P11.9 AVIATION ADVISORY CLIMATOLOGIES

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1. INTRODUCTION

Weather is a significant component of air traffic delays (Rodenhuis 2004) resulting in substantial costs[1]. The Convective SIGMET (CSIG) Climatology (Slemmer et al. 2004) has aided Federal Aviation Administration (FAA) evaluation of air traffic management performance regarding delays due to thunderstorms. Additional development of the CSIG climatology has been done. In addition, the National Climatic Data Center (NCDC) has taken over the routine generation of monthly convective frequencies (CF) that are provided to the FAA. The CSIG Climatology method has also been applied to other aviation advisories issued by the Aviation Weather Center (AWC). Examples of these climatologies will be presented along with a discussion on their potential value in further supporting air traffic management with the intent of reducing delays.

2. DATA AND METHODOLOGY

ASCII text files of each type of aviation advisory are processed to calculate their respective frequency of occurrence including Convective SIGMETs (thunderstorms), Non-convective SIGMETs (severe icing, severe turbulence), International SIGMETs (thunderstorms, tropical storms, severe turbulence, volcanic ash), and AIRMETs (moderate icing, moderate turbulence, IFR, mountain obscuration). All data is processed in a similar manner as described in Slemmer (2004). Additional diagnostics were developed such as a mean CSIG frequency over pre-defined areas, the frequency of when CSIGs are near major airports, average CSIG sizes for each month and year across the Continental United States (CONUS), and the CF distribution of different CSIG shapes (area, line, and isolated circles) across the CONUS.

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3. ADDITIONAL CSIG CLIMATOLOGY INFORMATION

3.1 Routine CSIG Climatology Production

Routine production of the CSIG monthly maps is performed at NCDC and can be found at http://lwf.ncdc.noaa.gov/oa/climate/research/sigmet/. The FAA is using this information to assess air traffic management performance.

Monthly maps showing the distribution of CF and graphs showing the average CF for the map area are generated for the CONUS, four regions of the CONUS, 20 Air Route Traffic Control Centers plus the Northeastern coastal waters, and for areas within a 75 nautical mile (nm) radius around 20 major airports (Fig. 1a). Anomaly maps are also generated for the same areas by taking the difference between a month's CF and that month's 1995 to 2004 mean CF (Fig. 1b). In addition, hourly and weekly CF maps and graphs may soon be added to this web-site. The CONUS CF maps agree well with Charba (2005).

3.2 CSIGs near Major Airports

Figure 2 shows the frequency of how many major airports had at least one CSIG within a 75 nm radius for each hour of July from 1995 to 2004. From around midnight to the late morning hours, only a few major airports had CSIGs near them. By the late afternoon when the greatest frequency usually occurs, around one-third of these airports had CSIGs near them about two-thirds of the time. In rare instances, nearly three-quarters of the airports will have active CSIGs then.

During July most airports have peak frequencies around 22 UTC when maximum heating occurred, but the diurnal ranges and trends vary. Atlanta (ATL) CSIG occurrences (Fig. 3a) were strongly driven by the diurnal cycle with nearly half the time having CSIGs near the airport around peak heating and very few occurrences in the late morning. ATL had the least CSIG occurrence near

[1] Data from the Air Transport Association, MIT Lincoln Labs, and National Research Council available at the following Cooperative Program for Operational Meteorology , Education, and Training (COMET) web-site: http://meted.ucar.edu/nas/indepth/id_costs.htm

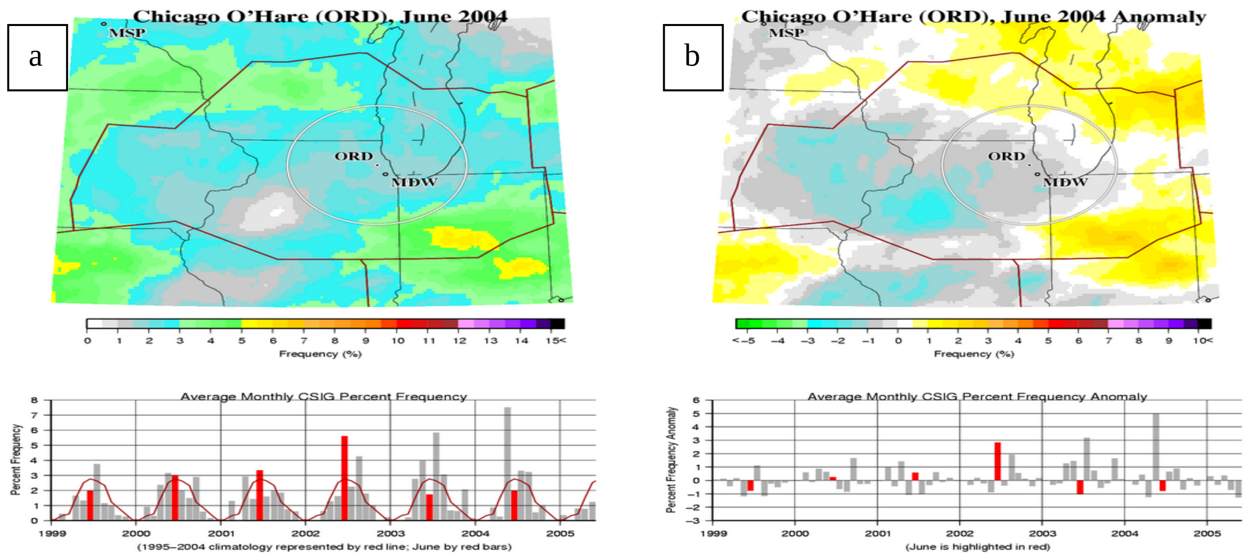

Figure 1. June 2004 Convective SIGMET Frequency (CF) maps and graphs (bar graph by month from January 1999 to May 2005): a) Chicago O'Hare (ORD) CF map and CF average value b) Chicago O'Hare (ORD) anomaly CF map and CF average anomaly value.

the airport of these four airports in the early morning. New York La Guardia (LGA) has a similar pattern as ATL although less extreme (Fig. 3b). Chicago O'Hare's (ORD) CSIG occurrence near the airport is more evenly distributed throughout the day due to more nocturnal convection events (Fig. 3c). Dallas/Fort Worth (DFW) had the least overall CSIG occurrence during July of these four airports since a sub-tropical high usually persists over the region during July resulting in a suppression of convection (Fig. 3d). There also appeared to be a second well defined peak in CSIG occurrences in the late morning which may be a result of nocturnal convection that originated further to the northwest having finally arrived into the area.

3.3 CSIG and Weather Anomalies

Correlations between weather patterns and associated thunderstorm development have been done using the NCEP/NCAR reanalysis data (http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl). These correlations may be particularly useful when attempting to anticipate future aviation impacts, especially as the accuracy of long range forecasting increases. As an example, CF's in May 2004 (Fig. 4a) were much higher than normal over the southern Great Lakes region due to anomalous ridging along the East coast and anomalous troughing over western Canada (Fig. 4b). A strong front persisted over the southern Great Lakes with above normal lift and moisture present (not shown) resulting in much above

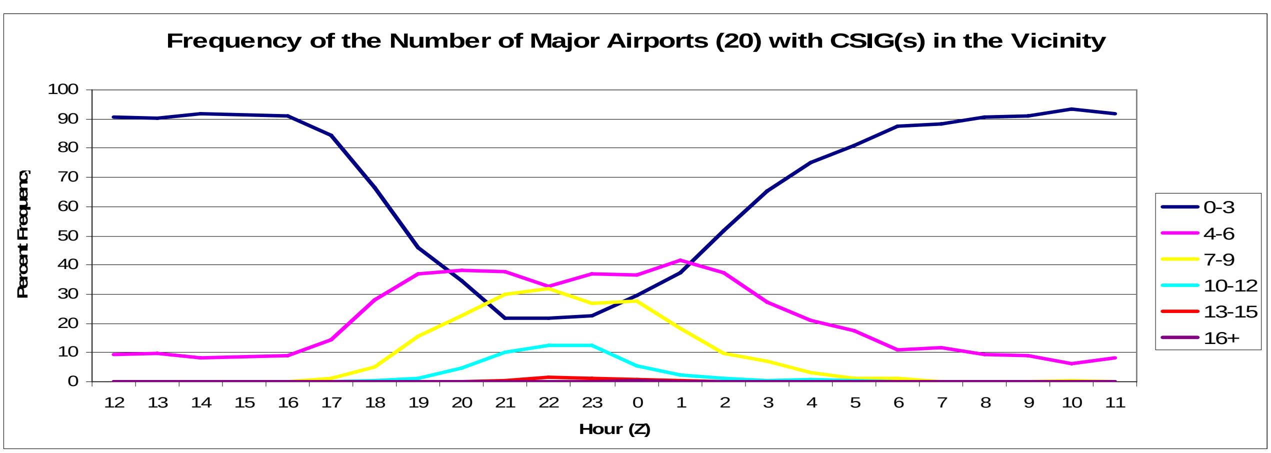

Figure 2. Number of major airports with active CSIG(s) within 75 nm by hour for July (1995 to 2004).

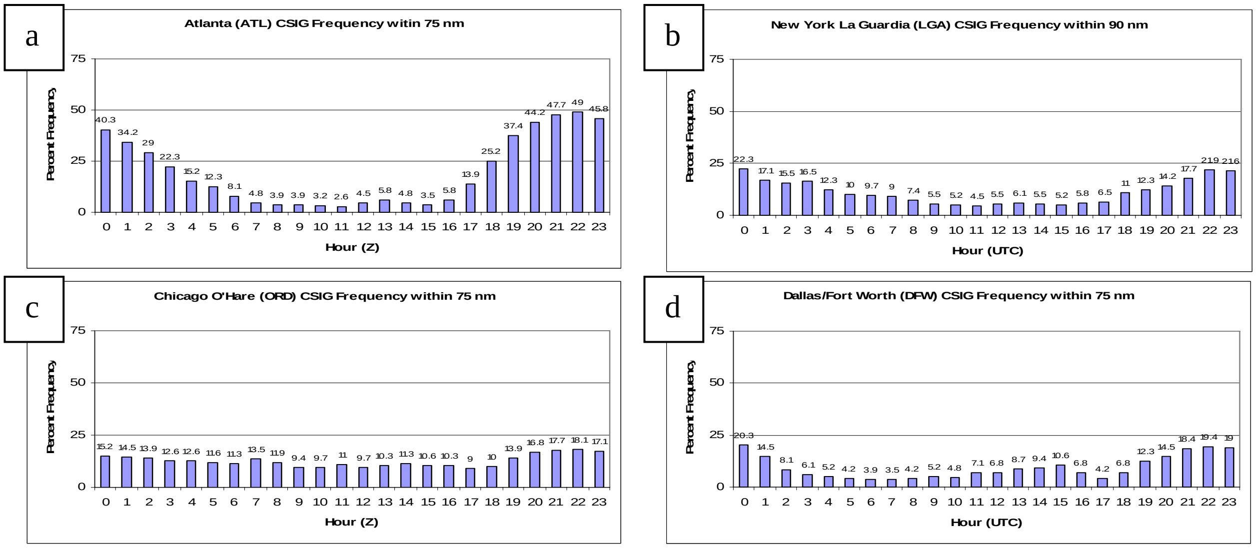

Figure 3. Frequency of CSIGs within 75 nm of a major airport by hour for July (1995 to 2004) a) Atlanta (ATL) b) New York La Guardia (LGA) c) Chicago O'Hare (ORD) d) Dallas Fort Worth (DFW).

normal convection. May 2005 had much below normal convection across the eastern CONUS (Fig. 4c). The height anomalies were nearly opposite as compared to May 2004 with much of the East under more stable northwest flow (not shown) due to anomalous troughing along the East Coast (Fig. 4d). By subjectively doing similar comparisons, it was found that large anomalies in CF values frequently correlated well with the anomalous weather patterns (not shown).

3.4 CSIG Issuances and Size

The number of annual CSIG issuances has been

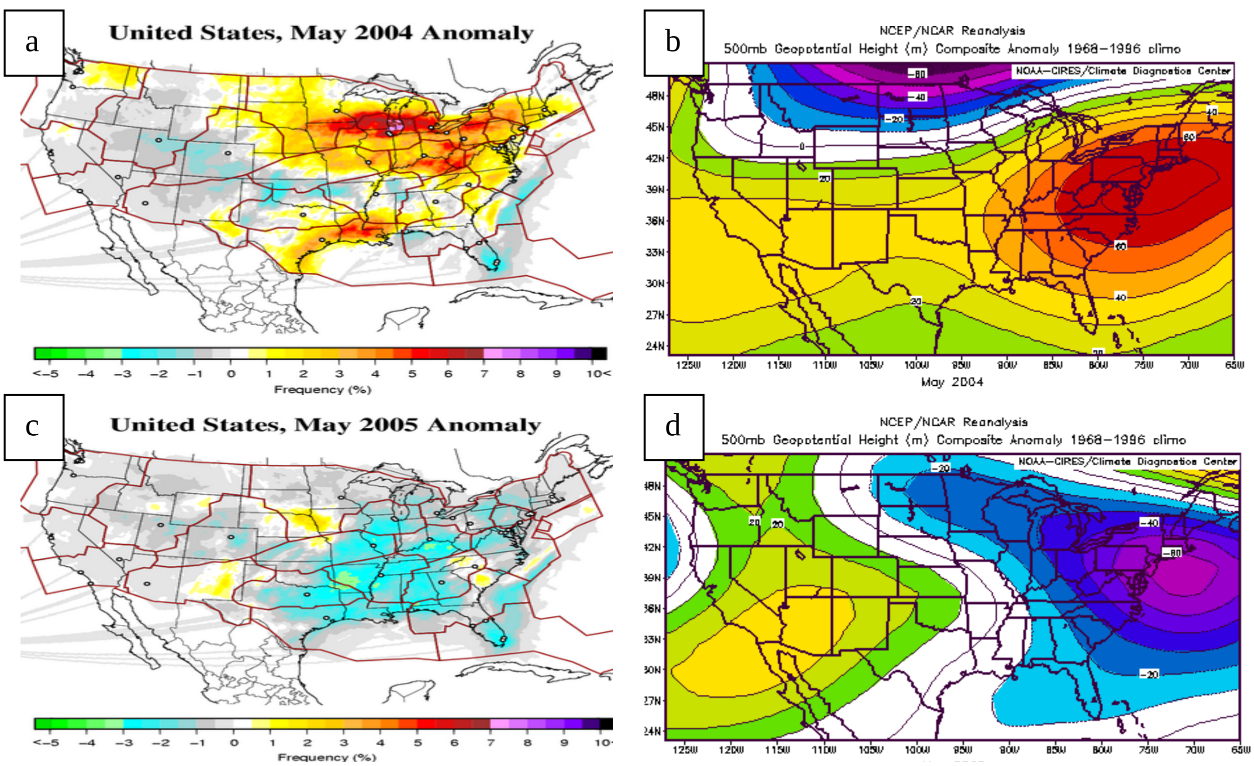

Figure 4. Anomalous CF and 500-mb height maps a) CONUS May 2004 anomalous CF b) CONUS May 2004 anomalous 500-mb heights c) CONUS May 2005 anomalous CF d) CONUS May 2005 anomalous 500-mb heights.

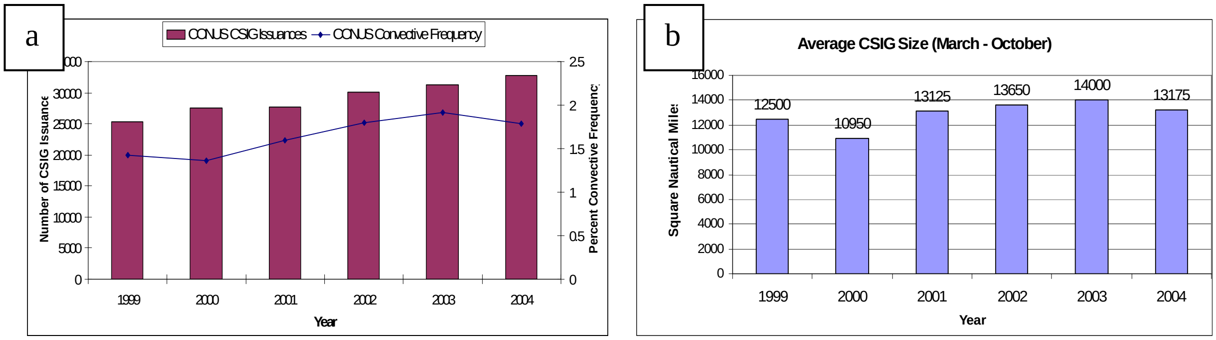

Figure 5. a) Number of annual CSIG Issuances and average CF values across the CONUS from 1999 to 2004. b) Average annual CSIG size (square nm) from March through October (1999 to 2004).

steadily increasing in recent years. It was initially thought that the number of CSIG issuances was increasing because better technology was allowing the forecaster to issue smaller, more precise CSIGs (Fig. 5a red bar graph). During this period (1999 to 2004), the average CF values were also increasing at a similar trend (Fig. 5a blue line). Consequently, the number of CSIG issuances was mostly increasing during this period because there was more convection to capture. Figure 5b shows that the overall CSIG size has not changed much from 1999 to 2004 during the convective season (March through October). This information is significant because the increase in the CONUS CF in recent years may also have resulted in greater air traffic weather related delays since thunderstorm frequency can be a major component of delays depending on time and location of occurrence. Although 2005 has yet to be assessed completely, initial results suggest that the CF in the Northeast and surrounding areas which are particularly sensitive to weather impacts will be lower in 2005 as compared to recent years which may result in overall fewer weather related aviation delays.

This information also provides some insight into the characteristics of CSIGs such as how CSIG size relates to where and when convection occurs. Figure 6 shows the number of CSIG issuances and average CSIG size by month from January 1999 to November 2004. The number of monthly CSIG issuances reaches a maximum in the summer and minimum in the winter. In general, the average CSIG size also follows this pattern with a maximum in the summer and minimum in the winter. September 2004 had the largest average monthly CSIG size because large CSIGs typically covered convection associated with three hurricanes that impacted the Southeast while the rest of the CONUS had very little convection. July 2001 had the second largest average CSIG size because the West had much above normal convection while the East had much below normal. The typical CSIG in the West is typically large due to the more scattered nature of the convection as compared to the East.

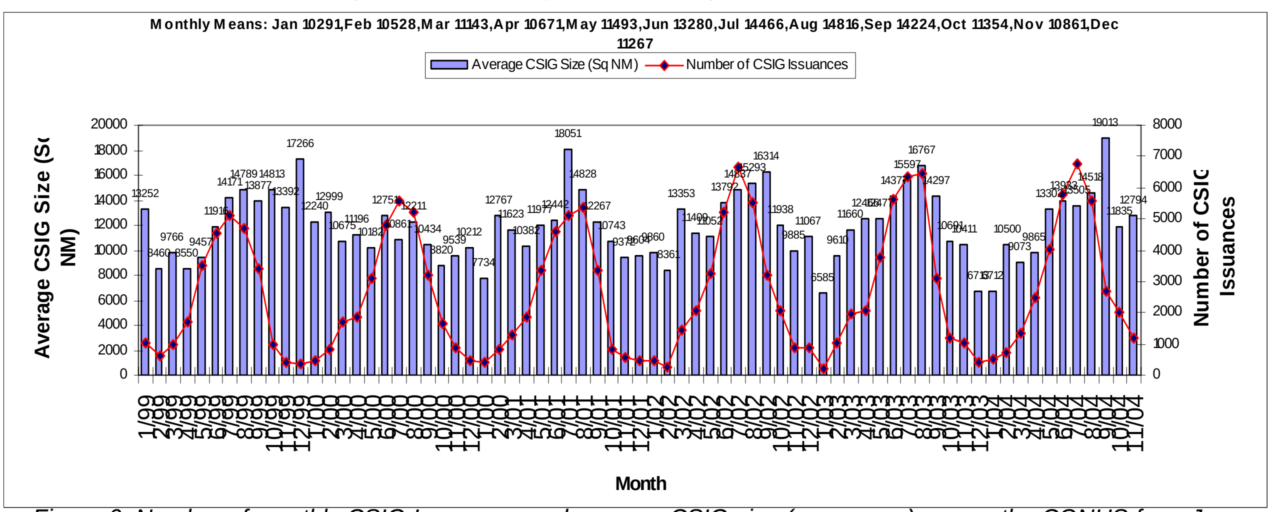

Figure 6. Number of monthly CSIG Issuances and average CSIG size (square nm) across the CONUS from January 1999 to November 2004.

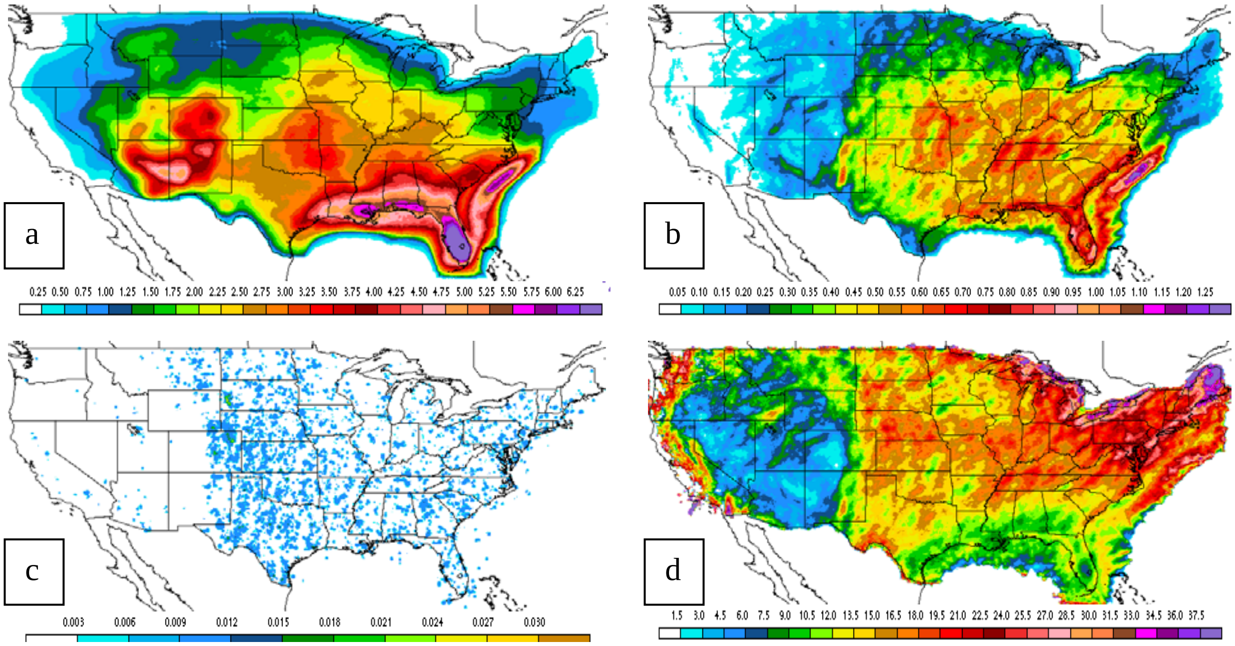

Figure 7. CONUS CF distribution for different CSIG shapes from March through October (1995 to 2005) a) areas b) lines c) isolated circles d) Frequency CSIG is a line when a CSIG occurred.

3.5 CF Distribution of Different Shapes

CSIGs can assume three different shapes when describing convection which are areas, lines, or circles. Areas were the most common and represent approximately 87 percent of the CONUS CF distribution during the convective season (March through October) from 1995 to 2005. Figure 7a shows the CF distribution of CSIG area shapes across the CONUS during this time. Similarly, Figure 7b shows the CF distribution of CSIG line shapes which represent approximately 13 percent of the CONUS CF distribution. Only about 0.001 percent of the CONUS CF distribution is represented by circles which are issued for either isolated severe or isolated embedded convection (Figure 7c). The Black Hills of South Dakota and portions of the Front Range extending from near the Wyoming/Nebraska/Colorado border region into East Central Colorado had the highest overall isolated frequencies. The Plains were also a region of higher frequencies probably due to isolated severe storm initiation along dry lines. In some cases, the area around large cities also had relatively high isolated frequencies.

Figure 7d shows the CONUS distribution of how often a CSIG is a line when a CSIG occurs. The greatest line frequency occurs in the Northeast ranging from about 20 to 40 percent of the time which suggests that when convection occurs it is frequently associated with fronts. The least line frequency occurs in portions of the Southwest where convection is typically more scattered and not associated with fronts. Florida has higher lines frequencies along coasts where land and sea breeze interactions are the greatest versus the inland areas.

4. OTHER AVIATION ADVISORY CLIMATOLOGIES

The CSIG climatology method has also been applied to other aviation advisories issued by the AWC such as Non-convective SIGMETs (severe icing and severe turbulence), International SIGMETs (thunderstorms, severe turbulence, tropical storms, and volcanic ash), and AIRMETs (moderate icing, moderate turbulence, IFR, and mountain obscuration). For additional information on criteria used for issuing these products, refer to http://www.nws.noaa.gov/directives/010/pd01008011d.pdf.

Since these products are issued for periods of either four or six hours, they tend to be a blend of both observed and forecasted conditions, whereas the CSIG is in essence an hourly observation of significant convection. Due to the infrequent number of issuances associated with some of these products, some of the frequency maps will appear "blocky" since the data is not smoothed and individual products can occasionally be seen. Amendments, corrections, and cancellations were ignored in order to simplify the data processing.

In addition, these product issuances, especially AIRMETs, can be greatly influenced by the quantity of pilot reports. For example, the same

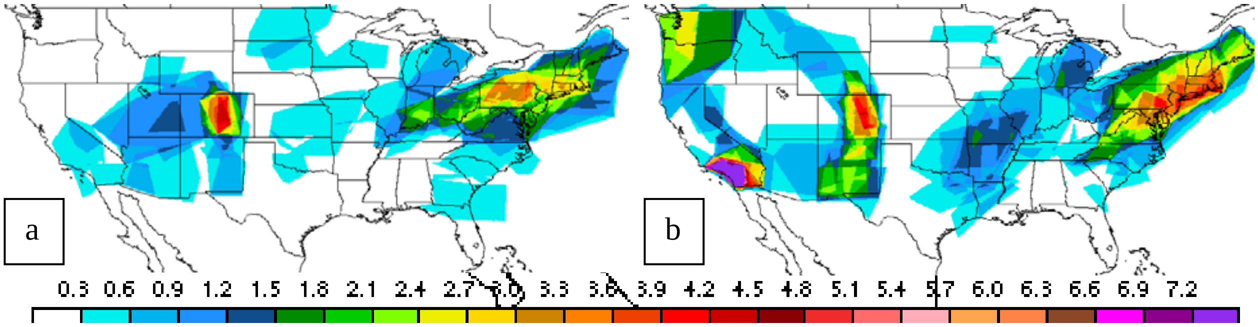

Figure 8. March 2002 to 2004 Non-convective SIGMET frequencies a) severe high-level turbulence b) severe low–level turbulence.

area of weather may generate more pilot reports of more significant weather depending on the time of day (00 UTC versus 12 UTC) and the location (Northeast versus the Northern Plains).

This additional aviation advisory climatology information may prove useful to the FAA in further assessing air traffic management performance.

4.1 Non-Convective SIGMETs

Non-convective SIGMETs are issued for a period of four hours across the CONUS for severe icing and turbulence.

Figures 8a-b shows the frequencies of high-level and low-level turbulence SIGMETs for March 2002 to 2004. High-level turbulence SIGMETs were most commonly issued over the central Rockies and the Northeast (Fig. 8a). Low-level turbulence tended to be most commonly issued in the Pacific Northwest, Southern California, along and in the lee of the Rockies, and along and in the lee of the Appalachians (Fig. 8b).

4.2 International SIGMETs

International SIGMETs issued by the AWC cover much of the northwestern Atlantic, portions of the northeastern Caribbean and the central Gulf of Mexico, and the North Pacific Ocean. International SIGMETs of thunderstorms and turbulence are issued for a period of four hours while tropical storms and volcanic ash are issued for a period six hours.

Figure 9a shows the tropical storm issuances for August 2005 within the Atlantic Basin domain which is within the five areas denoted by the thick black lines. The development of Hurricane Katrina can be seen in the western Bahamas and its subsequent path through the eastern and central Gulf of Mexico. In addition, a couple of tropical storm paths can be seen in the Atlantic. Figure 9b shows the tropical storm issuances for August 2001 to 2005 within the Pacific Basin domain which is within the two areas denoted by the thick black lines. The most common location for tropical systems in the Pacific Basin domain during these five years is in the southeastern corner where eastern Pacific tropical storms occur. Also, sometimes western Pacific tropical storms can track into the extreme western portion of the

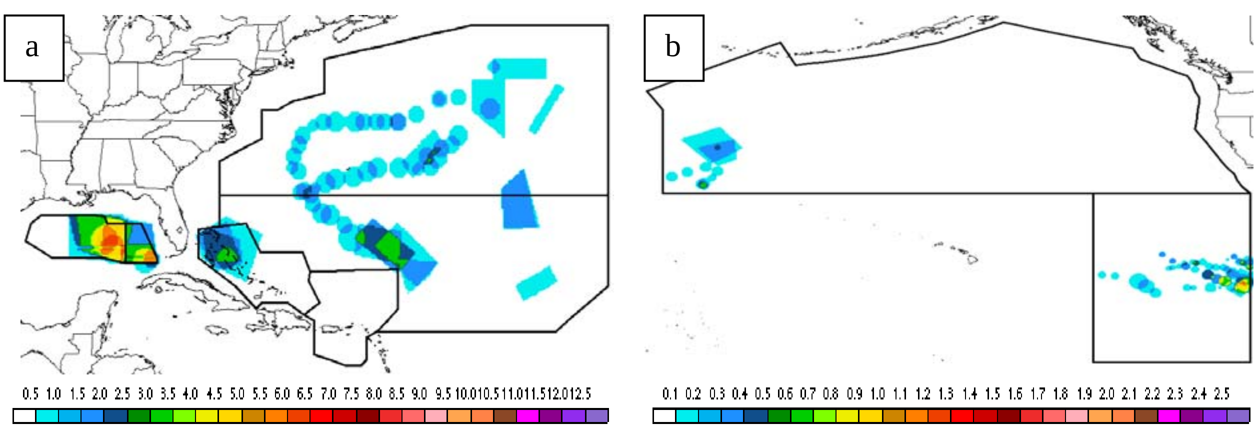

Figure 9. International SIGMET frequencies a) August 2005 Atlantic tropical storms b) August 2001 to 2005 Pacific tropical storms.

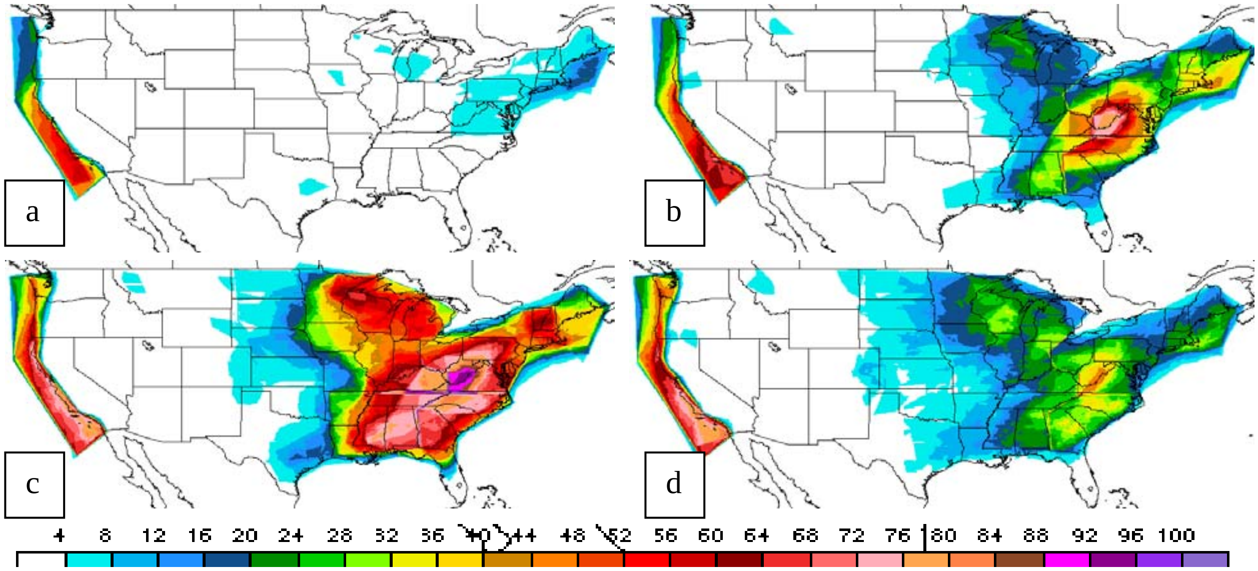

Figure 10. IFR Airmet frequencies for August 2001 to 2003 a) 00 UTC b) 06 UTC c) 12 UTC d) 18 UTC.

Pacific Basin domain. All of these tropical storms are relatively small compared to the tropical storms in the Atlantic Basin since they are typically weakening as the storms usually encounter cool sea surface temperatures in the Pacific Basin domain.

4.3 AIRMETs

AIRMETs are typically issued for a period of six hours across the CONUS for moderate turbulence and icing, IFR conditions, and mountain obscuration. The synoptic hour was used to describe the time of issuance which is basically centered around the typical AIRMET issuance times.

Figures 10a-d shows the diurnal nature of widespread IFR conditions from August 2001 to 2003. At 00 UTC (Fig. 10a), IFR AIRMET frequencies occurred about half the time in the California coastal waters but is less in the Pacific Northwest and very little exists in the East with the highest occurrence in the Northeast coastal waters. At 06 UTC (Fig. 10b), IFR AIRMET frequencies have greatly increased in the East with a maximum of around 75 percent frequency in the central Appalachians and IFR conditions are also increasing in the western coastal waters. By 12 UTC (Fig. 10c), IFR AIRMETs were often issued East of the Mississippi River and occurred almost 100 percent of the time along the border between Virginia and West Virginia. IFR AIRMETs have also peaked across much of the western coastal waters and have moved into the inland valleys. By 18 UTC (Fig. 10d), IFR AIRMET frequencies have greatly decreased in the East and have generally decreased a little along the West Coast. IFR AIRMET frequencies were rarely issued if at all for the interior West, High Plains, and southern Florida.

Figures 11a-f shows the AIRMET frequencies for 12 UTC for the three year period from May 2001 through April 2004. The Northeast has relatively high AIRMET frequencies which may be due to the higher traffic volume which results in more pilot reports of potentially more adverse weather conditions.

Moderate icing was most common in the Great Lakes/Northeast and also in the Pacific Northwest occurring as frequently as 30 to 45 percent of the year (Fig. 11a). A noticeable decrease in icing AIRMET frequency occurred in the lee of the Rockies. Icing frequency results tended to agree well with findings generated from pilot reports during the winter season (Young, et al. 2003 and Bernstein, et al. 2003).

Moderate low-level turbulence was most common in the Northeast, along and in the lee of the Rockies, Pacific Northwest, and southern California (Fig. 11b). The complex terrain in these areas contributed to the higher low-level turbulence frequencies of around 25 percent.

Moderate high-level turbulence tends to follow the jet stream around the ridge along the West coast and the trough in the Great Lakes and is more pronounced in the Rockies at around 25 percent and in the Northeast at around 20 percent (Fig. 11c). The interaction with the high terrain in the Rockies contributes to the maximum in high-level turbulence frequency but reasons for the

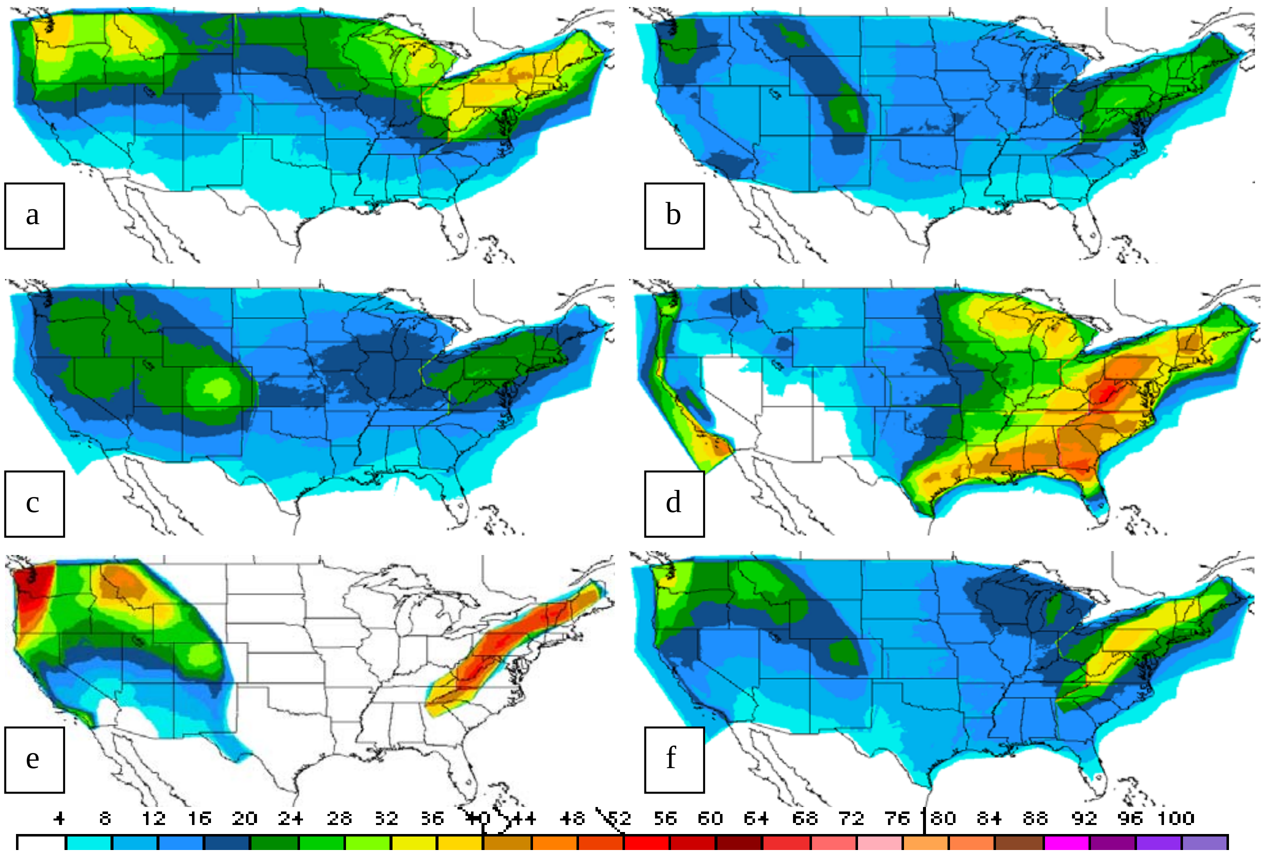

Figure 11. AIRMET frequencies for 12 UTC from May 2001 to April 2004 a) icing b) moderate low-level turbulence c) moderate high-level turbulence d) IFR e) mountain obscuration f) composite of all AIRMETs.

relatively high frequency in the Northeast are less clear and may be due to more frequent pilot reports or a more active storm track region. A previous climatology of high-level turbulence (Sharman, et al. 2003) was difficult to compare to this study, however it did agree well with the central Rockies having the highest frequency.

Widespread IFR conditions were most common along the Gulf Coast, the Appalachians, the Great Lakes, and the West Coast with about a 30 to 50 percent frequency (Fig. 11d). The highest frequency (55 percent) was located in West Virginia and along the Georgia/Florida border. Other notable regions of higher IFR frequency were in the Sacramento Valley and northern portions of the valleys in the inter-mountain region. IFR AIRMETs are rarely issued for the Southwest.

Mountain obscuration AIRMETs were issued frequently for many of the significant mountainous regions such as the Appalachians, northern/central Rockies, the Pacific Northwest, and the California coastal mountains (Fig. 11e). The southern Rockies and interior Southwest had a notable lack of mountain obscuration AIRMET frequencies.

Figure 11f is a composite of the other five figures showing the overall AIRMET frequencies. The highest frequencies of AIRMETs were along the Appalachians followed by the Pacific Northwest, central Rockies, and Great Lakes. The lowest frequencies of AIRMETs were in southern Florida followed by the desert Southwest and the High Plains. Since mountain obscuration has a relatively high frequency, many mountainous regions particularly standout. A potentially more useful way of assessing overall weather impacts would be to give different weights to the parameters rather than having equal weights for all parameters which could also include SIGMETs.

One of the parameters describing where icing and turbulence is occurring in their respective advisories is a vertical range done in increments of a thousand feet. Thus, the AIRMET frequency of icing or turbulence can be calculated in the vertical every thousand feet.

Figures 12a-d shows the frequency of moderate turbulence at various flight levels for December through February of 2002 to 2004. Central Colorado had the most consistently high overall frequencies ranging from 40 to 50 percent throughout. At 5000 feet MSL (Fig. 12a), the Northeast and Mid-Atlantic had a large area of

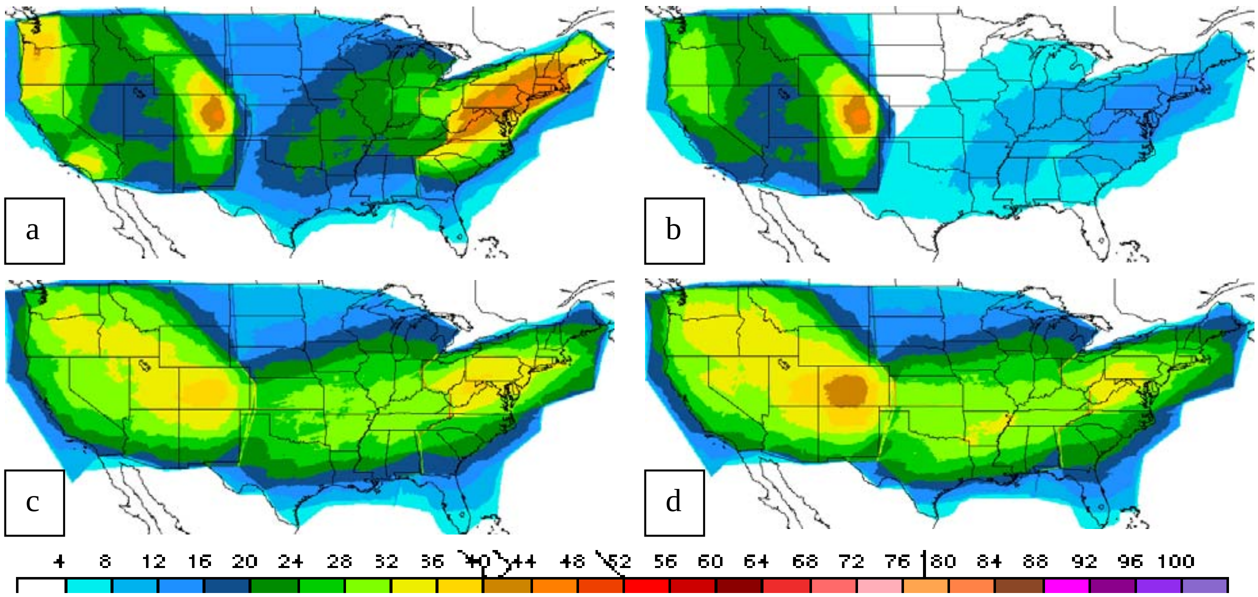

Figure 12. Turbulence AIRMET frequencies at specific flight levels for December through February (2002 to 2004) a) 5,000 ft MSL b) 15,000 ft MSL c) 25,000 ft MSL d) 35,000 ft MSL.

frequencies from 40 to 50 percent and high frequencies also occurred over the Pacific Northwest, Southern California, and along and in the lee of the Rockies. At 15,000 feet MSL (Fig. 12b), the geographical distribution of the higher frequencies had not changed much but all areas except for the Rockies had seen decreases, especially the Northeast which had only a 10 to 15 percent frequency. At 25,000 feet MSL (Fig. 12c), the influence of the jet stream generated more widespread and higher frequencies across the much of the CONUS and the pattern of the higher frequencies is suggestive of the typical weak ridge in the West and weak trough in the Great Lakes. At 35,000 feet MSL (Fig. 12d), not much has changed from 25,000 but the frequencies were slightly lower in the Northeast and slightly higher in the South and West possibly indicative of a lower tropopause in the Northeast during the winter. Turbulence AIRMET frequencies decrease quickly with increasing altitude at around 40,000 feet MSL (not shown).

Figures 13a-d shows the frequency of moderate icing at various flight levels for December through February of 2002 to 2004. Two regions that consistently had the highest frequencies are in the

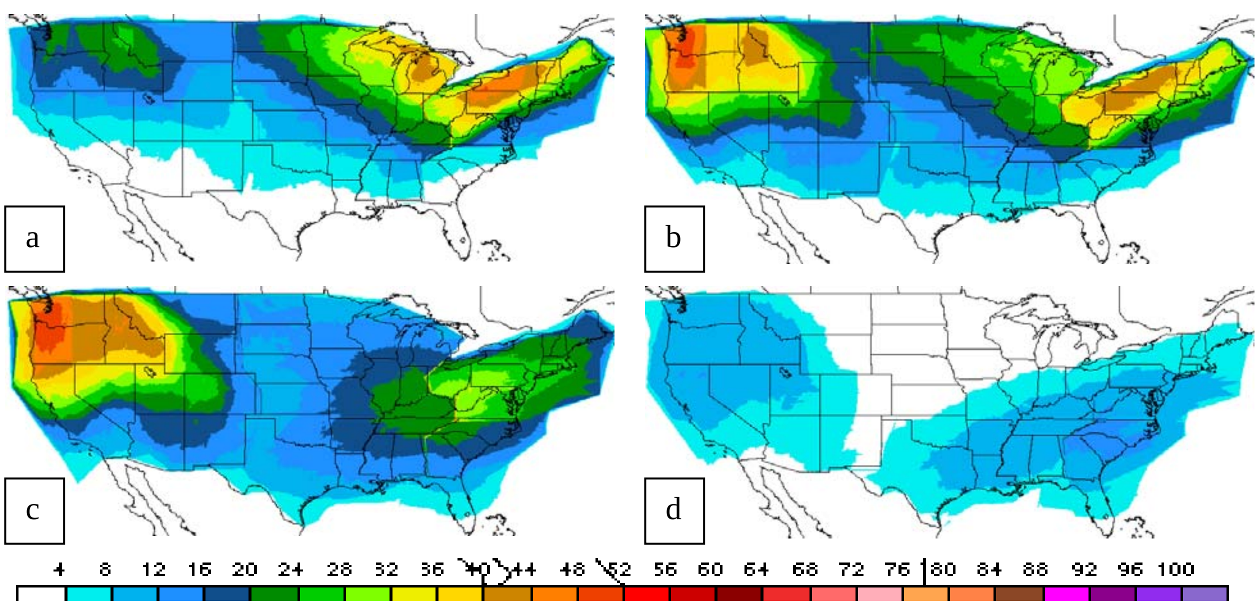

Figure 13. Icing AIRMET frequencies at specific flight levels for December through February (2002 to 2004) a) 3,000 ft MSL b) 9,000 ft MSL c) 15,000 ft MSL d) 21,000 ft MSL.

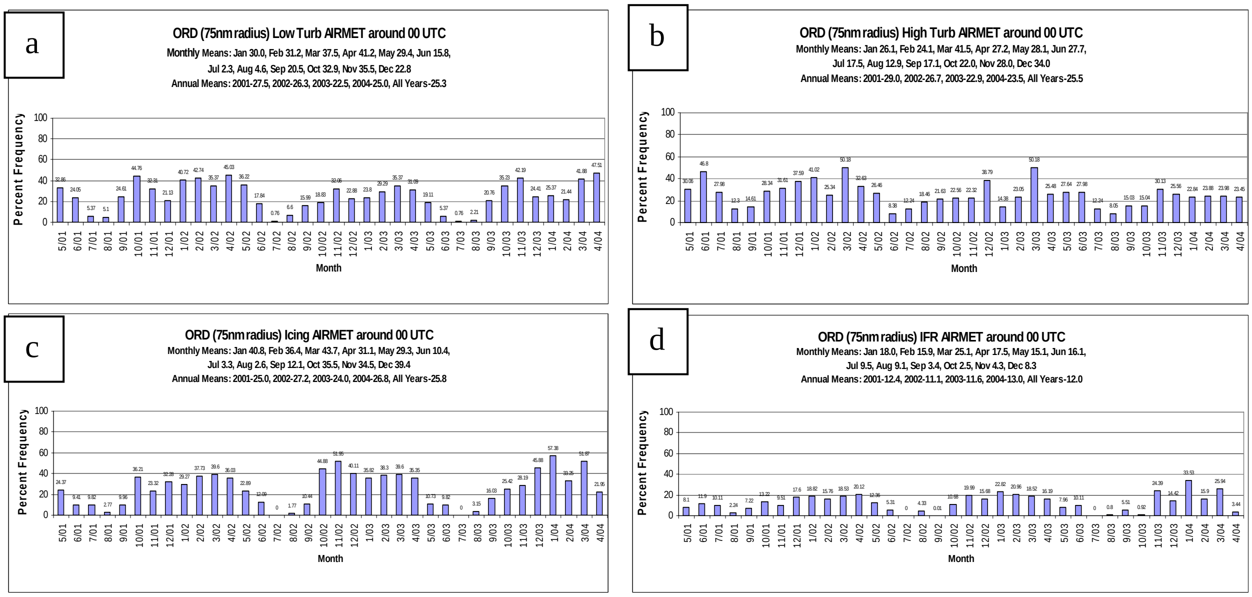

Figure 14. Graphs showing the average AIRMET frequencies for the area within 75 nm of Chicago O'Hare (ORD) by month for 00 UTC from May 2001 to April 2004 a) moderate low-level turbulence b) moderate high-level turbulence c) moderate Icing d) IFR.

Northwest and the Great Lakes region, although the Great Lakes region area migrates to the southeast with increasingly higher altitudes. At 3000 feet MSL (Fig. 13a), the highest frequency area extended from the upper Mid-West southeastward into the Northeast with highest frequencies of around 40 to 50 percent in the lee of the Great Lakes. The far Northwest had frequencies as high as 25 percent. At 9000 feet MSL (Fig. 13b), the geographical distribution of the area in the Great Lakes region had not changed but the frequencies are slightly less while the frequencies in the Northwest have increased substantially. At 15,000 feet MSL (Fig. 13c), the Great Lakes region had migrated to the southeast centered over the central Appalachians as higher altitude temperatures had become too cold to support ice in the upper Mid-West and the highest frequencies have decreased to around 30 percent. The area in the Northwest had further expanded to cover much of the West except for the desert Southwest and peak frequencies are in western Oregon and Washington ranging from 50 to 60 percent. At 21,000 feet MSL (Fig. 13d), temperatures were frequently too cold to support ice across the CONUS, so a significant decrease in frequencies had occurred with peak frequencies of 10 to 15 percent in the West and Southeast. The former Great Lakes icing region in the lower altitudes has shifted to the Southeast where freezing levels are higher.

The same method of calculating the average areal frequency of CSIGs has been applied to AIRMETs. Figures 14a-d shows the average areal frequency of AIRMETs within a 75 nm radius of Chicago O'Hare (ORD) by month for 00 UTC from May 2001 to April 2004. The peak in the frequencies for all AIRMETs occurred from October through May with all AIRMETs except for IFR with monthly averages around 30 to 35 percent frequency and peak monthly frequencies as high as 50 to 60 percent. IFR frequencies during this time had an average monthly frequency of 15 to 20 percent with peak monthly frequencies around 25 percent. Hardly any AIRMETs were ever in effect during the summer months with the exception of high-level turbulence which had around a 10 percent frequency.

5. DISCUSSION

When greater than normal aviation advisory frequencies occur over sensitive air routes or near major airports, air traffic impacts may increase. The CSIG climatology is being used by the FAA and other entities within the National Oceanic and Atmospheric Administration and the airlines to assist in evaluating air traffic management performance with the intent of improving future air traffic management decision making. Since Slemmer (2004), additional techniques have been developed to analyze aviation advisory climatology information in order to further support air traffic management. Resultant mitigation of air traffic weather impacts could lead to substantial cost savings. In the future, the aviation advisory climatologies could be incorporated into an air traffic management matrix that would generate recommendations on when the best times would be to use or avoid particular air traffic routes or major airports in order to mitigate aviation weather impacts. Correlations between weather patterns and aviation advisory climatologies may also prove useful in predicting which air traffic routes or major airports would be the most impacted by adverse weather in the longer range, especially as the accuracy of long range forecasting improves.

6. ACKNOWLEDGEMENTS

The author wishes to thank Steve Silberberg of the AWC for reviewing this manuscript. The author also wishes to thank Jay Lawrimore and Jesse Enloe of NCDC for managing the routine production of the CSIG Climatology.

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