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

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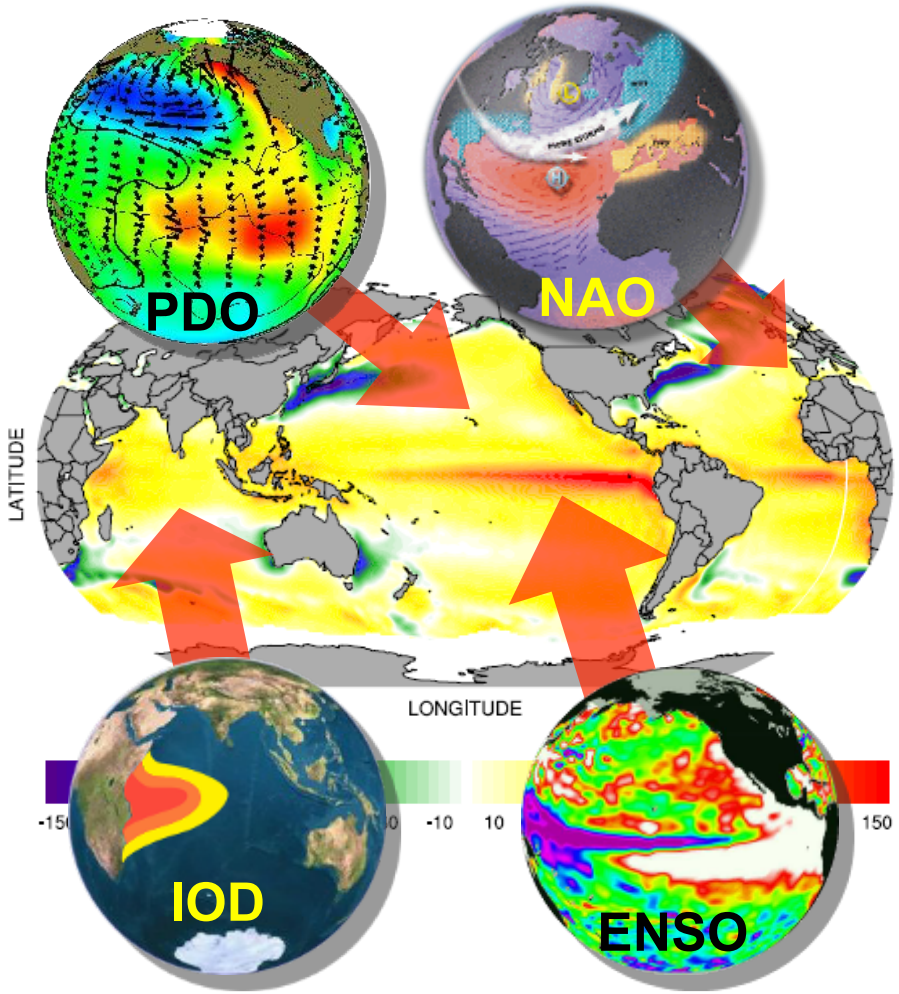
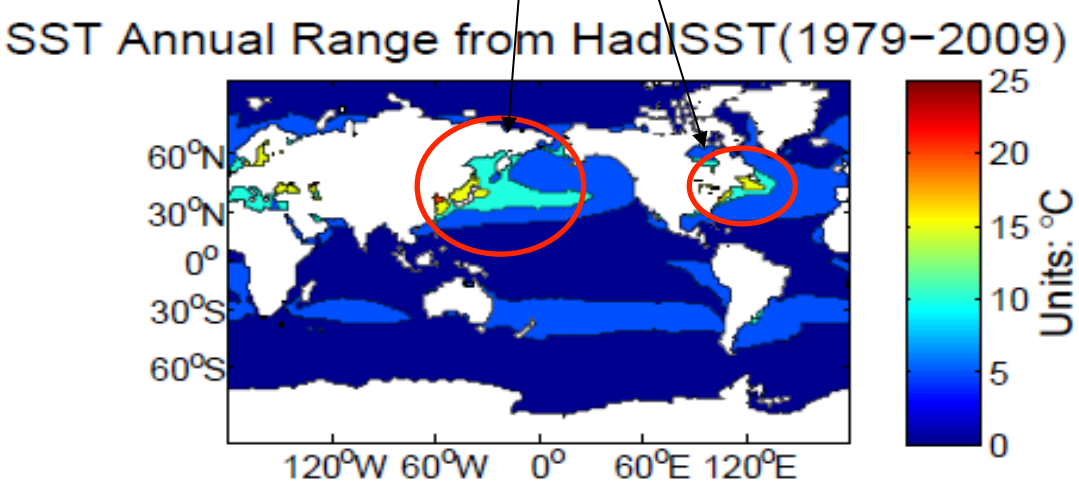
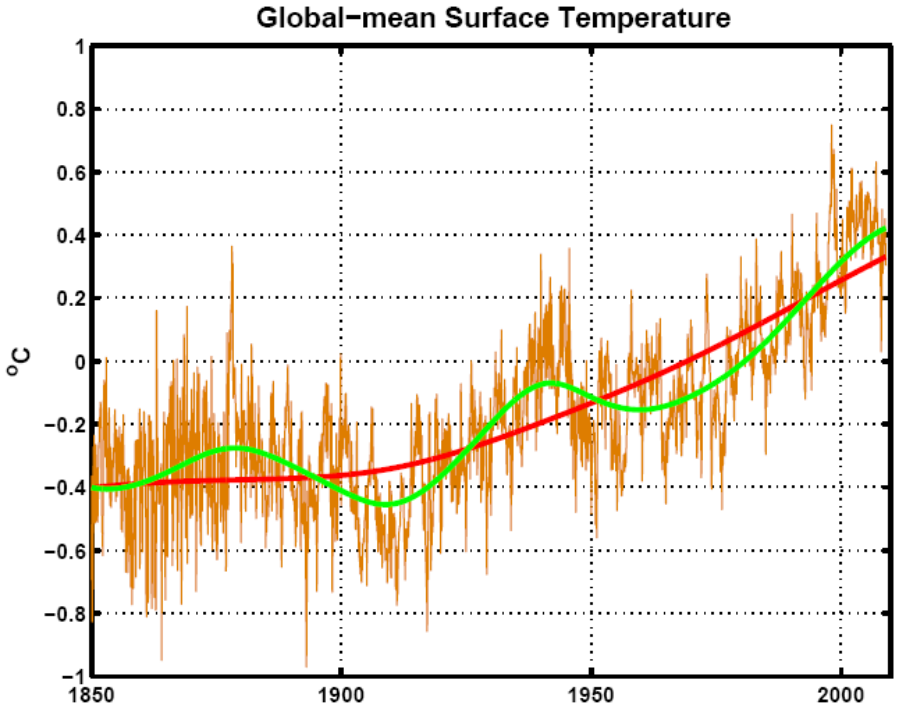
The typical climate modes have a SST anomaly of 1-2 ℃



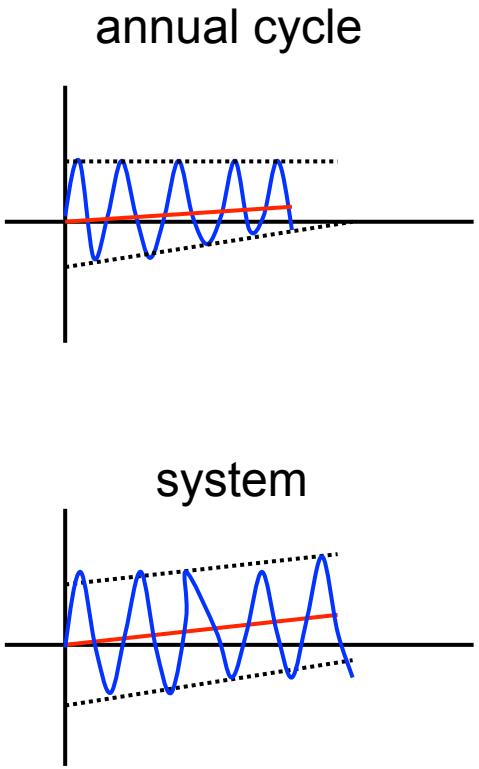
The amplitude of SST annual cycle can be 10-20 ℃



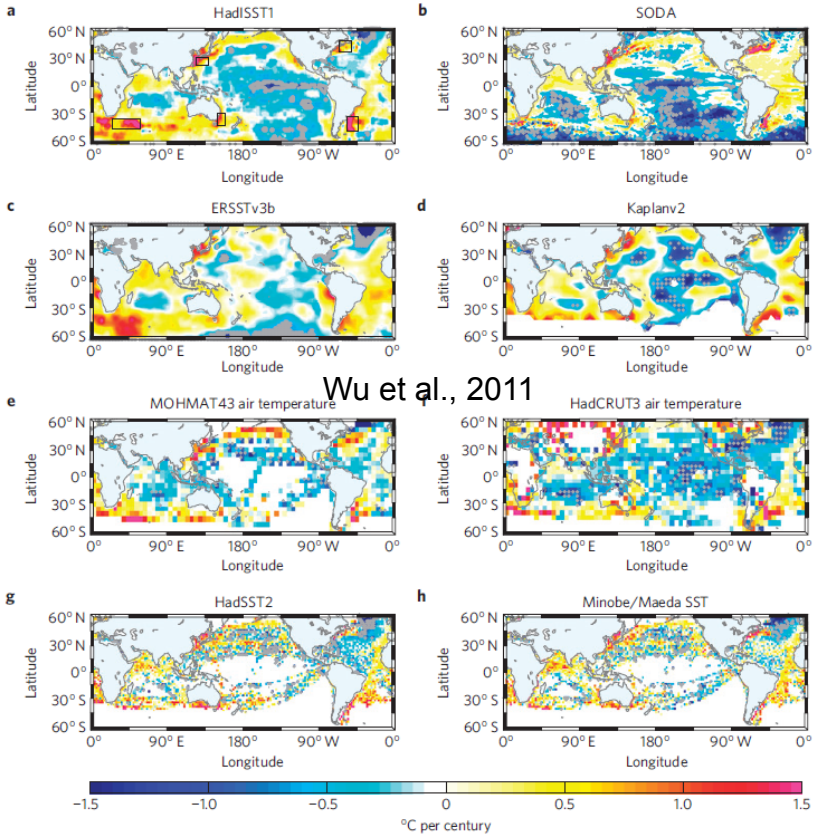
We already know the interannual to decadal variability could affect the SST trend. How about the changing of annual cycle?



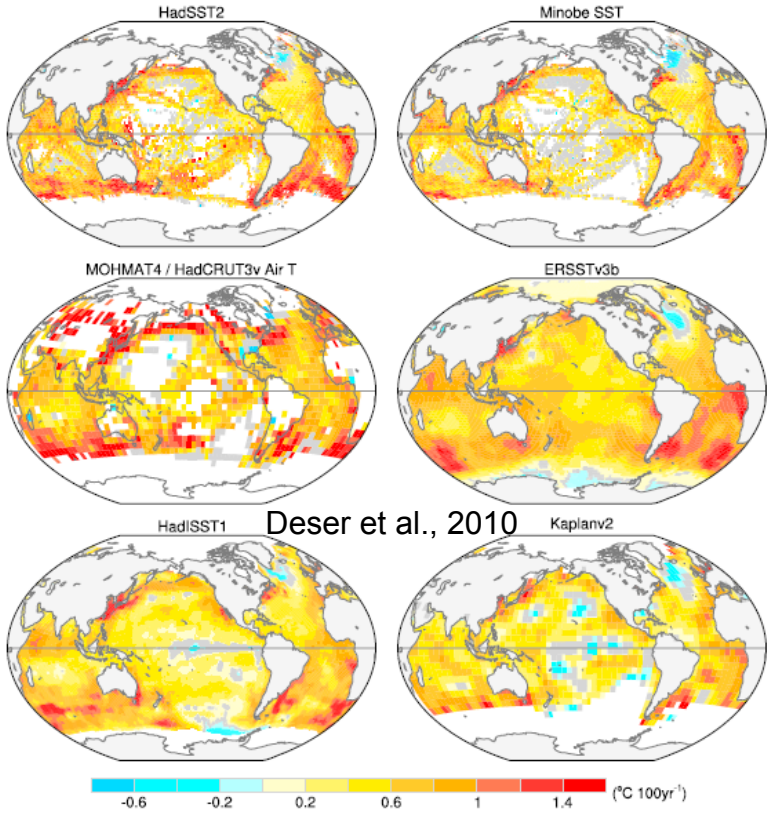
Huang et al., 2012



Trend (annual mean)=Trend (annual cycle) + Trend (system)



Wu et al., 2011



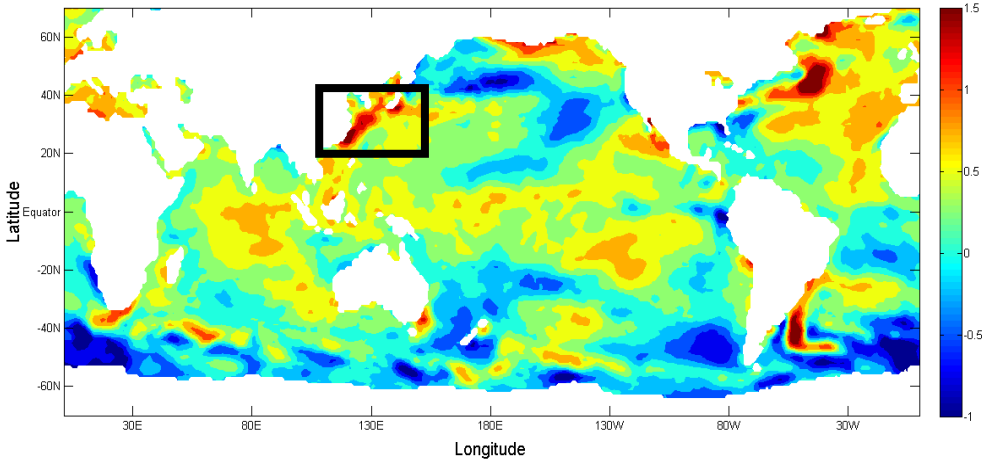
Deser et al., 2010

1 The global warming is uneven in the ocean

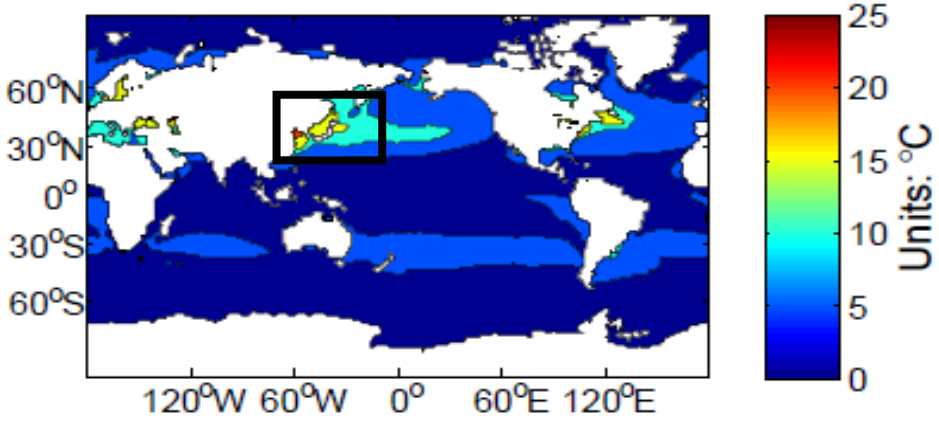
2 SST trend-“hot spot” in western boundary region

The SST Trend in the Past 30 years

Hadley SST trend（1979-2009）

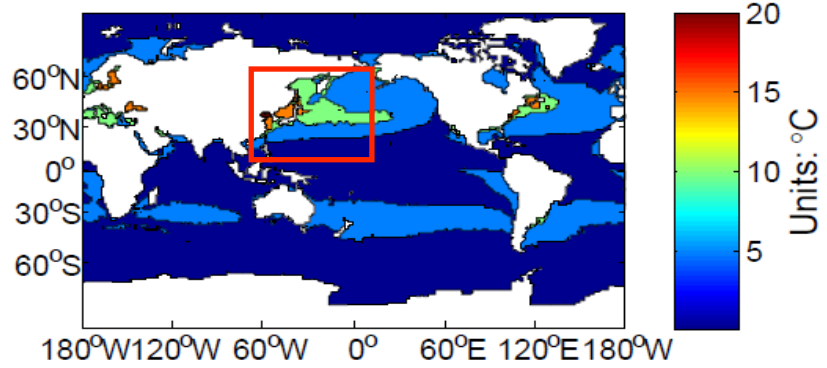


SST Annual Range from HadISST(1979−2009)

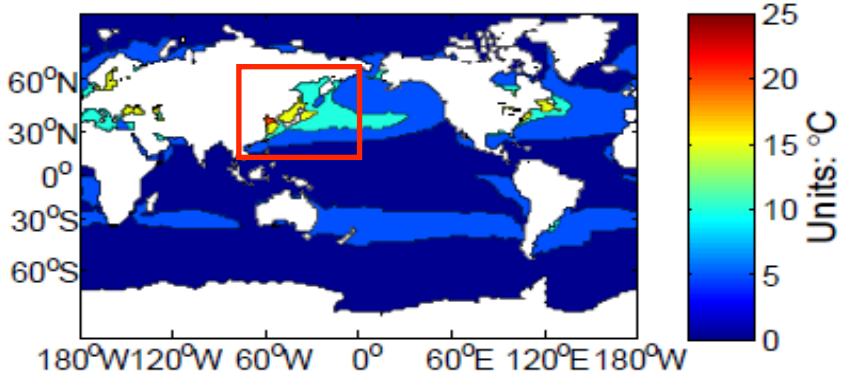


The fast warming region in North Western Pacific also has the maximum annual cycle

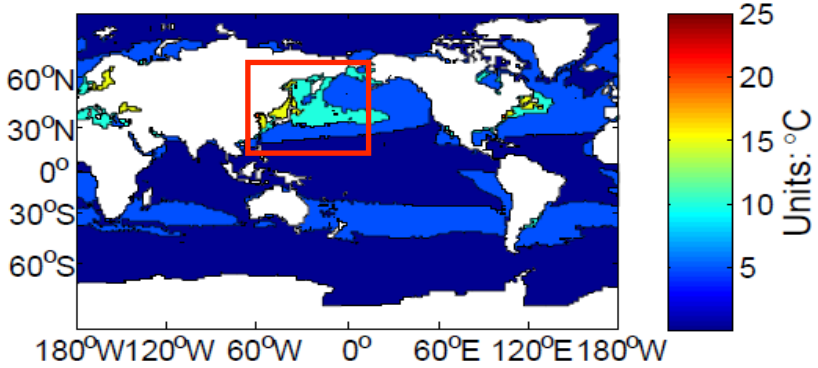
SST Annual Range from CFSR(1979−1989)



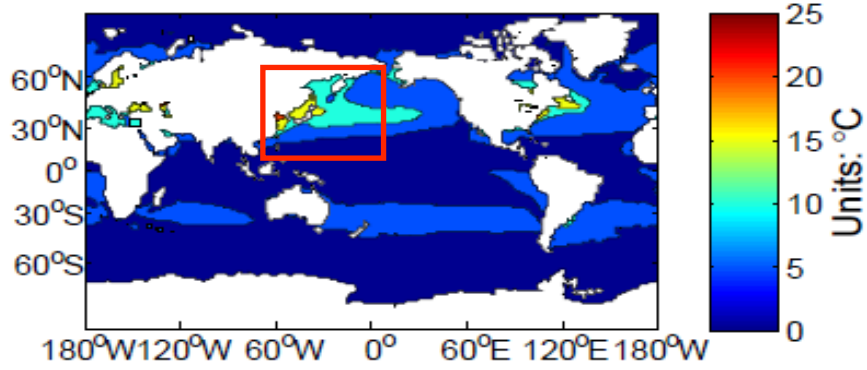
SST Annual Range from HadISST(1979−1989)



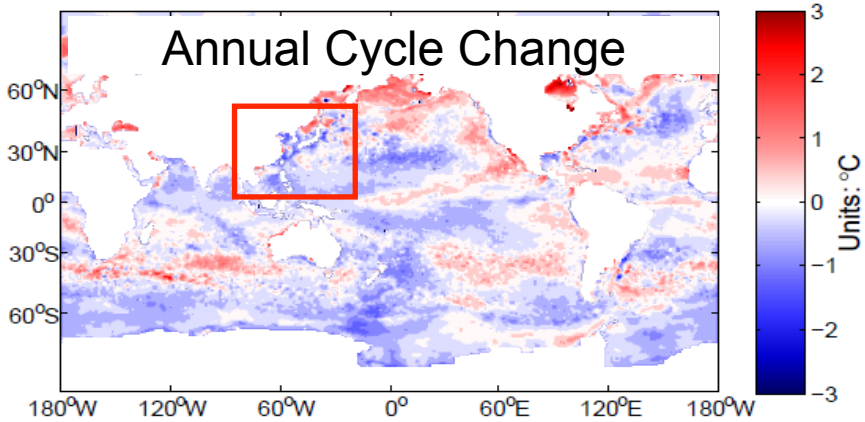
SST Annual Range from CFSR(1999−2009)



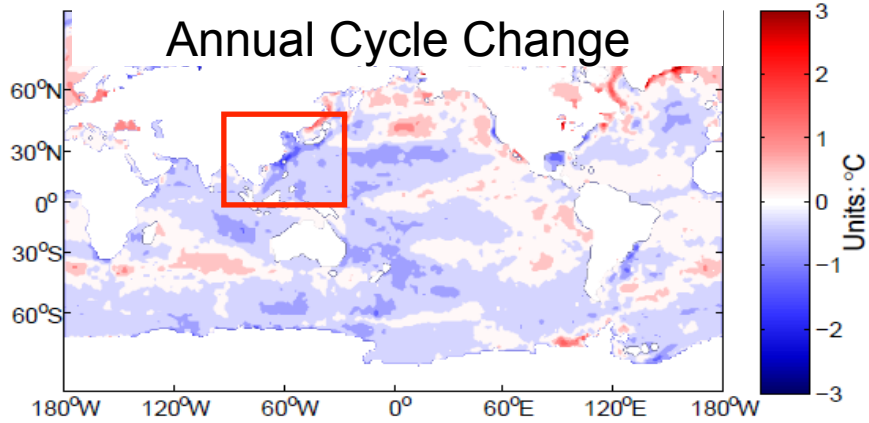
SST Annual Range from HadISST(1999−2009)

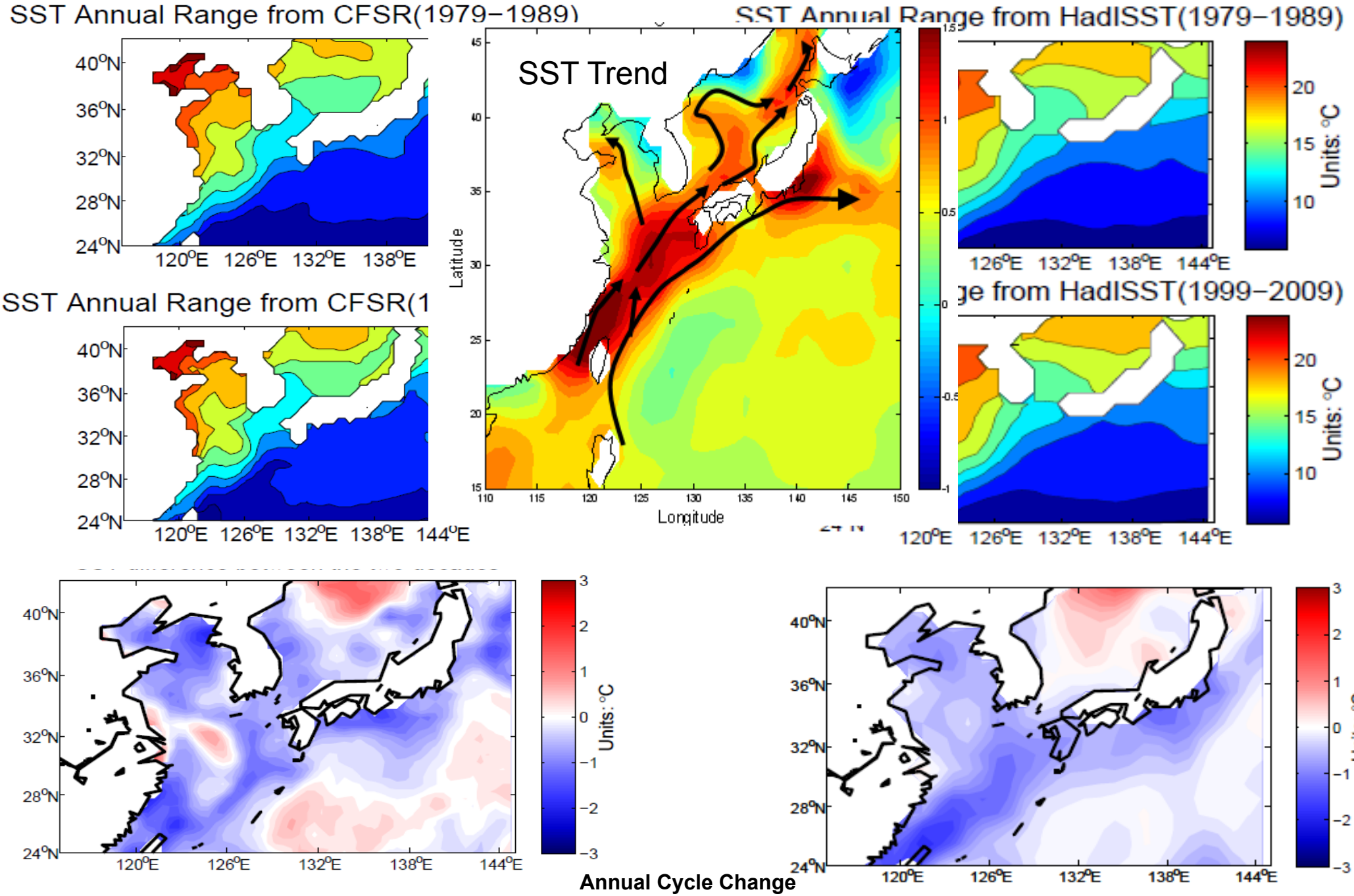


Annual Cycle Change



Annual Cycle Change

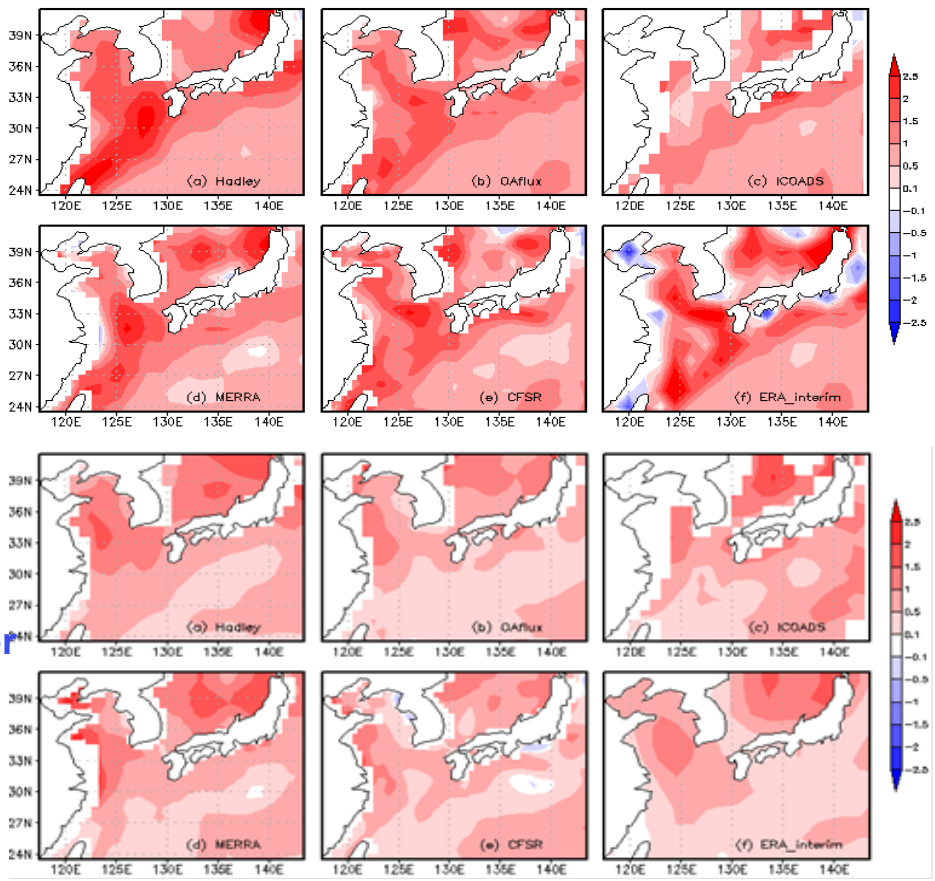



SST Annual Range from CFSR(1979–1989)
SST Annual Range from HadISST(1979–1989)
SST Trend
SST Annual Range from CFSR(1
ge from HadISST(1999–2009)
40°N
36°N
32°N
28°N
24°N
120°E
126°E
132°E
138°E
144°E
Latitude
Longitude
Units: °C
Annual Cycle Change

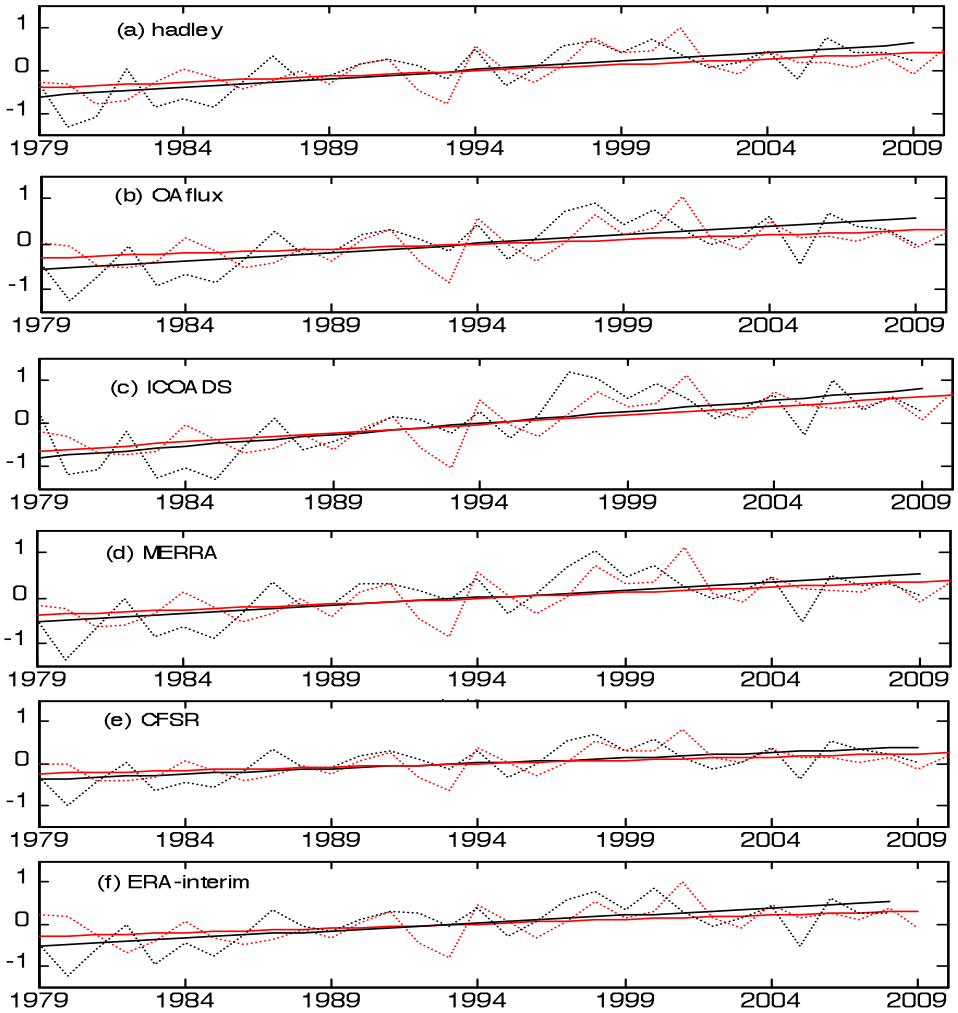
Warming in the winter is stronger than in the summer

winter

summer



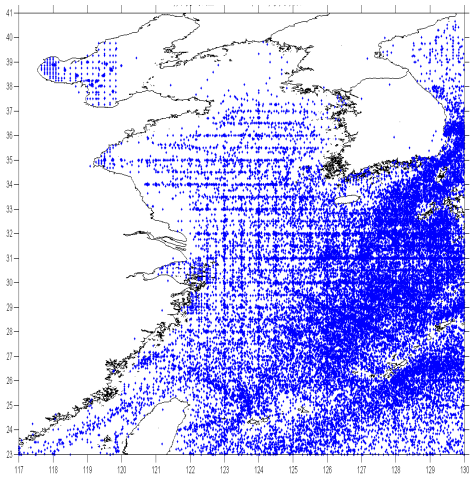
Winter（black）and summer（red）SST trend

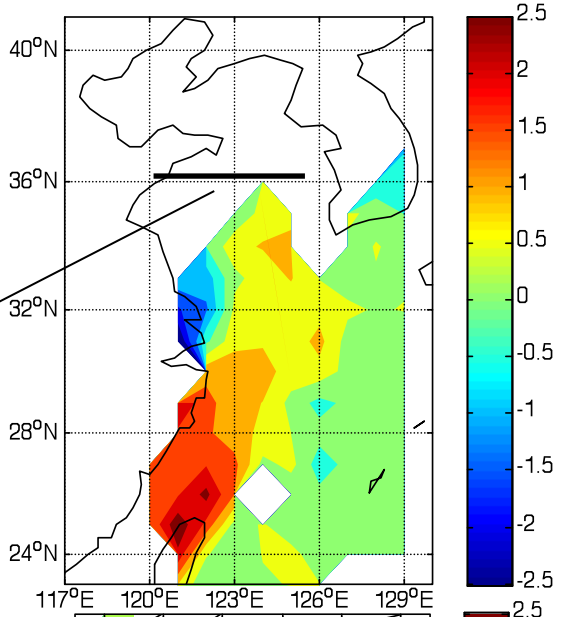


Warming Trend In the Northwest Pacific Ocean ° C/a

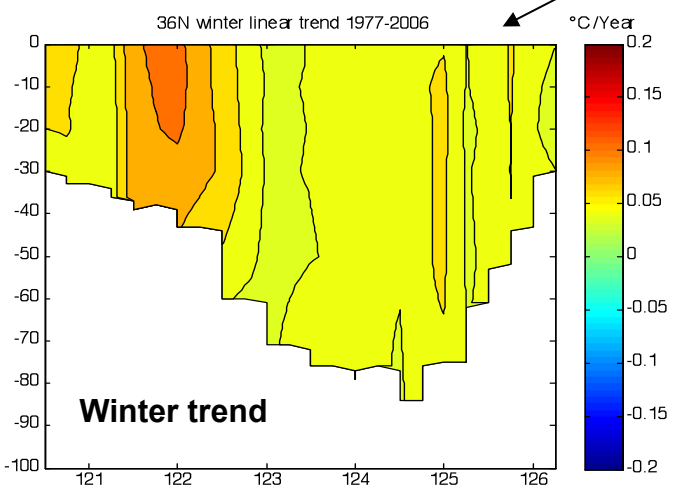
Data	Hadley	OAflux	ICOADS	MERRA	CFSR	ERA_interim	OFES	SODA
Winter	0.0411	0.0382	0.0525	0.0355	0.0254	0.0360	0.0265	0.0463
Summer	0.0270	0.0202	0.0412	0.0251	0.0163	0.0199	0.0109	0.0261

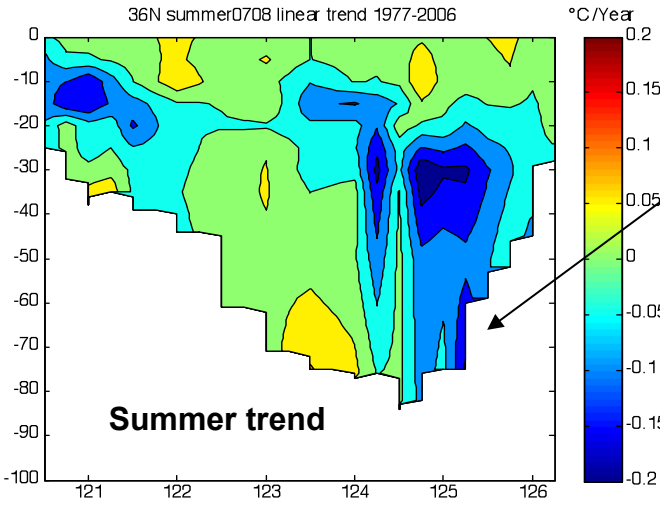
The trend of SST during 1960-2001年 (Hydrographic data from about 300000 profiles)

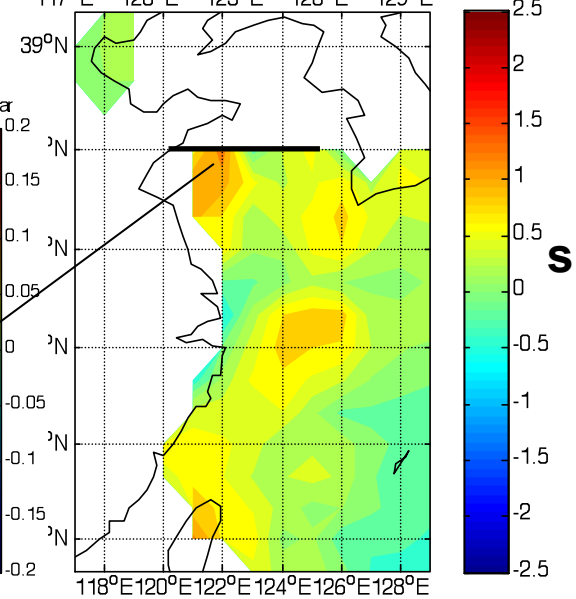




winter

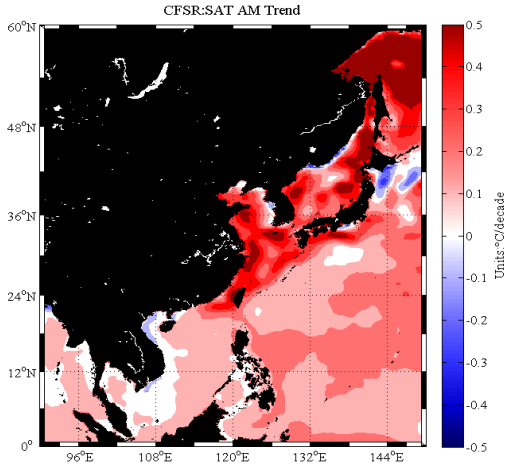




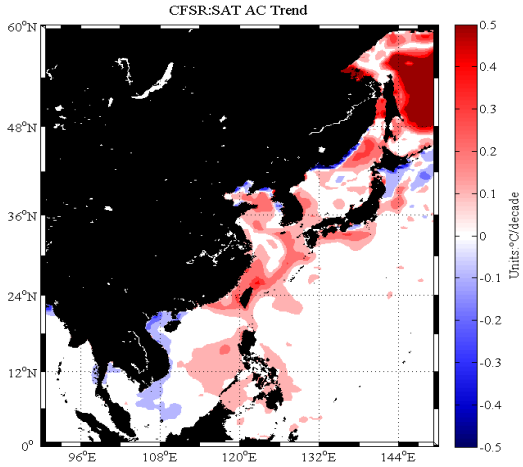


summer

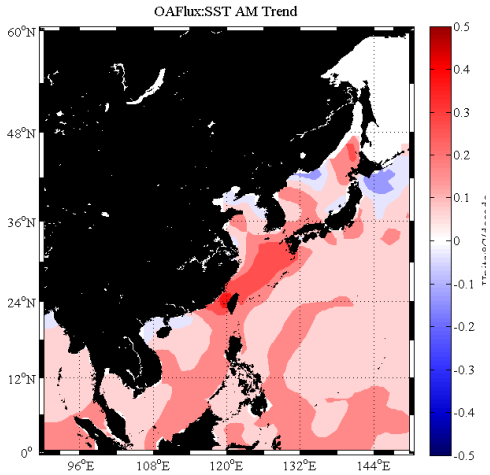
In the Northwest Pacific Ocean, change of annual cycle contributes about 50% SST trend in the past several decades.



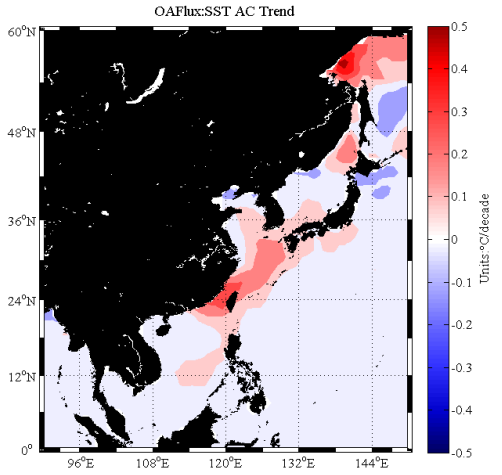
CFSR annual mean SST trend



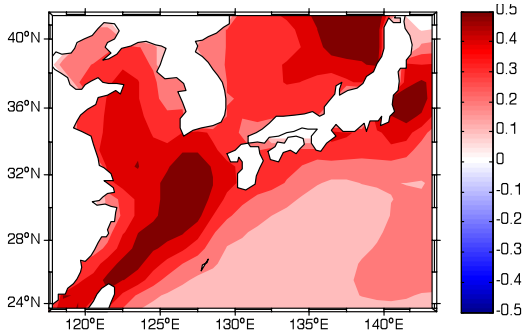
CFSR trend by annual cycle



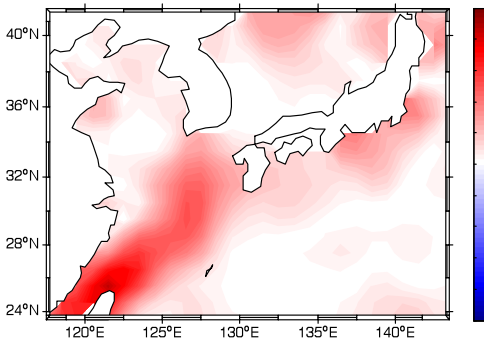
OAflux annual mean SST trend



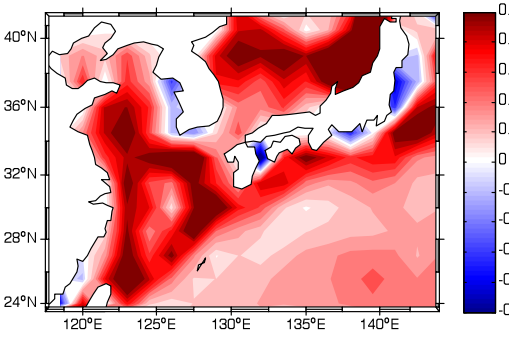
OAflux trend by annual cycle



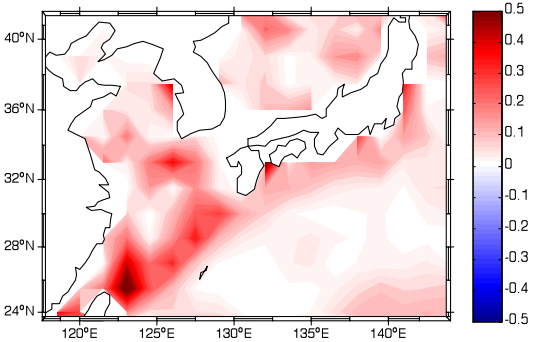
Hadley annual mean SST trend



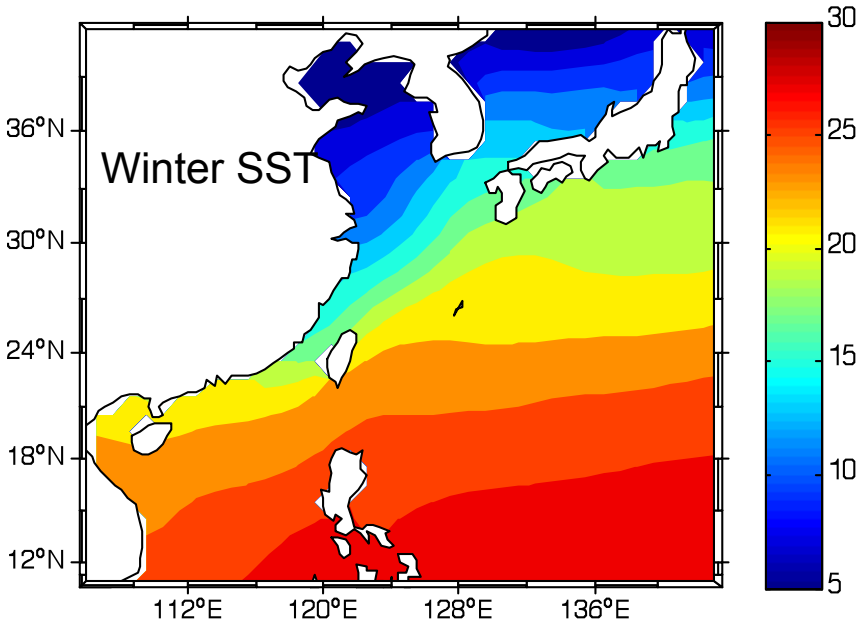
Hadley trend by annual cycle

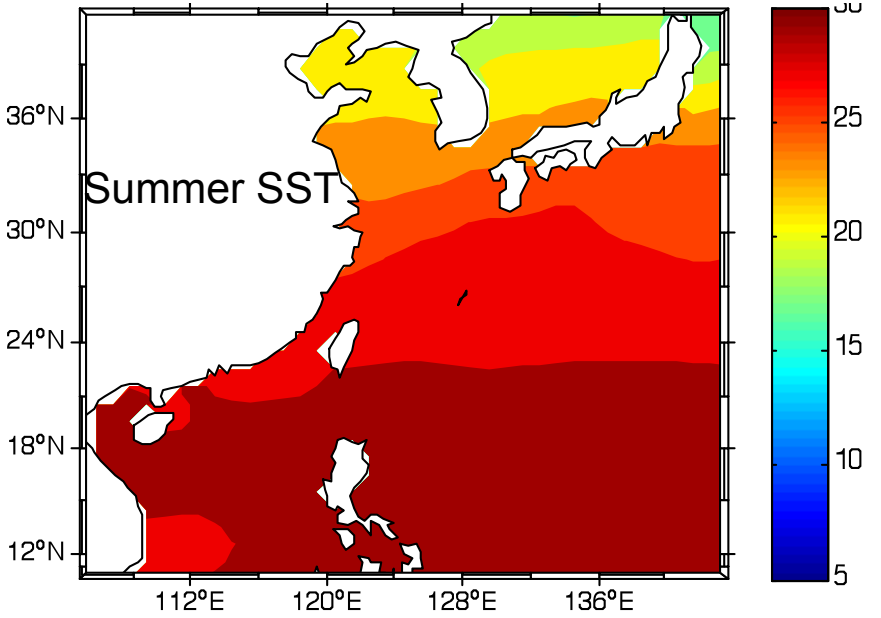


ERA-interim annual mean SST trend

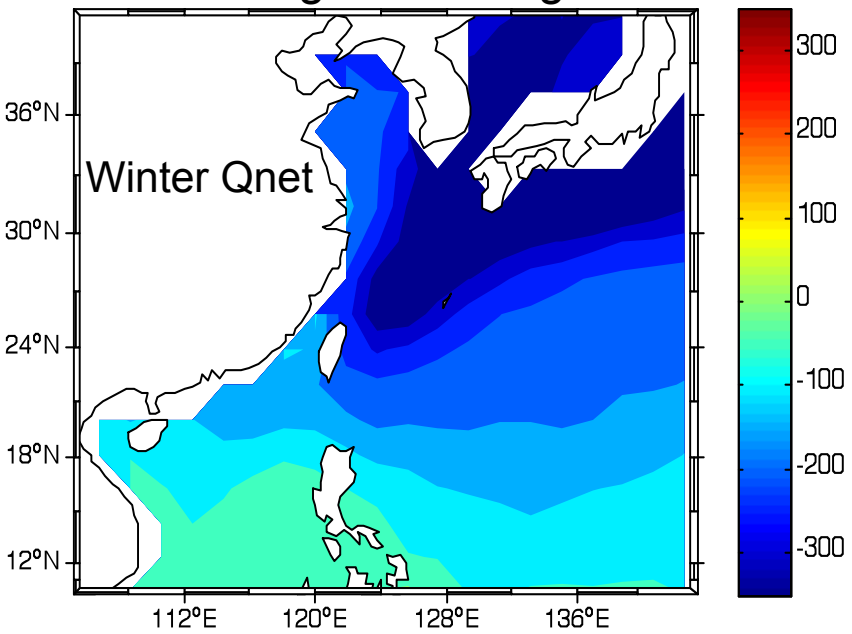


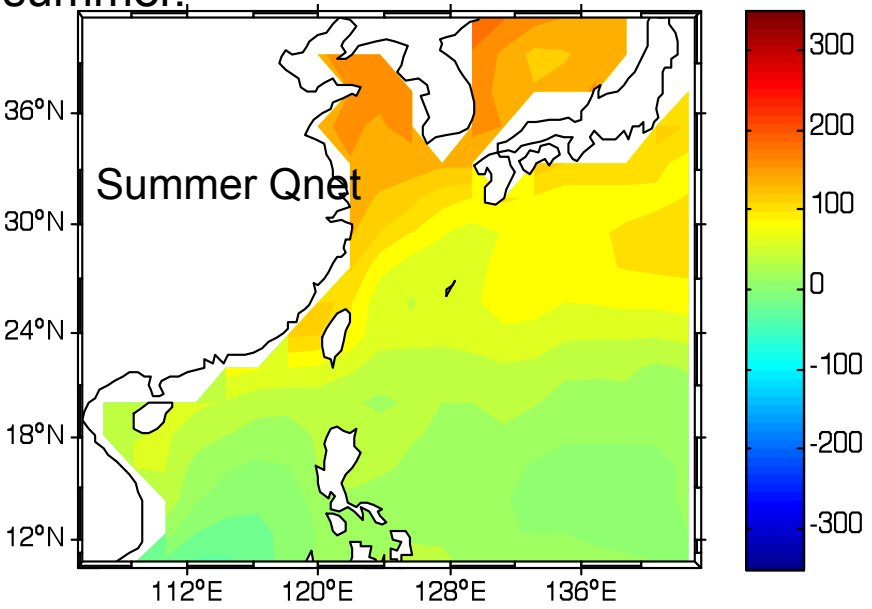
ERA-interim trend by annual cycle



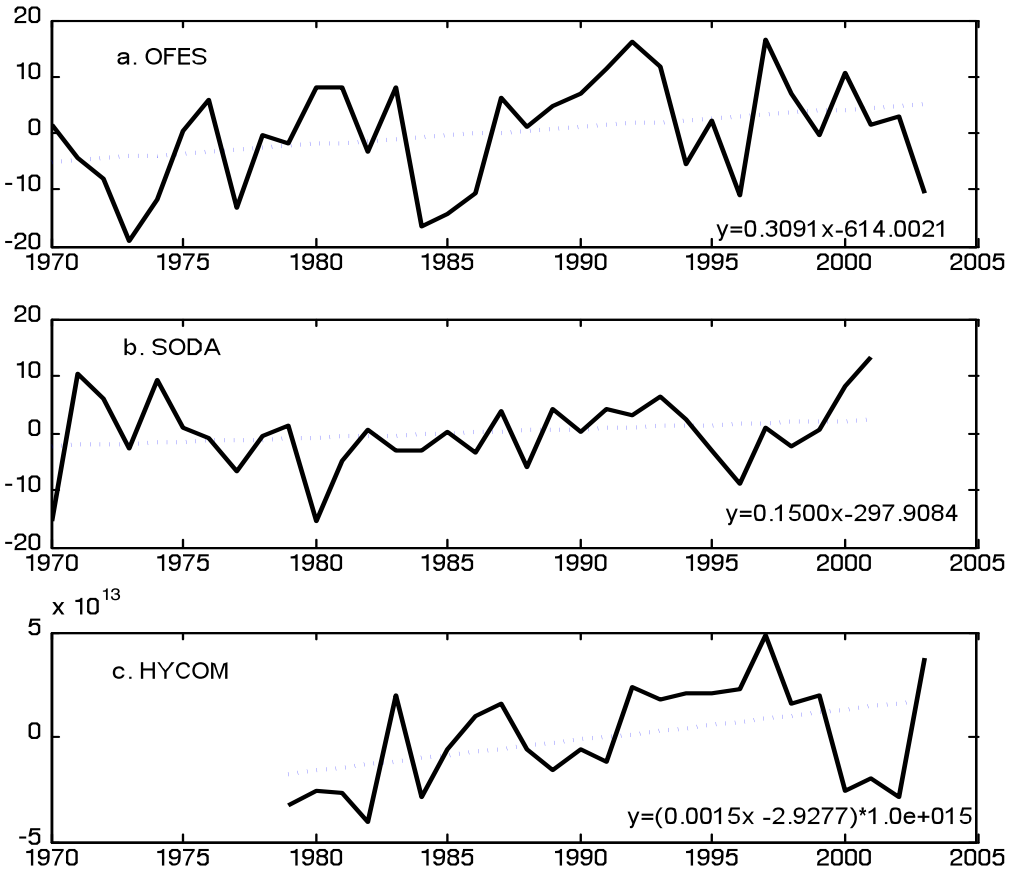


The local atmospheric forcing sets an strong annual cycle, with SST gradient large in winter and small in summer.

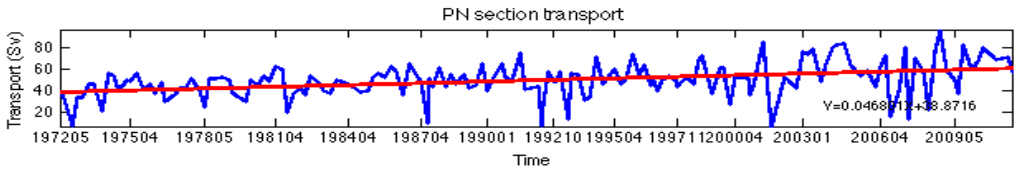


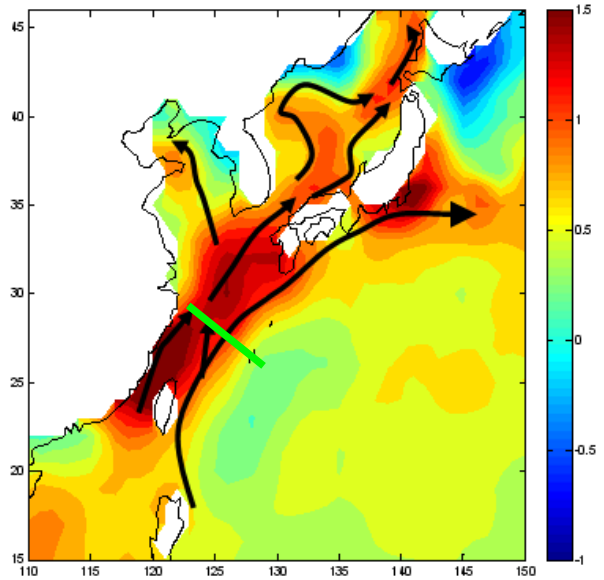


The ocean advection, like Kuroshio increases in the past several decades



Ocean heat advection





Heat transport by advection

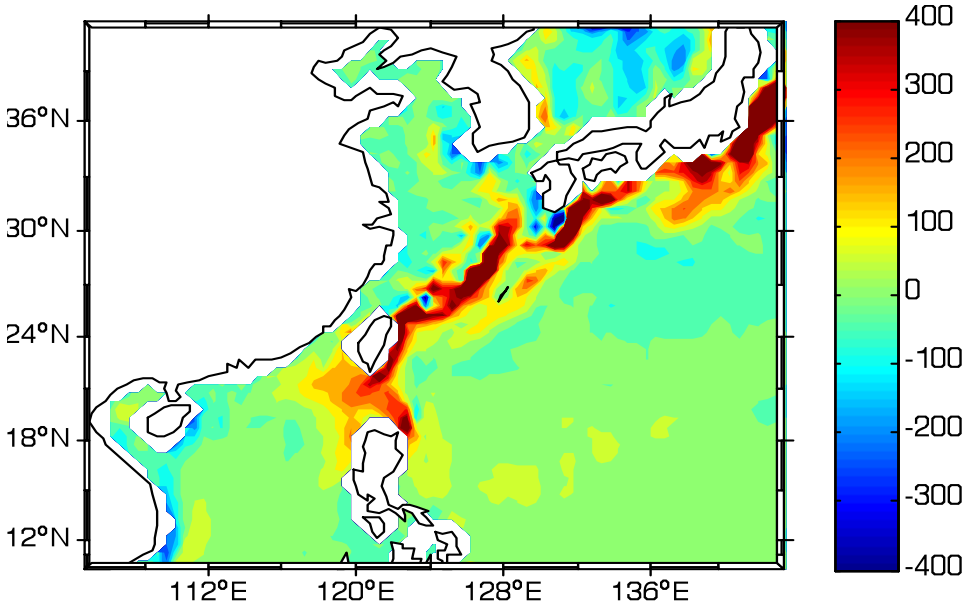
$$-\vec{u}\cdot\nabla T_m \quad \mathrm{W/m^2}$$

Mixing layer depth

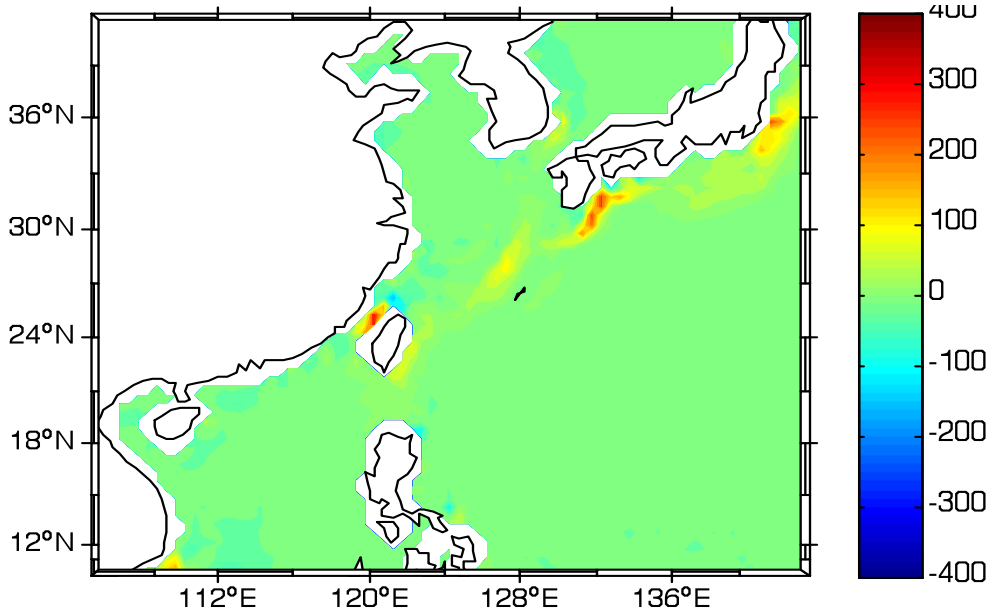
SST variability | Local Heat Flux | Horizontal Advection | Mixing and upwelling

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

Air-sea interaction | Downscaling | Local process



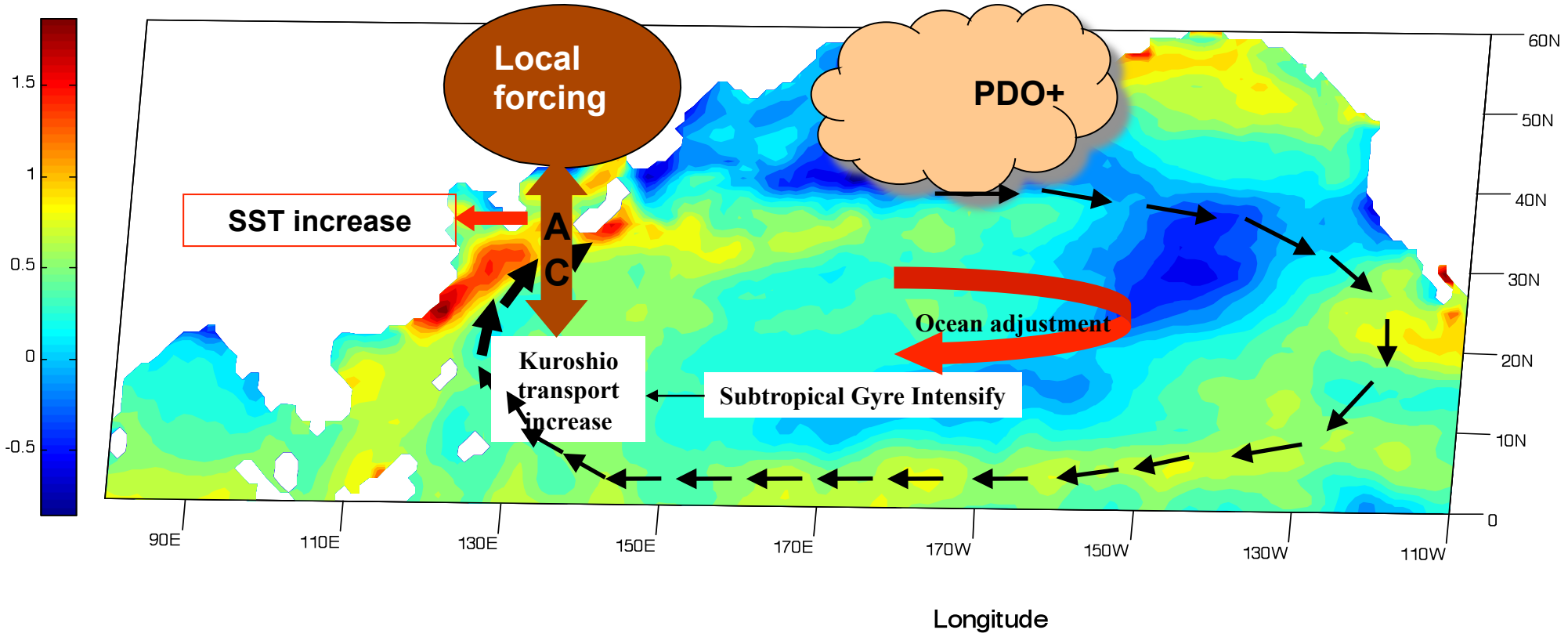
Winter mean heat advection



Summer mean heat advection

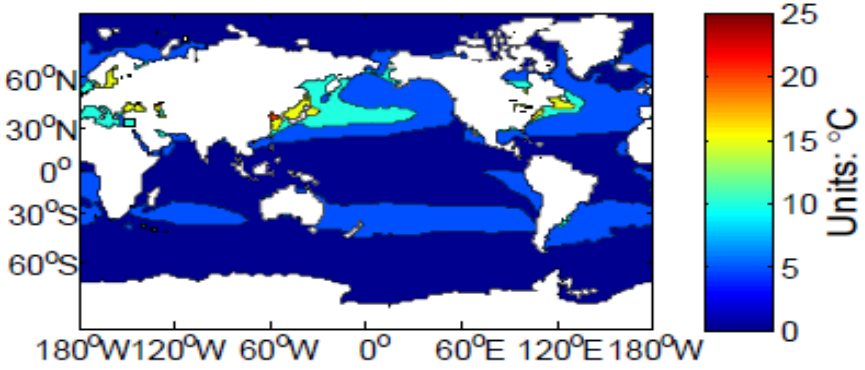
The ocean advection plays more important role in heat transport in winter than in summer. The increase of ocean transport will make the winter much warmer.

Summary

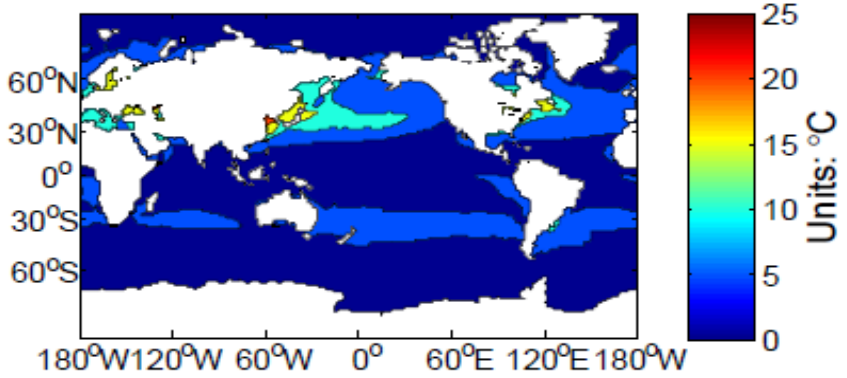


Decadal → ? → Annual → ? → Trend

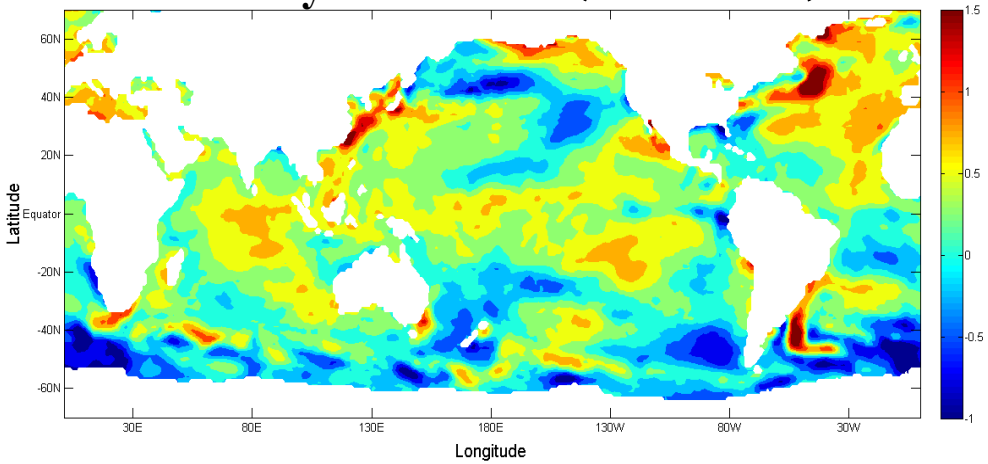
SST Annual Range from HadISST(1999−2009)



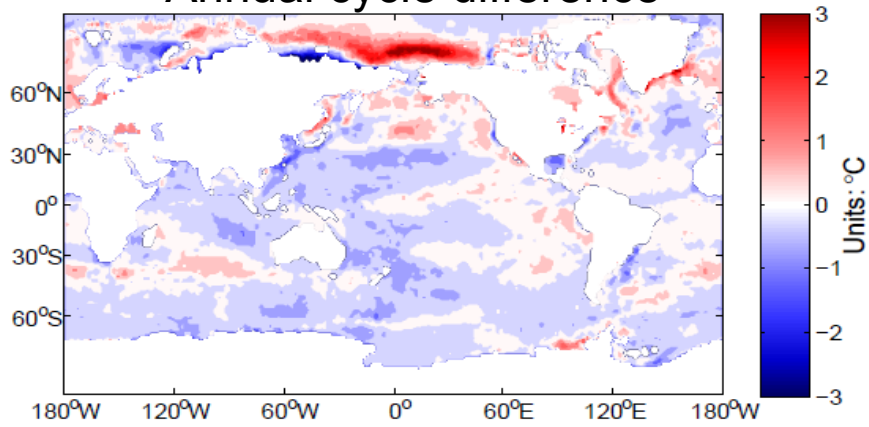
ST Annual Range from HadISST(1979−1989)



Hadley SST trend（1979-2009）



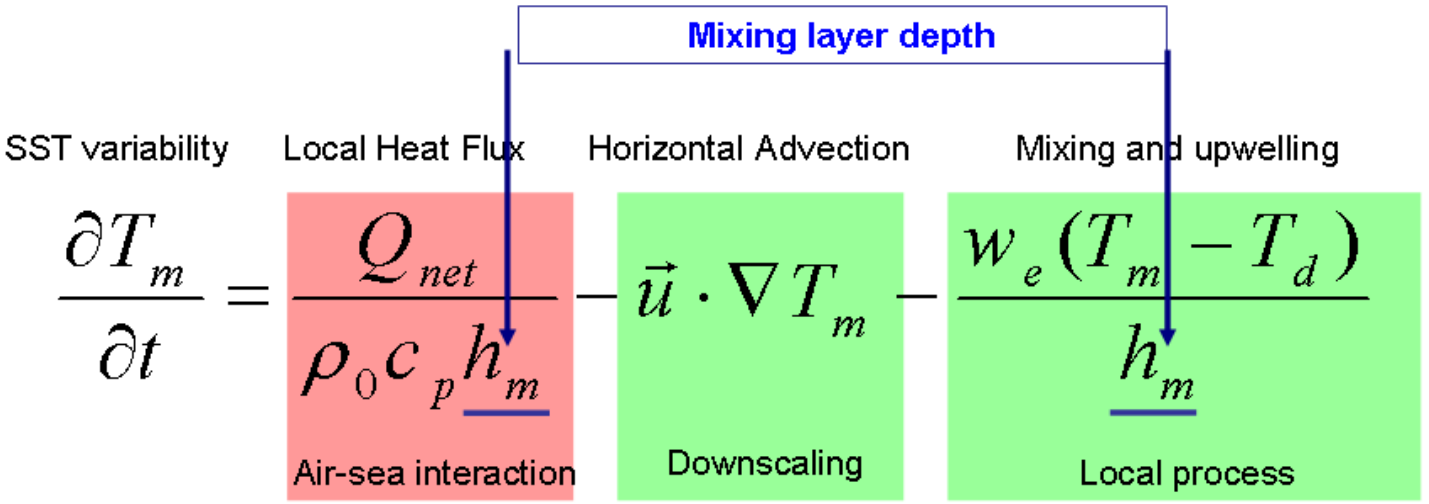
Annual cycle difference



We still have a long way to understand changing of annual cycle


Thanks!
中国海洋大学

Why there is a fast warming?



Is this ocean warming cased by the land warming?

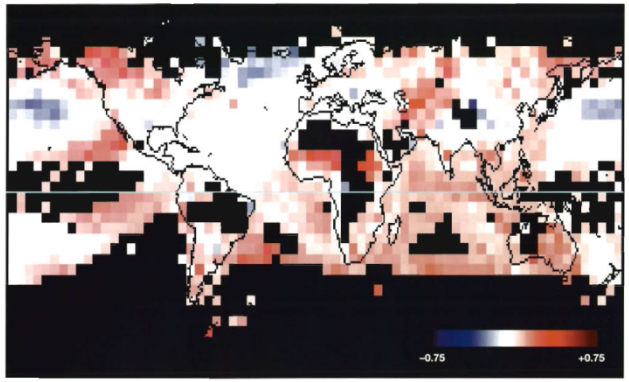


Fig. 1. Summer season temperature trends (°C decade⁻¹) for the IPCC near-surface data over the period 1946–1995

Balling et al., 1998

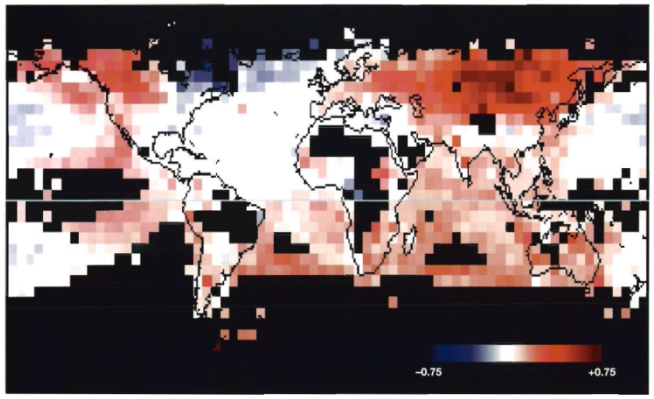
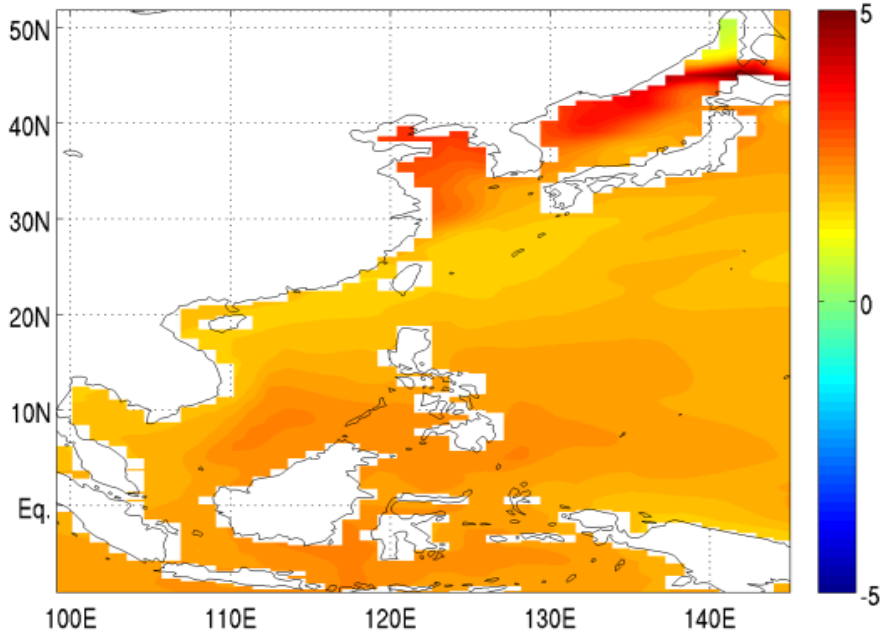


Fig. 2. Winter season temperature trends (°C decade⁻¹) for the IPCC near-surface data over the period 1946–1995

Surface Temperature Trends From IPCC data (1946-1995)

Summer

Winter

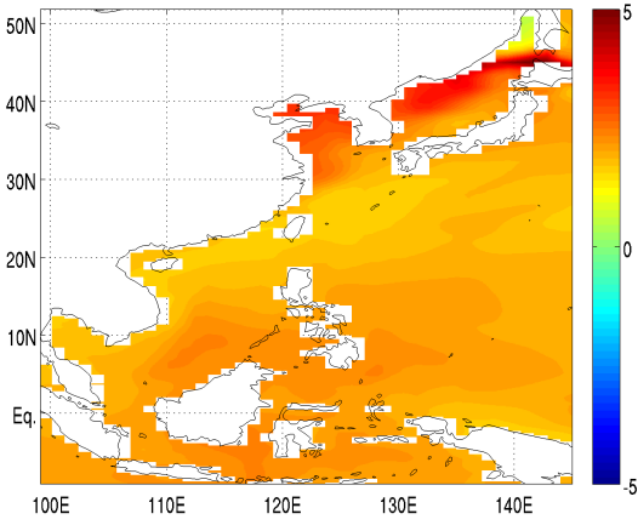


Surface Temperature Trends From IPCC Model CCSM3 (1950-2000)

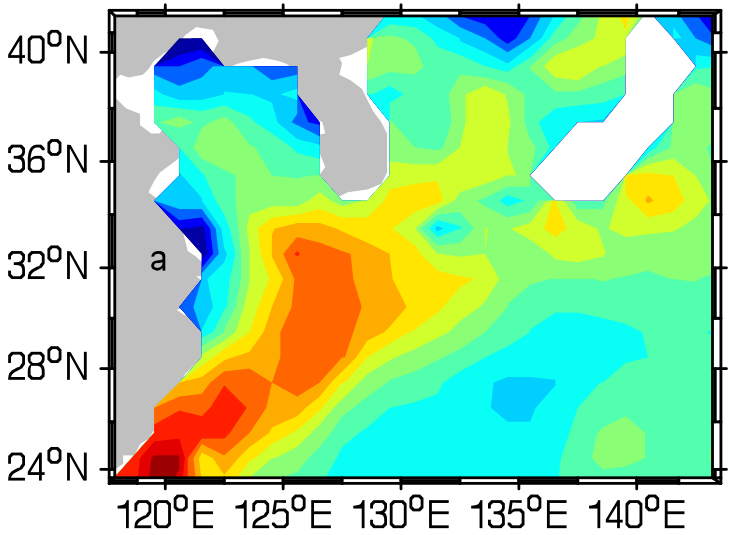
Warming in the Land is more obvious than in the Ocean

Warming in the Ocean is enhanced in the shallow bathymetry

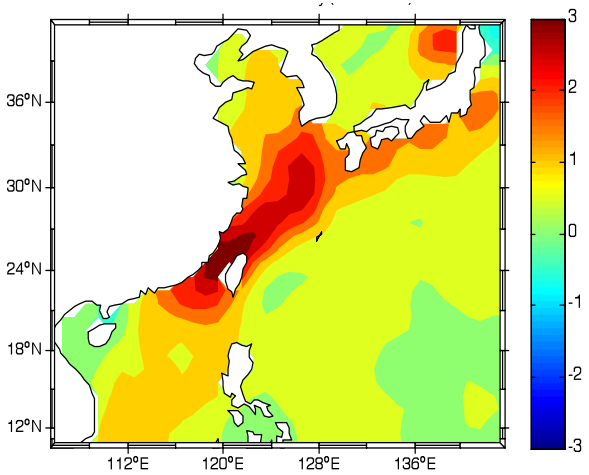
But the observation and reanalysis data show a unique warming pattern …



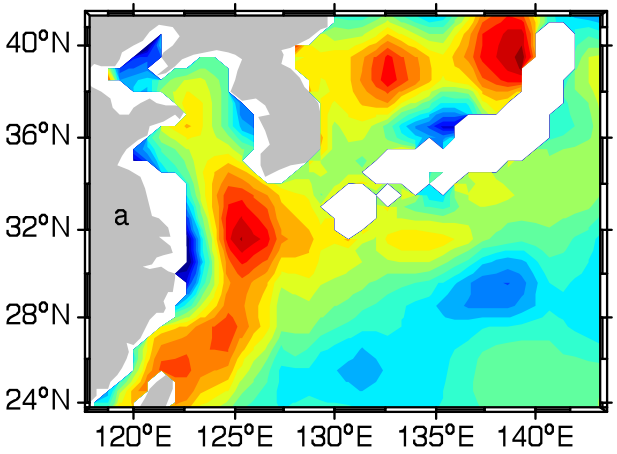
CCSM3 SST1970-2000 trend



SODA SST1970-2000 trend

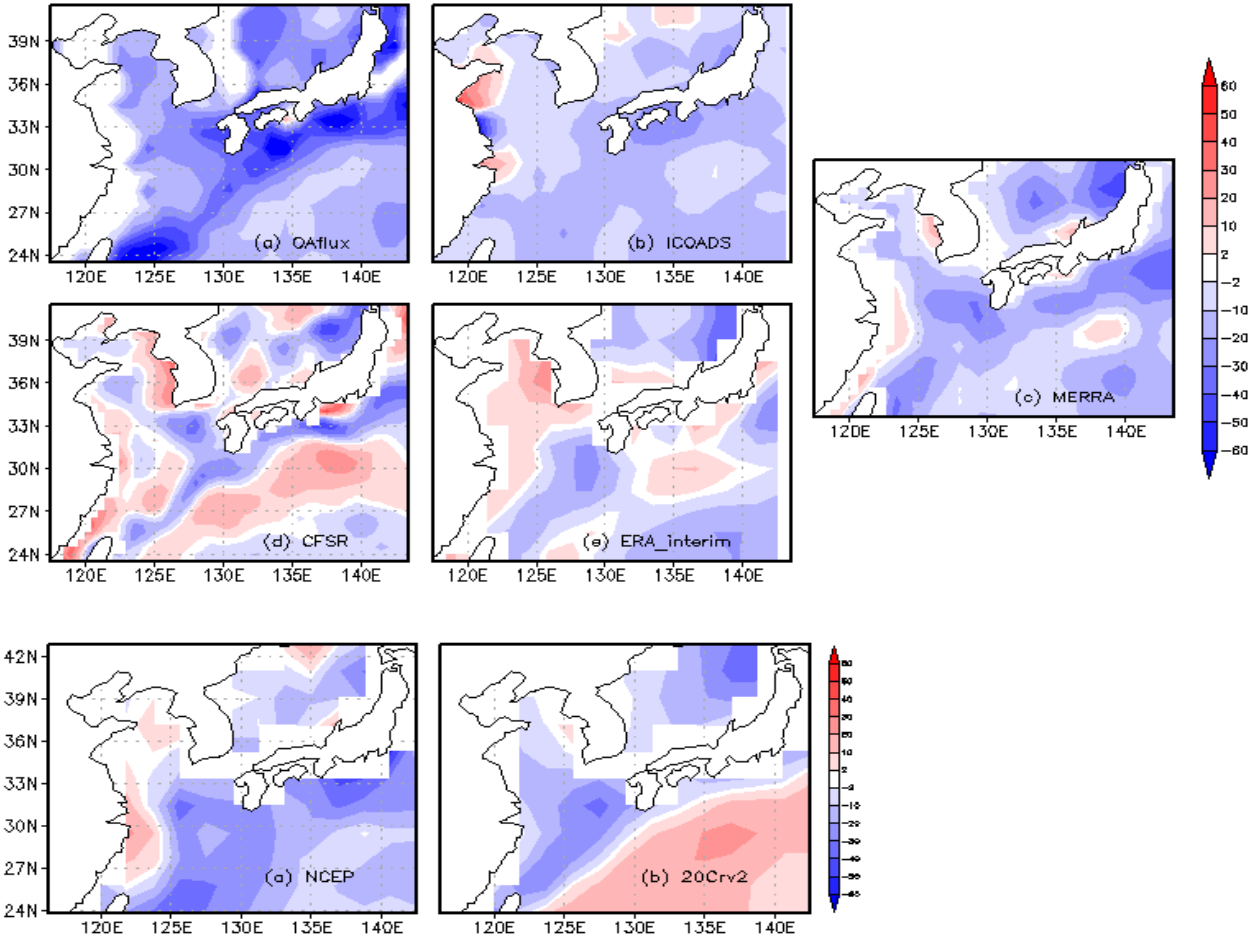


Hadley SST1970-2000 trend

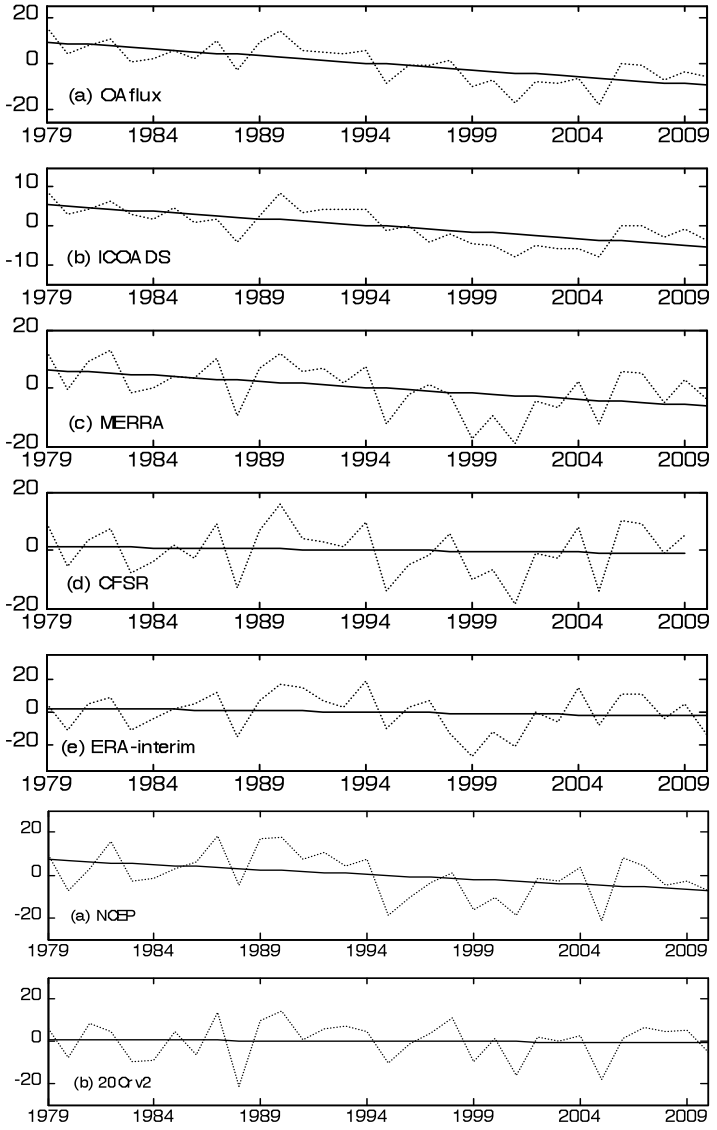


MERRA SST1979-2010 trend

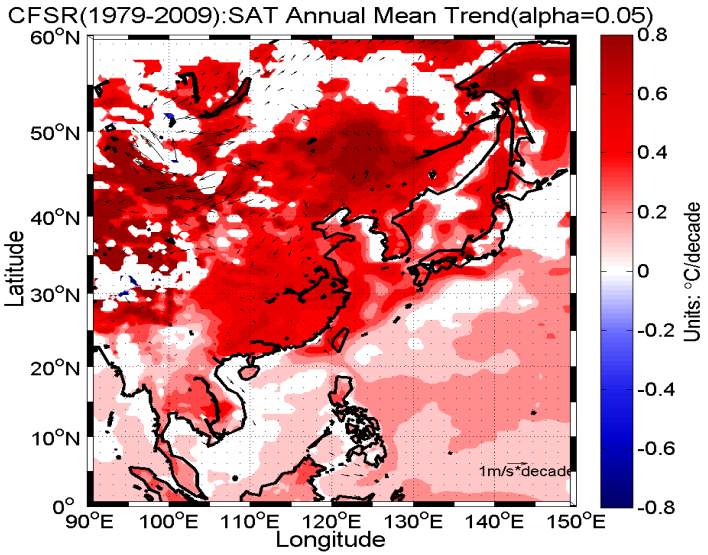
The Ocean release more heat into the air



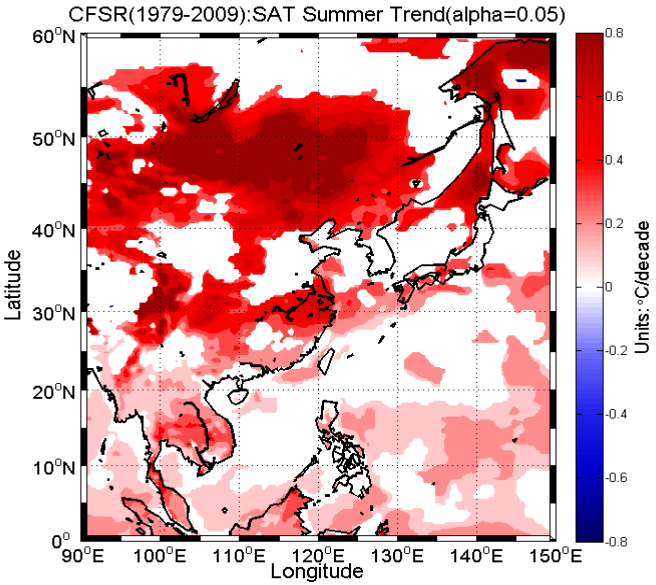
Net Heat Flux Trend (1979-2010) W/m^2

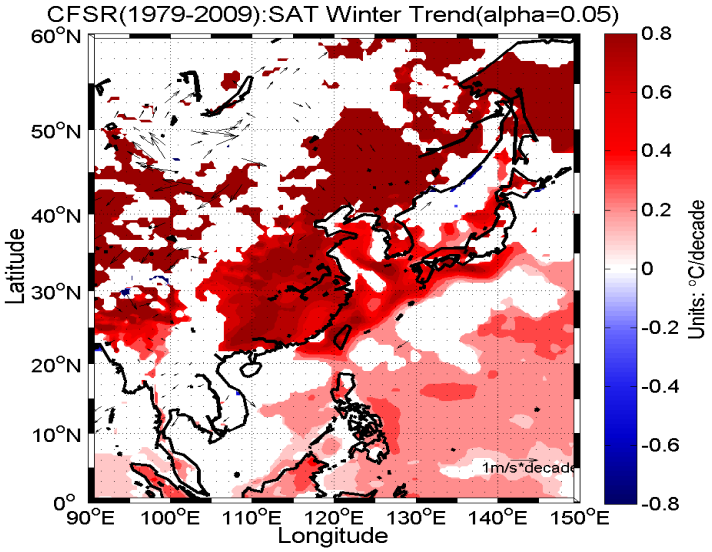


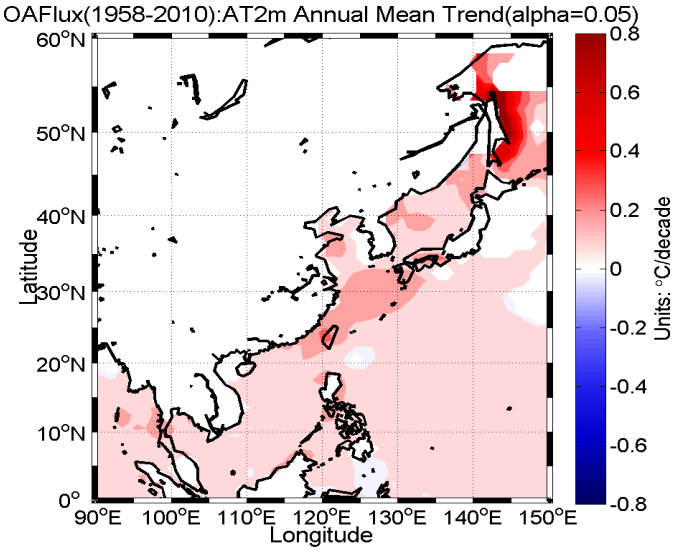
Net Heat Flux Trend



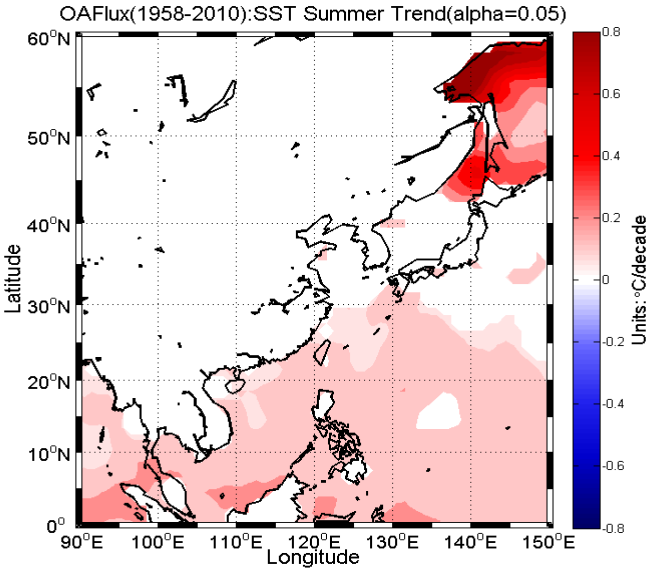
CFSR(1979-2009)
Surface Air Temperature at 0m

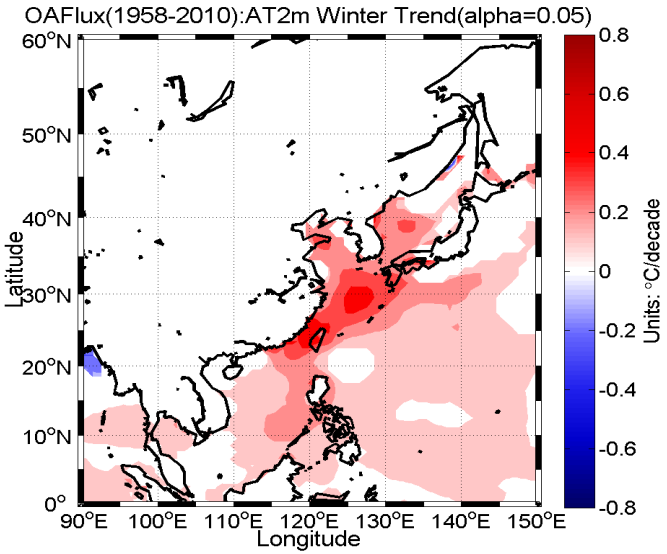






OAFlux(1958-2010)
SST Trend





ICOADS(1960-2010)
Sea Surface Temperature