JP1.15 AN ESTIMATION OF CONUS CONTRAIL FREQUENCY FROM RUC AND FLIGHT TRACK DATA

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Abstract. A new estimate of contrail coverage over the CONUS is developed using hourly meteorological analyses from the Rapid Update Cycle-2 (RUC-2) numerical weather prediction model and flight track data from FlyteTrax. This estimate is compared with the work of Sausen et al. (1998), and with contrail coverage estimates from an empirical contrail detection algorithm.

1. INTRODUCTION

Contrails can affect the global atmospheric radiation budget by increasing planetary albedo and reducing infrared emission. The total amount of the global radiative forcing depends on several poorly known factors including the global mean contrail optical depth, cloud microphysics and the frequency of contrail occurrence. Because air traffic is expected to grow by 2 to 5% annually (Minnis et al., 1999), it is becoming more important to estimate contrail frequency accurately.

Earlier estimates of global contrail coverage are based on empirically tuned models of contrail formation using a combination of European Centre for Medium Range Weather Forecast (ECMWF) meteorological analyses, criteria for contrail formation, and simplified distributions of fuel usage (Sausen et al., 1998). These models of contrail generation were normalized to satellite-based estimates of linear contrail coverage taken over the North Atlantic and central Europe (Bakan et al., 1994). However, recent estimates of contrail coverage over these areas from an objective detection algorithm (Mannstein et al., 1999; Meyer et al., 2001) are significantly smaller than those given by Bakan et al. (1994). Additionally, a comparison of the empirical contrail coverage of Sausen et al. (1998) with contrail coverage analyses of Advanced Very High Resolution Radiometer (AVHRR) data taken over the continental United States (Palikonda et al., 1999) show they compare well in overall magnitude of coverage, but differ in spatial distribution. These results illustrate the current uncertainty in contrail coverage estimation, a key component in the determination of contrail climate effects.

To address this uncertainty, we will use actual flight data and coincident meteorological data to compute a new estimate of contrail coverage over the continental United States (CONUS). This estimate will be compared with the earlier estimate by Sausen et al., and with contrail coverage estimates from an empirical contrail detection algorithm.

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2. DATA

2.1 Air Traffic Data

Commercial air traffic data from the FlyteTrax product (FT; FlyteComm, Inc., San Jose, CA) were used to determine air traffic density over the continental US (CONUS) during three weeks in November 2001. The database consists of 5-minute readings of aircraft (flight number) position (latitude, longitude, altitude) for every non-military flight over North America. Although the FT database does not include military flights, it contains most of the air traffic over the CONUS. Air traffic densities were tabulated on a 1°×1° grid that extends from 20°N to 50°N in latitude, and from 135°W to 60°W in longitude.

2.2 Meteorological Data

Atmospheric profiles of height, temperature, humidity and horizontal and vertical wind speeds were derived from the 40-km resolution, 1-hourly Rapid Update Cycle-2 (RUC-2) analyses (Benjamin et al., 1998) in 25 hPa intervals from 400 hPa to 150 hPa. The RUC-2 data were linearly interpolated at each pressure level to a 1°×1° grid that extends from 25°N to 56°N in latitude, and from 129°W to 67°W in longitude.

3. METHOD

Locations where persistent contrail formation is possible were computed according to the classical criteria of Appleman (1953) using the RUC profiles. The contrail formation algorithm follows Schrader (1997), modified with the aircraft propulsion efficiency parameter (η) of Busen and Schumann (1995). The mean value of the propulsion efficiency for the present commercial fleet is 0.30 (Sausen et al., 1998). The saturation vapor pressure coefficients of Alduchov and Eskridge [1996, AERW(50,-80) and AERWi(0,-80)] were used to compute saturation vapor pressure over water and ice.

According to the classical contrail formation theory, contrails can persist when the ambient air is super-saturated with respect to ice (that is, the environmental relative humidity with respect to ice (RHI) is greater than 100 percent), but not with respect to water. In Sausen et al. (1998), the use of ECMWF reanalysis data required a contrail parameterization to compute contrail coverage since the RHI in the ECMWF forecast model rarely exceed 100 percent. The RUC-2 model contains a more sophisticated cloud and moisture scheme that allows for ice-supersaturation. Assuming that the RUC-2 upper tropospheric moisture variables are accurate, we can follow a much simpler statistical evaluation of potential contrail frequency. For each 1°×1° grid location where the criterion for persistent contrails occurs at any level from 400 hPa to 150 hPa, a persistence indicator value is given a value of 1. The indicator value equals zero when none of the levels satisfies the persistence criterion. The frequency of potential contrail frequency over a time period becomes simply the frequency of the persistence indicator.

To compute the actual contrail coverage, the potential frequency must be multiplied by the air traffic density. For an initial estimate, we will assume that the air traffic density is sparse enough to relate contrail fractional coverage to traffic density linearly. An unknown quantity is the mean fractional persistent contrail coverage within an area resulting from a single flight track. If we estimate that the average persistent contrail spreads to 2 km wide and has a length of 60 km, it will cover approximately 120 km^2. Since the mean area of a 1°×1° grid cell in the midlatitudes is approximately 10000 km^2, the mean fractional persistent contrail coverage from a single flight track within a grid cell would be 0.012. Assuming random overlap of the contrails, the total persistent contrail coverage (c_{sum}) in a grid cell is

$$c_{sum} = P \times \left(1 - \prod_{n} (1 - c_{flt})\right) \qquad (1)$$

where P is the potential contrail frequency, c_{flt} is the mean fractional persistent contrail coverage within a grid cell from a single flight track, and n is the total number of flight tracks within a grid cell.

4. RESULTS AND DISCUSSION

4.1 Potential Persistent Contrail Frequency

Figure 1 shows the mean potential contrail frequency for three weeks in November 2001 (1 Nov - 6 Nov, 9 Nov – 18 Nov, 26 Nov – 30 Nov) for which both flight track data from FT and RUC-2 analyses were both available. The frequency was computed for pressure levels from 400 hPa to 150 hPa assuming an aircraft propulsion efficiency of 0.3. The region with the highest potential frequency is the Pacific Northwest, where values reach as high as 0.518. Other regions of high frequency occur in central Canada and the eastern Midwest portion of the US. The overall mean potential persistent contrail frequency for the three -week period is 0.269.

Figure 2 presents the potential persistent contrail frequency for December 2001. While a maximum in potential contrail frequency over the Pacific Northwest is also present in December, the overall distribution and the magnitude of potential contrails has changed dramatically as a result of changes in the synoptic-scale weather patterns between November and December. The overall mean potential frequency for the analysis region dropped to 0.197 in December.

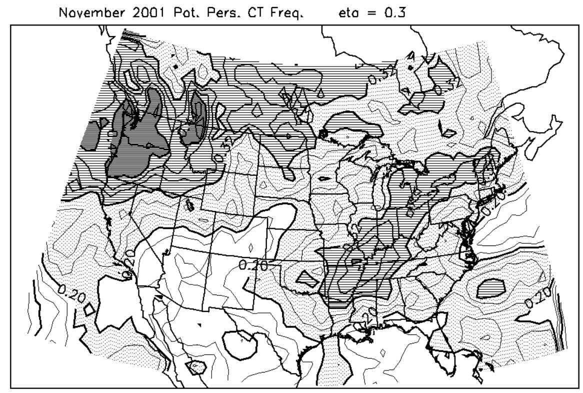

Figure 1. Potential persistent contrail frequency (between 400 and 150 hPa) derived from RUC-2 hourly analyses for three weeks in November 2001, assuming an aircraft propulsion efficiency factor of 0.3. The first contour is 0.04 and the contour interval is 0.04. The shading begins at 0.20 and its density increases at every third contour.

The potential persistent contrail frequencies calculated for nearly 6 months of RUC-2 data from 5 September 2001 to 28 February 2002 are shown in Figure 3. The overall mean potential contrail frequency for the period was 0.212. The minimum occurred during September with a maximum during November. This value is higher than the 11-year mean potential contrail coverage value derived by Sausen et al. (1998) for the US (0.141), but as noted their study, the moist areas where persistent contrails can form occur most frequently during the winter. More importantly, this study does not account for overlap from cirrus cloud, unlike the Sausen et al. study. Minnis et al. (2002) found a maximum in persistent contrail frequency over the USA during February from more than 2 years of surface observations. In their study, the frequency during November was ranked 7th overall.

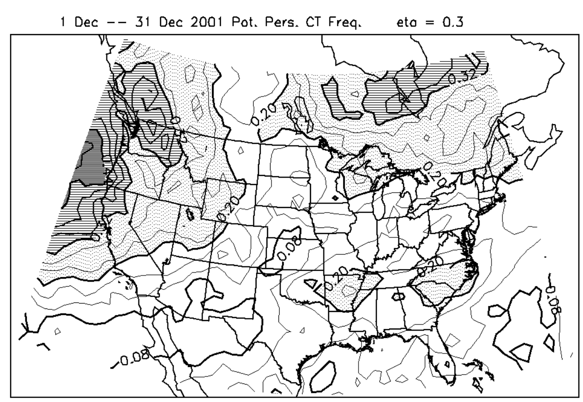

Figure 2. Same as Figure 1, but for December 2001.

4.2 Contrail Coverage from Air Traffic Density

Figure 4 shows a plot of persistent contrail coverage c_{sum} for November 2001. The contrail coverage is heavily influenced by the air traffic density pattern, and is similar in appearance to Sausen et al. (1998), with a maximum of approximately 0.07 in the eastern half of the CONUS, and relatively little coverage in the northern Great Plains. The mean contrail coverage for the CONUS is 0.009. This value is smaller than expected from the Sausen et al. (1998) analyses that yield 0.0160 and 0.0163 in October and January, respectively. Some of the differences may be due to differences in the domains. The present analysis includes significant areas over the ocean, Mexico, and Canada that may not be in the Sausen et al. (1998) domain and are certainly not included in the Minnis et al. (2002) study.

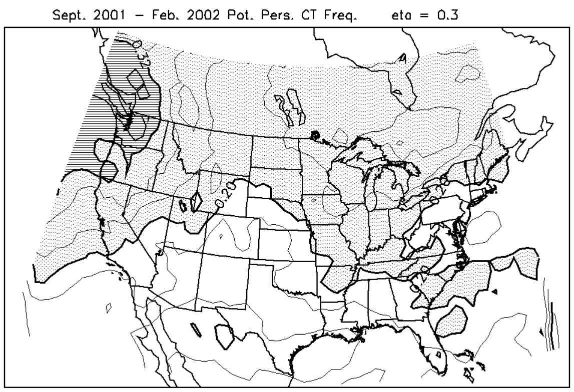

Figure 3. Same as Figure 1, but for 5 September 2001 through February 2002.

The persistent contrail coverage (assuming contrail coverage is proportional to air traffic density) for 5 September through 30 September 2001 is shown in Figure 5. Like Figure 4, the contrail coverage is heavily influenced by the air traffic density pattern. Work on an independent contrail coverage estimate for the CONUS for September and November 2001 is underway (Palikonda et al., 2002). That analysis will use NOAA Advanced Very High Resolution Radiometer (AVHRR) data and an objective contrail detection algorithm (Mannstein et al., 1999) to compute contrail coverage. Preliminary results from September (Palikonda et al., 2002) suggest that the contrail coverage may be more dependent on the potential contrail coverage (in other words, the environmental conditions) than the work of Sausen et al. (1998) and this work suggest. Several unresolved factors that may account for this difference. These factors include the likelihood that contrail coverage is non-linearly related to air traffic density, and the contrail coverage saturates in high traffic areas due to the competition for water vapor. Also, the current analysis neglects the advection of contrails, and assumes the contrails persist for one hour only. Both of these factors will affect the magnitude and location of the contrail coverage maxima. Additional tuning and testing of the contrail coverage estimates is in progress. An improved parameterization between contrail coverage and air traffic density, the implementation of contrail advection, and a more complete comparison of persistent contrail coverage from this work and Palikonda et al. (2002) will be presented at the conference.

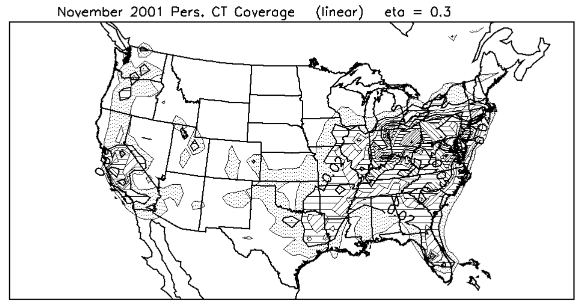

Figure 4. Persistent contrail coverage derived from RUC-2 and FT hourly analyses for three weeks in November 2001, assuming an aircraft propulsion efficiency factor of 0.3. The first contour is 0.01 and the contour interval is 0.01. The shading begins at 0.02 and its density increases at every third contour.

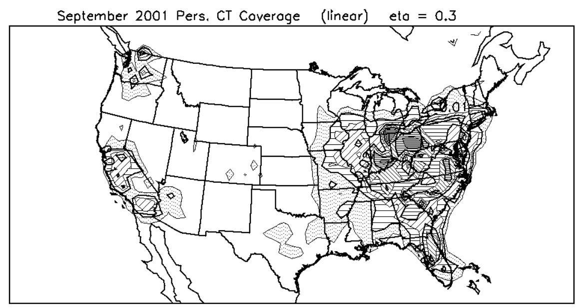

Figure 5. Persistent contrail coverage derived from RUC-2 and FT hourly analyses for 5 September through 30 September 2001, assuming an aircraft propulsion efficiency factor of 0.3. The first contour is 0.005 and the contour interval is 0.005. The shading begins at 0.005 and its density increases at every second contour.

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