Fast Warming in the Northwestern Pacific Ocean- Contribution by Modulation of Annual Cycle

Xiaopei Lin, Dexing Wu, Lixin Wu
Physical Oceanography Laboratory
Ocean University of China
linxiaop@ouc.edu.cn

Ping Chang
Texas A&M University
The typical climate modes have a SST anomaly of 1-2 °C.

The amplitude of SST annual cycle can be 10-20 °C.

SST Annual Range from HadISST (1979–2009)
We already know the interannual to decadal variability could affect the SST trend. How about the changing of annual cycle?

\[ \text{Trend (annual mean)} = \text{Trend (annual cycle)} + \text{Trend (system)} \]

Huang et al., 2012
1 The global warming is uneven in the ocean

2 SST trend—“hot spot” in western boundary region
The fast warming region in North Western Pacific also has the maximum annual cycle.
Warming in the winter is stronger than in the summer

<table>
<thead>
<tr>
<th>Data</th>
<th>Hadley</th>
<th>OAflux</th>
<th>ICOADS</th>
<th>MERRA</th>
<th>CFSR</th>
<th>ERA_interim</th>
<th>OFES</th>
<th>SODA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>0.0411</td>
<td>0.0382</td>
<td>0.0525</td>
<td>0.0355</td>
<td>0.0254</td>
<td>0.0360</td>
<td>0.0265</td>
<td>0.0463</td>
</tr>
<tr>
<td>Summer</td>
<td>0.0270</td>
<td>0.0202</td>
<td>0.0412</td>
<td>0.0251</td>
<td>0.0163</td>
<td>0.0199</td>
<td>0.0109</td>
<td>0.0261</td>
</tr>
</tbody>
</table>
The trend of SST during 1960-2001年 (Hydrographic data from about 300000 profiles)

Winter trend

Summer trend
In the Northwest Pacific Ocean, change of annual cycle contributes about 50% SST trend in the past several decades.
The local atmospheric forcing sets an strong annual cycle, with SST gradient large in winter and small in summer.
The ocean advection, like Kuroshio increases in the past several decades.
Heat transport by advection

\[-\vec{u} \cdot \nabla T_m\] W/m²

The ocean advection plays more important role in heat transport in winter than in summer. The increase of ocean transport will make the winter much warmer.
Summary

PDO+
Subtropical Gyre Intensify
Kuroshio transport increase
Local forcing
SST increase
Ocean adjustment
Kuroshio transport increase
Subtropical Gyre Intensify

Decadal ➔ Annual ➔ Trend
We still have a long way to understand changing of annual cycle
Thanks!
Why there is a fast warming?

\[
\frac{\partial T_m}{\partial t} = \frac{Q_{net}}{\rho_0 c_p h_m} - \vec{u} \cdot \nabla T_m - \frac{w_e (T_m - T_d)}{h_m}
\]

- **Mixing layer depth**
- **SST variability**
- **Local Heat Flux**
- **Horizontal Advection**
- **Mixing and upwelling**

- Air-sea interaction
- Downsampling
- Local process
Is this ocean warming cased by the land warming?

Surface Temperature Trends From
IPCC data (1946-1995)

Balling et al., 1998

Warming in the Land is more obvious than in the Ocean

Warming in the Ocean is enhanced in the shallow bathymetry

Surface Temperature Trends From
IPCC Model CCSM3 (1950-2000)
But the observation and reanalysis data show a unique warming pattern …
The Ocean release more heat into the air
CFSR(1979-2009)
Surface Air Temperature at 0m
OAFlux(1958-2010)

SST Trend
ICOADS(1960-2010): SST Annual Mean Trend (alpha=0.05)

ICOADS(1960-2010): SST Summer Trend (alpha=0.05)

ICOADS(1960-2010): SST Winter Trend (alpha=0.05)

Sea Surface Temperature