29B6

CONTRAIL STUDIES AT FARS: EVALUATION OF POTENTIAL FOR CLIMATE CHANGE

Kenneth Sassen, Randall Benson, and Keith Duffy

Department of Meteorology, University of Utah
Salt Lake City, UT 84112 USA

INTRODUCTION

That aircraft condensation trails (contrails) may be having an impact on the radiation balance of the earth/atmosphere system follows from the apparently causative relationship between the trends of increasing cirrus cloud cover and average surface temperature at certain locations, and the total consumption of commercial aviation jet fuels. As can be easily visualized by the creation and persistence of contrails in otherwise cloudless, or mostly cloudless skies, the aircraft supply abundant cloud-forming nuclei and water vapor emissions into an upper troposphere that is often lacking in these precursors to cirrus cloud formation. One of the areas that, on the basis of statistical cloud studies, seems to have been noticeably effected by contrails is the Salt Lake City region, owing to the local presence of major commercial jet air corridors. Fortunately for more indepth studies, a regular program of cirrus cloud research has been underway since December 1986 at the University of Utah Facility for Atmospheric Remote Sensing (FARS).

FARS DATA COLLECTION

The remote sensing cirrus cloud studies have been made in connection with the Extended Time Observation (ETO) component of Project FIRE. Normally, cirrus cloud data are collected over periods of 1- to 3-h bracketing the local overpass times of polar-orbiting satellites using a two-polarization channel ruby (0.694 μm) lidar, coaligned narrow-beam mid-infrared radiometer, all-sky (fisheye) photography, and a variety of roof-mounted radiometers in the visible and infrared spectral regions. Special, more intensive data periods currently incorporate the four-polarization channel, two-color (0.532 and 1.06 μm) Polarization Diversity Lidar (PDL), and a polarimetric Doppler 95 GHz (3.2 mm) radar. Although the "turnkey" ruby system monitors clouds in the zenith at a low 0.1Hz PRF, the scannable PDL system is a high spatial (1.5 m maximum) and temporal (10Hz) resolution system. The six-channel 95 GHz system displays a minimum range resolution of 30 m, and has a 0.25° beamwidth for relatively detailed radar cloud studies.

CONTRAIL STUDIES

Both retrospective Project FIRE ETO, and new more sophisticated scanning PDL and radar studies are underway at FARS. Since contrails are well represented in the approximately 1500 hours of ETO remote sensing observations this an important climatological contrail data record. Currently, regularly-collected fisheye photographs are being used to establish the hourly and monthly frequency of occurrence of contrails, and their relation to "natural" cirrus. With this knowledge, the synoptic weather and environmental conditions responsible for contrail formation and persistence are being evaluated. A number of contrail case studies have been identified for more intensive examination using the polarization lidar and LIRAD approaches, and local atmospheric sounding data. This research is establishing the range of contrail temperature/humidity values (for basic model parameterization purposes), as well as linear depolarization ratio, and derived optical cloud thickness τ and infrared emissivity ϵ values. The higher resolution scanning lidar and radar platforms are currently being used to study the evolution of contrail properties with time after formation, including estimates of mean particle size and mass content, and contrail spreading rate.

TYPICAL CONTRAIL FINDINGS

For illustration we provide in Fig. 1 results from two contrail case studies based on ruby lidar and a coligned PRT-5-type midinfrared radiometer measurements. In both cases, shown in the top panel is the infrared window brightness temperature (representing the sum of the downward emissions from water vapor and ozone, as well as the cloud), and below is a height-time display of range-normalized (0.694 μm) laser backscattering (using a logarithmic-based gray scale, where white is the maximum signal). In (a) a series of a few-minute old narrow contrails at ~11.3 km are shown embedded within an optically thin ($\tau \leq 0.1$) cirrostratus cloud layer. These young contrails typically produced strong optical attenuation (note the apparently "cloudless" streaks above the bright contrails), but due to their limited depths (100 m or less), they did not produce noticeable increases in τ or ϵ. In contrast, the 10-15 minute old contrails shown in (b) at ~10 km near the tops of a thinning cirrostratus layer did produce significant integrated scattering signatures in the visible and infrared regions. Over the period shown τ tended to gradually decrease from 0.25 to 0.1 as the layer thinned, but the three contrails in the middle part of the display, which have developed strongly-scattering convective towers and fallstreaks, generated average τ increases of 0.07, 0.42, and 0.24, respectively. The infrared brightness temperature correspondingly dropped by a total of nearly 10°C, except when the contrails passed overhead. In particular, note the 5° to 10°C increase caused by the middle contrail, which represents a significant increase in the ϵ of the entire cloud layer.

CONCLUSIONS

A climatologically-representative sample of contrail cirrus cloud properties is being developed to aid in the assessment of the climate forcing induced by commercial aircraft in a region of the globe subject to heavy air traffic. Preliminary findings indicate that contrails embedded in natural cirrus can produce significant, albeit relatively brief alterations in the optical properties of the atmospheric column, depending on contrail age and dimensions. Under some conditions, persisting contrails can spread and overlap so as to produce natural-appearing cirrostratus layers. Along with statistical research, both conditions, i.e., embedded contrail "scattering conduits" and more homogeneous-appearing contrail-cirrus, need to be examined with matched radiative transfer models to assess their impact on climate change.

ACKNOWLEDGEMENTS

Our current contrail research is being supported by a supplement to NASA grant NAG-11314 from the SASS project office.

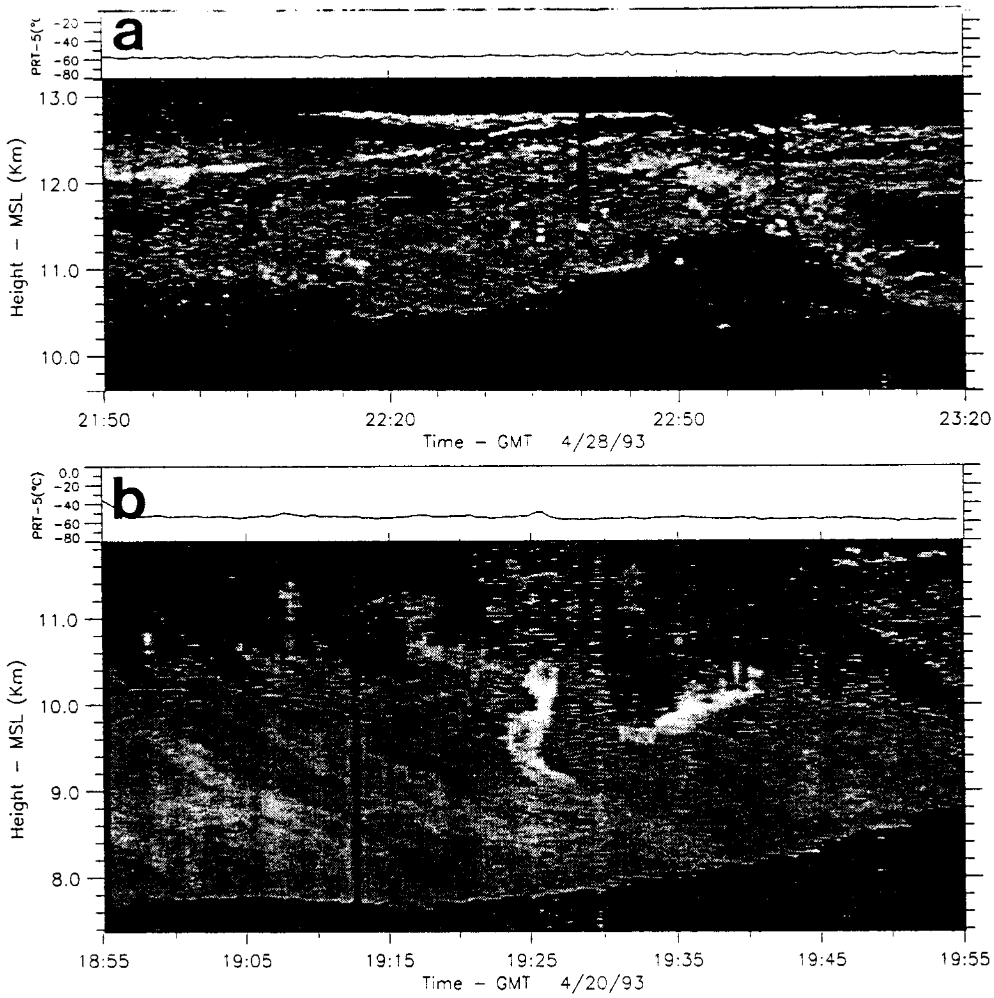

Figure 1. FARS ruby lidar height-time displays of returned power and effective infrared brightness temperature (top panels) for two contrail-cirrus cloud systems over the indicated dates and times.