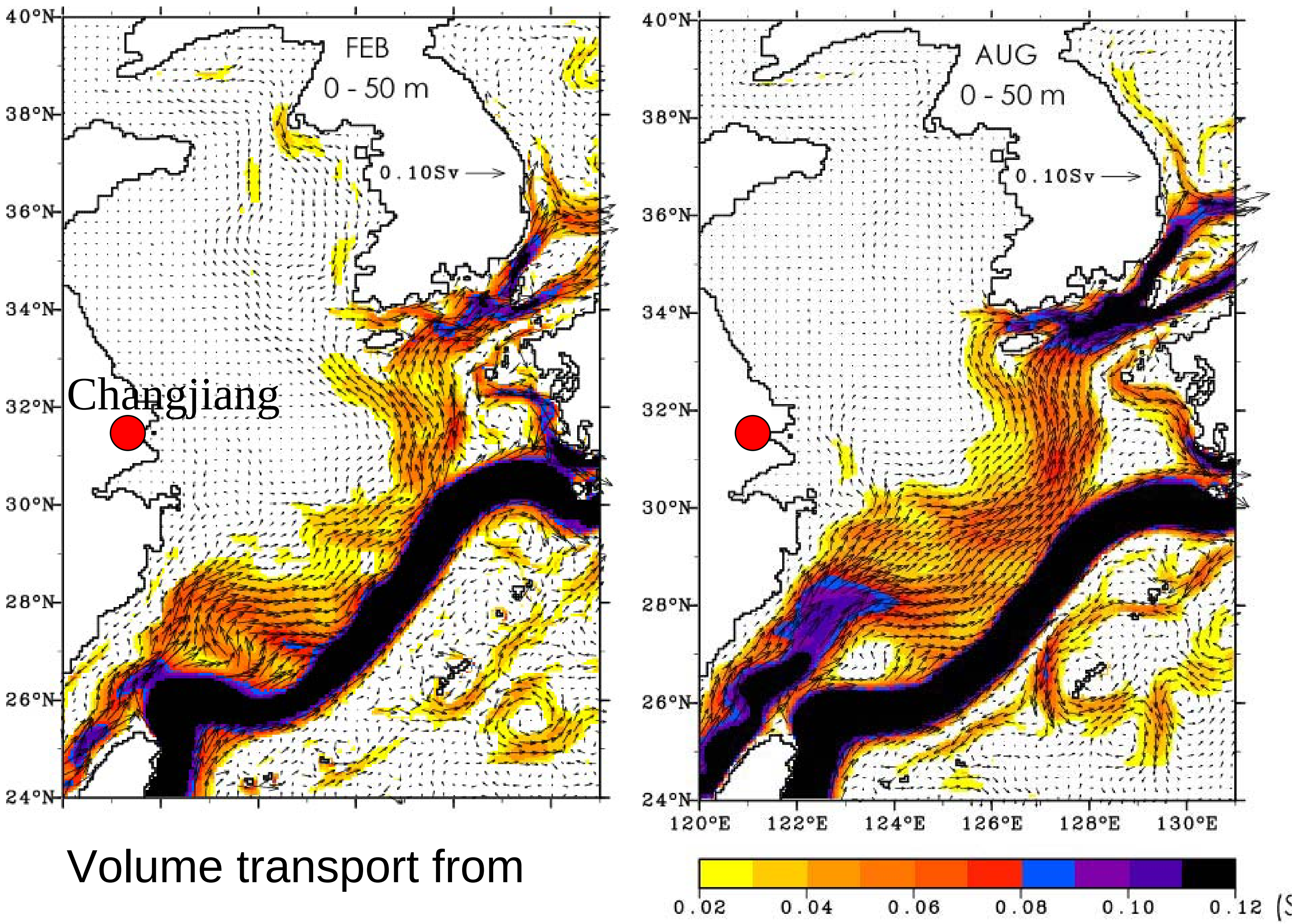
Intrusion of Kuroshio water onto the continental shelf in the East China Sea and its influences on the ecosystem

〇Xinyu Guo (CMES, Ehime University/FRCGC)

Yasumasa Miyazawa (FRCGC)

Toshio Yamagata (The University of Tokyo/FRCGC)



Volume transport from

50 m to 0 m

SW: Kuroshio Surface Water; TW: Kuroshio Tropical Water

IW: Kuroshio Intermediate Water; p: precipitation

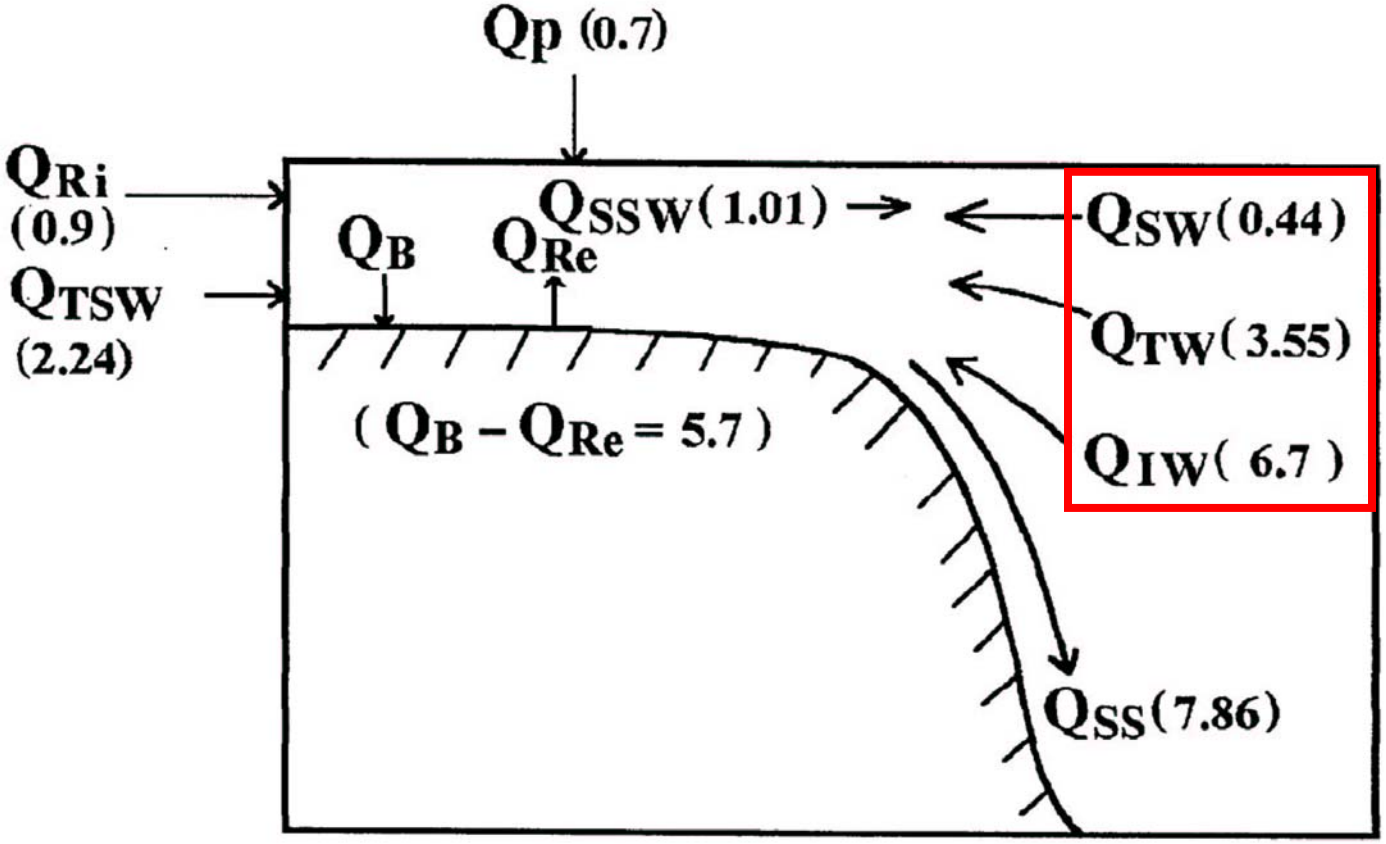


Figure 2. Schematic diagram for the annual phosphorus budget (numbers in 10^9 mol yr^{-1}).

Chen and Wang, JGR,1999

SW: Kuroshio Surface Water; TW: Kuroshio Tropical Water

IW: Kuroshio Intermediate Water; p: precipitation

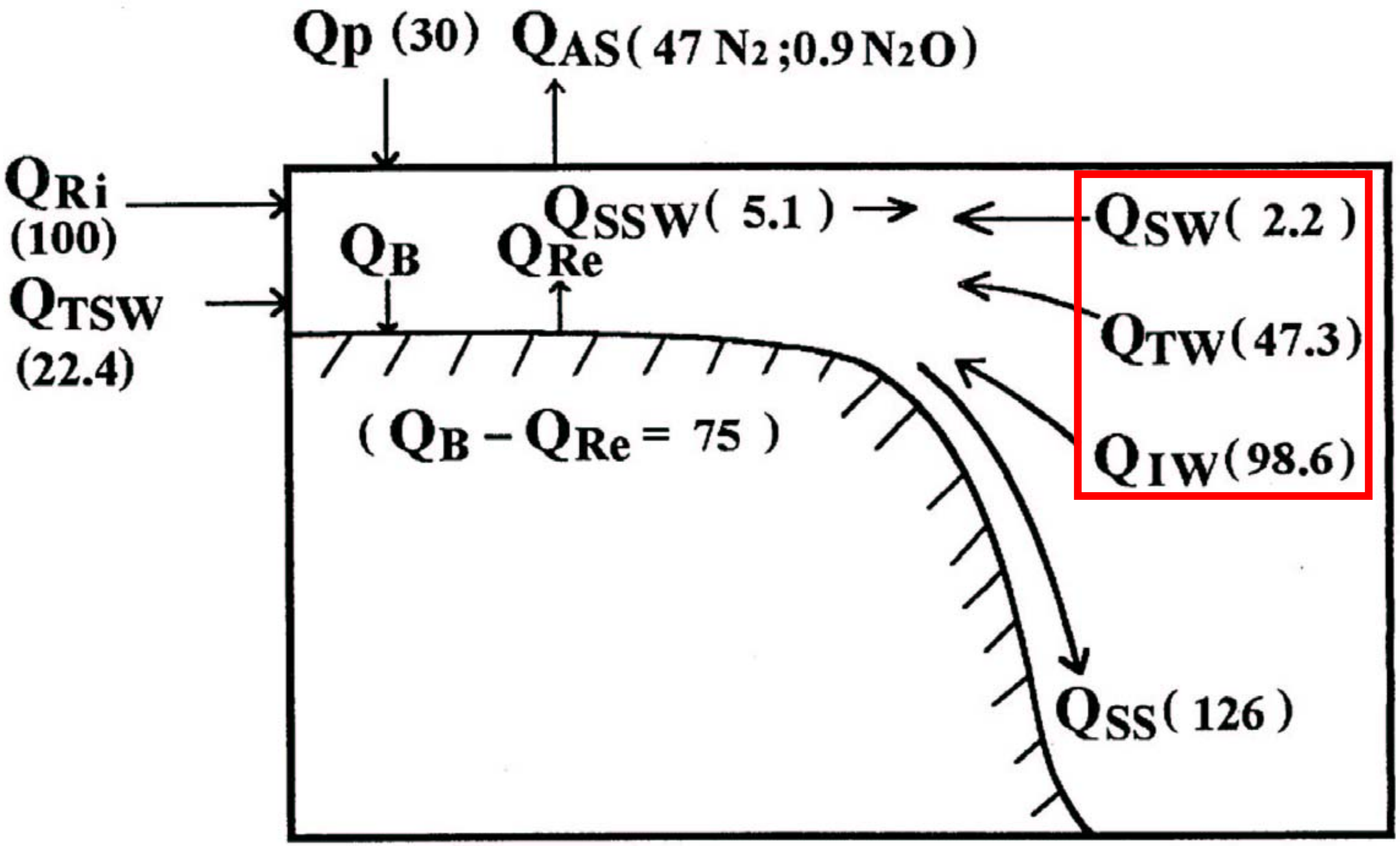
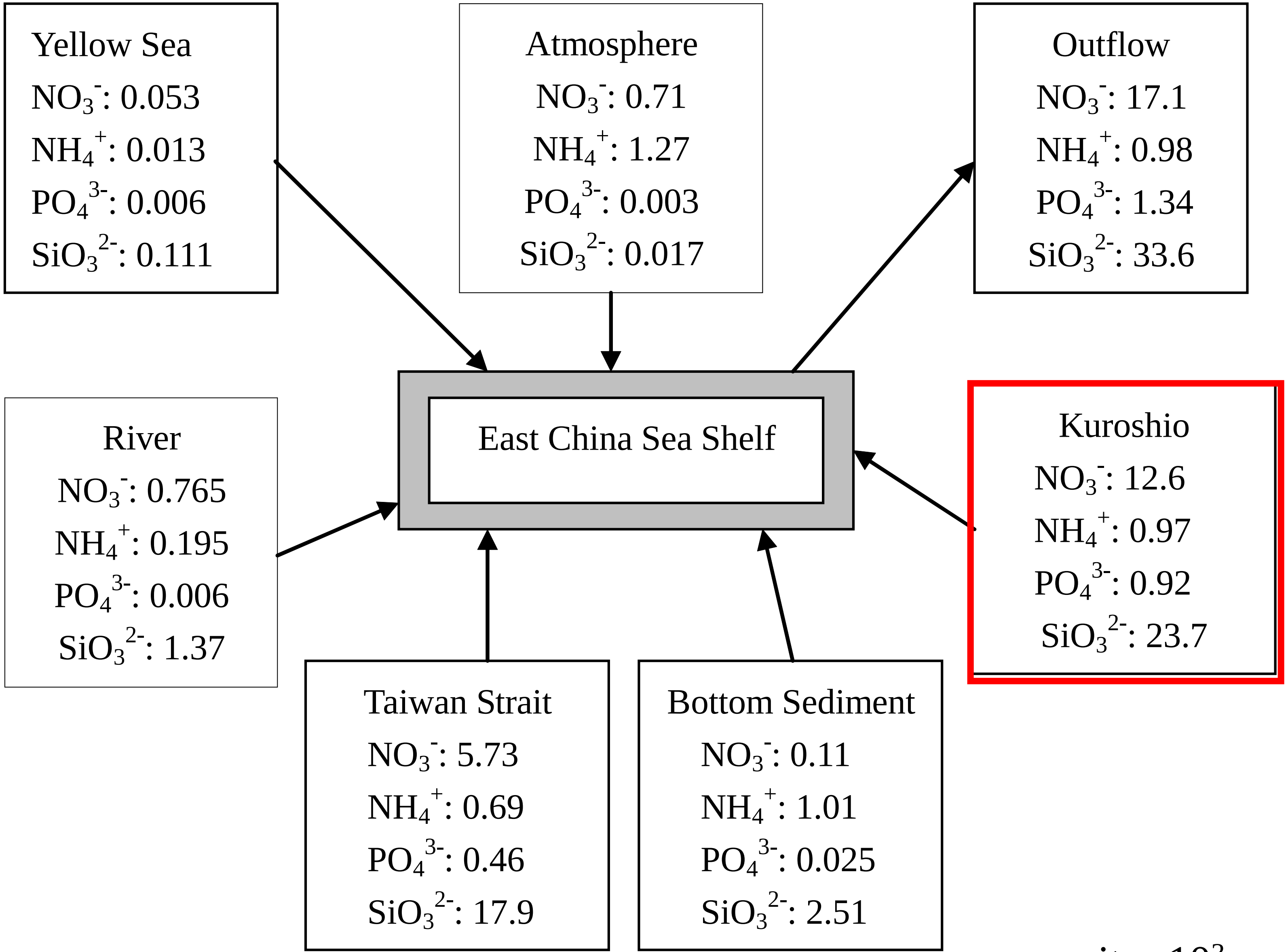


Figure 3. Schematic diagram for the annual nitrogen budget (numbers in 10^9 mol yr^{-1}).

Chen and Wang, JGR,1999

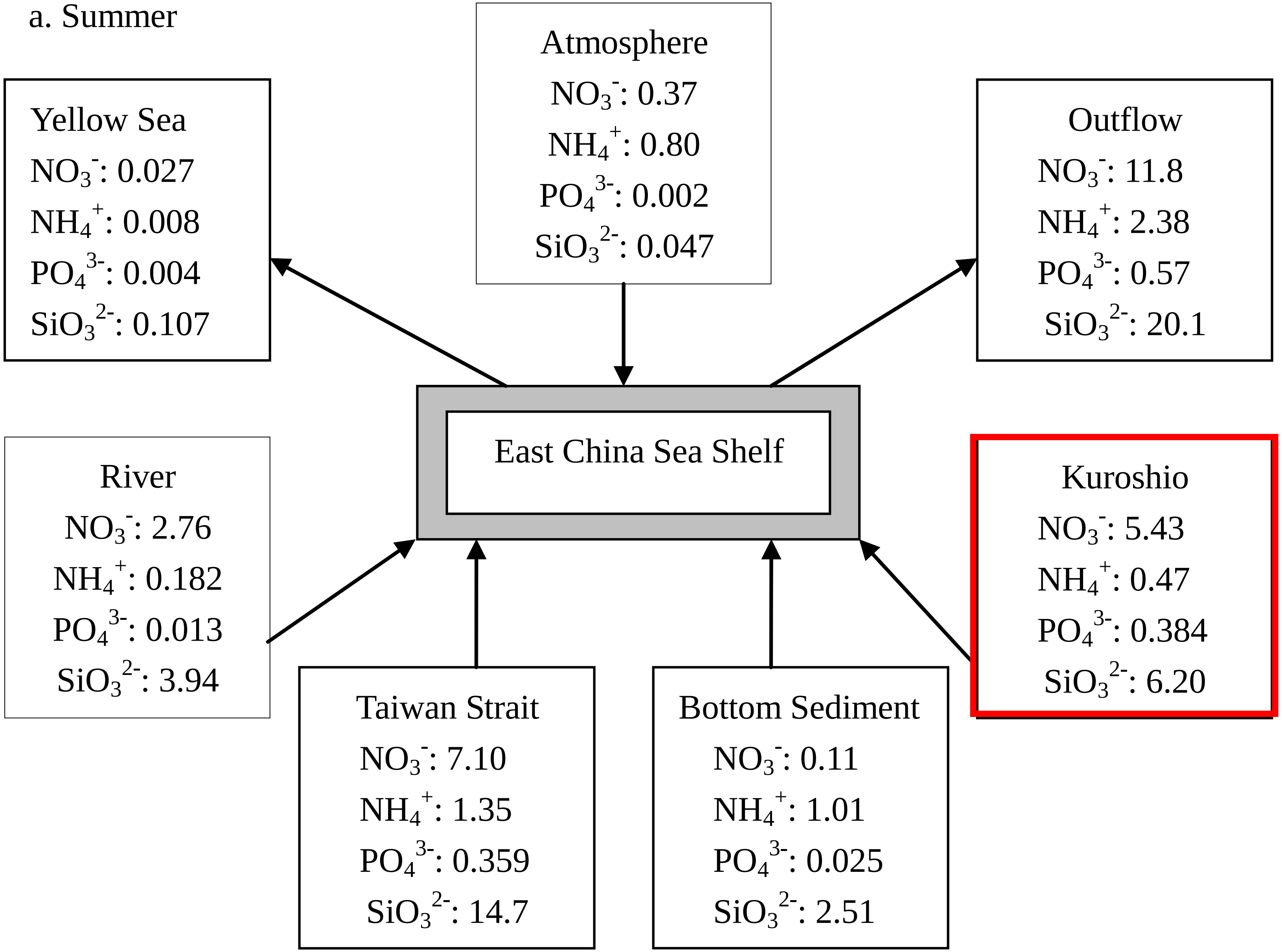
b. Winter



unit: $\times 10^3$ mol/s

Zhang et al., 2004

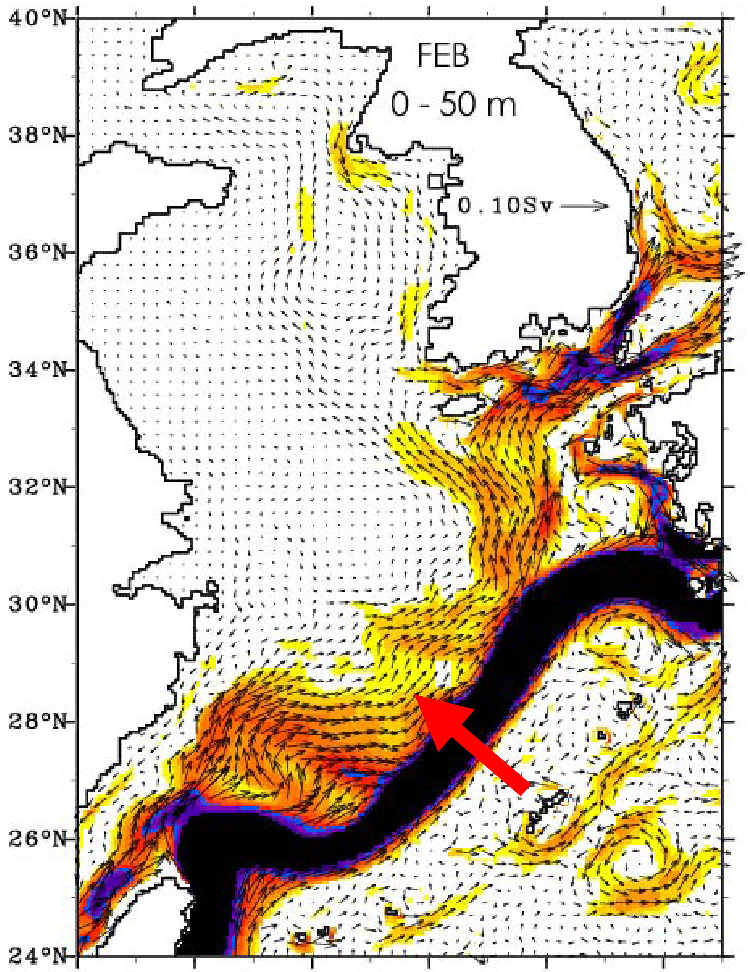
a. Summer



Zhang et al., 2004

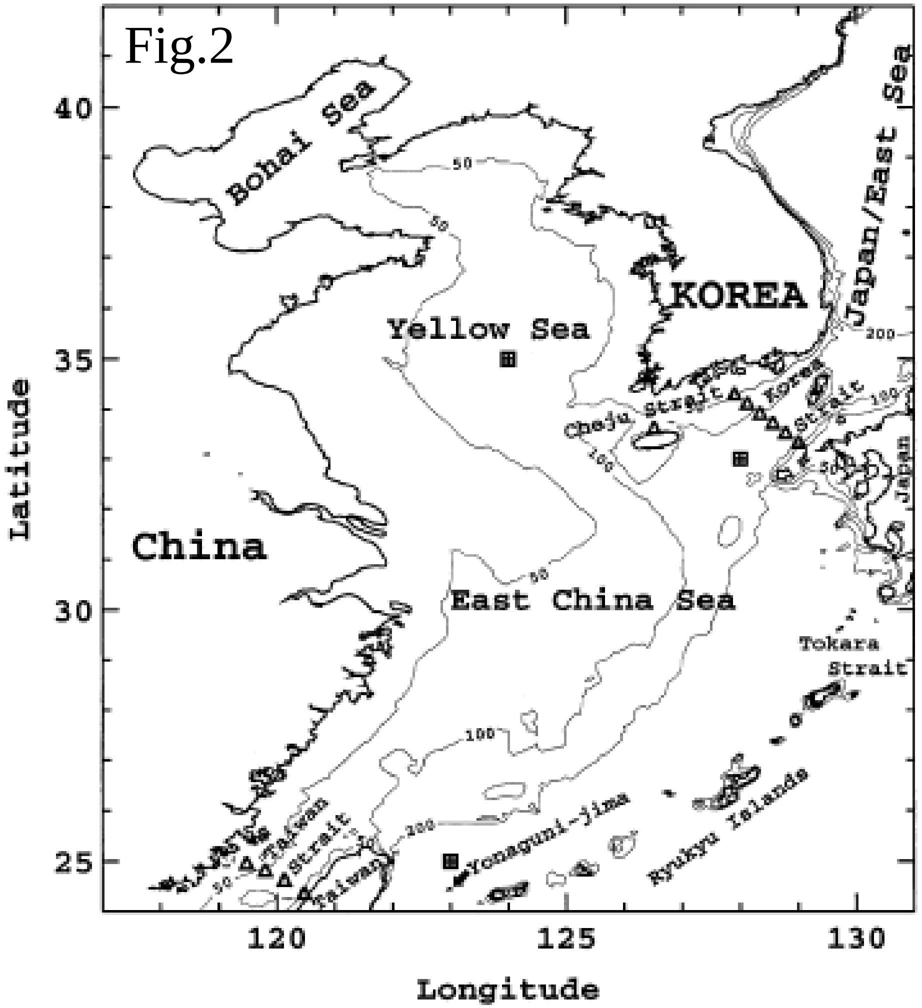
unit: $\times 10^3$ mol/s

We need an onshore flux from the Kuroshio to support the above results



1.2 Sv in Chen and Wang(1999), estimated by a box model

Fig. 2. Mooring locations (triangles) are indicated in the Taiwan, Cheju, and Korea Straits. Wind observation positions (boxes with plus signs) are located near the Taiwan Strait, in the Yellow Sea, and in the Korea Strait. Bathymetry is in meters.



Teague et al, CSR, 2003

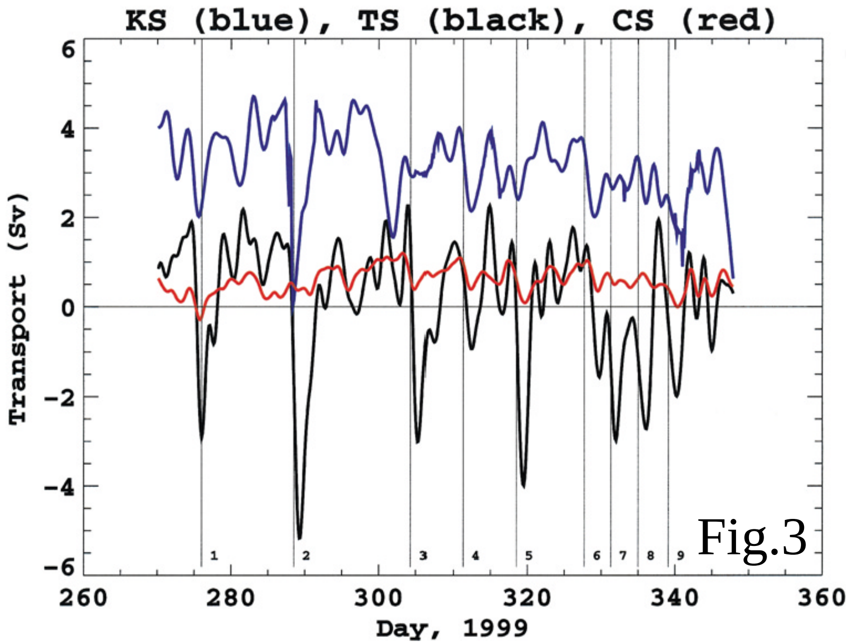


Fig. 3. Transports as a function of time (positive for flow to the north and east) are shown for the Korea Strait (blue line), Cheju Strait (red line), and Taiwan Strait (black line). Major wind events are marked by the light vertical lines numbered 1–9.

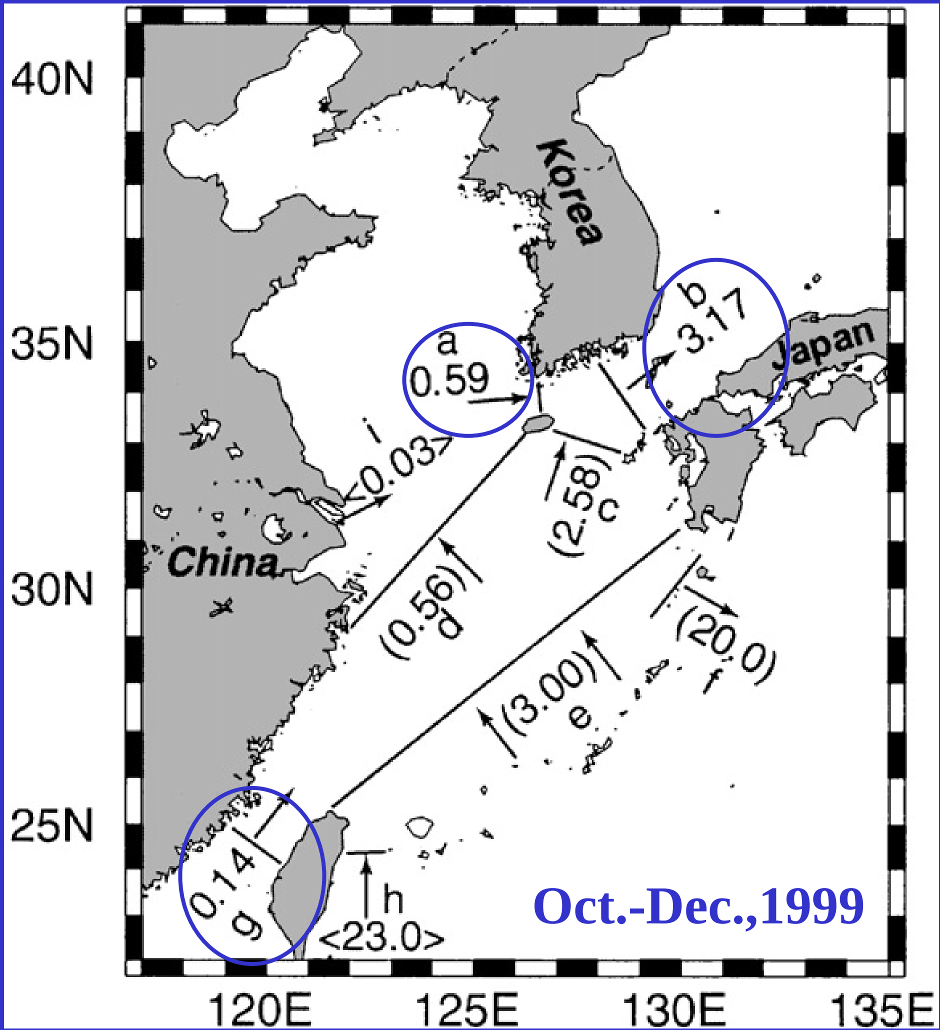


Fig. 5. Measured volume transports (a,b, and g), inferred (in parentheses) volume transports (c, d, e, and f), and climatological (in brackets) volume transports (h) and river outflows (i) are shown for October–December, 1999. Units are Sverdrups (10^6 m^3 s^{-1}).

Teague et al, CSR, 2003

As a annual mean,

Tsushima St.: ~2.7 Sv

Taiwan St.:1~2 Sv

Kuroshio onshore flux: ~1 Sv

(Autumn: ~3 Sv)

1) What is the seasonal variation of Kuroshio onshore flux?

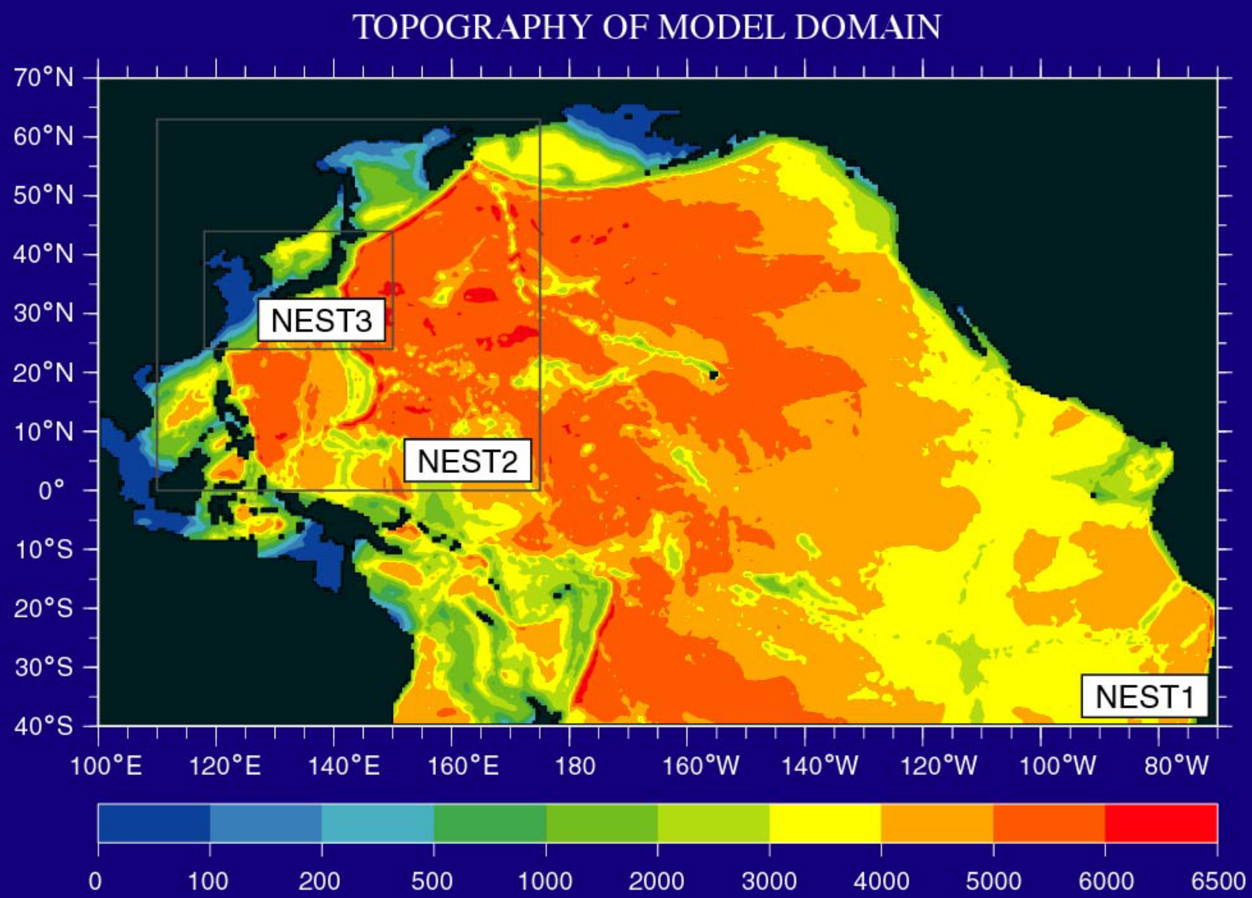
2) What is the spatial distribution of Kuroshio onshore flux?

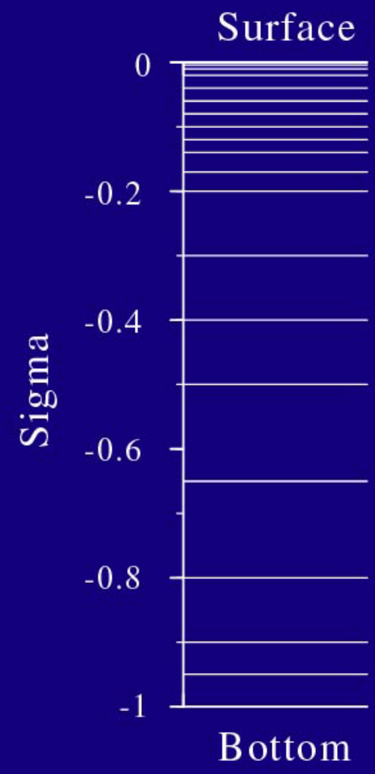
3) What is the role of Kuroshio onshore flux in the material transport in the ECS?

→ Examining results of numerical model

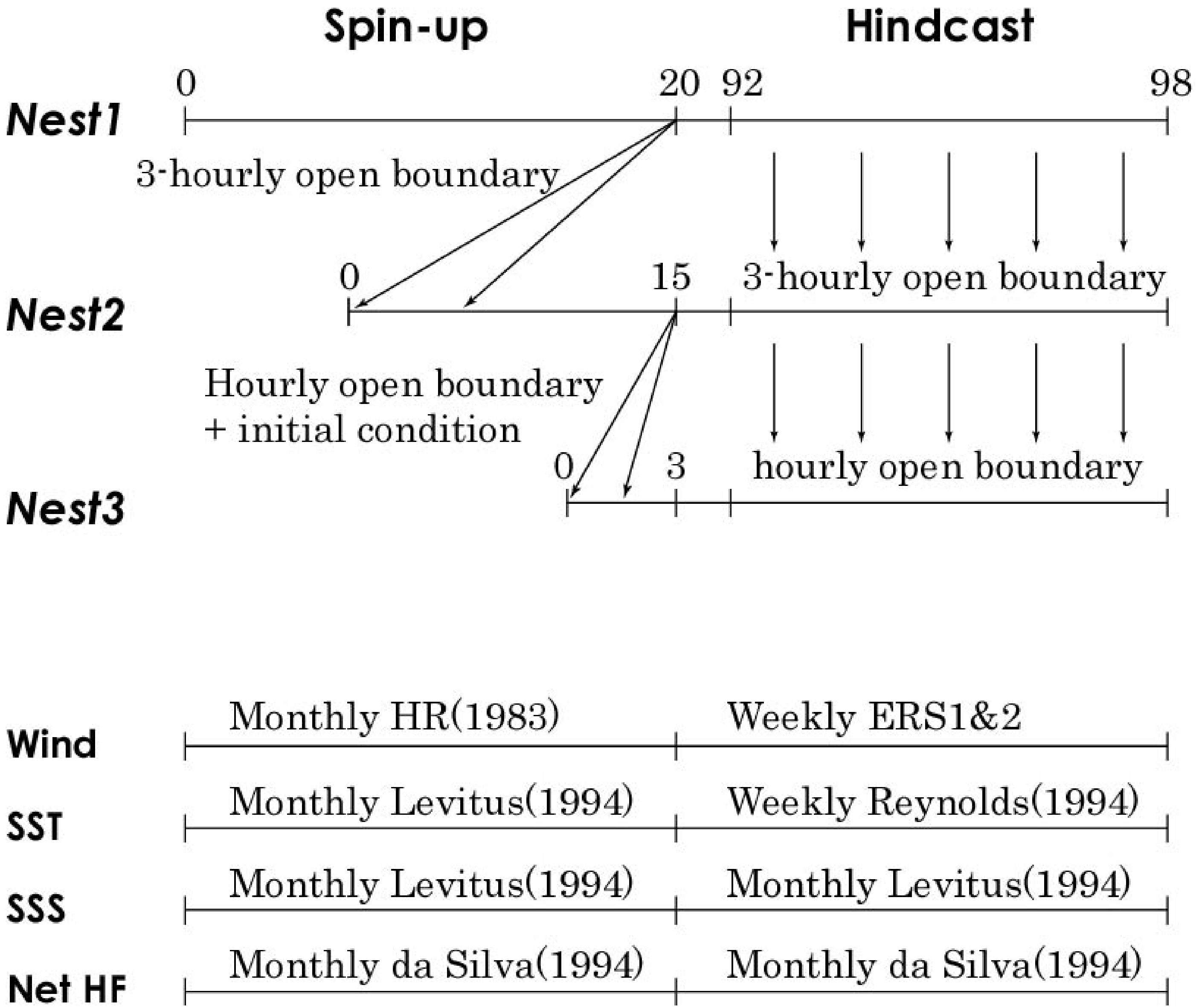
● Ocean Model – POM97(Princeton Ocean Model)

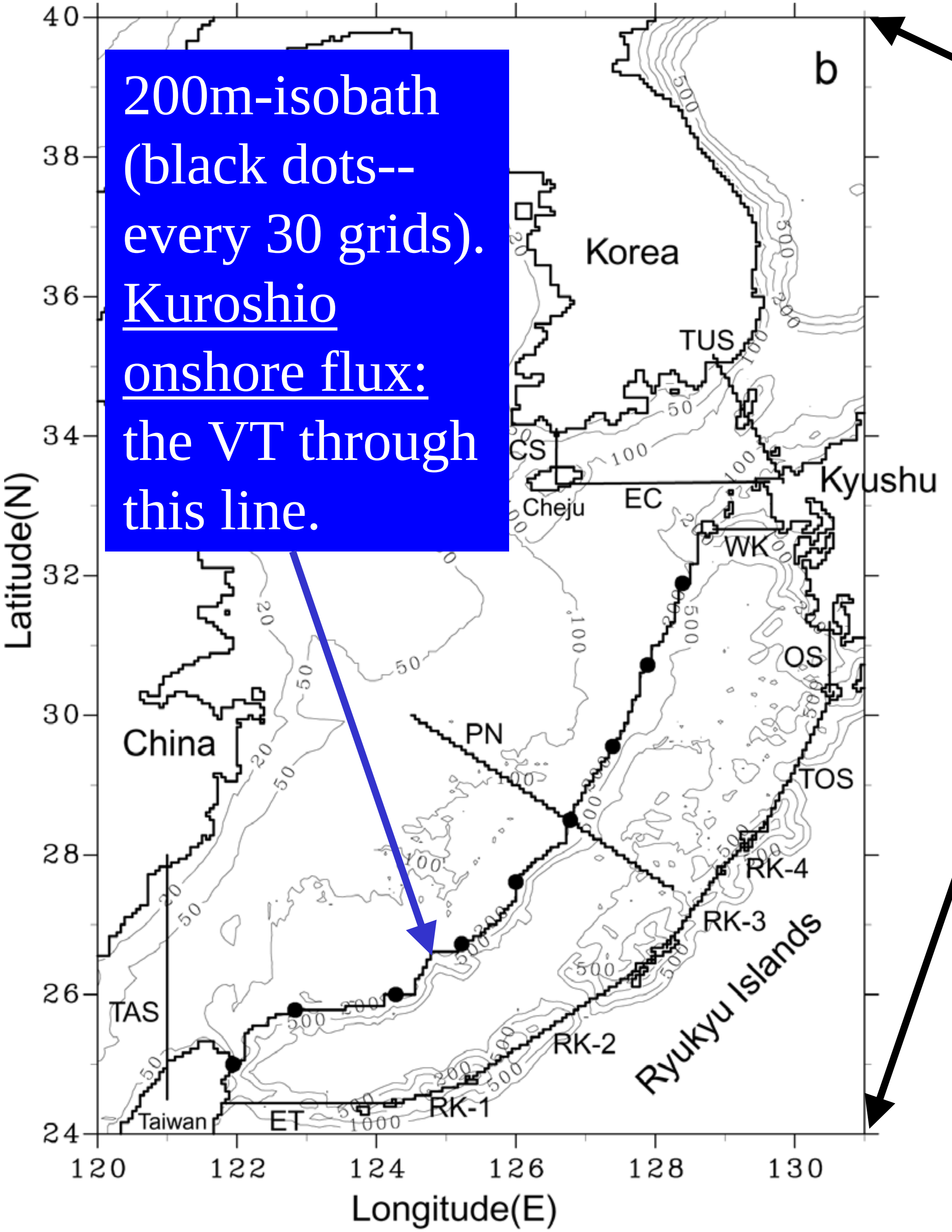
	Region	Grid	Forcing(wind/heat)		Lateral B.C	I.C.
Nest1	40S -70N/ 100E -70W	1/2 deg.	HR wind(1983) Da Silva(1994)	ERS1&2 wind Reynolds SST	Closed	U=V= η = 0 Levitus(1994)
Nest2	0 -63N 110 -175E	1/6 deg.	ibid.	ibid.	From Nest1	ibid.
Nest3	24-44N 118 -150E	1/18 deg.	ibid.	ibid.	From Nest2	From Nest2

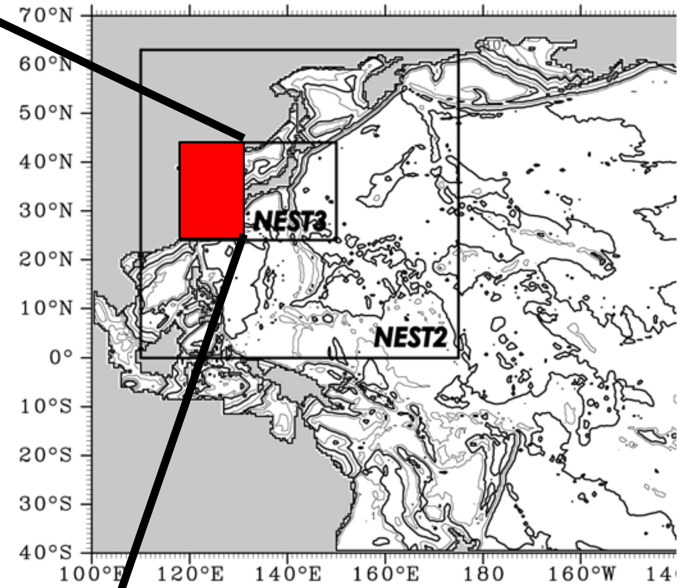




Guo et al., JPO, 2003.


Spin-up
Hindcast
0
20
92
98
Nest1
3-hourly open boundary
0
15
3-hourly open boundary
Nest2
Hourly open boundary
+ initial condition
0
3
hourly open boundary
Nest3
Monthly HR(1983)
Weekly ERS1&2
Wind
Monthly Levitus(1994)
Weekly Reynolds(1994)
SST
Monthly Levitus(1994)
Monthly Levitus(1994)
SSS
Monthly da Silva(1994)
Monthly da Silva(1994)
Net HF





TAS:Taiwan Strait

ET: East of Taiwan

RK-1~4:four sections

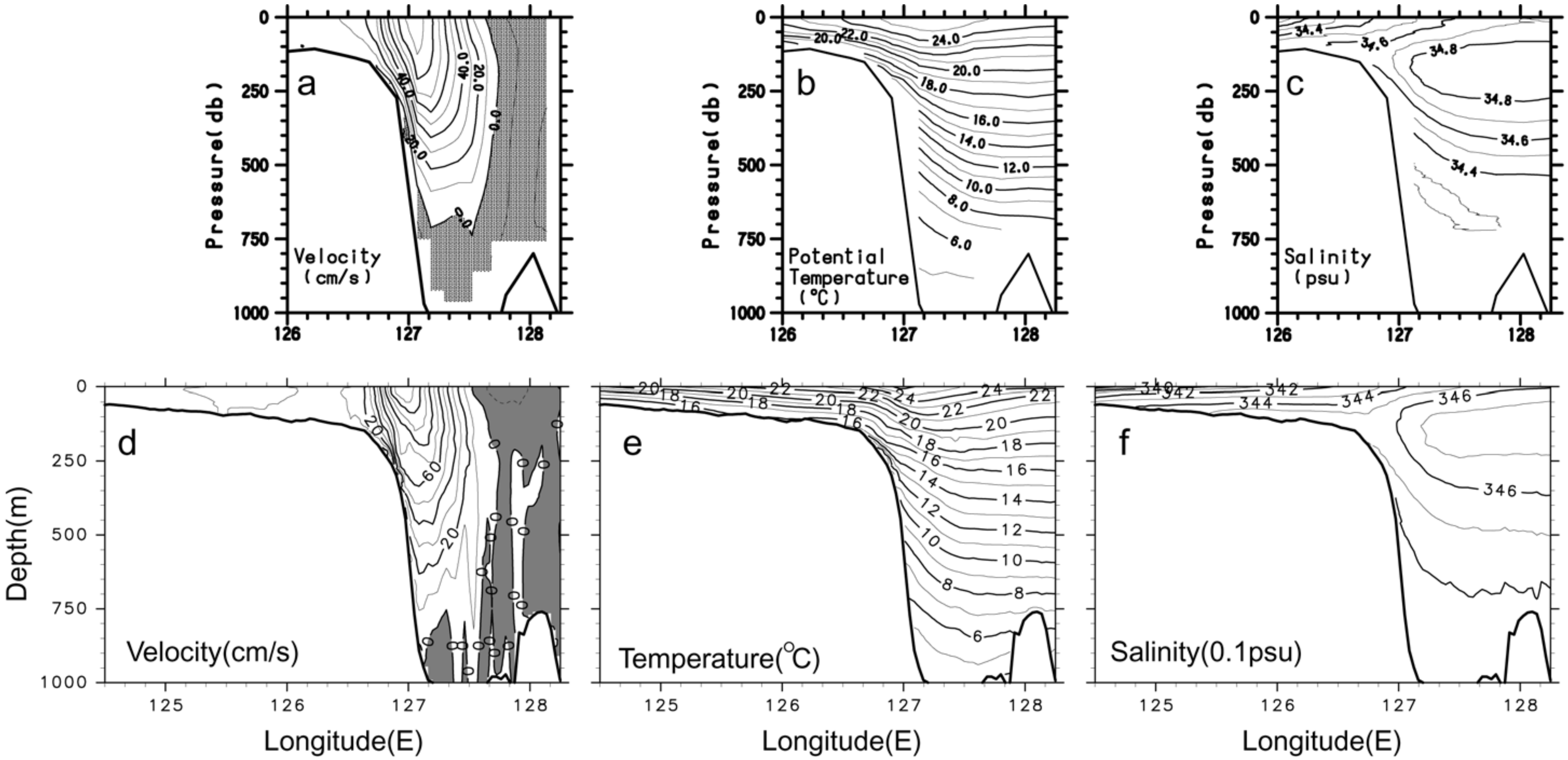
TOS: Tokara Strait

OS: Osumi Strait

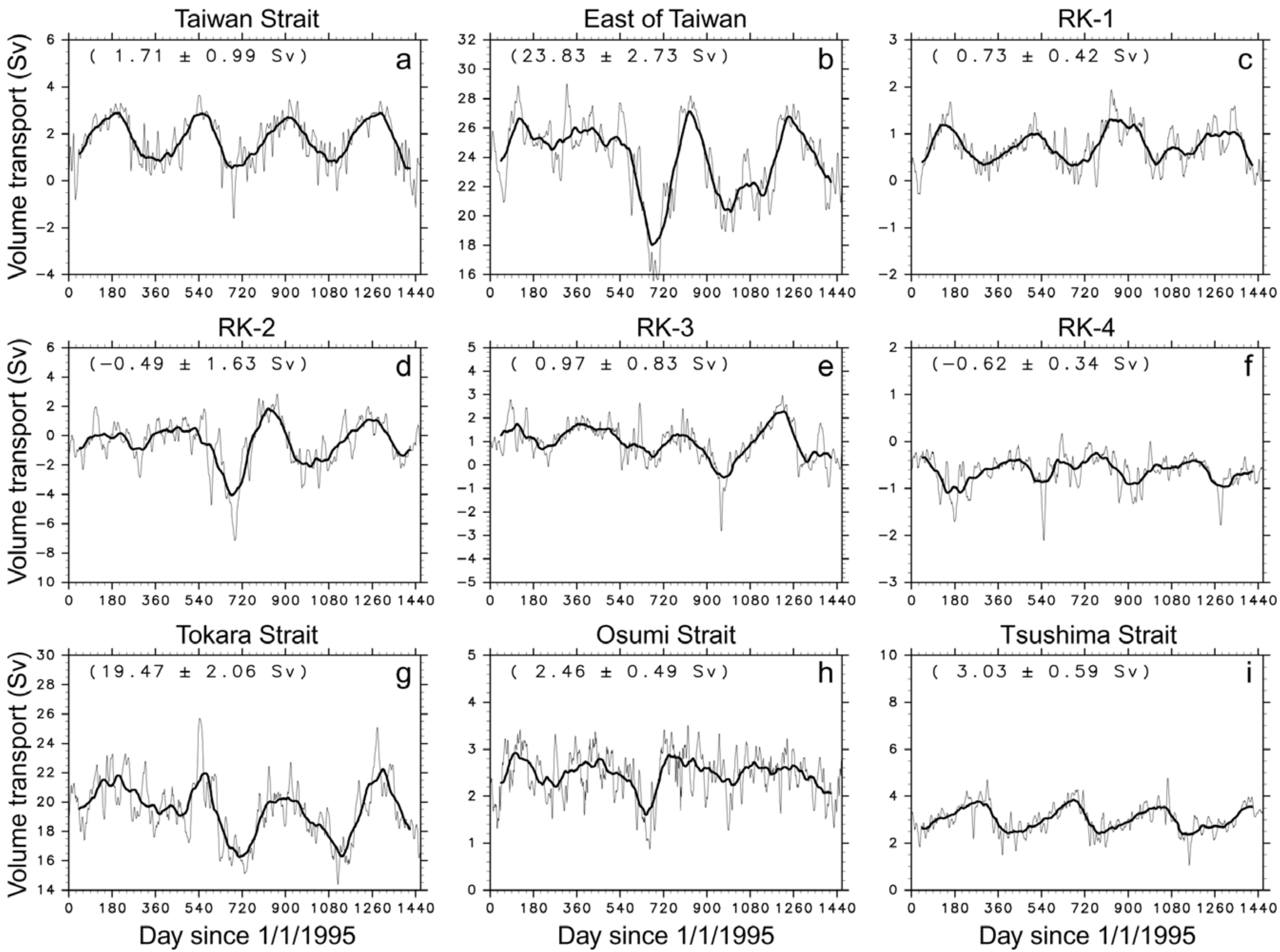
EC: East of Cheju

CS: Cheju Strait

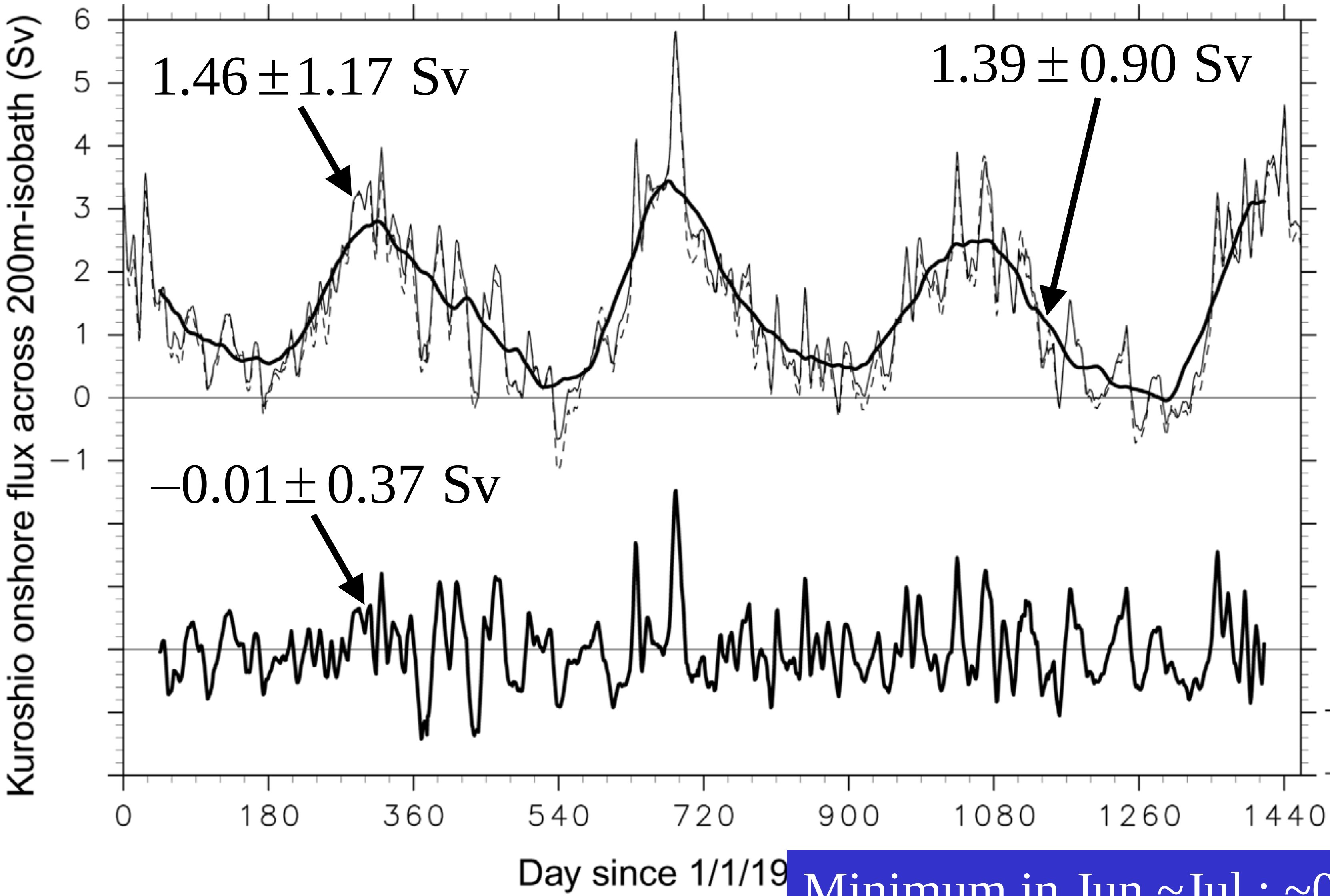
TUS: Tsushima Strait



Observed data at PN-line (upper panels) for along-shelf geostrophic velocity referred to 100 m ADCP current data, potential temperature and salinity, and the corresponding model results of NEST3 (lower panels). The observed potential temperature and salinity data are averaged from 1973 to 1993; the model results are from 1994 to 1998. Regions with negative values of along-shelf velocity are shaded.



Time series of daily volume transport (thin line) and 90-day running mean (thick line). The first and second numbers in the bracket of each panel are the time average and standard deviation, respectively.

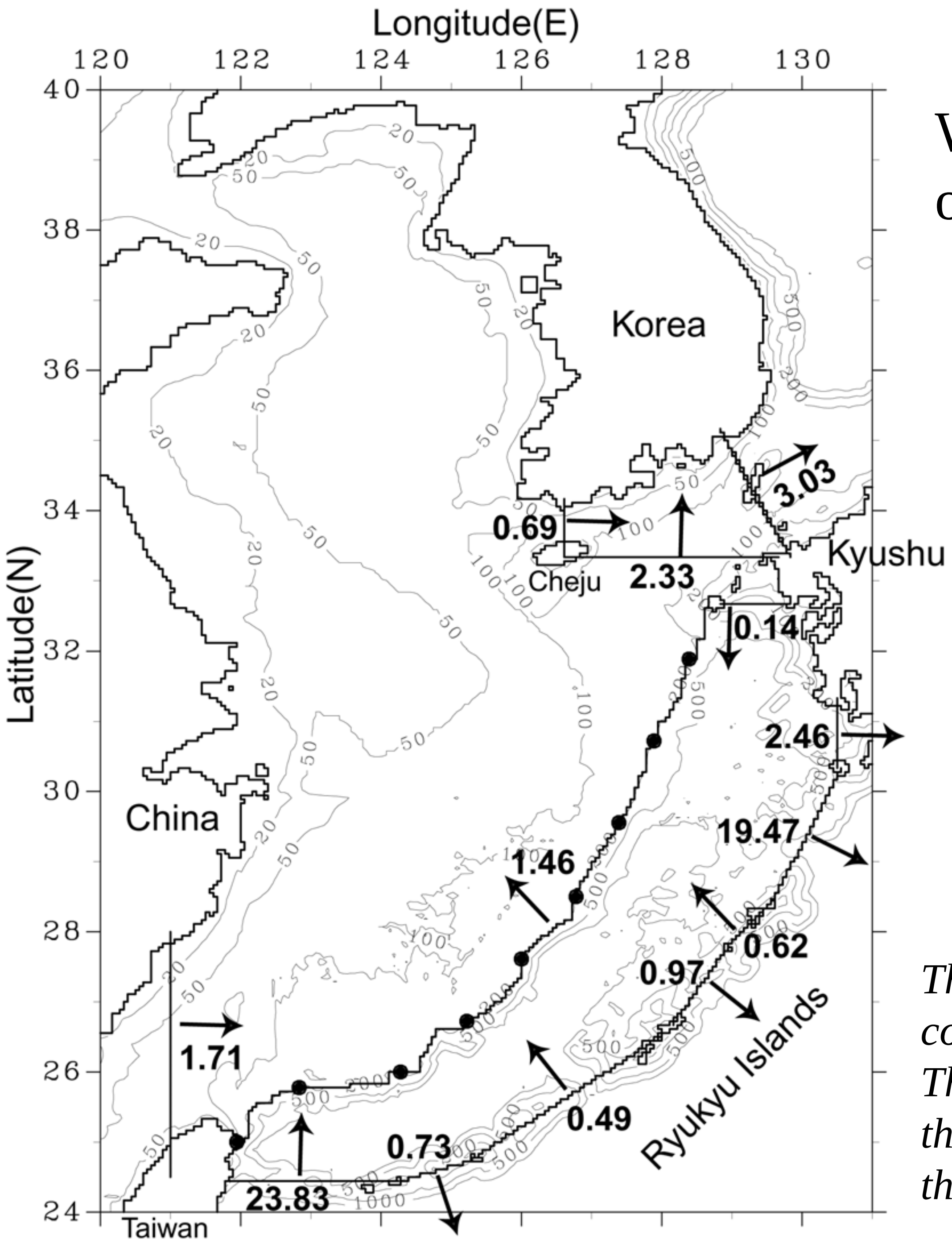


Thin line: *daily KOF;* upper thick line*: 90-day*
thin line: *difference between daily VTs through*
lower thick line: *difference between daily KOF*

Minimum in Jun.~Jul.: ~0.5 Sv

Maximum in Oct.~Nov. :~3Sv

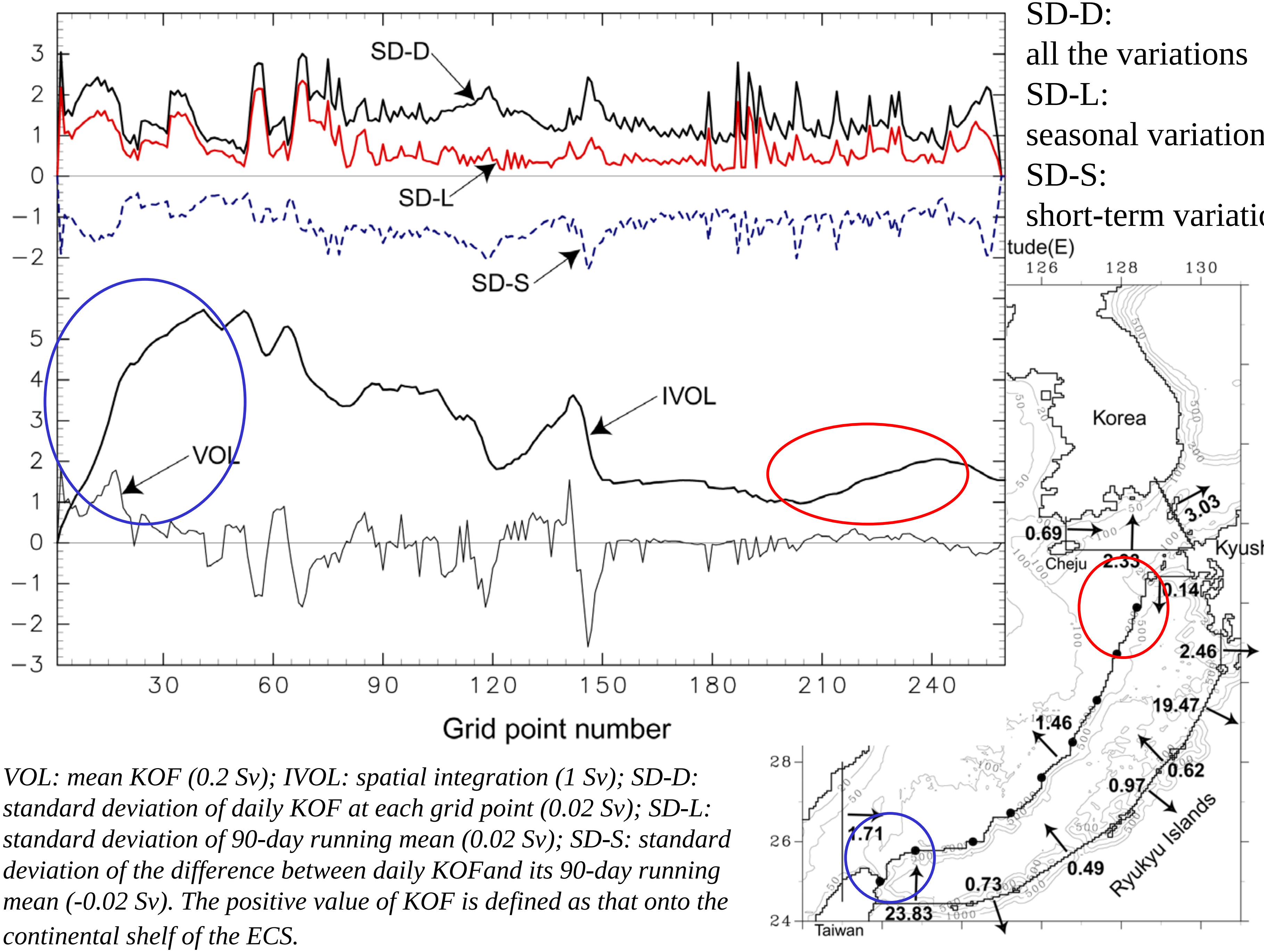
(consistent with Teague et al.,2003).



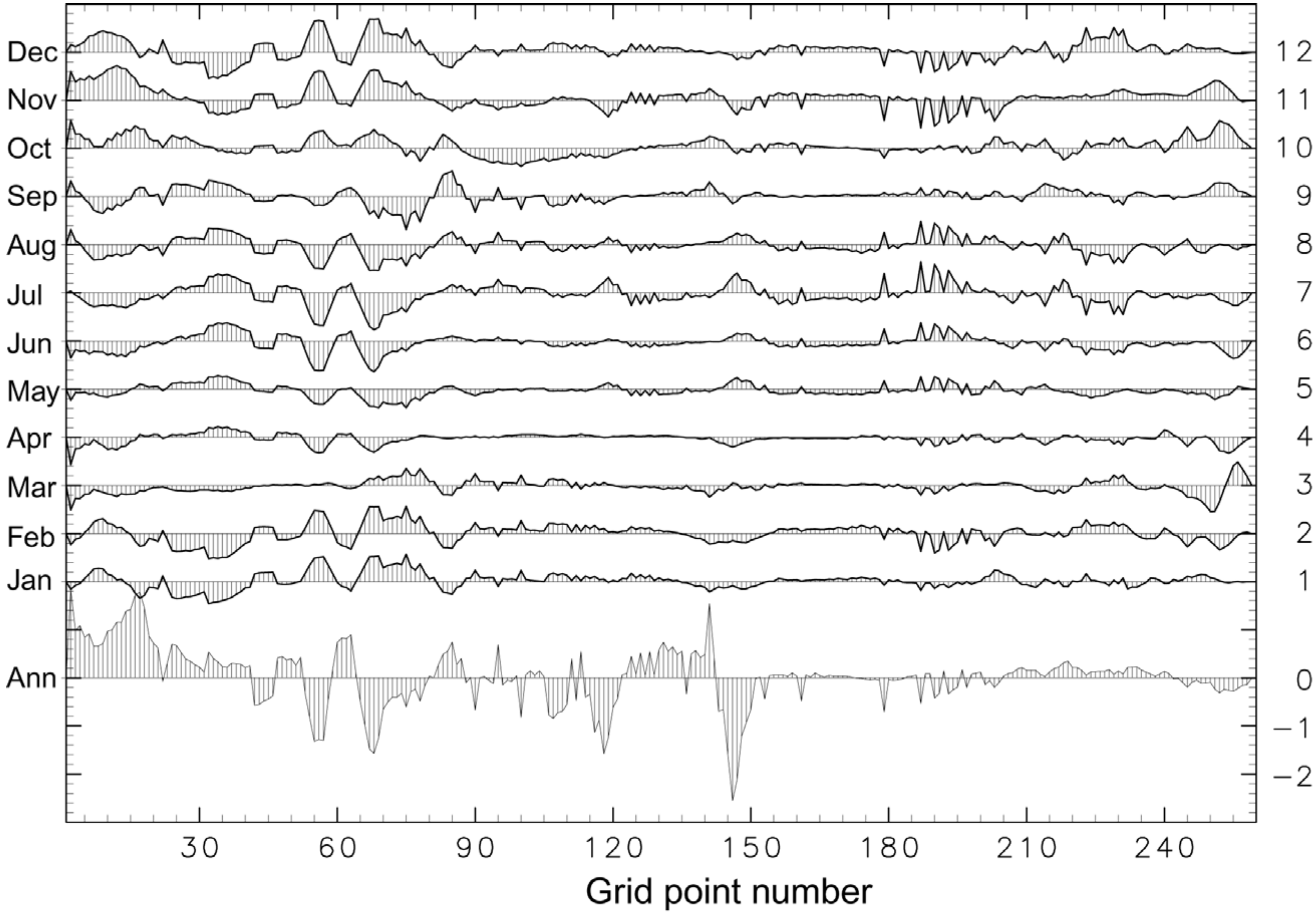
What is the spatial distribution of KOF (1.46Sv)?

The water budgets in the ECS and in the continental shelf of ECS as a mean state. The number shows volume transport (Sv) through each section; the arrow indicates the direction of volume transport.

SD-D:
all the variations
SD-L:
seasonal variations
SD-S:
short-term variations

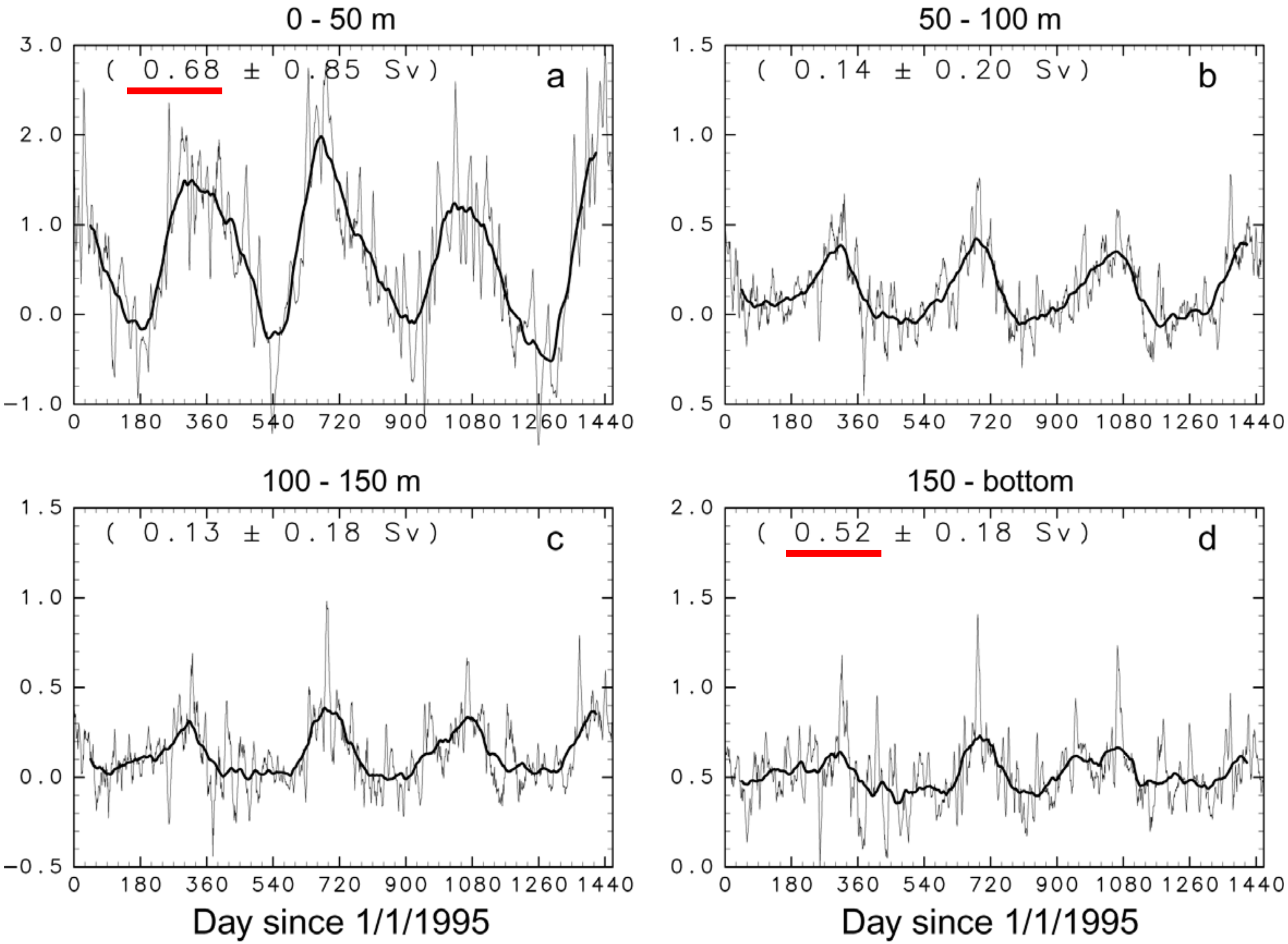


VOL: mean KOF (0.2 Sv); IVOL: spatial integration (1 Sv); SD-D: standard deviation of daily KOF at each grid point (0.02 Sv); SD-L: standard deviation of 90-day running mean (0.02 Sv); SD-S: standard deviation of the difference between daily KOFand its 90-day running mean (-0.02 Sv). The positive value of KOF is defined as that onto the continental shelf of the ECS.



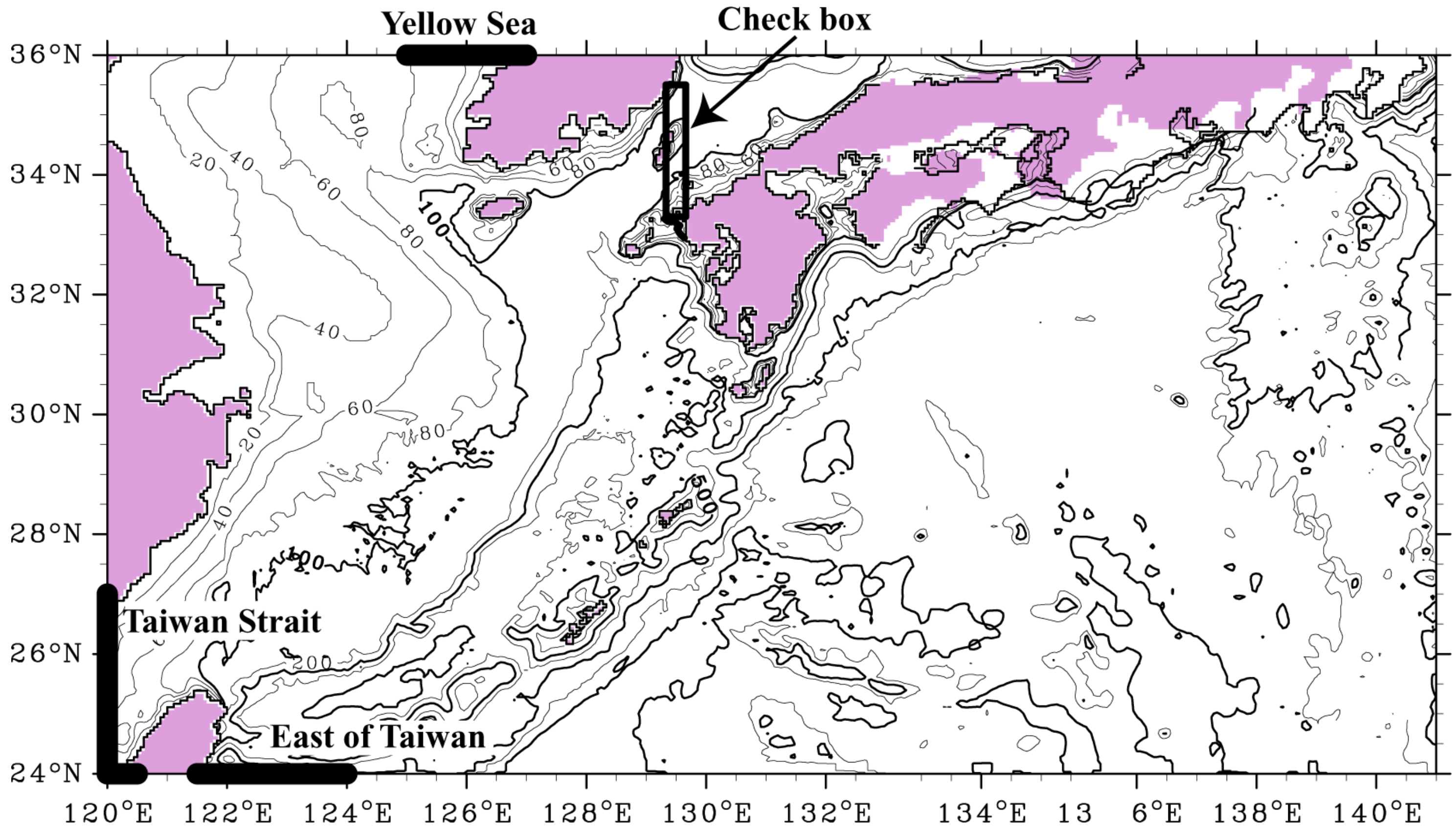
Monthly anomaly of KOF at each grid point of the 200m-isobath (Jan-Dec, unit is 0.1 Sv, origin is shifted to the corresponding number of the month); the temporal average of KOF is also presented for reference (Ann, unit is 0.2 Sv).

Depth dependence of KOF and its variation

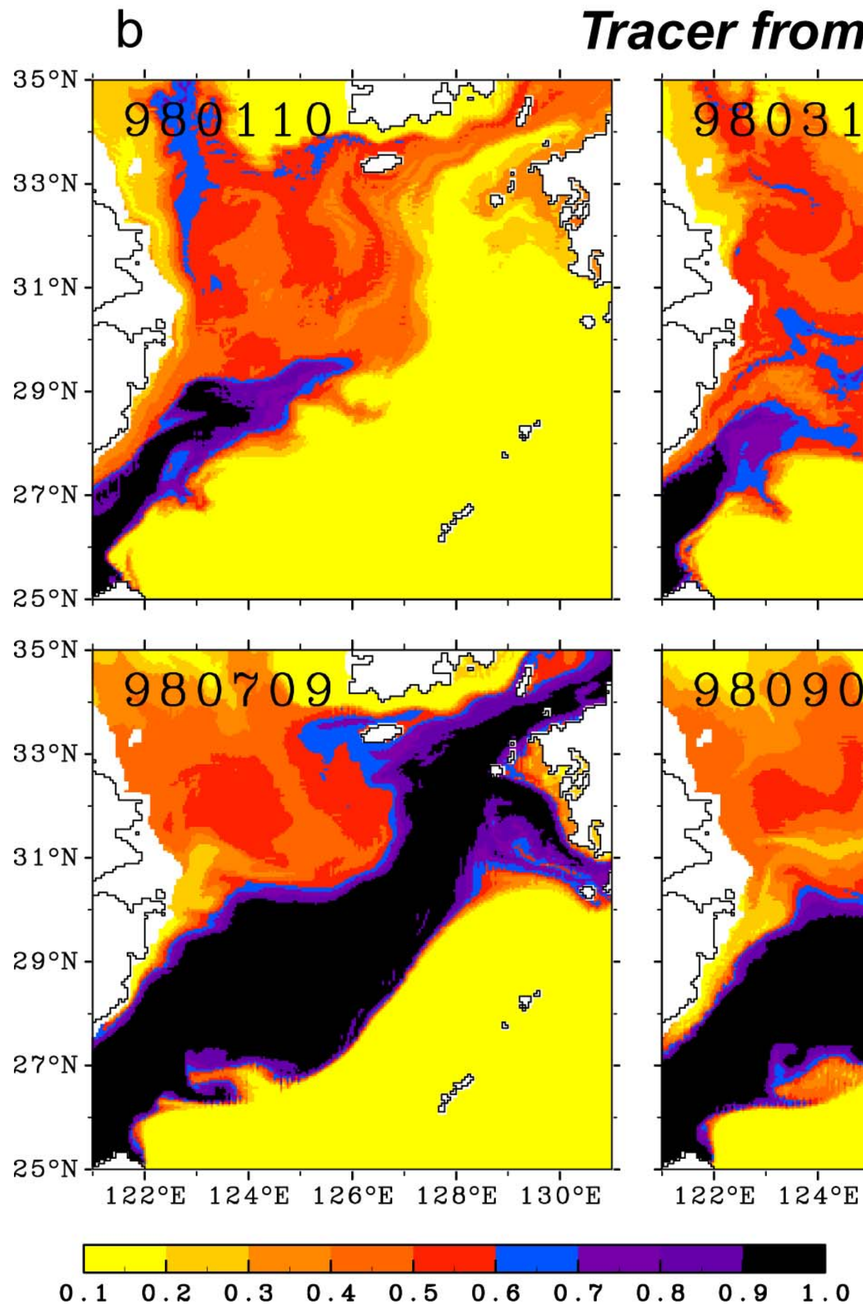


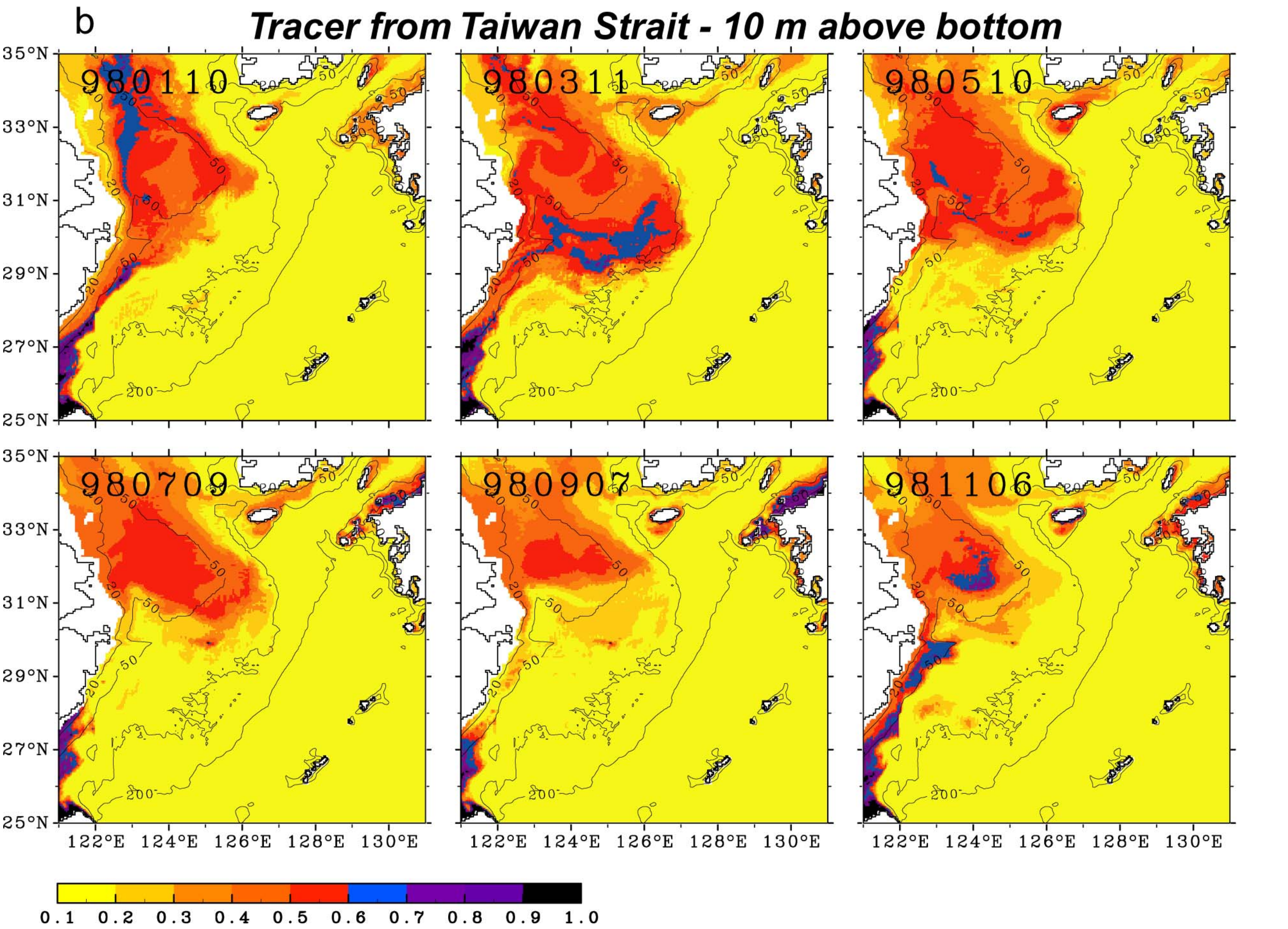
Time series of daily KOF(thin line) and its 90-day running mean (thick line) through the upper layer (a), two middle layers (b and c), and lower layer (d).

Passive tracer experiments

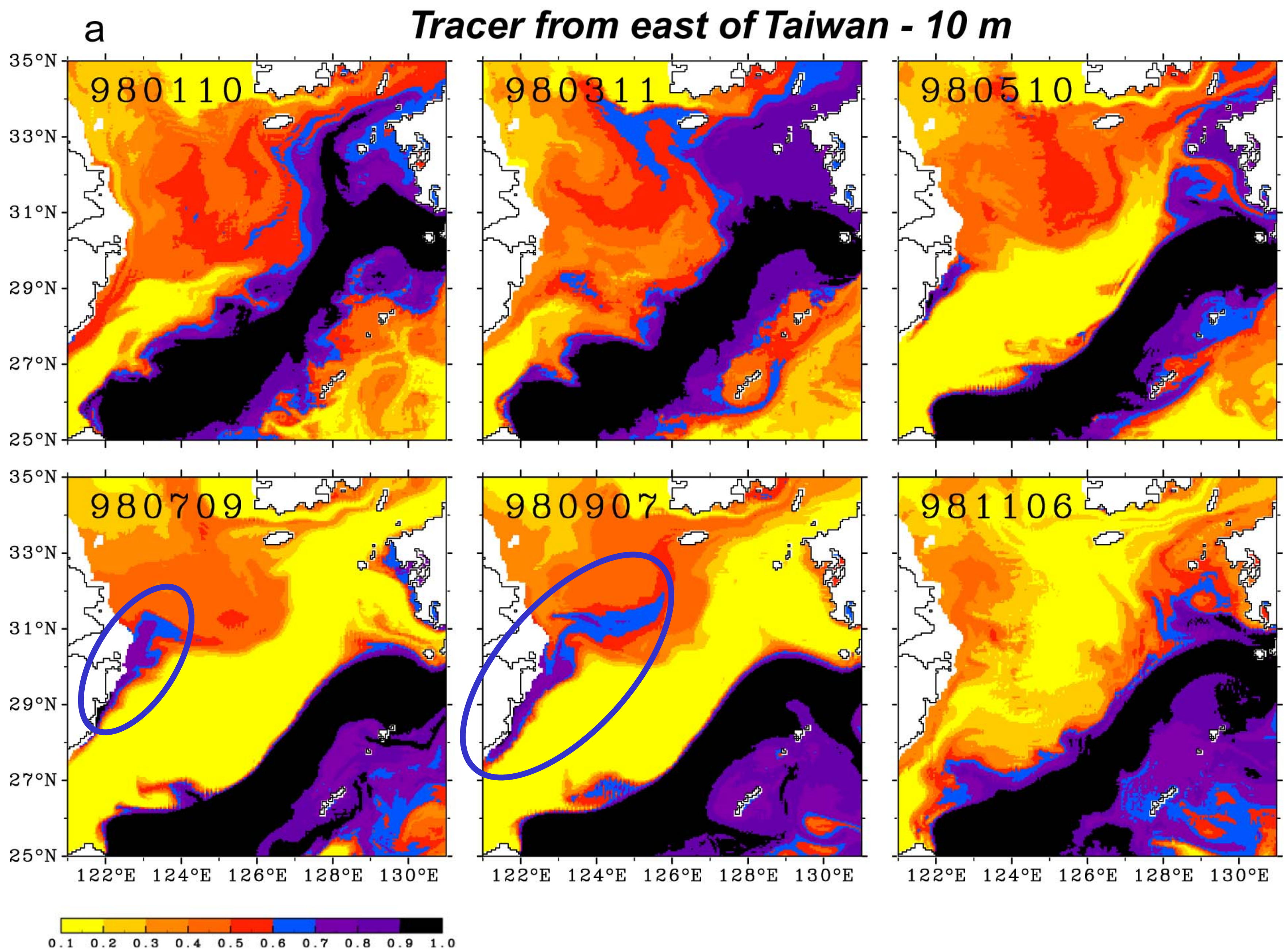


The calculation starts from 1993 with zero initial value over entire model domain and ends in 1998. During the calculation, the value of three tracers is fixed to 1.0 at three places denoted by Taiwan Strait, east of Taiwan and Yellow Sea and fixed to 0 at other places.

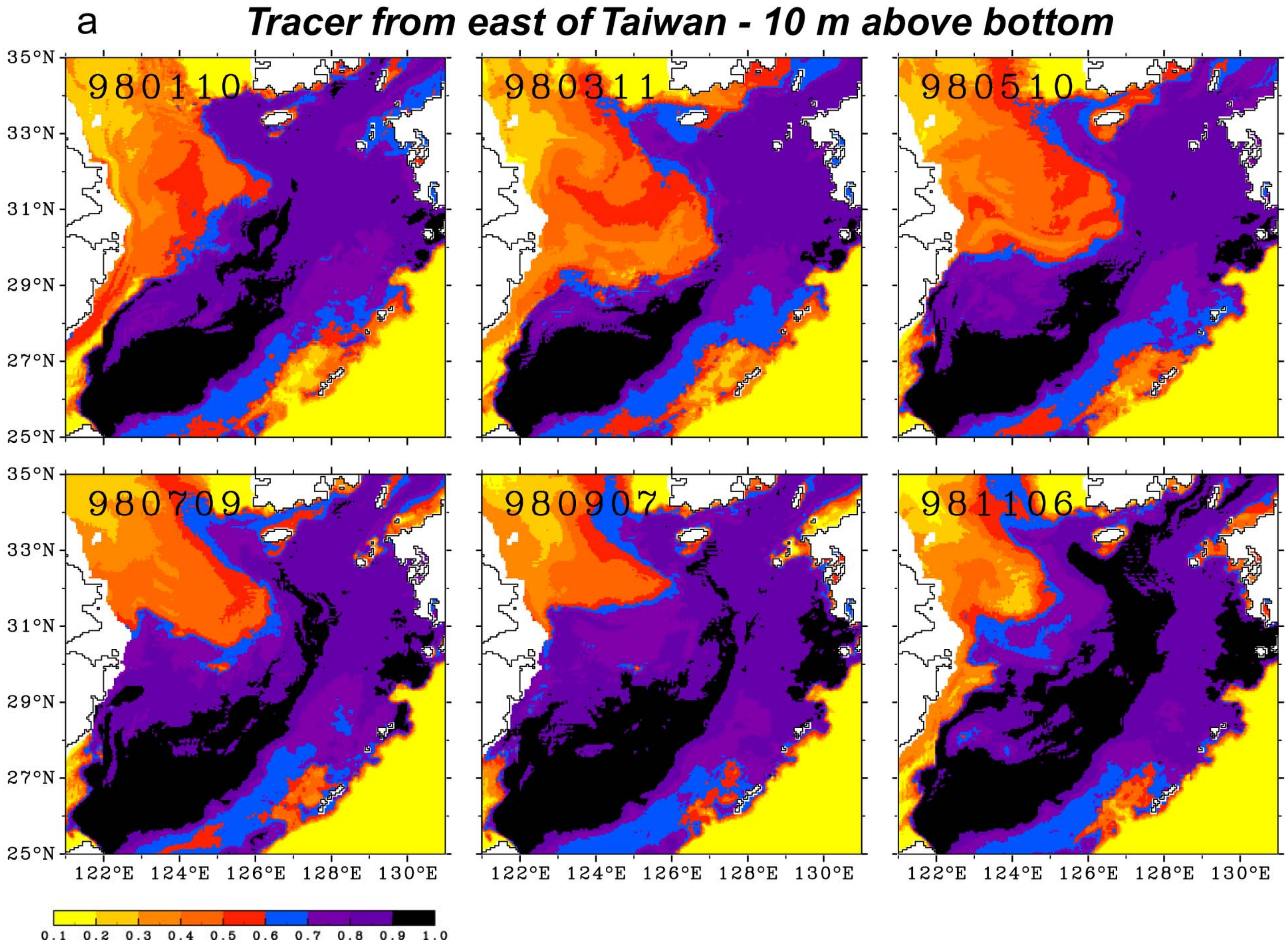

b
Tracer from Taiwan Strait - 10 m
980110
980311
980510
980709
980907
981106
35°N
33°N
31°N
29°N
27°N
25°N
122°E
124°E
126°E
128°E
130°E
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0



b
Tracer from Taiwan Strait - 10 m above bottom
980110
980311
980510
980709
980907
981106
35°N
33°N
31°N
29°N
27°N
25°N
122°E
124°E
126°E
128°E
130°E
20
50
200
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0



a
Tracer from east of Taiwan - 10 m
980110
980311
980510
980709
980907
981106
35°N
33°N
31°N
29°N
27°N
25°N
122°E
124°E
126°E
128°E
130°E
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0


a
Tracer from east of Taiwan - 10 m above bottom
980110
980311
980510
980709
980907
981106
35°N
33°N
31°N
29°N
27°N
25°N
122°E
124°E
126°E
128°E
130°E
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Summary

- KOF has a strong seasonal variation: ~0.5 Sv in summer and ~3 Sv in winter
- KOF has two major sources: northeast of Taiwan and southwest of Kyushu
- KOF has vertical structure: 0.68 Sv for 0-50 m, 0.27 Sv for 50 –150 m, 0.52 for 150 m – bottom
- KOF has strong effects on material transport
- Mechanism: local effects (wind, rivers runoff, heating and cooling) and remote effects (variations in the Kuroshio)

Volume Transport across isobaths

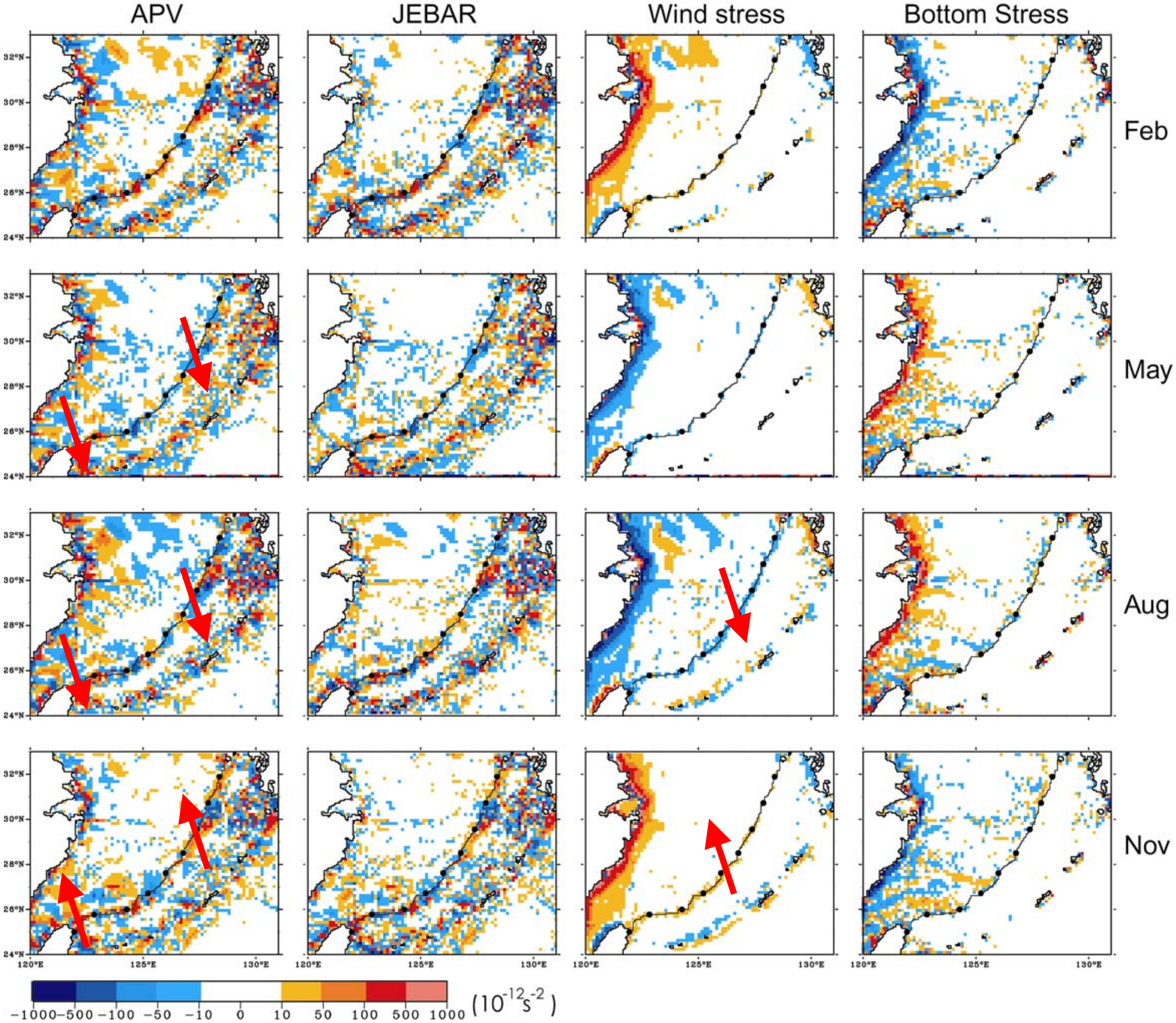
$$\frac{\partial}{\partial t} curl_z\left(\frac{\vec{M}}{H}\right) + \vec{M}\bullet\nabla\left(\frac{f}{H}\right) =$$

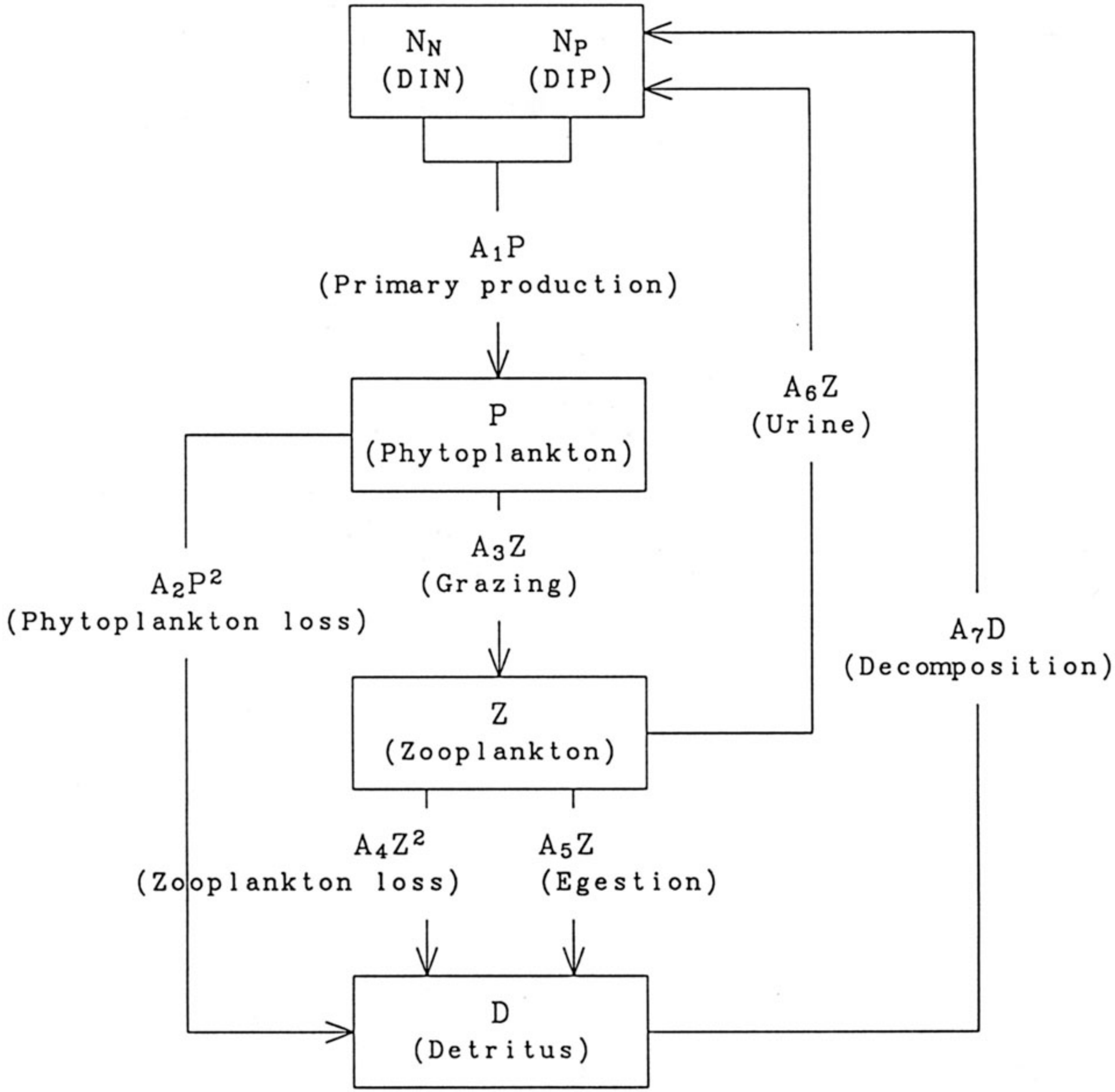
$$J(\chi, H^{-1}) + curl_z\left(\frac{\vec{\tau}_a}{\rho_0 H}\right) - curl_z\left(\frac{\vec{\tau}_b}{\rho_0 H}\right) + curl_z\left(\frac{\vec{D}}{H}\right) - curl_z\left(\frac{\vec{A}}{H}\right)$$

$$\Big\downarrow$$

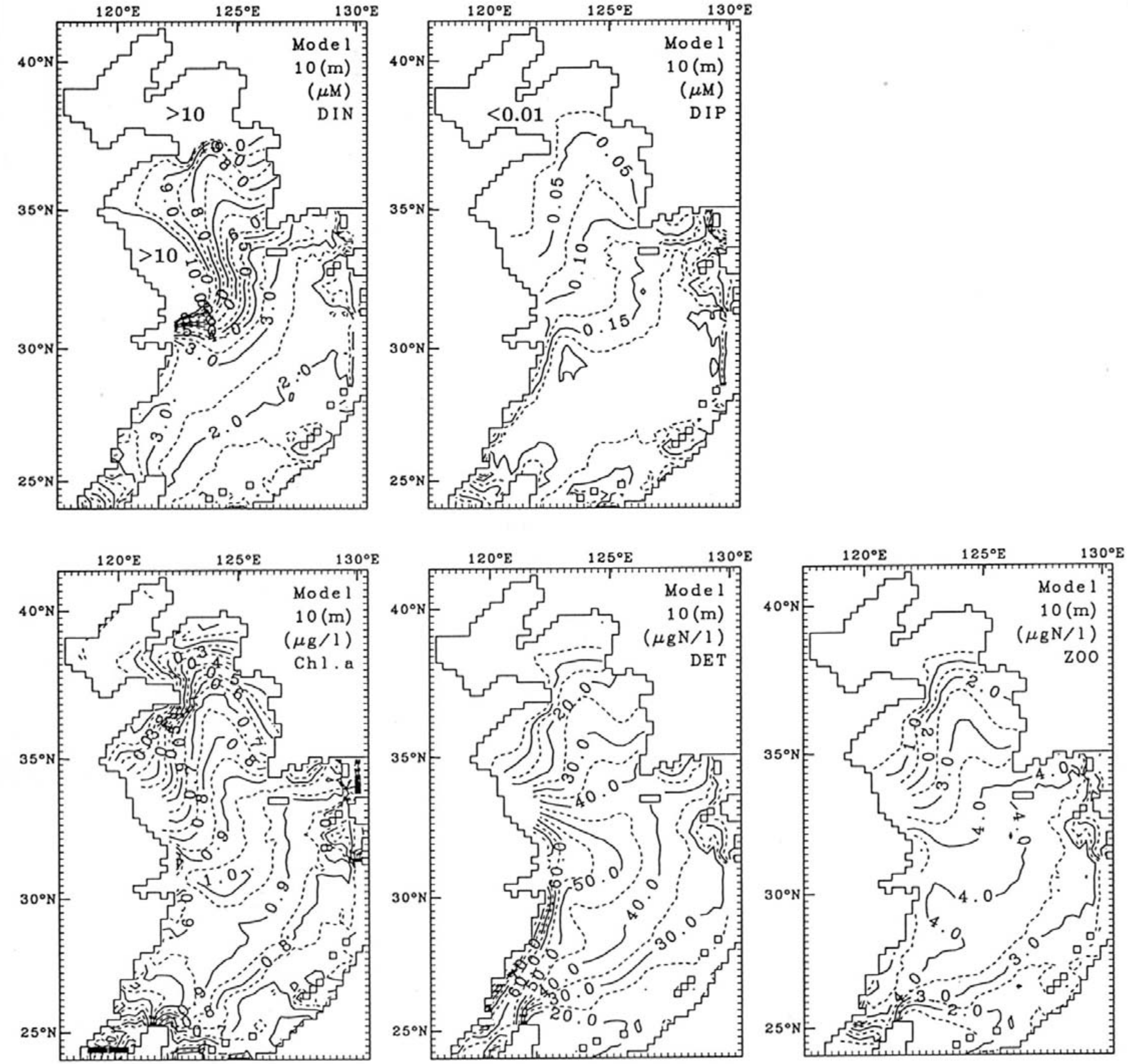
$$\vec{M}\bullet\nabla\left(\frac{f}{H}\right) = J(\chi, H^{-1}) + curl_z\left(\frac{\vec{\tau}_a}{\rho_0 H}\right) - curl_z\left(\frac{\vec{\tau}_b}{\rho_0 H}\right)$$

Anomaly of four terms

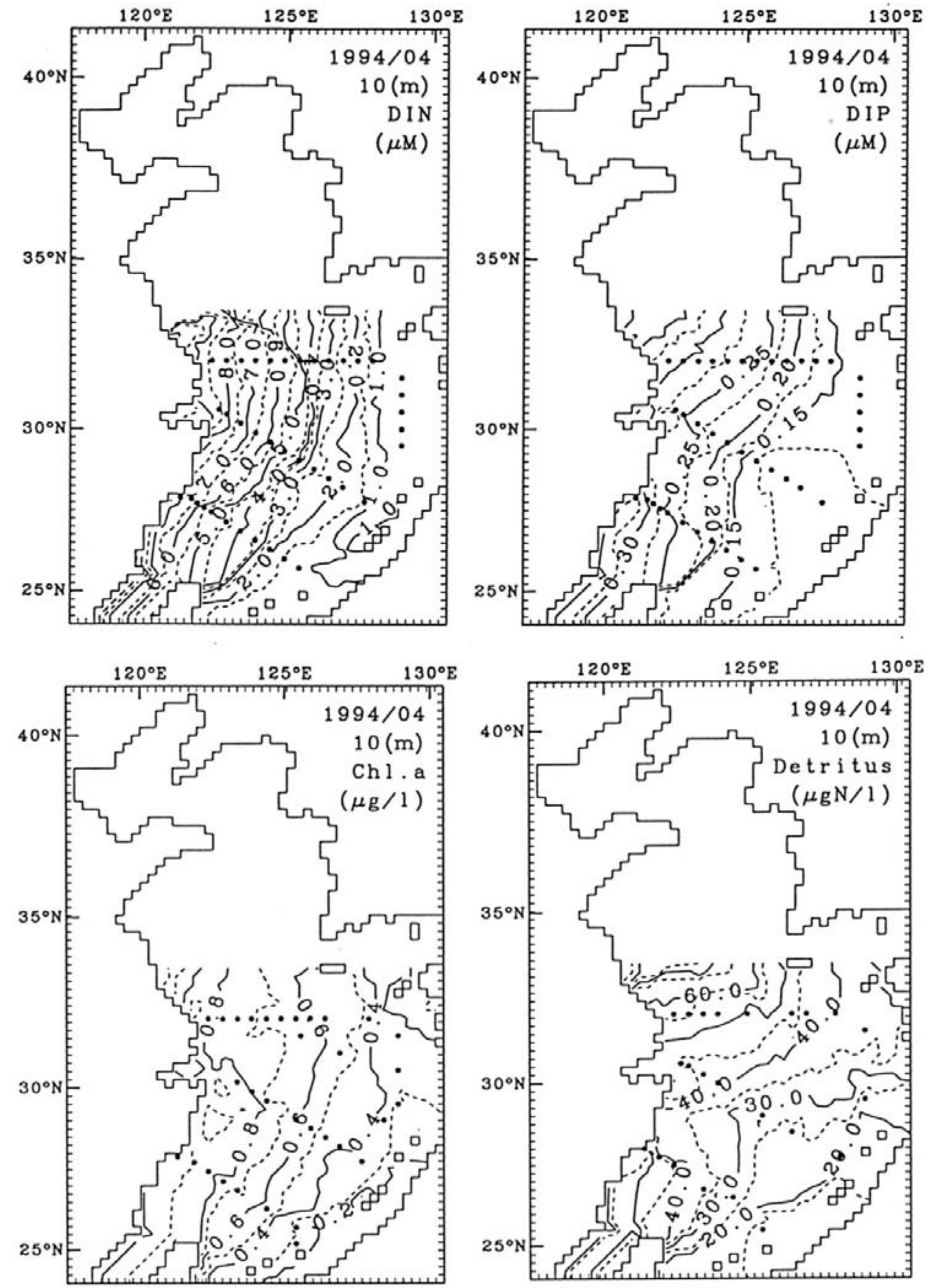




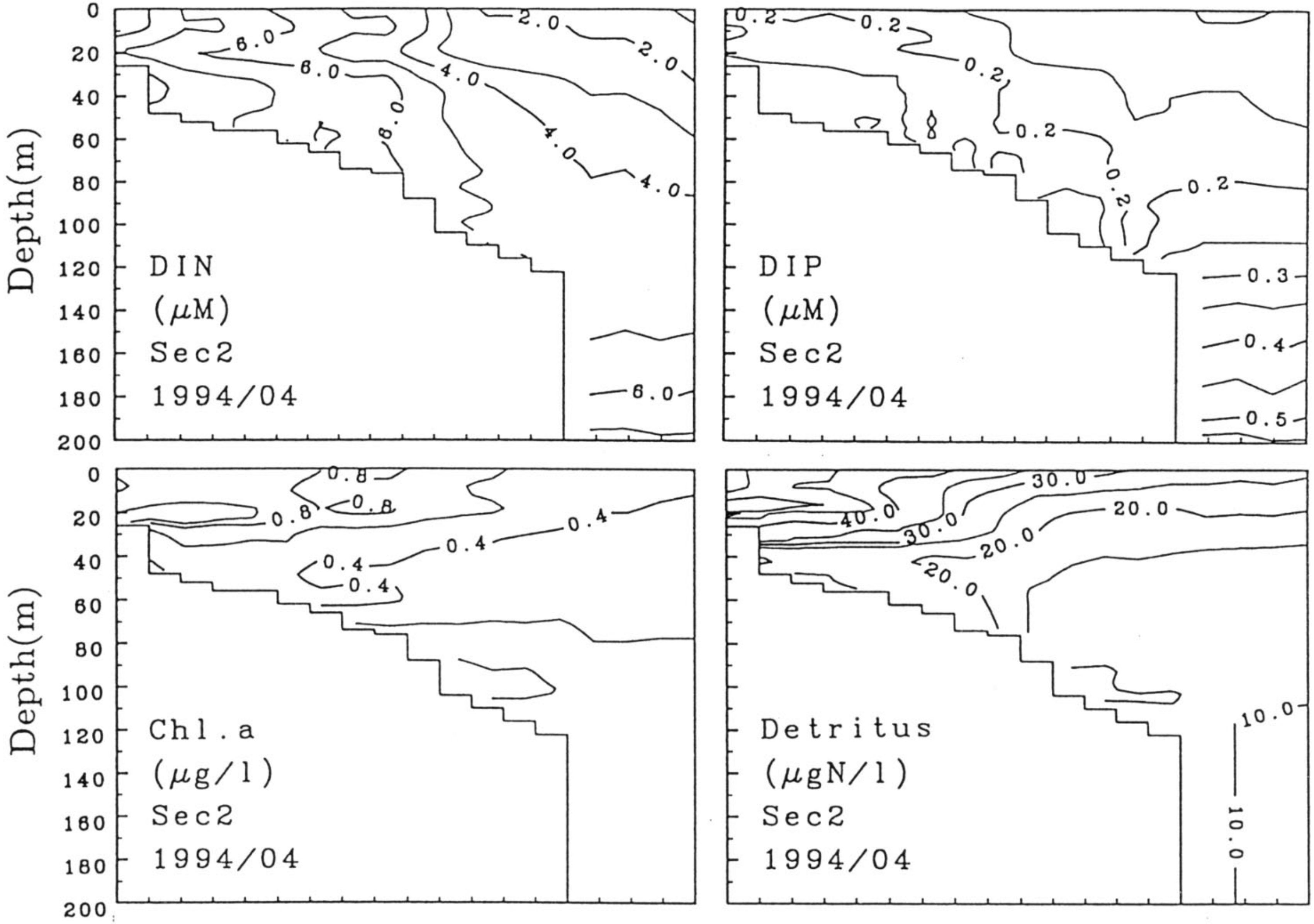
N_N (DIN)
N_P (DIP)
A_1P (Primary production)
P (Phytoplankton)
A_6Z (Urine)
A_2P^2 (Phytoplankton loss)
A_3Z (Grazing)
A_7D (Decomposition)
Z (Zooplankton)
A_4Z^2 (Zooplankton loss)
A_5Z (Egestion)
D (Detritus)



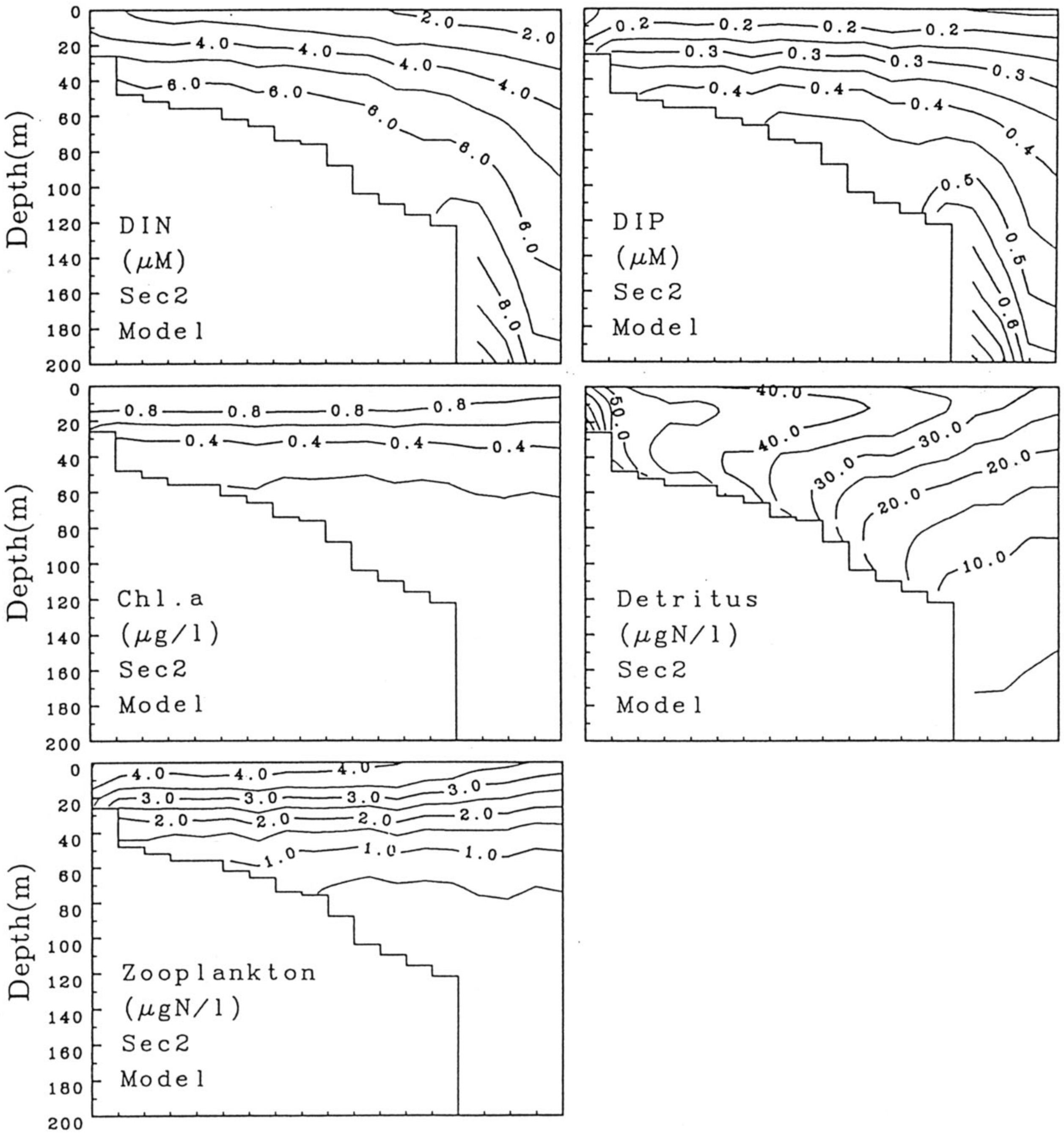
Model
10 (m)
(μM)
DIN
>10
Model
10 (m)
(μM)
DIP
<0.01
Model
10 (m)
(μg/l)
Chl.a
Model
10 (m)
(μgN/l)
DET
Model
10 (m)
(μgN/l)
ZOO
120°E
125°E
130°E
40°N
35°N
30°N
25°N

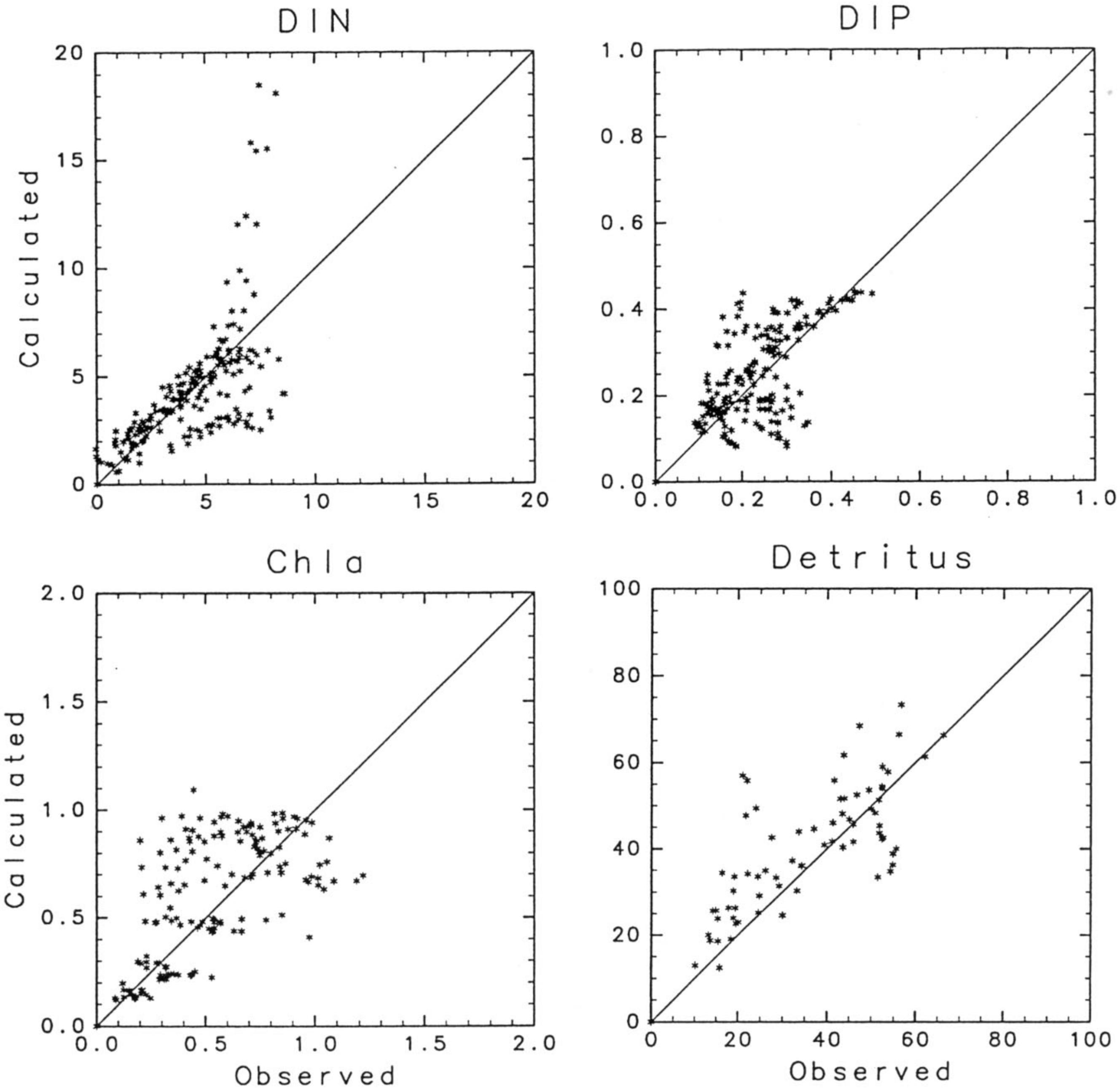


120°E
125°E
130°E
40°N
35°N
30°N
25°N
1994/04
10(m)
DIN
(μM)
1994/04
10(m)
DIP
(μM)
1994/04
10(m)
Chl.a
(μg/l)
1994/04
10(m)
Detritus
(μgN/l)



Depth(m)
DIN
(μM)
Sec2
1994/04
DIP
(μM)
Sec2
1994/04
Chl.a
(μg/l)
Sec2
1994/04
Detritus
(μgN/l)
Sec2
1994/04


Depth(m)
0
20
40
60
80
100
120
140
160
180
200
DIN
(μM)
Sec2
Model
2.0
4.0
6.0
8.0
DIP
(μM)
Sec2
Model
0.2
0.3
0.4
0.5
0.6
Chl.a
(μg/l)
Sec2
Model
0.8
0.4
Detritus
(μgN/l)
Sec2
Model
50.0
40.0
30.0
20.0
10.0
Zooplankton
(μgN/l)
Sec2
Model
4.0
3.0
2.0
1.0

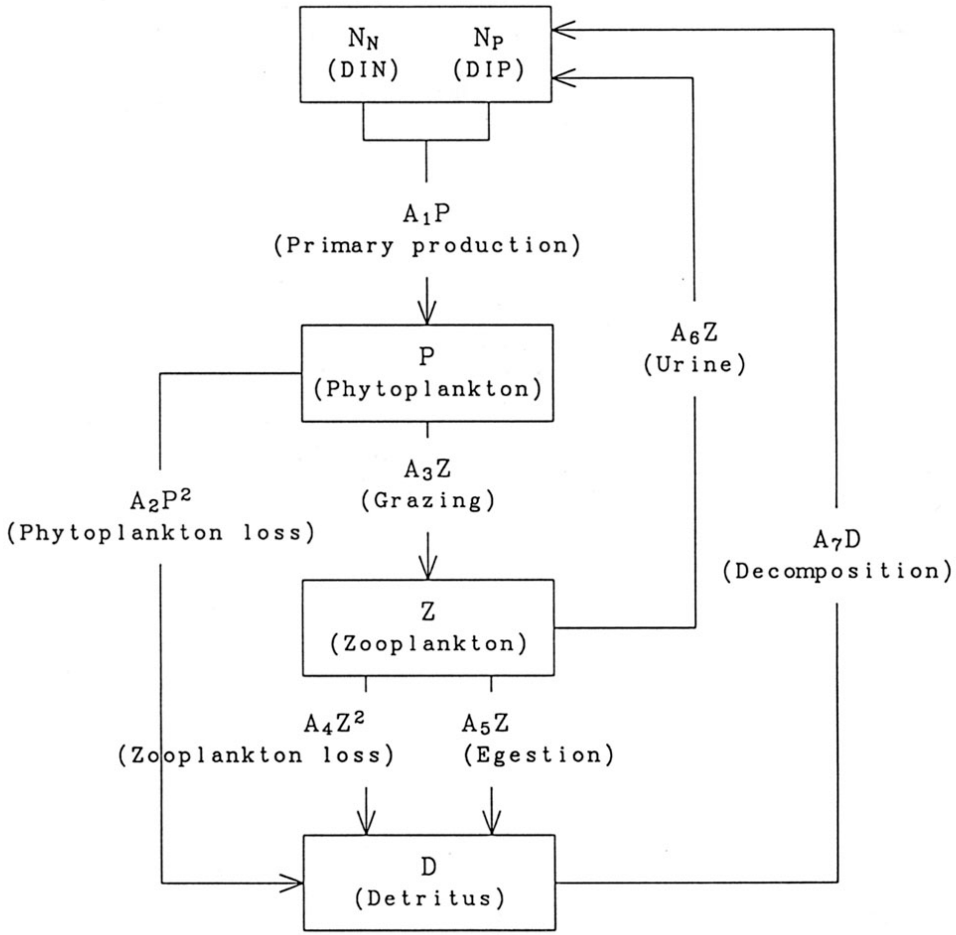


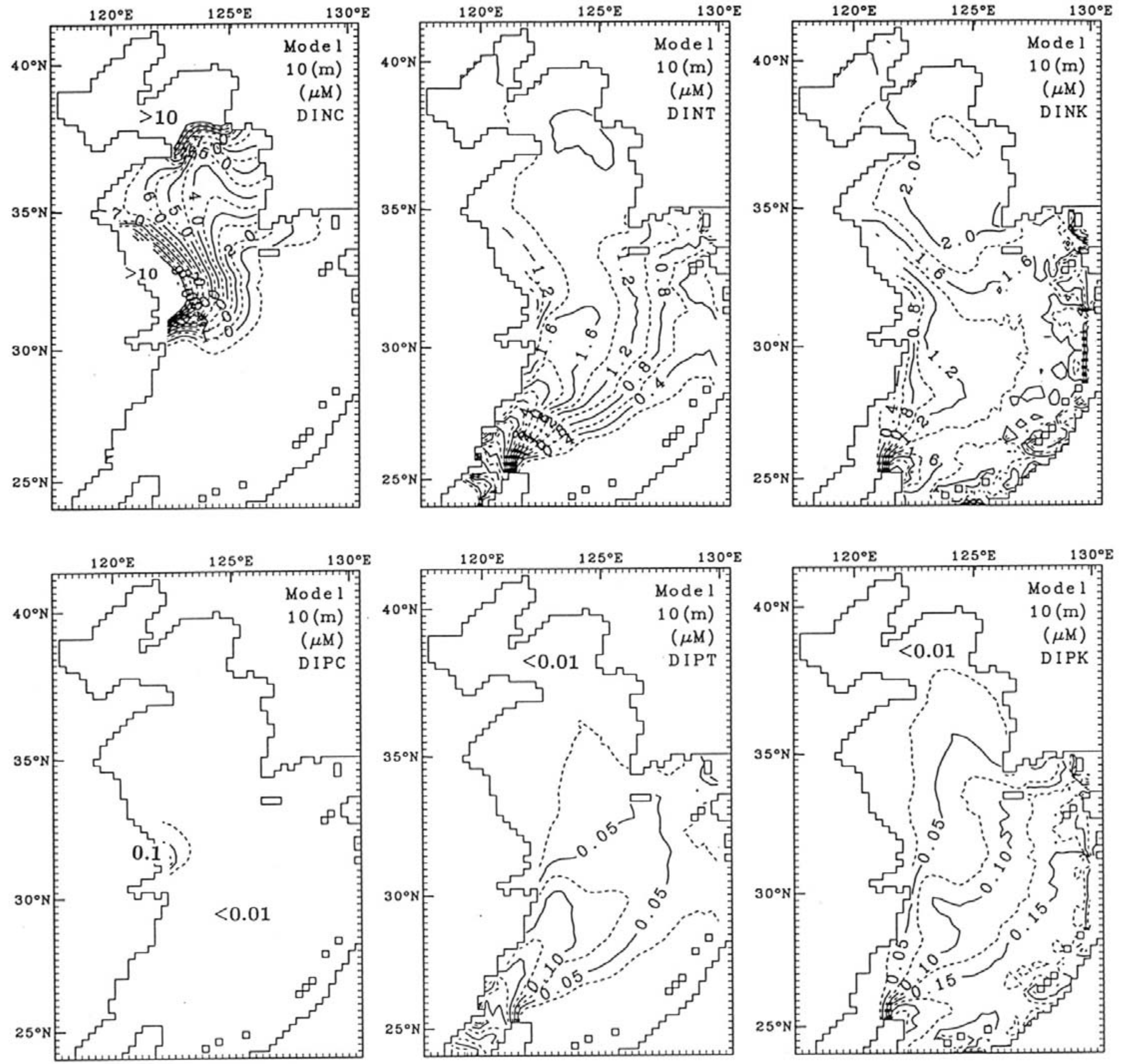
DIN
DIP
Chla
Detritus
Calculated
Calculated
Observed
Observed
0
5
10
15
20
0.0
0.2
0.4
0.6
0.8
1.0
0.5
1.5
2.0
40
60
80
100

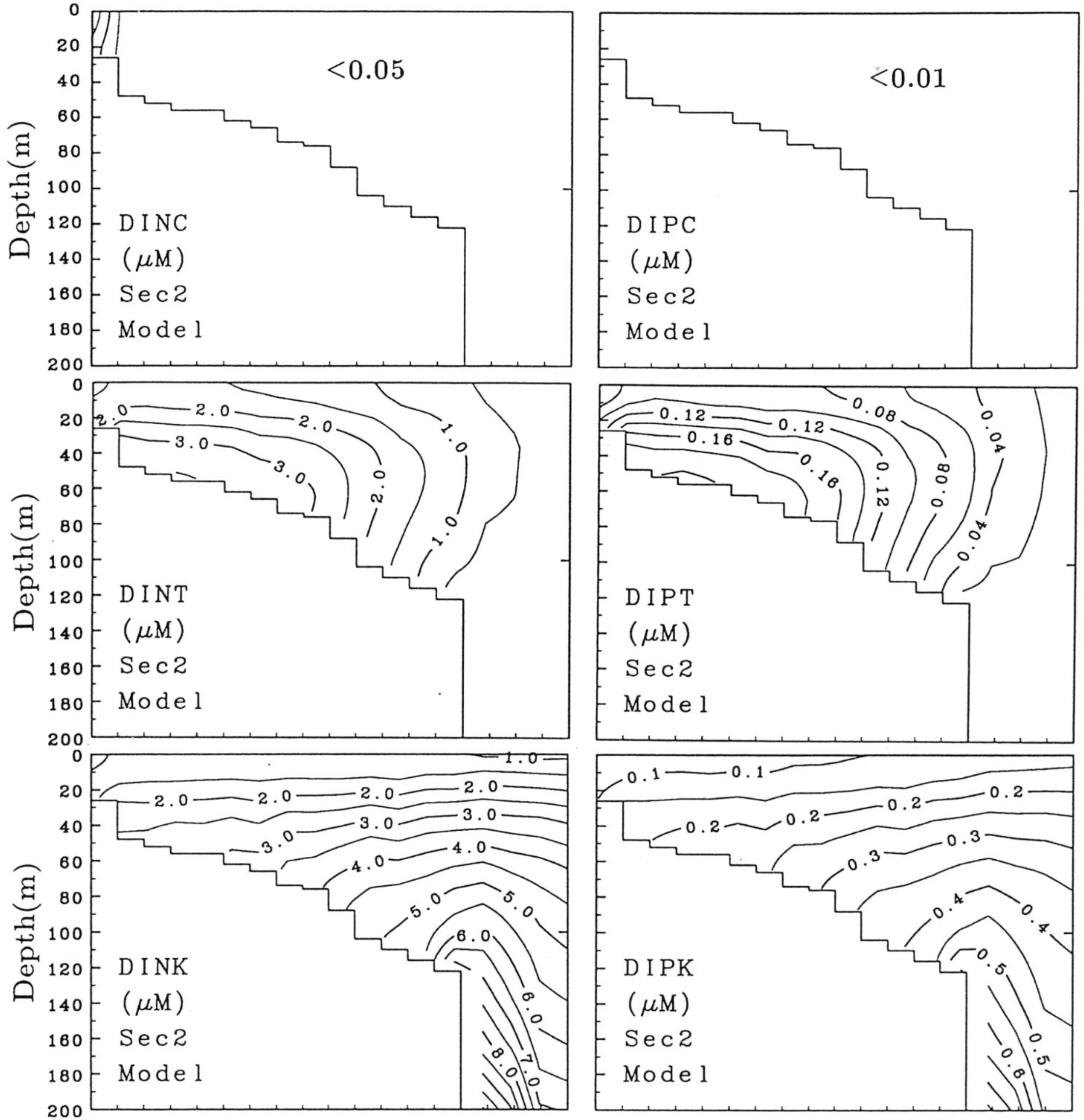
DIN → DINC, DINT, DINK

DIP → DIPC, DIPT, DIPK

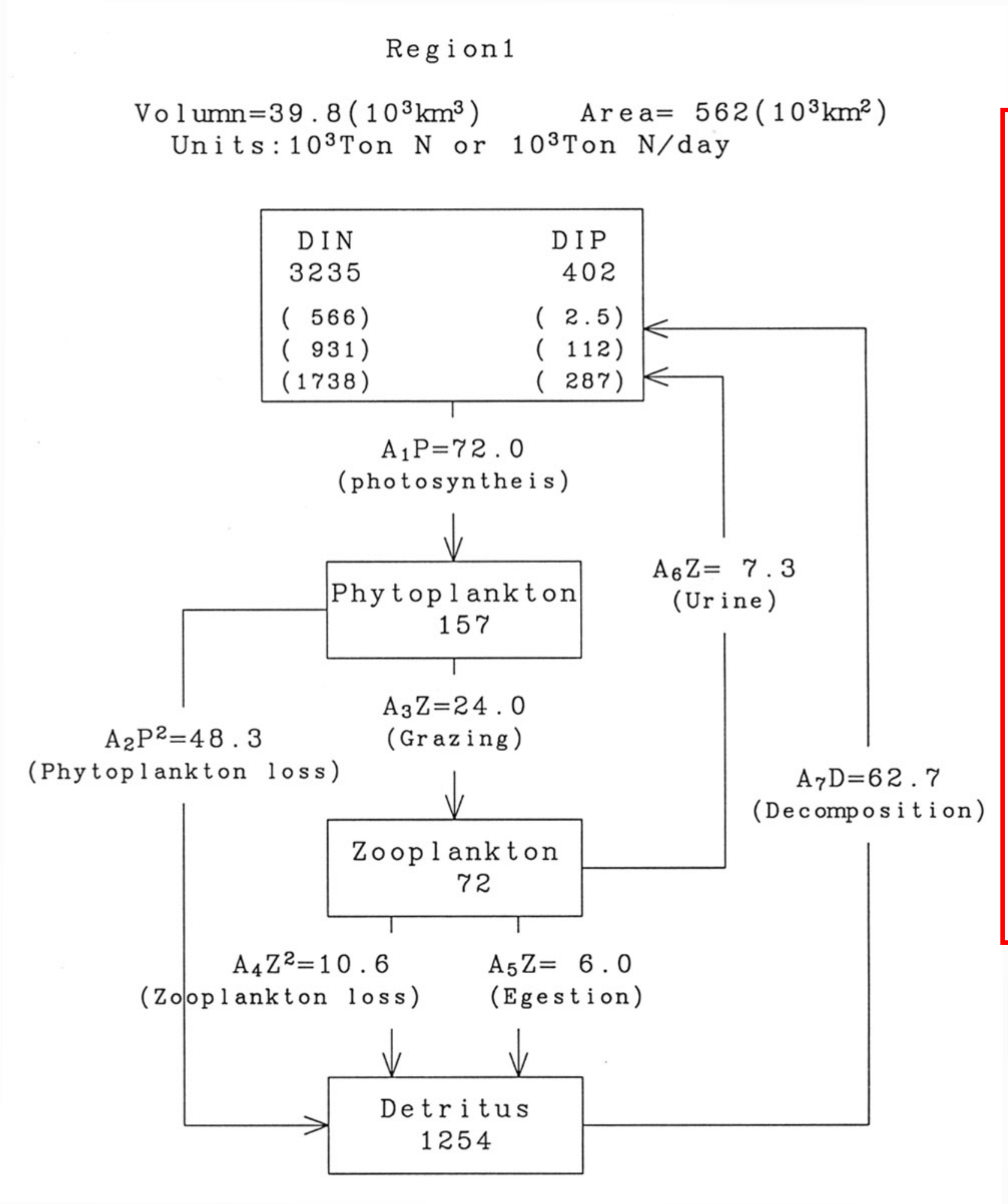
C: Changjiang, T: Taiwan Strait, K: Kuroshio




120°E
125°E
130°E
40°N
35°N
30°N
25°N
Model
10(m)
(μM)
DINC
>10
>10
Model
10(m)
(μM)
DINT
1.6
1.2
0.8
0.4
Model
10(m)
(μM)
DINK
2.0
1.6
1.2
Model
10(m)
(μM)
DIPC
0.1
<0.01
Model
10(m)
(μM)
DIPT
<0.01
0.05
0.10
Model
10(m)
(μM)
DIPK
<0.01
0.05
0.10
0.15



Depth(m)
<0.05
DINC
(μM)
Sec2
Model
<0.01
DIPC
(μM)
Sec2
Model
DINT
(μM)
Sec2
Model
DIPT
(μM)
Sec2
Model
DINK
(μM)
Sec2
Model
DIPK
(μM)
Sec2
Model



DIN=100

DINC=17.5

DINT=28.8

DINK=53.7

DIP=100

DIPC=0.6

DIPT=28

DIPK=71.4

Thanks