A USA commercial flight track database for upper tropospheric aircraft emission studies

Donald P. Garber, Patrick Minnis[1], and Kay P. Costulis

Atmospheric Sciences, NASA Langley Research Center, Hampton, Virginia, USA

European Conference on Aviation, Atmosphere, and Climate
Friedrichschafen at Lake Constance, Germany
June 30 - July 3, 2003

[1] *Corresponding author:* Patrick Minnis, MS 420, NASA Langley Research Center, Hampton, VA, USA 23681. Email: p.minnis@nasa.gov

A USA commercial flight track database for upper tropospheric aircraft emission studies

Donald P. Garber, Patrick Minnis[1], and Kay P. Costulis
Atmospheric Sciences, NASA Langley Research Center, Hampton, Virginia, USA

Keywords: air traffic, flight tracks, aircraft emission, contrail simulation

ABSTRACT: A new air traffic database over the contiguous United States of America (USA) has been developed from a commercially available real-time product for 2001-2003 for all non-military flights above 25,000 ft. Both individual flight tracks and gridded spatially integrated flight legs are available. On average, approximately 24,000 high-altitude flights were recorded each day. The diurnal cycle of air traffic over the USA is characterized by a broad daytime maximum with a 0130-LT minimum and a mean day-night air traffic ratio of 2.4. Each week, the air traffic typically peaks on Thursday and drops to a low Saturday with a range of 18%. Flight density is greatest during late summer and least during winter. The database records the disruption of air traffic after the air traffic shutdown during September 2001. The dataset should be valuable for realistically simulating the atmospheric effects of aircraft in the upper troposphere.

1 INTRODUCTION

Air traffic is expected to increase globally by a factor of 5 or 6 between 1990 and 2050 with a commensurate rise in emissions and contrails that may significantly affect air quality and climate (IPCC, 1999). Some of the aircraft exhaust effects, especially those impacting contrail and cirrus clouds, are still highly uncertain requiring exhaustive research to more accurately prognosticate the climatic impact of enhanced commercial fleets. Contrail formation, growth, and dissipation and their optical properties are highly dependent on aircraft engine type, and the temperature, humidity, and wind speed and direction at flight altitude. The contrail-cirrus radiative effects, which ultimately affect the average state of the atmosphere, depend on the underlying conditions (surface temperature and albedo), the contrail optical properties, air traffic density and altitude, and the time of day when the contrails are formed. Thus, to accurately assess current air traffic effects and future flight scenarios, it is necessary to simultaneously know the meteorological state and the distribution of flights at a given location. This report addresses the latter need for the contiguous United States (CONUS) with a focus on the upper tropospheric portions of commercial flights.

The release of United States of America (USA) near-real time air traffic control information to the commercial sector during the late 1990’s made the collection of more refined flight path data much easier than before. This report documents the collection, reduction, analysis, and availability of commercial flight information taken above 25,000 ft over the CONUS since late 2000. The result of the analysis is a flight track database that can be easily accessed and used by modelers.

2 DATA AND ANALYSIS

Commercial flight information taken in real time over the USA from the FlyteTrax system (FlyteComm, Inc.) has been purchased and archived at NASA Langley Research Center since September 2000. The raw data consist of 2, 5, or 10-minute reports of flight number, aircraft type, download time, latitude, longitude, altitude, heading, destination and origination locations, speed, and departure and arrival times. All portions of flights above 25,000 ft (7.6 km) within the domain (20°N - 50°N and 60°W - 135°W) were quality controlled and sorted by flight number and time.

[1] *Corresponding author:* Patrick Minnis, MS 420, NASA Langley Research Center, Hampton, VA, USA 23681. Email: p.minnis@nasa.gov

Table 1. Monthly sampling statistics for flight track database.

Month	2001 (number of days)				2002 (number of days)			
	Full	Partial	Empty	% Full	Full	Partial	Empty	% Full
Jan	12	1	18	39	18	2	11	58
Feb	0	0	28	0	22	1	5	79
Mar	17	2	12	55	29	1	1	94
Apr	21	8	1	70	30	0	0	100
May	11	18	2	35	26	4	1	84
Jun	20	10	0	67	29	1	0	97
Jul	19	11	1	61	31	0	0	100
Aug	25	3	3	81	31	0	0	100
Sep	30	0	0	100	26	3	1	87
Oct	24	3	4	77	29	1	1	94
Nov	21	1	8	70	21	7	2	70
Dec	26	4	1	84	24	2	5	77

The summary statistics for each month in Table 1, which shows the number days in each month that have complete (full), partial, or no (empty) sampling, indicate that the best sampling occurred during late 2001 and 2002. No military flights are available in this database. Not all flights over Mexico and Canada are represented either. All commercial and private flights over the USA should be included for those days noted as complete.

Flights remaining after passing the quality control checks were then used to develop the database, which is divided into two parts: linear and gridded. The former computes the node points for each flight track on a 1° latitude-longitude grid using interpolation along great circle arcs between each report. These standardized flight track positions comprise the linear database in the form of one file for each day consisting of a series of flights, each with its own header describing the general flight characteristics and followed by a series of flight segments. The gridded database, provided in cell files, uses the segmented flight tracks to determine for each hour the number and total length of flights within a 1-km vertical range in a given 1° grid box. The linear dataset should be useful for detailed simulation studies, while the gridded data should be more valuable for use in climate simulations.

3 RESULTS

The main parameters of interest for this database are the number of flights and the cumulative flight length (CFL). CFL can be computed as the sum of all flight segment lengths within a given box or domain for a selected time period, usually 1 hour.

3.1 *Spatial Variability*

The 1° CFL distribution for 10 September 2001 is sliced by altitude ranges in Figure 1. The maximum CFL in a single 1° box in the lowest altitude range is only ~22,000 km over southern Michigan and northern Virginia. Most CFLs within that layer are less than 4000 km with many flights occurring in southern California, northern Florida, and the Midwestern USA. Flights at these lower levels consist of portions of longer legs near the terminals or of the apex segments of short-distance commuter flights. The maximum CFL between 9 and 11 km exceeds 40,000 km over parts of eastern Ohio and western West Virginia. In addition to the large area of heavy traffic over the northeastern USA, a relatively dense traffic lane is evident over the Atlantic coast south of New York City. These flights are generally mid-range or longer flights. The maxima over the western USA are found over Nevada and the border between New Mexico and Arizona away from the large hubs at San Francisco and Los Angeles. The CFLs at the highest altitudes (Figure 1c), generally consisting of long distance flights, are greatest over Lake Erie, the central Great Plains, southern Utah, and coastal north Florida. The combined levels in Figure 1d yield a large number of regions with total CFL > 40,000 km. These include much of the northeastern USA exclusive of New England, the Atlantic coast, central Great Plains, the Southwest, and lower Mississippi Valley. The few CONUS areas with total CFL < 4,000 km are found along the western Canadian and central Mexican borders.

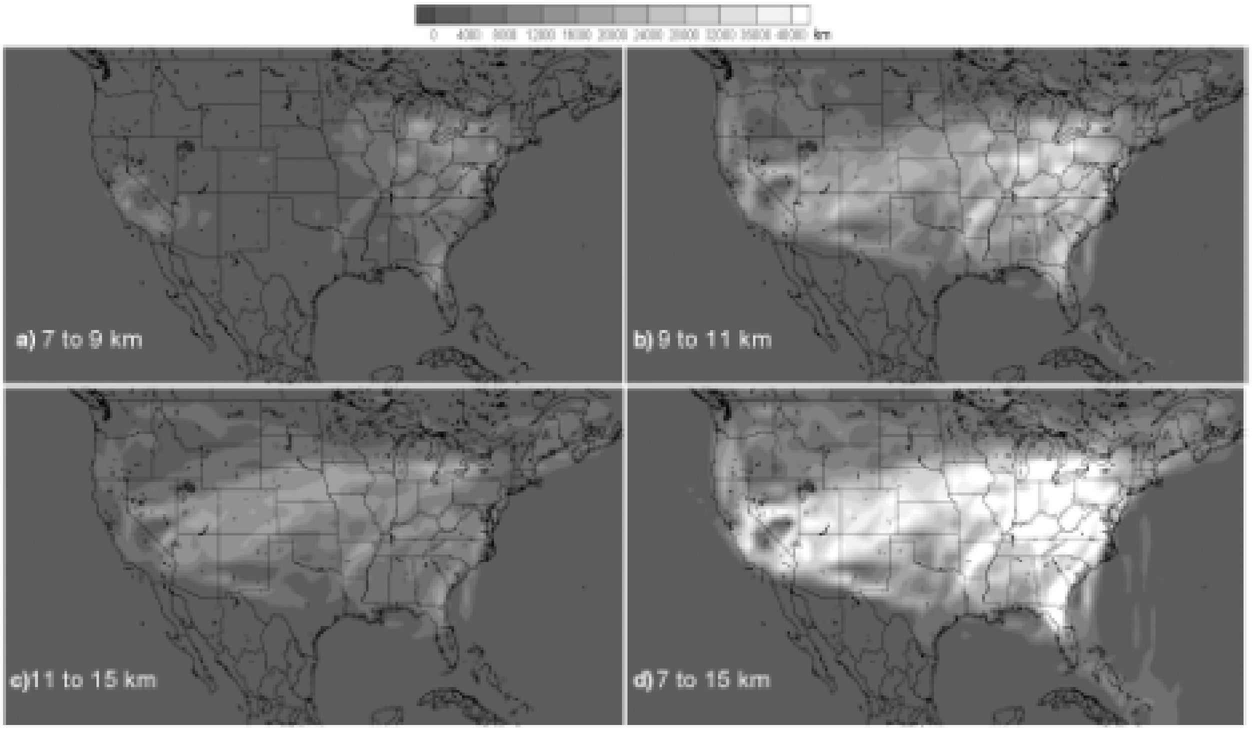

Figure 1. Cumulative flight lengths for 1° regions, 10 September 2001.

The latitudinal and longitudinal variations of the mean daily CFLs are summarized in Figure 2. Peak traffic occurs between 38°N and 39°N with a secondary maximum around 35.5°N (Figure 2a). A relative maximum (Figure 2b) at 120°W corresponds to the southern California traffic followed in the eastward direction by a dip and a relatively steady increase to the overall maximum at 81.5°W. The traffic then tails off to 30,000 km at 60°W. More flights are evident over the Atlantic than over the Pacific. The shapes of the longitudinal and zonal mean CFL curves are very similar for both March and August suggesting more of a general increase in traffic during summer than a changing of the air traffic patterns. The maximum CFL for the entire domain occurs between 10 and 11 km followed by the layer between 11 and 12 km (Figure 3). The March-August increase in air traffic is greatest between 10 and 11 km. The total daily CFLs for the domain are 19.6 and 25.1 million km during March and August, respectively.

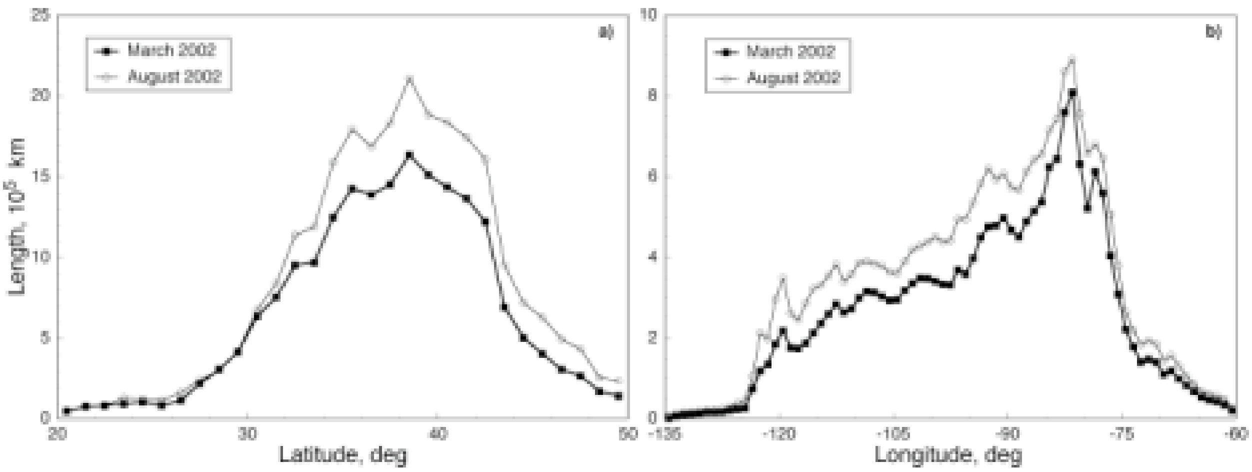

Figure 2. Mean daily cumulative flights lengths as a function of (a) latitude and (b) longitude over USA.

3.2 *Temporal Variability*

The diurnal cycle over the entire domain is summarized in Figure 4 using monthly means from March and August 2002. The variation with in Figure 4a shows a rapid increase in flights after 1100 UTC to a peak around 1830 UTC during March with a secondary maximum around 2330 UTC. The minimum occurs near 0730 UTC. During August, the air traffic begins in earnest an hour earlier

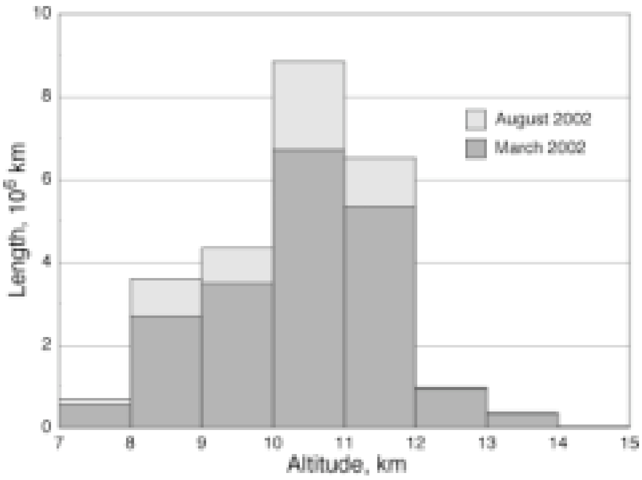

Figure 3. Mean daily layer CFL over USA domain.

than during March because of a shift to daylight savings time. The maximum during August occurs at 2230 UTC. Overall, the air traffic during August is ~28% greater than during March. The diurnal variation of air traffic shows no seasonal shift in local time (LT) with the daily cycle beginning in earnest after 0500 LT, reaching two maxima at 0930 and 1230 LT with a minimum at 0130 LT (Figure 4b). Considering the hours 0600 – 1800 LT as daytime and the remaining hours as night, a rough estimate of the day-night ratio in cumulative flight length is 2.5 and 2.3, respectively, during March and August 2002. The true day-night ratio, valuable for calculating the relative shortwave and longwave radiative forcing by contrails, is more accurately determined for each month by considering the actual hours of daylight for each location and month. Such information can be easily computed from the gridded database. The plots begin at 0400 UTC because it corresponds to local midnight in the easternmost portion of the domain.

The number of CONUS flights has a distinct weekly cycle. The mean air traffic minimum occurs on Saturday following a peak of 25,500 takeoffs and landings on Thursday. The range in the number of flights per day of week is typically around 5,000 except for the extreme minima occurring during certain holidays or as a result of the air traffic shutdown period after September 11, 2001. The weekly range in the average daily number of flights is 18%.

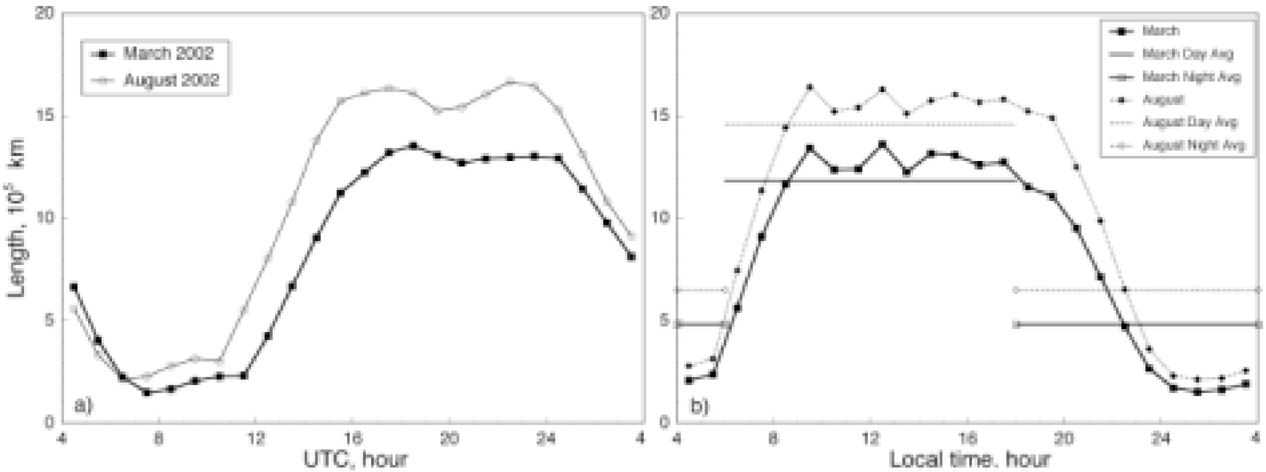

Figure 4. Mean hourly and day-night average CFL, (a) local time and (b) UTC.

4 DISCUSSION

While providing unprecedented air traffic detail, it should be noted that this dataset does not include flights below 25,000 ft, military air traffic, and some air traffic over oceans, Canada, Mexico, and Cuba. Development of a total inventory for this domain would require additional input. Data acquisition, while nominally continuous, was not complete except for a few months. Actions taken to ac count for the missing data when computing monthly means should minimize the impact of the poor

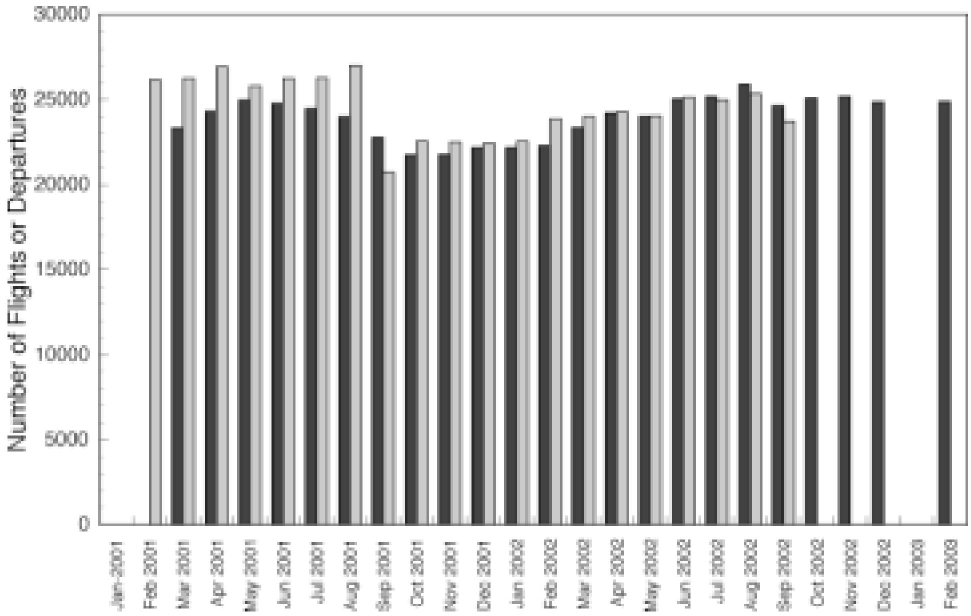

Figure 5. Mean number of daily flights above 7.6 km from FlyteTrax data (black) and departures of commercial carriers from OAI database (shaded).

data. Data were initially acquired from FlyteComm, Inc. every 2 minutes and the only time associated with each flight number was the local time on the acquisition computer. Thus, the actual flight time could be overestimated by up to 2, 5, or 10 minutes depending on the time interval of reporting for a given flight. Despite these uncertainties in actual time, the data should provide a realistic representation of air traffic over the CONUS.

Previous air traffic fuel usage data from USA sources were developed for 1992 (Baughcum, 1996, Gardner 1998) and include military sources (Metwally, 1995). A comparison of the fuel usage above 7 km from that earlier dataset (Figure 17 in Minnis et al. 1997) and the CFL distribution in Figure 1d reveal some differences that may be due to the lack of military and foreign flights and changes in air traffic patterns since 1992. For example, flights between California and Mexico evident in the 1992 dataset are absent in Figure 1d, while flights from Texas and the eastern USA to Acapulco and Mexico City (Figure 1d) are not as defined in the 1992 dataset. Air traffic over the Pacific is confined to a few narrow air lanes in the earlier dataset compared to the more diffuse air lanes in Figure 6d. Despite many similarities between the two datasets, this air-lane versus diffuse distribution difference is apparent over much of the domain. For example, the maximum fuel expenditure in the 1992 dataset is confined to a latitude strip between 40°N and 42°N between Philadelphia, PA and Iowa with a few secondary maxima over Las Vegas, NV and southern California. In Figure 1d, the maximum CFL covers a much larger area including the relatively narrow strip in the 1992 data. New secondary maxima are evident over northeastern Florida, eastern Arkansas, and eastern Kansas in Figure 1d. Perhaps, additional tourist traffic and the expansion of overnight delivery services with major hubs at Memphis, TN, Wilmington, OH, and Louisville, KY could have increased the traffic over the Midwest and Florida.

The seasonal variation in air traffic in the current dataset appears to be somewhat different than can be inferred from the seasonal variation in North American high-altitude aircraft emissions from the 1992 inventory (Figure 2-7, Friedl, 1997). The earlier data have a peak in NOx emissions during August followed by a 4% drop into September, nearly constant values through December, a 9% decrease to the January minimum, a gradual increase to May, and a rapid rise to the summer maximum. Figure 5 shows an initial May maximum with flight frequency decreasing into October. The number of flights remains depressed until March 2002 when they begin increasing until August 2002. A 6% decrease in flights during September is slightly offset by a 2% rise into October. The flight frequency remained steady through February 2003. This irregular variability is influenced by a number of factors, including the September 11, 2001 terrorist attacks, which can account for part of the October 2001 – February 2002 lull. The first maximum in May 2001 is probably due to sampling deficiencies that were not properly considered. The USA freight traffic, as expressed in overall ton-miles for scheduled and non-scheduled aircraft, increased almost monotonically by a factor of 2.7 between 1981 and 2000 with minor lulls during 1991 and 1999 (OAI, 2003). Similarly, the number of passenger originations increased by a factor of 2.4 during the same period. Both parameters decreased during 2001, especially the air passenger originations. The overall number of scheduled and non-scheduled airport departures for large certified air carriers, which account for most of the high-altitude air traffic are in good agreement with the current database (Figure 5) except for the period prior to September 2001 when sampling was the worst. When these sampling effects are taken into account, the monthly averages for the earlier period will probably be in better agreement.

The diurnal variation of flights is generally consistent with the available information on contrails over the CONUS. The unnormalized frequency of persistent contrails more than doubles between 0600 LT and 0800 LT when it reaches a maximum around 0900 LT (Minnis et al. 2003). The average CFL also increases by more than a factor of 2 between 0600 and 0800 LT and reaches a peak at 0930 LT (Figure 4). Mean CFL decreases very slowly during the daylight hours without a significant drop until after 1800 LT, while the contrail frequency also gradually decreases after 0800 LT before dropping at 1800 LT. The lack of contrail frequency data during the night precludes further comparison. However, the correspondence between contrails and flight lengths during the daytime suggests that the CFL data could be used to estimate the relative hourly frequency of contrail occurrence at night.

5 CONCLUDING REMARKS

This new database constitutes a different characterization of air traffic than previously available. It provides explicit flight paths and flight density in terms of cumulative flight length rather than fuel usage. Actual flight paths were used instead of estimated flight paths between terminals. Because of data dropouts, caution must be used when simulating the air traffic for a particular day. The statistics provided here represent an initial summary of the dataset but have not accounted for all of the effects of missing data. After final quality control has been completed (tentatively late 2003), the database will be made available via the World Wide Web.

Air traffic over the USA is marked by distinct daily, weekly, and annual cycles that can affect evaluations of aircraft effects on the atmosphere. When properly used, the dataset described herein should prove valuable for realistically simulating air traffic at a variety of scales.

REFERENCES

Baughcum, S. L., 1996: Subsonic aircraft emission inventories, In: *Atmospheric Effects of Aviation: First Report of the Subsonic Assessment Project,* NASA RP-1385, pp. 15-29.

Friedl, R. R. (ed.), 1997: *Atmospheric Effects of Subsonic Aircraft: Interim Assessment Report of the Advanced Subsonic Technology Program*, NASA RP 1400, 168 pp.

Gardner, R.M. (ed.), 1998: *ANCAT/EC Aircraft Emissions Inventory for 1991/92 and 2015.* Final Report EUR-18179, ANCAT/EC Working Group. Defence Evaluation and Research Agency, Farnborough, United Kingdom, 108 pp.

IPCC**,** 1996: *Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.)] and WMO/UNEP. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 572 pp.

Metwally, M. 1995: *Jet Aircraft Engine Emissions Database Development--1992 Military, Charter, and Non-scheduled Traffic*, NASA CR-4684.

Minnis, P. J. K. Ayers, and S. P. Weaver, 1994: *Surface-Based Observations of Contrail Occurrence Frequency Over the U.S., April 1993 - April 1994*, NASA RP 1404.

Minnis, P. J. K. Ayers, M. L. Nordeen, and S. P. Weaver, 2003: Contrail frequency over the USA from surface observations," *J. Climate*, in press.

OAI, 2003: *Air Traffic Statistics and Airline Financial Statistics, Historical Air Traffic Data for 1981-2001*, U.S. Department of Transportation, Bureau of Transportation Statistics, http://www.bts.gov/oai/indicators/top.html.