The Potential Predictability of the South China Sea Summer Monsoon in a Dynamical Seasonal Prediction System

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Abstract The potential predictability of climatological mean circulation and the interannual variation of the South China Sea summer monsoon (SCSSM) were investigated using hindcast results from the Institute of Atmospheric Physics Dynamical Seasonal Prediction System (IAP DCP), along with the National Centers for Environmental Prediction (NCEP) reanalysis data from the period of 1980–2000. The large-scale characteristics of the SCSSM monthly and seasonal mean low-level circulation have been well reproduced by IAP DCP, especially for the zonal wind at 850 hPa; furthermore, the hindcast variability also agrees quite well with observations**.**

By introducing the South China Sea summer monsoon index, the potential predictability of IAP DCP for the intensity of the SCSSM has been evaluated. IAP DCP showed skill in predicting the interannual variation of SCSSM intensity. The result is highly encouraging; the correlation between the hindcasted and observed SCSSM Index was 0.58, which passes the 95% significance test. The result for the seasonal mean June-July-August SCSSM Index was better than that for the monthly mean, suggesting that seasonal forecasts are more reliable than monthly forecasts.

Keywords: numerical prediction system, South China Sea summer monsoon, potential predictability

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1 Introduction

As the key research component of an international research program on climate variability and predictability (CLIVAR), monsoon activity has gained the attention of scientists in many studies. The Asian monsoon is considered to be the world's most prominent monsoon system and can be divided into two subsystems: the Indian monsoon system and the East Asian monsoon system (EAMS) (Chen and Jin, 1984; Tao and Chen, 1987). An important subsystem of the EAMS, the South China Sea summer monsoon (SCSSM), first occurs in the South China Sea and its vicinity, with its establishment indicating the onset of both the EAMS and the rainy season in China (Tao and Chen, 1987). Better understanding of the general features of the SCSSM and its predictability is of great significance to the study of the Asian monsoon and its variability.

Since the 1990s, especially after the South China Sea Monsoon Experiment (SCSMEX) in 1998 (Ding et al., 2001), many studies have been devoted to revealing the general features of SCSSM onset, its evolution and possible mechanisms (Zhao and Chen, 2000; Yang, 2003; Xu et al., 2002), and different monsoon indices have been proposed in order to represent better the onset and evolution of the SCSSM (Li and Zhang, 1999a; Wang et al., 2004b). Furthermore, the relationship between the SCSSM and atmospheric general circulation as well as its impact on East Asian climate anomalies, especially on the rainfall anomaly over eastern China (e.g., Li and Zhang, 1999b; Ma and Sun, 2001), have also been widely investigated. Additionally, numerical simulations of Asian monsoons have been investigated using meteorological models with different complexity (e.g., Lin and Zeng, 1997; Sperber et al., 2001; Zhou and Li, 2002). As for the SCSSM, Wu et al. (2000) adopted the Fifth-Generation NCAR/Penn State Mesoscale Model (MM5) to simulate the onset of the SCSSM in 1998, and the seasonal variation of the SCSSM in 1998 has also been studied using regional climate models (Liu and Ding, 2003; Ren and Qian, 2001). Using the Predictive Ocean Atmosphere Model for Australia (POAMA), Liu et al. (2005) evaluated the predictive skill of the SCSSM in two specific years. Until now, however, there has been very little effort devoted to evaluating the seasonal predictability of the SCSSM systematically. In this paper, therefore, we adopted the 21-year hindcast results of the Institute of Atmospheric Physics (IAP) dynamical seasonal prediction system to rigorously assess the potential predictability of the South China Sea summer monsoon.

2 Design of the ensemble hindcast experiments

The model that was adopted in this study is the IAP dynamical climate prediction system (IAP DCP), which has been widely applied to real-time climate predictions for summer flood rainfall anomalies and spring dust storm anomalies over China (Lin et al., 1998; Chen et al., 2004). The model's good performance in rainfall simulations shows its potential to serve as a useful tool for the simulation and prediction of summer monsoons over East Asia.

In order to assess the predictive skill of IAP DCP for the SCSSM systematically, ensemble hindcast experiments over the period of 1980–2000 were performed.

The atmospheric initial conditions were taken from

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National Centers for Environmental Prediction (NCEP) real-time reanalysis data. The ensemble size was the number of days of the initial month (e.g., 28 for February, 31 for March, etc.)

For monthly and seasonal means, integrations starting from February, March, and April were used. The only external boundary forcing was the global monthly mean SSTs. The monthly mean global sea surface temperature data proposed by Reynolds and Smith (1995) were used to obtain the observed sea surface temperature anomaly. For each ensemble member, the terminal integration date was 31 August. Finally, the ensemble prediction product was the arithmetic mean of those of the total ensemble members. For June-July-August (JJA) seasonal means, the 3-month daily output was averaged to produce seasonal-mean fields. The detailed experiment scheme is shown in Table 1.

3 The climatological mean of the 850 hPa wind

In this section, the mean state climatology simulated by the IAP DCP was investigated to evaluate the IAP DCP's performance in reproducing the large-scale circulation of the SCSSM. Here, the main activity of the SCSSM at 850 hPa has been chosen for analysis. For the ensemble product of IAP DCP with the initial month in February and in April, the distributions of the climatological mean of 850 hPa wind were very similar to that with the initial month in March. As an example, the 21-year averaged hindcast results of IAP DCP with initial month in March were analyzed here.

3.1 Large-scale feature of the onset of the SCSSM

It has been shown by numerous studies that the establishment of the SCSSM is at the fourth pentad of May. That is to say, in monthly time scales, April is the month before the onset of the SCSSM, in May, the onset of the SCSSM begins, and in June, the SCSSM has been established. In order to assess the predictive skill of IAP DCP for large-scale circulation during the onset of the SCSSM, here the hindcasted and observed 850 hPa wind fields in April and May were compared. The observed monthly mean 850 hPa wind for April (Fig. 1a) showed the high over the subtropical area, and the easterly wind at the southwest side of the subtropical high covers the South China Sea (SCS); meanwhile, there was an anticyclone over the Arabian Sea area, and northwesterlies dominated the Indian subcontinet. Obviously, this was the large-scale circulation of the winter monsoon. The cross-equatorial flow was not obvious; this means that, in April, the SCSSM had yet not been established. This winter monsoon circulation was successfully reproduced by IAP DCP (Fig. 1b), although the hindcasted subtropical high was a little farther east than the observed subtropical high. In May, the west Pacific subtropical high withdrew eastward with the west rim to the east of 120°E, and a low trough forms over the Bay of Bengal. Meanwhile, the cross-equatorial over 105°E was very clear, and the strong equatorial westerlies at 80°E propagated to the Bay of Bengal and the South China Sea. The intense southwesterly flow dominated the SCS, indicating the onset of the SCSSM (Fig. 1c). This transition of low level wind was captured by IAP DCP (Fig. 1d), but the position of the hindcasted Somali jet was a little northward compared with what was observed, and the trough over the area from India to Burma was weak.

3.2 The large-scale seasonal mean of the summer monsoon circulation

The anomalies of summer monsoon circulation after the onset of SCSM obviously affect the summer climate over China (Li and Zhang, 1999b). In this section, the hindcasted seasonal mean JJA monsoon circulation was validated by comparing it with observations.

In summer (averaged from June to August), at the 850 hPa wind field (Fig. 1e), there are three flows over the South China Sea: One is the easterly from the west tropical Pacific, which is connected with the west Pacific subtropical high; one is the southwesterly from the Indian monsoon trough; and another southwesterly originates from the Australian High and combines with the southwesterly from India to form a monsoon jet over the South China Sea. The easterly from the west tropical Pacific joins with these two southwesterlies, and forms an ITCZ over the South China Sea. The SCSSM circulation was successfully reproduced by IAP DCP (Fig. 1f), including these three flows and the monsoon trough over the Bag of Bengal and the South China Sea, although the hindcasted subtropical high was a little north-westward, and this discrepancy led to the failure of the prediction for the flow over Taiwan of China and the Philippines.

In conclusion, the IAP DCP has the ability to reproduce large-scale circulation before and after the onset. Of SCSSM.

4 The interannual variation of the SCSSM

The interannual variation of the intensity of the SCSSM

Table 1 Hindcast experiment design for the IAP DCP

Prediction system	IAP DCP
Climate model	IAP 2 Layers AGCM (horizontal resolution: 2.0° × 2.5° in latitude and longitude)
SST	Observed climatological SST+Observed sea surface temperature anomalies (SSTA) in initial month
Atmospheric initial conditions	Wind, geopotential height, and relative humidity, taken from NCEP real-time analysis
Hindcast period	21-year ensemble hindcast during 1980–2000
Ensemble size	Number of days of initial Month (28 for February, 31 for March, and 30 for April)
Ensemble scheme	Arithmetic average

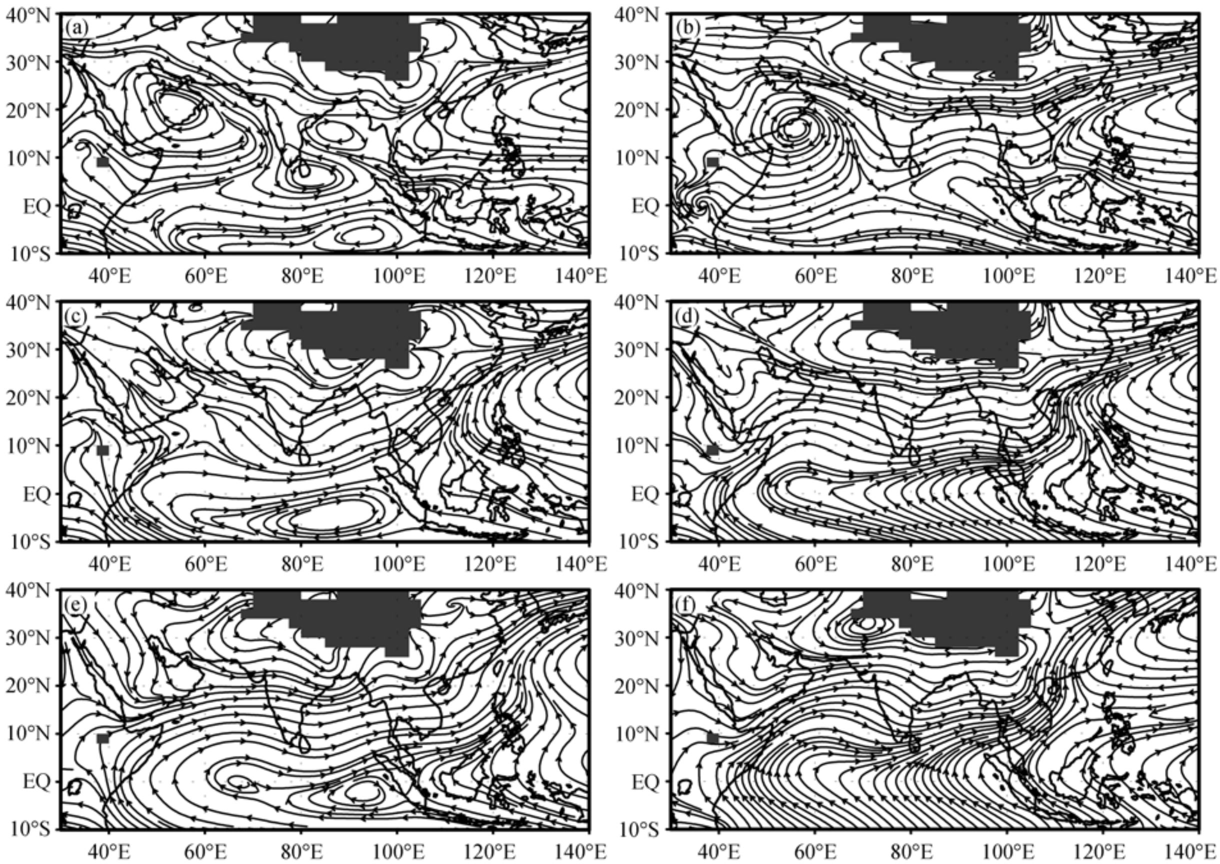

Figure 1 The observed and simulated winds at 850 hPa. (a), (c), and (e) are the observations in April, May, and JJA, respectively; (b), (d), and (f) are the hindcasts in April, May, and JJA, respectively.

has a significant influence on the climate of South and East China. In order to explore the ability of IAP DCP to predict the interannual variation of the SCSSM, first, the correlations between the observed and hindcasted zonal and meridional 850 hPa wind were investigated. Then, comparisons of the interannual variability of 850 hPa level wind between hindcast and observation were made. Finally, the monsoon index was adopted to demonstrate the predictability of IAP DCP for the interannual variation of the SCSSM. The hindcasted results used in this section are the JJA seasonal mean ensemble product of IAP DCP with initial month in March.

4.1 Correlations analysis

To the temporal correlations of the zonal 850 hPa wind in JJA (Fig. 2), high correlations exceeding the 95% significance level (i.e., correlation coefficient above 0.433) were found over the middle and southern parts of the South China Sea. To the correlations of JJA meridional wind (Fig. 2), positive values were found over the southeastern coastal areas of China and South China. Some values exceeded the 95% significance level, and the correlation coefficients were mainly positive over the South China Sea. This indicated that the IAP DCP shows a certain ability to predict the interannual variation of summer wind at 850 hPa in JJA over the South China Sea area. For the ensemble product of IAP DCP with the initial month in February and in April, the distribution of correlations was the same as in Fig. 2; the high correlations over the South China Sea for the ensemble product with the initial month in March, however, were higher those that with the initial month in February and a little lower than those with the initial month in April (figure not shown).

4.2 Interannual climate variability

Interannual climate variability can be determined by an analysis of the standard deviation of seasonal means.

From Fig. 3a, it can be seen that the maximum values of the interannual variability for zonal wind in JJA were distributed as two band-shapes. One shape was found over the lower reaches of the Yangtze River and expands eastward; another is located nearby at 10°N. Both the distribution and intensity of variability are well reproduced by the IAP DCP (Fig. 3b). This accuracy shows the important impact of SSTA on the interannual variability. As for the variability of meridional wind, the hindcasted result was not very similar to the observation; for example, the maximum area to the east of Japan was been reproduced by IAP DCP. For the ensemble product of IAP DCP with the initial month in February and in April, the distributions of interannual variability were similar to that with the initial month in March.

4.3 South China Sea summer monsoon index

In order to quantitatively evaluate the potential pre-

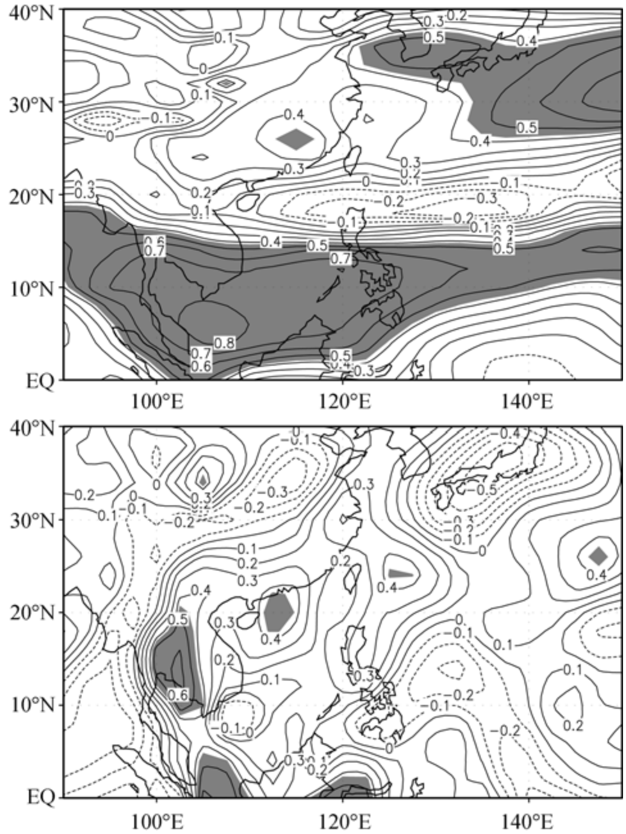

Figure 2 Temporal correlations between the observed and hindcasted winds at 850 hPa in JJA (Regions above the 95% significance level are shaded). Upper: zonal wind; lower: meridional wind.

dictability of IAP DCP for the intensity of SCSSM, we adopted the SCSSM index.

There are many definitions of the SCSSM index. Because the IAP DCP has high skills in hindcasting the zonal wind at the middle and south parts of the South China Sea, we adopted the index defined by Wang et al. (2004a). The index is defined as the 850-hPa zonal wind averaged over the region 5–15°N, 110–120°E.

Using the index of Wang et al. (2004a), we examined the hindcasted JJA seasonal mean summer monsoon indices from 1980 to 2000. Figure 4 shows that the intensity of the SCSSM from IAP DCP with the initial month in March was quite consistent with observed intensity and that the correlation between them was 0.58. This result denotes that IAP DCP had a high potential to predict the intensity of SCSSM. As for the hindcasted result with different initial months, this result shows that the intensity of seasonal mean SCSSM with a shorter lead time was a more skillful representation of the seasonal mean observation (Table 2); i.e., the skill when initiated from April was highest (0.74), and that initiated from February was lowest (0.39). This behavior may be due to the fact that the SSTA used in hindcast experiment is persistent SSTA; that is, the SSTA is more accurate with shorter lead time. The monthly mean monsoon index from June to August also was analyzed. The skill of the index was best in July and worst in June. In summary, the skill of the seasonal mean monsoon index was higher than that of the monthly mean index.

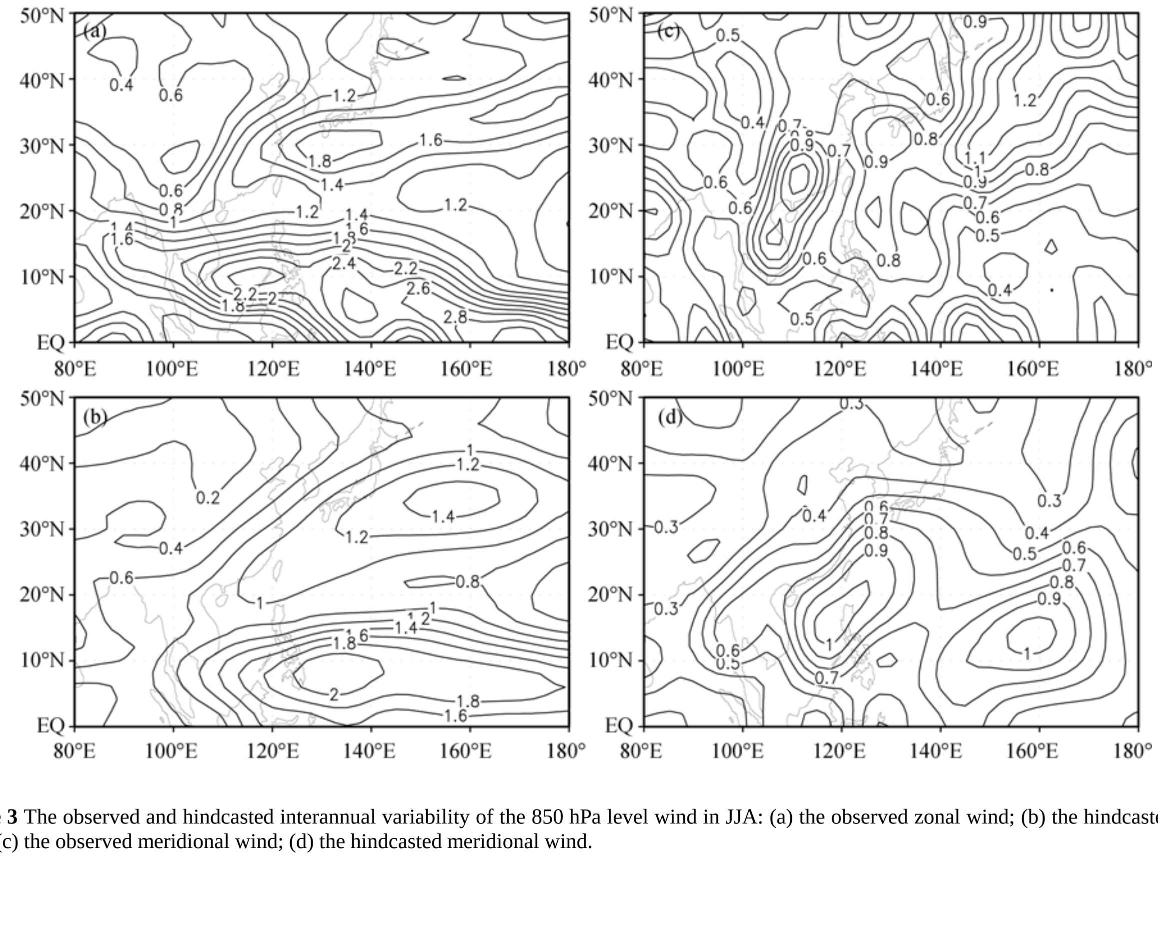

Figure 3 The observed and hindcasted interannual variability of the 850 hPa level wind in JJA: (a) the observed zonal wind; (b) the hindcasted zonal wind; (c) the observed meridional wind; (d) the hindcasted meridional wind.

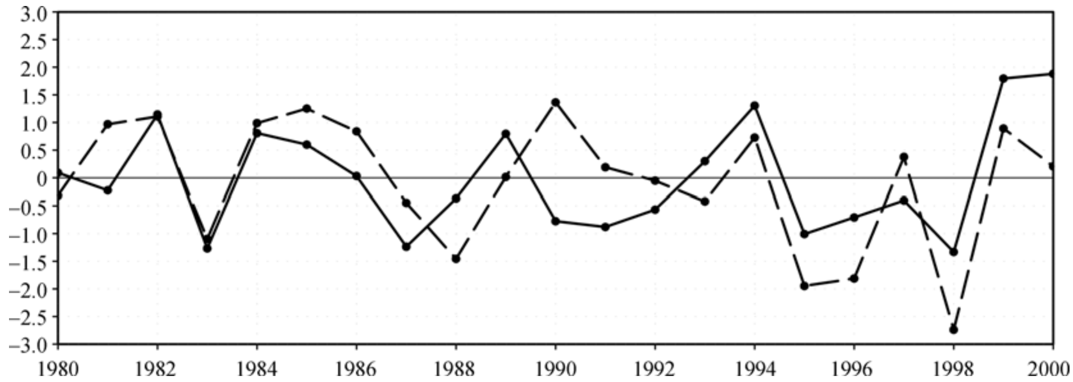

Figure 4 The interannual variation of SCSSM index (dashed line: observation; solid line: hindcast).

Table 2 The monthly and seasonal means of the JJA correlations of the monsoon index between observation and hindcast for IAP DCP for different initial months. Bold months represent the initial months.

Initial month	Research period			
	June	July	August	JJA
February	0.19	0.29	0.39	0.39
March	0.24	0.62	0.45	0.58
April	0.47	0.64	0.55	0.74

5 Summary and discussion

The potential predictability of climatological mean circulation and interannual variation of the SCSSM was investigated using hindcasted 850 hPa winds from the IAP DCP along with the corresponding data from NCEP-the National Center for Atmospheric Research (NCAR) reanalysis for the period of 1980–2000. The large-scale characteristics of the low-level circulation field of the SCSSM were well-reproduced by IAP DCP. We found that IAP DCP has the potential for predicting the interannual variability of the SCSSM, especially for the zonal wind at 850 hPa; the hindcasted variability was quite consistent with the observation. Meanwhile, IAP DCP has the potential for predicting the intensity of the SCSSM, as the correlations between the hindcasted and observed SCSSM index pass the significance test. Furthermore, the predictive skill for seasonal mean JJA summer monsoon index is higher than that of monthly means. As for the hindcasted result for different initial months with persistent SSTA, the study showed that, once the initial month is closer to the onset month of the SCSSM, the hindcasted skill of the seasonal mean SCSSM is higher.

It was found that IAP DCP has some ability to predict the large scale features of low-level circulation of the SCSSM and its interannual variation, but it still has some shortcomings. For example, the predicted subtropical high was a little eastward compared to observations. The prediction of monsoons is a difficult science problem and is related to many complicated physical factors. In this paper, only SST was considered. In the future, in order to further improve the predictive skill of IAP DCP, more factors, such as snow cover, soil humidity, and so on, should be considered in addition to sea surface temperature in this system.

In this paper, only the monthly mean monsoon circulation and the intensity of SCSSM were examined, and the predictability of IAP DCP for the onset time of monsoon was been considered. This approach was taken because the onset of a monsoon is a short-period event, not a climate anomaly on monthly or seasonal time scales, and most of the global climate models have no skill in predicting an abrupt event on a time scale of less than one month.

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