Oct. 23, 2009.

Observation of Near-Inertial Waves in an Anticyclonic Mesoscale Eddy in the Southwestern East/Japan Sea

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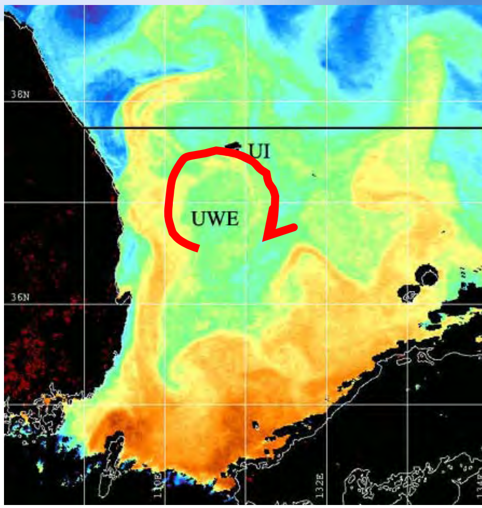
Contents

- Typical feature of the Ulleung Warm Eddy (UWE)

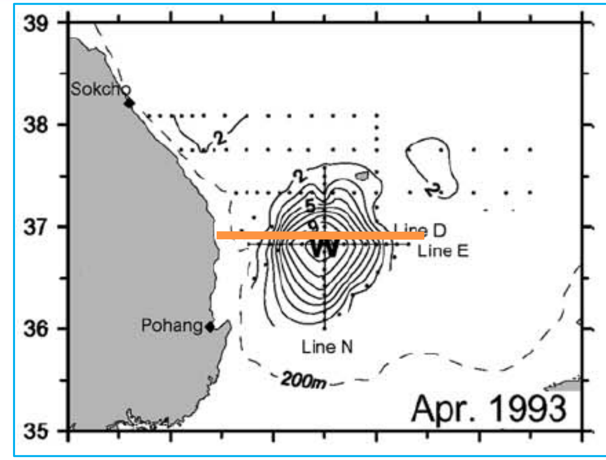
- The first observational evidence of near-inertial wave reflections upper thermostad layer of the UWE

- Near-inertial wave amplifications at the bottom of the UWE from a continuous time series

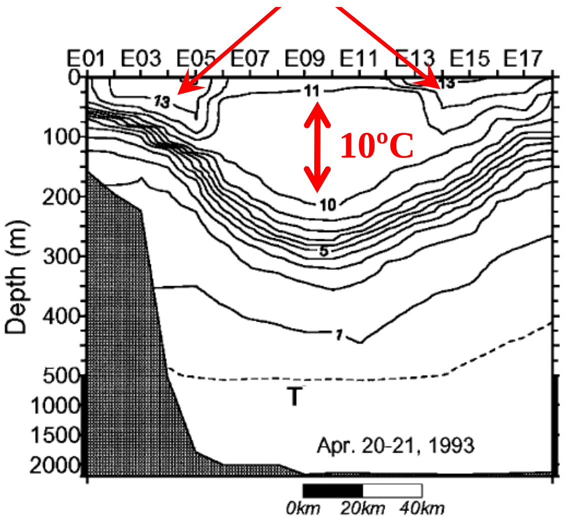
The Ulleung Warm Eddy

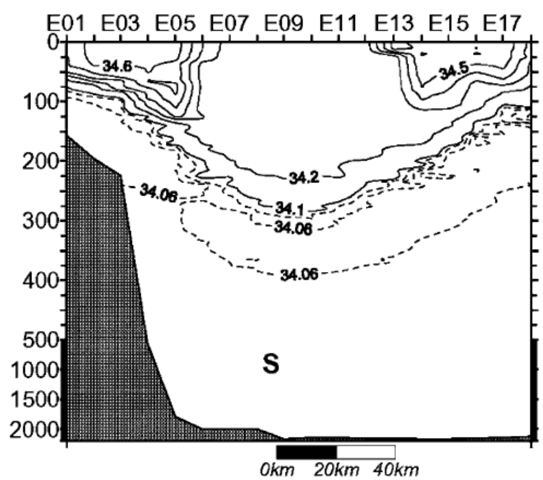


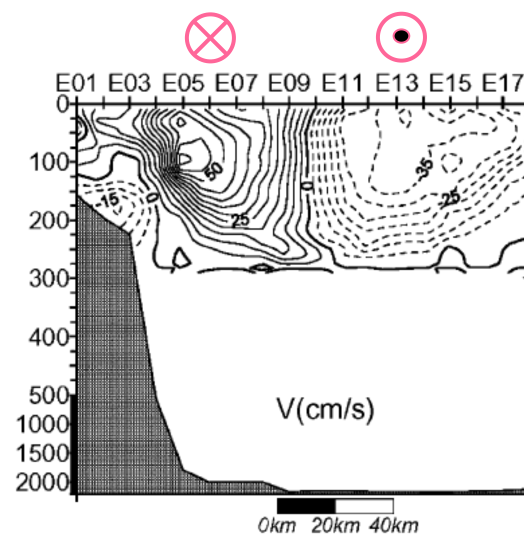
Surface signature
(Chang et al., 2004)



warm streamer

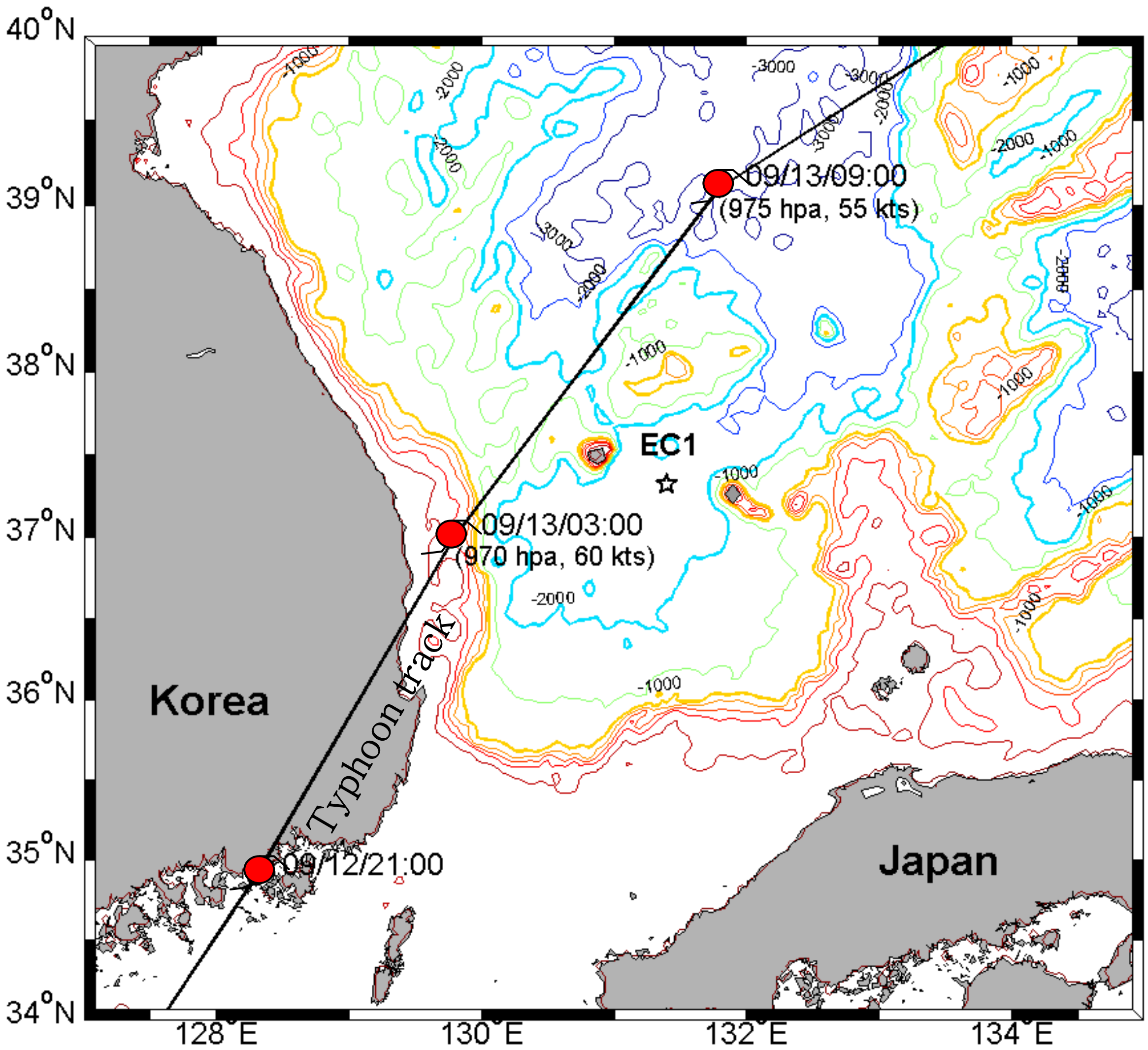




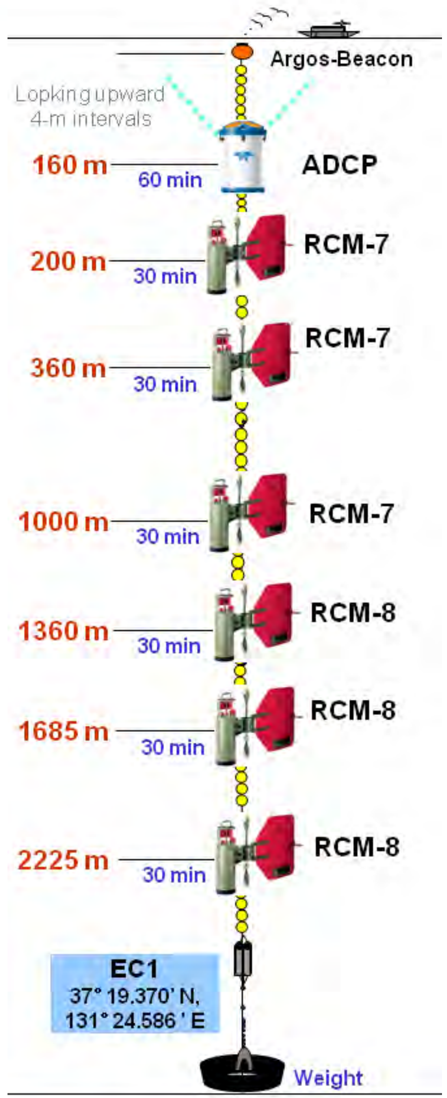


Shin et al. (2005)

Data : Nov 2002 ~ Apr 2004 (16.5 moth)

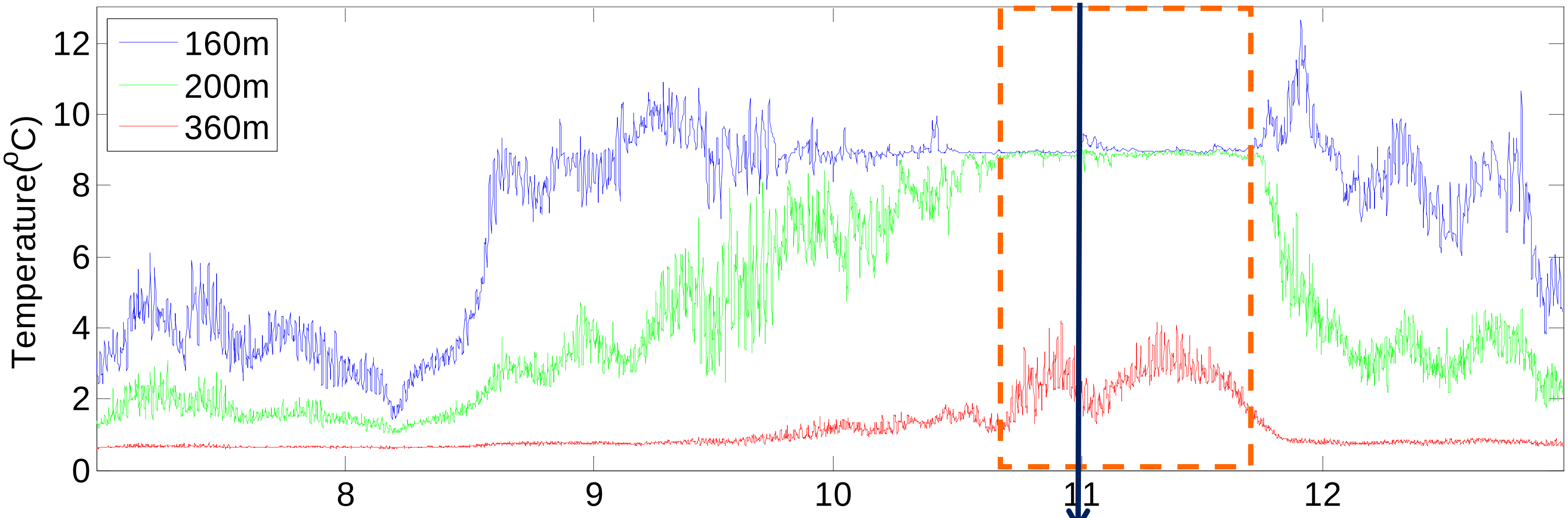


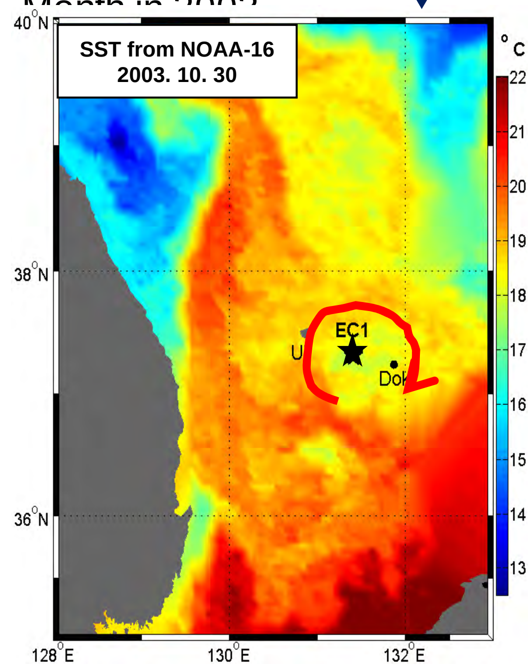
Study Area.

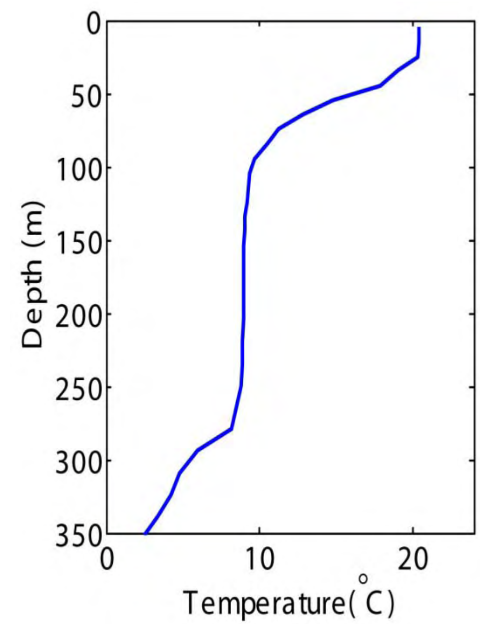


Mooring Configuration

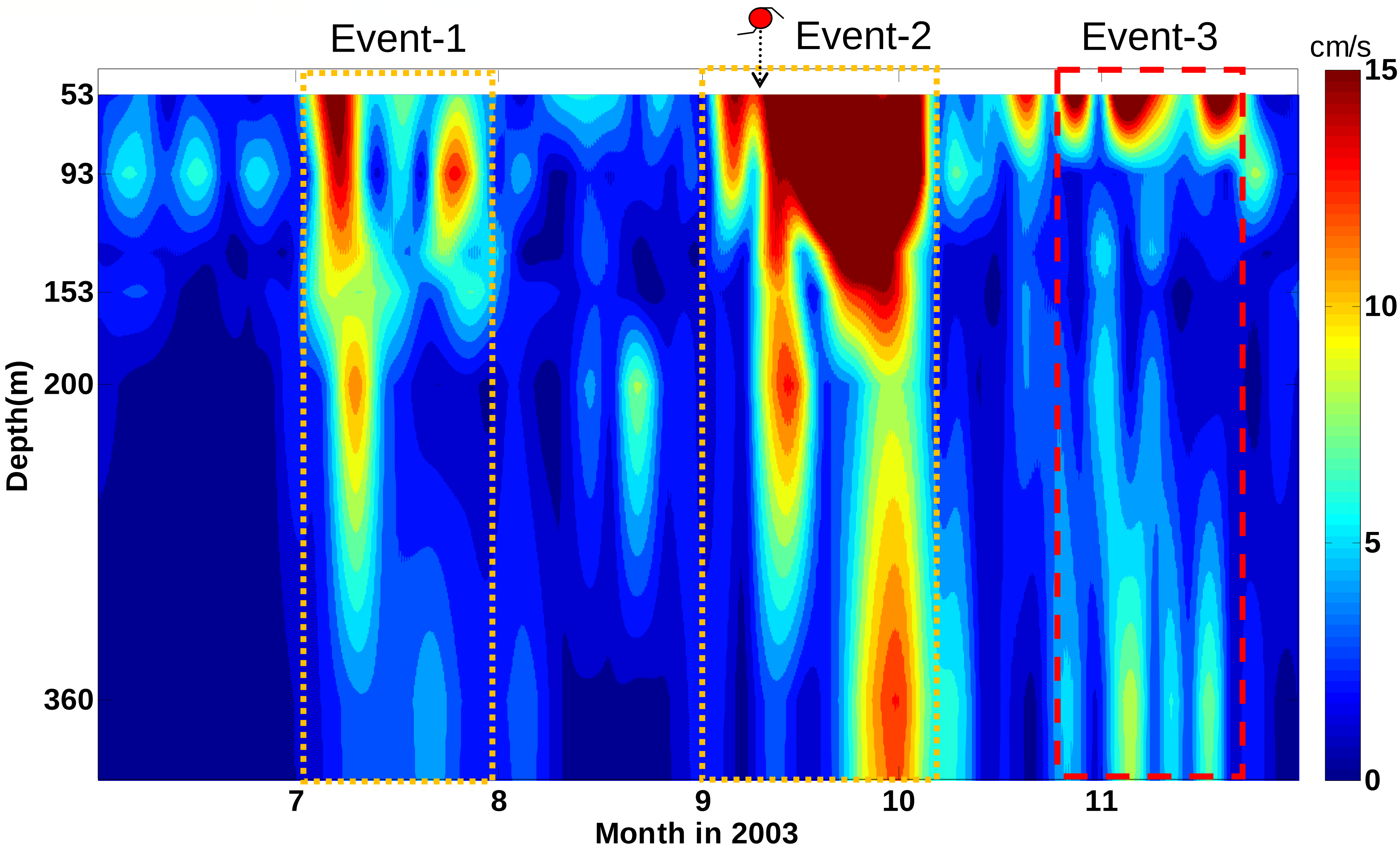
Observation of an Anticyclonic Eddy



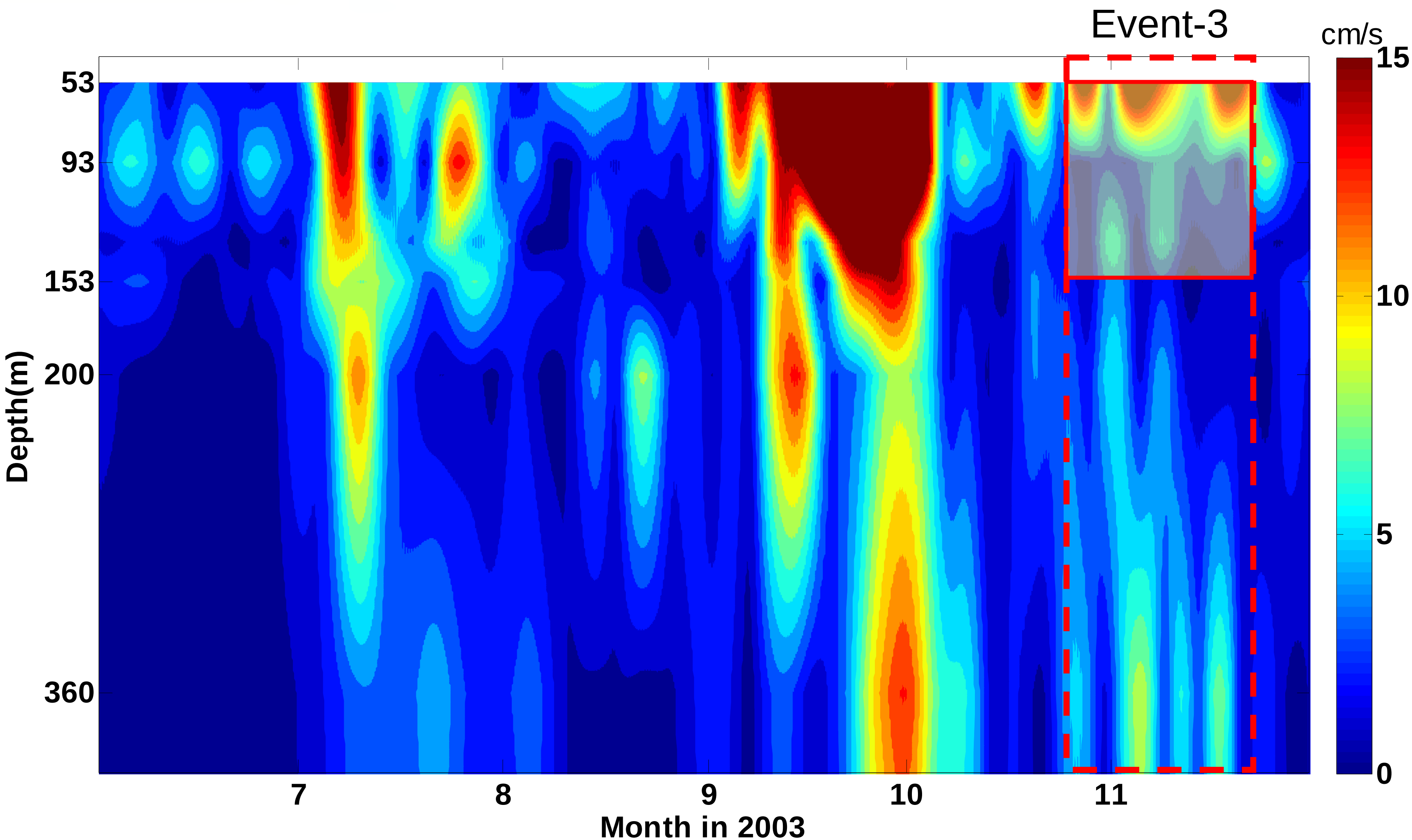




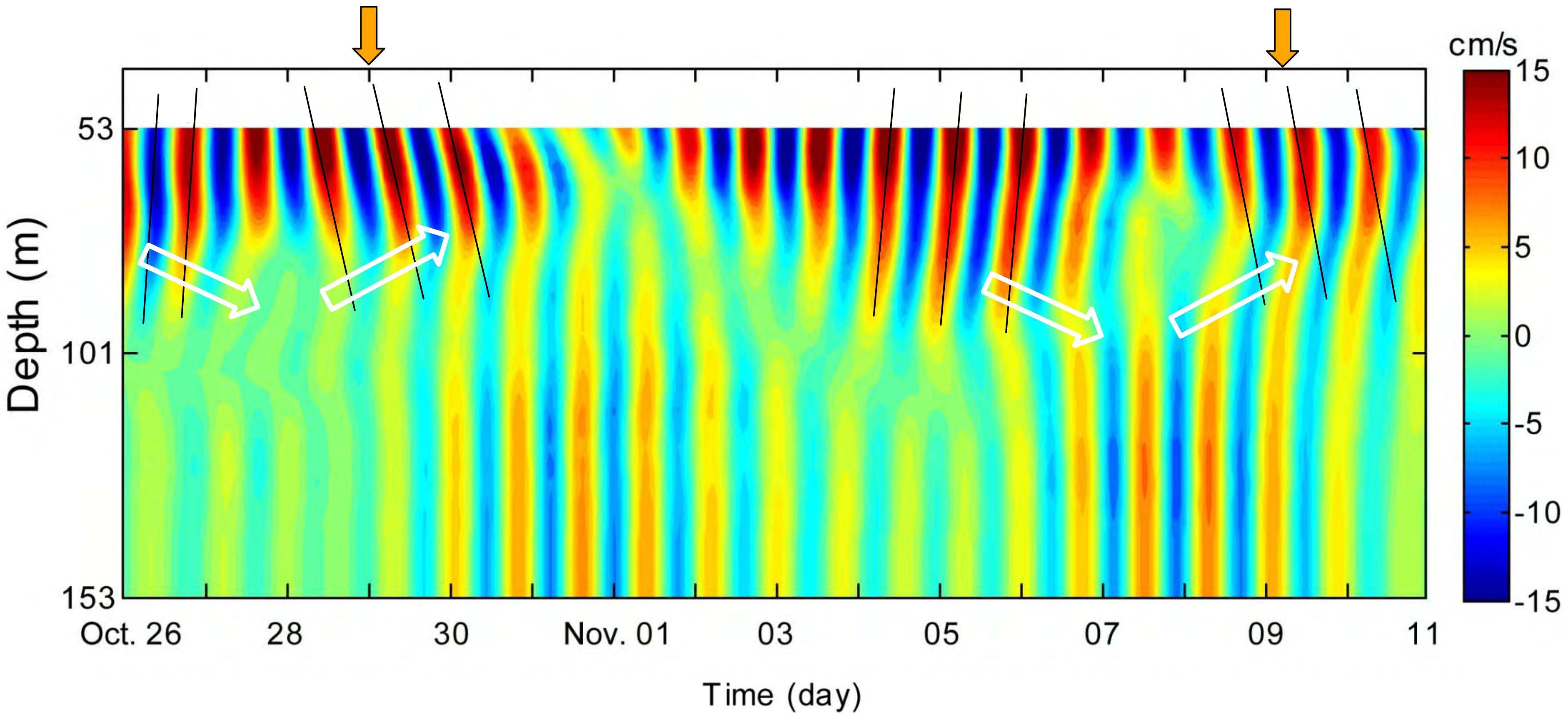
NIW amplitude $\left(\sqrt{u^2 + v^2}\right)$



① NIW reflections upper thermostad layer



NIW downward phase propagation



Scaling analysis

$$\omega_0 = \omega - (\mathbf{k}\cdot\mathbf{V}) \approx \left[f_{\text{eff}} + \frac{N^2 k_H{}^2}{2 f k_z{}^2} + \frac{1}{k_z}\left(\frac{\partial U}{\partial z} k_y - \frac{\partial V}{\partial z} k_x\right)\right]$$

$$\boxed{Cg_z = \frac{\partial \omega_0}{\partial k_z} \approx \frac{-N^2 k_H{}^2}{f k_z{}^3} - \frac{1}{k_z{}^2}\left(\frac{\partial U}{\partial z} k_y - \frac{\partial V}{\partial z} k_x\right)}$$

Considering isotropic NIW and maximum vertical shear,

$$|k_x| = |k_y|, \quad \left|\frac{\partial U}{\partial z}\right| + \left|\frac{\partial V}{\partial z}\right|$$

$$Cg_z = \frac{-N^2 k_H{}^2}{f k_z{}^3} + \frac{|k_x|}{k_z{}^2}\left(\left|\frac{\partial U}{\partial z}\right| + \left|\frac{\partial V}{\partial z}\right|\right),$$

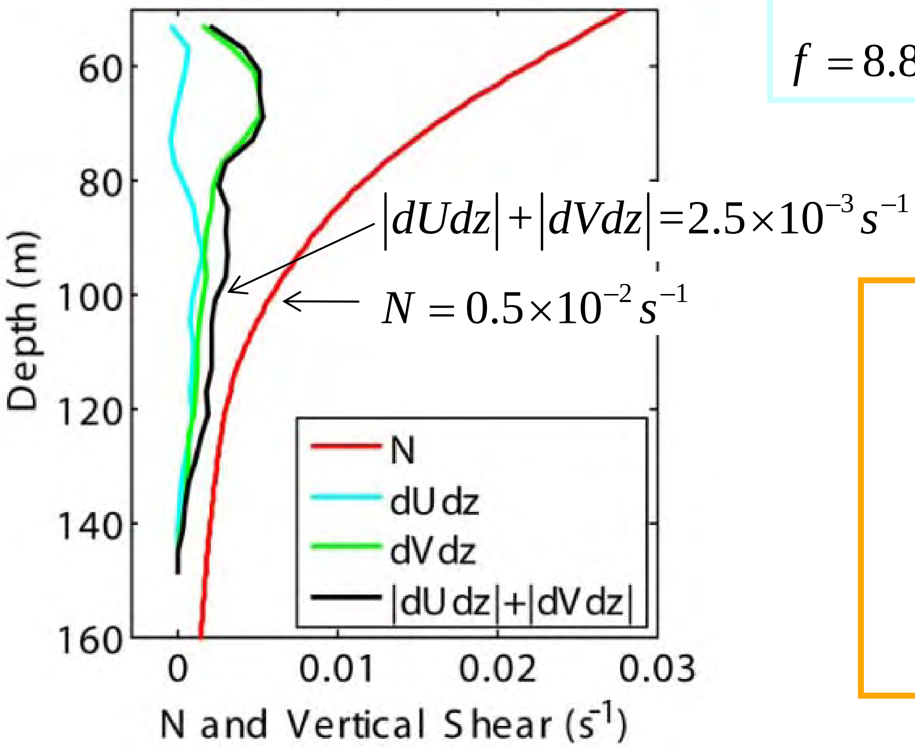
In order to compare the two terms in the equation,

$$\mu \equiv \frac{f\,|k_x||k_z|}{N^2 k_H^2}\left(\left|\frac{\partial U}{\partial z}\right| + \left|\frac{\partial V}{\partial z}\right|\right)$$

$\mu < 1$: downward energy propagation

$\mu > 1$: upward energy propagation

Scaling analysis



horizontal and vertical wavelengths : 40 km, 100 m

$f = 8.84\times10^{-5}s^{-1}$

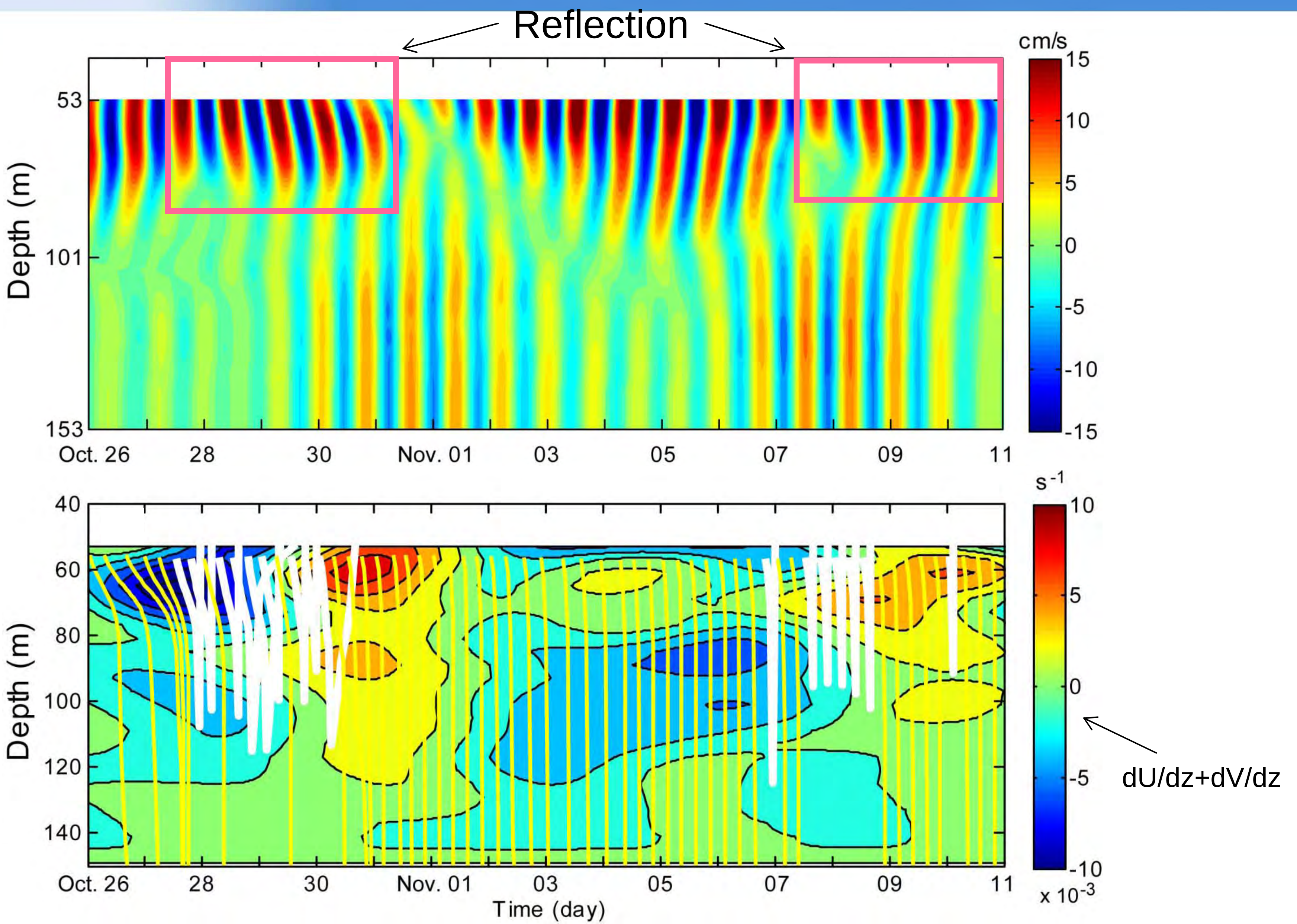
$$\mu \equiv \frac{f\,|k_x||k_z|}{N^2k_H^2}\left(\left|\frac{\partial U}{\partial z}\right|+\left|\frac{\partial V}{\partial z}\right|\right)$$

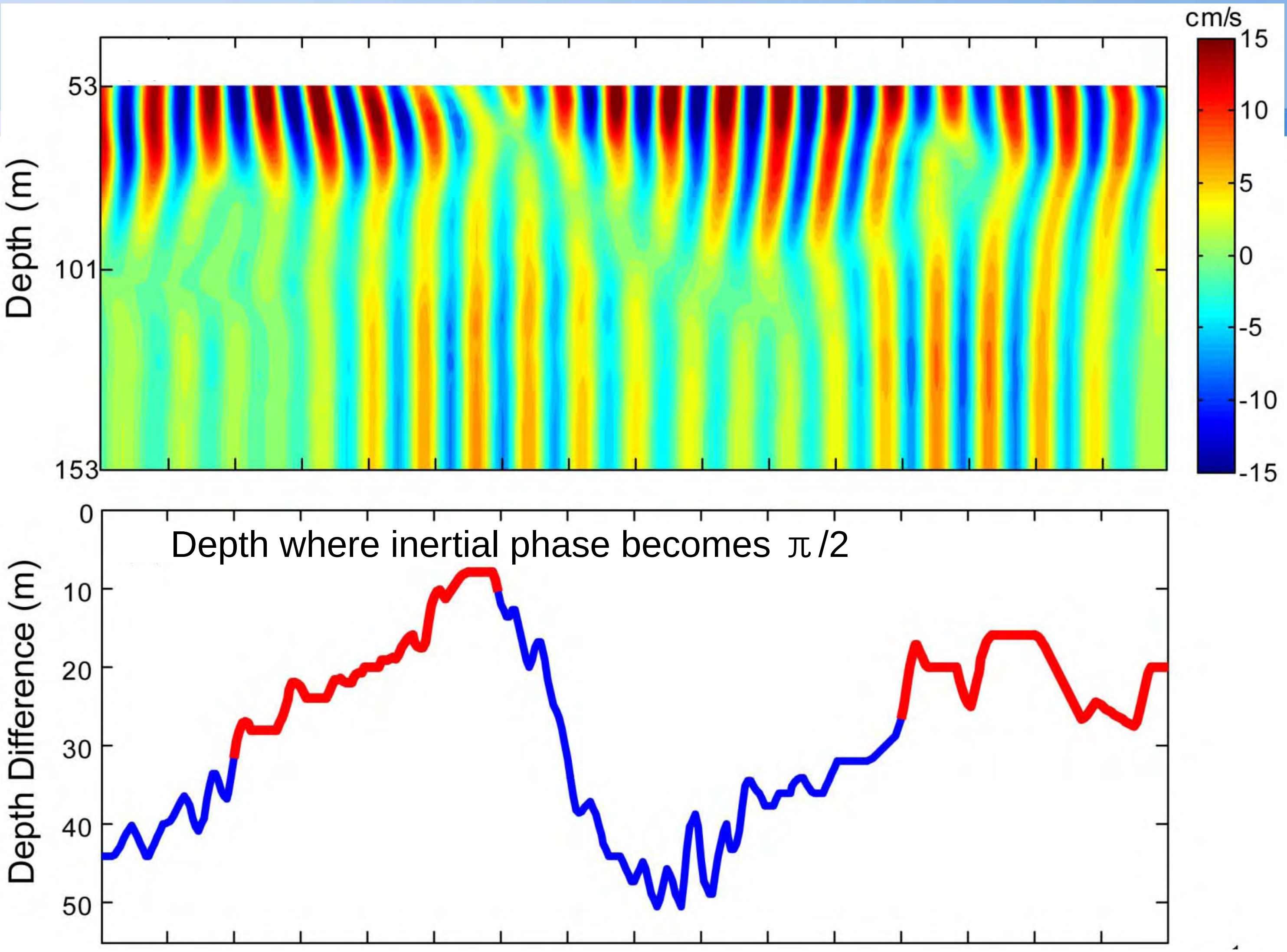
$\mu < 1$: downward energy propagation

$\mu > 1$: upward energy propagation

$$\mu = 2.5$$

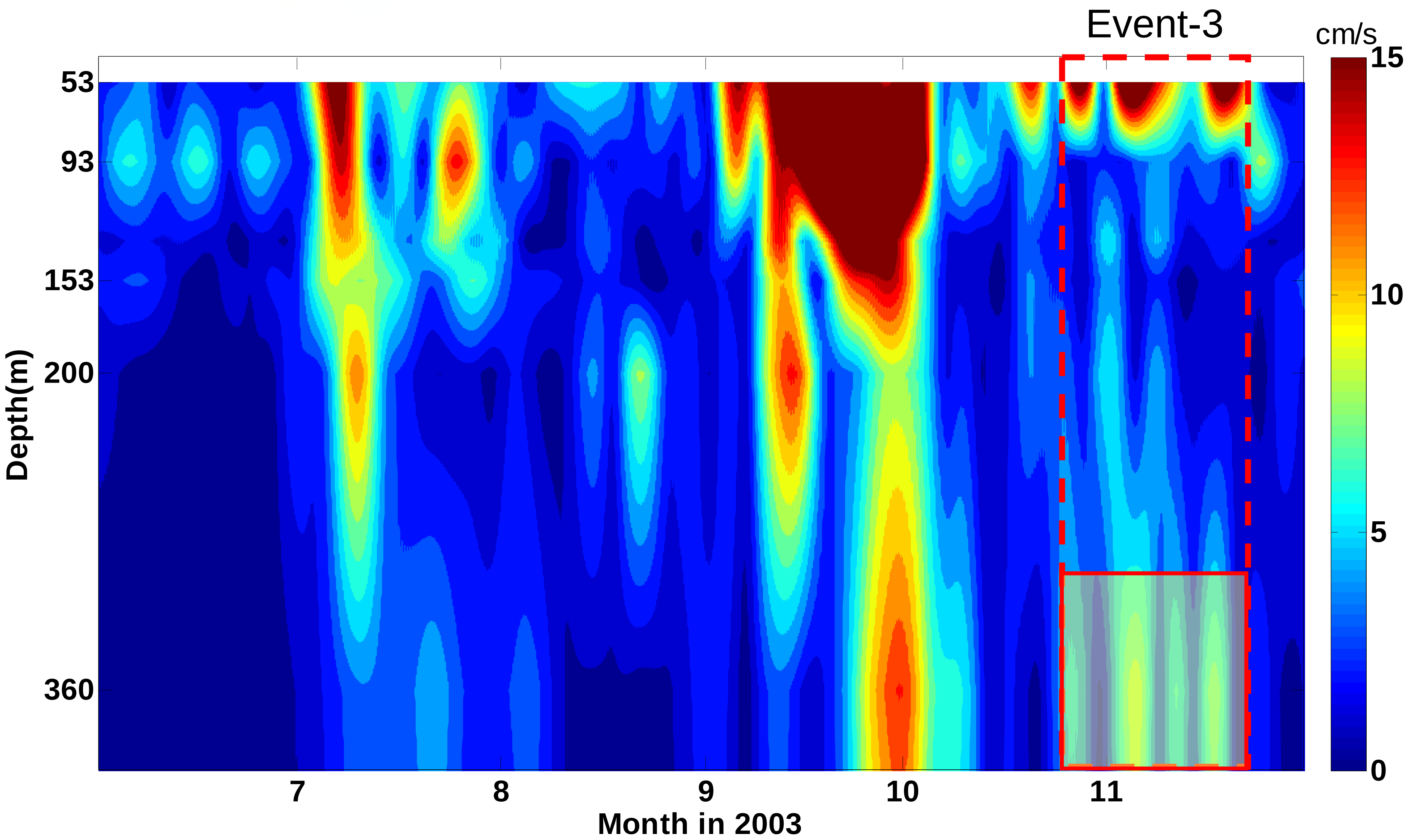
Ray-tracing


Reflection
cm/s
15
10
5
0
-5
-10
-15
53
101
153
Depth (m)
Oct. 26
28
30
Nov. 01
03
05
07
09
11
s -1
10
5
0
-5
-10
x 10-3
40
60
80
100
120
140
Depth (m)
Time (day)
dU/dz+dV/dz

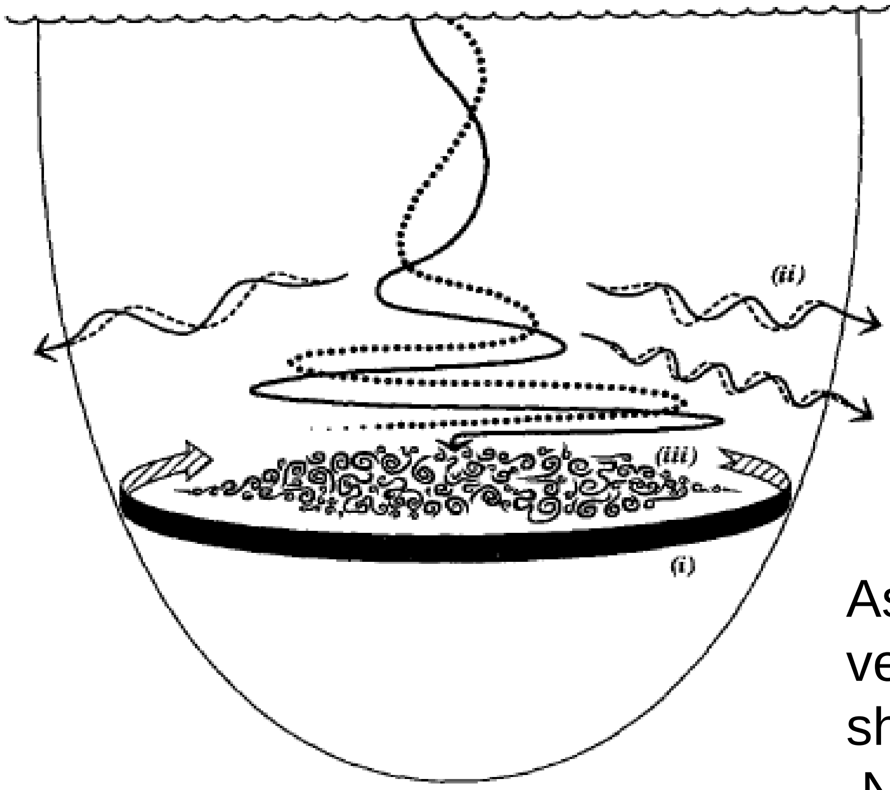


Jordi and Wang [2008] indicated that downward propagating free NIWs can be suppressed by bottom reflected NIWs and induce turbulence.

② NIW amplification at the bottom of the eddy



NIW amplifications at the bottom of the eddy

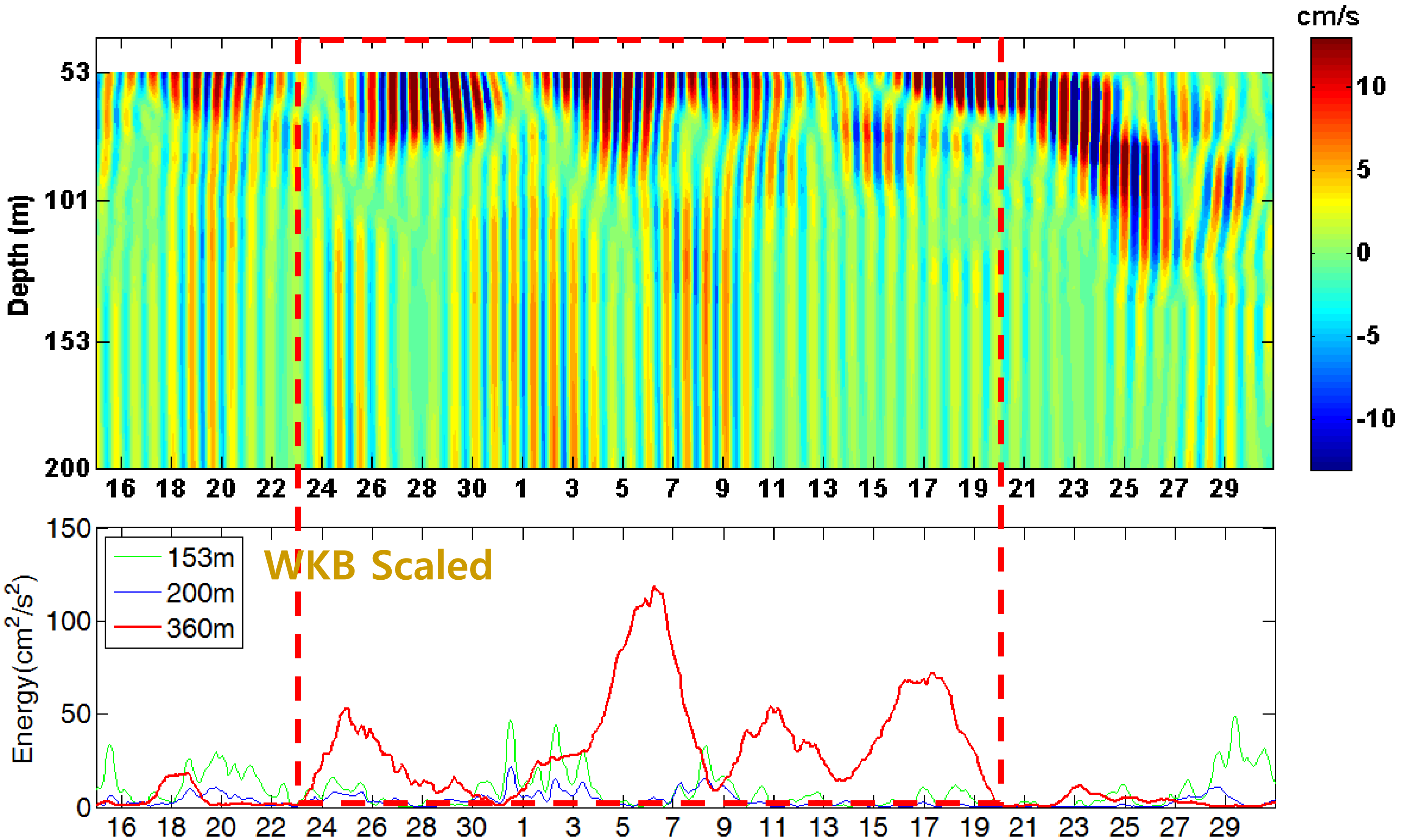


(Kunze et al., 1995)

As NIW approaches its critical depth, vertical wavelength and group velocity shrink.

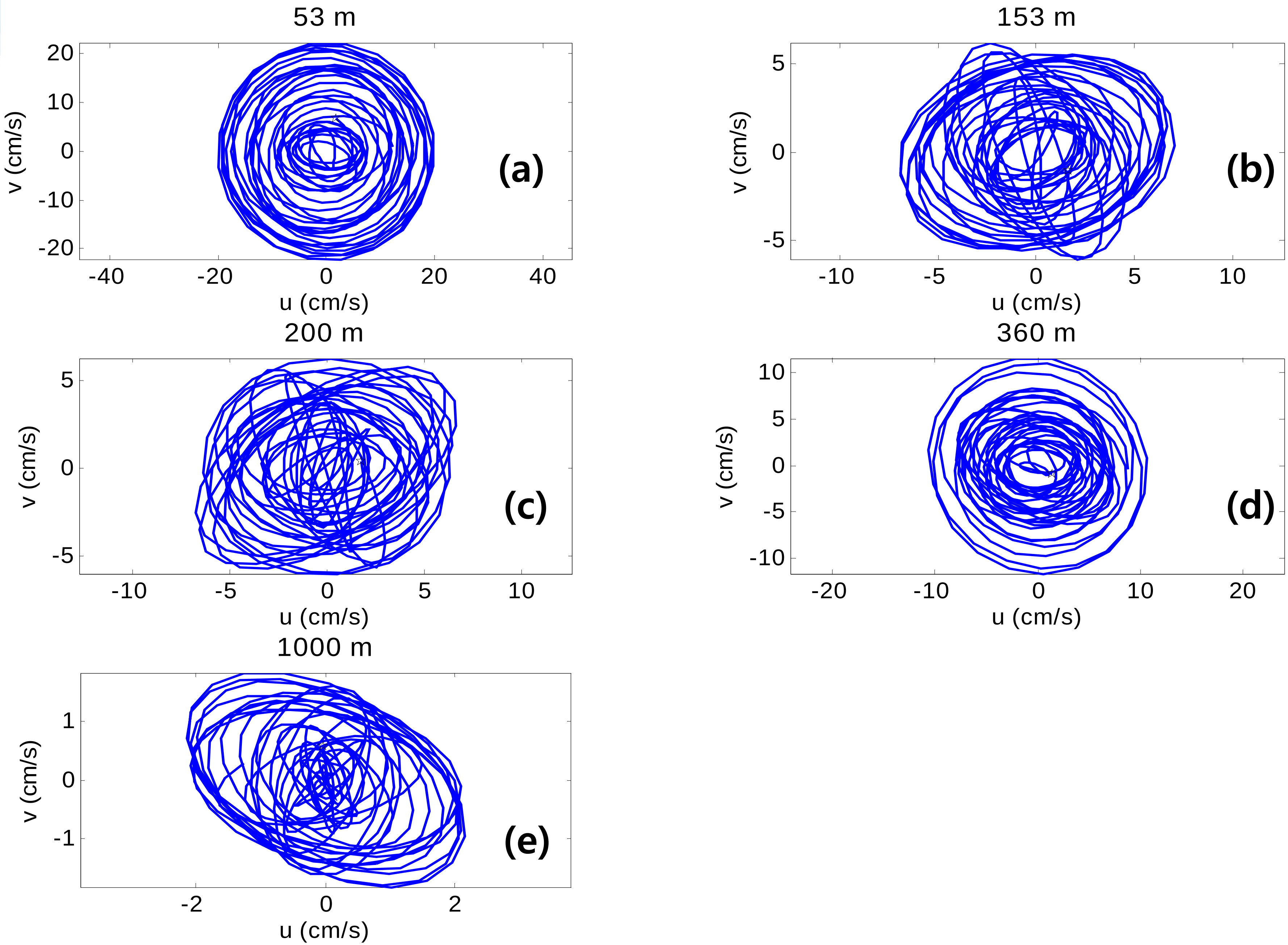
NIW energy builds up until it is lost to turbulence.

WKB (Wentzel–Kramers–Brillouin) scaled NIW energy

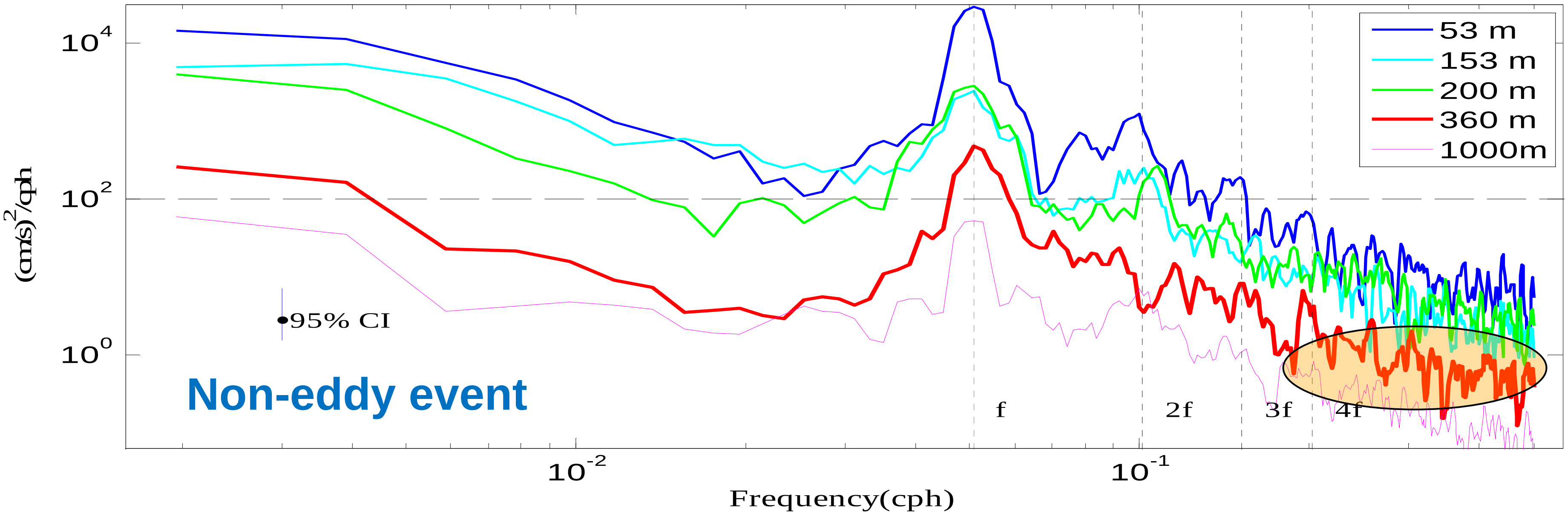


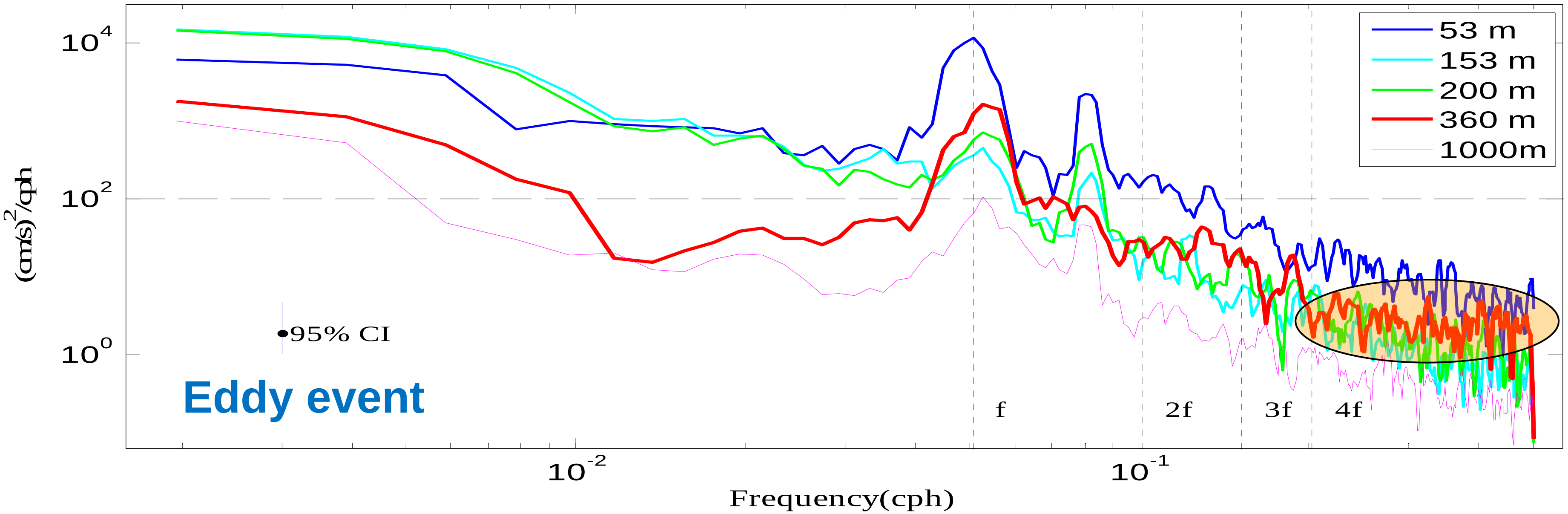
(10/15 ~ 11/30)

NIW hodographs



Power Spectra

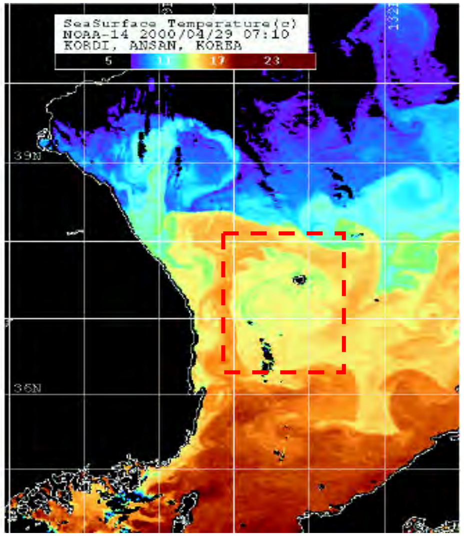


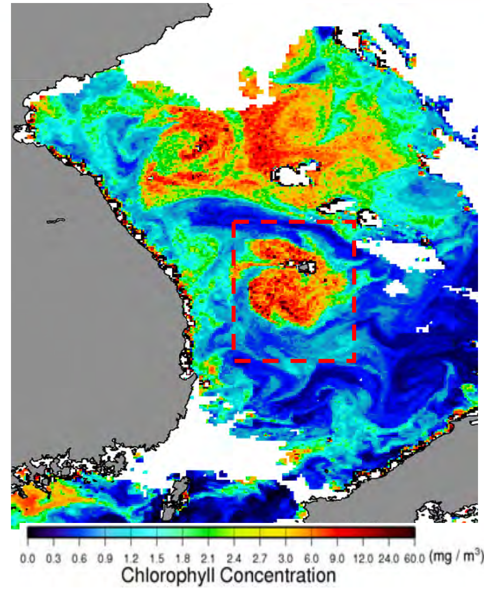


Plankton bloom in the UWE core

SST

(Apr. 29, 2000)

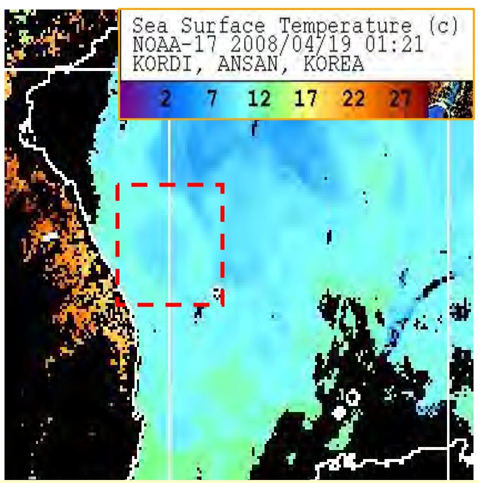


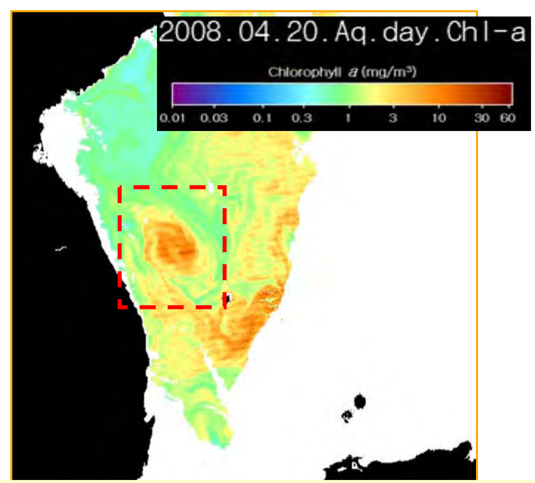


Chlorophyll Concentration

(May 3, 2000)

(Apr. 19, 2008)



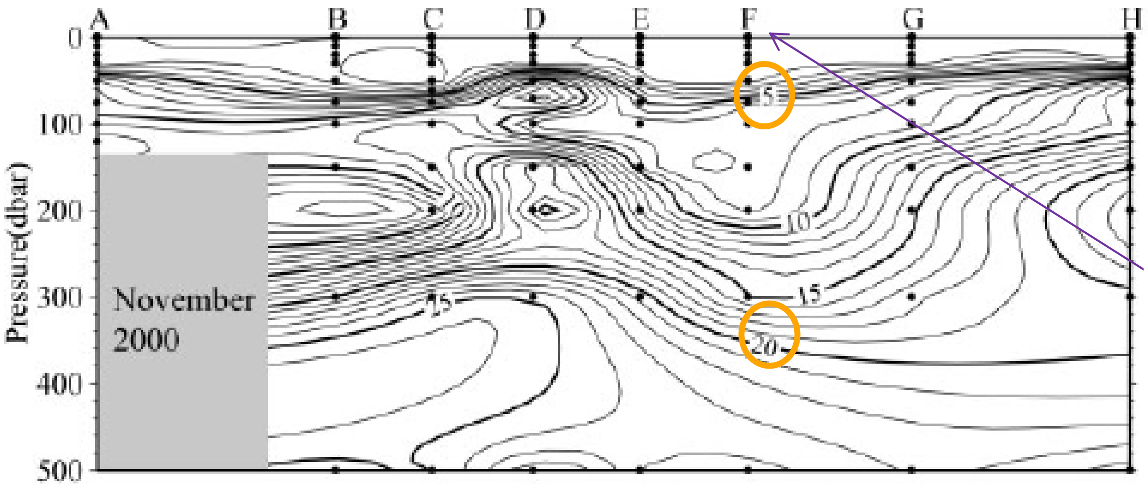


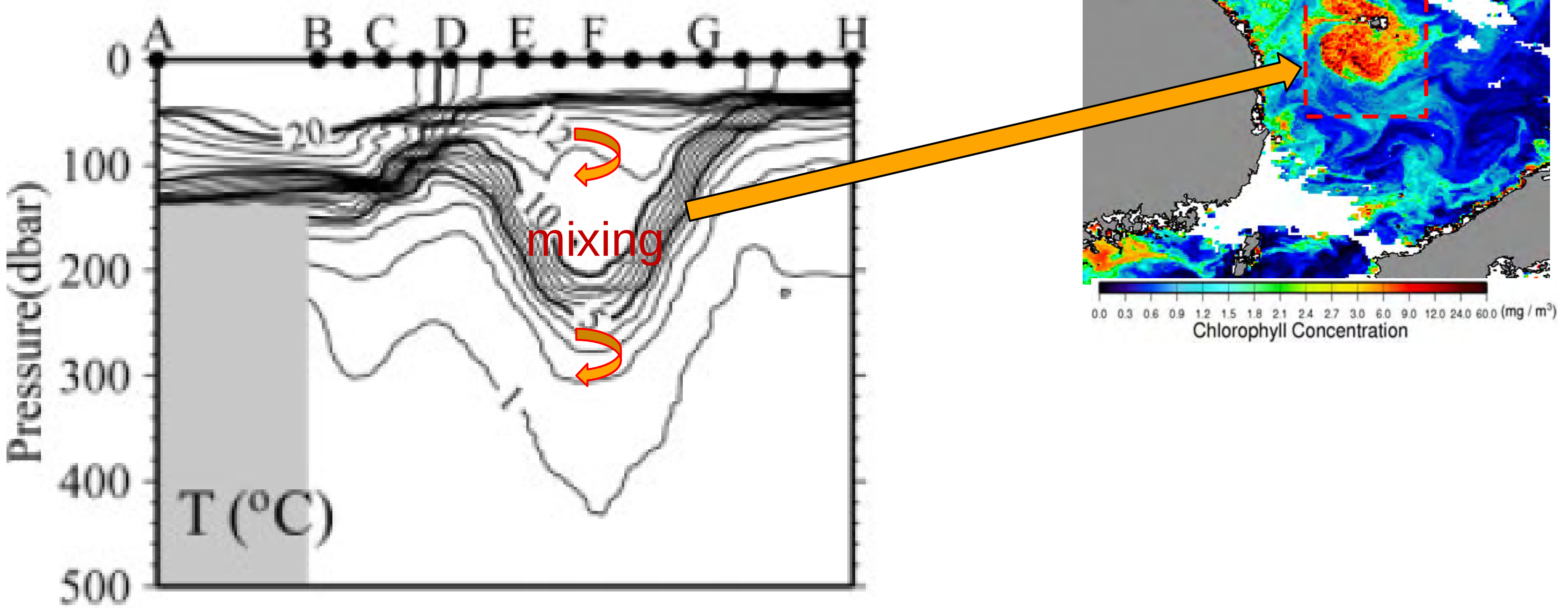
(Apr. 20, 2008)

McGillicuddy et al. [2007] : eddy-wind interactions
Mahadevan et al. [2008] : submesoscale process related upwelling

Discussion

Vertical distribution of nitrate concentration





Summary

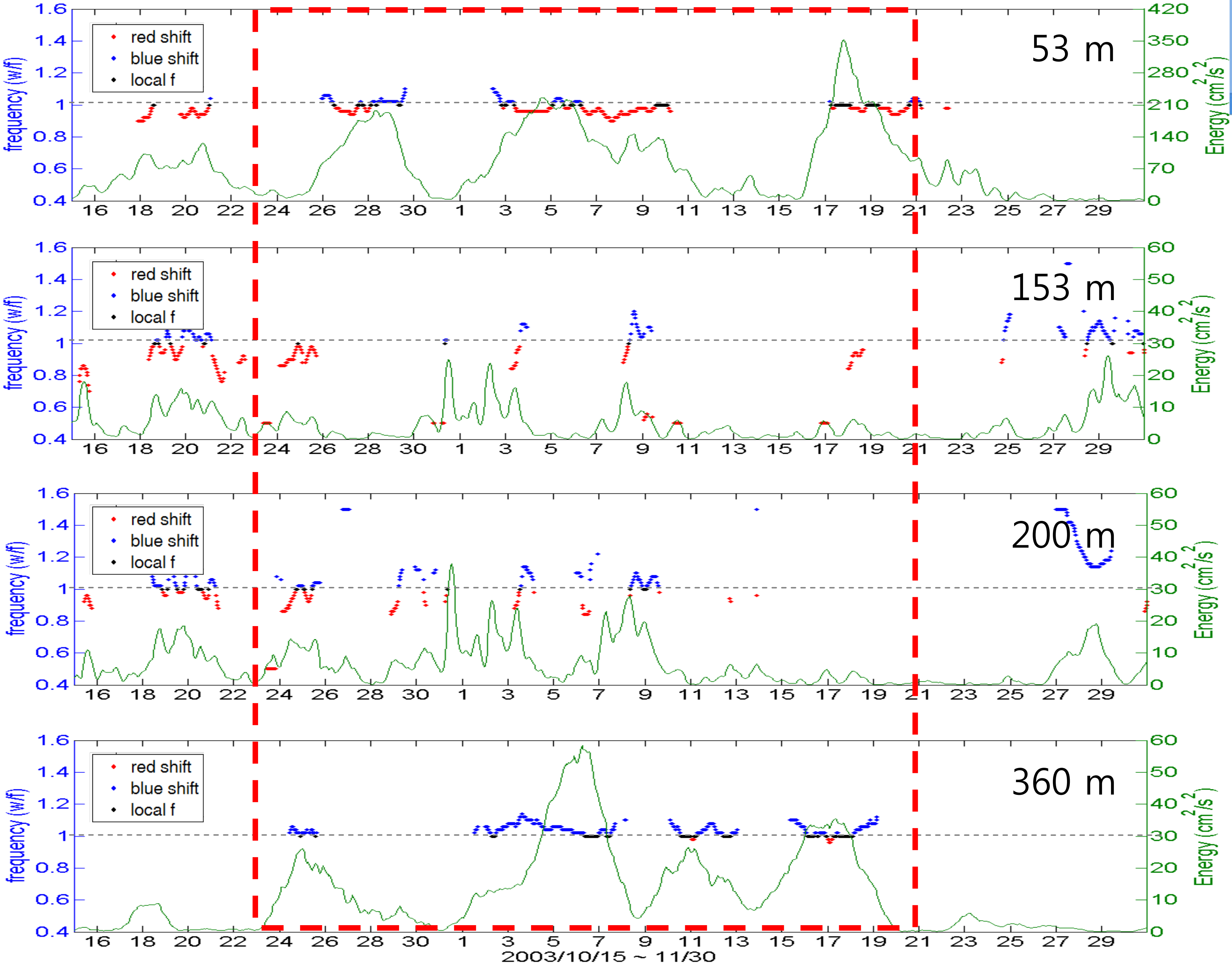
- A 16.5-month-long moored current observation captured an anticyclonic mesoscale eddy (Ulleung Warm Eddy) feature for a month.

- Near-inertial wave reflections and amplifications were firstly observed from a continuous time series data.

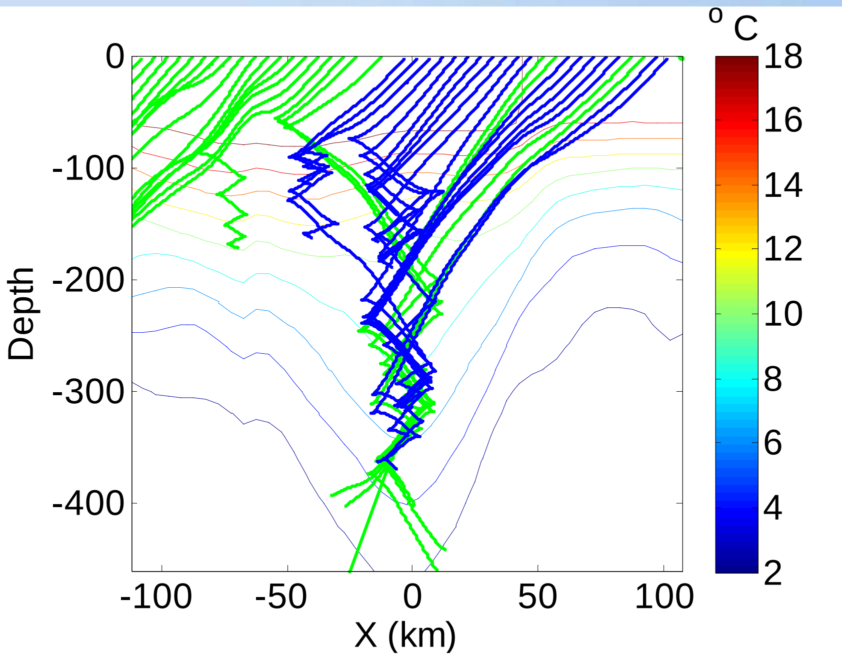
- The reflected and amplified NIWs can be lost to turbulence and mixing, and this can transfer nutrients upward (precondition of plankton bloom).

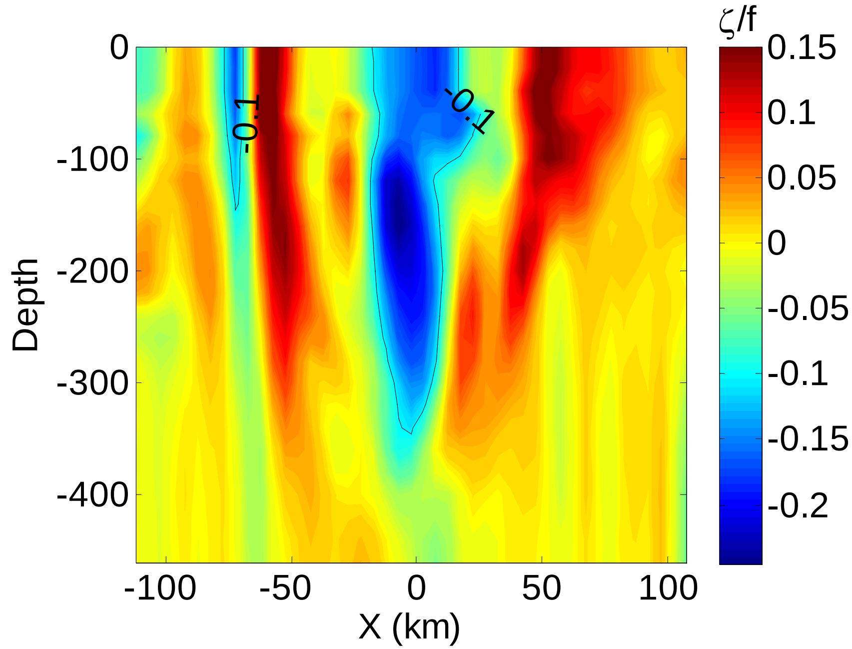
- We need to more closely examine the impact of NIW-induced mixing in the UWE on ecosystem in the southwestern East Sea.

Thank You !!


53 m
153 m
200 m
360 m
red shift
blue shift
local f
frequency (w/f)
Energy (cm²/s²)
2003/10/15 ~ 11/30

Preliminary result of ray tracing model





Ray-tracing equation

✓ Group velocities

$$Cg_x = \frac{\partial \omega_0}{\partial k_x} \approx \frac{N^2 k_x}{f k_z^2} - \frac{1}{k_z}\frac{\partial V}{\partial z}$$

$$Cg_y = \frac{\partial \omega_0}{\partial k_y} \approx \frac{N^2 k_y}{f k_z^2} + \frac{1}{k_z}\frac{\partial U}{\partial z}$$

$$Cg_z = \frac{\partial \omega_0}{\partial k_z} \approx \frac{-N^2 k_H^2}{f k_z^3} - \frac{1}{k_z^2}\left(\frac{\partial U}{\partial z}k_y - \frac{\partial V}{\partial z}k_x\right)$$

✓ Wave position

$$\frac{dr}{dt} = Cg + V$$

✓ Wave vector

$$\frac{dk}{dt} = -\nabla\omega$$

✓ Dispersion relation for NIWs

$$\omega = f_{eff} + \frac{N^2 k_H{}^2}{2 f k_z{}^2} + \frac{1}{k_z}\left(\frac{\partial U}{\partial z}k_y - \frac{\partial V}{\partial z}k_x\right) + (k \cdot V) = \text{const.}$$

Model configuration

Horizontal wavelength : 40 km,
Vertical wavelength : 100 m,
Impinging angle : 180 °