P1.14 GLOBAL CLIMATOLOGY OF CLEAR AIR TURBULENCE ACTIVITY DEDUCED FROM A NUMERICAL MODEL INDEX

Gary P. Ellrod *
Office of Research and Applications (NOAA/NESDIS)
Camp Springs, Maryland

1. INTRODUCTION

The steady increase in transcontinental air travel requires improved knowledge of enroute weather hazards such as clear air turbulence (CAT). According to the United States' National Transportation Safety Board, turbulence is the greatest single cause of inflight injuries to passengers and crew members. To improve inflight safety, climatological data on the likelihood of CAT would be useful for both long range and daily air route planning.

Previous turbulence climatology studies (e.g., Colson 1968) have been based chiefly on aircraft pilot reports (PIREPs). Since some air routes are lightly traveled at certain times of the day, PIREPs can often be sparse. Merging PIREPs with upper air data, such as from radiosondes (Endlich and Mancuso, 1968) is most reliable over land, and still suffers from data voids. Recent improvements in numerical prediction models, a result of increased computer power, better physical paremterization, and the assimilation of high altitude winds and temperatures from aircraft and satellite sensors, has made numerical model data a more logical choice for the generation of CAT climatology. A preliminary CAT climatology based on two years of model data was previously described (Ellrod 1993). This paper presents updated results, deduced from eight years of data in the Northern Hemispheres, combined with the two most recent years for the Southern Hemisphere.

2. DATA AND PROCEDURES

The raw data used in this study were u and v wind components and pressure heights (z) from the National Centers for Environmental Prediction (NCEP) Aviation (AVN) Model. Until recently, the AVN has been run every twelve hours, but only data from the 0000 UTC model run was used in this study.

An operational turbulence index (TI) for the diagnosis and prediction of CAT, described in Ellrod and Knapp (1992), has been averaged monthly, seasonally, and annually for the past eight years in an attempt to determine preferred locations for CAT in the Northern Hemisphere. For the past two years, this analysis has been extended to the Southern Hemisphere also. Data was save for three layers: 400-300 hPa, 300-250 hPa, and 250-200 hPa, but only the middle layer, representing the most common cruising altitudes for commercial jet aircraft (29,000 to 35,000 ft above Mean Sea Level), will be presented here. The TI data are in Man-computer Interactive Data Analysis System (McIDAS) gridded format, reduced to 65 rows and columns, resulting in a coarse resolution of approximately 3° x 3° latitude - longitude. The TI is based on the product of resultant horizontal deformation and vertical wind shear in each layer:

$$TI = [(\partial u/\partial x - \partial v/\partial y)^2 + (\partial v/\partial x + \partial u/\partial y)^2]^{1/2} \times \partial \mathbf{V}/\partial z \quad (1)$$

where u and v are east-west and north-south wind components (m s^{-1}), **V** is the vector wind and z the height of a standard pressure surface (m). Physically, this quantity is related to frontogenetic forcing, which has a direct effect on vertical wind shear. Previous validation of the index derived from the AVN model indicated a high probability of detection (~80%) for significant turbulence episodes with a false alarm rate of ~20% (Ellrod and Knapp 1992).

A simple numerical average was calculated for monthly periods, which were then averaged seasonally and annually. The mean index grids were converted to an image which was scaled such that mean TI values from 0 to 6 were depicted by gray scale values of 0 to 255, respectively. Color enhancement tables were developed to show regions of low risk (green), moderate risk (yellow) and high risk (red). The moderate risk threshold was assigned as TI =2, while the high risk threshold was TI = 4. Seasonal and multi-year images have

* *Corresponding author address:* Gary P. Ellrod, E/RA2, Room 601, WWBG, NOAA, 5200 Auth Road, Camp Springs, Maryland 20746-4304; E-mail: gary.p.ellrod@noaa.gov

been made available via an Internet Web site at:

http://orbit-net.nesdis.noaa.gov/arad/fpdt/ticli.html

There have been occasional periods of missing data due to computer workstation failures, software changes, network data transfer problems, etc. The percentage of possible days for which TI data were produced generally ranges from 70 to 95%.

3. RESULTS

3.1 Geographic Variability

The global mean TI for the Northern Hemisphere winter (December - February) converted to a gray scale image is shown in the top panel of Figure 1, with the summer season (June - August) in the lower panel. Regions of preferred CAT occurrence can be found in elongated bands associated with major polar and subtropical jet streams and mid-latitude storm tracks. The maximum likelihood of CAT in the Northern Hemisphere during the winter months is found in eastern Asia over northern China and Japan, extending into the Central Pacific to just north of Hawaii. Other areas prone to CAT are: North Africa eastward across the Middle East to south central Asia, the Canadian Maritimes, and the central and southwestern United States.

Preliminary results for the Southern Hemisphere based on only two years of data show considerably less activity than for the Northern Hemisphere. This result is expected because of the more homogeneous west to east flow found in the Southern Hemisphere, a result of less land mass and few large mountain ranges. The largest mean TI values are centered over southern Australia and northern New Zealand, with weaker maxima near the west coast of South America, and to the east of South Africa.

3.2 Seasonal Variations

Seasonal variations show the expected poleward retreat and decrease in regions of significant turbulence activity during the summer months, as can be expected with the weakening of the polar and subtropical jet streams, and the shrinking of the circumpolar vortices. Inter-annual variations also provide valuable insight. For example, the strong El Nino winter of 1997-98 produced well above normal mean turbulence index values, whereas La Nina years such as 1999-2000 were much lower than average. These results are shown in the three panel image in Figure 2 for North America (excluding Alaska). The El Nino year shows pronounced mean TI values from the northeast Pacific extending across the southern United States, with a secondary maximum in the Northeast United States. The prior and following years have much weaker mean TI values.

3.3 Variation with Altitude

Mean TI values typically diminish significantly with height from the 250-300 hPa to 200-250 hPa layers. It can be inferred from this that flight at the higher altitudes is, on average, smoother. This result agrees with the findings of an International Civil Aeronautical Organization (ICAO) PIREP study during four 5-day periods in 1964-65 (Colson, 1968). Alignment of the axes of maximum TI is observed to shift slightly poleward with increasing altitude, consistent with the typical slope of strong baroclinic zones in which jet streams are embedded.

4. ESTIMATION OF CAT PROBABILITY

The use of mean TI in estimating CAT probability in flight is difficult and requires simplifying assumptions. There is a great difference in scale between a coarse numerical grid box (> 100 km) versus turbulent eddies encountered by aircraft (~100 m or less). One possible approach is to determine the typical distribution of TI for various mean values during a month. The TI threshold from the AVN model for significant turbulence is ~2. Based on more than 1,000 PIREPs, only about 25% of moderate or greater CAT occurred with TI <2 (Ellrod and Knapp, 1992). The number of turbulent grid points in the sample can then be reduced by 20% to account for possible "false alarms." The percentage of turbulent vs non-turbulent values can then be determined.

Based on these assumptions, it was estimated that a mean TI of 2.0 (moderate risk) represents about a 20% chance of encountering moderate or greater CAT somewhere within one grid box (3 x 3 lat./lon. X 50 mb thick) on a given day. Assuming that each aircraft would have a 50% probability of encountering CAT within a box, this translates to about a 10% chance per flight for a mean TI of 1.0. Expressed another way, a flight scheduled for the same time and route each day would encounter significant CAT on one out of every ten days for that region. In high risk areas, it is estimated that there

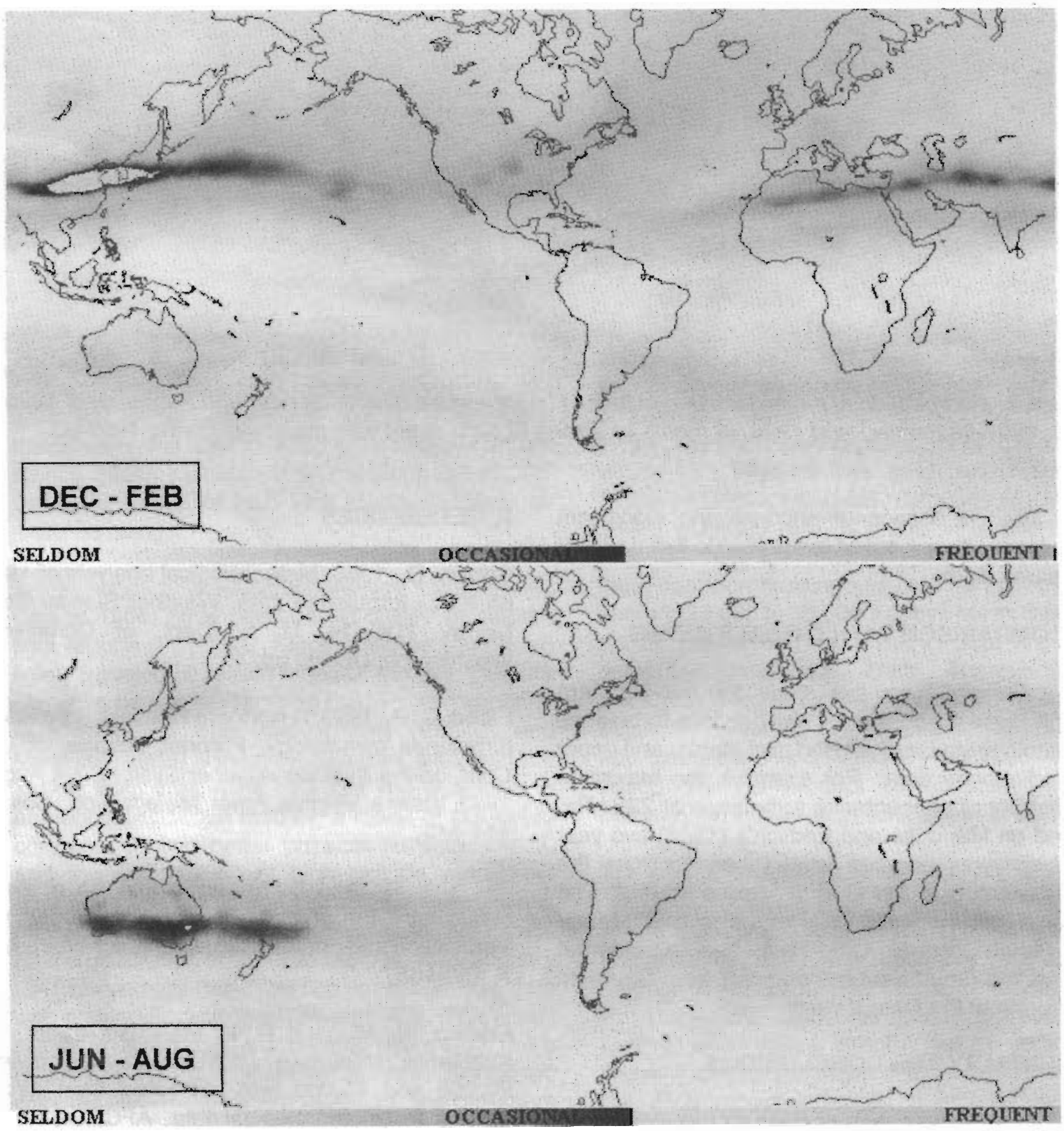

__Figure 1.__ Images derived from mean gridded Turbulence Index (TI) based on once daily (0000 UTC) Aviation Model wind data (250 - 300 hPa) for December through February (top) and June through August (lower). Data period is eight years for Northern Hemisphere, two years for Southern Hemisphere. Moderate risk areas are darker gray, frequent risk areas are lighter gray embedded within dark shades (e.g., northeast China in top panel).

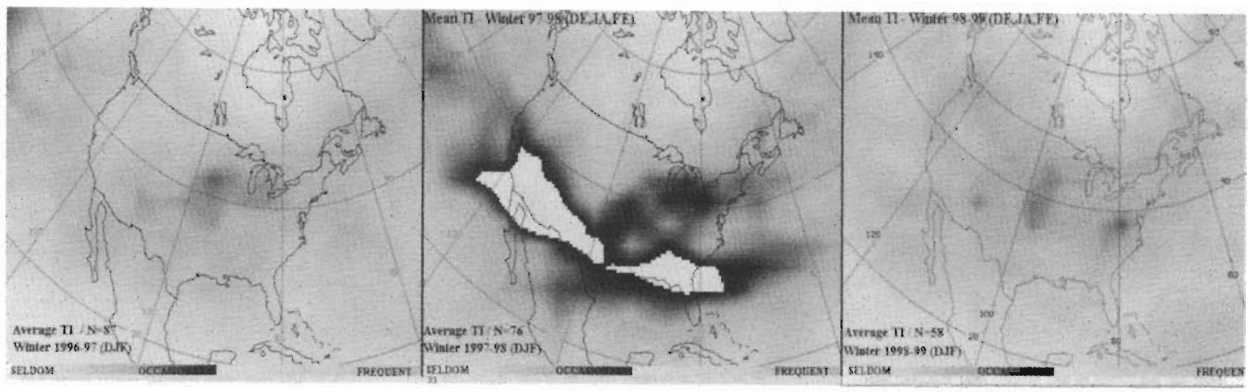

Figure 2. *Comparison of mean Turbulence Index (TI) for winters (December through February) of 1996-97 (left), 1997-98 (center) and 1998-99 (right). A strong El Nino event was underway during 1997-98.*

is a 20-25% chance of encountering significant turbulence, thus 1 out of every four to five days for the same flight.

5. COMPARISON WITH OTHER STUDIES

Results from this study for the Northern Hemisphere are consistent with previous turbulence climatology studies that used pilot reports and upper air radiosonde data. For example, the maximum probability of encountering turbulence at 225 hPa, based on Mancuso and Endlich's (1968) two year analysis, was oriented west to east across the Southwestern to the Gulf of Mexico states. The mean TI for the same level was also located over the south central U.S., but had a different orientation (southwest to northeast from Southern California to the Ohio Valley).

6. SUMMARY AND CONCLUSIONS

A global distribution of clear air turbulence has been inferred based on a mean turbulence index derived from eight years of numerical model wind and pressure height data in the Northern Hemisphere, and two years for the Southern Hemisphere. Regions of maximum CAT likelihood have been identified, as well as pronounced seasonal changes in location and intensity related to shifts in storm tracks and jet stream activity. Inter-annual strengthening probably related to the El Nino phenomenon have also been observed. It is expected that such data may be helpful to aircraft operators in planning air routes, or deciding on strategies for inflight seat belt use.

7. REFERENCES

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