha_5 g^2 f^{-5}$

**Toba, 1974** $E(f) \sim \alpha_4 u g f^{-4}$

where

$\alpha_4$ is the equilibrium range coefficient and

$u$ is term with units of velocity.

**Resio, Long, & Vincent 2004** $E(f) \square\ \alpha_4 (u^2 c_p)^{1/3} f^{-4}$

Where
$C_p$ = phase velocity of spectral peak

**Forristall, 1981** $E(f) \sim \alpha_4 u g f^{-4} \quad \rightarrow \quad \sim \alpha_5 g^2 f^{-5}$

for $\hat{f}\ (= u f g^{-1}) > const.$

## Switching to wavenumber spectral basis

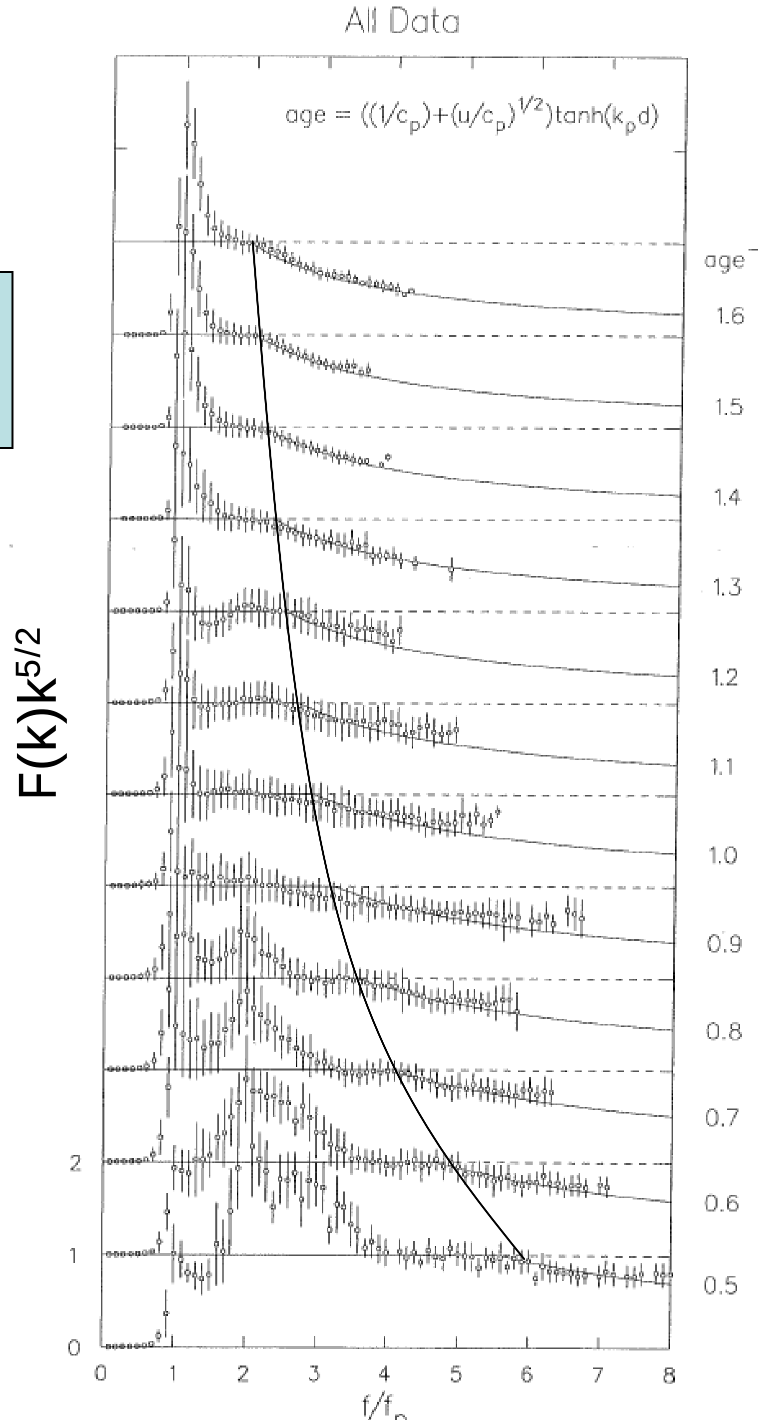
$$F(k) = \frac{\beta}{\sqrt{g}} k^{-5/2}$$

where

$\beta$ is the equilibrium range coeff.

$k$ is wavenumber.

1



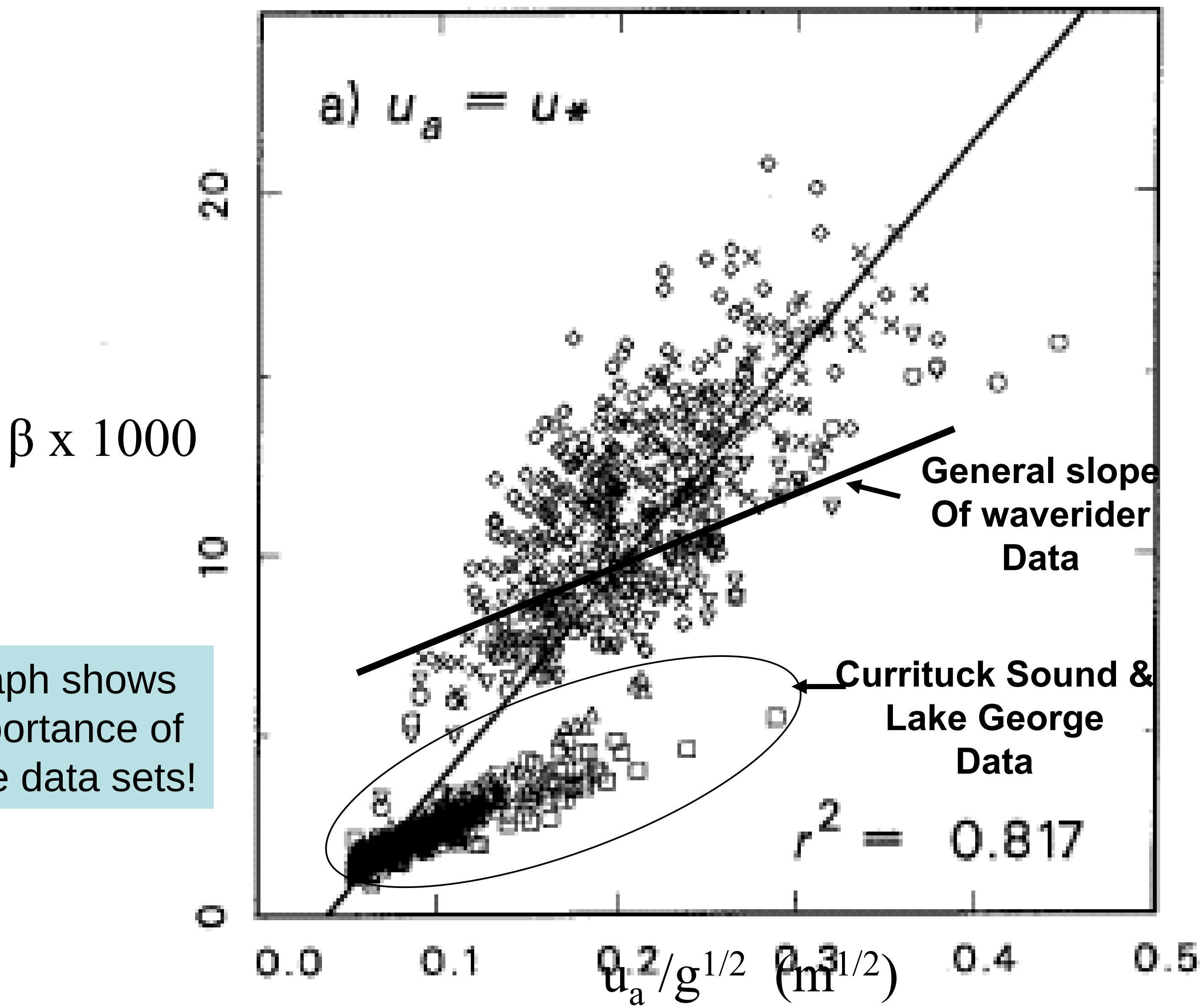

In deep water:

$$\beta = \tfrac{1}{2}\alpha_4 u g^{-1/2}$$

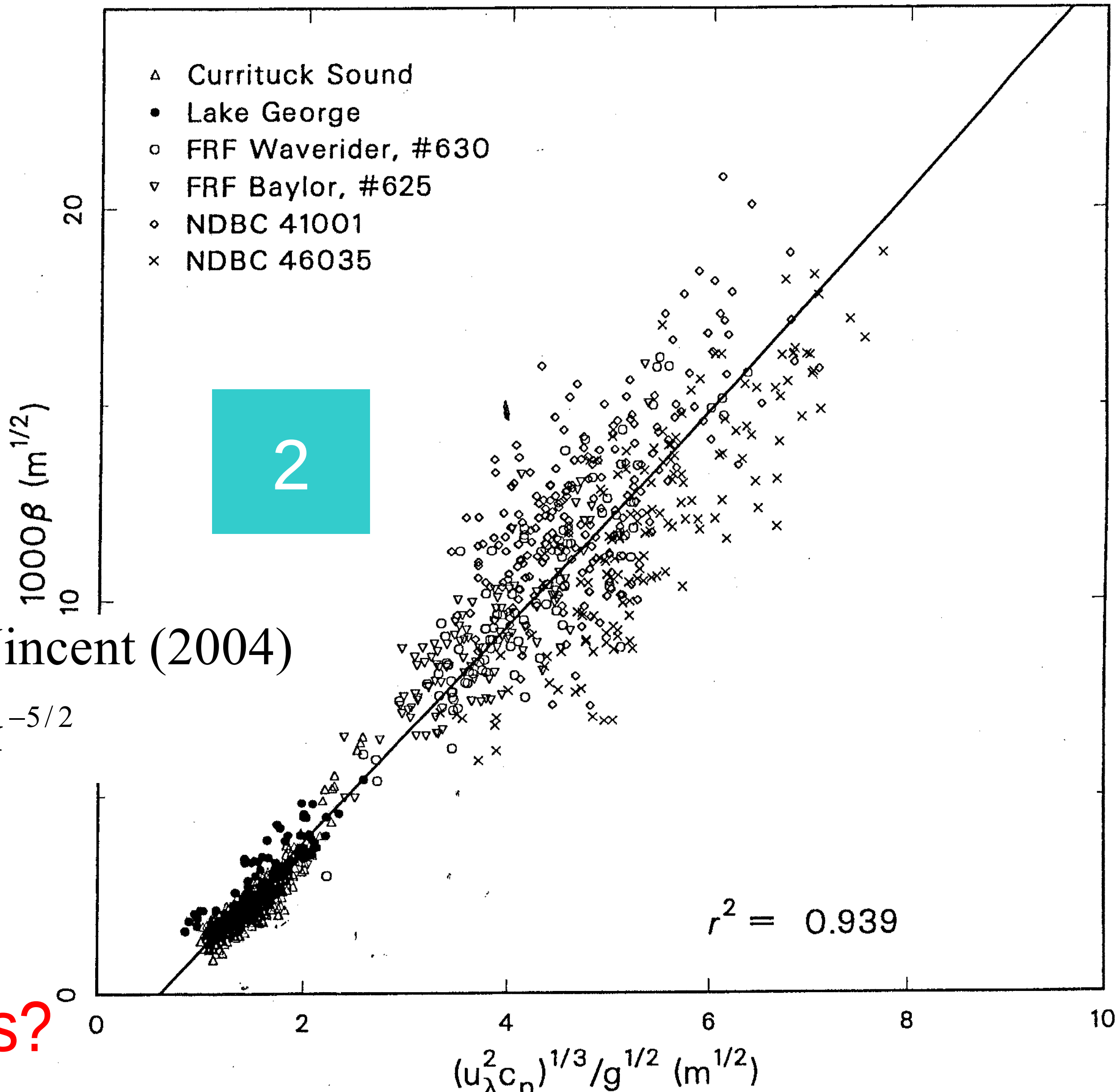
**Equilibrium form appears to transition from $f^{-4}$ to $f^{-5}$ form at high frequencies**

**But what is the eq. value?**

Toba, Belcher and others have postulated that β is linearly proportional to wind speed. This clearly does not work for multiple data sets.




This graph shows the importance of multiple data sets!

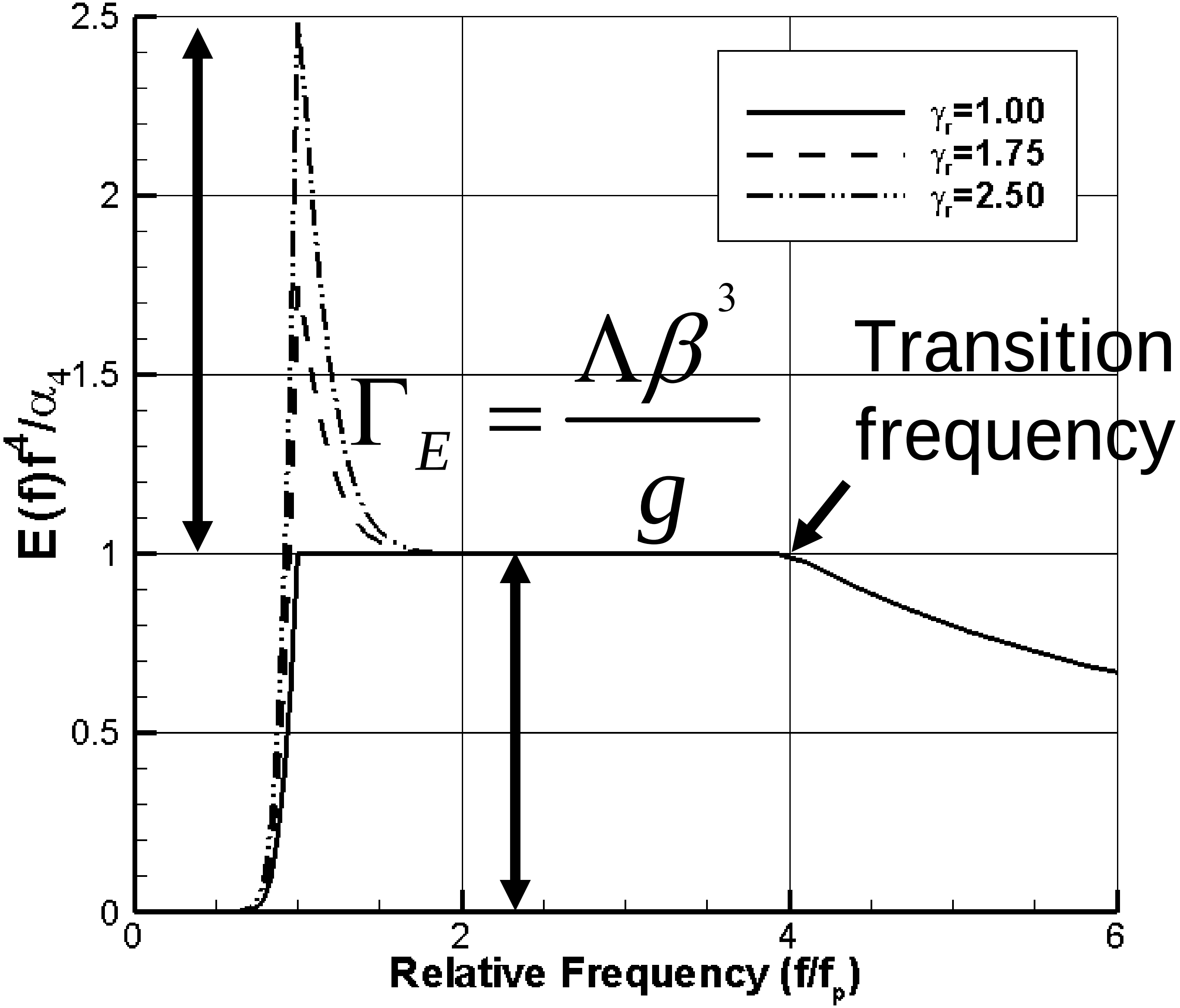


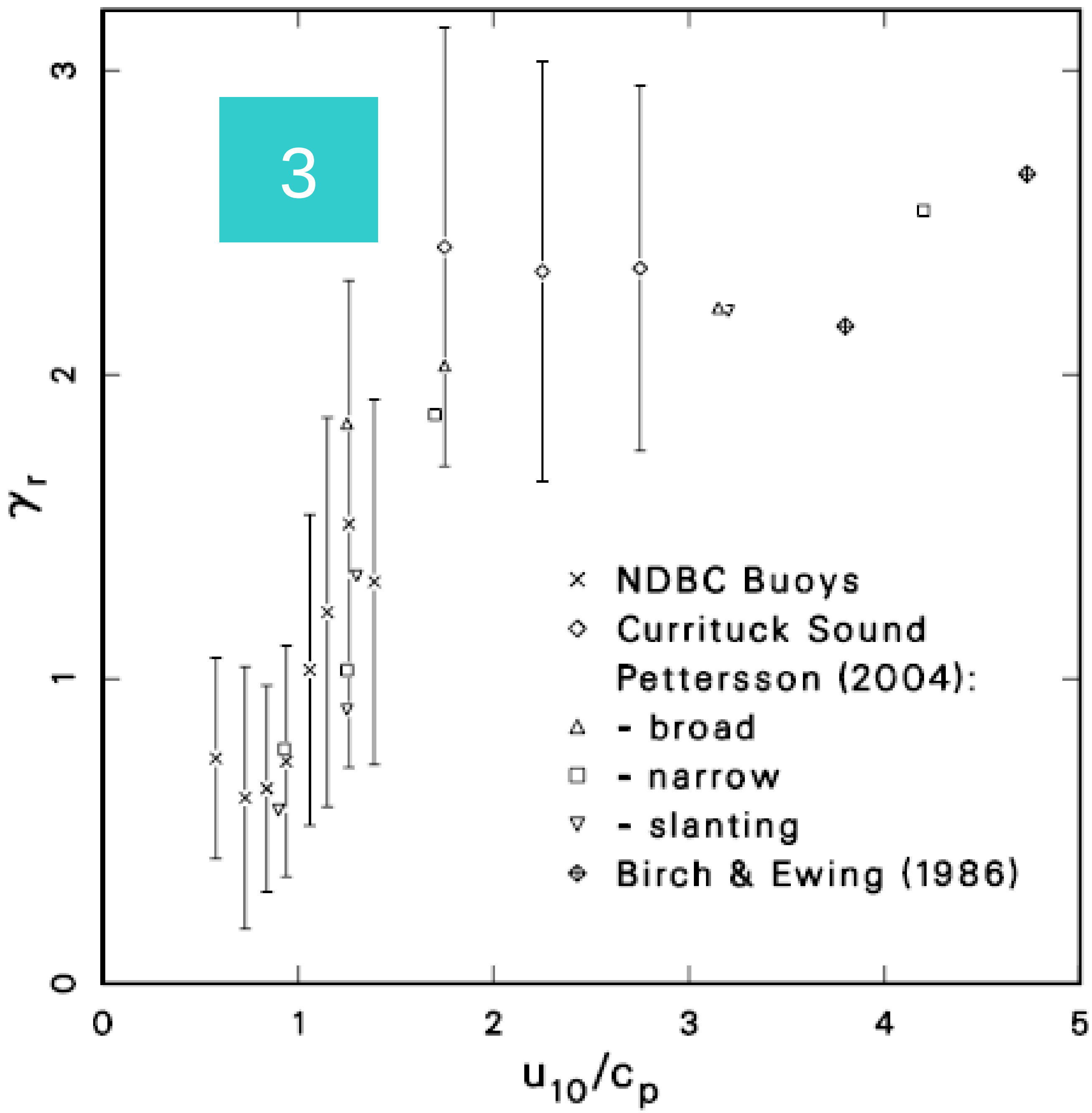

Resio, Long & Vincent (2004)

$$F(k) \,\square\, (u^2 c_p)^{1/3} k^{-5/2}$$

But what About the Peakedness?

# Peakedness is now based on $f^{-4}$ form!





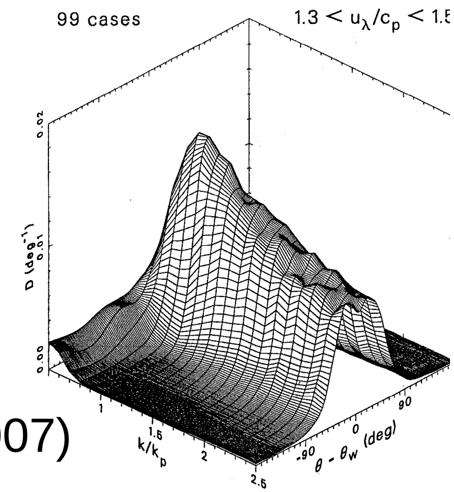

Peakedness is well behaved.

But we need to move beyond Directionally Integrated Spectra.....

**Characteristics of directional distributions of energy:**

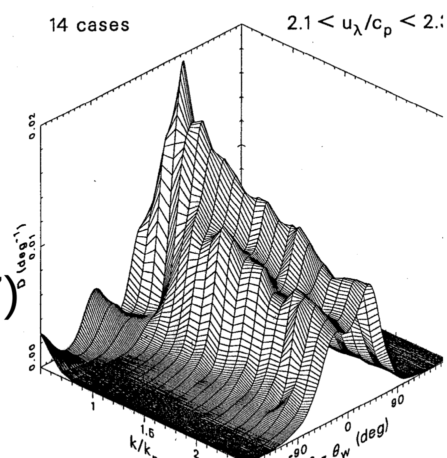
1. **“Young” waves are very bimodal**
2. **“Old” waves approach unimodal**
3. **Both distributions are similar to Hasselmann et al. (1980)**

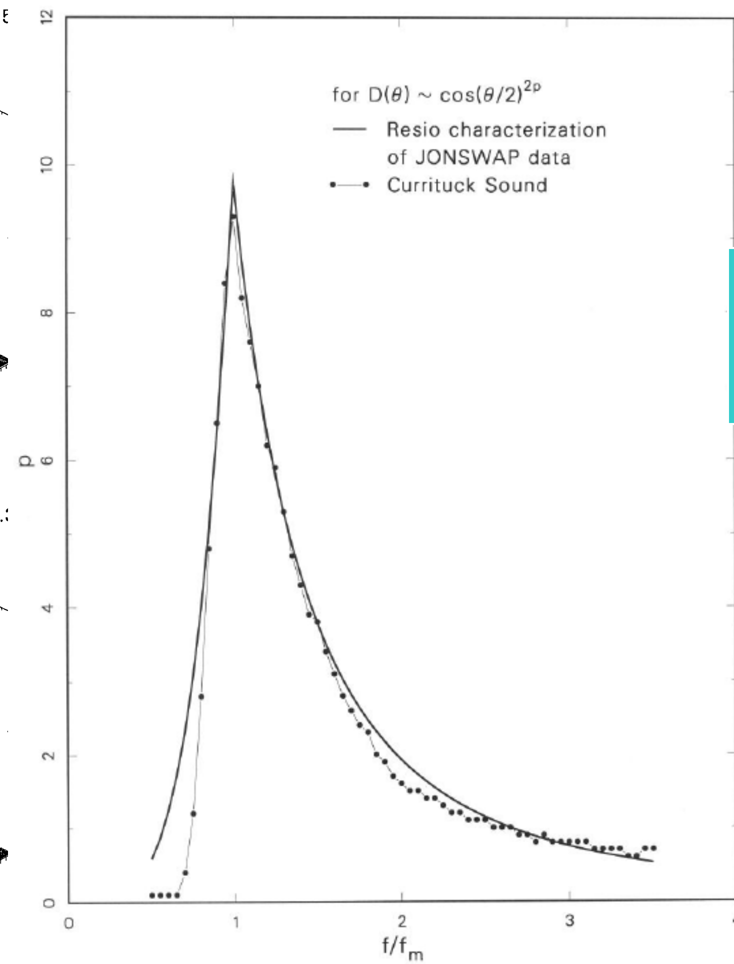
Low inverse wave age (old waves) (Long and Resio, 2007)




Directional form:

High inverse wave age (young waves) (Long and Resio, 2007)




4

**Directional Distribution depends on peakedness….**

Variation in “n” obtained when fitting a $\cos^{2n}$ function compared to the data from Hasselmann *et al* (1980)

5 **TBD**

Resio and Vincent : 1877

The relative importance of the nonlinear source behavior to the quasi-linear terms strongly affects the fetch-time equivalence in models

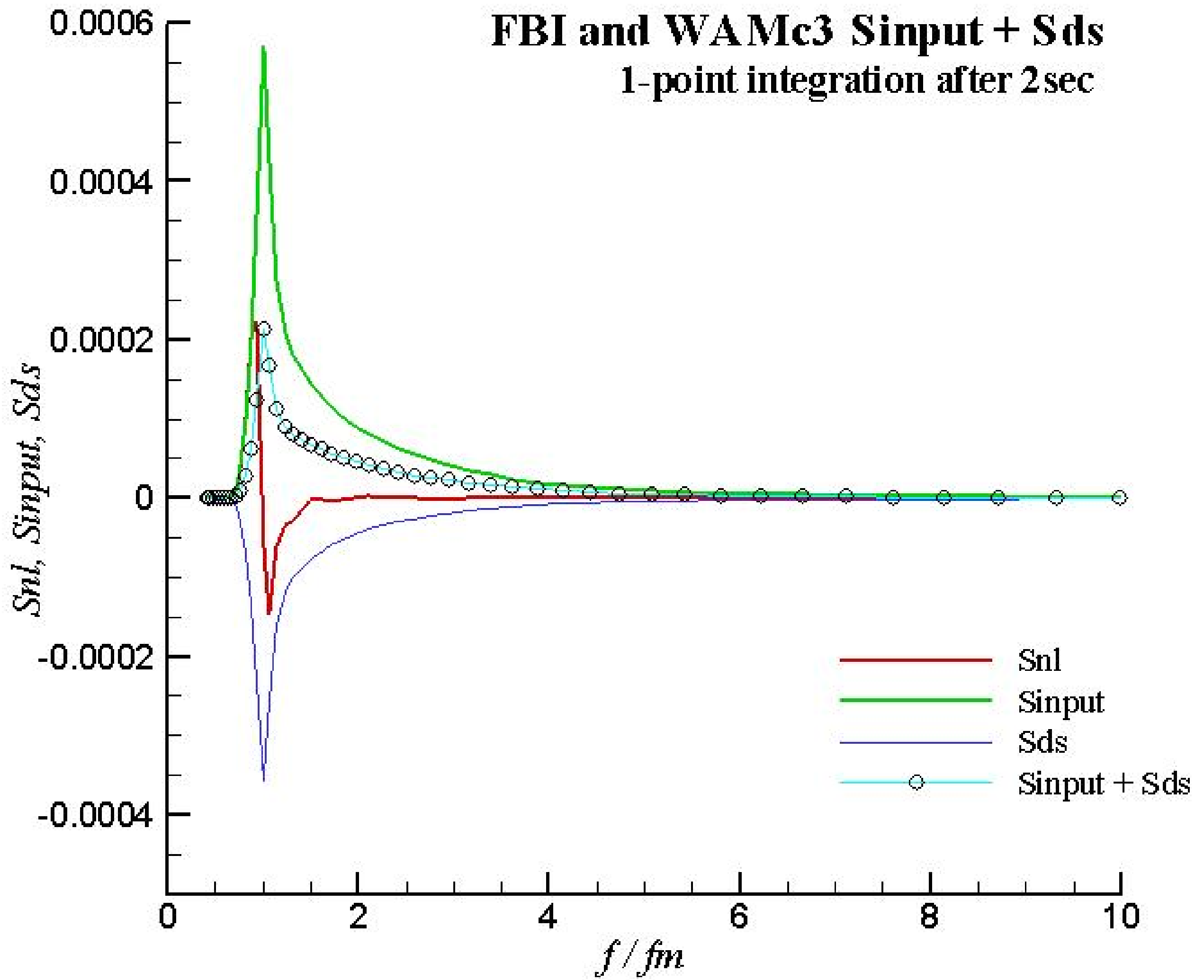



**Figure 1. Magnitudes of source terms in the WaveWatch III version of WAM cycle 3 physics for initial spectrum with peakedness of 2, and the equilibrium range energy and shape consistent with class-averaged Currituck Sound data.**

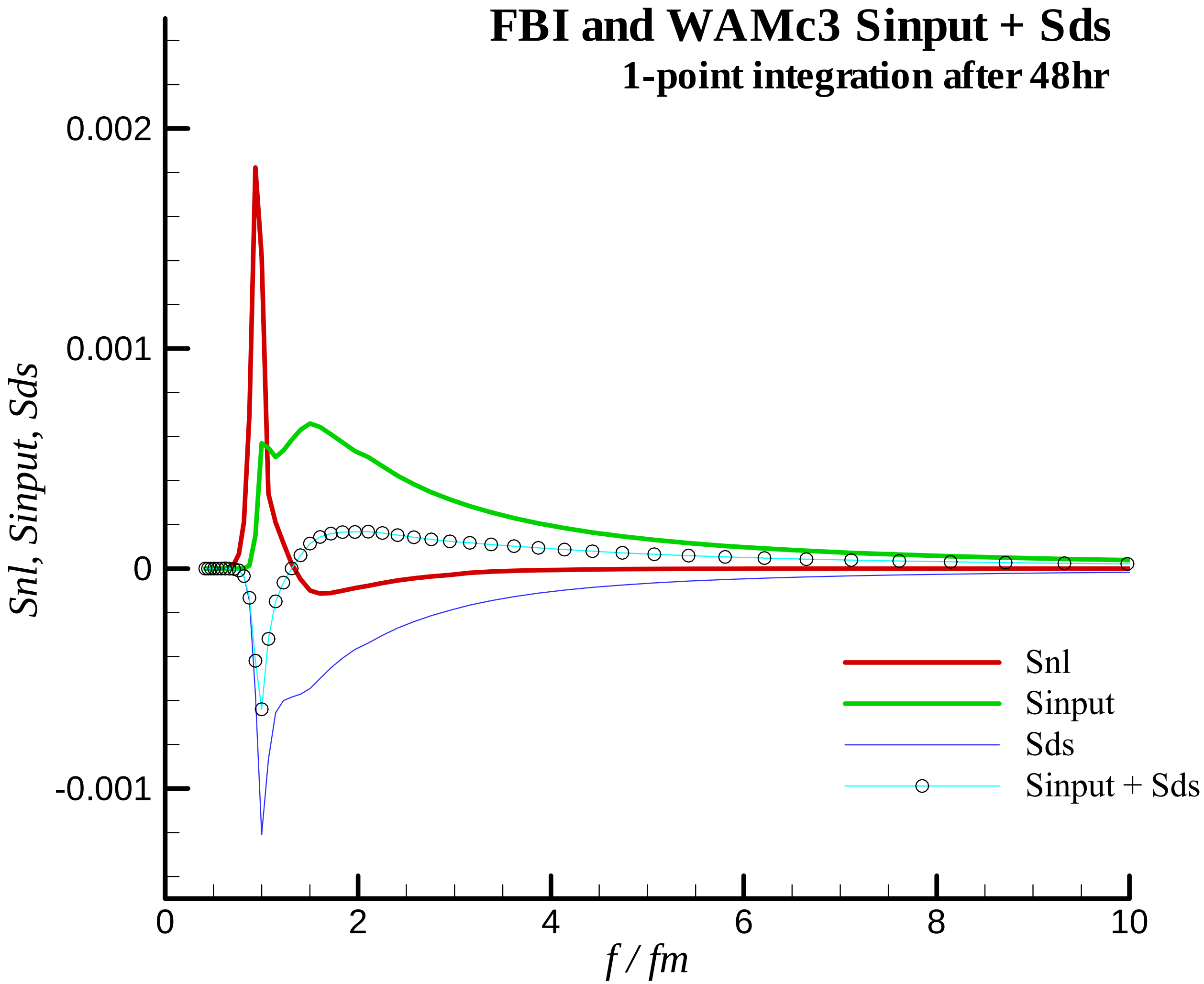
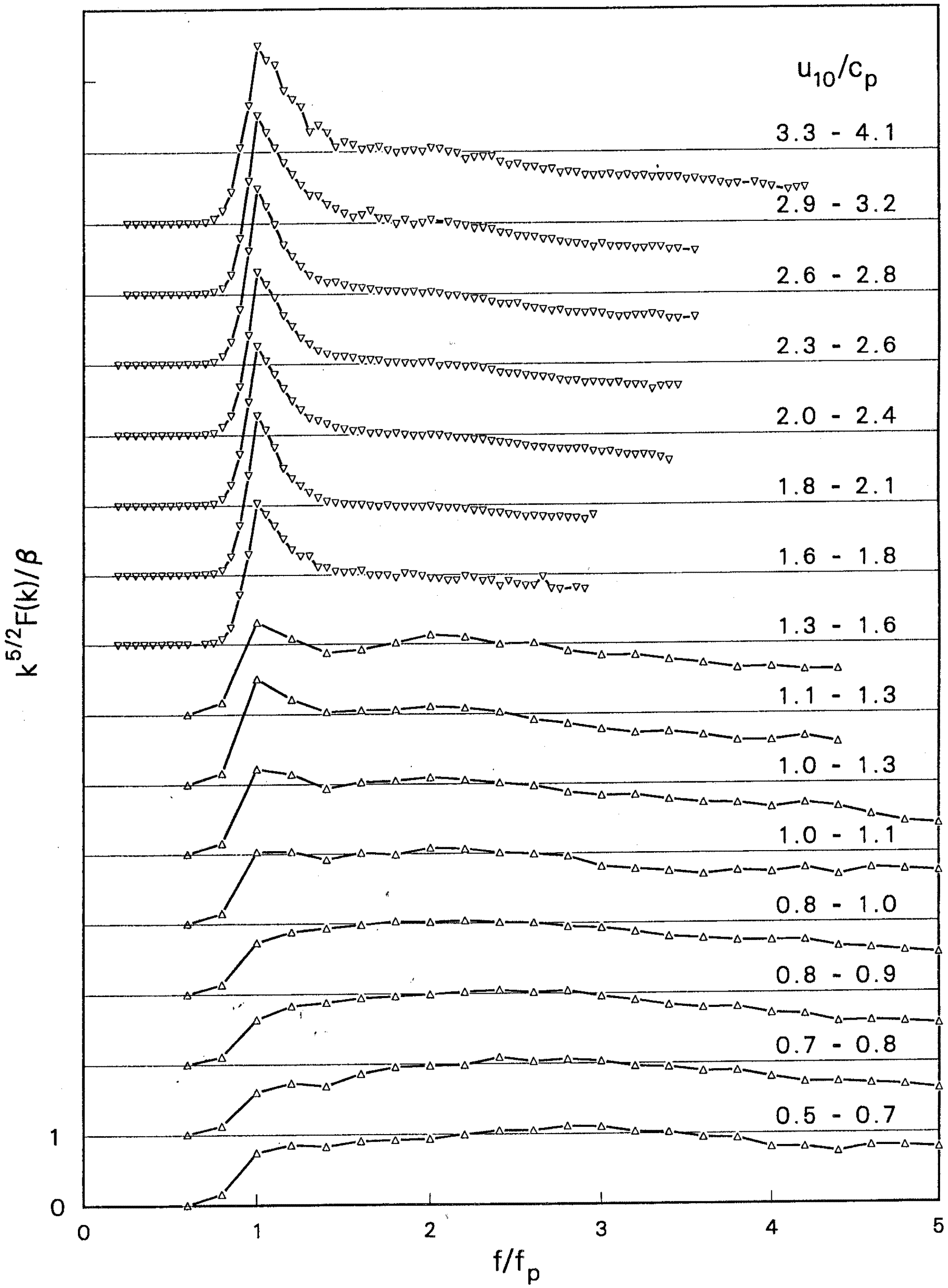
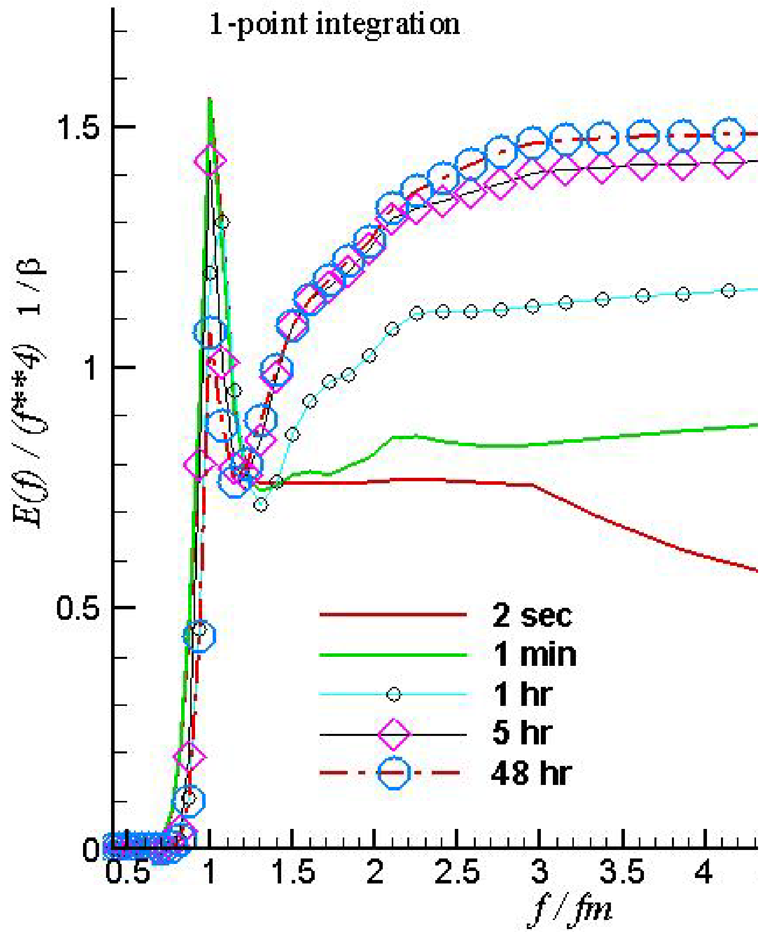



Figure 4. Magnitudes of source terms in the WaveWatch II version of WAM cycle 3 physics after 48 hours of simulation time.



$u_{10}/c_p$
3.3 - 4.1
2.9 - 3.2
2.6 - 2.8
2.3 - 2.6
2.0 - 2.4
1.8 - 2.1
1.6 - 1.8
1.3 - 1.6
1.1 - 1.3
1.0 - 1.3
1.0 - 1.1
0.8 - 1.0
0.8 - 0.9
0.7 - 0.8
0.5 - 0.7
$k^{5/2}F(k)/\beta$
$f/f_p$

1-point integration
E(f) / (f**4) 1/β
f / fm
2 sec
1 min
1 hr
5 hr
48 hr

# Dissipation Source Term

- Spectra consistently transition from equilibrium range to an $f^{-5}$ form at high frequency in all data sets
- Transition location is consistent with a balance between nonlinear fluxes and high-frequency dissipation
- Kinematic constraints suggest little or no breaking in the spectral peak region
- High-frequency breaking primarily due to "squeezing" of intermediate frequencies (Irisov and Voronovich, 2011)

# Wind Input Term

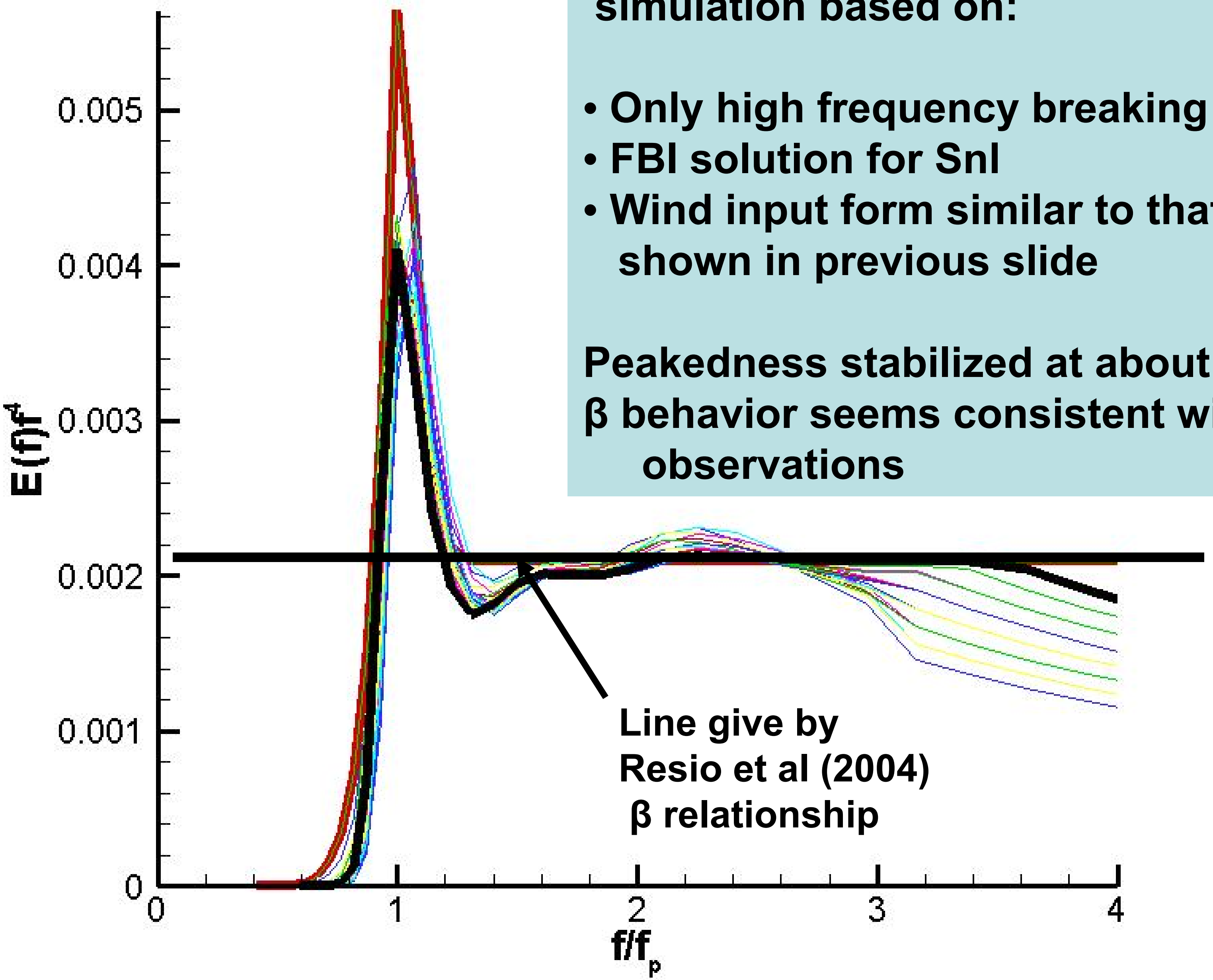
- **Based on effects of integrated surface not spectral components**
- **Input is much narrower in frequency and direction**
- **Input produces bimodal ranging to unimodal directional distribution**

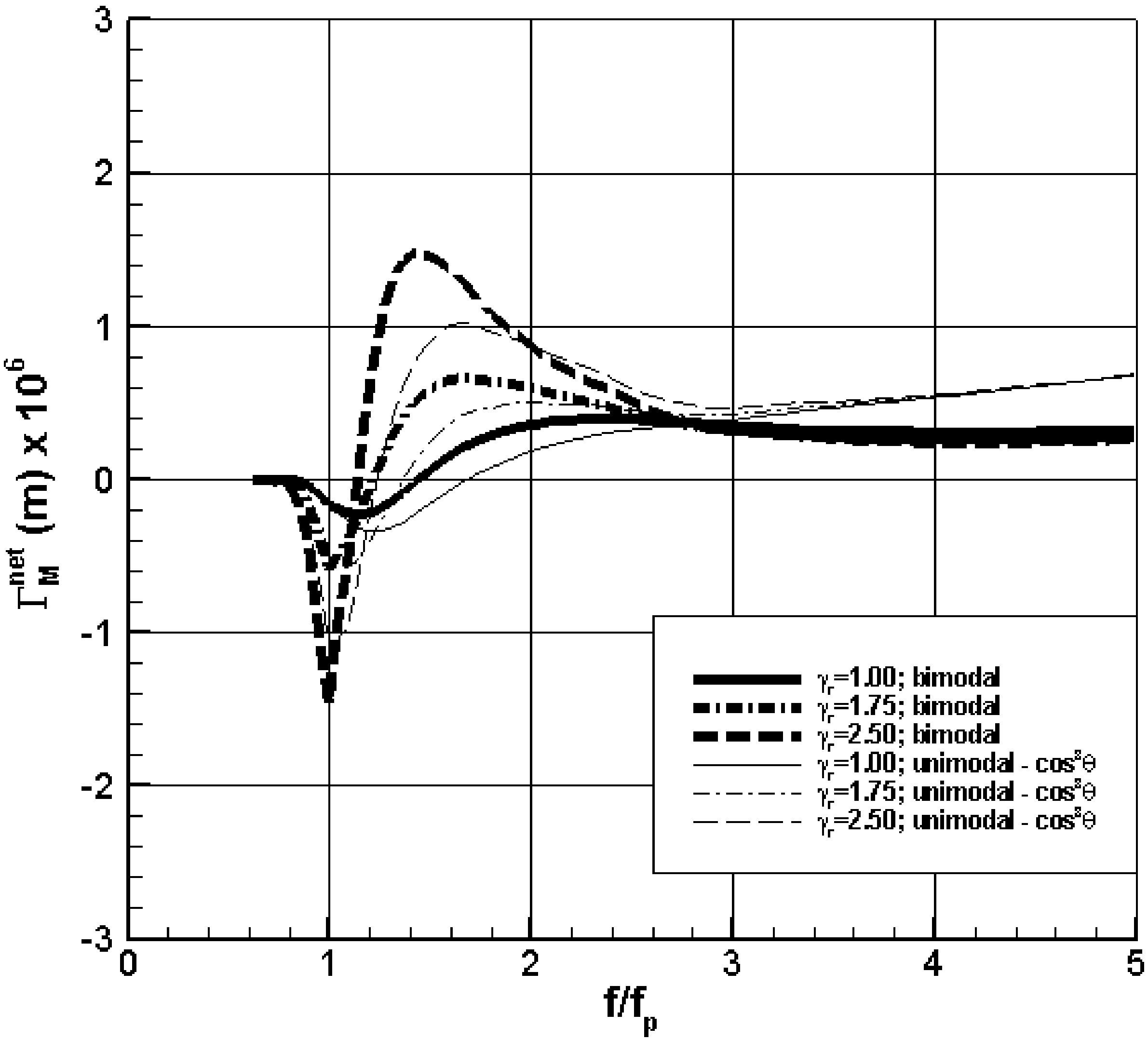
**Compensated spectra from simulation based on:**

- **Only high frequency breaking**
- **FBI solution for Snl**
- **Wind input form similar to that shown in previous slide**

**Peakedness stabilized at about 2**

**β behavior seems consistent with observations**

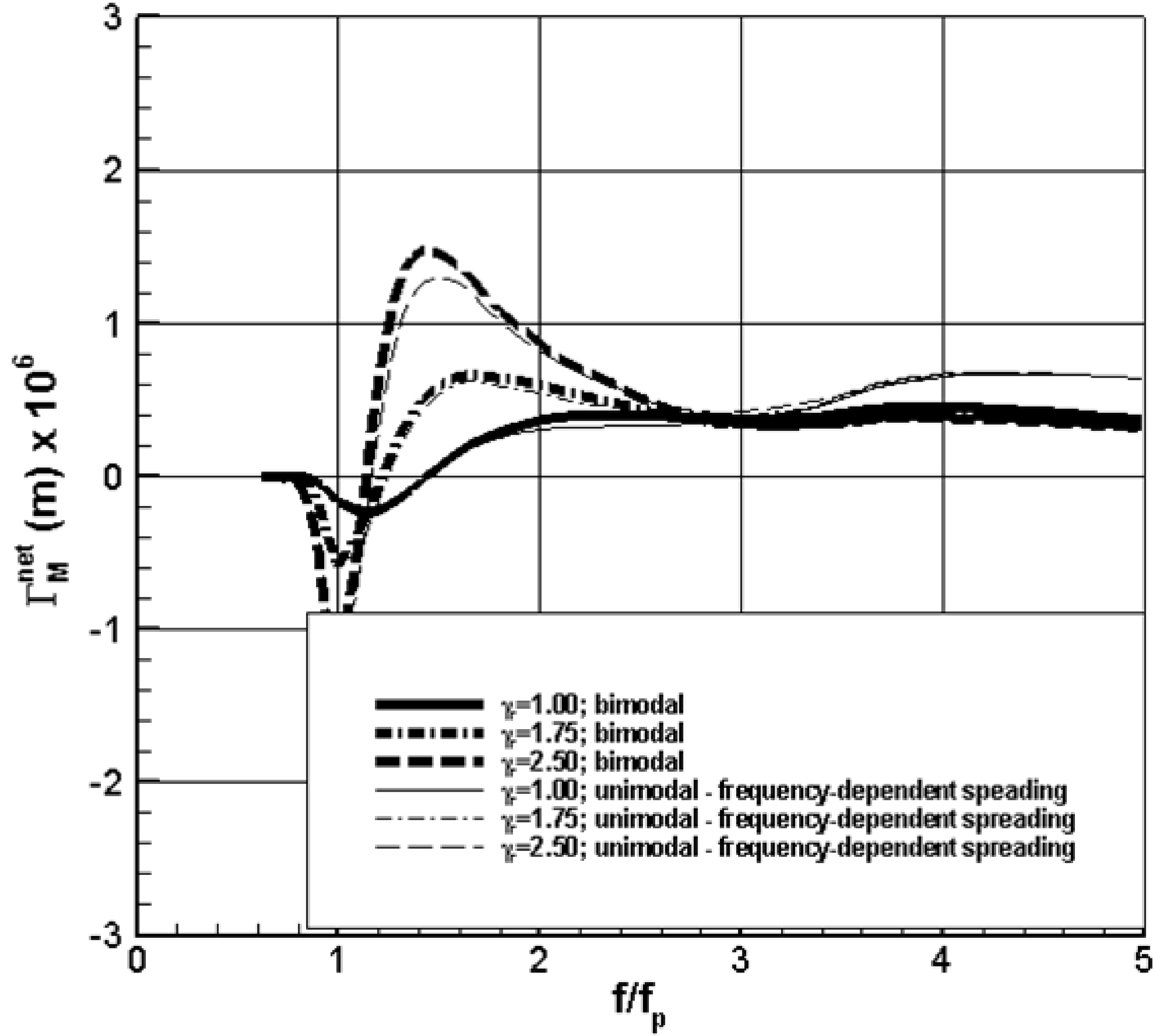





Resio et al. 2011, JPO

No transition to $f^{-5}$

This new source term helps us develop a quasi-stationary directional form – with no divergence in Snl fluxes




**Typical momentum fluxes for constant angular spreading – transition frequency 4fp**

QUESTIONS??????