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Brief Review of Some CLIVAR-Related Studies in China

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ABSTRACT

The Climate Variability and Predictability (CLIVAR) program is one of the sub-programs of the World Climate Research Program (WCRP). In this paper, CLIVAR related research in China (2003–2006) is briefly reviewed, including four major components, namely, low-frequency intraseasonal oscillations, interannual variability, decadal variations in East Asia, and global warming simulations.

Key words: CLIVAR, WCRP, intraseasonal oscillation, interannual variability, decadal variation, global warming

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1. Low frequency oscillation

Intraseasonal oscillations (ISOs) are strong signals within the tropical atmosphere and common also within tropical oceans. The Madden-Julian Oscillation (MJO) represents the most dominant mode of atmospheric variability in the tropics on intraseasonal timescales.

1.1 *ISO in East Asia*

Many studies indicate that the anomalous summer rainfall in East China is closely associated with the strengthened or weakened East Asian Summer Monsoon (EASM) circulation. A strengthened (weakened) atmospheric ISO at 850 hPa near the South China Sea (SCS) region results in a strong (weak) SCS summer monsoon (Ding et al., 2004). This study also revealed that the variability of the atmospheric ISO in the SCS region is usually opposite in phase with that in the Yangtze-Huaihe River basin. The strong (weak) atmospheric ISO in the SCS region is associated with the weak (strong) atmospheric ISO in the Yangtze-Huaihe River basin. The low-frequency oscillation (LFO) of 30–60 days is quite remarkable in strong summer monsoon surge years in the SCS and closely related to the flooding in the middle and lower reaches of the Yangtze valley. In the weak summer monsoon surge years, the LFO of 10–20 days is more active than that of 30–60 days and likely related to drought conditions. The propagation of the monsoon surge LFO is important to medium and long-range prediction of rainfall in the Yangtze River valley (Ju and Zhao, 2005).

ISOs of convection intensity during the summer half year relates to sea surface temperatures (SST) of the SCS in the following winter. When the intensity of ISO convection is strong (weak), SST anomalies of the SCS in the following winter is negative (positive) (Lin et al., 2005). Analyses also suggest that the interannual variability of the winter monsoon over East Asia is associated with the interannual variability of tropical atmosphere in the 30–60-day oscillation. Corresponding to a strong (weak) winter monsoon over East Asia, cumulus convection over the tropical western Pacific is strengthened (weakened) and the atmospheric 30–60-day oscillation is active (inactive) (Long and Li, 2001). A meridional wave train along the East Asian coast was shown to accompany propagation of the 30–60-day oscillation northward. It was observed that the northward propagation of this meridional ISO wave along the east coast of China is coupled with variations in the EASM in tropical and subtropical region (Ju et al., 2005b). The characteristics of zonal and meridional propagation of ISOs in the tropical atmosphere and kinetic energy transport were noted by Yang and Li (2005). The climate characteristics of tropical intraseasonal oscillations (TIOs) can be presented by using spectral and wavelet analysis. It was found that there are three regions where TIOs are ac-

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tive, namely, the West Pacific, tropical Indian Ocean, and the region north of the equator in the East Pacific. TIOs have obvious seasonal transitions. Two centers of maximum transition, the western Pacific and Indian Ocean, move southward to 10°S in winter and northward to 10°N in summer. They are inactive during spring and autumn. The TIO in the eastern Pacific north of the equator is active only in summer. It is very weak during winter and it does not shift to the southern hemisphere at any time.

1.2 *The relationships between ISOs and climate over East Asia-Pacific region*

ISOs were studied during the severe flood and drought years of the Yangtze River-Huaihe River basins using National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data and precipitation data within China (Yang and Li, 2003). The results show that the upper-level (200 hPa) ISO pattern in severe flood (drought) years is characterized by an anticyclone (cyclone) over the south of Tibetan Plateau and a cyclone (anticyclone) over the north of Tibetan Plateau. The lower-level (850 hPa) ISO pattern is characterized by an anticyclone (cyclone) over south of the Yangtze River, the South China Sea, and the western Pacific, and a cyclone (anticyclone) extending from north of the Yangtze River to Japan. According to a vector EOF expansion, the low-level ISO circulation pattern is the first mode of the ISO wind field with a relatively large value of the temporal coefficient during severe flood years. The analyses also revealed that the atmospheric ISO in the middle and high troposphere over the Yangtze River-Huaihe basins, North China, and the middle-high latitudes in North China are more active in flood years than in drought years. The meridional winds of the ISO over middle-high latitudes propagates southward and meet with those propagating northward from low latitudes over the Yangtze River-Huaihe basins during severe flood years (Yang and Li, 2003). Their research revealed that JJA-mean atmospheric ISO kinetic energy between severe flood years and severe drought years are quite different in the high and middle troposphere (Fig. 1, from Yang and Li, 2003). Thus ISO variability and its roles in East Asian climate should motivate more study, via both data analysis and climate model simulations.

The extremely hot weather with daily maximum temperatures over 35°C in 2003 occurred mainly during early July to August. The number of hot day increased by 100% to ~200% in most regions except for the Leizhou Peninsula. These high temperatures coincided with the positive phase of the 60–80-day seasonal oscillation (Ji et al., 2005).

The modulation of tropical depressions/cyclones (TDs/TCs) over the Indian-western Pacific Oceans by the MJO was addressed for the period of September 1996 to June 1997 on the basis of daily wind vectors in the NCAR/NCEP reanalysis and outgoing longwave radiation (OLR) data sets. Results suggested that there are more (less) TD/TCs forming in the wet (dry) phase of MJO convection, except in the western North Pacific sectors where TDs/TCs can be affected also by the eastward or westward propagation of MJOs. Along with eastward propagating MJO convection, the region-average position of TD/TC occurrence also appears an eastward shift (Zhu et al., 2004).

1.3 *Simulation of ISOs*

Jia et al. (2004) studied the ability of an atmospheric general circulation model to simulate ISOs by comparison with the NCEP/NCAR Reanalyses which have been largely used to study the ISO variability (Ding et al., 2004; Ju and Zhao, 2005; Yang and Li, 2003). The model displays an evident periodic signal of intraseasonal oscillation in tropical regions. The basic propagation characteristics of ISOs is prominent, and the changes in phase speed between eastern and western hemispheres are strongly evident. The simulated eastward propagation is better than that of westward propagation, and simulations of winter and spring are better than in summer and autumn. The model can simulate the strength of ISOs well, especially the marked strong kinetic energy of at 200 hPa. The model can simulate the horizontal structure of ISO wind fields with convergence at lower levels and divergence aloft, as well as depicting the vertical structure of the zonal wind. However, there remain discrepancies between simulation and observation. The simulated ISO is strong in winter and summer but weak in spring and autumn, while the observed ISO is strong in winter and spring but weak in summer and autumn. The structures of some physical elements such as vertical velocity, divergence and specific humidity and the spatial distribution of ISO differ also with the reanalysis data. However, as a model product, the NCEP/NCAR reanalysis data have also some uncertainty on intraseasonal timescale (Newman et al., 2000). The actual model behaviors need further evaluation based on observational data (Newman et al., 2000).

2. Interannual variability of the East Asian climate

2.1 *The East Asian summer climate interannual variability*

East Asia is a typical region that is influenced

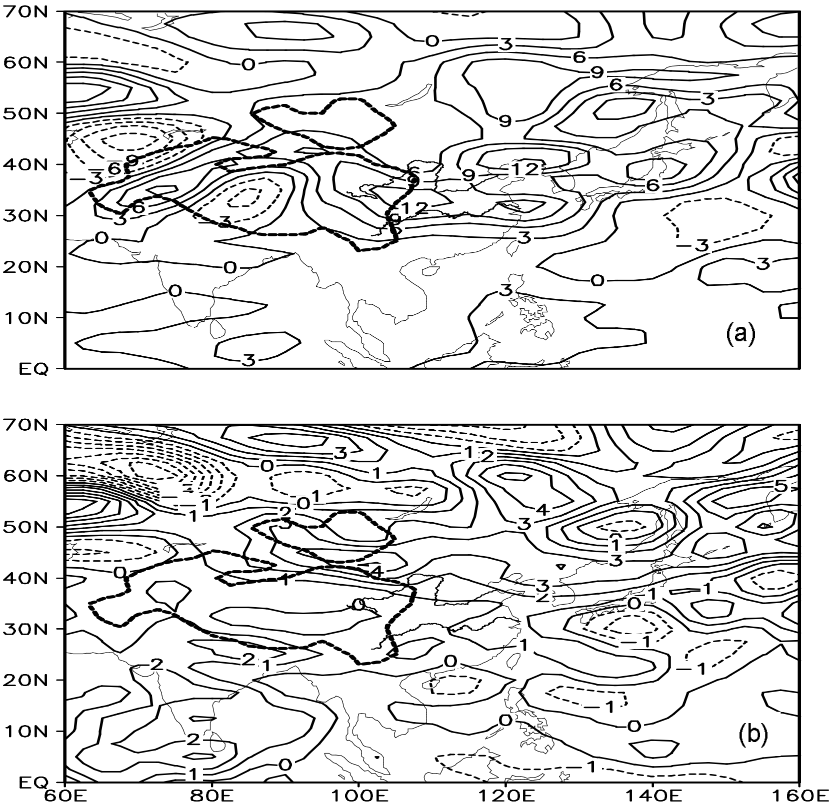

Fig. 1. Composite difference of JJA-mean atmospheric ISO kinetic energy between severe flood years and severe drought years at (a) 200 hPa and (b) 500 hPa (from Yang and Li, 2003).

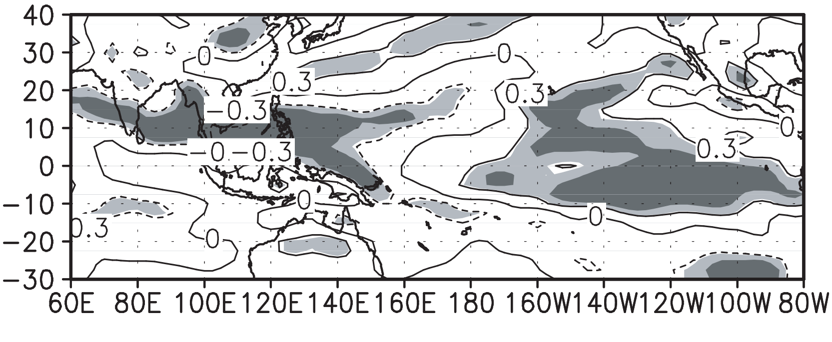

Fig. 2. Correlations of the winter WP index with 850 hPa westerlies in the following May–July. The gray and black area denotes areas exceeding a 5% and 1% level of significance, respectively (from Wu et al., 2003).

mainly by the summer monsoon (Ding and Chan, 2005). In the last four years the major progress in the study of the EASM has focused on exploring the causes of monsoon related anomalies. Xu et al. (2004) and Zhou and Yu (2005) analyzed atmospheric water vapor transports associated with typical anomalous summer rainfall patterns in China. They found that variability in long-distant transports of moisture from over tropical oceans (tropical western Pacific, tropical Indian Ocean, South China Sea) was responsible for whether floods or droughts occurring in China. Thus, the tropical oceans are important for the East Asian summer climate by providing the main source of moisture for the monsoon rainfall. Additionally, the importance of the tropics is demonstrated by teleconnection patterns between the variability in East Asian monsoon circulations and conditions over tropical oceans (Zhang et al., 2003a; Huang et al., 2005). The influence of tropi-

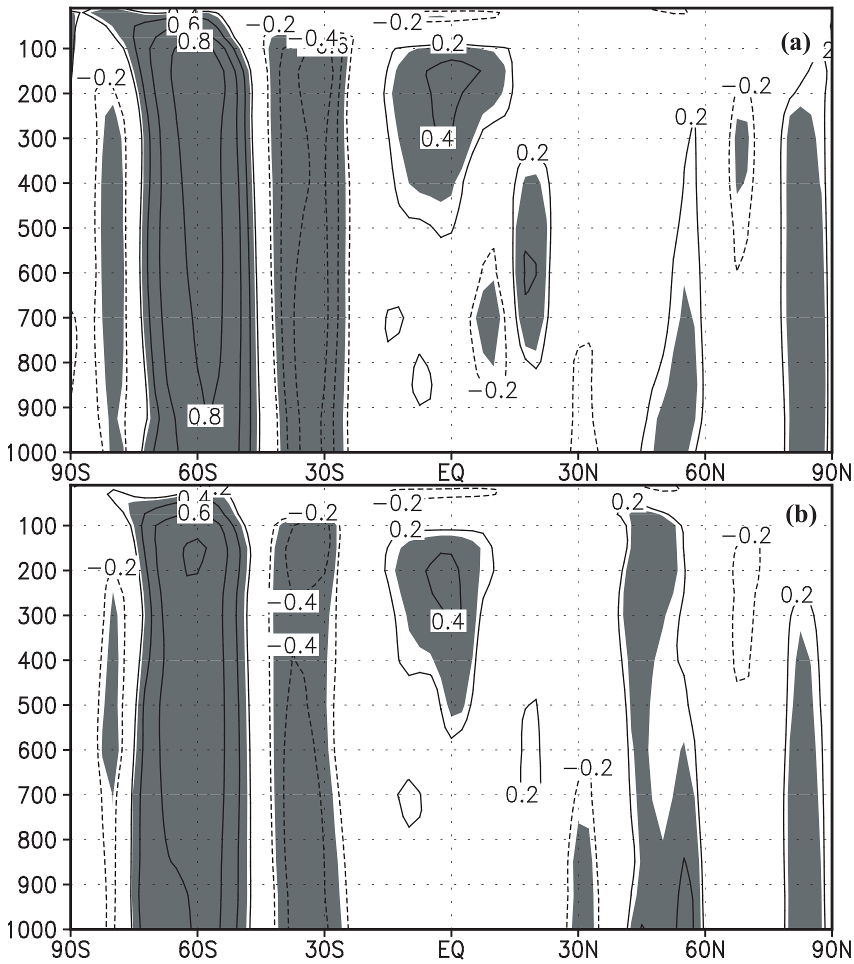

Fig. 3. The latitude-height cross sections for the correlation coefficients between JJA ISH and mean zonal winds for 1949–2002. (a) Whole zonal mean; (b) 0°–180°E zonal mean. Shaded areas indicate significant changes at 95% level estimated by a local student t-test (from Wang and Fan, 2006).

cal oceanic regions on the EASM is being investigated also via model simulations (Gao et al., 2004).

Atmospheric teleconnections are very important in East Asian climate variability. Many components having close links with the East Asian climate are documented, e.g., the boreal winter sea level pressure anomaly over the tropical western Pacific (Wu et al., 2003), the May Arctic Oscillation (Gong and Ho, 2003), the ridge-line of the subtropical anticyclone over the western Pacific (Zhang and Tao, 2003), the boreal spring Hadley circulation (Zhou and Wang, 2006a), the East Asia-North Pacific zonal dipole of the sea-level pressure (Zhao and Zhang, 2006), etc. These tropical and Northern Hemisphere (NH) atmospheric circulation systems are strongly tied to the East Asian summer climate. Interestingly, Wu et al. (2003) defined a normalized equatorial western Pacific circulation index (WP) as the December-January-February mean sea-level pressure over the region of 10°S–10°N, 130°–160°E. They found that this index in winter is significantly linked with the following season circulation in East Asia. Figure 2 shows the correlation between the WP index and the following May–June–July mean zonal wind in the East Asian region (Wu et al., 2003).

In addition, climate systems in the Southern Hemisphere (SH) have recently been found to be closely related to the EASM, as well as to the East Asian climate more generally. Some studies (Xue et al., 2003; Gao et al., 2003a; Wang and Fan, 2005, 2006; Fan, 2006; Nan and Li, 2003; Xue et al., 2004) investigated the relationships between the Antarctic Oscillation (AAO) and summer rainfall in the Yangtze River valley. Fan and Wang (2004) found the relationship between the

AAO and dust weather frequency in North China. This is associated with the cross equatorial flow, especially the Somali jet, in bridging SH circulations and the EASM (Wang and Xue, 2003). The mechanisms of the connection between the SH high latitude circulation and the East Asian climate also have been studied by, among others, Wang and Fan (2006). They showed clearly that the meridional teleconnection from the SH to the EASM region by displaying a latitude-height cross section of the correlation coefficient between a SH upper-troposphere index (ISH) and zonally averaged zonal wind (Fig. 3, from Wang and Fan, 2006). The index is defined as the difference of normalized zonal mean zonal winds between 30°S and 60°S at 150 hPa.

The above mentioned variability of atmospheric circulations and associated teleconnection patterns, especially those with lag relationships, can provide valuable signals in prediction of the East Asian summer climate.

2.2 *East Asian winter climate interannual variability*

The Intergovernmental Panel on Climate Change (IPCC) has reported on the substantial warming trend observed since the 1980s. Superimposed upon this warming trend of the background climate, East Asia also exhibits strong climate variability on both interannual and decadal time scales. Over the last 54 years, the winter of 2002 was the warmest in North Asia (Wang, 2003). Analysis of atmospheric circulations show that natural interannual variability was the primary contributor to this event, i.e., related global-scale atmospheric circulation anomalies with substantial components in the Eastern Hemisphere and in the middle and high latitude regions of the Southern Hemisphere.

Some later studies were conducted to investigate the reasons for the variability in atmospheric circulation. Chen and Sun (2003) suggested that snow cover over the Eurasian continent influences the boreal winter atmospheric circulation, for example, the Eurasian teleconnection with the East Asian winter monsoon (EAWM). Chen et al. (2004) indicated that the tropical Quasi-Biennial Oscillation (QBO) has an important role in the general circulation evolution in the Northern Hemisphere winter. Zhao and Zhang (2006) found that the sea-level pressure over the Eurasian continent has an out-of-phase relationship with that over the North Pacific. The phase of this zonal dipole is associated with changes in the EAWM. Gong and Wang (2003) suggested that in a strong (weak) Arctic Oscillation (AO) year the air temperature and precipitation increases (decreases) over most of China in winter. Fan and Wang (2006) found that the AAO is closely associated with the Eurasian zonal wind and the Pacific-North American teleconnection pattern via the meridional teleconnection pattern from the Antarctic to the Arctic.

2.3 *East Asian dust events*

Dust events are the most frequent weather over East Asia in the boreal spring but have a strong interannual component in variability and, therefore, the significance of their impacts on air quality, weather, and climate of East Asia (Shi and Zhao, 2003; Zhou and Zhang, 2003; Wang and Fang, 2004; Qian et al., 2006). Recently, Yuan and Zhang (2006) found that East Asian dust events are closely related to the increased productivity in north Pacific oceanic plankton by transporting nutrients from the land to ocean.

Zhai and Li (2003) pointed out that the dust events in North China are attributable to many weather elements, the most important of which is the interannual variability in rainfall. Thus, the previous boreal summer rainfall can be regarded as a predictor for the following spring dust events of North China. Fan and Wang (2004) revealed a relationship between the AAO and the dust events over North China. They showed that these two climate phenomena are significantly negatively correlated with each other. The meridional teleconnection pattern from the Antarctic to the Arctic and the circle teleconnection around the Pacific are responsible primarily for the linkage between the AAO and dust events (Fan and Wang, 2004). Zhao et al. (2004a) investigated the relationship between climatic factors and dust storm frequency in Inner Mongolia of China. They found that the main climate factors controlling dust storm frequency in this region are the number of days with gale force winds, an index of the intensity of the Asian polar vortex, and an index of the areal extent of the Northern Hemisphere vortex. These factors signal the variability of cold-air outbreaks over the Inner Mongolia. In addition, Xu and Chen (2006) indicated that the vegetation and snow cover over western China are important terrestrial conditions for dust event frequency. Based on these observational findings, Wang et al. (2003) began seasonal prediction of winter and spring dust weather frequency, and as it turns out the seasonal forecast for the year of 2003 was successful.

2.4 *The relationship between the East Asian Monsoon and ENSO*

Lu (2005) suggested that the SST in the tropical eastern Pacific could affect the summer rainfall in the North China via modulating the East Asian jet. Li et al. (2005a) explored the mechanism for the impact of the EAWM on ENSO evolution. They found that the EAWM could change the meridional gradient of pressure over the tropical western Pacific, which in turn can stimulate anomalous zonal wind over the equatorial western Pacific and cyclone/anticyclone circulations over the east of the Philippines. These changes of atmospheric circulation favor the occurrence of ENSO events. The numerical simulation supports the observational results (Yang and Li, 2005). The strong EAWM is associated with a La Niña pattern of SST anomaly in the tropical region in winter and even to the following summer. However, it would gradually change to an El Niño pattern from the following autumn as a result of the forcing of west wind stresses connected with the strong EAWM in the western tropical Pacific. For a weak EAWM, the process is reversed. Thus, both observation and model simulation indicate that the anomalous East Asian winter monsoon plays an important role in the evolution of the ENSO.

3. Decadal variations of the East Asian climate

Because of its complexity and short length of the instrumental record, decadal variations of the climate system became noteworthy only after the 1990's. Many studies suggest that interdecadal climate change occurred during the 1970's, which was characterized by changes in a wide number of phenomena in various atmospheric elements and SST (Hurrell, 1995; Zhang et al., 1997; Wang, 1995, 2001).

3.1 *Precipitation and temperature*

Changes in precipitation in East China have multi-timescale variations and are area-dependent (Dai et al., 2003; Gu et al., 2005; Qin and Wang, 2005). The spatial distribution of summer precipitation in China changed abruptly and significantly beginning in the late 1970s (Zhai et al., 2005). Such changes can result in large societal impacts and require more study, for example, in the effects of the major decrease in rainfall in the North China and large increase in the Yangtze River valley. The background for interdecadal variations in precipitation is quite different from that for interannual variations (Lu, 2003). Spectral analysis of the structure of precipitation from the historical record shows that, especially in recent decades, temporal scales with 5- and 2-year periods are weakening, while decadal time scales are increasing markedly (Dai et al., 2003). As for the persistent drought in North China in the late 20th century, Yang et al. (2005b) indicates that it reflects a decadal variation superimposed on a longer-term decreasing trend in rainfall that magnifies the strength of the drought. Generally, total rainfall over North China has an out of phase relationship with the Yangtze River valley and in-phase relationship with South China. The result is precipitation increasing notably over the Yangtze River valley, even to the extent of causing devastating floods, and decreases in rain over South China (Xin et al., 2006). Additionally, decadal timescale changes occur over India and Africa (Wu, 2005).

The surface air temperature increases over northern China, northeastern China and northwestern China, but decreases downstream of the Tibetan Plateau (Yu and Zhou, 2004; Li et al., 2005b). Temperatures in the high troposphere increased at the same time (Zhou and Zhang, 2005; Duan et al., 2006).

3.2 *Monsoon circulation systems*

The components of tropical and subtropical monsoons over East Asia include airflows from tropical oceans, the ITCZ over the SCS, subtropical high over the northwestern Pacific, mei-yu fronts, and westerlies over middle latitudes. Complicated interactions between these components are responsible for multi-timescale monsoon variations.

Studies reveal that circulation anomalies in the Northern Hemisphere and weakening of the summer monsoon are the main signals for decreased precipitation in North China (Xu et al., 2005a; Dai et al., 2003). Strengthened westerlies, positive geopotential height anomalies at 500 hPa and Eurasian (EU) teleconnection patterns are associated with a warm ridge over North China (Wei et al., 2003; Zhang et al., 2003b) and the corresponding northerly winds diverging from this high pressure system. The subtropical high in the western Pacific became stronger and shifted southwest after the 1970's, thereby enhancing the moisture transportation to the Yangtze River valley. Consequently, moisture convergence tended to increase over the Yangtze River valley, and when associated with favorable circulation anomalies in mid to high latitudes, results in heavy precipitation over this region. (Ping et al., 2006; Zhou and Wang, 2006b).

Additionally, systems distant from the monsoon region show decadal changes. The large variation in the AAO after the 1970's has been associated with precipitation over the Yangtze River valley (Nan and Li, 2003). The primarily positive phase after the 1970s in the AO also appears to be related to rainfall over the Yangtze River valley (Ju et al., 2005a). Kang and Wang (2005) and Fan and Wang (2004) documented the decreasing dust storm frequency with decreasing strength of AAO and AO. Li et al. (2005b) and Xin et al. (2006) found that anomalies in surface temperature and precipitation are connected with a tendency for eastward propagation of the North Atlantic Oscillation (NAO) as it has become more frequently positive in recent years. Relationships between the NAO and precipitation in China are not consistent and exhibit large variability (Fu and Zeng, 2005).

3.3 *SST and ocean-atmosphere interaction*

Oceans are an important factor in decadal climate variability. Circulation and climate features corresponding to two phases of decadal variations in North Pacific Ocean are distinctly different (Li and Xian, 2003. The Pacific decadal oscillation (PDO), a strong signal in climate change discovered recently (Yang and Zhang, 2003), has a lead-lag relationship with the AO with the lag correlation maximum when AO leads PDO by 7–8 years (Sun and Wang, 2006). They indicates that decadal changes of precipitation over North China are related to the warm phase of PDO, which is characterized by warming in the mid-east tropical Pacific and cooling in the North Pacific. The westerlies over North China strengthened by PDO suppress moisture flow to the region. Although the spatial patterns are similar, temporal scales of the PDO are much longer than the ENSO cycle, such that the former modulates the latter. The phase of PDO cycles is associated with rainfall anomalies in North China. The strong climate anomalies associated with ENSO are related to extreme events in tropical Pacific, especially the SST anomalies over the western Pacific warm pool (Zhou and Huang, 2003), which in turn have a considerable impact on China's climate. Su and Wang (2007) found that the relationship between ENSO and the drought-wet index in China is not consistent, but with the warm phase of ENSO favoring dry conditions in North China and wet conditions in the South and the opposite in the cool phase. Zhao et al. (2004b) suggested that anomalies of sea ice extent over Bering Sea and the Sea of Okhotsk are closely related to the summer monsoon.

4. Global warming simulations

Chinese scientists have paid considerable effort in the recent several years to address global and East Asian climate changes related to human activities. Ma et al. (2004) employed the IAP/LASG GOALS coupled model, created and developed by the Institute of Atmospheric Physics of the Chinese Academy of Sciences (IAP/CAS) (Zhang et al., 2000; Yu et al., 2004), to simulate 20th century climate changes forced by atmospheric greenhouse gasses, sulfate aerosols, and solar variability. Zhou et al. (2005) examined the response of the Atlantic thermohaline circulation (THC) to global warming as simulated by the model. The evidence indicates that the gradually warming climate associated with increased atmospheric CO_2 leads to warmer and fresher surface waters at high latitudes of the North Atlantic Ocean, which prevents downwelling of the surface waters. The reduction of the pole-to-equator meridional potential density gradient then results in a decrease of the intensity of the THC. When atmospheric CO_2 concentration is doubled, the maximum value of the Atlantic THC decreases approximately by 8%.

The NCC/IAP T63 coupled model, developed jointly by the National Climate Center of the China Meteorological Administration and the IAP/CAS (Climate System Modeling Division, 2005), was used to project the global and East Asian climate changes under the IPCC SRES A2 and A1B scenarios (Xu et al., 2005b). The model computed a global warming of 3.6°C (100 yr)$^{-1}$ and 2.5°C (100 yr)$^{-1}$ under the SRES A2 and A1B scenarios over the 21st century, respectively.

In addition to the above simulations based on Chinese CGCMs, CGCMs world wide have been used to further explore near-future climate changes in China. Jiang et al. (2005) used observational and reanalysis data throughout the 1961–1990 period to evaluate East Asian surface temperature, precipitation and sea-level pressure climatology as simulated by seven CGCMs, namely CCSR/NIES, CGCM2, CSIRO-Mk2, ECHAM4/OPYC3, GFDL-R30, HadCM3, and NCARPCM. Overall, the above models can successfully reproduce annual and seasonal surface temperature and precipitation climatologies in East Asia. The models' ability to simulate surface temperature is relatively reliable, more so relatively speaking for the simulations of precipitation. It was found that the simulation errors for surface temperature, precipitation and sea-level pressure are generally large over and around the Tibetan Plateau.

Based on the above seven CGCMs' outputs, climate changes in Northwest China over the 21st century due to both increasing of greenhouse gasses alone and increasing of greenhouse gasses plus sulfate aerosol were investigated, respectively, by Xu et al. (2003) and Zhao et al. (2003). Moreover, Jiang et al. (2004) employed the above seven CGCMs' outputs under the SRES A2 and B2 scenarios to address East Asian climate changes through the 21st century. During the first half of the 21st century, increases in the concentration of atmospheric greenhouse gasses only slightly impacts annual and seasonal precipitation in China, except for the Tibetan Plateau where summer precipitation increases significantly. Both annual and seasonal precipitation will increase notably in China during the latter half of the 21st century (Jiang and Wang, 2005).

Recently, a multi-model ensemble mean under about 40 emission scenarios for atmospheric greenhouse gasses and aerosols was used also to analyze future climate changes in China (Luo et al., 2005). They found that global warming during the 21st century results in an ensemble average 4.5°C surface temperature rise in China, but with the range of uncertainty being from 1.2°C to 9.2°C by the end of the 21st century. Changes of precipitation in the future are more complicated than that of surface temperature. In general, most models project wetter conditions in China over the 21st century.

Gao et al. (2003e) simulated climate changes under a doubled atmospheric CO_2 concentration with the regional climate model RegCM2 nested in a one-way mode within a globally coupled atmosphere-ocean model. The model computes also a warming over China due to the greenhouse effect with an average increase of 2.8°C and range from 2.2°C in southern China to 2.8°C in northern China. Annual surface temperature increases by an average of 2.5°C with a range from 2.0°C to 3.0°C. The largest warming occurs in winter season. Daily maximum and minimum surface temperatures also increase over China, giving rise to many hotter spell days in summer and fewer cold spell days in winter. Precipitation increases in all seasons of the year, with the highest value in summer. Annual precipitation increases significantly in western China, parts of the area south of the Yangtze River, and northern parts of Northeast China, while decreases occur in the area from the southern part of Northeast China to North China. Additionally, the RegCM2 was used to investigate the impacts of the greenhouse effect upon the typhoons affecting inland China (Gao et al., 2003c). Results indicate that the number of typhoons affecting China increases on average by 26% under a doubled atmospheric CO_2 concentration. In addition, the greenhouse effect also causes changes in typhoon tracks, and there is a substantial increase in the number of land-falling typhoons over Mainland China. However, Li et al. (2007) indicated that the frequency of tropical cyclones formation would likely decrease by 5% within the next half century. Thus, the contribution of global warming to typhoon activity still has large uncertainty (Trenberth, 2005; Chan and Liu, 2004)

Furthermore, the RegCM2 was used to investigate the direct climate effects of anthropogenic sulfate aerosol under the doubling of atmospheric CO_2 (Gao et al., 2003b). Preliminary analysis shows that aerosols directly result in a decrease of surface temperature. This decrease tends to be larger in winter and in South China. The area-averaged monthly precipitation also decreases in most months. Annual precipitation decreases in East China and increases in West China. But the simulated changes of both surface temperature and precipitation are much weaker as compared to the greenhouse effect alone.

Gao et al. (2003d) simulated climate effects of land use changes over inland China by the RegCM2. It was found that land use changes give rise to a decrease of annual precipitation in the already arid and semi-arid of Northwest China, an increase of annual surface temperature in the southern portions of Northeast China and the Sichuan Basin and parts of Northwest China, and a decrease of surface temperature along coastal areas. Additionally, summer daily maximum surface temperature increases in many locations, while winter daily minimum surface temperature decrease in East China and increase in Northwest China. The upper soil moisture decreases significantly across China. The results indicate that same land use changes can cause different climate effects in different regions, depending on the surrounding environment and climate characteristics.

It should be noted here that there are large uncertainties in the prediction of future regional climate changes by numerical models. These mainly arise from inadequacies in the climate model's formulation and representation of physical processes, specification of future emission estimates of atmospheric greenhouse gasses and aerosols. Nevertheless, scientists have confidence in the ability of the complex physically-based climate models to provide useful projections of near-future climate due to their demonstrated performances on a range of space and time-scales.

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APPENDIX

List of Abbreviations on Global Warming Simulations

SRES

Special Report on Emission Scenarios

A2 scenario

The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

A1B scenario

The A1 scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1B is one of the three A1 groups. It describes a "Balanced" progress across all resources and technologies from energy supply to end use.

B2 scenario

The B2 scenario describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

CCSR/NIES

A coupled global model developed by Center for Climate System Research of the University of Tokyo (CCSR) and National Institute for Environment Studies (NIES), Japan

CGCM2

A coupled global model developed by the Canadian Centre for Climated Modelling and Analysis (CCCma), Canada

CSIRO-Mk2

A coupled global model developed by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia

ECHAM4/OPYC3

A coupled global model developed by the Max-Planck-Institute for Meteorology (MPI) and Deutsches Klimarechenzentrum (DKRZ), Germany

GFDL-R30

A coupled global model developed by the Geophysical Fluid Dynamics Laboratory (GFDL), America

HadCM3

A coupled global model developed by Hadley Centre for Climate Prediction and Research/Met Office, England

NCAR/PCM

A coupled global model developed by the Department of Energy (DOE) and National Center for Atmospheric Research (NCAR), America

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