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Original Research Paper

The Relationship of Atmosphere and Sea Surface Temperature (SST) with Asian Cold Events in Winter

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ABSTRACT

Based on the analysis of Asian temperature, the Asian Warming Hole (AWH) index is proposed in this paper to measure the intensity during the cold events process under the background of global warming in the early 21st century winter. The results show that the Asian continent is indeed experiencing a cold stage in the early 21st century winter, but it is just in a cold phase and will become warmer in the future. The relationship of AWH with atmospheric circulation is statistically close. Moreover, the sea surface temperature (SST) lead of 6 months, shows a higher correlation coefficient with AHW index. The SST anomalies over mid-latitude and high latitude Pacific regions may play an important role in Asian cold events in winter, but it is not stable as a precursor factor. The mechanism of this phenomenon is very complex, the atmosphere can reflect some characteristics, while ENSO cycle signal is more and more significant in recent years.

INTRODUCTION

Global warming is a consensus in observational data since industrialization (IPCC 2007, Otani et al. 2015, Jones et al. 1999), the possible reason is anthropogenic forcing, comparing with the historical period. For example, climate numerical models show that global warming will still continue if greenhouse gases (GHGs) enhanced, and atmospheric prominent decadal variabilities have been proposed as key factors in climate simulations (Huang et al. 1998). However, because of the differences in local regional condition, global warming rate is not consistent anywhere. In 2001, Folland et al. proposed the cooling trend in center North American continent in summer (Houghton et al. 2001). Subsequently, Pan et al. (2004) implied "Warming Hole" for the summer cold regions of North American continent, and simulated the "North American Warming Hole" feedback mechanism by local greenhouse gas model, analysed the effects of evaporation, precipitation, low level jet in this region. Kunkel et al. (2006) used super multi-model ensemble program to elaborate the predictability of North American Warm Hole and further discuss the reason for this phenomenon whether it is from natural variability or boundary condition forcing (Robinson et al. 2002).

Climate variability consists of climate signals and noise. Climate signals are variations forced by slowly varying anomalous boundary conditions of the climate system (Hoskins & Karoly 1981, Blackmon et al. 1983, Ye et al. 2015). When the proportion of the climate signal variability is high enough to overcome the destruction effects of the noise, the climate anomaly may exhibit a particular degree of predictability (Chen &Van den Dool 1997). Additionally, climate system does not advance gradually, it changes from one relative steady stage to another in a short time, which is known as an abrupt climate change (He et al. 2013, Wu et al. 2015). Previous studies about developing a detection method and dealing with the transition process have shown that some signals can be detected during (before) abrupt climate change (Yan et al. 2015, He et al. 2015, Jin et al. 2015).

How to detect the signal of global (trend) and regional climate change is always a central issue in recent climate change studies (Ren et al. 2008). Wallace et al. (2012) proposed the partial least squares (PLS) to apply the dynamical adjustment to remove the surface air temperature trend over extra tropical Northern Hemisphere continents during the cold season. Guan et al. (2015) followed this work to investigate the warming trend slowdown (WTS) in recent years, and confirming that dynamically induced variability caused the WTS over the Northern Hemisphere. It is well known that the global temperature is warmer at a fast speed in last 30 years, and a lot of papers have discussed the possible mechanism of "hiatus" in 21st century (Kosaka & Xie 2013, Chen & Tung 2014, Easterling & Wehner 2009, Ji et al. 2014). However, there is still less concern on this phenomenon in Asia.

Since 21st century, Asian cold disaster occurred frequently in winter, which makes people's life inconvenient and influences the economic development very much. For

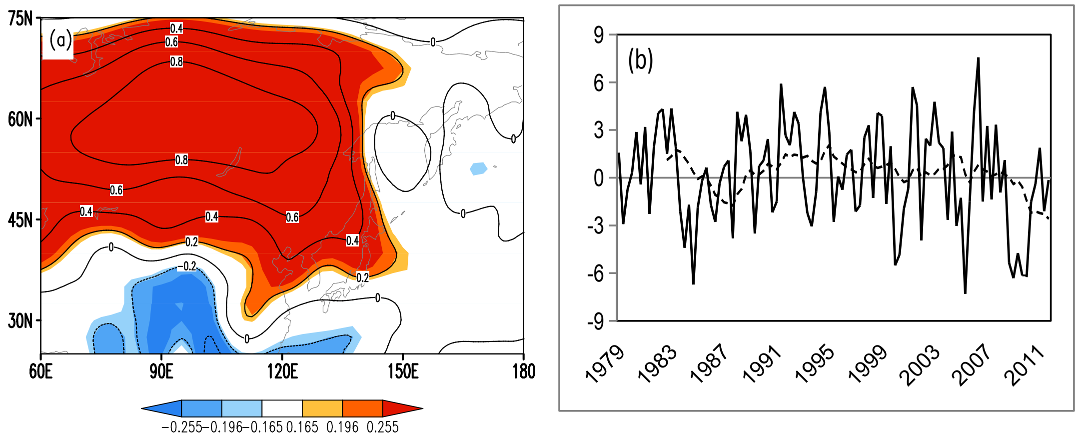

Fig. 1: a) Correlation coefficient between winter temperature field at 1000 hPa level and AWH index; b) The variation of AWH index, the dotted line is 4-years running mean.

example, most areas of South China historically suffered rare cold disaster in January 2008 (Meng et al. 2015, Feng et al. 2015a, Wang et al. 2012a), and in the Northeast and North China sustained snow storm occurred from November 2009 to April 2010 (Wang et al. 2011). Previous results have analysed each cold case from different angles to explain the mechanism (Wang et al. 2013, Wang et al. 2012b, Feng et al. 2015a). However, the overall view of cold events in a long timescale in Asian winter is still less under the background of global warming. What is the possible precursor factor of cold events? Is there any similar phenomenon in the history? For answering these questions, based on an Asian Warming Hole (AWH) index, this paper investigates the role of sea surface temperature (SST) and atmospheric circulation in cold events, compares with the similar period in history to analyse the possible mechanism, and summarizes conclusions at last.

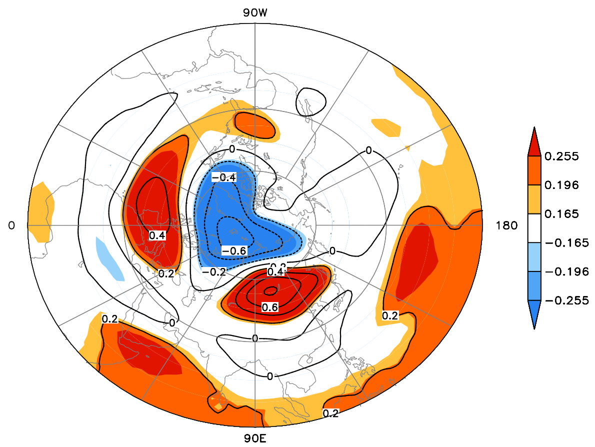

Fig. 2: The correlation coefficient between AWH and geopotential field at 500 hPa level.

METHODS AND DATA

This paper mainly used NECP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) reanalysis of 2 monthly average global temperatures and geopotential data (Kanamitsu et al. 2002), which has a spatial resolution of 2.5º×2.5º for 1979-2012, with 17 levels from 1000 hPa to 10 hPa. The ocean data are the extended reconstructed sea surface temperatures (SST) V3b published by the National Oceanic and Atmospheric Administration (NOAA), whose spatial resolution is 2.0º×2.0º for 1979-2012 (Smith & Reynolds 2003, 2004). All data have been calculated anomalies (relative 1979-2012). The AO index used in this study is published by CPC (Climate Prediction Center).

The methods include empirical orthogonal function (EOF) decomposition to get domain and principal components (PC), correlation analysis and wavelet analysis. The winter time present here is from December to February.

RESULTS AND DISCUSSION

Characteristics of cold event in the early 21st century: In this study, a significant relative "cold" region (75º E-125º E, 52.5º N-65º N) in central Asia is defined as the key area of AWH, and the average temperature over this region at 1000 hP is defined as AWH index. The relationship between winter temperature field level and AWH index is shown in Fig. 1a. The AWH index can capture the characteristics of winter temperature field in Asia because the correlation coefficient in most regions of the Asian continent is above 99%

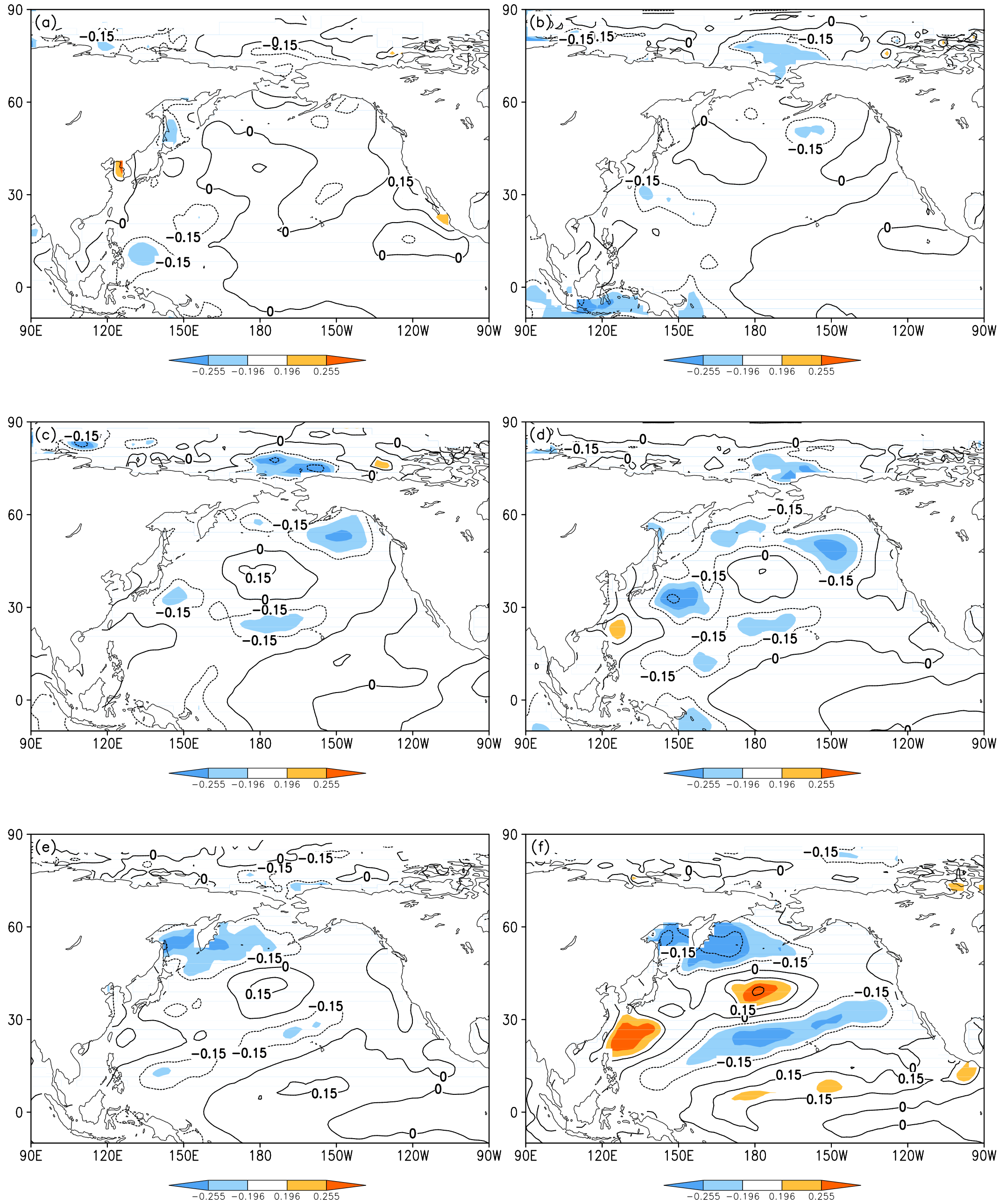

Fig. 3: The relationship between AWH and Pacific SSTA in lead time: a~f) 1-6 months.
The different color bars represent the areas exceeding 90%, 95%, 99% confidence level separately by *t* test.

confidence level by *t* test. Fig. 1b is the variation of AWH index, which is always in positive phase before 2007 except 1980s, and then declined, since 2007 was turning towards negative phase, which means that the AWH index can indicate the strength and cycle of Asian continent cold events. Based on the past data, it is not the first time for AWH index in cold trend since 1979, comparing with a similar case of 1983-1987, the 21st century cold event is stronger and the duration is relatively longer. The wavelet analysis of AWH index is calculated, which shows that there is a decadal cycle since early 1980s; and a significant 4 year cycle has appeared since the early 21st century (figure not given). As

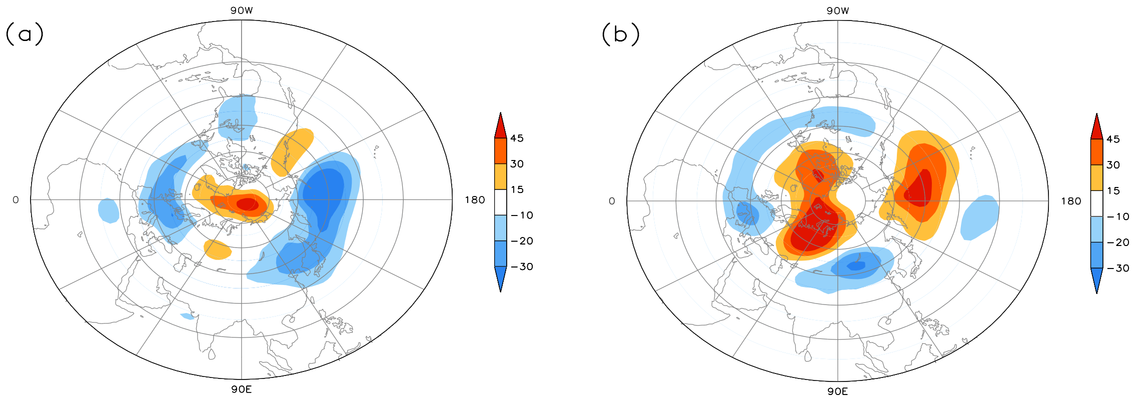

Fig. 4: The geopotential height anomalies of two similar cold events at 500 hPalevel: a) 1983-1987; b) 2007-2011.

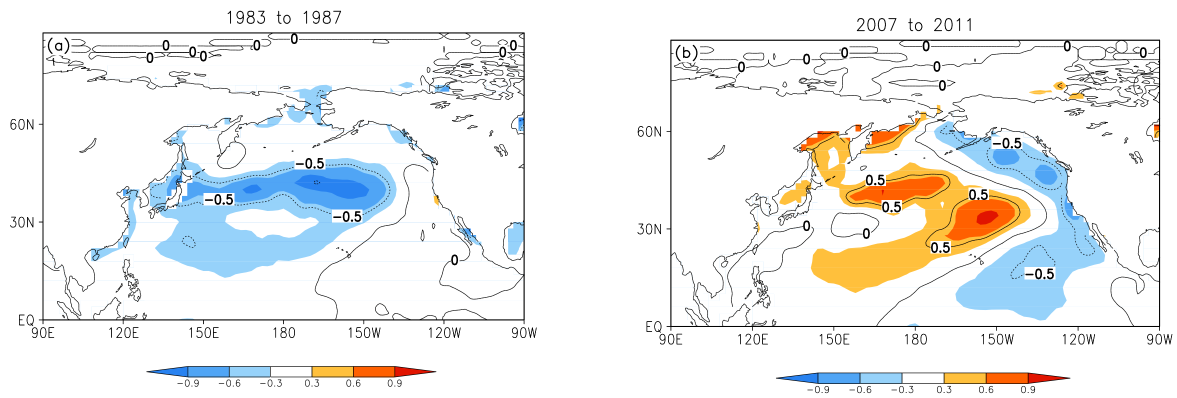

Fig. 5: The leading 6 months SST anomalies of two similar cold events over Pacific region:
a) 1983-1987; b) 2007-2011.

Fig. 1 has shown that in the beginning of the 21st century, the Asian continent turned into negative phase, and cyclical activity is significantly enhanced with a new cycle. The Asian winter temperature reached its minimum value in 2011 and will be higher in the coming 3-4 years comparing with 2011 winter.

The role of atmospheric circulation and SST in cold events: Previous studies have shown that there is a close relationship between Asian cold events and atmospheric circulation, such as AO and NAO (North Atlantic Oscillation) (Stockdale et al. 2015, Li et al. 2013, Qiao et al. 2015, Li & Li 2000). The atmospheric oscillation is a significant precursor factor, so the correlation coefficient between AWH index and geopotential field at 500 hPa level is shown in Fig. 2a. The different colour represents the areas exceeding 90%, 95%, 99% confidence level separately by *t* test. In Fig. 2, the correlation coefficients above 99% confidence level are mostly over high latitudes, which is like the AO pattern. A negative center over polar vortex and two positive centers over extratropical in Asian, Atlantic and European areas over high latitudes. Moreover, AWH index and AO index are similar in cycle and trend in history, and consistently better in recent years. These results mean that the Asian cold events can be reflected by atmospheric circulation, and AO may play a very important role.

Besides atmospheric circulation, the influence of boundary condition such as SST cannot be neglected in an air-sea coupled system (Shen et al. 2012, Wang et al. 2015). Fig. 3 shows the relationship of AWH with Pacific SSTA in different lead time from 1 month to 6 months, it is interesting that the relationship is not significant when the SSTA leads AWH 1 month, and shows some negative areas in North Pacific in a longer lead time. When SSTA leads AWH 6 months, their relationship is more significant, showing three latitude regions as "- + -" pattern from low to high latitude. Moreover, in Fig. 3 the tropical ocean does not correlate well with AWH, which shows that the mid-latitude and high latitude Pacific regions play an important role in Asian cold events in winter.

The comparison between similar period 1983-1987 and 2007-2011: In the previous section, we proposed some possible ways to explain the mechanism for AWH. In order to find precursor factor, two periods of cold events for 1983-1987 and 2007-2011 are selected by AWH index in Fig. 1b. The geopotential height anomalies at 500 hPa level and leading 6 months SST anomalies over Pacific region in these two periods are compared in Fig. 4 and Fig. 5.

As shown in Fig. 4, there is a positive center in polar vortex, where negative anomalies are over high latitudes in 1983-1987 winter. In 2007-2011, the positive center is stronger and moves over Ural region, and a negative center appears over north Asia. Comparing Fig. 4a and Fig. 4b, it is obvious that in 2007 and 2011, the AO like pattern is stronger, which forces more cold air from polar vortex to north Asia. This may be the reason why the AHW index is lower in 2007-2011 than 1983-1987 in Fig. 1b.

Fig. 5 is the leading 6 months SST anomalies of two similar cold events over Pacific region, in 1983-1987, there is no positive anomalies while two negative centers appear over east and central Pacific in mid-latitudes. In 2007-2011, the SST anomalies show a significant La Niña pattern, a negative center in equatorial east Pacific, and the west and north Pacific show positive anomalies. Comparing Fig. 5a and Fig. 5b, the SST is not consistent, it is negative in all regions in 1983-1987 cold event while La Niña pattern in 2007-2011, which shows that SST external forcing is different in these two cases.

CONCLUSIONS

In this paper, we analysed the features of Asian cold events in winter in the early 21st century under global warming, proposed AWH index to measure the intensity of cold events in the process, and analysed the atmospheric and SST external forcing in cold events. Results show that the winter temperature in Asian continent in the 21st century is indeed experiencing a cold phase under global warming, which is similar to the historical period of 1983-1987, but the intensity is stronger and lasts longer. The relationship of AWH with atmospheric circulation is close and AO may play a very important role. Moreover, the SST leading 6 months shows a higher correlation coefficient with AHW index.

Based on the above analysis, the Asian cold events can be reflected by atmospheric circulation; when AO is strong, it drives the cold air from high latitudes to low latitudes, reducing the temperature over Asia and triggering the occurrence of cold events. The SST anomalies over mid-latitude and high latitude Pacific regions may play an important role in Asian cold events in winter, but it is not stable as a precursor factor. Therefore, the mechanism of cold events is very complex, the atmosphere can reflect some characteristics, and the ENSO cycle signal is more and more significant in recent years.

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AUTHOR CONTRIBUTIONS

Kuo Wang planned the research, Lian Chen and Chaohui Song performed data analysis. Tao Feng and Dawei Gao gave the suggestions about the structure of the paper. Kuo Wang wrote the first draft of the manuscript.

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