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A TIME FILTERING SCHEME FOR THE SHORT RANGE CLIMATE PREDICTION MODEL PRODUCTS AND ITS REAL CASE ANALYSIS

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ABSTRACT: A filtering / extracting scheme for various timescale processes in short range climate model output is established by using the scale scattering method. And the climatological meanings as well as the importance of the filtered series are discussed. In the latter part of work, the effectiveness of the filtering method and the performance of the prediction model are analyzed through a real case.

Key words: products of short-range climate model; scale filtering scheme; factors describing the predicted climate; performance of model

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1 INTRODUCTION

Climatic predictions employing dynamic models have been in use operationally in the United States, Japan and Britain. Some of them, especially on monthly scales (including general situation and precipitation) are useful in real forecasting, as verified with air-sea coupling predictive models, though the correlative coefficients of anomalies are rather low on scales above the month (Gao and Zhao, 1997). Regional climate models, in particular, are capable of simulating variations of weather events within the length of the month as well as reproducing the trend on the monthly scale, due to the inclusion of high resolution and fine physical processes (Zhao, Luo and Leung et al., 1997). According to a diagnostic method using interactions between the transient wave and mean basic flow, the latter can check the long-term overhaul behavior of the former and the long-term group forcing by the former on the latter should have predictability comparable to the latter (Geng, 1997). In other words, despite the essential importance of low-frequency processes in the climate prediction (Yang and Ji, 1996), the overall features of the transient wave (of the synoptic scale), such as frequency and amplitude, must also be analyzed, for it holds high significance to short-term prediction on the monthly scale in general and modeling and prediction with regional climate models in particular. It is based on this recognition that the current work involves itself in discussing ways of splitting temporal scales in monthly-scale climate predictions and respective importance, which is illustrated by real case study.

2 BRIEF SUMMARY OF MODEL SCHEME

The model used for simulation and prediction is a "short-term climate prediction model for south China region" developed at the institute the author is working at. It is an improved version

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over a mesoscale synoptic model introduced from Germany. For the operational version, the horizontal resolution is 20 layers at 0.5° with 81×73×20 grids. Refer to Yan (2000) for more detail. The model has been proved to have reliable performance.

Following the scale splitting theory, the temporal sequence of meteorological elements is expressed as:

$$x(t) = x_0(t) + x_1(t) + x_2(t) + x_3(t) + x_4(t) + x_5(t) \tag{1}$$

$$y(t) = y_0(t) + y_1(t) + y_2(t) + y_3(t) + y_4(t) \tag{2}$$

in which x is the observation, y the prediction by model and t the time. The subscript "0" is the changes taking place on scales longer than the month, which are related to planetary scale factors such as seasonal fluctuations, intermediate-term oscillations, inter-annual variations. The subscript "1" is related to intermediate-to-monthly scales of index cycles, ultra-long waves and earth-atmospheric interactions, being the main targets of monthly scale climate prediction. The subscript "2" is the weather phenomena changes that are resulted from those on the planetary scale by a scale of 3 to 5 days. The subscript "4" is the mesoscale variation, which is caused by mesoscale events resolvable by the model usually spanning from a few hours to a day or two. The subscript "5" is the fine scale changes, which are not resolvable by model and caused by meso-and-fine scale weather systems and local effects with a magnitude of a few dozen kilometers. It is obvious that the model is incapable of predicting this kind of change.

Due to the multi-scale nature of element variations, appropriate treatment has to be conducted of the original series against set goals and objects before detailed and quantitative study of every climatically meaningful index for results desired. As far as the monthly climate prediction is concerned, evolutions on scales longer than the intermediate terms, i.e. low-frequency signals, have to be put before those below the synoptic scales. It is also supported by the theory of predictability such that weather systems with smaller scales and higher frequencies are bound to produce predictions with smaller predictability and larger errors. It is, therefore, necessary to withhold signals that are most useful and interested and to eliminate those that are less so. Apart from it, some group features in weather processes such as the rate of temperature drop, diurnal amplitude, frequency in the process and other transient information, are also part of the climatic indexes. It is not appropriate to ignore it completely in the prediction and analysis of climate. For a fuller and more quantitative conclusion in climatic prediction, we must extract features with scales fit for their own purposes.

There are many ways for time filtering, including various (low and high) band-pass filter and digital filter. Setting from variation of the atmosphere as it is, the current work employs a simple but useful moving average method. It is, as shown in real case study, reasonable and effective. The following is how we do it.

According to the theory of atmospheric waving, processes of weather evolution can be, with reference to their temporal scales, described as waves with different quasi-periods, or

$$a_i(t) = A \cdot \sin(2p \frac{t}{t_i} + d_0) = A \cdot \cos(2p \frac{t}{t_i} + d_1) \tag{3}$$

where $a_i(t)$ is the scale evolution at the i^{th} time for any element, t_i the period, d_0, d_1 the phase and *A* the amplitude. Meanwhile we have

$$\overline{a_i(t)}^{t_i} = 0 \tag{4}$$

where $\overline{}^{t_i}$ means to seek mean over time t_i. Furthermore, the triangular formula

$$\overline{a_i(t)}^{t_j} = \frac{1}{t_j}\int_{t-\frac{1}{2}t_j}^{t+\frac{1}{2}t_j} A\cdot\cos(2p\frac{t}{t_i}+d_1)\mathrm{d}t = \frac{p_i}{2pt_j}\cdot A\cdot\sin(2p\frac{t}{t_i}+d_1)\Bigg|_{t-\frac{1}{2}t_j}^{t+\frac{1}{2}t_j} \qquad (5)$$

$$\sin - \cos b = 2\cos\frac{a+b}{2}\sin\frac{a-b}{2} \qquad (6)$$

is used. Then Eq.(5) is reduced to

$$\overline{a_i(t)}^{t_j} = \frac{t_i}{pt_j}\cdot A\cdot\cos(2p\frac{t}{t_i}+d_1)\sin\left(\frac{pt_j}{t_i}\right) \qquad (7)$$

Substituting the Taylor expansion

$$\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} + \cdots + (-1)^n\frac{x^{2n+1}}{(2n+1)!} + \cdots$$

into Eq.(7) and when t_j《t_i, the Taylor expansion can take zero-order approximation and Eq.(7) becomes

$$\overline{a_i(t)}^{t_j} = \frac{t_i}{pt_j}\cdot A\cdot\cos(2p\frac{t}{t_i}+d_1)\cdot\frac{pt_j}{t_i} = a_i(t) \qquad (t_j《t_i) \qquad (8)$$

In other words, for series with long periods, its mean series within short-time intervals are approximated to the original one.

Taking temporal average for Eqs.(1) and (2), we have

$$\overline{x(t)}^t = \overline{x_0(t)}^t + \overline{x_1(t)}^t + \overline{x_2(t)}^t + \overline{x_3(t)}^t + \overline{x_4(t)}^t + \overline{x_5(t)}^t \qquad (9)$$

$$\overline{y(t)}^t = \overline{y_0(t)}^t + \overline{y_1(t)}^t + \overline{y_2(t)}^t + \overline{y_3(t)}^t + \overline{y_4(t)}^t \qquad (10)$$

Following what is carried in Eqs.(4) and (8) and individual terms in Eqs.(1) and (2), we deduce that

$$\overline{x(t)}^{3\text{–}5\mathrm{d}} = x_0(t) + x_1(t) \qquad (11)$$

$$\overline{y(t)}^{3\text{–}5\mathrm{d}} = y_0(t) + y_1(t) \qquad (12)$$

$$\overline{x(t)}^{1\mathrm{d}} = x_0(t) + x_1(t) + x_2(t) + \overline{x_4(t)}^{1\mathrm{d}} \qquad (13)$$

$$\overline{y(t)}^{1\mathrm{d}} = y_0(t) + y_1(t) + y_2(t) + \overline{y_4(t)}^{1\mathrm{d}} \qquad (14)$$

$$\overline{y(t)}^{1\mathrm{d}} - \overline{y(t)}^{3\text{–}5\mathrm{d}} = y_2(t) + \overline{y_4(t)}^{1\mathrm{d}} \qquad (15)$$

That is to say, the difference between the two time series reflect the variations undertaken in large scale and mesoscale weather processes. The series can be used to study their specific features. On the other hand,

$$y(t) - \overline{y(t)}^{1\mathrm{d}} = y_3(t) + \left(y_4(t) - \overline{y_4(t)}^{1\mathrm{d}}\right) \qquad (16)$$

$$x(t) - \overline{x(t)}^{1\mathrm{d}} = x_3(t) + \left(x_4(t) - \overline{x_4(t)}^{1\mathrm{d}}\right) + x_5(t) \qquad (17)$$

Eq.(16) describes what the diurnal changes and mesoscale processes are in the prediction while Eq.(17) presents what the diurnal changes and meso-and-fine scale processes are in the observation.

From Eqs.(2) and (3), we have

$$y(t+1\mathrm{d}) - y(t) = y_0(t)\Big|_t^{t+1\mathrm{d}} + y_1(t)\Big|_t^{t+1\mathrm{d}} + y_2(t)\Big|_t^{t+1\mathrm{d}} + y_4(t)\Big|_t^{t+1\mathrm{d}} \quad (18)$$

Substitute it into Eq.(3) and use Eq.(6) at the same time, we then have

$$y_0(t)\Big|_t^{t+1\mathrm{d}} = 2\cos\left(2p\,\frac{t+\frac{1}{2}\mathrm{d}}{t_0} + d_0\right)\cdot\sin\left(2p\,\frac{1\mathrm{d}}{t_0}\right) \approx 0 \qquad (t_0 \gg 1\mathrm{d})$$

Similarly,

$$y_1(t)\Big|_t^{t+1\mathrm{d}} \approx 0 \qquad (t_1 \gg 1\mathrm{d})$$

Thus, Eq.(18) is reduced to

$$y(t+1\mathrm{d}) - y(t) = y_2(t)\Big|_t^{t+1\mathrm{d}} + y_4(t)\Big|_t^{t+1\mathrm{d}} \quad (19)$$

In this way, the effects of large scale and mesoscale weather are reflected.

Similarly,

$$x(t+1\mathrm{d}) - x(t) = x_2(t)\Big|_t^{t+1\mathrm{d}} + x_4(t)\Big|_t^{t+1\mathrm{d}} + x_5(t)\Big|_t^{t+1\mathrm{d}} \quad (20)$$

3 ANALYSIS OF SIMULATED CASES

Next, a real case in simulation for prediction will be examined to study the role of time filter in the monthly predictive series and the performance of the model. Take the Guangzhou station as example. The initial field begins at 1200 GMT February 1, 1998 and the integration is forwardly done for a month. Only the element of temperature is discussed due to space of text allowed.

Fig.1 gives the time series of temperature at the Guangzhou observation at a height of 2 m. The observation is plotted every 3 hours and the prediction every 1 hour. No time filtering of any kind is conducted, which makes it somewhere near the situation like Eqs.(1) and (2). As a result, the observation includes variations within the month, synoptic scale processes, diurnal, mesoscale and fine scale changes while the prediction is made up of all but fine scale processes. It is known from the figure that the diurnal variation, which is caused by that in solar radiation and at a scale of 24 hours, are well displayed in both observation and prediction. As the surface and soil processes included in this model are good and reasonable, the diurnal change predicted is in agreement with the observation. The variation in temperature that is caused by mesoscale weather of the same temporal scale as the diurnal variation is also well-defined. An example is shown in the case around February 4, when the diurnal variation of temperature is made less definite by overcast sky blocking incident solar radiation due to the passage of a cold front. This is what the (model-resolvable) mesoscale weather has created over scales from a few hours to a few days. The effect on the variation of large scale processes are more evident, in which the planetary scale

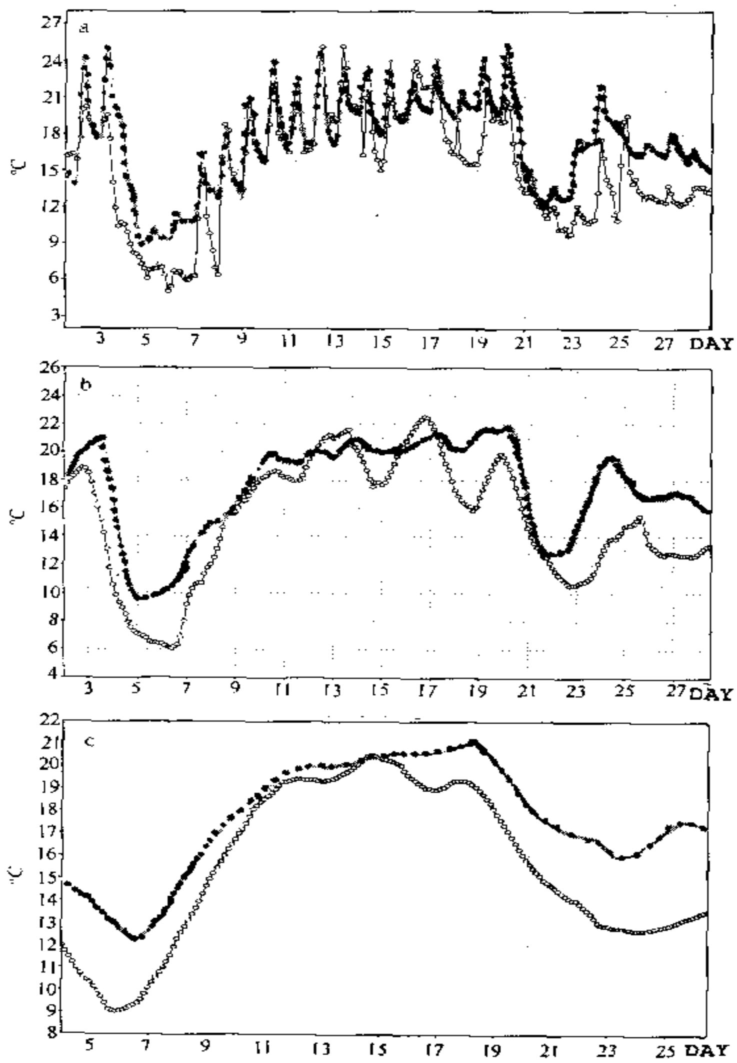

Fig.1 Observed and simulated temperature for Guangzhou station. (a) original series; (b) 1-day running mean series; (c) 5-day running mean series. Hollow dots: observed; solid dots: simulated

weather serves as the fuse over scales of 3 ~ 5 days. A illuminating case is one on February 2 ~ 3, when a wave of strong cold airmass was traveling south and bringing forth a net temperature drop for 15°C and it didn't warm up until February 6 ~ 8. Another similar case is recorded around February 22. As regards the fine scale variation not resolvable by the model, systems on the meso-and-fine scale or local effects, lasting with a magnitude from a few minutes to a few hours, are the triggers. Difference is unavoidable between the prediction and observation due to exclusion of such signals in the model. For instance, the out-of-phase distribution and difference in characteristics between the simulation and observation for February 18 and 25 may have been caused by fine scale variations. It is generally the case that consistent amplitude and phase suggests good prediction to processes with every scale. Nonetheless, it is almost impossible to have quantitative and detailed separation and study of the scales as weather systems active on them are mangled all together, despite of full coverage of information.

Let's see the moving average series next (Fig.1b). From Eqs.(13) and (14), we know that the curve of the series become smoother with the diurnal and fine scale effects filtered. It is displayed as a low-frequency variation (mean flow) on intermediate scales or larger that is superposed with large-scale and mesoscale variations (transient wave). The consistence suggests that both waves are able to predict accurately. It is also found that the amplitude (the intensity of temperature rise and fall) and rate of the main trends are basically the same as the original series.

Then we'll see how the 5-day moving mean changes (Fig.1c). From Eqs.(11) and (12), we know that the treatment has eliminated all high-frequency variations and retained climatic information on and above the intermediate scales (mean flow). The figure shows that only the variation on the low frequency section is left in the series. It is cool, warm and cooler in the first, middle and late 10-day periods of the month, respectively, agreeing with the observation. The prediction through "mean flow" can be labeled a success. It is noted, however, that the rate of temperature rise or fall is about 5°C or smaller and the speed is slower in the current series than in the original series, in spite of the consistence between them. It is an indication that the intermediate-scale variation (mean flow) reflects qualitatively the main features of variation within the monthly scale. Only with superposition of large scale and mesoscale weather processes (the transient wave) can it produce amplitude and speed close to reality. In other words, the low-frequency variation is capable of reflecting the characteristics of short-term climatic changes, but the information it contains is not enough to reflect those in the real world. To predict extreme intensity and speed of variation, the effects of weather systems on the large scale and mesoscale must be considered.

Next we 'll have a close look at the effects of the transient wave (with large- and- mesoscale systems). From Eq.(15), the effect is readily available when we subtract the 5-day moving mean from the 1-day one. It is clear in Fig.2 that the amplitude can be as much as 8°C on the synoptic scale, having an important role in the real temporal variation of elements. Just as what is pointed out in Geng (1997), a comprehensive reflection of real climatic changes is possible only when the synoptic variation is also included in the climatic prediction. Two of the major cold air surges in the month of interest are both the result of low-frequency processes (of ultra-long wave, see Fig.1c) in superposition with synoptic scale events, causing large temperature drop.

Fig.1 depicts a high percentage of diurnal variance in the whole variation of the series. Following Eqs.(16) and (17), the diurnal and meso-and-fine scale variations of elements are obtained by subtracting the original series from the 1-day mean series. The major component is the diurnal

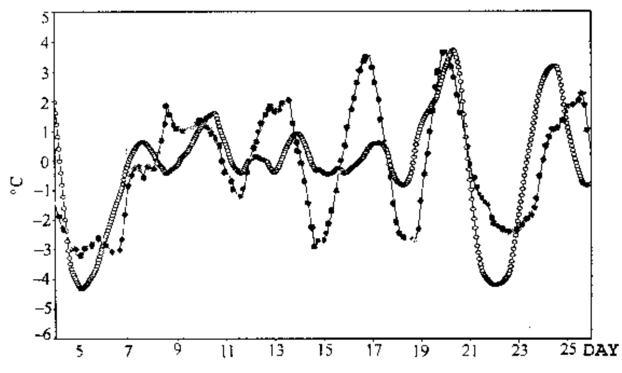

Fig.2 Differences between the 1-day running mean and 5-day running mean of the temperature. Solid dots: observed; hollow dots: simulated

variation, as is shown in Fig.3. An obvious feature of it is that it fluctuates in significant phases, such as large amplitudes in early and middle days of the month, small amplitudes on February 4 ~

6 and even smaller amplitude in most of latter February. The simulation is successful in reflecting the trend.

The size of diurnal variation (such as difference of temperature between day and night) is directly related with climatic types and has been used as one of the variables in describing climate

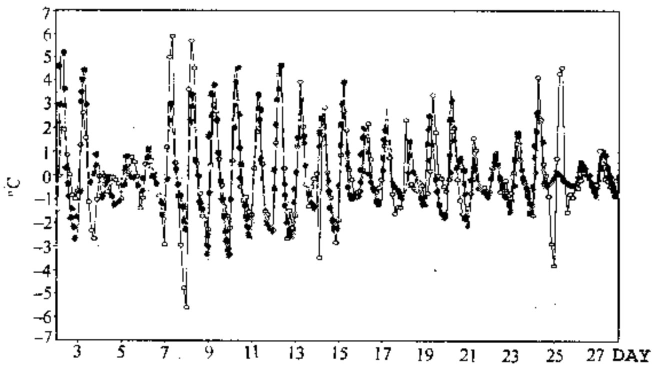

Fig.3 Differences between the original and 1-day running mean of the temperature. Hollow dots: observed; solid dots: simulated

and should be used as one for climatic prediction. It should not be ignored just because it is active on scales relatively smaller than others. This is due to the fact that different climatic types are reflected with different amplitudes of diurnal variation given the same low-frequency process (of, for example, 5-day mean, see Fig.1c). Take the relative humidity and cloudage as one more example (Figure omitted). If only the 5-day low-frequency variation is known, then it is not possible to judge whether the real climatic state fluctuates within a limited zone around the mean or widely goes around it (for example, the humidity could be 30% in the day but 90% in the night while the cloudage varies from 0 to 10). The two pictures differ vastly indeed!

The 24-h variation field of any element is vital to operation as it can be used as an index for the evolution, movement and degree of maturity and moving velocity. From Eqs.(19) and (20), we know that the index points to results interacting among weather variations on large and small

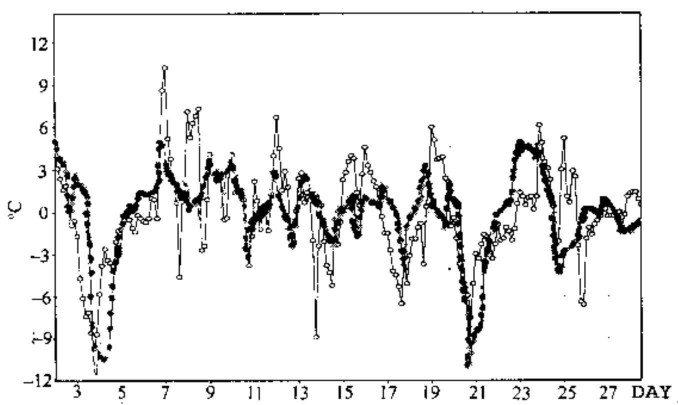

Fig.4 Series of the 24-h change of surface temperature. Hollow dots: observed; solid dots: simulated

scales and the ones in between. They are the right means to give illustrative and quantitative study of the indexes of "number of process", "extent of influence" and "extent of sustaining" used in climatic prediction. Fig.4 is the series of 24-h variation for the surface temperature. It clearly shows indexes such as the "number of process" and "extreme amount of 24-h temperature rise/fall". The agreement between simulation and observation suggests that the simulation is meaningful of the "number of process" (group features of the transient wave) and should be analyzed and used in climate prediction.

4 CONCLUDING REMARKS

a. The scale splitting method presented and used in the work is convenient and useful;

b. For a more accurate and complete description of climatic change, the monthly scale climate prediction should study indexes of important indication, such as "number of process", "extent of influence and speed", "extreme maximum and minimum", "frequency of process in a phase" and "diurnal variation amplitude", as well as low-frequency events (mean flow);

c. The current regional climate prediction model has been proved to perform well, being able to simulate all of the aforementioned indexes with efficiency and usefulness.

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