Impact of nonlinear energy transfer on the wave field

Tamura et al. (2010): JGR -Oceans

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Motivations

The 3rd generation wave model

resonant interaction

$$\frac{\partial F}{\partial t} + c_g \nabla F = \underbrace{S_{in} + S_{ds}}_{\text{external source: } Sf} + S_{nl}$$

Snl controls the evolution of wave spectra

1. To understand whether accurate ***Snl*** scheme improve the model representation of wave parameters and spectral shapes.
2. To investigate the role of ***Snl*** in the source balance in conjunction with the parameterization of the external source ***Sf***.

Methodologies

Snl schemes:

DIA:	Hasselmann et al. (1985)
TSA:	Resio and Perrie (2008)
Multiple DIA or XDIA:	Van Vledder (2001), Tolman (2004)….
SRIAM method:	Komatsu (1996), Tamura et al. (2008)
RIAM:	Komatsu and Masuda (1996)
WRT:	Van Vledder (2006)
Masuda method:	Masuda (1980)
…	

Pacific hindcast experiments:

WAVEWATCH-III v2.22 (Tolman, 2002)

Wind input & Dissipation : Tolman & Chalikov (1996)

Validation:

NOAA/NDBC buoys –Hs, Tp, Freq. spectra-

(46035, 46066, 46005, 46006, 46089, 51001, 51004, 51028)

Conclusions

- A negligible difference between SRIAM and DIA for Hs. However, the difference for the Tp was quite pronounced, especially around the tropical Pacific, where a persistent bias in Tp was improved by using SRIAM.
- SRIAM can quantitatively capture the overshoot phenomena around the spectral peak during wave growth.
- Snl played a major role in maintaining the equilibrium range; it reacted to changes in the net external sources to cancel out the total source term.
- The magnitude of external source controls the spectral tail exponent in the equilibrium range so as to support Resio et al. (2004).

Numerical treatment of the nonlinear transfer function

SRIAM method: Komatsu (1996), Tamura et al. (2008)

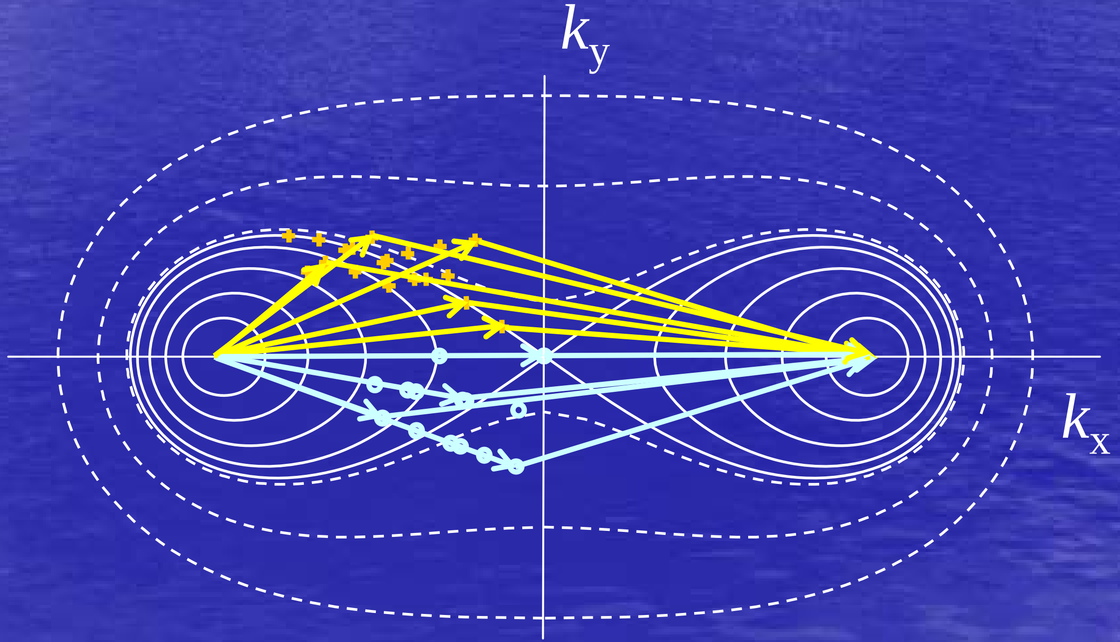
an efficient scheme for operational use

DIA	: 1 resonant configuration
SRIAM	: 20 resonant configurations
Exact method	: 10^3 to 10^4 resonant configurations

Resonance condition

$$\boldsymbol{k}_1 + \boldsymbol{k}_2 = \boldsymbol{k}_3 + \boldsymbol{k}_4$$

$$\sigma_1 + \sigma_2 = \sigma_3 + \sigma_4$$



20 optimized resonant configurations

2004 hindcast experiments
Model configuration

Third-generation wind-wave model

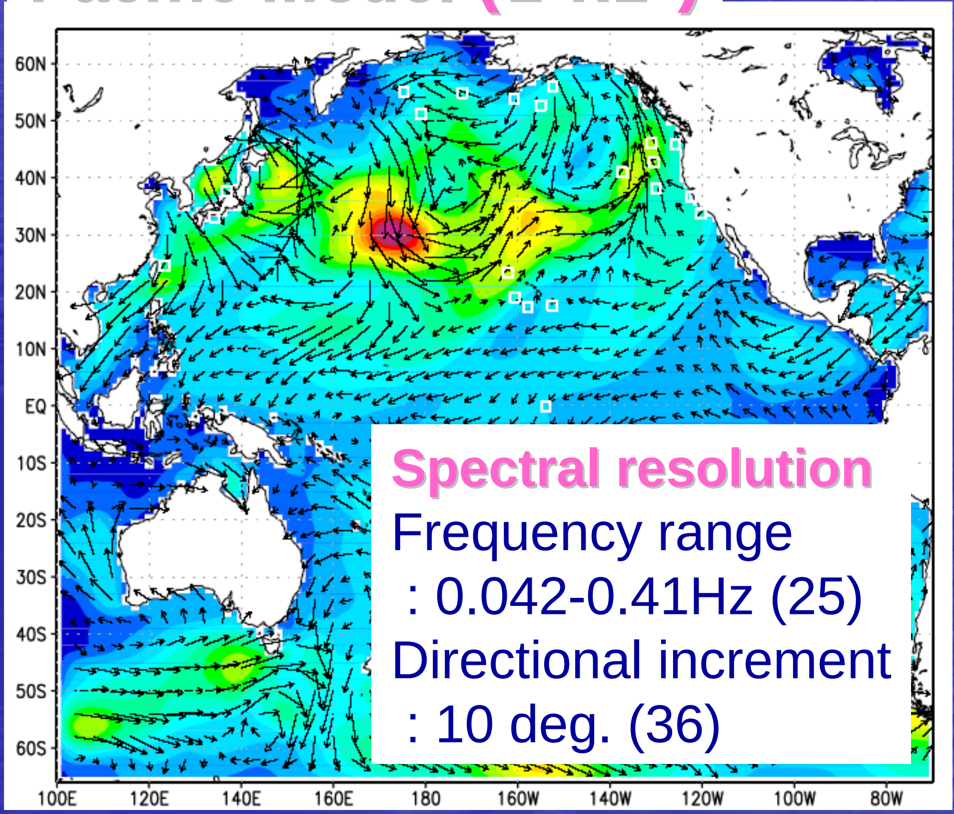
<u>WAVEWATCH-III v2.22 (Tolman, 2002)</u>

Wind input & Dissipation
: Tolman & Chalikov (1996)
Nonlinear transfer function
: SRIAM method

non-parametric spectral tail

Surface wind field:
NCEP/NCAR Reanalysis

Pacific model (1^ox1^o)

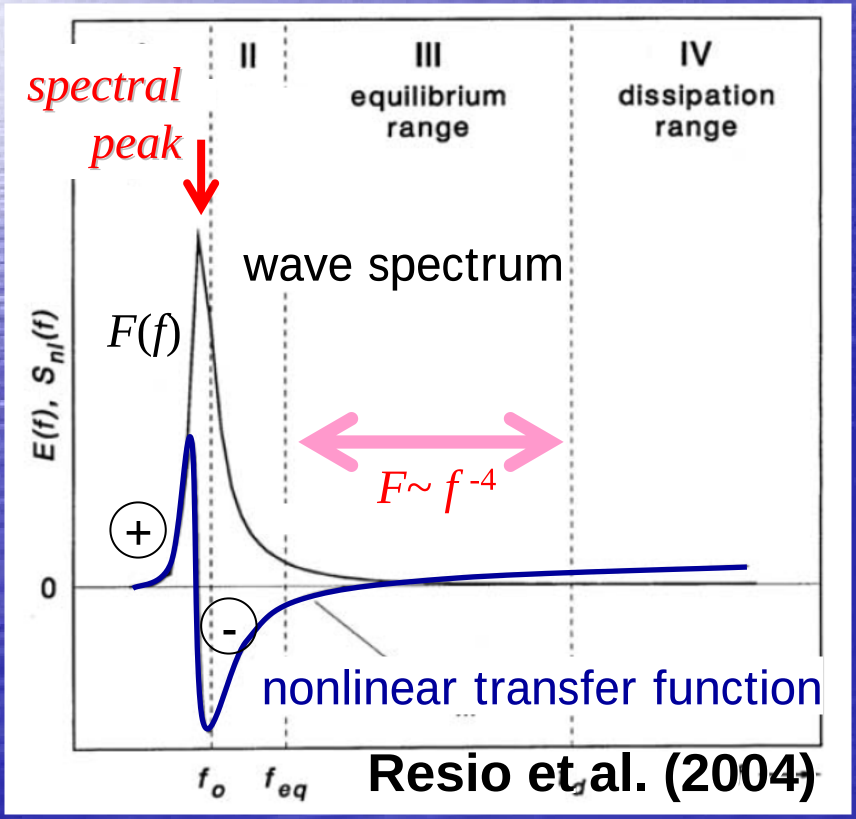


Spectral resolution
Frequency range
: 0.042-0.41Hz (25)
Directional increment
: 10 deg. (36)

Evolution of wave spectra in the equilibrium range

$$\frac{\partial F}{\partial t} = S_{in} + S_{nl} + S_{ds} \approx 0$$

To maintain the equilibrium range, the sum of the three source terms should be zero within the equilibrium range



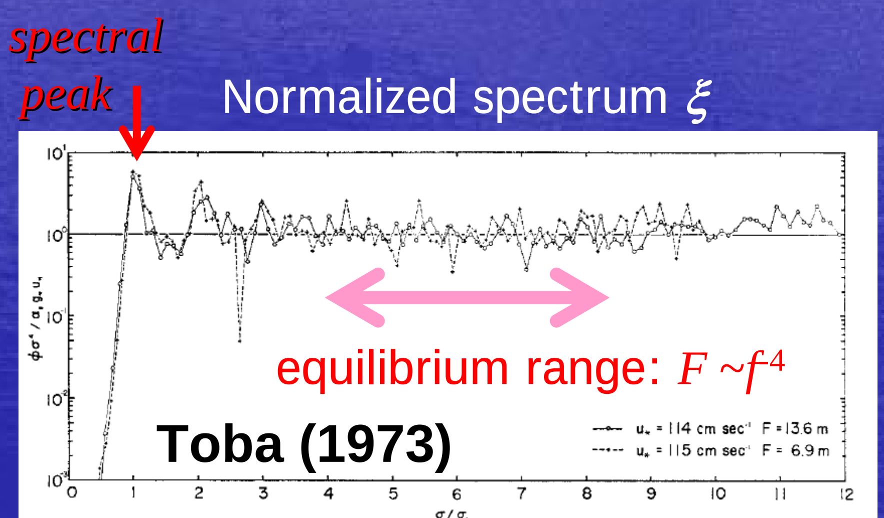


Fig. 3. Two examples showing the deviation of the actual spectra from the gross form expressed by Equation (2.24).

$$\xi = \frac{F(f)\,f^4}{\alpha \cdot u_* g}$$

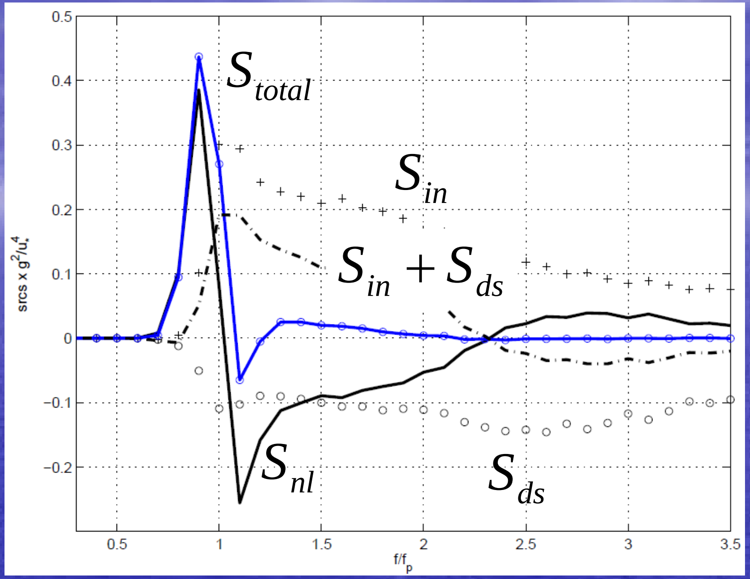
Wave spectral shape and source balance

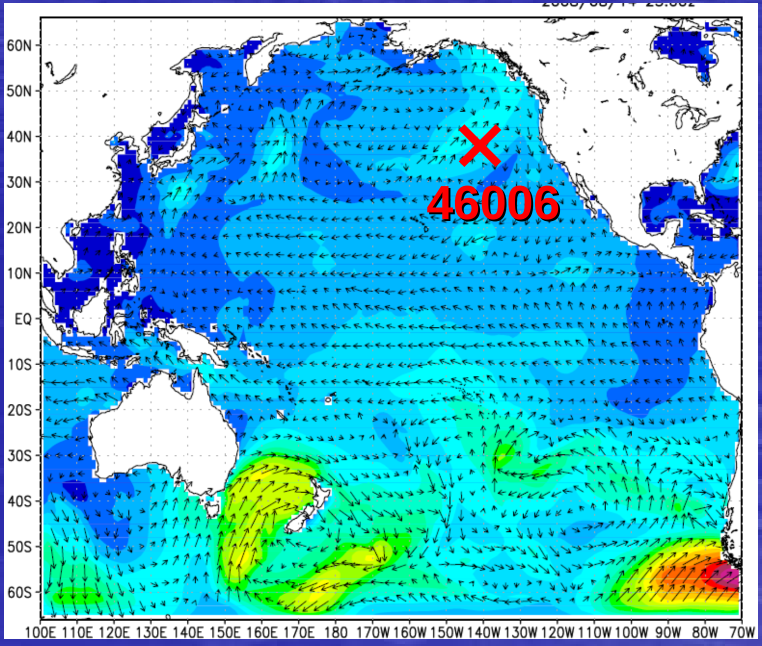
S_{in} :Tolman & Chalikov (1996)

$$S_{ds} = S_{ds}^{low} + \beta \cdot S_{ds}^{high}$$

β = 0, 0.25, 0.5, 0.6, 0.75, 1

S_{nl} : SRIAM Komatsu (1996)

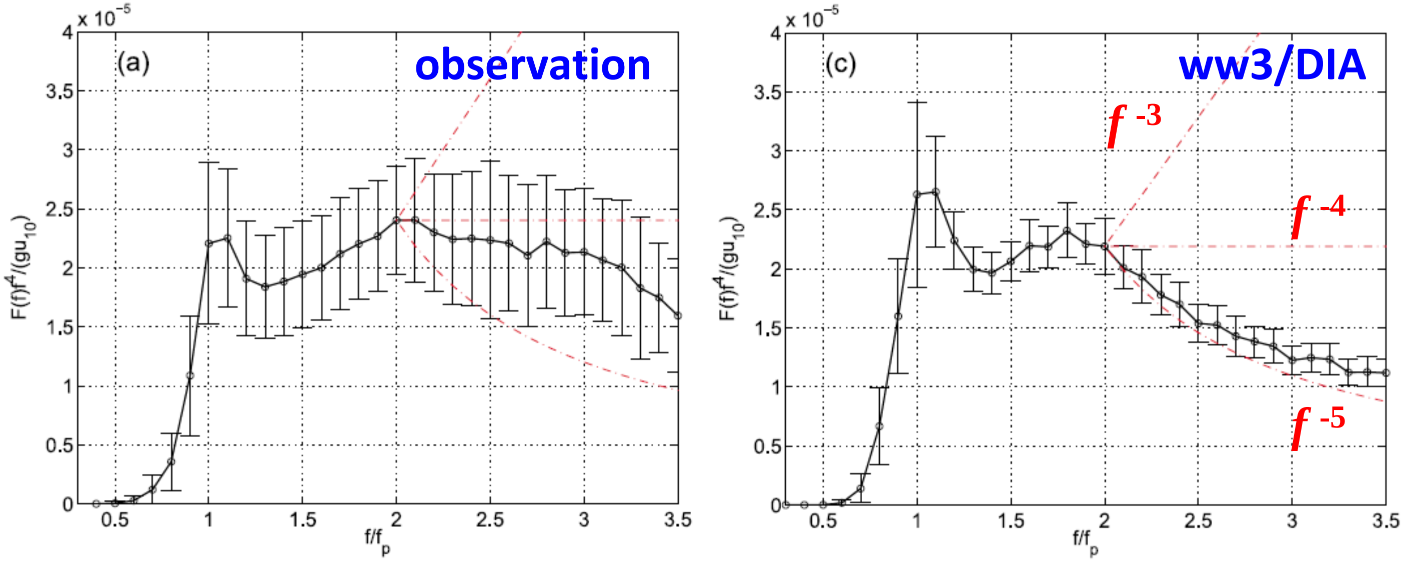


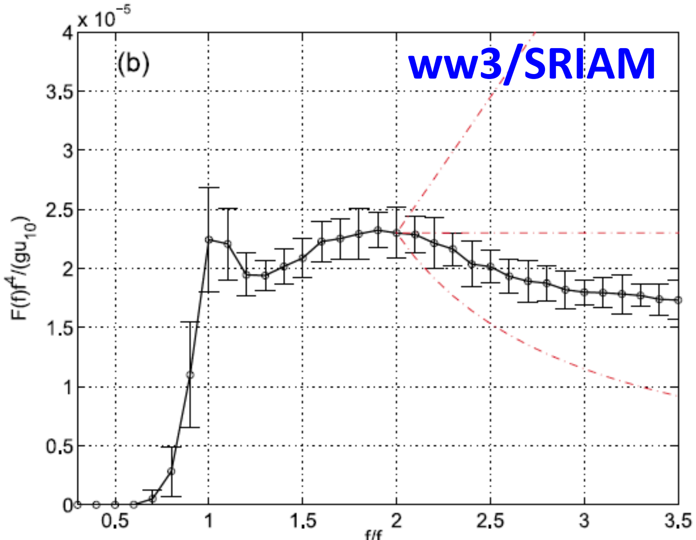


Wave spectra investigated

1. single peak
2. for growing sea state ($U_{10}/c_p>1$)

Mean wave spectra @46006





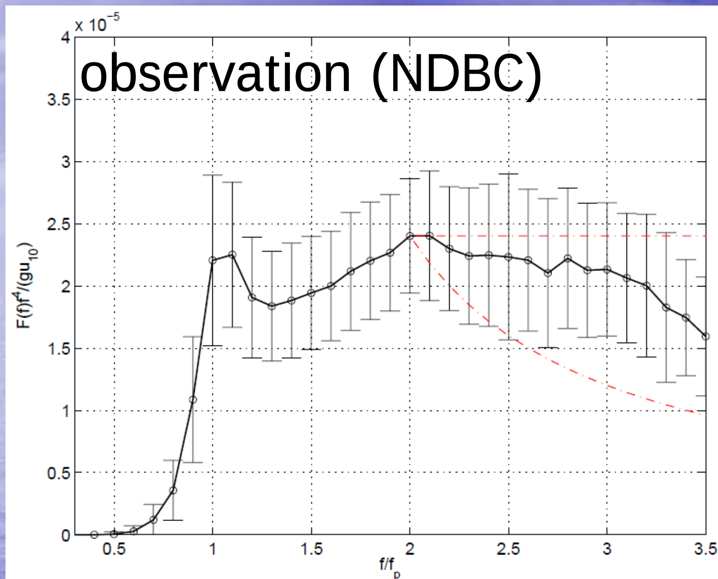
Saturation spectrum:

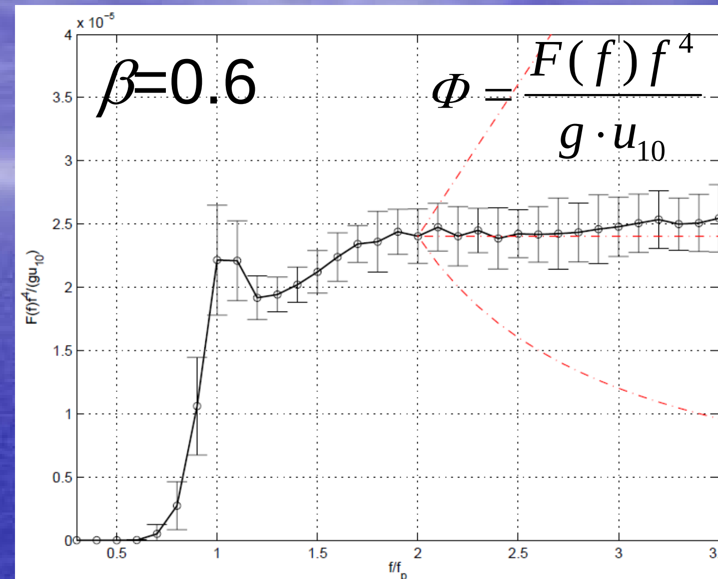
$$\Phi(f/f_p) = F(f)f^4/gu_{10}$$

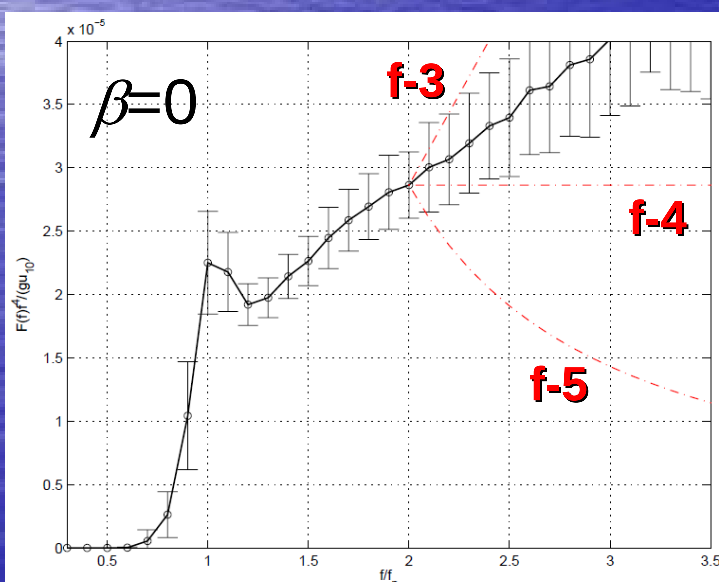
where $u_{10}/c_p > 1$

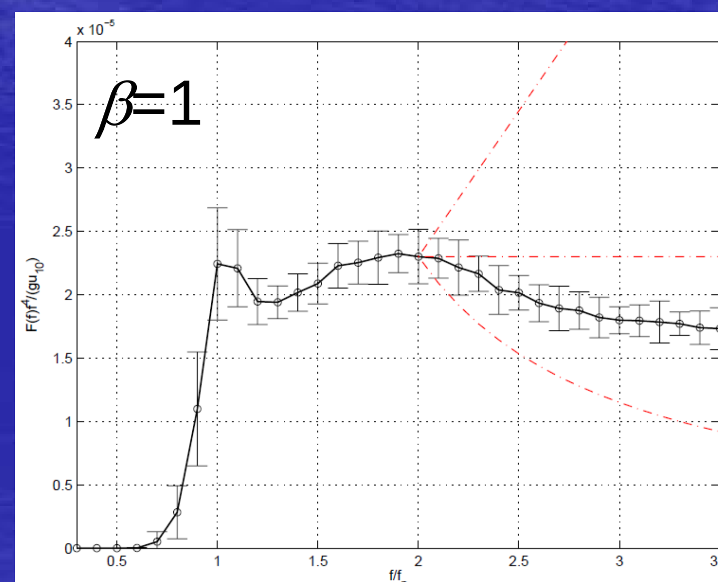
β=1

Wave spectrum in the equilibrium range





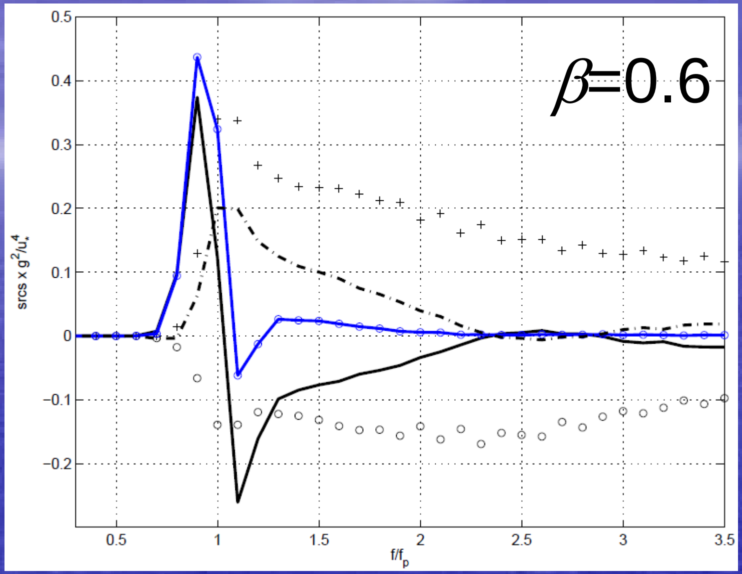


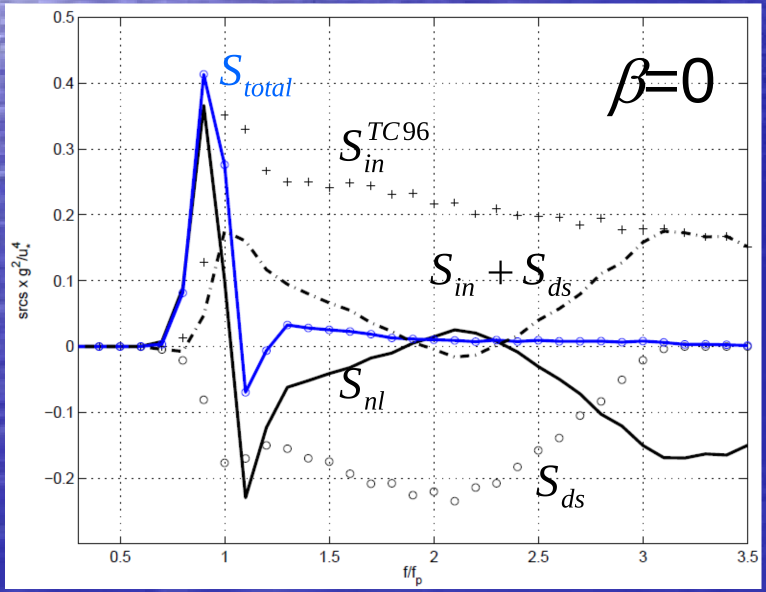


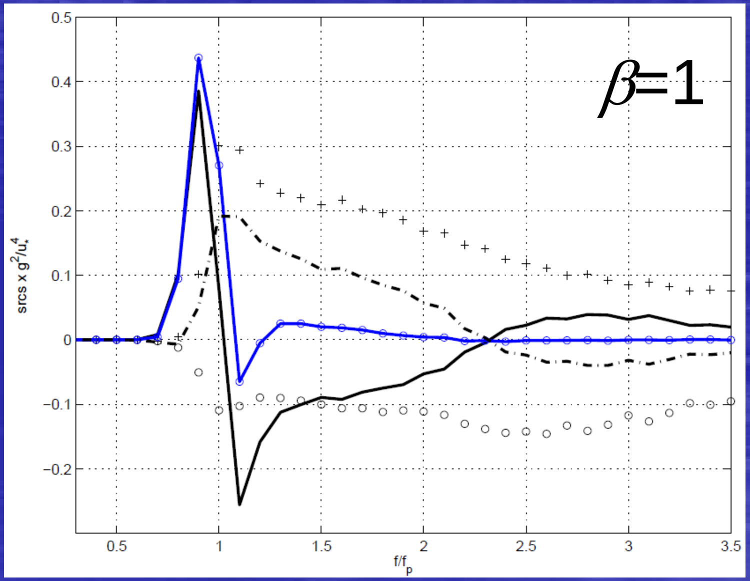
Source terms and their balance

$$S_{total} = S_{in}^{TC96} + S_{nl}^{SRIAM} + S_{ds}^{low} + \beta \cdot S_{ds}^{high}$$

normalized by $S^* = S \cdot g^2 u_*^{-4}$







Wave spectrum in the equilibrium range

Resio et al. (2004)

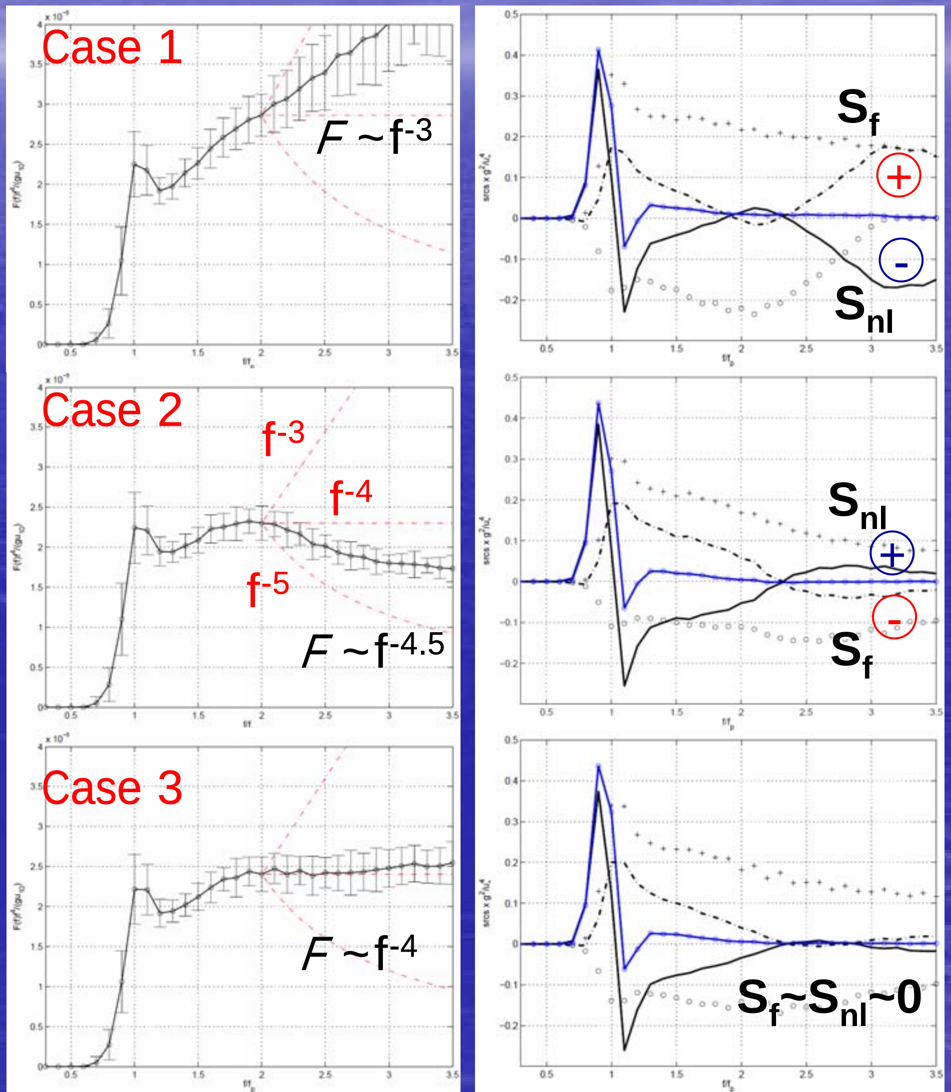
$$\int_{feq}^{f} \frac{\partial \xi^3}{\partial f} df = \xi^3(f) - \xi^3(f_{eq}) \sim \int_{feq}^{f} [S_{in} + S_{ds}] df$$

Any net gain or loss of energy within the equilibrium range would tend to force the spectrum away from an f^{-4} shape

Case 1
For a net gain (Sin>Sds) and significant Snl, the equilibrium spectrum would have to fall off less steeply than f^{-4}

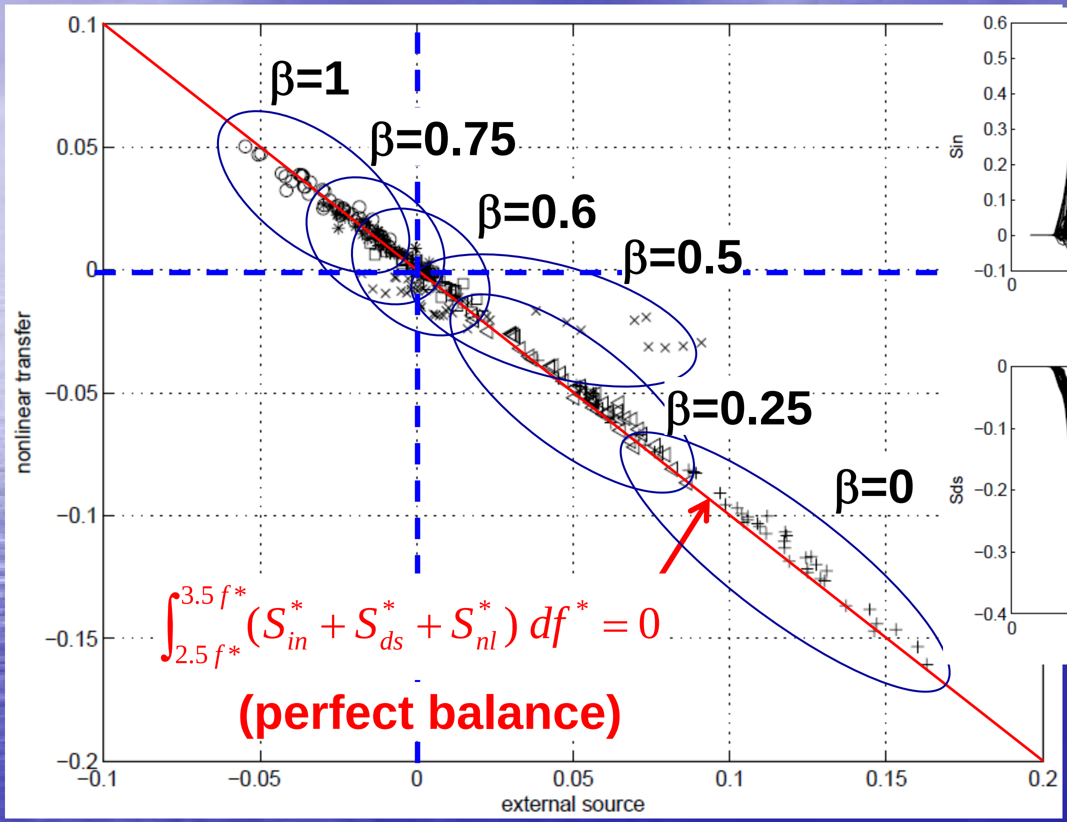
Case 2
For a net loss (Sin<Sds) and significant Snl, the equilibrium spectrum would have to fall off more steeply than f^{-4}

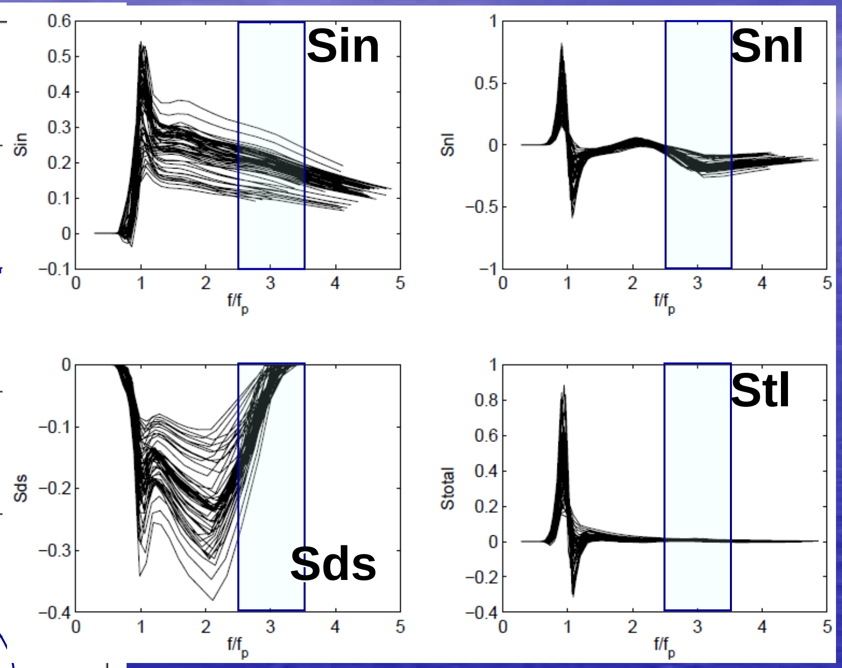
Case 3
If the net effect is negligible (Sin+Sds~0) within the equilibrium range, spectrum should be f^{-4} shape.



Intensity of the external source term and the Snl

$$\int_{2.5f^*}^{3.5f^*} S_{nl}^* \, df^*$$





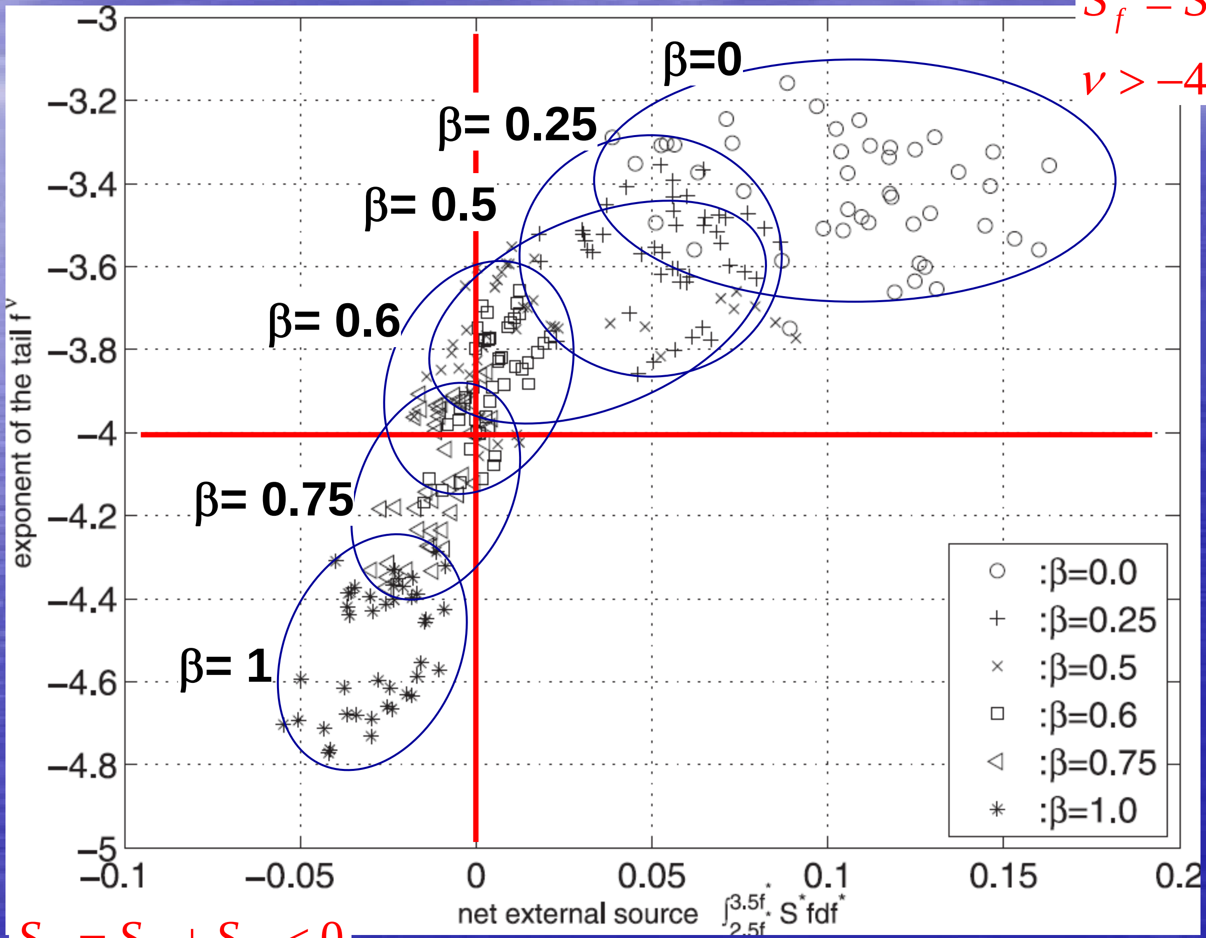
$$\int_{2.5f^*}^{3.5f^*} (S_{in}^* + S_{ds}^*) df^*$$

The total source term approached zero during the wave evolution whatever external source Sf is used.

External source term and the exponent of the spectral tail

$$S_f = S_{in} + S_{ds} > 0$$
$$\nu > -4$$

Estimated exponent of the tail $f^{-\nu}$



$$S_f = S_{in} + S_{ds} < 0$$
$$\nu < -4$$

$$\int_{2.5 f^*}^{3.5 f^*} (S_{in}^* + S_{ds}^*) df^*$$

Summary and discussions

Equilibrium condition: $Sin + Sds + Snl \approx 0$

Kitaigorodskii (1983)

$$Sin \sim Sds \sim Snl \sim 0$$

Phillips (1985)

$$Sin \sim Sds \sim Snl$$

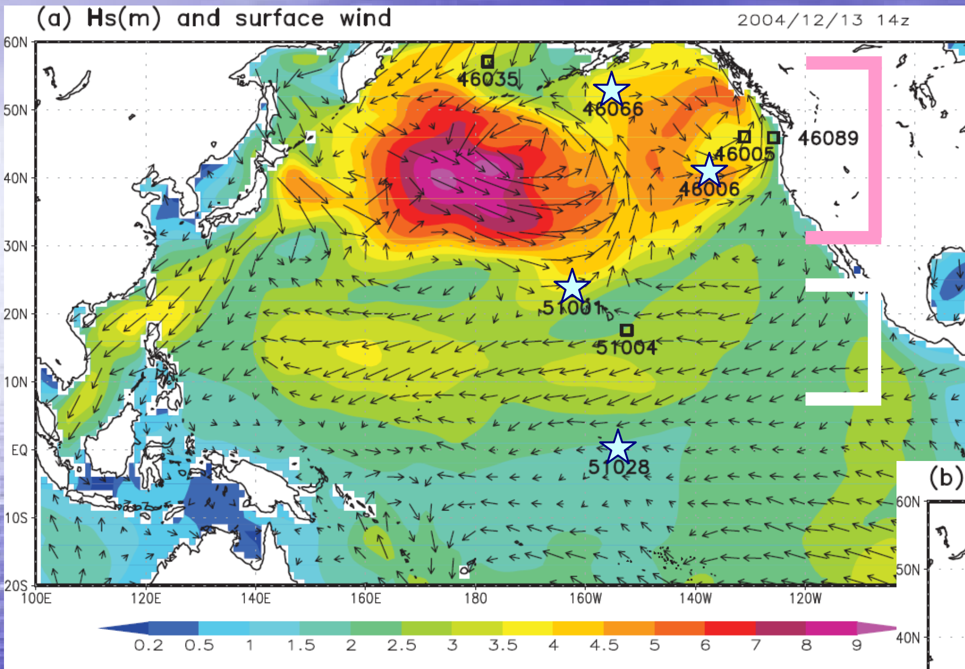
Komen et al. (1984)

$$\text{``}Sds\text{''} = -Sin - Snl$$

The sum of the three source terms approaches zero largely as a result of ***Snl*** adjustment. However, the exponent of the spectral tail was also quite sensitive to ***Sf***, in agreement with Resio et al (2004). The net external source ***Sf*** is the key factor that reproduces the f^{-4} tail.

Typical snapshot of Hs and Tp in the North Pacific

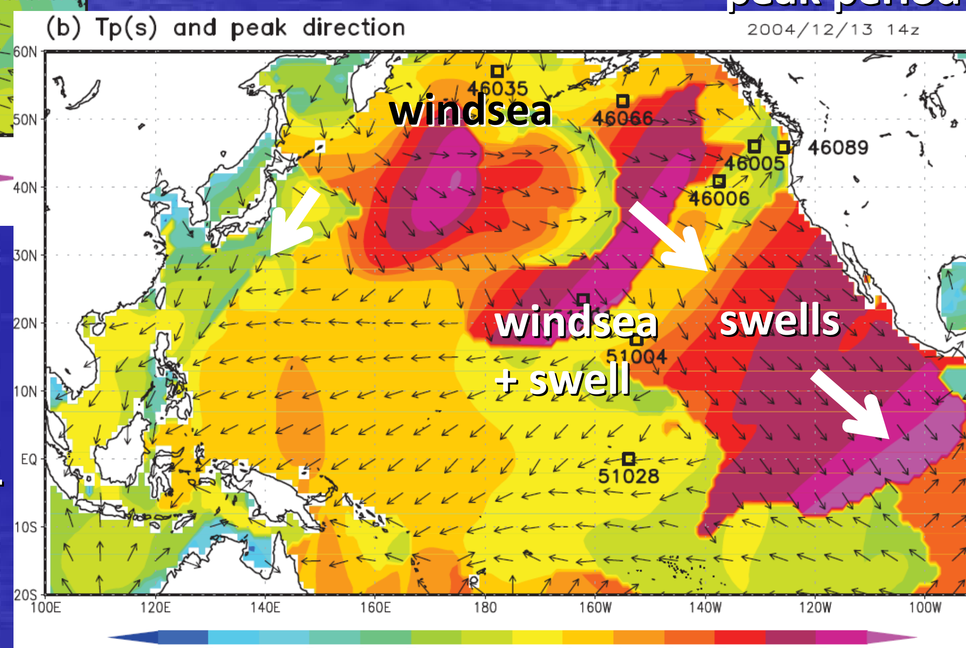
significant wave height



Enormous quantities of wind energy are transferred to surface waves in the mid-latitudes (associated with storm track)

Trade winds constantly generate local windsea in low latitudes

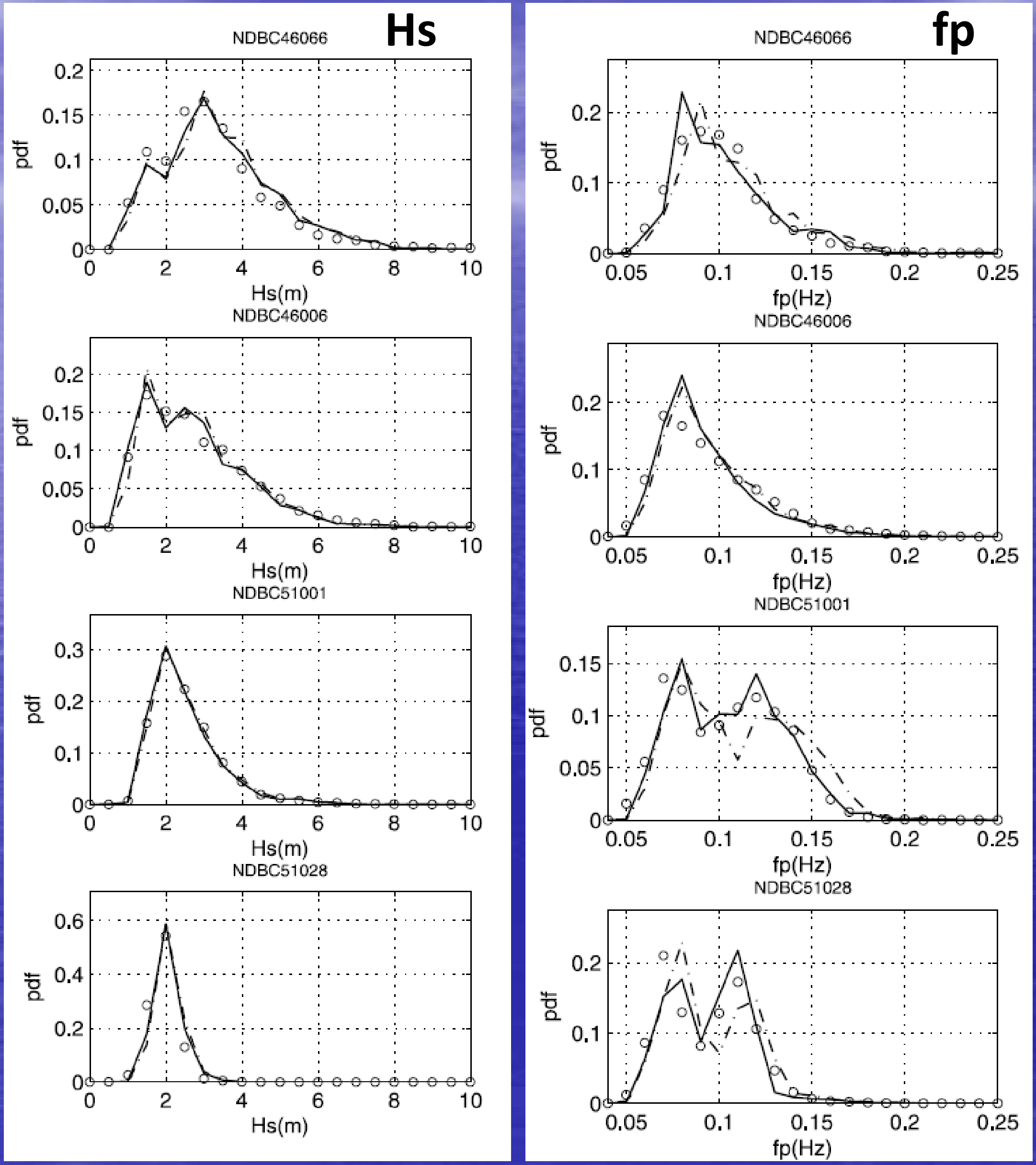
peak period



Ocean waves generated in the mid-lat. propagate to lower lat. as swells

The probability density functions of Hs and fp

Higher latitude



Lower latitude

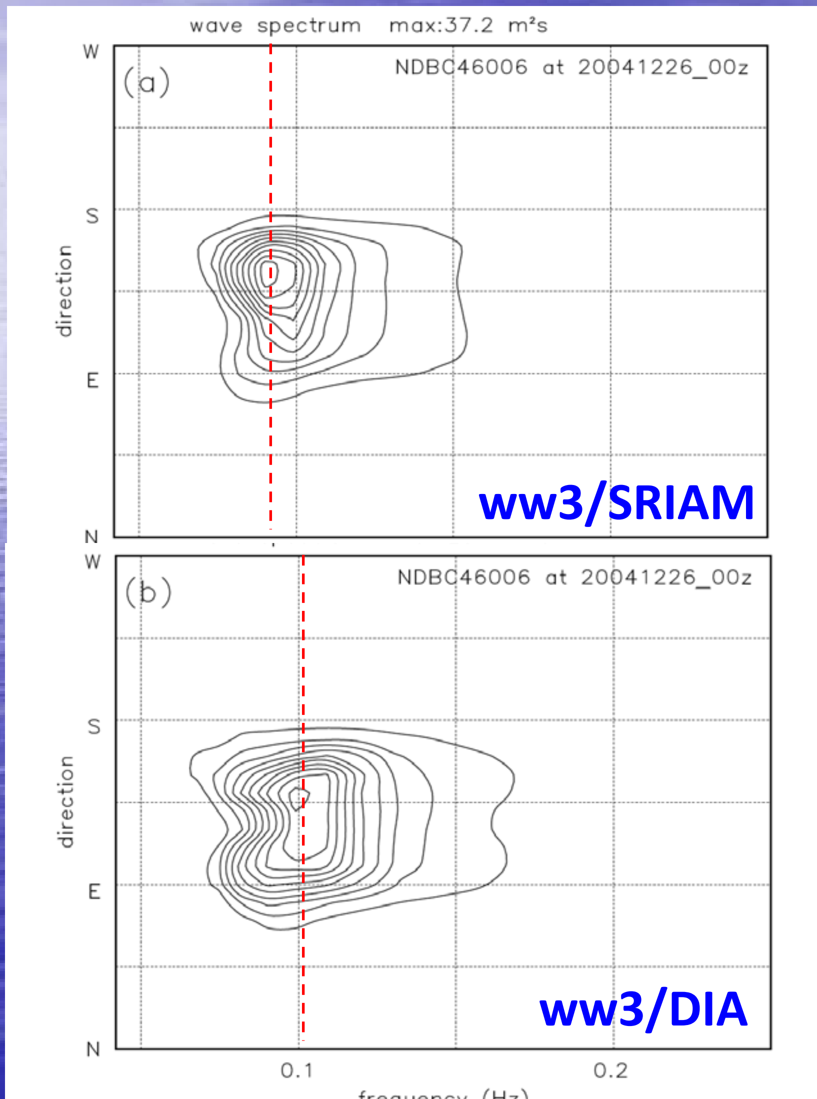
○ :in-situ data

—— :ww3/SRIAM

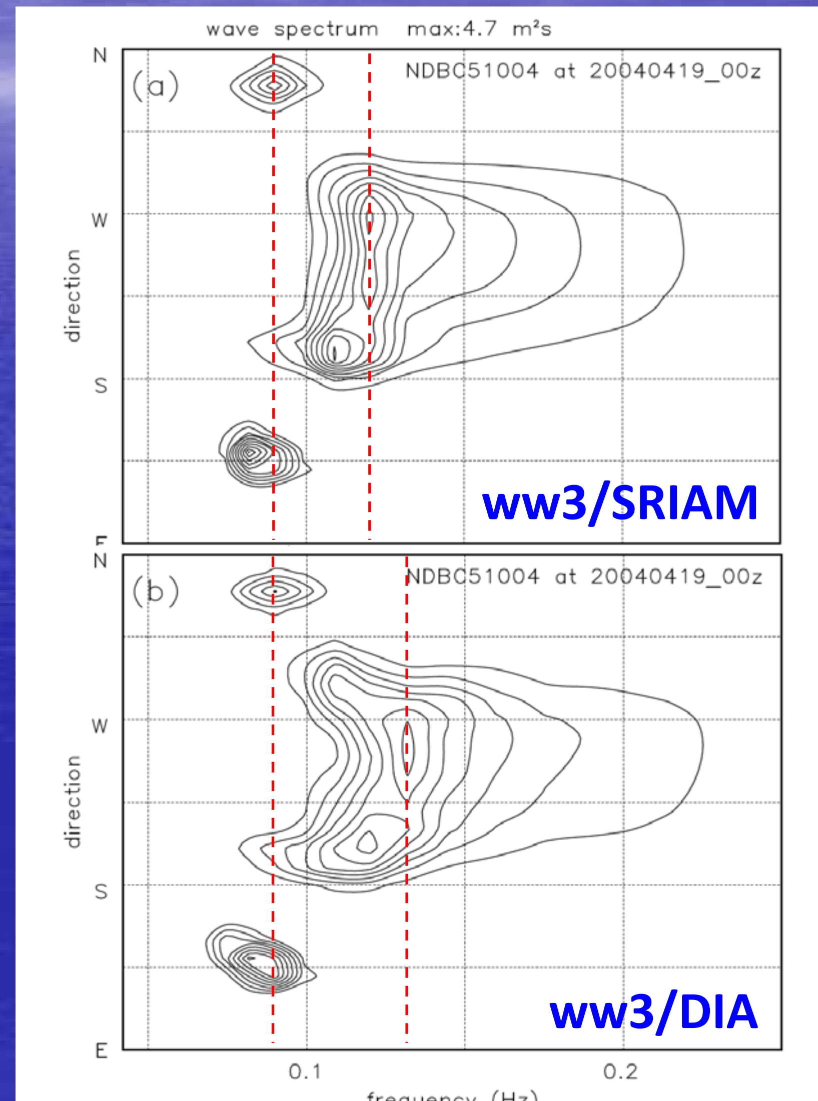
- · - :ww3/DIA

2D spectral shapes

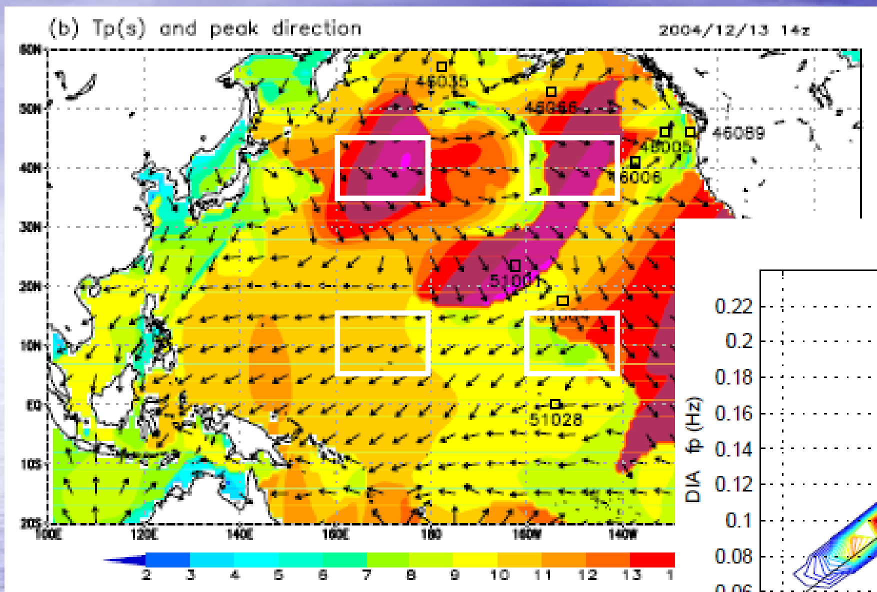
Station 46066 - S Aleutians 380NM

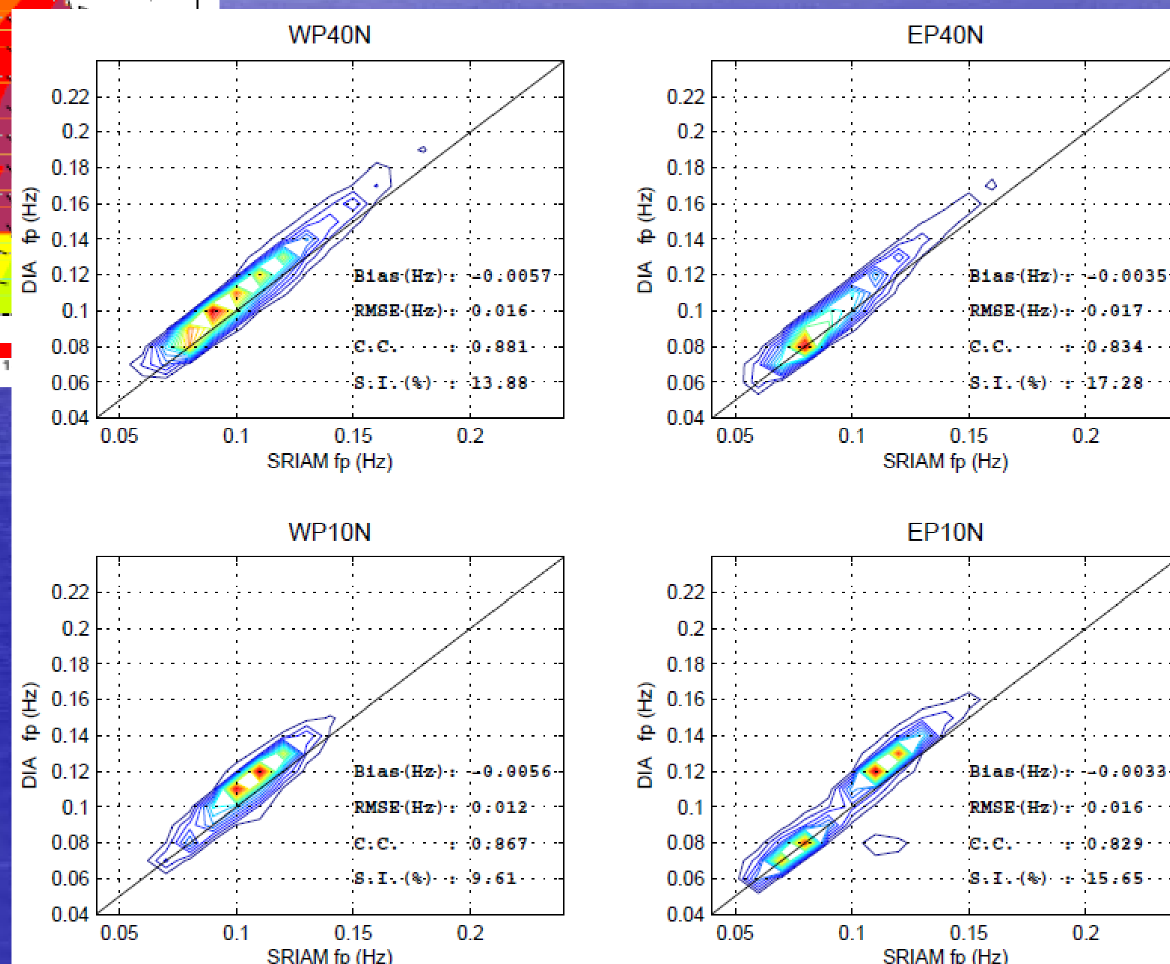


Station 51004 SE HAWAII 185 NM



Joint PDFs of peak frequency

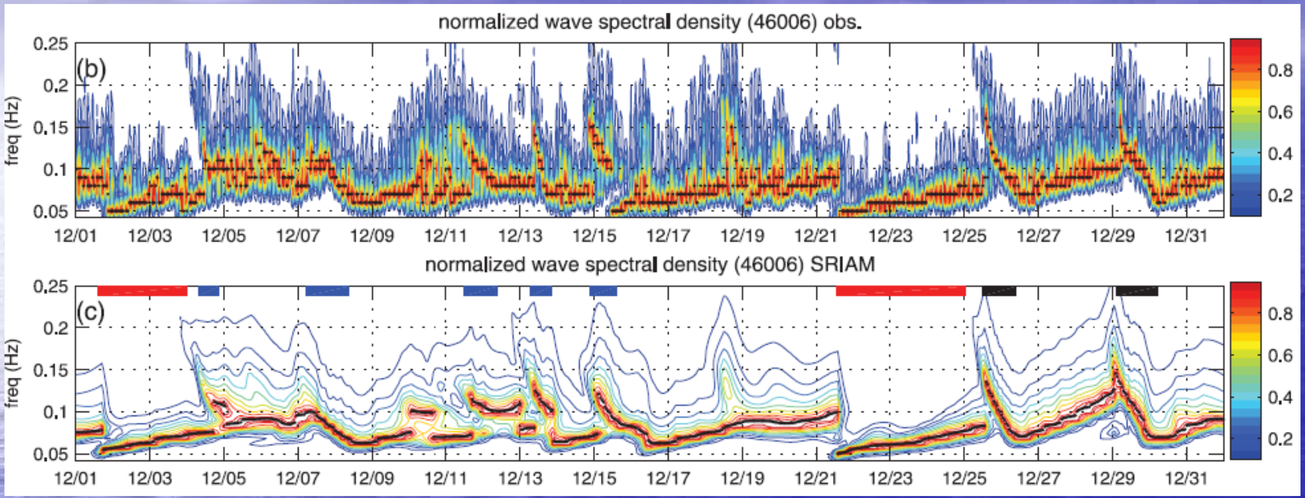




Evolution of wave spectra

in-situ vs model (SRIAM)

in the mid-latitude Pacific (46006)



in the low-latitude Pacific (51004)