J1.1 JET AIRCRAFT CONTRAILS: SURFACE TEMPERATURE VARIATIONS DURING THE AIRCRAFT GROUNDINGS OF SEPTEMBER 11-13, 2001

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I. INTRODUCTION

The grounding of all commercial aircraft in U.S. airspace for the 3-day period September 11-13, 2001, following the terrorist attacks on New York and Washington, D.C., provides a unique opportunity to study the potential role of jet aircraft condensation trails (contrails) in climate. During this period, surface observations and satellite data confirm that the skies over the U.S. were noticeably lacking contrails, other than the relatively few produced by military aircraft.

The ability of contrails to modify surface climate at regional scales has been speculated upon for the latter half of the 20th century (e.g. Murcray, 1970; Changnon, 1981; Sassen, 1997), especially for those regions favored by a high density of jet traffic (e.g. the U.S. Midwest). There, "outbreaks" of contrails, can occur and persist for a day or more when atmospheric conditions are favorable (Travis et al, 1997), and may obscure a substantial portion of the sky or mix with the natural cirrus coverage to enhance the overall cloud amount.

Because contrails contain a higher density of relatively small ice crystals when compared to natural cirrus (Murcray, 1970, Gothe and Grassl, 1993), they often have the higher albedo, and thus a greater ability to decrease the amount of solar radiation reaching the surface. Although contrail coverage decreases at night because of a reduction in the number of flights, its occurrence at that time can contribute to the high cloud coverage and increase the back-radiation to the earth's surface. Hence, the contrail cloud-radiative forcing may be significant for those regions of the U.S. characterized by many contrails (Duda *et al.*, 2001). Contrails have the potential to suppress the surface diurnal temperature range (DTR) beyond that normally done by natural clouds (Travis, 1996). Significant decreases in DTR have been reported for some areas of the U.S. where contrails are most abundant (Karl et al, 1994).

The objective of this study is to evaluate the 3-day grounding period of Sept. 11-13, 2001 as a "control" for quantifying the effects of contrail coverage over the U.S. on DTR. By analyzing the DTR temporal and spatial characteristics during this period it should be possible to identify the potential contribution of contrails to the overall DTR pattern for the typical situations when commercial aircraft are flying.

2. DATA AND METHODS

Station data on the daily maximum and minimum temperature for all first order, automated, and cooperative stations in the U.S., were obtained from the National Climate Data Center (TD 3200/3210 data set) for September 1971-2001. Data were initially available from an average of approximately 5500 weather stations per year. However, because the number of available stations varied from year to year, we chose to analyze data from only those stations available for a majority of the overall period. This provided approximately 4000 stations for the analysis.

Daily DTR values were calculated for the Sept. 11-13 period for each year by subtracting the daily minimum temperature for each station from its corresponding daily maximum temperature on that day. Additionally, the DTR was calculated for the adjacent 3-day periods (Sept. 8-10; Sept. 14-16) for comparison purposes.

AVHRR digital satellite data (1.1. km resolution) were also obtained for the U.S. and adjacent coastal waters for the period of Sept. 8-16, 1995-2001, to determine the variations in frequency and density of "normal" contrail coverage across the U.S. during mid-September. A total of 623 AVHRR scenes were obtained for analysis (average of 10 per day). The locations of contrail outbreaks were noted and stored in a geographic information systems (GIS) database. Contrails are best distinguished from natural clouds using the infrared band (band 4) and following the pattern recognition method described in Carleton and Lamb (1986) and DeGrand *et al.* (2000). Although contrails were seen on more than half of the images, only outbreaks of contrails, both spatially (i.e. across multiple states) and temporally (i.e. occurring on multiple scenes for a minimum of 6 hours), were cataloged. To identify the spatial coverage of each outbreak, a coordinate box was drawn around its boundaries using the image when contrail coverage was at maximum density.

A final step in the satellite analysis was to determine the total number of contrail outbreaks occurring during Sept. 8-16, 1995-2001 over each weather station. This was accomplished using the GIS database and spatially associating the locations of each contrail outbreak box with the locations of each weather station.

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3. RESULTS AND DISCUSSION

3.1 DTR Temporal Trends

The average (1971-2000) DTR for the continental U.S. during mid-September, stratified by 3-day periods (Figure 1), demonstrates a gradual decrease in DTR over the 9 days. This decrease is attributed to a gradual decrease in daytime maximum temperatures at this time of year. The daytime temperature decrease apparently exceeds the rate of decrease of nighttime cooling and expresses an overall DTR decrease.

Figure 2 shows the departure from the climatological normal (1971-2000) of the trend in DTR during the same 3-day periods for 2001. An increase in DTR for the Sept. 11-13 period coincides with the period of aircraft grounding. This increase in DTR is in contrast to the adjacent 3-day periods of 2001 that demonstrate DTR near or below climatological normals, and suggests that an anomalous "spike" in DTR occurred during Sept. 11-13, 2001.

To further investigate this possibility, a summary of the differences between DTR for the Sept. 11-13 and adjacent periods of 1971-2001 is presented in Figure 3. Although increases in DTR occur for Sept. 11-13 during other years, none of these is as large as that during 2001: The magnitude of the 2001 increase (1.8 °C) is the only value for all 31 years that is 2 standard deviations away from the mean value in either a positive or negative direction (SD=0.9 °C). This suggests that factors other than air mass changes may have contributed to the large DTR increase seen during Sept. 11-13, 2001.

It is worth noting that this analysis is for the entire continental U.S., with no additional weight given to those stations located in areas where contrails are most frequent. Hence, the DTR differences between 2001 and climatology shown here potentially underestimate the magnitude of the DTR change for those "favored" regions (e.g. U.S. Midwest).

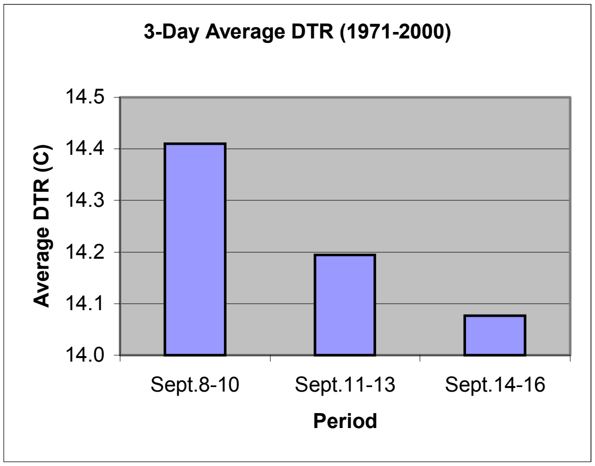

Figure 1: 3-Day Average DTR for 1971-2000.

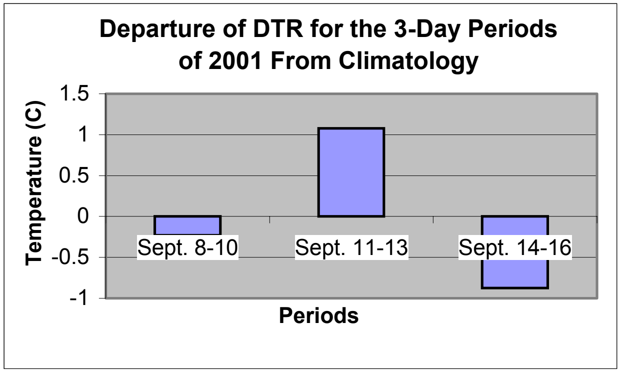

Figure 2: 2001 DTR Differenced From Climatology.

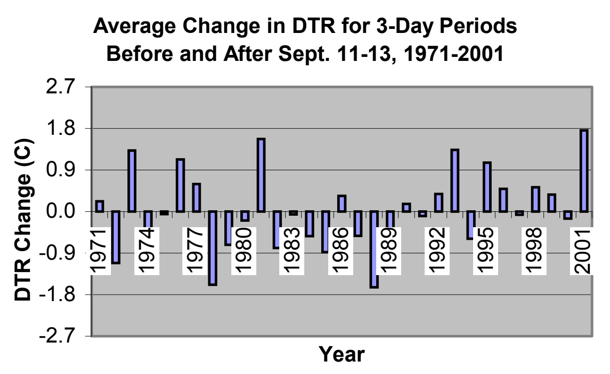

Figure 3: Average Difference in DTR for 3-day periods.

3.1 DTR Spatial Trends

To better characterize the increase in DTR noted for Sept. 11-13, 2001, a spatial comparison was completed to determine if this increase dominantly occurred where contrail coverage is typically greatest during mid-September (1995-2001).

The spatial variation of the average DTR for the Sept. 11-13 climatology period (Figure 4) shows that DTR is typically greatest in the Intermountain West and Southwest U.S. regions and gradually decreases towards the east and northwest. This seems reasonable because the air is typically driest and likely to be cloud-free in the Intermountain West and Southwest U.S. (other than the extreme coastal locations), especially during mid-September, which allows for a large temperature range between day and night.

In contrast to the spatial variations shown in the 30-year mean map, the map for the Sept. 11-13, 2001 period shows that the largest DTR values spread eastward across portions of the central and northeast U.S. (Figure 5). When the two maps are compared, larger than "normal" DTR values are apparent for the Midwest, Northeast, and Northwest regions of the U.S. (Figure 6). We argue that at least a portion of this increase can be attributed to the lack of contrail coverage during the Sept. 11-13, 2001 aircraft grounding period. Previous research using both satellite and surface observations has demonstrated that many of the same regions showing the greatest increase in DTR for 2001 typically experience the greatest amount of contrail coverage (Minnis *et al*., 1997; DeGrand *et al*,, 2000).

To further investigate this apparent relationship between the regional DTR increases of Sept. 11-13, 2001 and contrail coverage, Figure 7 summarizes the frequency of the contrail outbreaks identified on AVHRR satellite data for 1995-2001 for each observing station. A total of 48 outbreaks were identified from the satellite analysis. The frequency pattern of outbreaks for mid-September appears to be similar to that shown in previous studies for other times of the year with maxima occurring in the Midwest, Northeast, and Northwest regions of the U.S. (Minnis *et al*., 1997; DeGrand *et al*., 2000).

The change in DTR for 2001 compared to climatology is shown by the number of contrail outbreaks occurring during mid-September 1995-2001 per station in Figure 8. A distinct increase in DTR is evident as the number of contrail outbreaks per station increases, especially when going from no contrails to only a few outbreaks. These results support the earlier contention that the largest increase in DTR occurred where contrail coverage is typically greatest during mid-September.

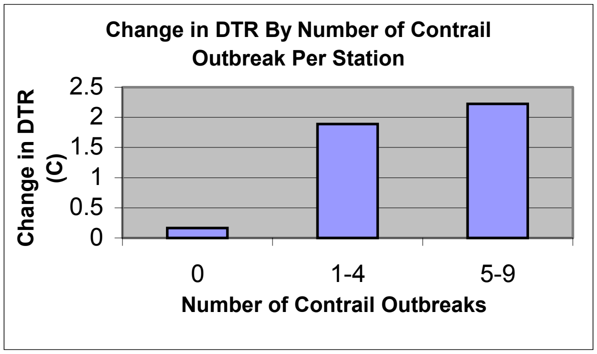

Figure 8: Change in DTR stratified by number of contrails outbreaks (1995-2001) per station.

4. Summary and Conclusions

The results presented here suggest strongly that the grounding of all commercial aircraft in U.S. airspace, and the consequent elimination of substantial jet contrail coverage during the Sept. 11-13, 2001 period, resulted in an enhanced surface DTR for the U.S. as a whole, but especially in those areas typically experiencing the greatest numbers of jet contrails (e.g. the Midwest U.S).

A logical extension to this research is to determine where contrail coverage would have occurred had commercial aircraft not been grounded during Sept. 11-13, 2001. The analysis of AVHRR imagery available for this period indicates numerous occurrences of single contrails produced by military aircraft. Moreover, the analysis of imagery available for the grounding period shows contrails occurring just over the border in Canada on multiple occasions. Both observations suggest that contrail outbreaks would have occurred in portions of the U.S. had commercial aircraft not been grounded between September 11-13, 2001.

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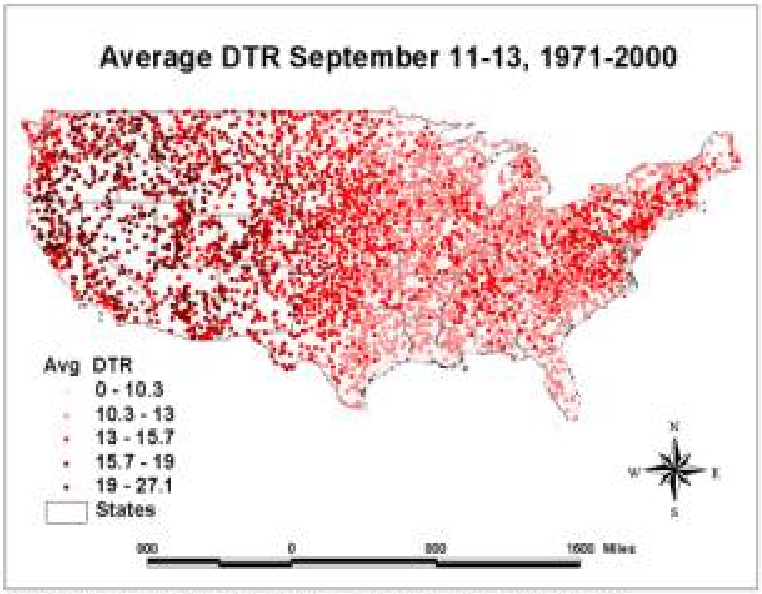

Figure 4: Average DTR for the period Sept. 11-13, 1971-2000.

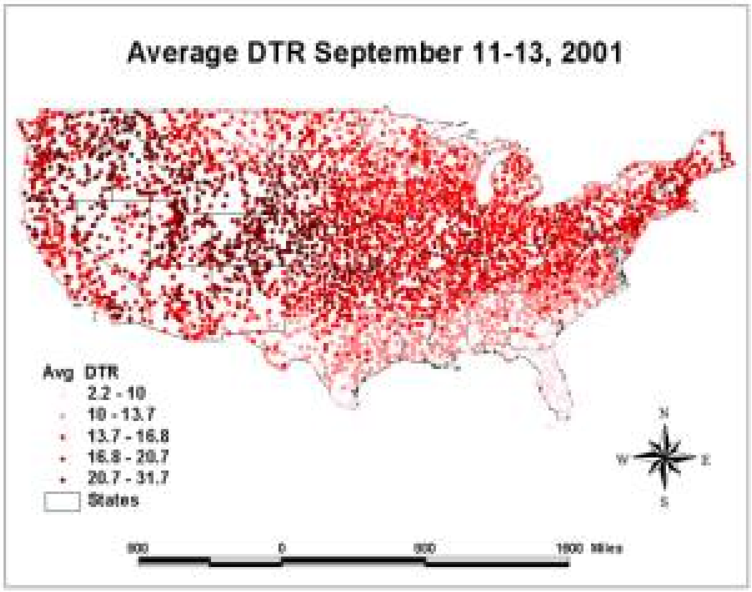

Figure 5: Average DTR for Sept. 11-13, 2001

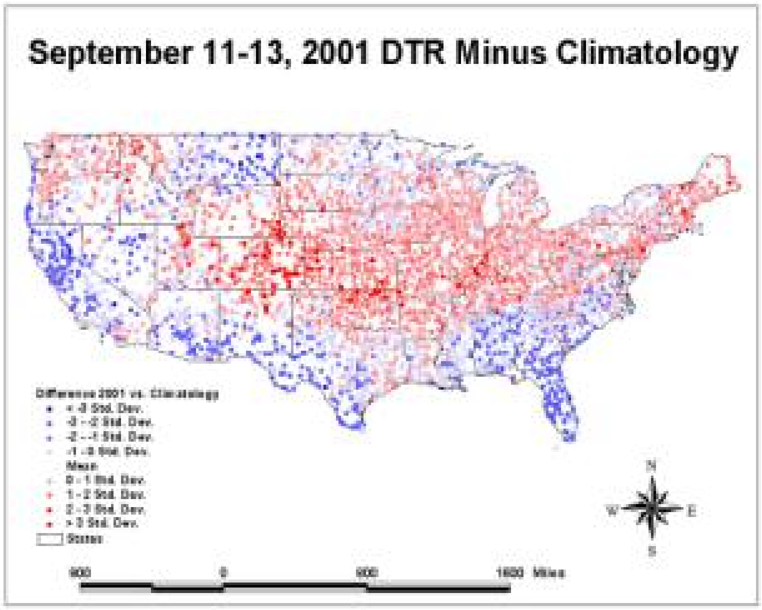

Figure 6: Difference in DTR values depicted in Figures 4 and 5.

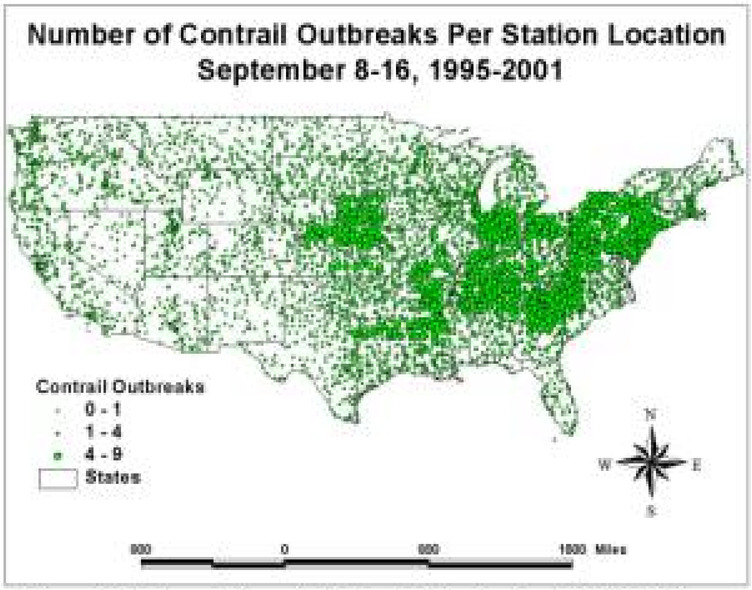

Figure 7: Number of Contrail Outbreaks Per Station for 1995-2001.