Seasonal Prediction of Summer Temperature over Northeast China Using a Year-to-Year Incremental Approach*

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ABSTRACT

We present a model for predicting summertime surface air temperature in Northeast China (NESSAT) using a year-to-year incremental approach. The predicted value for each year's increase or decrease of NESSAT is added to the observed value within a particular year to yield the net forecast NESSAT. The seasonal forecast model for the year-to-year increments of NESSAT is constructed based on data from 1975–2007. Five predictors are used: an index for sea ice cover over the East Siberian Sea, an index for central Pacific tropical sea surface temperature, two high latitude circulation indices, as well as a North American pressure index. All predictors are available by no later than March, which allows for compilation of a seasonal forecast with a two-month lead time. The prediction model accurately captures the interannual variations of NESSAT during 1977–2007 with a correlation coefficient between the predicted and observed NESSAT of 0.87 (accounting for 76% of total variance) and a mean absolute error (MAE) of 0.3°C. A cross-validation test during 1977–2008 demonstrates that the model has good predictive skill, with MAE of 0.4°C and a correlation coefficient between the predicted and observed NESSAT of 0.76.

Key words: seasonal prediction model, Northeast China summer surface temperature, year-to-year increment

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1. Introduction

The seasonal prediction of summer surface air temperature (SAT) is especially valuable to the development of agriculture and the economy of Northeast China, where the lower than normal summertime (June-August) SAT will directly cause decreases in crop production. Results have shown that a higher frequency of summer Northeast China cold vortex activities leads to lower NESSAT (summertime surface air temperature in Northeast China) and more precipitation (Sun et al., 2000). The North Pacific oscillation (NPO) (Liu et al., 2002), the sea surface temperature (SST) over the Pacific (Zeng and Zhang, 1987; Wang and Zhu, 1985; Zhen and Ni, 1999; Lian and An, 1998; Sun and Wang; 2006; Zhou and Wang, 2008), the Pacific decadal oscillation (Zhu and Yang, 2003), and the large-scale atmospheric circulations in the Northern Hemisphere (Wang and Wu, 1997; Chen and Zhu, 2004; Sun and Wang, 2006; Wang and Sun, 2009; Yue and Wang, 2008; Wang and Fan, 2009) all play important roles in Northeast China summer climate. Due to the high-latitude geographic location of Northeast China, it is more challenging to develop an operational prediction scheme for NESSAT for this area than for some other areas (Wang and Fan, 2009).

Fan et al. (2008) proposed a year-to-year incremental approach to forecast the summer rainfall over the Yangtze River valley. The year-to-year increment of a variable refers to the difference in a variable between successive years (DY). It gives the year-to-year increment of a predictand instead of directly

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predicting the predictand itself. A possible rationale for the new approach over a method that predicts the absolute level of a variable may arise from the existence of the tropospheric biennial oscillation (TBO) as a strong feature that modulates the Asian monsoon, El Niño/Southern Oscillation (ENSO), etc., and hence also impacts seasonal rainfall and temperature. The year-to-year increment of a variable may produce amplified signals, thereby facilitating the capturing/identification of marginal changes in the underlying variables. Year-to-year incremental prediction approaches have shown good predictive abilities for forecasting summer rainfall in China (Fan et al., 2008, 2009), typhoon activity (Fan and Wang, 2009), landfalling tropical cyclone numbers over China (Fan, 2009b), and winter surface air temperature over Northeast China (Fan, 2009a). In this paper, we develop an operational seasonal forecast model for NESSAT using the year-to-year incremental approach and validate the model's potential prediction skill.

2. Data and method

Monthly surface air temperature at 160 stations in China is obtained from the China Meteorological Administration. The monthly atmospheric reanalysis dataset from the US NCEP/NCAR is used for the circulation and pressure analysis. The Hadley Center for Climate Prediction and Research monthly mean sea ice concentration with a horizontal resolution of $1°\times1°$ is used as well. SST is obtained from the National Ocean and Atmospheric Administration (NOAA) monthly extended reconstructed version 2 (ERSST.v2) dataset, with a horizontal resolution of $2°\times2°$. DY indicates a difference in a variable between the current year and the previous year; for example, DY of NESSAT in 1998 represents NESSAT in 1998 minus NESSAT in 1997. All the data described above are analyzed for the period of 1977–2008.

A year-to-year incremental prediction approach is adopted in this paper. First, a statistical forecast model for DY of NESSAT is established to forecast the DY of NESSAT, and from this quantity a forecast for NESSAT can then be generated (i.e., the forecast of DY of NESSAT is added to the previous observed NESSAT). The forecast model for DY of NESSAT is constructed using a multilinear regression method based on the DY of data taken from 1977–2007 (31 yr). There are two reasons for the choice of this training period. First, this period allows for sufficiently good quality of sea ice cover data and other atmospheric data during the post-satellite era. Second, this period also contains robust signals captured by the forecast variables.

3. The predictors

In choosing the predictors of the DY of NESSAT, two factors should be considered. First, the predictors must be available and easily accessible no later than March so that a forecast can be made two months ahead. Second, the predictors should have a physical link with the DY of NESSAT. Based on these considerations, five predictors associated with DY of NESSAT (see Fig. 1) are selected.

We examined the correlation coefficients between the DY of NESSAT and several other quantities: the

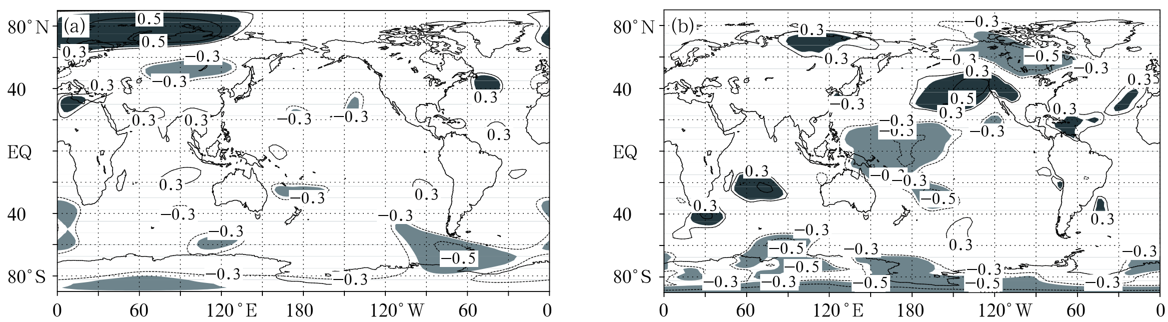

Fig. 1. Correlation coefficients between the DY of NESSAT and (a) the DY of geopotential height (GHT) at 200 hPa in the previous autumn, (b) the DY of SLP in March of the current year. Shadings indicate areas with correlation coefficients exceeding the 95% significance level, as estimated by a local student's t-test.

DY of geopotential height (GHT) at 200 hPa in the previous autumn, the DY of sea level pressure (SLP) in March of the current year (see Fig. 1), the DY of sea surface temperature in the previous March-April-May (MAM), and the DY of sea ice cover in the Northern Hemisphere in winter of the current year. Associated with positive yearly increments of NESSAT, the relationship with the 200-hPa DY of GHT in the previous autumn shows positive (negative) correlation coefficients dominating Eurasia at high latitudes (mid latitudes), and there are concurrently negative correlations at high latitudes in the Southern Hemisphere for the 200-hPa DY of GHT, as well. Note that these correlation patterns at high latitudes are still present in March (Fig. 1), which indicates that polar vortices in both hemispheres might play a significant role in the DY of NESSAT (Zhang et al., 1985). Therefore, we define an index for the Northern Hemispheric high latitude circulation (INHC) based on the area-averaged 200-hPa GHT in the region of 70°–80°N, 60°–120°E. This index is related to the intensity of the Northern Hemispheric polar vortex, with the correlation coefficient between the DY of INHC and DY of NESSAT being 0.7 (Fig. 2a) for the period 1977–2007.

Research has shown the impact of the Antarctic Oscillation (AAO) on the climate of East Asia (Fan and Wang, 2004, 2006; Fan, 2006; Wang and Fan, 2005; Sun et al., 2008; Zhu, 2009; Li, 2009). A positive AAO index represents the condition of a deepened circumpolar low, so here an index for Southern Hemispheric high latitude circulation (ISHC) is defined as the area-averaged 200-hPa GHT within 60°–70°S, 270°–300°E; the correlation coefficient between DY of ISHC and DY of NESSAT is –0.5 for the period of 1977–2007 (Fig. 2b).

In March of the same year in which a forecast will be made, it is found that a weakened North American high and enhanced North Pacific high correspond to increases of NESSAT. These two factors have a significant statistical correlation with each other during 1977–2007, so only the index for the North American high (INAH) is selected as a predictor for DY of NESSAT. INAH is defined as the area-averaged SLP in the region of 50°–60°N, 240°–270°E. Figure 2c shows that the correlation coefficient between DY of INAH and DY of NESSAT is –0.5 for the period 1977–2007.

Literature exists that discusses the role of SST in various regions in controlling the summer temperature over Northeast China via sea-air interaction. Some findings demonstrate that a cold summer in Northeast China can occur concurrently with appearance of an El Niño event (Lian and An, 1998; Wang and Zhu, 1985; Zeng and Zhang, 1987; Zhen and Ni, 1999). These studies point out that SST anomalies over eastern tropical Pacific will affect the intensity of the South-Asian high and the location of the westerly belt, which may influence the summer temperature over Northeast China. When DY of SST over central tropical Pacific in the previous MAM is positive, this generally indicates the El Niño phase of ENSO, with decreases in DY of NESSAT. Thus, the index of tropical Pacific SST (ITPSST) in the previous MAM can represent the summer El Niño signal as a predictor in the forecast of DY of NESSAT. ITPSST is defined as the area-averaged SST in the region 10°S–0°, 160°–190°E. The correlation coefficient between DY of ITPSST and DY of NESAT is –0.5 during 1977–2007 (Fig. 2d).

Liu et al. (2002) noted that positive NPO in wintertime, with the accompanying deepened Aleutian low and enhanced North Pacific subtropical high, provides conditions for weaker summertime Northeast China vortex activities. Here, we found that more sea ice cover over the East Siberian Sea in winter would tend to increase DY of NESSAT. An index of sea ice cover (ISIC) constructed over the East Siberian Sea for December-January-February is positively correlated with DY of NESSAT at the 0.54 level during 1977–2007 (Fig. 2e). The ISIC is defined as area-averaged sea ice cover over the region 5°–80°N, 160°–180°E. When more sea ice over the East Siberian Sea in winter is generated, the NPO phase tends to be substantially positive in spring, and subsequently the Northeast China vortex activity in summer appears to be weakened (figure omitted). The sea ice cover over the East Siberian Sea in winter may be responsible for the linkage between the NPO and NESSAT.

These five predictors are treated as independent statistics due to the lack of significant

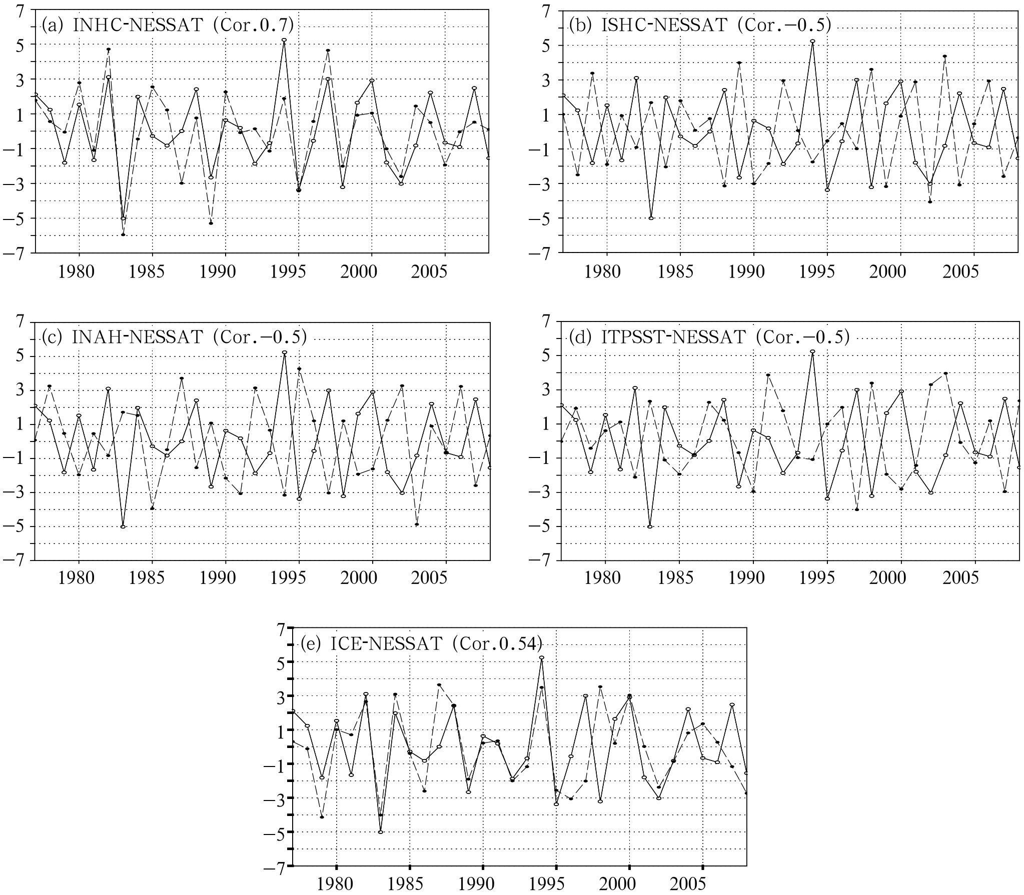

Fig. 2. Time series of five normalized predictors (dashed) and the normalized observed DY of NESSAT (solid) during 1977–2008. "Cor" indicates the correlation coefficient between the predictor and DY of NESSAT during 1977–2008.

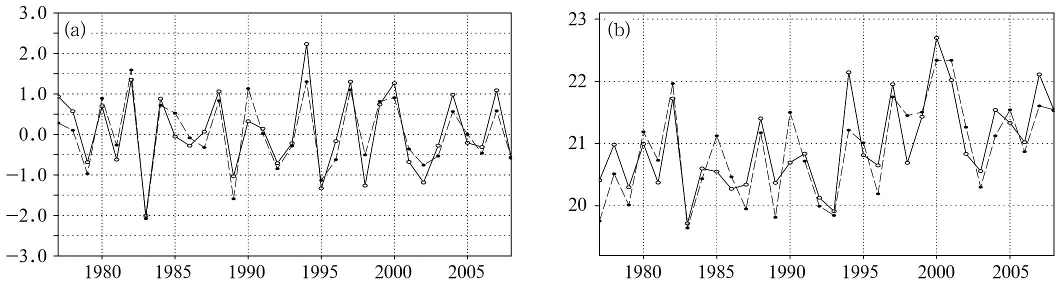

Fig. 3. (a) The observed (solid) and simulated (dashed) DY values (°C) of NESSAT. (b) The observed (solid) and simulated (dashed) NESSAT (°C) during the calibration period from 1977 to 2008.

cross-correlations with each other. Figure 2 illustrates that each of the predictors tracks well with the interannual variability of DY of NESSAT, indicating their good predictive ability.

4. The prediction model

The prediction model for DY of NESSAT is established by using multilinear regression.

$$\Delta y = 0.42x_1 - 0.26x_2 - 0.07x_3 - 0.22x_4 + 0.38x_5, \quad (1)$$

$$y = \Delta y + Ynm_{-1}, \quad (2)$$

where all variables are normalized; Δy denotes the modeled DY of NESSAT; y is the modeled NESSAT; Ynm_{-1} represents the observed NESSAT of the previous year; x_1 is INHC in the previous autumn, which is related to the intensity of the Northern Hemispheric polar vortex; x_2 is ISHC in the previous autumn, which is related to the AAO; x_3 is INAH in March of the same year as the forecast, which is related to intensity of the North American high; x_4 is ITPSST in the previous MAM, which is related to ENSO; x_5 is ISIC in the winter ending the same year as the forecast, which is related to the NPO in spring.

The correlation coefficient is 0.91 (at better than 1% confidence level, and with 83% of total variance explained) between the modeled and observed DY of NESSAT during the training period 1977–2007 (31 yr). Figure 3 illustrates that the model can decently fit the interannual variability of observed DY of NESSAT, with a good agreement between the modeled and observed values. The model is able to successfully capture not only the larger positive anomalies of DY of NESSATs in 1982, 1984, 1988, 1994, 1997, 1999, 2000, 2004, and 2007, but also the larger negative anomalies of DY of NESST in 1983, 1989, 1992, 1995, and 2002 with inappreciable errors. In addition, the DY of NESSAT exhibits features of the TBO, which supports the hypothesis that the year-to-year incremental prediction approach could fare better than a direct model for NESSAT, as we proposed.

The modeled NESSAT is obtained by adding the observed NESSAT of the preceding year to the modeled DY of NESSAT according to Eq. (2) (Fig. 3b). Clearly, the modeled NESSAT closely follows the observed NESSAT during 1977–2007, with the correlation coefficient between the simulated and observed series being 0.87, accounting for 76% of the total variance. The mean absolute error (MAE) is 0.3°C during 1977–2007. To examine the predictive capability for anomalous NESSAT, years with anomalies of NESSAT greater than ±0.5°C relative to the average NESSAT of 20.96°C are designated as strongly anomalous. The simulated (observed) NESSATs for the strongly anomalously cold NESSAT years of 1977, 1979, 1981, 1983, 1986, 1987, 1989, 1992, and 1993 are respectively 19.8 (20.4), 20.0 (20.3), 20.7 (20.4), 19.6 (19.7), 20.5 (20.3), 19.9 (20.3), 19.8 (20.4) 20.1 (20.1), and 19.8°C (19.9°C), with a mean absolute error (MAE) of 0.29°C. The simulated (observed) NESSATs for years with strongly anomalously warm temperatures (1982, 1984, 1997, 2000, 2001, and 2007) are respectively 22.0 (21.7), 20.4 (20.6), 21.7 (22.0), 22.3 (22.7), 22.3 (22.0), 21.1 (21.5), and 21.6°C (22.1°C), with an MAE of 0.28°C. Therefore, the model is able to successfully capture the observed pattern of strongly anomalous NESST years during 1977–2007.

Using the forecast model, we created a hindcast of both the DY of NESSAT and NESSAT for 2008, and the hindcast values are quite consistent with the observed values, respectively (Figs. 3a, b).

5. Validation of the forecast model

We apply cross-validation to further verify the prediction model. Cross-validation is applied by removing each year, one at a time, from the training set and generating a new set of regression coefficients based on the retained years. This process is repeated to generate blind forecasts for each year of the entire dataset. Figure 4 shows that the predicted DY of NESSAT (NESSAT) from the model cross-validation closely tracks the observed DY of NESSAT (NESSAT),

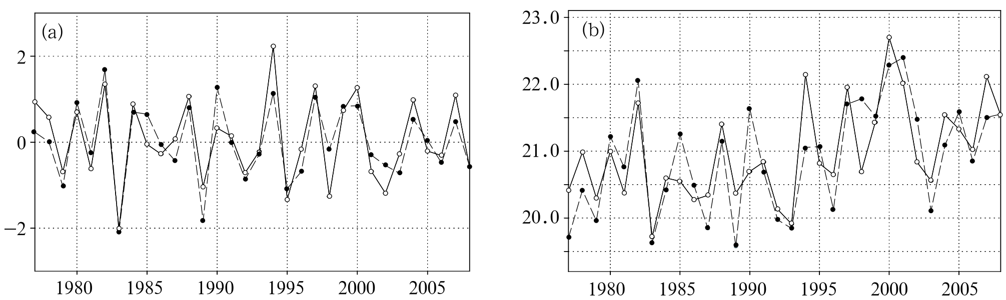

Fig. 4. Observed (solid) and predicted (dashed) values in °C for the cross-validation test for (a) the DY of NESSAT and (b) NESSAT during the period from 1977 to 2008.

with a high correlation coefficient of 0.83 (0.76) between the predicted and the observed quantities during 1977–2008, and with a low value of MAE for NESSAT of 0.4°C. The model shows better prediction skill in the forecast of anomalously high NESSAT in 1999-2002 than the model proposed by Yang et al. (2005), and it is able to predict the anomalously low NESSAT in 1983, 1992, and 1993 as well. However, the forecast model failed to produce accurate forecasts for 1994 and 1998, and in those years the predicted (observed) NESSAT values are 21.2°C (22.1°C) and 21.5°C (20.7°C). A possible reason might be due to the poor prediction ability of both DY of ICE and DY of IEHC for those two years (see Fig. 2).

6. Conclusion

We applied a year-to-year incremental prediction approach as proposed by Fan et al. (2008) to forecast the DY of NESSAT (and NESSAT). Five predictors of DY of NESSAT are identified, including DY of the winter sea ice cover over the East Siberian Sea, DY of central tropical Pacific SST in the previous MAM, DY of two high latitude circulation indices in both hemispheres in the previous autumn, and DY of the North American high in March. These five predictors in their original forms display the same 2–4-yr cycles as the NESSAT, which might partly contribute to their good prediction skill for NESSAT. The results of a cross-validation test further illustrate the good prediction ability of the model in the forecast of anomalous NESSAT during 1977–2008. The physical link between the predictors and NESSAT will be discussed in subsequent research.

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