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The development of Third Generation wave Model MRI-III for operational use.

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Contents

1.Introduction

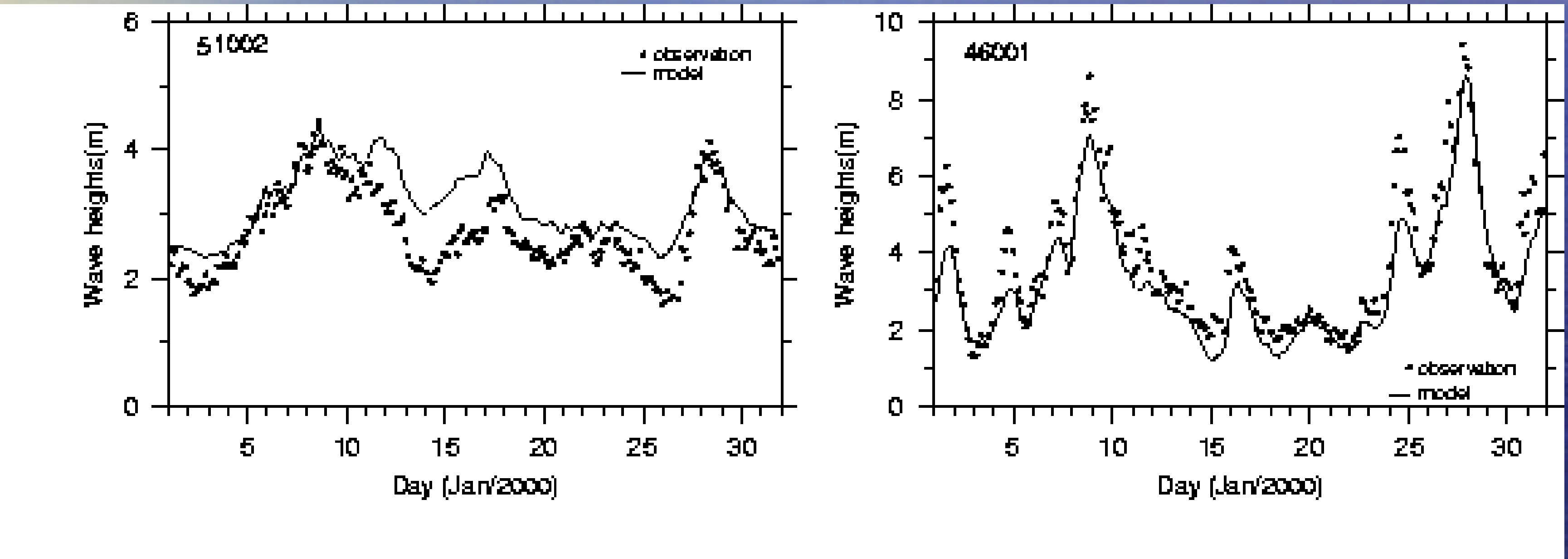
- The third generation wave model MRI-III (Ueno and Kohno, 1998)
  - developed in Meteorological Research Institute (MRI)
  - operationally used in Japan meteorological agency (JMA) from 00UTC 27/Apr/1998

- Improvements of physical treatment (Ueno and Kohno, 2001)
  - The correction of bug in S_{nl}
  - The improvement of S_{in} and S_{ds}

- **generation of new problem**
  - **overestimation of swell**

A global calculation results of Jan/2000

Hawaii(51002) and Aleutian(46001)



overestimation of swell (51002)
though correct estimation of wind waves(46001)

2.Outline of MRI-III

Energy balance equation

$$\frac{\partial F}{\partial t} + \nabla \cdot (C_g F) = S_{in} + S_{nl} + S_{ds}$$

$F = F(f,?\ )$: 2D spectrrum

S_{in}: energy input

S_{nl}: non-linear energy transfer

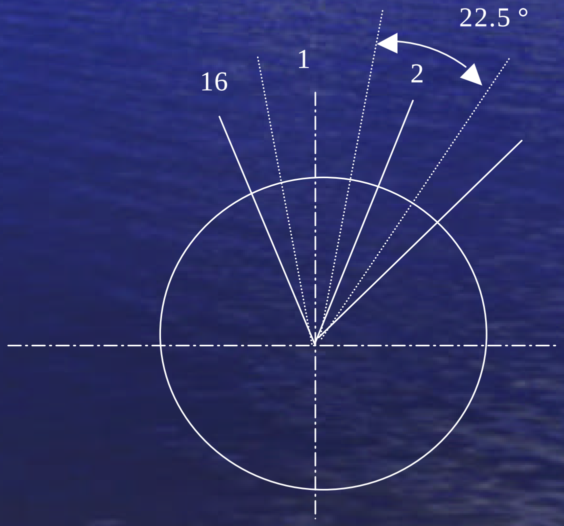
S_{ds}: energy dissipation

? advection term expressed swell propagation

Spectral components of MRI-III

Wave spectra : 400 components

frequencies : 25(logarithmically devided)
(22 components of both sides is extended in Snl calculation.)
Maximum f : 0.3000(period of 3.33sec)
Minimum f : 0.0375(period of 26.67sec)
directions : 22.5deg.(16directions)
(wave direction is defined where waves come.)



Expression of terms of MRI-III

energy balance equation in spherical coordinate

S_{in} (exponential) : Plant(1980) , Mitsuyasu-Honda(1982) type
(linear) : Cavaleri & Maranotte-Rizzoli(1981)

S_{nl} : the EDIA scheme
(*tripled the configuration of the DIA scheme*)

S_{ds} : newly determined (Ueno, 1997)
(laboratory measurements and dimensional analysis)

S_{swell} : newly introduced
(though empirical)

Advection : the first order upstream scheme

The expression of source functions (1)

- **Energy input Sin**

$$S_{in} = A + B \cdot F(f, \theta)$$

  - Linear term : **Cavaleri & Maranotte-Rizzoli (1981)**

$$A = \frac{1.5\times10^{-3}}{g^2 2\pi} \exp\left[-\left(\frac{\sigma}{\sigma_{PM}}\right)^{-4}\right] \cdot \left(u_* \cdot \max(0, \cos\varphi)\right)^4$$

  - Exponential term : **Plant(1982), Mitsuyasu-Honda(1982)**

$$B = 0.29 \frac{u_*^2}{g^2} \omega^3 F(f, \theta) \cdot \cos^2\varphi \frac{\cos\varphi}{|\cos\varphi|}$$

The expression of source functions (2)

- **Non-linear energy transfer Snl**
- **? ? ? ? ? ? ? ? ? ? ? ?**

  ? ? ? ? ? ? ? ? ? ? (4? ? ?)

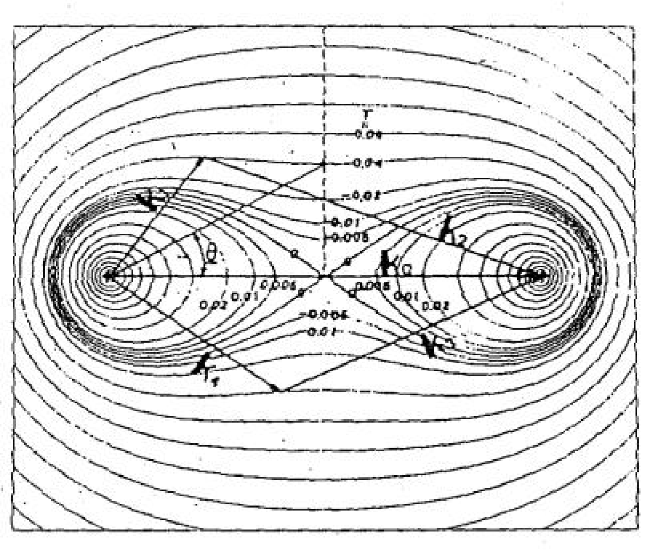
$$S_{nl}(\mathbf{k_4}) = \iiint w_4 \cdot s(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3, \mathbf{k}_4)$$

$$\times d(\mathbf{k_1} + \mathbf{k_2} - \mathbf{k_3} - \mathbf{k_4}) \cdot d(w_1 + w_2 - w_3 - w_4)$$

$$\times \{ n_1 n_2 (n_3 + n_4) - n_3 n_4 (n_1 - n_2) \} d\mathbf{k}_1 d\mathbf{k}_2 d\mathbf{k_3}$$

$$F(\mathbf{k_i}) = E(f, q),\ n_i = F(\mathbf{k_i}) / w_i,$$

$$w_i = \sqrt{g \mathbf{k}_i} \quad (i = 1, \cdots, 4)$$



Which need vast computation

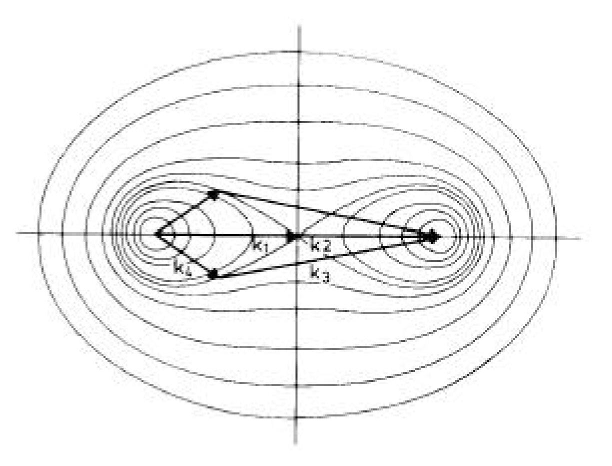
It is not yet available in practical use.

The expression of source functions (2)

- **The practical scheme of Snl calculation**

  Discrete Interaction approximation (DIA)

  (Hasselmann et al., 1985)



$$\begin{bmatrix} w_1 = w_2 = w \\ w_3 = (1+l)w = w_+ \\ w_4 = (1-l)w = w_- \end{bmatrix}$$

$$l = 0.25 \quad q_3 = \pm 11.5, q_4 = \mp 33.6$$

$$\begin{Bmatrix} S_{nl} \\ S_{nl}^+ \\ S_{nl}^- \end{Bmatrix} = \begin{Bmatrix} -2 \\ (1+l)\dfrac{\Delta w \, \Delta q}{\Delta w_+ \Delta q} \\ (1-l)\dfrac{\Delta w \, \Delta q}{\Delta w_- \Delta q} \end{Bmatrix} \cdot C_0 \frac{w^{11}}{g^4} \cdot \left[F^2 \left\{ \frac{F_+}{(1+l)^4} + \frac{F_-}{(1-l)^4} \right\} - 2 \frac{FF_+F_-}{(1-l^2)^4} \right]$$

The expression of source functions (2)

- **Non-linear energy transfer Snl**

The Extended Discrete Interaction Approximation (EDIA)
based on the DIA scheme by Hasselmann et al.(1985)

(Uses <u>three configurations</u> of the resonant four waves, not only one.)

$$\begin{bmatrix} w_1 = w_2 = w \\ w_3 = (1+l)w = w_+ \\ w_4 = (1-l)w = w_- \end{bmatrix}$$

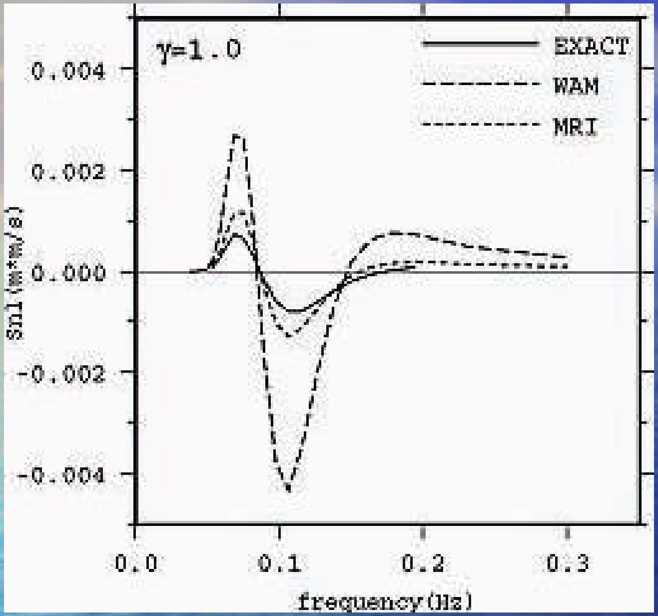
$$l = 0.25 \quad q_3 = \pm 11.5, q_4 = \mp 33.6$$

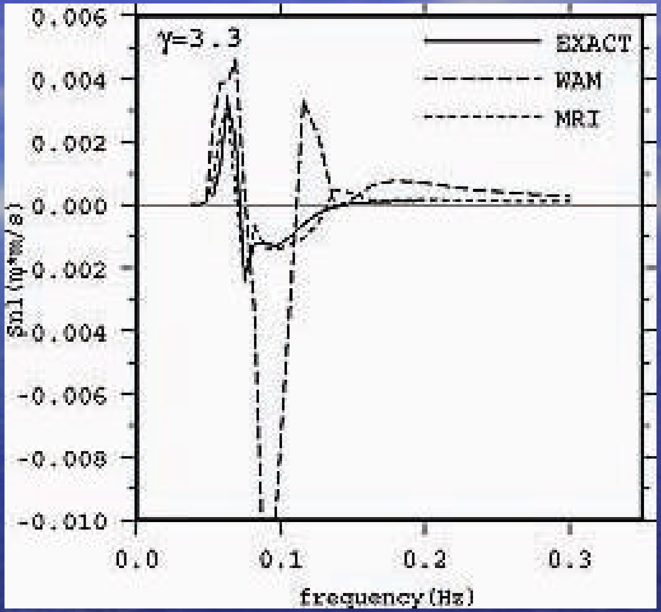
$$\begin{Bmatrix} S_{nl} \\ S_{nl}^{+} \\ S_{nl}^{-} \end{Bmatrix} = \begin{Bmatrix} -2 \\ (1+l)\dfrac{\Delta w\,\Delta q}{\Delta w_+ \Delta q} \\ (1-l)\dfrac{\Delta w\,\Delta q}{\Delta w_- \Delta q} \end{Bmatrix} \cdot C_0 \frac{w^{11}}{g^4} \cdot \left[F^2 \left\{ \frac{F_+}{(1+l)^4} + \frac{F_-}{(1-l)^4} \right\} - 2\frac{FF_+F_-}{(1-l^2)^4} \right]$$

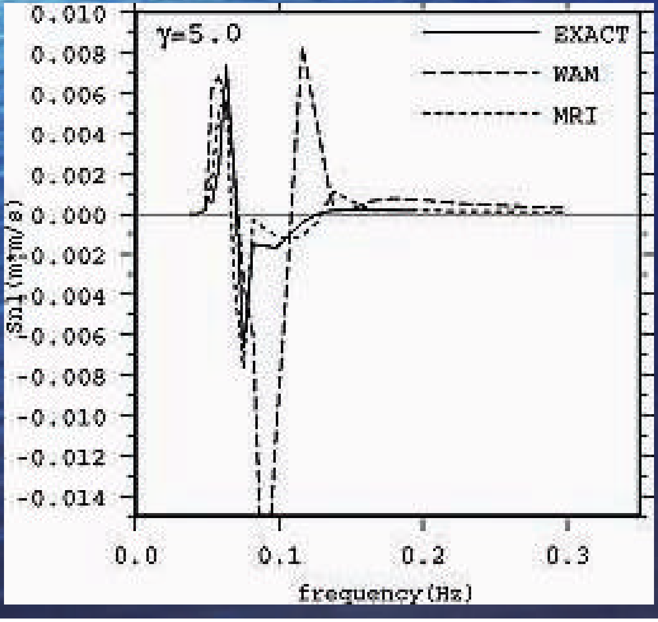
$$\begin{bmatrix} l^1 = 0.19 & q_3^1 = \pm 10.2, q_4^1 = \mp 22.5 \\ l^2 = 0.24 & q_3^1 = \pm 11.3, q_4^1 = \mp 31.5 \\ l^3 = 0.33 & q_3^1 = \pm 11.7, q_4^1 = \mp 53.3 \end{bmatrix}$$

$$S_{nl} = \sum_k c^k S_{nl}^k$$

Example of nonlinear energy transfer







? the transfer rate are converted to non-dimensional value by energy spectrum

? the exact values were calculated by Dr. Komatsu and Prof. Masuda

The expression of source functions (3)

- **Energy Dissipation Sds**

newly determined based on indoor laboratory experiments and dimensional analysis (Ueno, 1997)

$$(1) S_{in} \propto \left(\frac{u_*}{C_p} \right)^2 f \cdot \cos^2 q \cdot F(f, q)$$

$$(2) S_{in} \approx S_{ds}$$

$$(3) F(f, q) \propto g u_* f^{-4} \cos^2 q$$

$$S_{ds} = -c \cdot \max(u_*, 0.174) \cdot \frac{w^7}{g^3} \cdot F(f, q)^2$$

The expression of source functions (3)

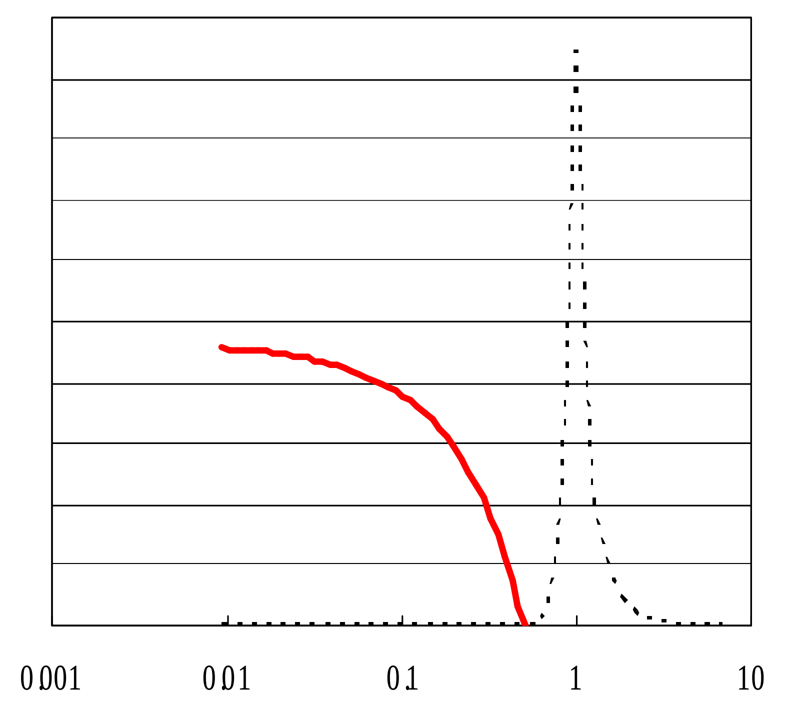
- **Swell Decay Sswell**

empirically determined

$$S_{sds} = -4.01\times10^{-6}\tanh\left(\frac{f_s - f}{f_p}\right)\cdot F(f,q)$$

for f < *fs* (= 0.5 *fp*)

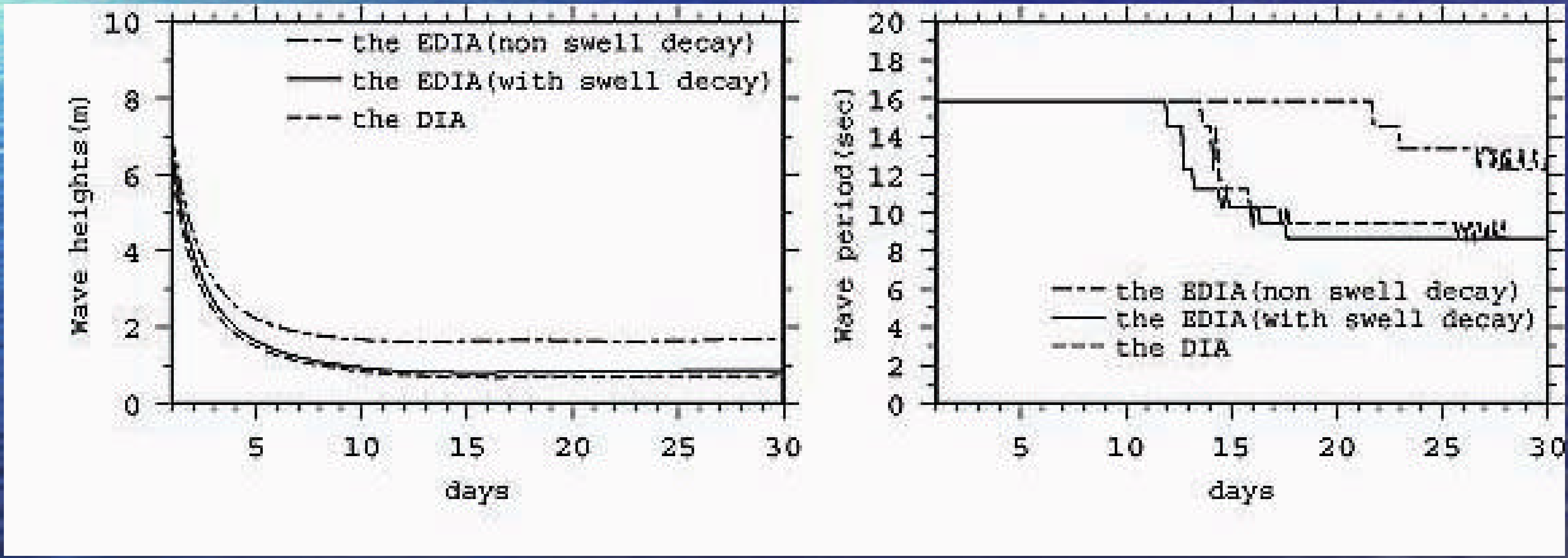
fp : peak frequency of windsea



The test of swell decay

The peak wave height during 30 days under wind speed of 5m/s.

The initial wave energy is JONSWAP spectra of 20m/s wind.



Modification of wave at off Hawaii(51002)

wave at North Pacific(46001)

Other change points

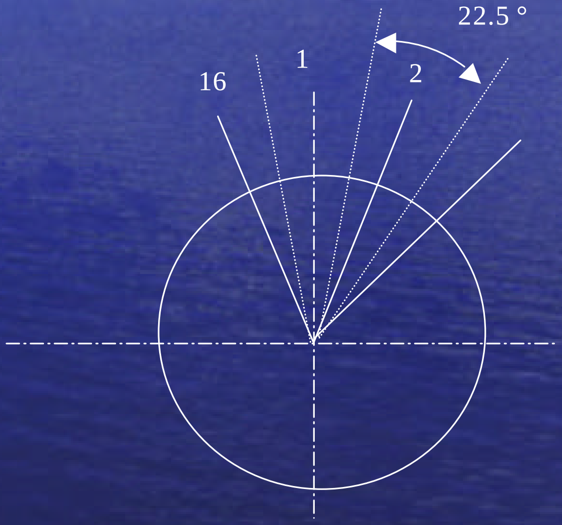
1 . Adjustment of S_{nl} value

product of 1.4 to adjust the peak value to exact calculation.

2 . Definition of directional spectra

define at central points of element

(the direction of product is same)



3 . Change of the drag coefficients

$$u_* = \sqrt{C_d} \cdot u_{10}$$

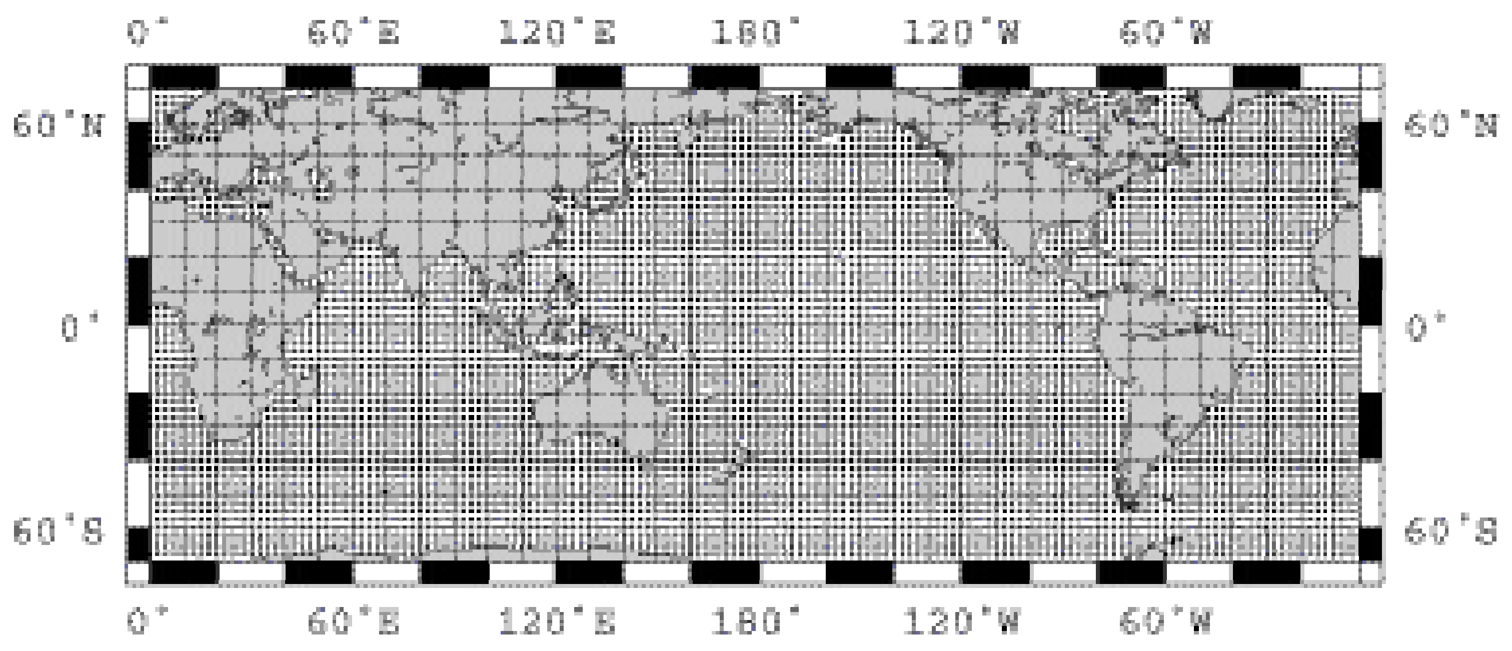
$$C_d = 0.581 \times 10^{-3} + 0.063 \times 10^{-3} \cdot u_{10}$$

$$previous \ : \ C_d = \max(0.520 \times 10^{-3} + 0.073 \times 10^{-3} \cdot u,\ 1.83 \times 10^{-3})$$

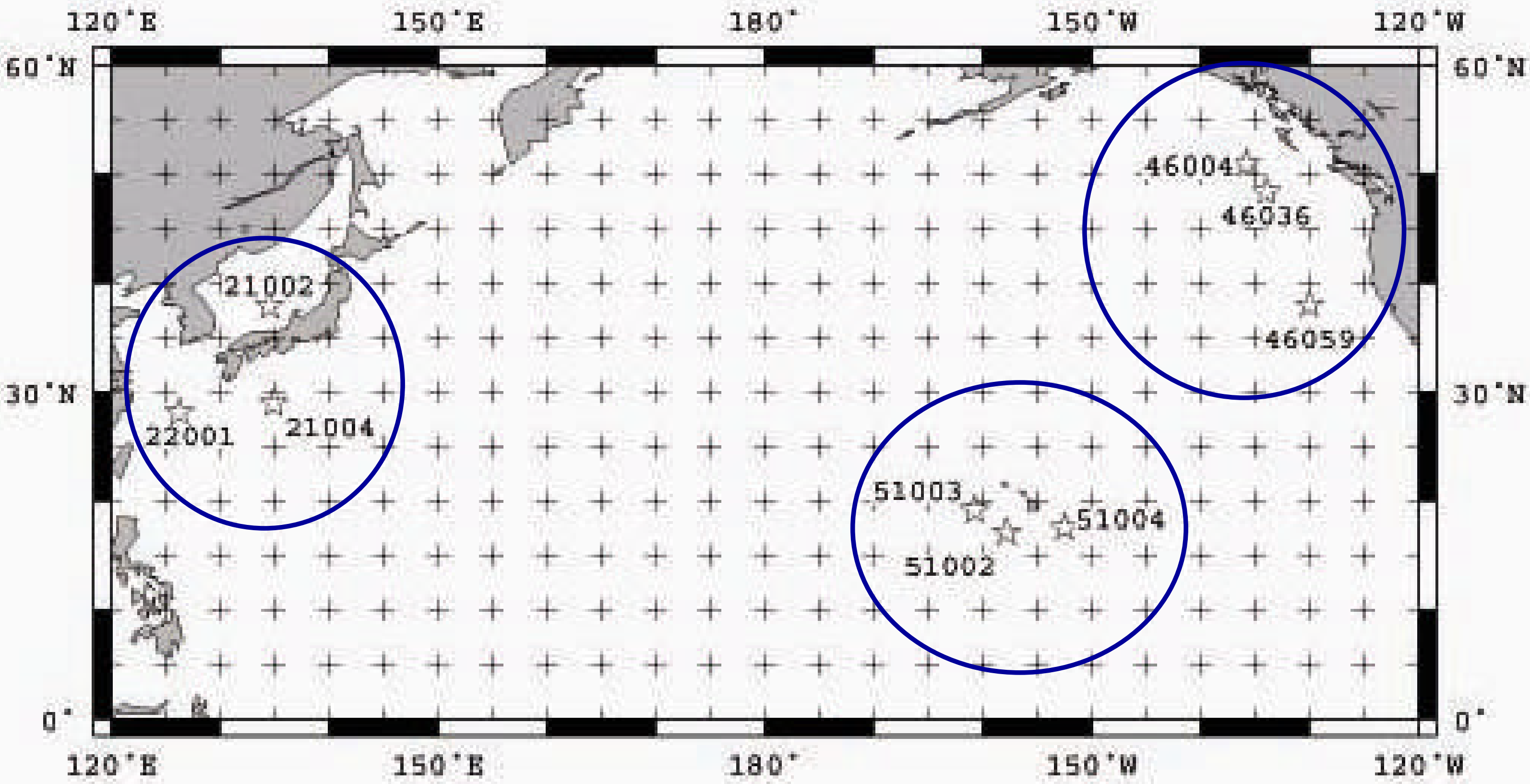
3.Calculation results

- Global calculation (January, 2000)
- Conditions

Area	global without pole region
grid resolution	2.5 degree
initial condition	Static state(Dec,1,1999) and 1 month hindcast
surface winds	6 hourly JMA global analysis (GANAL)

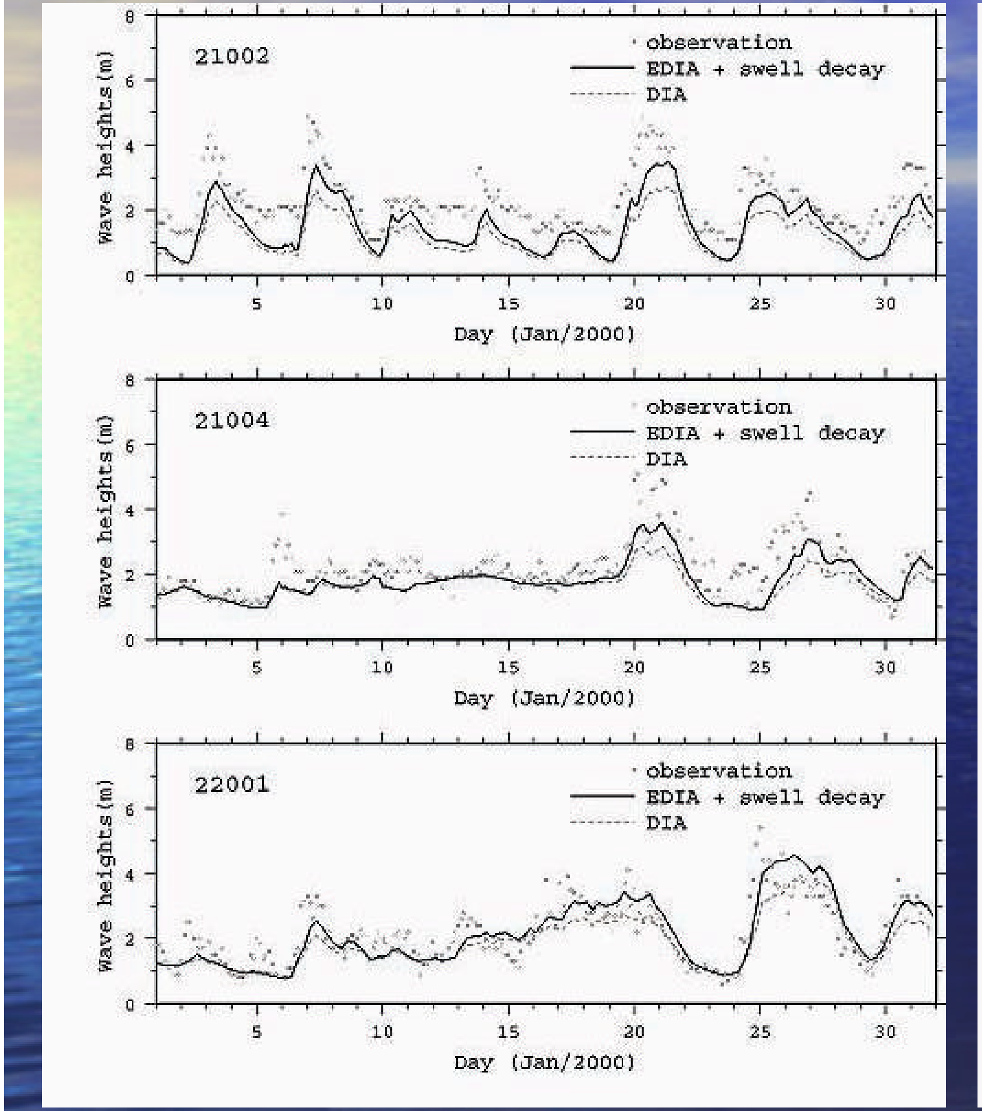


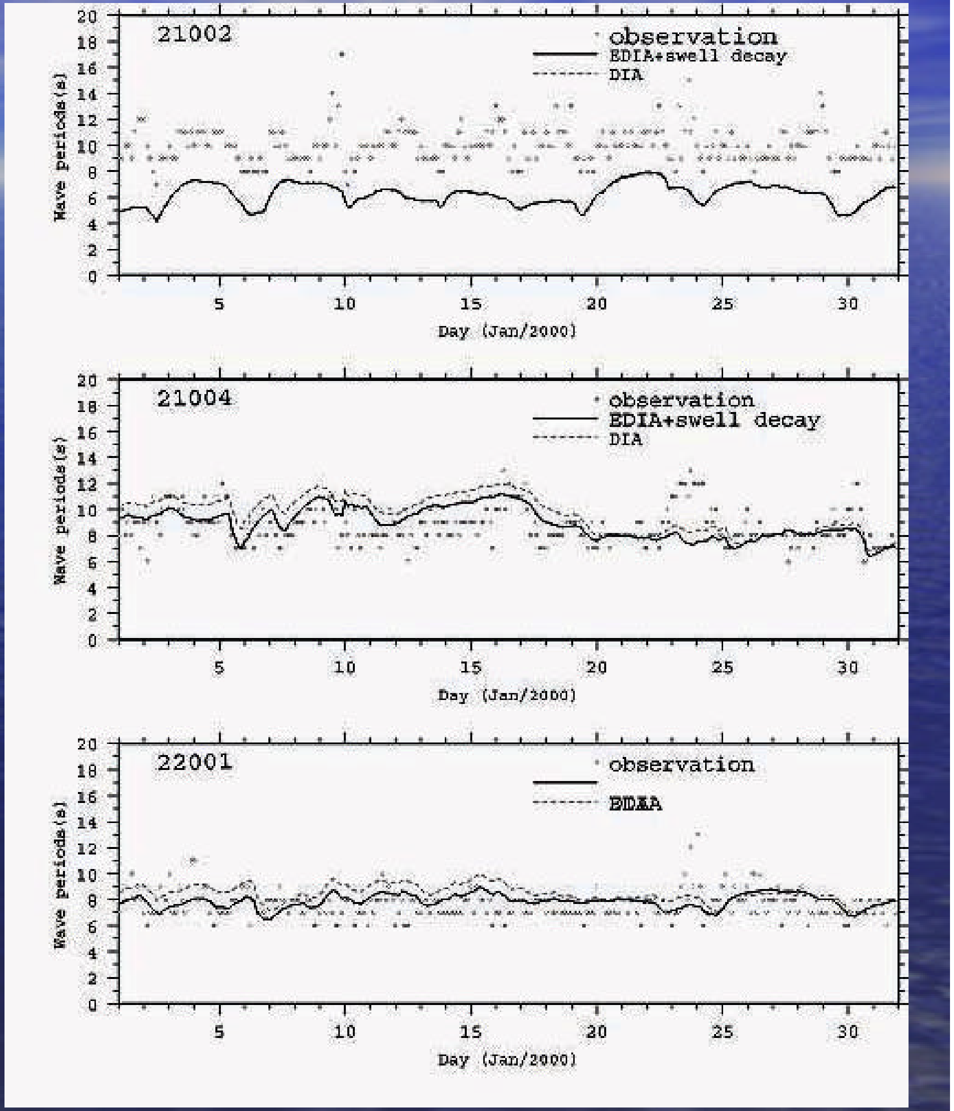
Buoy points



120°E
150°E
180°
150°W
120°W
60°N
30°N
0°
21002
22001
21004
46004
46036
46059
51003
51004
51002

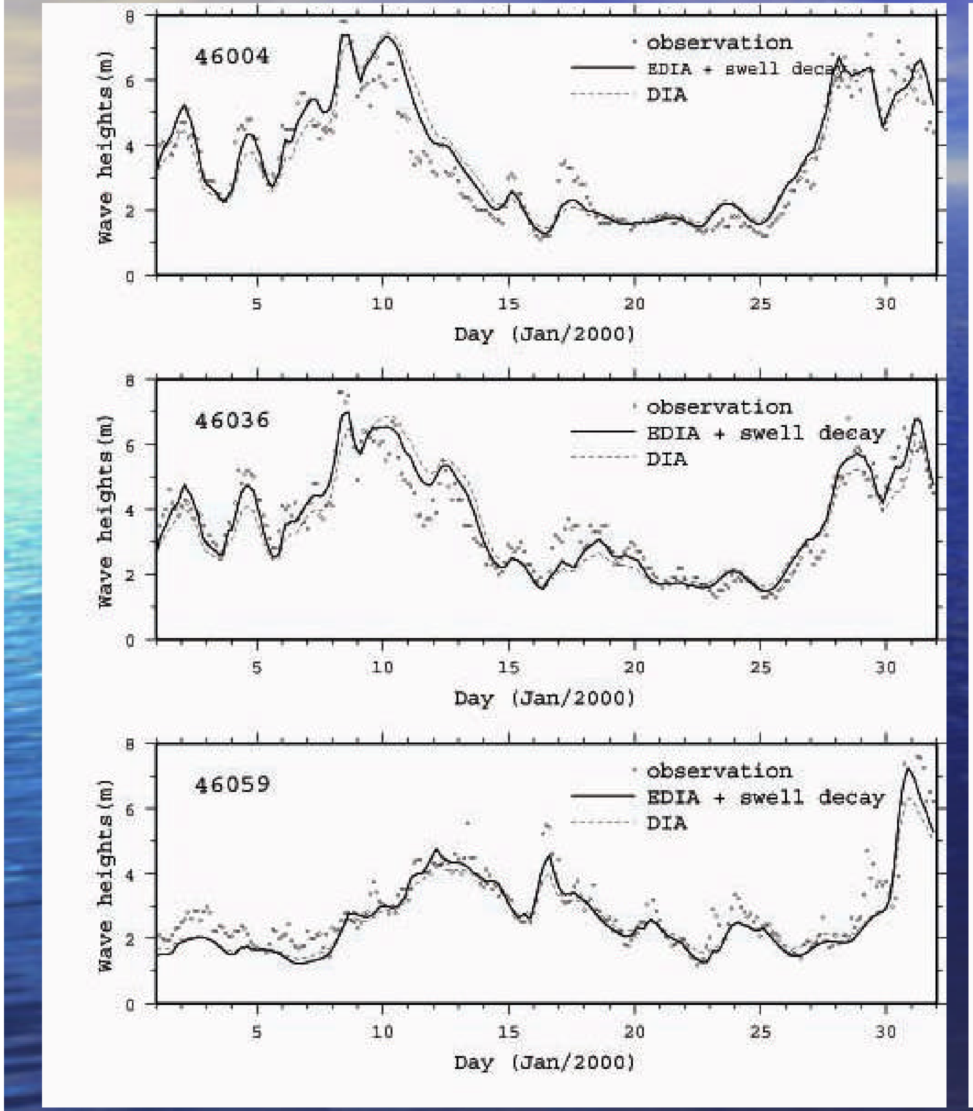
Waves around Japan(Jan/2000)

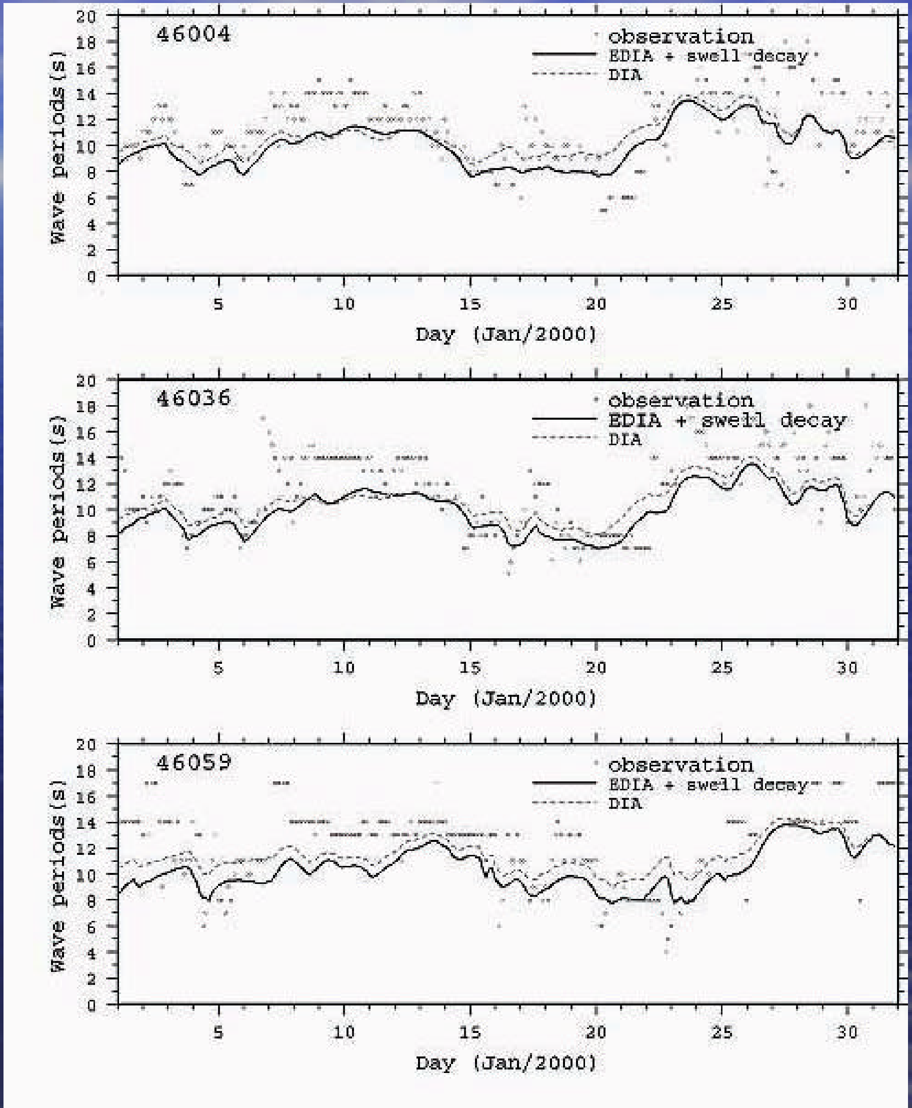




Surface wind speed at 21002 (Jan. 2000)

Waves in the North Pacific(Jan/2000)





Waves off Hawaii (Jan/2000)

4.Discussion

Why S_{nl} has relation to swell dissipation?

- The DIA scheme transfers almost same amount of energy toward higher frequency side, not only lower side, especially the spectrum width is narrow.

  (This is false value and never occurs in rigorous calculation)

- The EDIA scheme transfers almost same value as rigorous calculation, therefore energy transfer toward lower side is small.

  (no false transfer occurs.)

Why Snl has relation to swell dissipation? (cont.)

- The general feature of S**ds** term

  In general much energy dissipates in high frequency region.
  (This comes from observational research and reasonable itself.)

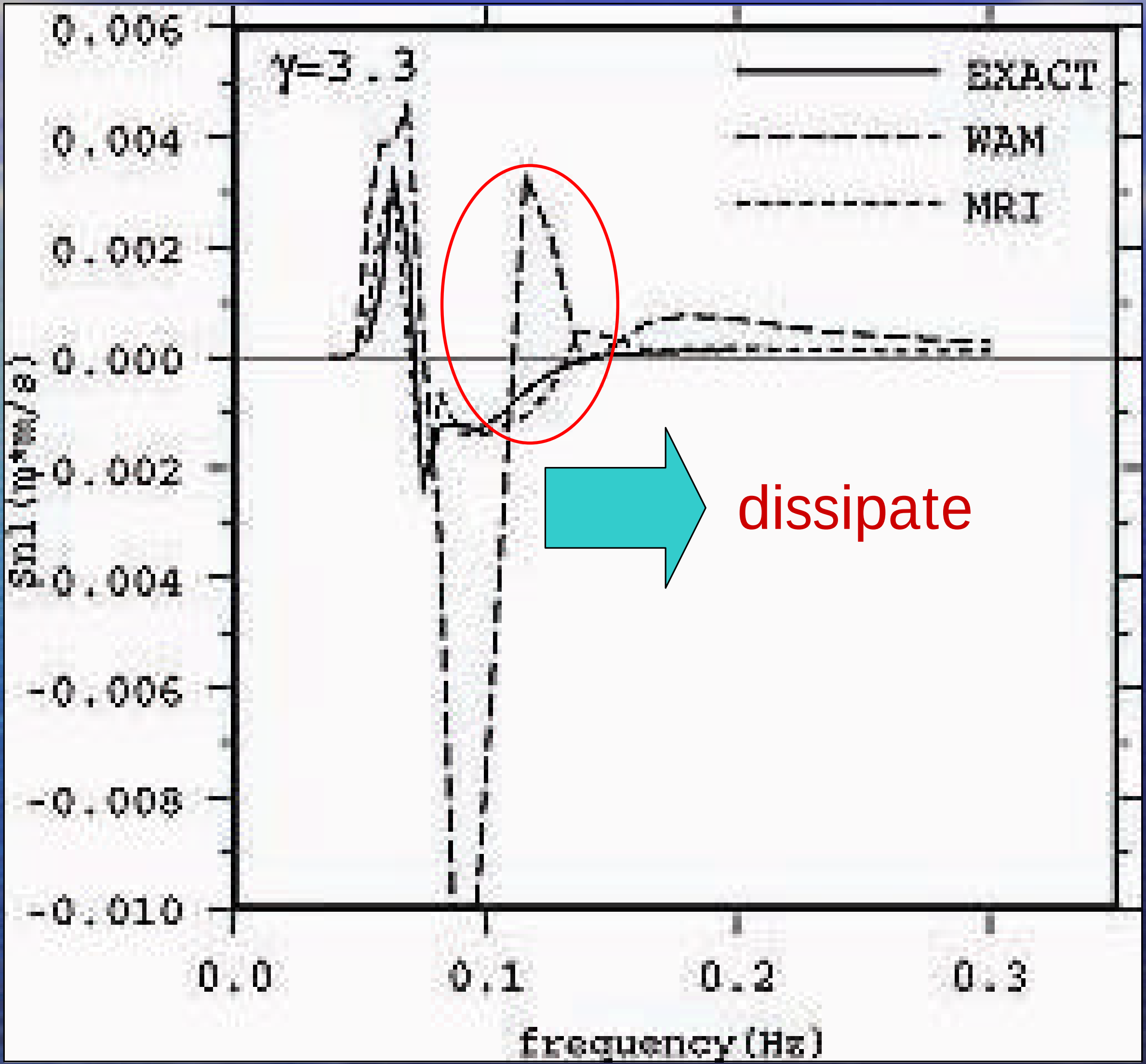
? The energy transferred to higher frequency region are effectively dissipated.

- Although wave height agree with observation, it is due to additional dissipation by false energy transfer.

  (which means over dissipation of energy by the DIA)

  The EDIA does not occur additional dissipation, though this leads to overestimation of swell heights

cf. wavewatch-3 decrease the coefficient of Snl in order to restrict swell decay.


γ=3.3
EXACT
WAM
MRI
0.006
0.004
0.002
0.000
0.002
0.004
-0.006
-0.008
-0.010
Snl (m*m/s)
0.0
0.1
0.2
0.3
frequency (Hz)

dissipate

5.Summary

- MRI-III calculates non-linear energy transfer with the EDIA scheme, which has much accuracy than the DIA scheme used in WAM etc.
- The EDIA scheme, that has the ability of almost rigorous S**nl** calculation, fears to overestimate swell heights.
- By including swell decay term, MRI-III comes to have quite good accuracies both in windseas and swell, which is worth being operated.

further problems

- Since swell decay term is hypothetical and determined empirically, we must further research the feasibility of this expression or seek a proper expression, in theoretical method and experiments.

- We should clear the mechanism of energy input when swell exists, which may connected with our well decay term.