Multifractal Thermal Structure in the Western Philippine Sea Upper Layer with Internal Wave Propagation

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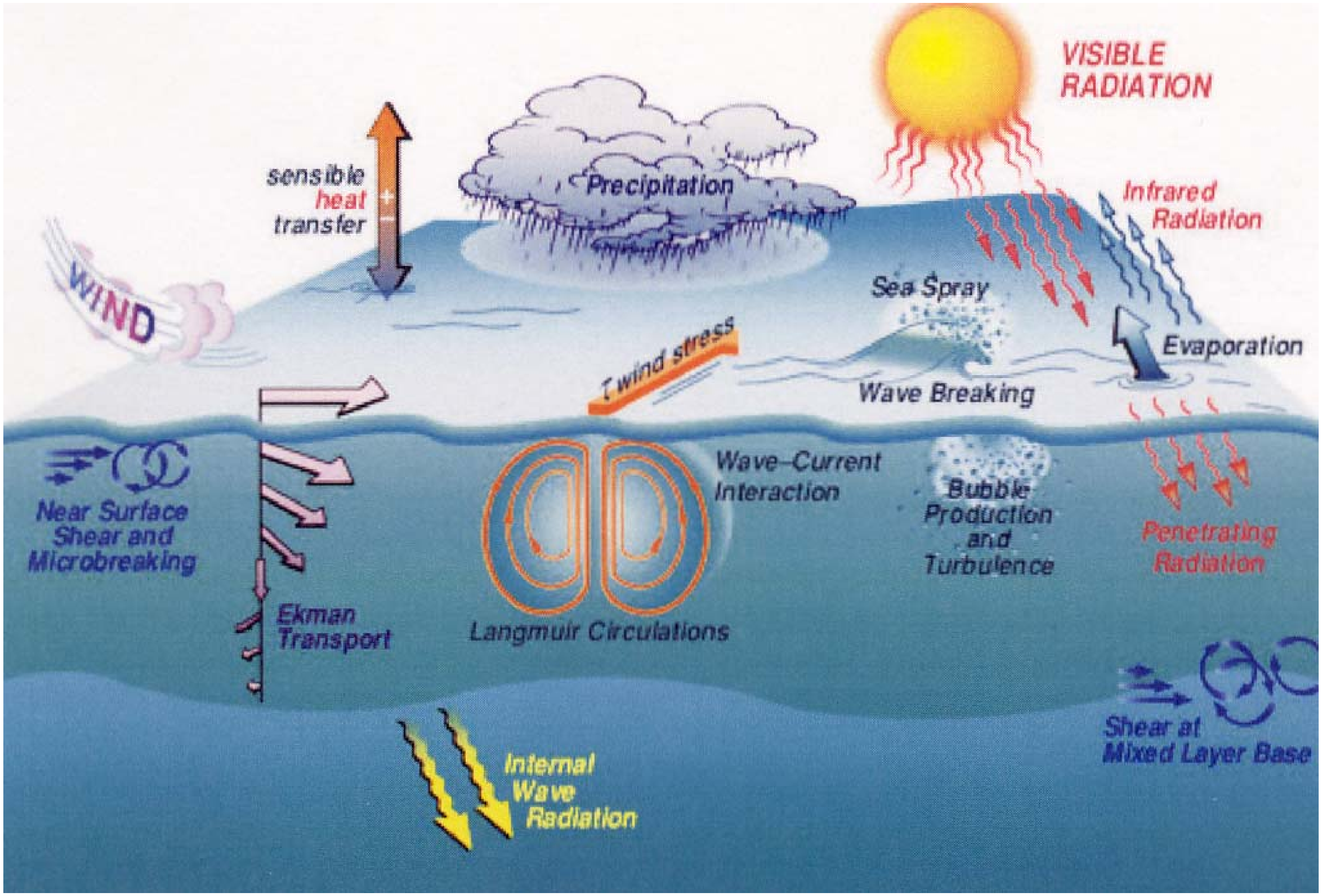
TURBULENCE REVISTED

Upper Ocean Dynamics

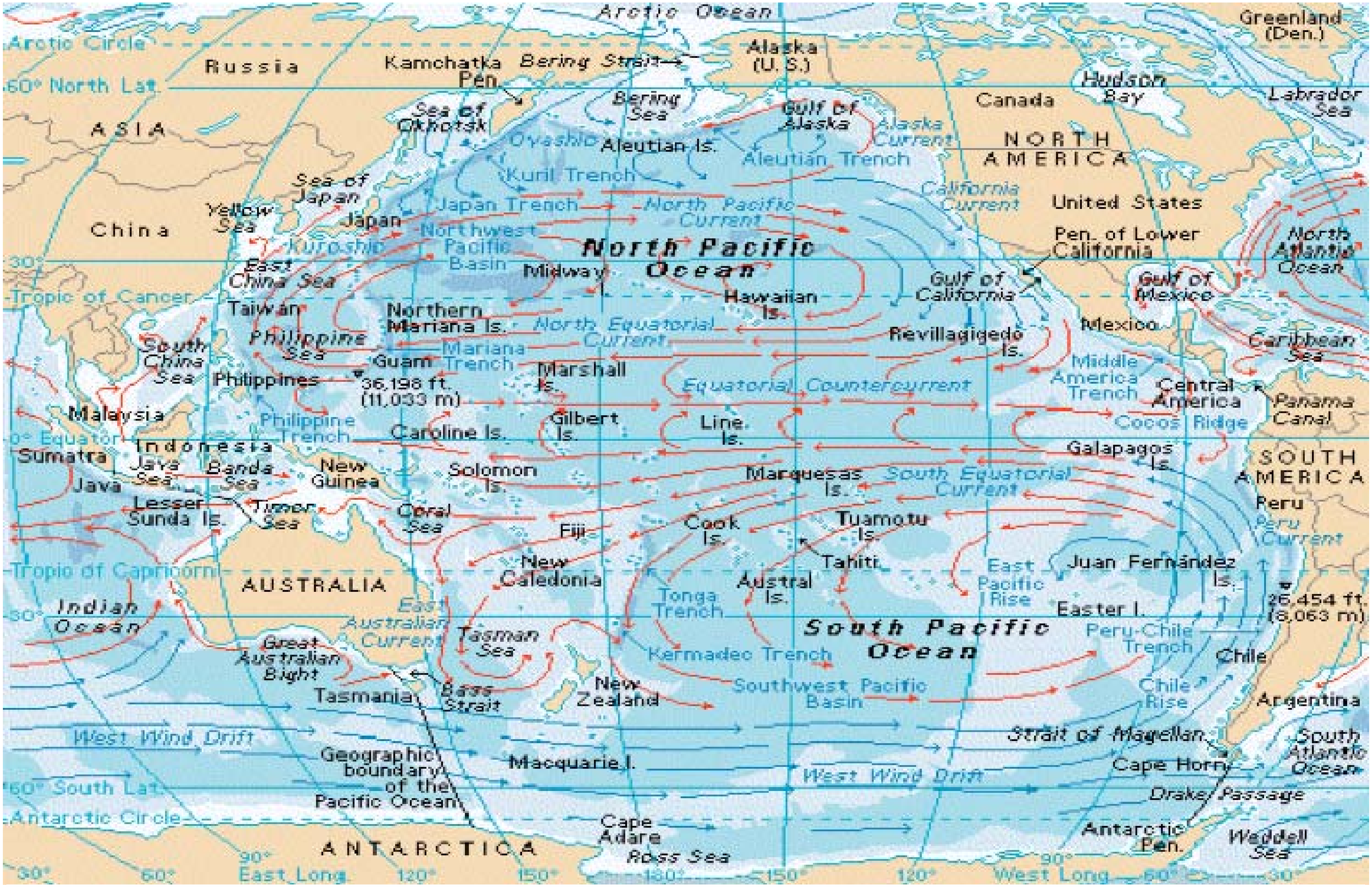
from http://www.hpl.umces.edu/ocean/sml_main.htm

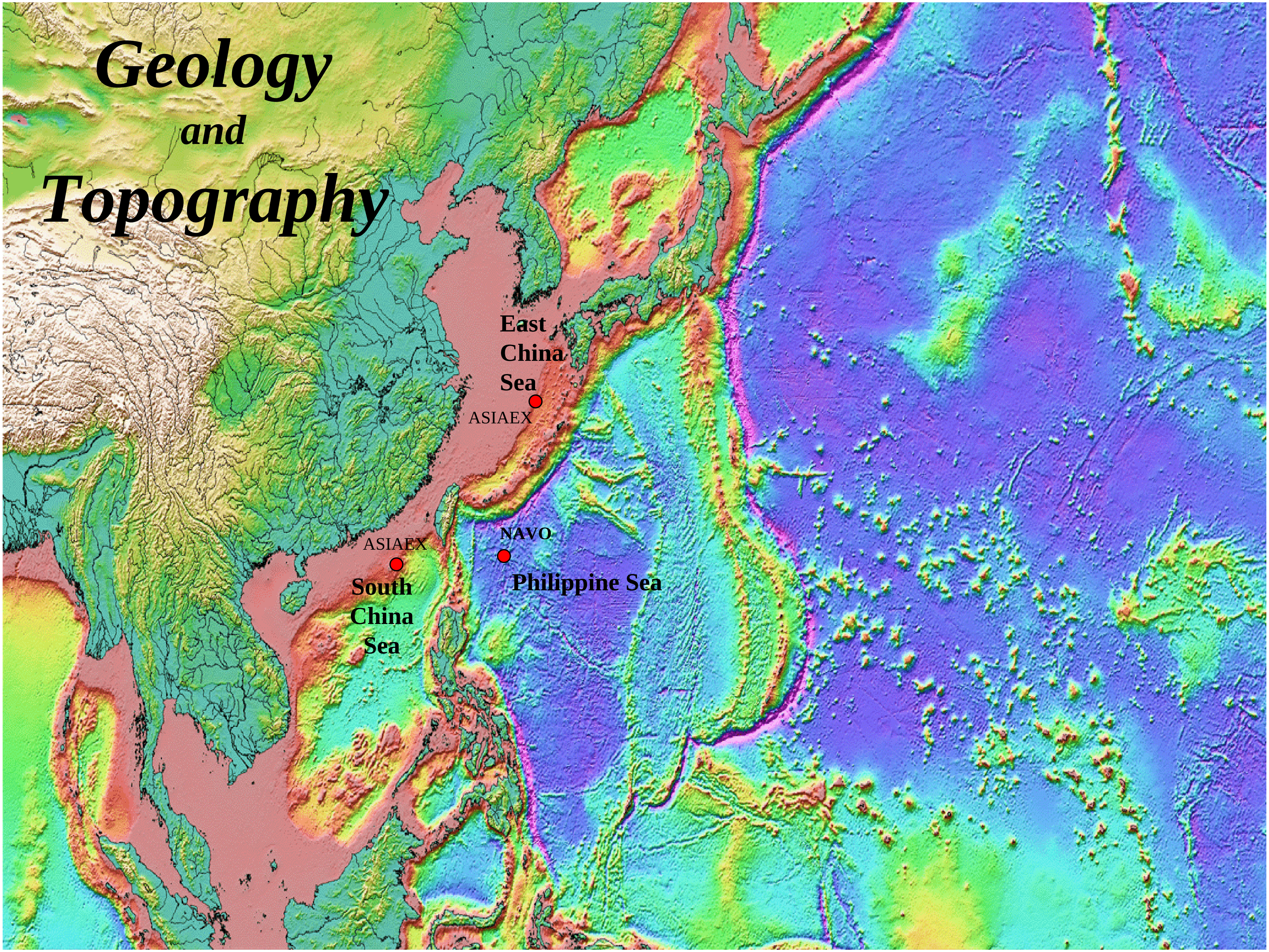


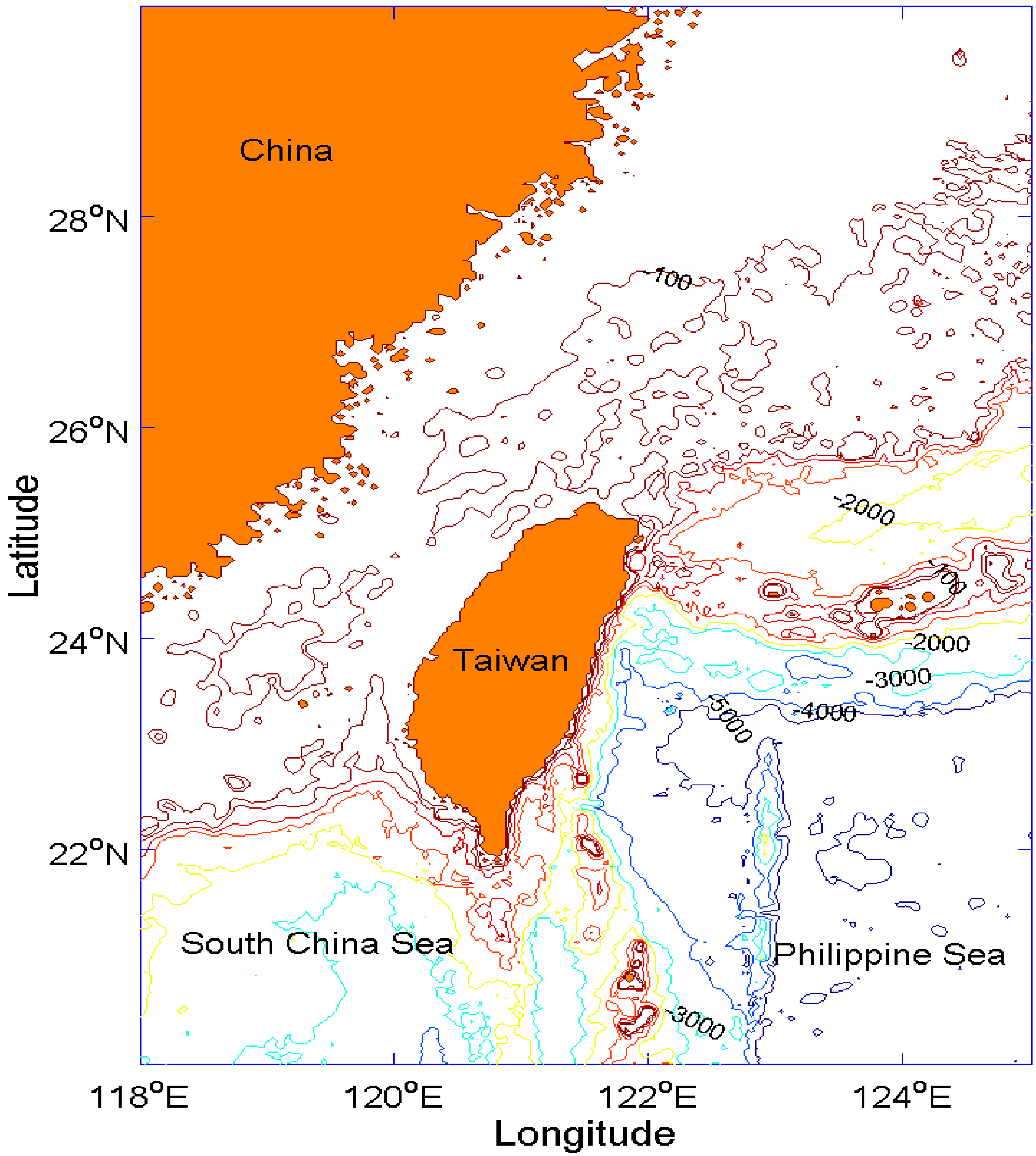
What is the upper ocean thermal structure with internal wave propagation?

An observational study in the western ***Philippine Sea*** is taken as an example for illustration.

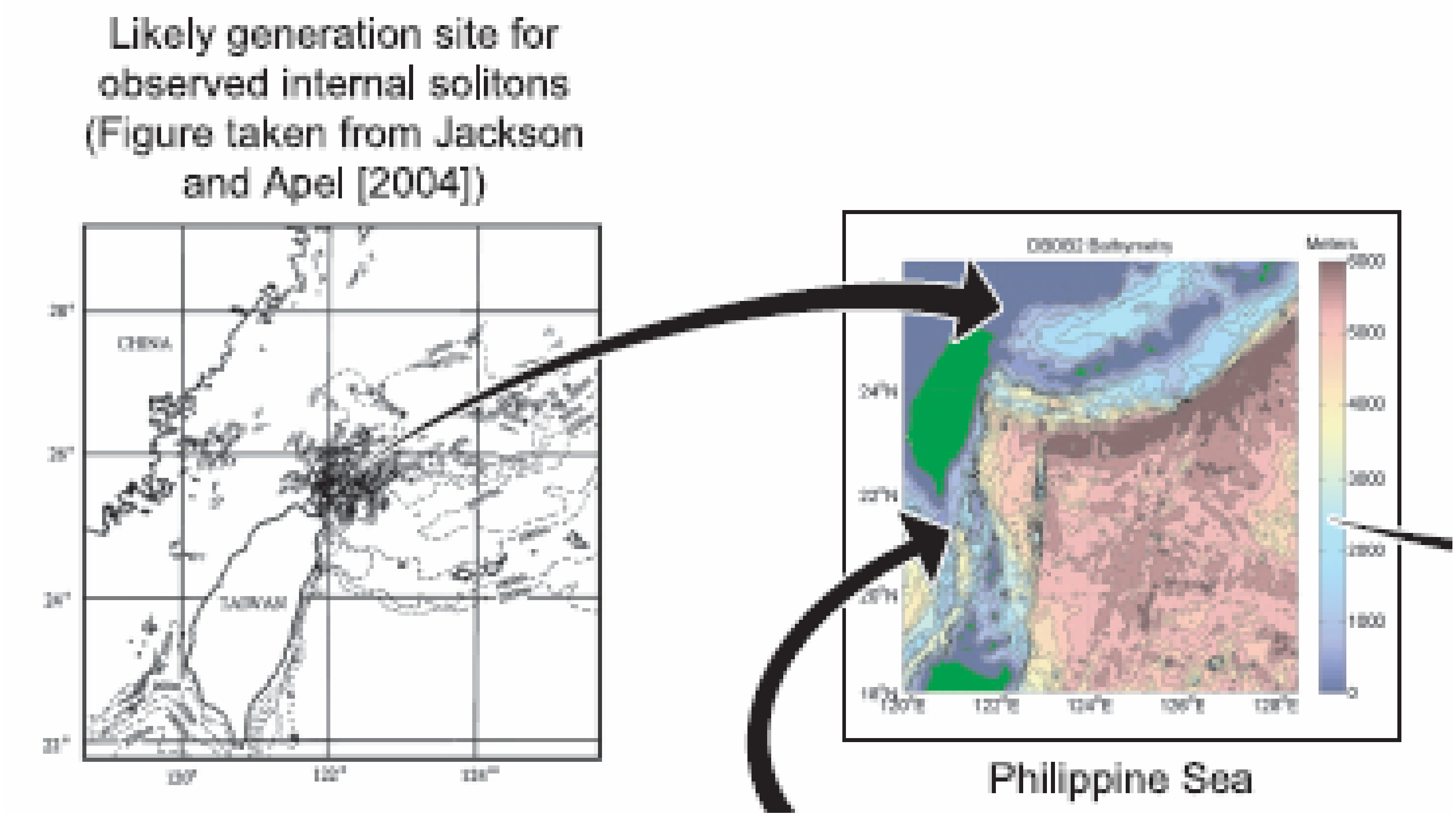
Philippine Sea in World Oceans




Geology
and
Topography
East
China
Sea
ASIAEX
ASIAEX
NAVO
South
China
Sea
Philippine Sea


China
Taiwan
South China Sea
Philippine Sea
-100
-2000
-100
-2000
-3000
-4000
-5000
-3000
28°N
26°N
24°N
22°N
Latitude
118°E
120°E
122°E
124°E
Longitude

Internal Waves and Solitons near Taiwan



(Liu et al., 1998)

MODIS (bands 1,3,4) 250-m resolution visible image over the East China Sea August 3, 2003 at 0235 UTC (Alpers et al. 2004)

Internal Waves/Solitons in the South China Sea (Liu and Hsu, 2007) width ~ 0.8 km

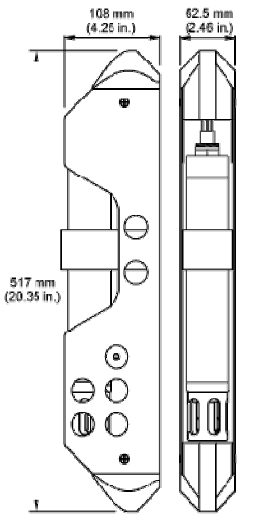
ESA 4/26/2000

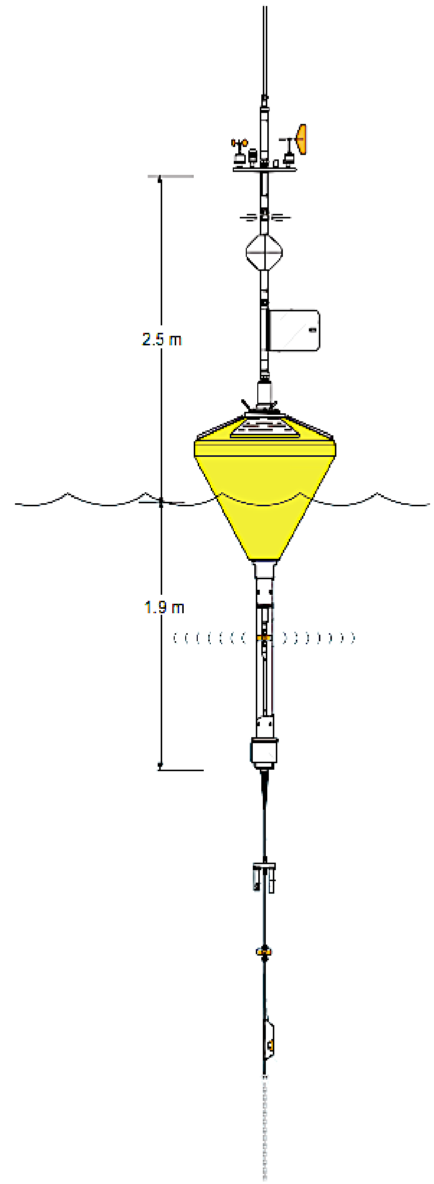
RADARSAT 4/22/2000

Data Observation

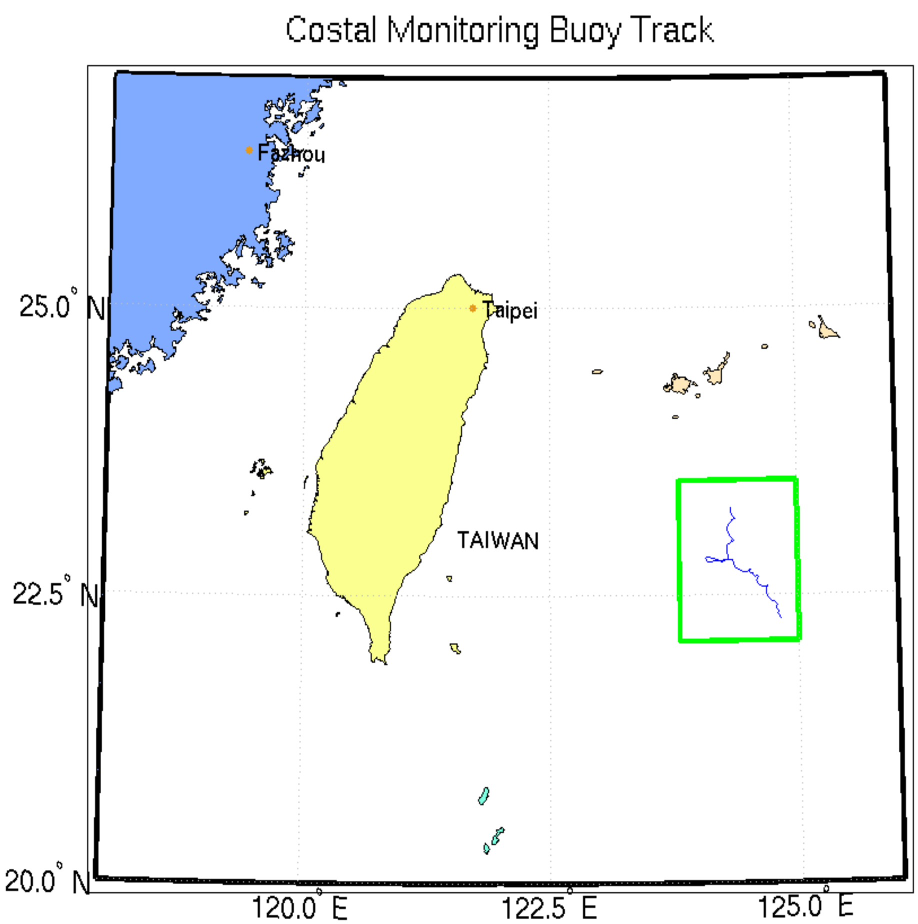
- Coastal Monitoring Buoy (CMB)
  - U.S. Naval Oceanographic Office
  - July 28 - August 7, 2005
  - Ocean data 1,3,5,18, and 20 m

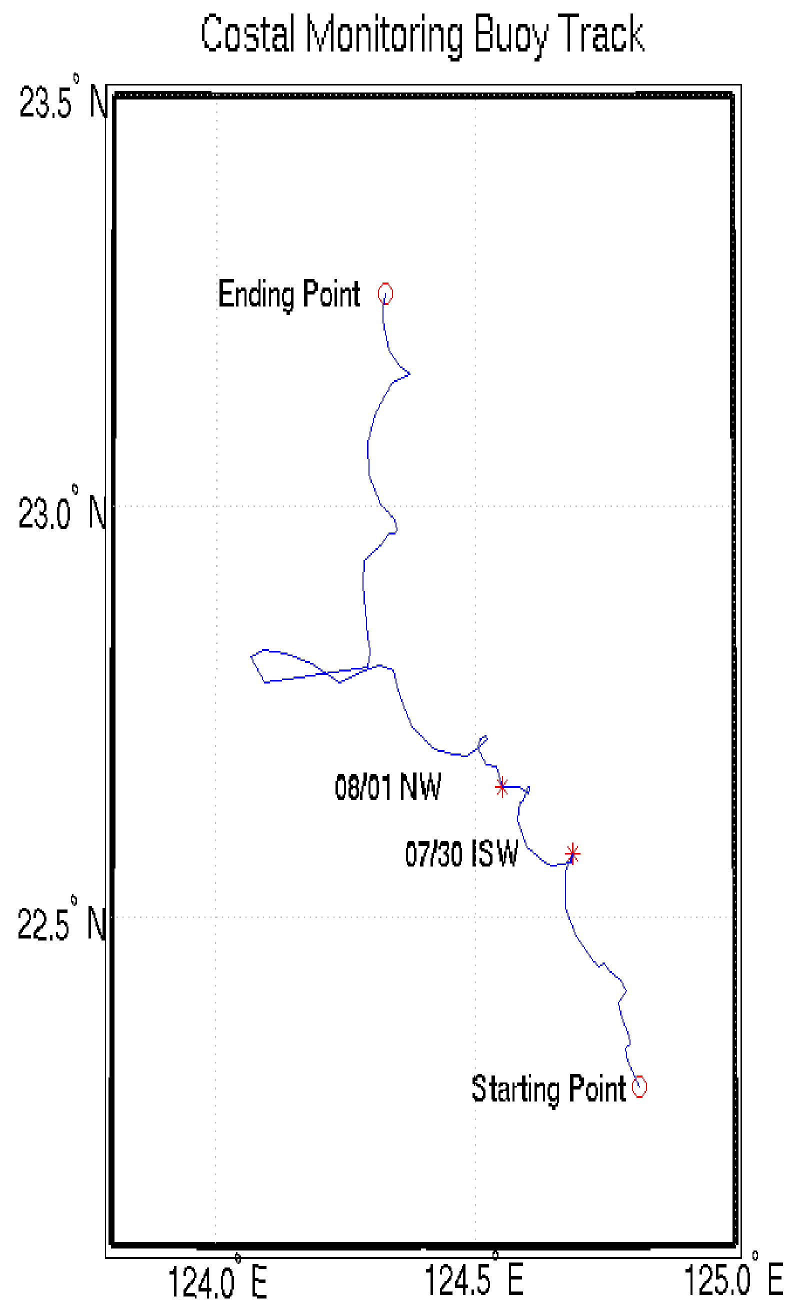
    Surface atmospheric data
  - Record intervals - 10 min
- Thermistors
  - SBE 39
  - Attached at 15 depths from 25 to 140 m.
  - Records intervals - 15 s.

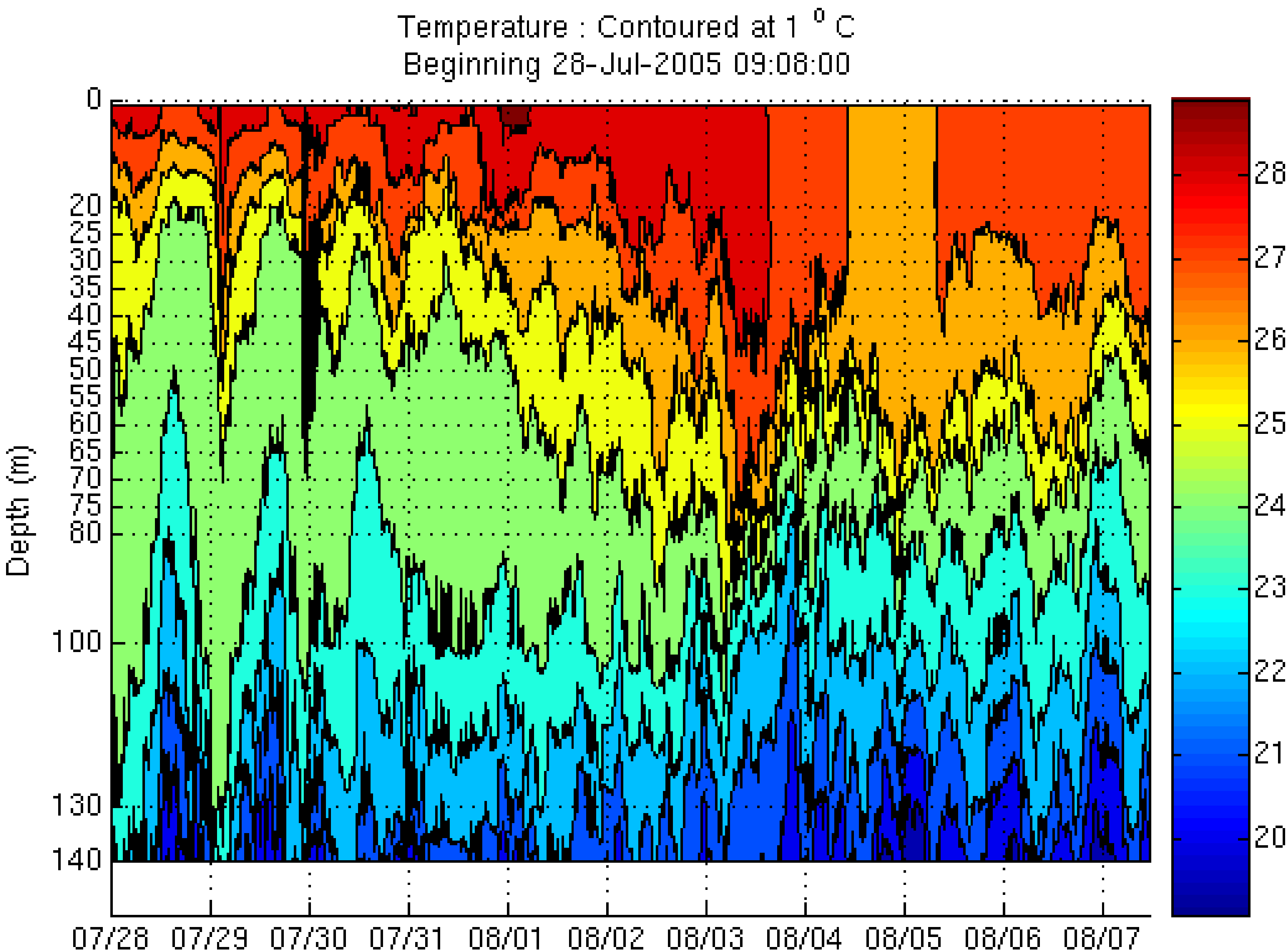




- Latitude - 22°17´N - 23°15´ N
- Longitude - 124°14´E - 124°49´ E
- Distance - 229.14 Km
- Velocity - 3.82m/ 15s







Temperature : Contoured at 1 °C
Beginning 28-Jul-2005 09:08:00
Depth (m)
0
20
25
30
35
40
45
50
55
60
65
70
75
80
100
130
140
07/28
07/29
07/30
07/31
08/01
08/02
08/03
08/04
08/05
08/06
08/07
28
27
26
25
24
23
22
21
20

Taylor Hypothesis for Drifting Buoy Measurements

- Difference between measurements at some time t and a later time $t + \tau$ acts as a proxy for the difference between measurements made at two points x and $x + l$.
- $T(t_1)$, $T(t_2)$, …, $T(t_n)$ … temporal interval τ
- $T(x_1)$, $T(x_2)$, …, $T(x_n)$, …spatial interval l

High-Order Structure Function

$$T_i = T(x_i), \quad x_i = il, \quad i = 0,1,\ldots,\Lambda, \quad L = \Lambda l\,,$$

$$|\Delta T(x_i, rl)| = |T(x_{i+r}) - T(x_i)|, \quad i = 0,1,\ldots,\Lambda - r$$

$$S(r,q) \equiv \left\langle |\Delta T(x, rl)|^q \right\rangle = \frac{1}{\Lambda - r}\sum_{i=0}^{\Lambda - r} |\Delta T(x_i, rl)|^q\,.$$

Here, r is the lag, q is the order of the structure function.
$S(r, 1)$ is the commonly used structure function.

$$S(1,1) = \frac{1}{\Lambda - 1}\sum_{i=0}^{\Lambda - 1} \left|T(x_{i+1}) - T(x_i)\right|$$

S(1,1) is the mean gradient .

Scale-Invariance

$$\left|\Delta T(x_i, l)\right| = r^{-H} \left|\Delta T(x_i, rl)\right|,$$

H is the scaling exponent, or called the Hurst exponent. In 1941, Kolmogorov suggested that the velocity increment in high-Reynolds number turbulent flows should scale with the mean (time-averaged) energy dissipation and the separation length scale.
The Hurst exponent *H* is equal to 1/3.

- Simple self-similarity

$$\left\langle \left| \Delta T(x_i, l) \right|^q \right\rangle = r^{-qH} \left\langle \left| \Delta T(x_i, rl) \right|^q \right\rangle .$$

- Multifractal behavior

$$\left\langle \left| \Delta T(x_i, l) \right|^q \right\rangle = r^{-\zeta(q)} \left\langle \left| \Delta T(x_i, rl) \right|^q \right\rangle .$$

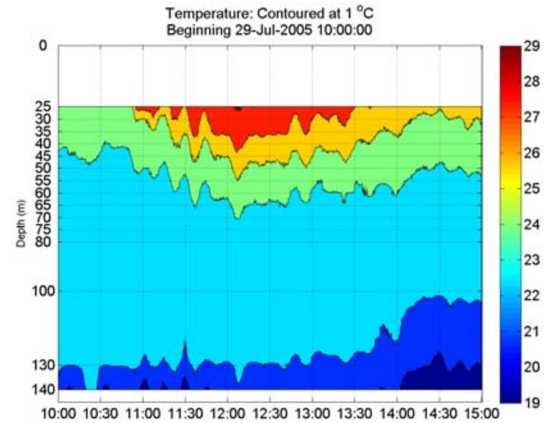
$$\zeta(q) \neq qH .$$

$$S(r,q) \sim r^{\zeta(q)}$$

Three Types

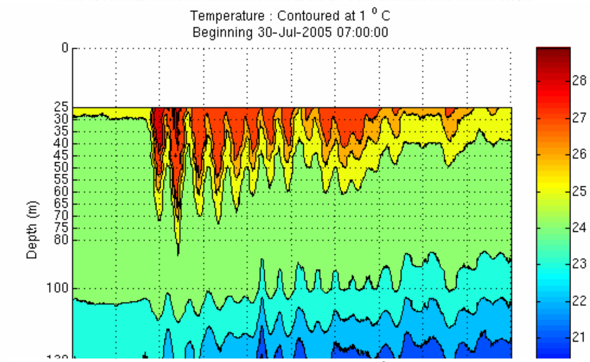
(a) Internal Wave -turbulence (IW-T)

(1000-1500 GMT July 29)

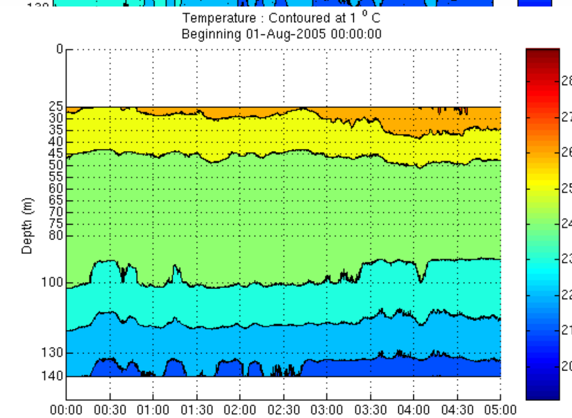


(b) Internal Soliton - turbulence (IS-T)

(0700-1200 GMT July 30)



(c) Turbulence-dominated (T) (0000- 0500 GMT August 1)



Isopycnal Displacement

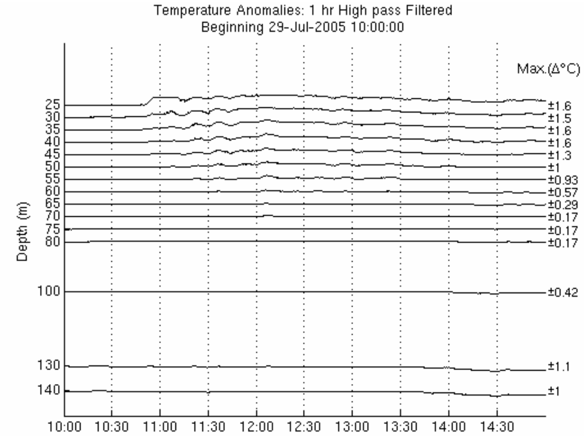
(Desaubles and Gregg, 1981,JPO)

$$T'(t,z) = T(t,z) - \bar{T}(z),$$

$$\eta(t,z) = -\frac{T'(t,z)}{d\bar{T}/dz},$$

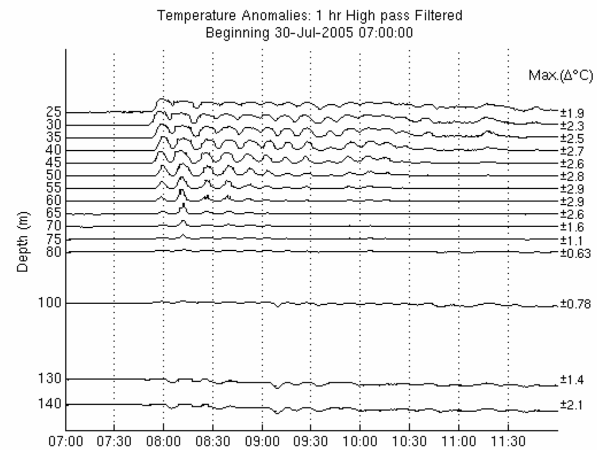
(a) IW-T type

(1000-1500 GMT July 29)



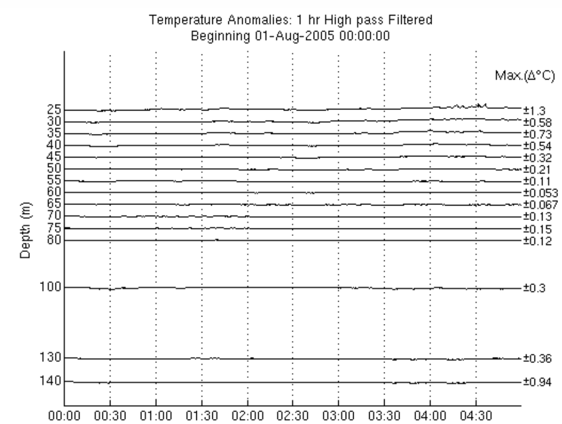
(b) IS-T type

(0700-1200 GMT July 30)



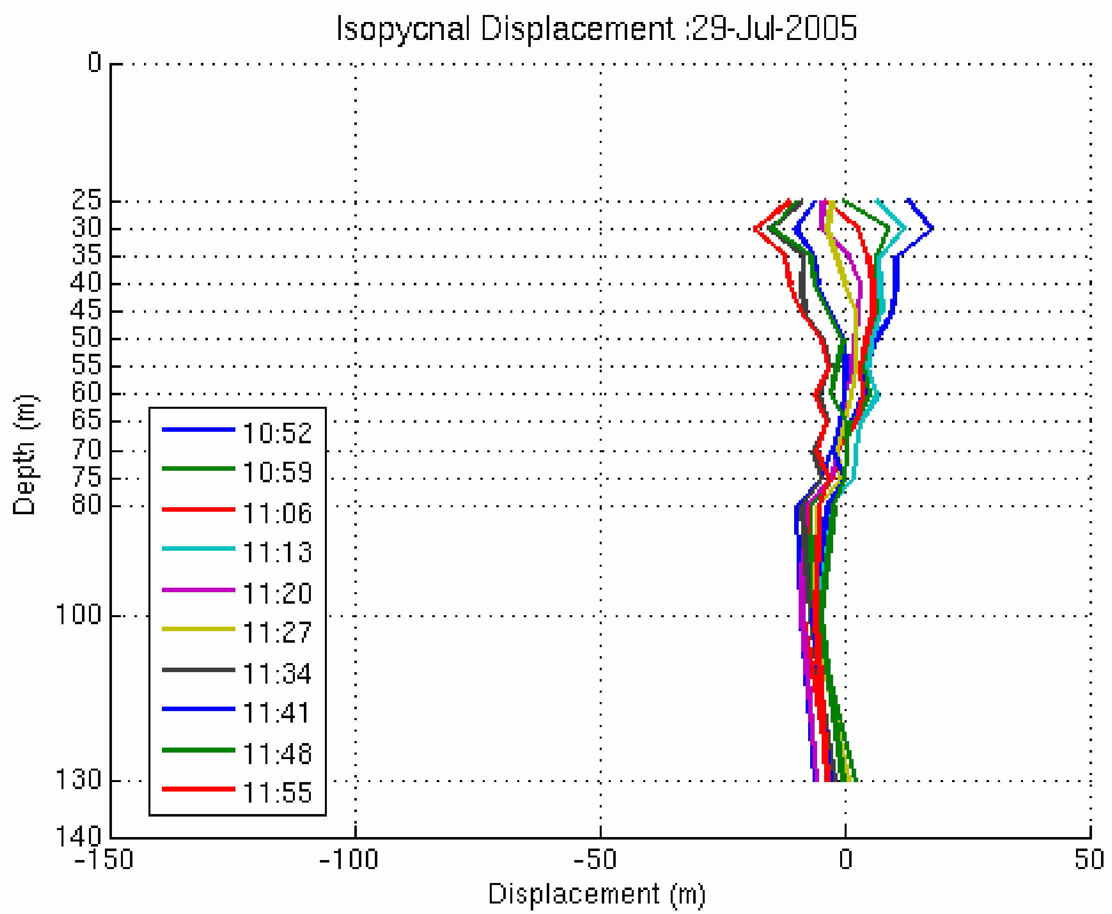
(c) T- type

(0000- 0500 GMT August 1)



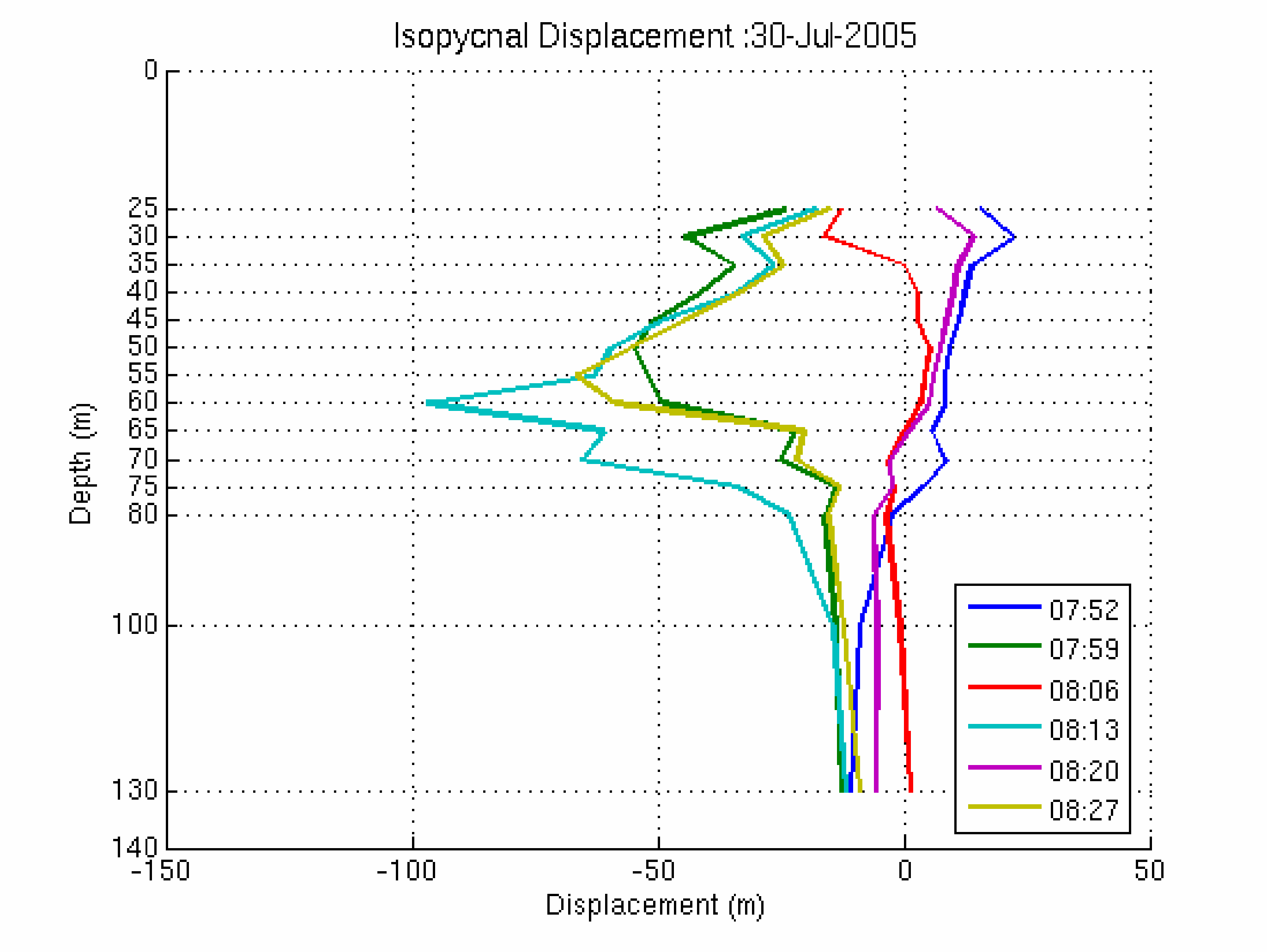
Isopycnal Displacement

IW-T (10-15 GMT July 29)



Isopycnal Displacement

IS-T (07-12 GMT July 30)

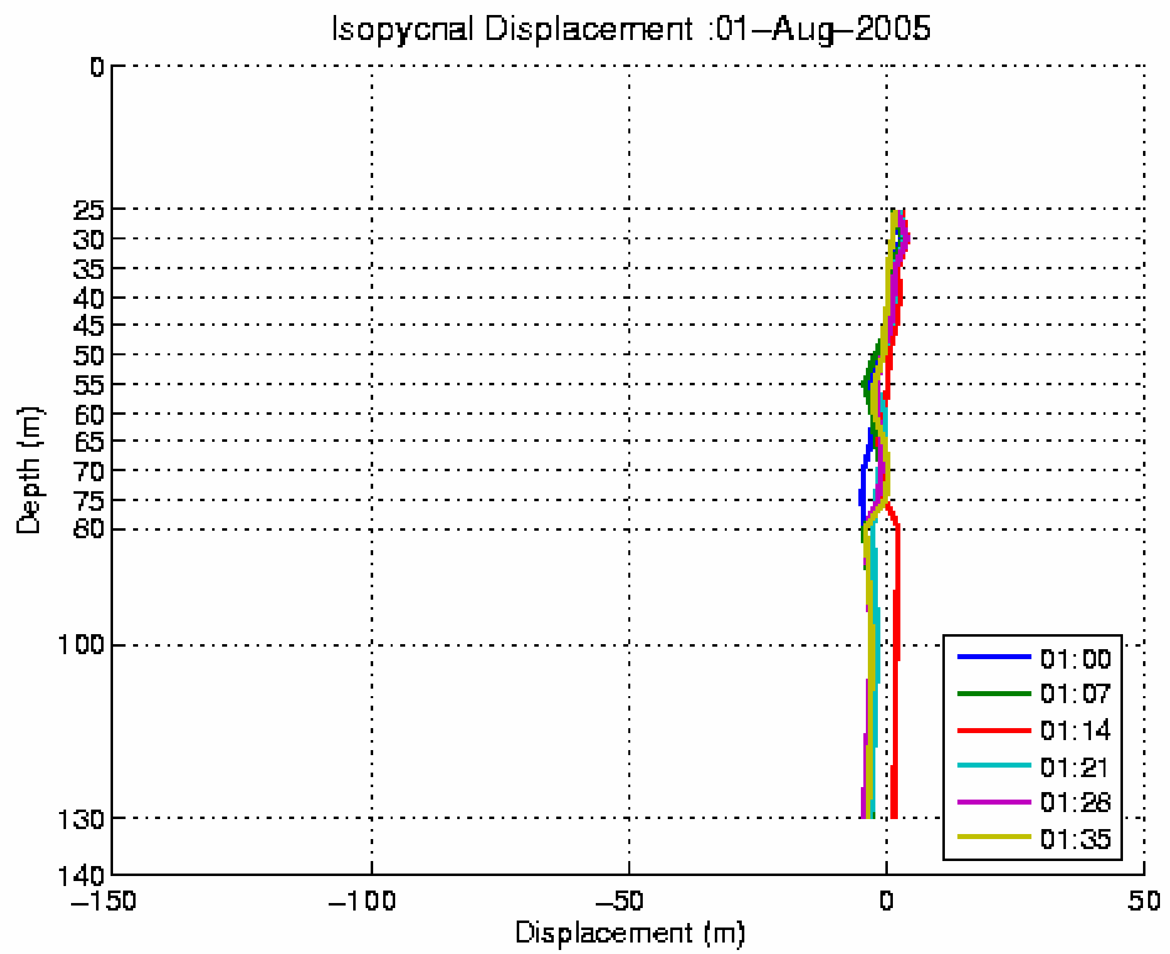


Frequency is around

4 CPH

Isopycnal Displacement

turbulence-Dominated (00-05 GMT Aug 1)

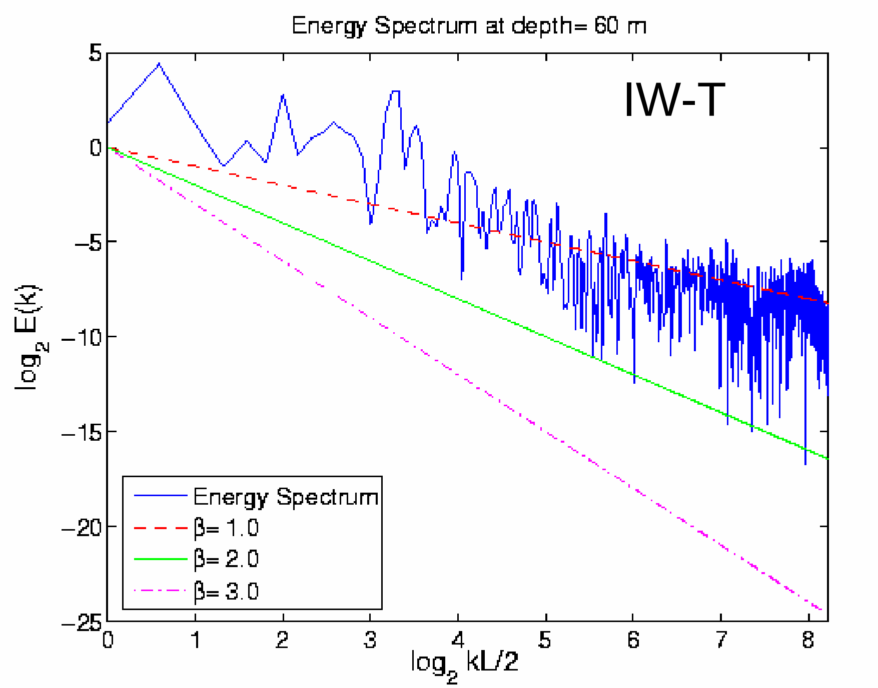


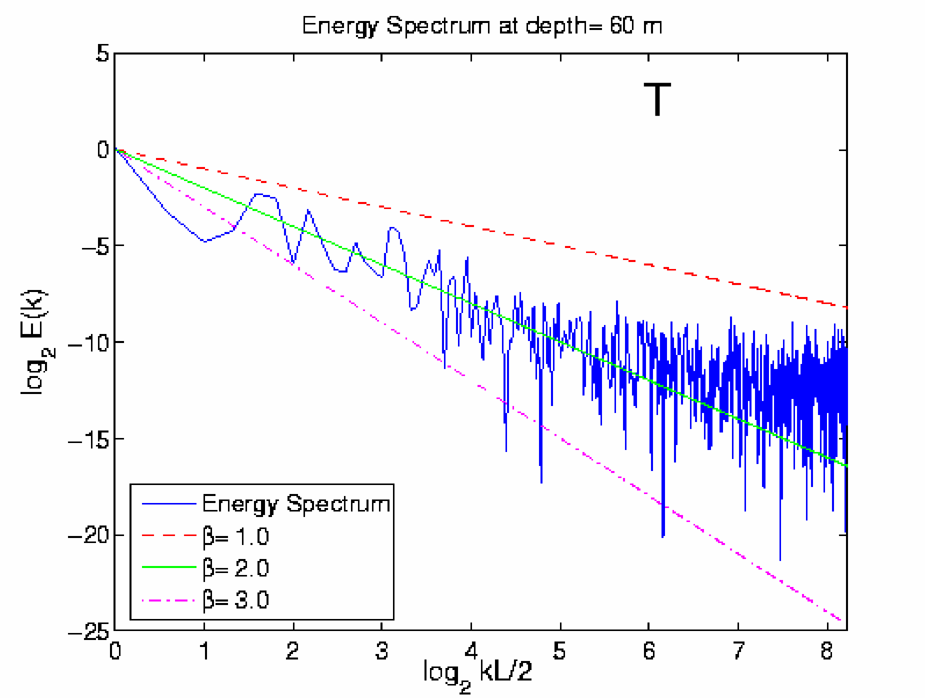
Power Spectrum

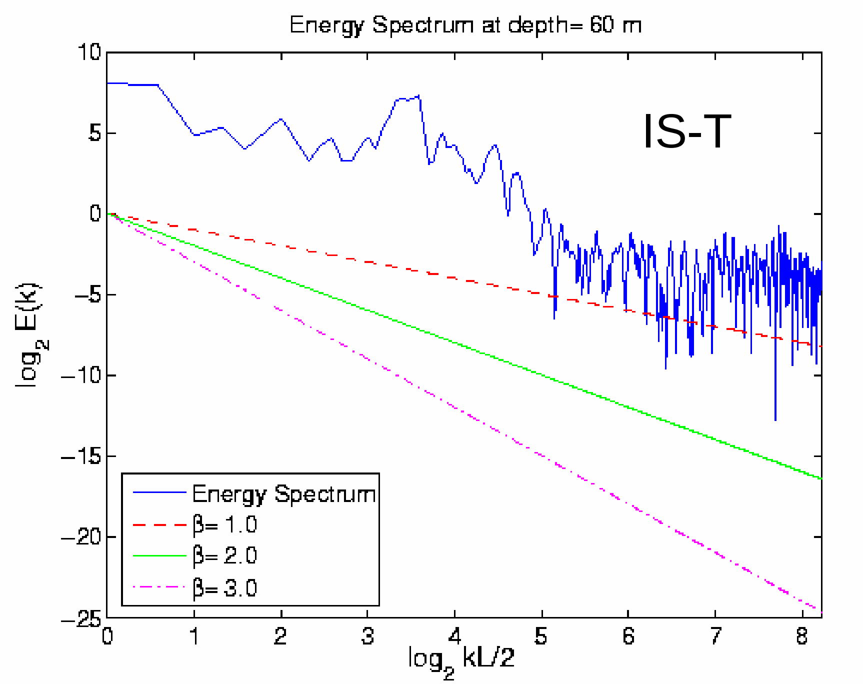
$$E_j = E(k_j), \quad k_j = j / L, \quad j = 1, 2, \ldots, \Lambda / 2, \quad L = \Lambda l \qquad \Lambda = 1{,}200)$$

$$E(k) \propto k^{-\beta},$$

$\beta < 1,$	Stationary
$1 < \beta < 3,$	Nonstationary with stationary increments
$\beta > 3,$	Nonstationary with nonstationary increments



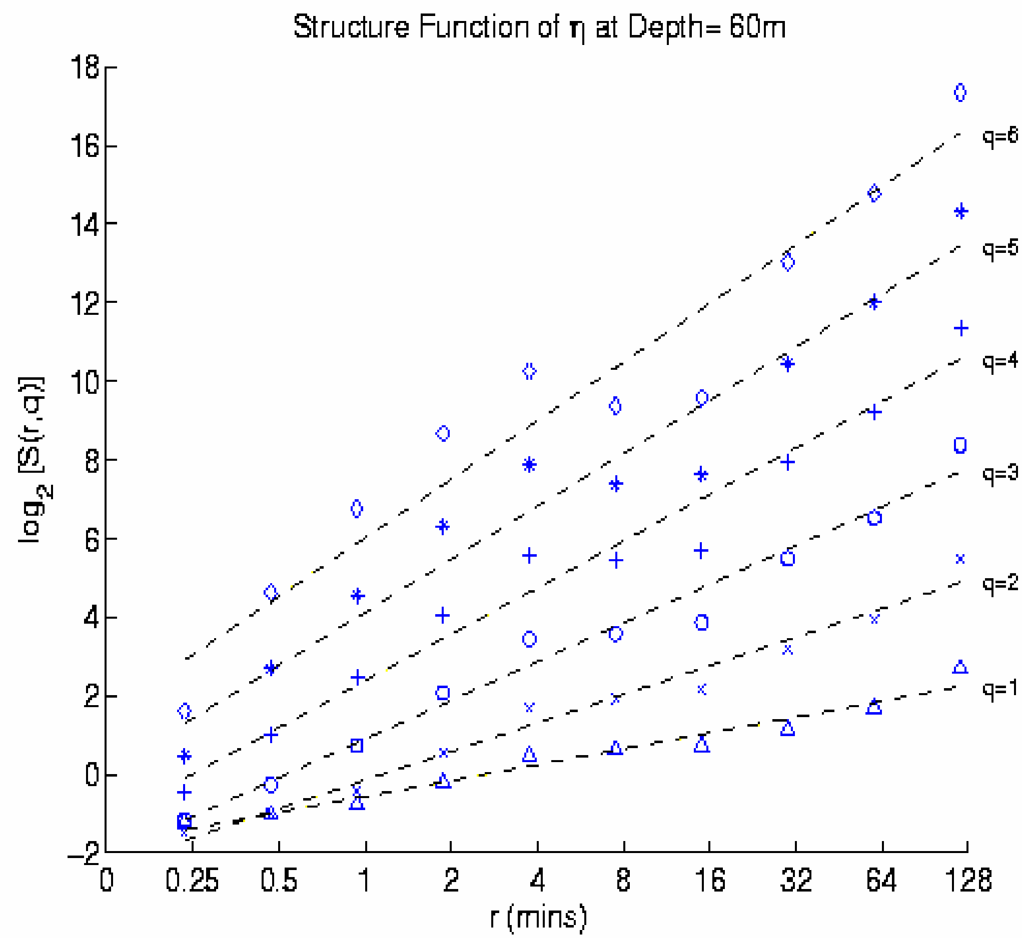




IW-T and T have similar multi scaling characteristics with β around 0.4 (stationary) for low wavenumbers and nearly 5/3 (non-stationary with stationary increment) for high wave numbers.

60 m depth

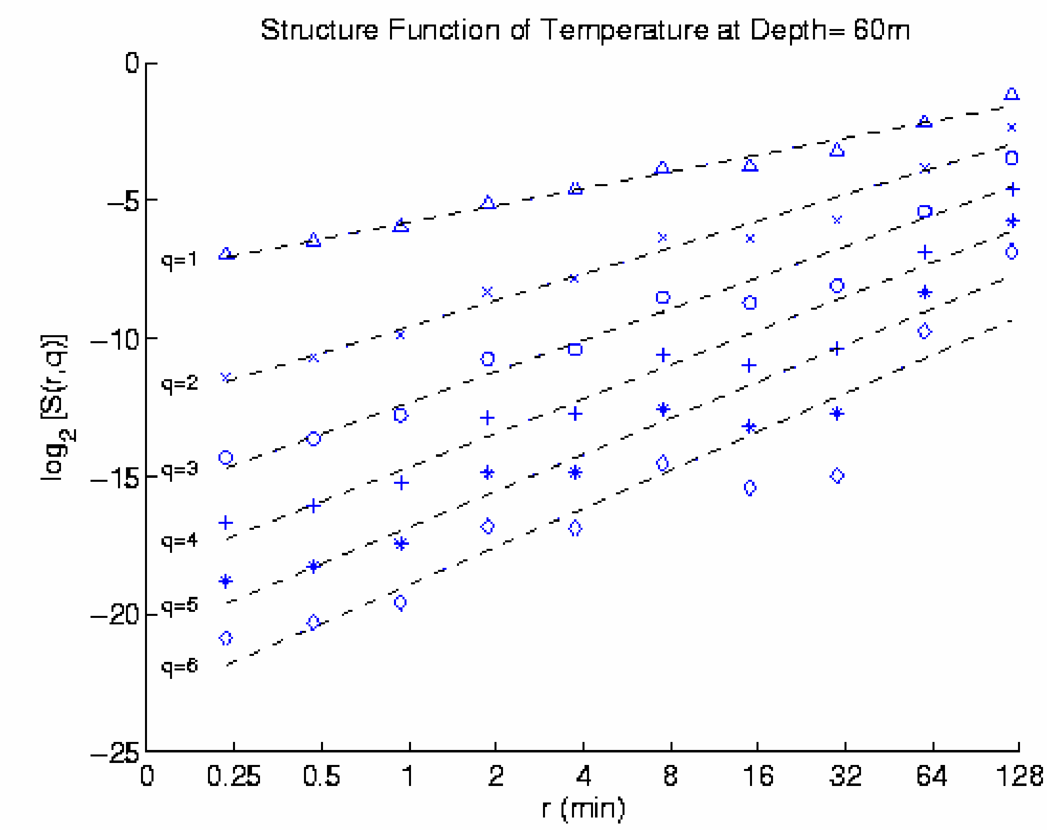
Structure Function (Power Law) IW-T type



$$S(r,q) \propto r^{\zeta(q)},$$

$$\zeta(q) = H(q)q,$$

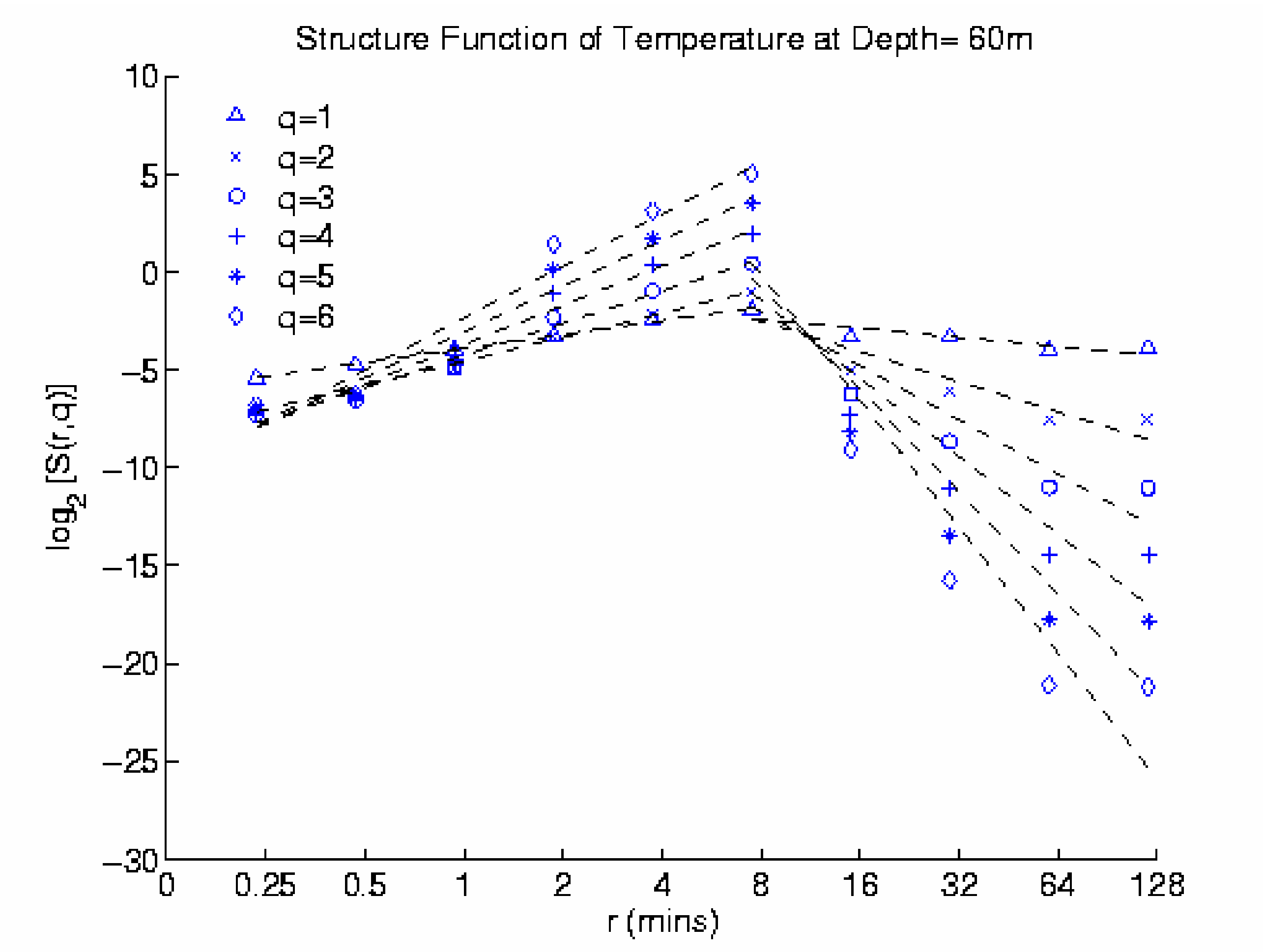
Structure Function (Power Law)
T type



$$S(r,q) \propto r^{\zeta(q)},$$

$$\zeta(q) = H(q)q,$$

Structure Function
IS-T type



Power law breaks at 8 min, near half period (4 CPH) of the internal solitons

Possible Reason for Preservation of the Power Law in IW-T Type

Using the Hamitonian formulation, Lvov and Tabak (2001) modified the Garrett-Munk spectrum into

$$E(k,m) = \frac{2fNE}{\pi}\frac{(m/m^*)A(m/m^*)}{N^2k^2 + f^2m^2},$$

$$m^* \equiv \gamma(\omega^2 - f^2)^{-\delta/2},\; A(\lambda) \equiv \frac{t-1}{(1+\lambda)^t}$$

which represents both internal waves and wave turbulence.

Possible Reason for Break of the Power Law in IS-T Type

- The internal solitary waves are a class of nonsinusoidal, nonlinear, more-or-less isolated waves of complex shape that maintain their coherence. Their energy spectrum is totally different from the internal wave spectrum.

Conclusions

- (1) Three types of thermal variability (IW-T, IS-T, and T) are identified.
- (2) Multifractal structures are found in the upper layer of the western Philippine Sea.
- (3) Power law preserves in structure function with multifractal characteristics for the IW-T and T types, but not for the IS-T type.
- (4) The internal waves increase the power of the structure function especially for high moments.
- (5) The internal solitons destroy the multifractal characteristics of the structure function at the lag of 8 min, which is nearly half period of the IS (with frequency of 4 CPH).