Interannual and Interdecadal Variations of Tropical Cyclone Activity in the South China Sea

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Introduction

• Tropical Cyclones (TCs)
  – Storms with wind speeds > 40 km/h
  – Typical occurrences: May to October
  – Areas of interest:
    • Western North Pacific (WNP) (West of 180°)
    • South China Sea (SCS) (0° to 25° N, 100° to 120° E)

• TCs in WNP
  – Occurrences affected by El-Niño Southern Oscillation (ENSO)
  – Interdecadal and interannual variations observed
Introduction

• Factors Affecting Cyclogenesis (Gray 1979)*
  – 850mb Vorticity
  – Vertical Shear of Horizontal Wind
  – Sea Surface Temperature
  – Coriolis Parameter
  – Mid-level Moisture
  – Low- to Mid-level Moist Instability

Introduction

• Factors Affecting Movement
  – 500mb Height Gradient
  – 500mb Wind

• TCs inside SCS
  – Formed in SCS
    • Depends on the conditions in SCS?
  – Entered SCS
    • Formed in the WNP and then moved in?
Objectives

• To study the variations in number of TCs inside the SCS;
• To determine the factors leading to changes in the frequency of TC occurrences in the SCS;
• To decide if and how large-scale atmospheric phenomena can have an effect on the factors affecting TC behaviour
TC Data

- Hong Kong Observatory TC data from 1946 to 2005 (60 years)
- Only those after 1965 used (41 years)
- Only those with at least tropical storm strength (max winds >65 km/h) used
- Season divided into 2 halves
  - 1st: May to August
  - 2nd: September to December
- TCs can enter SCS from WNP (ENT) or formed inside SCS (FORM)
Flow Pattern Data

- NCEP Reanalysis data starting from 1965
- Parameters studied:
  - 850-hPa vorticity
  - 850-hPa height
  - 200-hPa – 850-hPa wind shear
  - 200-hPa divergence
  - 500-hPa height
  - Moist static energy
  - 500-hPa u-wind
- May to December, divided into 2 seasons
- Anomalies, EOF calculated
### Wavelet Analysis

<table>
<thead>
<tr>
<th>ENT</th>
<th>EARLY</th>
<th>LATE</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="chart1.png" alt="Wavelet Analysis Chart" /></td>
<td><img src="chart2.png" alt="Wavelet Analysis Chart" /></td>
<td><img src="chart3.png" alt="Wavelet Analysis Chart" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FORM</th>
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</tr>
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<tbody>
<tr>
<td><img src="chart4.png" alt="Wavelet Analysis Chart" /></td>
<td><img src="chart5.png" alt="Wavelet Analysis Chart" /></td>
<td><img src="chart6.png" alt="Wavelet Analysis Chart" /></td>
</tr>
</tbody>
</table>
TC Trends (per 100 years)

**WHOLE**
- TOT: -5.7 (95%)
- ENT: -5.2 (95%)
- FORM: -0.2 (not sig)

**EARLY**
- TOT: -2.4 (95%)
- ENT: -2.6 (95%)
- FORM: +0.2 (not sig)

**LATE**
- TOT: -2.6 (95%)
- ENT: -2.1 (95%)
- FORM: -0.5 (not sig)
## Effect of ENSO

<table>
<thead>
<tr>
<th>Above/Below</th>
<th>EN (12 events)</th>
<th>LN (10 events)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Whole</td>
<td>Early</td>
</tr>
<tr>
<td>TOT</td>
<td>1/5</td>
<td>2/1</td>
</tr>
<tr>
<td>ENT</td>
<td>3/6</td>
<td>3/4</td>
</tr>
<tr>
<td>FORM</td>
<td>5/4</td>
<td>5/3</td>
</tr>
</tbody>
</table>

- Effect more prominent in late season
  - Due to ENSO peaking in winter
- Effect on ENT apparently more significant than on FORM
# Effect of PDO

<table>
<thead>
<tr>
<th>Above/Below</th>
<th>PDO+ (16 events)</th>
<th>PDO- (13 events)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Whole</td>
<td>Early</td>
</tr>
<tr>
<td>TOT</td>
<td>4/7</td>
<td>3/4</td>
</tr>
<tr>
<td>ENT</td>
<td>4/5</td>
<td>6/4</td>
</tr>
<tr>
<td>FORM</td>
<td>4/6</td>
<td>3/6</td>
</tr>
</tbody>
</table>

- **Effect more prominent in late season**
  - Due to PDO peaking in winter
- **Effect of PDO similar to that of ENSO**
  - Due to possible forcing of PDO by ENSO forcing?
Stepwise Linear Regression

<table>
<thead>
<tr>
<th>Late ENT (R=0.956)</th>
<th>Late FORM (R=0.955)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor</strong></td>
<td><strong>% Var</strong></td>
</tr>
<tr>
<td>500U1</td>
<td>26.72</td>
</tr>
<tr>
<td>500H1</td>
<td>55.09</td>
</tr>
<tr>
<td>MSE3</td>
<td>10.37</td>
</tr>
<tr>
<td>VOR2</td>
<td>13.98</td>
</tr>
<tr>
<td>DIV3</td>
<td>11.03</td>
</tr>
<tr>
<td>500H3</td>
<td>9.65</td>
</tr>
<tr>
<td>500H2</td>
<td>19.22</td>
</tr>
<tr>
<td>VOR1</td>
<td>17.08</td>
</tr>
</tbody>
</table>

- 500U: 500-hPa zonal wind, DIV: 200-hPa divergence, 500H: 500-hPa geopotential height, 850H: 850-hPa geopotential height, MSE: moist static energy, SHR: 200-850-hPa shear, and VOR: 850-hPa vorticity. The last number indicates the EOF, 1 for the first EOF, 2 for the second etc.
### FORM in late season

<table>
<thead>
<tr>
<th>FORM</th>
<th>EN (12 events)</th>
<th>LN (10 events)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late</td>
<td>Above: 2, Below: 1</td>
<td>Above: 5, Below: 1</td>
</tr>
</tbody>
</table>

#### EN Composites

**500U1 (ms⁻¹)**

#### LN Composites

**DIV3 (×10⁻⁶ s⁻¹)**
FORM in late season

EN Composites

LN Composites

MSE1 (×10^6 Wm^-2)

SHR3 (ms^-1)
**FORM in late season**

<table>
<thead>
<tr>
<th>FORM</th>
<th>PDO+ (16 events)</th>
<th>PDO- (13 events)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late</td>
<td>Above: 2, Below: 3</td>
<td>Above: 4, Below: 0</td>
</tr>
</tbody>
</table>

**500U1 (ms\(^{-1}\))**

**PDO+ Composites**

**DIV2 (x10\(^{-6}\) s\(^{-1}\))**

**PDO- Composites**
FORM in late season

PDO+ Composites

PDO- Composites

MSE1 ($\times 10^6$ Wm$^{-2}$)

MSE2 ($\times 10^6$ Wm$^{-2}$)
FORM in late season

PDO+ Composites

PDO- Composites

SHR3 (ms\(^{-1}\))
## ENT in late season

<table>
<thead>
<tr>
<th>ENT</th>
<th>EN (12 events)</th>
<th>LN (10 events)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late</td>
<td>Above: 2, Below: 8</td>
<td>Above: 5, Below: 1</td>
</tr>
</tbody>
</table>

### EN Composites

**500U1 (ms\(^{-1}\))**

![EN Composites](image1)

### LN Composites

**500H1 (gpm)**

![LN Composites](image2)
ENT in late season

500H2 (gpm)

500H3 (gpm)
ENT in late season

EN Composites

LN Composites

DIV3 \( (\times 10^{-6} \text{ s}^{-1}) \)

MSE3 \( (\times 10^6 \text{ Wm}^{-2}) \)
ENT in late season

VOR2 \( \times 10^{-6} \text{ s}^{-1} \)

EN Composites

LN Composites
ENT in late season

<table>
<thead>
<tr>
<th>ENT</th>
<th>PDO+ (16 events)</th>
<th>PDO- (13 events)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late</td>
<td>Above: 5, Below: 10</td>
<td>Above: 5, Below: 1</td>
</tr>
</tbody>
</table>

**PDO+ Composites**

500U1 (ms⁻¹)

**PDO- Composites**

500H2 (gpm)
ENT in late season

PDO+ Composites

PDO- Composites

500H3 (gpm)

MSE3 ($\times 10^6$ Wm$^{-2}$)
ENT in late season

PDO+ Composites

PDO- Composites

VOR1 (×10^{-6} s^{-1})

VOR2 (×10^{-6} s^{-1})
Summary

• SCS TCs show interannual and interdecadal variations
• ENT: Decreasing trend, FORM: no trend
• ENT:
  – EN, PDO+: Below-normal
    • WNP formation inhibited, TCs recurve
  – LN, PDO-: Above-normal
    • WNP formation, easterly flow prevail
Summary

• FORM:
  – EN vs LN:
    • Below-normal vs Above-normal
    • SCS formation inhibited vs preferred
    • Location & strength of monsoon trough
      → North-South discrepancy
  – PDO+ vs PDO-:
    • Below-normal vs Above-normal
    • Difference more due to dynamical factors
    • Monsoon trough virtually constant
      → No North-South discrepancy
Conclusion

ENSO and PDO

Variations in factors affecting TC activities

Interannual and interdecadal variations in SCS TCs
THANK YOU