Variability in Kuroshio axis in the northeast of Taiwan

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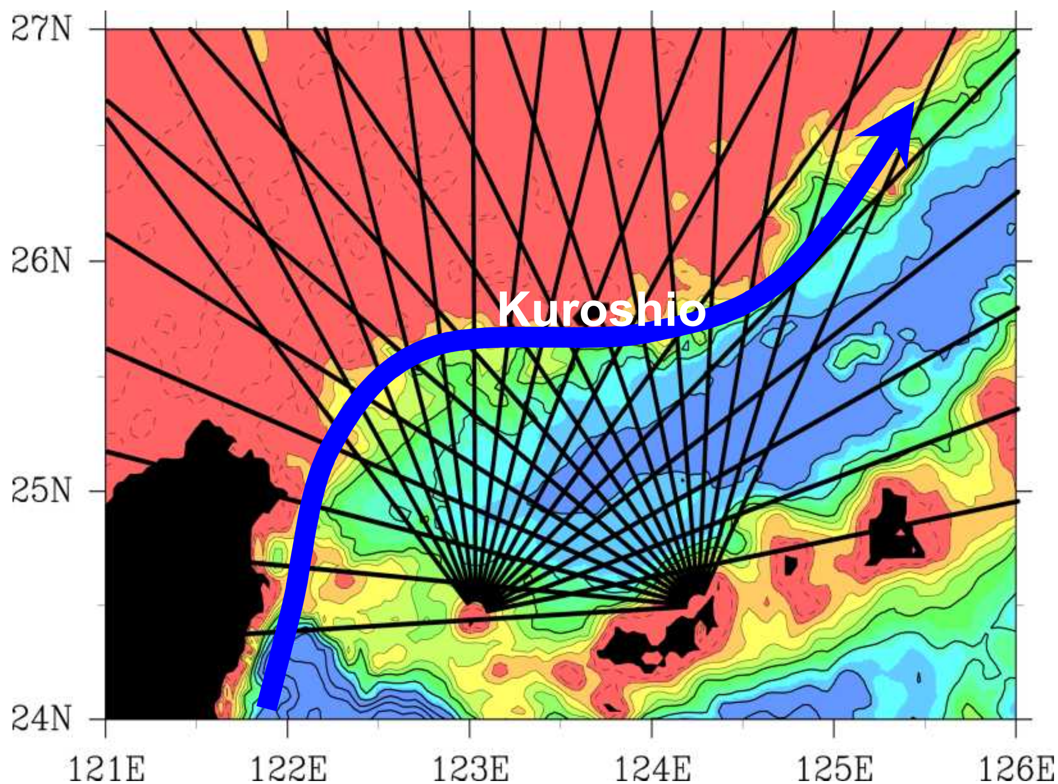
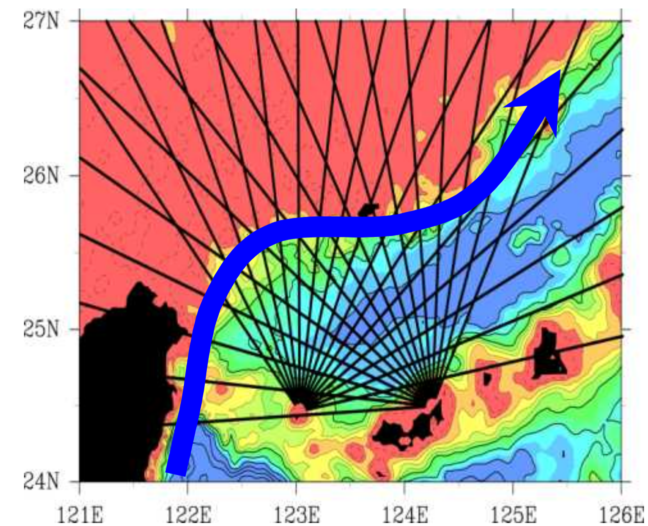


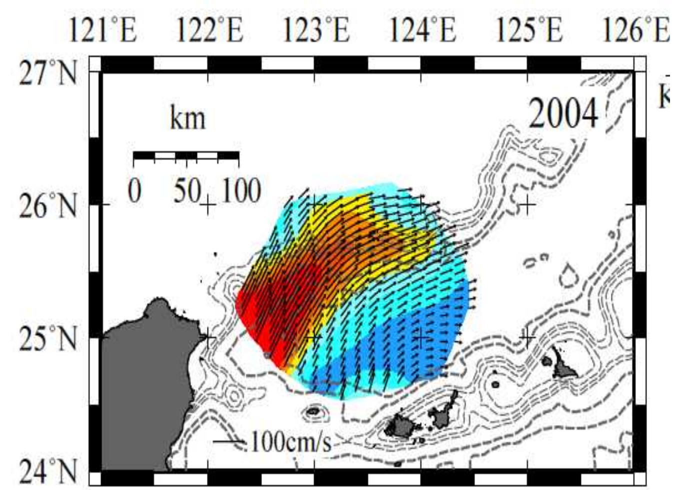
Introduction

- It is well-known that the Kuroshio in the northeast of Taiwan fluctuates with various time-scales.
- Seasonally, the Kuroshio flows along the shelf edge in summer and moves shoreward in winter (e.g. Tang and Yang, 1993; Chuang and Liang, 1994, Guo et al., 2006).
- 10-18 days variation of current velocity was observed by mooring (Zhang et al., 2001).
- The Kuroshio axis variations associated with episodic event such as typhoon were reported by several studies (Chuang and Liang, 1994; Chang et al., 2008; Tsai et al., 2008, Morimoto et al., 2009).
- Kuroshio variations northeast of Taiwan play an important role to material cycle in the East China Sea.

Introduction

- Using Long Range Ocean Radar (LROR), Ichikawa et al. (2008) revealed that the Kuroshio northeast of Taiwan tends to move northward (or southward) from summer to autumn when speed of the Kuroshio is slower (or faster).
  Takahashi et al. (2009) indicated that biweekly periodic variation of the Kuroshio axis is dominant there.
- Seasonal signals are not significant in variations of position of the Kuroshio axis (Ichikawa et al. 2008).
- Variations of the northern boundary of the Kuroshio were not fully described due to limitation of the LROR observation area.

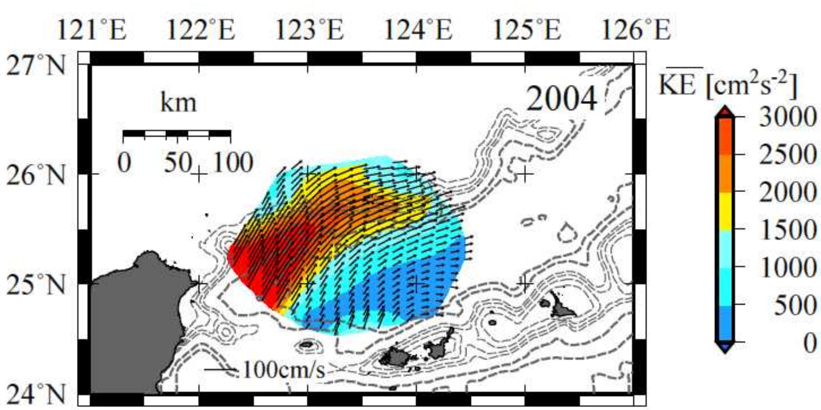




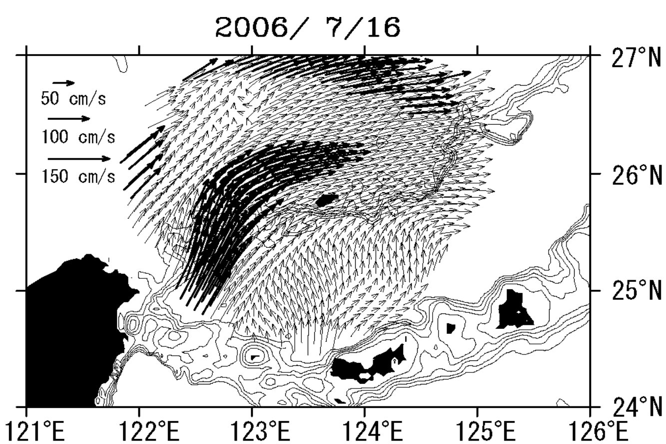
Takahashi *et al*. (2009)

Objectives

- Reprocessing LROR data from 2001 to 2008 (Recalculate radial velocities from spectral data)
- The Kuroshio axis variations in the northeast of Taiwan are examined using LROR data for 8 years.



Takahashi *et al*. (2009)



Morimoto *et al*. (2009)

Data

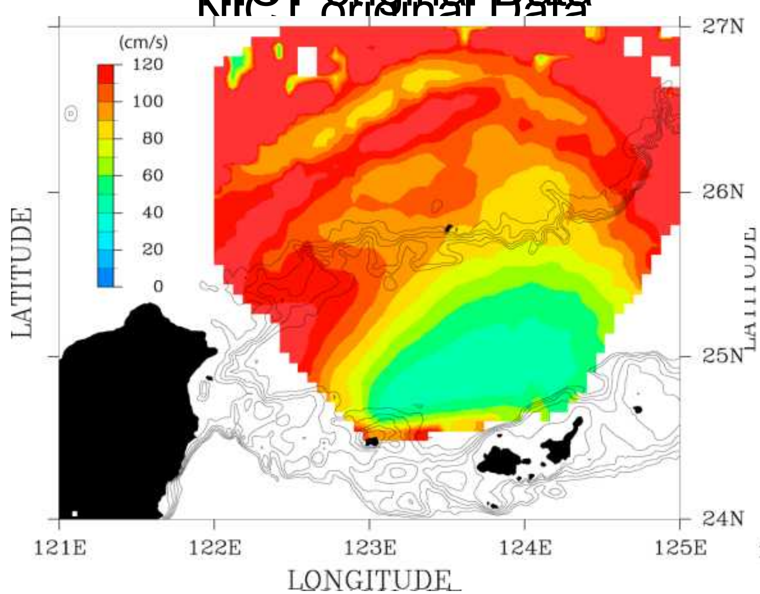
- LROR was installed at Ishigaki and Yonaguni islands by NICT, and the LROR observed sea surface current with range of about 200 km from radar sites from 2001 to 2010.
- LROR data have been provided from NICT. However we use reprocessed data.
- Tidal currents were removed by harmonic analysis.
- Wind driven current was removed using JAR25 wind data based on Tokeshi et al. (2007)

RMS Variability of sea surface current

Data Acquisition Rate

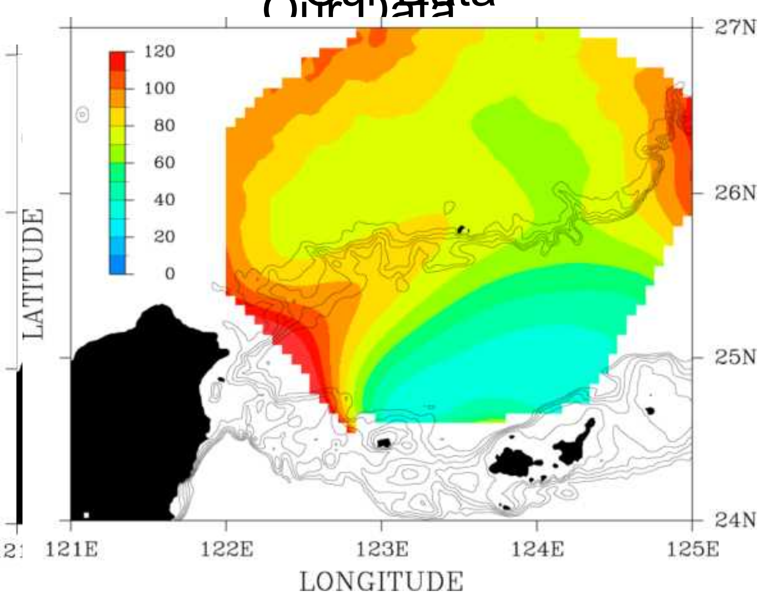
NICT original Data

NICT original Data



Our Data

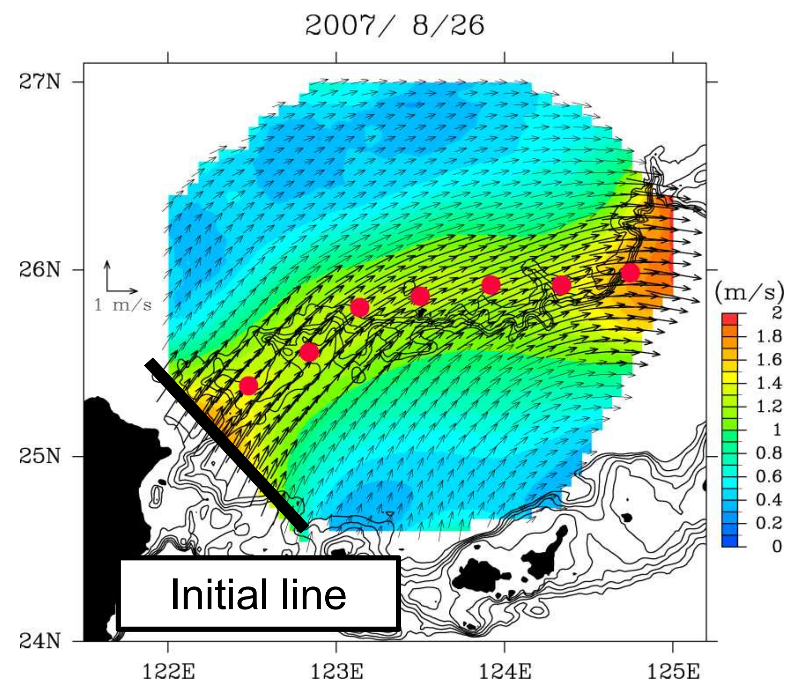
Our Data

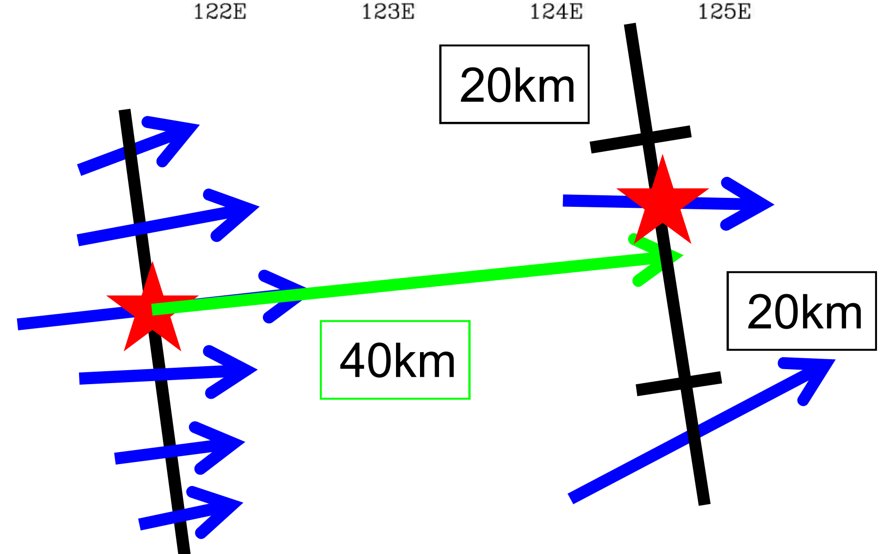


Determination of the Kuroshio axis

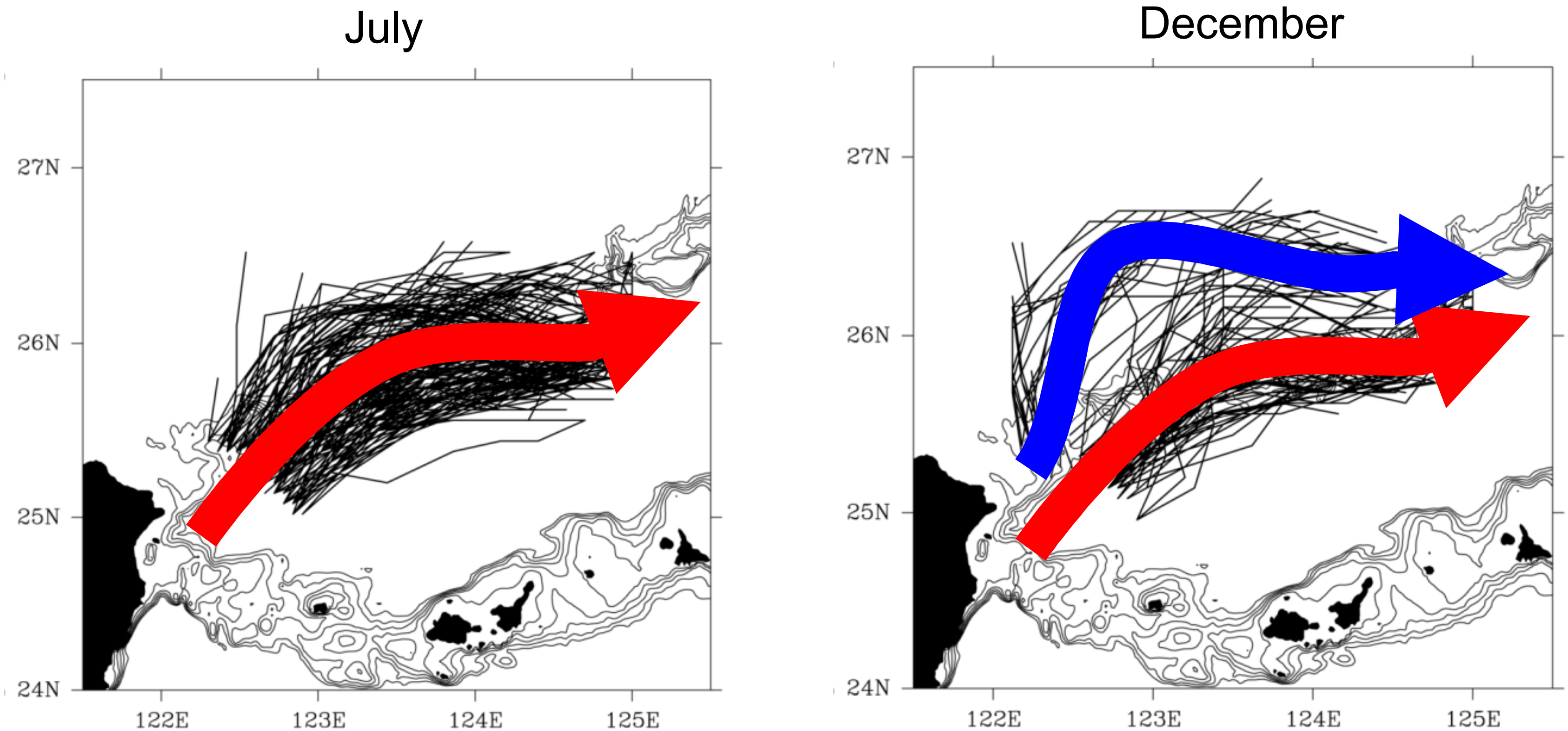
① After applying 21km running mean along initial line, we find a position of the fastest velocity as the Kuroshio axis.

② We define next line which is 40 km far from the initial line and is normal to the direction of current direction of the Kuroshio axis at the initial line.
On the next line, we find the Kuroshio position within 40 km from the center of the line.





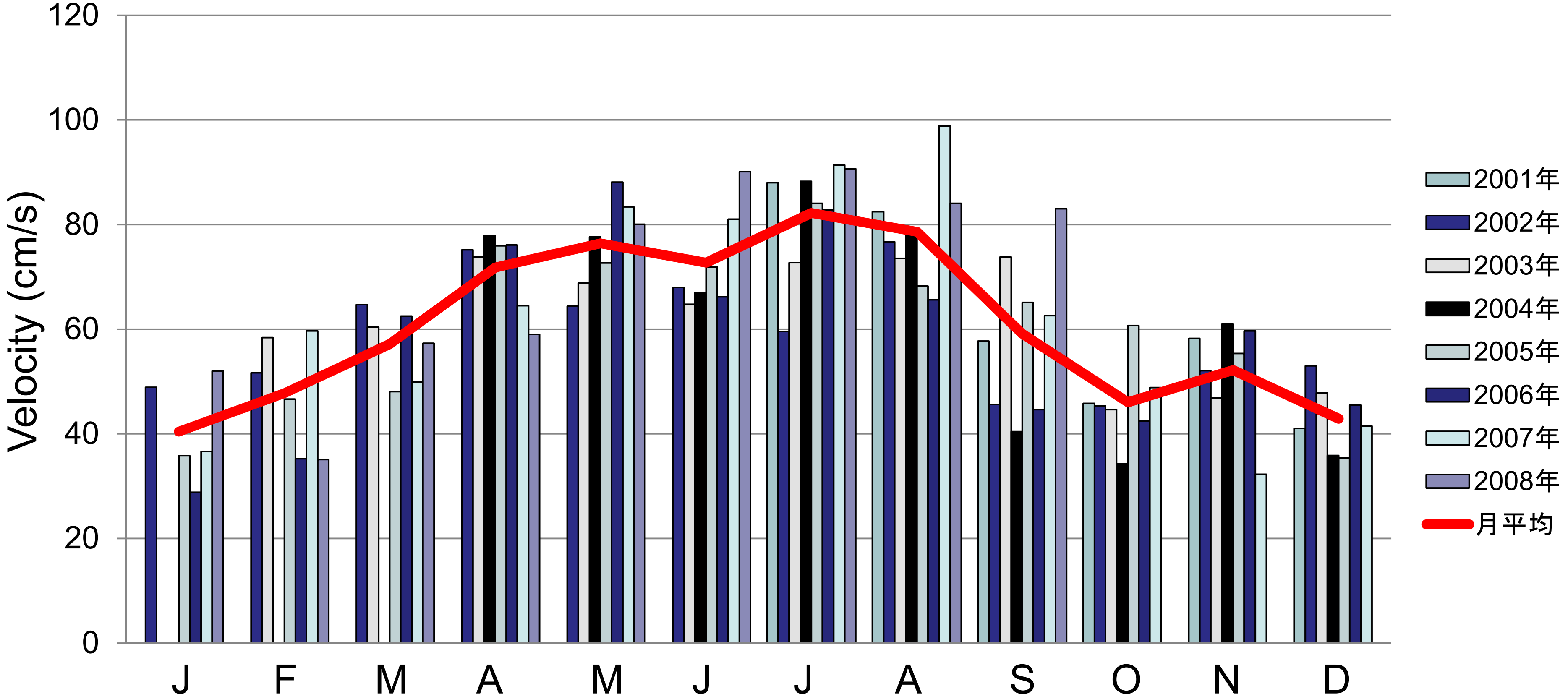
Kuroshio axis in July and December from 2001 to 2008



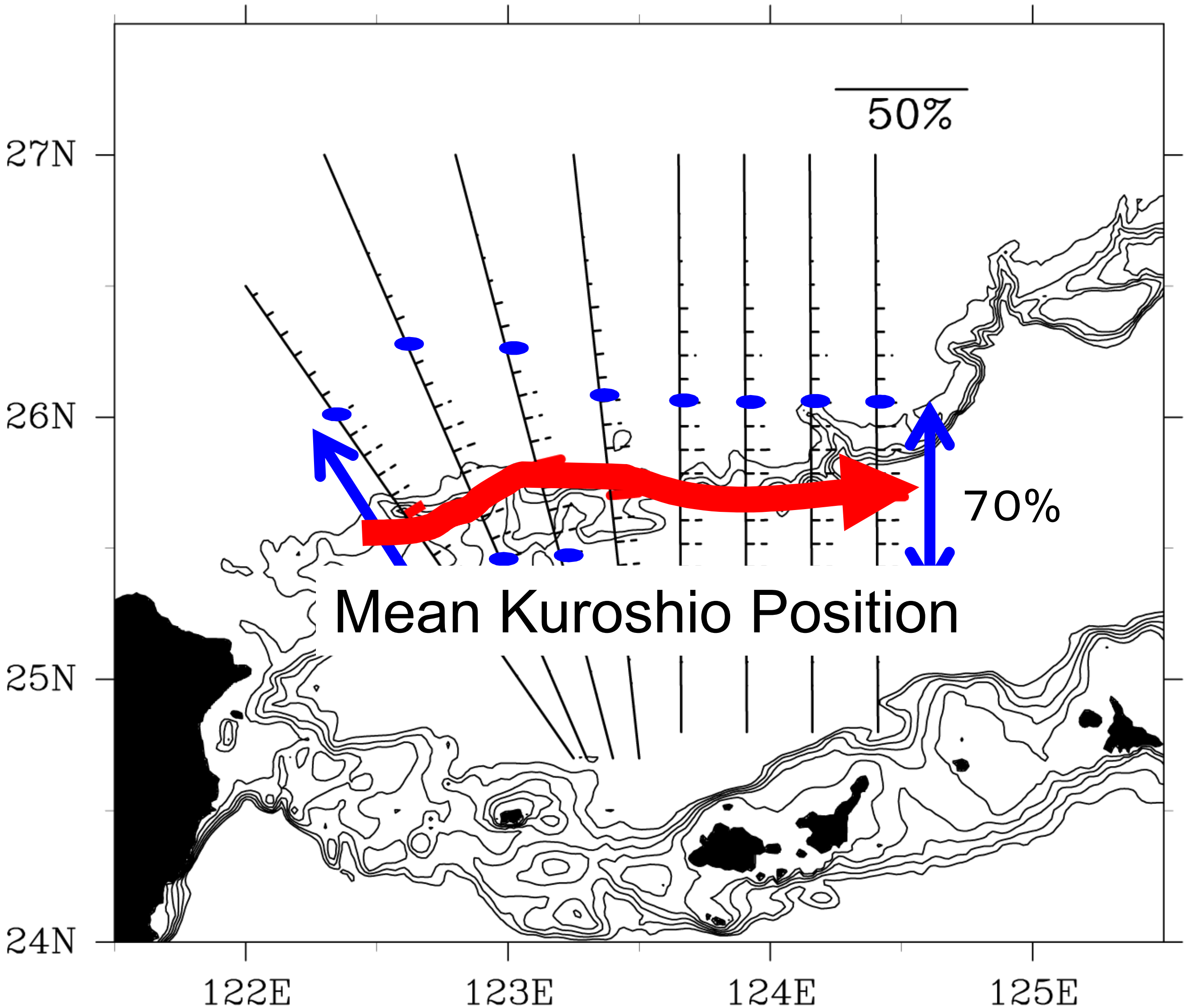
- The Kuroshio in summer is relatively stable.
- The Kuroshio in winter tends to intrude into the shelf.

Results

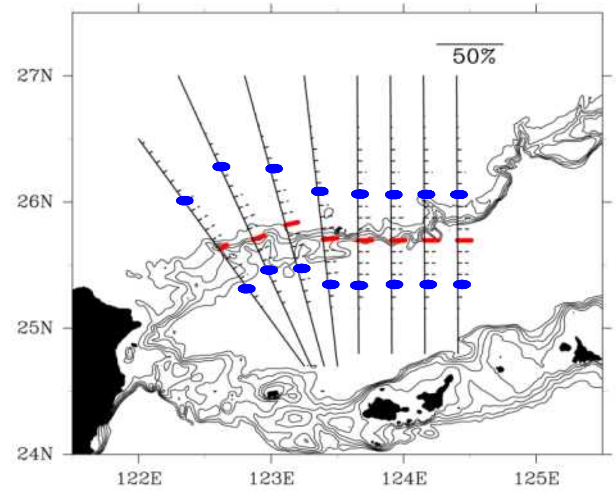
Seasonal variation in current speed of the Kuroshio

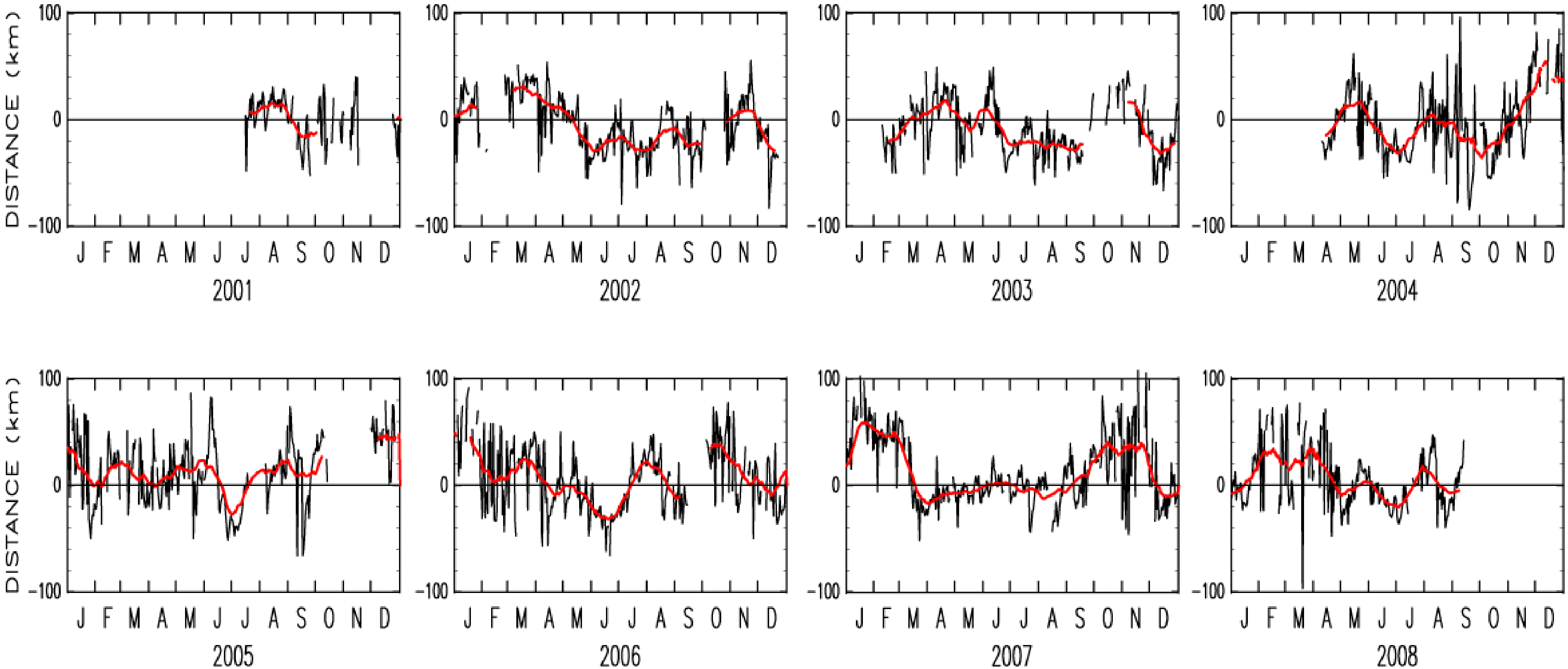


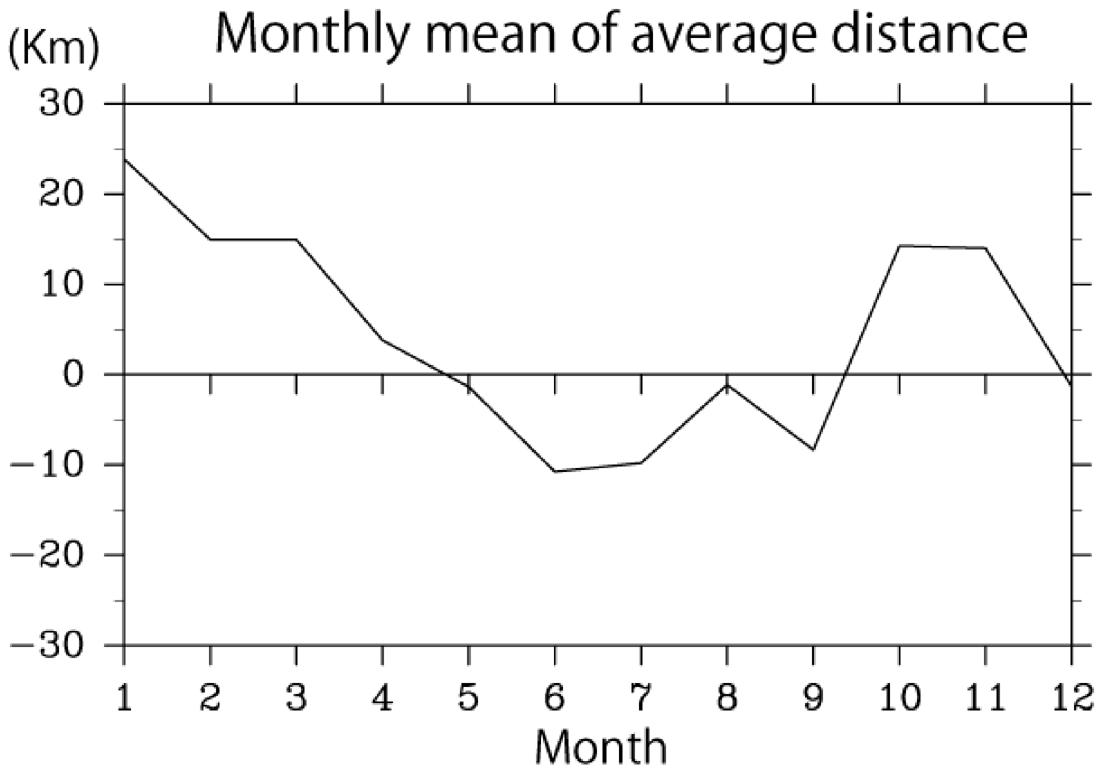
Frequency distribution of the Kuroshio axis



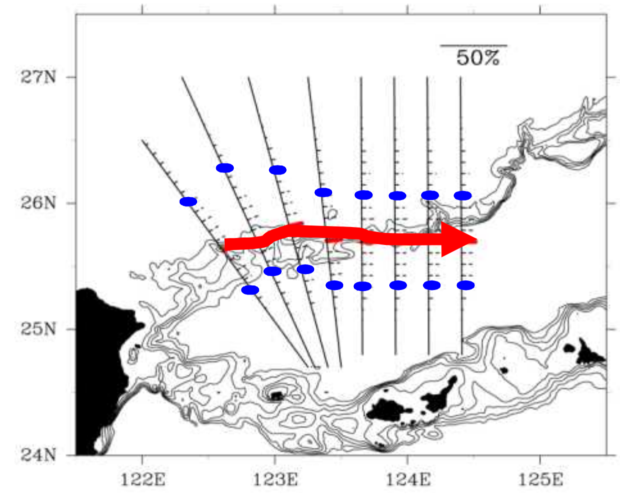
Average distance from mean Kuroshio position from 2001 to 2008



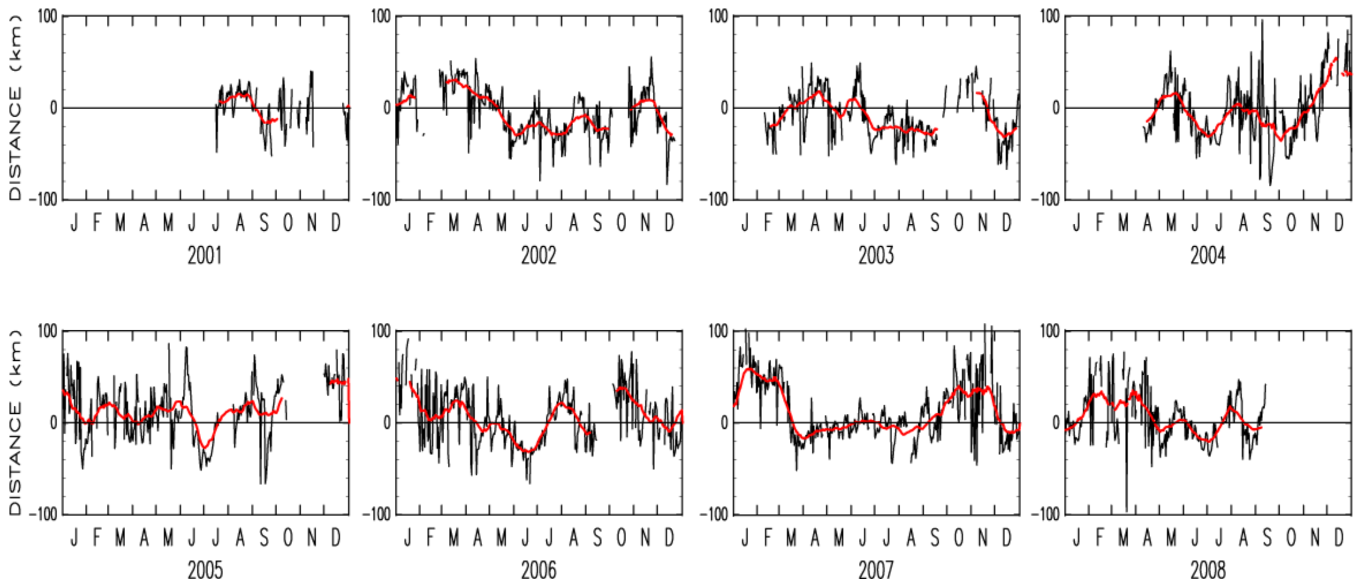




Monthly mean of average distance
(Km)
30
20
10
0
−10
−20
−30
1
2
3
4
5
6
7
8
9
10
11
12
Month



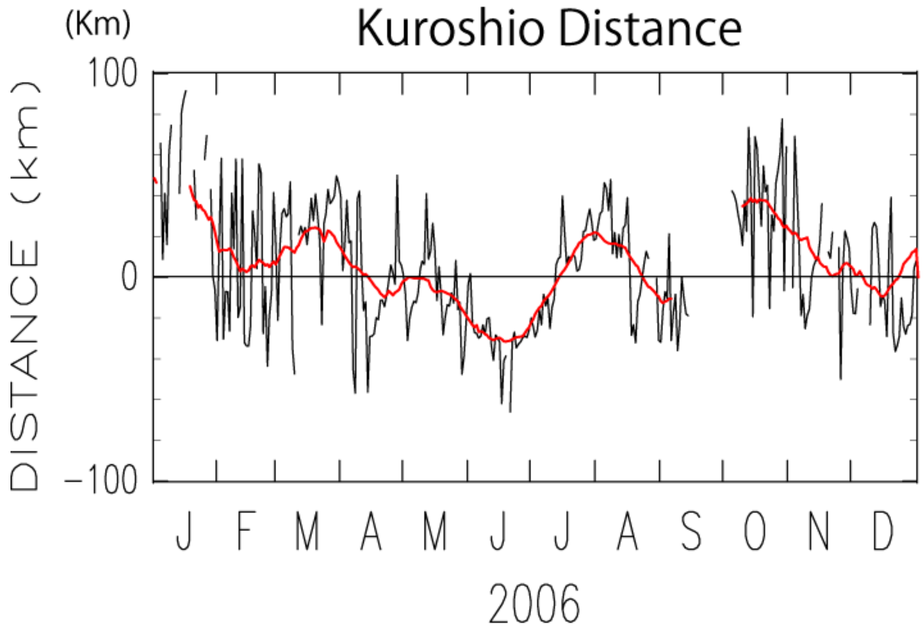
50%
27N
26N
25N
24N
122E
123E
124E
125E

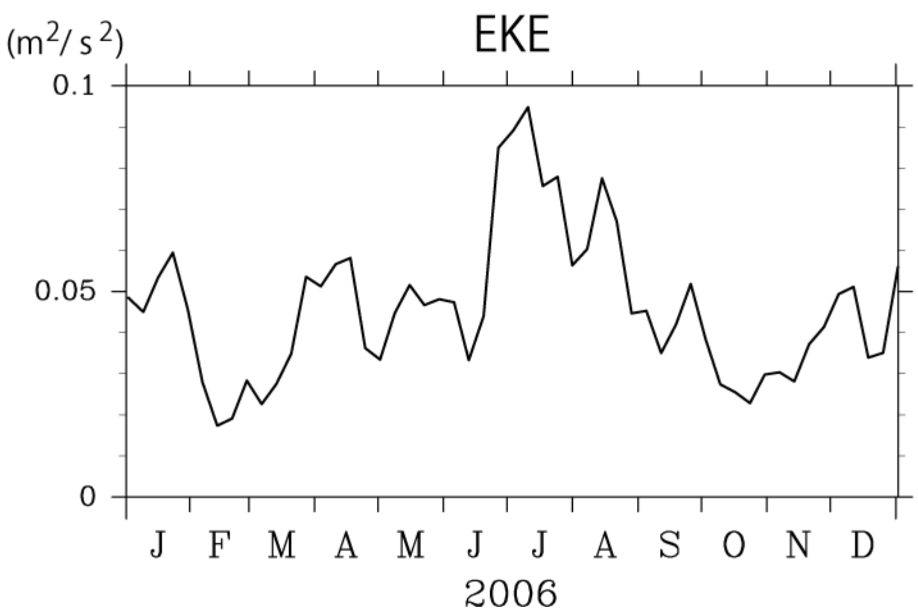


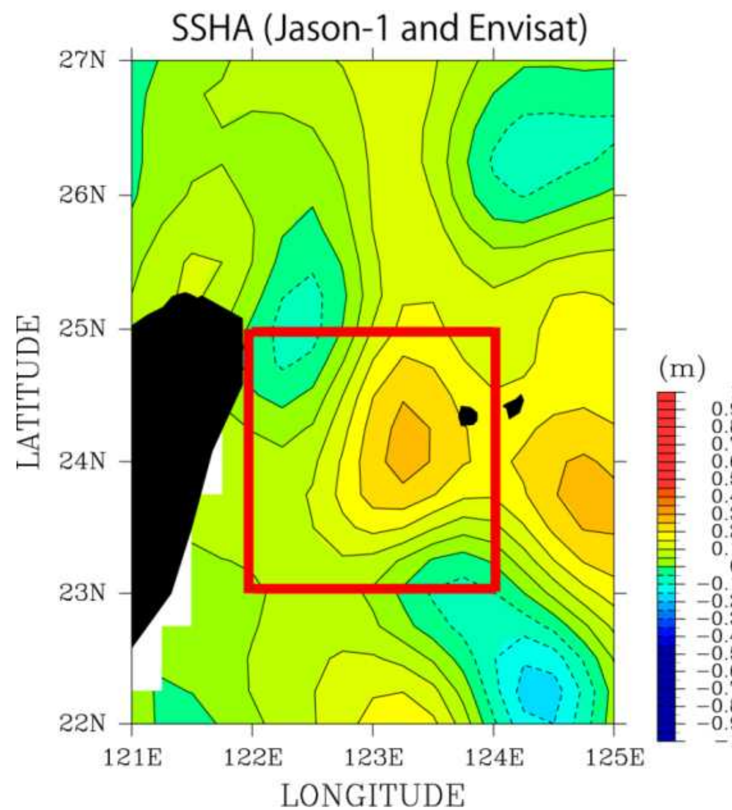
DISTANCE (km)
100
0
−100
J F M A M J J A S O N D
2001
2002
2003
2004
2005
2006
2007
2008

Previous studies pointed out that meso-scale eddy affects to the Kuroshio axis variation

Eddy Kinetic Energy (EKE) was calculated from altimetry data



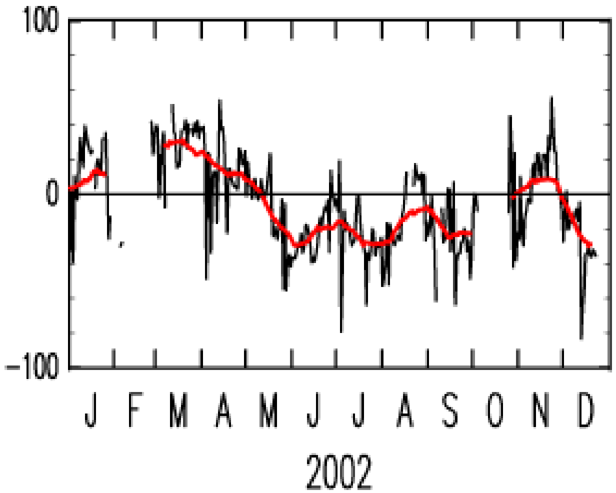


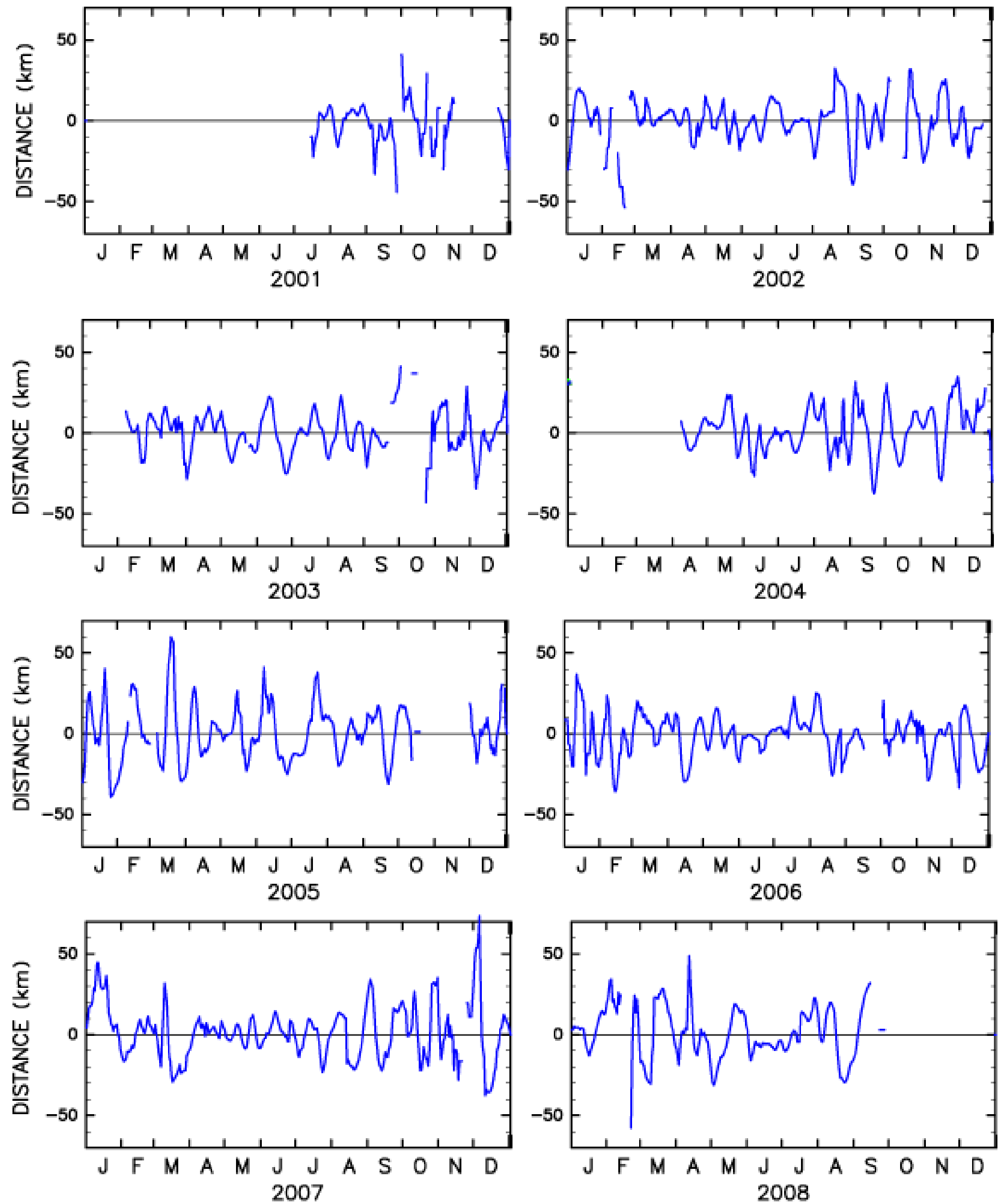


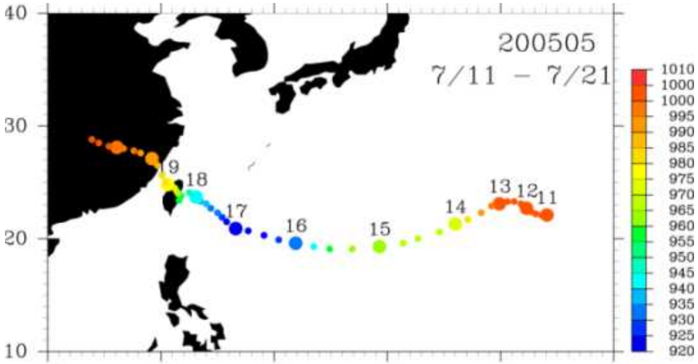
High frequency variation
(5 days – 1 month)

Anomaly from 1 month running mean of the Kuroshio distance

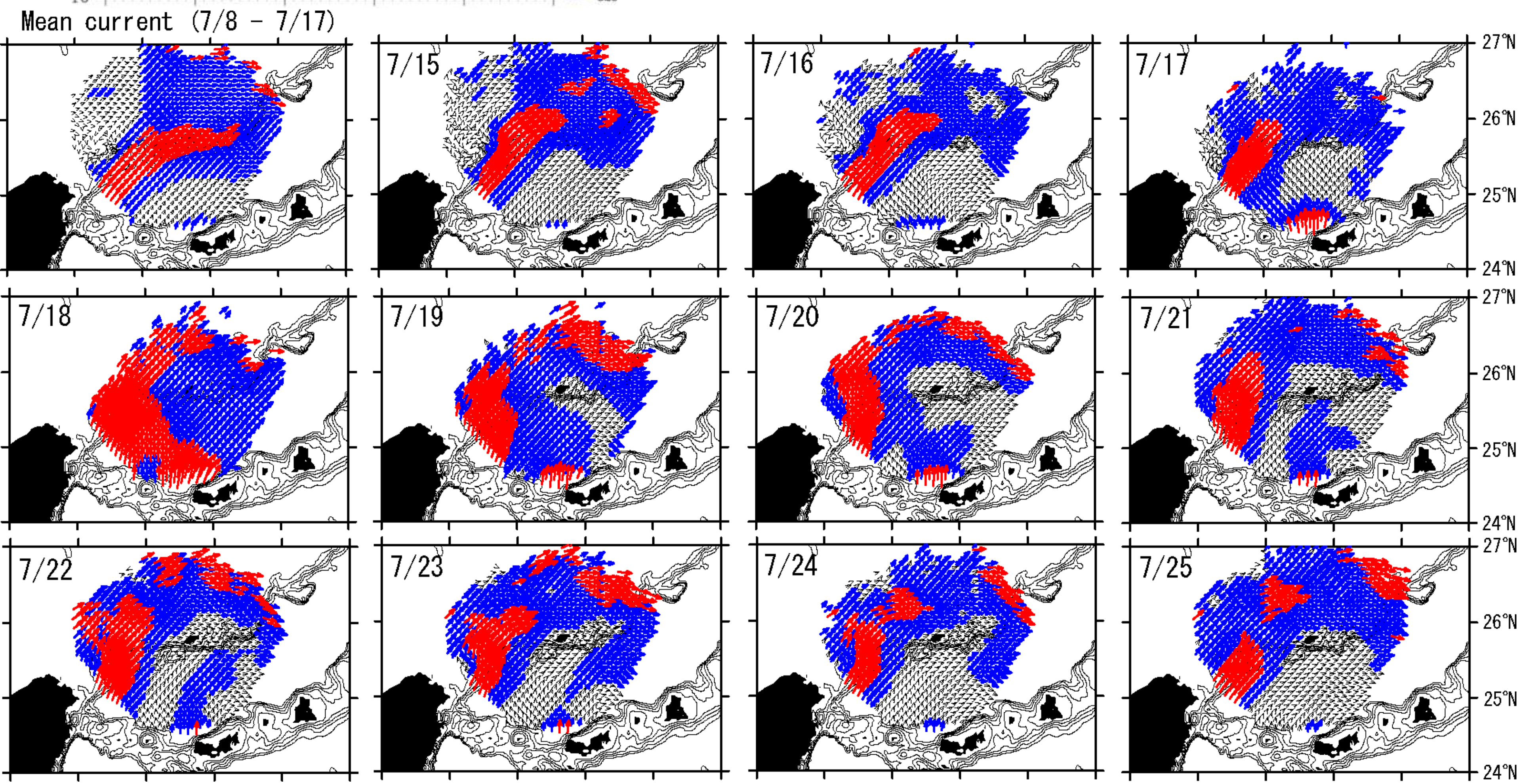
(5 days running mean)



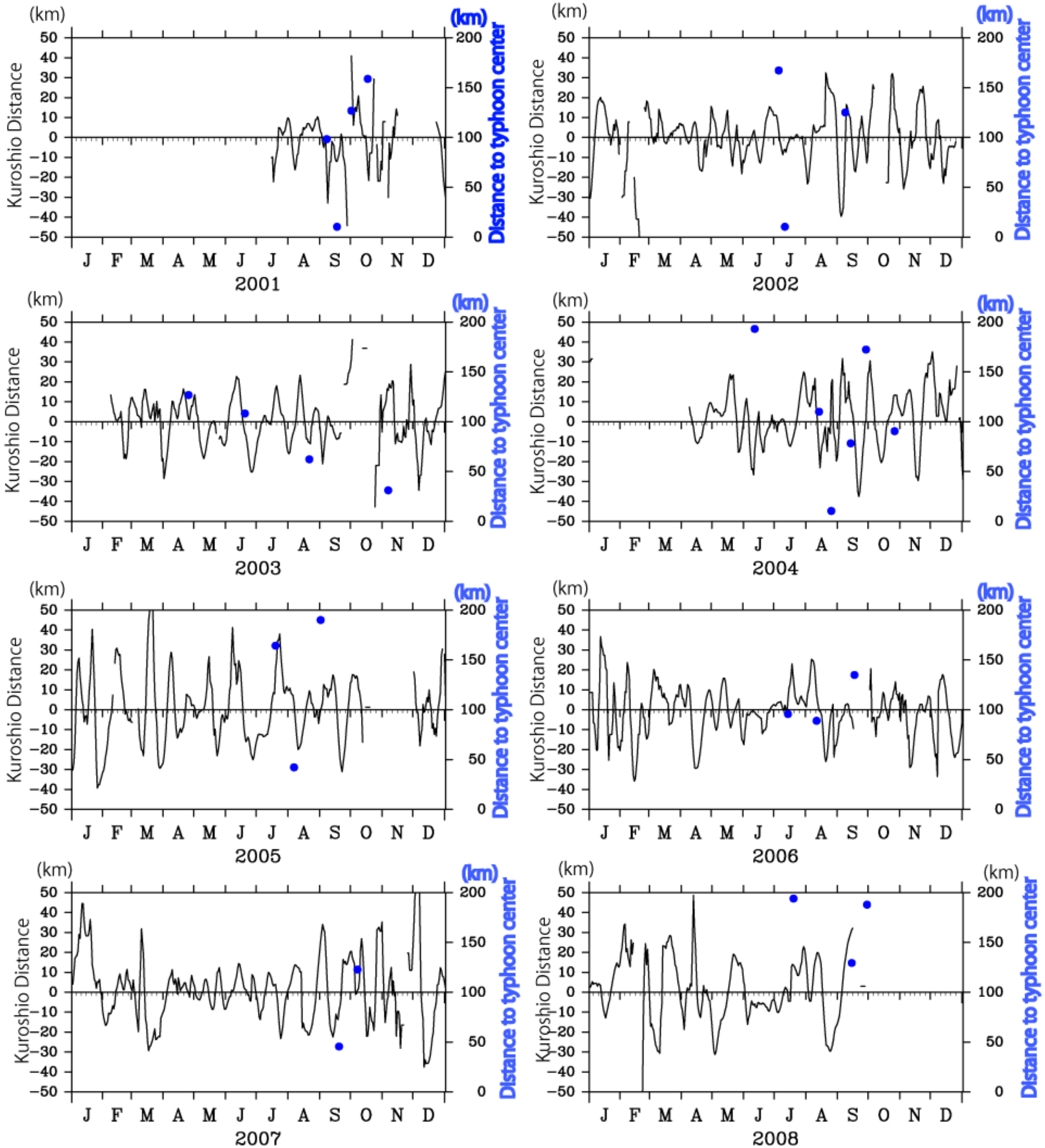




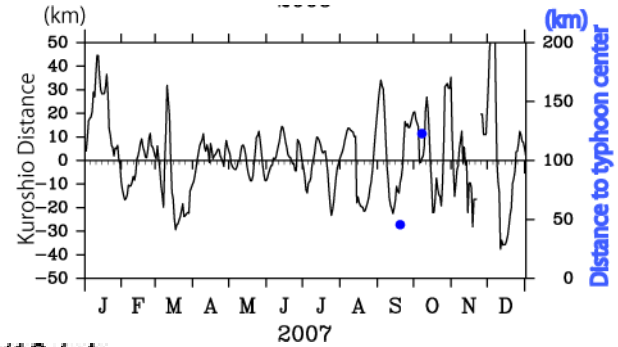
Before typhoon passage
the Kuroshio flows northeastward.
After typhoon passage
the Kuroshio intrudes into the shelf.

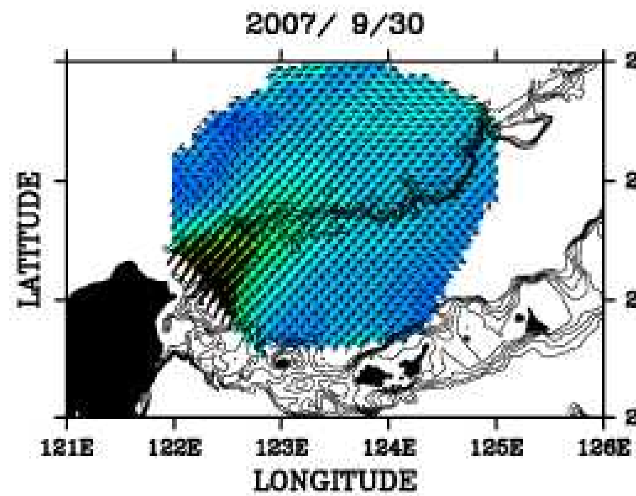


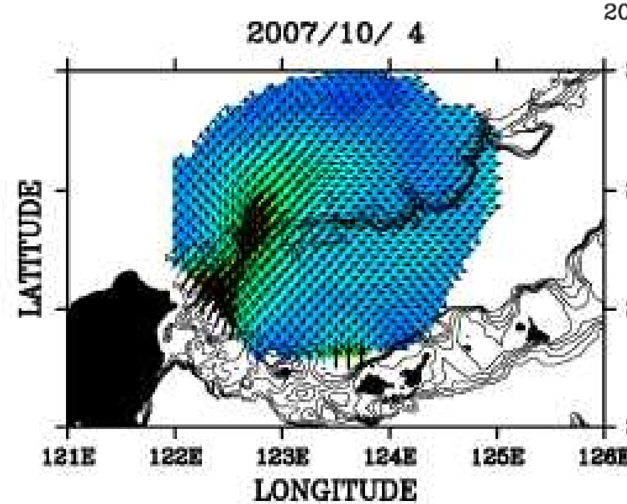
Morimoto et al. (2009)

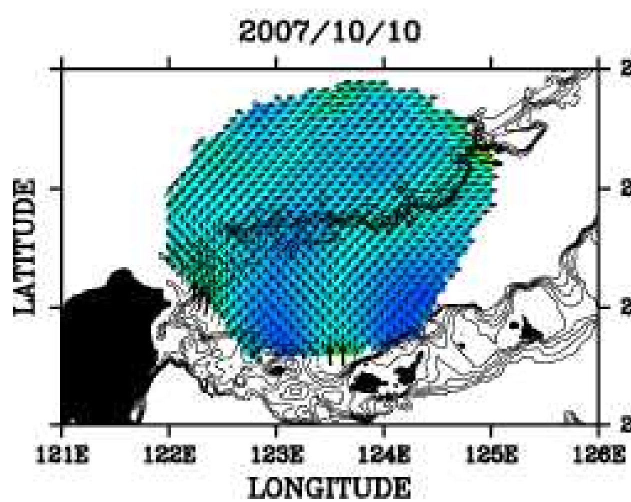

(km)
Kuroshio Distance
(km)
Distance to typhoon center
50
40
30
20
10
0
−10
−20
−30
−40
−50
200
150
100
50
0
J F M A M J J A S O N D
2001
2002
2003
2004
2005
2006
2007
2008

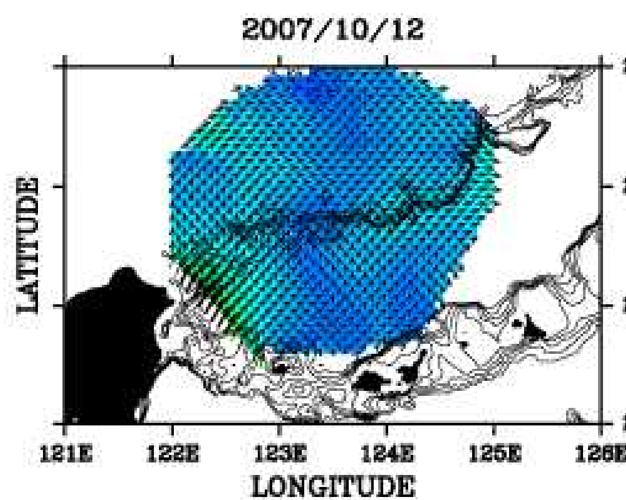
Typhoon Kurosa (925 hpa)



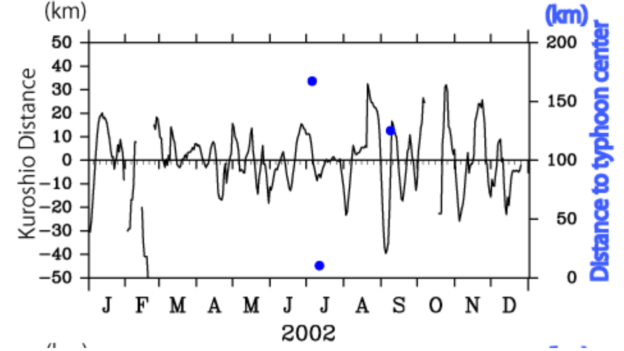


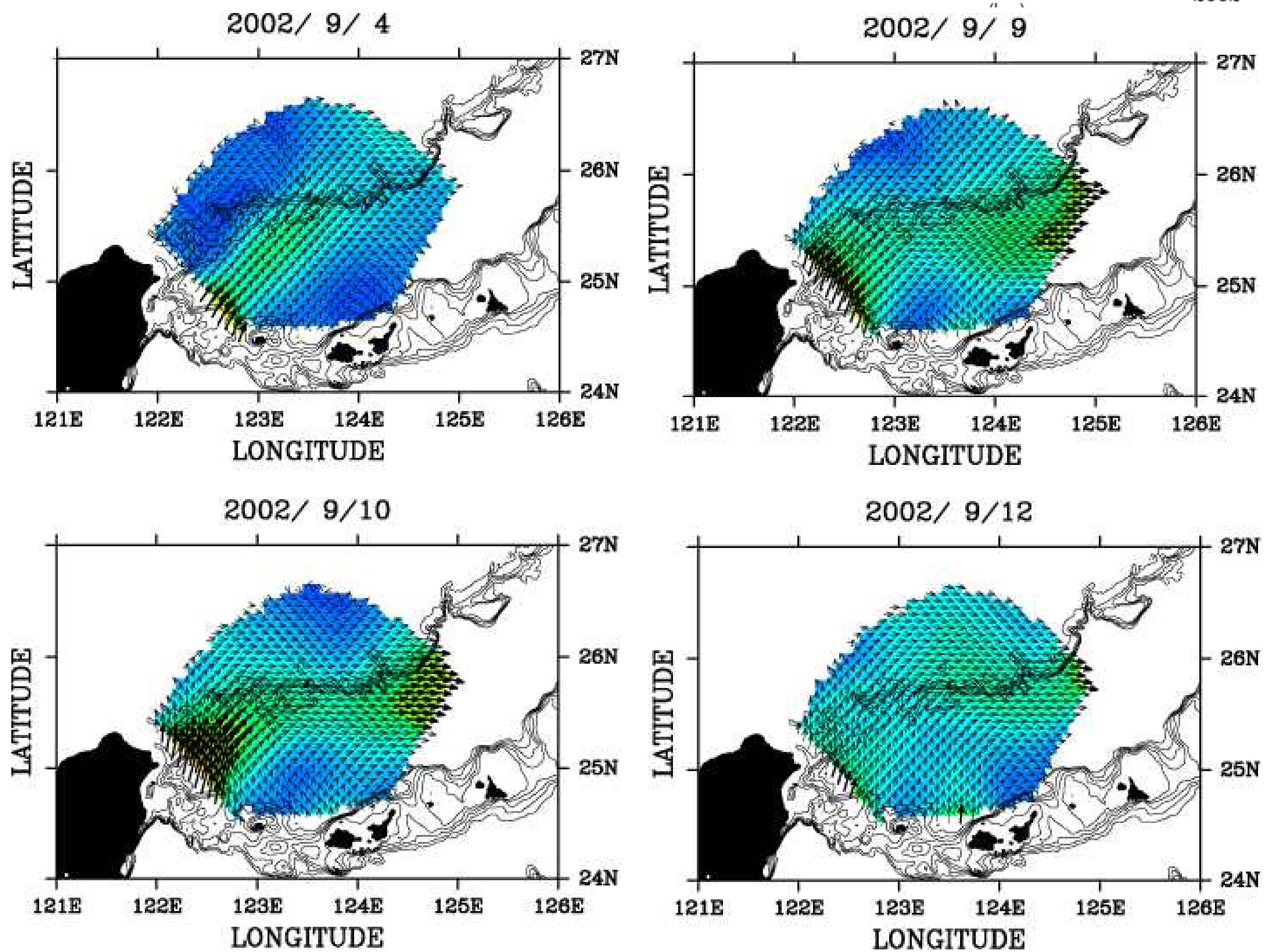






Typhoon Sinlaku (955 hpa)

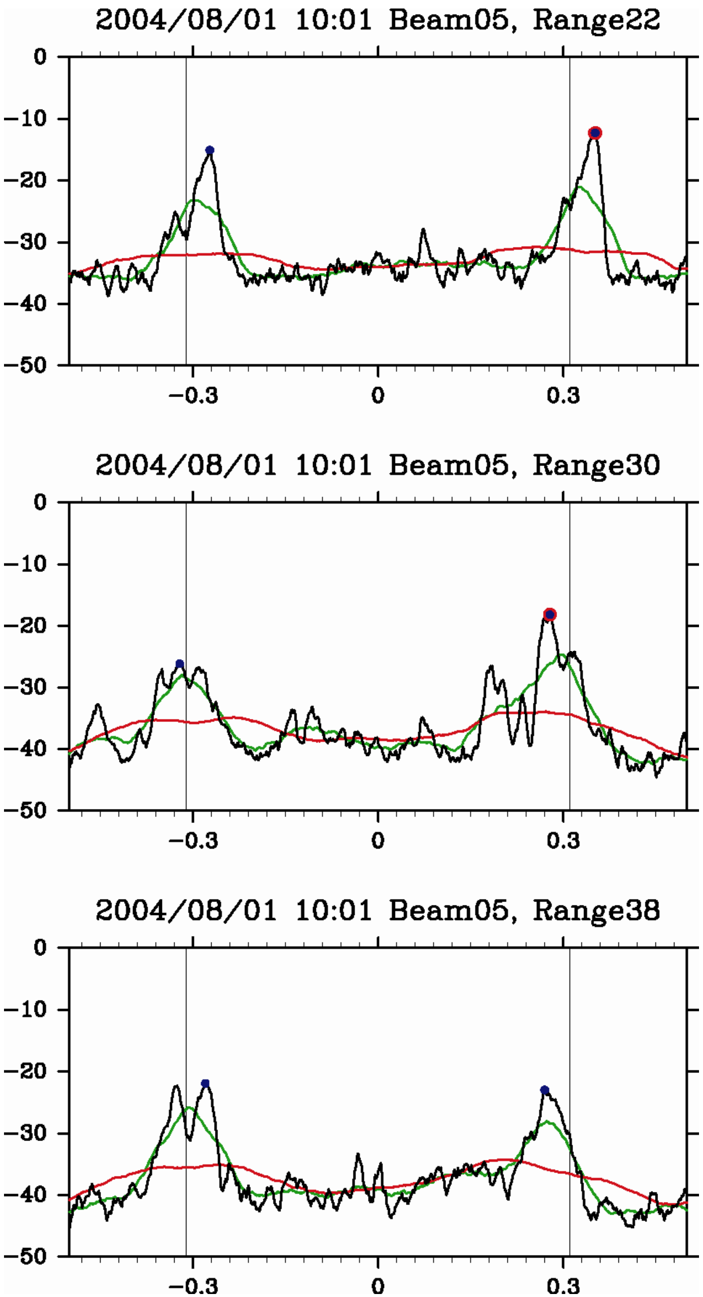




Summary

- The Kuroshio variation in the shelf can be seen by reprocessed LROR data.
- Kuroshio axis variations in the northeast of Taiwan were investigated using the LROR data for about 8 years.
- Basically, the Kuroshio flows along shelf edge as would be expected but fluctuation is considerably large.
- As previous studies suggested, the Kuroshio tends to flow along shelf edge in summer and intrude into the shelf in winter.
- The Kuroshio axis variation with a time scale of more than 1 month might related to meso-scale eddy activity in the upstream region of the LROR observation area.
- In several case, the Kuroshio intrudes into the shelf associated with strong typhoon passage.

スペクトルピークの決定方法



- ピークは5dB以上とする。
- ピークが20dB以上（決定）

↓

- 正負の片側にしかピークがない（決定）

↓

- 正負両方のピークの周波数がほぼ同じ（決定）

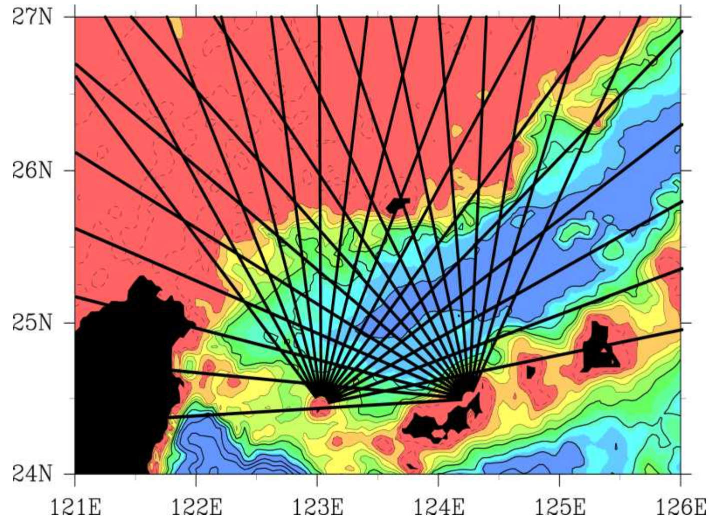
↓

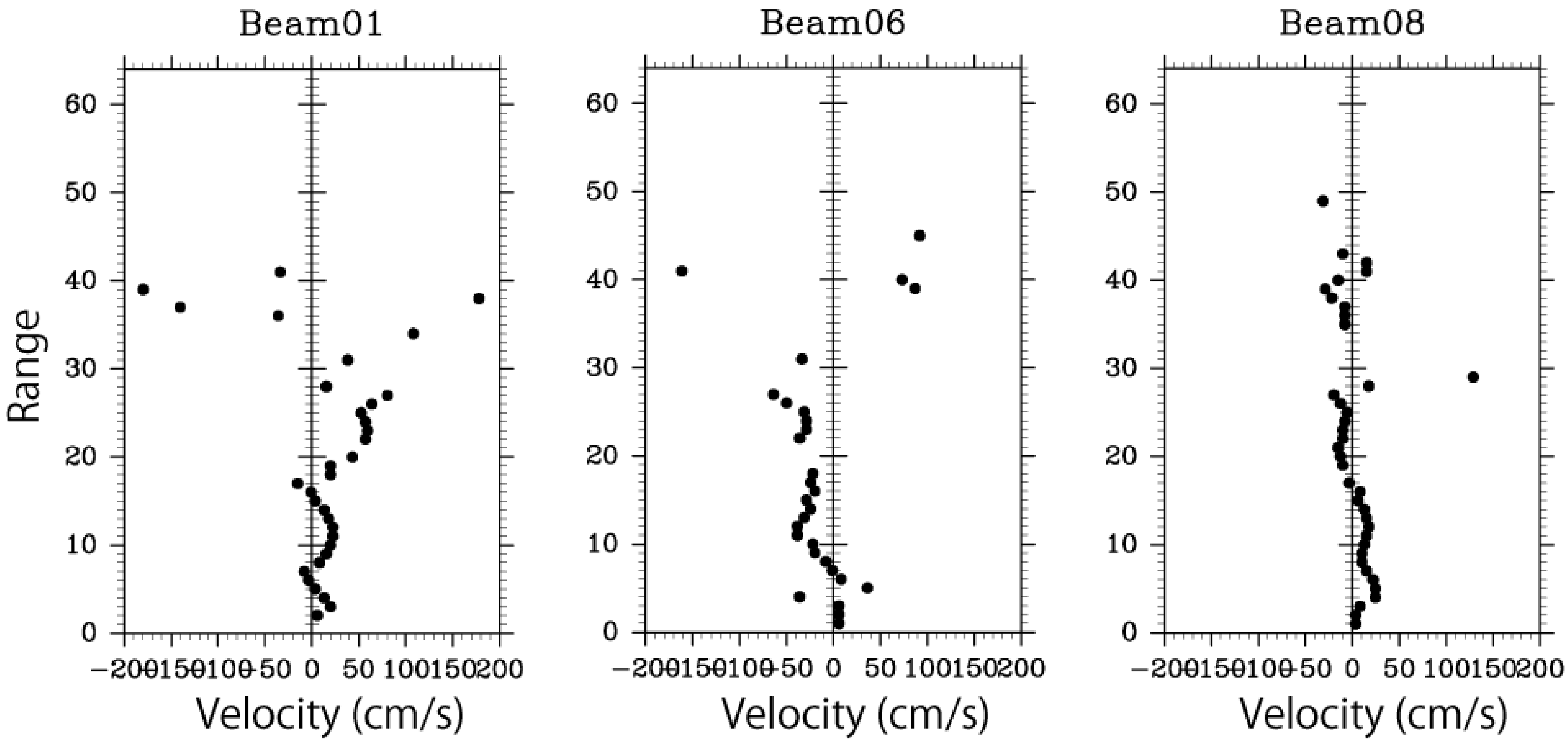
- 正負それぞれのピークに対応したピーク（小さくても）がある場合（決定）

↓

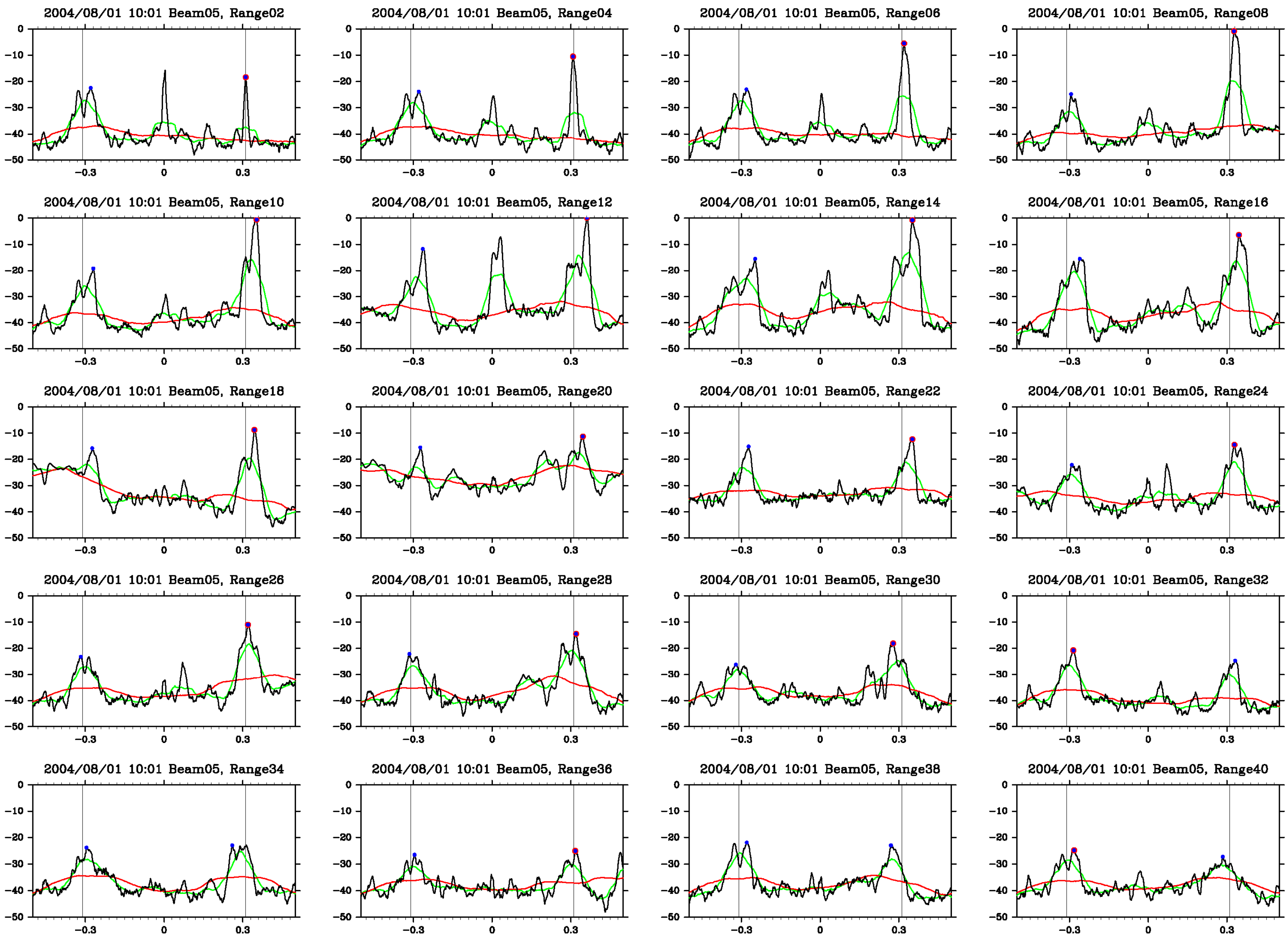
- 判定不能
- 空間方向の連続性をチェックし、フラグをつける。

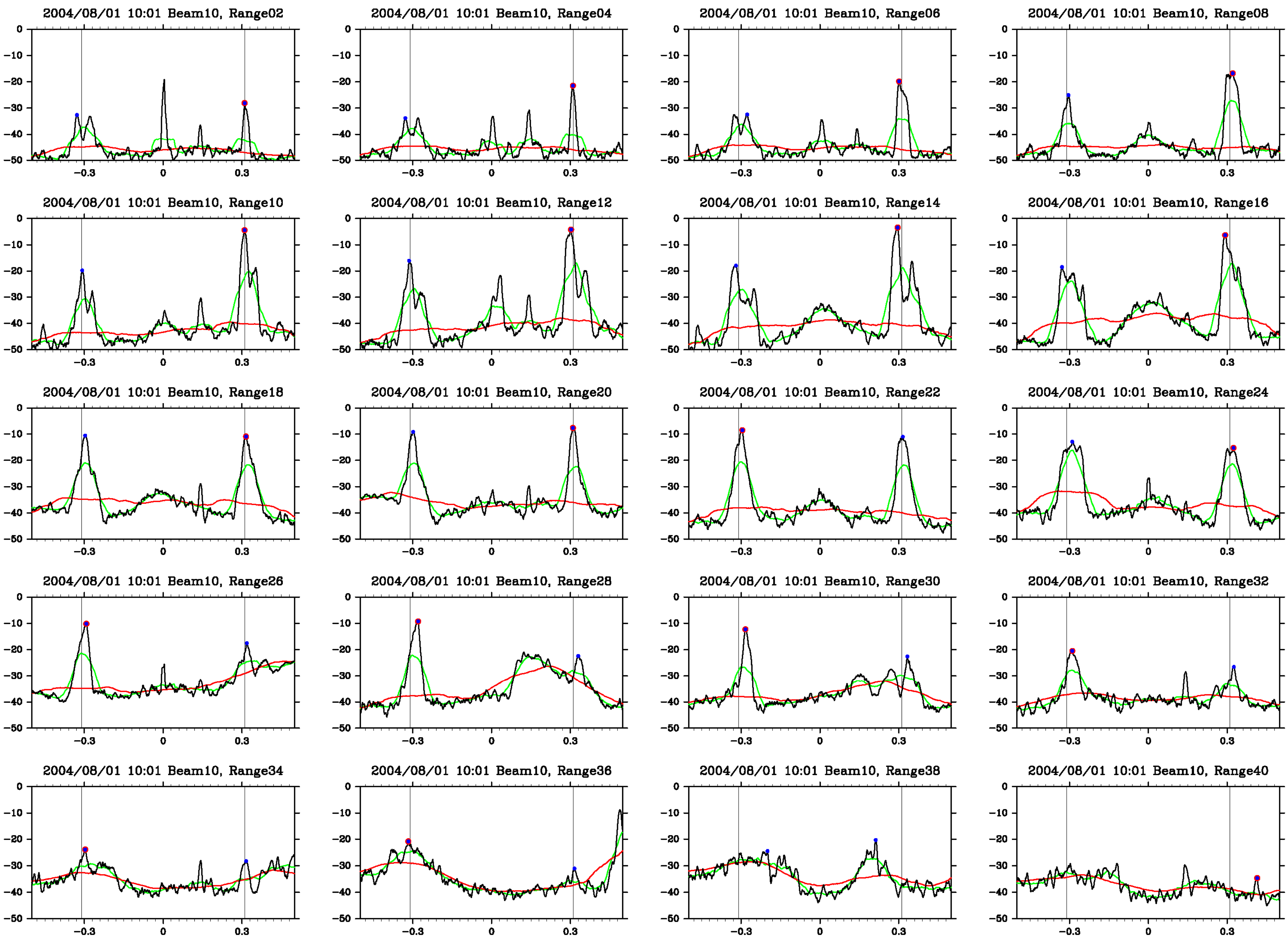
レンジ方向の流速分布を使いフラグを設定





スペクトルピークの検出結果
（計算時間：1ヶ月約10分）




2004/08/01 10:01 Beam10, Range02
2004/08/01 10:01 Beam10, Range04
2004/08/01 10:01 Beam10, Range06
2004/08/01 10:01 Beam10, Range08
2004/08/01 10:01 Beam10, Range10
2004/08/01 10:01 Beam10, Range12
2004/08/01 10:01 Beam10, Range14
2004/08/01 10:01 Beam10, Range16
2004/08/01 10:01 Beam10, Range18
2004/08/01 10:01 Beam10, Range20
2004/08/01 10:01 Beam10, Range22
2004/08/01 10:01 Beam10, Range24
2004/08/01 10:01 Beam10, Range26
2004/08/01 10:01 Beam10, Range28
2004/08/01 10:01 Beam10, Range30
2004/08/01 10:01 Beam10, Range32
2004/08/01 10:01 Beam10, Range34
2004/08/01 10:01 Beam10, Range36
2004/08/01 10:01 Beam10, Range38
2004/08/01 10:01 Beam10, Range40
0
-10
-20
-30
-40
-50
-0.3
0
0.3

Ocean- Atmosphere coupled model

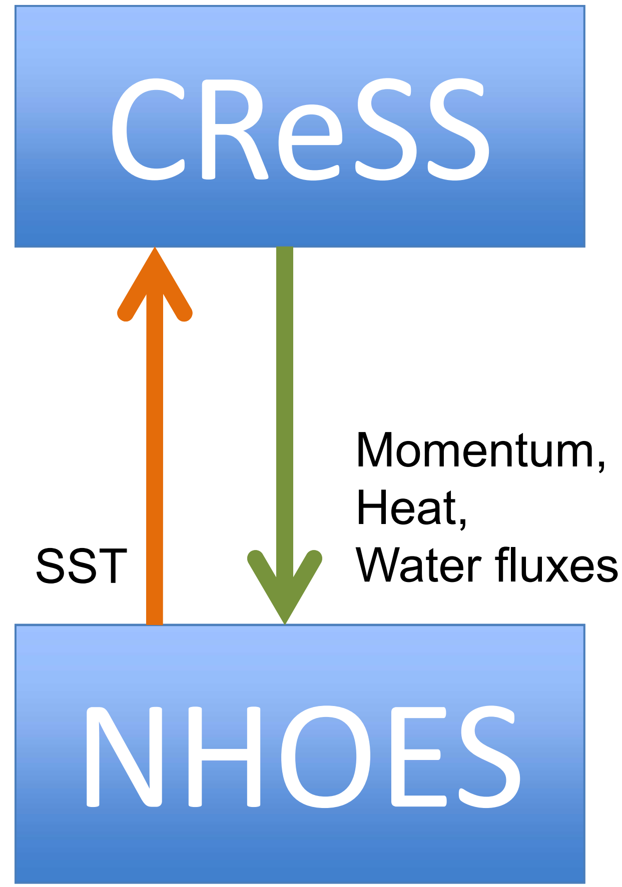
Cloud Resolving Storm Simulator (CReSS)

Tsuboki and Sakakibara (2002)
DX = 4km, 384 * 240 * 60 grid
Initial and lateral B. C.:
RANAL from NPD/JMA

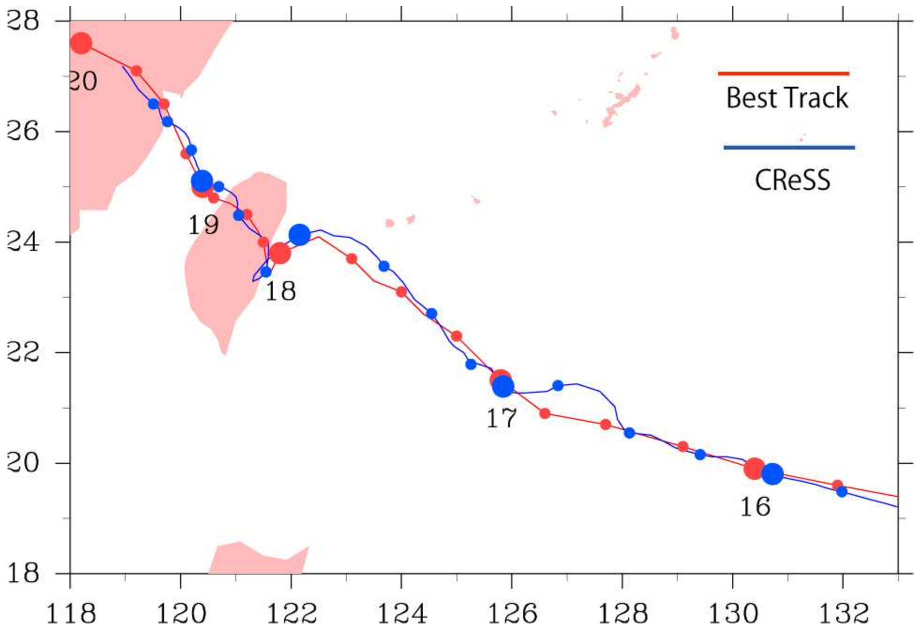
NonHydrostatic Ocean model for ES (NHOES)

Aiki and Yamagata (2004)
Aiki et al. (2006)
Menesguen et al. (2009)

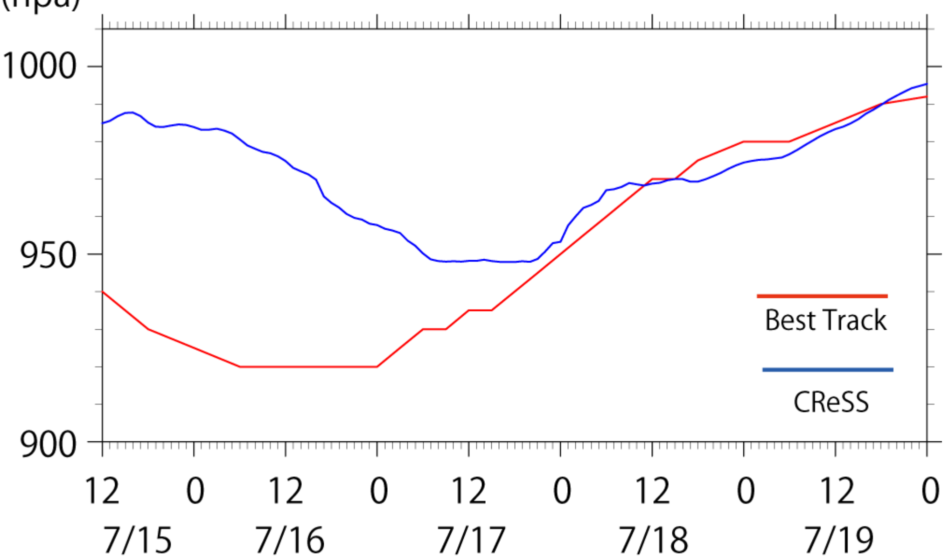
DX = 4km, DZ = 2 m for top 100 m
385 * 241 * 100 grid
Initial and lateral B. C.:
JCOPE2 reanalysis



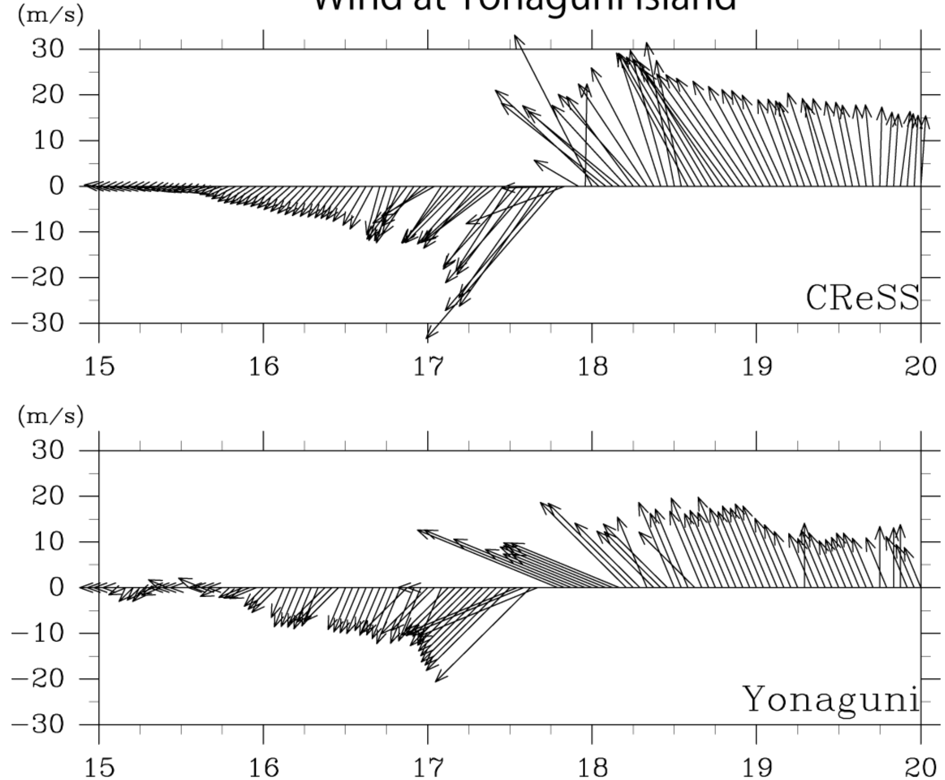
Validation of results of CReSS (meteorological model)



Pressure at 1.5 m

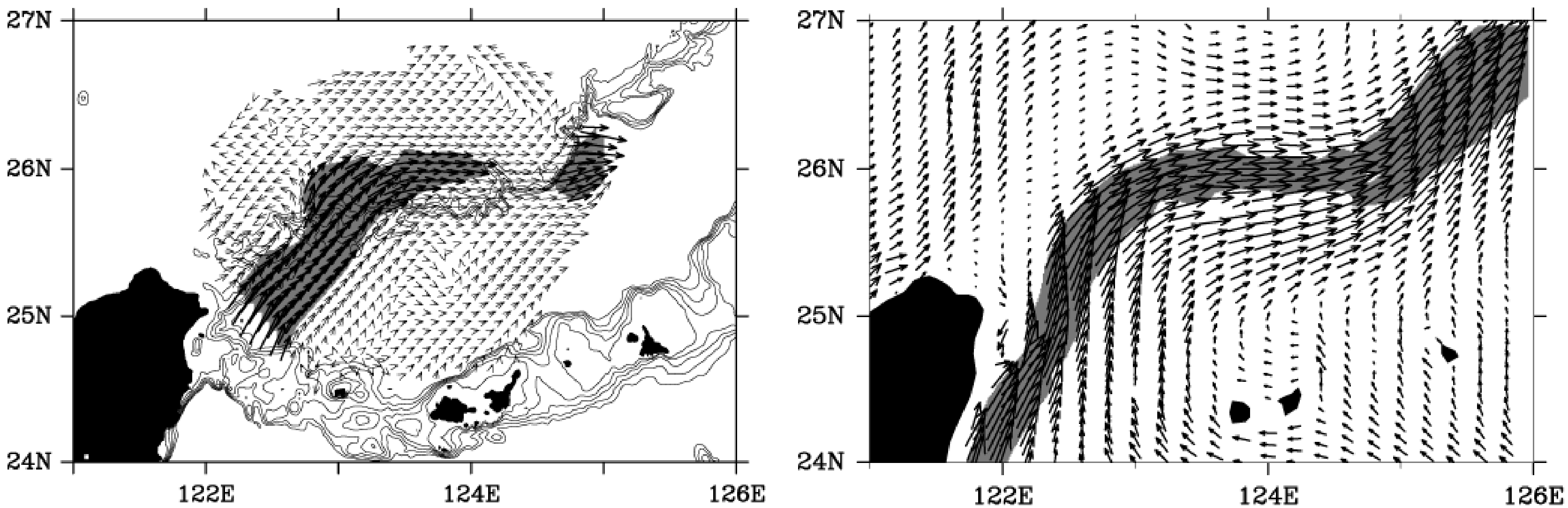


Wind at Yonaguni Island

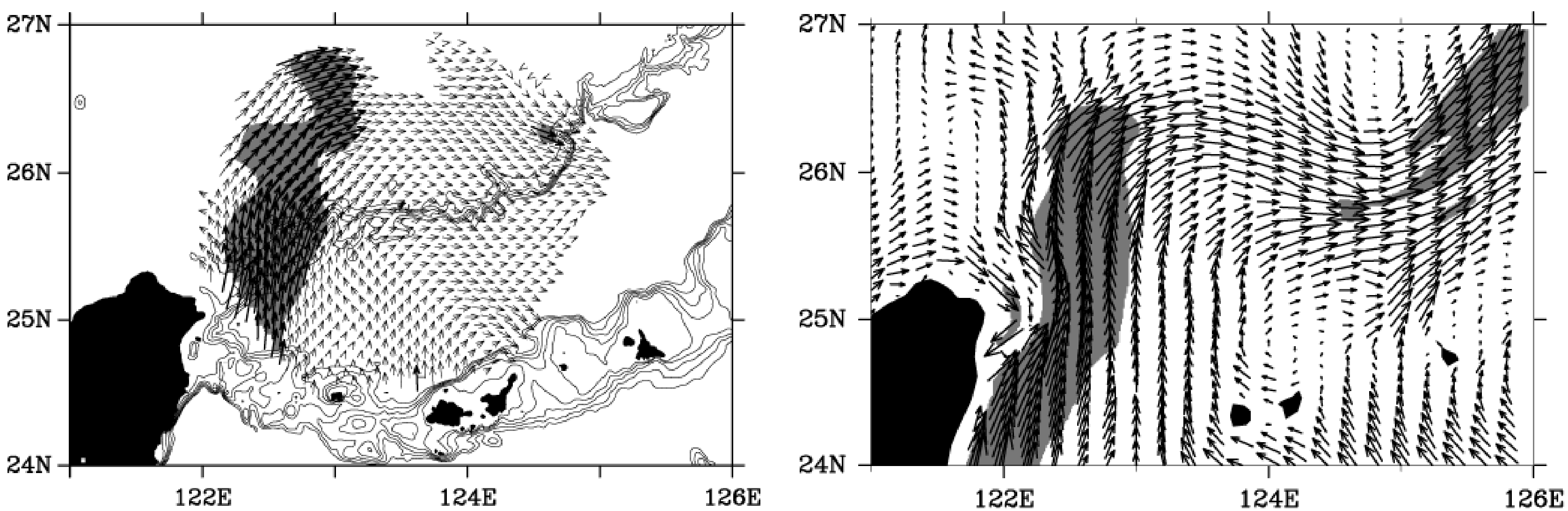


Comparison of sea surface currents
(Shadowed areas > 1m/s)

Before typhoon (July 16, 01:00 UTC)

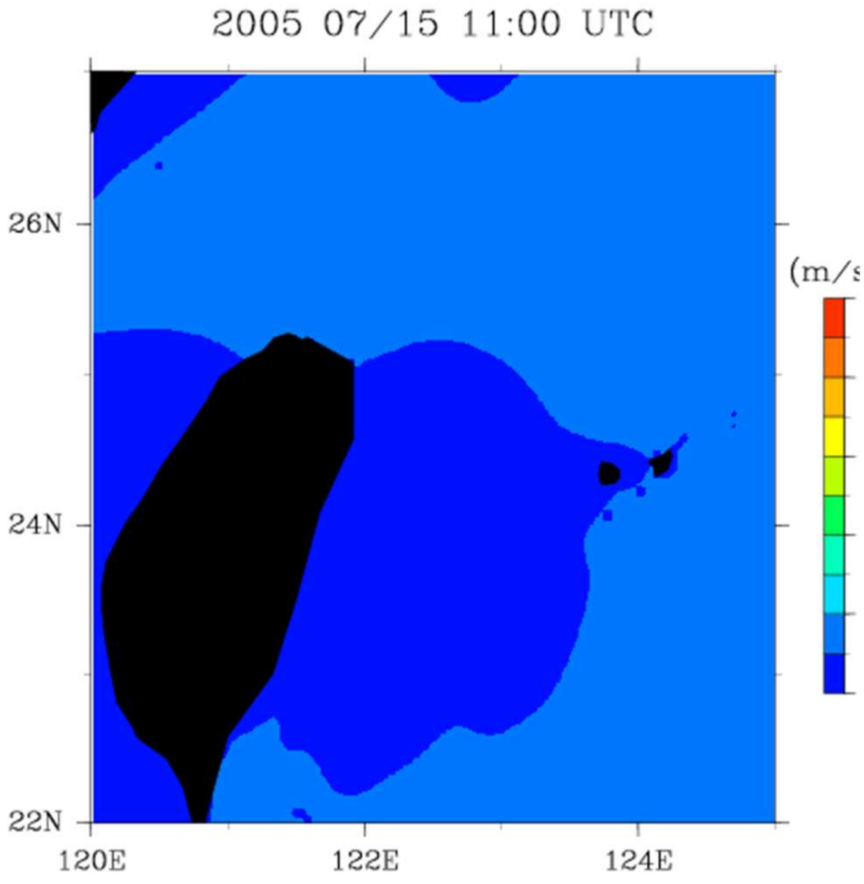


After typhoon passage（July 21, 01:00 UTC）

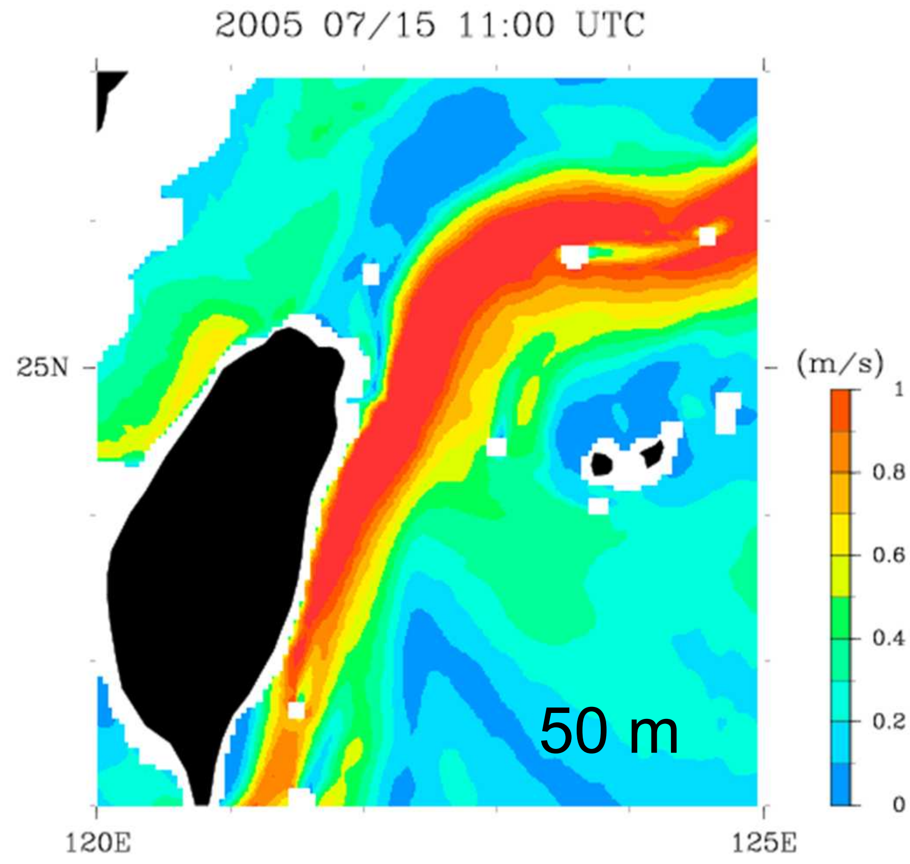


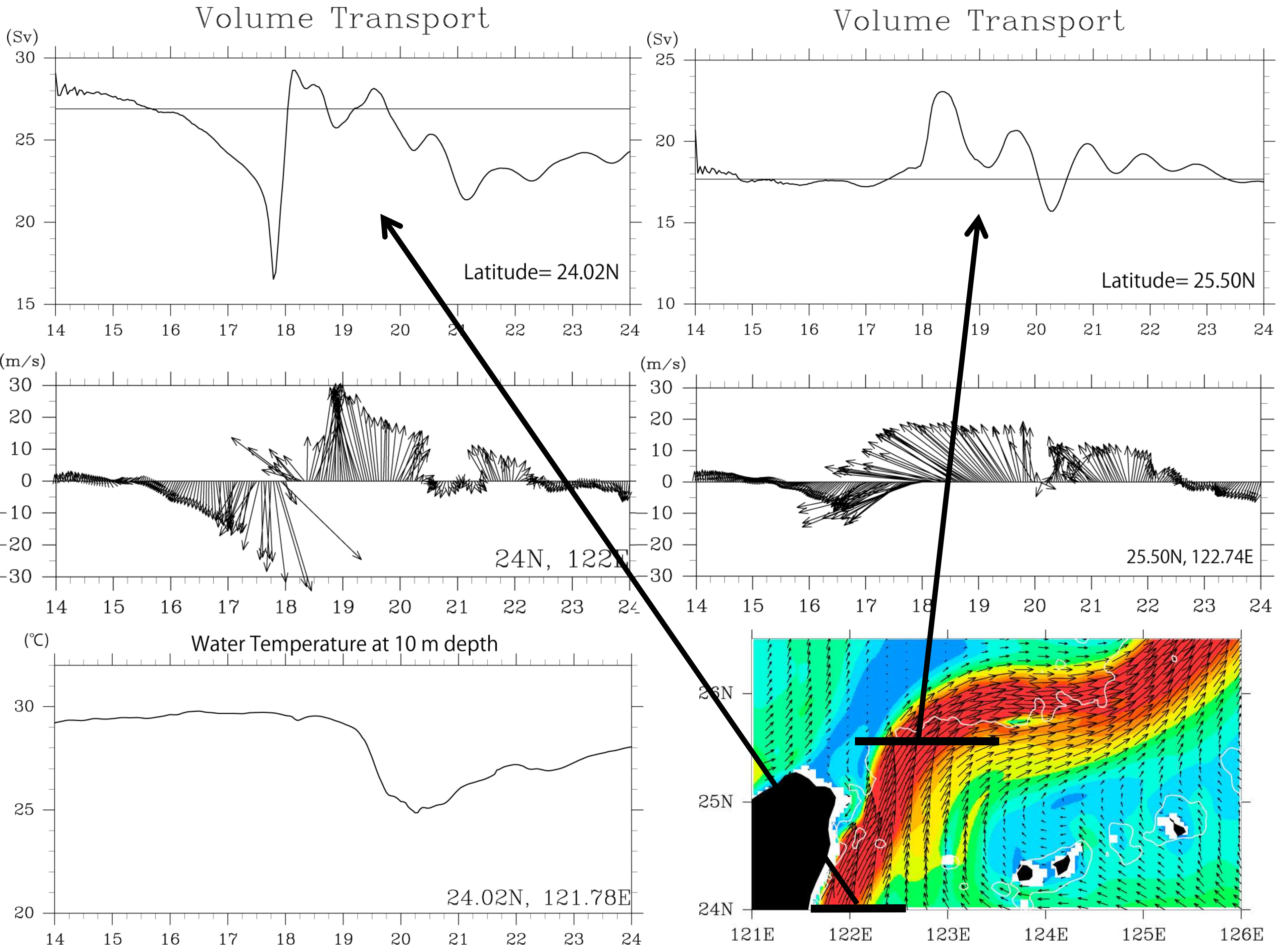
Movement of Kuroshio axis

Wind Speed

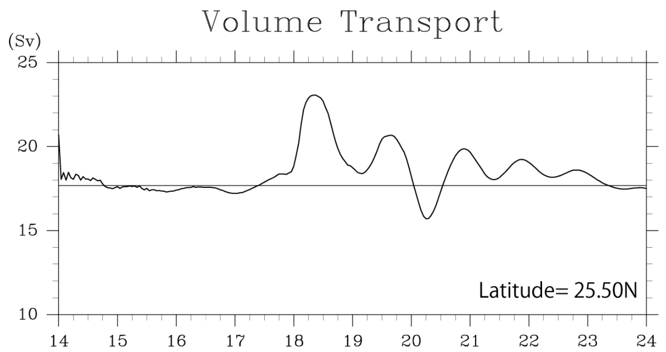


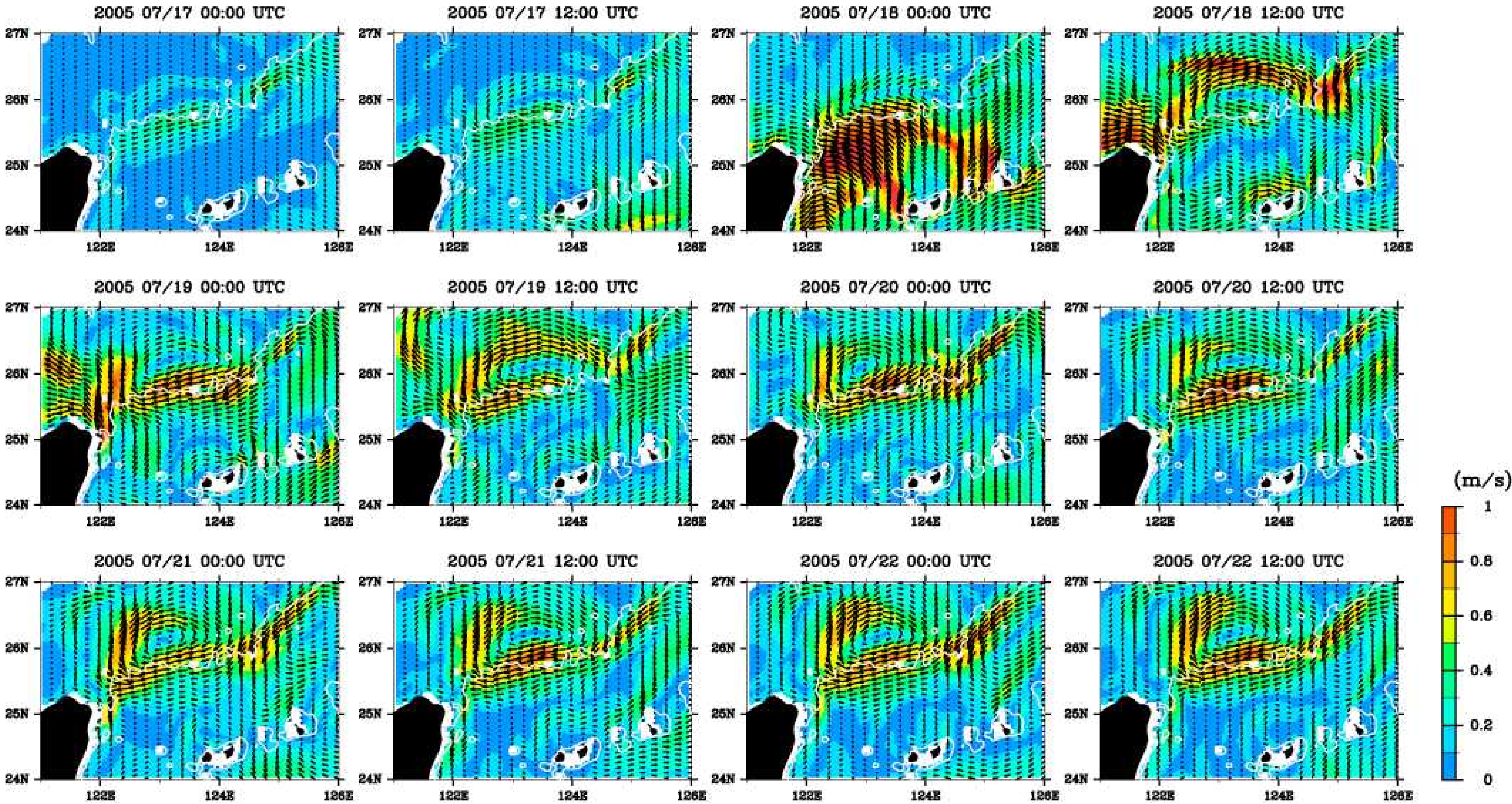
Current Velocity




Volume Transport
(Sv)
Latitude= 24.02N
Volume Transport
(Sv)
Latitude= 25.50N
(m/s)
24N, 122E
(m/s)
25.50N, 122.74E
(℃)
Water Temperature at 10 m depth
24.02N, 121.78E
26N
25N
24N
121E
122E
123E
124E
125E
126E

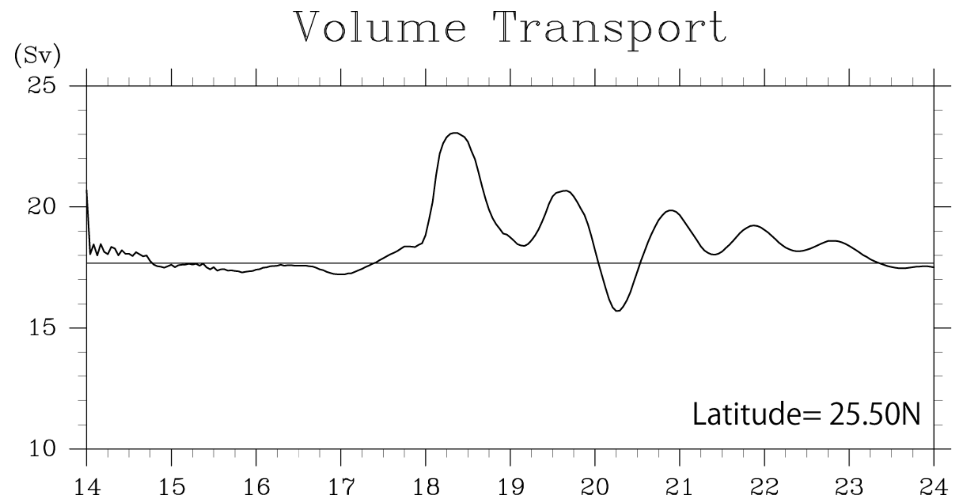
Vertical averaged (100-m) current velocity anomaly from mean current before typhoon approach (7/14-7/16)



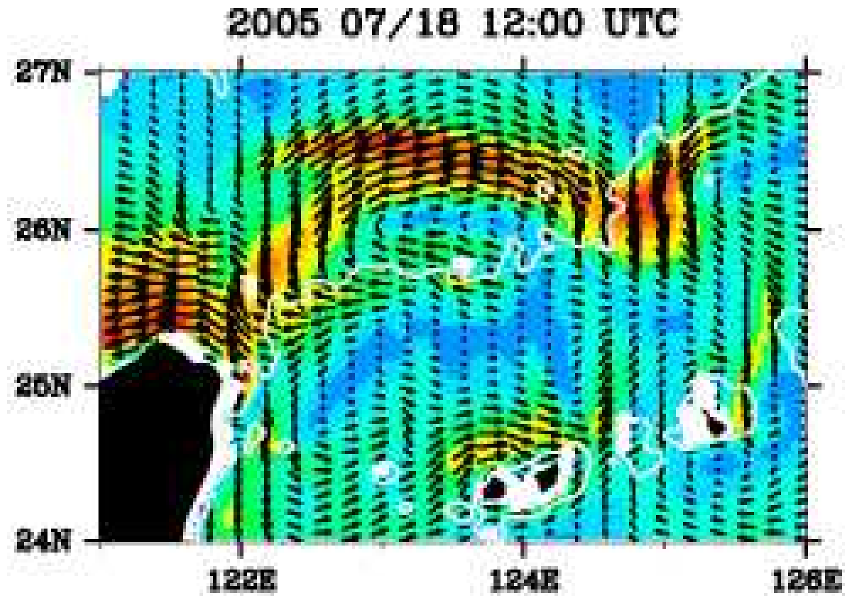


Kuroshio axis movement onto the shelf

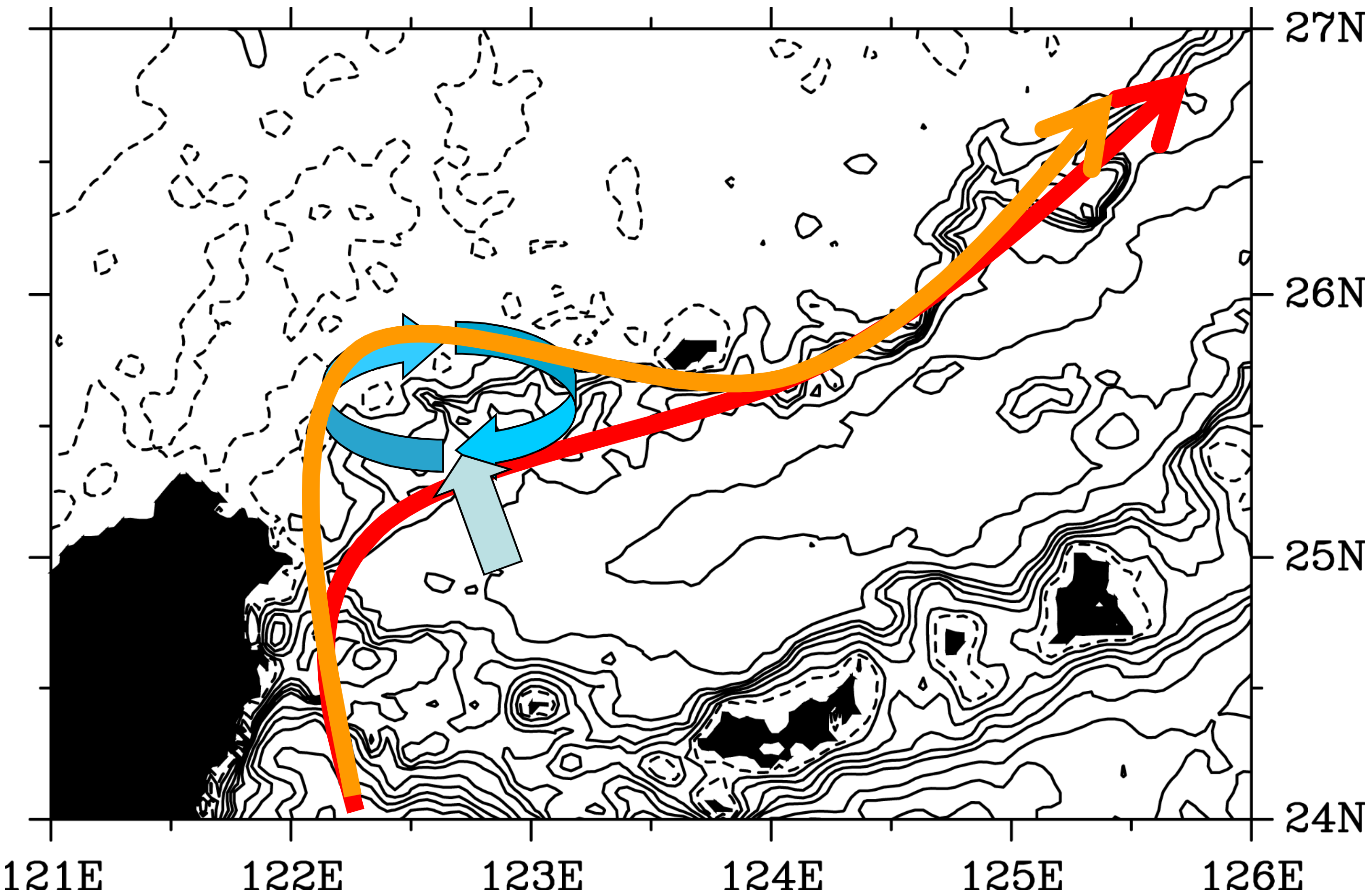
When southerly wind blew, volume transport across shelf increased.



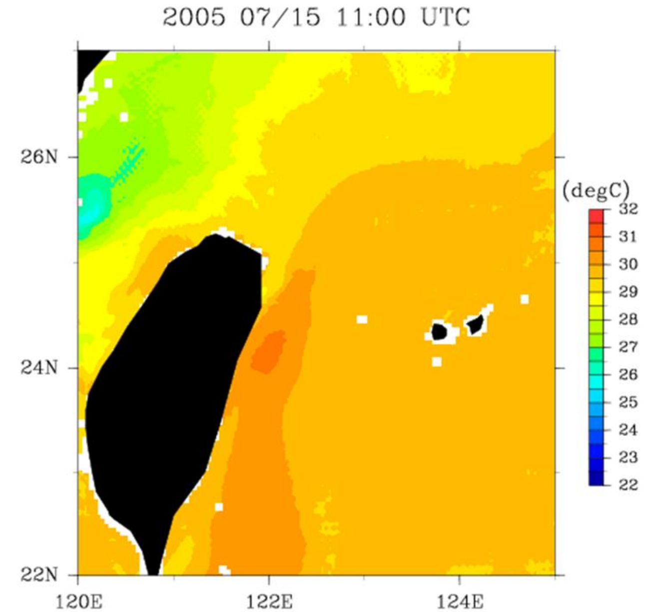
Considering conservation of potential vorticity, negative vorticity was supplied.



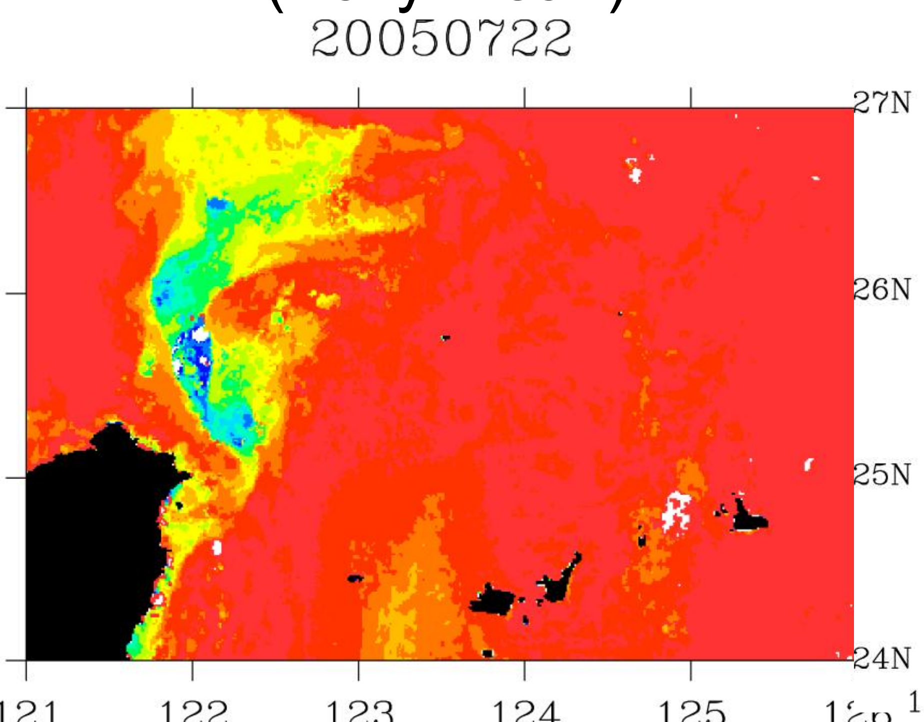
Kuroshio axis movement onto the shelf



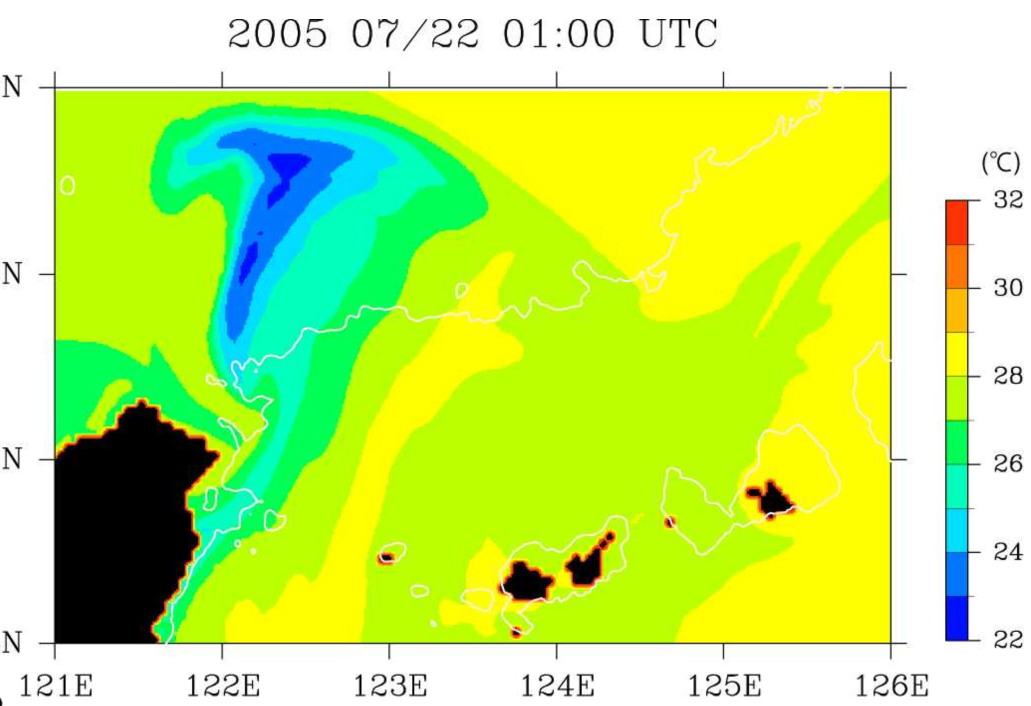
Low water temperature area appeared in the shelf after typhoon passage

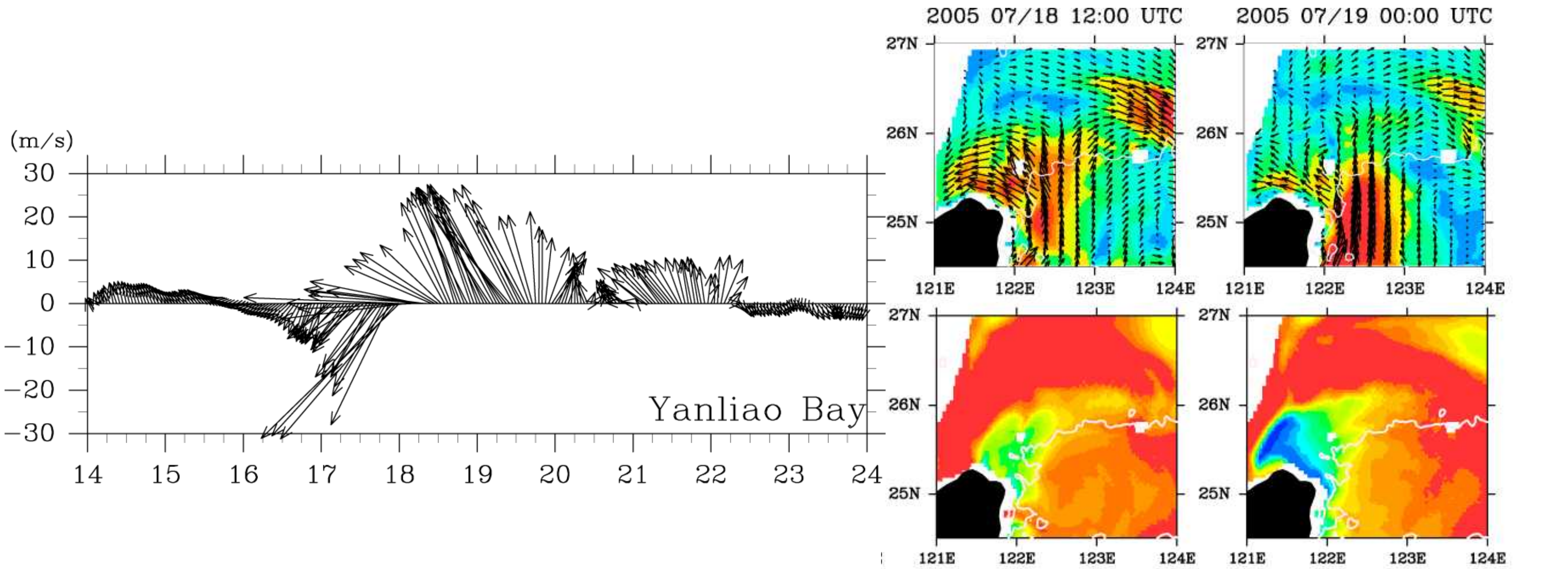


Satellite SST
(Daily mean)

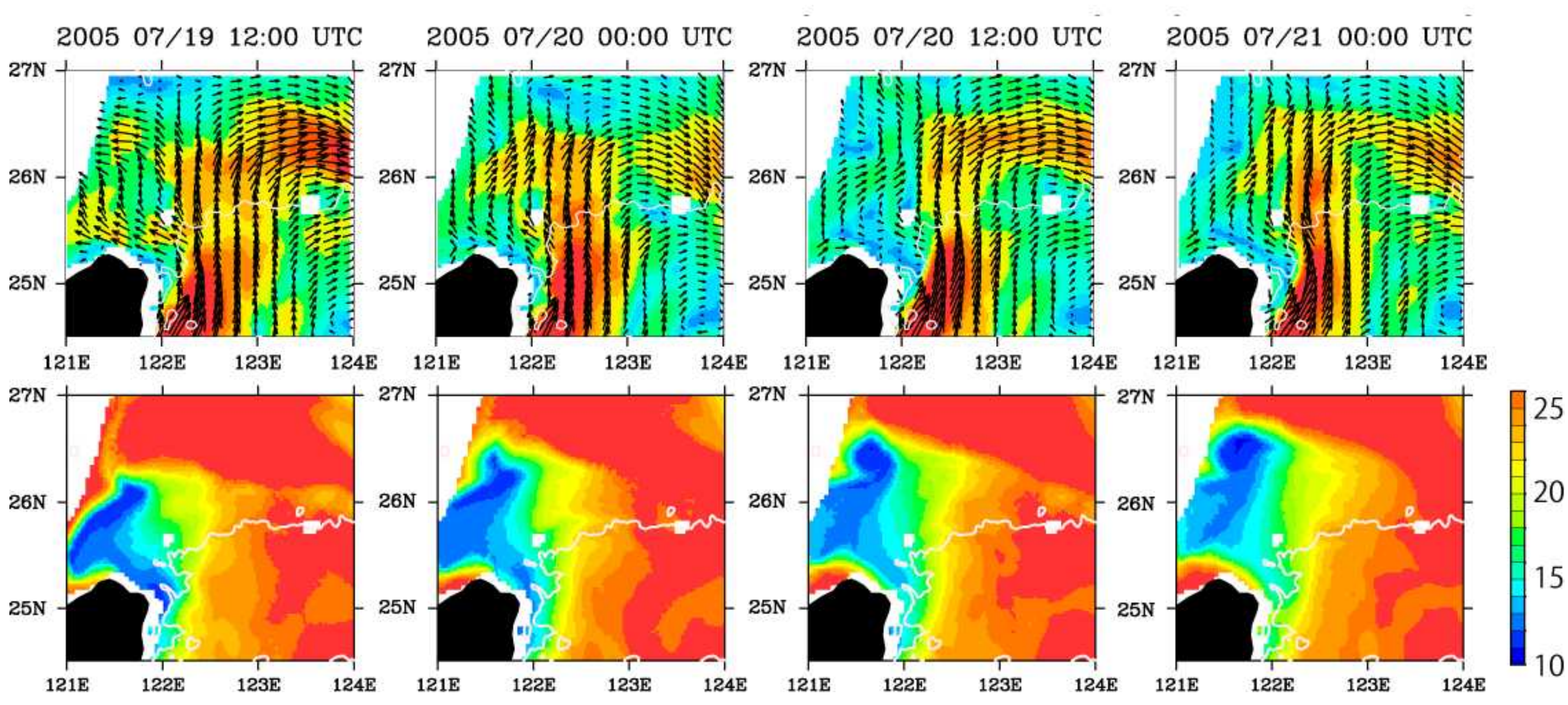


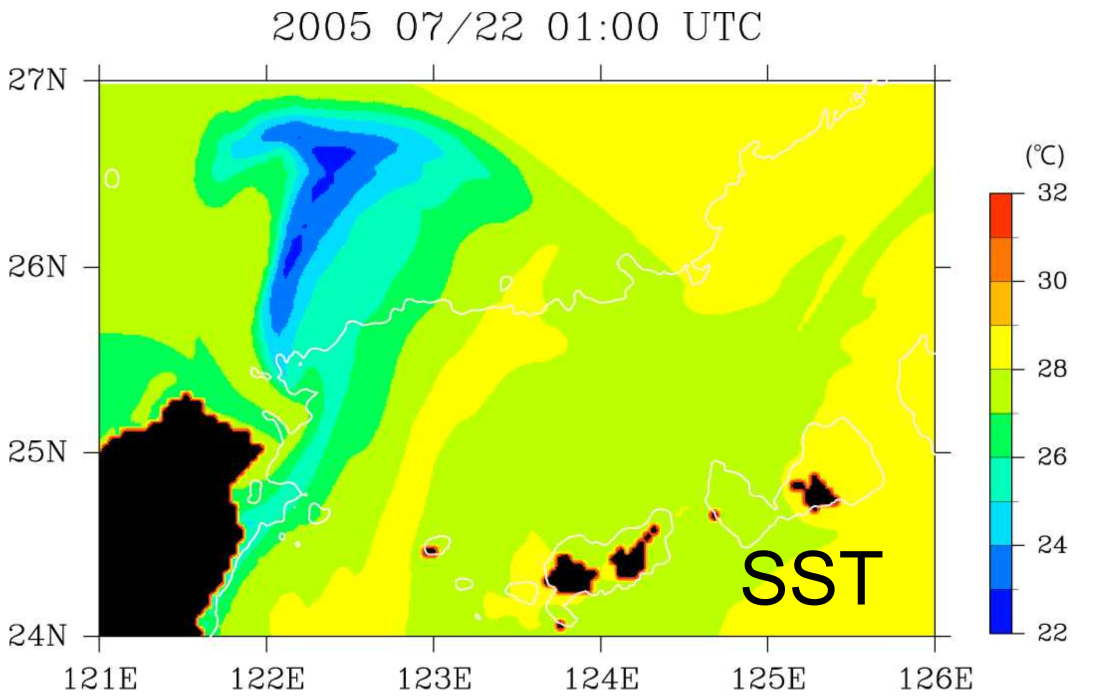
NHOES-CReSS SST



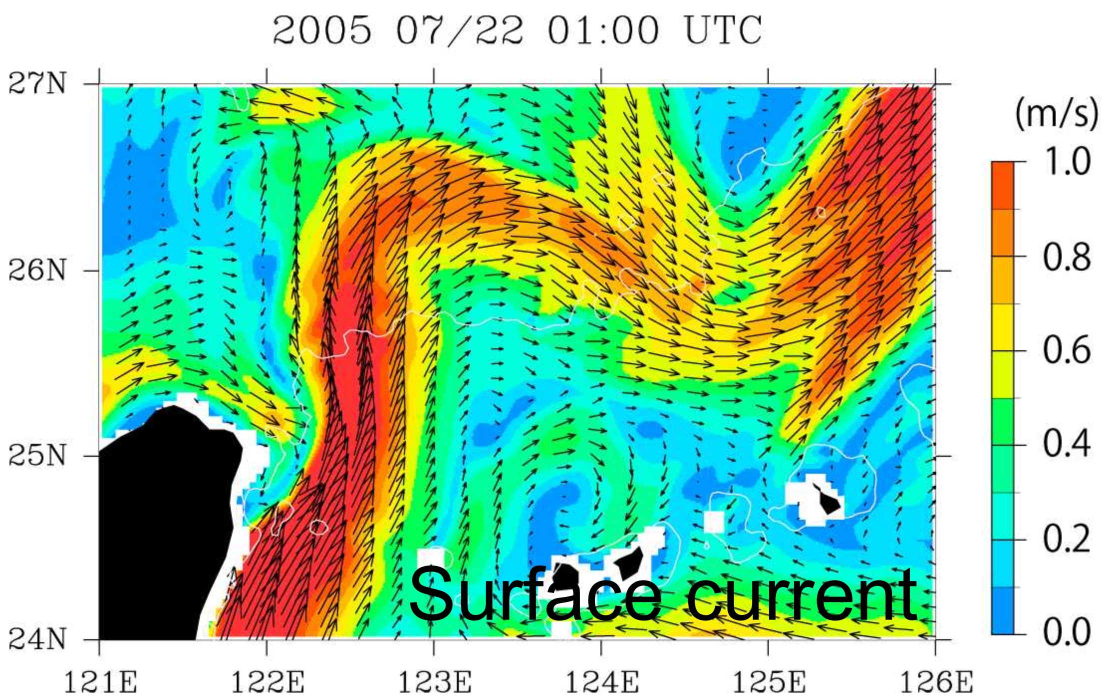


Current and water temperature at 60m





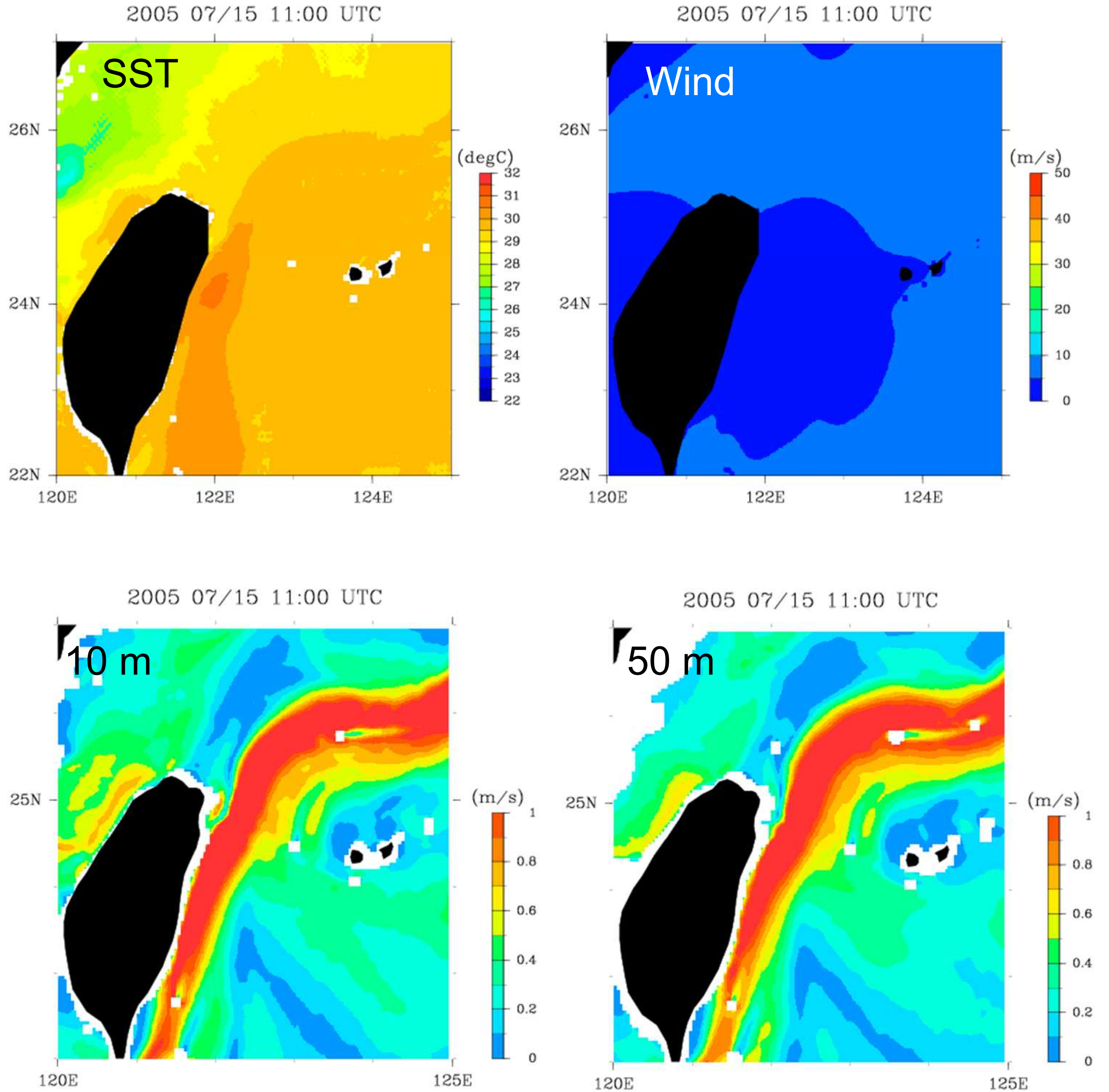
2005 07/22 01:00 UTC
27N
26N
25N
24N
121E
122E
123E
124E
125E
126E
(℃)
32
30
28
26
24
22
SST



2005 07/22 01:00 UTC
27N
26N
25N
24N
121E
122E
123E
124E
125E
126E
(m/s)
1.0
0.8
0.6
0.4
0.2
0.0
Surface current

Summary

- We reproduced the Kuroshio axis variation during typhoon Hai-Tang passage by mean of a ocean-atmosphere coupled model.
- Meteorological model well reproduced typhoon path, pressure, and wind variation.
- Ocean model well reproduced the Kuroshio axis variation and appearance of large area of low water temperature.
- When wind direction changed from north to south, volume transport across the shelf edge increased. Anti-cyclonic eddy generated on the shelf, as a result the Kuroshio axis changed direction to the north.
- Water mass with low water temperature around the Kuroshio transported to the shelf when southerly wind start to blow.


2005 07/15 11:00 UTC
SST
(degC)
32
31
30
29
28
27
26
25
24
23
22
26N
24N
22N
120E
122E
124E
2005 07/15 11:00 UTC
Wind
(m/s)
50
40
30
20
10
0
26N
24N
22N
120E
122E
124E
2005 07/15 11:00 UTC
10 m
(m/s)
1
0.8
0.6
0.4
0.2
0
25N
120E
125E
2005 07/15 11:00 UTC
50 m
(m/s)
1
0.8
0.6
0.4
0.2
0
25N
120E
125E