

South China Sea Circulation and Thermohaline Structure

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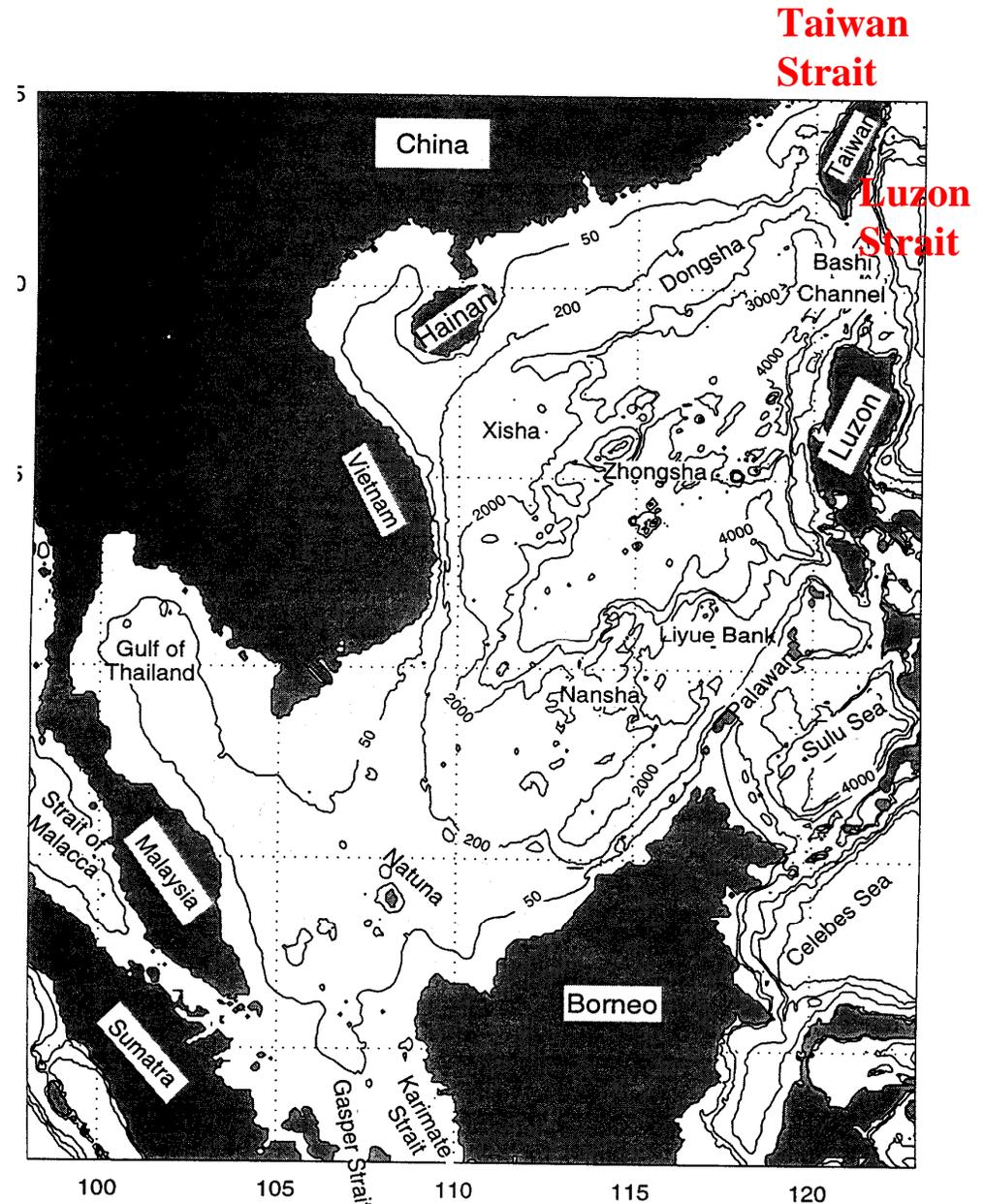
<http://www.oc.nps.navy.mil/~chu>

Contributors

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SCS – a basin with fascinating physical processes

- (1) WBC driven by monsoon winds
- (2) Effects of tropical cyclones
- (3) Kuroshio intrusion (two types)
- (4) Rossby wave propagation
- (5) Multi-eddy structure



References – SCS Thermohaline Variability (Basin-Scale)

- Chu, P.C., and G.H. Wang, 2003: Seasonal variability of thermohaline front in the central South China Sea. *Journal of Oceanology*, 59, 65-78.
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References – SCS Thermohaline Structure (Eddy-Scale)

- Chu, P.C., and C.P. Chang, "South China Sea warm pool", *Advances in Atmospheric Sciences*, 14, 195-206, 1997.
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References - SCS Circulation

- Chu, P.C., N.L. Edmons, and C.W. Fan, "Dynamical mechanisms for the South China Sea seasonal circulation and thermohaline variabilities." *Journal of Physical Oceanography*, 29, 2971-2989, 1999.
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References – SCS Modeling

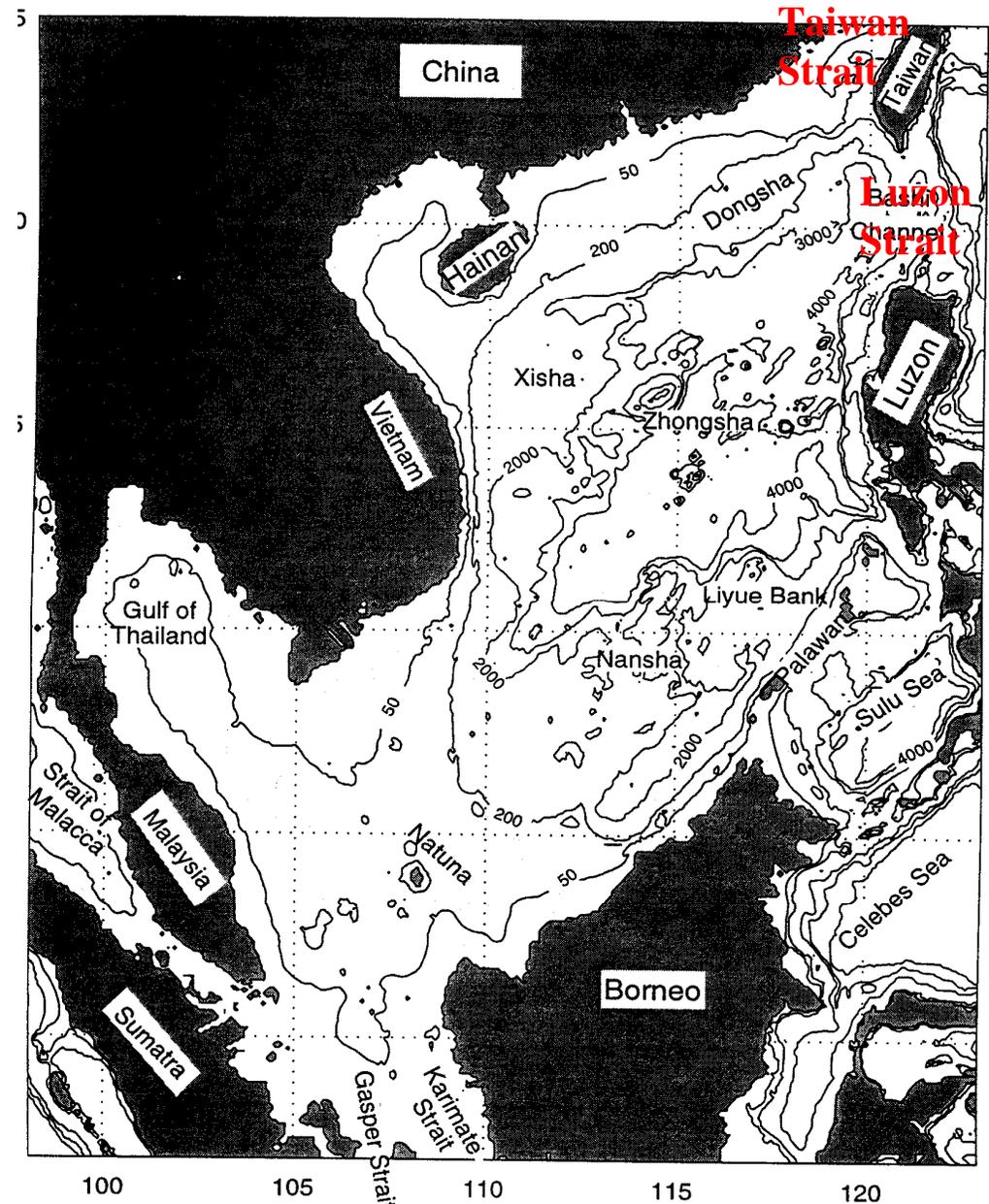
- Chu, P.C., S.H. Lu, and Y.C. Chen, 2001: Evaluation of the Princeton Ocean Model using the South China Sea Monsoon Experiment (SCSMEX) data. *Journal of Atmospheric and Oceanic Technology*, 18, 1521-1539.
- Chu, P.C., S.H. Lu, and W.T. Liu, “Uncertainty of the South China Sea prediction using NSCAT and NCEP winds during tropical storm Ernie 1996,” *Journal of Geophysical Research*, 104, 11273-11289, 1999.
- Chu, P.C., S.H. Lu, and Y.C. Chen, A coastal atmosphere-ocean coupled system (CAOCS) evaluated by an airborne expandable bathythermograph survey in the South China Sea, May 1995. *Journal of Oceanography*, 55, 543-558, 1999.

SCS Bathymetry

Straits are relatively shallow except the Luzon Strait (sill depth = 2,400 m)

Broad shallows of the Sunda shelf in the S/SW

Continental shelf in the N extends from Gulf of Tonkin to the Taiwan Strait



Atmospheric Forcing

— Monsoon

Tropical Cyclones

Winter Monsoon

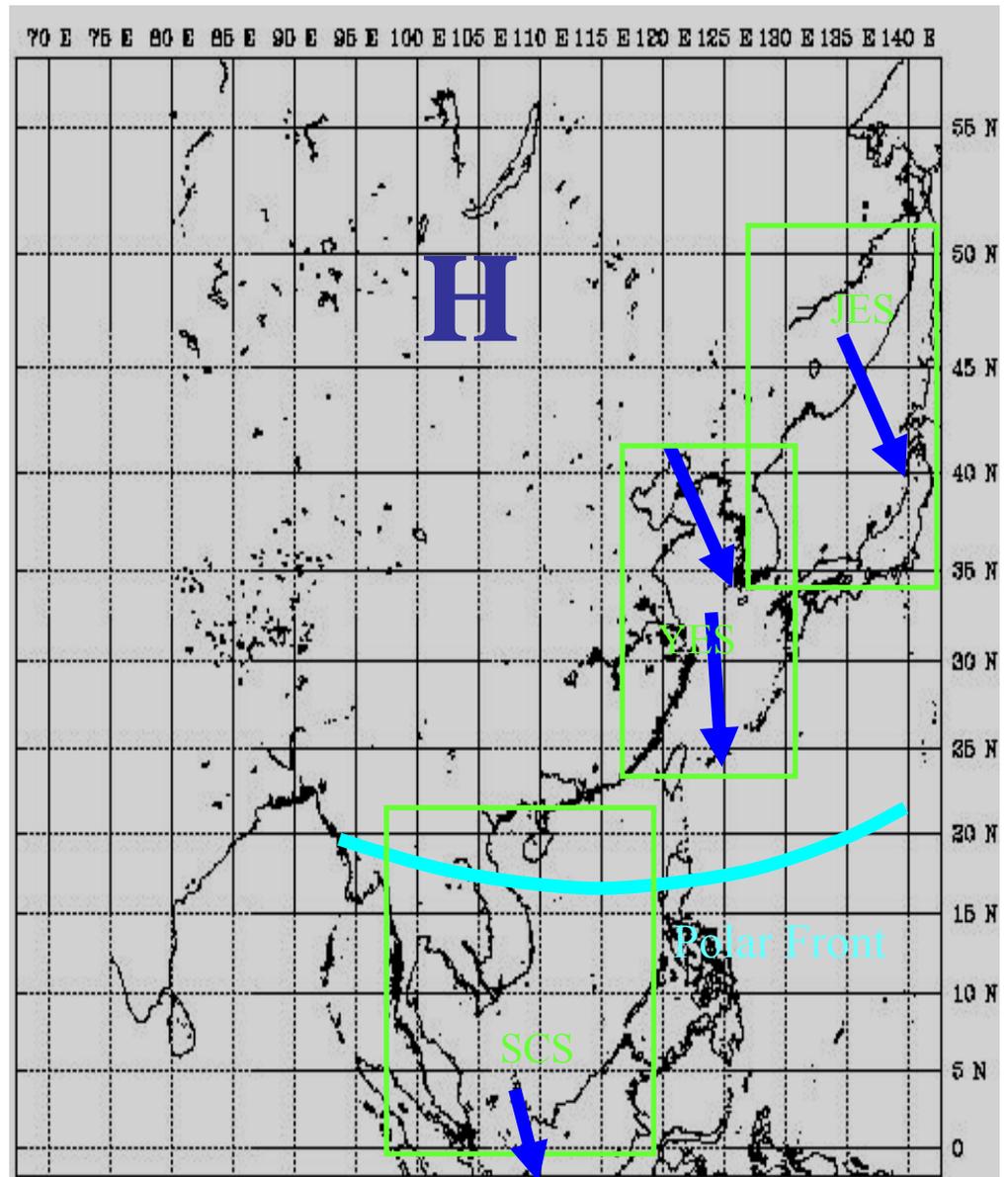
November through March

Siberian High over East Asia continent

Polar Front positioned north of the Philippines

Equatorial Trough located south of equator

Relatively stronger, cold, and dry NW/N/NE winds flow over the EAMS



Winter-to-Summer Monsoon Transition Period

March through May

- (1) The Siberian High rapidly weakens in April
- (2) Polar Front moves northward toward Korea

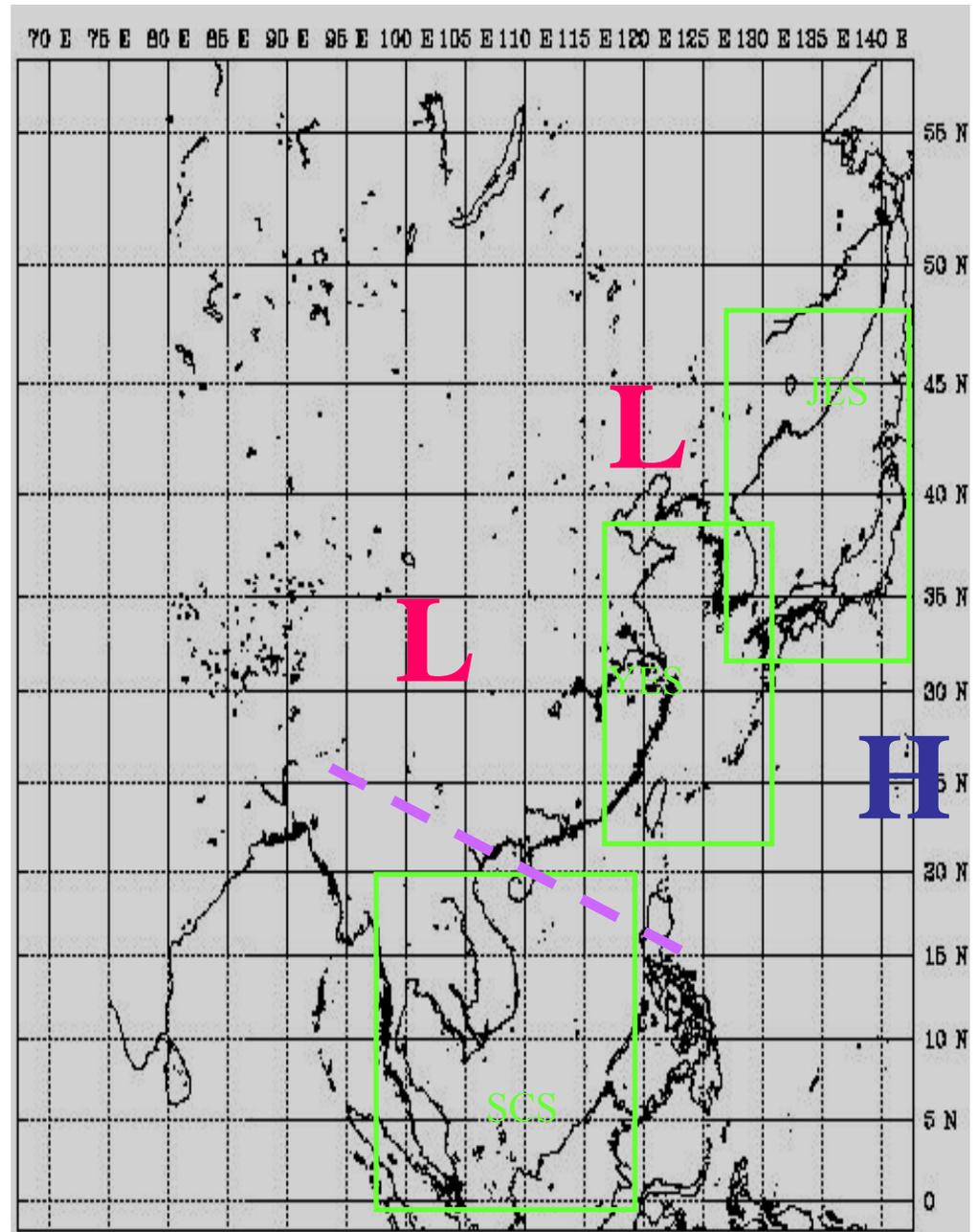
Summer Monsoon

Mid-May through Mid-September

Heat Lows over East Asia continent due to high solar insolation

Higher pressure over Pacific Ocean but subtropical ridge is displaced poleward

Equatorial Trough lies over central Philippines and extends NW to Tibetan Plateau.



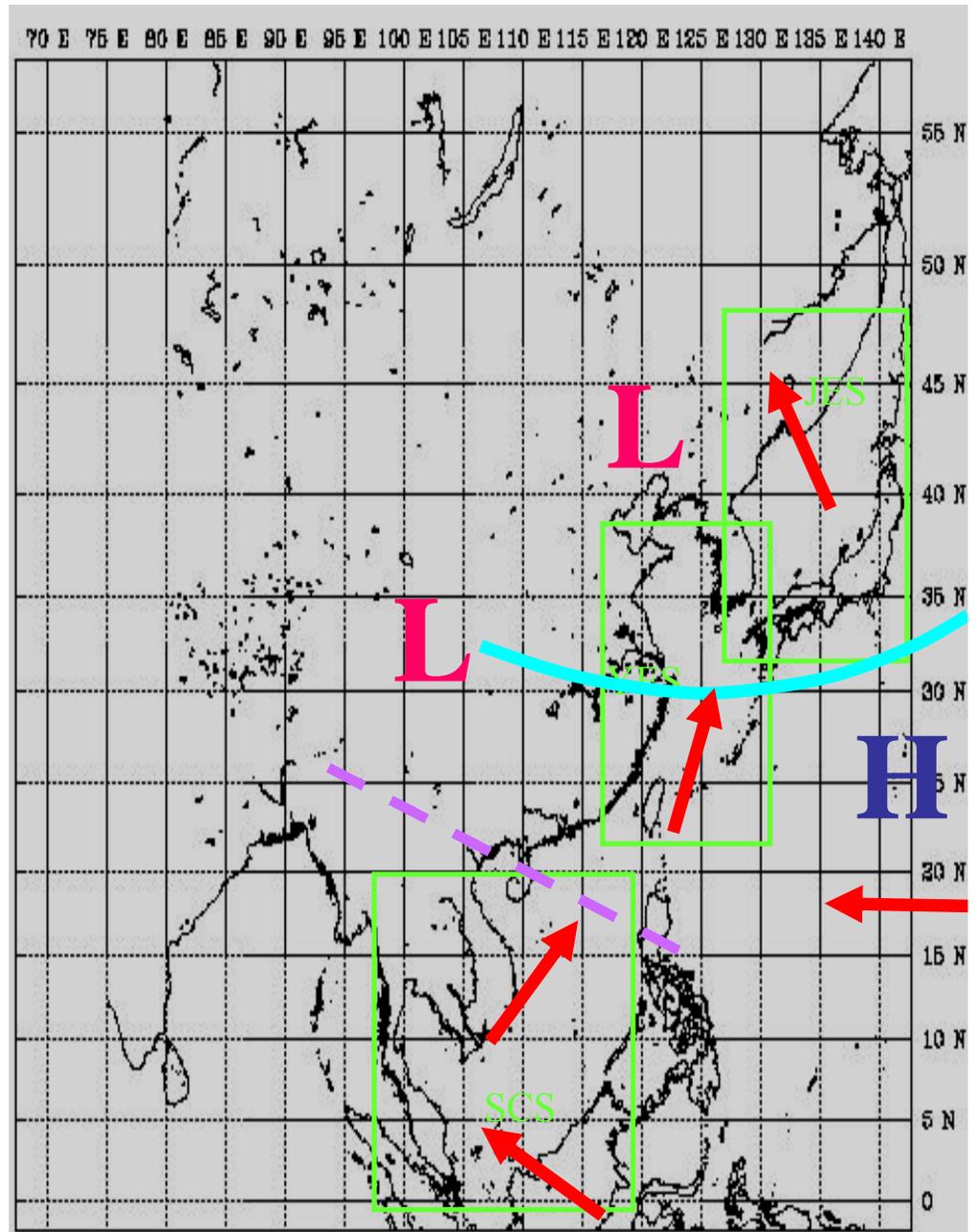
Summer Monsoon

Polar Front moves north at 30° - 35° N

A Tropical Easterly Jet is found at 125-mb between the subtropical ridge and the Equatorial trough

Air flows SE south of equator and turns SW over the SCS due to Coriolis Force

Relatively weaker, warm, and moist SW/S/SE winds flow over the northern SCS

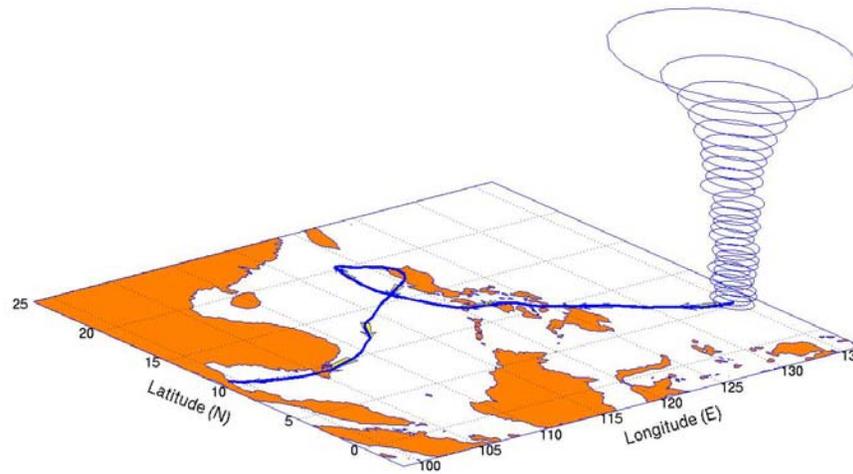


Summer-to-Winter Monsoon Transition Period

Mid-September through October

- (1) Southerly winds weaken as the Manchurian Low is replaced by the Siberian High
- (2) Polar Front begins to move southward away from the Korean Peninsula
- (3) SST steadily decreases

Tropical Cyclone



Tropical Cyclones Passing Through SCS in 2000

Tropical Cyclone	Number	TC Name	Times	Start/End Date	Start/end Coordinate	Tend toward
Tropical Depression	03W		21 – 22 May	21 00h – 22 00h	118.3E,18.3N 125.1E,21.0N	SW-NE
Tropical Depression	04W		29 May–01 Jun	29 00h – 01 12h	133.4E,13.1N 147.1E,42.3N	SE-NW
Typhoon	06W	KAI-TAK	03 – 11 Jul	03 06h – 11 00h	118.1E,15.7N 123.9E,38.0N	S-N-wc -NE -N
Tropical Depression	07W		11 – 15 Jul	11 00h – 15 00h	130.6E,10.0N 113.9E,17.2N	
Tropical Depression	08W		14 – 17 Jul	14 12h – 17 12h	115.9E,16.1N 111.8E,22.7N	SSE- NNW
Tropical Depression	18W		17 – 24 Aug	17 06h – 24 06h	139.2E,08.3N 116.0E,26.5N	SE-NW
Tropical Storm	19W	KAEMI	18 – 23 Aug	18 18h – 23 00h	114.7E,11.0N 106.2E,16.5N	SE-NW
Tropical Storm	21W	MARIA	27 Aug–01 Sep	27 12h – 01 18h	115.2E,21.4N 113.4E,26.1N	N-S-C- N-NNW
Typhoon	23W	WUKONG	04 – 10 Sep	04 18h – 10 12h	116.9E,16.9N 104.8E,18.3N	SE-NE- C-W
Tropical Storm	28W		06 – 14 Oct	06 18h – 14 18h	110.5E,10.8N 109.5E,17.4N	SW-E-C 3 -W
Typhoon	30W	XANGSANE	25 Oct–01 Nov	25 06h – 01 18h	137.2E,08.6N 129.4E,31.9N	SE-NW C-NE
Typhoon	31W	BEBINCA	30 Oct–08 Nov	30 18h – 08 00h	134.5E,06.8N 112.9E,21.5N	SE-NW
Tropical Storm	33W	RUMBIA	27 Nov–09 Dec	27 18h – 09 06h	132.4E,08.4N 105.3E,06.8N	E-W

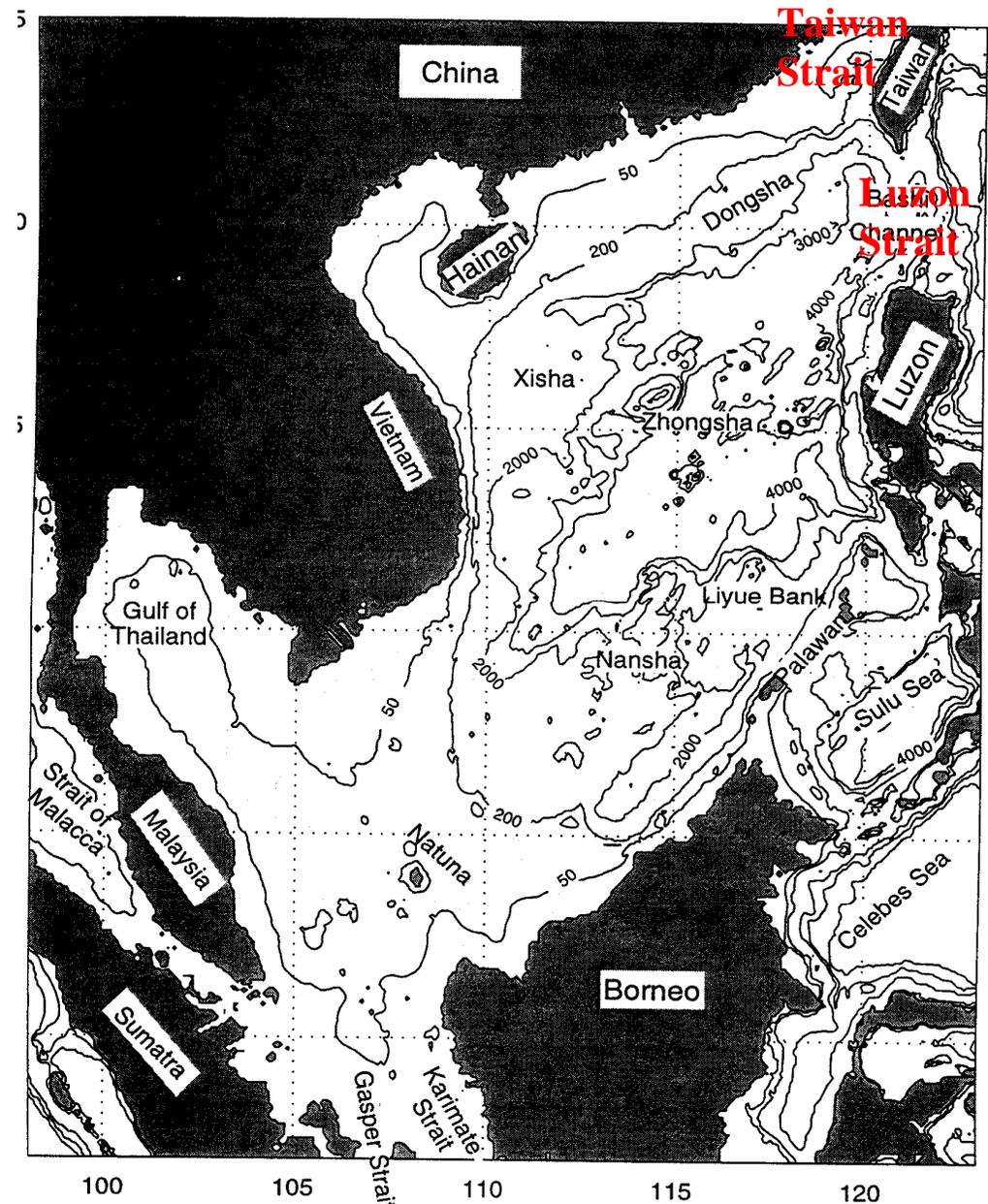
SCS Dynamical Regimes

(1) Kuroshio Intrusion
Northern SCS

(2) Wind Driven
Circulation
Whole SCS

(3) Multi-Eddy Structure
Northern SCS

(4) Rossby Waves
Northern SCS

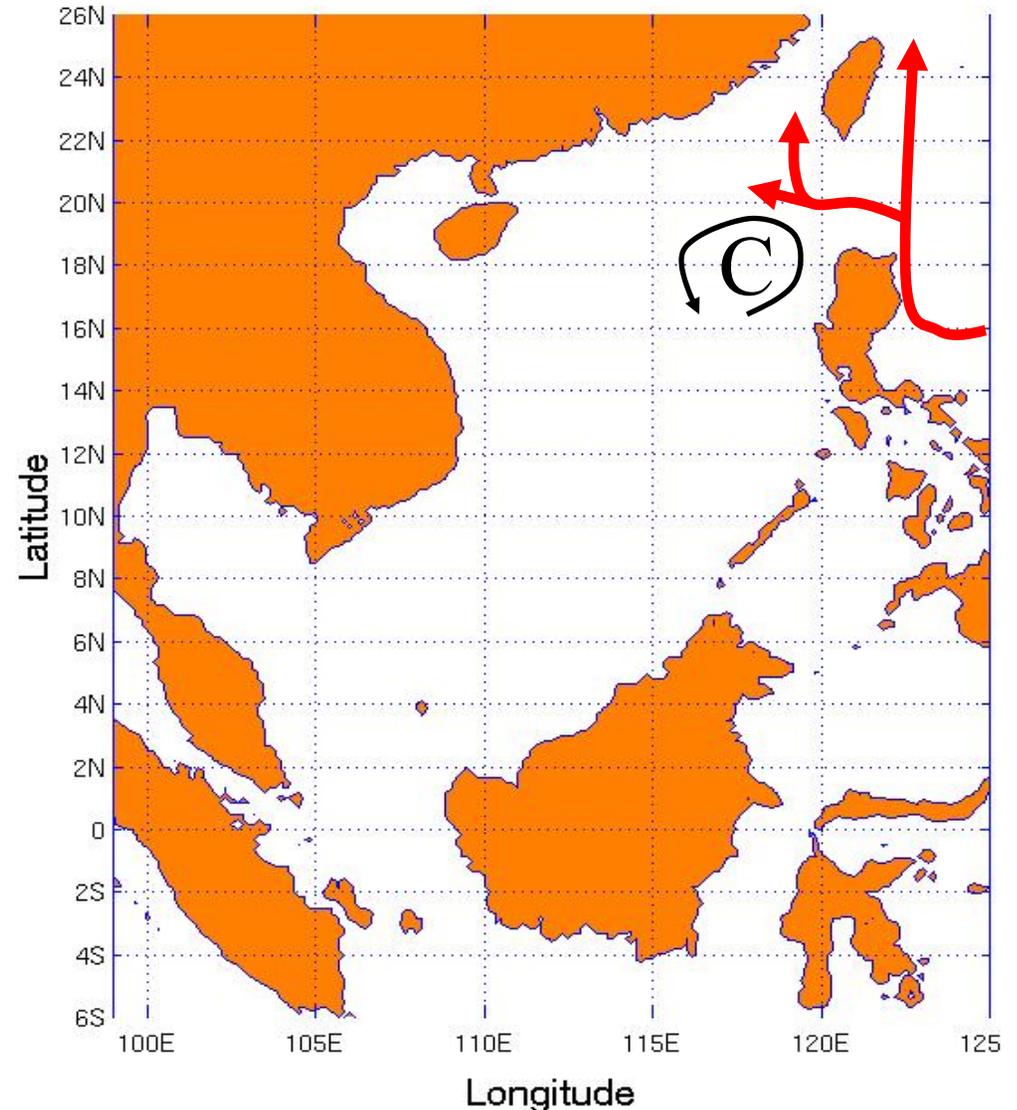


Kuroshio Intrusion

Northern SCS (north of 10°N)

Cold Cyclonic
Eddy

Northwestern Luzon
(NWL) Eddy



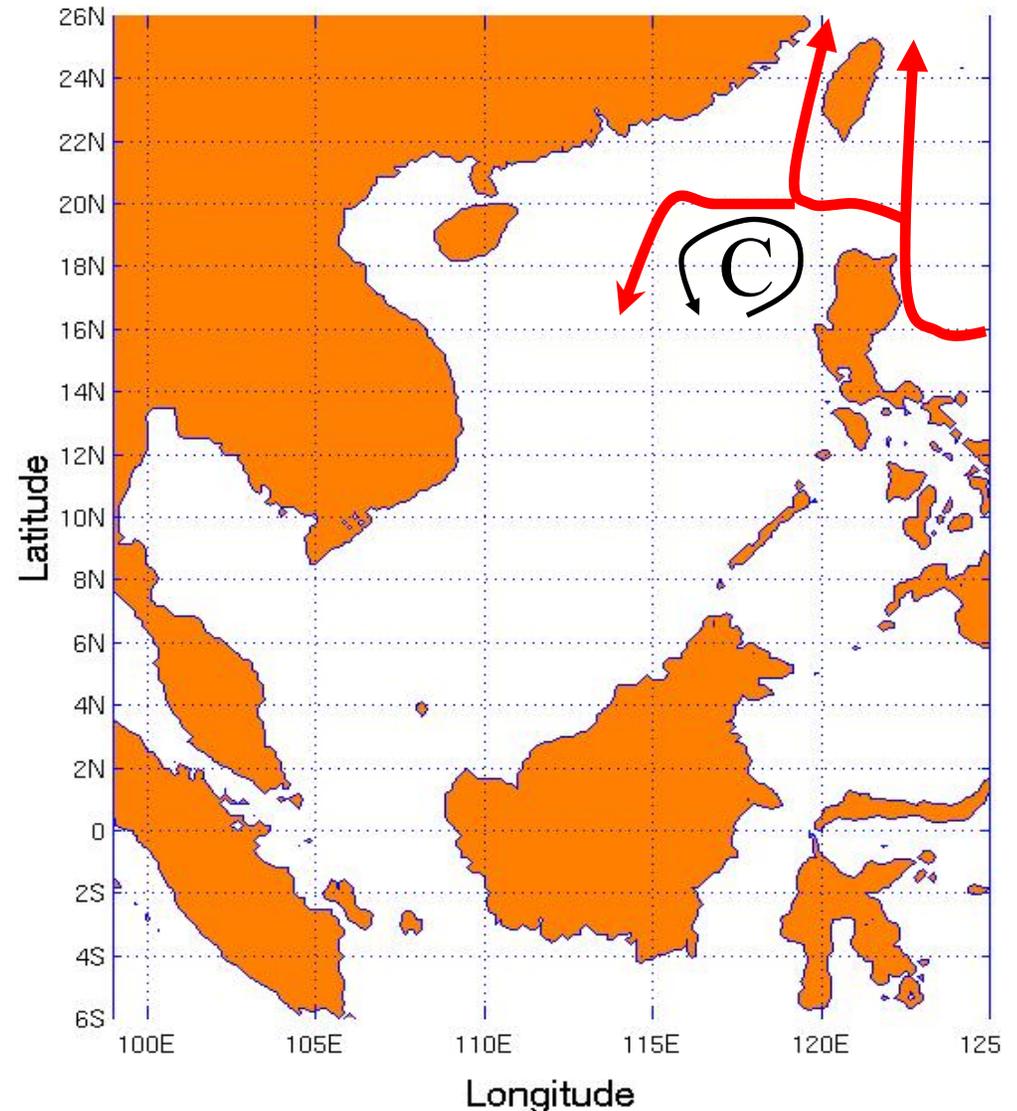
Kuroshio Intrusion

Northern SCS (north of 10°N)

(1) The northward branch flows northward along the western coast of Taiwan.

SCS Warm Current.

(2) The northwestward branch makes a cyclonic turn around the NWL eddy



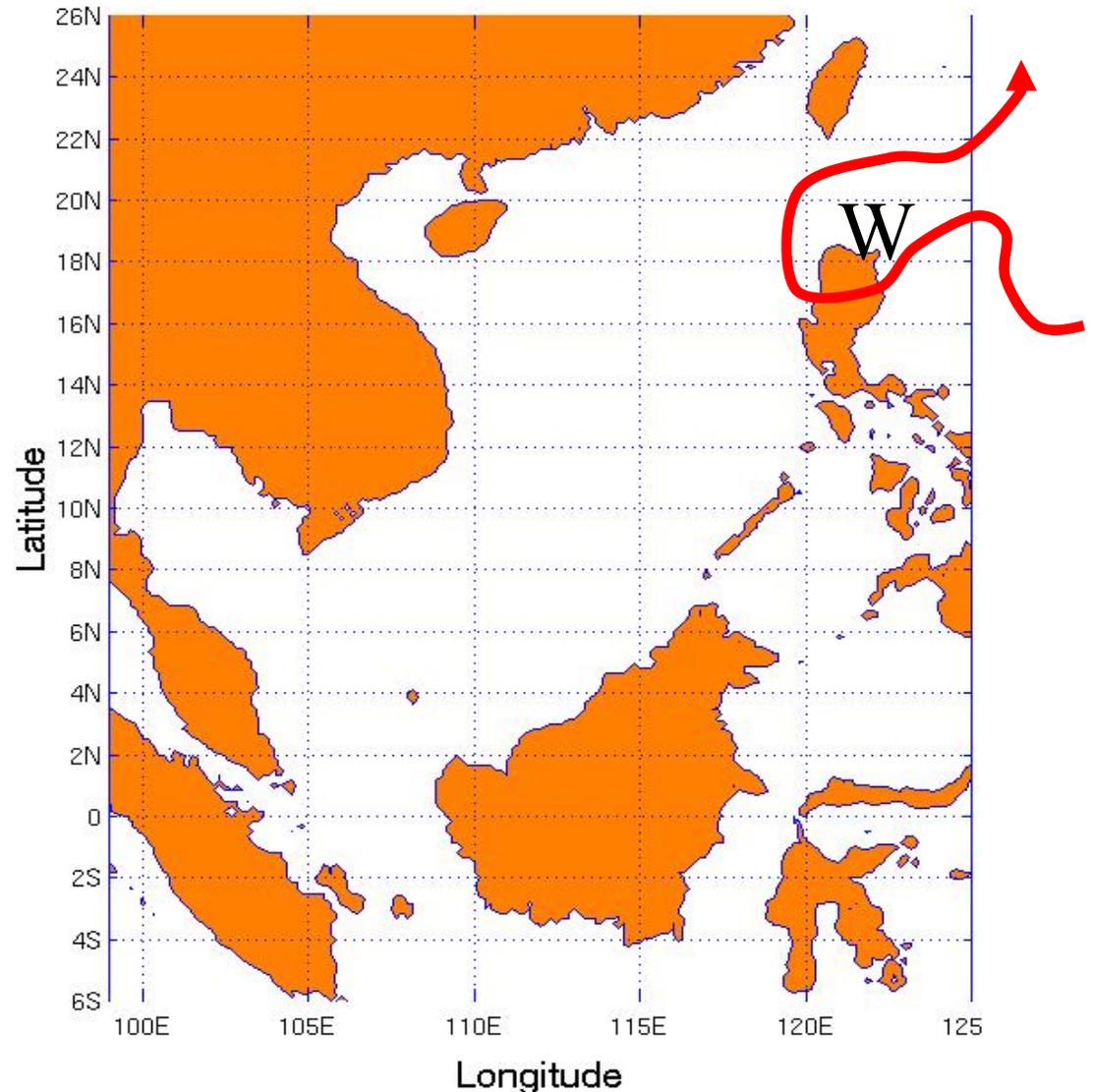
Kuroshio Intrusion

Northern SCS (north of 10°N)

Warm Eddy

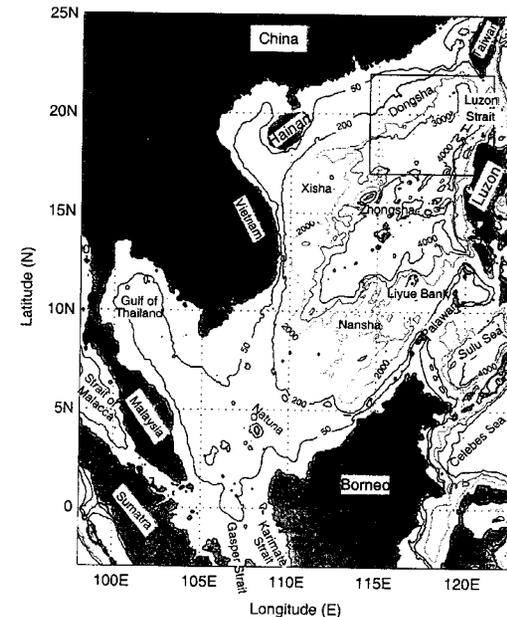
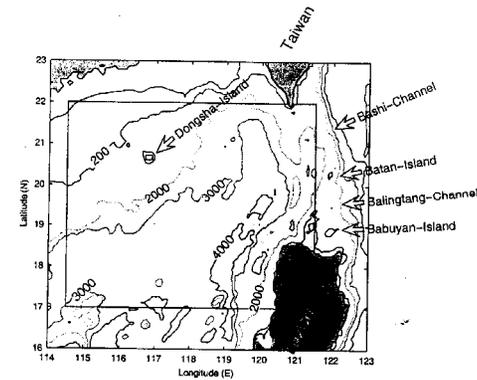
Originates from
the North
Equatorial
Current

Flows northward
as a WBC east
of Luzon

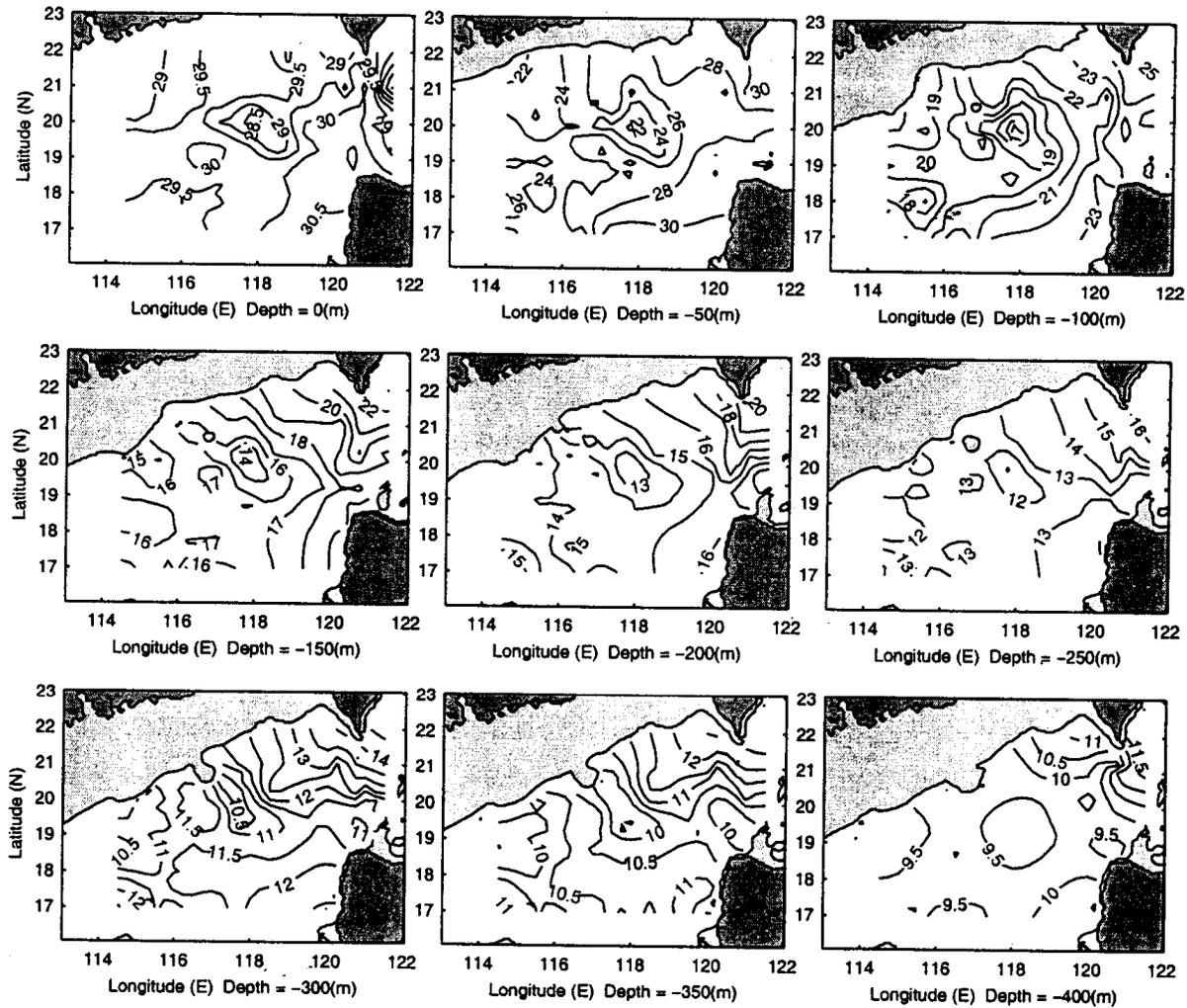


Observed Cold NWL Eddy During SCSMEX on 16-21 July 1998 (Chu and Fan, JO 2001)

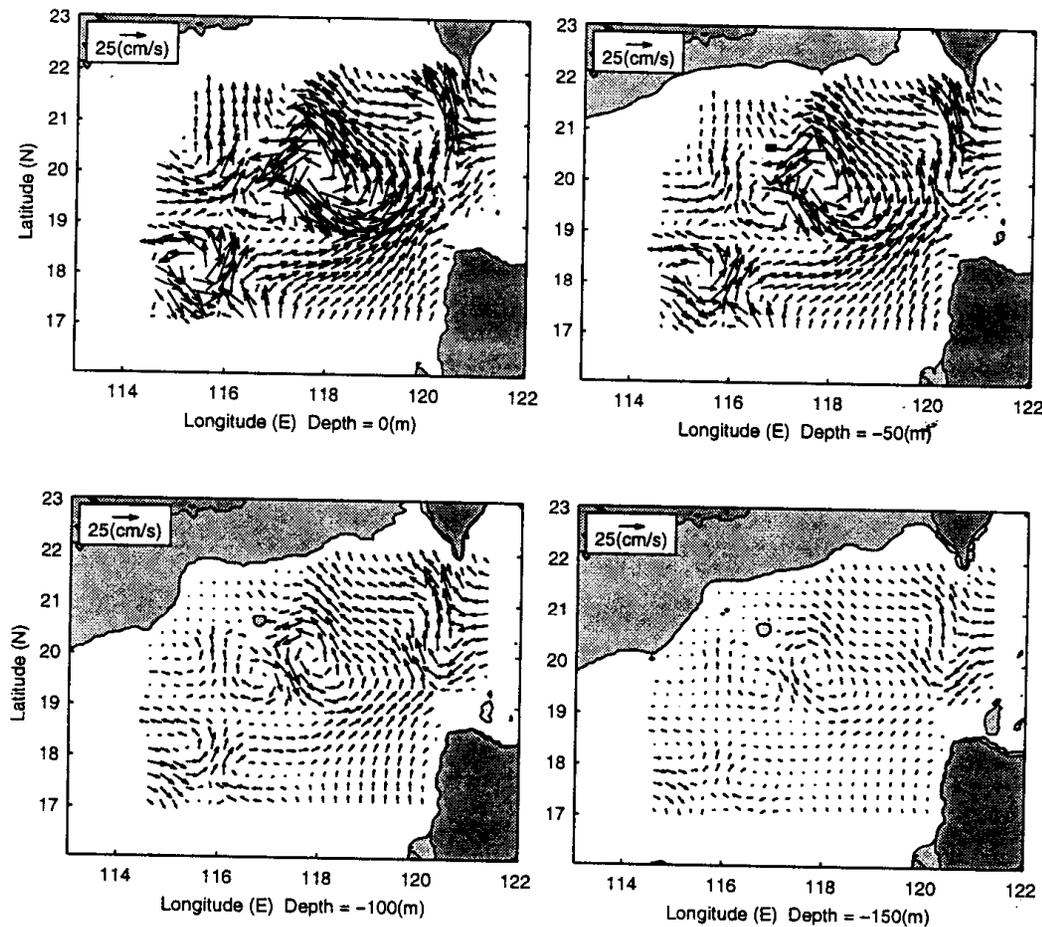
- AXBT (307)
- AXCTD (9)
- ADCP
R/V Shiyan 3



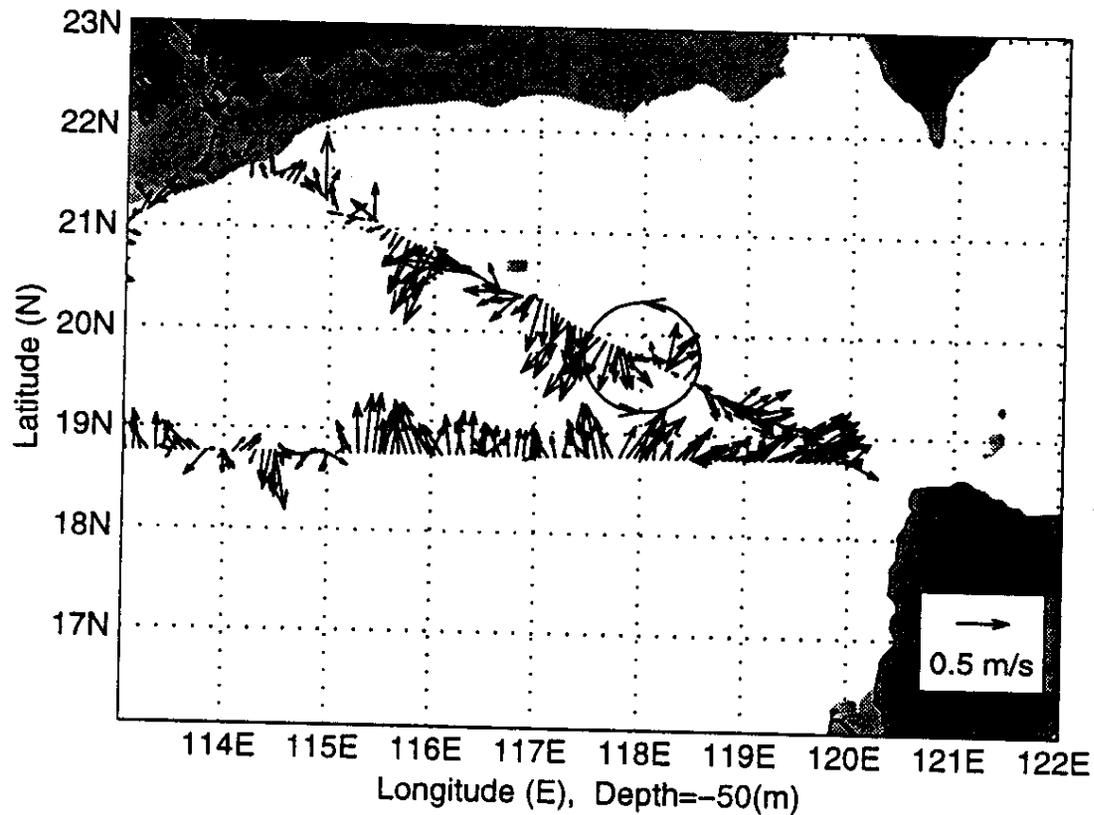
Cold NWL Eddy



Circulations inverted from (T, S) fields using the P-vector Method



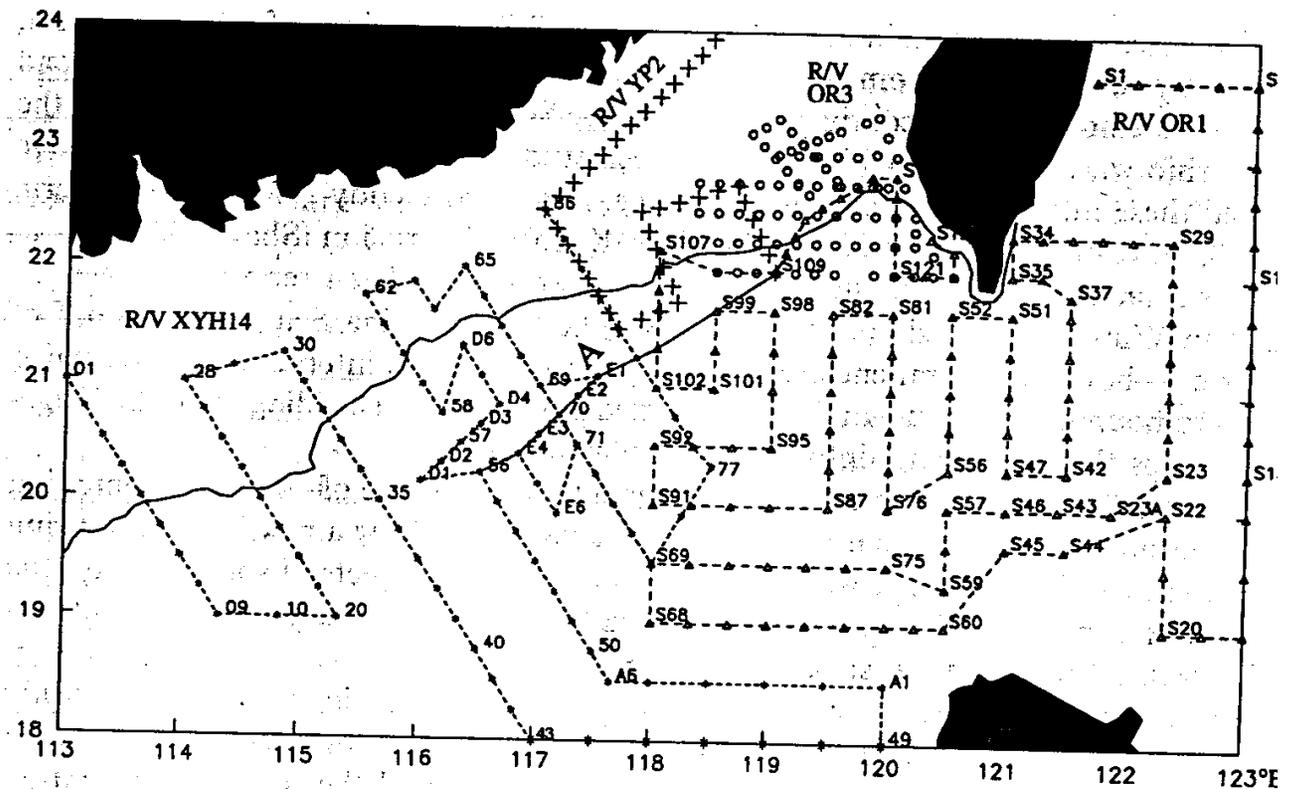
ADCP velocity vectors (15 min averages) at 50 m depth



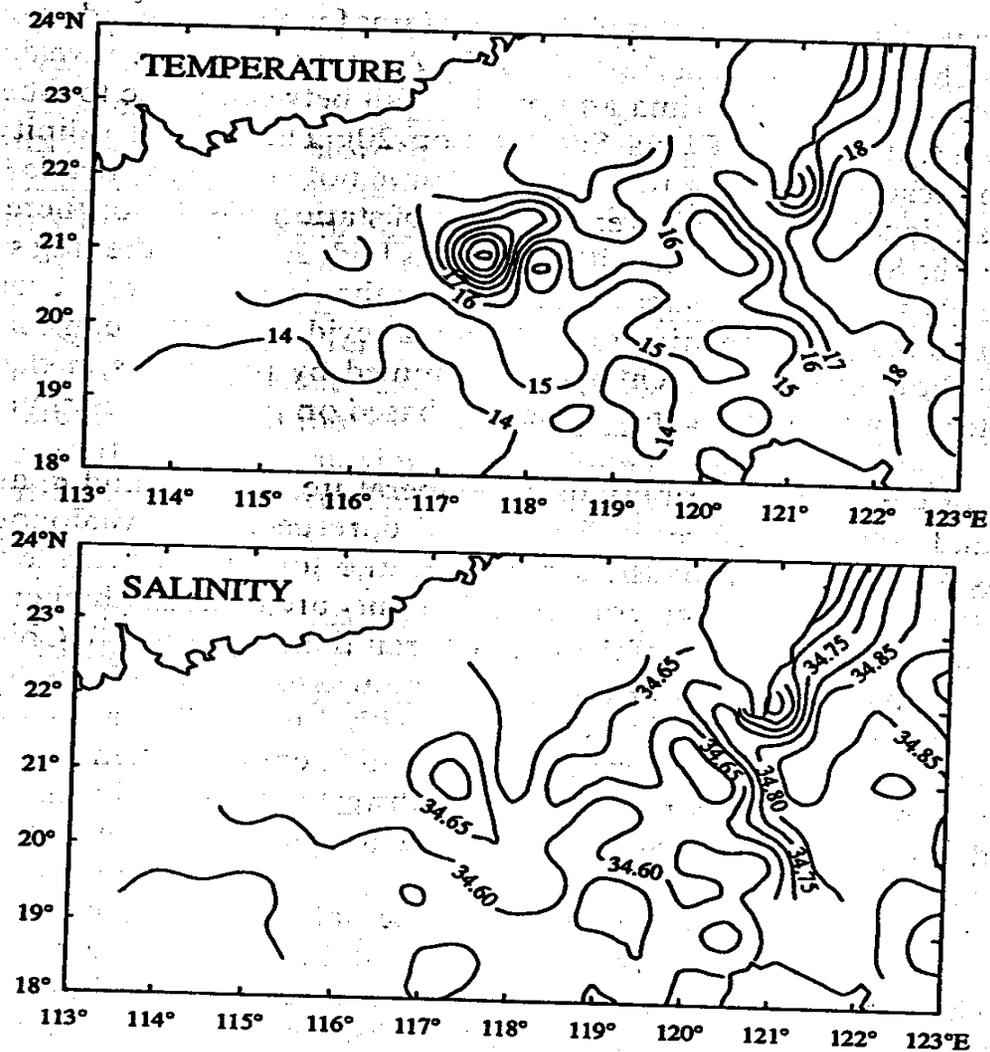
Observed Warm Anticyclonic NWL eddy

(Li et al., Deep Sea Res., 1998)

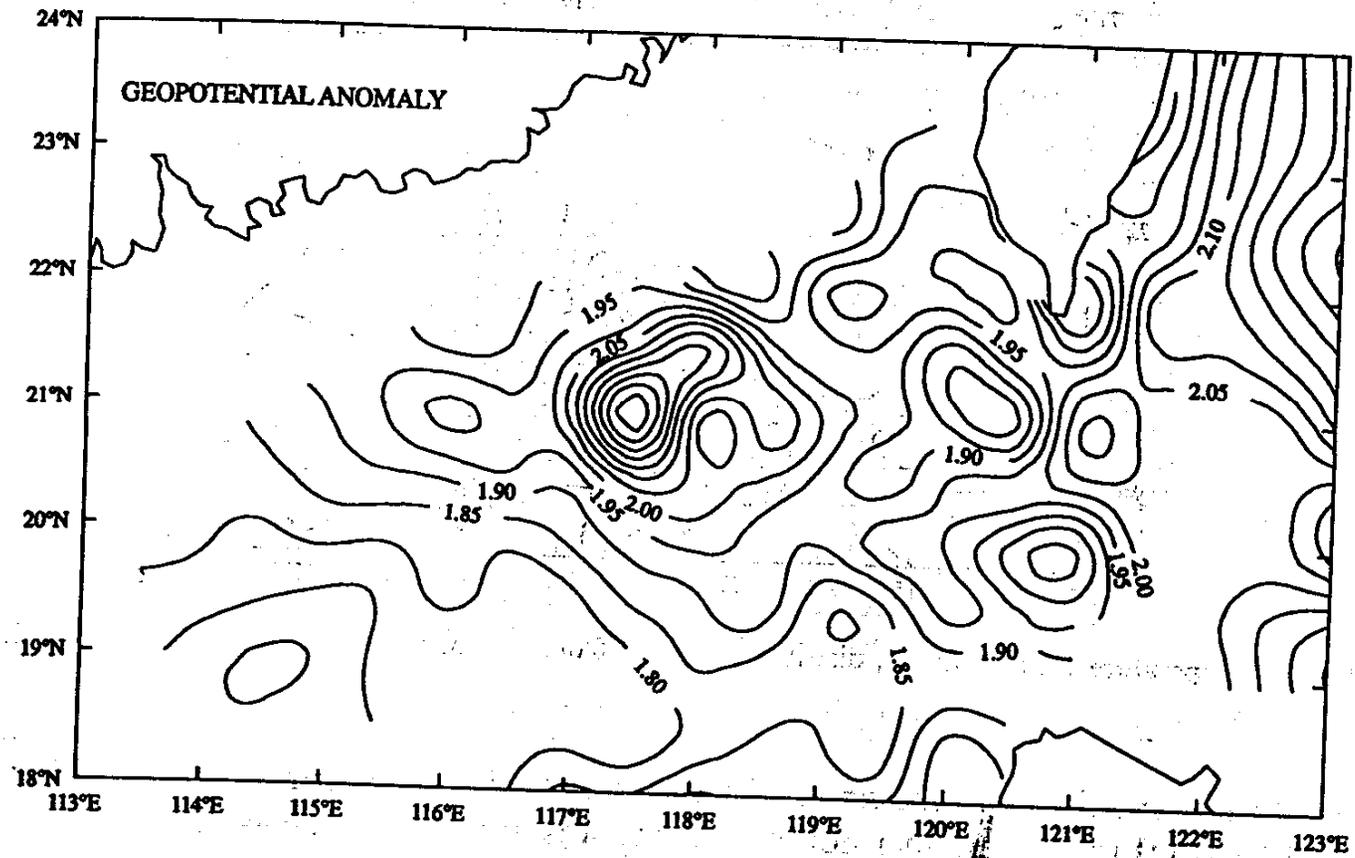
CTD & ADCP
Measurements
Aug-Sept 1994



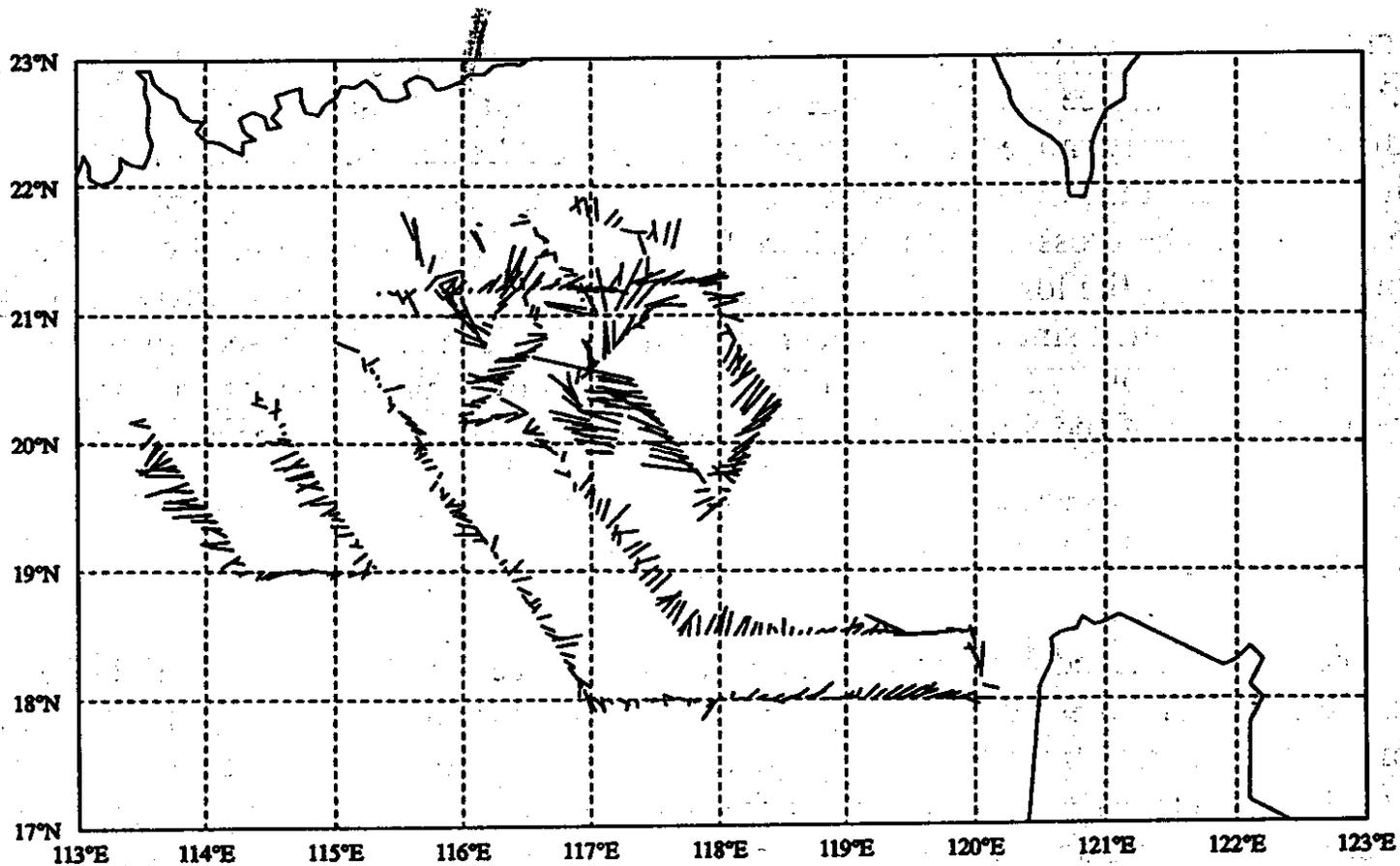
Warm and Salty NWL Eddy



Geopotential Anomaly Relative to 1000 db

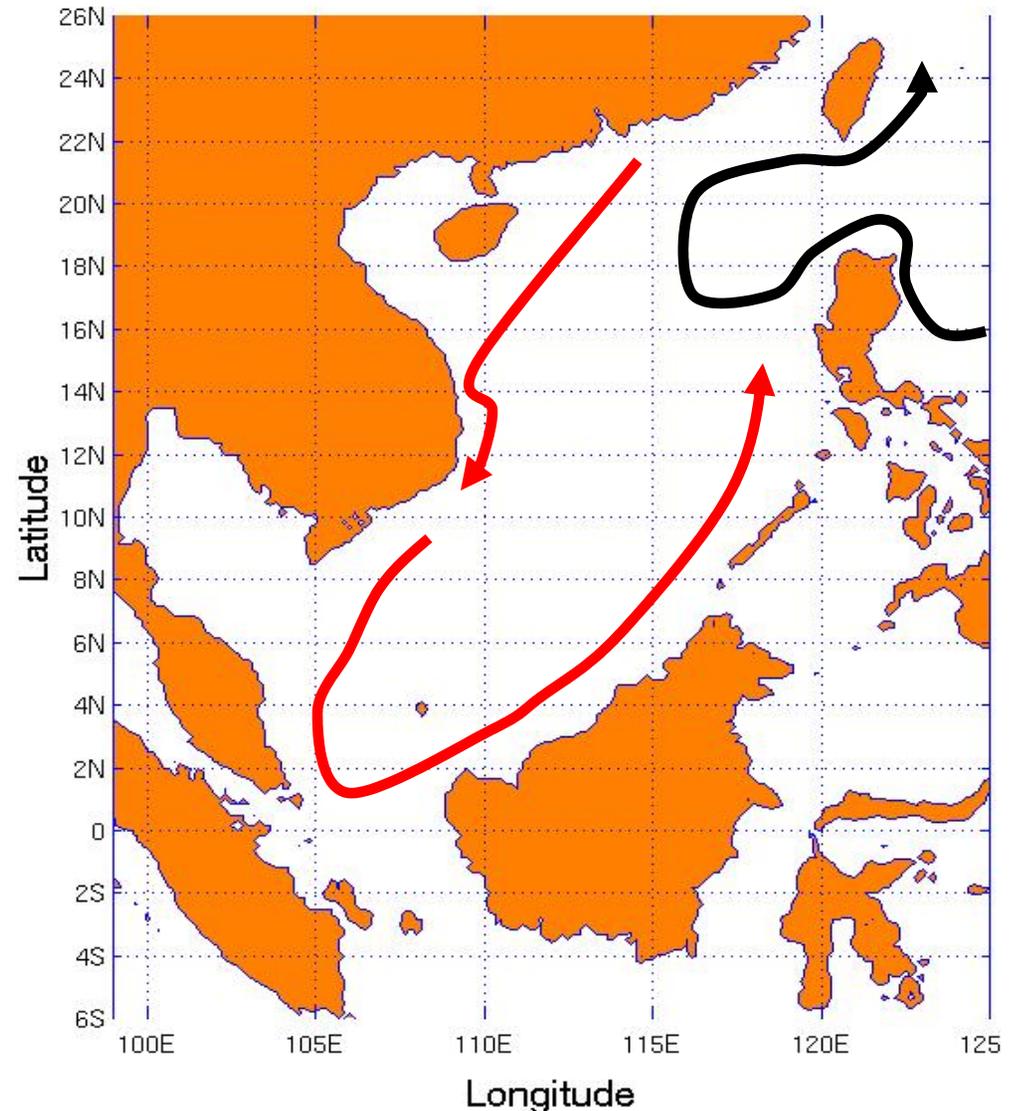


ADCP Velocity Vectors at 100 m Depth



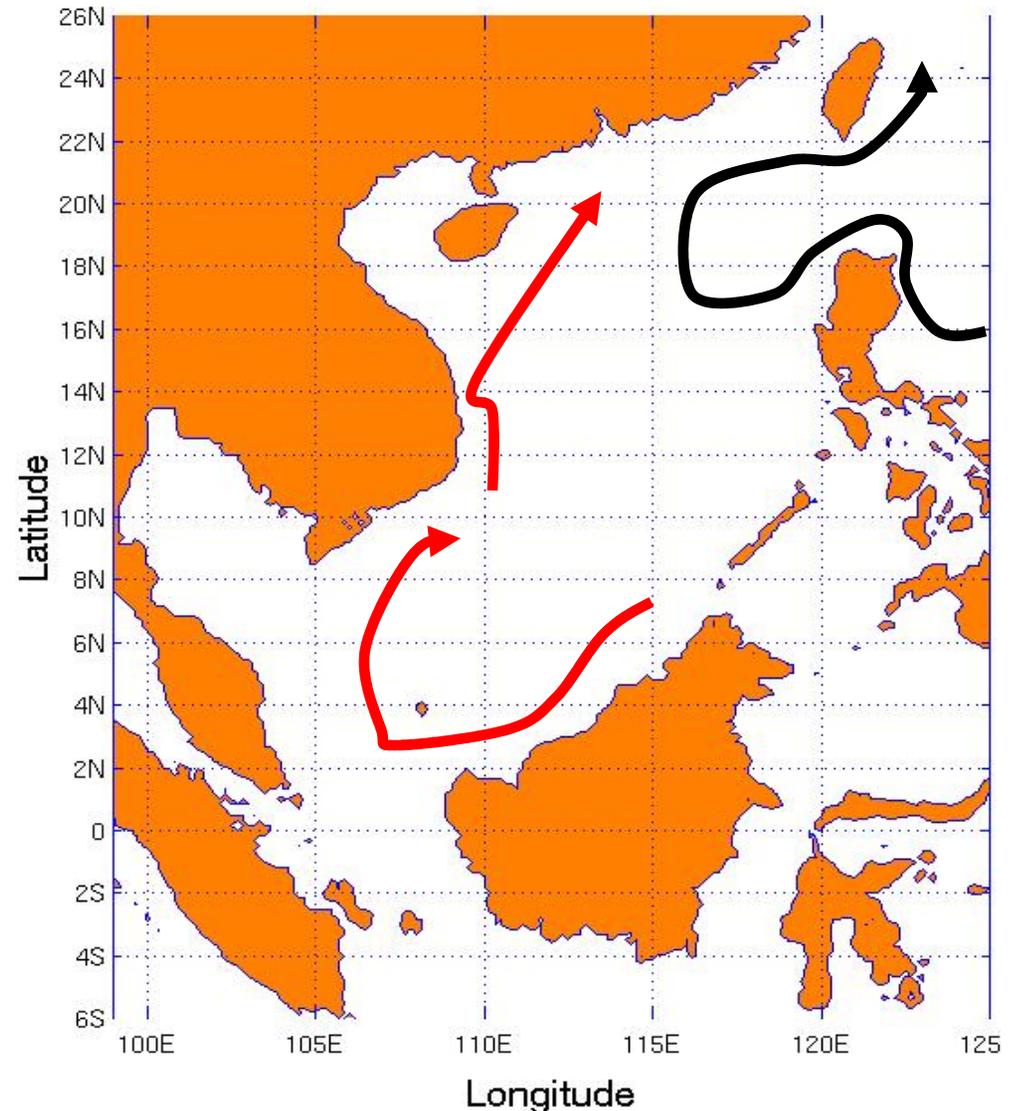
Seasonal Wind-Driven Gyre (Winter)

A southward coastal jet off the Vietnam coast and a cyclonic gyre throughout the SCS



Seasonal Wind-Driven Gyre (Summer)

A northward coastal jet off the Vietnam coast and an Anticyclonic gyre throughout the SCS

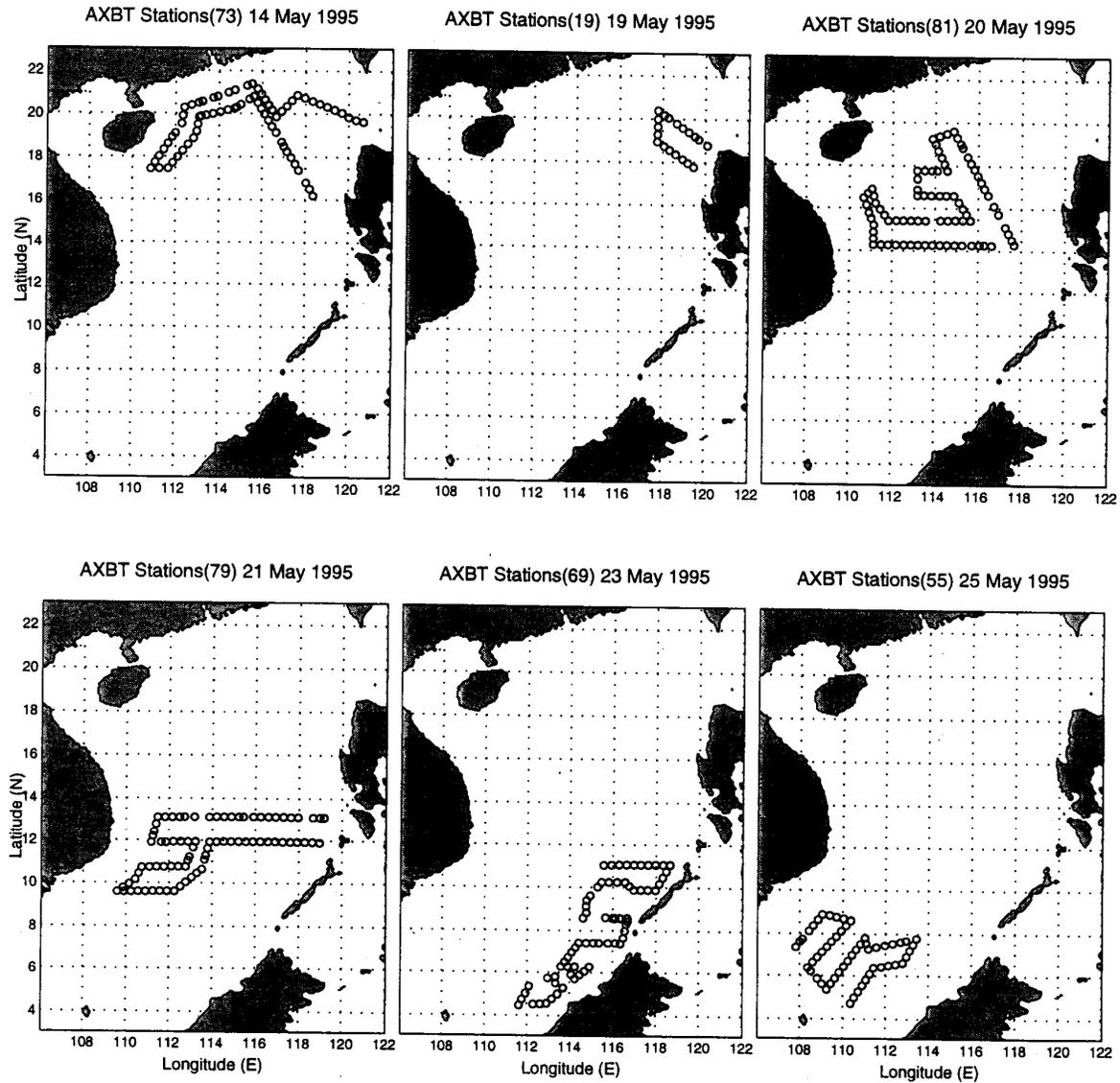


Multi-Eddy Structure

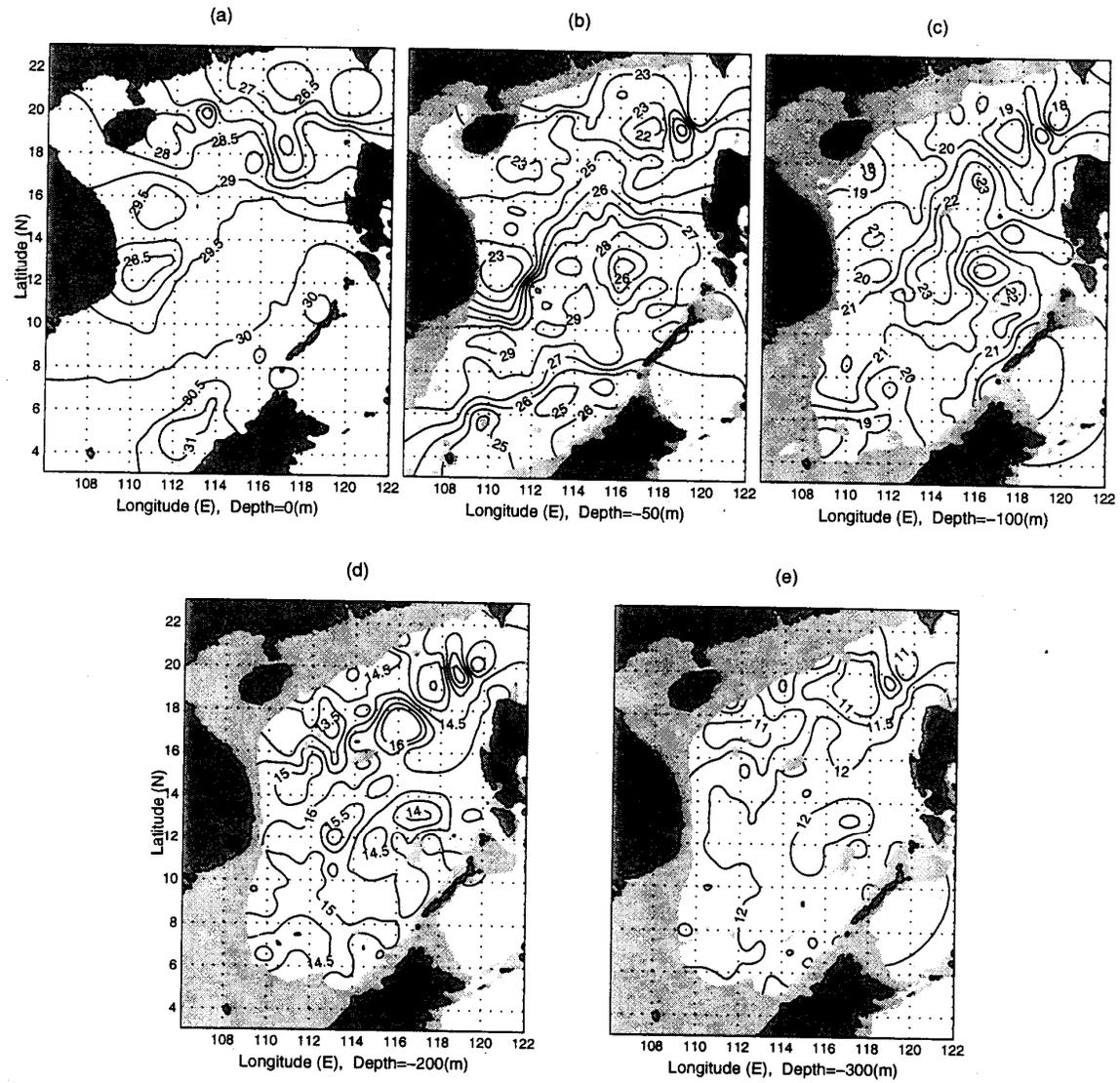
(Chu et al. JGR, 1997, 1998, 1999, JPO, 1999)

- Northern SCS: Eddy (Active)
- Southern SCS: Eddy (Non-active)

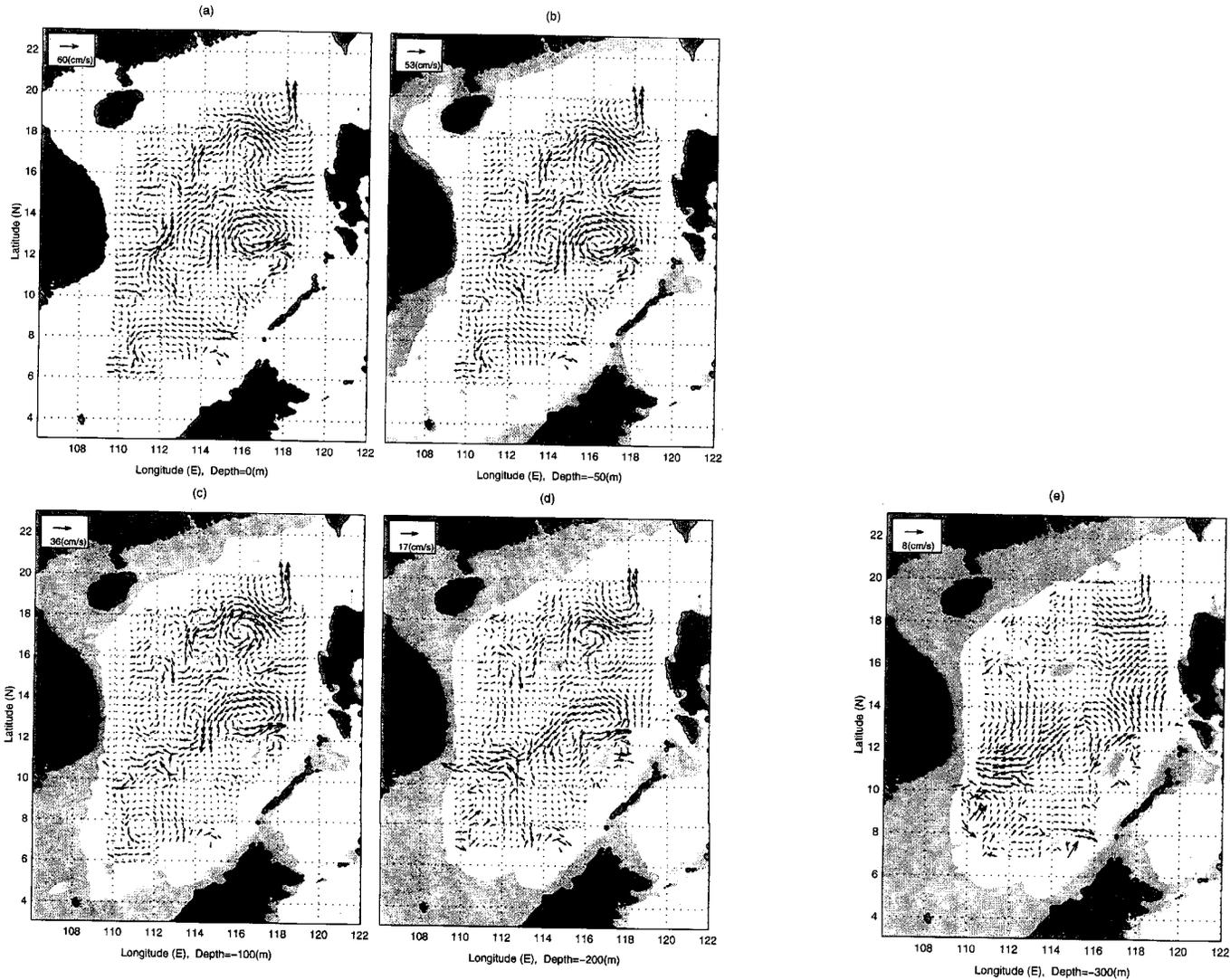
AXBT Observations May 14-25, 1995



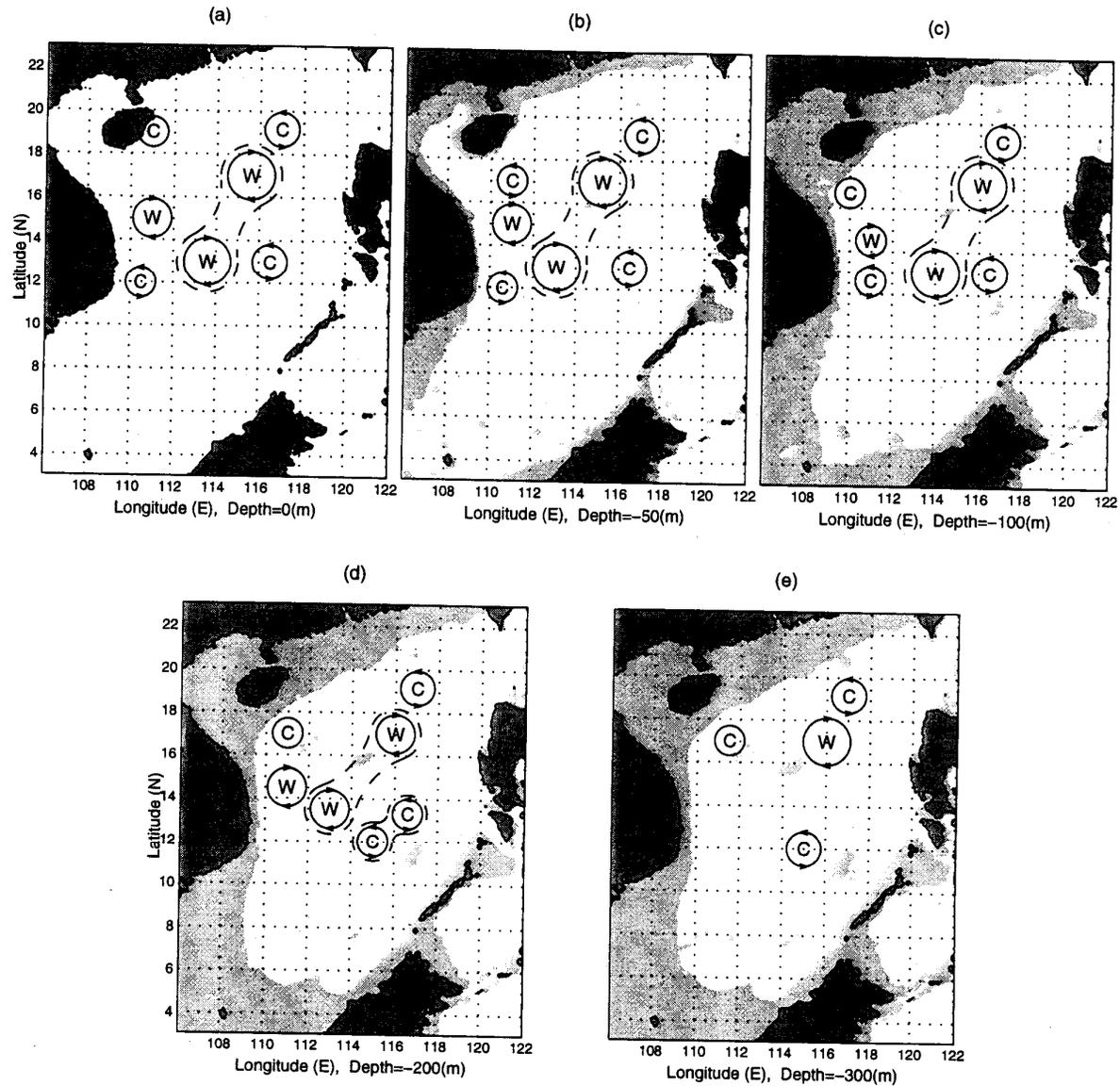
Temperature



P-Vector Inverted Velocity Vectors

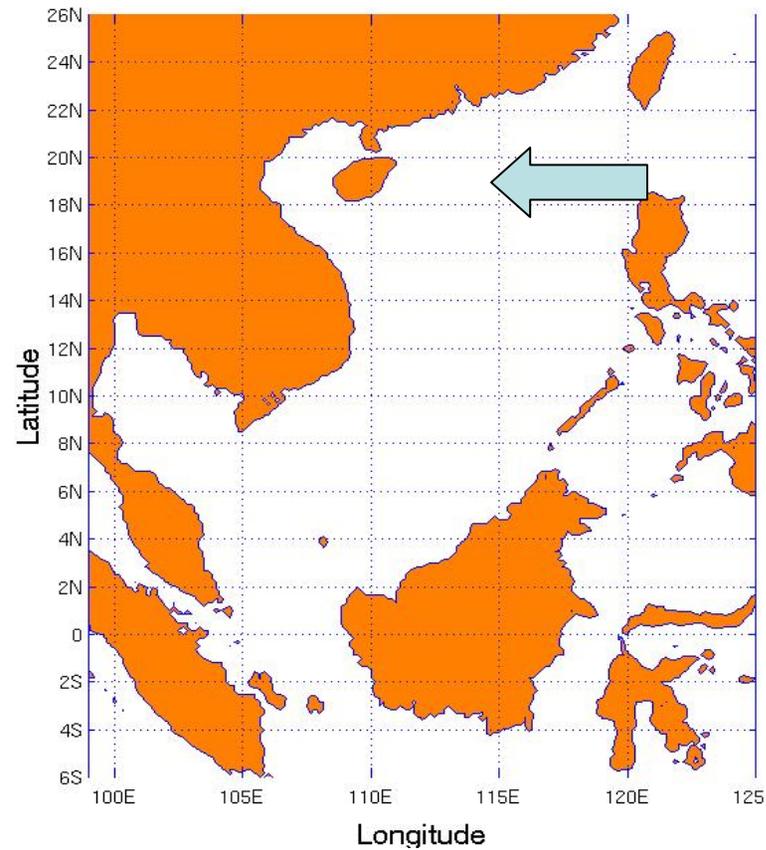


Identified Eddies

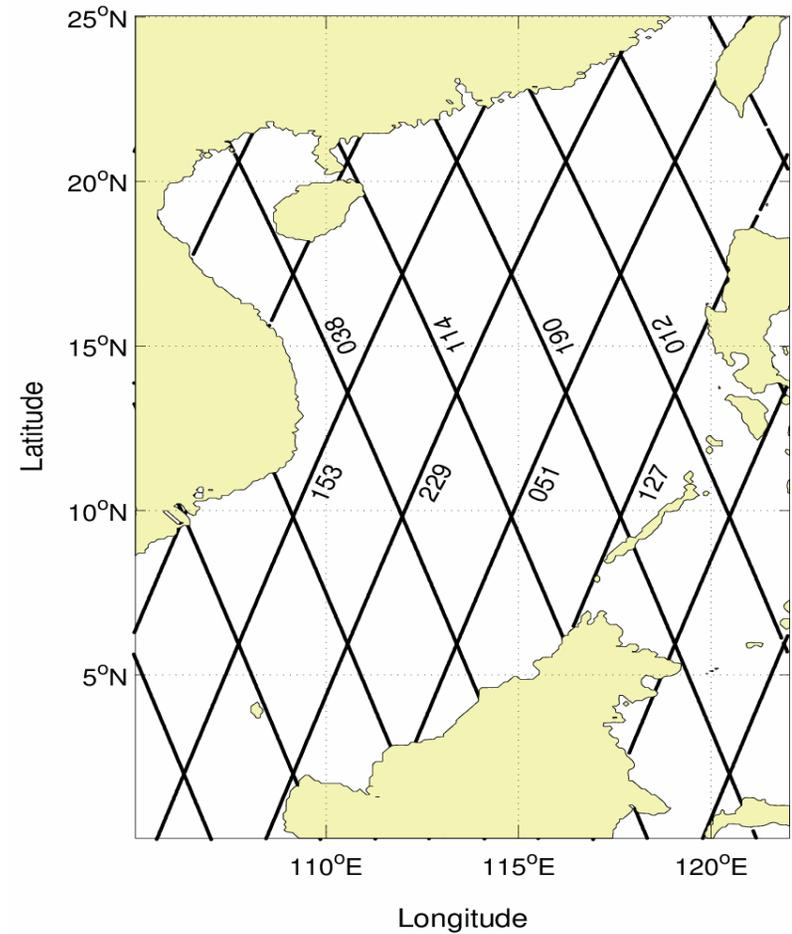
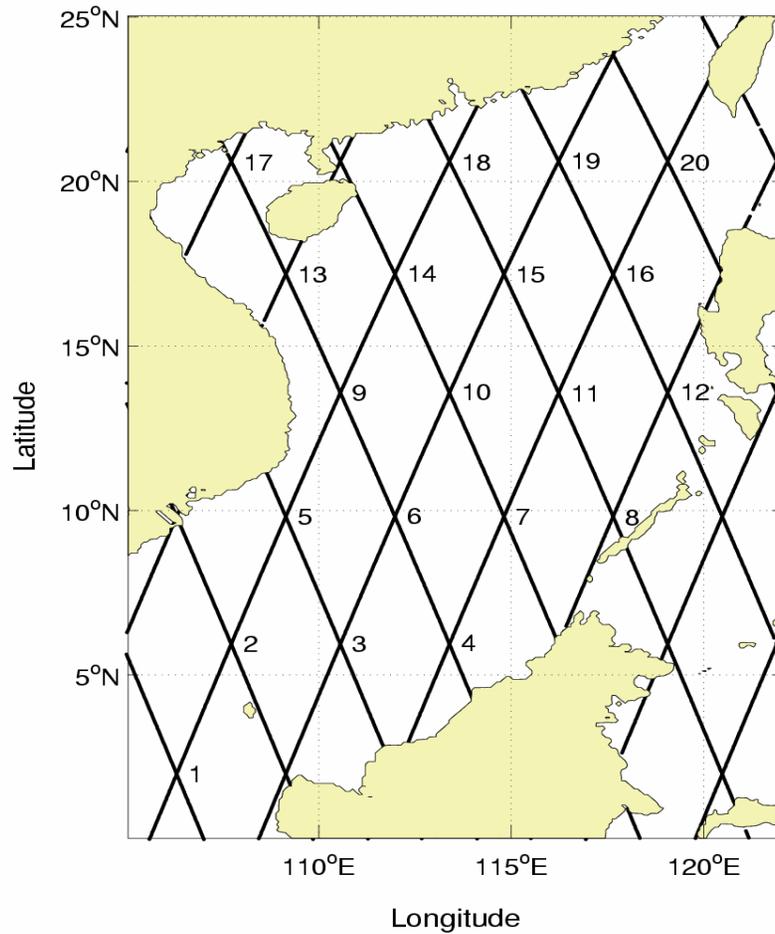


Rossby Waves in SCS

- Rossby Waves Propagation in Northern SCS

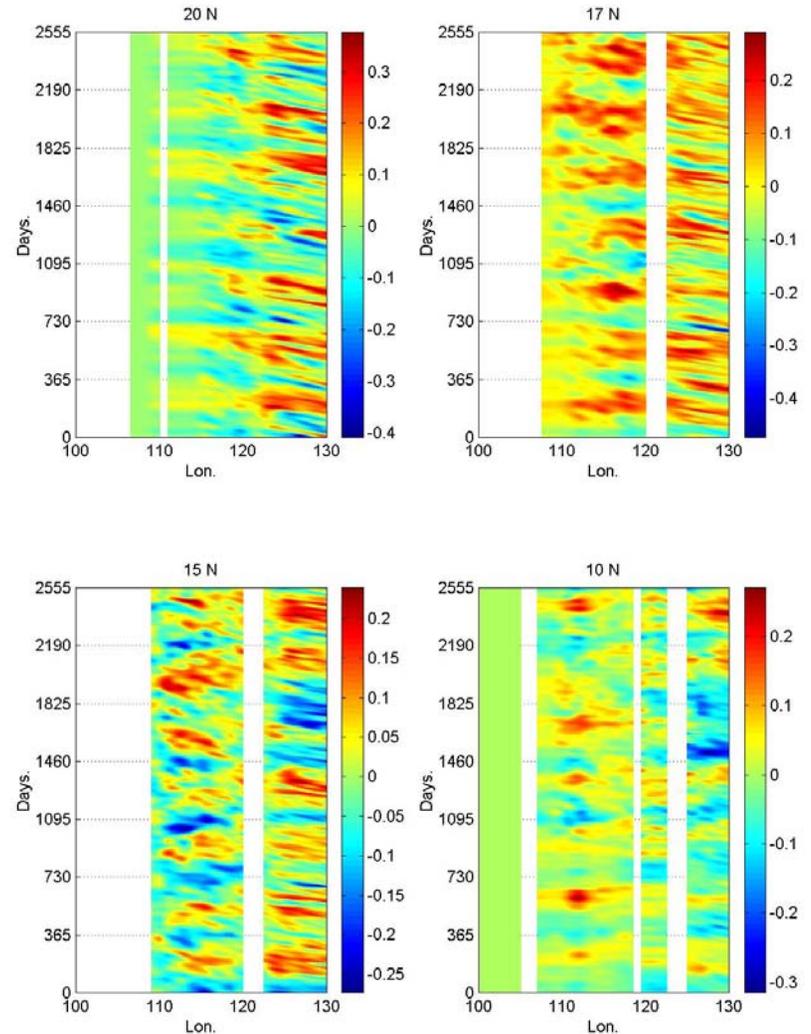


TOPEX/POSEIDON Tracks

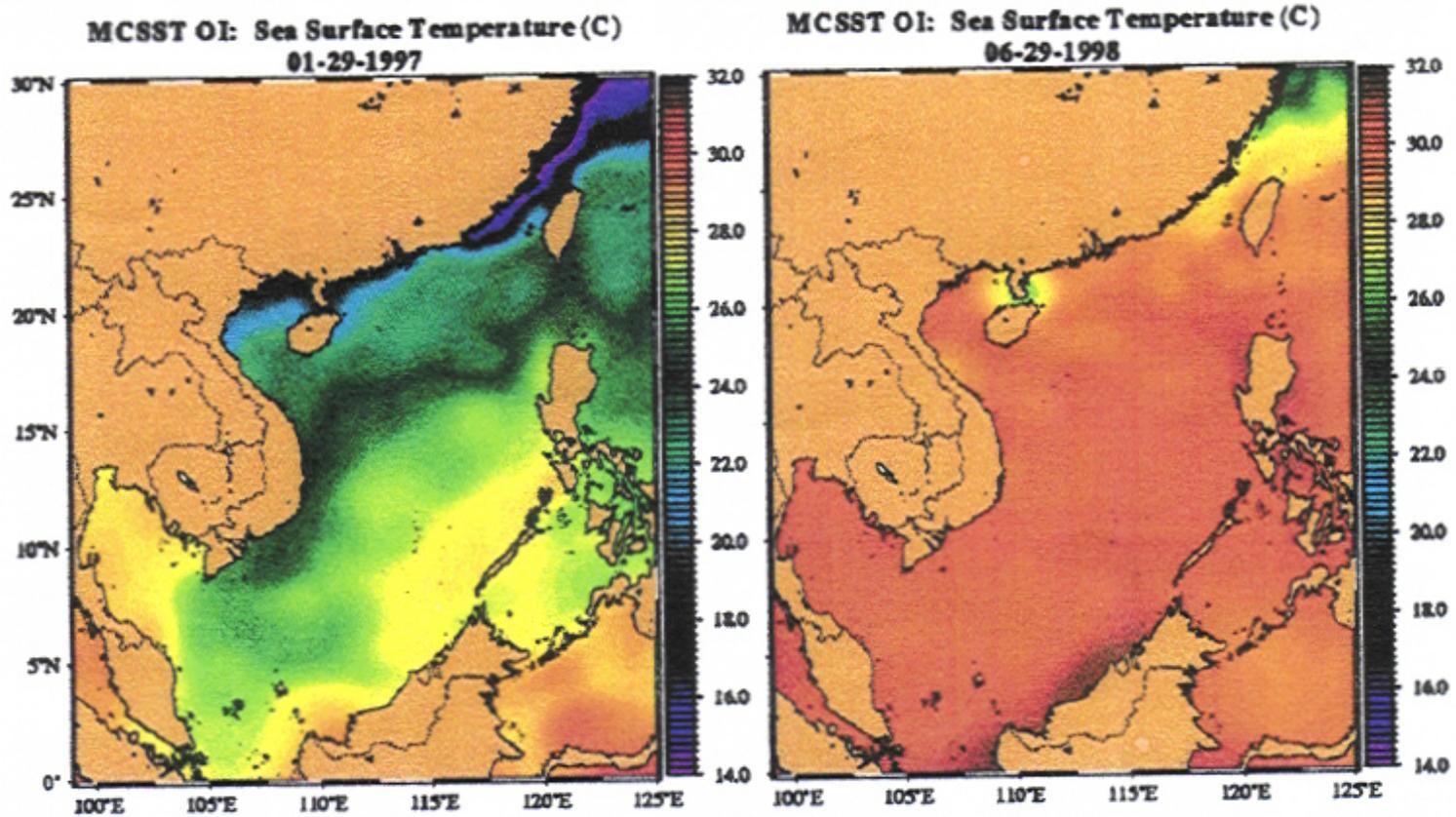


SSH Anomaly (Interpolated using MODAS)

- Westward propagation in northern SCS (15°, 17°, 20°N)
- No apparent westward propagation at 10°N
- Day-0: January 1, 1993
Day-2555: December 31, 1999.



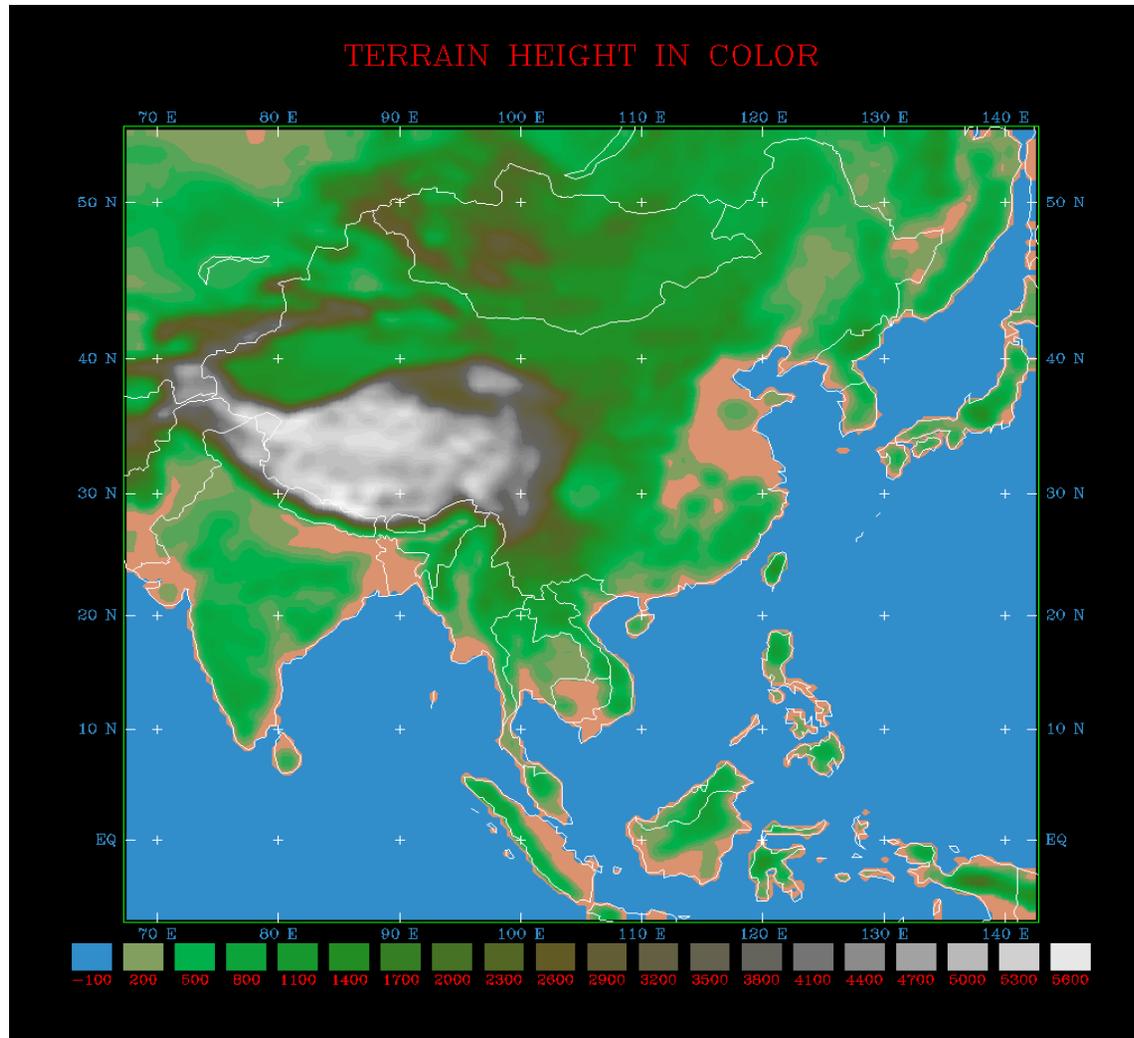
Thermohaline Front



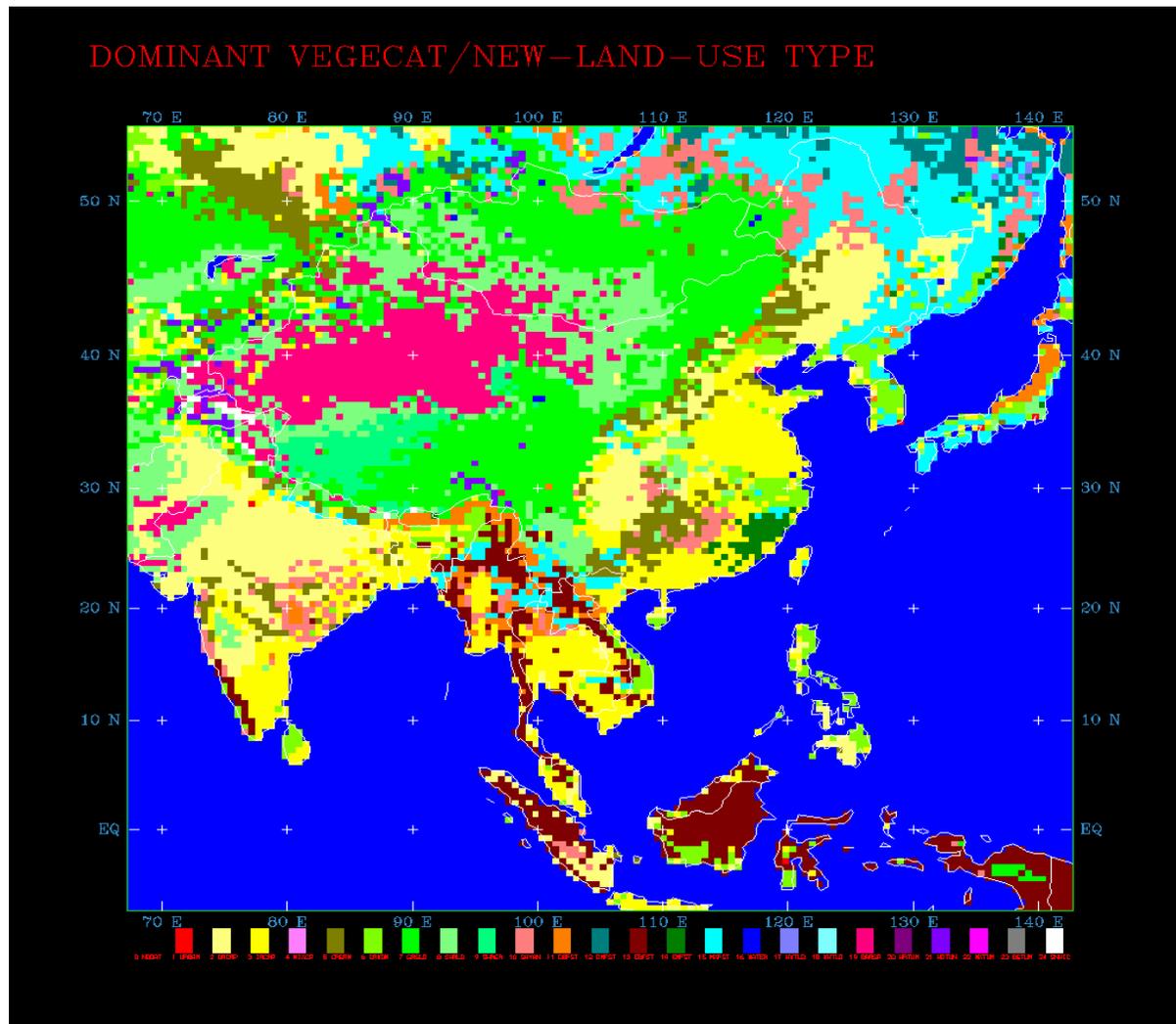
Coastal Air-Ocean Coupled System (CAOCS)

Chu et al. (1999, 2000)

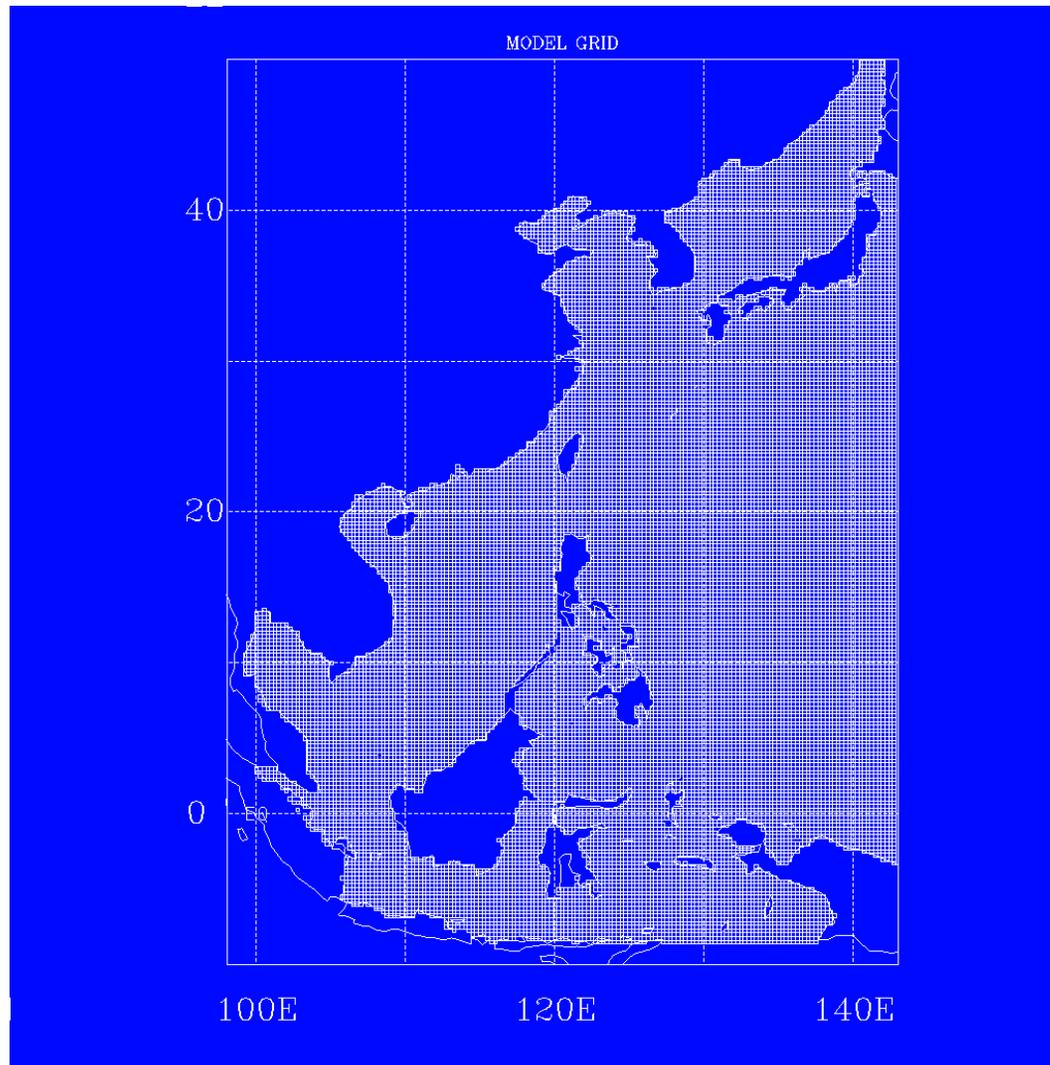
Area for Atmospheric Model



Distribution of Vegetation



Area for Ocean Model



CAOCS Numerics

- MM5V3.4
 - Resolution
 - Horizontal: 30 km
 - Vertical: 16 Pressure Levels
 - Time step: 2 min
- POM
 - Resolution
 - Horizontal: $1/6^\circ \times 1/6^\circ$
 - Vertical: 23 σ levels
 - Time Steps: 25 s, 15 min

Ocean-Atmospheric Coupling

- Surface fluxes (excluding solar radiation) are of opposite signs and applied synchronously to MM5 and POM
- MM5 and POM Update fluxes every 15 min
- SST for MM5 is obtained from POM
- Ocean wave effects (ongoing)

Lateral Boundary Conditions

- MM5: ECMWF T42
- POM: Lateral Transport at 142°E

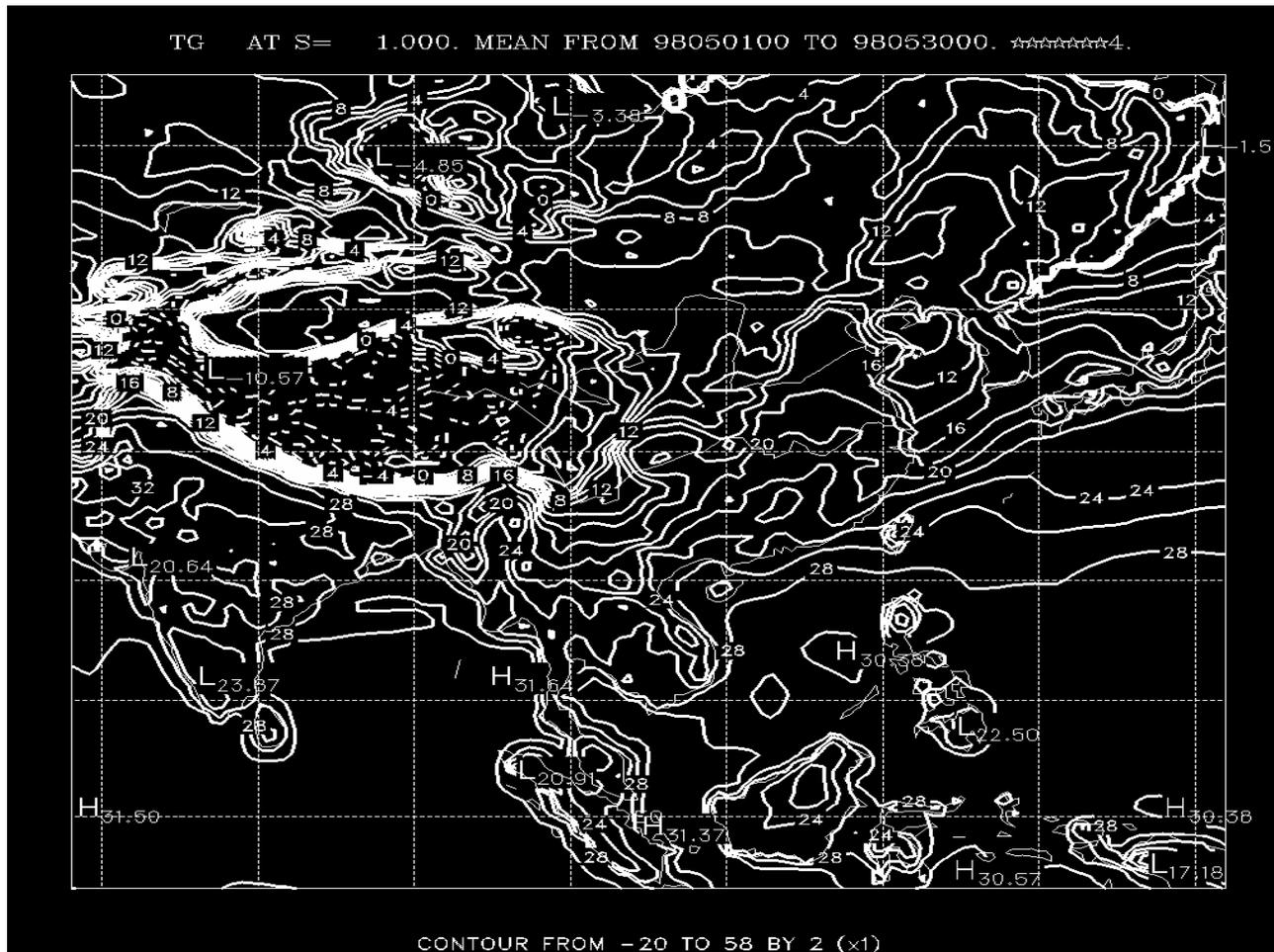
MM5 Initialization

- Initialized from: 30 April 1998 (ECMWF T42)

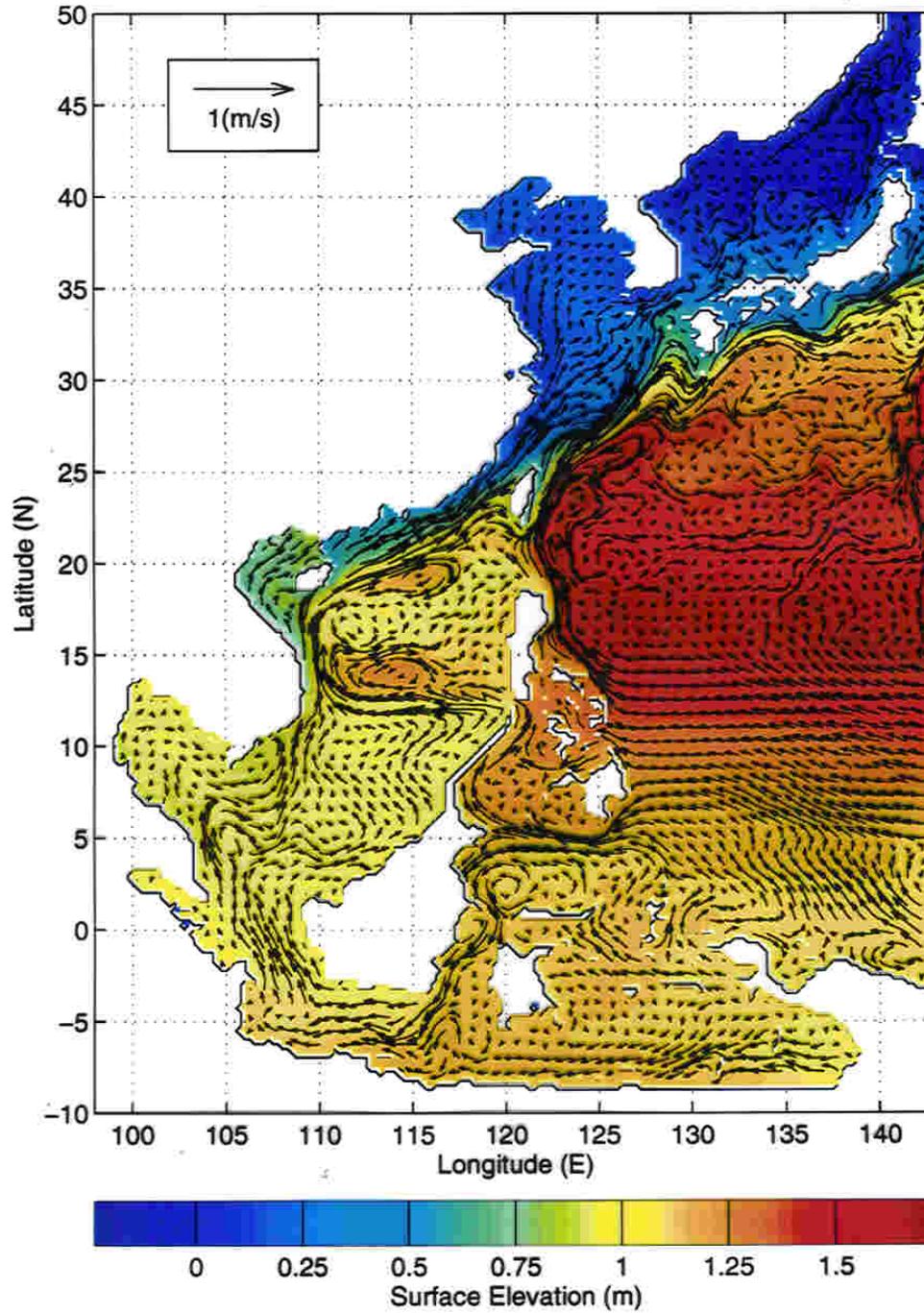
Three-Step Initialization of POM

- (1) Spin-up
 - Initial conditions: annual mean (T,S) + zero velocity
 - Climatological annual mean winds + Restoring type thermohaline flux (2 years)
- (2) Climatological Forcing
 - Monthly mean winds + thermohaline fluxes from COADS (3 years)
- (3) Synoptic Forcing
 - Winds and thermohaline fluxes from NCEP (1/1/96 – 4/30/98)
- (4) The final state of the previous step is the initial state of the following step

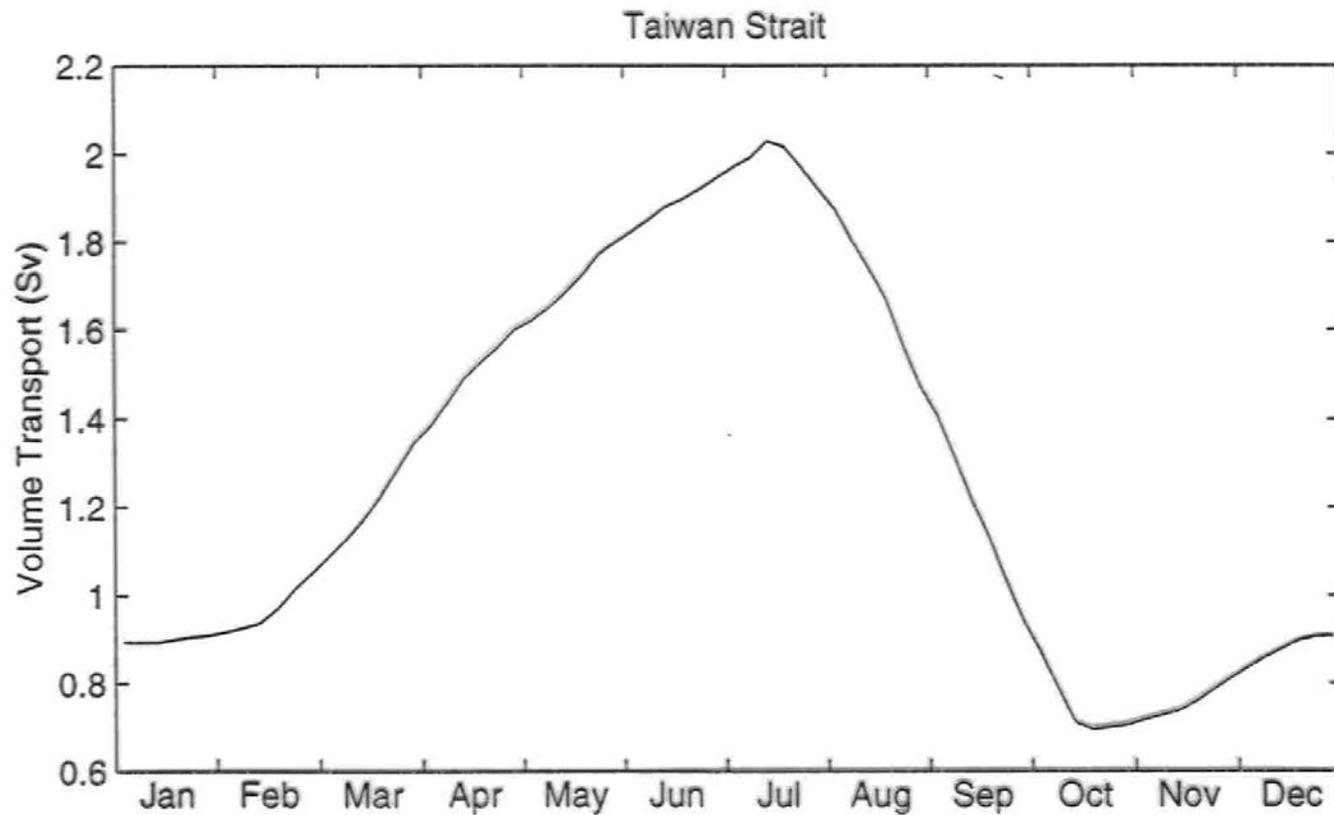
Simulated Surface Air Temperature, May 98



Simulated 1998 Jun Surface Elevation and Velocity Fields



Volume Transport (Sv) Through Taiwan Strait



Conclusions

- SCS is a natural lab for various dynamical problems.
- Different regimes
 - Northern SCS: Rossby wave dynamics, Kuroshio intrusion, monsoon
 - Southern SCS: monsoon
- More observations needed