JP2.6 CHARACTERISTICS OF JET CONTRAIL INCREASES AND IMPLICATIONS FOR AVIATION POLICY DECISION-MAKING

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1. INTRODUCTION

The potential impacts of jet condensation trails (contrails) on surface climate have been widely discussed in recent years (IPCC, 1999), with a growing body of evidence demonstrating that a signal already exists in the current climate record. Physical modeling studies have shown that the increase in contrail-generated cirrus may be causing a net warming at the surface (Minnis et al., 2004), while empirical studies have also demonstrated a decrease in the surface diurnal temperature range in regions where contrail frequency is most abundant (Travis et al., 2003). As global dependency on aviation continues to increase, it is reasonable to assume that contrail coverage, and its effects on climate, will continue to increase.

Beyond the bulk number of aircraft capable of producing contrails, a major control on contrail abundance, particularly their persistence time, is the atmospheric conditions co-occurring at aircraft cruising altitudes (e.g. Travis et al., 1997). These conditions include maximum (minimum) temperature (relative humidity) thresholds, among other variables (e.g. wind). One method to better understand the importance of these factors is to investigate changes in contrail coverage during the past quarter century. Heretofore, such a study has not been undertaken and is presented here.

Improved understanding of the atmospheric controls on past changes in contrail frequency will better inform public policy attempts to reduce future contrail increases (Williams et al. 2003). For instance, contrails capable of substantially affecting surface climate primarily occur in clusters, or "outbreaks" (Travis et al., 2003). These are similar in size to mesoscale convective complexes (MCCs) (e.g., Velasco and Fritsch 1987) commonly avoided by aircraft. We encourage policy makers to consider implementing plans for identifying contrail susceptible areas on a proposed flight route and avoiding them, if feasible from time and cost perspectives.

2. DATA AND METHODS

Advanced Very High Resolution Radiometer (AVHRR) images (1.1 km resolution) for the mid-season months (January, April, July, October) of 2000-02 were visually inspected to determine the frequency of contrails for the conterminous U.S. An average of 6 images per day was inspected (two each for the local nighttime, morning, and afternoon hours, respectively). A total of 2182 images were analyzed. Because each day's images included an equal number of overpasses for the eastern and western halves of the U.S., it was possible to inspect the entire country for contrails on most days. Contrails were identified using well-established pattern recognition techniques that distinguish them from natural clouds through their characteristic linear shape, occurrence in clusters, and orientations different from the synoptic flow of the upper troposphere revealed by natural cirrus. All contrail locations were recorded into a geographic information systems (GIS) database in 1x1 degree latitude and longitude grid-scale increments. Contrail frequency characteristics were then analyzed based on a total of 900 grids covering the conterminous U.S. (Figure 1).

To allow comparison of the contemporary contrail frequency dataset to a recent historical period, we obtained the only other satellite-based data set of contrails for the conterminous U.S. (DeGrand et al., 2000). That study used high-resolution (0.6km) Defense Meteorological Satellite Program (DMSP) hard-copy imagery to determine contrail frequency for the mid-season months of 1977-79. Because of the differences in resolution and media type of the DMSP imagery compared to the AVHRR, we analyzed contrail frequency for the 1977-79 period using all available digital AVHRR for the conterminous U.S (n=46; mostly for the eastern half of the country). Although the distribution of contrails was quite similar between the two types of imagery, the AVHRR revealed approximately 2.1 times as many contrails; most likely a result of our ability to apply contrast enhancement to the digital images. Thus, we applied a correction factor to the 2000-02 dataset to allow a fair comparison with the 1977-79 dataset and to determine the contrail frequency increase (CFI) between the two periods (Figure 2).

Because the vast majority of contrails occur in outbreaks representing mesoscale-sized regions having atmospheric conditions ideal for their formation and persistence (e.g.,Travis et al. 1997)

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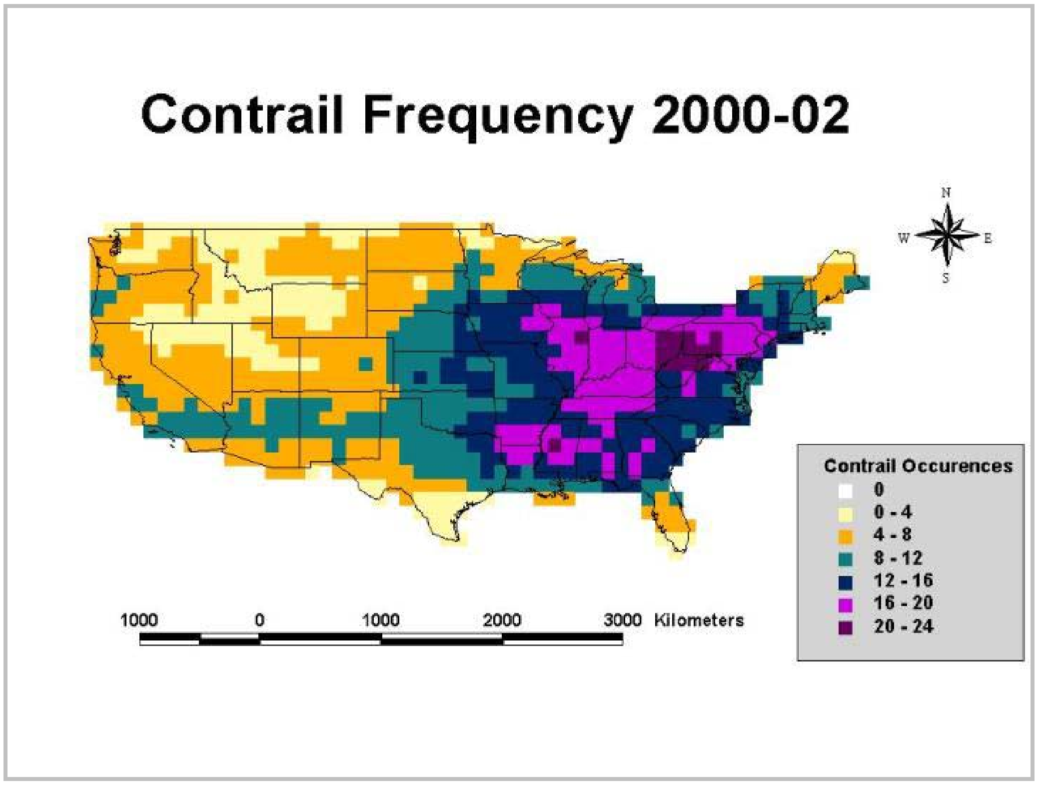

Figure 1: Contrail frequency for the mid-season months of 2000-02 (#contrails/grid/100 images).

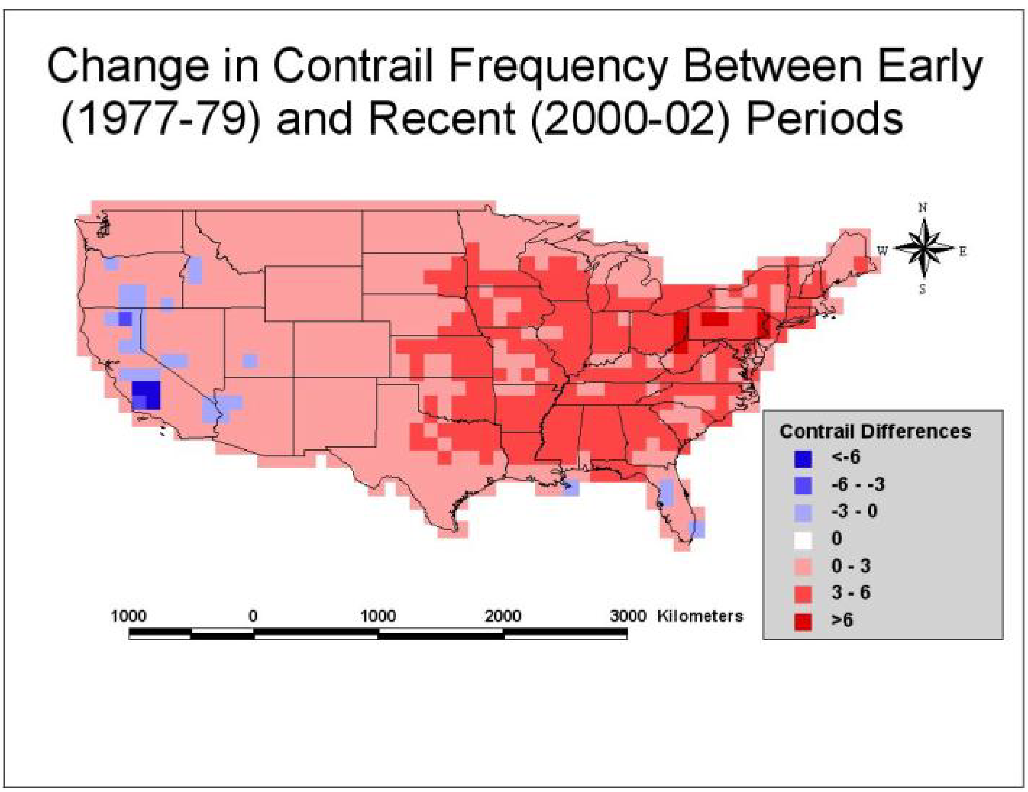

Figure 2: As in Figure 1 but representing the difference in contrail frequency between the 1977-79 and 2000-02 periods.

we completed geographical analysis on these regions. A contrail outbreak region was defined as an area where contrails covered at least 25% of the sky when natural clouds comprised less than 10%, and/or made up 50% of the total cloud cover when substantial natural cloud cover was present. Outbreak GIS "box" coordinates were then generated by determining the boundary edges of each group of contrails, and recorded in a separate GIS database to permit area calculations and further geographic analysis to be completed.

3. Results and Discussion

a. Spatial Distribution of CFI

Contrail frequency during 2000-02 was greatest over the eastern half of the country (Fig. 1). This is likely a result of the combination of the relatively high density of flights for that portion of the country, compared to the western half, and more favorable upper tropospheric conditions (i.e. higher relative humidities and/or lower air temperatures). A similar association with atmospheric conditions was previously determined for the 1977-79 period (not shown) (DeGrand et al., 2000) Using GIS to difference the contrail frequency distributions for the 2000-02 and 1977-79 periods yields further evidence that CFI has also been greatest for the eastern half of the U.S., with only a slight CFI, and even some negative values, in the West (Figure 2). Because flight frequencies in the West have undoubtedly increased between the 1977-79 and 2000-02 periods, it is reasonable to assume that the asymmetrical rate of increase between the eastern and western parts of the U.S. are a result of changes in upper tropospheric conditions related to atmospheric circulation.

To investigate the possible role of changes in upper tropospheric conditions between the 1977-79 and 2000-01 periods, we used NCEP-NCAR Reanalysis data to determine changes in tropopause temperature and pressure for the conterminous U.S. at 5 x 5 degree grid resolution (Figure 3). The CFI values were then scaled to a similar 5 x 5 degree resolution to permit a correlation analysis (Figure 4).

Visual inspection of Figure 4 suggests a strong negative correlation ($R=-.68$; $p<0.01$) between CFI and the tropopause temperature change. This relationship is consistent with the importance of upper tropospheric temperature on contrail frequency; i.e., a cooler (higher) tropopause provides a higher relative humidity and thus, more favorable environmental for contrail formation and persistence (DeGrand et al., 2000). These results support the contention that flying aircraft at lower altitudes likely would reduce the frequency of persisting contrail formation (IPCC, 1999).

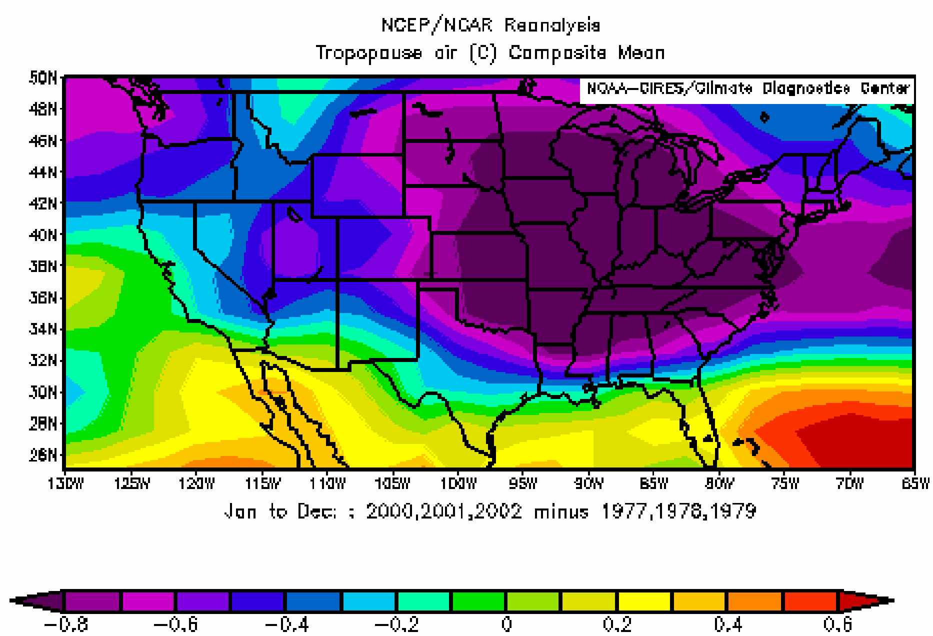

Figure 3: Change in Tropopause Temperature for 2000-02 minus 1977-79 mid-season months.

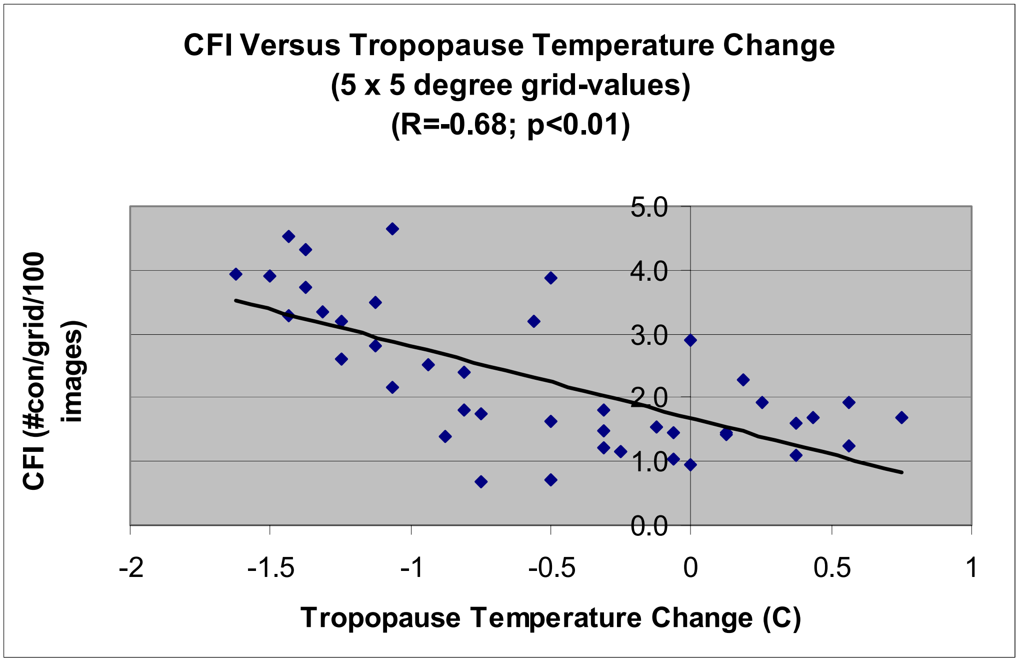

Figure 4: Relationship between CFI and Tropopause Temperature Change between 1977-79 and 2000-02 periods.

b. Characteristics of Contrail Outbreaks

A total of 267 contrail outbreaks were identified on the AVHRR imagery for the 2000-02 study period. The GIS characteristics of these outbreaks by mid-season month, averaged across all outbreaks, are presented in Table 1. Although more outbreaks occur during the transition months (April, October), the larger mean size of outbreaks in July provides a total overall coverage similar to that of April and October. January has substantially less contrail outbreak coverage than the other three months, primarily due to the smaller mean size of outbreaks. When comparing the contrail outbreak total coverage to the total number of days analyzed, the mean contrail outbreak coverage for the conterminous U.S. is 229,238.8km^2 day^{-1}. Interestingly, this aerial coverage accounts for approximately 5% of the land area comprising the conterminous U.S., an amount slightly less than the area of the state of Montana.

Month	**Sample Size**	**Area (km^2)**	**Total Coverage (km^2)**
January	59	256,066.9	15,107,947.1
April	86	322,806.8	27,761,384.8
July	52	412,554.6	21,452,839.2
October	70	276,135.3	19,329,471.0
Total	267	316,811.8	84,588,750.6

Table 1: Characteristics of Contrail Outbreaks 2000-02

Although the mean area of contrail outbreaks for the U.S. is substantial (316,811.8km^2), it is similar to that of MCCs in the U.S. Midwest and Great Plains states (Velasco and Fritsch 1987). It is common for airplanes to avoid MCCs for safety reasons by diverting their flight plan. We propose that an aviation policy be considered whereby flights are encouraged to avoid contrail susceptible areas along a particular flight path. The use of real-time meteorological data to forecast such locations as well as prior pilot reports of persisting contrails as an alerting mechanism for subsequent flights along the same path should make this plan viable, assuming the impacts on travel time and cost are not substantial.

4. References

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