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Monitoring and Maintenance of a Cold-Season Drought

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1. Introduction

A once-in-a-century severe drought swept across Southwest China during fall 2009 and the subsequent winter. It made over 16 million people and 11 million livestock short of drinking water, and devastated crops in more than 4 million hectares of farmland with making a fourth of them yield no harvest. The goal of this study is to monitor the drought at a daily scale and examine the regional atmospheric anomalies that fostered the severe drought.

2. Monitoring the drought at a daily scale

The weighted average of precipitation (WAP) developed by Lu (2009) is used to monitor the drought. The suggested form of the index for the general monitoring of drought at a daily scale is

$$WAP = 0.1\sum_{n=0}^{44} 0.9^n P_n$$

which combines the precipitation (P) of the recent 45 days (n = 0, 1 , …, 44) with weights that decay with time. Although the period-averaged negative anomaly of precipitation (figure not shown) can also indicate the drought, WAP can provide more details of the drought process. Figure 1 shows that the drought in Yunnan and Guizhou, two provinces of the Southwest, is severer-than-normal almost every day during the long period of the drought.

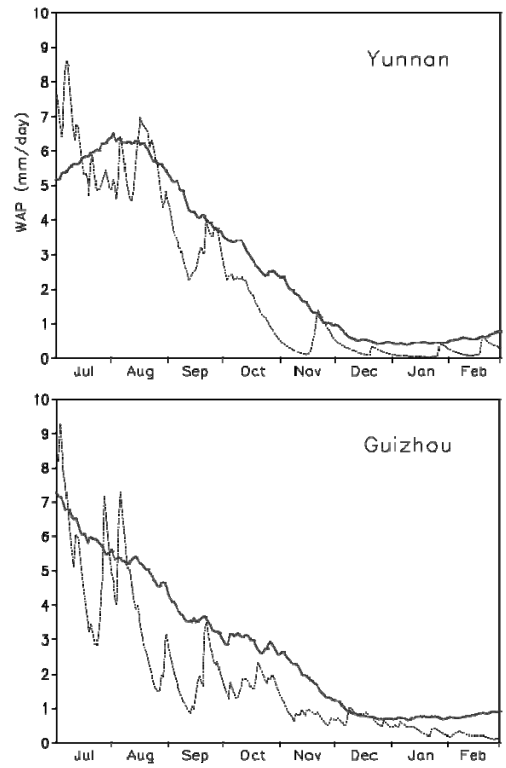

Fig. 1 Daily WAP of the 2009-2010 cold-season drought (thin) and the climatic mean (thick) for Yunnan (upper) and Guizhou (lower) Provinces.

3. Regional atmospheric anomalies of the cold-season drought

a. Contributions from less water vapor and warmer air temperature

Atmospheric circulation is important to precipitation; its ultimate effect is to increase the water vapor in the local air and lower the air temperature, through transporting water vapor and invading cold air, and thus make the air become saturated.

Lu and Takle (2010) concluded, from large spatial samples, a tight positive relation between precipitation and relative humidity at interannual timescale. This relation is broader than the conventionally recognized water vapor-precipitation link.

The relative humidity of the 2009-2010 cold-season drought has negative anomaly in the Southwest (Fig. 2), which reflects not only the role of the less-than-normal water vapor in the region but the effect of the warmer-than-normal temperature as well. Their contributions to the drought can be compared with the precipitation-relative humidity relation.

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Denote the lower-than-normal relative humidity of the drought ($P_{dry} < P_{nor}$) as $r_{dry} < r_{nor}$, or $D_r \equiv r_{dry}/r_{nor} < 1$. With expressing relative humidity r in terms of specific humidity q and saturation vapor pressure e_s at temperature T, it can further be written as

$$D_r = D_q D_T < 1,$$

where

$$D_q \equiv q_{dry} / q_{nor}$$

and

$$D_T \equiv e_s (T_{nor}) / e_s (T_{dry})$$

measure the contributions of the less water vapor and warmer air temperature to the decrease of relative humidity.

Figure 3 shows that, over the Southwest, D_q ranges from 1 to 0.6, whereas D_T from 1 to 0.8, and their minima both appear in the severest drought area. This suggests that at the interannual timescale (*i.e.*, comparing this drought year with the normal year), while less water vapor contributes more, warmer air temperature also contributes significantly to the formation of the severe drought.

b. Changes in atmospheric circulation and water vapor transport

Figure 4 shows that the water vapor transport field of the 2009-1010 cold-season drought is pretty similar in spatial pattern to the climatic mean, and the major difference is in the strength; the vapor transport of this drought is weaker than normal across the Southwest.

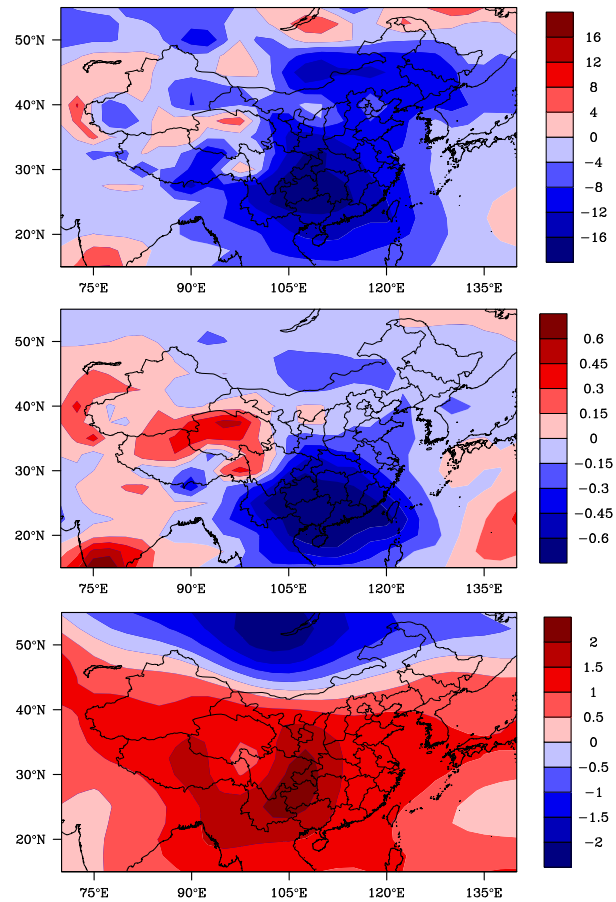

Fig. 2 Anomalies of relative humidity (%, top), specific humidity (g kg^{-1}, middle), and temperature (K, bottom) at 600hPa of the 2009-2010 cold-season drought, relative to the climatic mean.

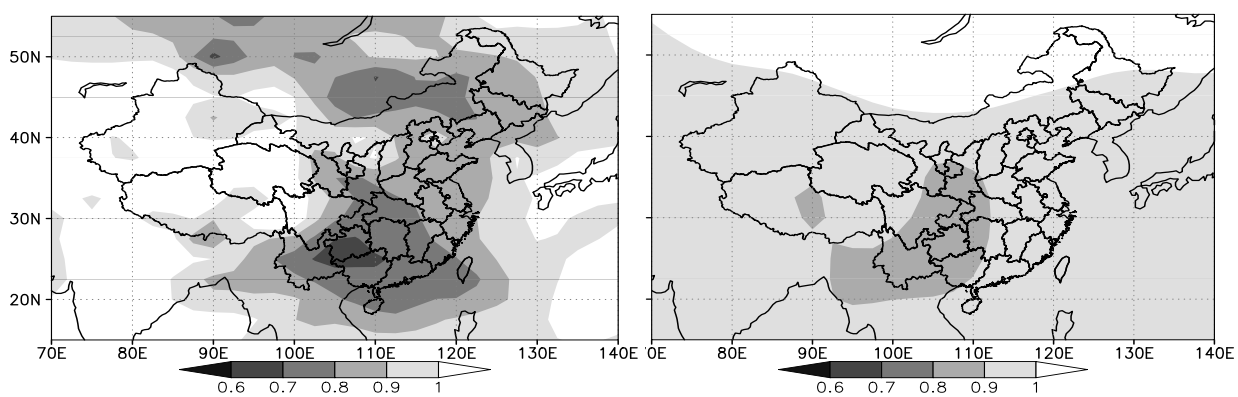

Fig. 3 D_q (left) and D_T (right) at 600hPa calculated with data of the 2009-2010 cold-season drought and the climatic mean.

This is different from the 1999 summer drought over North China (Ding et al. 2003), during which vapor transport has a significant anomaly in the track, and the strength is not weak from the source of vapor and along the track. The southwest monsoon transports water vapor along the low latitudes all the way to the east, and water vapor cannot reach North China. Since summer is the rainy season of the region, the normal

transport of water vapor can lead to much precipitation, which sometimes can even form floods. If the vapor transport in a particular year is along the normal track but just weaker in strength, it can still bring precipitation. This precipitation might be less than normal, but would be far from forming a severe drought. To form severe drought in the summer of the region, the transport of water vapor needs to have a significant change in track.

By contrast, the Southwest severe drought analyzed in this study maintains mainly in cold season. It is normally very hard to form persistent strong precipitation at this time of the year. To form severe drought in cold season, a weakening in the strength of vapor transport can be sufficient, and there is no need to have a major change in the transport track.

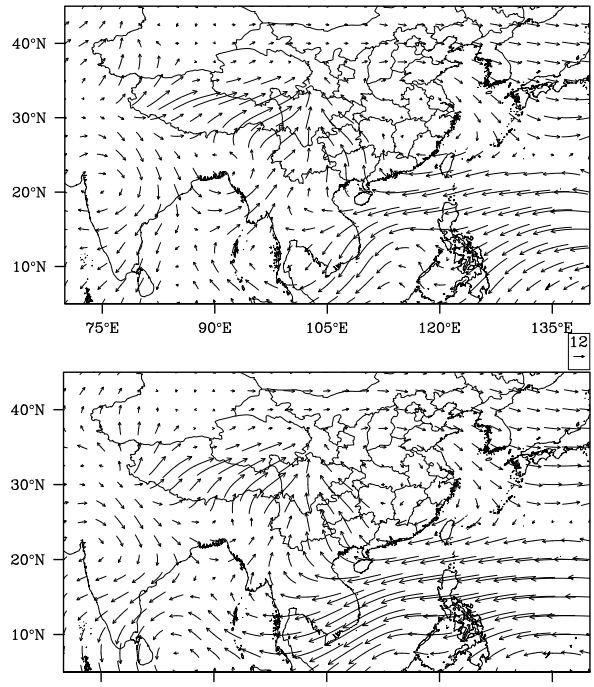

Fig. 4 Water vapor transport (g kg^{-1} m s^{-1}, 850hPa) of the 2009-2010 cold-season drought (upper) and the climatic mean (lower).

c. The higher-than-normal pressure at upper levels

Figure 5 shows that there is positive anomaly of geopotential height at the upper level in the Southwest, while negative anomaly at the lower level. Geopotential thickness thus has a positive anomaly in the region, which manifests the warmer-than-normal air temperature of the drought. The dominance between the warmer air temperature and the upper-level higher pressure needs to be further analyzed.

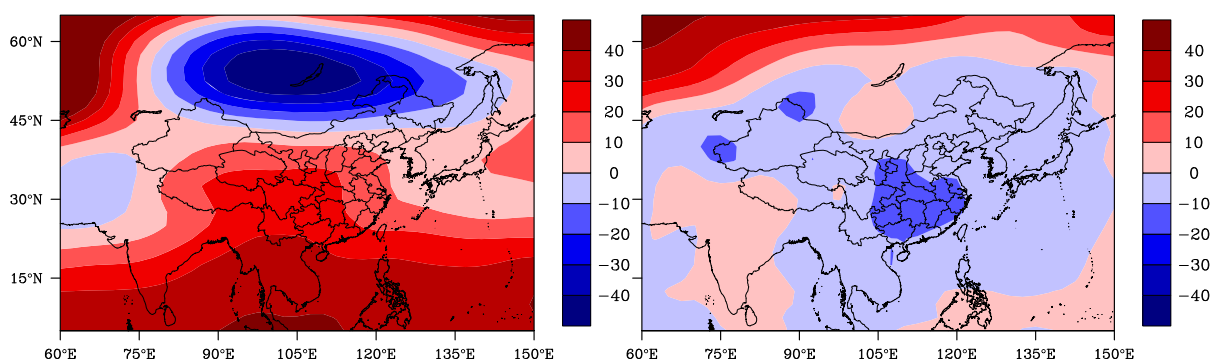

Fig. 5 Anomalies of geopotential height (gpm) at 200 (left) and 925hPa (right) of the 2009-2010 cold-season drought, relative to the climatic means.

d. The effect of warmer air temperature on cold-season drought

In summer, the East Asian monsoon season, water vapor transport and convergence are strong. Making the air saturated is easy, even if the air is much warmer than normal. Strong and persistent vapor supply can lead to heavy rain and even floods. So, heavy rain and floods in summer are dominated dynamically by the atmospheric circulation and the related water vapor transport.

In cold season, though water vapor transport is weak, light to moderate rains are still expectable. Whether air temperature can be low, relative to the season, is key to formation of precipitation. If it is low, weak precipitation may form from time to time, which may still efficiently mitigate the drought. Warmer air temperature is therefore particularly important to the formation of the cold-season drought.

e. The positive feedback in the regional atmosphere

With weaker water vapor transport and convergence, warmer air temperature is not helpful to the saturation of the air, and thus can help bring a clear weather. Whereas the clear weather can in turn warm the air through less cloud, stronger solar radiation, and thus more sensible heat from the surface. Such warmer temperature - less precipitation positive feedback, an inherent mechanism in the regional atmosphere, can facilitate the maintenance of the severe cold-season drought.

4. Summary

The 2009-2010 cold-season severe drought can be well monitored at a daily scale with the WAP index. Water vapor is less than normal during the drought. The atmospheric circulation and water vapor transport do not show significant anomalies in the track. To form drought in the cold season, a weakening in the strength of vapor transport can be sufficient. Air temperature is much warmer than normal during the drought. Though it has less influence on summer precipitation, which is dynamically controlled, air temperature is particular important to the formation of cold-season drought. The warmer air temperature in the cold season makes the air harder to saturate, and thus harder to form even light rains. Moreover, the warmer temperature - less precipitation feedback in the regional atmosphere can facilitate the maintenance of the cold-season drought.

References

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