Forecaster Assessment of Turbulence Algorithms: A Summary of Results for the Winter 2002 Study

Jennifer Luppens Mahoney[1], Tressa Fowler[2], Barbara G. Brown[2],
Jamie Braid[2], Chris Fischer[1,3], Mike Kay[1,3], and Jamie Wolf[2]

Submitted to:
FAA Aviation Weather Research Program Turbulence Product Development Team

16 October 2002

[1]NOAA Forecast Systems Laboratory, 325 Broadway R/FS5, Boulder, CO 80305-3328
[2] National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80303
[3] Cooperative Institute for Research in the Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80305.

1. Introduction

This report summarizes a subjective evaluation of the forecasting capability of the Integrated Turbulence Forecasting Algorithm (ITFA). This report is one in a series of reports that has been funded by the FAA Aviation Weather Research Program (AWRP) Turbulence Product Development Team (PDT) to assess quality of the ITFA algorithm as evaluated by operational forecasters at the Aviation Weather Center (AWC). Previous studies (Mahoney and Brown 2000; Mahoney et al. 2001) are available on the Web at http://www-ad.fsl.noaa.gov/fvb/rtvs; link publications.

The goals of the evaluation were to: 1) supplement the objective assessment with a meteorological classification of turbulence events, 2) identify the frequency of the meteorological factors leading to turbulence, 3) obtain a subjective evaluation of algorithm performance, and 4) compare the differences/similarities between the objective and subjective assessments of the quality of the turbulence forecasts. Addressing the concerns of the 2001 evaluation, the questionnaire used for this evaluation was modified so that individual turbulence cases could be identified and more easily compared with the objective results.

Two separate groups, the forecasters at the AWC and the airline dispatchers at ComAir, were asked to evaluate the quality of ITFA from 9 February to 9 April 2002. Only the evaluations from AWC are included in this report. The ITFA developers are analyzing the comments provided by ComAir to evaluate performance of ITFA for specific turbulence cases.

The information presented in this document is intended to supplement the objective verification information provided in Brown et al. (2002) and is used to help identify some of the strengths and weakness associated with ITFA. This report is organized as follows. The study approach is presented in Section 2. Section 3 describes the results and a summary is provided in Section 4.

2. Description of Assessment

As compared to previous subjective exercises, the methodology for this evaluation was slightly modified. The changes include: 1) only the performance of ITFA was evaluated while other turbulence algorithms were excluded from the evaluation, 2) the questionnaire was modified so that specific turbulence regions could be identified, and 3) the questionnaire was distributed and completed electronically.

The ITFA algorithm was designed to predict clear-air turbulence (CAT) at altitudes above 20,000 ft over the continental U.S. (CONUS). It is applied to data from the RUC-2 (Rapid Update Cycle, version 2) model (Benjamin et al. 1998), with model output obtained from the National Centers for Environmental Prediction Environmental Modeling Center (EMC). The enhanced 20-km version of the RUC was not available at the time of this evaluation. ITFA uses fuzzy logic techniques to integrate available turbulence observations [in the form of voice pilot reports (PIREPs)] together with a suite of turbulence diagnostic algorithms to obtain a turbulence forecast (Sharman et al. 1999).

Model forecasts issued at 1200, 1500, 1800, and 2100 UTC, with lead times of 0, 3, 6, 9, and 12 hours were included in the evaluation, although not all leads were available for all issue times. The evaluation was limited to the region of the atmosphere at 20,000 ft and above.

Displays of the various CAT algorithms were created at NCAR and made available to the forecasters in a variety of ways; through ADDS (http://adds.aviationweather.gov/), through the RTVS Web site (http://www-ad.fsl.noaa.gov/fvb/rtvs; link turbulence; link forecast displays), and on the forecasters' NAWIPs workstations. The forecasters were asked to view the displays each day and compare the output from these model-based forecasts to their assessment of the location of CAT, its strength, and its source (e.g., mountain waves). Forecasters were allowed to use all available sources of data and observations [e.g., pilot reports (PIREPs), satellite data, model forecasts] to evaluate these CAT features. An example of an ITFA display is presented in Fig. 1. The gray/black areas represent areas of turbulence as indicated by ITFA. The variations in color represent different turbulence intensity. The forecasters were able to obtain larger views of each panel by clicking on the selected image.

During the evaluation period, forecasters at the AWC were asked, but not required, to fill out a questionnaire each day during their shift describing the weather situation at a specific time period and the performance of ITFA in capturing the character of the turbulence at that time. Since this process was voluntary, only a subset of the total number of turbulence cases was classified.

The questionnaire addressed two main topics, a classification of the turbulence and an assessment of ITFA performance. In Section 1 of the questionnaire, the forecasters first addressed the location of the turbulence. In particular, they were allowed to select from ten regions based on the FA regions used by AWC forecasters (SFO-north, SFO-south, SLC-north, SLC-south, CHI-west, CHI-east, DFW-west, DFW-east, BOS, and MIA); any number of regions could be selected. In addition, the forecasters were asked to describe the severity, cause, altitude, and time frame of the turbulence events in each region. In Section 2, forecasters assessed the quality of ITFA by describing the lead/issue times considered in the evaluation, the overall performance, the severity, and altitude of the turbulence as forecasted by ITFA. All of the questions allowed the forecasters to provide separate responses for each region of interest. The questionnaire, shown in Appendix A, was created with guidance from other members of the Turbulence PDT and then enhanced based on feedback from the forecasters and other AWC staff prior to the start of the evaluation. The forecasters completed the questionnaire on a web site and submitted it electronically for inclusion in the study.

In addition to the evaluation at AWC, dispatchers at ComAir were also asked to evaluate the quality of ITFA forecasts. Although the number of surveys collected from

ComAir was insufficient for statistical analysis and are excluded from this report, the details provided by the dispatcher comments are being analyzed and used to improve the ITFA forecasts. ComAir dispatchers were also instrumental in soliciting an additional 275 PIREPs reports that were used to enhance the verification dataset.

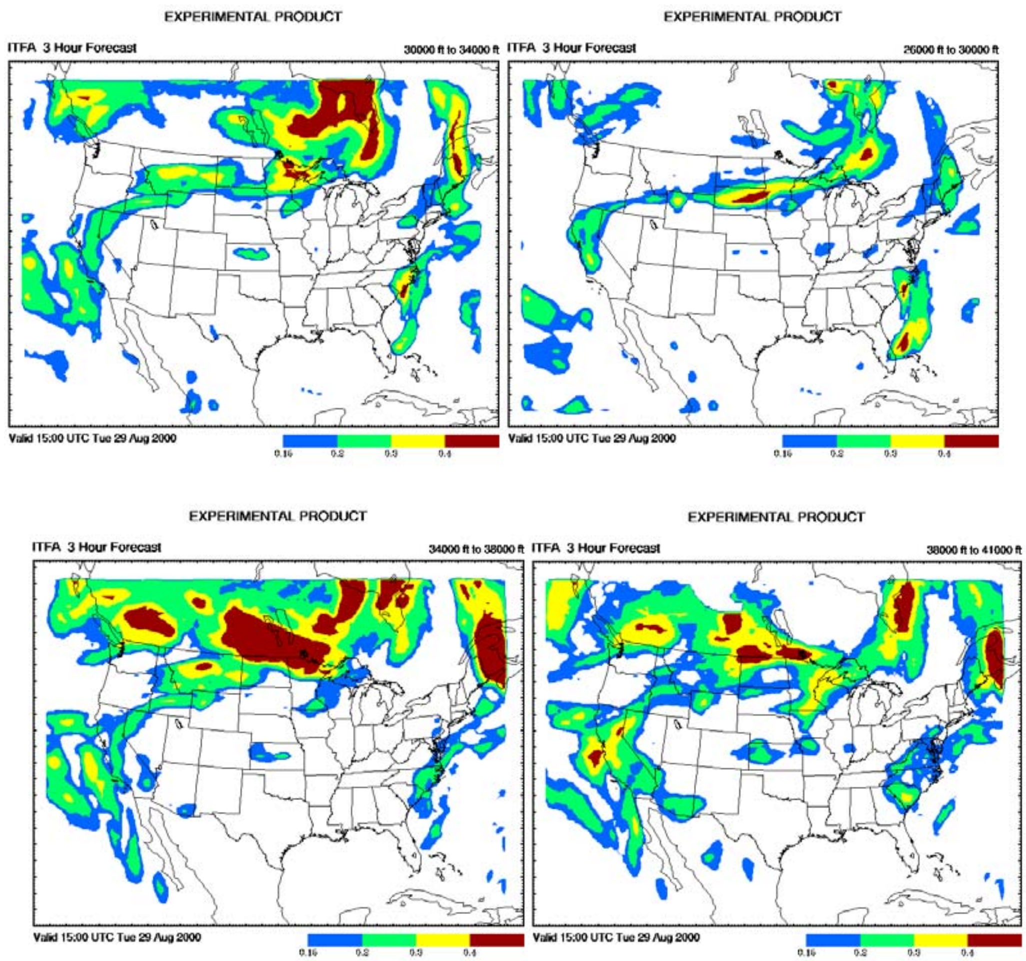


Figure. 1. Experimental ITFA, 3-h forecasts. Each panel represents forecasts for different sets of flight levels; various shades indicate different turbulence severities.

3. Results

Seven AWC forecasters completed 165 evaluation forms from 9 February – 9 April 2002. A distribution of the number of responses received by forecaster is shown in Fig. 2. The largest number of surveys received from a single forecaster was 17 while the smallest number was only 2. Other forecasters not listed on the pull down menu completed thirteen of the questionnaire forms and were classified as “unknown” on the questionnaire. In addition, on 12 of the submitted forms, the forecaster could not be identified.

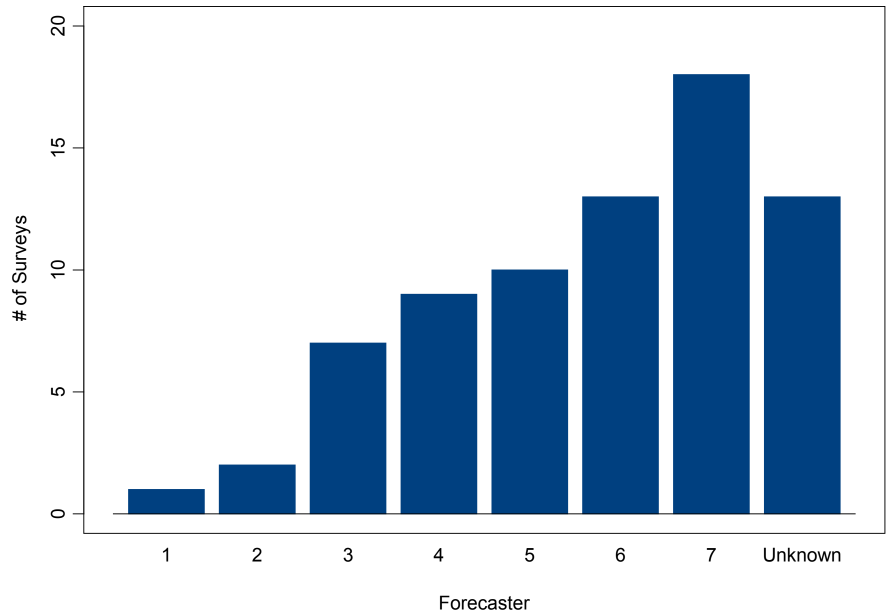


Figure 2. Histogram indicating the number of responses received per forecaster.

3.1 Turbulence Description

As part of the evaluation, the AWC forecasters were asked to characterize the turbulence at the time when they were evaluating the performance of ITFA. The responses to the weather description section of the questionnaire are summarized below.

In an attempt to capture specific turbulence cases, the forecasters were asked to classify the turbulence into 16 regions (shown in Appendix A). The results shown in Fig. 3 indicate that the turbulence events in the Salt Lake City-South region received the greatest percent of responses. The Boston region had the second greatest response rate while the fewest responses were submitted for the San Francisco-South region. The large number of responses gathered for the Salt Lake City-South region may have been due to the larger volume of airspace covered by that region or due to a larger response rate from personnel monitoring that turbulence region.

As shown in Fig. 4, more than half of the turbulence events were caused by the jet stream, while about a third were from “other” or unlisted causes. In future questionnaires it would be valuable to ask the forecasters to indicate what phenomenon they are thinking of when they indicate “other.” Mountain waves accounted for nearly 10% of the events. Upper ridges, upper troughs, and convection were infrequently identified as the remaining causes of turbulence.

When the turbulence severity was considered, the maximum severity (Fig. 5) was moderate or greater for over 90% of the cases. Less than 10% of the cases were light and nearly 30% of the cases were severe or greater.

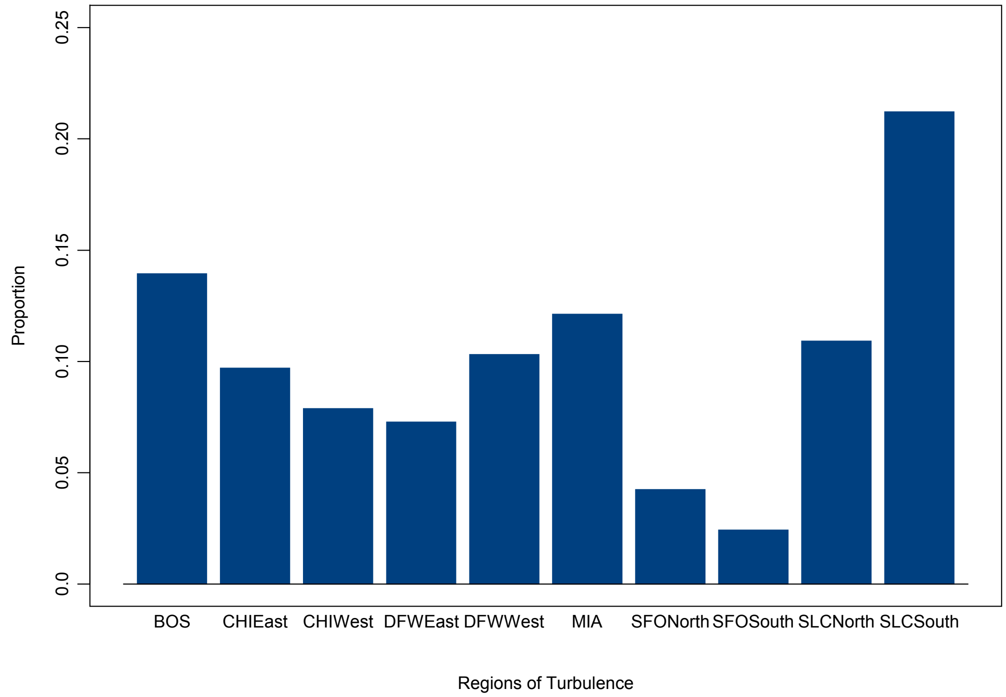


Figure 3. Histrogram of turbulence cases as classified by forecast region.

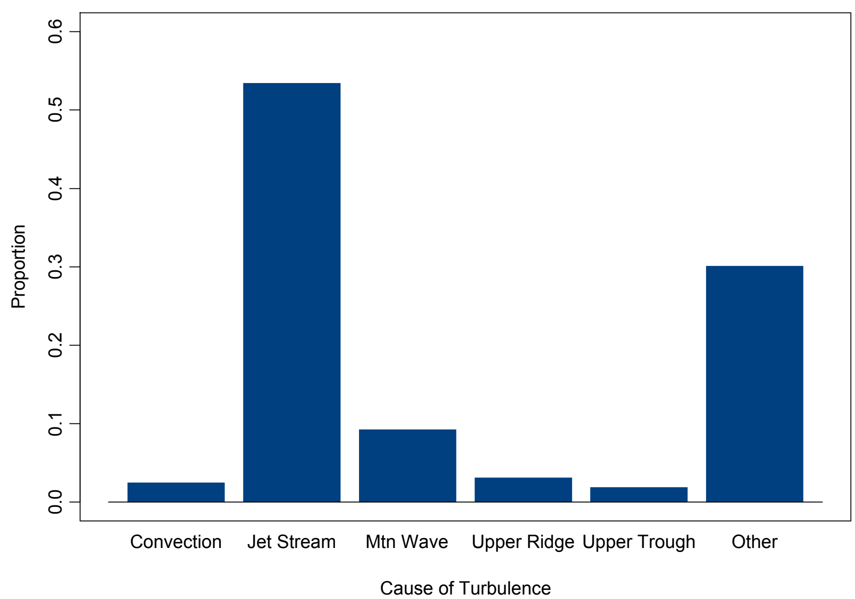


Figure 4. Histogram indicating causes of turbulence as identified by AWC forecasters.

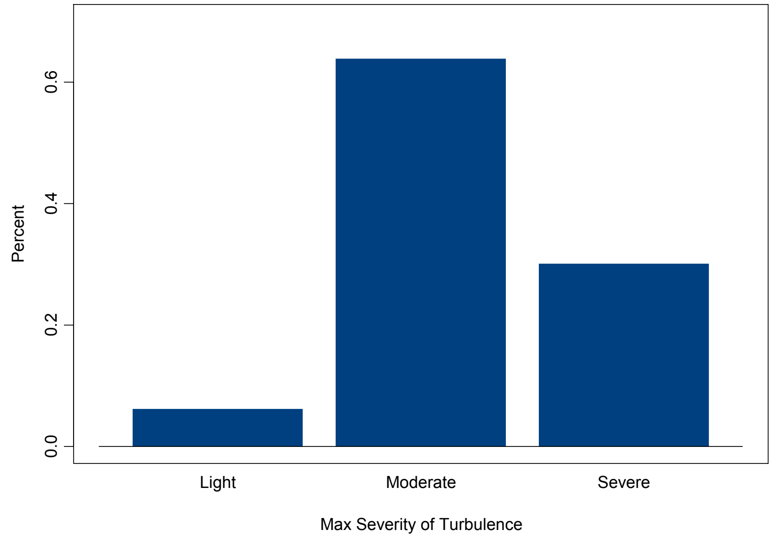


Figure 5. Histogram indicating maximum severity of turbulence as identified by AWC forecasters

Nearly all turbulence events with known duration exceeded 4 hours. However, over a third of the turbulence events evaluated by the AWC forecasters had an unknown duration (Fig. 6). These cases may actually be very short events that are characterized by only a small number of PIREPs, making it difficult to determine exactly how long they persisted; alternatively, they may be events that span forecast shift changes. Thus, the events of short duration may be as frequent as those of longer duration, but are more difficult to categorize correctly.

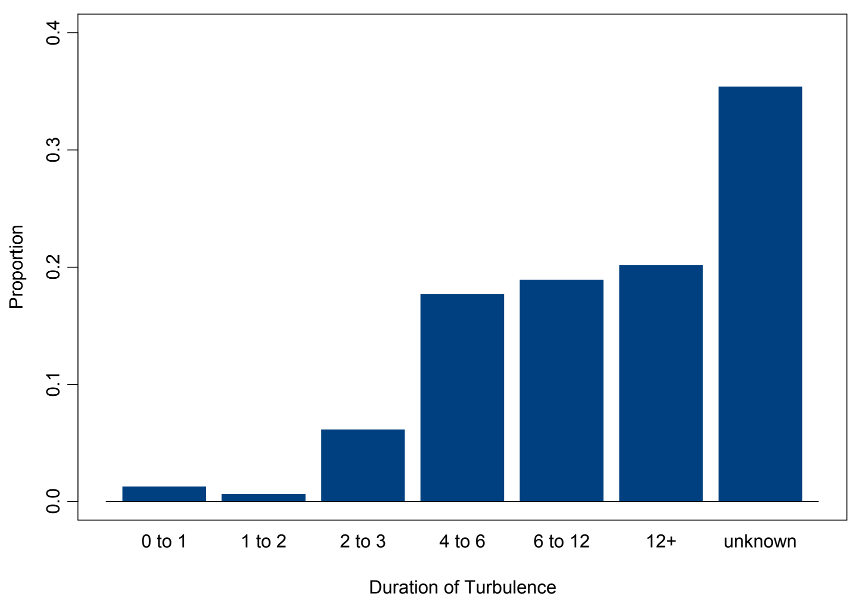


Figure 6. Histogram indicating turbulence duration.

3.2 ITFA Evaluation

The AWC forecasters were asked to evaluate the overall performance of ITFA pertaining to the over- or under-forecasting of the turbulence region, coverage of turbulence by ITFA, severity, and altitude location. The responses are summarized in Figs. 7 - 9.

As summarized by the AWC forecasters, nearly half of the ITFA forecasts captured turbulence *about right* (Fig. 7). About one third of the cases were judged to *underforecast* the turbulence. The remaining 20% of the events were considered to be *overforecast* by ITFA.

The AWC forecasters were asked to characterize the size of the turbulence forecasts and the results of this evaluation are shown in Fig. 8. It may seem that the information regarding the over/under/correct forecast designation presented in Fig. 7 would be closely related to the classification of the size of the forecast shown in Fig. 8. However, this does not appear to be the case. If an *about right* forecast (Fig. 7) was of *about right* size (Fig. 8), then the percent of responses in these categories would be roughly equal. However, the forecast was *about right* nearly half the time (Fig. 7), while the size was *about right* less than 20% of the time (Fig. 8). Similarly, *underforecast* and *Too Small* were selected 36% and 57% of the time, respectively. However, the *overforecast* and *Too Large* designations were chosen in much closer proportions, 16% and 24% respectively. The results are consistent in the fact that both *underforecast* and *too small* were selected more frequently than *overforecast* and *too large*.

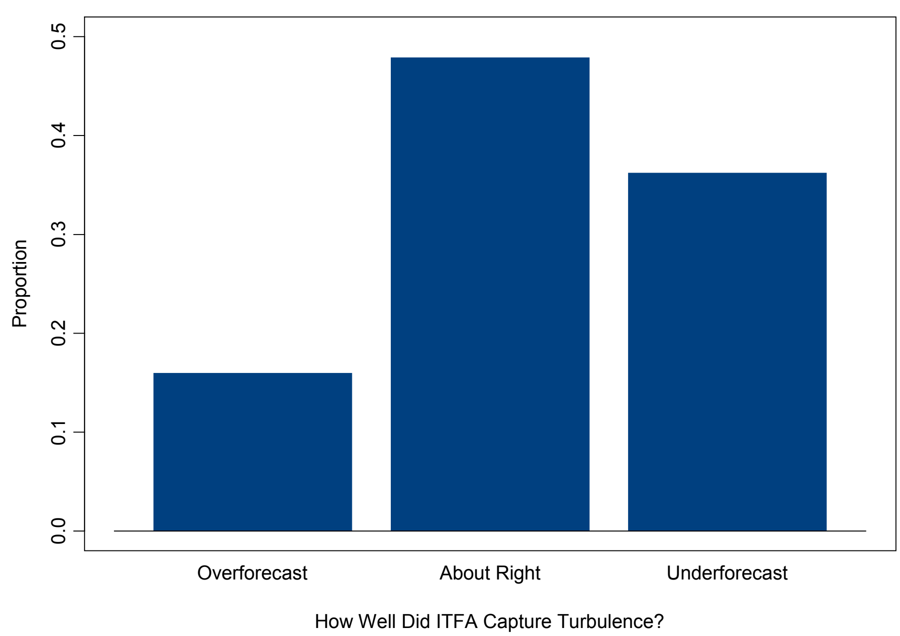


Figure 7. Histogram indicating whether ITFA overforecast/underforecast or captured the turbulence just about right.

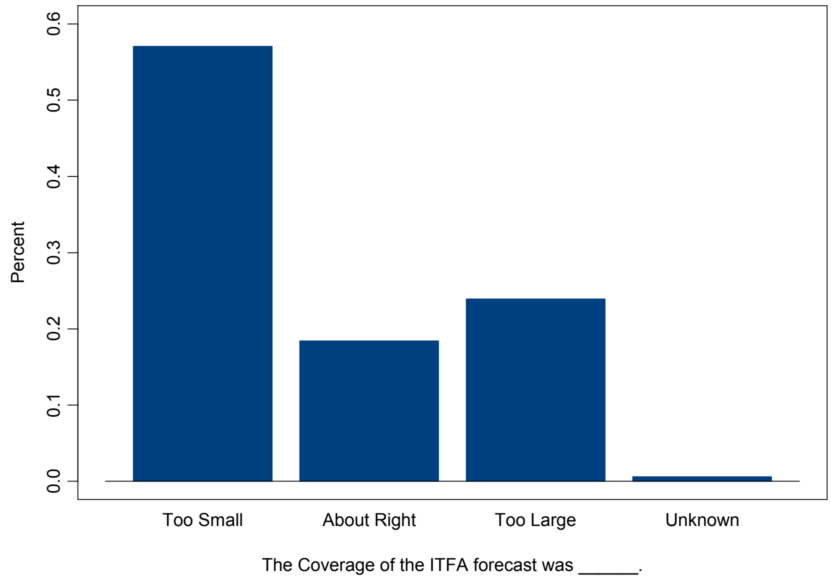


Figure 8. Histogram indicating the coverage of turbulence as indicated by ITFA.

The severity of turbulence as forecast by ITFA, was *about right* in roughly 40% of the events evaluated (Fig. 9). For over half of the cases, the indicated severity *was too light.* Rarely, for less than 10% of the events, did ITFA forecast turbulence at an intensity that was judged to be *too severe*.

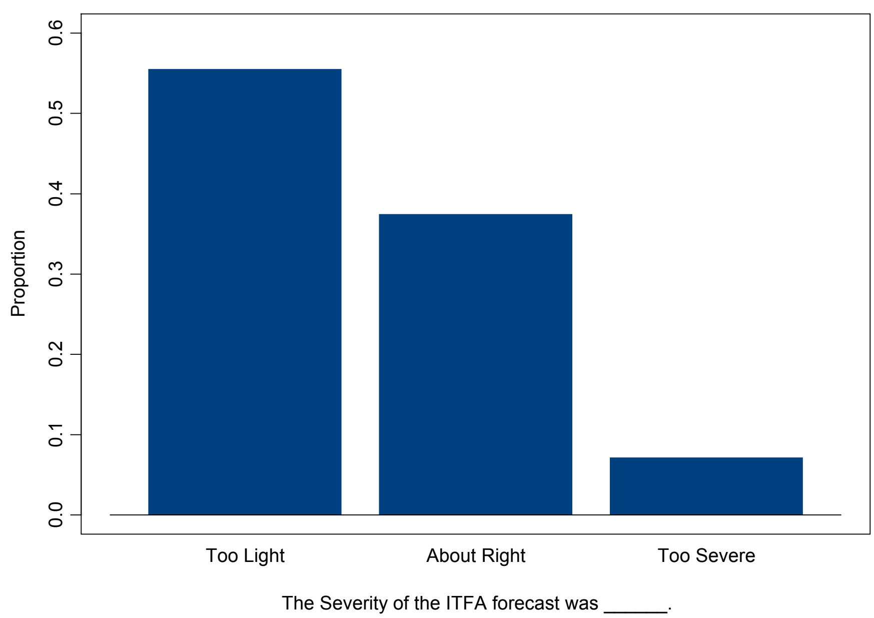


Figure 9. Histogram indicating the severity of turbulence as indicated by ITFA.

Intercomparisons between the results that were previously presented are summarized in Figs. 10-14. Through this analysis, some surprising discrepancies between questions were discovered.

The results from a comparison between the actual turbulence, as defined by the AWC forecaster, and the severity of turbulence as forecasted by ITFA are presented in Fig. 10. When the actual turbulence was severe, the severity predicted by ITFA was *about right* in 73% of the cases. However, when the true turbulence was light or moderate, the forecasters judged that ITFA tended to forecast turbulence that was less severe than what was actually encountered. Because each bar in Fig. 10 represents 100% of the column total, the percentages on the chart can be misleading when the column totals are small. The total counts for each category are shown in Table 1. In this case, the true severity of

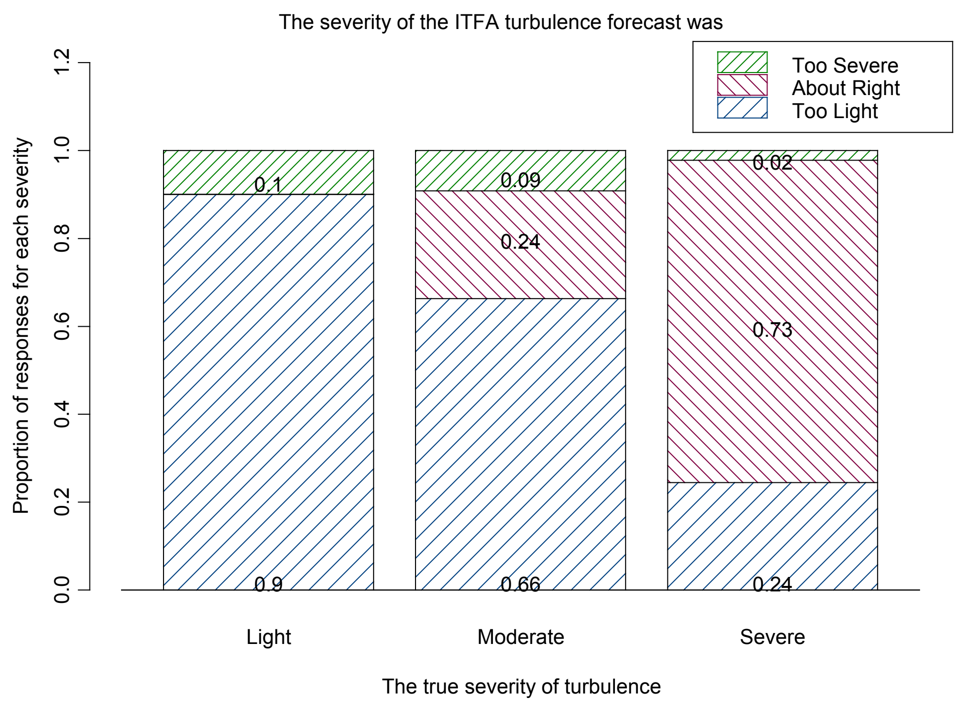


Figure 10. Stacked bar chart relating the true severity of turbulence, as indicated by AWC forecasters, to the severity indicated by ITFA.

Table 1. The total counts for each turbulence severity category as it relates to the severity of ITFA.

ITFA Severity	*Turbulence Severity*		
	Light	Moderate	Severe
Too Light	9	65	11
About Right	0	24	33
Too Severe	1	9	1
Total	10	98	45

turbulence was rated as "light" in only 10 of the responses. Breaking down those 10 responses into 3 categories results in even smaller sample sizes and some empty "cells." Thus the relative performance of ITFA's severity assessment versus the true severity should be based on the responses in the moderate and severe columns where the total sample size is large enough to be meaningful.

The results for the coverage of turbulence as forecasted by ITFA as compared to the altitude at which the turbulence was forecasted to occur are shown in Fig. 11. These results indicate that when the area of turbulence forecasted by ITFA was judged to be *too small*, the altitude was judged to be *too low* 72% of the time, *about right* 19% of the time, and *too large* 0.09% of the time. When the area of turbulence predicted by ITFA was felt to be *about right*, the proportion of *too high* cases increased slightly to 0.2% and the proportion of *too low* cases decreased to 63%. When the area of turbulence predicted by ITFA was judged to be *too large*, the percentage of *too low* cases decreased to 39%, while the *about right* and *too high* cases increased to 28 and 33%, respectively. The total numbers of counts associated with each category are listed in Table 2.

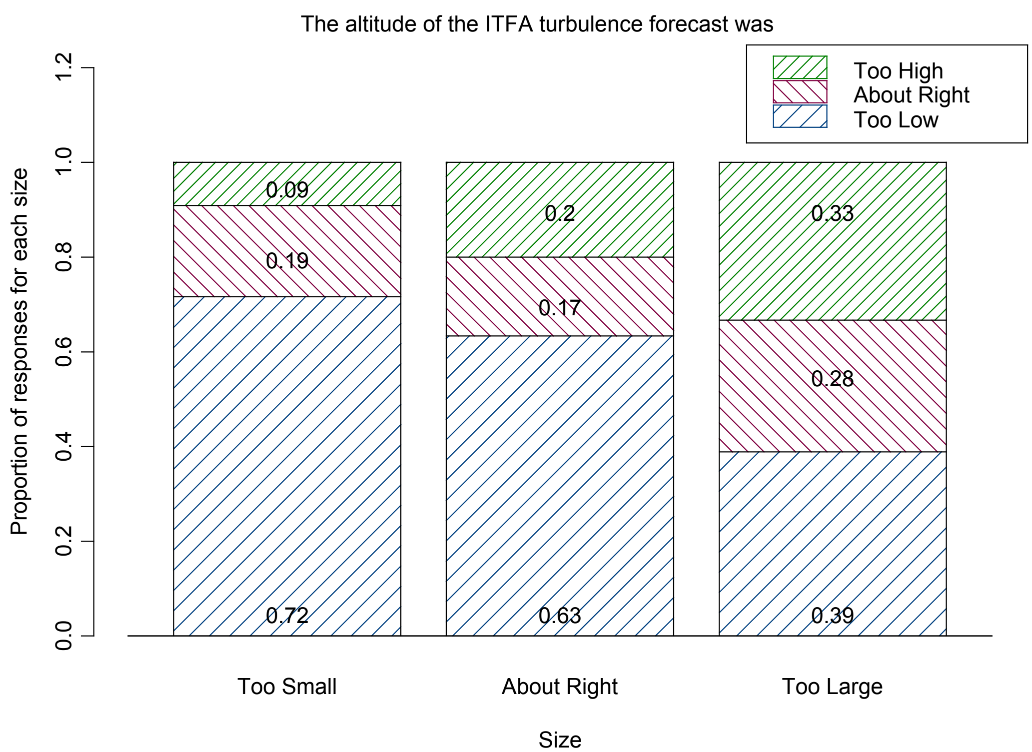


Figure 11. Stacked bar chart relating forecast turbulence coverage to the altitude of turbulence that was indicated by ITFA.

In this case, the turbulence coverage for ITFA was rated *about right* when the altitude was *about right* and *too high* in only 5 and 6 of the cases, respectively. Although the responses in each cell are low, the total number or responses is adequate for basing the percentages.

Table 2. The total counts for each category of turbulence coverage as it relates to the altitude of the turbulence predicated by ITFA.

Altitude	***Turbulence coverage as Predicted by ITFA***		
	Too Small	About Right	Too Large
Too Low	63	19	14
About Right	17	5	10
Too High	8	6	12
Total	88	30	36

The results interrelating Figs. 7 and 8 (i.e., coverage of turbulence as predicted by ITFA and how well did ITFA capture the turbulence), reveal some contradictory information regarding the forecasters' evaluations of ITFA performance (Fig. 12). For instance, when the forecast was judged to be *too small*, ITFA was felt to capture the turbulence well in 77% of the cases, but when the forecast was judged *too large*, ITFA was determined to be underforecasting the turbulence 85% of the time. In addition, when the ITFA forecast coverage was *about right* the AWC forecasters believed that ITFA overforecasted the turbulence nearly 80% of the time. One possible explanation for these unsettling results could be the way in which the questions were presented. In the future, a clearer connection between the two attributes should be more thoroughly described in the questionnaire and the requested information clarified. The total number of counts associated with each category presented in Fig. 12 is listed in Table 3.

A summary of the maximum severity of turbulence by forecast region is shown in Fig. 13. The maximum severity of turbulence was most often moderate in all regions except Miami (MIA) where severe turbulence occurred most frequently (56%). Light turbulence was the worst observed in only a small proportion of cases in all regions, with four regions (Chicago East and West, and Dallas/Ft. Worth East and West) having no cases with a maximum severity lower than moderate. The region with the greatest proportion of light turbulence was San Francisco North, which also had no cases with severe turbulence. However, the San Francisco South region had only 4 responses; thus, the percentages for this region should be ignored, as the sample size is too small to draw any conclusions. The small number of light turbulence cases is likely due to the fact that AWC forecasters generally focus on moderate-or-greater turbulence severity for formulating the operational turbulence forecasts (i.e., AIRMETs).

A summary of the severity of ITFA turbulence forecasts by forecast region is shown in Fig. 14. ITFA was judged by the AWC forecasters to indicate turbulence at the appropriate severity level more often than not in the Boston (BOS), Chicago-West (CHI-W), and Miami (MIA) regions. The indicated severity was least often correct in the Salt Lake City North and South regions (SLC-N and SLC-S). In all regions other than BOS and MIA, forecasters most often judged that ITFA indicated a severity that was *too light*. Only rarely did forecasters believe that ITFA indicated turbulence that was *too severe*. It is important to note that this result may be due to differences in calibration of the algorithm from region to region rather than different levels of skill of the algorithm in different regions. Again, the San Francisco South region had only 4 responses so percentages for this region should be ignored.

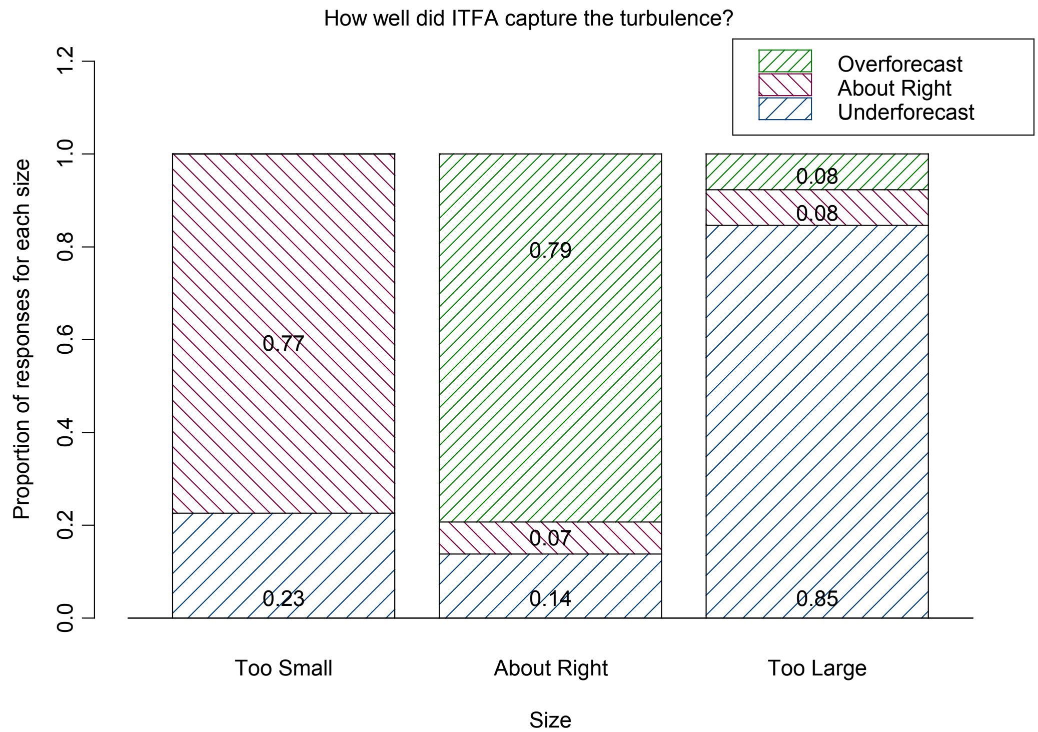


Figure 12. Stacked bar chart relating ITFA coverage to how well ITFA captured the turbulence.

Table 3. The total counts for each category of turbulence coverage as it relates to how well ITFA captured the turbulence.

How well ITFA captures turbulence	***Turbulence Coverage as Predicted by ITFA***		
	Too Small	About Right	Too Large
Too Low	21	4	33
About Right	72	2	3
Too High	0	23	3
Total	93	29	39

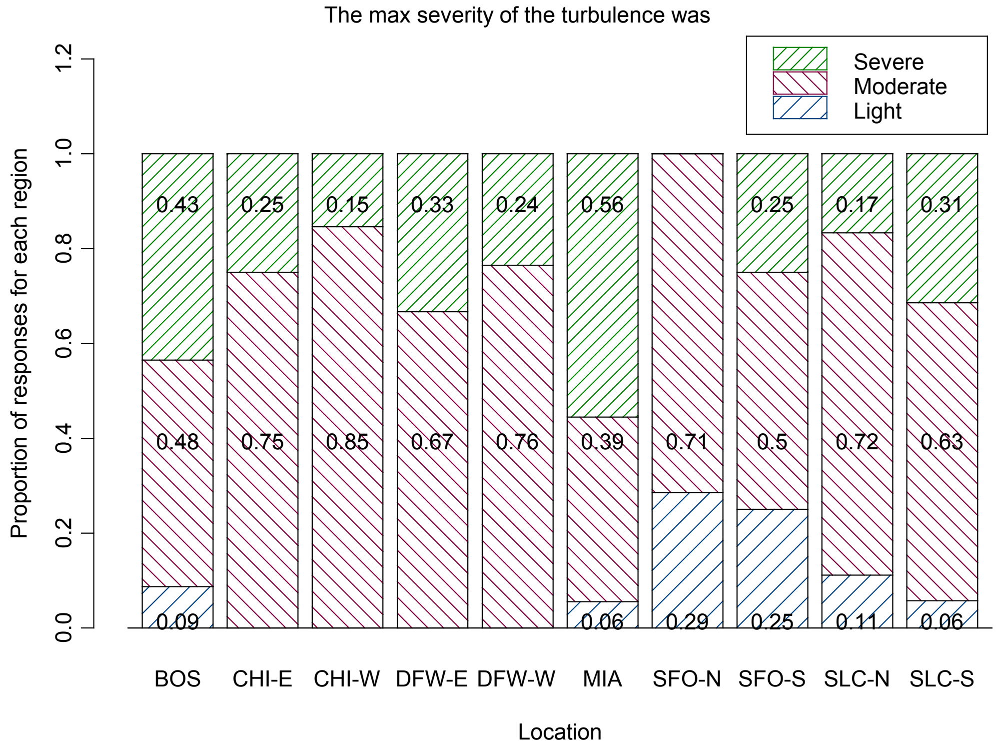


Figure 13. Stacked bar chart relating maximum turbulence severity to forecast region.

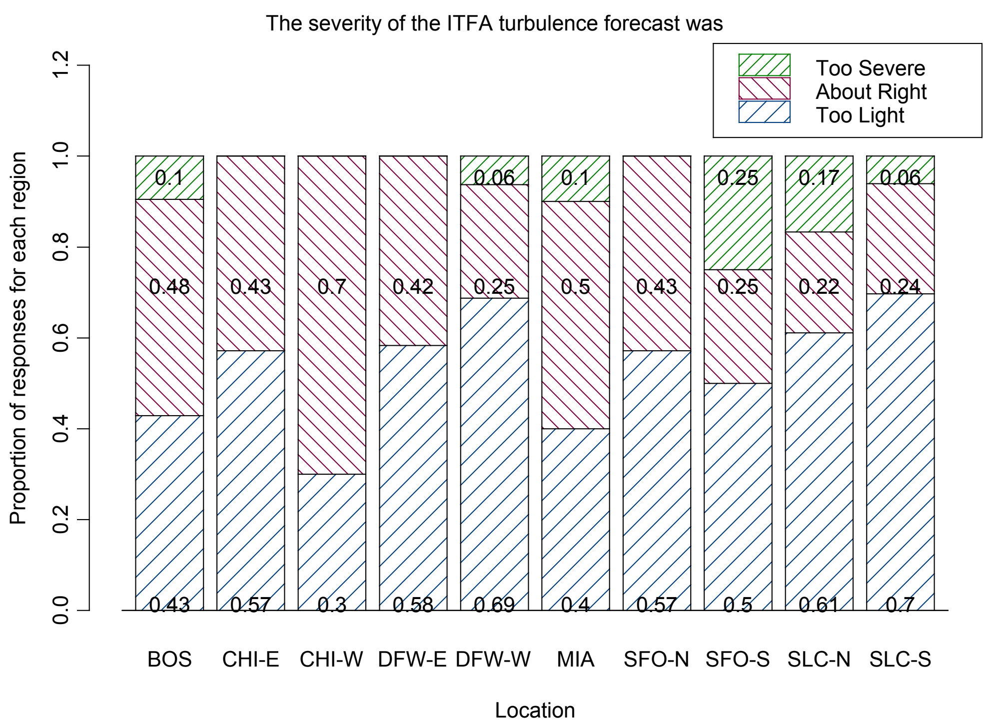


Figure 14. Stacked bar chart relating strength of the turbulence severity to forecast region.

3.3 Case Studies

Along with the responses logged on the questionnaire, the forecasters were able to enter additional comments regarding the performance of ITFA. After analyzing the comments,"good" and "bad" ITFA days were examined in more detail. A small selection of the results is presented in the following section.

A series of turbulence diagrams representing two turbulence case studies (one good case and one bad case) are presented in Figs. 15 – 18. On each diagram, 4 panels of information are presented. The upper-left panel lists the date along with the forecast issue and lead time, whether it is for AIRMETs or ITFA (threshold 0.325; associated with moderate turbulence), and a key to the symbols used to identify the forecast/observation pairs on the other panels. The upper-right panel is a 2-D display where the hatched areas represent the composite forecast area indicating turbulence from either the AIRMETs or ITFA from 20,000 to 40,000 ft, and the numbers overlaying the hatches represent the location of the PIREPs. The bold numbers indicate that turbulence was reported at more than one level at that PIREP location. Above the upper-right panel, the statistics (PODy and PODn) and the counts for the forecast/observation pairs are listed. Next, the middle left panel shows the lightning data (Orville 1991) that corresponded to the forecast issue and lead time. The bottom panel is a 3-D graphic of the turbulence (long gray lines) as forecasted by ITFA or AIRMETs and the PIREPs. Although the AIRMETs extend throughout the atmosphere, the height plotted along the y-axis only extends from 20,000 to 40,000 ft. The numbers listed on the 3-D display represent the PIREP information and are consistent with the PIREP numbers displayed on the 2-D map on the panel above. The symbols (i.e., '+' or triangle) located next to the numbers on the 3-D display indicate whether or not turbulence was reported by the PIREP. A symbol intersecting a long gray line as shown on the 3-D display, indicates that the PIREP landed within an area where turbulence was forecasted to occur.

On 30 March 2002 the AWC forecasters indicated that ITFA inaccurately captured the turbulence occurring over the High Plains States. In this case, a large number of PIREPs, associated with a deep low-pressure system, were located over eastern Colorado and western Kansas. A closer look at the performance of the AIRMETs and ITFA is presented in Figs. 15-17. At 1500 UTC, the PIREPs indicating turbulence (#8, 9, 10, 11, 16) were missed by both the AIRMETs (Fig. 15a) and ITFA (Fig. 15b). Interestingly, two different PIREPs issued in the same area but at different altitudes encountered a difference in turbulence. In this case, ITFA correctly captured the PIREP reporting No turbulence (#14), but missed the PIREP that did report turbulence (#15).

At 1800 UTC (three hours later), the turbulence over the High Plains was picked up by the AIRMETs (Fig. 16a) and by ITFA (Fig. 16b). As indicated by the long gray lines in Fig. 16a and b, the area covered by the AIRMETs in this situation was considerably larger than the area covered by ITFA.

At 2100 UTC (Fig. 17 a and b), the major turbulence shifted slightly to the east, anchoring itself over Kansas and Missouri. PIREP #20 reported 12 levels of turbulence from 30,000 to nearly 41,000 ft. In this case, 10 out of the 12 levels were correctly captured by the AIRMETs. ITFA correctly captured only 2 of the 12 levels. However, in most cases, ITFA correctly classified the PIREPs reporting No turbulence, as indicated by PIREP #1, 2, 3, 4, 5, 6, 7, 14, 19, 23, and 24.

In summary, ITFA was able to correctly classify areas with *No* turbulence and, as compared to the AIRMETs, reduce the size of the domain where turbulence was forecasted to occur. However, ITFA had a difficult time accurately pin-pointing the specific levels of turbulence that occurred over the High Plains as was indicated by the diagrams and by the low values of PODy. To determine the origin of the error, the members of the Turbulence PDT are pursuing further analysis of this case.

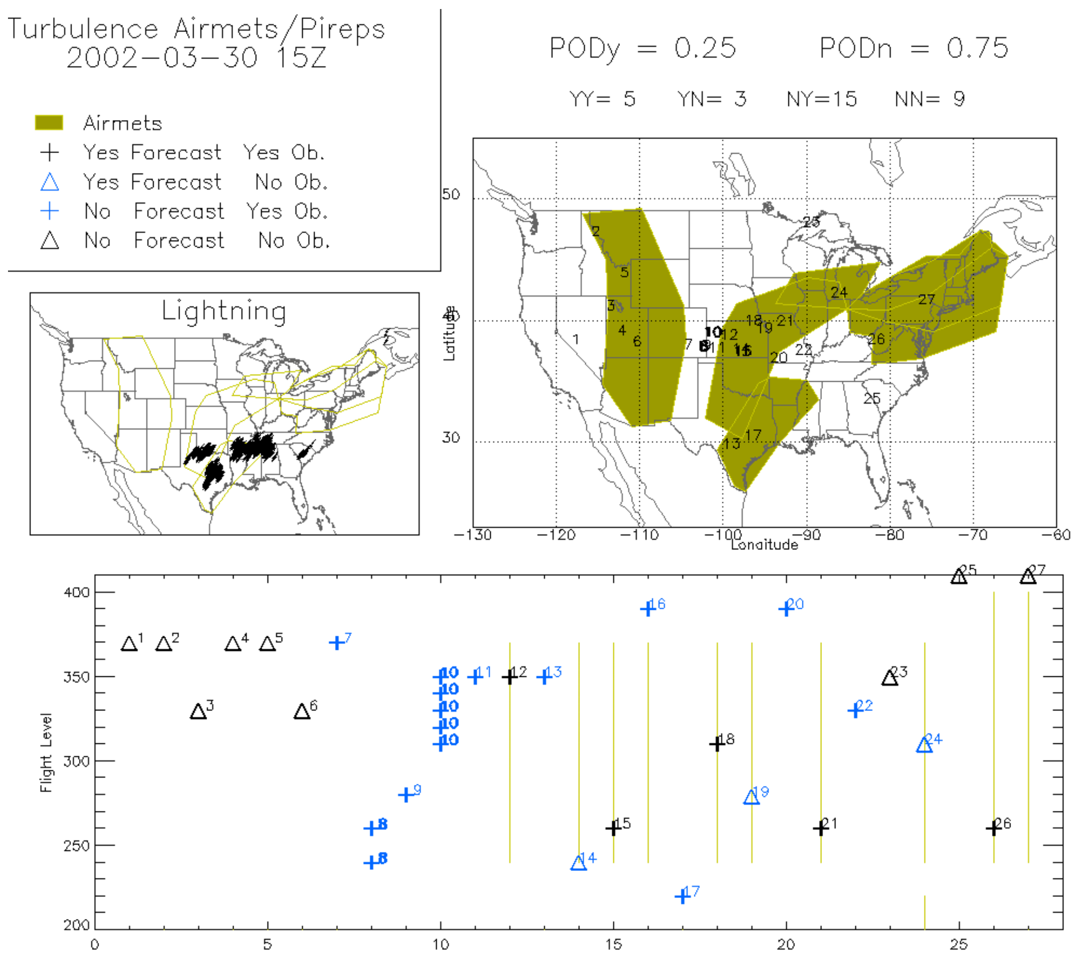


Figure 15a. Diagram for 30 March 2002, valid at 1500 UTC for AIRMETs. The upper-left panel lists the date, forecast valid or issue and lead time, AIRMETs or ITFA (threshold 0.325), and symbols used to identify the forecast/observation pairs on the other panels. The upper-right panel represents the turbulence (hatched areas) and the PIREPs (numbers). The bold numbers indicate turbulence reported at more than one level at that PIREP location. PODy and PODn and the forecast/observation counts are listed. Middle left panel shows the lightning data. Bottom panel is a 3-D graphic of the turbulence (long green lines) and the PIREPs from 20,000 to 40,000 ft. The numbers identify each PIREP and are consistent with those displayed on the 2-D display. The symbols (i.e., '+' or triangle) located next to the numbers on the 3-D display indicate whether or not turbulence was reported in the PIREP message.

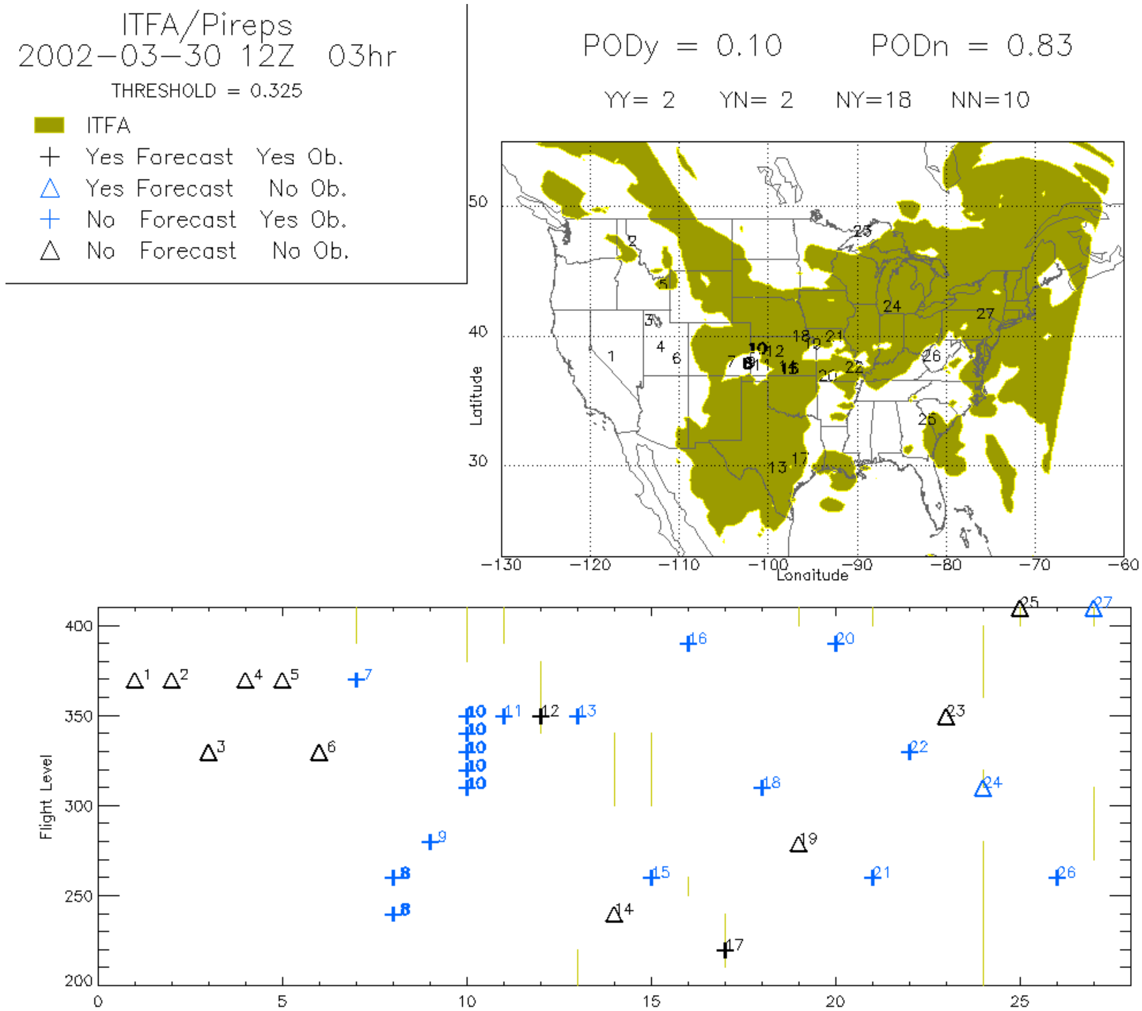


Figure 15b. Same as Fig. 15 a, except for ITFA (0.325).

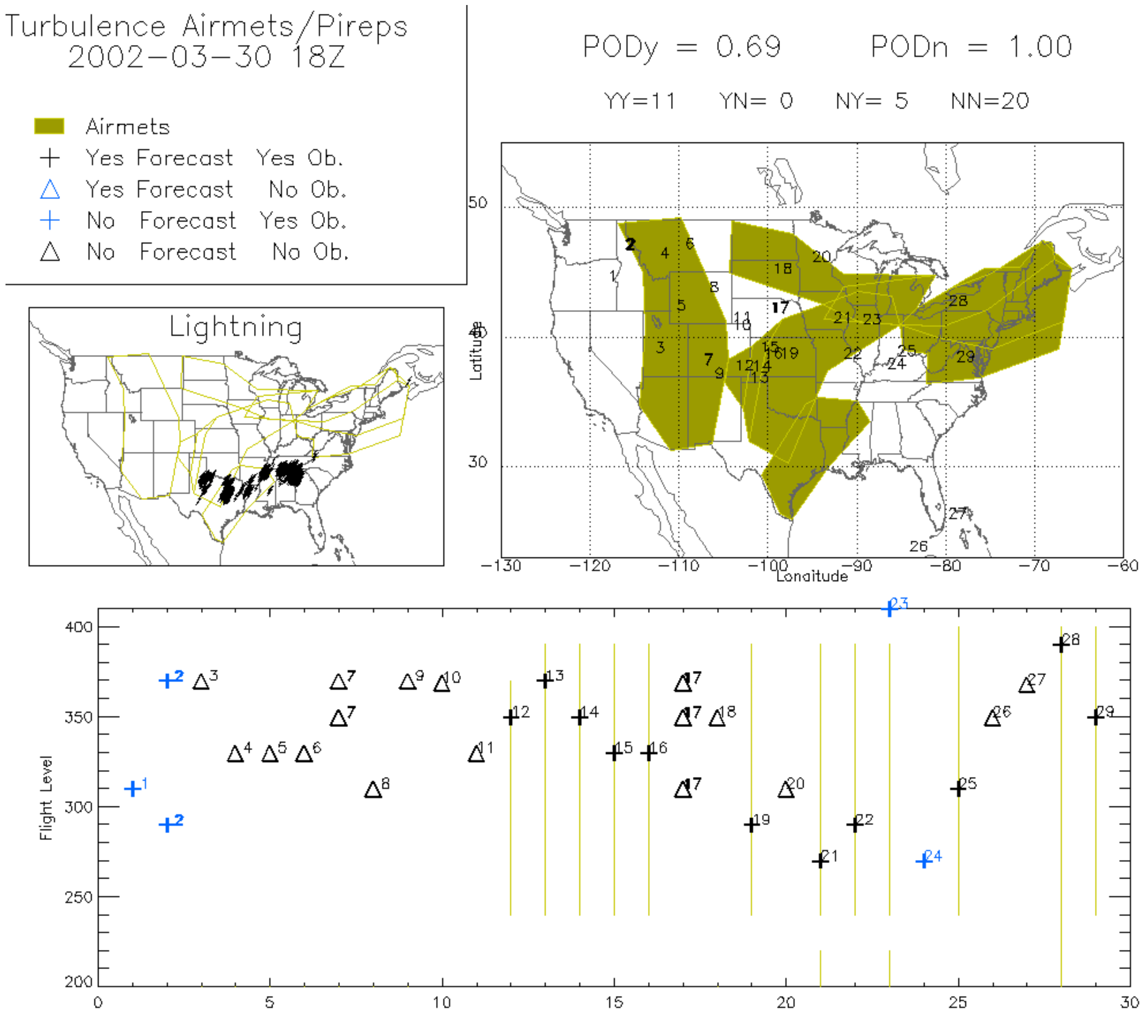


Figure 16a. Same as Fig. 15a, except for valid at 1800 UTC.

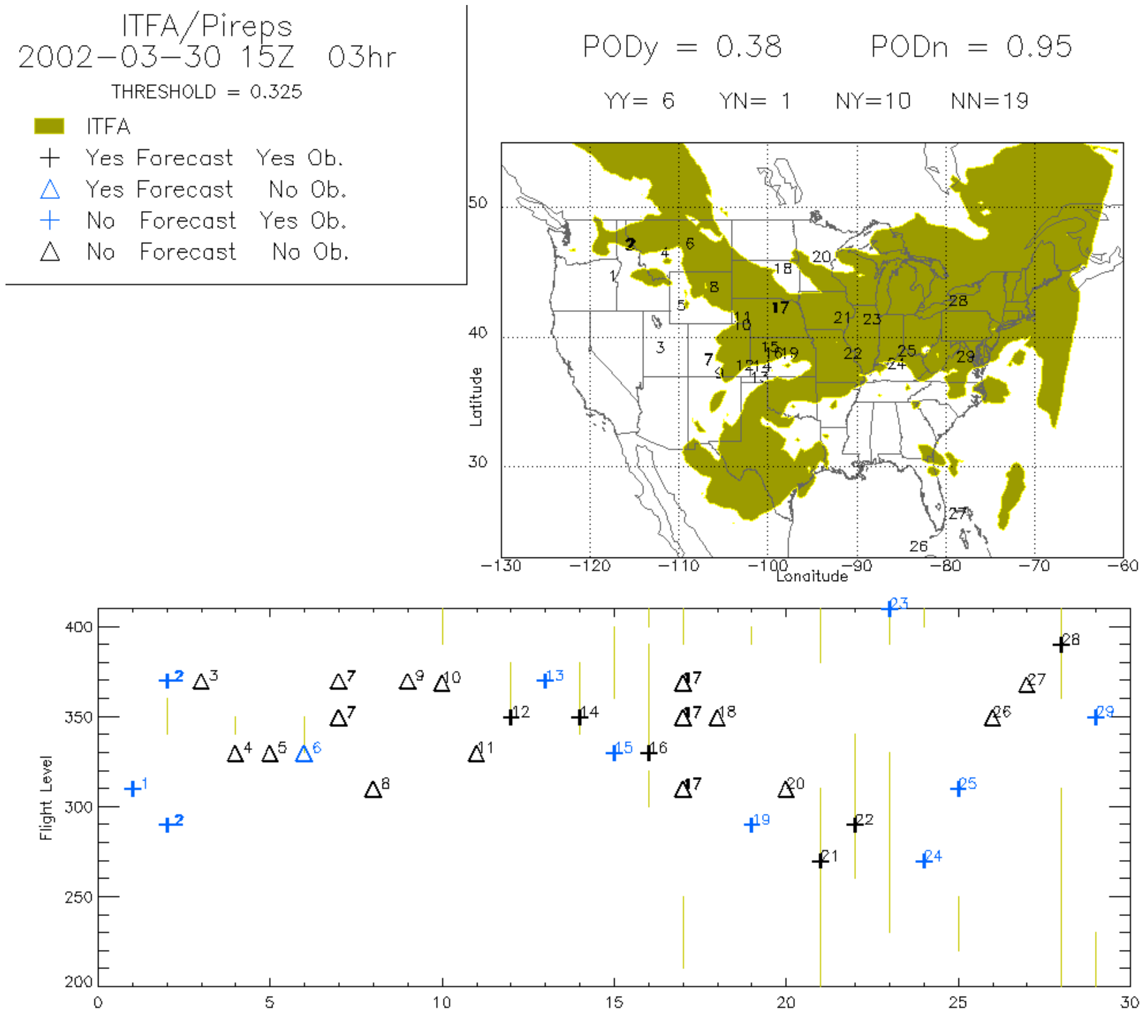


Figure 16b. Same as Fig. 16a, except for ITFA (0.325)

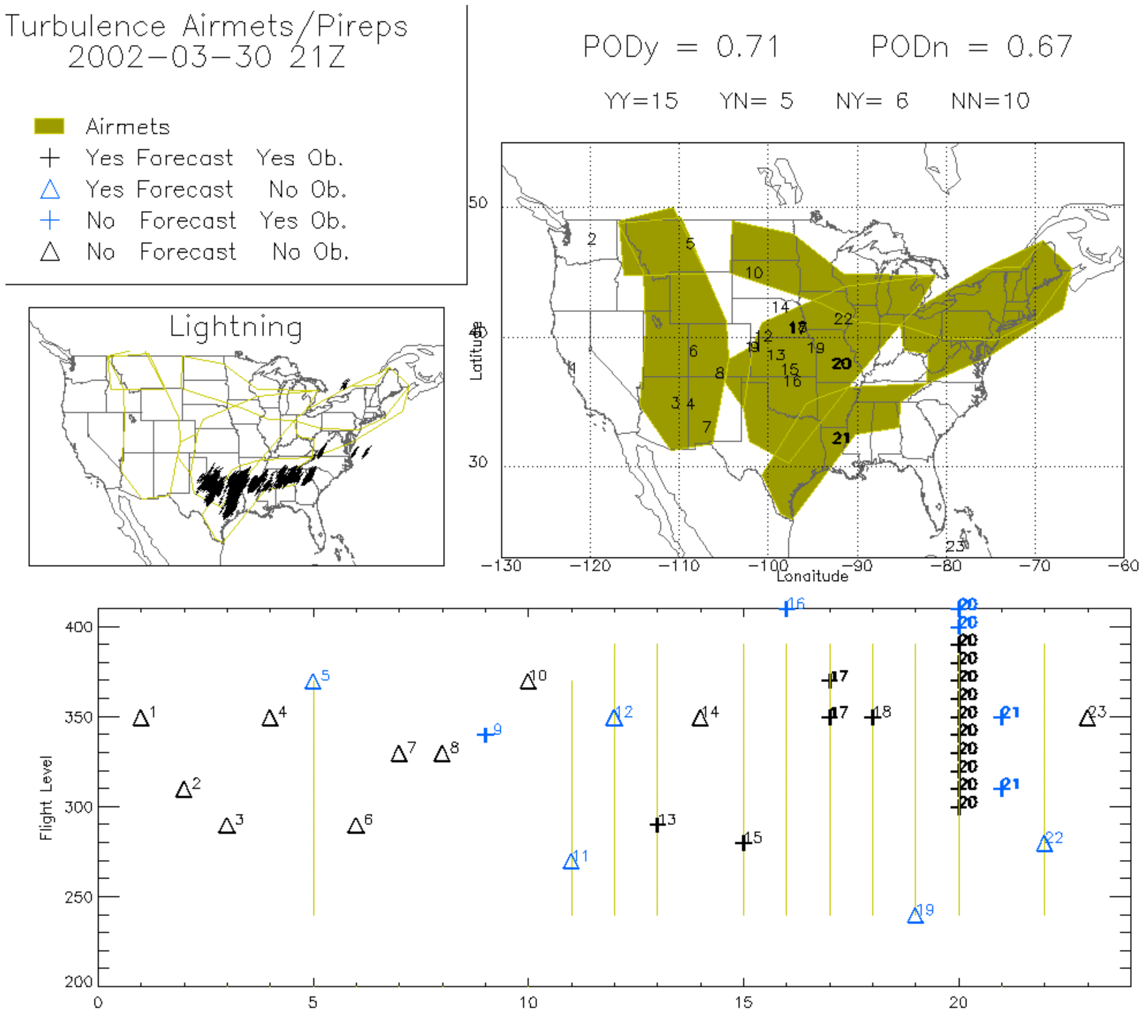


Figure 17a. Same as Fig. 15a, except for 30 March 2002, valid at 2100 UTC.

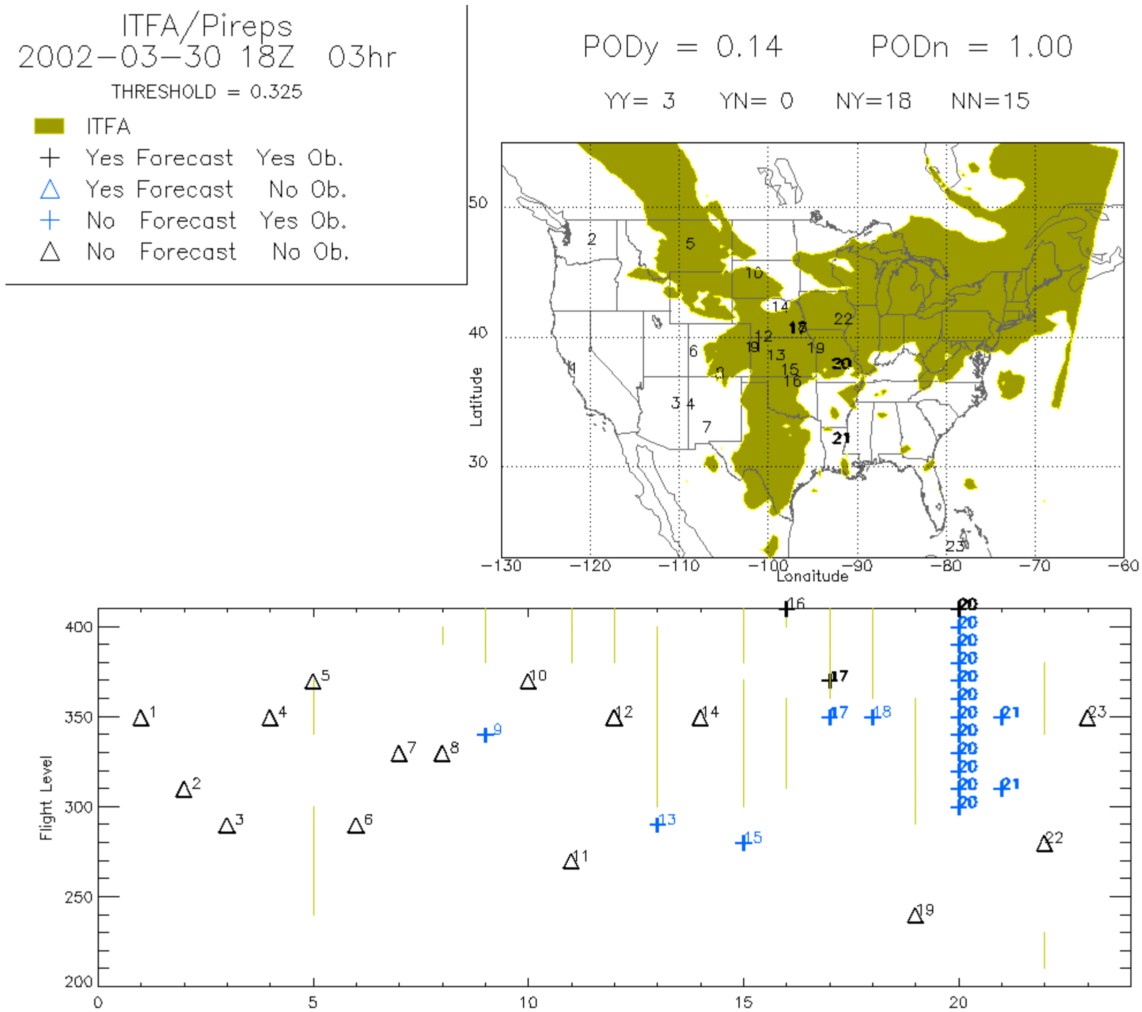


Figure 17b. Same as Fig. 17a, except for ITFA (0.325).

On 11 February 2002 the AWC forecasters indicated that ITFA preformed well. A closer look at this case is presented in the turbulence diagrams shown in Figs. 18 a and b, starting with an analysis of the AIRMETs followed by an analysis of ITFA. For this case, the AIRMETs covered a large portion of the U.S. (Fig. 18a; 2-D panel), with the forecast region often extending from 20,000 to 40,000 ft as indicated by the gray lines on the 3-D panel. Although the AIRMET forecast domain was large (Fig. 18a), the areas did accurately capture the turbulence reported by PIREPs #6, 10, 12, and 17. ITFA, on the other hand (Fig. 18b), captured PIREPs #6 and 12 and reduced the size of the turbulence coverage. In many instances, PIREPs reporting *No* turbulence were accurately classified outside the turbulence as predicted by ITFA. An example of this is shown on the 3-D panel of Fig. 18b where the thin gray lines stopped just short of PIREP #11, 16, and 18.

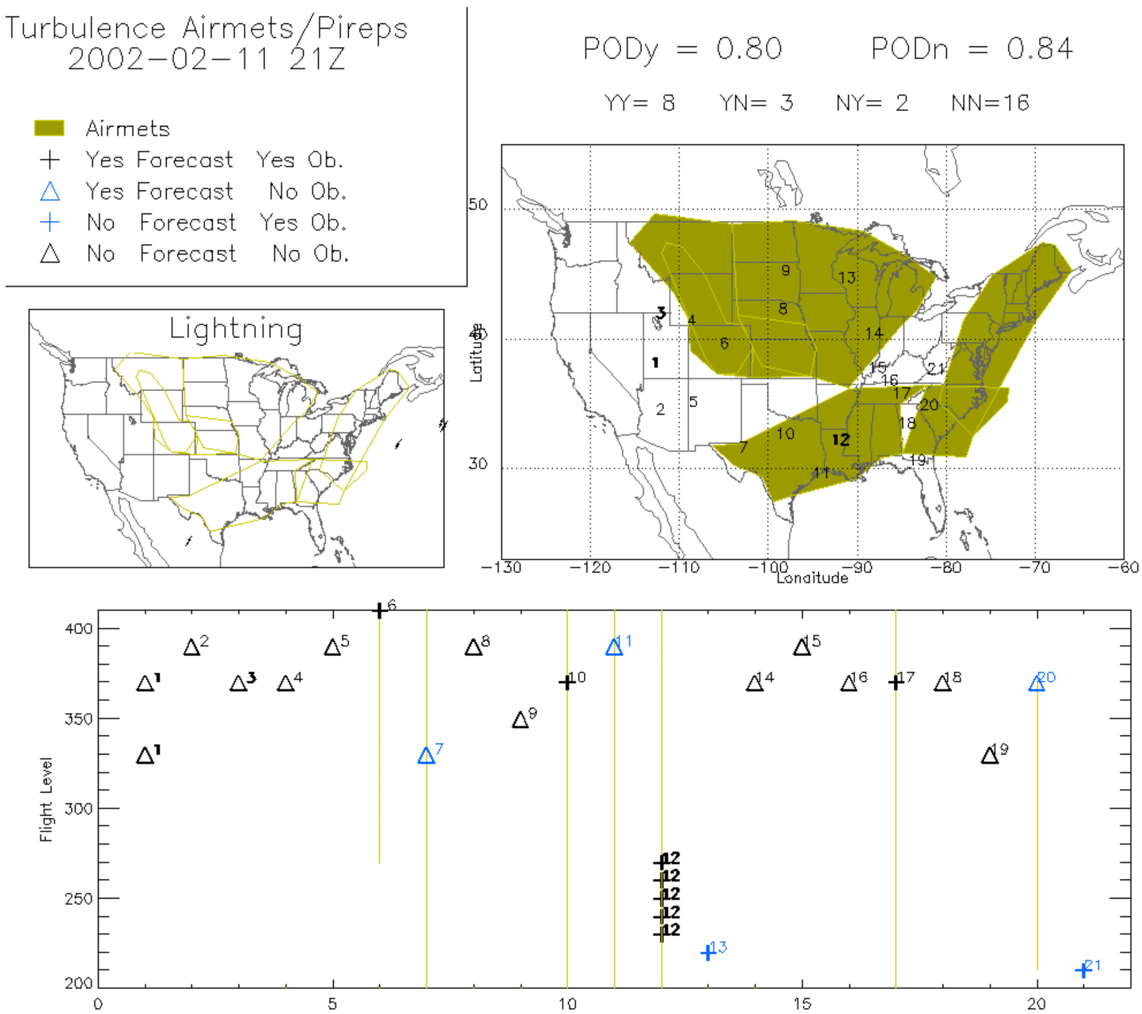


Figure 18a. Same as Fig. 15a, except for 11 February 2002, valid at 2100 UTC.

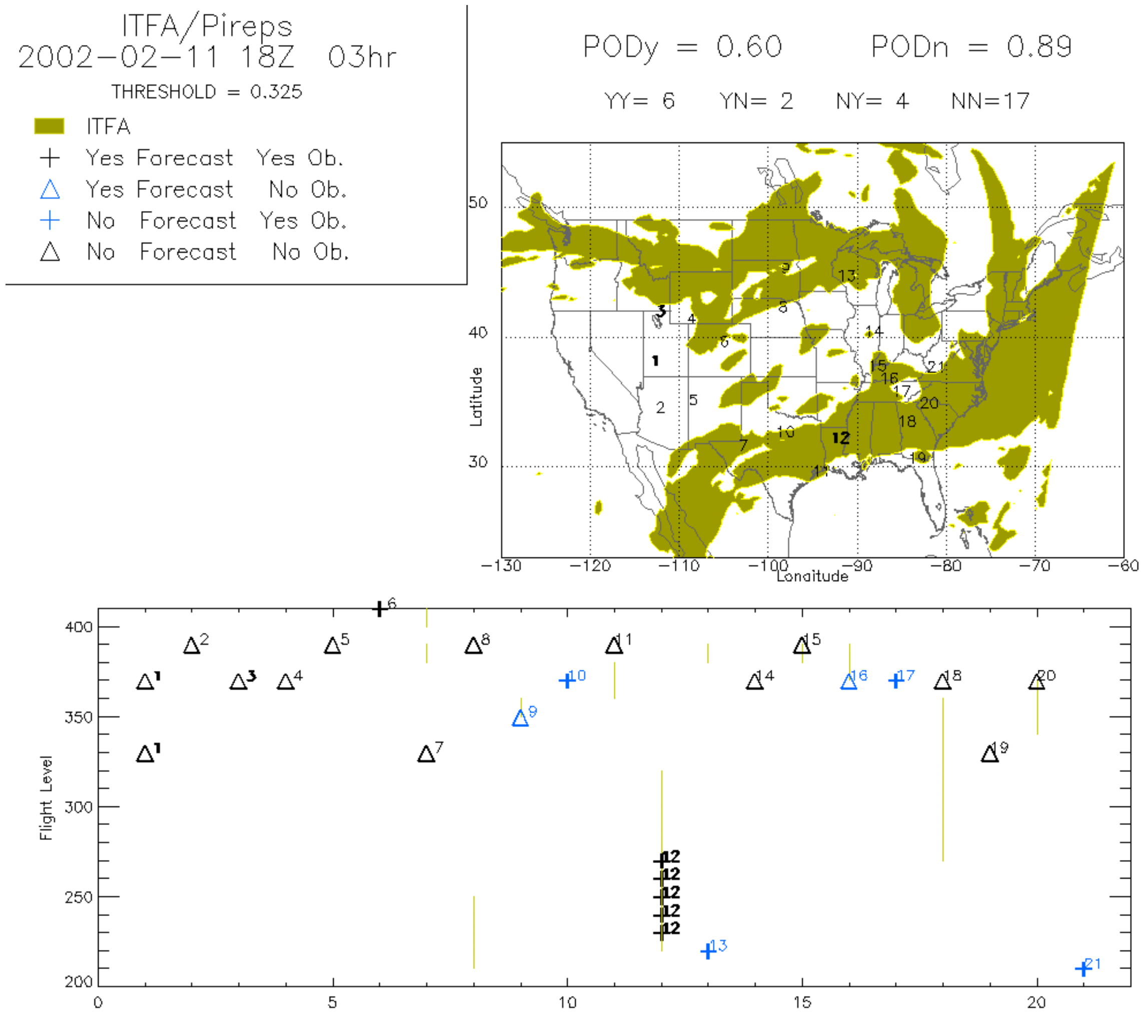


Figure 18b. Same as Fig. 18 a, except for ITFA.

4. Conclusions

This report summarized the results from the 2002 Winter subjective evaluation of ITFA. Forecasters from AWC were asked to evaluate the performance of ITFA from 9 February – 9 April 2002. The results provided a great deal of information regarding the important sources of turbulence and the performance of the ITFA, although there were some discrepancies in the results between a few of the questions. In the future, the structure of the questionnaire will be modified to address these discrepancies.

Overall, the results suggested that most of the turbulence as characterized by the AWC forecasters was caused by the jet stream, was moderate or greater intensity, and had a duration of over 4 hours. ITFA forecasts were judged to capture the turbulence well about half the time. However, generally the forecasters thought the severity of turbulence indicated by ITFA was too light, the coverage was too small, and the altitude was too low. Responses regarding the severity of turbulence varied among the different forecast regions, with the largest proportion of responses indicating severe turbulence in the Miami region. The Chicago West region was most likely to report moderate turbulence as well as most likely to report that the severity of turbulence forecast by ITFA was about right.

Two case studies were examined. The first case, 30 March 2002, ITFA had a difficult time pin-pointing specific layers of turbulence that were observed by PIREPs over the High Plains. ITFA did, however, correctly capture many areas of *No* turbulence. In the second case, 11 February 2002, ITFA correctly classified many of the PIREPs and the forecast area produced by ITFA was reasonable.

Future work includes: expanding the evaluation to United Airlines, investigating additional turbulence cases that were identified by the AWC forecasters, and modifying the questionnaire to address discrepancies between questions. In particular, it will be valuable to include similar evaluations from airline meteorologists to understand differences in their perceptions of ITFA quality. Some of the problems with interpretation of the questions that were found with this evaluation can be corrected for future studies.

Acknowledgments

This research is in response to requirements and funding by the Federal Aviation Administration. The views expressed are those of the authors and do not necessarily represent the official policy and position of the U.S. Government.

We would like to thank the Aviation Weather Center forecasters who participated in this evaluation. Without them, this work could not have been performed. We also would like to thank Fred Mosher of the AWC for being the AWC focal point for this evaluation and for providing guidance to the forecasters when needed. We would like to express our appreciation to the dispatchers at ComAir for their insightful comments. We would also like to thank the RTVS Team (Judy Henderson, Joan Hart, Andy Loughe, Beth Sigren, and Chris Fischer who are the developers of the RTVS), and Nita Fullerton for her helpful review of this work. We also would like to thank Mike Chapman for completing several test questionnaires.

References

Benjamin, S.G., J.M. Brown, K.J. Brundage, B.E. Schwartz, T.G. Smirnova, and T.L. Smith, 1998: The operational RUC-2. *Preprints, 16th Conference on Weather Analysis and Forecasting*, Phoenix, AZ, American Meteorological Society, 249-252.

Brown, B.G., J.L. Mahoney, R. Bullock, M.B. Chapmen, C. Fischer, T. L. Fowler, J.E. Hart, and J.K. Henderson, 2002: Integrated Turbulence Forecasting Algorithm (ITFA): Quality Assessment Report. Report to the FAA Aviation Weather Research Program (available from bgb@ucar.edu).

Mahoney, J.L. and B.G. Brown, 2000. Forecaster Assessment of Turbulence Algorithms: A Summary of Results for the Winter 2000 Study. Report to the FAA Aviation Weather Research Program (available from mahoney@fsl.noaa.gov).

Mahoney , J.L., J. Braid, B. Brown, T. Fowler, and J. Wolff, 2001: A Forecaster Evaluation of Turbulence Algorithms: A Summary of the Winter 2001 Study. Report to FAA Aviation Weather Research Program (available from mahoney@fsl.noaa.gov).

Orville, R.E. 1991: Lightning ground flash density in the contiguous United States-1989. *Mon. Wea. Rev*., **119**, 573-577.

Sharman, R, C. Tebaldi, and B. Brown, 1999: An integrated approach to clear-air turbulence forecasting. Preprints, *Eighth Conf. On Aviation, Range, and Aerospace Meteorology*, Dallas, TX, American Meteorological Society, 68-71.

APPENDIX A

Turbulence Algorithm Questionnaire

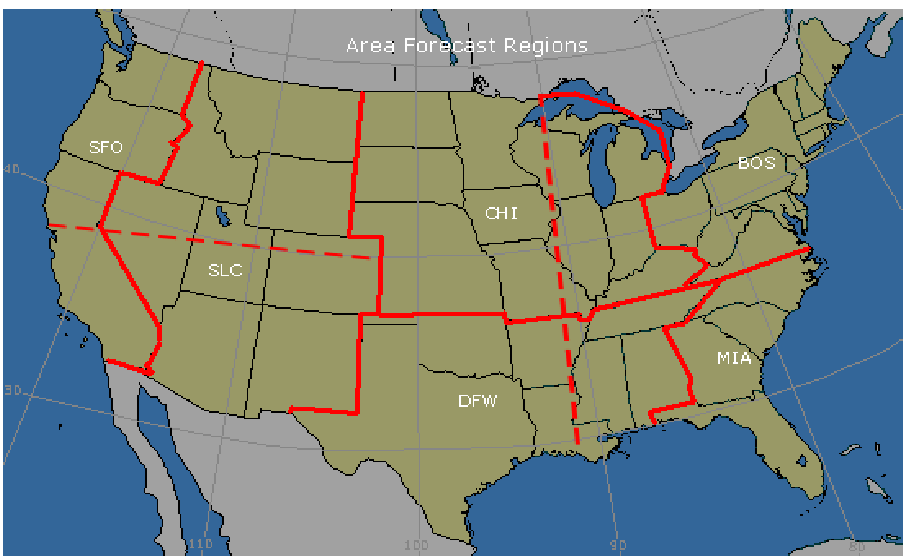
Forecaster Evaluation Form

Winter 2002

Please fill out one questionnaire every day, considering turbulence at 18,000 ft and above.
Problems or questions: Contact Jennifer Mahoney (mahoney@fsl.noaa.gov/303-497-6514) or Barbara Brown (bgb@ncar.ucar.edu/303-497-8468).
Note: The ITFA and PIREP displays are on the web.

Forecaster last name: Choose One ▾ If your last name did not appear in the list, please type it in:

The current date is **20020919**. If you are submiting an evaluation for turbulence which occurred on a different date then please enter that date here (YYYYMMDD)



1. Turbulence Locations

a. Which regions shown on the map above had upper-level turbulence?

- ☐ SFO North
- ☐ SFO South
- ☐ SLC North
- ☐ SLC South
- ☐ DFW West
- ☐ DFW East
- ☐ CHI West
- ☐ CHI East
- ☐ BOS
- ☐ MIA

b. Which regions did you concentrate on in your work today? (check all that apply)

- ☐ SFO
- ☐ SLC
- ☐ DFW
- ☐ CHI
- ☐ BOS
- ☐ MIA

Continue | Reset entire form

2. Turbulence Descriptions

For each region where turbulence was reported please select one item for each question below that best describes the turbulence reports in that region.

a. The maximum severity of the turbulence was:

SFO South Region	○ Light ○ Moderate ○ Severe
CHI West Region	○ Light ○ Moderate ○ Severe

b. The most likely cause of the turbulence was:

SFO South Region	○ Jet Stream ○ Upper Trough ○ Mountain Wave ○ Upper Ridge ○ Convection ○ Other
CHI West Region	○ Jet Stream ○ Upper Trough ○ Mountain Wave ○ Upper Ridge ○ Convection ○ Other

c. The turbulence was located primarily:

SFO South Region	○ in clear air ○ near-cloud ○ in-cloud
CHI West Region	○ in clear air ○ near-cloud ○ in-cloud

d. The altitude of the turbulence (feet) was located mainly: (check all that apply)

SFO South Region	☐ 18-22000 ☐ 23-27000 ☐ 28-32000 ☐ 33-37000 ☐ 38-42000 ☐ all levels
CHI West Region	☐ 18-22000 ☐ 23-27000 ☐ 28-32000 ☐ 33-37000 ☐ 38-42000 ☐ all levels

e. When did the turbulence begin to be reported? (UTC)

SFO South Region	○ 12-15 ○ 15-18 ○ 18-21 ○ 21-00 ○ 00-03 ○ Don't Know
CHI West Region	○ 12-15 ○ 15-18 ○ 18-21 ○ 21-00 ○ 00-03 ○ Don't Know

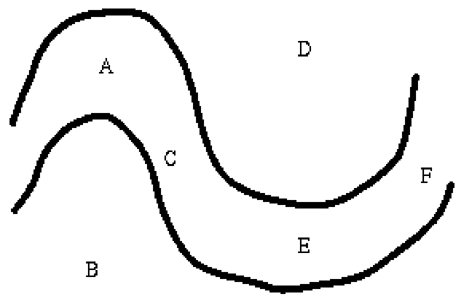
f. How long did the turbulence reports persist? (hours)

SFO South Region	○ < 1 ○ 1-2 ○ 2-3 ○ 4-6 ○ 6-12 ○ > 12 ○ Don't Know
CHI West Region	○ < 1 ○ 1-2 ○ 2-3 ○ 4-6 ○ 6-12 ○ > 12 ○ Don't Know

3. Upper Feature Locations

If turbulence related to troughs or ridges occurred in any of the regions, please use the figure to the right to identify the portions of the trough or ridge that was involved. Check all that apply.

SFO South Region	☐ A ☐ B ☐ C ☐ D ☐ E ☐ F
CHI West Region	☐ A ☐ B ☐ C ☐ D ☐ E ☐ F



4. ITFA Performance

Describe the performance of the ITFA turbulence forecasts (considering yellow and red areas on the ITFA display).

a. Which ITFA forecast issue and lead times did you consider?

Issue Time	Lead Time
1200	☐ 0h ☐ 3h ☐ 6h ☐ 9h ☐ 12h
1500	☐ 0h ☐ 3h ☐ 6h ☐ 9h
1800	☐ 0h ☐ 3h ☐ 6h
2100	☐ 0h ☐ 3h

b. The overall performance of ITFA can be considered

SFO South Region	○ An Underforecast ○ Reasonable ○ An Overforecast
CHI West Region	○ An Underforecast ○ Reasonable ○ An Overforecast

c. The sizes of the areas where turbulence was forecast by ITFA were:

SFO South Region	○ Too Small ○ Appropriate ○ Too Large
CHI West Region	○ Too Small ○ Appropriate ○ Too Large

d. The ITFA forecast severity of the turbulence was:

SFO South Region	○ Too Light ○ Appropriate ○ Too Severe
CHI West Region	○ Too Light ○ Appropriate ○ Too Severe

e. The altitude where turbulence was forecast by ITFA was:

SFO South Region	○ Too Low ○ Appropriate ○ Too High
CHI West Region	○ Too Low ○ Appropriate ○ Too High

f. If the ITFA performance was considered poor for this evaluation, do you consider this to have been caused by:

SFO South Region	○ a failure of the ITFA algorithms ○ a failure of the RUC model ○ a failure of both ITFA and RUC ○ don't know
CHI West Region	○ a failure of the ITFA algorithms ○ a failure of the RUC model ○ a failure of both ITFA and RUC ○ don't know

g. What platforms did you use to view the data: (Select all that apply)

SFO South Region	☐ NCAR/RTVS	☐ NAWIPS/NTrans	☐ ADDS
CHI West Region	☐ NCAR/RTVS	☐ NAWIPS/NTrans	☐ ADDS

5. Additional Comments (e.g., incorrect PIREPS, model problems, etc.)

Submit form | Reset entire form | Start over