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DECREASING CLOUDINESS OVER CHINA: AN UPDATED ANALYSIS EXAMINING ADDITIONAL VARIABLES

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1. INTRODUCTION

As preparation of the IPCC's Third Assessment Report takes place, one of the many observed climate variables of key interest is cloud amount. For several nations of the world, there exist records of surface-observed cloud amount dating back to the middle of the 20th Century or earlier, offering valuable information on variations and trends. Studies using such databases include Sun and Groisman (1999) and Kaiser and Razuvaev (1995) for the former Soviet Union, Angell et al. (1984) for the United States, Henderson-Sellers (1986) for Europe, Jones and Henderson-Sellers (1992) for Australia, and Kaiser (1998) for China. The findings of Kaiser (1998) differ from the other studies in that much of China appears to have experienced decreased cloudiness over recent decades (1954–1994), whereas the other land regions for the most part show evidence of increasing cloud cover. This paper expands on Kaiser (1998) by analyzing trends in additional meteorological variables for China [station pressure (*P*), water vapor pressure (*e*), and relative humidity (*rh*)] and extending the total cloud amount (*N*) analysis an additional two years (through 1996).

2. DATA

The China meteorological data analyzed here were extracted from a database of 6-hourly weather observations provided by the China Meteorological Administration (CMA) to the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory via a bilateral research agreement between the CMA and the U.S. Department of Energy. Six-hourly observations [0200, 0800, 1400, and 2000 Beijing Time (BT)] of *N* (0–10 tenths of sky cover), *P* (hPa), *e* (hPa), and *rh* (percent) are available from 196 Chinese stations covering the period 1954–94. In addition to the observations of *N* through 1994 from the CMA data, 6-hourly observations of *N* for 190 of the 196 CMA stations were obtained from the database of Hahn and Warren (1999) for 1995 and 1996.

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3. ANALYSIS PROCEDURE

The analysis of *N* carried out in Kaiser (1998) used only "midday" observations (1400 BT), since it has long been recognized that it is much more difficult to accurately estimate cloud amount at night (e.g., Schneider 1972), especially if thin cirrus clouds are present. While this is probably the best approach to use in independently examining long-term changes in *N*, the present analysis seeks to compare changes in several variables and also take advantage of as many observations of *P*, *e*, and *rh* as possible; therefore, for all four variables analyzed here, all four 6-hourly observations from each day were used. In fact, this is not thought to be a serious problem for analysis of *N*, since Kaiser (1998) found similar long-term trend results for midday and midnight (0200 BT) observations over China.

In order to screen for inhomogeneities in the station records of *P*, *e*, and *rh*, time series of annual means in these variables over 1954–1994 were constructed and examined graphically using SAS/INSIGHT®. (Most of the CMA stations do not have detailed station histories currently available for research use.) Those stations' records displaying any obvious jumps in any of these variables were excluded from the analysis of *P*, *e*, and *rh* (resulting in 162 stations being retained for these variables). Step-like changes in the pressure time series for most of the 34 rejected stations implied station moves that likely resulted in at least one significant change in station elevation over the period of record. Kaiser (1998) found no obvious problems of this type when screening values of *N*, therefore all station records were used for this variable. It seems that the nature of any station moves typically did not effect visual estimates of *N* made by human observers.

The 6-hourly observations of all four variables were averaged for each station over the four traditional meteorological seasons (winter: months 12, 1, and 2; spring: months 3, 4, and 5, etc.) and over each year. Linear regression analysis was used to characterize trends in the seasonal and annual means of all variables over 1954–1994 at individual stations and for China as a whole. Using the additional two years of *N* data from Hahn and Warren (1999), a *midday only* time series for all of China was also produced.

4. RESULTS AND DISCUSSION

Station trends in annual mean *N*, *P*, *rh*, and e are depicted in Figure 1. The data clearly indicate decreasing total cloud amount (Fig. 1a) over much of China from 1954–1994, especially in northeastern China, where trend magnitudes are typically -2 to -3 percent sky cover per decade. Seasonal trends in *N* (not shown) were found to be quite similar to those shown for the year, with the exception of summer being the only season exhibiting decreasing *N* in southern China. Decreasing *N* was found for all seasons in northeastern China (strongest in spring). This finding is consistent with decreases in precipitation in northeastern China found by Zhai et al. (1997) for 1951–1995.

Annual mean station pressure was found to have increased significantly over most of China over the period of record (Fig. 1b), on the order of 0.4 hPa per decade for many stations in central China. The implied negative correlation between these significant trends in *P* and *N* makes physical sense, as higher atmospheric pressure tends to be associated with increased atmospheric stability, thereby inhibiting the formation of many types of clouds. The greatest seasonal increases in *P* were found in summer and fall (not shown).

Annual mean relative humidity has decreased significantly over much of northeastern China, while increasing over northwestern China (Fig. 1c). The *rh* decreases in the northeast are consistent with that area showing the largest decreases in *N*. The decreases in *rh* in the northeast are greatest in spring, while the increases in the northwest are greatest in summer and fall (not shown). These observed changes in *rh* are geographically consistent with precipitation changes analyzed by Zhai et al. (1997), i.e., decreasing precipitation in the northeast and increasing precipitation in the northwest of China.

Annual mean water vapor pressure has increased significantly over several specific areas of China (Fig. 1d): the northwest, the extreme south (the island province, Hainan), in the south-central region (mainly Yunnan Province), and east-central China. Changes are on the order of 0.1 to 0.3 hPa per decade. On an annual mean basis there is no significant evidence of decreasing *e* in any region of China, however, interestingly, most of the northern tier of China *was* found to exhibit significant decreases in summer (not shown).

All-China, annual time series of departures from the 1954–1994 means of *N*, *P*, *rh*, and *e* were produced and are shown in Fig. 2. The series were produced by first taking an unweighted average of station annual departures for each 5°x5° grid box over China. Grid box departures were then weighted by the cosine of latitude and the fraction of the grid box actually lying within China and then averaged to produce the all-China series.

The striking decrease in annual mean *N* (Fig. 2a) has a trend of -0.76% sky cover per decade. The annual mean *P* departure series (Fig. 2b) has an increasing trend of 0.14 hPa per decade. Both series' linear trends are highly statistically significant (p=0.0001). For China as a whole, there is no trend in annual mean *rh* (Fig. 2c) although, as pointed out above, regional trends do exist. The significant increasing trend in water vapor pressure for China as a whole (Fig. 2d) would appear to be an artifact of the very dry years very early in the record and the several moist years near the end of the record. Certainly no obvious linear trend would be apparent in the series between about 1960 and 1990. As pointed out above, however, there are regions of China that have exhibited increasing *e* over the period of record (Fig. 1d).

Finally, an all-China time series of departures in annual mean *N* that extends through 1996 (Fig. 3) was produced using data from 190 of the CMA stations that are also present in the database of Hahn and Warren (1999), which contains 3- and 6-hourly observations of *N* over global land areas. The series shows 1995 to be the least cloudy year of the record, with 1996 being the third least cloudy. The magnitude of the linear trend over 1954–1996 is -0.8% sky cover per decade.

It is interesting to note that the significant decreases in total cloud amount over China since the mid 1950s are unique among the linear trends deduced from the various national cloud data sets made available in recent years (e.g., for the former USSR, United States, and Australia). An intriguing aspect of the all-China *N* series (*P* series) is the rather abrupt decrease (increase) in annual mean values around 1977-1978. These changes coincide closely with the large increase in global mean temperature identified in the literature in recent years [e.g., Karl et al. (1993) and Easterling et al. (1997); mainly driven by increases in daily minimum temperature], which in turn coincides with what has been described by the IPCC (1996) as a fundamental shift in the ENSO phenomenon at about this same time.

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5. REFERENCES

Angell, J. K., J. Korshover, and G. F. Cotton, 1984: Variations in United States cloudiness and sunshine, 1950–82. *J. Climate Appl. Meteor.*, **23**, 752–761.

Easterling, D.R., B. Horton, P.D. Jones, T.C. Peterson, T.R. Karl, D.E. Parker, M.J. Salinger, V. Razuvaev, N. Plummer, P. Jamason, and C.K. Folland, 1997: Maximum and minimum temperature trends for the globe. *Science*, **277**, 364–367.

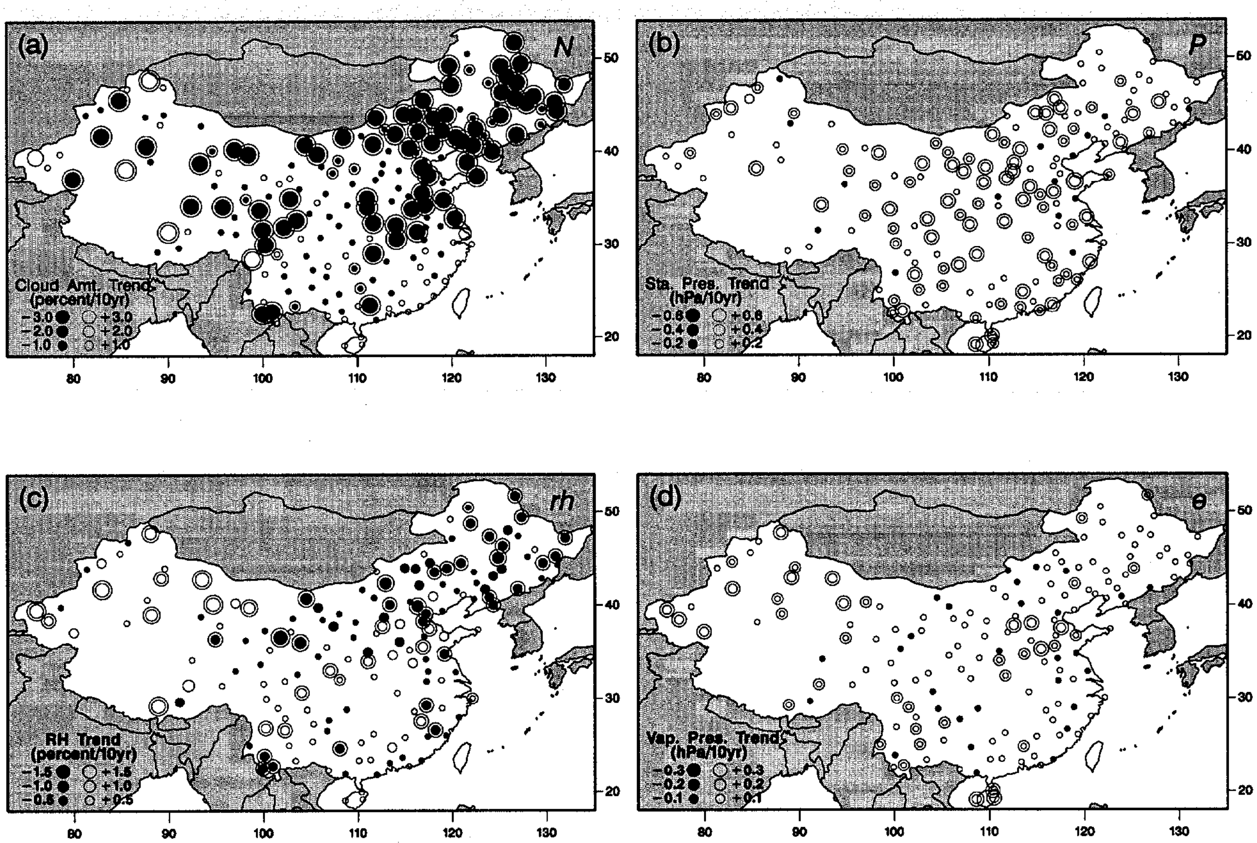

Figure 1. Trends in annual mean (a) total cloud amount (*N*; percent of sky cover); (b) station pressure (*P*); (c) relative humidity (*rh*); and (d) water vapor pressure (*e*) for 1954-1994. Station trend indicators with circles around them are significant at least at the 95% confidence level.

Henderson-Sellers, A., 1986: Cloud changes in a warmer Europe. *Climatic Change*, **8**, 25–52.

Hahn, C.J., and S.G. Warren, 1999: Extended Edited Synoptic Cloud Reports from Ships and Land Stations Over the Globe, 1952–1996. ORNL/CDIAC-123, NDP-026C, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee.

IPCC, 1996: *Climate Change 1995: The Science of Climate Change. The Second IPCC Scientific Assessment*, J.T. Houghton, L.G. Meira Filho, B.A. Callendar, N. Harris, A. Kattenberg, and K. Maskell, Eds., Cambridge University Press, 572 pp.

Jones, P. A., and A. Henderson-Sellers, 1992: Historical records of cloudiness and sunshine in Australia. *J. Climate*, **5**, 260–267.

Kaiser, D. P. 1998: Analysis of total cloud amount over China, 1951-1994. *Geophys. Res. Lett.* **25**(19), 3599–3602.

Kaiser, D. P., and V. N. Razuvaev, 1995: Cloud cover and type over the former USSR, 1936–83: Trends derived from the RIHMI-WDC 223-station 6- and 3-hourly meteorological database. In *Proceedings of the 6th International Meeting on Statistical Climatology*. (Galway, Ireland).

Karl, T.R., P.D. Jones, R.W. Knight, G. Kukla, N. Plummer, V. Razuvaev, K. P. Gallo, J. Lindseay, R.J. Charlson, and T.C. Peterson, 1993: Asymmetric trends of daily maximum and minimum temperature. *Bull. Amer. Met. Soc.*, **74**, 1007–1023.

Schneider, S.H., 1972: Cloudiness as a global climatic feedback mechanism: The effect on the radiation balance and surface temperature of variations in cloudiness. *J. Atmos. Sci.*, **29**, 1413–1422.

Sun, B., and P. Ya. Groisman, 1999: Cloudiness variations over the former Soviet Union. *Int. J. Climatology* (submitted).

Zhai, P.M., F. Ren, and Q. Zhang, 1997: Indicators of change for extreme precipitation in China. *Proc. of Workshop on Indices and Indicators for Climate Extremes*, National Climatic Data Center, Asheville, North Carolina, June 3–6.

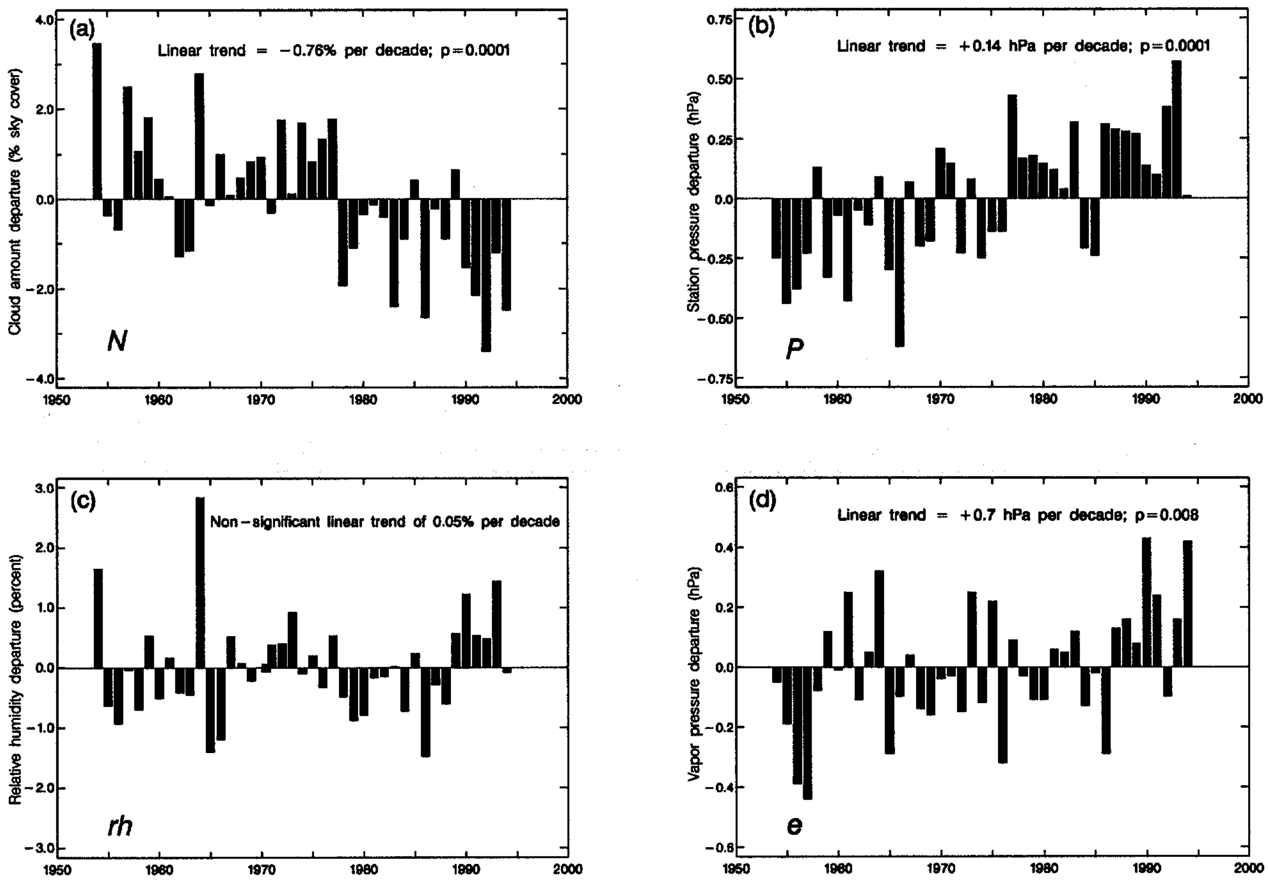

Figure 2. Time series of annual departures of (a) total cloud amount (*N*; percent sky cover); (b) station pressure (*P*); relative humidity (*rh*); and (d) water vapor pressure (*e*) for 1954–1994.

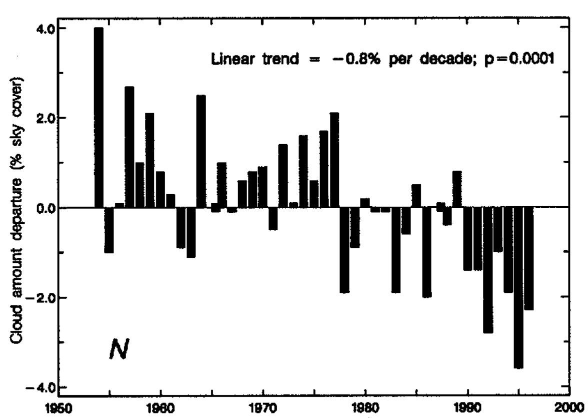

Figure 3. Time series of annual departures in midday total cloud amount (*N*; percent sky cover) for 1954–1996. Departures for 1995 and 1996 were calculated using the data of Hahn and Warren (1999).