South China Sea Circulation and Thermohaline Structure

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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)


References – SCS Thermohaline Structure (Eddy-Scale)


References - SCS Circulation


References – SCS Modeling


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 insulation

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

<table>
<thead>
<tr>
<th>Tropical Cyclone</th>
<th>Number</th>
<th>TC Name</th>
<th>Times</th>
<th>Start/End Date</th>
<th>Start/end Coordinate</th>
<th>Tend toward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Depression</td>
<td>03W</td>
<td></td>
<td>21 – 22 May</td>
<td>21 00h – 22 00h</td>
<td>118.3E,18.3N 125.1E,21.0N</td>
<td>SW-NE</td>
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<tr>
<td>Tropical Depression</td>
<td>04W</td>
<td></td>
<td>29 May–01 Jun</td>
<td>29 00h – 01 12h</td>
<td>133.4E,13.1N 147.1E,42.3N</td>
<td>SE-NW</td>
</tr>
<tr>
<td>Typhoon</td>
<td>06W</td>
<td>KAI-TAK</td>
<td>03 – 11 Jul</td>
<td>03 06h – 11 00h</td>
<td>118.1E,15.7N 123.9E,38.0N</td>
<td>S-N-NE</td>
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<tr>
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<td>07W</td>
<td></td>
<td>11 – 15 Jul</td>
<td>11 00h – 15 00h</td>
<td>130.6E,10.0N 113.9E,17.2N</td>
<td>SSE-NNW</td>
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<tr>
<td>Tropical Depression</td>
<td>08W</td>
<td></td>
<td>14 – 17 Jul</td>
<td>14 12h – 17 12h</td>
<td>115.9E,16.1N 111.8E,22.7N</td>
<td>SE-NNW</td>
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<tr>
<td>Tropical Depression</td>
<td>18W</td>
<td></td>
<td>17 – 24 Aug</td>
<td>17 06h – 24 06h</td>
<td>139.2E,08.3N 116.0E,26.5N</td>
<td>SE-NW</td>
</tr>
<tr>
<td>Tropical Storm</td>
<td>19W</td>
<td>KAEMI</td>
<td>18 – 23 Aug</td>
<td>18 18h – 23 00h</td>
<td>114.7E,11.0N 106.2E,16.5N</td>
<td>SE-NW</td>
</tr>
<tr>
<td>Tropical Storm</td>
<td>21W</td>
<td>MARIA</td>
<td>27 Aug–01 Sep</td>
<td>27 12h – 01 18h</td>
<td>115.2E,21.4N 113.8E,26.1N</td>
<td>N-S-CN-NNW</td>
</tr>
<tr>
<td>Typhoon</td>
<td>23W</td>
<td>WUKONG</td>
<td>04 – 10 Sep</td>
<td>04 18h – 10 12h</td>
<td>116.9E,16.9N 104.3E,18.3N</td>
<td>SE-NE-CW</td>
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<tr>
<td>Tropical Storm</td>
<td>28W</td>
<td></td>
<td>06 – 14 Oct</td>
<td>06 18h – 14 18h</td>
<td>110.5E,10.8N 109.5E,17.4N</td>
<td>SW-E-C9-W</td>
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<tr>
<td>Typhoon</td>
<td>30W</td>
<td>XANGSANE</td>
<td>25 Oct–01 Nov</td>
<td>25 06h – 01 18h</td>
<td>137.2E,08.6N 129.4E,31.9N</td>
<td>SE-NW C-NE</td>
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<tr>
<td>Typhoon</td>
<td>31W</td>
<td>BEBINCA</td>
<td>30 Oct–08 Nov</td>
<td>30 18h – 08 00h</td>
<td>134.5E,06.8N 112.9E,21.5N</td>
<td>SE-NW</td>
</tr>
<tr>
<td>Tropical Storm</td>
<td>33W</td>
<td>RUMBIA</td>
<td>27 Nov–09 Dec</td>
<td>27 18h – 09 06h</td>
<td>132.4E,08.4N 105.3E,06.8N</td>
<td>E-W</td>
</tr>
</tbody>
</table>
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

- Northern SCS: Eddy (Active)
- Southern SCS: Eddy (Non-active)
AXBT Observations May 14-25, 1995
Temperature

(a) Longitude (E), Depth=0(m)
(b) Longitude (E), Depth=50(m)
(c) Longitude (E), Depth=100(m)
(d) Longitude (E), Depth=200(m)
(e) Longitude (E), Depth=300(m)
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
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° × 1/6°
    - 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

1 (m/s)

Latitude (N)

Longitude (E)

Surface Elevation (m)

0 0.25 0.5 0.75 1 1.25 1.5
Volume Transport (Sv) Through Taiwan Strait

![Volume Transport (Sv) Through Taiwan Strait](image)
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