The response of SST in the offshore area of China to variations in the East Asian Monsoon under global warming and its marine ecological effects

Rong-shuo CAI[1], Hong- jian TAN[1], Qing-liang Yang[1] , Ji-long CHEN[2], Qi Qinghua[1]

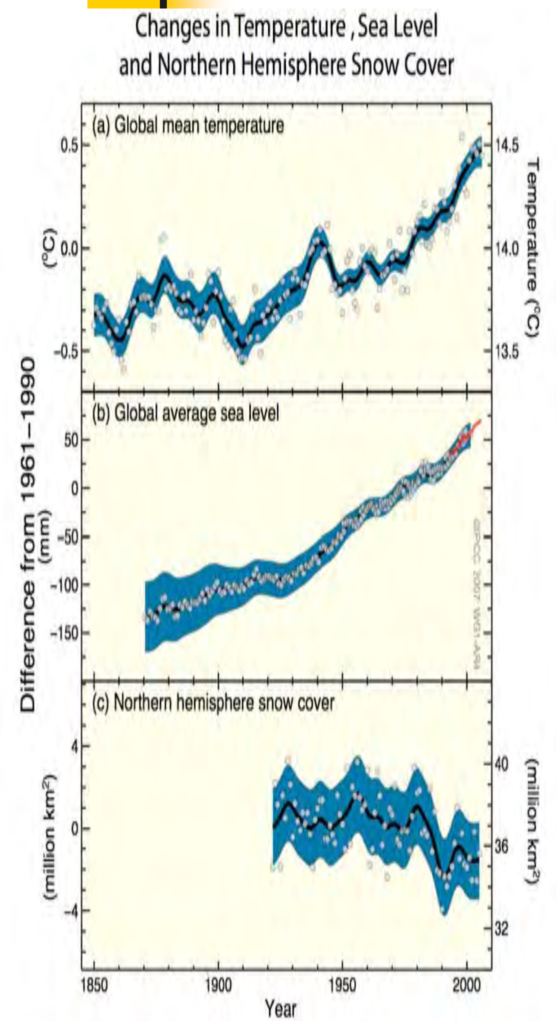
1. Key Lab of Global Change and Marine-Atmospheric Chemistry, Third Institute of Oceanography, State Oceanic Administration, Xiamen 361005, China;

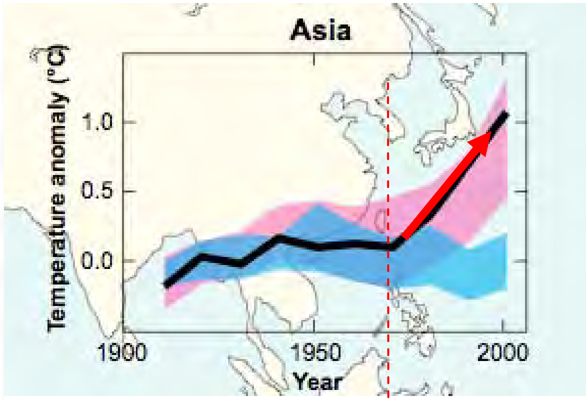
2. Center for Monsoon System Research, Institute of Atmospheric Physics, Chinese Academy of Science, Beijing 100190, China

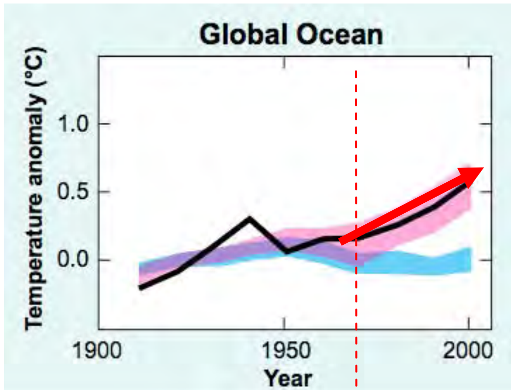
East Asian Marginal Seas warming and its marine ecological effects

- 1. Rapid East Asian Marginal Seas Warming?
- 2. What Causes Rapid Warming?
- 3. Marine Ecological Effects of Rapid Warming?
- 4. Summary

1. Rapid East Asian Marginal Seas Warming







（From AR4 of IPCC, 2007）

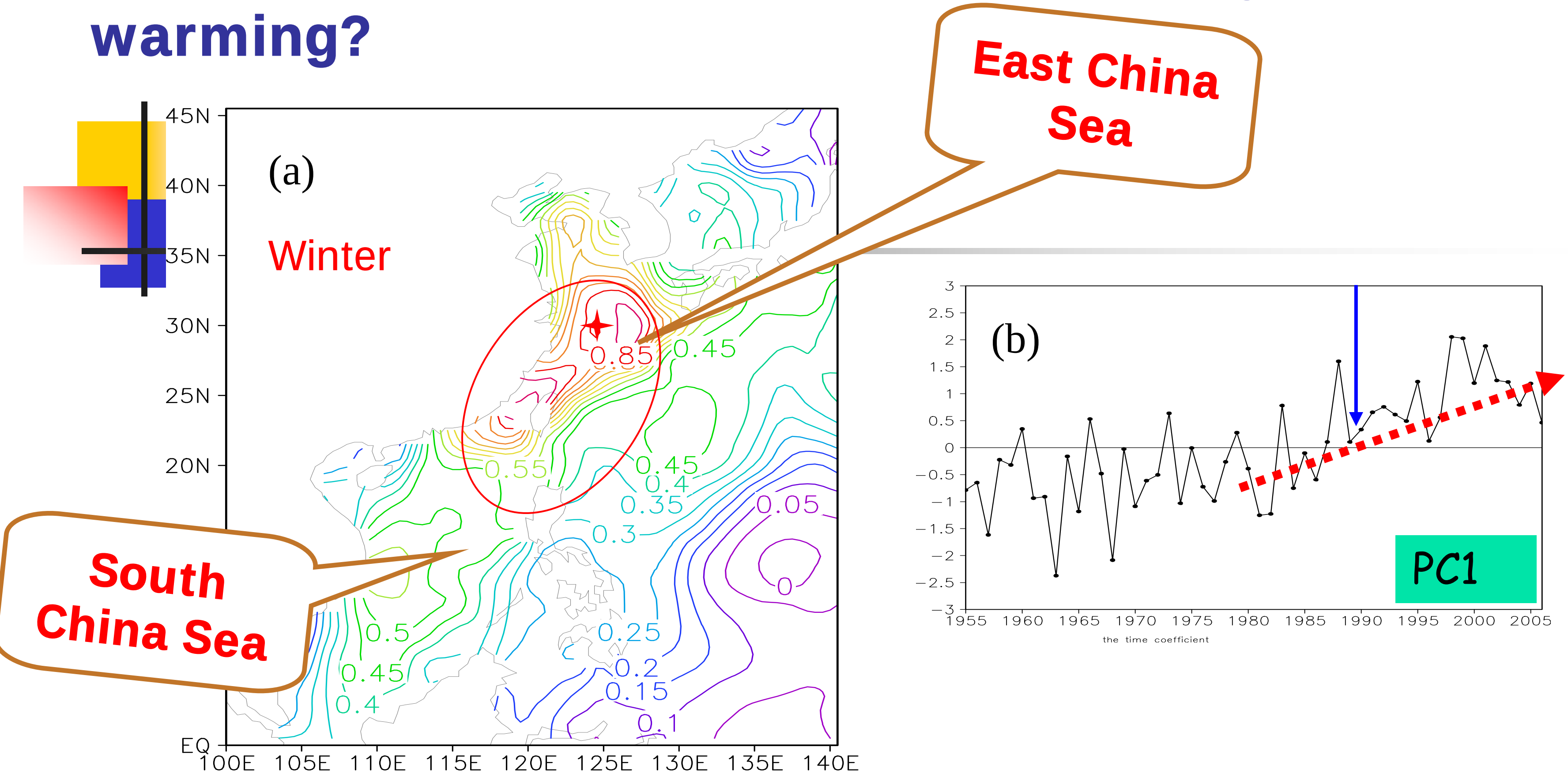
It is well known that globe is experiencing a significant warming anomaly in the last hundred year. Meanwhile, East Asian Marginal Seas have kept an obvious persistent warming in the past decades. Here, we focus on the following three issues:

1) How about the East Asian Marginal Seas warming?

2) what causes marginal seas warming?

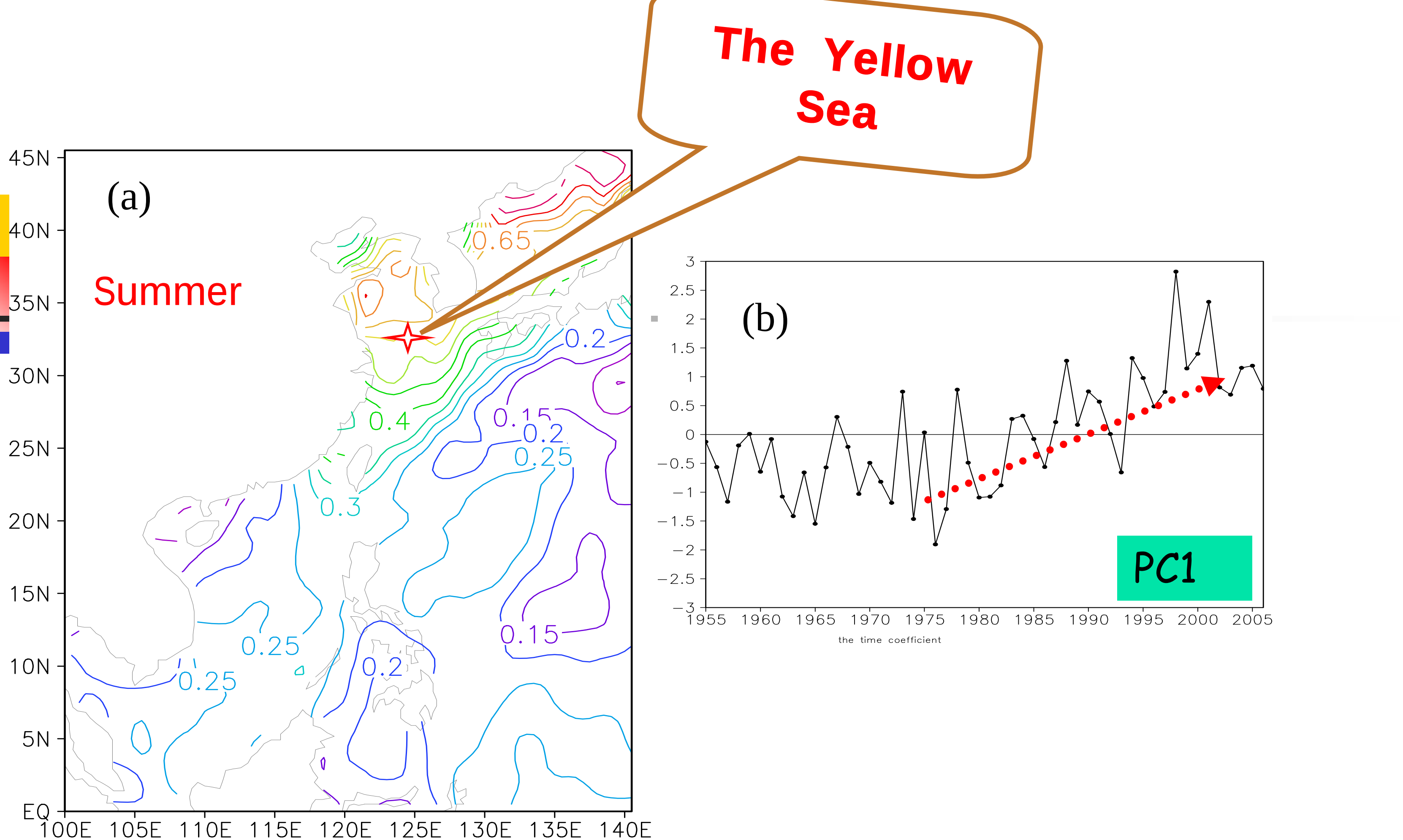
3) What's the marine ecological effects of the regional seas warming?

Q1：How about the Western Pacific marginal seas warming?



Spatial pattern (a) and time coefficient (b) of the leading EOF mode for winter Sea Surface Temperature Anomaly (SSTA) in East Asian Marginal Seas for the period of 1955-2006, 51.9%; Data from HadISST

The analyzed results indicate that SST in the offshore area of China in winter experienced a climate shift in the mid-1980s, and then keeps persistent warming. The area with strongest increase in SST is located in the East China Sea (ESC) .

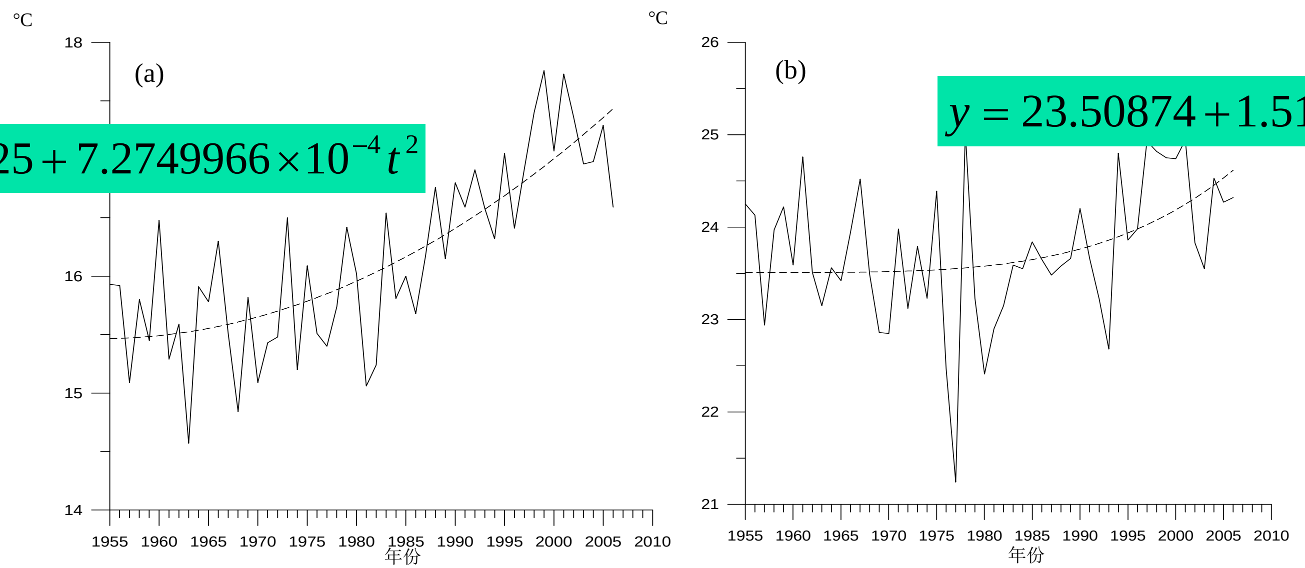


Spatial pattern (a) and time coefficient (b) of the leading EOF mode for summer Sea Surface Temperature Anomaly (SSTA) in the offshore area of China for the period of 1955-2006; 43.6%

The analyzed results show that SST in the offshore area of China in summer experienced a climate shift in the mid-1980s and keeps warming since 1980s.

- Linear regression

$$y(t)=c_0+c_1t+c_2t^2+c_3t^3+c_4t^4+c_5t^{1/2}+c_6t^{-1}+c_7t^{-1/2}+c_8t^{-2}+c_9e^{-t}+c_{10}\ln t$$



$$y = 15.46525 + 7.2749966\times10^{-4}t^2$$

$$y = 23.50874 + 1.5130692\times10^{-7}t^4$$

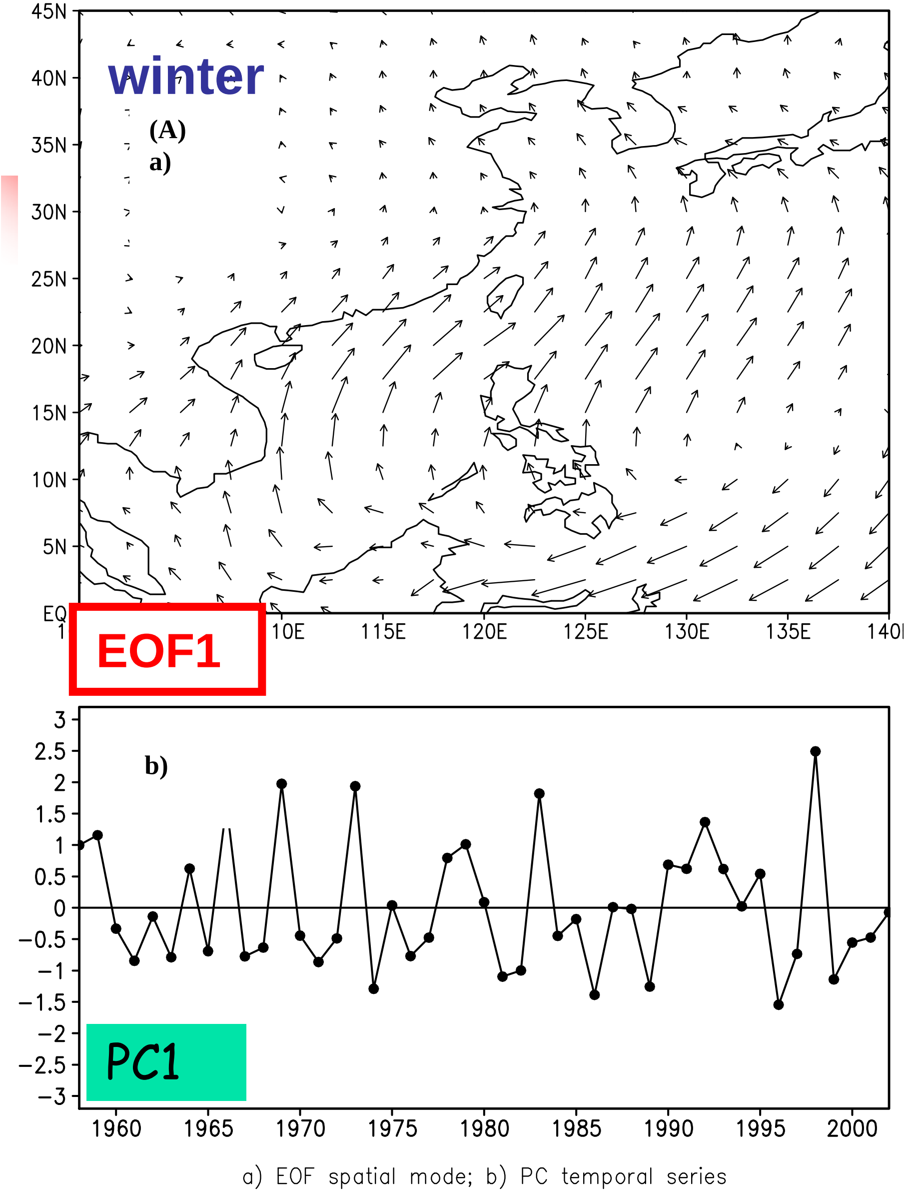
Long-term trends of winter (a) and summer (b) mean SST (dashed line) over the remarkable warming regions in the offshore area of China for the period of 1955-2006. Unit: ℃.

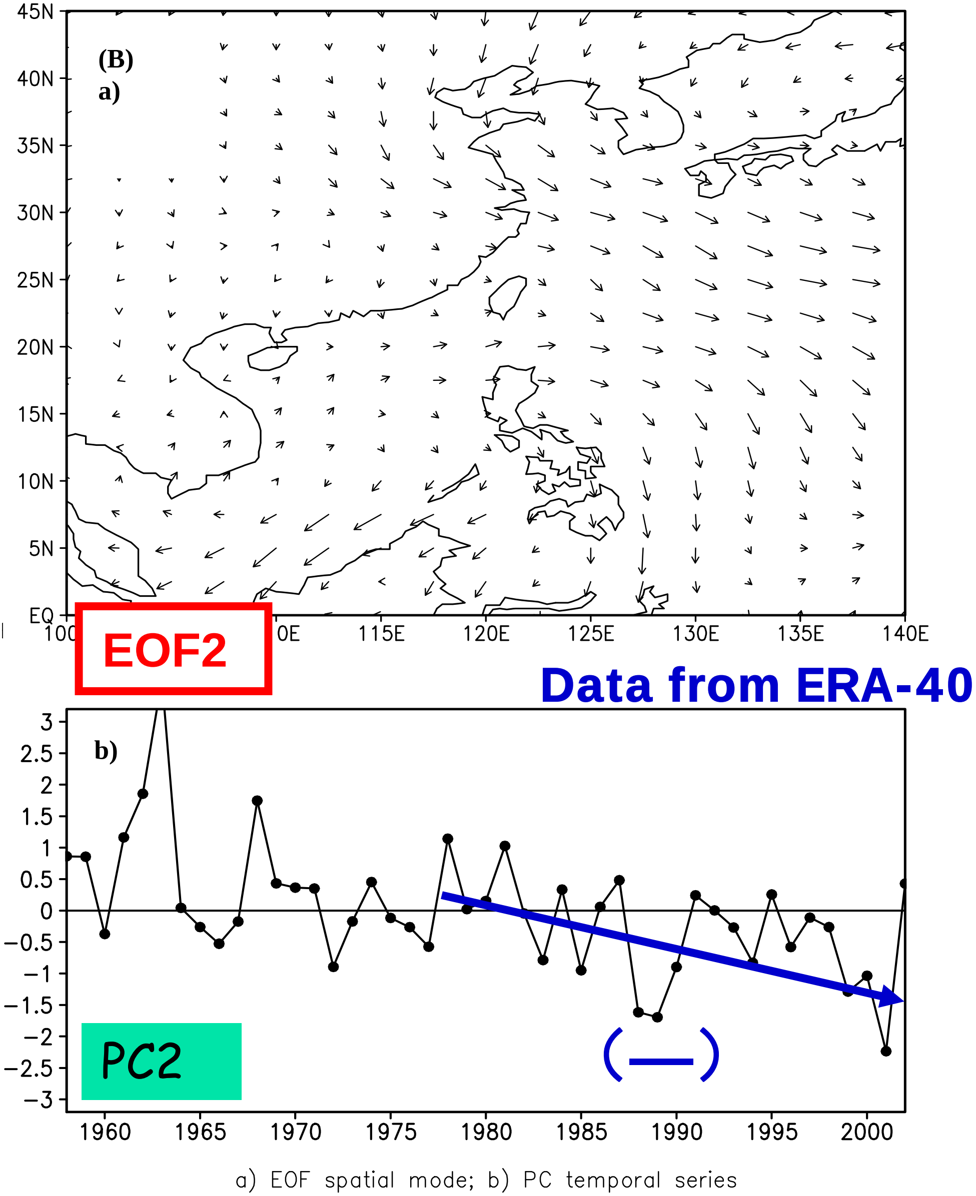
The SST increased by 1.96°C in winter for the period of 1955-2005 and 1.10°C in summer for the period of 1971-2006.

Q2：What causes rapid East Asian Marginal Seas warming?

- **1）East Asian Monsoon？**
- Air-sea interaction has a great influence on marine environment, especially, wind field variation can greatly affect heat fluxes between air-sea boundary.
- **2）Western Pacific boundary currents, e.g. Kuroshio？**
- The Kuroshio affects its downstream marine environment (heat and freshwater balance) by transporting warm & saline water from the tropical regions to the high latitude regions.
- **3）The other impact factors？**
- PDO or the other air-sea couple mechanism?

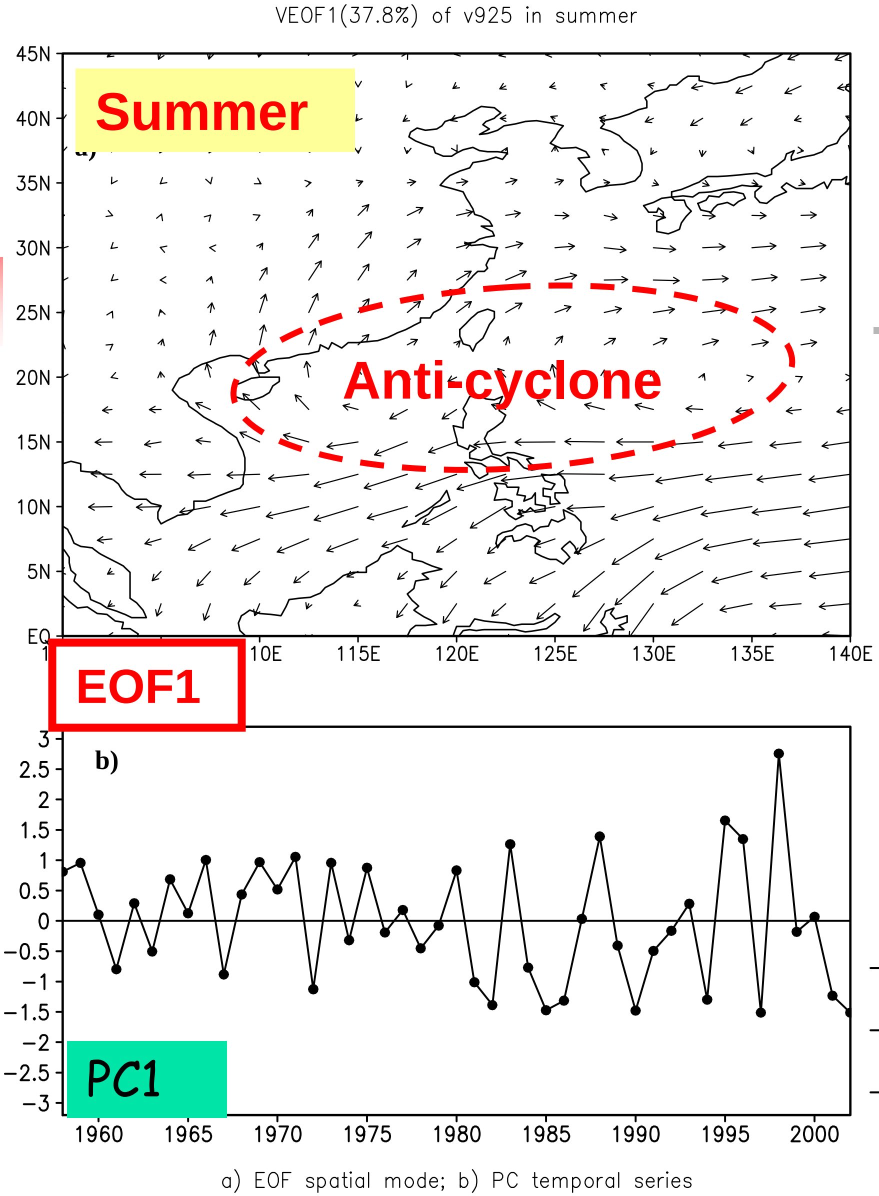
2.1) Variations of East Asian Monsoon (in winter & summer)



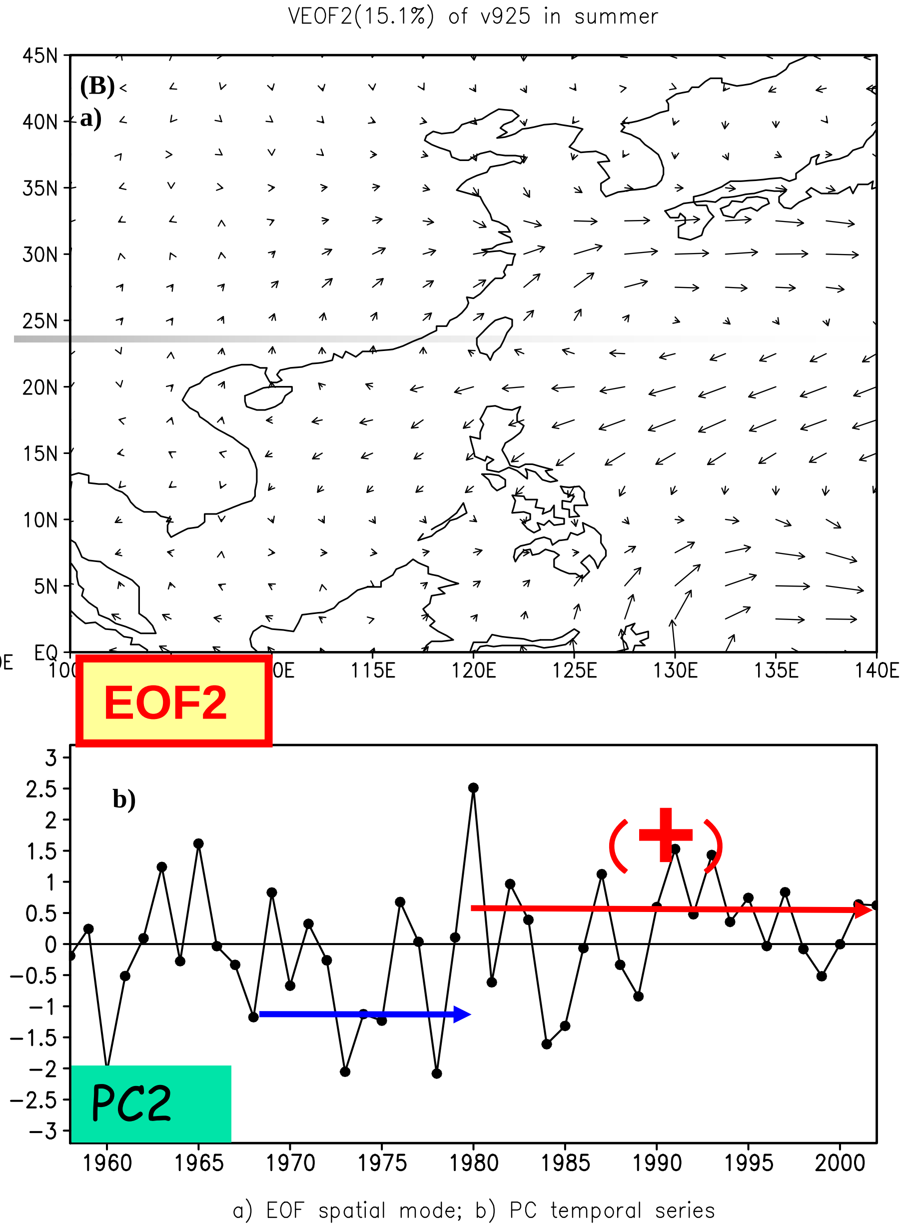


EOF1 shows the inter-annual variations of winter wind field for the period of 1958-2002, 35.4%.

EOF2 shows the inter-decadal variations of winter wind field for the period of 1958-2002,16.1%.

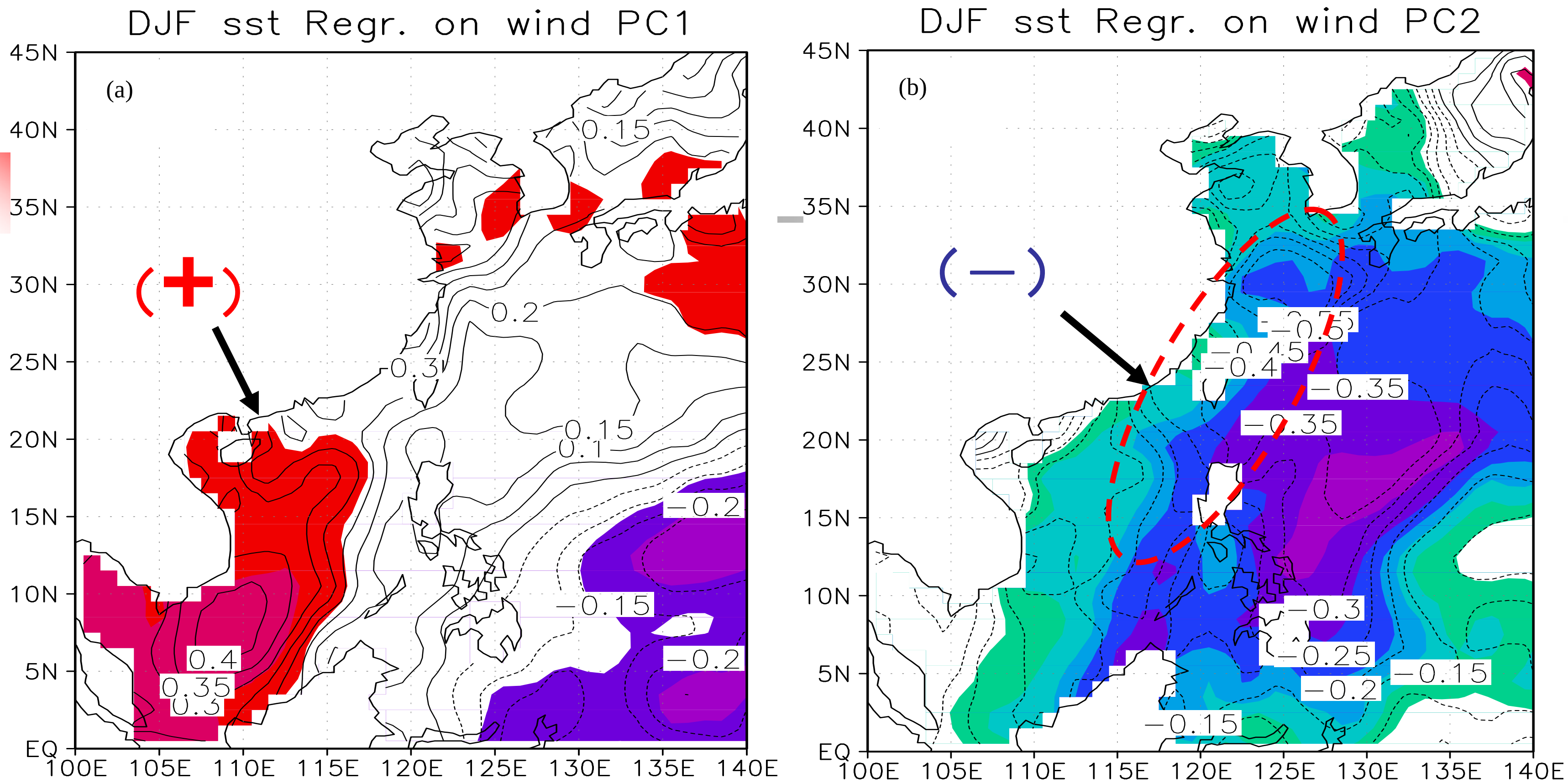


EOF1 shows the inter-annual variations of summer wind-field for the period of 1958-2002, 37.8%.



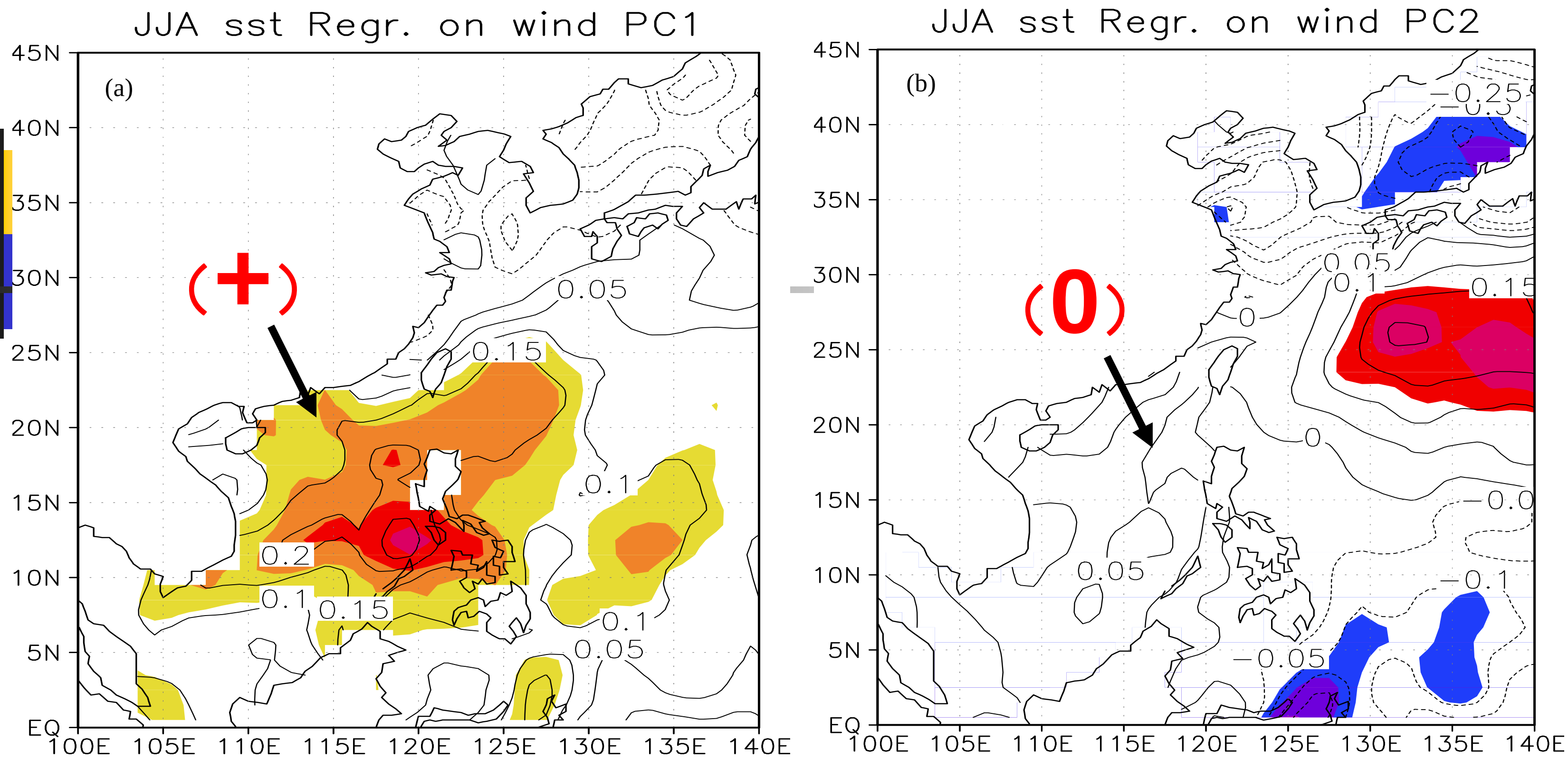
EOF2 shows the inter-decadal variations of summer wind field for the period of 1958-2002, 15.1%.

Relationship between SST and East Asian monsoon



Distributions of the regression patterns for SST in the offshore area of China with respect to East Asian Winter Monsoon lower wind field for PC1 (a) & PC2 (b) of EOF mode. The shaded, 95% confidence.

SST to PC1 is positive relation, that means SST rises with the weakening of EAWM (North wind become weak) on inter-annual timescale in SCS; SST to PC2 is negative relation, it shows that SST rises with the weakening EAWM on inter-decadal timescale.



The same as the former, but for summer

The shaded, 95% confidence.

SST to PC1 is positive relation, and it indicates SST rising in summer is related to Anti-cyclone (Subtropical High Pressure) on inter-annual timescale in SCS; and relation of SST to PC2 is not significant on inter-decadal timescale.

（to be published in 2011）

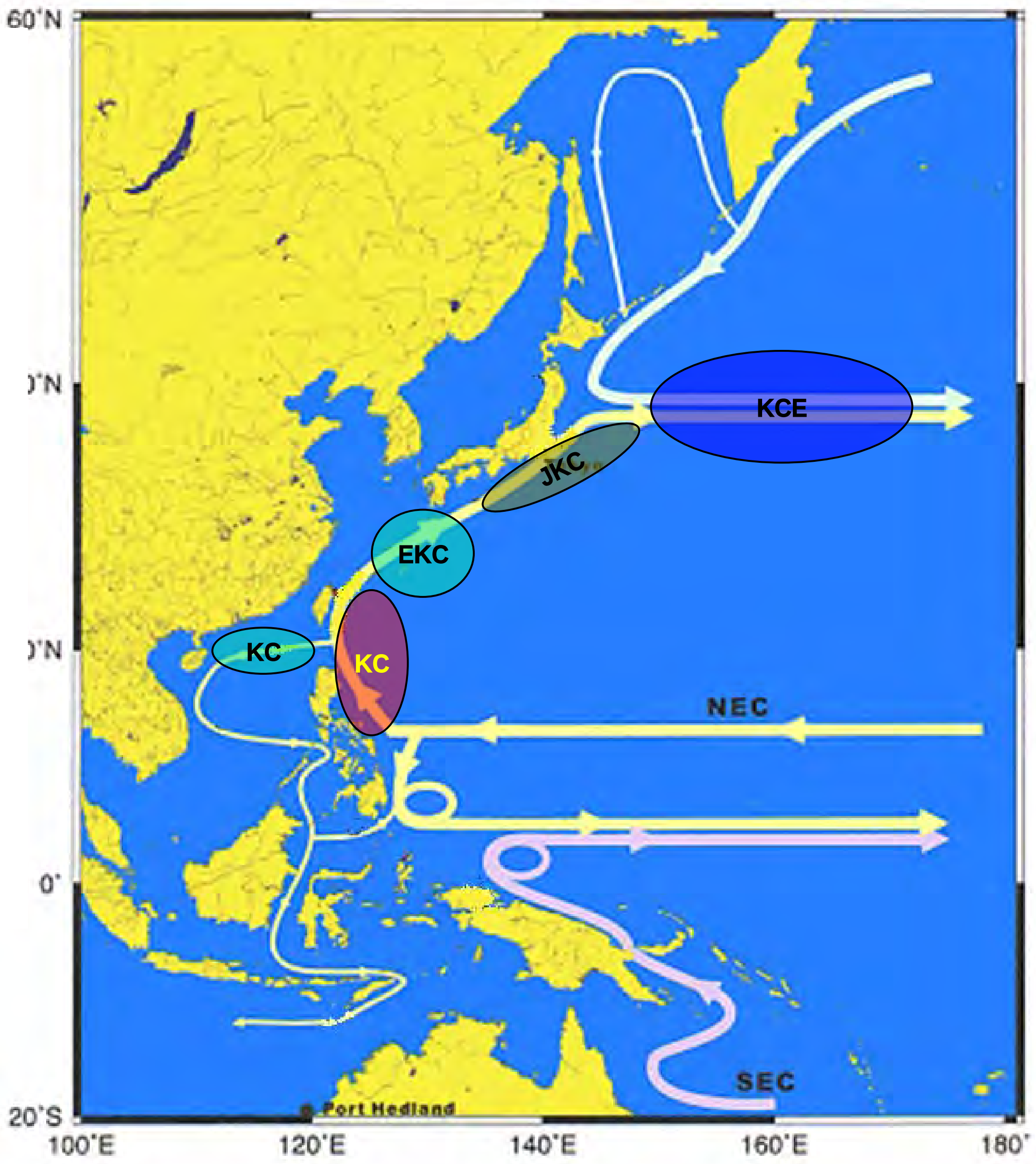
- Summary 1
- 1) East Asian Marginal Seas in winter or summer keep rapid warming in the past decades.
- 2) Relation areas of winter or summer SSTs on the inter-annual timescales in the offshore area of China to the EAM are located in the South China Sea (SCS).
- 3) Relation of SST to EAM in winter on inter-decadal timescales was greater than that on inter-annual timescales or in summer.
- 4) Inter-decadal weakening trend of EAM in winter might greatly contribute to the rise in SST of the offshore area of China, particularly in ECS.

2.2) Variations of western Pacific boundary currents

The Kuroshio (KC) originates to the east of the Philippines, where the North Equatorial Current (NEC) bifurcates into the northward flowing Kuroshio and the southward flowing Mindanao Current (MC) (Nitani, 1972)

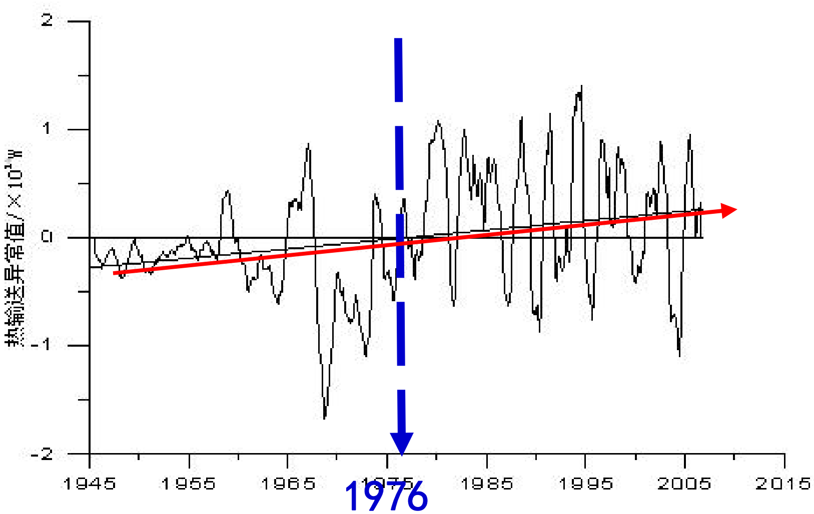
Therefore, we should also pay attention to the transport variations of KC and its relation to SST in East Asian marginal seas.

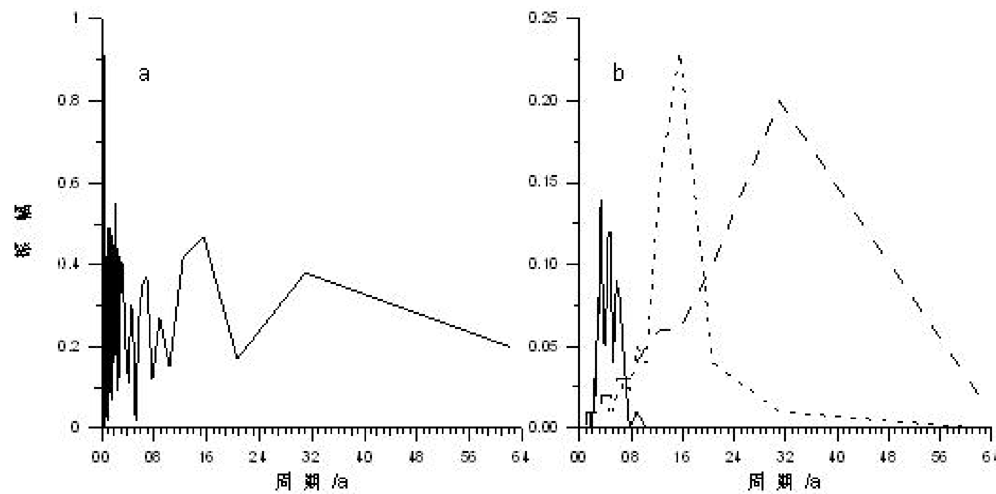
KC:warm & saline water



Variations of heat transport of Kuroshio

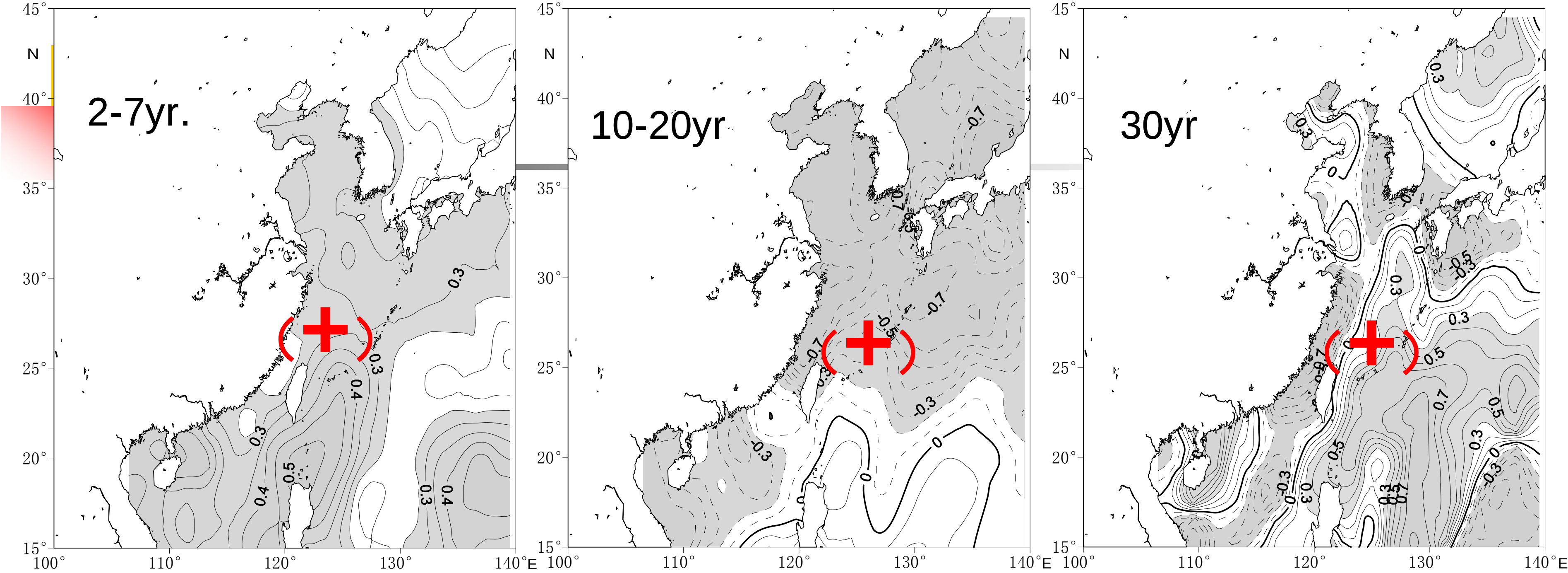
The heat transport anomalies of the source area of Kuroshio





It presents striking inter-annual and inter-decadal variations with a obvious linear trend of increasing, there is a climate shift in the heat transport anomaly of the source area of Kuroshio around 1976.

Relation between the heat transport anomalies of source area of Kuroshio and SST anomaly in the offshore area of China



The correlation field of heat transport anomaly of source area of Kurohio and SST anomaly in the offshore area of China by Vondrak band-pass filtering (a) 2-7a, (b) 10-20a, (c) major period of 30a (The shaded, 95% confidence)

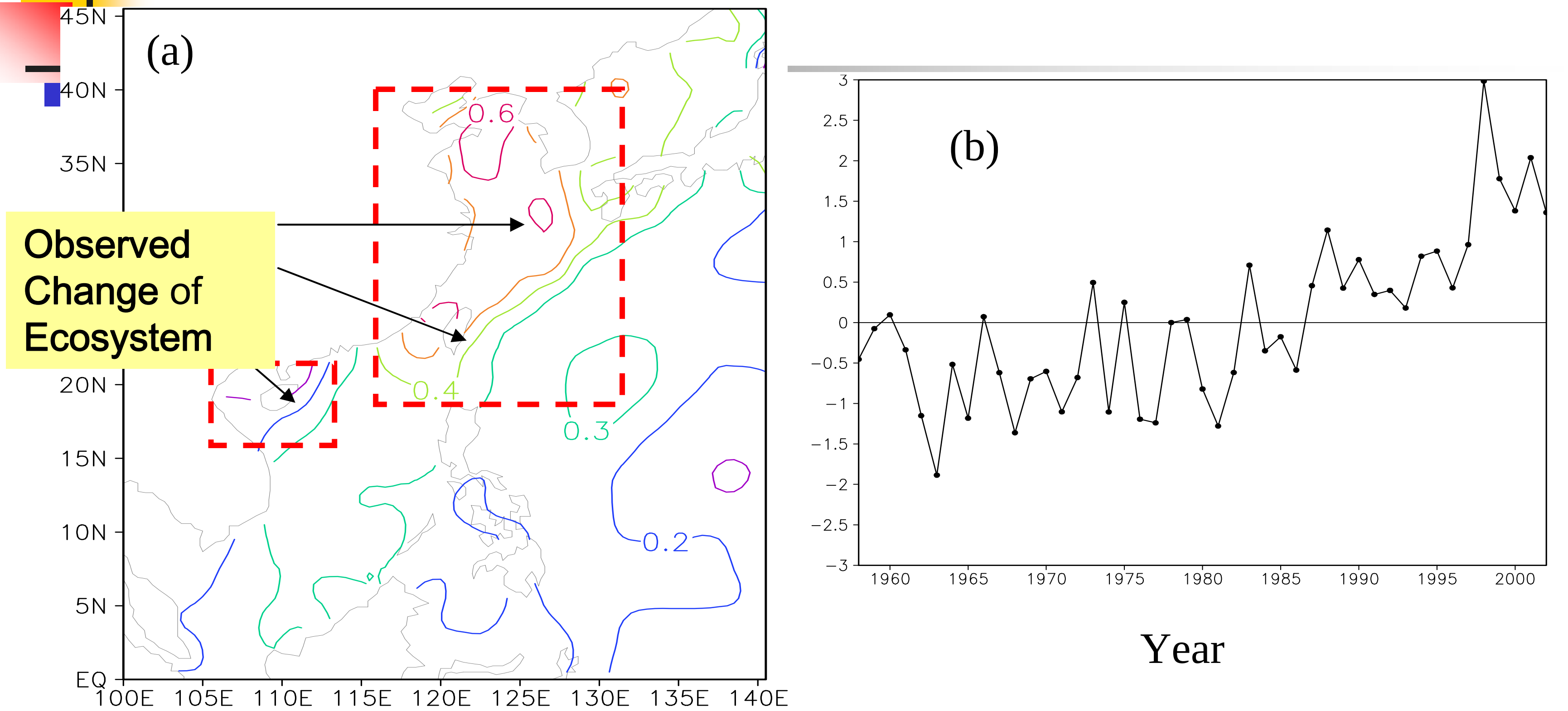
The results show, that the heat transport anomaly of the source area of Kuroshio is an important factor to affect the SST in the offshore area of China, too.

（Published in 2010）

- Summary 2
- 1) Heat transport anomaly of the source area of Kuroshio presents distinct inter-annual and inter-decadal variations with a obvious linear trend of increasing, and it experience a climate shift around 1976.
- 2) Variations of SST in the offshore area of China are closely related with the heat transport of the source area of Kuroshio on inter-annual and inter-decadal timescales.
- However, we still have no idea that EAM or KC has much more influence on the variations of SST in the offshore area of China so far?
- Actually, SST in the mentioned area is also affected by many other impact factors, e.g. ENSO, PDO, and so on.

- **3. Marine Ecological Effects of Rapid Marginal Seas Warming**

Q3: How about the rapid EAMSs warming affect marine ecosystem in the offshore area of China?

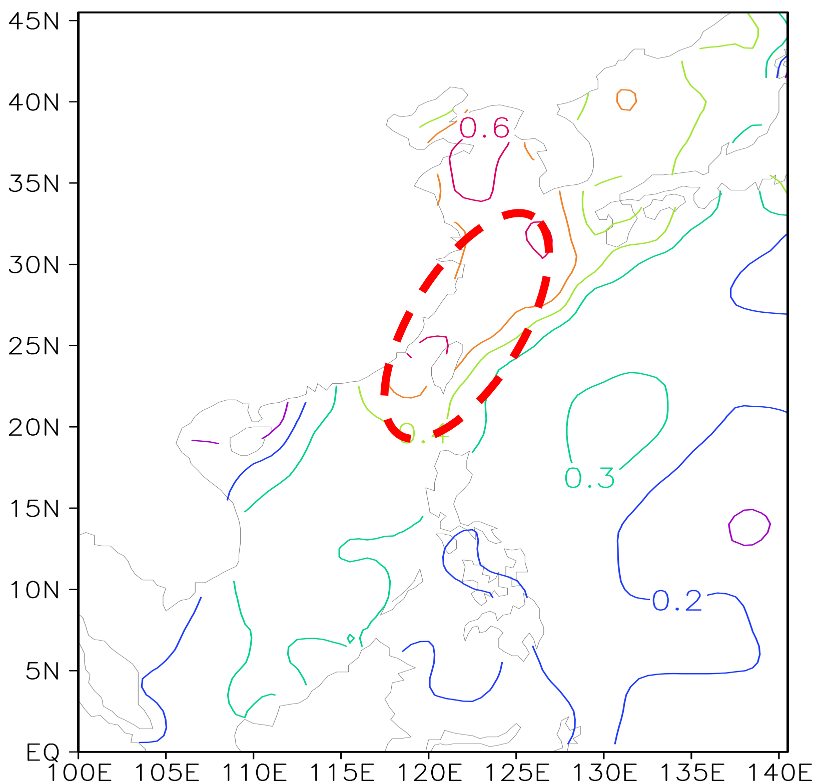


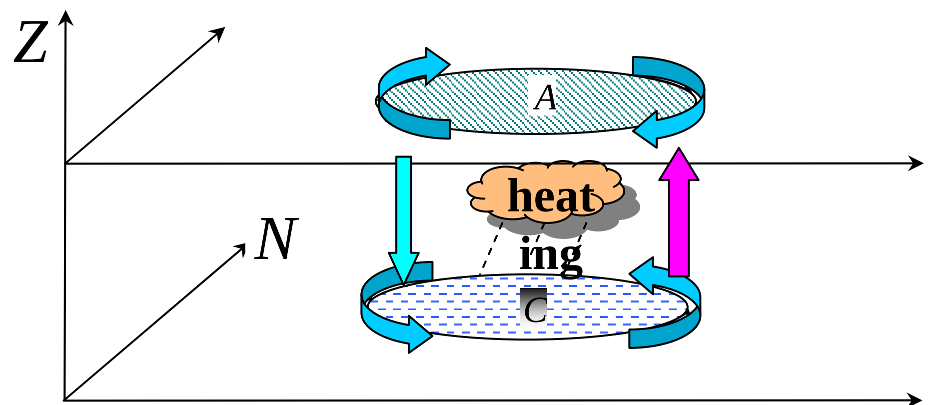
3.1) On the Hab (Red tide) frequency in East China Sea

3.2) On the marine bio-geographic distribution, including the variations of temperate water species, warm water species of plankton, fish, etc.

3.1) Impacts of rapid warming on the Hab (Red tide) frequency in East China Sea

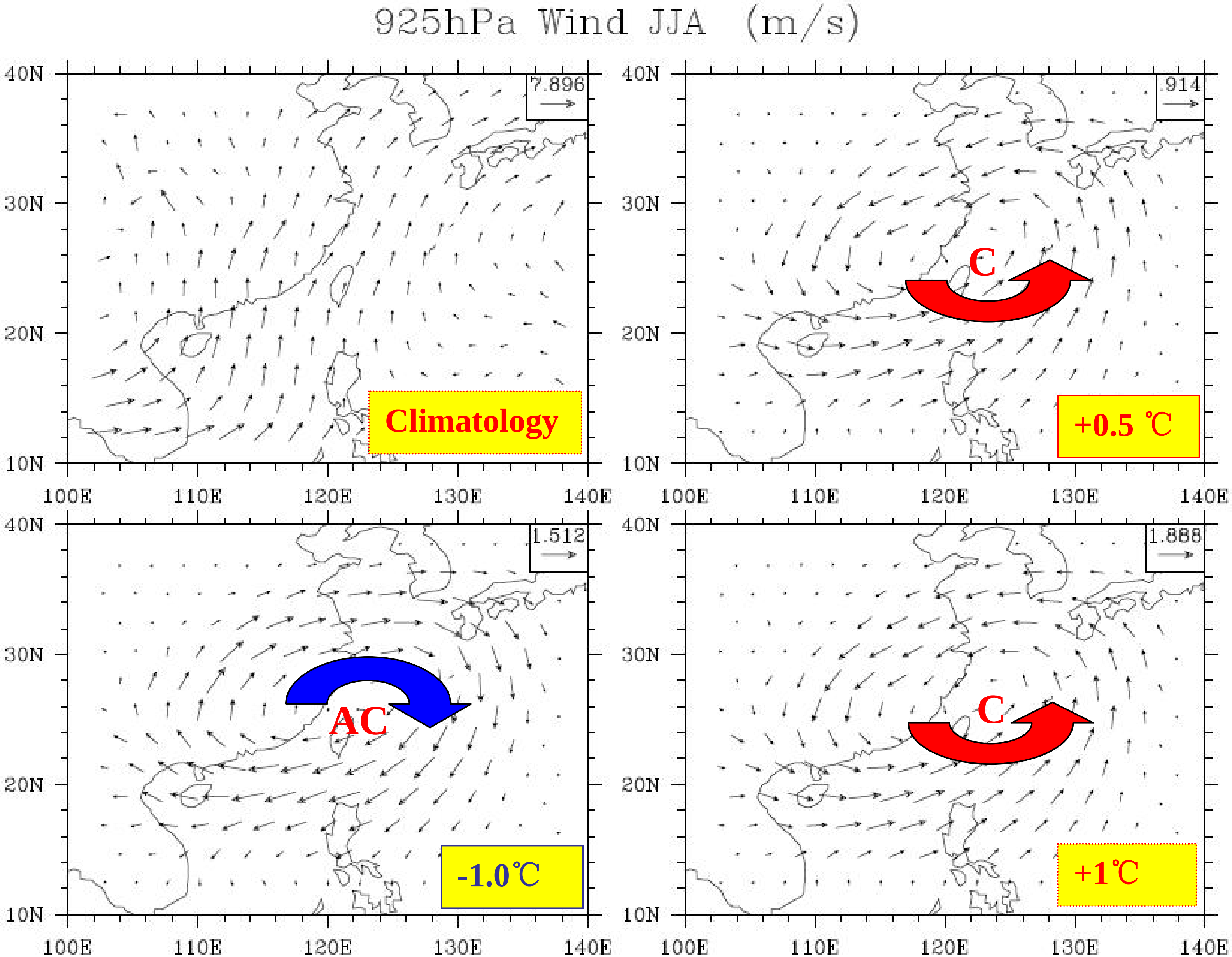
Thermal Adaptation- heating





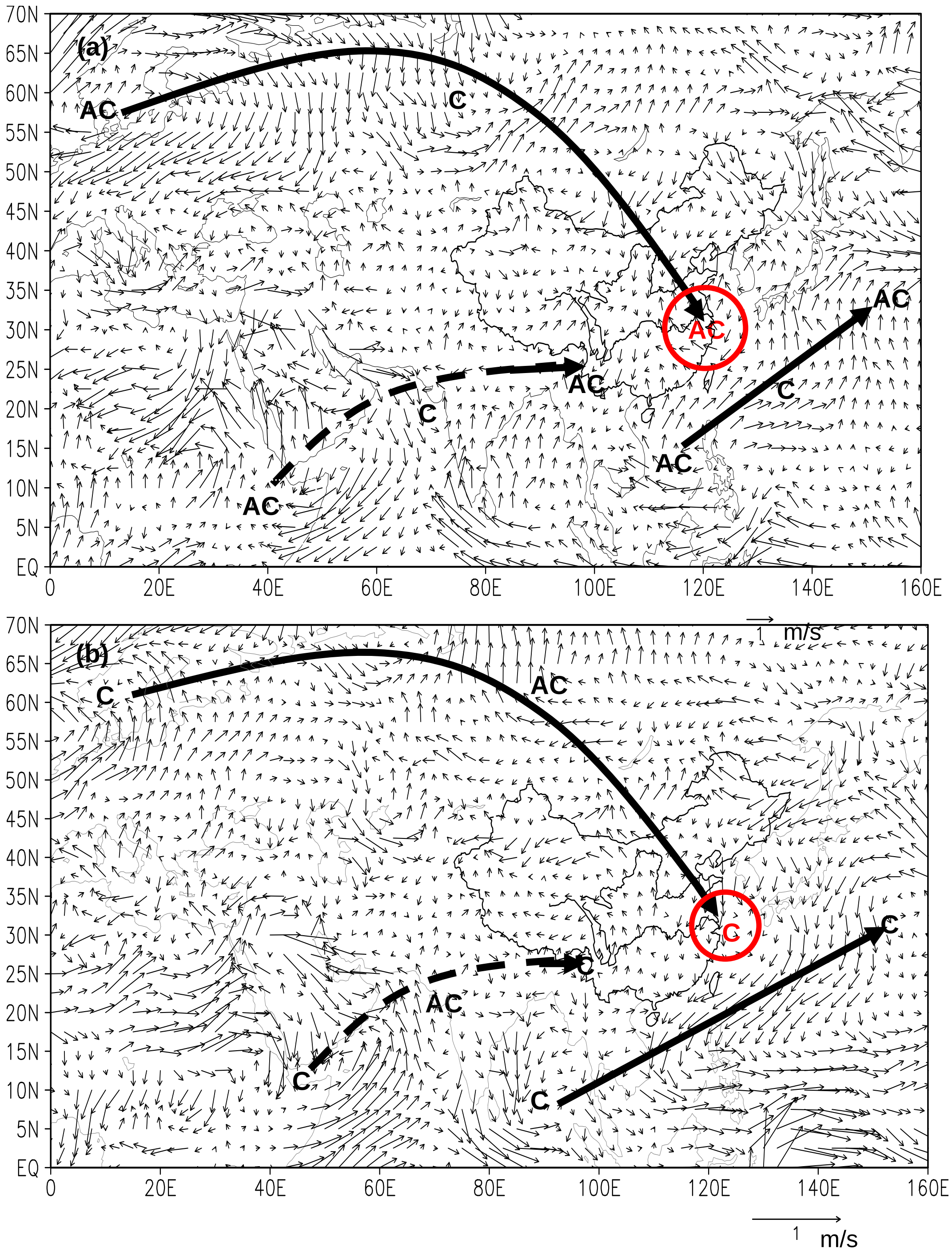
From Wu et al, 2008

$$w \propto -\beta \frac{\partial v}{\partial z}$$



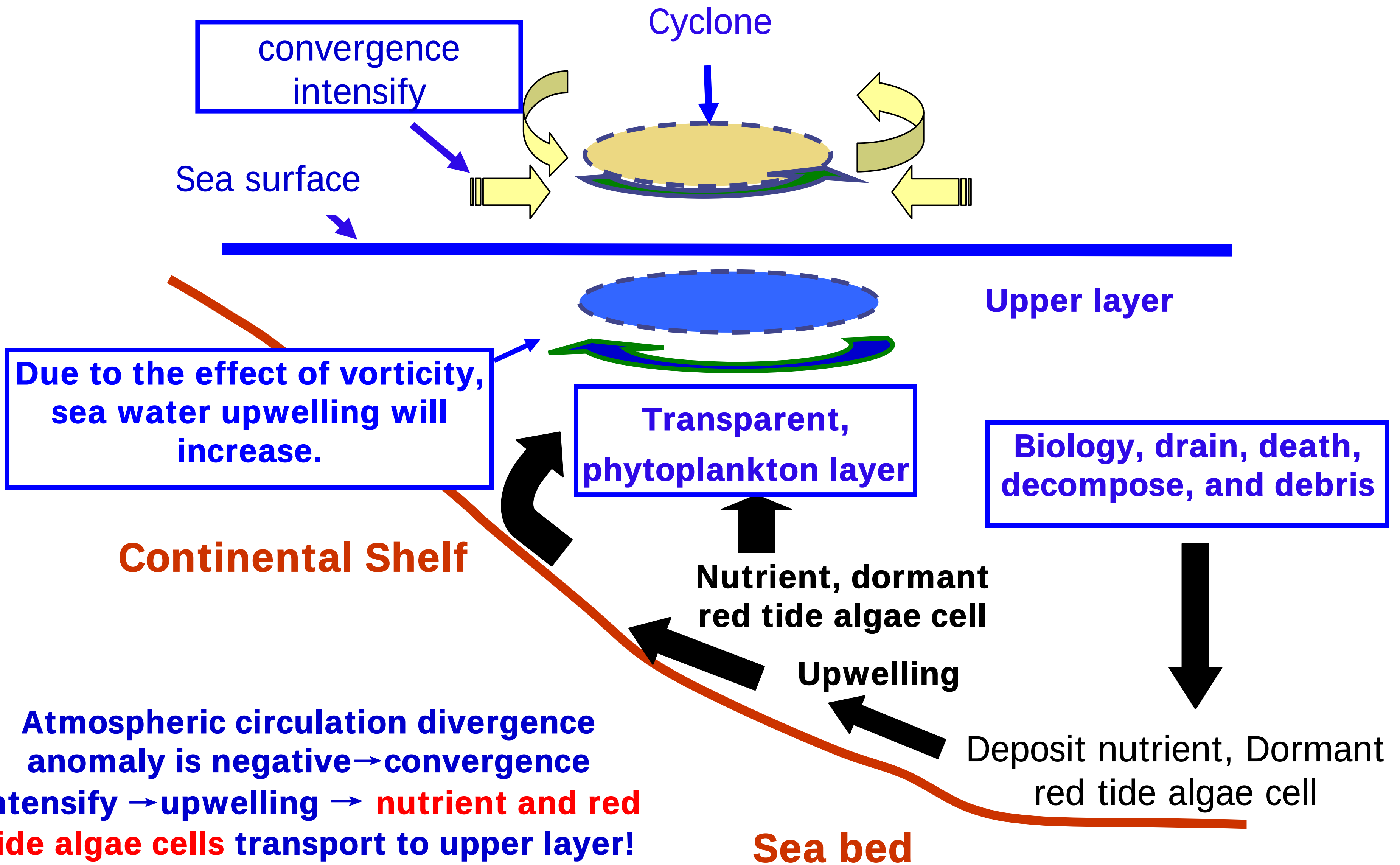
(**Climatology**\ +0.5℃ \ -0.5℃ \ +1℃ **)**scenarios numerical experiment

by Regional Climate Model 3 (RegCM3, ICTP).



Inter-decadal variation of summer (Jun.-Aug.) circulation anomaly at 700hPa over East Asia.
(a) 1966~1976,
(b) 1977~2000.
In the figures, C and AC indicate cyclonic and anti-cyclonic anomaly circulations, respectively.
The climatological mean of monthly circulation for 1961~1990 is taken as the normal, and data is from the ERA-40, NCEP reanalysis data

3.1.1 Impacts of rapid warm on the Hab (Red tide) frequency by air-sea interaction



Atmospheric circulation divergence anomaly is negative→convergence intensify →upwelling → nutrient and red tide algae cells transport to upper layer!

(Hypothesis talked in PICES 2008 meeting)

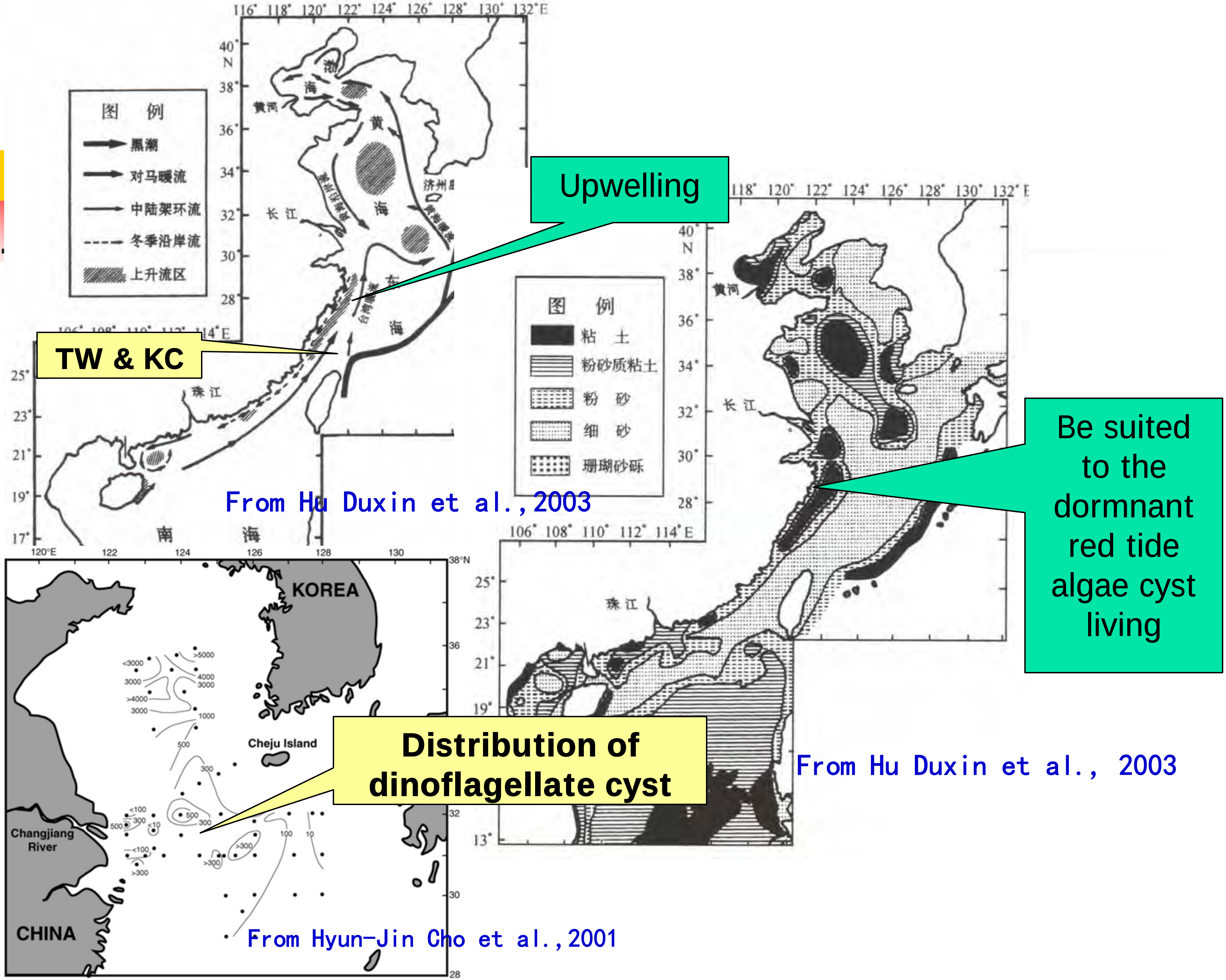


图 例
黑潮
对马暖流
中陆架环流
冬季沿岸流
上升流区
Upwelling
TW & KC
From Hu Duxin et al.,2003
图 例
粘 土
粉砂质粘土
粉 砂
细 砂
珊瑚砂砾
Be suited to the dormant red tide algae cyst living
From Hu Duxin et al., 2003
KOREA
Cheju Island
Changjiang River
CHINA
Distribution of dinoflagellate cyst
From Hyun-Jin Cho et al.,2001

Atmospheric convergence will intensify local air-sea interaction between lower atmosphere and upper oceanic layer.

↓

The Coastal upwelling will intensify!

↓

The nutrient and dormant red tide algae cell to be transported from the sea bottom to upper layer with the coastal upwelling. Meanwhile, Kuroshio current (Taiwan warm current) northward transport intensify, especially in spring (Zhou Mingjiang, 200?), and it will lead sea water warming than before, and more and more water pollutant release to the offshore areas. And the eutrophicated water become more serious than before.

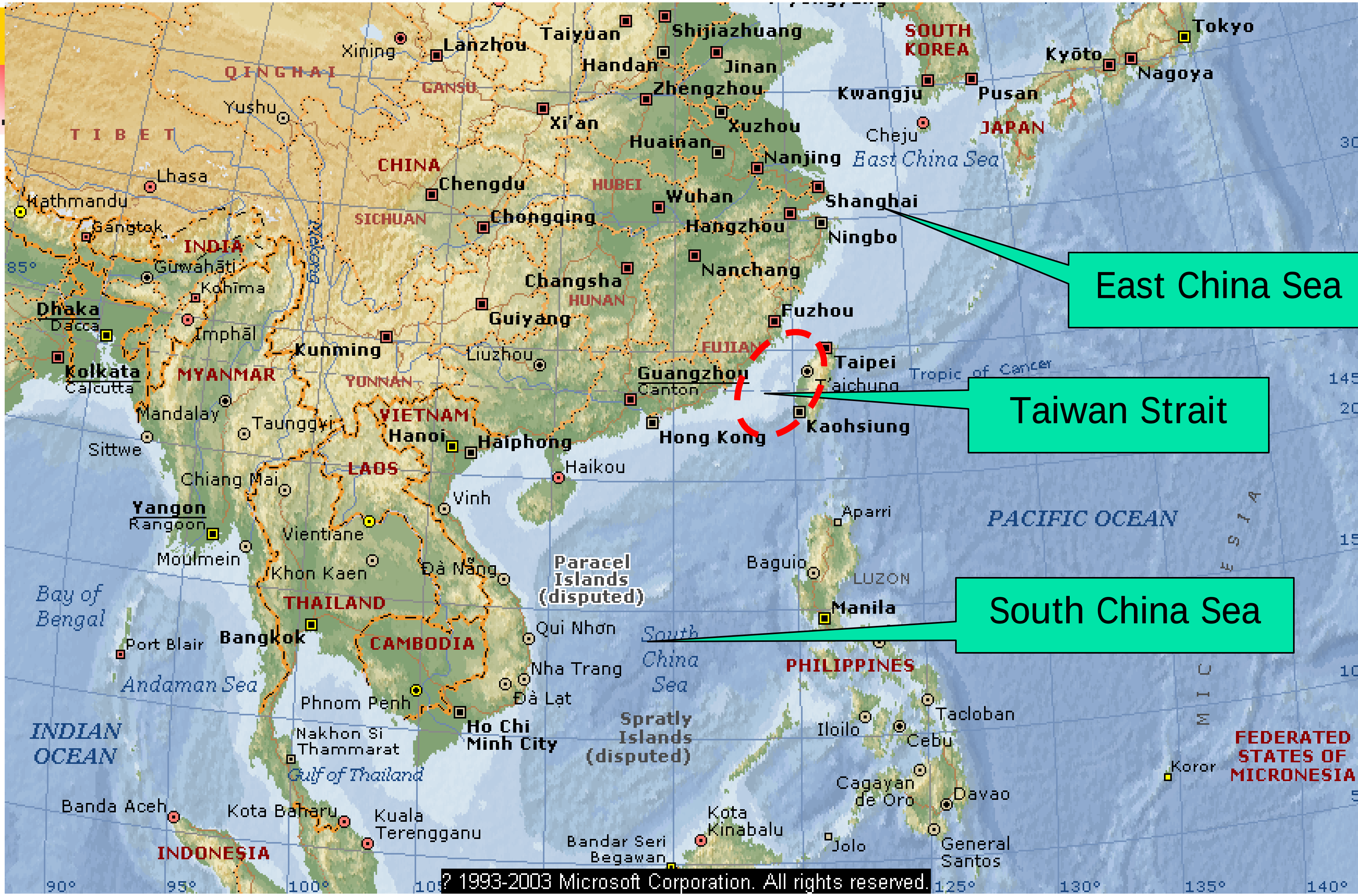
↓

HAB (Red tide) will be easier to form!

3.1.2) Impacts of rapid warm on the Red tide frequency by changing zooplankton community

- Some people, e.g. Xu (2004), found that the red tide frequently occurring in East China Sea might be due to the sea water warming earlier than as usual from winter to spring under the background of regional warming.
- It will drive the zooplankton community change, e.g., zooplankton community alternate time in season will be earlier than normal, but the number of zooplankton could not increase at the same time (Xu, 2004). Therefore, it will reduce the intensity of zooplankton feeding on phytoplankton. Finally, phytoplankton can be easier to develop than as usual.

3.2) Impacts of rapid warming on the offshore ecological system of China



2.1) Impacts of rapid warming on the phytoplankton ecology in Taiwan Strait

Variations of Species richness, Abundance, Evenness, Diversity index of phytoplankton in Taiwan Strait in the past decades

Year	Species richness S/ (Species)	Abundance N/ (10^4 cells/m^3)	Eveness J	Diversity Index H′ (log2)
1984.05—1985.02	257	371.967	0.622	3.290
1988.04—1987.12	274	656.60	—	3.290
2006.08—2008.01	301	1738.771	0.554	2.902

Increase

Decrease

Comparing with the investigated data in 1980s, 1990s and 2000s, the results show that phytoplankton biodiversity index in Taiwan Strait declined, but cell numbers, species richness and warm-water species have a significant increase since the 1980s!

Variation of phytoplankton species composition in Taiwan Strait

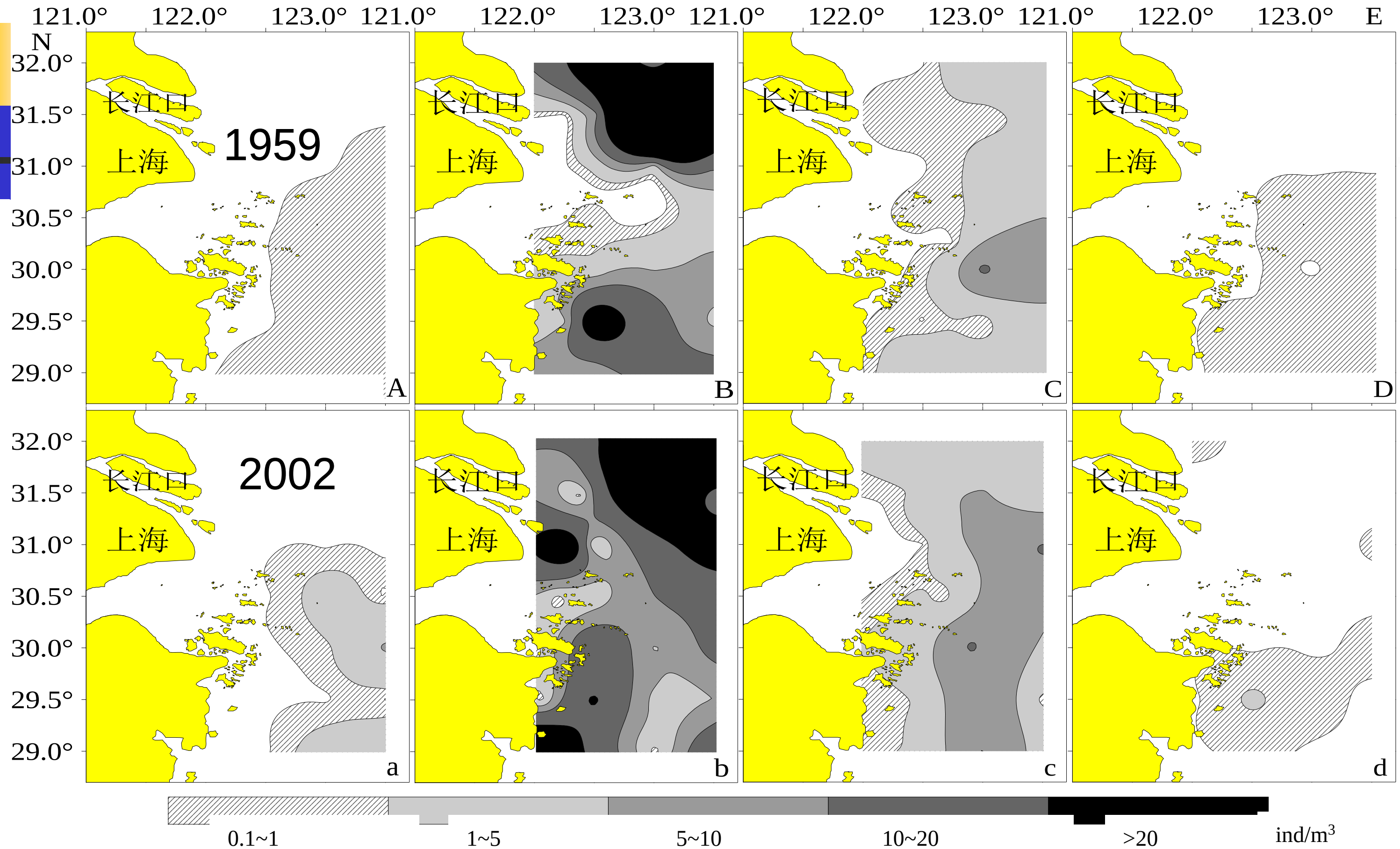
Categories and major groups	1983—1984 (Center and north Strait)		1984—1985 (North 、center and south Strait)		1988 (Minnan - Taiwan Bank fishing ground upwelling area)		1988 (Minnan - Taiwan Bank fishing ground upwelling area, hydromining)		1997—1999 (North 、center and south Strait)		2006—2008 (North 、center and south Strait)	
	1980s								1990s		The 21st century	
	Species Number	Proportion (%)	Species Number	Proportion (%)	Species Number	Proportion (%)	Species Number	Proportion (%)	Species Number	Proportion (%)	Species Number	(%)
Total number	244		257		298		274		85		301	
Bacillariophyta	177	72.5	167	65.0	185	62.0			77	90.6	174	57.8
Pyrroptata	60	24.6	84	32.7	105	35.2			7	8.2	122	40.5
Chrysophyta	2	0.8	2	0.8	2	1.7					2	0.7
Xanthophyta	—		1	0.4	—	—					1	0.3
Cyanophyta	5	2.0	3	1.1	5	1.7			1	1.2	2	0.7
Chlorophyta	—		—	—	1	0.3					—	—
Eurythermal species			123	47.9					49	57.3	130	43.2
Warm water species			118	45.9		>60.0		34.0	25	29.3	160	53.2
Warm temperate species			16	6.2					11	12.7	11	3.6

Comparing of the proportion of warm water species categories in 1980's and 2000's

	1984—1985			2006—2008		
	Species Number	Warm water species number	Proportion (%)	Species Number	Warm water species number	Proportion (%)
Bacillariophyta	167	53	31.7	174	61	35.1
Pyrroptata	84	63	75.0	122	97	79.5
Chrysophyta	2	0	0.0	2	0	0.0
Xanthophyta	1	0	0.0	1	0	0.0
Cyanophyta	3	2	66.7	2	2	100.0
Total number	257	118		301	160	

Species number from 257 increase to 301, warm-water species ratio from 45.9% increase to 53.2%. This is related to algae dramatically increasing than before. Warm-water species generally have increased in various categories of phytoplankton group composition.

2.2) Impacts of rapid warming on zooplankton ecology in the East China Sea



1959： A. Spring ;B. Summer ;C. Autumn ;D. Winter

2002： a. Spring ;b. Summer ;c. Autumn ;d. Winter

Change of distribution area of typical warm water species *Sagitta enflata* in northern East China Sea in 1959 & 2002(Xu .2009)

Variations of zooplankton species diversity in Taiwan Strait between 1984-1985 &2006-2007

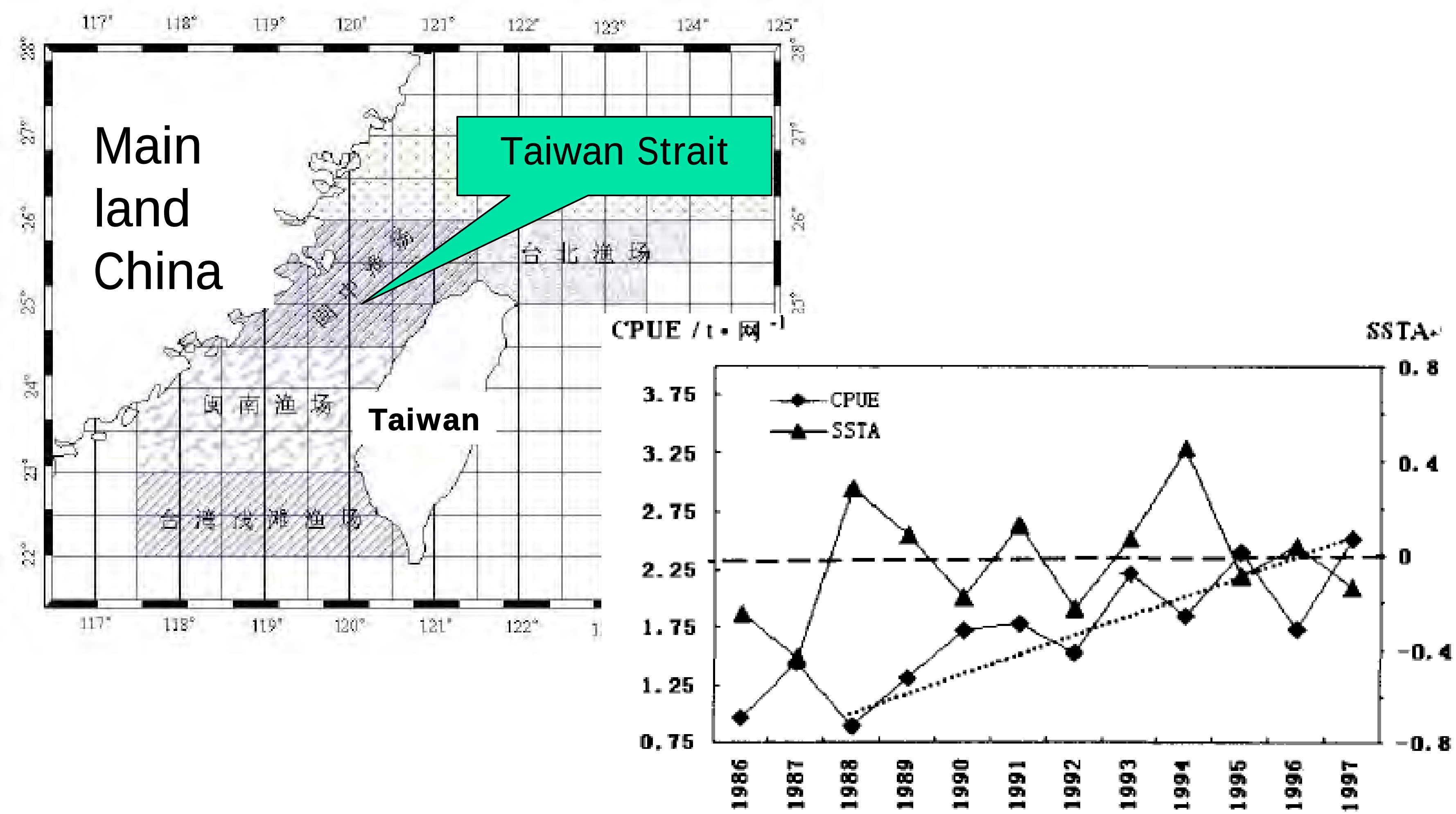
Species diversity	Species richness /(Species)		Abundance / (ind./m³)		Eveness (J)		Diversity Index (H')	
Period	1984-1985	2006-2008	1984-1985	2006-2008	1984-1985	2006-2008	1984-1985	2006-2008
Summer	355	267*	127.4	271.1	0.64	0.71	3.95	3.87
Winter	231	281	34	43.6	0.5	0.74	2.11	3.58
Spring	328	305	200.2	105.1	0.59	0.65	3.61	3.45
Autumn	271	234	45.1	85.8	0.71	0.69	4.17	3.45
Seasonal mean	499**	< 500**	101.7	< 126.4	0.61	< 0.7	3.46	< 3.59

Change of zooplankton dominant species in Taiwan Strait between 1984-1985 &2006-2007

		Average abundance (/m^3)		Abundance ratio (%)		Dominance	
Dominant species		1984-1985	2006-2008	1984-1985	2006-2008	1984-1985	2006-2008
Calanus sinicus	Temperate water species	8.49	14.7	8.34	11.63	0.16	0.13
Muggiaea atlantica		9.8	0.1	9.64	0.09	0.04	0
Euchaeta plana		1.03	0.38	1.01	0.3	0.02	0
Sagitta enflata	Warm water species	9.23	13.	9.08	10.28	0.07	0.1
Euchaeta concinna		2.14	5.3	2.1	4.21	0.04	0.05
Undinula vulgaris		2.27	8	2.23	6.29	0.02	0.04
Temora discaudata		2.23	5.6	2.2	4.44	0.01	0.02
Oikopleura rufescens		-	5.4	0	4.26	0	0.05
Sagitta bedoti		1.04	3.1	1.02	2.46	0.01	0.03

The investigated results show that dominance of temperate water species distinctly decrease, and warm water species increase in Taiwan Strait.

2.3) Impacts of rapid warming on the bio-geographic distribution of fish species



Variations of CPUE and SST of Minnan-Taiwan bank fishing ground in 1986-1997 (From Zhang XueMin et al., 2005)

Variation of species composition of chub mackerel and round scad catch in the Minnan-Taiwan Bank Fishing Ground between 1987 and 1997

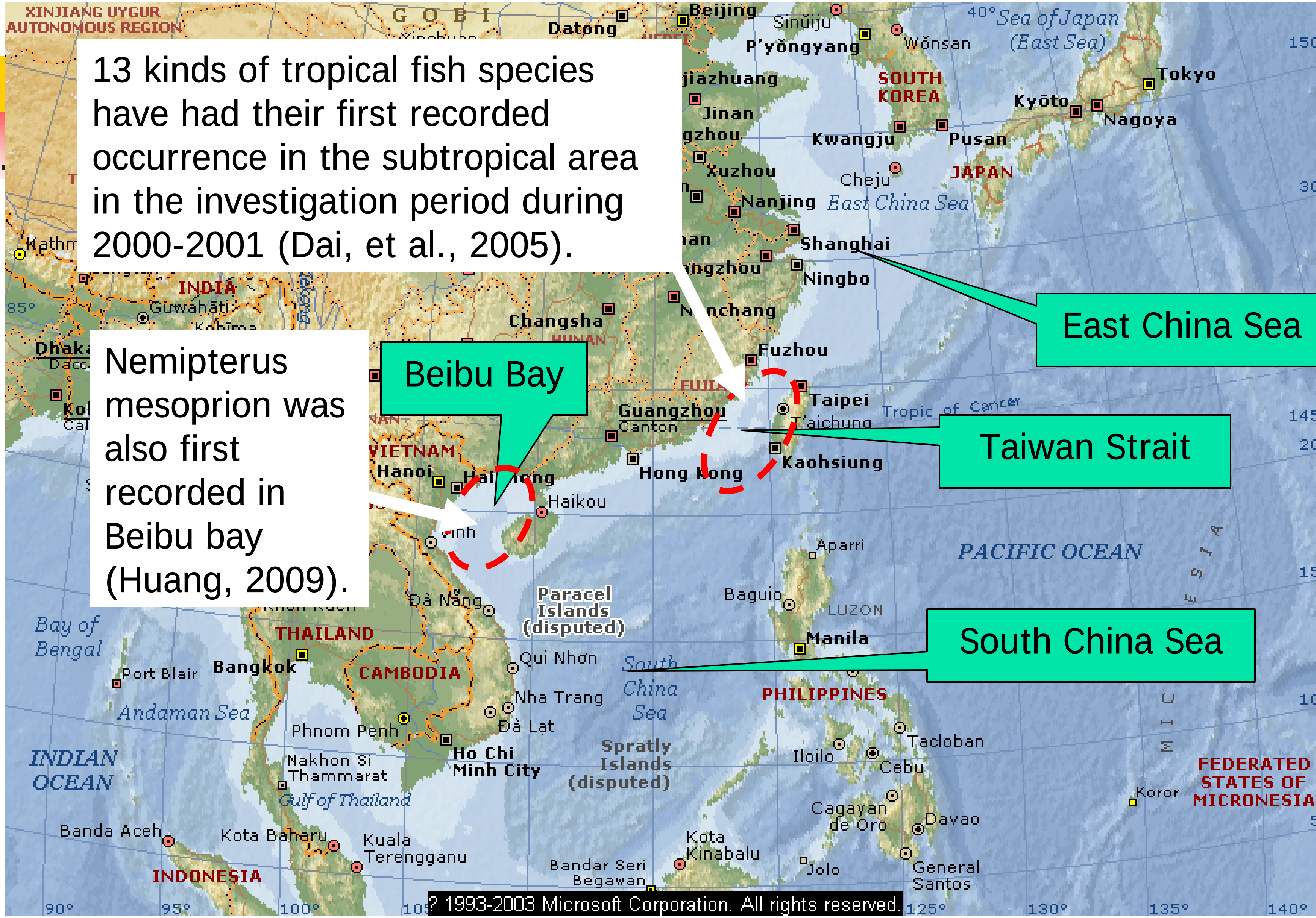
适温性	种类	渔获物组成 / %										
		1987—1991 年					1992—1997 年					
		1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
emperate species	蓝圆鲹 *(Decapterus marudsi)*	63.9	70.9	56.3	65.6	65.9	47.4	51.2	54.8	55.5	45.9	/
Warm species	鲐鱼 *(Pneumatophrus japonicus)*	11.4	14.4	19.7	17.4	14	35.6	30.7	27.8	24.5	28.5	23.6
	金色小沙丁鱼 *(Sardinella aurita)*											

(From Zhang Xuemin et al., 2005)

The SST anomaly data demonstrated the possibility that there was one shift from cold to warm regime occurring in 1988, while Catch Per Unit Effort (CPUE) of Chub Macherel and Round Scad was likely to show a tendency of gradual increase after 1988. However, the proportion of warm water species relative to warm temperate species changed only after 1992.

13 kinds of tropical fish species have had their first recorded occurrence in the subtropical area in the investigation period during 2000-2001 (Dai, et al., 2005).

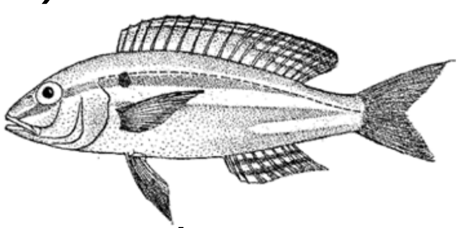
Nemipterus mesoprion was also first recorded in Beibu bay (Huang, 2009).



The above mentioned 13 tropical fish species are first recorded in Taiwan Strait as following:

慧琪豆娘鱼（*Abudefduf vaigiensis*）、峨嵋条鳎(*Zebrias quagga*)、豹鳎(*Pardachirus pavominus*)、海蠋鱼（*Halicampus koilomatodon*）、拟三刺鲀(*Triacanthodidae anomalus*)、尖牙鲈(*Synagrops japonicuus*)、尖尾黄姑鱼(*Nibea acuta*)、孔鳐(*Raja porosa*)、美鳐（*Raja pulchra*）、棘鳞蛇鲭（*Ruventtus tydemani*）、节鳞鳎(*Aseraggodes kobensis*)、褐斜鲽(*Plagiopsetta glossa*)、黄鳍马面鲀(*Navodon xanthopterus*)等

And they mainly distribute in the South China Sea (Dai Tianyuan, et al,2005)。



Nemipterus mesoprion(Bleeker,1853)

Nemipterus mesoprion was first recorded in Beibu bay in the northern South China Sea in 2008, which is one of tropical ground fish species (Huang Zirong et al., 2009) and appears mainly in Indonesia before.

- Summary 3
- 1) Rapid EAMSs warming will strengthen local air-sea interaction, and it will intensify the upwelling. Meanwhile, KC & TC northward transport intensify, it will lead sea water warming earlier than as usual, and will provide a favorable climate background for the frequent occurrence of HAB.
- 2) Phytoplankton biodiversity index in Taiwan Strait declined, but cell numbers, species richness and warm-water species have a significant increase since the 1980s!
- 3) Rapid Warming trend may greatly affect marine species composition and bio-geographic distribution, especially for the HAB (Red tide) frequently occurred and tropical fish expanding their range northward into the subtropical in the offshore area of China.
- Not only sea water temperature, but also wind & current, perhaps play also an important role in bio-geographic distribution. However, it should be need much more investigated in future.

Thank you!