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INTEGRATED TURBULENCE FORECASTING ALGORITHM 2001 METEOROLOGICAL EVALUATION

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1.0 INTRODUCTION

The Federal Aviation Administration (FAA) Aviation Weather Research Program (AWRP) has provided funding to the National Center for Atmospheric Research (NCAR) to develop a forecasting tool for unexpected, hazardous, clear-air turbulence (CAT). This effort is within the domain of the Turbulence Product Development Team (PDT). The PDT includes meteorological experts from private, government and academic organizations and receives its overall funding and direction from the AWRP. In response to the direction provided, NCAR has developed the Integrated Turbulence Forecasting Algorithm (ITFA), which produces CAT forecasts for the contiguous United States.

In support of ITFA's development in 2000 the FAA William J. Hughes Technical Center (WJHTC) Weather Branch (ACT-320) performed an event-driven meteorological evaluation of the ITFA. Ten severe turbulence events were used in the 2000 ITFA study, which focused on the predictions, meteorological conditions, and operational impact of the predictions (Passetti, 2000). In 2001, a revised version of ITFA was rerun on the ten events from the 2000 study. ACT-320 analyzed output from this latest version to determine how the performance, characteristics, and trends compared to the 2000 ITFA. In addition, each index that composes ITFA was analyzed.

2.0 ALGORITHM OVERVIEW

2.1 Algorithm Processing

ITFA generates predictions of CAT produced by upper level influences (e.g., jet stream and upper fronts) above 15,000 feet (4,573 meters). ITFA does not produce forecasts for CAT resulting from convection, mountain waves or turbulence of any type below 15,000 feet. To create CAT forecasts, ITFA relies on several indices and algorithms, each having strengths and weaknesses as CAT predictors. ITFA uses the forecasted fields of the Rapid Update Cycle (RUC) to compute each index and algorithm then integrates the outputs of each predictor to produce a forecast of CAT potential and intensity (Sharman, 2000).

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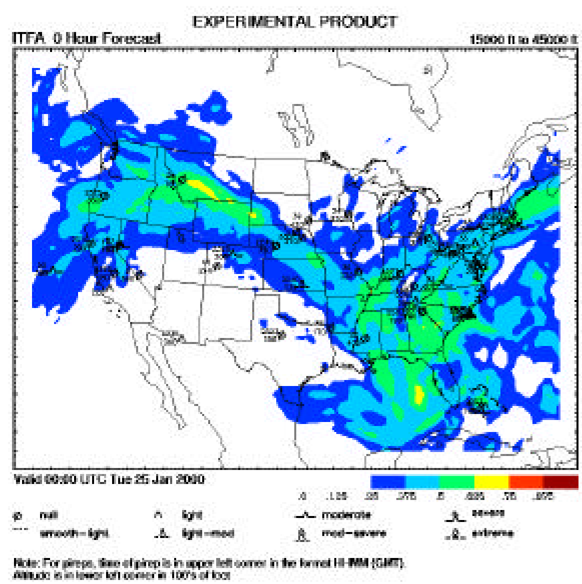
2.2 Algorithm Differences from ITFA 2000 to ITFA 2001

Several changes were instituted in the algorithm processing for ITFA 2001. The number and types of indices used in processing the algorithm were changed. In addition, the range of altitudes was also changed. ITFA 2001 has a forecast range of 15,000 feet to 45,000 feet, while ITFA 2000 had a range of 22,000 feet to 41,000 feet. The forecast range also increased from 4,000-foot layers to 5,000-foot layers.

2.3 Algorithm Output

The ITFA is run every three hours in conjunction with the RUC model run. Output includes 0, 3, 6, 9 and 12-hour CAT forecasts for each 5,000-ft layer between 15,000 and 45,000 ft. A composite product that displays the greatest value predicted in any layer is also created and displayed. Figure 1 contains a sample of the ITFA composite forecast product.

Figure 1. ITFA Composite Forecast.



The ITFA output contains turbulence predictions ranging from 0.0 to 1.0; higher values imply the likelihood of turbulence of a higher intensity. Table 1 provides an approximate correlation of the ITFA predictions to operational turbulence interpretations that were used in the evaluation.

Table 1. Range of ITFA Forecasts Versus Operational Interpretations.

ITFA Prediction	Turbulence Interpretation
0.0 to 0.25	No Turbulence Likely
0.25 to 0.5	Light Turbulence Likely
0.5 to 0.75	Moderate Turbulence Likely
0.75 to 1.0	Severe Turbulence Likely

The ITFA forecasts are presented graphically on a contoured national map that coincides with the RUC model domain. Initial 0-hr forecast products include plots of Pilot Reports (PIREPs) received during the 90 minutes previous to the corresponding RUC model run. The color scheme applied for turbulence predictions ranges from no coloring for negligible turbulence, to cool colors (blues) for light turbulence, then warm colors (greens and yellows) for moderate turbulence, and finally to hot colors (reds and maroons) for severe turbulence.

3.0 METHODOLOGY

3.1 Data Collection

The ten turbulence events occurred from 1 January through 30 April 2000. The events were identified through a collection of Significant Meteorological Information advisories (SIGMETs) issued by the Aviation Weather Center (AWC) and PIREPs. Data was collected and stored in the WJHTC Aviation Weather Laboratory. The data included the SIGMETs, PIREPs, upper air plots, RUC output, and ITFA output.

For the 2001 evaluation, visible and infrared (IR) satellite imagery that corresponds to the identified events was acquired from NCAR via their ftp site. In addition NCAR re-ran the ITFA 2001 for the ten events used in the 2000 evaluation.

3.2 Data Analysis

The 2001 ITFA Meteorological Evaluation first reevaluated the meteorological environments associated with each of the ten turbulence events. This reevaluation involved analyzing visible and infrared (IR) satellite imagery (that was not available for the 2000 ITFA Meteorological Evaluation) for the presence of mountain waves and convection in and near the event areas. If the presence of mountain waves and or convection was identified, then the event would be removed from the study since ITFA is not configured to forecast turbulence resulting from these two phenomena. The satellite imagery did not identify any mountain wave or convective activity in the vicinity of the turbulence events, thus all events were retained.

After the meteorological environments associated with each event were clarified, ITFA 2001 output, beginning 12 hours prior to the beginning of each event, was analyzed and compared to the output from the 2000 evaluation in order to determine algorithm differences.

In addition each of the ITFA 2001 indices were analyzed to determine how they compared to the overall ITFA output and the turbulence event.

4.0 RESULTS

4.1 Lead-time

The methodology for determining the ITFA lead-time involved identifying how long prior to the event ITFA predicted turbulence. While subjective in nature, this methodology attempted to evaluate the ITFA more in terms of its ability to "point out" regions of concern to users rather than statistically match ITFA forecast values with reported conditions.

For the overall evaluation period, ITFA lead times ranged from 0 to 12 hours (see Table 2). ITFA 2001 increased the lead-time for some events, the increase shown in the last column of Table 2, compared to ITFA 2000. Four of the events had no lead-time increase for ITFA 2001, while the remaining six events had a lead-time increase over ITFA 2000. Events 6 and 7 had lead-times of six and twelve hours respectively, however, these forecast lead-times were isolated to individual layers and did not appear in subsequent forecasts until the start of the overall events.

Table 2. Differences in Lead-time.

Events	ITFA 2001 Lead-time (hours)	ITFA 2000 Lead-time (hours)	Difference in Lead-time (hours)
1	12	9	+3
2	0	0	0
3	0	0	0
4	12	3	+9
5	12	0	+12
6	6	0	+6
7	12	3	+9
8	9	3	+6
9	12	12	0
10	6	6	0

4.2 End-time

In 2000, ITFA generally diminished forecasts towards the end of the events. For many of the events, ITFA 2001 increased the forecast area and intensity for the approximate time the event was ending. However, the events were partially identified using SIGMETs and the end of the events corresponded with the ending time of the SIGMETs. Some of these cases could have been turbulence moving away from United States' airspace, thus a

SIGMET was no longer applicable, or there was a lack of substantiating PIREPs. The lack of PIREPs could have been due to overnight hours and the absence of air traffic. Thus, it was possible, but not confirmed, that the turbulence event was continuing. It is not known whether the ITFA 2001 increases at the end times were due to a general forecast increase over 2000 or a more accurate indication that turbulence was continuing despite the cancellation of the SIGMET.

4.3 Intra-event Consistency

ITFA products created prior to and during each event were compared to determine how ITFA resolved each particular event over time. Overall, it was observed that ITFA output from successive generation times valid for the same time periods were consistent with each other, with onset, evolution and end of the event generally being resolved with greater accuracy with each successive ITFA run. However, observations showed for some of the events that ITFA products produced at 1200 UTC contained forecasts with decreased spatial resolution and or lower forecast values than the preceding 0900 UTC forecast and successive 1500 UTC forecast. While the ITFA 1200 UTC products are not generated in a manner different from other runs, it is possible that the RUC fields used as input to ITFA at 1200 UTC may be the cause of the observed discrepancy. In ITFA 2001, this occurred in events 1, 7, and 9.

4.4 PIREP Processing and Correlation

In 2000 a PIREP override function was used so that a PIREP of severe turbulence would result in a bulls-eye of higher intensity plotted on the output and could remain on future output (up to six hours). This was not observed in any of the events in 2001.

In addition, ITFA 2001 output appeared to be better correlated with moderate and greater PIREPs than ITFA 2000. However, as in ITFA 2000, no forecast values above 0.75 (i.e., severe turbulence according to Table 1) were observed during any of the ten turbulence events, even though numerous severe PIREPs existed.

4.5 Indices Results

The sixteen indices that are a part of ITFA 2001 were analyzed and compared to the ITFA 2001 output. Table 3 list the various indices. ITFA developers at NCAR (see http://www.rap.ucar.edu) should be contacted for further information or explanation of the various indices.

The indices that most closely portrayed the overall ITFA output and also tended to have the smallest forecasted areas that still contained the observed turbulence were Richardson Number and Vertical Wind Shear. Vertical Wind Shear was virtually identical to ITFA for both area coverage and intensity, most of the time. Richardson Number was very similar to ITFA for area coverage, however, intensity was higher than ITFA for all cases.

Table 3. ITFA 2001 Resident Indices.

Richardson Number
Ellrod TI1 Index
Ellrod TI2 Index
Brown's 2 Index
Potential Vorticity Gradient
Colson-Panofsky Index
Endlich Empirical Wind Index
Diagnostic Turbulence Forecast (DTF)3
DTF5
Anomalous Gradient Index (AGI)
Absia
Vorticity Squared
Horizontal Shear
Divergence
Vertical Wind Shear
Nested Grid Model (NGM) 1 Predictor

Occasionally, Colson-Panofsky Index, Potential Vorticity, and NGM 1 gave widespread forecasts of turbulence across the United States with no specific area of turbulence identified.

Divergence and Absia generally were scattered and widespread in nature across the United States.

Brown's 2, Ellrod TI1 and TI2, DTF3, DTF5, Horizontal Shear, and Vorticity Squared gave very broad indications of possible turbulence regions.

The Endlich index was observed to have a mixture of values with some inconsistencies in the output from event to event. The Anomalous Gradient Index generally had area and intensity coverage for most of the events that was in a different location than ITFA and the other indices.

Generally most of the individual indices tended to forecast very high values for turbulence intensity, with the exception of Vertical Wind Shear. However, even with the high values for the indices, the overall ITFA output never gave any severe values.

5.0 CONCLUSIONS

The FAA AWRP has provided funding to NCAR through the Turbulence PDT to develop a forecasting tool to identify clear-air turbulence. In response, NCAR has developed ITFA. In support of this development the Weather Branch at the FAA WJHTC has performed two subjective meteorological evaluations of ITFA, one in 2000 and one in 2001. The 2001 evaluation focused upon a comparison to ITFA 2000 and the performance of the individual ITFA indices.

Overall, ITFA 2001 demonstrated an increase in forecast intensity and area. While not specifically discussed, the overall pattern to ITFA output appeared to change little from 2000 to 2001. It is not known whether this increase is due to an improved

ITFA in 2001 or an apparent shift of the ITFA turbulence scale to reflect higher values.

ITFA lead-time ranged from 0 to 12 hours for the ten events used in the evaluation. ITFA 2001 showed an increased lead-time for six of the events compared to ITFA 2000.

ITFA 2001 tended to show increased forecast areas and intensity for the end-time of the events compared to 2000. However, it is not known whether these increases are due to a general forecast increase in 2001 compared to 2000 or a more accurate indication of turbulence continuing despite the cancellation of the SIGMETs used in the evaluation.

Overall, it was observed that ITFA output from successive generation times valid for the same time periods were consistent with each other, with the onset, evolution, and end of the event generally being resolved with greater accuracy with each successive ITFA run. Although the end of the events may not have been well forecasted by ITFA. In addition, it was observed that some products produced at 1200 UTC contained forecasts with decreased areas and or lower forecast values than preceding and subsequent produced products . This may be due to issues with the RUC.

ITFA output appeared to be correlated with PIREPs of moderate or greater intensity. However, no ITFA output of severe turbulence was ever observed. In addition, the PIREP override function from ITFA 2000 was not observed in ITFA 2001.

Vertical Wind Shear and Richardson Number were found to have the highest correlation with the observed turbulence events and the overall ITFA output. Other indices were observed to give turbulence too widespread with no specific area of turbulence or too scattered. The Anomalous Gradient Index, in general, did not correlate with ITFA or the other indices. Generally, all the indices gave very high intensities, except for Vertical Wind Shear.

6.0 RECOMMENDATIONS

The 2001 ITFA meteorological evaluation continued to demonstrate the trend from the ITFA 2000 evaluation, i.e., that ITFA has the potential to be a forecasting tool for upper level clear-air turbulence. However, it is recommended that further development in the following areas be considered: 1) The reasons for the overall increase in ITFA 2001 forecasts should be identified and examined; 2) It needs to be determined why overall ITFA output never had any forecasted areas of turbulence greater than moderate even though all ten turbulence events had numerous severe PIREPs; 3) It needs to be investigated why some ITFA 1200 UTC products in the evaluation underforecasted turbulence compared to 0900 and 1500 UTC products; and 4) Determine the impact of certain indices, which did not appear to be contributing to accurate turbulence forecasts, in order to assess whether the indices are worthwhile components of ITFA.

Feedback from the ITFA 2001 meteorological evaluation was presented to the Turbulence PDT for the improvement of ITFA. A full report on the evaluation documenting procedures, results, conclusions and recommendations is available from ACT-320.

7.0 ACKNOWLEDGEMENTS

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