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A Case Study of the Improvement of Soil Moisture Initialization in IAP-PSSCA

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ABSTRACT

A prediction system is employed to investigate the potential use of a soil moisture initialization scheme in seasonal precipitation prediction through a case study of severe floods in 1998. The results show that driving the model with reasonable initial soil moisture distribution is helpful for precipitation prediction, and the initialization scheme is easy to use in operational prediction.

Key words: soil moisture, climate change, precipitation prediction

1. Introduction

Soil moisture exerts its influence on short-term climate change by changing soil heat capacity, evaporation, land surface albedo, and land-atmosphere interface fluxes, including sensible/latent heat fluxes and momentum flux (Chahine, 1992; Trenberth, 1999; Brubaker et al., 1993). The importance of soil moisture to seasonal transition of the general circulation was noted by Namias for the first time (Namias, 1958). A bucket model was introduced by Manabe in 1965 to reproduce the hydrological cycles in a climate model (Manabe et al., 1965; Manabe, 1969). Sensitivity experiments conducted by Rowntree show that dry soil is favorable for higher air temperature and less precipitation while wet soil is advantageous for lower temperature and persistent rainfall (Rowntree and Bolton, 1983). Yeh et al. (1984) studied the impact of irrigated land on climate with a GCM and came to a similar conclusion. Effects of different land surface conditions to climate change over the Sahara region were compared by Xue with a land-atmosphere coupled model (Xue et al., 1991). The results show that land surface conditions can influence climate change not only by affecting cloud amount and precipitation but also by changing air temperature.

Although soil moisture is an important factor of land surface processes, such an important factor has not been described correctly in current land surface models and GCMs (Dirmeyer, 1995). The reason lies in two aspects: firstly, it is difficult to get observations of soil moisture over a large area because of the high expense; secondly, soil moisture has notable variation both spatially and temporally.

Moreover, the attention paid to soil moisture in operational short-term climate prediction is far from enough. There are more than 10 factors like SST and snow cover, etc. involved in operational precipitation prediction during the flood season in China, but soil moisture is not even mentioned. Therefore, how to consider the role of the soil moisture anomaly in precipitation prediction is the motivation of this work.

In this paper, we study the relationship between soil moisture and seasonal climate change through a numerical model with an improved soil moisture initialization scheme.

2. Brief description of the climate model and scheme for retrieving soil moisture

2.1 *A numerical model system to predict seasonal climate anomaly*

The climate model used in this study is IAP-PSSCA, that is, IAP Prediction System for Seasonal

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Climate Anomaly. Besides the core of the system—an air-sea coupled GCM, it includes a set of the the air/sea data assimilation scheme, ensemble integration technique, error correction system, and an assessment section (Wang, 2001).

Operational prediction of IAP-PSSCA has been conducted for more than 10 years. Generally speaking, most of the severe climate abnormal events in East China were predicted by the model system, including extreme floods along the Yangtze River and Nenjiang River basins in 1998 and the main rainy belt in South China with dryness in the north in 1999.

2.2 *A scheme for retrieving soil moisture*

In order to drive the model with proper initial soil moisture, a retrieving scheme is introduced. The scheme was developed and validated by Ma (1999). It takes the comprehensive effects of the two most important factors into consideration, namely precipitation and surface evaporation, which dominate the soil water budget processes, and only some basic observations like precipitation and temperature are involved in the retrieving process.

The soil column in the scheme consists of 11 layers from the land surface to 1 m in depth. First of all, soil moisture at the surface layer is retrieved based on the relationship between soil moisture and surface precipitation/evaporation. Values at deeper layers are then deduced according to a set of linear equations. Model output was checked by Ma (1999). The results show that the model is capable of retrieving soil moisture at different layers and can reproduce geographical distribution, and seasonal and interannual variation of soil moisture reasonably.

3. Design of experiments

The severe floods along the Yangtze and Nenjiang River basins in the summer of 1998 are a typical short-term climate abnormal event. There are many papers concerning the reason for the formation of this event. In this paper, we try to figure out the role of abnormal initial distribution of soil moisture in forming the severe floods of that year.

Before introducing the experiments, we look at the original soil moisture initialization scheme of IAP-PSSCA as shown in Fig. 1, which is just a 'climate mean' of model output in February after integration for 30 years.

It is evident that such an initial field is unable to reflect the real distribution of soil moisture. Furthermore, the pattern in Fig. 1 is almost totally opposite to observation. All these reasons stress the necessity to improve the initialization scheme.

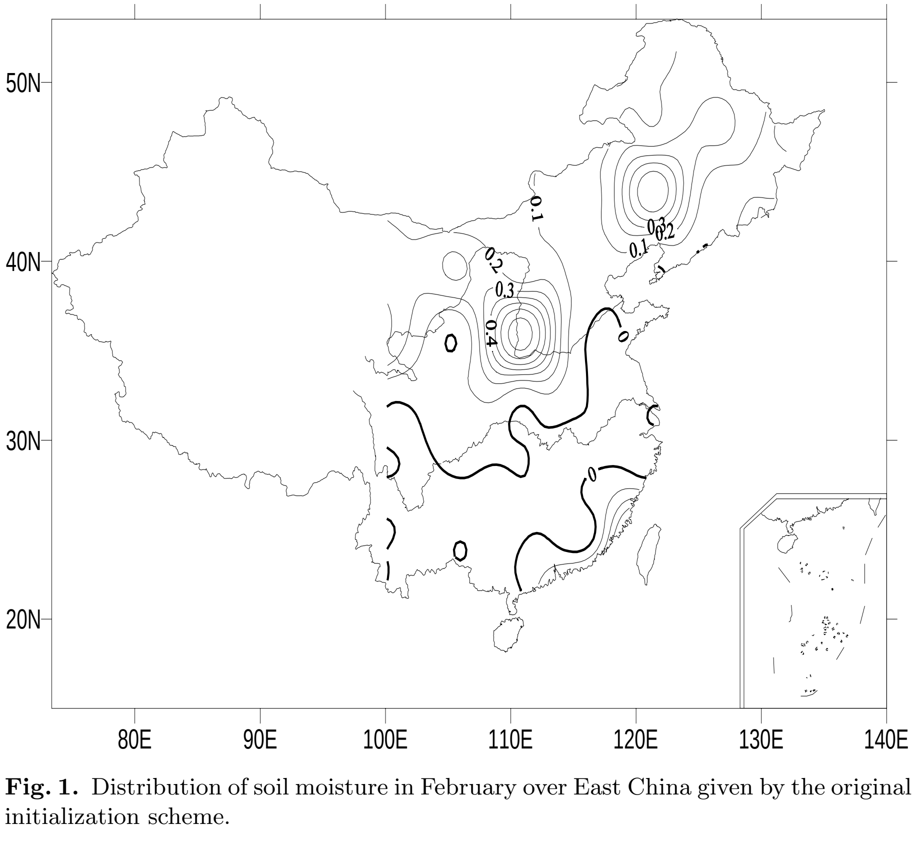

Fig. 1. Distribution of soil moisture in February over East China given by the original initialization scheme.

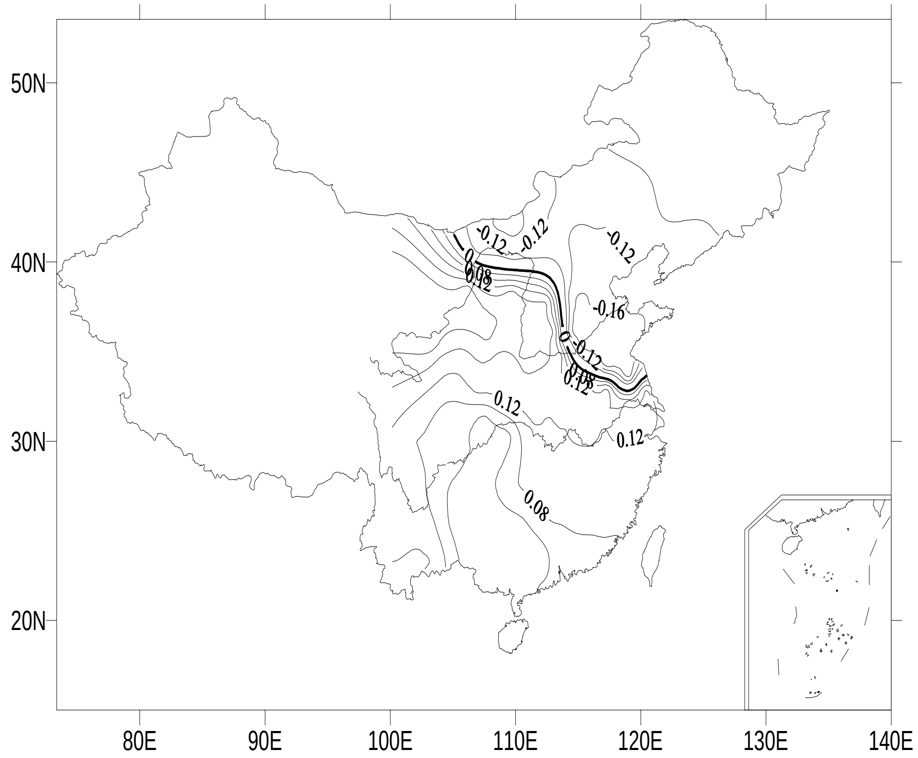

Fig. 2. Distribution of retrieved soil moisture anomaly in February 1998 over East China.

There are 15 ensemble samples contained in the control run, namely, the model was started with 15 atmospheric initial fields obtained from NCEP/NCAR reanalysis data (Kalnay et al., 1996). Monthly SSTA data are obtained from the global optimal interpolation SST database (Reynolds and Smith, 1994). Integration covers the course from the beginning of February to the end of August. The averages from March to May are defined as spring and June to August as summer. The ensemble technique taken in the control run is the arithmetical mean.

In the contrast run, the soil moisture initialization scheme was replaced by the retrieving one. Due to the limitation of available soil property parameters, retrieving can only be carried out at 139 stations in East China (east of 100°E). Integration was executed with the same procedure as the control run but the soil moisture in the beginning month (February) over East China was substituted with the retrieved data (averaged over 0–10 cm).

Since the soil moisture observations in 1998 are unavailable, we are unable to compare the retrieved pattern with the actual distribution directly. Figure 2 shows the distribution of retrieved soil moisture anomaly in February 1998 calculated from monthly retrieved data during 1951 to 1999. An extensive area with high soil moisture along the middle to lower reaches of the Yangtze River was reproduced very well by the retrieved data. The distribution is also consistent with the fact that there were frequent rains and the water level was much higher than normal in this region in the winter of 1997.

4. Results and discussions

The model performance in predicting seasonal precipitation is evaluated by a skill score, which is obtained through comparing prediction with observation. It is widely used in operational assessment in the National Climate Center of China, and is defined as (Chen and Zhao, 1998):

$$P=\frac{N_0+f_1\times n_1+f_2\times n_2}{N+f_1\times n_1+f_2\times n_2}\times 100 \tag{1}$$

where P is the skill score, N is total station number with precipitation observation over East China, N_0 is station number with a predicted abnormal signal the same as observation, n_1 and n_2 indicate station number with correct prediction for different abnormal degree, and f_1 and f_2 are coefficients. The values of precipitation abnormal grades and coefficients are listed in Table 1.

Table 1. Precipitation abnormal degrees and value of coefficients

	Normal range	Second degree abnormality	First degree abnormality
Percentage of precipitation abnormality ($R'\%$)	$\mid \triangle R'\% \mid \leqslant 15\%$	$\mid \triangle R'\% \mid \geqslant 20\%$ $f_2 = 1.60$	$\mid \triangle R'\% \mid \geqslant 50\%$ $f_1 = 4.39$

The score of precipitation prediction over East China in the control run is 72.0 in spring compared with the observation at 160 fundamental stations. It is 66.2 in summer. The results are encouraging because the scores in spring and summer are 83.2 and 76.5 respectively in the contrast run. Both scores increased by 10 points! This is certainly a remarkable improvement as far as short-term climate prediction is concerned.

Results of this case study indicate that abnormal distribution of soil moisture plays an important role in short-term climate change and driving the model with reasonable initial soil moisture distribution is helpful for precipitation prediction. More than that, the initialization scheme applied in this study is easy to use in practice because it only involves available observations. Meanwhile, the capability of IAP-PSSCA with the new soil moisture initialization scheme in simulating seasonal precipitation needs further analysis through more case studies.

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