JP1.18 CLIMATOLOGICAL STUDY OF AIRCRAFT TURBULENCE VERSUS CLOUD COVER

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1. INTRODUCTION

One nagging question concerning atmospheric turbulence is the relative volume, duration, and intensities of turbulence within clouds (stratiform and cumuliform) compared to clear air. This has important consequences for such fundamental issues as the determination of global dissipation rates for use in numerical weather prediction (NWP) and general circulation (GCM) or climate models and the parameterization of turbulence in such models. It also has practical importance for the verification of turbulence forecasting systems, most of which assume the source of turbulence is related to clear-air synoptic scale features such as upper-level fronts and jet streams.

Unfortunately, in-cloud versus out-of-cloud turbulence statistics cannot be obtained directly since such observations do not exist. Verbal reports of turbulence encounters by aircraft (PIREPs) are a source of information about turbulence location and intensities, however, information about whether encounters were in-cloud or out-of-cloud is usually not provided. In this paper a method is proposed and preliminary results offered which uses PIREPs in conjunction with satellite derived cloud top and observations of cloud base to determine the frequency of occurrence of both in-cloud and out-of-cloud turbulence encounters. Both positive and negative (i.e., null or smooth) PIREPs are compared to cloud top and cloud base heights and classified into regions of above cloud, below cloud, in-cloud, or clear air. The cloud top and cloud base heights are determined from output of the Integrated Icing Diagnosis Algorithm (IIDA; McDonough and Bernstein, 1999).
Although the derived statistics may have NWP or GCM implications, the major motivation for this work is to determine the effect clouds have on the performance of turbulence forecasting systems in general and the Integrated Turbulence Forecasting Algorithm (ITFA) in particular. ITFA was developed at the National Center for Atmospheric Research (NCAR) and is described elsewhere (Sharman et al., 2000), but is intended to predict upper-level, clear-air turbulence (CAT) using PIREPs for verification. The results from this study will help to determine whether the ITFA performance is negatively affected by the use of PIREPs that are actually in cloud or near cloud rather than clear air only.

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2. DATA AND ANALYSIS PROCEDURES

2.1 PIREPs

PIREPs are known to have location and timing uncertainties associated with them, and the intensity reported is a subjective assessment by the pilot. However, for many purposes they are the only routine observations of atmospheric turbulence available. The database used for this study is a collection of PIREPs gathered since November 2000, which corresponds to the beginning of IIDA cloud top and cloud base data. The PIREPs provide the latitude, longitude, altitude, time and intensity of the turbulence encounter.

A variety of factors can affect the accuracy of the PIREP location and time. These inaccuracies can come from imprecise reporting of a location and/or time of turbulence or from human error when the reports are typed in. Another error that can occur is in the altitude of the PIREP. The error occurs during the conversion of standard atmospheric pressure used by pilots to the actual pressure, which may be non-standard, resulting in an incorrect altitude of the report. After calculating a few cases it became apparent that errors in this conversion can account for an error in the reported altitude of more than 2000 ft. This makes it difficult to pinpoint the true aircraft altitude relative to cloud top and cloud base. In order to account for these uncertainties in this study, PIREPs that fall within 3000 ft. of the top of the cloud are classified as near top and PIREPs that fall within 3000 ft. of the base of the cloud are classified near base instead of in cloud or above/below cloud.

2.2 Cloud top/base Fields

The complete process by which the cloud top and cloud base heights are determined is detailed in McDonough and Bernstein (1999). To briefly summarize, the cloud top height product is created by first binning all GOES-8 IR pixels within each RUC gridpoint. If the pixels in the bin are more than 40% cloudy, then the coldest IR measured cloud top temperature is compared to the RUC temperature sounding and the cloud top height is determined by interpolating the temperature in the column. The cloud base is determined by identifying the height of the lowest cloud base from nearby surface observations, or METARs, and mapping them to the RUC gridpoints. Both the cloud top and cloud base heights are determined hourly and are based on observations near the top of the hour.

A few shortcomings are apparent in this process. Clouds can exist in multiple layers. This is very hard to detect with an automated system and may lead to over-estimates of cloud depth. Another problem is that if there is an inversion in the column at or above the highest cloud tops, then the cloud top height may be overestimated. An inversion can result in the cloud top height being placed up to 2000 ft. higher than the actual cloud top height. This usually occurs in lower levels and near the tropopause. However, PIREPs that fall within 3000 ft. of the cloud top are already being classified as unknown which helps compensate for this possible error. Also, cloud identification can be particularly difficult within the solar terminator causing some clouds to be missed.

3. RESULTS

Over the one-year study period, nearly 220,000 PIREPs were compared to cloud cover derived from IIDA when both data sets were available. The time window of comparisons is limited to PIREPs occuring within a half hour of the IIDA valid time. The reported turbulence intensities are categorized into either nulls or moderate or greater (MOG) for all altitudes and are examined by month, season and year. The seasons are broken into "summer" (April – September) and "winter" (October – March).

Each PIREP latitude, longitude and time is compared to the nearest time of available cloud top/base data and categorized as follows:

- Above: PIREP > 3,000 ft. above the cloud top
- Below: PIREP > 3,000 ft. below the cloud base
- In cloud: PIREP from 3,000 ft. above the cloud base to 3,000 ft. below the cloud top
- Near top: within 3,000 ft. of the cloud top
- Near base: within 3,000 ft. of the cloud base
- Clear air: No clouds apparent in the entire depth of the atmosphere at the latitude, longitude, and time of the PIREP

Figure 1 shows the percentage of reported smooth (null) PIREPs relative to total PIREPs of all intensities (ignoring light intensity reports which tends to be ambiguous) within each cloud category. Figure 2 shows the percentage of reported MOG PIREPs relative to total PIREPs within each cloud category. The percentage of null PIREPs that are in any of the cloud categories are 55% - 65% while the MOG percentages are 35% - 45%. Overall, there is little substantial difference in either nulls or MOG percentages across the cloud categories and the percentage of nulls to MOGs on the average across all categories is about 60% to 40%, which agrees with the PIREP climatology study of Sharman et al. (2002).

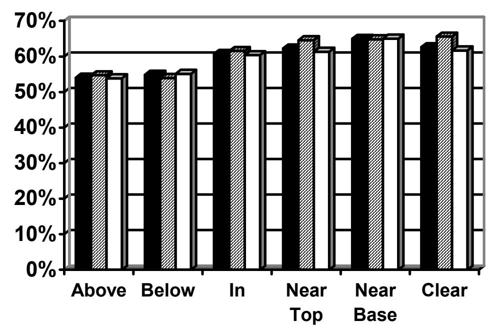

Figure 1. *Percentage of null turbulence in each cloud category: solid black, whole year; gray, summer season; white, winter season.*

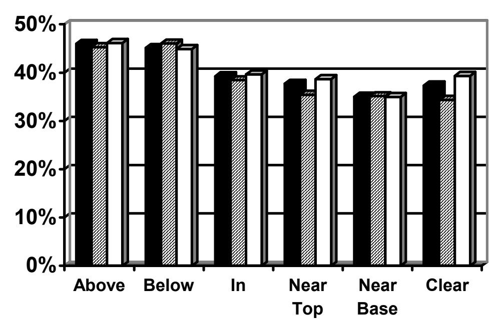

Figure 2. *Same as Figure 1 but for MOG turbulence.*

Figure 3 shows the percentage of nulls relative to TOTAL PIREPs of all intensities in all cloud categories and Figure 4 shows the percentage of MOGs relative to TOTAL PIREPs in all cloud categories. Note that the majority of PIREPs in this study, both null and MOG, are in-cloud. In addition, there are more nulls than MOGs within cloud. In both cases the percentages of PIREPs that are definitely above or below cloud is a small portion of the total, but when taken with those near the cloud top or base they could become more substantial. Without a more careful analysis of the PIREP altitude it is not possible to combine these at this time. Interestingly, the percentage of in-cloud PIREPs is not very seasonally dependent.

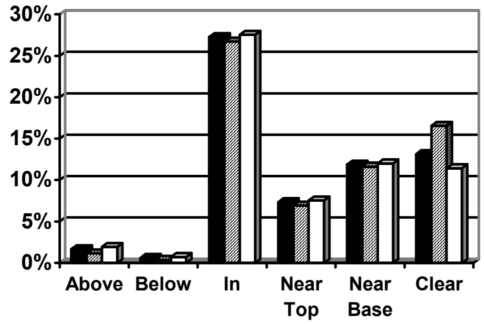

Figure 3. *Percentage of total null turbulence for all cloud categories: solid black, whole year; gray, summer season; white, winter season.*

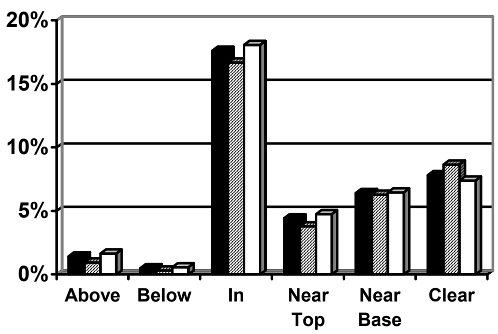

Figure 4. *Same as Figure 3 but for MOG turbulence.*

The categories of above cloud, below cloud and clear air may technically all be considered as clear air. Combining these categories, and discarding the near cloud top and near cloud base categories results in Figures 5 and 6. Nulls are more frequent then MOGs for all seasons, both in-cloud and in clear air. Also, for all seasons, the percentage of PIREPs of all intensities is greater in-cloud than in clear air, i.e., there are more reports, both of null and MOG, in-cloud than in clear air.

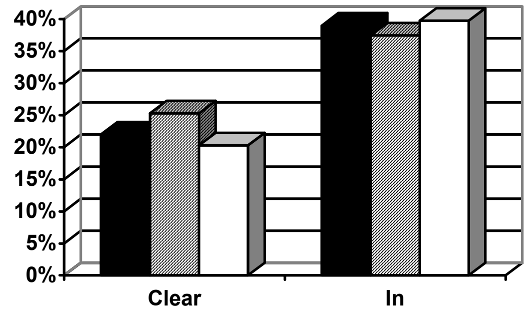

Figure 5. *Percentage of total null turbulence for clear air and in-cloud categories: solid black, whole year; gray, summer season; white, winter season.*

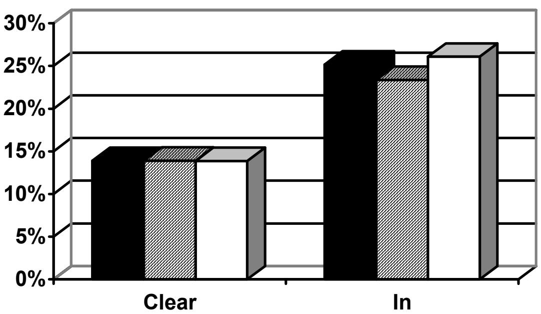

Figure 6. *Same as figure 5 but for MOG turbulence.*

Figures 7 and 8 show the percentage of PIREPs reported in different cloud depths, derived from the cloud top and cloud base data, for both null and MOG reports during the summer and winter seasons. In the case of both seasons, as the cloud depth increases, the percentage of null reports decreases and the percentage of MOG reports increases.

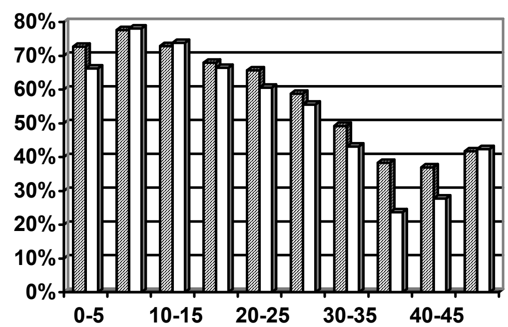

Figure 7. *Percentage of null turbulence compared to cloud depth measured in thousands of ft.: gray, summer season; white, winter season.*

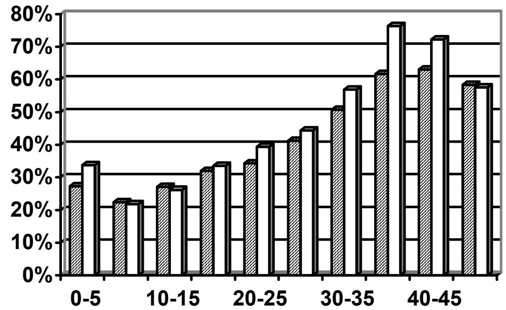

Figure 8. *Same as Figure 7 but for MOG turbulence.*

4. SUMMARY

Based on these results and of those in Sharman et al. (2002), the distribution of PIREP intensities is roughly 60% null and 40% MOG, in both clear air and in-cloud; there is no difference in the ratio of nulls to MOGs whether in-cloud or out-of-cloud. Also, the percentages of both null and MOG reports are always greater in-cloud than out-of-cloud, and those percentages do not change much with season. When concentrating on just the in-cloud reports the percentage of MOG PIREPs increases with increasing cloud depth.

However, there are several factors which may effect these results and these have to be assessed before firm conclusions can be derived. For example, if multiple cloud layers exist, some PIREPs currently being classified as "in-cloud" could fall into the "clear-air" category. However, in the summer these effects should be small, and the fact that the data are similar in summer and winter suggests that the effect may always be small, however, this needs further investigation.

In any event, the percentages of in-cloud reports versus out-of-cloud reports is likely to be an underestimate when one considers the fact that the percentage of volume of clear air at any given time over the continental United States is much greater than the percentage of volume of clouds.

Another possible issue that may be skewing the results is that commercial aircraft, which make up a great majority of the PIREPs every day, are able to get above clouds. This again may bias the results to give more clear air reports.

5. FUTURE WORK

Future work includes collection of more PIREPs to compare to cloud top and cloud base height output. Categorizing the data differently by keeping the severe and extreme reports by themselves instead of including them in the MOG category will also be looked at to see if that yields different results.

With more data the next step is to look strictly at altitudes of 15,000 ft. and above, corresponding to the altitudes of the ITFA forecasts. Comparisons of PIREPs and cloud regions will then be compared to the scores coming out of ITFA to see whether the algorithm is negatively affected by using in cloud or near cloud PIREPs at upper levels instead of using only clear air PIREPs.

Another issue that needs to be addressed is the differences in the percentage of the volume of clear skies versus clouds. This will require finding an average horizontal and vertical cloud distribution throughout the time period within the data set used and deriving a ratio of these volumes.

ACKNOWLEDGMENTS

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