Internal solitary wave and the nutrient transport in Dongsha Atoll

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Taiwan

Motives

- The cold bottom water moved up to the shelf helps decrease the water temperature, an important mechanism that prevents bleaching of coral reefs
- The bottom cold water has high concentrations of dissolved nutrients and contributes significantly to the isolated ecosystem nearshore

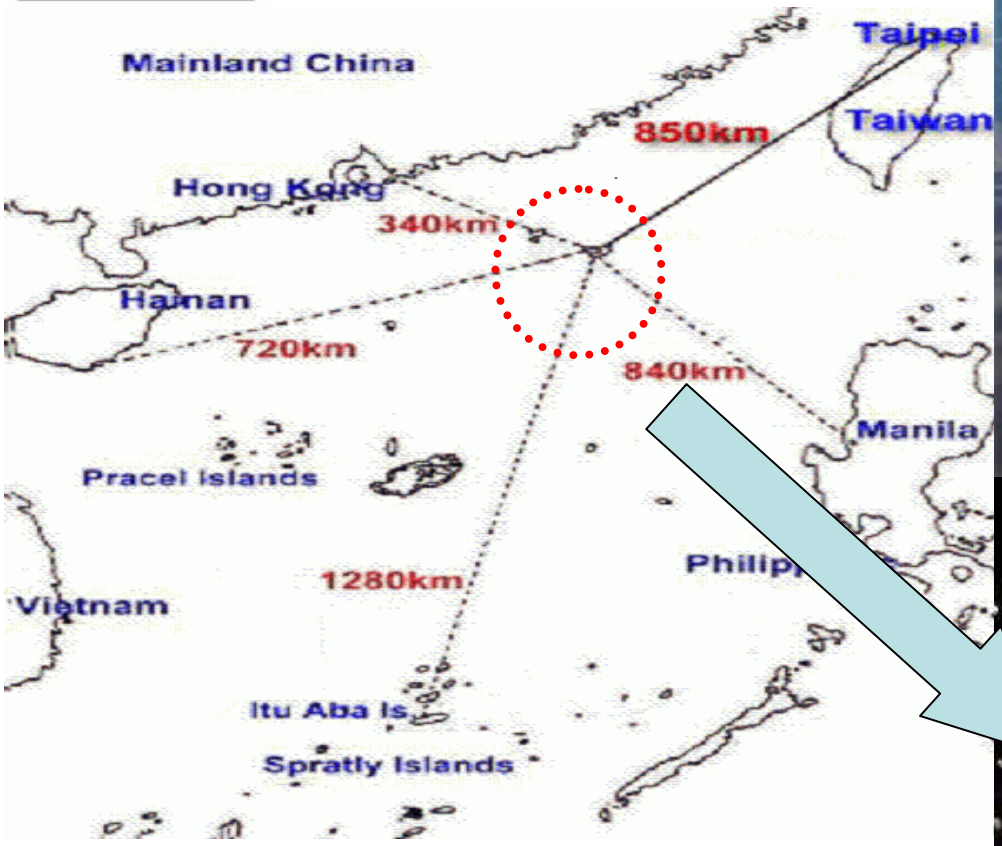
Contents

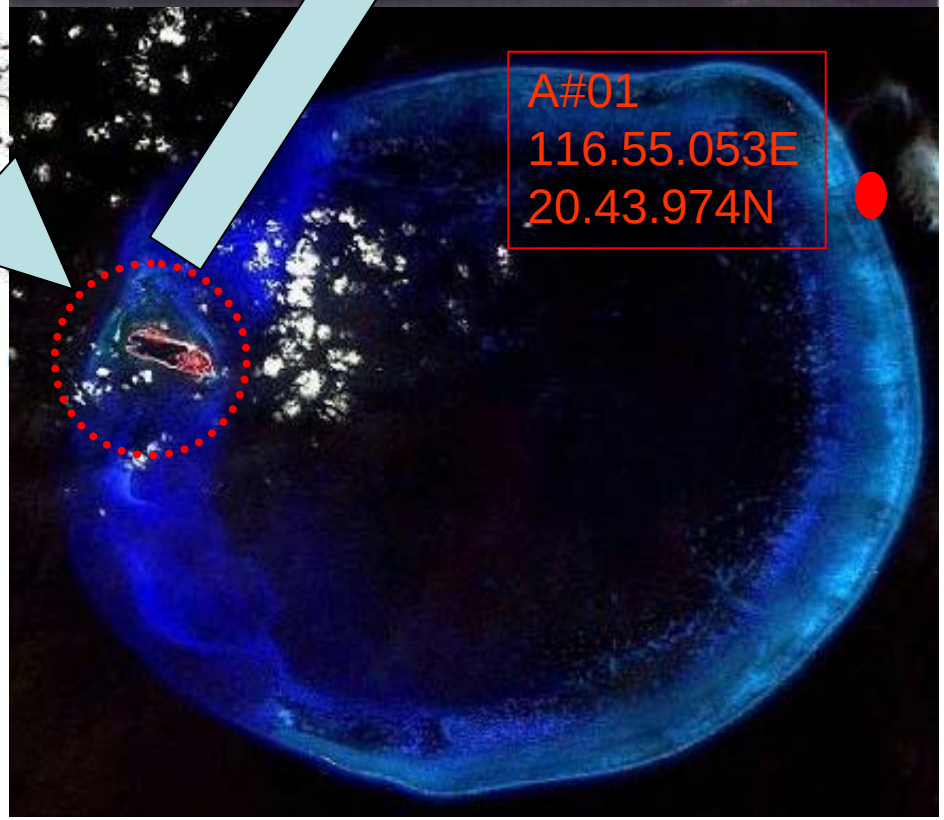
- 1. Cooling Simulation

A. ISW simulation
B. Internal tide simulation
C. Fine grid (10m) bolus simulation

- 2. Nutrient Transport Simulation

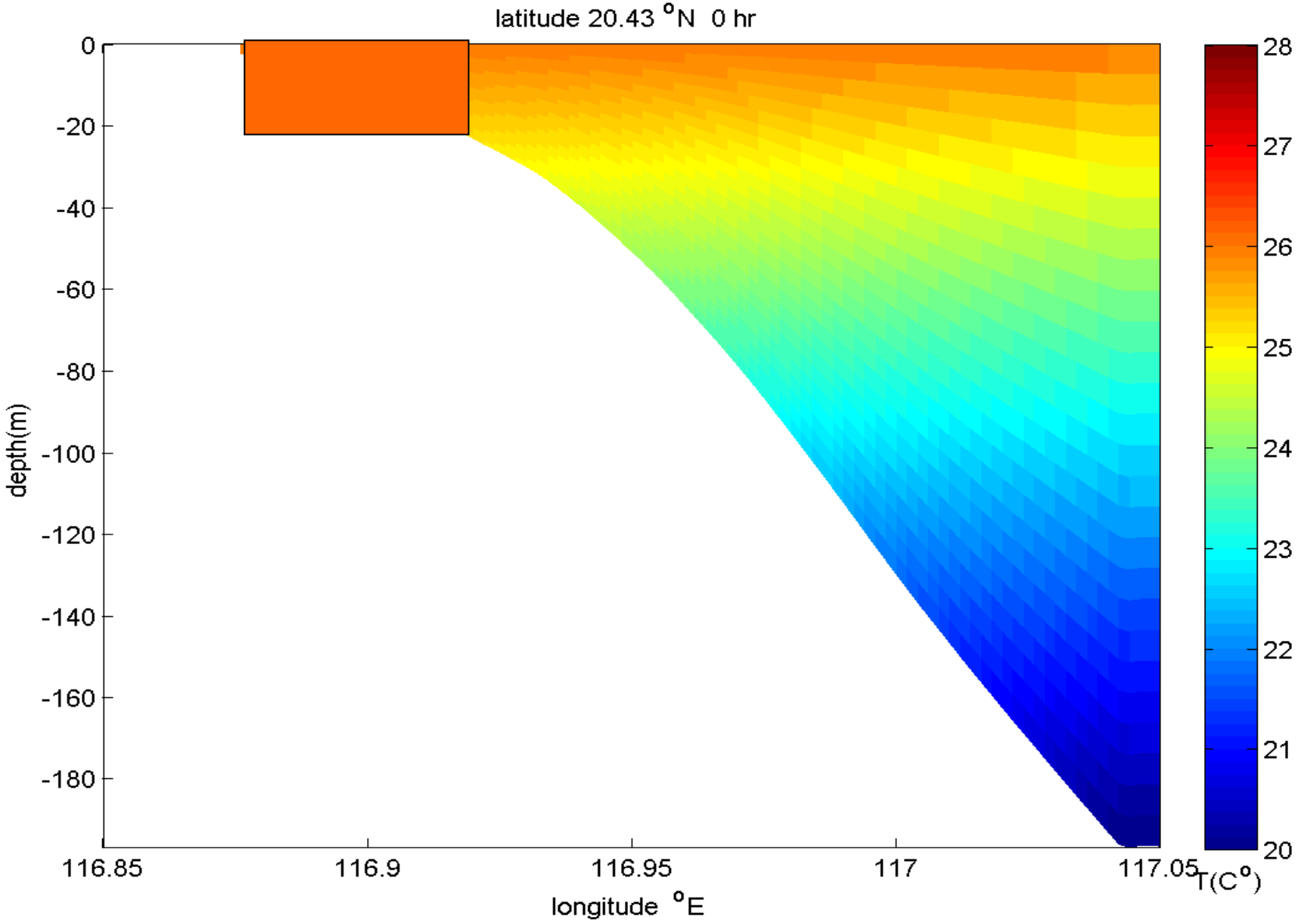
A. Comparing with satellite image
B. Comparing with field measurement

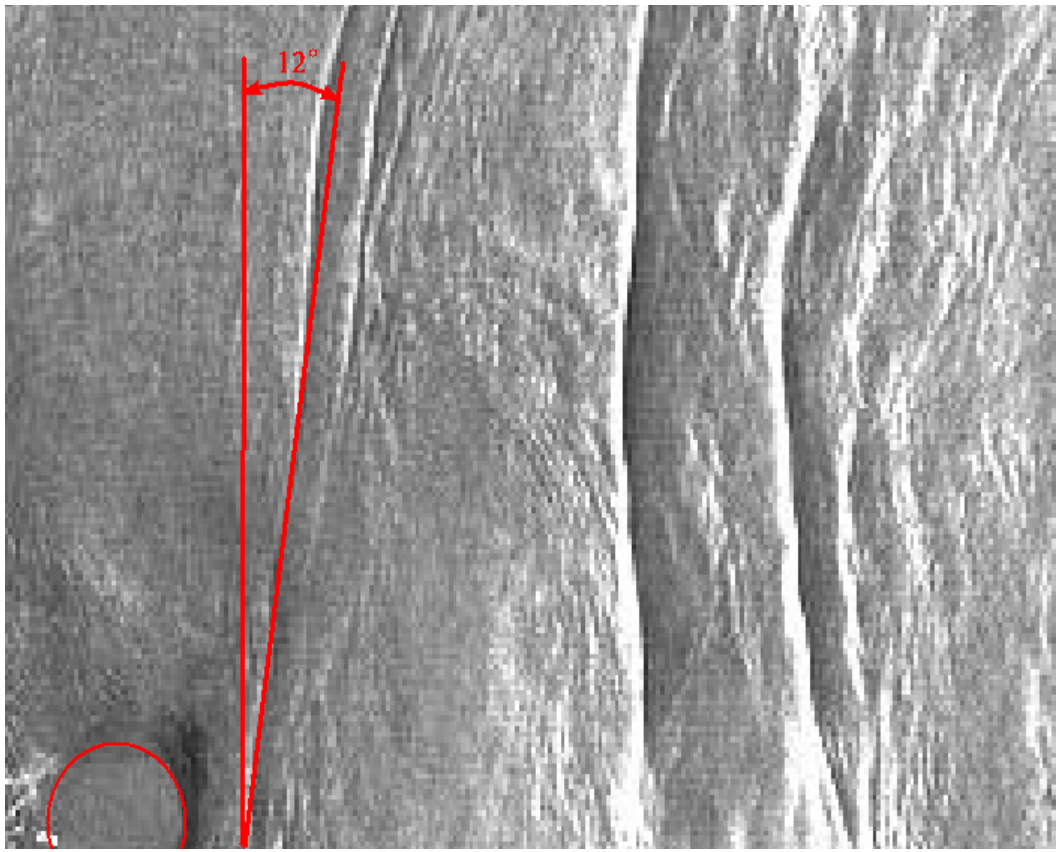


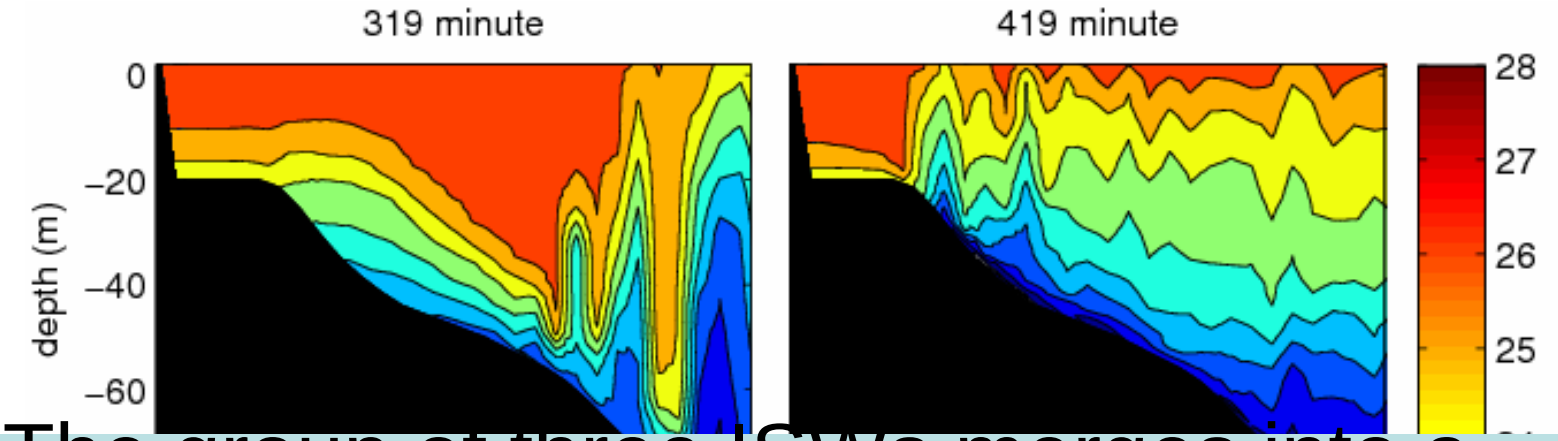


Field measurement by
Prof. Y.-H.Wang

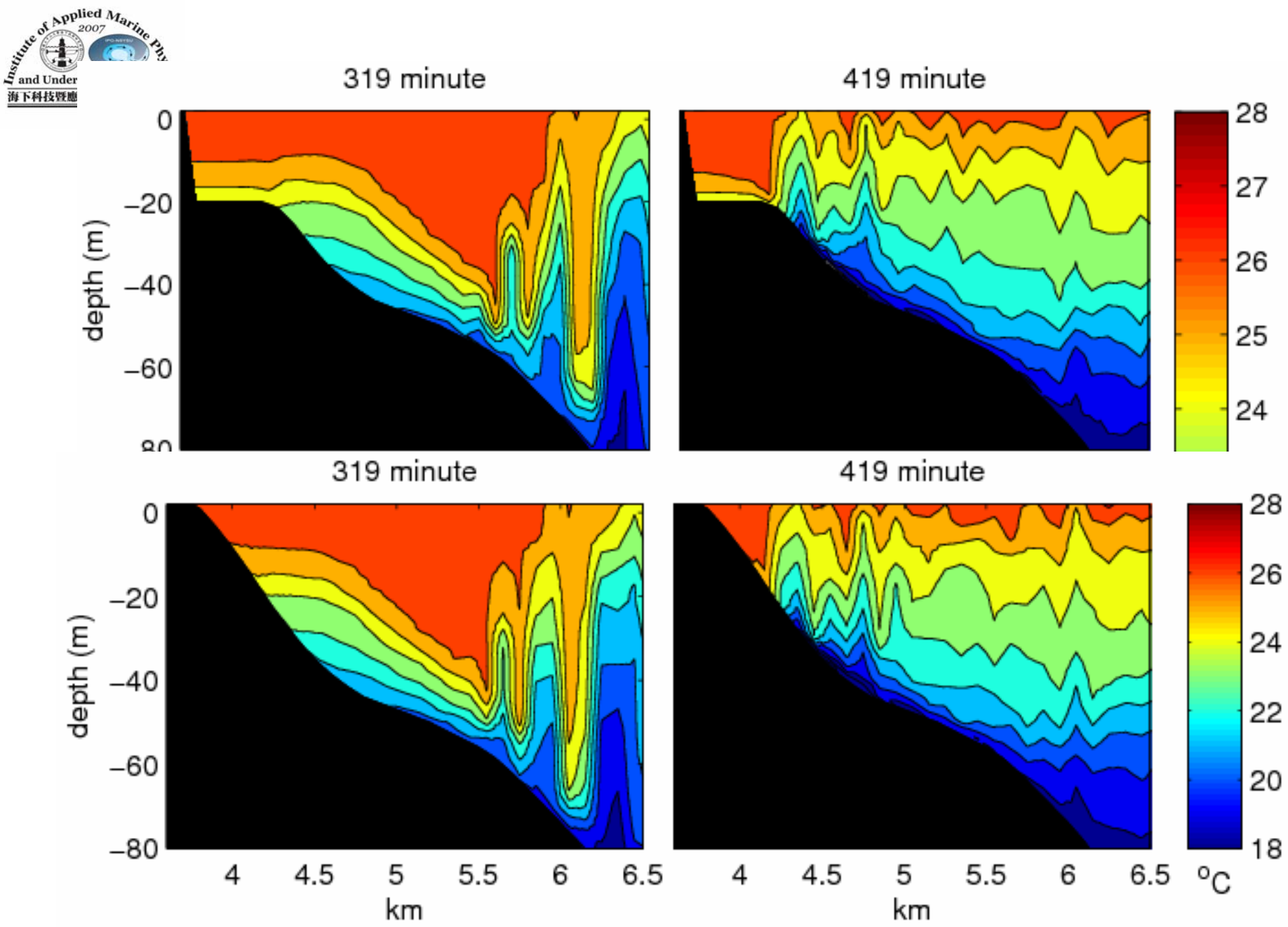
Originally a single ISW is simulated over a smooth slope




12°

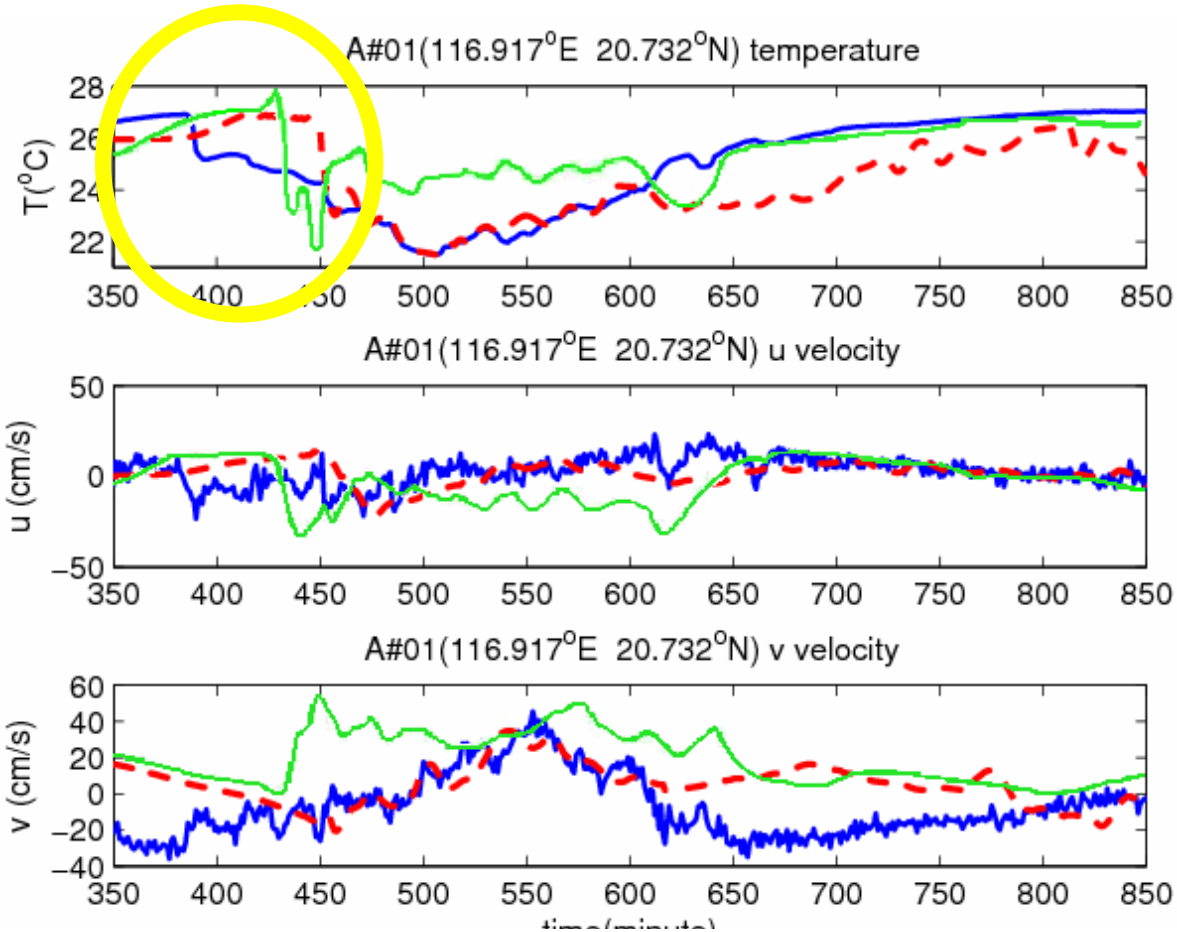


The group of three ISWs merges into a longer wave. The internal boluses are formed after the wave breaks The simulation includes the breaking of the rear part of the longer wave, the violent tidal bore that runs up the slope, and the surge of cold deep water to the shallow waters.

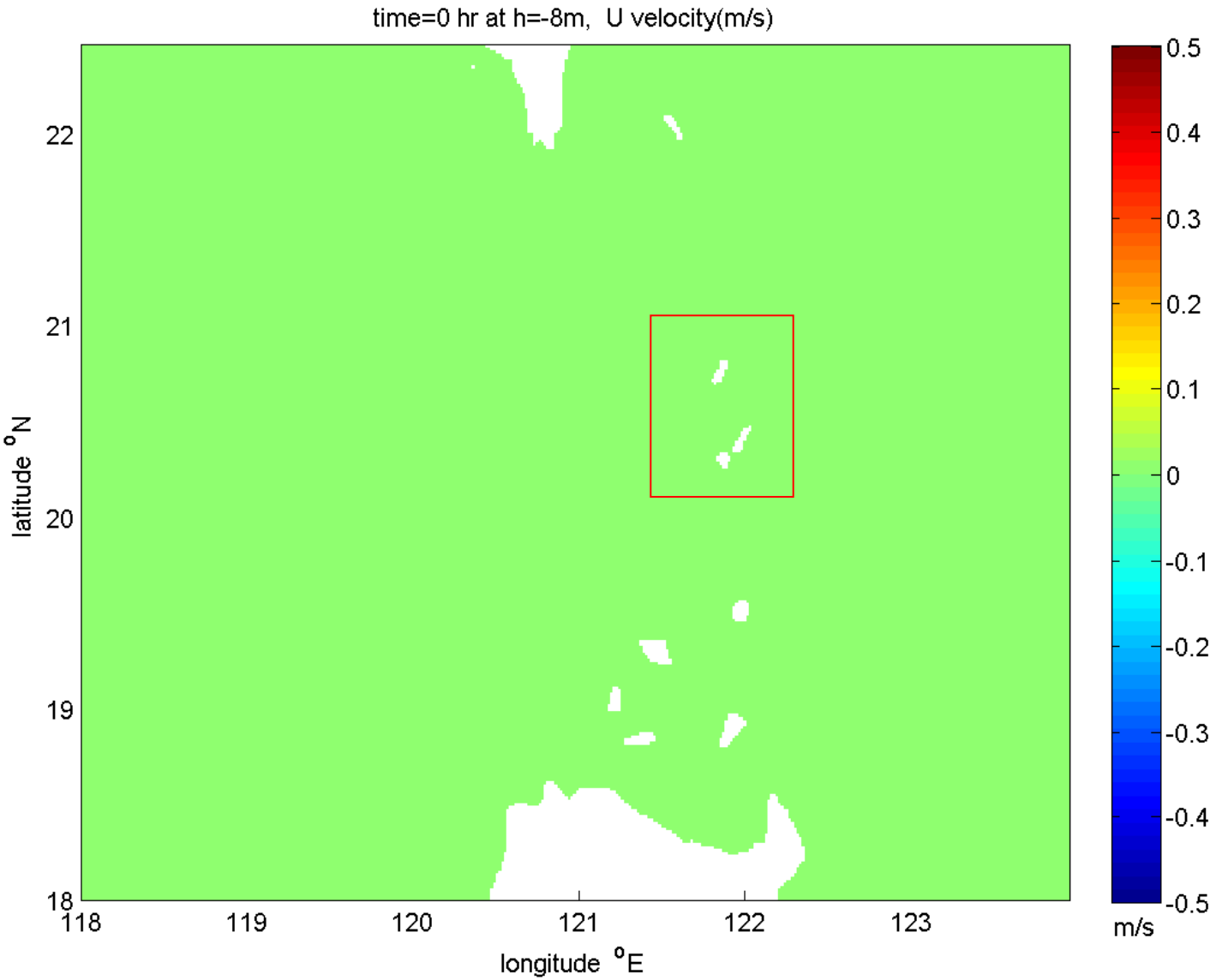

319 minute
419 minute
0
−20
−40
−60
depth (m)
28
27
26
25
24
319 minute
419 minute
0
−20
−40
−60
−80
depth (m)
4
4.5
5
5.5
6
6.5
km
4
4.5
5
5.5
6
6.5
km
28
26
24
22
20
18
°C

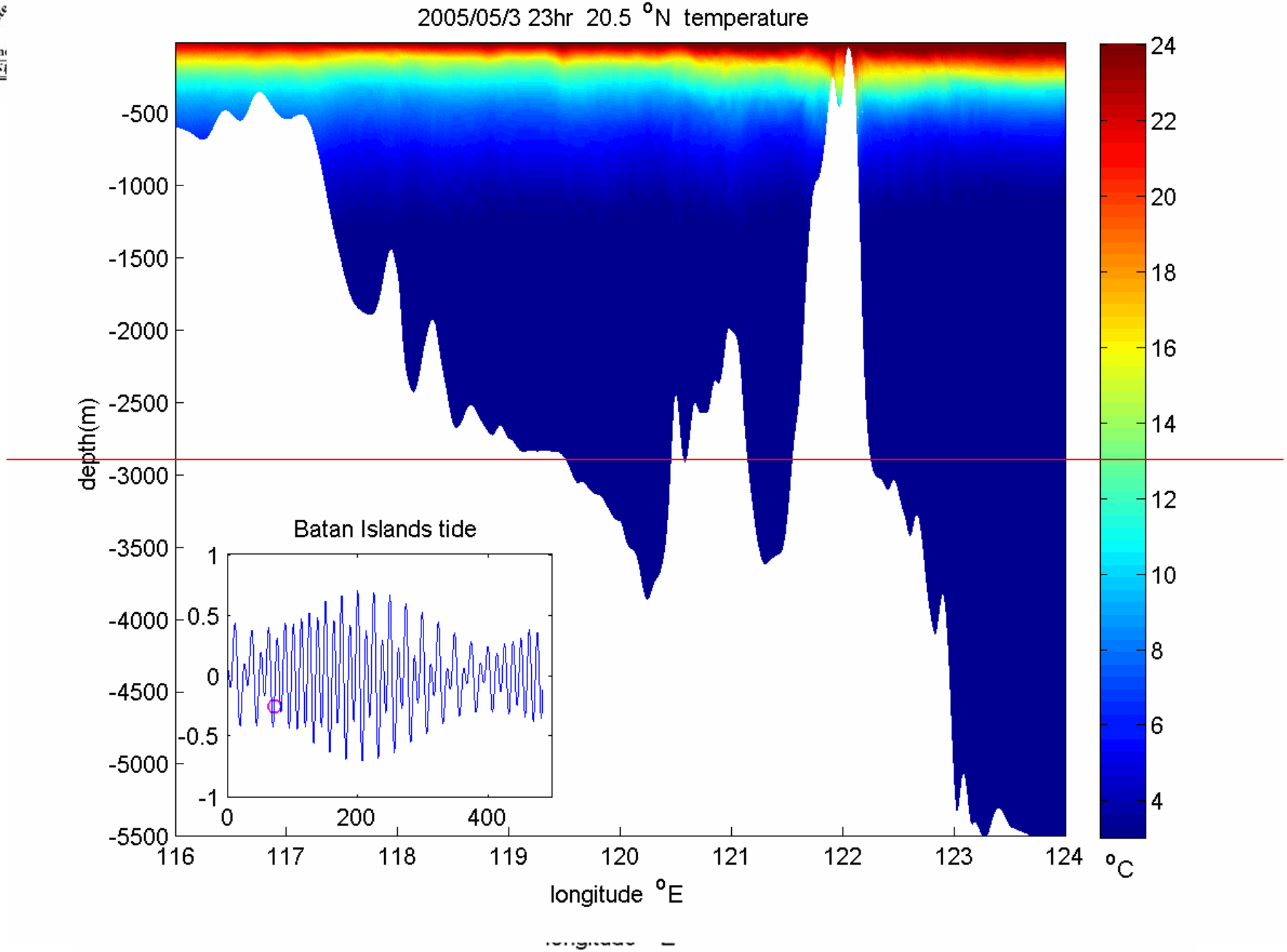
Effect of Internal Tide:

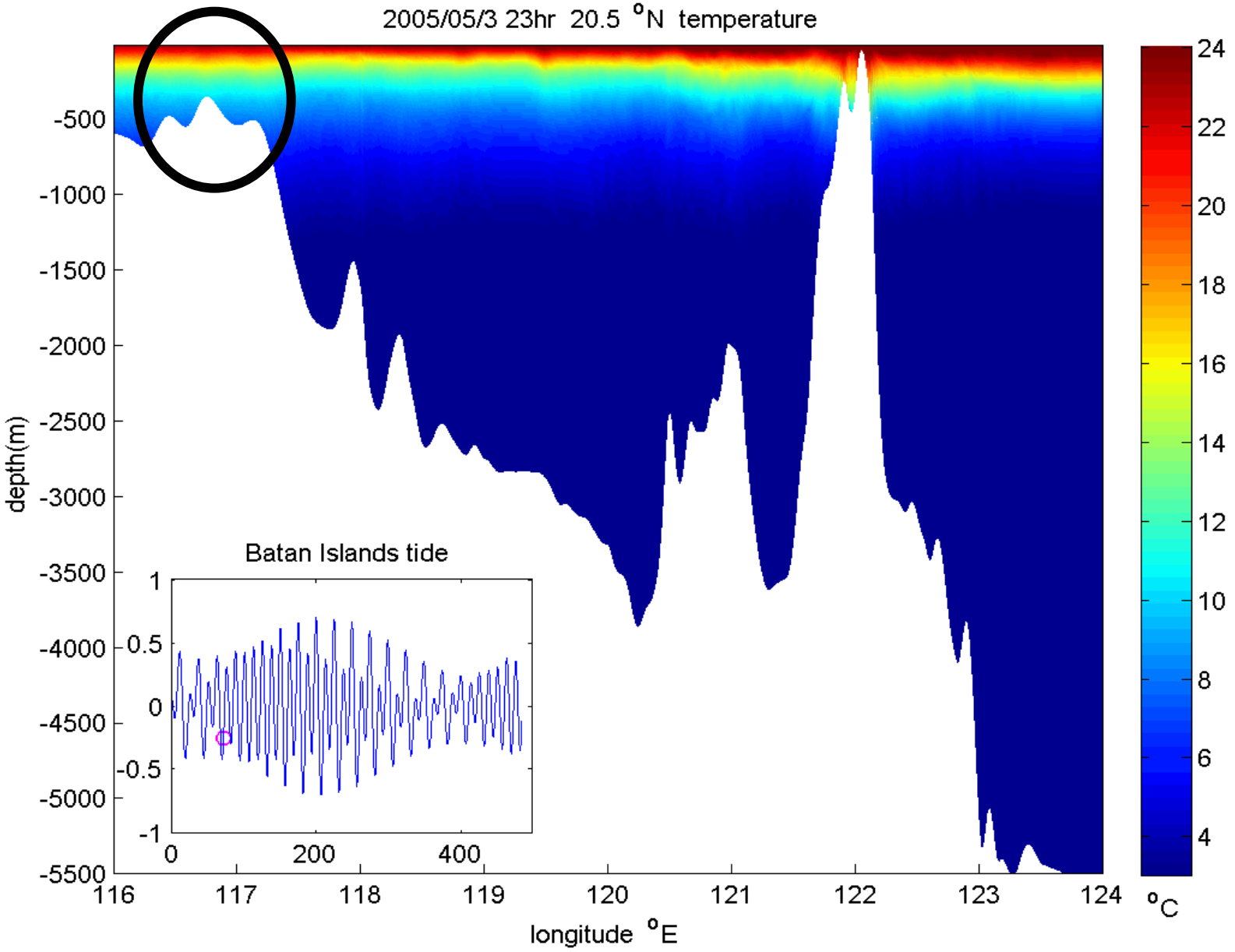
Internal Tides also contribute to the Cooling?



Tidal levels are used to drive the hydrodynamic model.

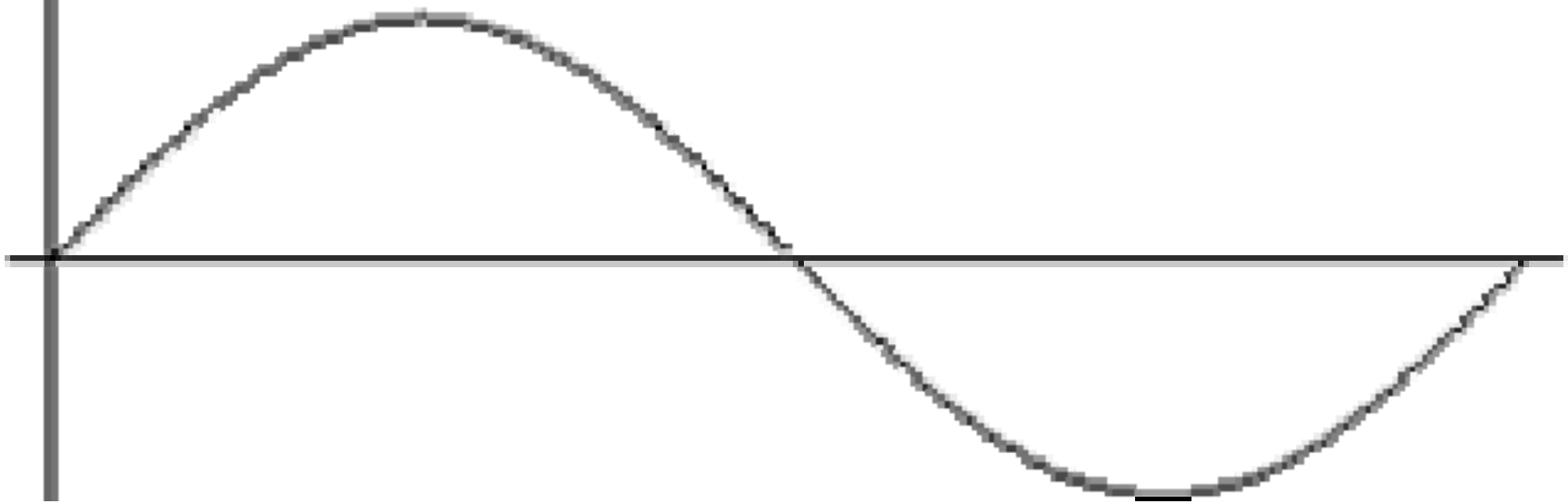



2005/05/3 23hr 20.5 °N temperature
depth(m)
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
-5500
116
117
118
119
120
121
122
123
124
longitude °E
Batan Islands tide
1
0.5
0
-0.5
-1
0
200
400
24
22
20
18
16
14
12
10
8
6
4
°C

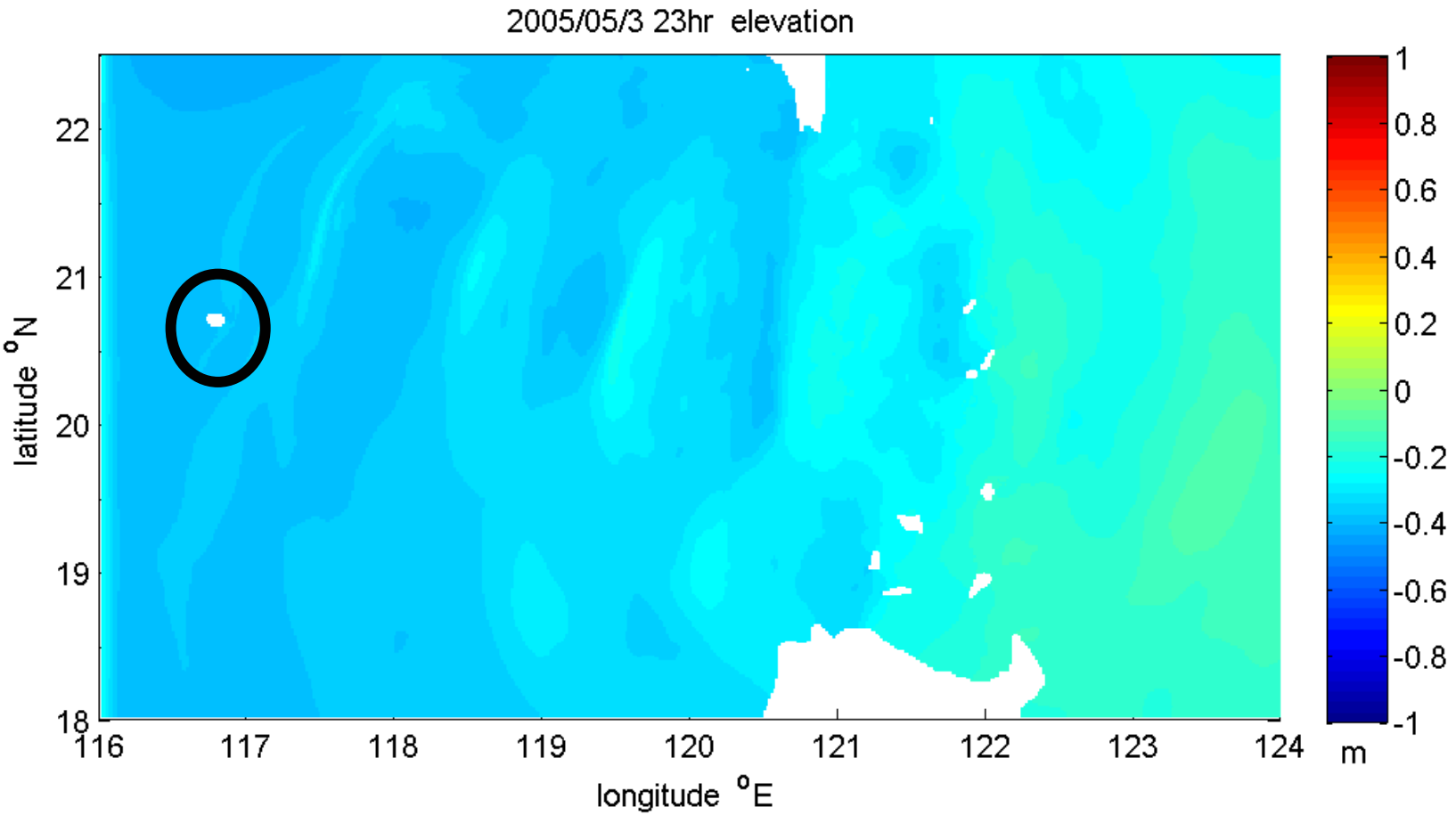


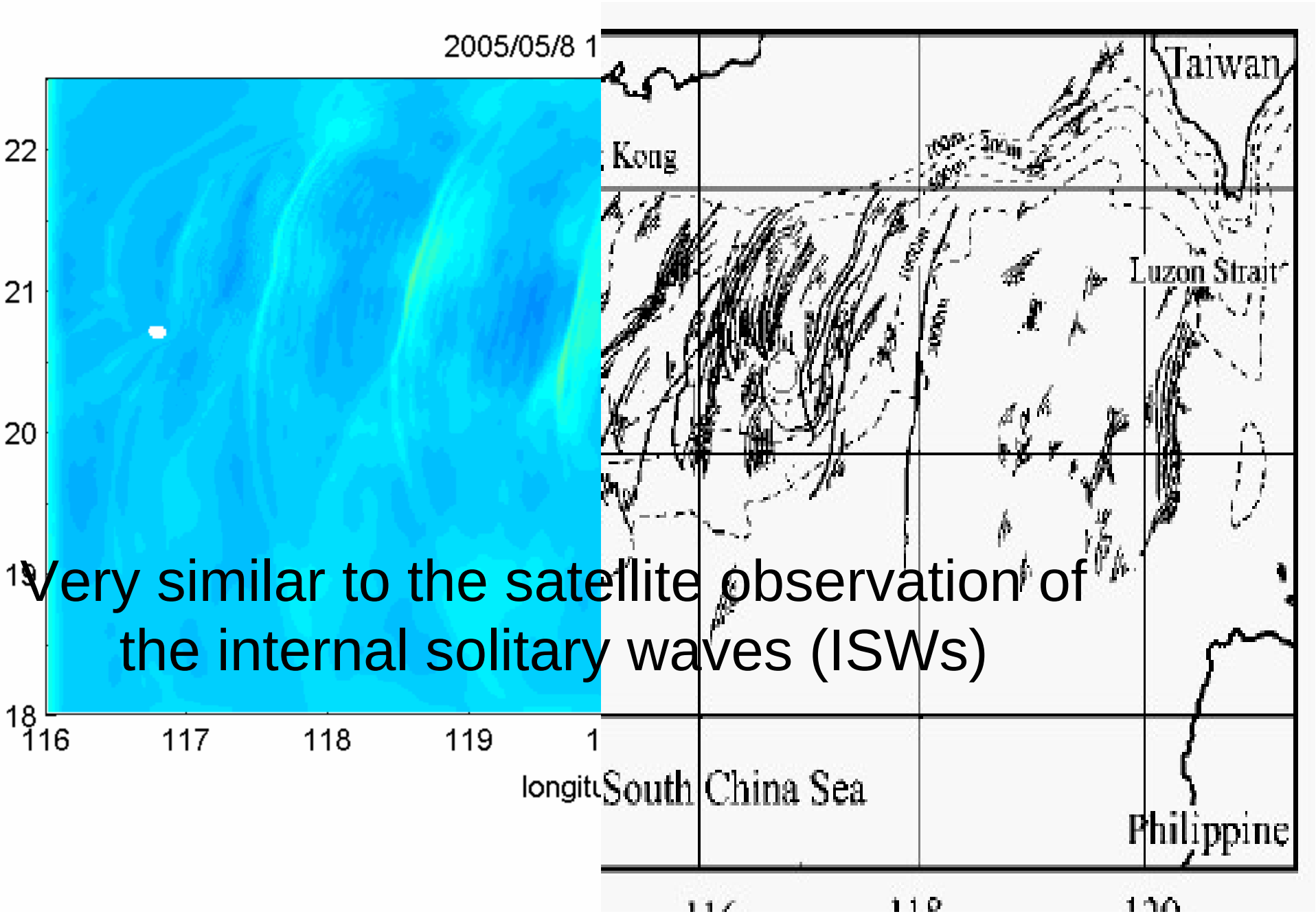
Large internal waves are generated and propagate westward to Dongsha

Nonlinear steepening makes dispersion stronger and balance the nonlinearity



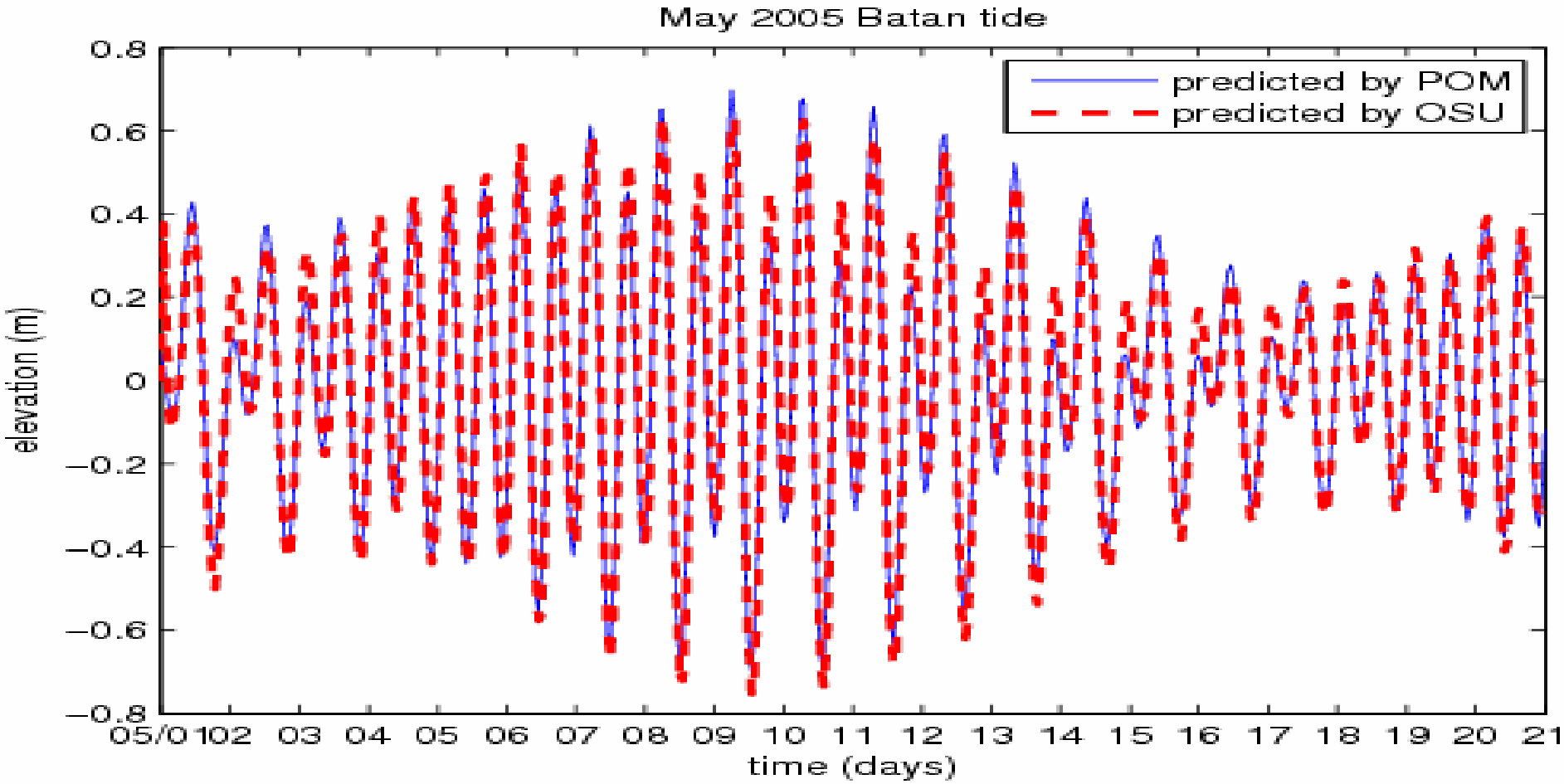
Internal tide turns into ISWs


2005/05/3 23hr elevation
latitude °N
22
21
20
19
18
116
117
118
119
120
121
122
123
124
longitude °E
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
m

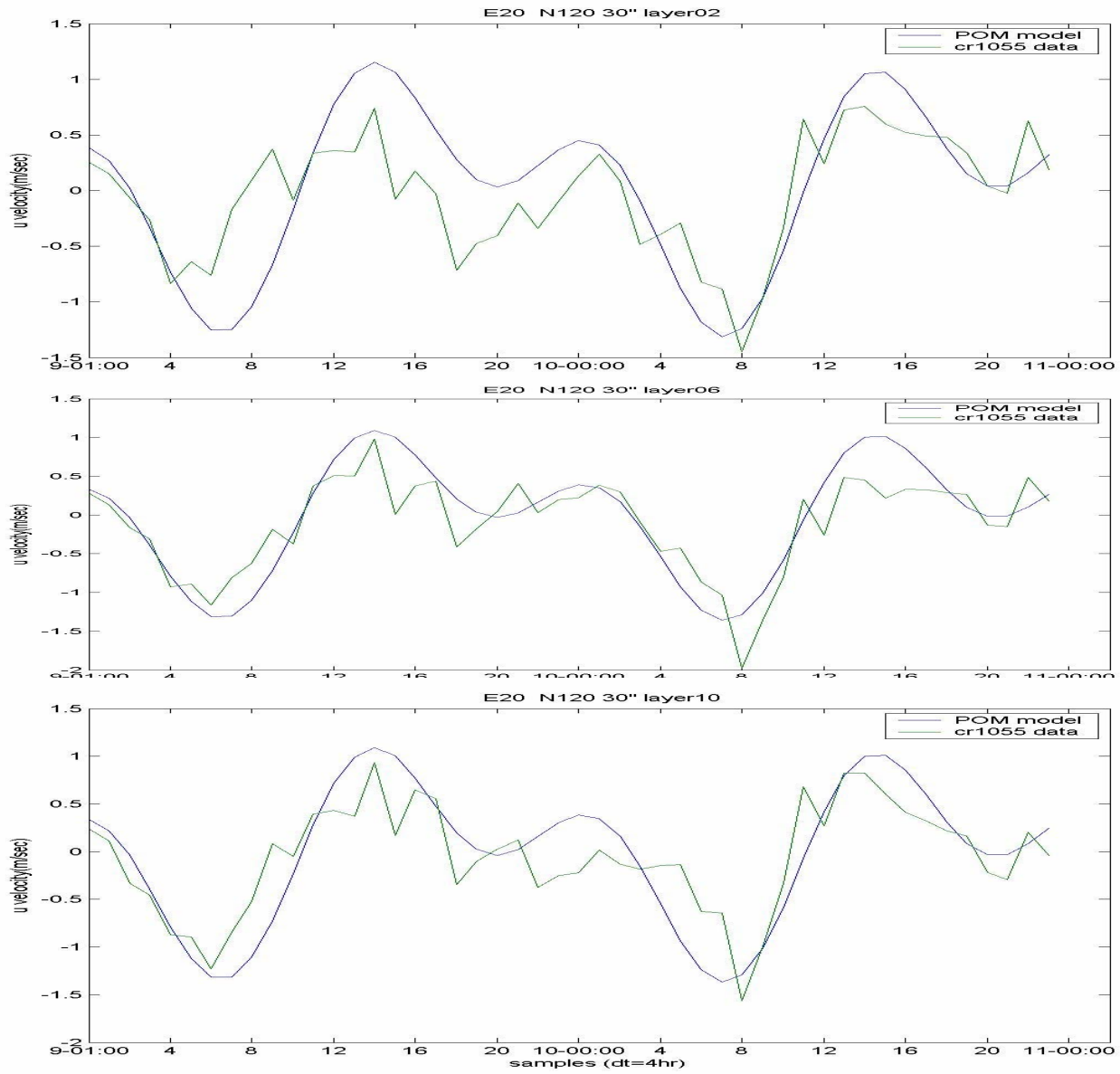


Very similar to the satellite observation of the internal solitary waves (ISWs)

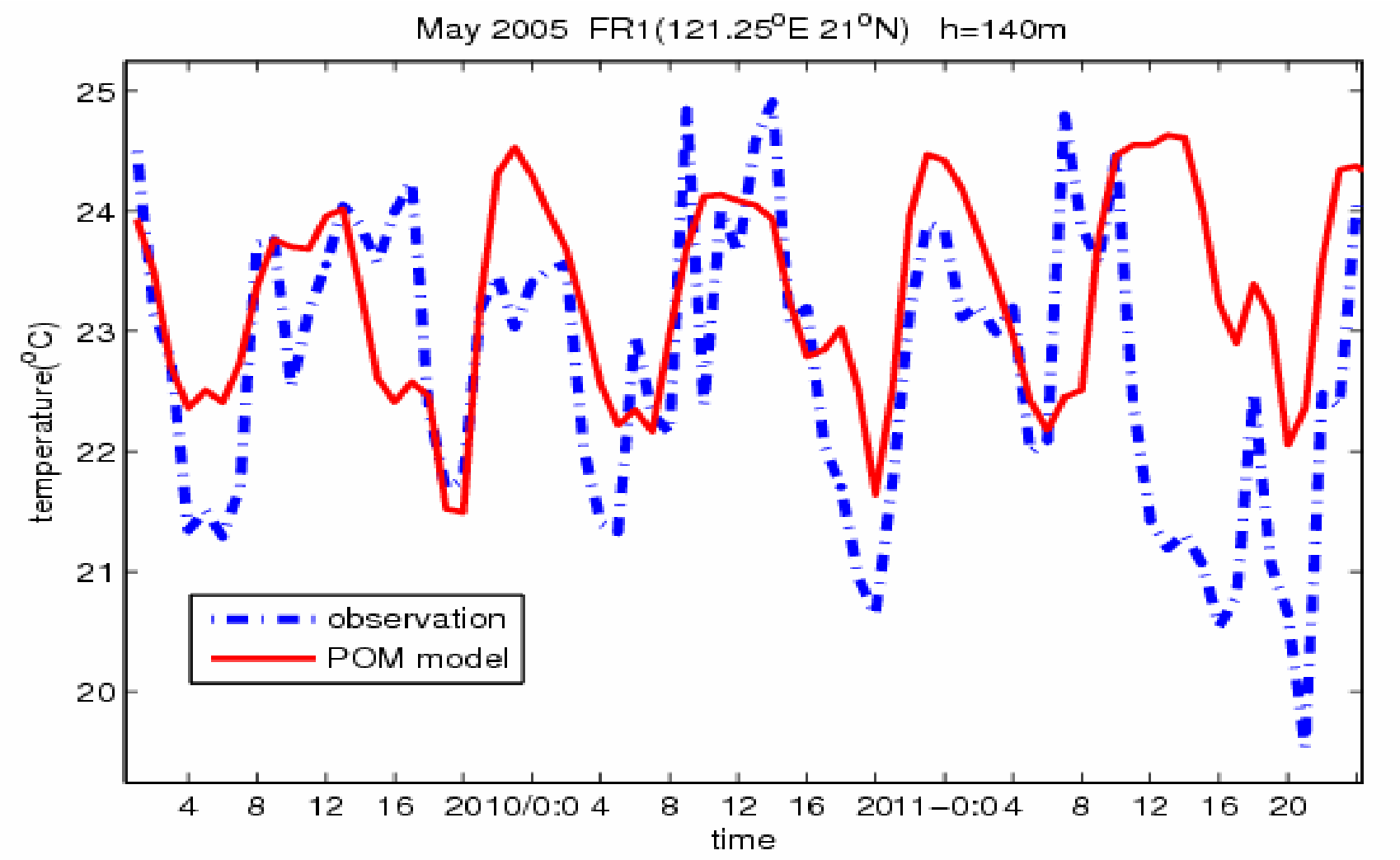
Satisfactory Surface Elevation at Batan Island is simulated



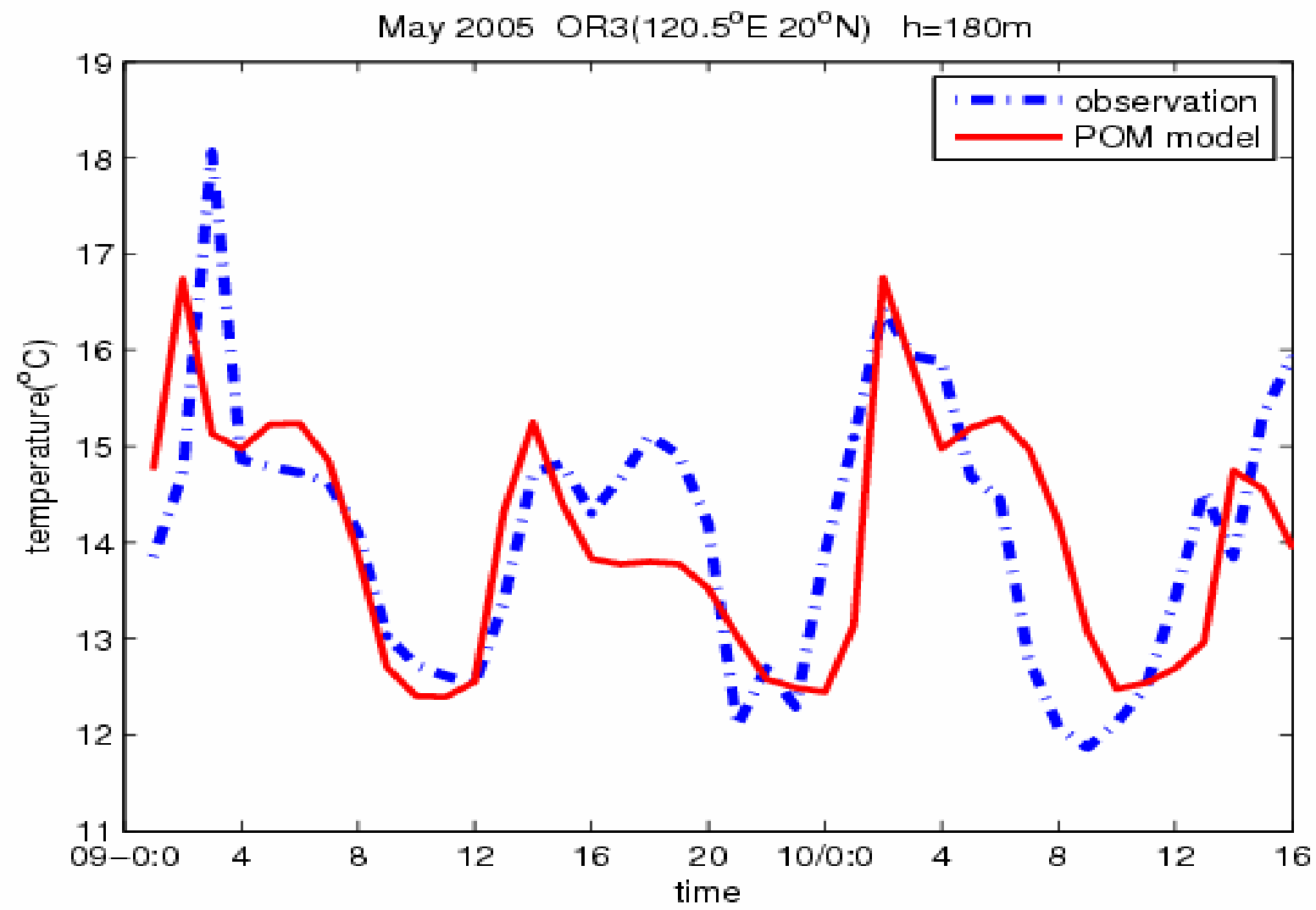
Flow at the location of OR3 in the Luzon Strait is properly simulated



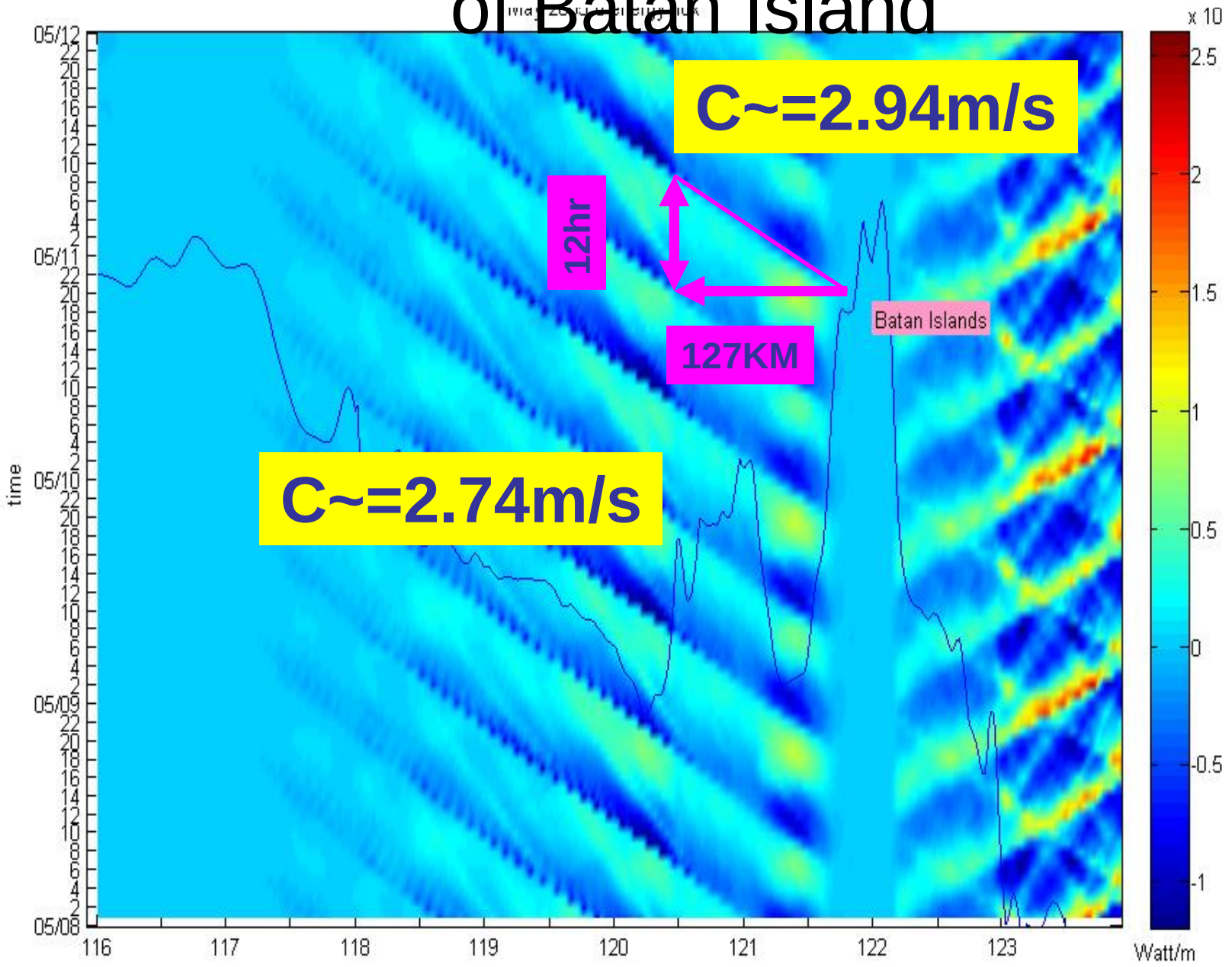
- Simulated temperature at FR1 (depth 140m)

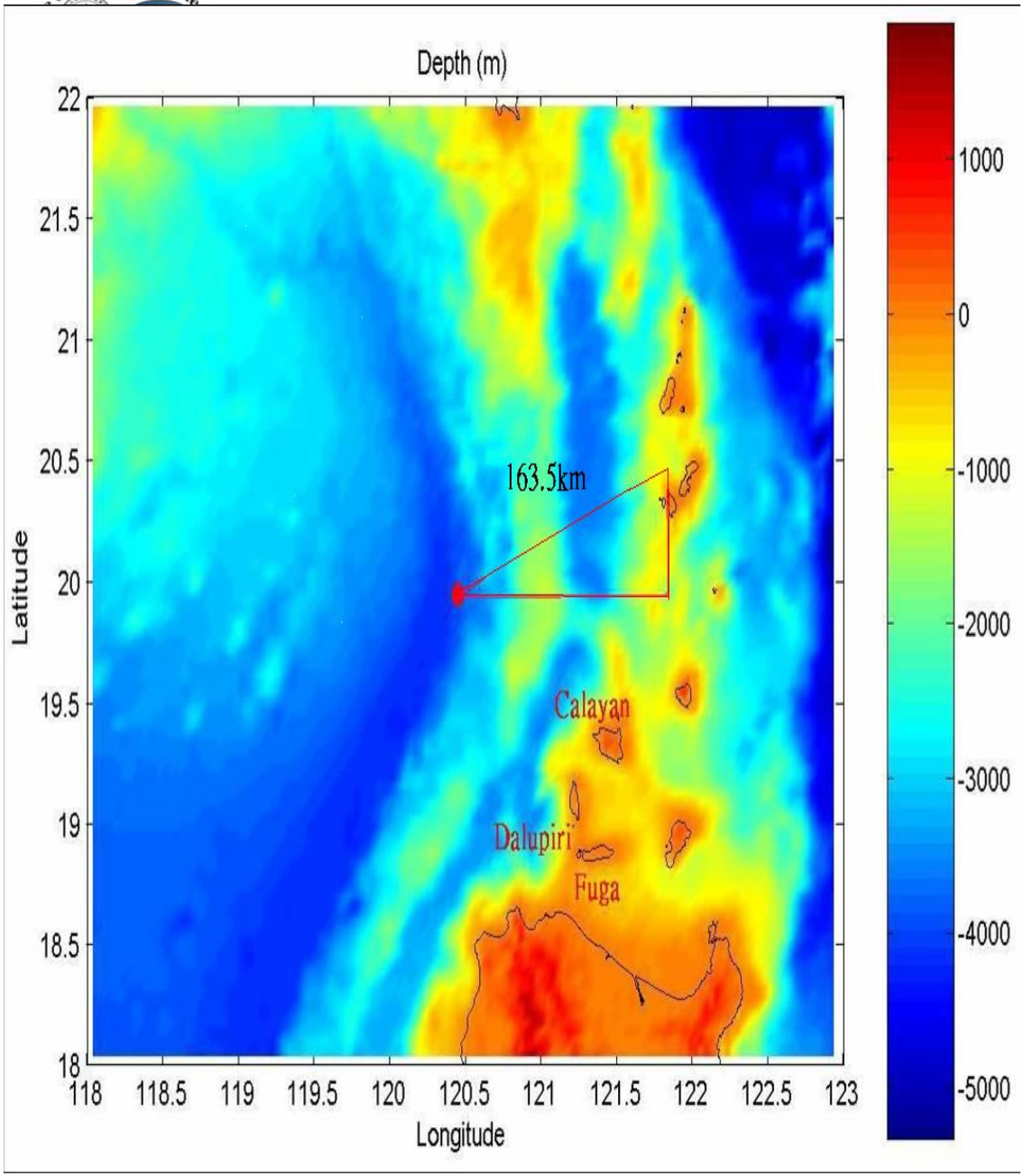


- Simulated temperature at OR3 (depth 180m)



Baroclinic energy flux along the latitude of Batan Island





OR3 to Batan

$=\sqrt{150^2 + 65^2}$

=163.477km=163477m

Wave velocity 2.94m/s

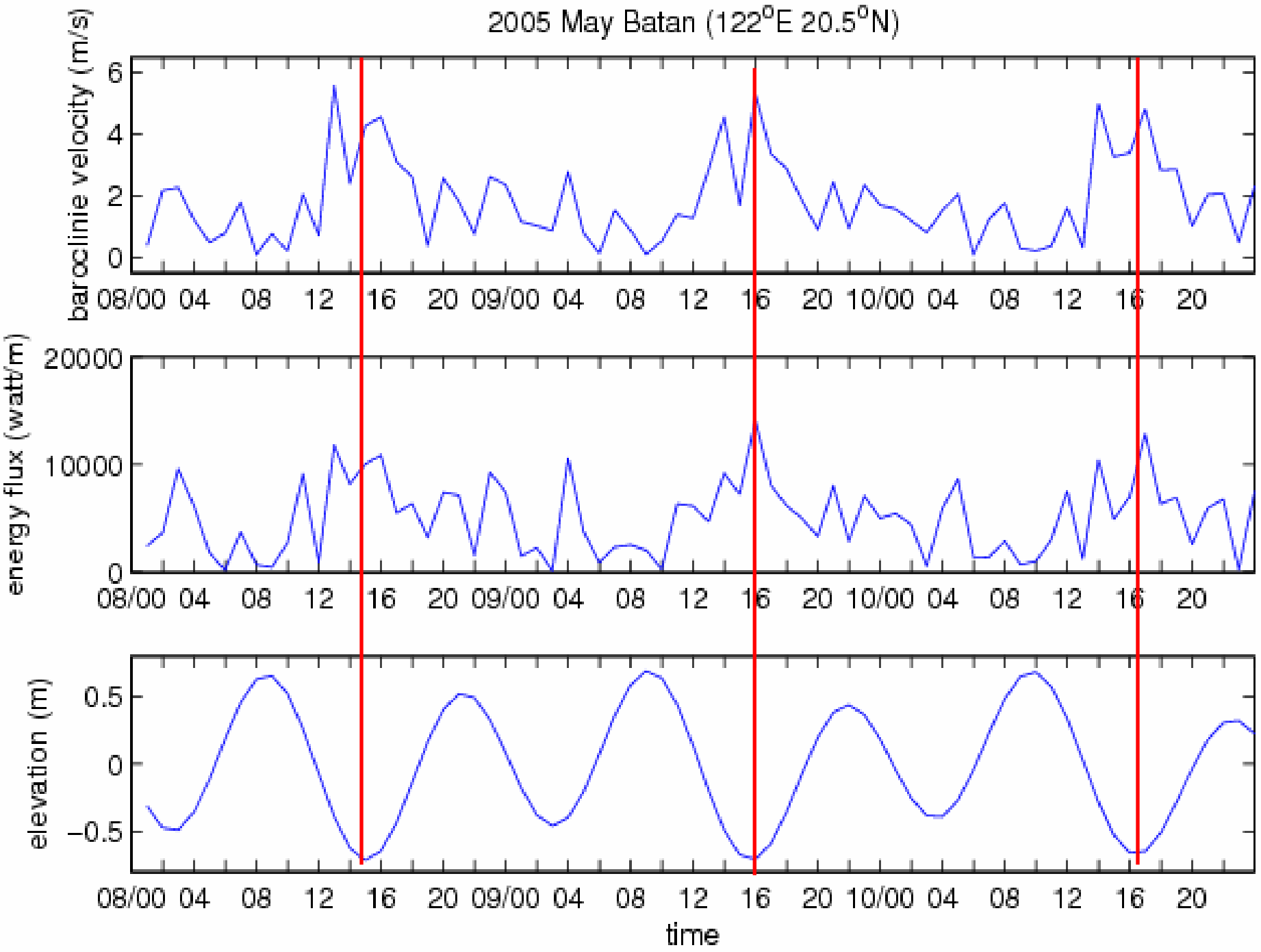
Time=163477/2.94 =15 h
25 min

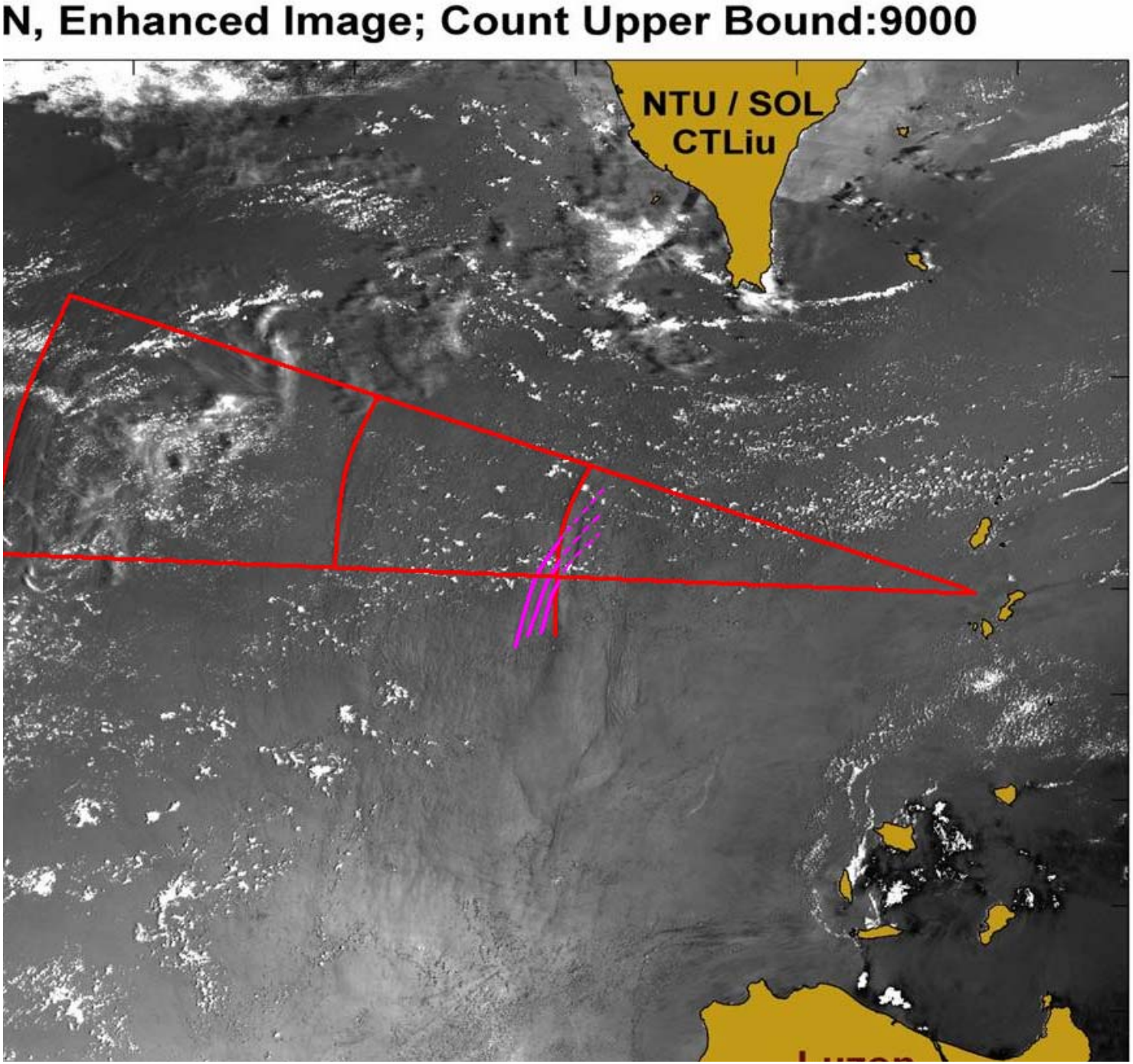
ISWs were observed by OR3 on 5/09/2005

at AM 06:00~08:00

The waves are generated on 5/08/2005

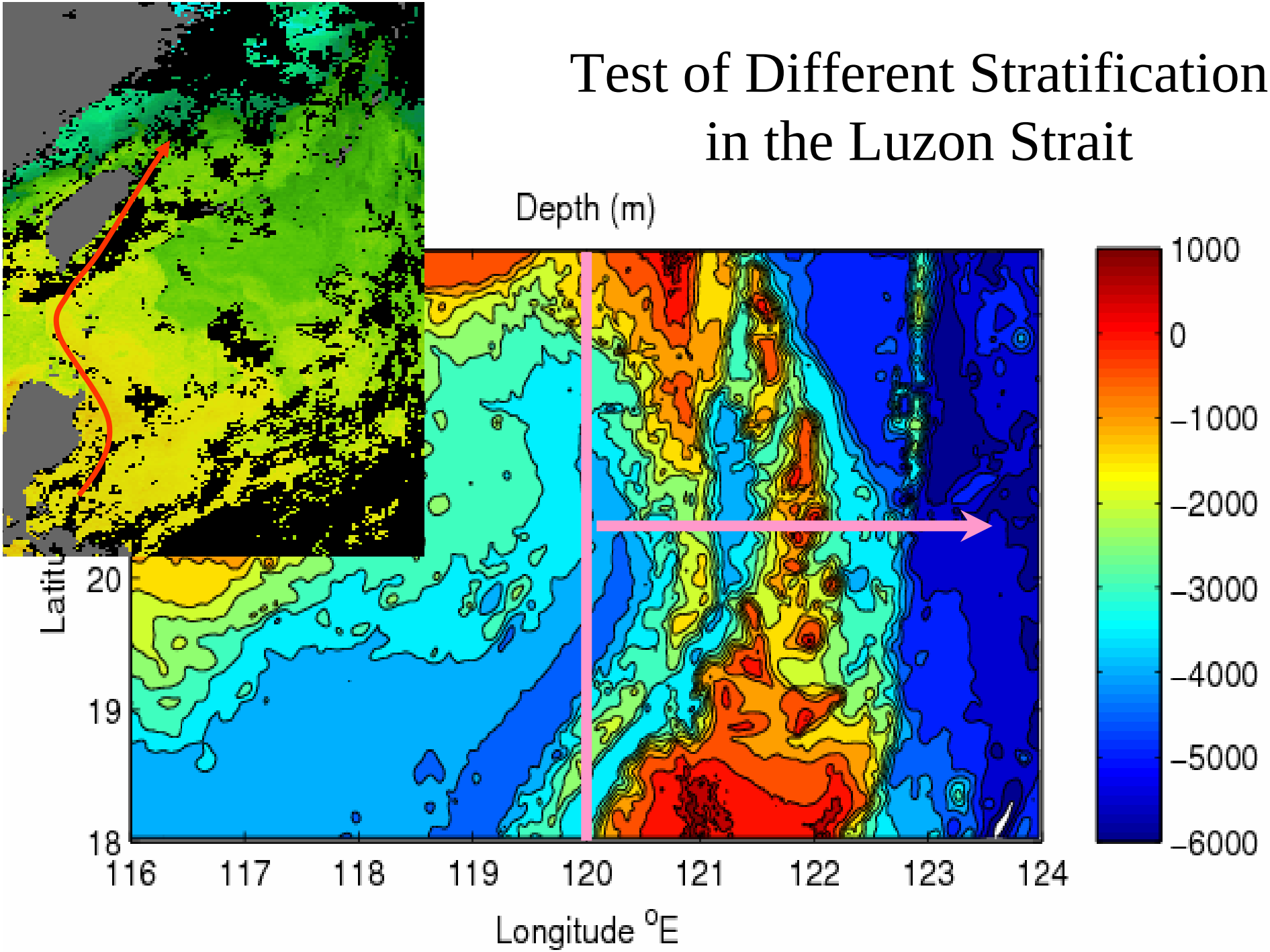
at PM 03:00~05:00

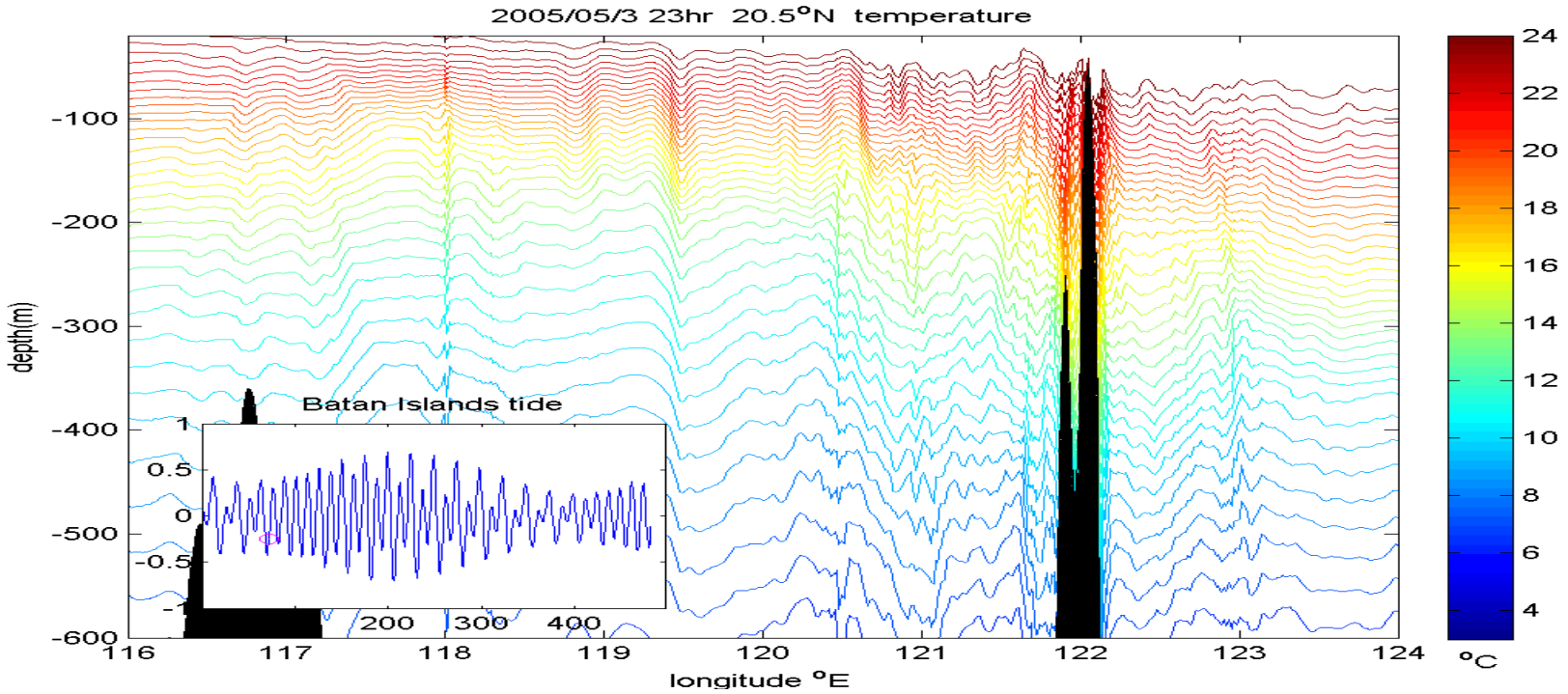

2005 May Batan (122°E 20.5°N)
baroclinie velocity (m/s)
6
4
2
0
08/00 04 08 12 16 20 09/00 04 08 12 16 20 10/00 04 08 12 16 20
energy flux (watt/m)
20000
10000
0
08/00 04 08 12 16 20 09/00 04 08 12 16 20 10/00 04 08 12 16 20
elevation (m)
0.5
0
−0.5
08/00 04 08 12 16 20 09/00 04 08 12 16 20 10/00 04 08 12 16 20
time

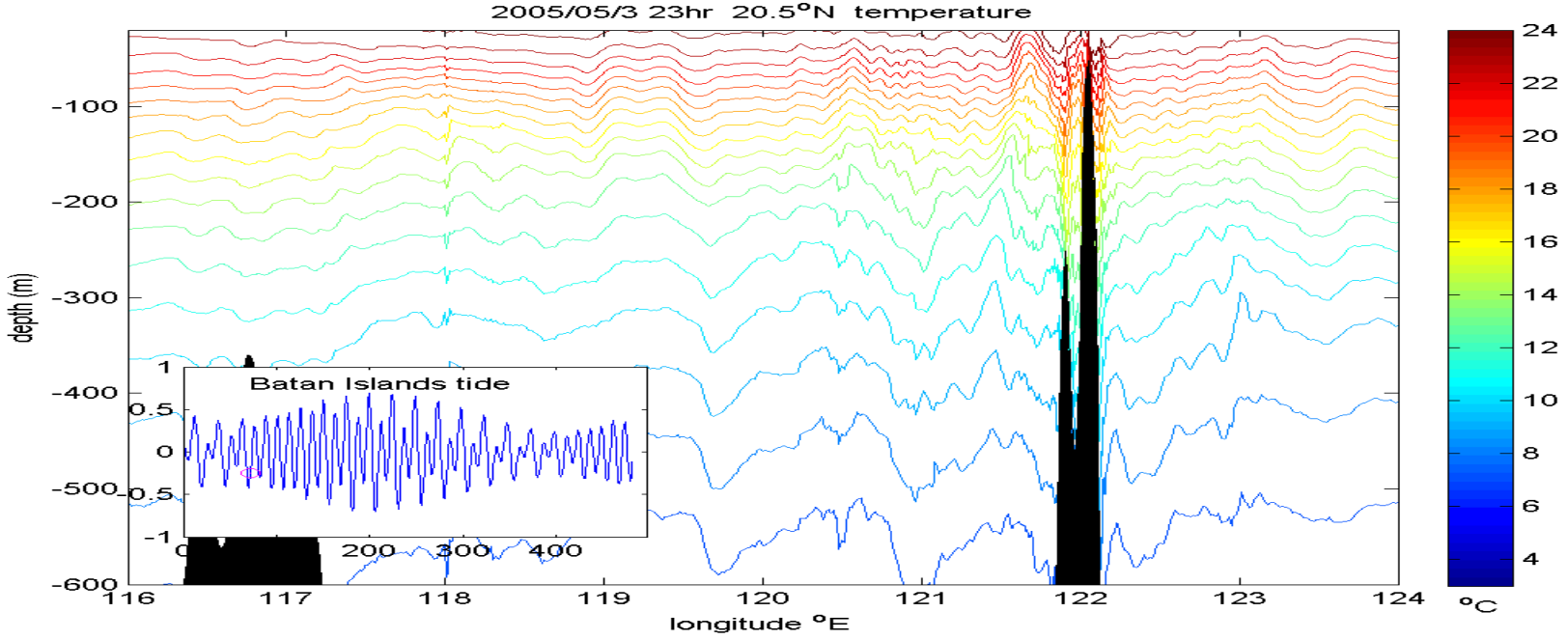


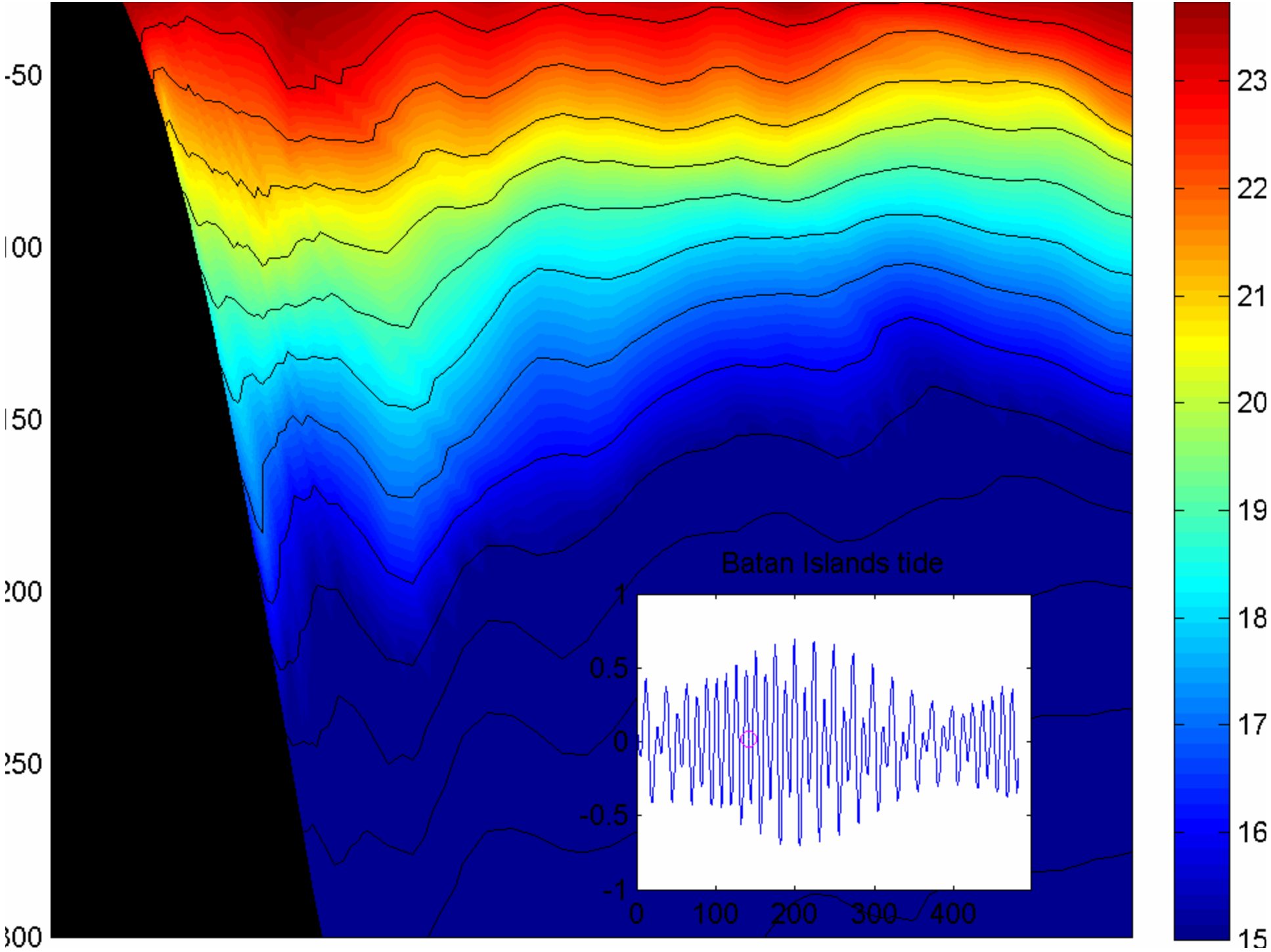
MODIS image taken on 8/22/2005 Trace the curvature of the wave fronts can find the approximate source zone locations.

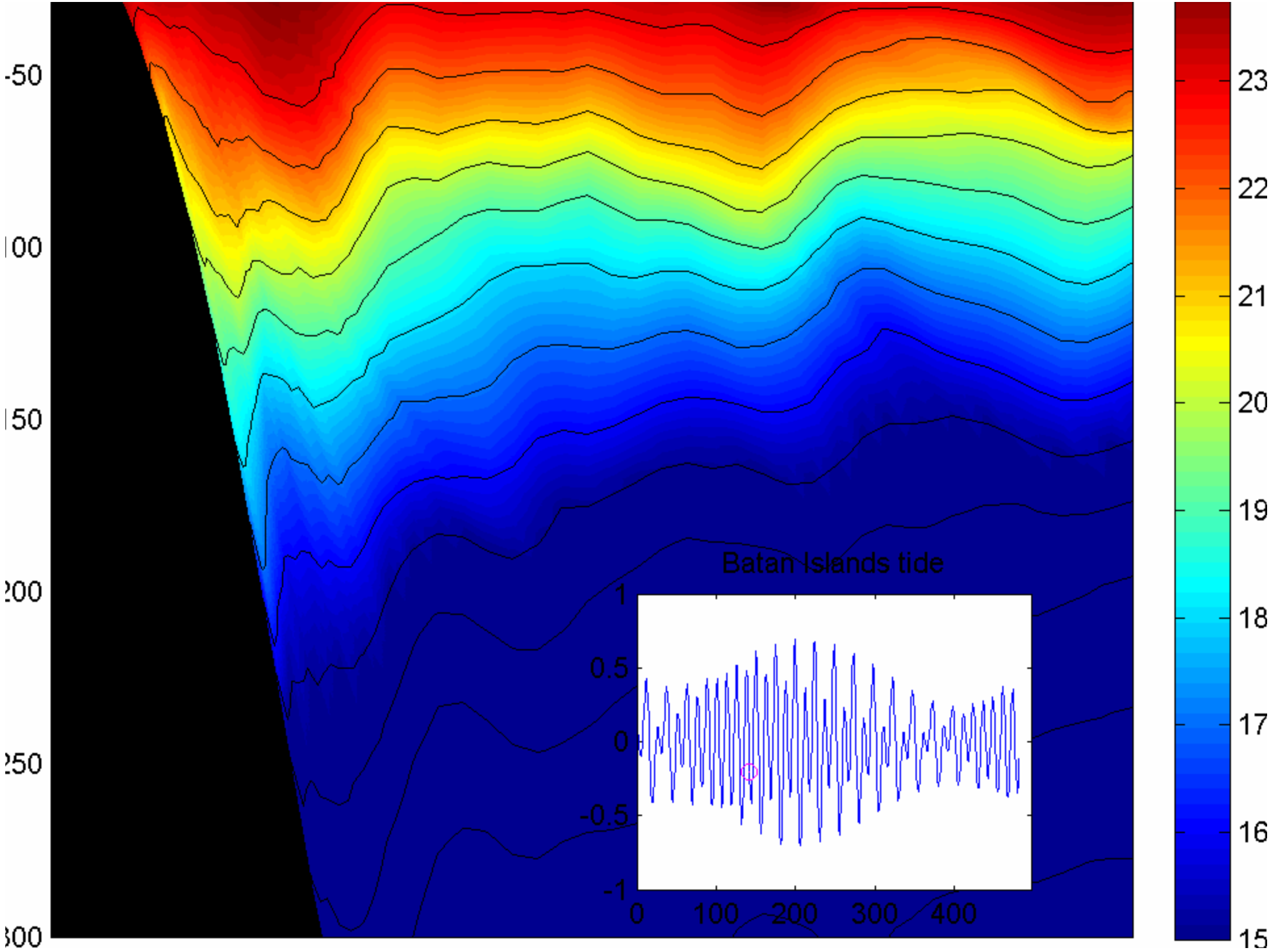
Test of Different Stratification in the Luzon Strait

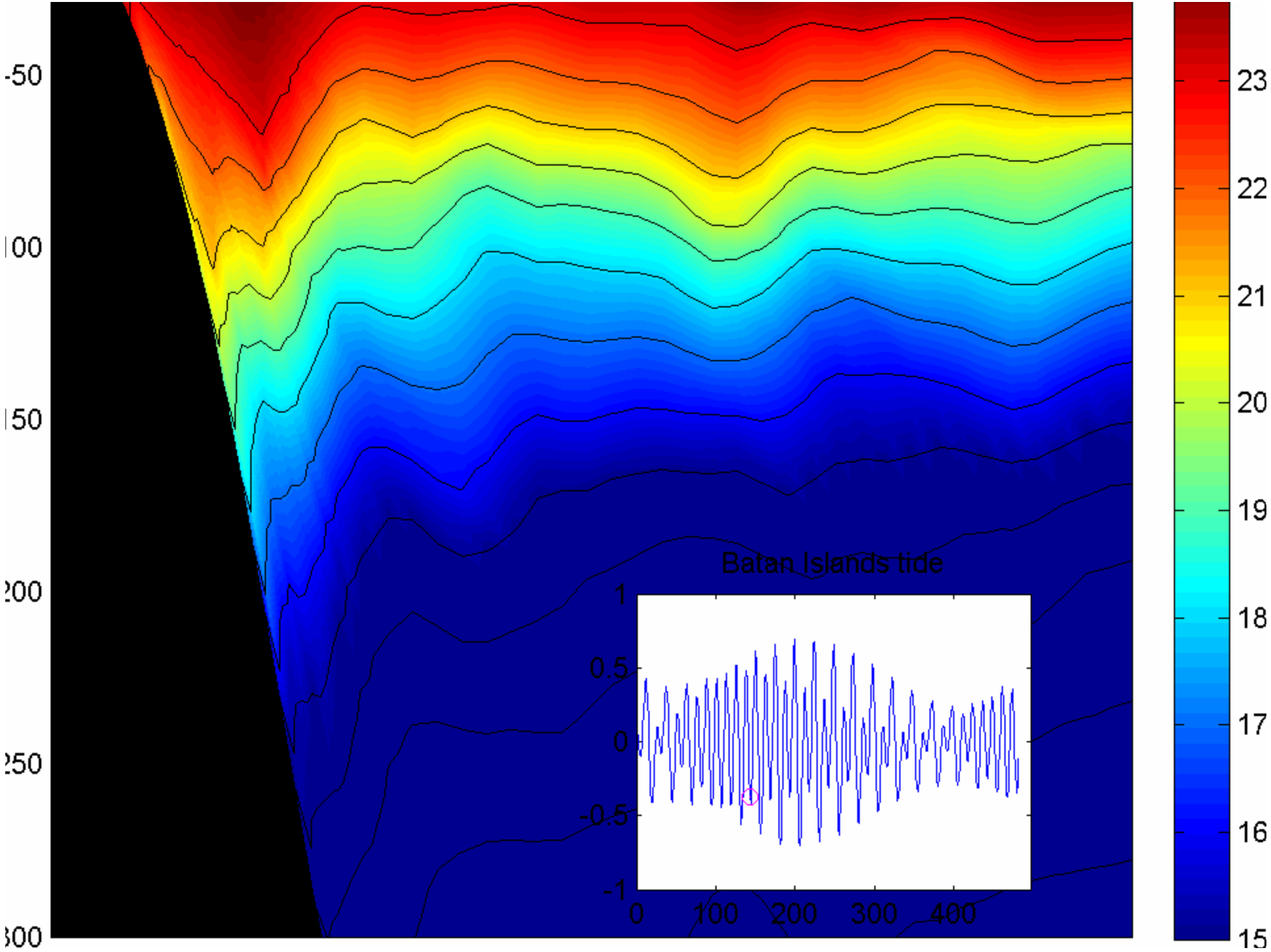


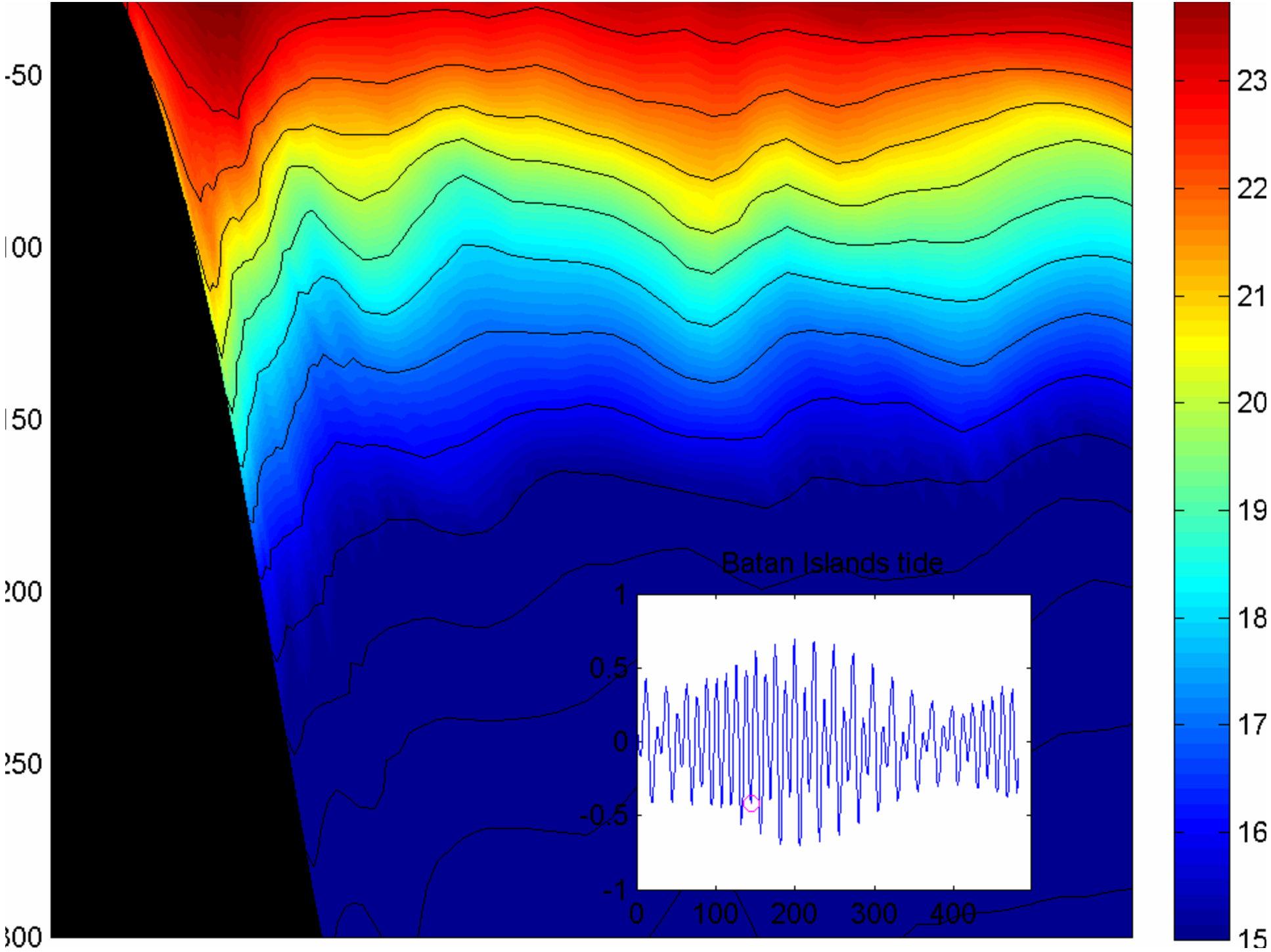

2005/05/3 23hr 20.5°N temperature
depth(m)
-100
-200
-300
-400
-500
-600
Batan Islands tide
1
0.5
0
-0.5
-1
200
300
400
116
117
118
119
120
121
122
123
124
longitude °E
24
22
20
18
16
14
12
10
8
6
4
°C

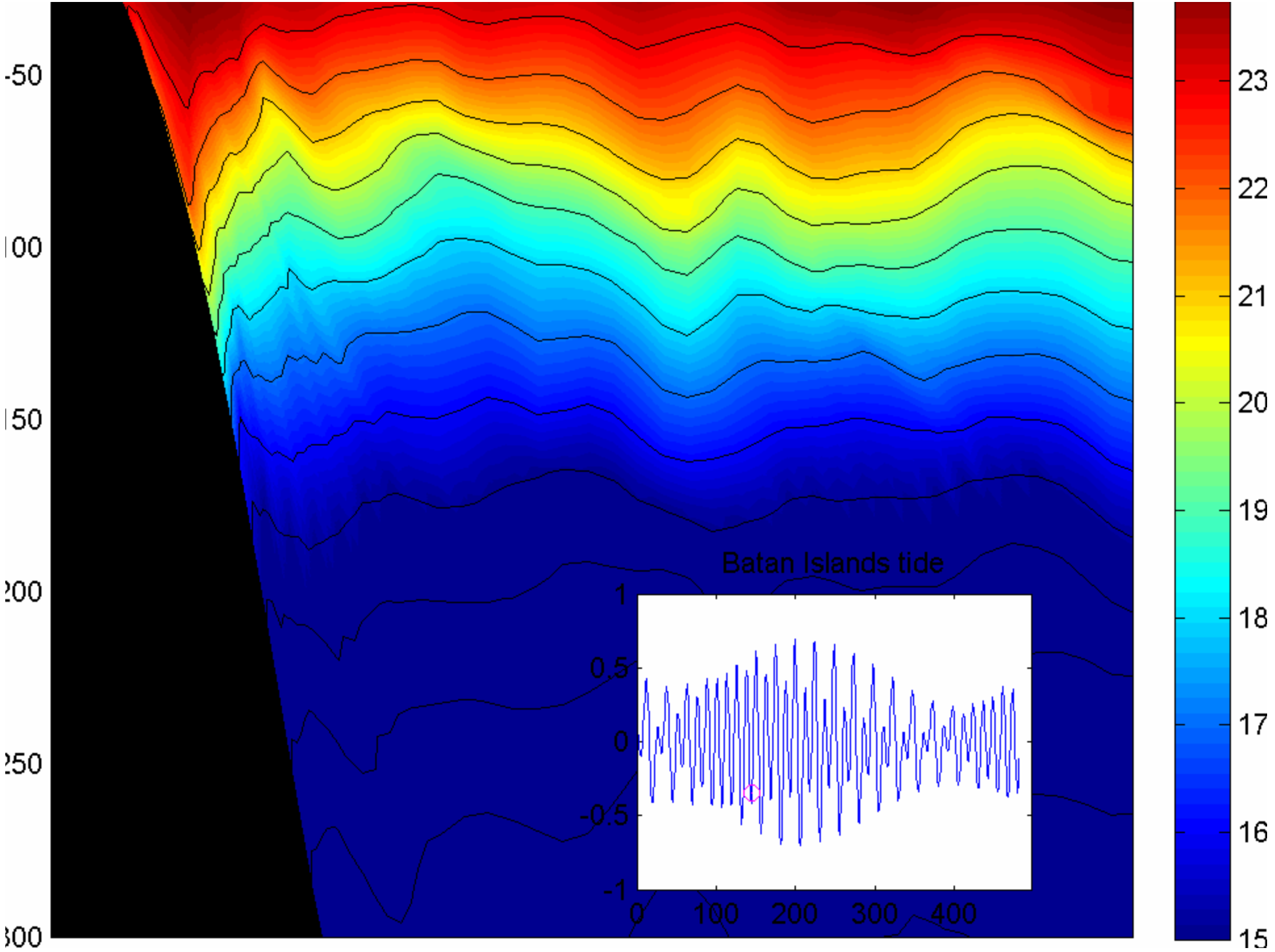

2005/05/3 23hr 20.5°N temperature
depth (m)
-100
-200
-300
-400
-500
-600
Batan Islands tide
1
0.5
0
-0.5
-1
200
300
400
116
117
118
119
120
121
122
123
124
longitude °E
24
22
20
18
16
14
12
10
8
6
4
°C

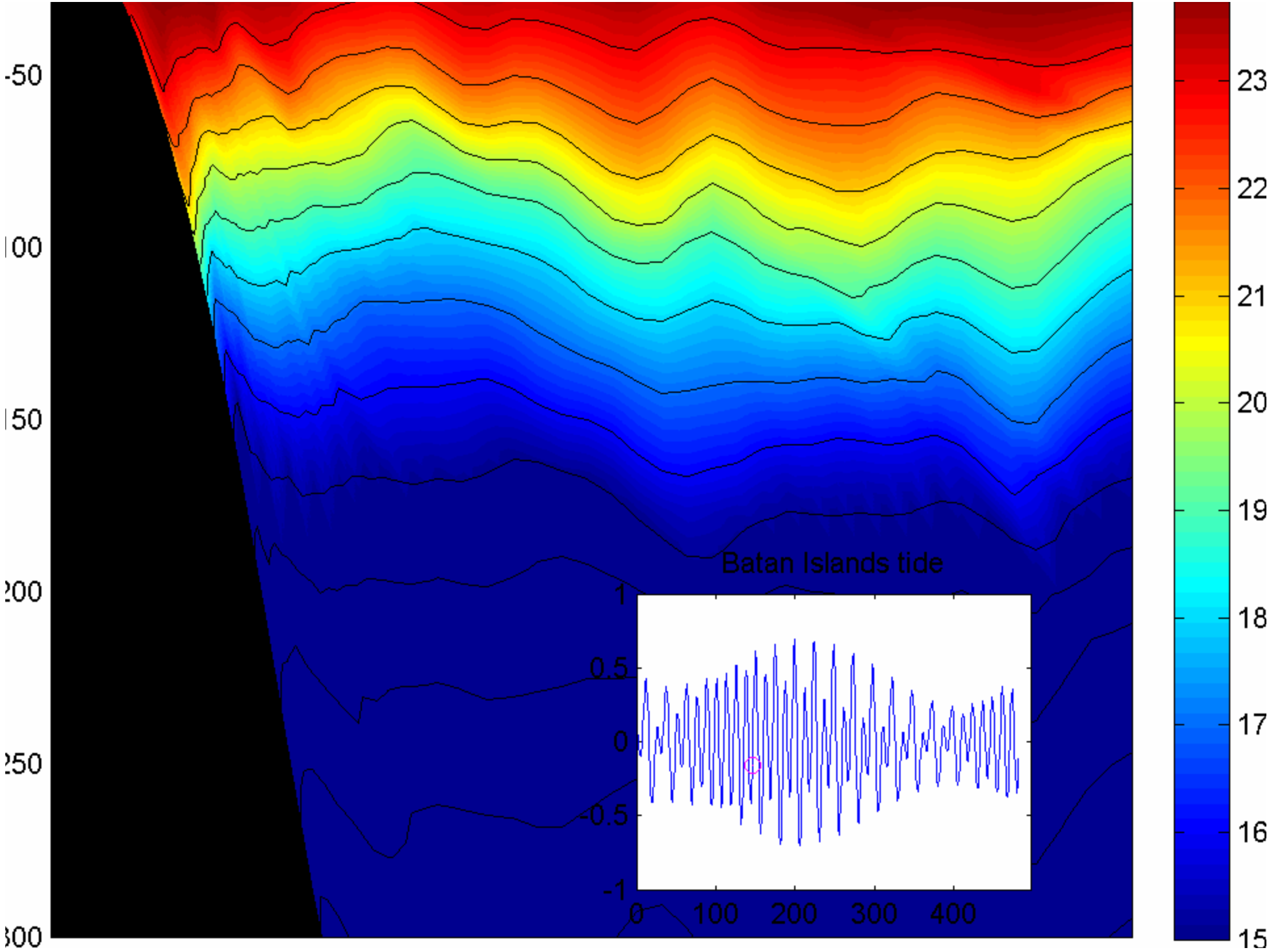

-50
100
150
200
250
300
23
22
21
20
19
18
17
16
15
Batan Islands tide
1
0.5
0
-0.5
-1
0
100
200
300
400

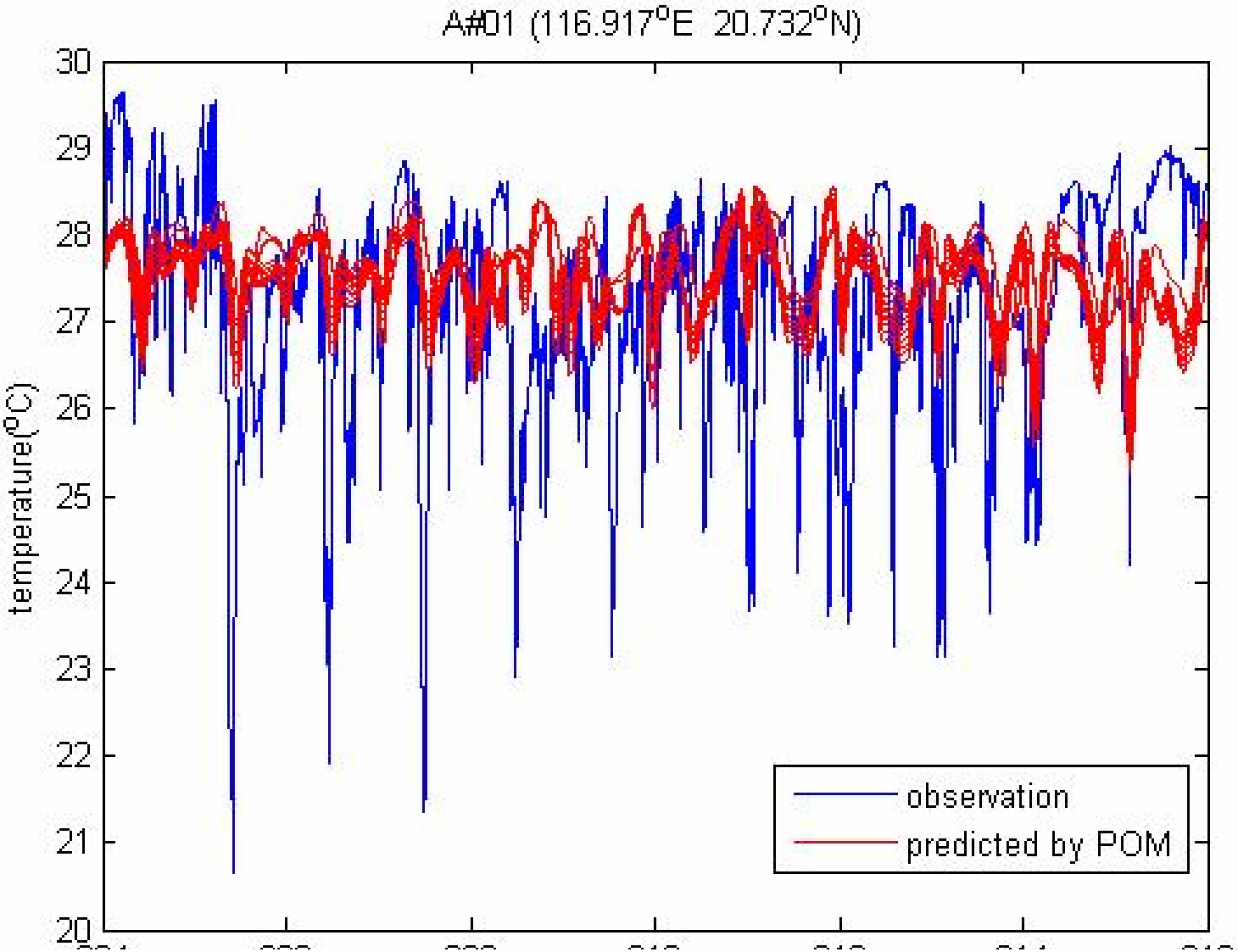

-50
100
150
200
250
300
23
22
21
20
19
18
17
16
15
Batan Islands tide
1
0.5
0
-0.5
-1
0
100
200
300
400


-50
100
150
200
250
300
23
22
21
20
19
18
17
16
15
Batan Islands tide
1
0.5
0
-0.5
-1
0
100
200
300
400


-50
100
150
200
250
300
23
22
21
20
19
18
17
16
15
Batan Islands tide
1
0.5
0
-0.5
-1
0
100
200
300
400

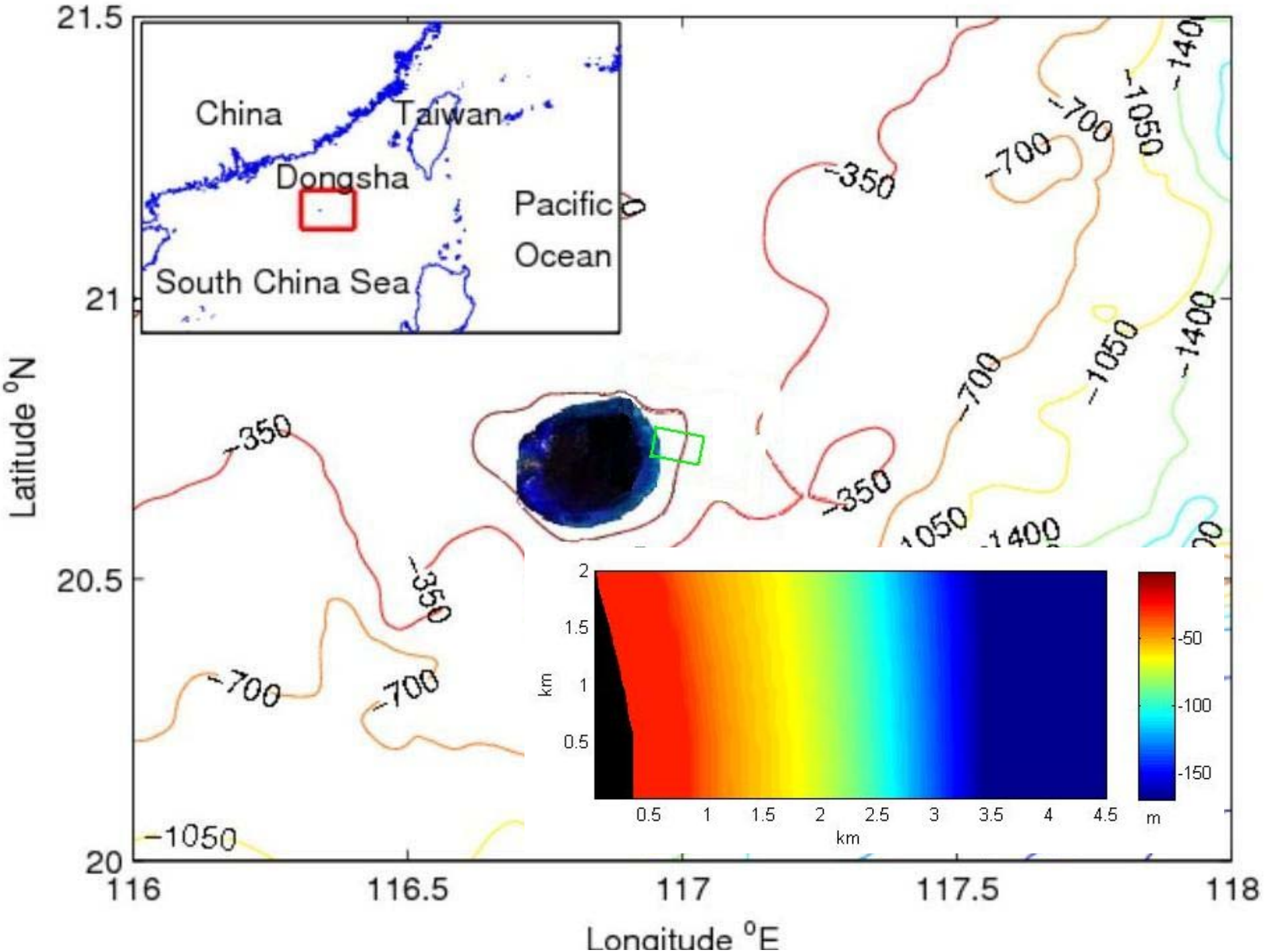

-50
100
150
200
250
300
23
22
21
20
19
18
17
16
15
Batan Islands tide
1
0.5
0
-0.5
-1
0
100
200
300
400

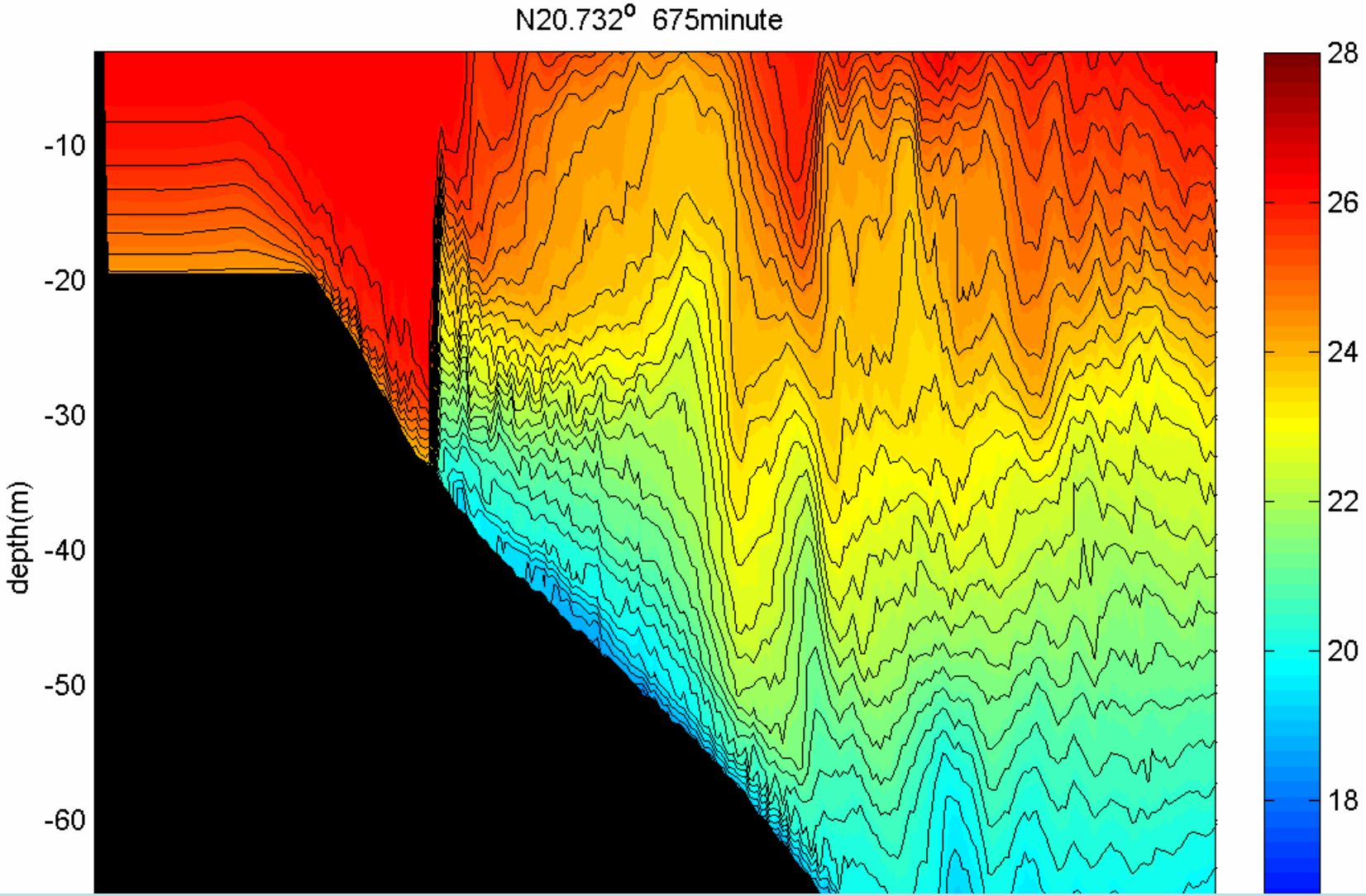

-50
100
150
200
250
300
23
22
21
20
19
18
17
16
15
Batan Islands tide
1
0.5
0
-0.5
-1
0
100
200
300
400


A#01 (116.917°E 20.732°N)
temperature(°C)
30
29
28
27
26
25
24
23
22
21
20
observation
predicted by POM

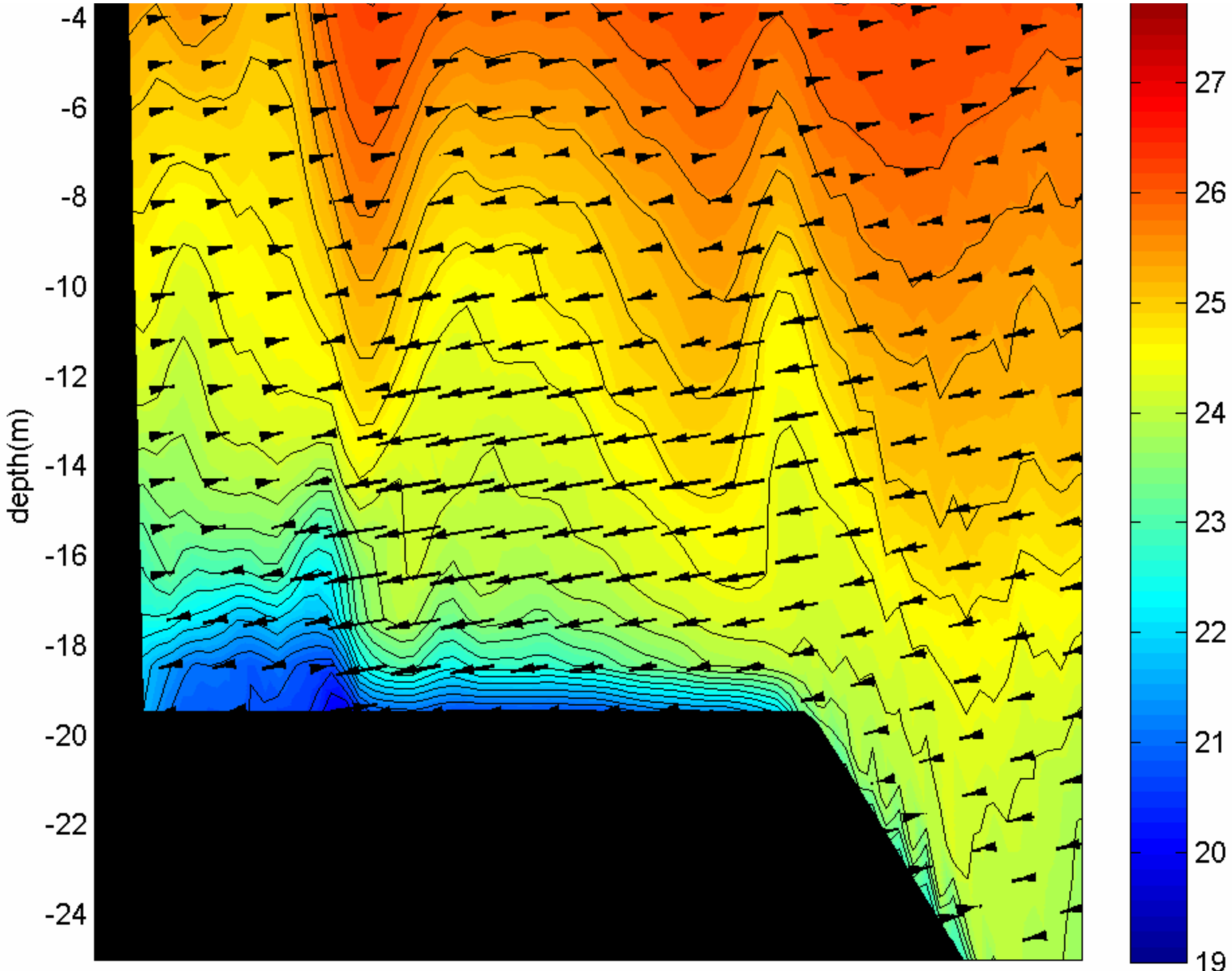
Internal boluses (elevated internal wave) formed after the ISW breaks contribute significantly to the cooling. This motivates a detailed investigation on the structure of boluses

Internal solitary waves (ISWs) ride on Internal tide


China
Taiwan
Dongsha
Pacific
Ocean
South China Sea
-350
-700
-1050
-1400
21.5
21
20.5
20
116
116.5
117
117.5
118
Latitude °N
Longitude °E
km
m
-50
-100
-150
0.5
1
1.5
2
2.5
3
3.5
4
4.5



The breaking of the rear part of the longer wave


depth(m)
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
27
26
25
24
23
22
21
20
19

Summary

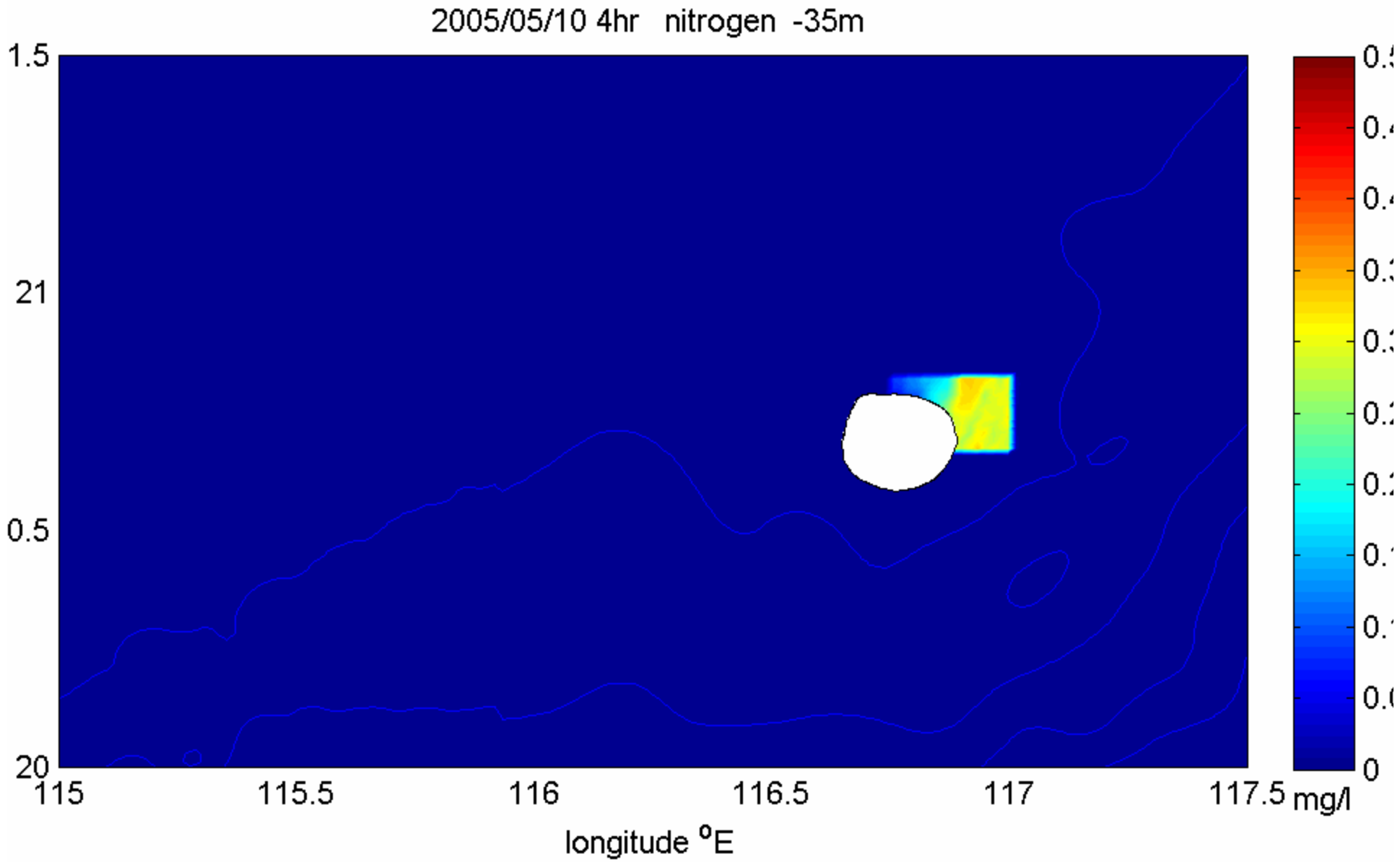
- Internal solitary waves ride on Internal tide
- Internal solitary waves can form boluses
- Internal tides and boluses contribute to the cooling

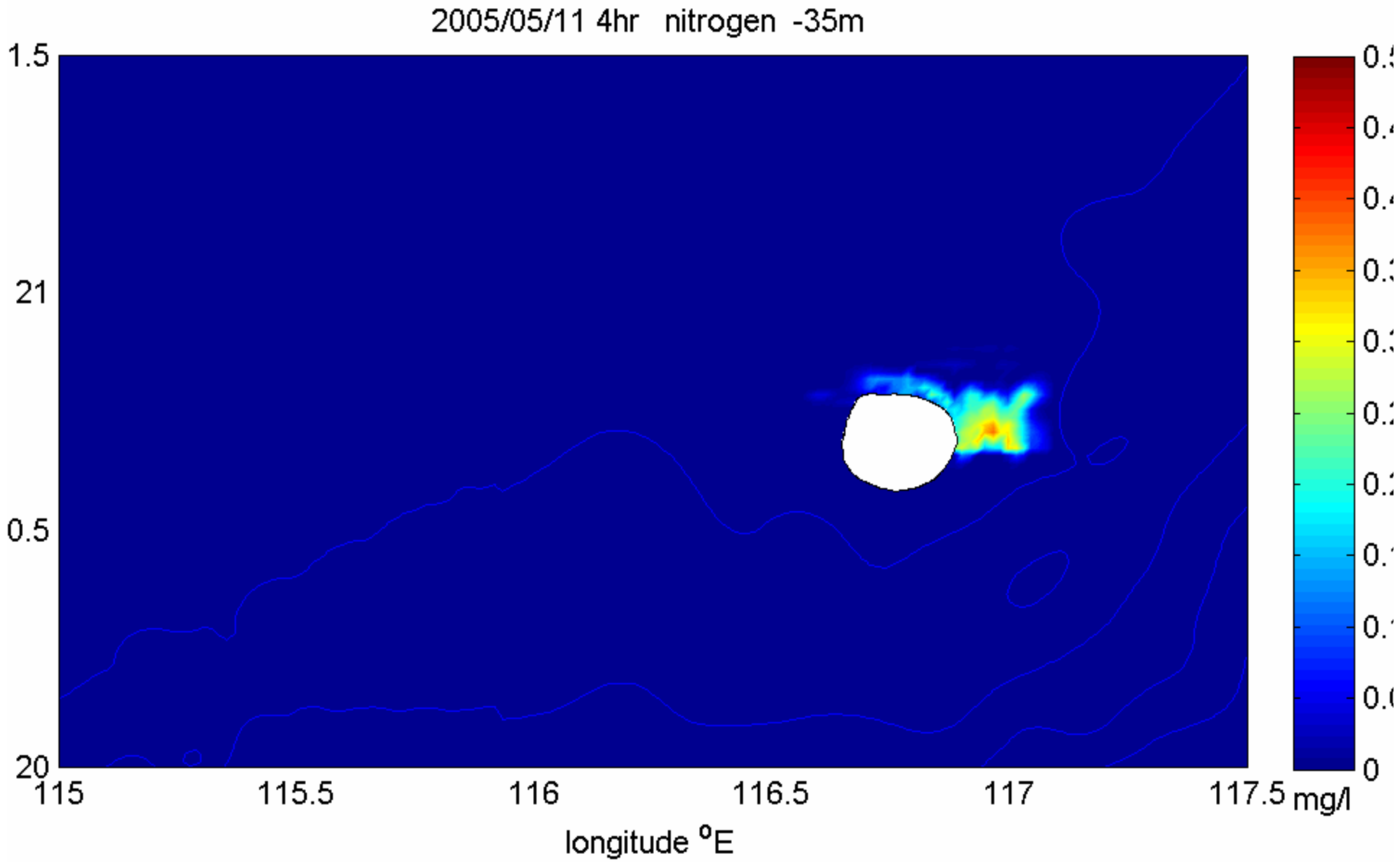
Initial Nutrient Concentration: Silicon Dioxide, Soluble Reactive Phosphate, NO2 (Nitrite) +NO3(Nitrate)

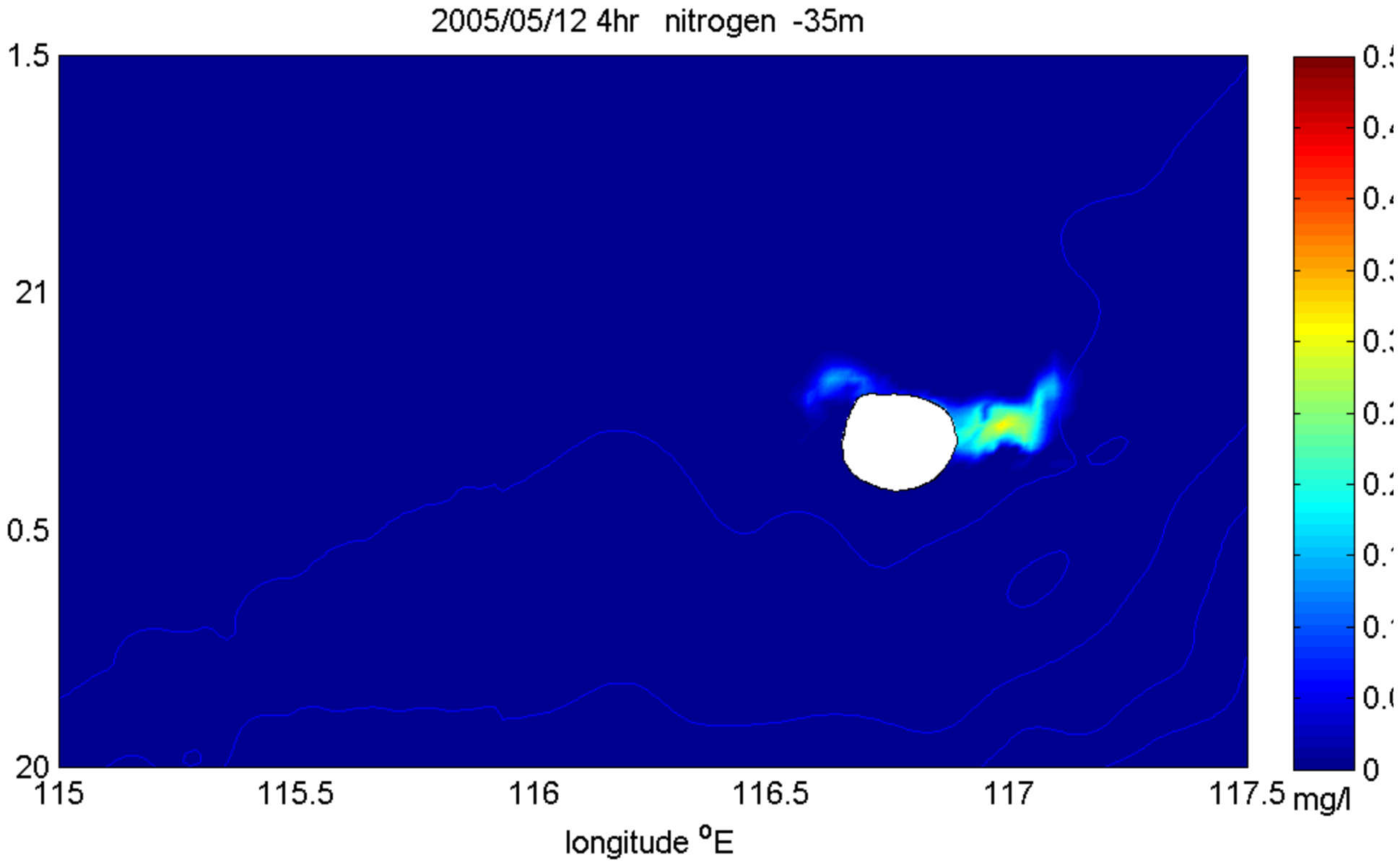
- 1. assumed zero nutrient everywhere except for the nutrient pumped up by ISW near Dongsha
- 2.taken from the monthly average value in National Oceanographic Data Center (NODC), NOAA

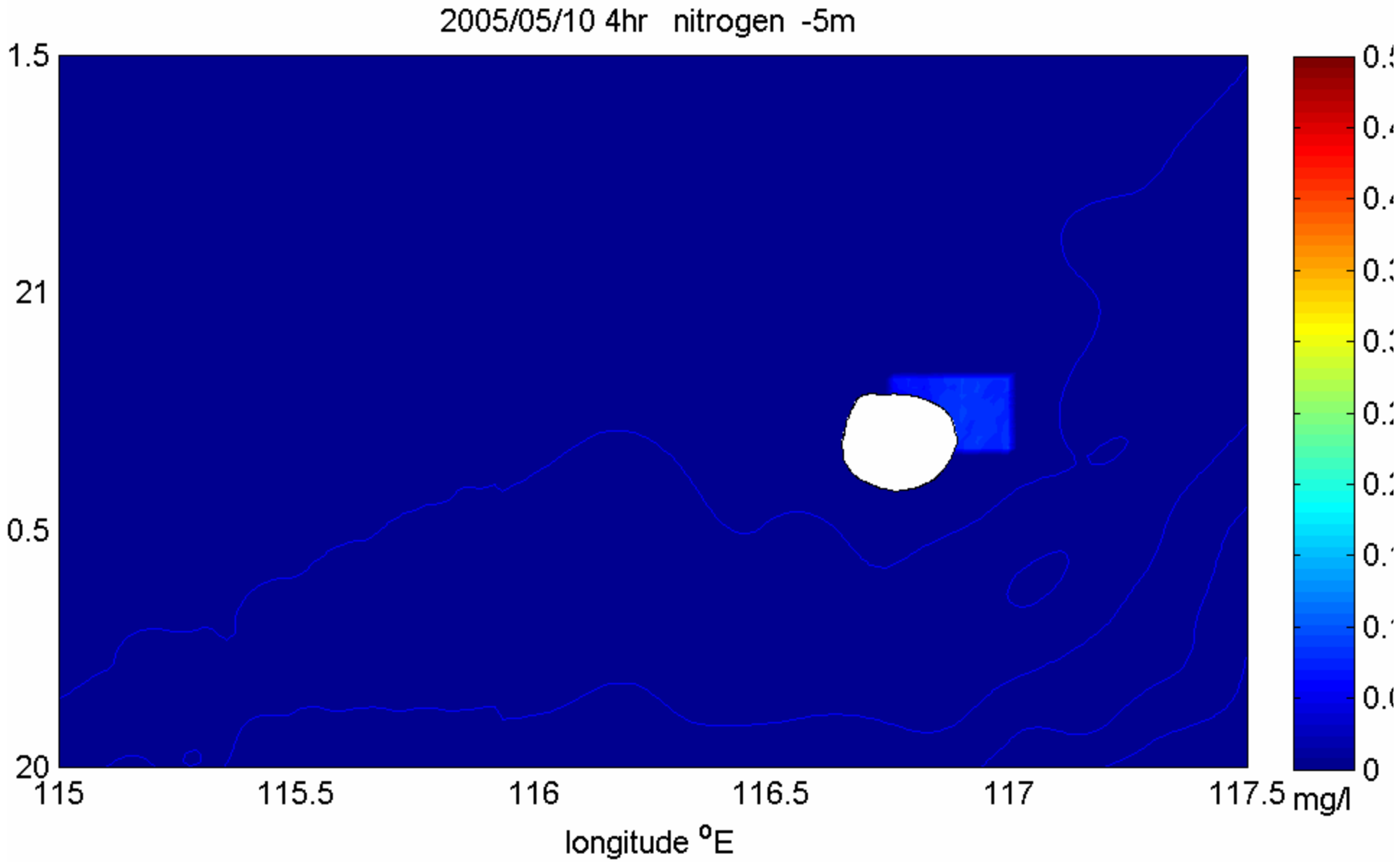
The northern South China Sea is nitrogen-insufficient
Nitrogen is the control factor for the ecosystem

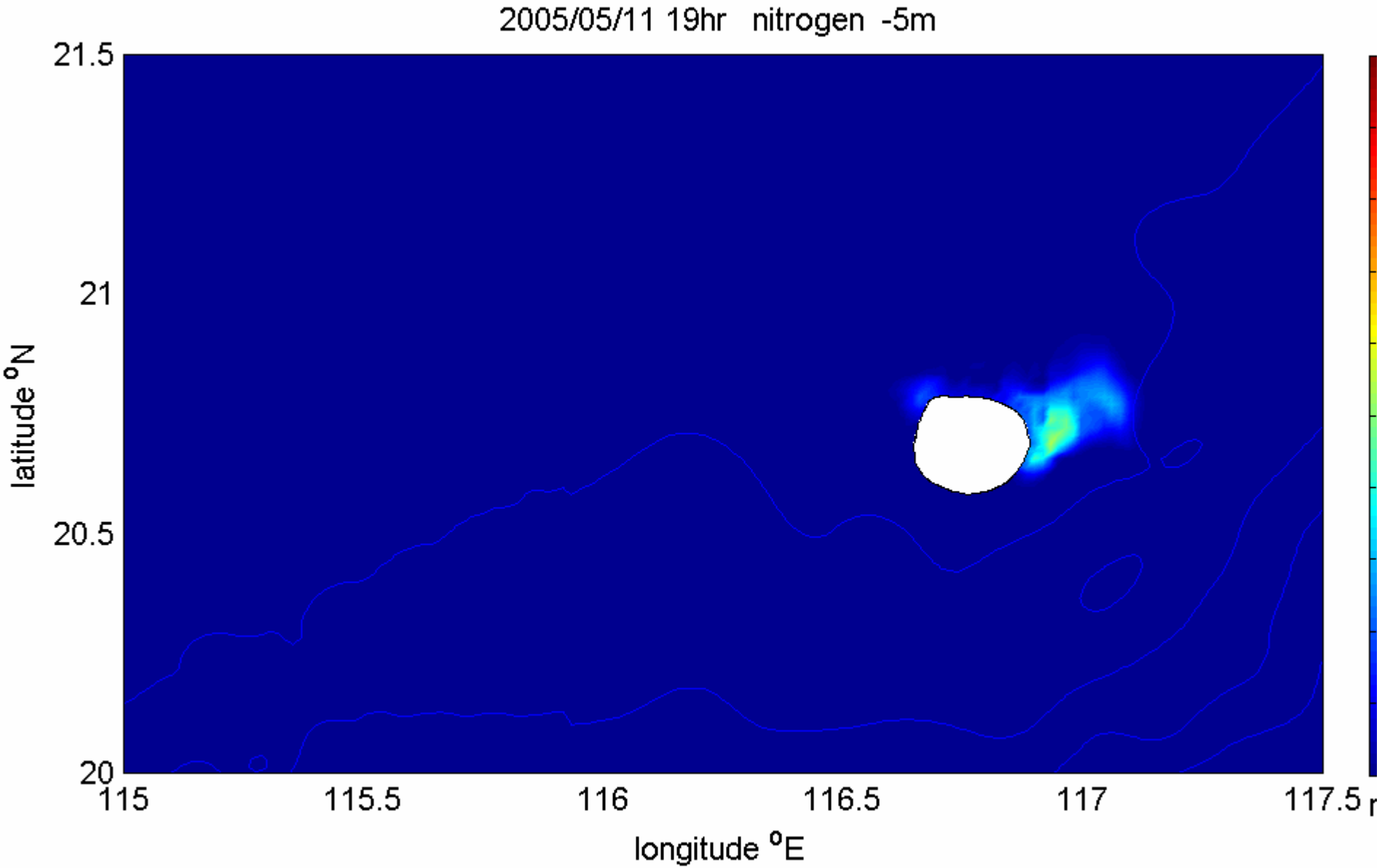
Initial nutrient concentration is assumed zero everywhere except for the nutrient pumped up by ISW near Dongsha


2005/05/10 4hr nitrogen -35m
1.5
21
0.5
20
115
115.5
116
116.5
117
117.5
longitude °E
mg/l
0


2005/05/11 4hr nitrogen -35m
1.5
21
0.5
20
115
115.5
116
116.5
117
117.5
longitude °E
mg/l
0


2005/05/12 4hr nitrogen -35m
1.5
21
0.5
20
115
115.5
116
116.5
117
117.5
longitude °E
mg/l
0

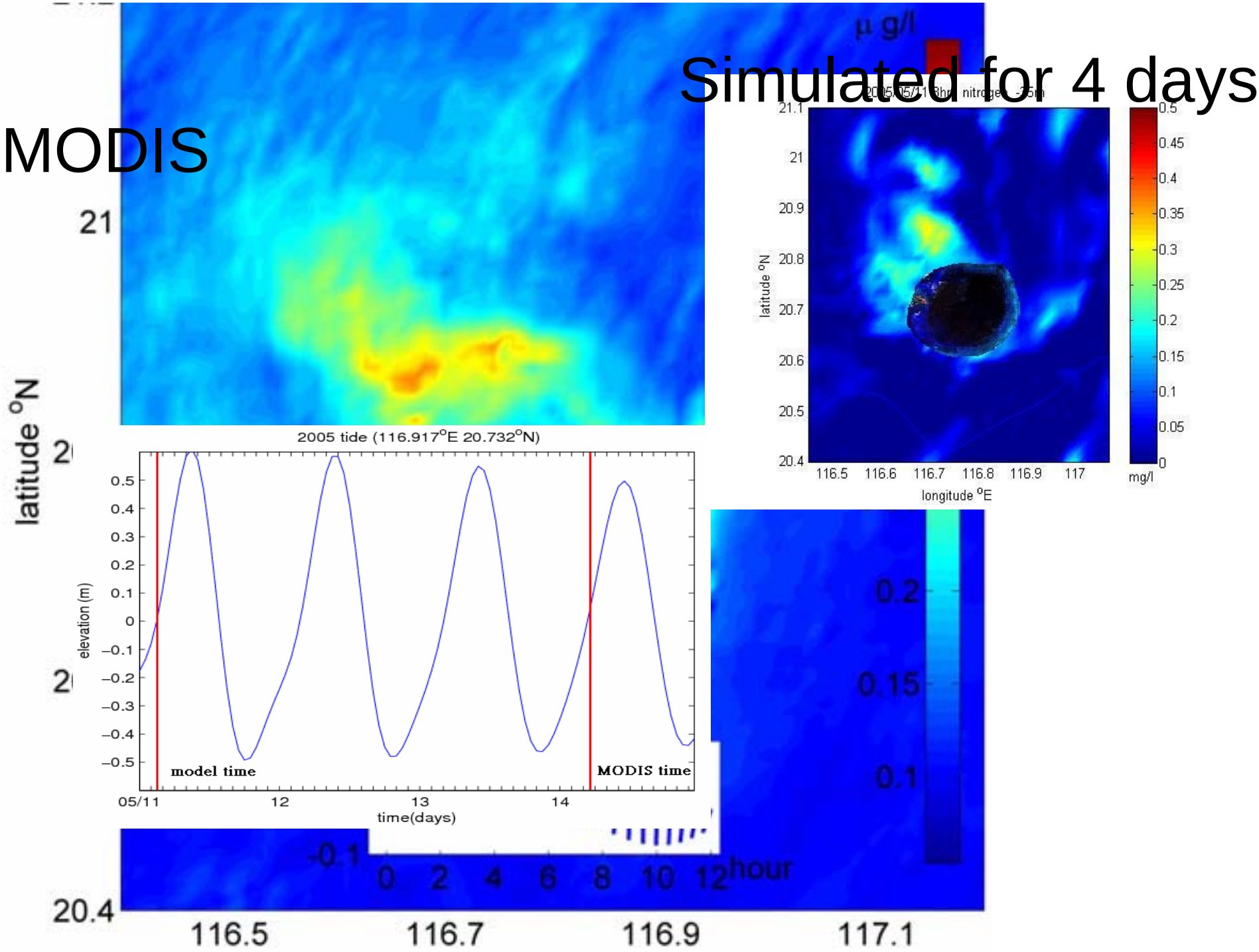

2005/05/10 4hr nitrogen -5m
1.5
21
0.5
20
115
115.5
116
116.5
117
117.5
longitude °E
mg/l
0.5
0.4
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
0

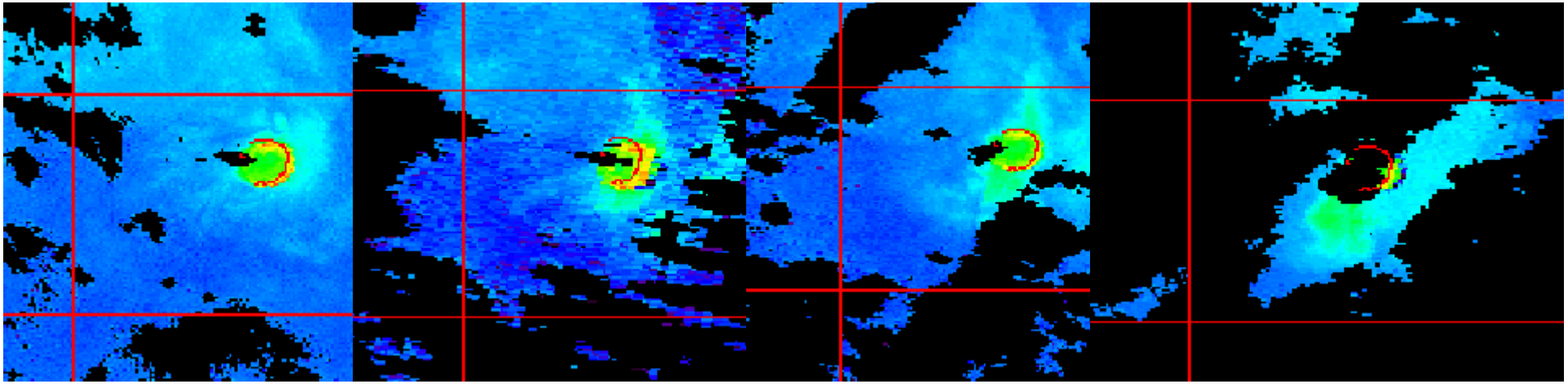

2005/05/11 19hr nitrogen -5m
21.5
21
20.5
20
latitude °N
115
115.5
116
116.5
117
117.5
longitude °E
r

- Besides the nutrient pumped up by ISW, more nutrient is moved upward by internal tide and spread by tidal current
- If the time needed for the phytoplankton to grow is known, we can choose a day and add the nutrient once. The bloom observed by the satellite is then compared with the nutrient distribution.
- If we add the nutrient everyday, a nitrogen cycling model is needed

MODIS

Simulated for 4 days



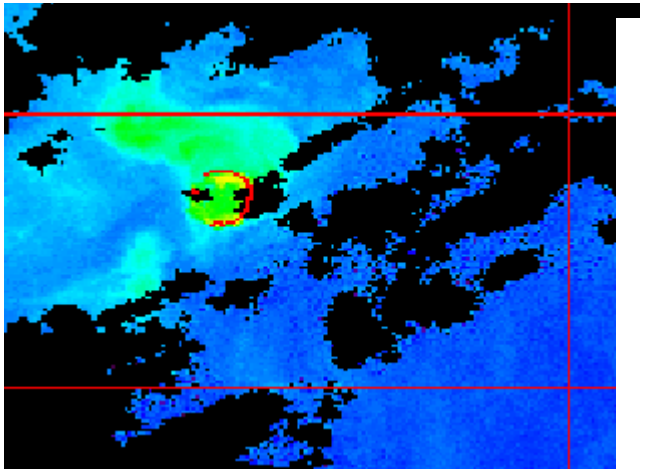


2003/108/04/29/54

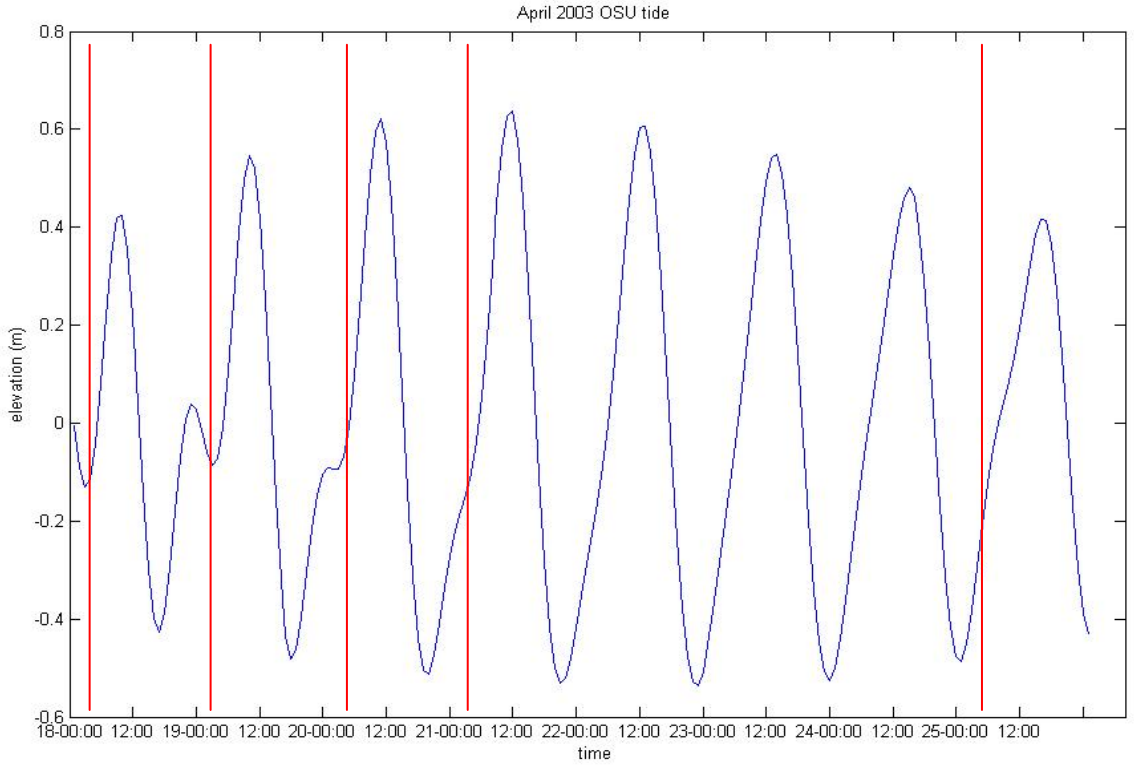
109/05/10/43

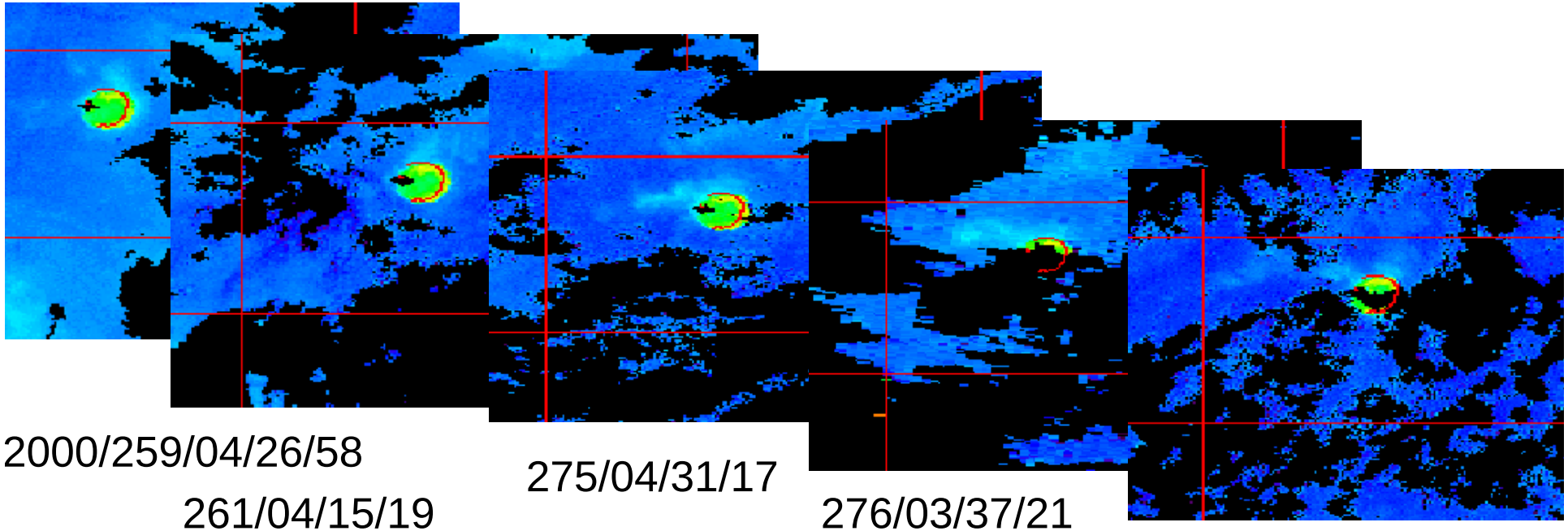
110/04/13/44

111/04/54/05



115/04/42/24





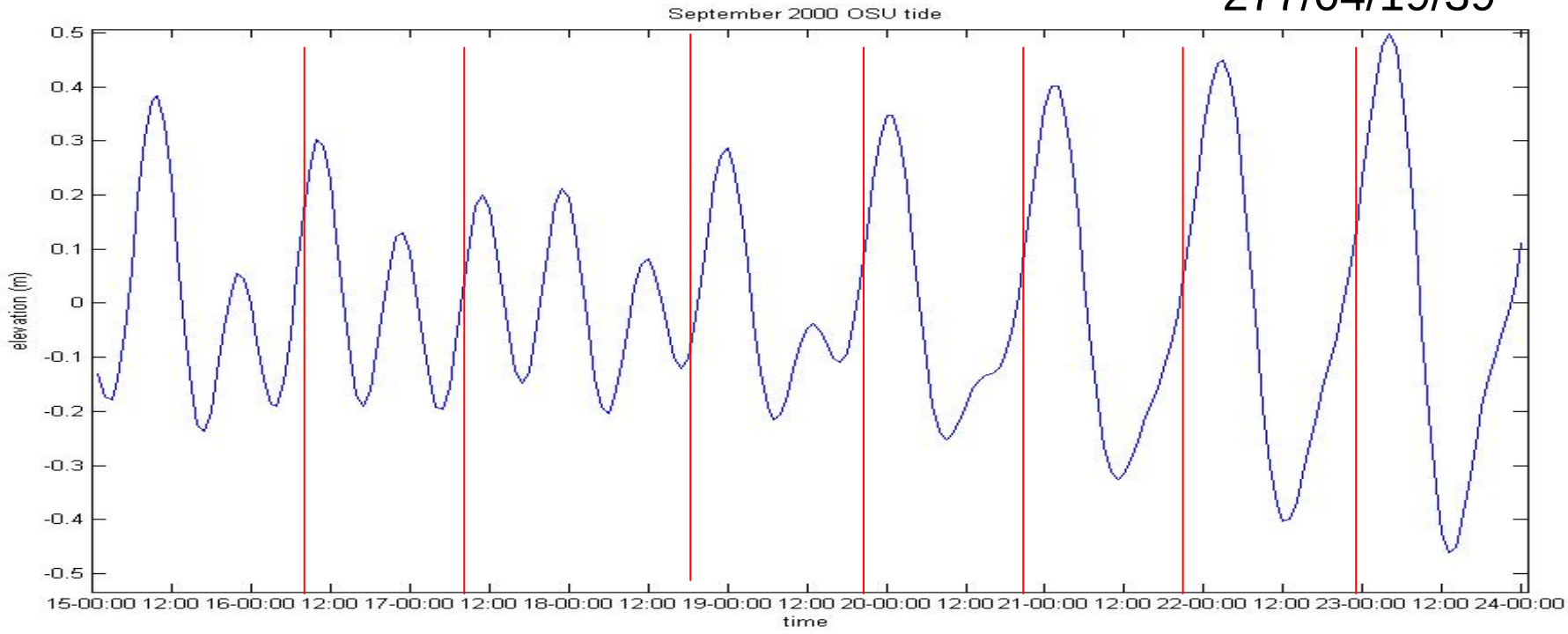
2000/259/04/26/58

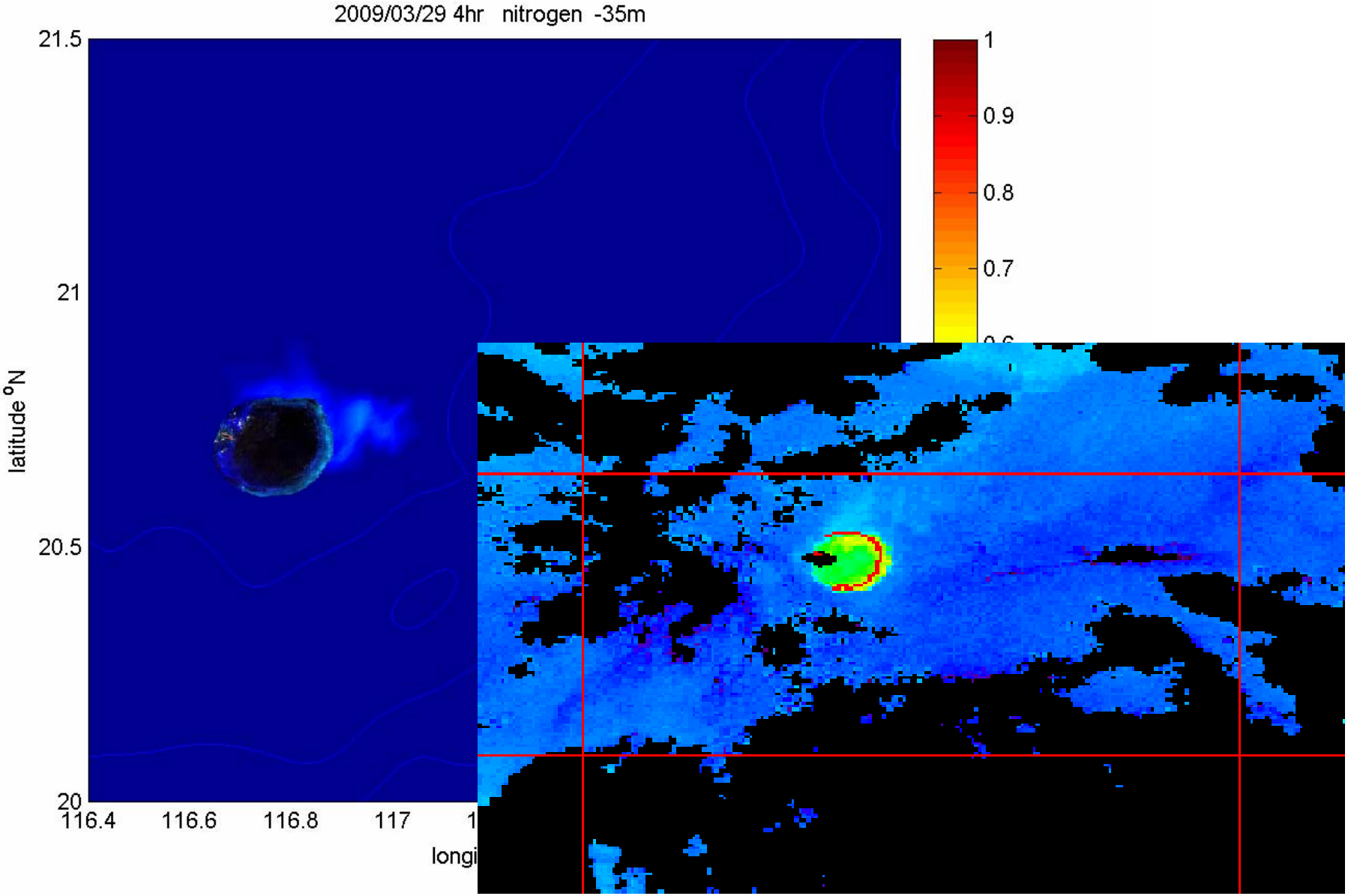
261/04/15/19

275/04/31/17

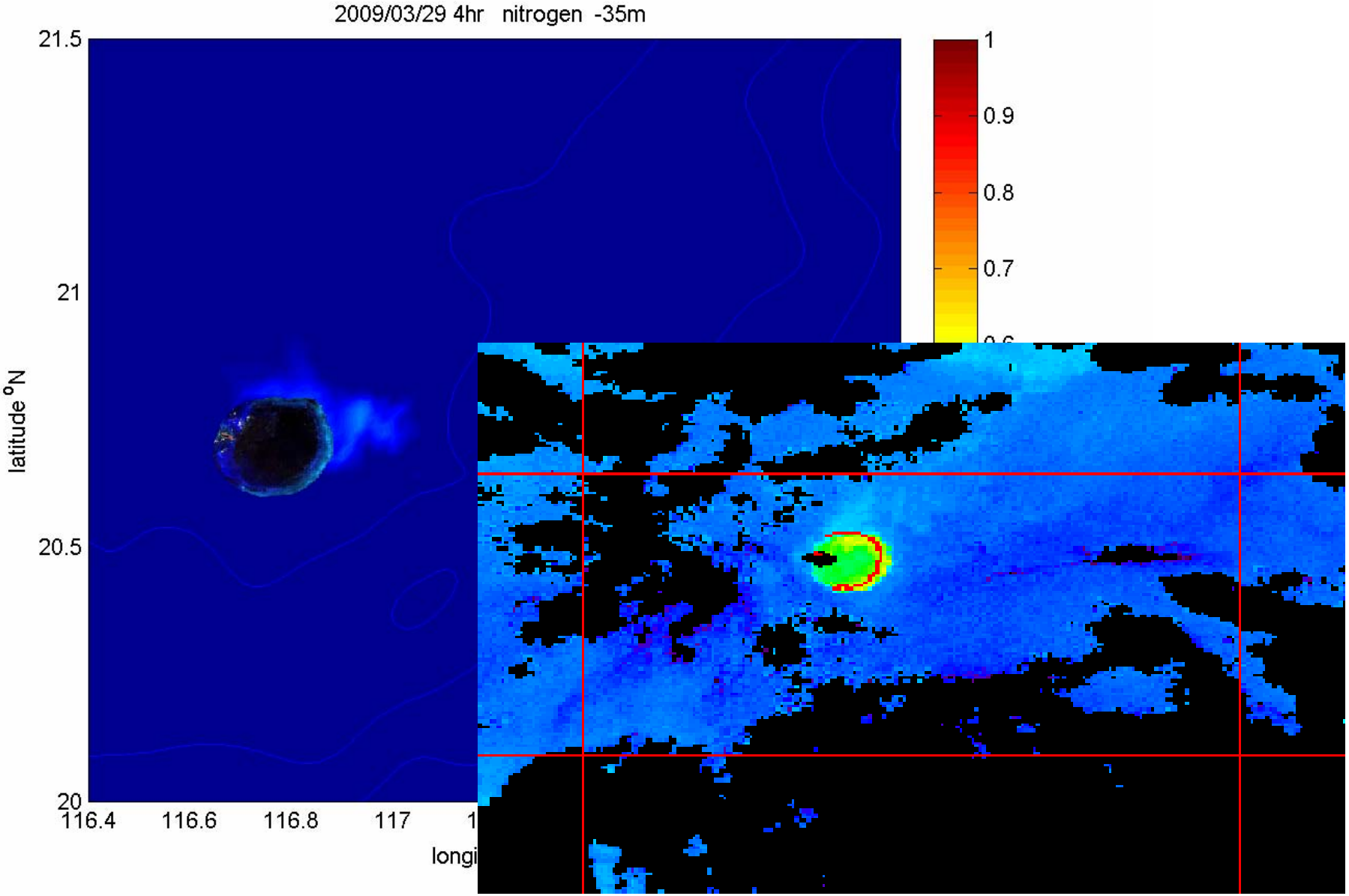
276/03/37/21

277/04/19/39



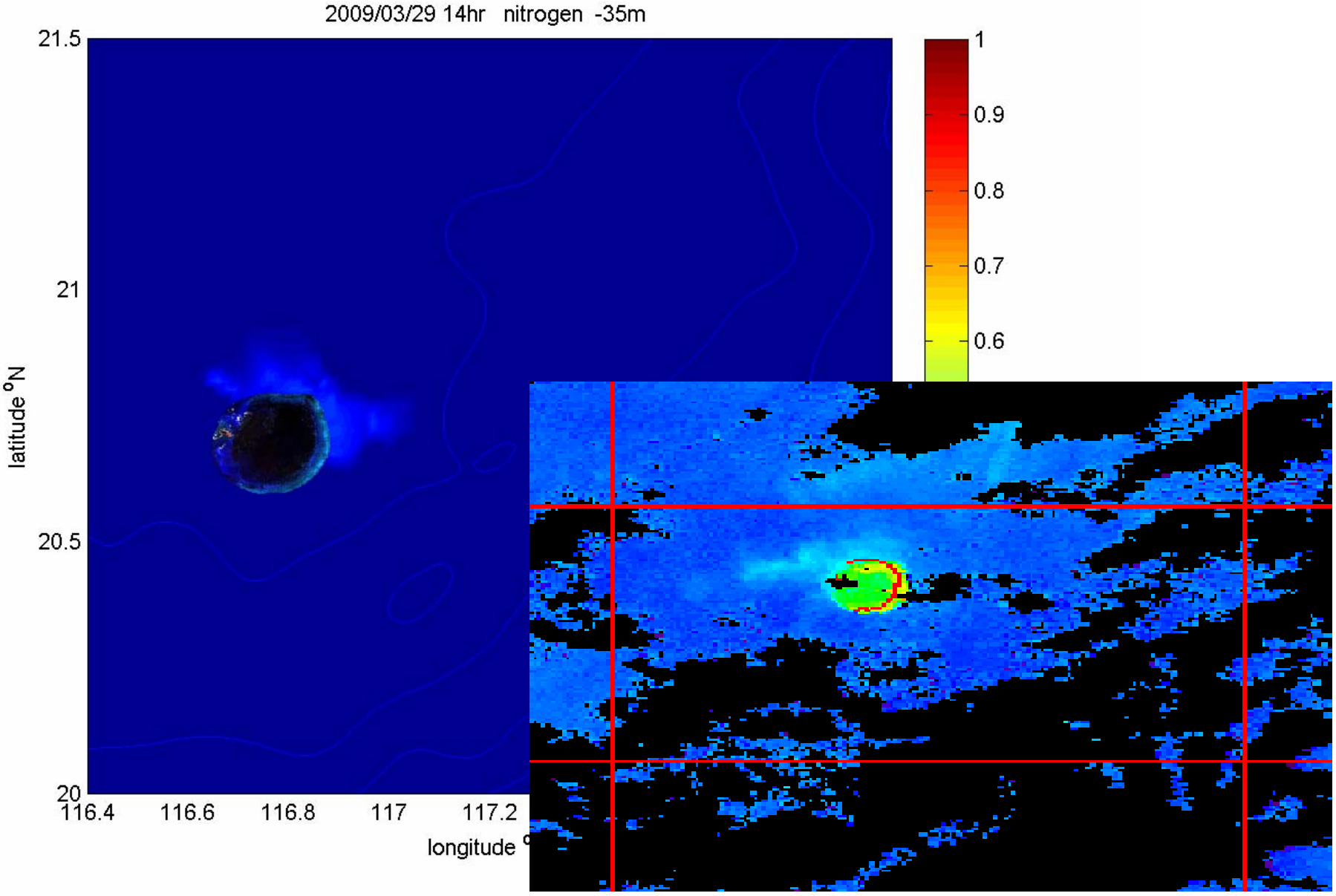


2000/261/04/15/19

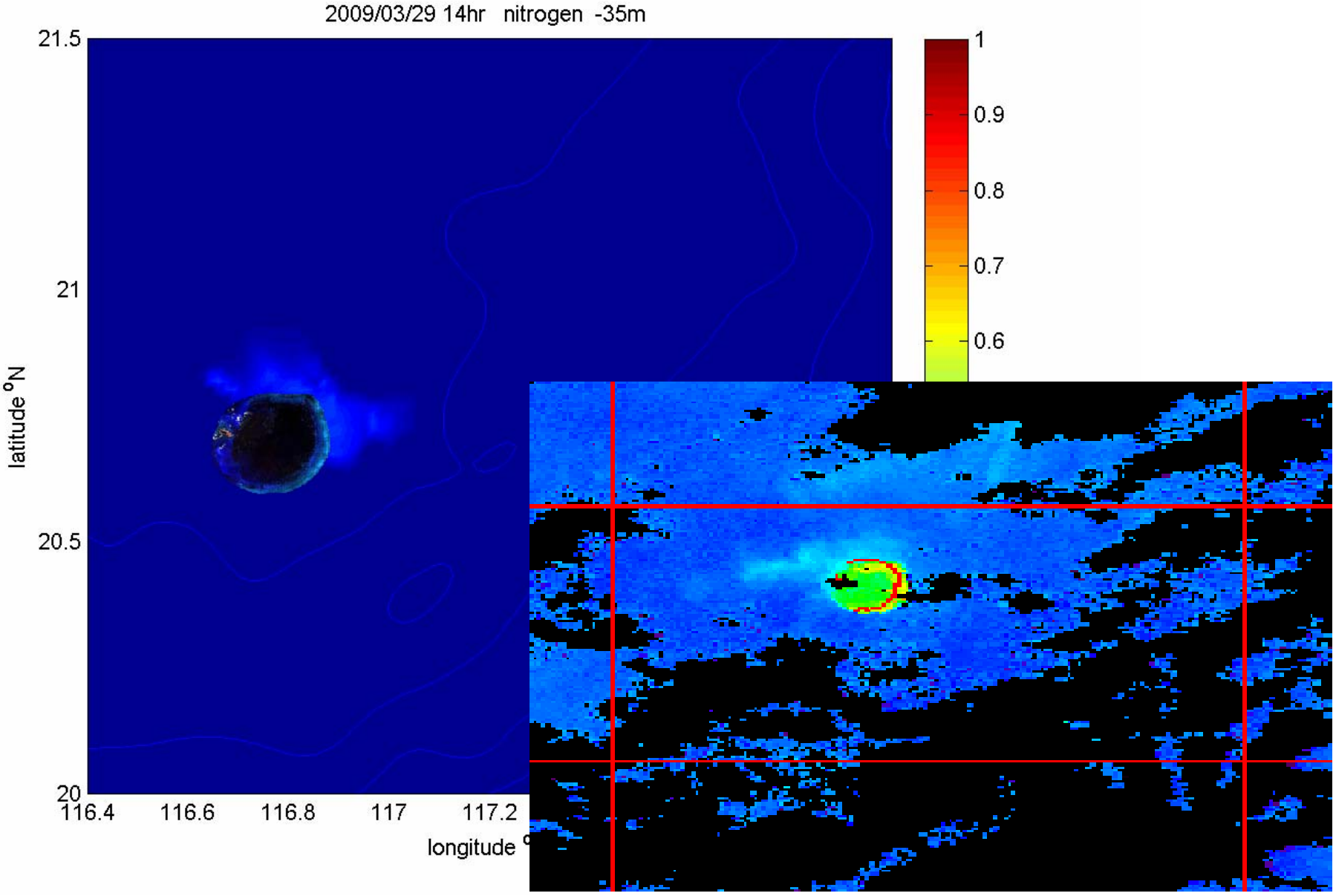


Simulated for 3 days

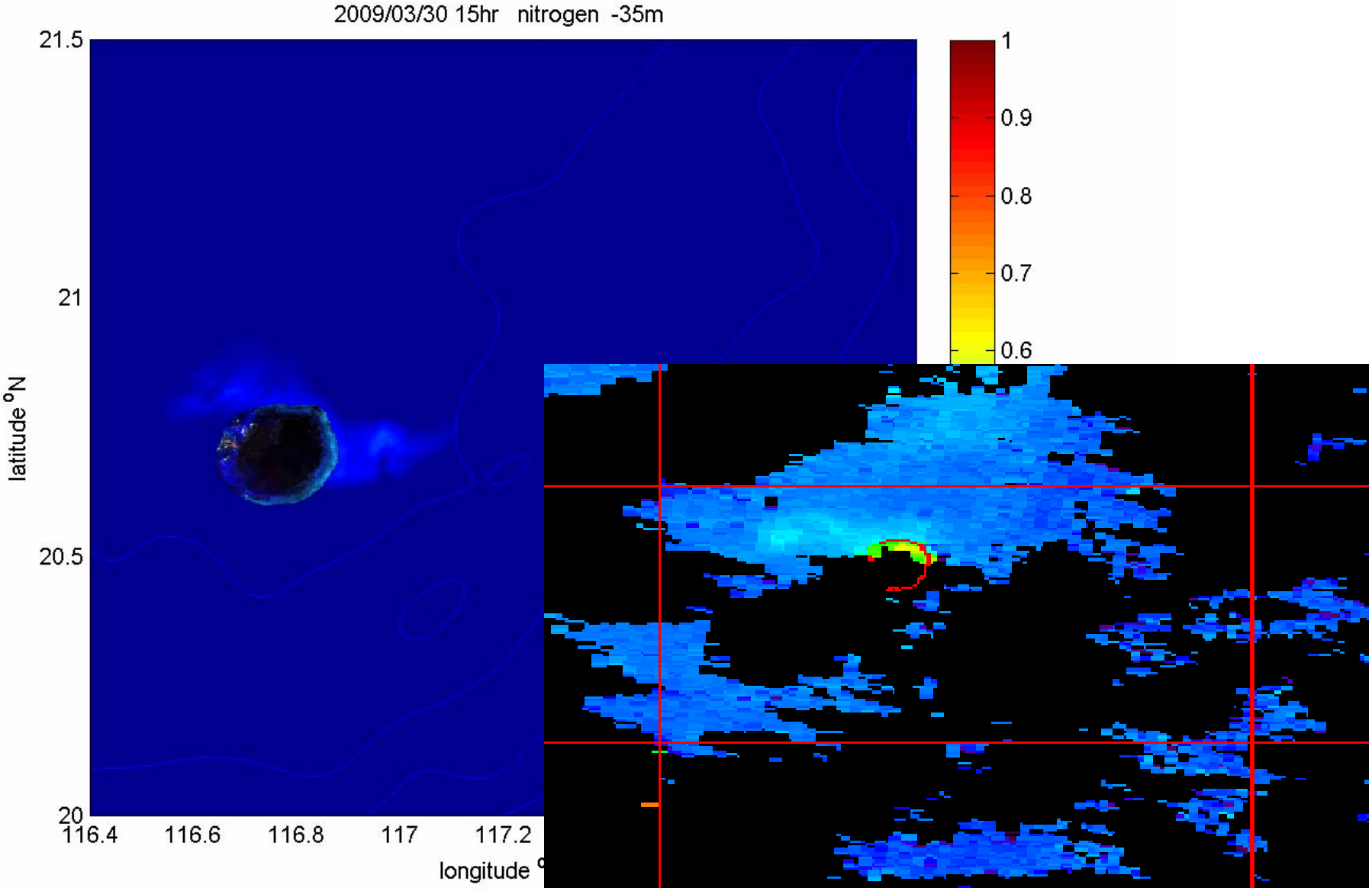
2000/261/04/15/19



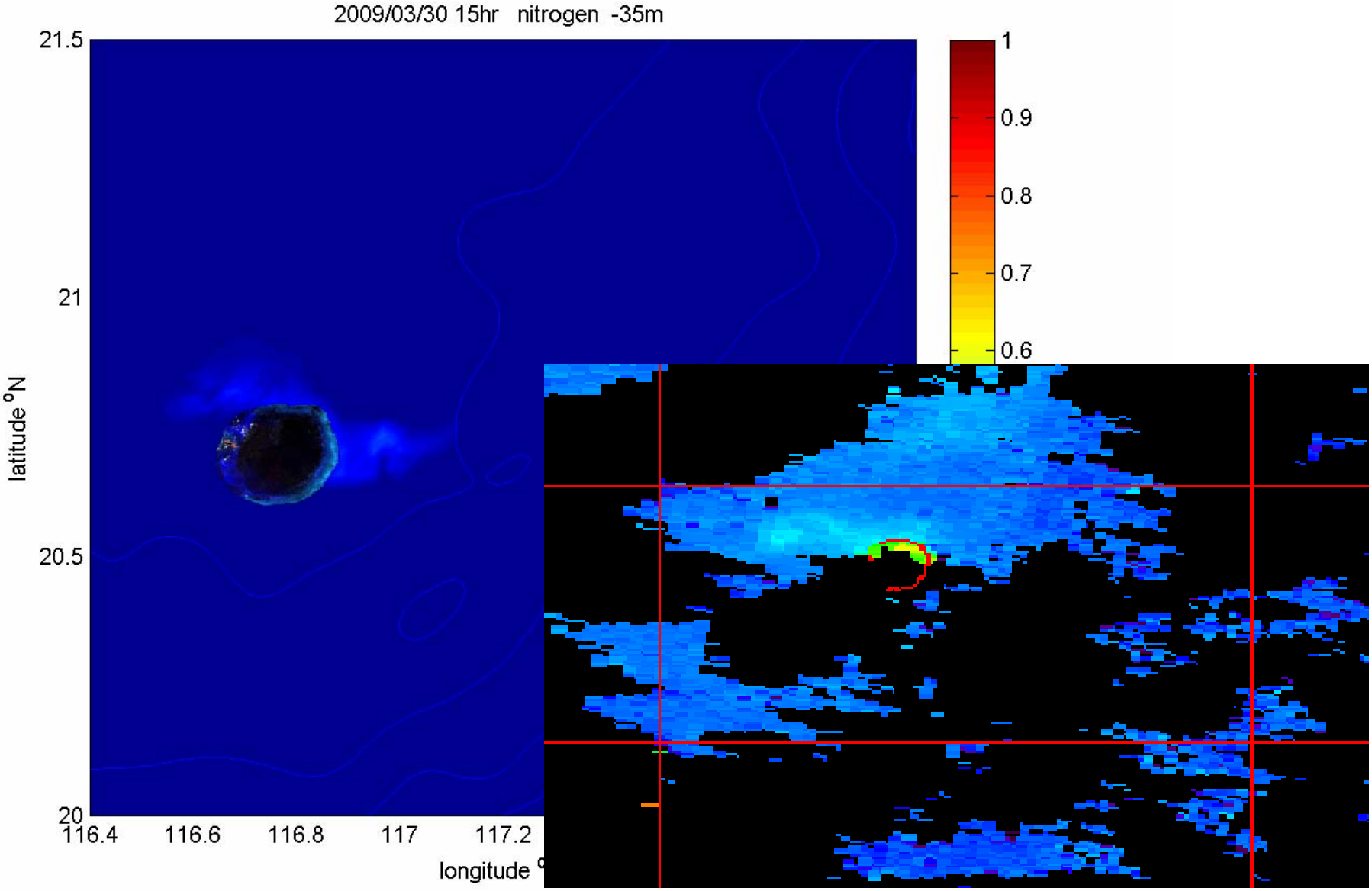
2000/275/04/31/17



Simulated for 3 days and 8 hrs 2000/275/04/31/17

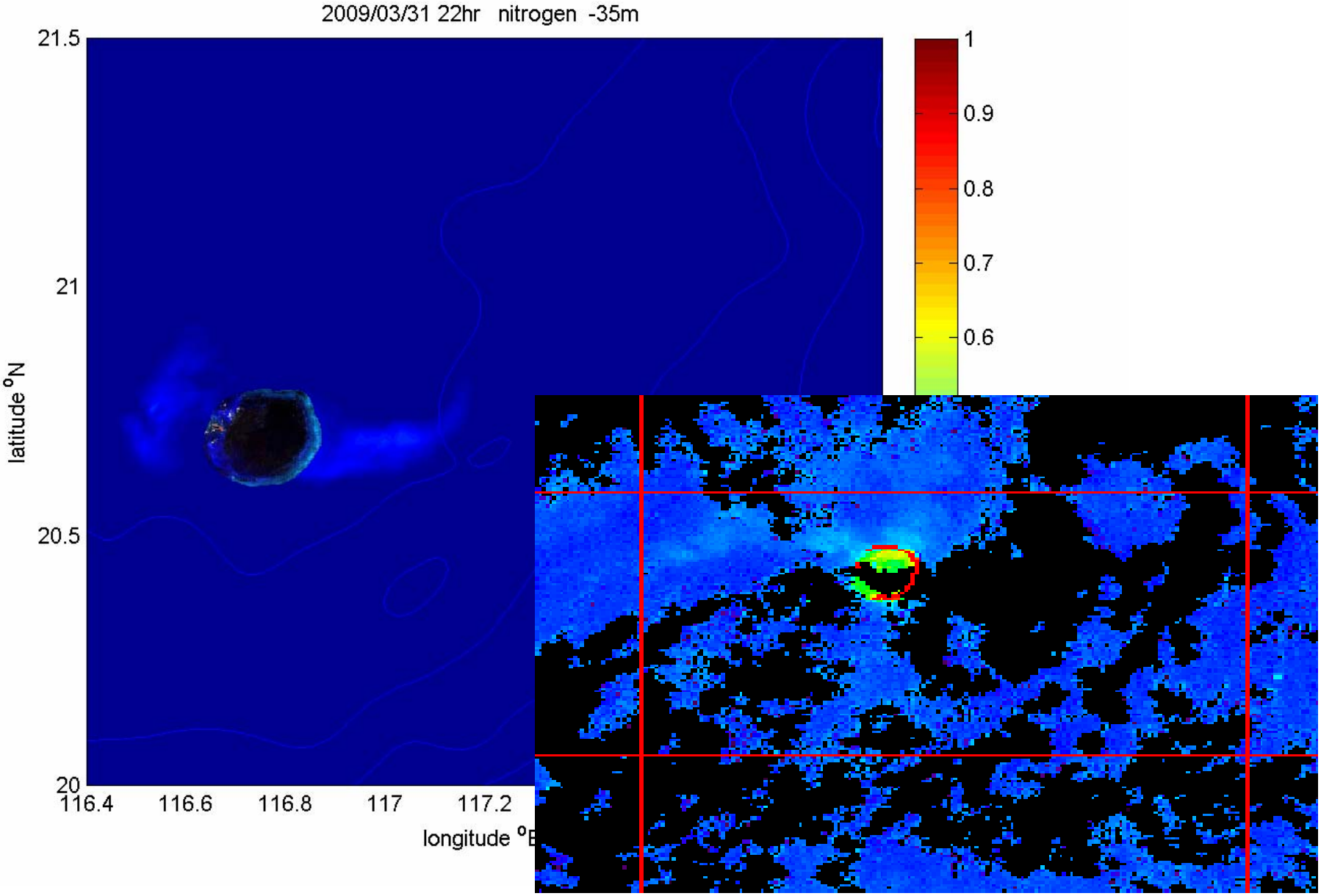


2000/276/03/37/21



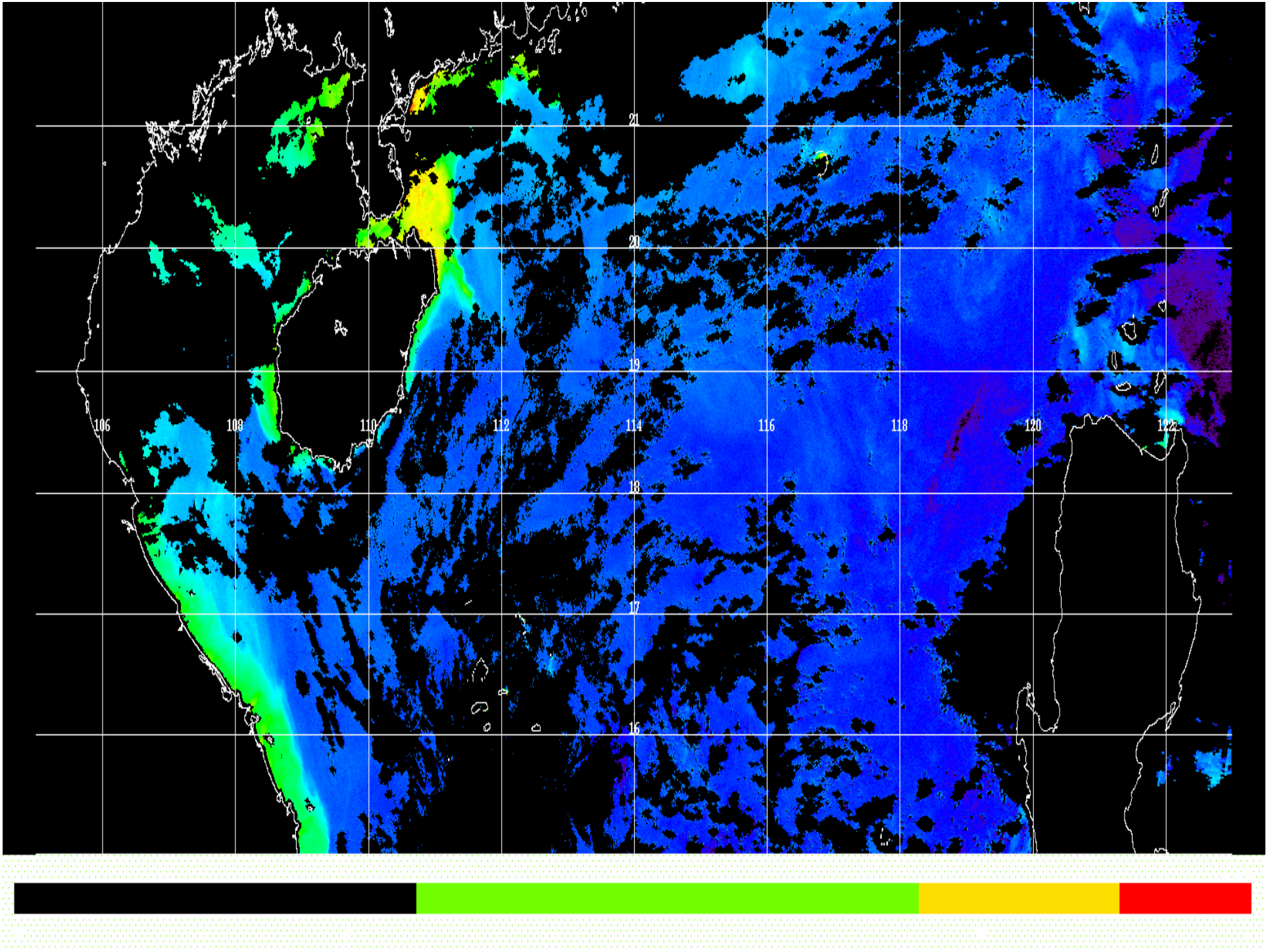
Simulated for 4 days and 9 hrs

2000/276/03/37/21



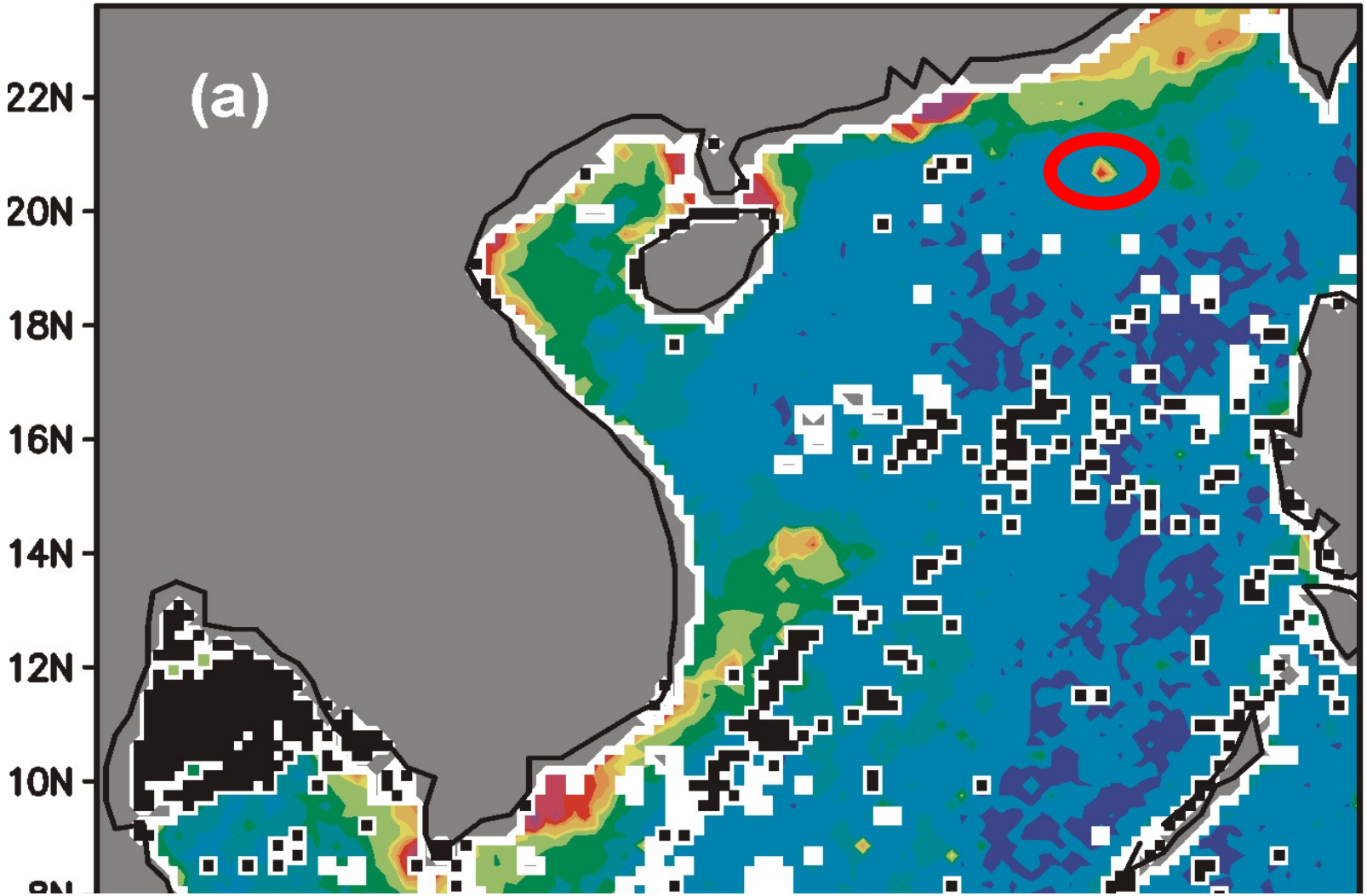
2000/277/04/19/39

Bloom observed near Dongsha is the due to the nutrient pumped up by ISW?

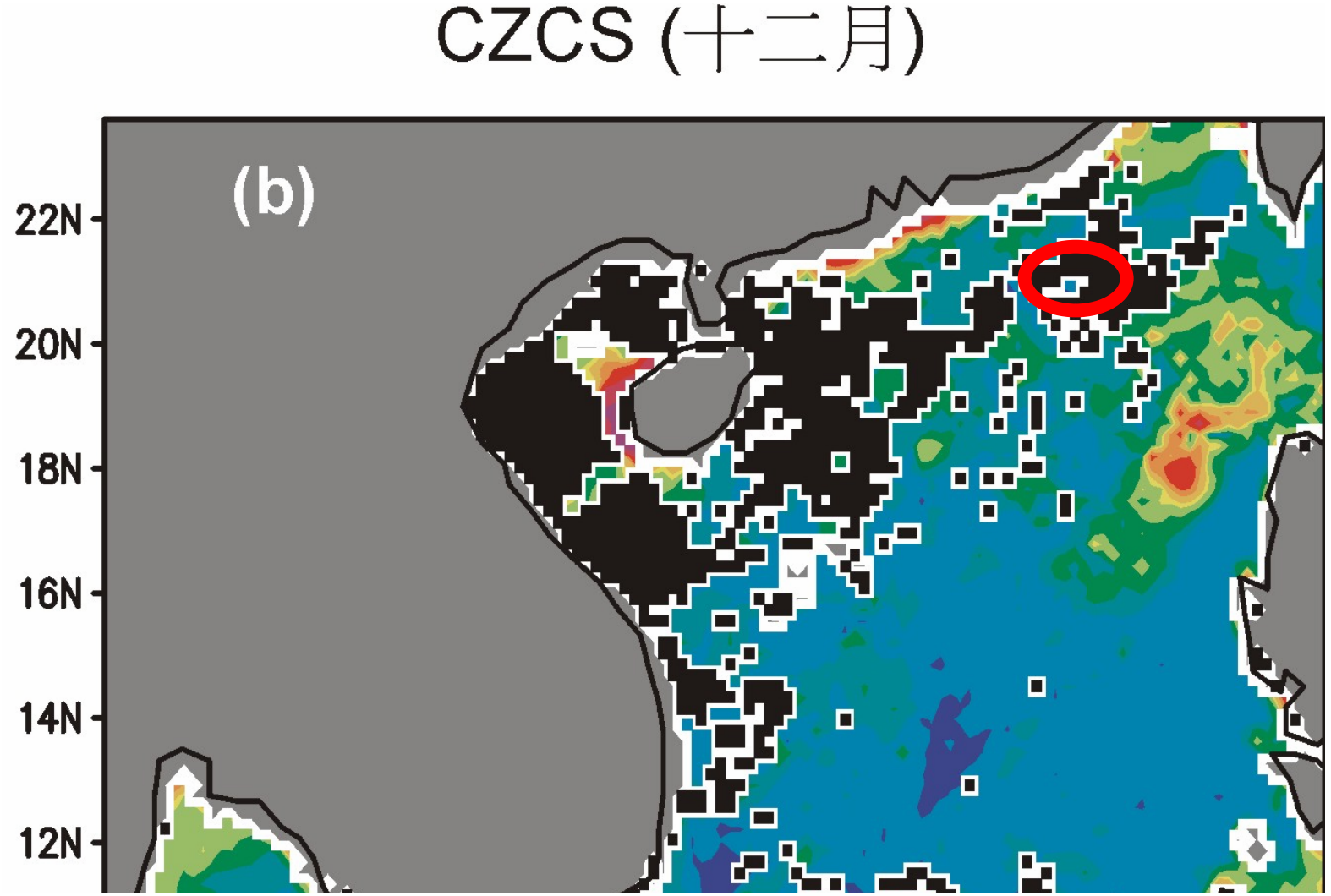

21
20
19
18
17
16
106
108
110
112
114
116
118
120
122

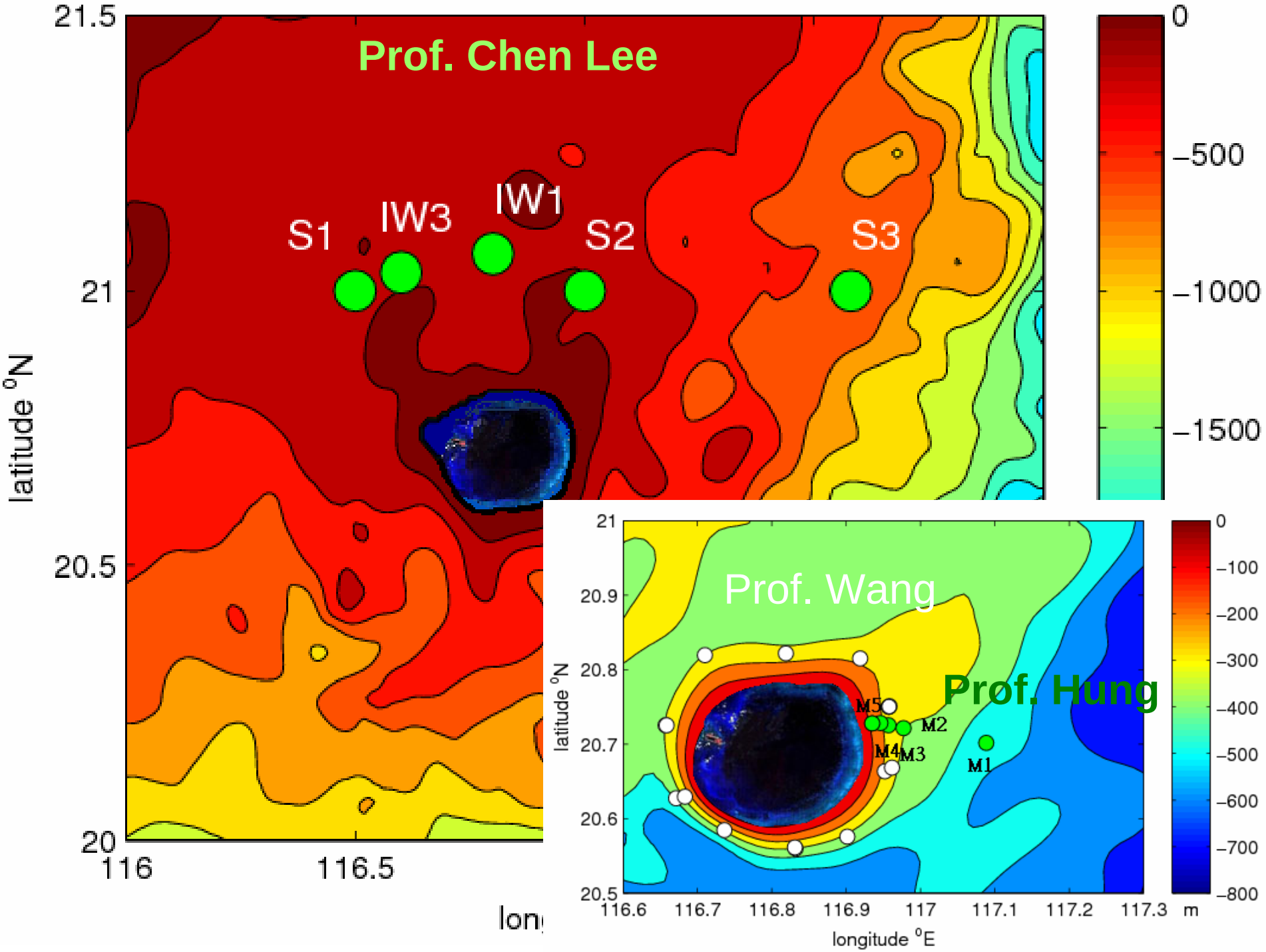
In summer, high chlorophyll a is observed by satellite in Dongsha

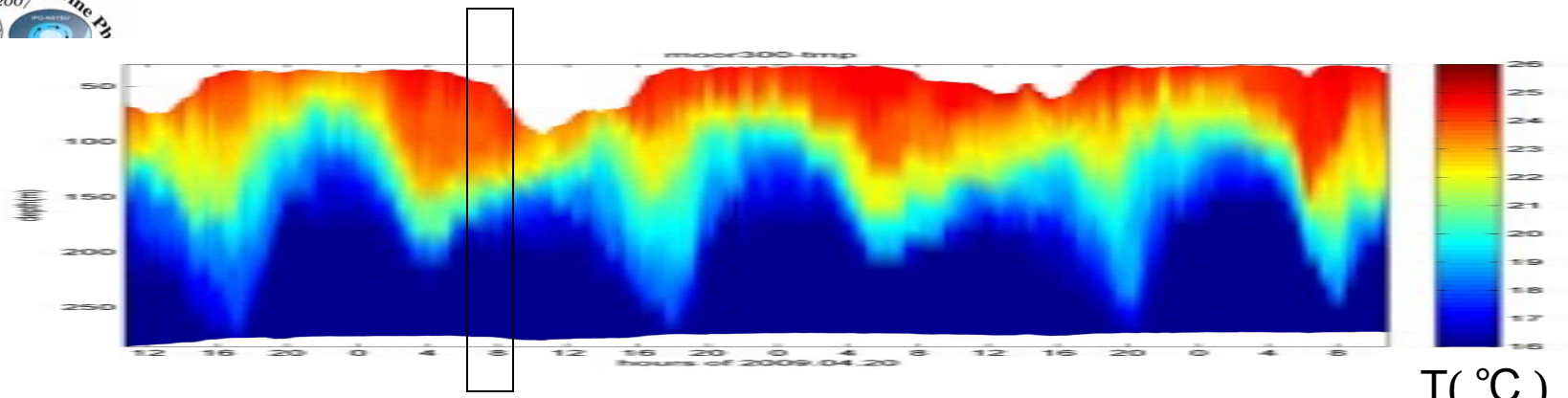
SeaWiFS Chl (八月)



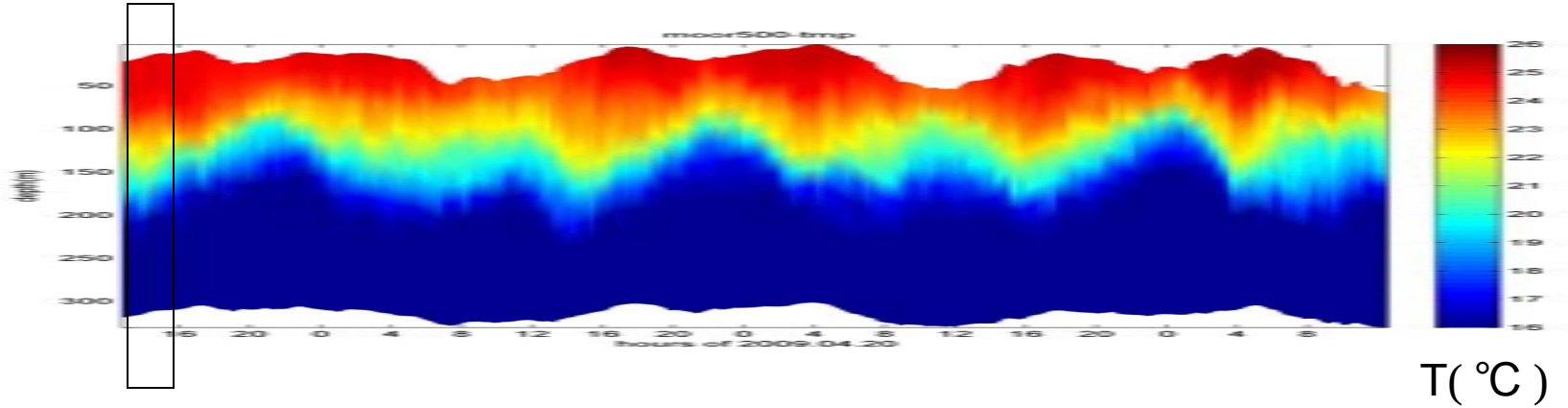
In winter, high chlorophyll a is not observed in Dongsha




Prof. Chen Lee
S1
IW3
IW1
S2
S3
21.5
21
20.5
20
116
116.5
latitude °N
0
−500
−1000
−1500
Prof. Wang
Prof. Hung
M5
M2
M4
M3
M1
21
20.9
20.8
20.7
20.6
20.5
116.6
116.7
116.8
116.9
117
117.1
117.2
117.3
longitude °E
m
−100
−200
−300
−400
−500
−600
−700
−800

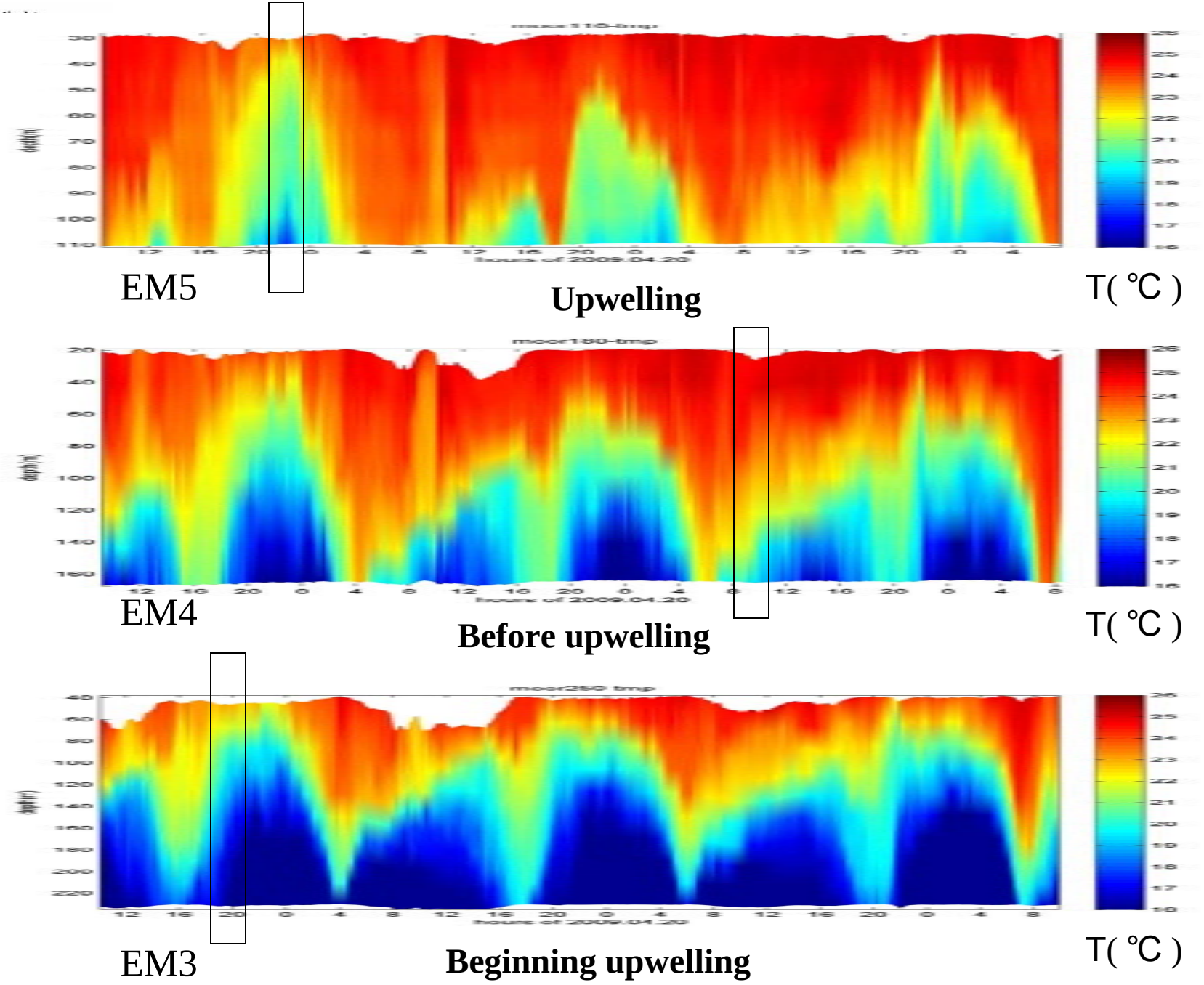


EM2

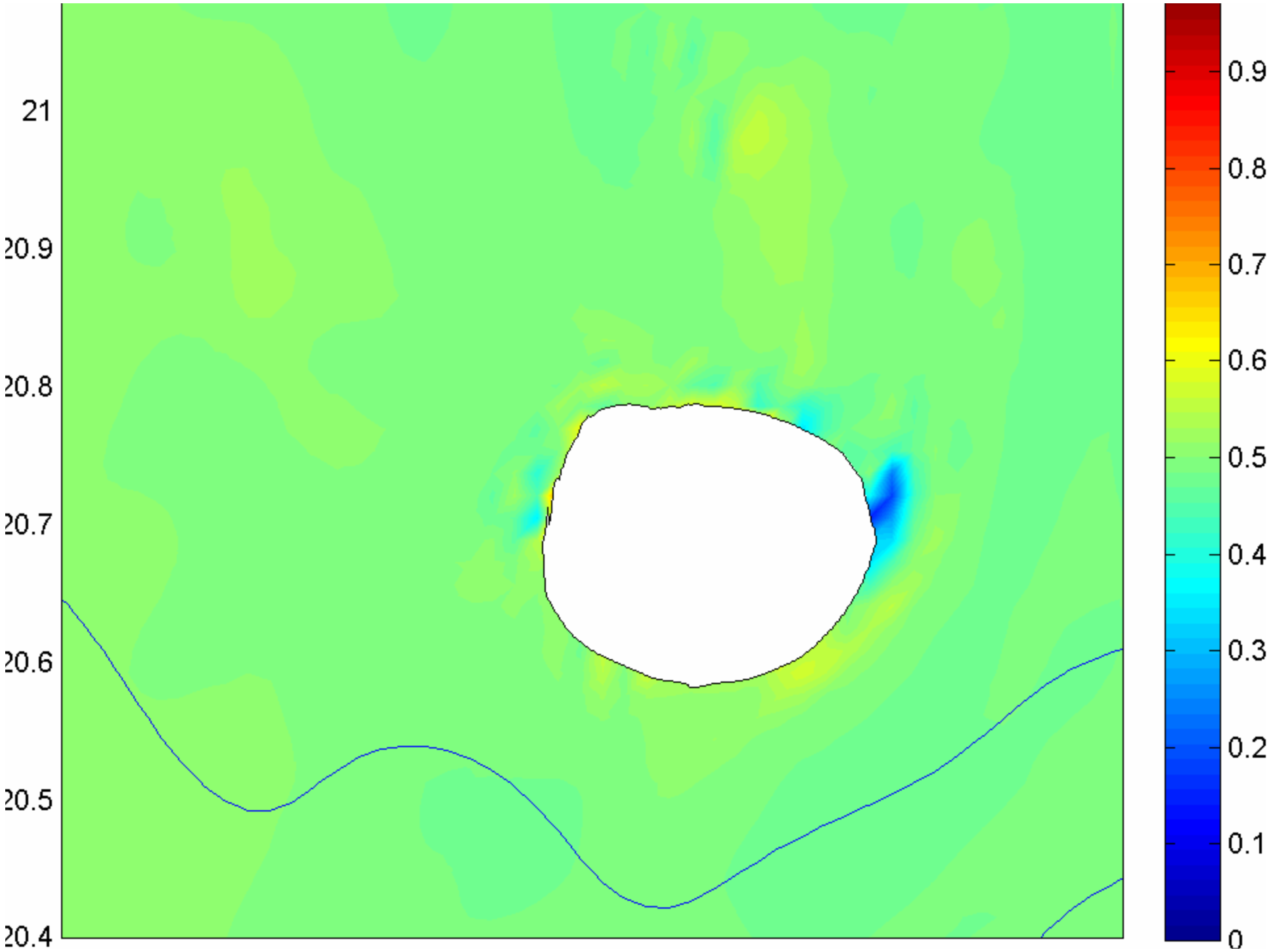


EM1

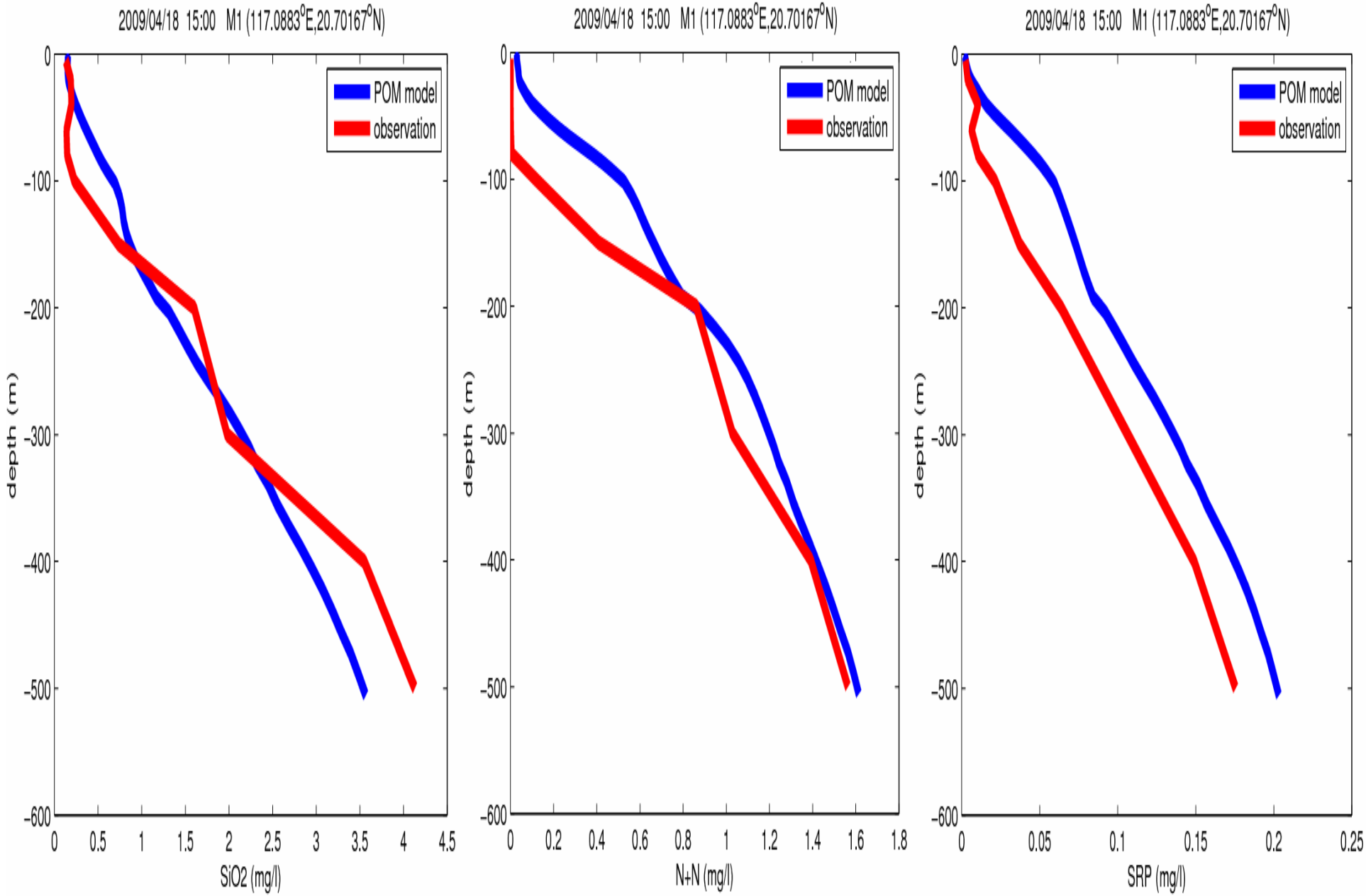
Vertical column indicates sampling time


EM5
Upwelling
T(℃)
EM4
Before upwelling
T(℃)
EM3
Beginning upwelling
T(℃)

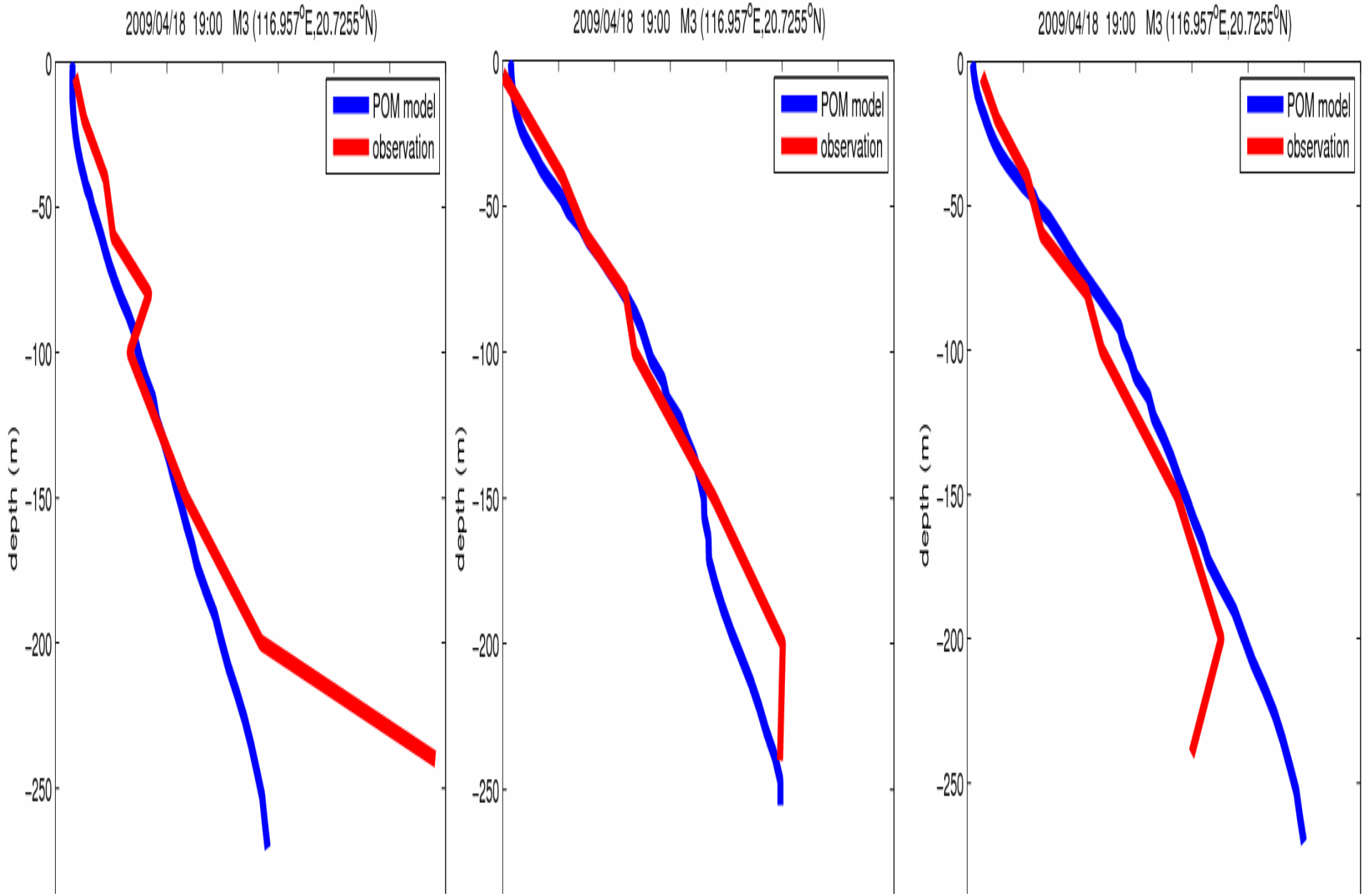
- The monthly average value of National Oceanographic Data Center (NODC), NOAA, is used as the initial state

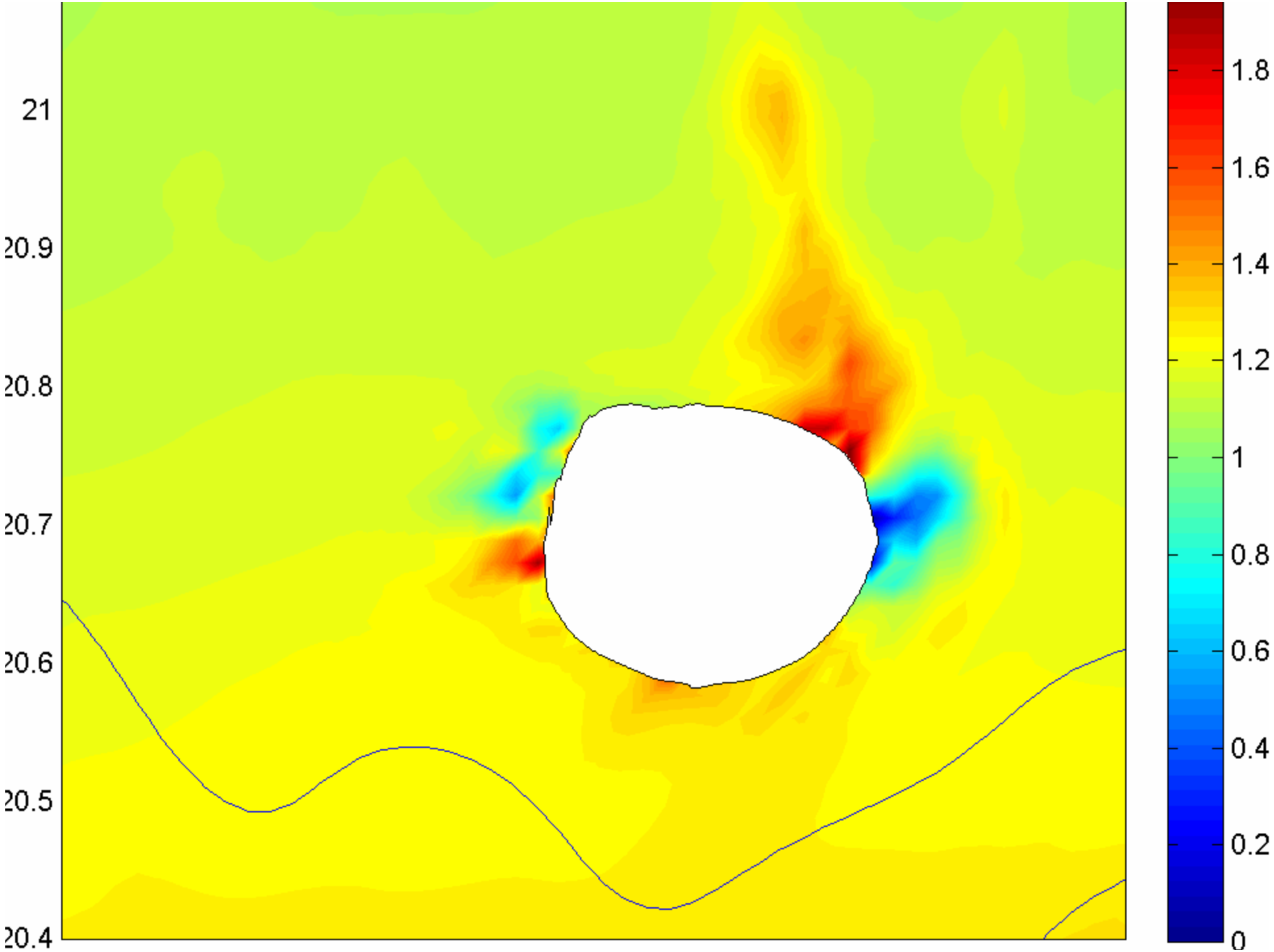

21
20.9
20.8
20.7
20.6
20.5
20.4
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

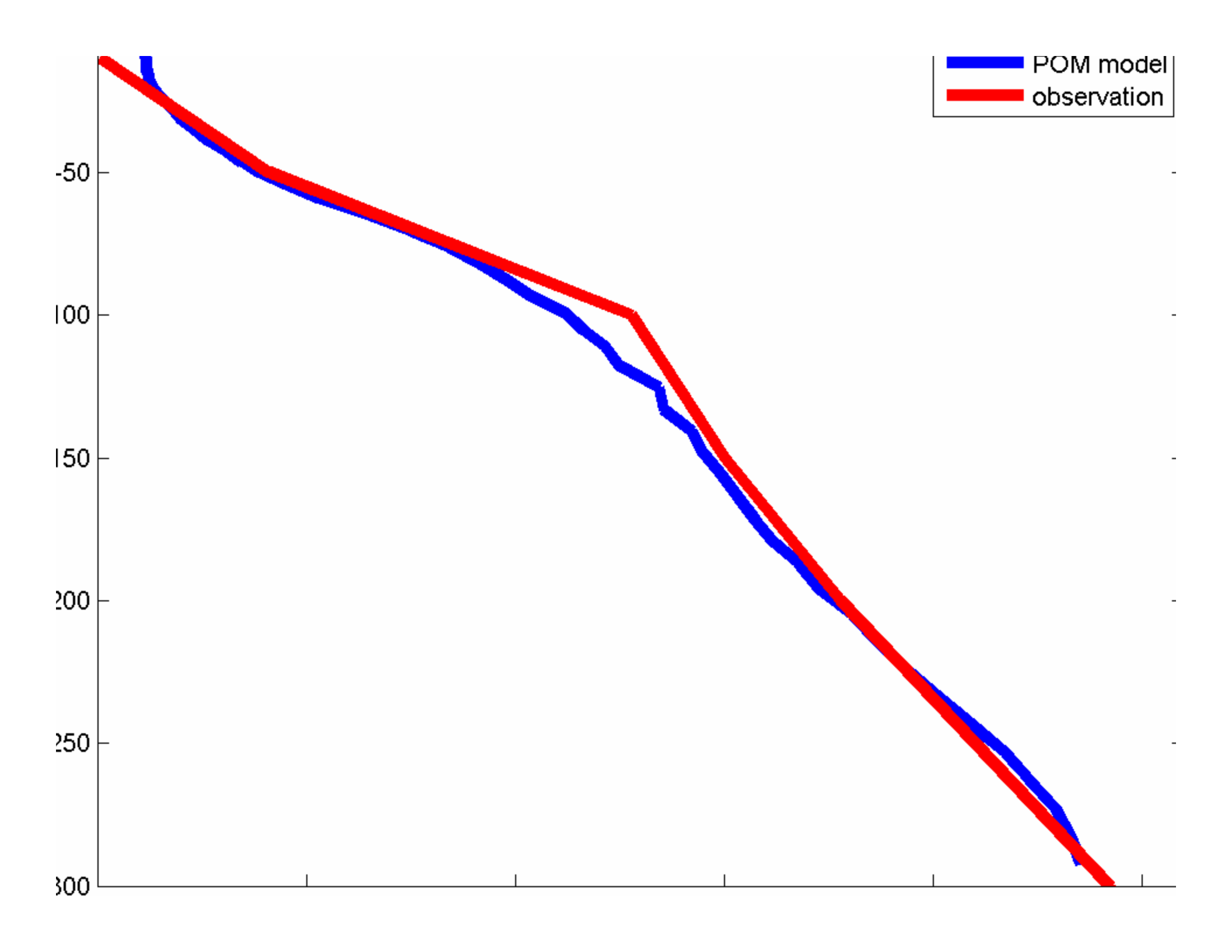
Simulated Nutrient at M1

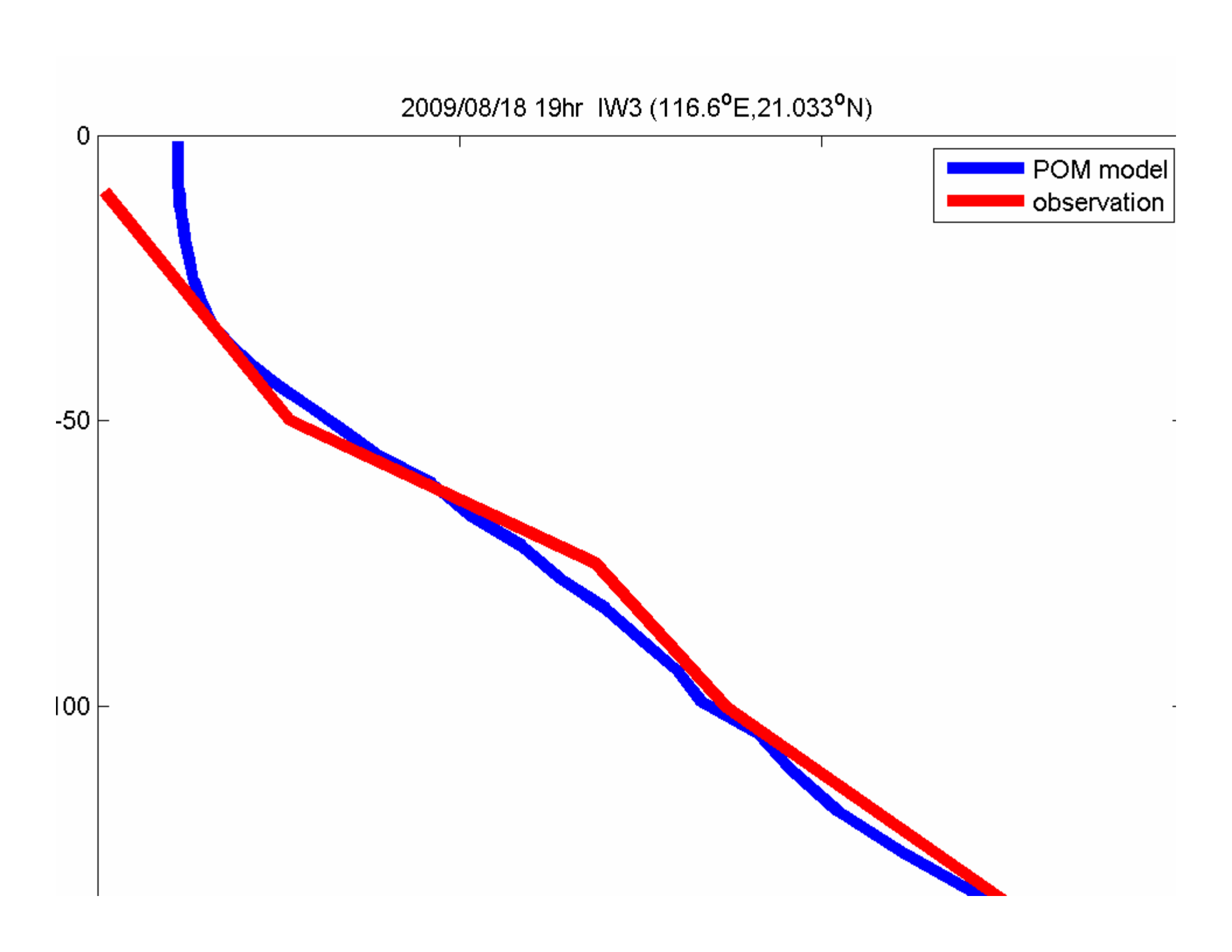


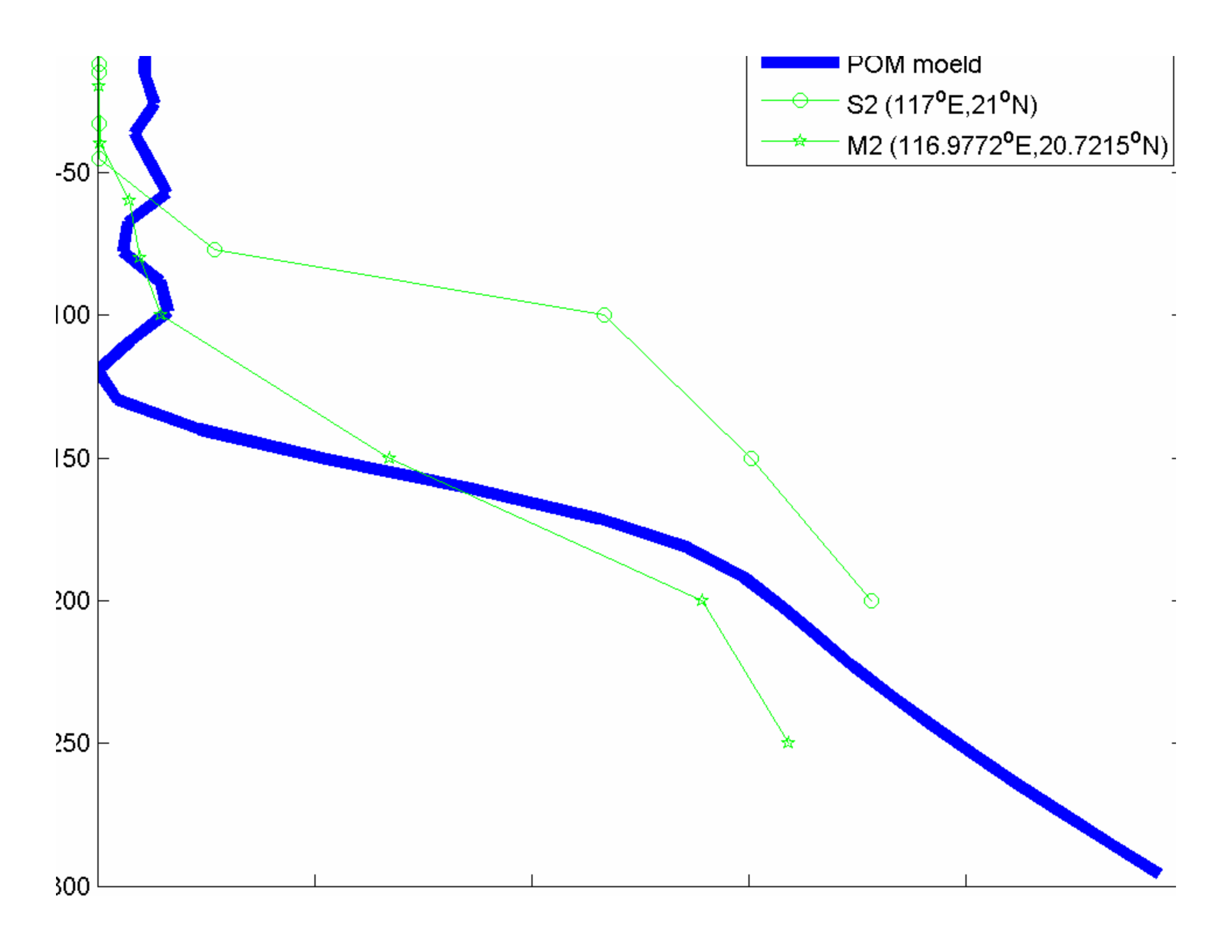
Simulated Nutrient at M3




21
20.9
20.8
20.7
20.6
20.5
20.4
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0


POM model
observation
-50
100
150
200
250
300


2009/08/18 19hr IW3 (116.6°E,21.033°N)
0
-50
100
POM model
observation


POM moeld
S2 (117°E,21°N)
M2 (116.9772°E,20.7215°N)
-50
100
150
200
250
300

Summary

- Field measurement of nutrient is easily affected by internal tide and ISW
- The nutrient near Dongsha can be attributed to both ISW and internal tide
- Bloom observed near Dongsha is due to the nutrient pumped up by ISW?
- Besides tide, more environmental factors should be added in the hydrodynamic model (POM)
- More biogeochemical studies are required

Thank you
for your
attention

Seasonal change alters the ISW amplitude and the Nutrient pumping (Provided by Prof. YH Wang)