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Do contrails significantly reduce daily temperature range?

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[1] One of the most visible anthropogenic phenomena in the atmosphere is the occurrence of contrails. The direct effects of contrails on surface temperature are investigated on the basis of the data sets for the cloud cover and surface temperature over the conterminous United States for the period 1971–2001. It is shown that the increase of the average daily temperature range (DTR) over the United States during the three-day grounding period of 11–14 September 2001 cannot be attributed to the absence of contrails, a subject was debated in several previous studies. The present analysis suggests that the DTR is attributed to the change of low cloudiness. **Citation:** Hong, G., P. Yang, P. Minnis, Y. X. Hu, and G. North (2008), Do contrails significantly reduce daily temperature range?, *Geophys. Res. Lett.*, *35*, L23815, doi:10.1029/2008GL036108.

1. Introduction

[2] Contrails from jet aircraft exhaust are one of the most visible anthropogenic constituents in the atmosphere in regions with heavy air traffic, such as the United States and Europe [e.g., *Boucher*, 1999; *Jensen and Toon*, 1997; *Sassen*, 1997; *Penner et al.*, 1999; *Minnis et al.*, 2004]. Since they reflect solar radiation and absorb and emit thermal infrared radiation, contrails may affect climate, especially in the future as jet air traffic is expected to grow by 2%–5% per annum worldwide through 2050 [e.g., *Penner et al.*, 1999; *Minnis et al.*, 1999, 2003, 2004]. However, the potential impact of contrails on regional-scale surface temperatures has been debated for years [e.g., *Reinking*, 1968; *Changnon*, 1981; *Travis and Changnon*, 1997; *Sassen*, 1997; *Minnis et al.*, 2004]. The data sets about cloudiness and surface temperature during the 3-day grounding of all commercial aircraft in the United States after the terrorist attacks on 11 September 2001 can be used to examine the direct temperature effects of contrails. It was argued [*Travis et al.*, 2002] that the absence of contrails during the grounding period increased the daily temperature range (DTR) at the surface based on their analysis of maximum and minimum temperature anomalies over the conterminous United States for the period 1971–2001. The theoretical underpinnings for the contrail-induced DTR change are that contrails reduce the surface heating during the day by reflecting sunlight and diminish the net surface cooling at night by slightly increasing the amount of long-wave radiation reaching the surface. If contrails that normally occur fail to materialize, the DTR would be greater than normal.

[3] In addition to contrails, other factors that affect the DTR are the variations in natural cloud cover, temperature, humidity, and winds. It has been shown that the air masses after the terrorist attacks were anomalously dry and clear in the Northeastern US, conditions that favor anomalously large DTRs [*Kalkstein and Balling*, 2004]. The air-mass approach takes cloud cover into consideration, which, however, is assumed not to be affected by contrails on the hypothesis that the change in contrail-related cloud cover is negligible. Here we examine the impact of cloud cover on the DTR anomalies for the grounding period of 11–14 September 2001. We demonstrate that average DTR during the grounding was within the range of natural variability observed from 1971 to 2001. We suggest that the increase of the DTR during the grounding period, 11–14 September 2001, is most likely due to anomalies in low cloudiness and not the result of the absence of contrails. Because low clouds are generally thicker and warmer than high cirrus clouds and contrails, they reflect more sunlight and emit more longwave radiation to the surface and, thus, should have a greater impact on the DTR than contrails.

2. Data

[4] The daily maximum and minimum temperature are taken from the National Climatic Data Center Data Set 3200 (DSI-3200) (http://dss.ucar.edu/datasets/ds510.0). The daily DTRs are calculated at 7600 weather stations distributed in the 48 states within the conterminous United States (not including Alaska and Hawaii) for the period 1971–2001. DTR anomalies were computed for three 3-day periods during 1971–2001, which correspond to immediately before (8–11 September), during and after (14–17 September) the 3-day aircraft grounding period (11–14 September). These are the same periods used by *Travis et al.* [2002]. The DTR is calculated as the difference between the first day's highest temperature and the next day's lowest temperature since the grounding period in 2001 extended from the late morning of 11 September to the morning of 14 September.

[5] The cloud cover data used here consist of the 6-hourly cloud amounts from the European Centre for Medium-range Weather Forecast (ECMWF) reanalysis data sets (ERA-40) [*Simmons and Gibson*, 2000] for the period 1971–2001 and from the 3-hourly International Satellite Cloud Climatology Project (ISCCP) [*Rossow and Schiffer*, 1999] gridded cloud product D1 for the period 1983–2001. To examine the effect of natural cloud variability on DTR, the mean cloud amounts over given weather stations were correlated with the DTRs. It is assumed that the cloud amount for a station is the same as that in the corresponding ERA-40 (2.5° × 2.5°) or ISCCP (280 km × 280 km) grid box. The ERA-40 and ISCCP cloud amounts are broken down into low, middle, and high layers. To match the daily DTRs, 24-hour average cloud cover is estimated from the ERA-40 and

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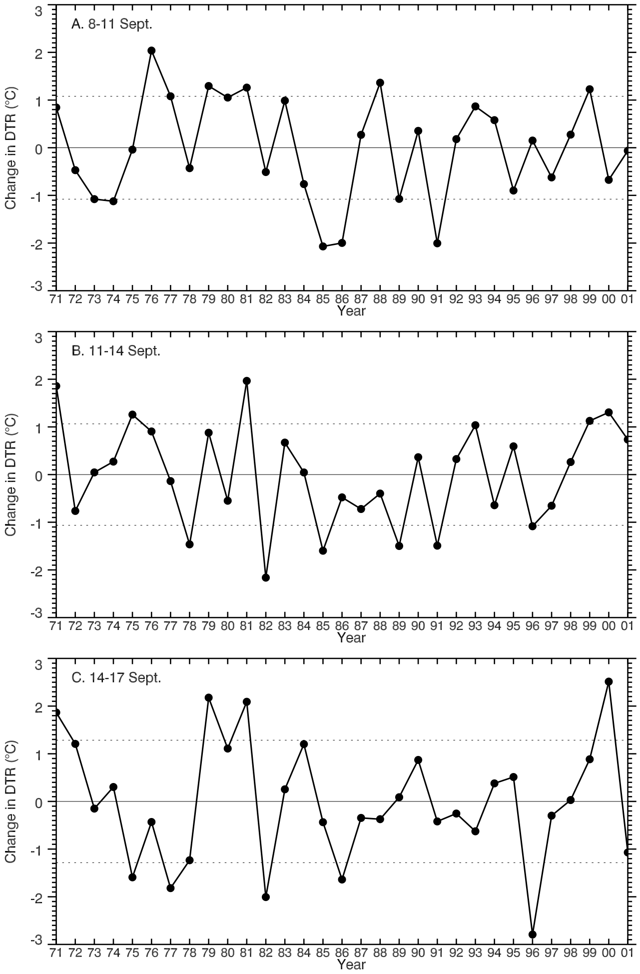

Figure 1. Departures of average DTRs from the normal values from 1971 to 2001 for the three 3-day periods (a) 8–11, (b) 11–14, and (c) 14–17 in September 1971–2001. The standard deviations for the three 3-day periods are indicated by the dotted lines.

ISCCP daily layer cloud amounts beginning at 1800 UTC and ending at 1800 UTC on the next day.

3. Analysis and Discussion

[6] The departures of average DTRs from the normal values from 1971 to 2001 for the three 3-day periods (8–11, 11–14, 14–17) in September 1971–2001 are shown in Figure 1. The standard deviations for the three 3-day periods are also calculated to investigate the variations of DTRs. The changes in DTRs for the three 3-day periods in September 2001 are in the ranges of the standard deviations. Though there were no contrails on 11–14 September 2001, the change in DTRs for 11–14 September 2001 was within the range of natural variability observed from 1971 to 2001.

[7] To investigate the variations in the three 3-day periods, the variances of departures of average DTRs from the normal values from 1971 to 2001 for the three 3-day periods (8–11, 11–14, 14–17) in September 1971–2001 are calculated and shown in Figure 2 with the departures of average DTRs for the three 3-day periods. It shows that the variance in 2001 is not the strongest. There are 11 years that have larger variances than that in 2001. Specially, the departures of average DTRs in 1975 have similar features as those in 2001, i.e., the sudden change from negative anomaly (8–11) to positive anomaly (11–14) back to negative anomaly (14–17). Furthermore, the variance is stronger in 1975 than in 2001 during the three-day grounding period.

[8] Two independent cloud datasets, the ERA-40 and ISCCP cloud covers, are used to investigate the effect of clouds on the DTRs. Both of the ERA-40 and ISCCP cloud datasets have three types of clouds, namely, high, middle, and low clouds. For each cloud dataset, the correlations between cloud amounts for different cloud types and the DTRs are investigated. It is found that the cloud amounts of the ERA-40 low clouds have the highest correlation with the DTRs with respect to the ERA-40 high and middle clouds. The cloud amounts of the ISCCP middle clouds have the highest correlation with respect to the ISCCP high

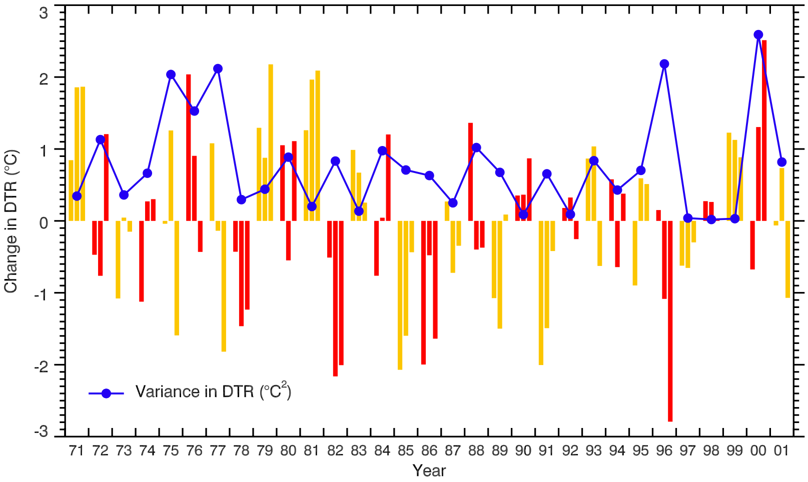

Figure 2. Variances for the departures of average DTRs from the normal values from 1971 to 2001 for the three 3-day periods (8–11, 11–14, 14–17) in September 1971–2001. The corresponding departures for the three 3-day periods (shown separately in Figure 1) are also shown here by the brown and red bars. The continuous three color bars in each year are for the 3-day periods in the year.

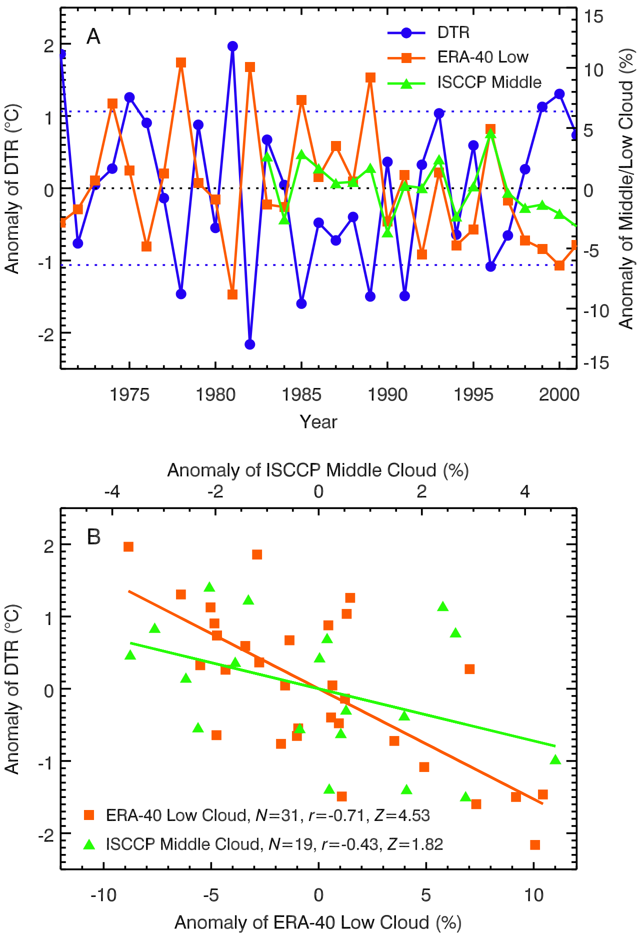

Figure 3. (a) Anomalies of the DTRs, ERA-40 low cloud covers, and ISCCP middle cloud covers for the 3-day period of 11–14 in September from 1971 to 2001. The blue dotted lines indicate the standard deviation of the anomalies of the DTRs. (b) Correlations between the anomalies of the DTRs and the anomalies of cloud covers for ERA-40 low cloud and ISCCP D1 middle cloud, respectively.

and low clouds. Figure 3 shows the anomalies of the DTRs, ERA-40 low cloud covers, and ISCCP middle cloud covers for the 3-day period of 11–14 in September from 1971 to 2001. The correlations between the anomalies of the DTRs and the anomalies of cloud covers are also shown. The ERA-40 low cloud covers and ISCCP middle cloud covers have the same variations, but are inversely correlated to the variations of the DTRs (Figure 3a). The DTR shows the highest correlations with the ERA-40 low and ISCCP mid-level cloud amounts, with corresponding linear correlation coefficients, $r = -0.71$ and -0.43 (Figure 3b). The levels of significance (p) for two-tailed test are less than 0.01 and 0.1 for the correlations with the ERA-40 low clouds and the ISCCP middle clouds, respectively.

[9] In 2001, we see negative anomalies in ERA-40 low cloud amounts relative to the 1971–2000 period (Figure 4a). Similarly, we see negative anomalies in the ISCCP middle and ERA-40 low cloud amounts relative to the 1983–2001 period (Figure 4b). The DTR anomalies, relative to the 1971–2000 means (Figure 4a), have the same signs as those of *Travis et al.* [2002] and are similar in magnitude. These anomalies and the earlier correlations suggest that natural cloud cover played an important role in the behavior of DTR during 8–17 September 2001.

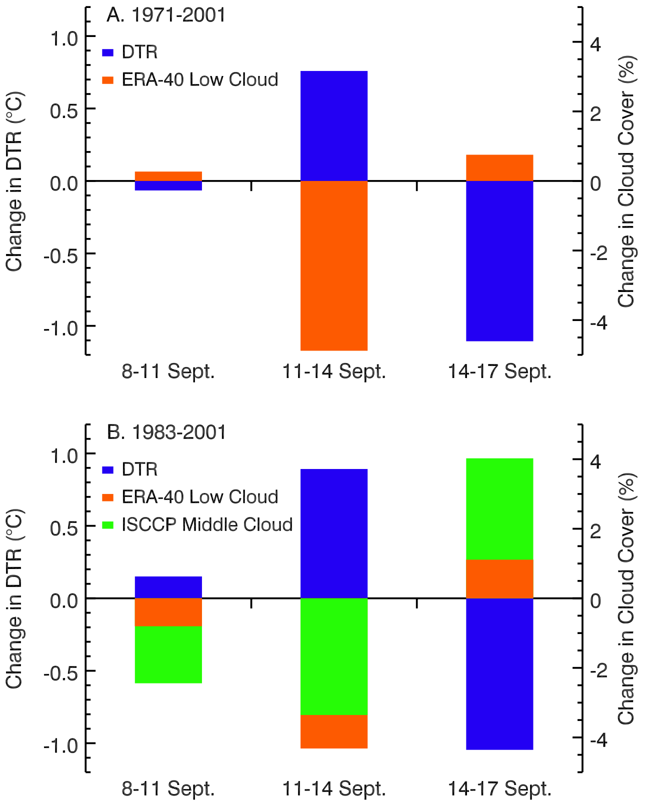

Figure 4. Departure of average DTRs and cloud covers from the normal values from 1971 to 2000 for the three 3-day periods (8–11, 11–14, 14–17) in September 2001. (a) The normal values are from 1971 to 2000 for the DTRs and ERA-40 low cloud covers, (b) the normal values are from 1983 to 2000 for the DTRs, ERA-40 low cloud covers, and ISCCP middle cloud covers.

[10] It is common to assume that DTR data are normally distributed [e.g., *Bruhn et al.*, 1980; *Mearns et al.*, 1995]. To determine the overall influence of cloud cover on the DTR anomalies, the separate contributions from high, middle, and low cloudiness from both the ERA-40 and the ISCCP were determined by performing multiple linear regression between the DTR anomalies and the layer cloud amount anomalies in the form:

$$DTR = a_h \cdot HCC + a_m \cdot MCC + a_l \cdot LCC. \tag{1}$$

The DTRs without transformation are used for the multiple linear regression. The p-value of the regression for ISCCP

Table 1. Coefficients for the Multiple Linear Regressions Performed for the Anomalies of DTRs and High, Middle, and Low Clouds for the ERA-40 and ISCCP[a]

	8–11 Sep		11–14 Sep		14–17 Sep	
Coefficient	ERA-40	ISCCP	ERA-40	ISCCP	ERA-40	ISCCP
a_h	0.0033	0.0259	−0.0245	−0.0196	−0.0401	−0.0388
a_m	−0.0250	−0.3394	0.0023	−0.1595	−0.0261	−0.2333
a_l	−0.1731	0.02587	−0.1442	0.0006	−0.1673	0.0182
F-value	22.43	30.93	9.87	1.13	20.98	9.10
p-value	<0.001	<0.001	<0.001	0.367	<0.001	0.001

[a] F-values and p-values for the regressions are also listed.

clouds on 11–14 September is 0.367, while all other p-values are much less than 0.01, which show that the regressions are significant. The anomalies of high, middle, and low cloud cover are *HCC*, *MCC*, and *LCC*, respectively. The a_h, a_m, and a_l are coefficients indicating the contributions of the *HCC*, *MCC*, and *LCC* on the DTR anomalies, respectively. The ERA-40 a_l and ISCCP a_m are negative and their values are higher than the others by an order of magnitude (Table 1) while the *HCC*, *MCC*, and *LCC* have the same order of magnitude. This indicates the ERA-40 *LCC* and ISCCP D1 *MCC* play a significant role in the changes of the DTRs. An increase of *LCC* and *MCC* decreases the DTRs. Because the method used by ISCCP tends to significantly overestimate the heights of low clouds [*Dong et al.*, 2008], a large percentage of the ISCCP middle-level clouds are, in reality, most likely low-level clouds, comparable to the ERA-40 low clouds. Thus, both datasets show that low clouds are the dominant cloud influence on DTR. High clouds, of which contrails are a subset, have a very minor, if any, influence on the DTR anomalies.

[11] We conclude that the increase of the diurnal temperature range over the United States during the three-day grounding period of 11–14 September 2001 cannot be attributed to the absence of contrails. While missing contrails may have affected the DTR, their impact is probably too small to detect with a statistical significance. The variations in high cloud cover, including contrails and contrail-induced cirrus clouds, contribute weakly to the changes in the diurnal temperature range, which is governed primarily by lower altitude clouds, winds, and humidity.

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