Contrails Over the U. S. and Their Potential Impact on the Radiation Budget

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A methodology for assessing the contrail impact on the radiation budget is developed to use data characterizing the frequency, areal coverage, optical depth, particle size, and altitude of contrails with observations of cloud and surface properties. The method is tested using various scenarios over the United States to estimate contrail-induced albedo changes based on current aircraft fuel usage statistics. The technique can be used for estimating infrared effects and the impact of future fuel-use rates.

1. INTRODUCTION

Increases in cloud cover due to contrails can alter the local radiative balance by reflecting more solar radiation and absorbing and emitting longwave infrared radiation [1]. Under certain conditions, such changes can affect regional weather and climate. The overall effect of contrails on climate depends on a number of factors including frequency and timing of occurrence, areal coverage, lifetime, altitude, location, and microphysical properties. Because the upper troposphere is a relatively clean (aerosol-free) environment, the addition of high concentrations of cloud condensation nuclei have the potential for making a larger impact than they would in the lower troposphere. With commercial air traffic expected to increase by more than 200 percent by 2015 [2], the effects of aircraft exhaust on the atmosphere have become a subject of considerable interest leading to the NASA Atmospheric Effects of Aircraft Program (AEAP), sponsor of the Subsonic Assessment (SASS) Project [3]. One of the SASS goals is the evaluation of the contrail effect on climate. This paper develops a new approach for assessing the radiative impact of contrails, the first step to understanding the overall climatic effect.

Only a few satellite analyses have been performed to determine the change in cloudiness due to contrails. For example, Bakan et al. [4] used visual analysis of thousands of quicklook from the NOAA Advanced Very High Resolution Radiometer (AVHRR) infrared images taken over the northeast Atlantic and Europe to estimate contrail cloudiness for 1979-1981 and 1989-1992. They found a distinct seasonal cycle with a southward displacement of the contrail maximum during winter. Maximum contrail coverage in their analysis occurred during summer centered along the North Atlantic air routes. The coverage over that area increased during the 10-year interim. Similar analyses over the air corridors of the U.S. have not yet been performed. In this paper, a new surface-based contrail occurrence data base is used to estimate potential changes in albedo over the United States due to contrail-cloud cover. A modeling approach is used to relate aircraft fuel usage to contrail-enhanced cloud cover and ultimately to albedo changes.

2. METHODOLOGY

For a given area and local time, the albedo *a*

The mean differences in albedo shown in Fig. 4 do not accurately portray the regional variability in the albedo change. Maximum increase in albedo, 0.003 (τ = 0.2, c = 30%) would be expected over the midwestern U.S. from Chicago to New York with a secondary maximum from Miami to Charleston, South Carolina. The contrail albedo change is even seen 1000 km off the North Carolina coast. A third maximum would be expected over southern Nevada where it is relatively clear and air traffic is heavy. Minimum albedo changes are found over the northern tier of the U.S. and northern Mexico. Although fuel use patterns are the predominant influence on the albedo changes, the correspondence is not entirely straightforward because of the cloud patterns.

5. CONCLUDING REMARKS

A methodology for studying the impact of contrails on the radiation budget has been developed using realistic fuel usage-contrail occurrence data, cloud observations, and surface albedos. This method can also be adapted to examine the longwave warming effects of contrails and used to study the effects of projected increases in fuel usage and changes in flight corridors. In this study, only 1 month of data over the U.S. was examined to study the impact of contrails albedo. Other months and areas can be examined given the proper relationship between fuel use, contrails, and weather conditions. Much additional information is also needed to determine the best values for contrail optical depth, coverage, and lifetimes.

6. REFERENCES

[1] Kuhn, P. M. 1970: Airborne Observations of Contrail Effects on the Thermal Radiation Budget. *J. Atmos. Sci.*, **27**, 937-942.

[2] Baughcum, S. L. 1996: Subsonic Aircraft Emission Inventories. *Atmospheric Effects of Aviation: First Report of the Subsonic Assessment Project,* NASA RP-1385, pp. 15-29.

[3] *Effects of Aviation: First Report of the Subsonic Assessment Project*, NASA RP-1385, pp. 1-14.

[4] Bakan, S.; Betancour, M.; Gayler, V.; and Grassl, H. 1994: Contrail Frequency Over Europe From NOAA-Satellite Images. *Annal. Geophys.*, **12**, 962-968.

[5] Baughcum, S. L., T. G. Tritz, S. C. Henderson, and D. C. Pickett, 1996: Scheduled Civil Aircraft Emission Inventories for 1992: Database Development and Analysis. *NASA Contractor Report CR-4700,* 205 pp.

[6] Metwally, M., 1995: Jet Aircraft Engine Emissions Database Development--1992 Military, Charter, and Nonscheduled Traffic. *NASA Contractor Report CR-4684,* 61 pp.

[7] Minnis, P., J. K. Ayers, and S. P. Weaver, 1996: Surface-Based Observations of Contrail Occurrence Frequency Over the U.S., April 1993 - April 1994. *NASA Reference Paper*, submitted.

[8] Rossow, W. B. and R. A. Schiffer, 1991: ISCCP cloud data products. *Bull. Amer. Meteorol. Soc.*, **72**, 2-20.

[9] Charlock, T. P., D. Rutan, G. L. Smith, T. L. Alberta, N. Manalo-Smith, L. H. Coleman, D. P. Kratz, T. D. Bess, and K. A. Bush, 1995: Compute Surface and Atmospheric Fluxes (Subsystem 5.0). "Clouds and the Earth's Radiant Energy System (CERES) Algorithm Theoretical Basis Document, Volume IV: Determination of Surface and Atmosphere Fluxes and Temporally and Spatially Averaged Products (Subsystems 5-12)", *NASA Reference Paper RP-1376 Vol. 3,* edited by CERES Science Team, December, pp. 1-37.

[10] Fu, Q. and K.-N. Liou, 1993: Parameterization of the Radiative Properties of Cirrus Clouds. *J. Atmos. Sci.*, **50**, 2008-2025.

[11] Briegleb, B. P., P. Minnis, V. Ramanathan, and E. F. Harrison, 1986: Comparison of Regional Clear-Sky Albedos Inferred from Satellite Observations and Model Computations. *J. Climate Appl. Meteorol.*, **25**, 214-226.