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THE INTEGRATED TURBULENCE FORECASTING ALGORITHM (ITFA) METEOROLOGICAL EVALUATION FINAL REPORT

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16. Abstract

This report summarizes the Integrated Turbulence Forecasting Algorithm (ITFA) Meteorological Evaluation conducted by ACT-320 from January to August 2000. The ITFA, developed at the National Center for Atmospheric Research (NCAR), combines several turbulence forecasting techniques into a single algorithm that produces a forecast of the potential for high-level, clear-air turbulence.

The purpose of the evaluation was to provide a subjective assessment of the performance, characteristics, and trends of the ITFA before and during periods of widespread, significant turbulence.

Evaluation results indicate that ITFA has the potential to be a useful tool for the detection and prediction of jet-stream/wind shear induced upper-level turbulence. In addition, several recommendations were made for further development.

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EXECUTIVE SUMMARY

This report summarizes the Integrated Turbulence Forecasting Algorithm (ITFA) Meteorological Evaluation that was conducted at the Federal Aviation Administration (FAA) William J. Hughes Technical Center from January through August 2000. Specific results, conclusions, and recommendations for the evaluation are detailed in this report.

The Research Applications Program at the National Center for Atmospheric Research (NCAR) has developed the ITFA by combining several turbulence forecast techniques into a single algorithm that produces a forecast of turbulence potential. The ITFA makes use of numerical weather prediction output to calculate the individual turbulence indices while turbulence observations obtained from pilot reports and aircraft vertical accelerometer reports are used to weight the different outputs before they are integrated into a single forecast. The algorithm output consists of five layered products and a composite product that graphically depict the ITFA forecasts of turbulence potential for altitudes above 22,000 feet.

The Weather Branch (ACT-320) at the FAA William J. Hughes Technical Center conducted the meteorological evaluation. Rather than provide a purely statistical measure of algorithm performance, the evaluation focused on providing a subjective assessment of the performance, characteristics and trends of the ITFA before and during periods of widespread, significant turbulence.

The evaluation results indicate that the ITFA has the potential to be a useful tool for the detection and prediction of jet-stream/wind shear induced upper-level turbulence. ITFA displayed skill in forecasting the onset and end of the identified turbulence events. In addition, it was evident that ITFA tended to resolve the identified turbulence events better over time. Areas of improvement include the mapping of output of ITFA resident indices to turbulence potential and predictions of turbulence due to directional wind shear.

Based on the evaluation results, ACT-320 recommends the FAA Aviation Weather Research Program continue to provide funding and direction for future development of the ITFA. Specific direction should focus on improving the mapping of the ITFA diagnostics to turbulence potential which would result in a more accurate correlation of ITFA forecast values to observed conditions. In addition, NCAR should investigate whether or not adding additional indices to ITFA that are designed to detect regions of directional shear would result in ITFA better resolving regions of turbulence produced by upper low pressure systems. Additional investigations into a possible bias where ITFA 1200 Universal Coordinated Time (UTC) products under forecast turbulence potential and into finding more efficient ways to incorporate turbulence reports into ITFA processing should lead to noticeable product improvement.

1. INTRODUCTION.

1.1 BACKGROUND.

The Federal Aviation Administration (FAA) Aviation Weather Research Program (AWRP) has provided funding to the National Center for Atmospheric Research (NCAR) Research Applications Program (RAP) to develop a forecasting tool that mitigates the dangers to commercial and general aviation aircraft from unexpected, hazardous, clear-air turbulence. This effort falls under the umbrella of the Turbulence Product Development Team (PDT), which is made up of 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/RAP has developed the Integrated Turbulence Forecasting Algorithm (ITFA), which produces timely turbulence forecasts for the contiguous United States.

In support of the ITFA development, the FAA William J. Hughes Technical Center Communication/Navigation/Surveillance Engineering and Test Division, Weather Branch (ACT-320) performed an event-driven meteorological evaluation of the ITFA. The evaluation was conducted from January to August 2000 and focused on providing a subjective assessment of the performance, characteristics, and trends of ITFA before and during significant turbulence events.

1.2 PURPOSE OF REPORT.

The purpose of this report is to document activities, results, conclusions, and recommendations from the ITFA Meteorological Evaluation. This report will be provided to NCAR/RAP to assist with future development of the ITFA. NCAR/RAP and the National Oceanic and Atmospheric Administration (NOAA) Forecast Systems Laboratory (FSL) are conducting separate verification activities to measure the quantitative performance of the product, and will be responsible for issuing results on their verification work.

2. REFERENCE DOCUMENTS.

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Sharman, R. and L. Coleman, 1998: An Integrated Approach to Clear-Air Turbulence Prediction. *American Institute of Aeronautics and Astronautics*, 98, 1-6.

Sharman, R., C. Tebaldi, and B. Brown: An Integrated Approach to Clear-Air Turbulence Forecasting. National Center for Atmospheric Research, 1-4.

3. PRODUCT OVERVIEW.

The ITFA forecasting process is illustrated in figure 1. The ITFA produces forecasts of turbulence by integrating the weighted output of several algorithms and indices that have proven strengths as turbulence predictors. The weightings are determined by comparing the output of the algorithms and indices to turbulence observations deduced from both Pilot Reports (PIREPs) and Aircraft Vertical Accelerometer Reports (AVARS). Table 1 contains the meteorological indices and algorithms that are currently included in the ITFA. The following sections are devoted to the description of the ITFA inputs, processes and output.

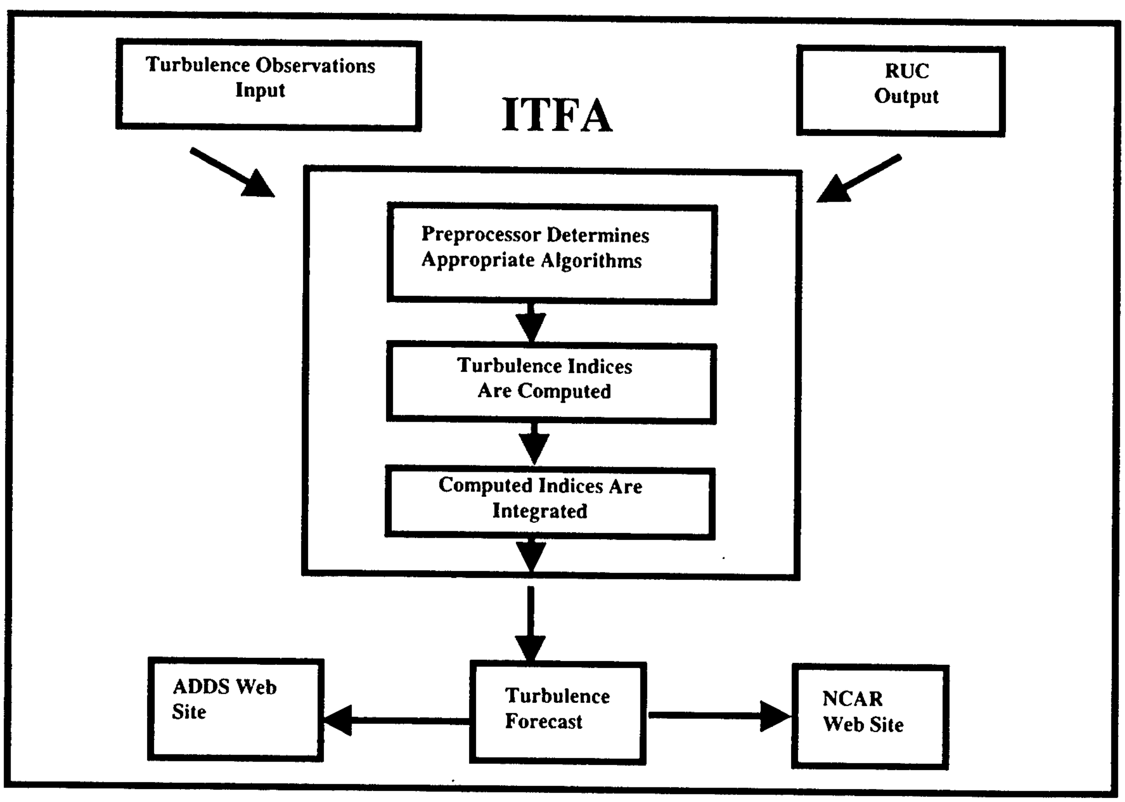

FIGURE 1. THE ITFA FORECAST PROCESS

TABLE 1. ITFA RESIDENT TURBULENCE INDICES

Richardson Number
Ellrod Indices
Brown's Index
Potential Vorticity Gradient
CCAT Index
Colson-Panofsky Index
Dutton's Empirical Index
Endlich Empirical Wind Index
Reap MOSS Predictors
SCATR Index
Diagnostic Turbulence Forecast (DTF) Algorithms
Aviation Weather Center (AWC) Algorithms

3.1 ITFA INPUT.

The ITFA uses the following data inputs:

a. Rapid Update Cycle (RUC) numerical weather prediction model output for levels above 22,000 feet.

b. Turbulence reports received from PIREPs.

c. Turbulence reports deduced from AVARS data.

3.1.1 Rapid Update Cycle (RUC).

The turbulence indices and algorithms within ITFA are calculated using the forecasted fields of the RUC. The RUC is a meteorological forecast model that was developed for the purpose of providing timely and accurate numerical weather predictions for the zero to 12-hour range. The latest iteration of the RUC runs at the highest frequency of any forecast model at the National Centers for Environmental Prediction (NCEP), making it very useful for aviation forecasting. RUC 12-hour forecasts are generated every three hours with three-hour forecasts produced hourly.

3.1.2 Pilot Reports (PIREPs).

ITFA uses PIREPs to identify areas of turbulence, to assign appropriate weighting factors to the output of ITFA's individual turbulence indices, and to override under-forecasted output. A PIREP is a meteorological observation received from the cockpit of an aircraft during flight. This information is vital to successful turbulence forecasting because a PIREP is usually the only direct means of observing turbulent conditions. A typical PIREP contains the location of the reporting aircraft, time of day, aircraft altitude, type of aircraft, sky condition, flight visibility, encountered weather, temperature, wind velocity, turbulence intensity and type, icing intensity and type, and general remarks.

The turbulence is documented in PIREPs by using standard contractions for intensity and type. Table 2 classifies each turbulence intensity level according to its effects on aircraft control, structural integrity, and articles and occupants within the aircraft.

TABLE 2. TURBULENCE INTENSITY REPORTING CRITERIA (GLEIM 1999)

Intensity	Aircraft Reaction	Reaction Inside Aircraft
Light	Turbulence that momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw). Reported as light turbulence or light clear air turbulence (CAT). Or Turbulence that causes slight, rapid, and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude. Reported as light chop.	Occupants may feel a slight strain against belts or shoulder straps. Unsecured objects may be displaced slightly. Food service may be conducted and little to no difficulty is encountered in walking.
Moderate	Turbulence that causes changes in altitude and/or attitude occurs but the aircraft remains in positive control at all times. It usually causes variations in indicated airspeed. Reported as moderate turbulence or moderate CAT. Or Turbulence that is similar to light chop but of greater intensity. It causes rapid bumps or jolts without appreciable changes in aircraft or attitude. Reported as moderate chop.	Occupants feel definite strains against seat belts or shoulder straps. Unsecured objects are dislodged. Food service and walking are difficult.
Severe	Turbulence that causes large, abrupt changes in altitude and/or attitude. It usually causes large variations in indicated airspeed. Aircraft may be momentarily out of control. Reported as severe turbulence or severe CAT.	Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Food service and walking are impossible.
Extreme	Turbulence in which the aircraft is violently tossed about and is practically impossible to control. It may cause structural damage. Reported as extreme turbulence or extreme CAT.	

3.1.3 Aircraft Vertical Accelerometer Reports.

Like PIREPs, ITFA uses AVARS data for the identification of turbulence and to assign appropriate weighting factors to the individual turbulence indices computed by ITFA. However, since aircraft accelerometers measure all aircraft accelerations, which can be the result of turns, climbs, descents, or turbulence encounters, the accelerometer data is mainly used by ITFA, in conjunction with null pilot reports, to confirm non-turbulent events.

Aeronautical Radio, Inc. (ARINC) via the Aircraft Communications Addressing and Reporting System, Meteorological Data Collection and Reporting System (ACARS-MDCRS) data network, and the National Airspace Data Interchange Network (NADIN II) receives the accelerometer measurements in real-time. They are then provided to the National Weather Service (NWS) for distribution on a high priority, Internet data delivery system.

3.2 ITFA OUTPUT.

The ITFA is executed every three hours in conjunction with the RUC 12-hour model run. Algorithm output consists of a mosaic of turbulence forecasts presented on a map of the contiguous United States that coincides with the RUC model domain. An example of an ITFA forecast product is presented as figure 2. The algorithm generates 0, 3, 6, 9 and 12-hour forecasts for layers between 22,000 and 41,000 ft. See table 3 for the available ITFA forecast layers. The forecast hour and the forecast layer are displayed in the upper-left and upper-right corners of the product, respectively. In the lower left corner is the forecast valid time and date for that particular product. Finally, a color legend is presented at the lower-right quadrant of the product.

3.2.1 The ITFA Forecast.

The ITFA forecast output ranges from 0.0 to 1.0. Table 4 gives the correlation of ITFA forecasts to operational turbulence interpretations. The representative color scheme employed to represent the turbulence forecasts ranges from no coloring for negligible turbulence, to cool colors (blues and greens) for light turbulence potential and warm colors (yellows and reds) for moderate or greater turbulence potential.

3.2.2 PIREPs and AVARS Overlay.

Symbols that represent turbulence observations obtained from PIREPs and AVARS data are overlaid on ITFA products. This information is based on data that are not more than 90 minutes old at the generation time of the ITFA. Null aircraft accelerometer reports are represented by the 'o' symbol and turbulence observations derived from PIREPs are presented using the traditional turbulence symbols shown in figure 3.

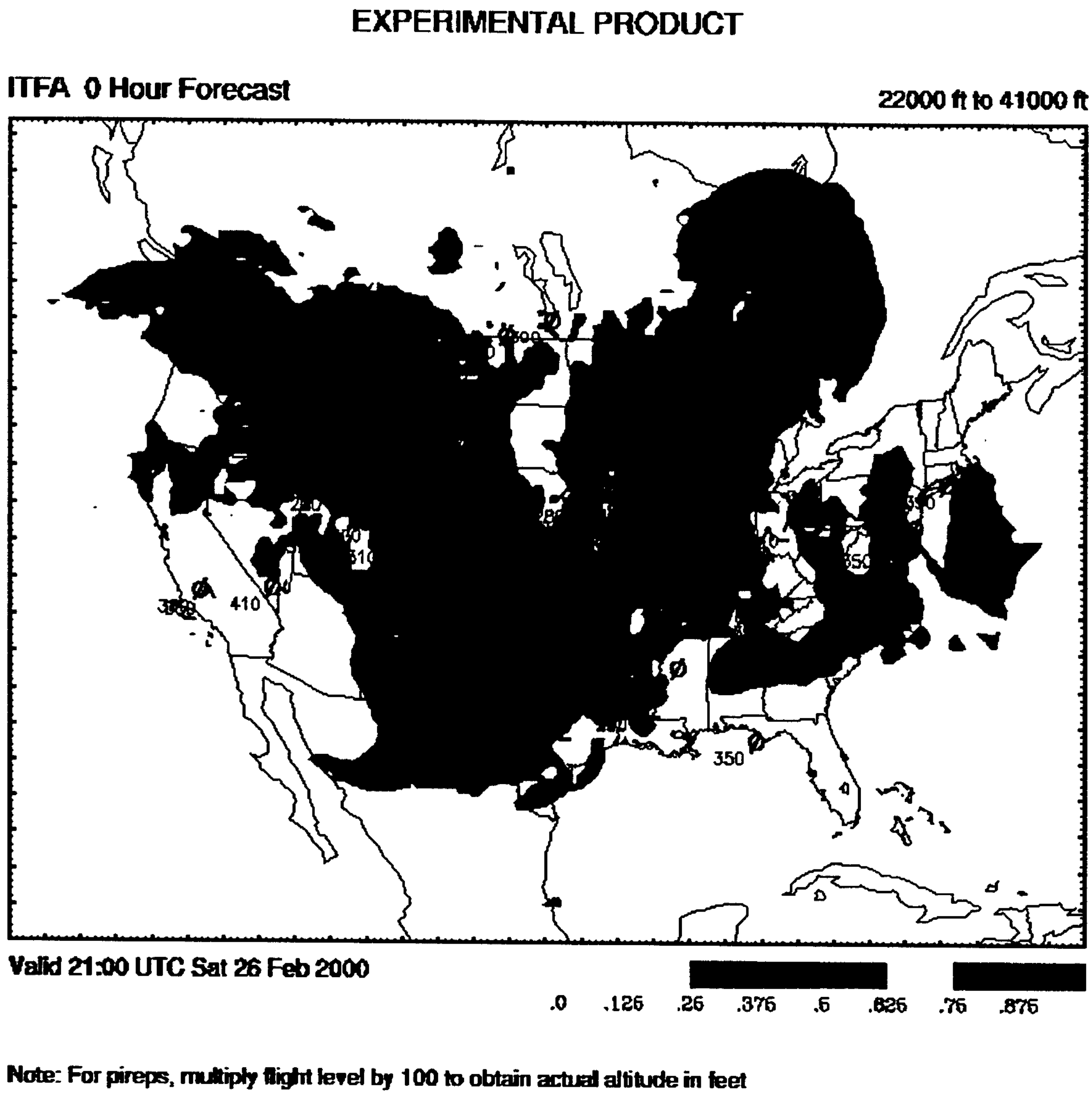

FIGURE 2. SAMPLE ITFA FORECAST PRODUCT

TABLE 3. THE ITFA FORECAST LAYERS

ITFA Forecast Layers
22,000 - 41,000 feet
22,000 – 26,000 feet
26,000 – 30,000 feet
30,000 – 34,000 feet
34,000 – 38,000 feet
38,000 – 41,000 feet

TABLE 4. ITFA COLOR LEGEND AND RELATION OF ITFA PREDICTIONS TO TURBULENCE INTENSITIES

ITFA Prediction (0.0 to 1.0)	Turbulence Interpretation
0.0 to 0.25	No Turbulence Likely
0.25 to 0.5	At Least Light Turbulence Likely
0.5 to 0.75	At Least Moderate Turbulence Likely
0.75 to 1.0	At Least Some Moderate or Greater Turbulence Likely
.0 .125 .25 .375 .5 .625 .75 .875	

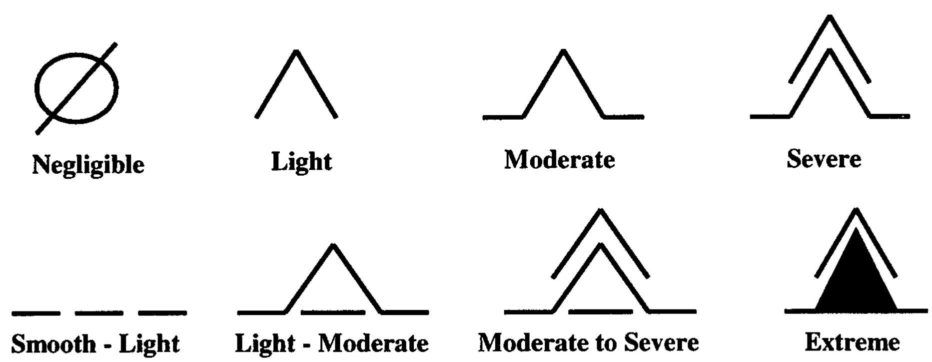

FIGURE 3. PIREP TURBULENCE SYMBOLS AND MEANINGS

4. METEOROLOGICAL EVALUATION DESCRIPTION.

4.1 SCHEDULE AND LOCATION.

The ITFA Meteorological Evaluation was conducted at the William J. Hughes Technical Center, with data collection taking place from January to April 2000 and data reduction and analysis activities performed from April to August 2000.

4.2 APPROACH.

The evaluation focused on providing a subjective assessment of the performance, characteristics, and trends of ITFA products produced before and during periods of widespread, significant turbulence. Employing several UNIX korn shell scripts developed by ACT-320, PIREPs, SIGMETs (SIGnificant METeorological Information), numerical weather prediction output, and ITFA products were automatically collected, sorted, and archived on a Sun Sparc60 workstation located in the William J. Hughes Technical Center AWRP Laboratory. This information was used to identify areas of significant turbulence, to determine the meteorological environment associated with the turbulence, and to determine how ITFA performed during each event. Specifics related to the goals and conducts of the meteorological evaluation are presented in the following sub-sections.

4.3 METEOROLOGICAL EVALUATION TOOLS.

Tools used during the meteorological evaluation include:

a. Evaluation forms developed by ACT-320 to document the turbulence events, the associated meteorological environment, and the corresponding ITFA products.

b. UNIX shell scripts for accessing, sorting, archiving, and processing the PIREPs, SIGMETs, numerical weather prediction, and ITFA forecasts.

c. Database of PIREPs, SIGMETs, numerical weather prediction, ITFA forecasts, and associated documentation.

d. Aviation Weather Center (AWC) software for plotting the SIGMETs.

e. The Grid Analysis and Display System (GrADS) for the manipulation and display of numerical weather prediction output.

4.4 METEOROLOGICAL EVALUATION OBJECTIVES.

The objective of the ITFA Meteorological Evaluation was to provide a subjective assessment of ITFA performance and to document characteristics and trends of the ITFA before and during significant turbulence events. Rather than provide a purely statistical measure of algorithm performance, the evaluation concentrated on the operational implications of forecast accuracy as well as the synoptic conditions of each event studied.

4.5 METEOROLOGICAL EVALUATION DESCRIPTION AND METHODOLOGY.

The first step of the evaluation was to identify significant turbulence events. To accomplish this, SIGMETs and PIREPs were examined to identify reported or anticipated large-scale regions of significant turbulence. SIGMETs are aviation advisories produced by the AWC and are described in detail in section 4.6.1.1.

Once the regions of significant turbulence were identified from the analysis of the SIGMETs and PIREPs, ACT-320 meteorologists examined upper-air meteorological observations and RUC output to determine the meteorological environment associated with each turbulence event, as well as the evolution of that environment over time. The RUC was chosen for this analysis since its output is used to compute ITFA and thus directly influences ITFA's performance.

Finally, the corresponding ITFA forecasts were analyzed to determine how the algorithm anticipated the onset and evolution of each event. This analysis looked to identify operational perspectives, such as forecast lead-time, performance in a specific geographic region or during certain meteorological conditions that would provide helpful input for the future development of the algorithm.

4.6 DATA COLLECTION AND ANALYSIS.

The following subsections are devoted to documenting the data collection and analysis effort. Data used in the evaluation is described in detail, as are the data collection and analysis techniques. In addition, descriptions of the UNIX korn shell scripts that were developed by ACT-320 to streamline simple but time-consuming tasks are presented.

4.6.1 SIGMETs.

4.6.1.1 SIGMETs Defined.

The SIGMET is a meteorological advisory issued by the AWC for weather conditions, other than convective activity, that are potentially hazardous to all aircraft. This includes:

a. Severe icing,
b. Severe or extreme turbulence,
c. Dust storms and sandstorms lowering visibilities to less than 3 miles,
d. Volcanic ash.

SIGMETs are issued when the above phenomena are considered to be widespread, or affecting or forecast to be affecting an area of at least 3,000 square miles at any one time. However, if the total area to be affected during the forecast period is very large, it could be that only a small portion of the total area would be affected at any one time.

SIGMETs are issued for 6-hour periods for conditions associated with hurricanes and for 4 hours for all other events. If conditions persist beyond the forecast period, the SIGMET is updated and reissued.

4.6.1.2 Use of SIGMETs.

SIGMETs issued for severe turbulence were analyzed to identify potential turbulence events. This analysis involved determining that the turbulence was caused by jet-stream/wind shear influences that occurred above 22,000 ft, the lowest level of prediction for the ITFA. It was assumed that turbulence identified using SIGMETs was non-convective in nature. If convection existed, then a turbulence SIGMET would not have been issued by AWC. Candidate SIGMETs were plotted using software obtained from the AWC to illustrate the given boundaries for later analysis with the PIREPs, meteorological data and ITFA output.

4.6.1.3 Access, Storage and Processing of SIGMETs.

The SIGMETs were acquired via automated ftp from the Florida State University public ftp site. The SIGMETs were received in files that also included several other aviation advisories, such as convective and international SIGMETs. To streamline the manipulation of these files, several UNIX scripts were employed to extract the SIGMET data from the received files, organize the extracted information into daily files, and archive the data in the SIGMET database.

4.6.2 PIREPs.

4.6.2.1 PIREPs Defined.

As noted in section 3.1.2, PIREPs are meteorological observations received from the cockpit of an airplane.

4.6.2.2 Use of PIREPs.

After the SIGMET analysis produced a potential event for study, the PIREP database was searched for PIREPs that corresponded to the region and time noted in a candidate SIGMET. This search focused on identifying PIREPs that included reports of moderate or greater turbulence from in and near the advisory area defined in the SIGMET. PIREPs are subjective in nature and are influenced by such factors as the reporting aircraft's size or pilot experience. As a result, the PIREPs analysis also focused on documenting the reporting aircraft's type and size with reports of moderate or greater turbulence from larger aircraft being viewed as better indicators of significant turbulence than similar reports from smaller, lighter aircraft.

As the PIREP analysis focused on obtaining reports of moderate or greater turbulence from in and near the area defined by a SIGMET, the initial horizontal and vertical boundaries defined by the SIGMETs were modified to correspond with the actual turbulence reports. This resulted in the identification of event areas that were defined by both the AWC forecasters' and pilot's input.

4.6.2.3 Access, Storage and Processing of PIREPs.

PIREPs were acquired via automated ftp from the NWS Telecommunications Gateway (NWSTG). This information was processed via shell scripts that were created by ACT-320 to streamline the data reduction and analysis efforts. The scripts first extracted reports of moderate or greater turbulence from PIREP files received from the NWSTG each hour, and then incorporated these reports into a single file each day. The raw and processed data was automatically archived on a Sun workstation that was accessible for data analysis either in the William J. Hughes Technical Center AWRP Laboratory or at the evaluator's desktop.

4.6.3 Upper Air Data.

4.6.3.1 Upper Air Data Defined.

For this analysis, upper air data is defined as the graphical plots of the meteorological information obtained from instrument packages such as radiosondes and rawinsondes, that are carried aloft by weather balloons and transmit data back to a receiving station on the ground. This upper air data consists of temperature, relative humidity, atmospheric pressure, and wind information and is collected twice daily, around 0000 Universal Time Coordinated (UTC) and 1200 UTC.

Maps of the upper air data were obtained from the NWS Storm Prediction Center (SPC) Internet site. These maps were created using information obtained directly from the launched instrument packages and were accompanied by analysis contours of select meteorological fields that were produced by the Eta numerical weather prediction model. The 0000 UTC maps were produced at 0100 UTC using the available upper air data with a first guess from the 1800 UTC Eta 6-hour forecast for the objective analysis. The 1200 UTC maps were produced at 1300 UTC using the 0600 UTC Eta 6-hour forecast as a first guess for the objective analysis. If the 1800 UTC or 0600 UTC Eta runs were unavailable, a first guess from the 12-hour forecast of the 0000 UTC or 1200 UTC Eta was used. Errors in the analysis were possible if the Eta model data was not available, or if the sounding data was late or erroneous.

4.6.3.2 Use of Upper Air Data.

Once a significant turbulence event was identified, ACT-320 meteorologist examined the upper-air data from before, during and after each event to determine the meteorological features associated with the reported or expected turbulence as well as the movement and evolution of the atmospheric features over time. Special attention was paid to identifying the synoptic and mesoscale features in the atmosphere that may produce jet stream/wind shear induced turbulence. In addition, as ITFA is designed to predict turbulence potential for altitudes above 22,000 feet, the analysis of the upper air data focused on this region of the atmosphere.

4.6.3.3 Access, Storage and Processing of Upper Air Data.

The upper-air data was collected from the NWS SPC Internet Site and stored on a Sun Sparc60 workstation in the William J. Hughes Technical Center AWRP Laboratory. The data was accessible for analysis either in the laboratory or at the evaluator's desktop.

4.6.4 Numerical Weather Prediction.

4.6.4.1 Numerical Weather Prediction Defined.

Numerical Weather Prediction (NWP) involves the use of powerful computers to create weather forecasts. NWP computer programs, or forecast models, provide predictions for many atmospheric variables such as temperature, pressure, wind, and rainfall.

As stated in Section 3.1.1, the RUC is a numerical weather prediction model that was developed for the purpose of providing timely and accurate numerical weather predictions for the 0-12 hour range, making it very useful for aviation forecasting. As the RUC's output is used to compute the ITFA resident indices and algorithms, it was acquired and stored for use in the ITFA Meteorological Evaluation.

4.6.4.2 Use of Numerical Weather Prediction.

After a significant turbulence event was identified through the analysis of the SIGMETs and PIREPs, the output from the RUC model was used, along with upper air data to determine the meteorological environment associated with each turbulence event. This was an important procedure since the RUC's representation of the meteorological environment directly impacts ITFA's ability to forecast turbulence potential. For example, if the RUC forecasts a meteorological feature too rapidly that produces turbulence, this could result in ITFA forecasting an area of associated turbulence to progress too rapidly as well.

4.6.4.3 Access, Storage and Processing of Numerical Weather Prediction.

The RUC output was acquired via automated ftp from the NWSTG, the FAA Bulk Weather Telecommunications Gateway (FBWTG), and from the NCAR. This information was automatically archived in a database that organized the information according to the RUC's generation date.

As numerical weather prediction data is very large, the information was accessed and stored in GRIB (GRIdded Binary) format. GRIB is a World Meteorological Organization (WMO) format for gridded data and is used by the operational meteorological centers for storage and the exchange of gridded fields. GRIB's major advantages are that the files are typically 1/2 to 1/3 of the size of normal binary files, the fields are self-describing, and GRIB is an open, international standard.

In support of the ITFA Meteorological Evaluation, the GrADS software was installed on a Sun Sparc60 workstation in the William J. Hughes Technical Center AWRP Laboratory. GrADS is an interactive desktop tool that is currently in use worldwide for the analysis and display of earth science data. The GrADS software was used to analyze the RUC data to ascertain the meteorological conditions associated with each turbulence event.

4.6.5 ITFA Evaluation.

4.6.5.1 ITFA Evaluation Defined.

After a turbulence event and the corresponding meteorological environment were identified, the ITFA output was examined to determine how well the algorithm represented the identified conditions. Performance issues such as lead-time, over-forecasting, under-forecasting, and identifying geographical biases are examples of the operational aspects of the evaluation. In addition, the evaluation looked to identify trends and characteristics of the ITFA. These included evaluating the run-to-run consistency of the ITFA, the impacts of various inputs, and the trends during particular meteorological conditions.

After this procedure was completed for each event, the results were compared to each other to determine overall performance issues, characteristics and trends from the evaluation period.

4.6.5.2 Access, Storage and Processing of ITFA Information.

ITFA output was acquired via automated ftp from the NCAR public ftp server. The output consisted of all the composite and layer forecasts produced by each ITFA run. This information was produced and saved in the .gif format (graphics interchange format). Due to the complex directory structure of the data, the automated ftp process involved downloading the data to the William J. Hughes Technical Center Sun workstation using the Tape ARchive utility (TAR), which is a UNIX shell command that creates a single file called an "archive" from a number of specified files. After the information was received at the William J. Hughes Technical Center, additional scripts decompressed the data and archived the information according to the output's generation date.

4.7 METEOROLOGICAL EVALUATION PROCEDURES.

The previous sections detailed the data collection and analysis effort. Some explanation for how this data was used was also provided. In this section, detailed descriptions of the steps used to evaluate ITFA are presented.

4.7.1 Case Identification.

Step 1. For each day of the evaluation period, the SIGMETs issued by the AWC were examined to determine if any large-scale areas of severe turbulence were reported or anticipated throughout the Nation. If a turbulence-related SIGMET was issued, was for non-mountain wave turbulence, and the turbulence was forecast to occur above 22,000 feet, the SIGMET was plotted using AWC software.

Step 2. The details of the SIGMET were documented. This included the anticipated duration, initial horizontal and vertical boundaries, and expected conditions.

Step 3. Additional SIGMETs that extended or amended the initial SIGMET were plotted, with the details pertaining to duration, new horizontal and vertical boundaries, and expected conditions being documented.

Step 4. Once an area of reported or anticipated turbulence was identified, the PIREP database was examined for PIREPs from in and near the area defined by the corresponding SIGMET.

Step 5. The details of the PIREPs were documented. This included the aircraft type, reported turbulence and intensity, altitude, and comments.

Step 6. If necessary, the event boundaries obtained from the SIGMETs were modified using the information from the PIREPs analysis.

4.7.2 Meteorological Environment Analysis.

Step 7. Once the event area was identified, the meteorological environment associated with the turbulence was evaluated. This involved the examination of upper air data to identify meteorological features associated with the turbulence as well as the RUC's interpretation of these features over time. This portion of the evaluation avoided strict procedures and relied on the evaluator to subjectively determine and document the specific atmospheric features associated with each turbulence event.

4.7.3 ITFA Analysis.

Step 8. After the meteorological environment associated with a turbulence event was identified, the corresponding ITFA output was examined. This involved examining ITFA predictions from both before and during the events. The evaluation focused on providing a subjective assessment of ITFA's performance, characteristics and trends. Specific parameters for the analysis are given below.

Step 9. Once the analysis of the individual events was completed, the results were compared to each other to determine overall results from the evaluation period.

4.7.3.1 Performance Issues.

a. Lead-Time: Analysis focused on when ITFA began to resolve the onset of each event.

b. End-Time: Analysis focused on how well ITFA resolved the end of each event.

c. Forecast vs. Observed Conditions: Observe how ITFA output compares to the turbulence reported in the event areas.

d. Geographical Biases: Note the geographic region for each event. Compare individual results to each other and attempt to determine any geographical biases.

4.7.3.2 Characteristics and Trends.

a. Intra-Event Consistency: Determine whether or not ITFA output is presented consistently from run to run and whether or not the output improves with each successive run.

b. Meteorological Correlation: Document the meteorological environment associated with each turbulence event. Compare the results to each other to determine overall trends.

c. PIREP Processing: Determine the impact of turbulence reports on ITFA output.

5. RESULTS AND DISCUSSION.

This section presents the results of the ITFA Meteorological Evaluation. Section 5.1 presents information pertaining to the turbulence events that were identified during the evaluation period. Section 5.2 discusses performance issues while section 5.3 details the characteristics and trends documented during the evaluation.

5.1 IDENTIFIED EVENTS.

The turbulence events identified during the evaluation period are presented in table 5. This table also contains information pertaining to the number of associated PIREPs as well as a brief description of the meteorological environment identified with each event. Though 12 turbulence events were identified for study, processing difficulties resulted in the elimination of Events 10 and 12 from the study. Additional information pertaining to the details of each event is available from ACT-320.

5.2 PERFORMANCE ISSUES.

5.2.1 Lead-Time.

The methodology for determining the ITFA lead-time for each case involved identifying the ITFA products that contained forecasts of turbulence potential that corresponded spatially with the event area defined by the SIGMET/PIREP analysis. While subjective in nature, this methodology attempted to evaluate the ITFA more in terms of its ability to "point out" to a user a region of concern rather than statistically match ITFA forecast values (0.0 to 1.0) with reported conditions. For example, figure 4 illustrates the initial event area for Event 4, which began at 1530 UTC on February 26, 2000 and is where occasional severe turbulence was expected between 20,000 and 35,000 feet due to wind shear associated with the jet stream. Figures 5a-d, generated at 1200 UTC and valid for 1500 UTC, indicate that roughly three hours before the start of the event, ITFA was focusing on the event area, especially in the products that focused above 30,000 feet. For example, notice the ITFA values of .5 to .625 (the green areas) in figures 5c-d. In contrast, images from the 0900 ITFA run (figures 6a-d), valid for 1500 UTC, show considerably less spatial resolution of the event area when compared to the products produced at 1200 UTC. Thus, the lead-time for this event was determined to be three hours.

For the overall evaluation period, ITFA lead times ranged from zero to 12 hours. However, while ITFA did not always provide lead-time, no event was entirely undetected. In cases with zero lead-time, either the ITFA algorithms and/or the incorporation of actual turbulence observations resulted in at least a partial identification of the turbulent region. In contrast, the human-produced SIGMET product failed to provide any lead-time for each event identified throughout the evaluation period. While human forecasters are trained to be conservative in their approach to issuing SIGMETs, and this conservatism may be reflected here, the ITFA results show that ITFA has some value in alerting forecasters to the potential for jet stream/wind shear induced upper-level turbulence prior to onset.

TABLE 5. IDENTIFIED SIGNIFICANT TURBULENCE EVENTS AND THE ASSOCIATED DURATION, NUMBER OF PIREPS, AND METEOROLOGICAL ENVIRONMENT

Event	Region	Duration Date and Time (UTC)	# of PIREPs	Meteorological Environment
1	Northeast, Midwest, Mid-Atlantic	1/24/00 1320 - 1/25/00 1255	33	Broad positive-tilt trough over the central U.S. moves east and becomes negatively tilted. Turbulence is reported along and ahead of the approaching trough axis.
2	Plains	2/11/00 1500 - 2/11/00 2320	4	Short wave trough at 500 millibars (mb) and above moves out of the southern Rockies into the southern Plains. Turbulence is reported along and ahead of the short wave.
3	Midwest, Great Lakes	2/14/00 0100 - 2/14/00 0945	5	Trough axis over the central U.S. moves slowly east. Turbulence is reported along and ahead of the approaching trough axis.
4	Midwest, Great Lakes	2/26/00 1530 - 2/27/00 0305	20	Trough axis over the central U.S. with associated 500 and 300 mb closed low over west central Illinois moves slowly east with closed low opening up by 2/27 0000 UTC. Turbulence is reported along and ahead of the approaching trough axis.
5	Pacific Northwest	3/2/00 2010 - 3/3/00 0525	20	Approaching trough axis at 3/2 1200 UTC moves into the Pacific Northwest...developing a 500 mb closed low just off the central CA coast at 3/3 0000 UTC. Turbulence is reported along and ahead of the approaching trough axis.
6	Midwest, Mid-Atlantic	3/3/00 1000 - 3/4/00 0230	13	At 3/3 1200 UTC broad trough over the central U.S. with a closed low 500 and 300 mb centered over southeast Kansas...additional trough axis extends over the northwestern Atlantic with a closed low at 500 mb off Maine. Both systems shift eastward through 3/4 0000 UTC. Turbulence is reported along and ahead of the central U.S. trough axis in a region of directional and speed shear.
7	Plains, Midwest, Great Lakes	3/10/00 1945 - 3/11/00 0655	6	Upper level trough deepened as it moved out of the Rockies and into the Plains. Turbulence was reported along and ahead of the eastward moving trough axis.
8	Central CA	3/4/00 1945 - 3/5/00 0420	10	Closed low at 500 mb and above centered off the southwest California coast moved inland through the advisory period. Turbulence was reported along and ahead of the low in a region dominated more by directional shear than speed shear.
9	Mid-Atlantic	3/22/00 1310 - 3/23/00 0135	4	Negative-tilt trough and associated 500 mb closed low over the Mid-Atlantic states progressed quickly to the southeast and off the North Carolina coast by 3/23 0000 UTC. Turbulence was reported along and ahead of the trough axis as it moved southeast.
10	Ohio Valley	3/29/00 1900 - 3/30/00 0130	3	N/A - No ITFA data available.
11	Iowa/Great Lakes	4/2/00 1525 - 4/3/00 0050	9	Broad trough over the central U.S. at 4/2 1200 UTC with 500 mb short wave trough over the Montana/North Dakota border. By 4/3 0000 UTC the short wave phases with the long wave trough as the whole system moves slightly east. Turbulence was reported along and ahead of the trough axis, from Iowa into the Great Lakes.
12	Mid-Atlantic	4/9/00 1521 - 4/9/00 2330	9	N/A - No ITFA data available.

FIGURE 4. EVENT AREA FOR EVENT 4

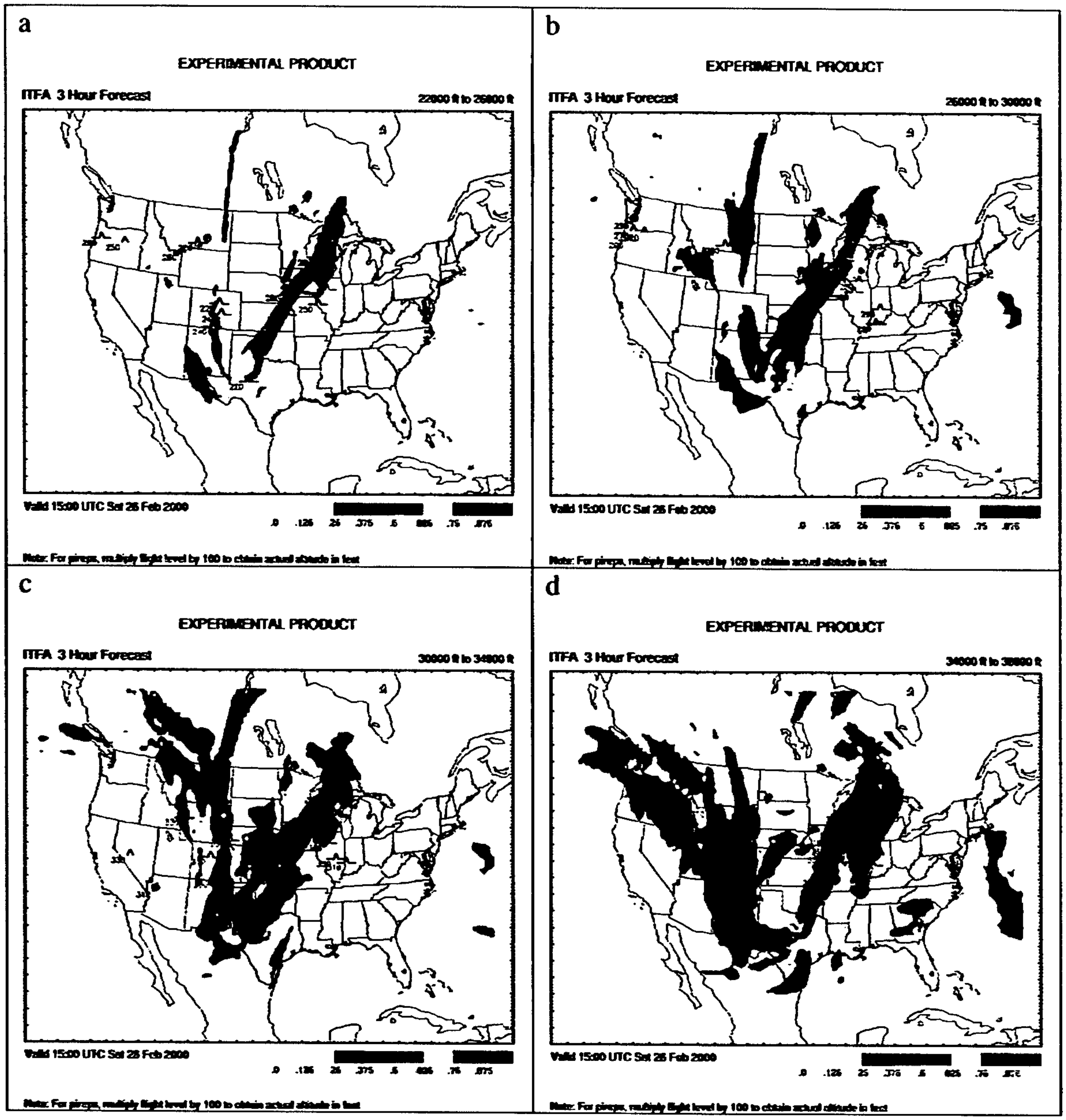

FIGURE 5A-D. FROM EVENT 4, 1200 UTC ITFA THREE-HOUR FORECAST PRODUCTS FOR 22,000-26,000 FT (A), 26,000-30,000 FT (B), 30,000-34,000 FT (C), AND 34,000-38,000 FT (D) VALID FOR 1500 UTC

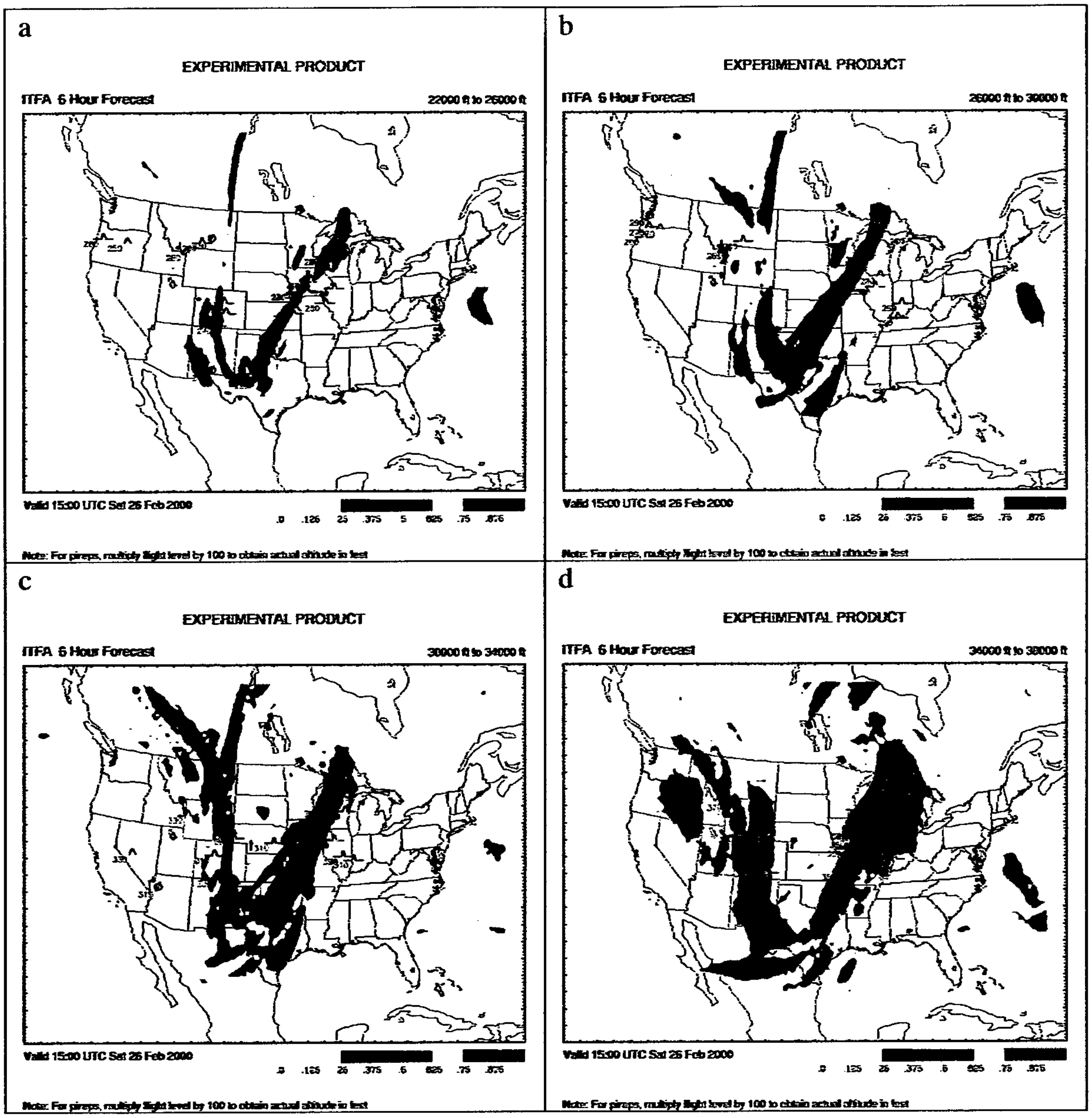

FIGURE 6A-D. FROM EVENT 4, 0900 UTC ITFA SIX-HOUR FORECAST PRODUCTS FOR 22,000-26,000 FT (A), 26,000-30,000 FT (B), 30,000-34,000 FT (C), AND 34,000-38,000 FT (D) VALID FOR 1500 UTC

5.2.2 End-Time.

As with lead-time, end-time, or the ITFA representation of the end of the event as defined by the SIGMET/PIREP analysis, was subjective in nature. Throughout the evaluation period ITFA generally agreed with the event end-time as deduced from the SIGMET/PIREP analyses. However, there were cases where ITFA indicated an event might be continuing beyond the expiration of the associated SIGMET. For these cases either the turbulence was moving away from United States' airspace or a lack of substantiating PIREPs (usually into the overnight hours) prompted the AWC to either cancel the SIGMET or allow it to expire. Thus, it is possible, but not confirmed, that ITFA was correct in continuing an event.

5.2.3 Forecast vs. Observed Conditions.

Table 4, presented previously in section 3.2.1, illustrated the correlation of ITFA forecasts (0.0 to 1.0) to operational turbulence interpretations. While observations of severe turbulence were associated with each turbulence event, the analysis of the ITFA forecast values found no forecasts above .75 (yellow) were produced before or during any of the identified events. In addition, ITFA forecasts of .625 to .75 (yellow) were generally only generated in response to the PIREP override function of the ITFA. The override causes a pre-determined value for a received light, moderate or severe turbulence PIREP to override the result of the ITFA processing. Typical ITFA forecasts for detected events were blues and greens (.375 to .625).

As the mapping of the ITFA diagnostics to turbulence potential is one of the more difficult aspects of ITFA processing (Sharman et. al. 2000), the above results are not surprising. Current work by NCAR and NOAA FSL that is using the FSL Real Time Verification System (RTVS) to evaluate ITFA and each of its sub-indices should help provide guidance in determining turbulence threshold values for the ITFA diagnostics.

5.2.4 Geographical Biases.

Though turbulence events from throughout the United States were evaluated in this study, these cases do not comprise an adequate sampling to determine whether or not ITFA performs better or worse in any particular region of the Nation. Results of additional meteorological evaluations, along with the results of work performed by NCAR and FSL are needed before any geographical biases can be identified.

5.3 CHARACTERISTICS AND TRENDS.

5.3.1 Intra-Event Consistency.

ITFA products created prior (12, 9, 6 and 3 hours) and during each event were compared to each other to determine how ITFA resolved each particular event over time. The focus of this analysis was to subjectively determine whether ITFA output produced from successive runs demonstrated increasing value in identifying the onset, evolution and end of each event and that the output was relatively consistent from run to run.

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. However, observations were made of ITFA products produced at 1200 UTC that contained forecasts with decreased spatial resolution and/or lower forecast values than those products valid for the same time and space produced at 0900 and 1500 UTC. Two examples of this observation are presented in the following subsections.

While the ITFA 1200 UTC products are not generated in a manner different from other runs, it is possible that the RUC fields that are input to ITFA at 1200 UTC may be the cause of the observed discrepancy. The RUC 1200 UTC and 0000 UTC output includes direct observations of upper air measurements from rawinsondes. It is not known whether these additional data are the source of the ITFA inconsistency. Further research and coordination with NCAR is needed to determine if this is true, as well as whether or not the discrepancy also occurs at other times.

5.3.1.1 Event 9 - 1200 UTC Forecast Discrepancy.

Event 9 was a turbulence event that occurred between 24,000 and 30,000 feet over the Mid-Atlantic States on March 22, 2000. The initial advisory area is presented as figure 7 and was defined by the SIGMET issued at 1350 UTC on March 22, 2000. Figure 8 through figure10 contain the ITFA products for 22,000 to 26,000 feet and 26,000 to 30,000 feet valid for 1500 UTC that were produced at 0900 UTC, 1200 UTC and 1500 UTC, respectively. Comparison of these products to the advisory area illustrated in figure 7 shows that the products produced at 1200 UTC (figure 9a-b) show decreased spatial resolution and lower overall forecast values for the Mid-Atlantic region than those products produced at 0900 UTC (figure 8a-b) and 1500 UTC (figure 10a-b).

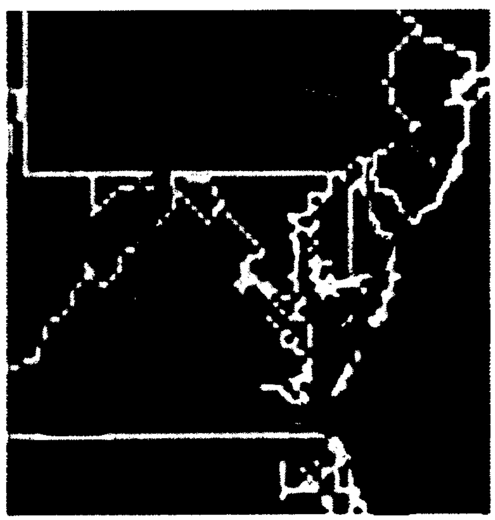

FIGURE 7. INITIAL ADVISORY AREA FOR EVENT 9

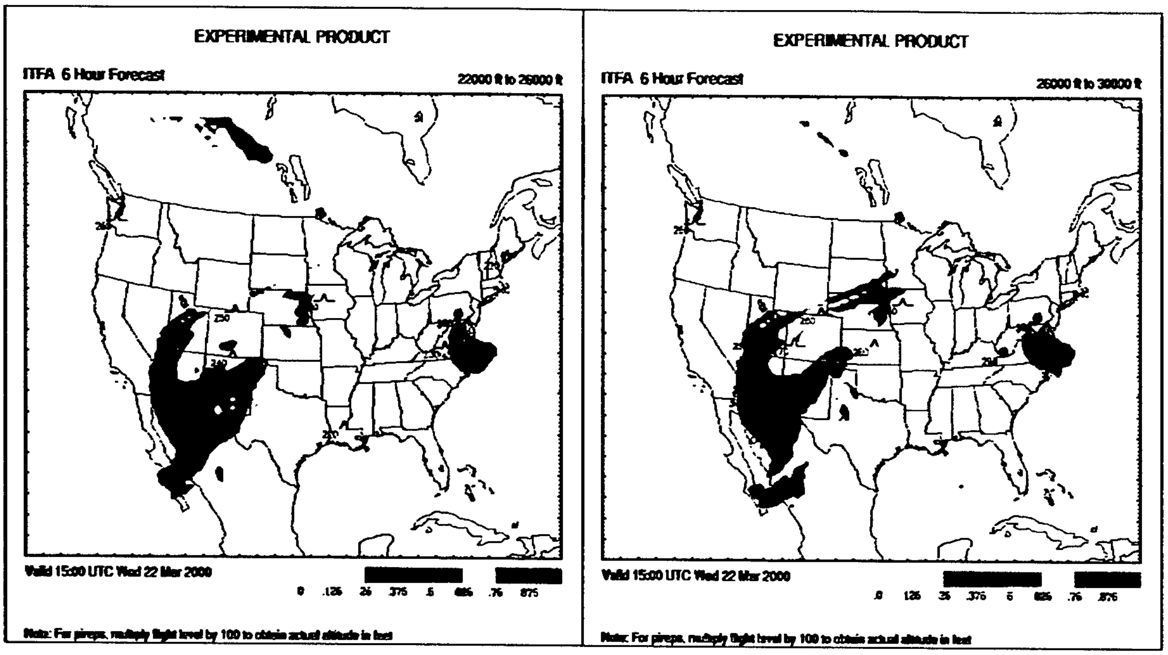

FIGURE 8A-B. FROM EVENT 9, ITFA PRODUCTS VALID 1500 UTC, FOR 22,000-26,000 FT (A) AND 26,000-30,000 FT (B), PRODUCED AT 0900 UTC

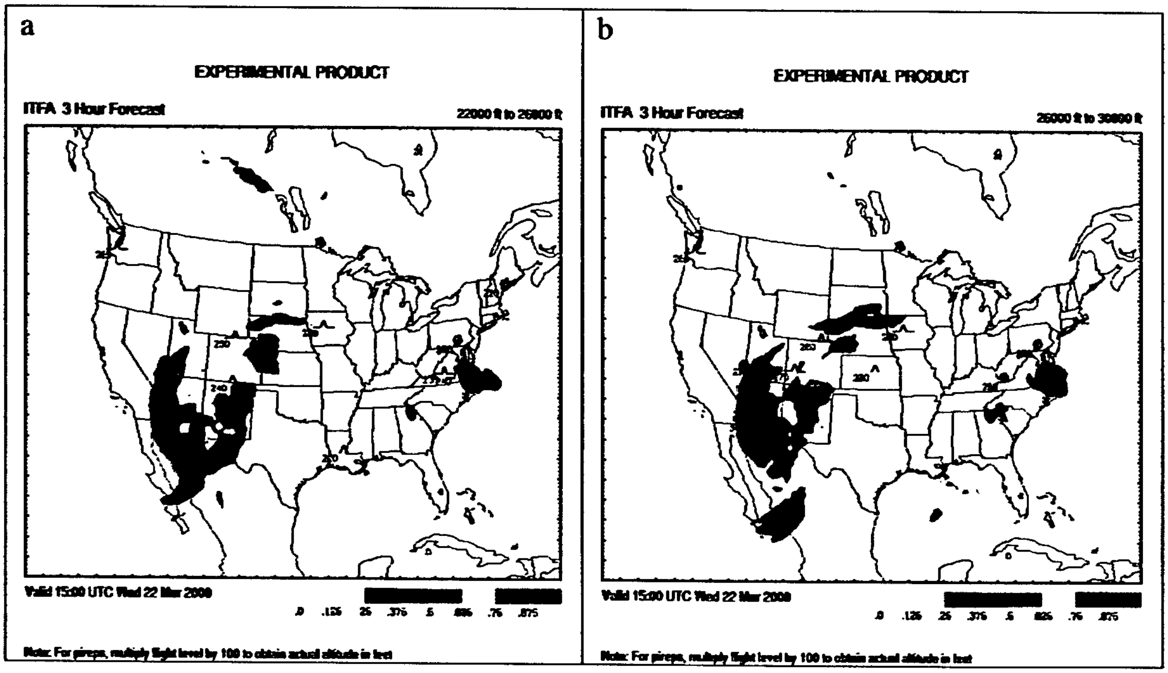

FIGURE 9A-B. FROM EVENT 9, ITFA PRODUCTS VALID 1500 UTC, FOR 22,000-26,000 FT (A) AND 26,000-30,000 FT (B), PRODUCED AT 1200 UTC

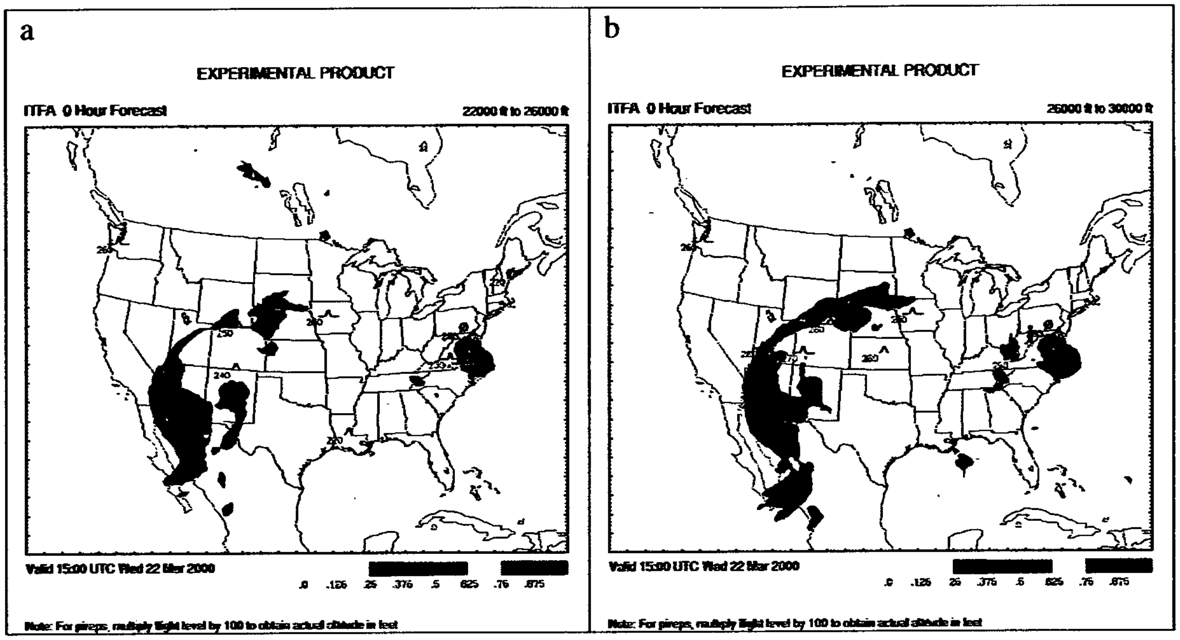

FIGURE 10A-B. FROM EVENT 9, ITFA PRODUCTS VALID 1500 UTC, FOR 22,000-26,000 FT (A) AND 26,000-30,000 FT (B), PRODUCED AT 1500 UTC.

5.3.1.2 Event 11 - 1200 UTC Forecast Discrepancy.

Event 11 was a turbulence event that occurred between 22,000 and 30,000 feet over the Midwest and Great Lakes regions on April 2, 2000. The initial SIGMET issued at 1550 UTC and the amended SIGMET issued at 1650 UTC are presented as figure 11a-b. The amended SIGMET boundaries were used to represent the initial advisory area as the analysis of the SIGMETs and PIREPs indicated that the amended SIGMET boundaries were more representative of the turbulence potential than the initial SIGMET boundaries.

Figures 12 through 14 contain the ITFA products for 22,000 to 26,000 feet and 26,000 to 30,000 feet valid for 1500 UTC that were produced at 0900 UTC, 1200 UTC and 1500 UTC, respectively. Though the 1200 UTC (figure 13a-b) products do not show a significant decrease in spatial resolution compared to products produced at 0900 (figure 12a-b) and 1500 UTC (figure 14a-b), the 1200 UTC forecast values for the Midwest and Great Lakes regions (the green areas) are notably lower than those produced at 0900 and 1500 UTC.

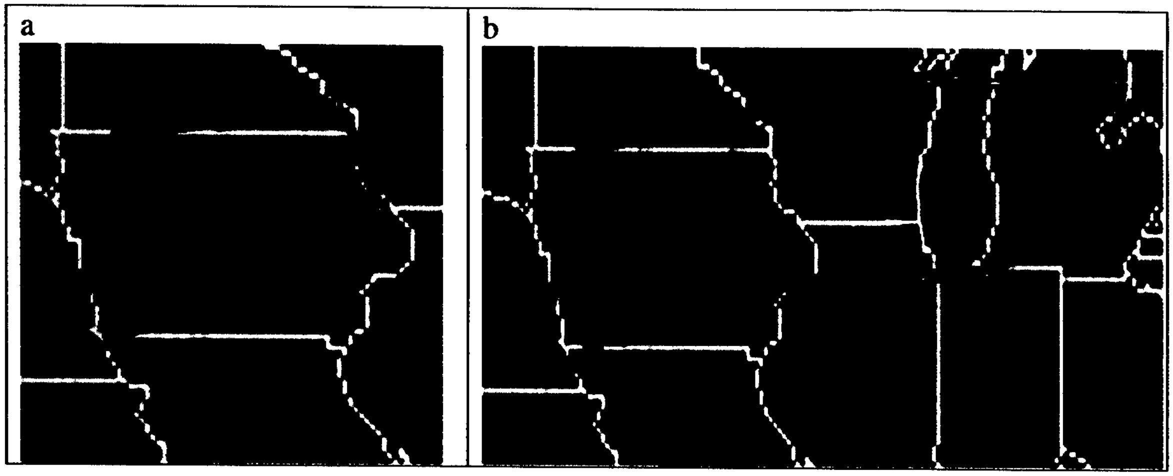

FIGURE 11A-B. FROM EVENT 11, INITIAL (A) AND AMENDED (B) SIGMET BOUNDARIES.

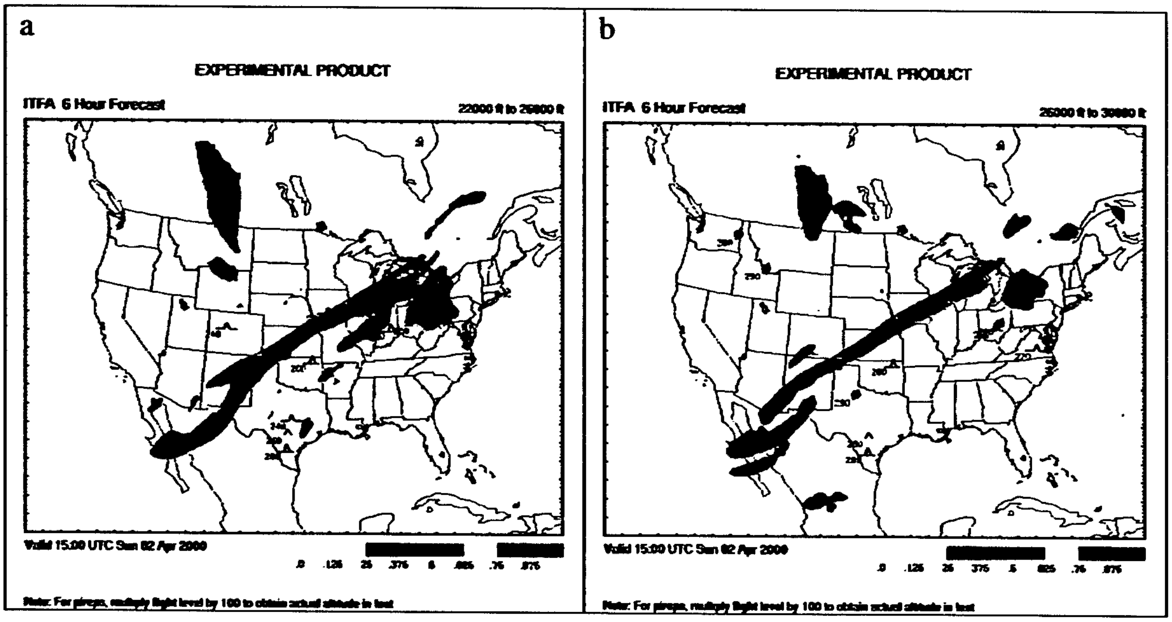

FIGURE 12A-B. FROM EVENT 11, ITFA PRODUCTS VALID 1500 UTC, FOR 22,000-26,000 FT (A) AND 26,000-30,000 FT (B), PRODUCED AT 0900 UTC

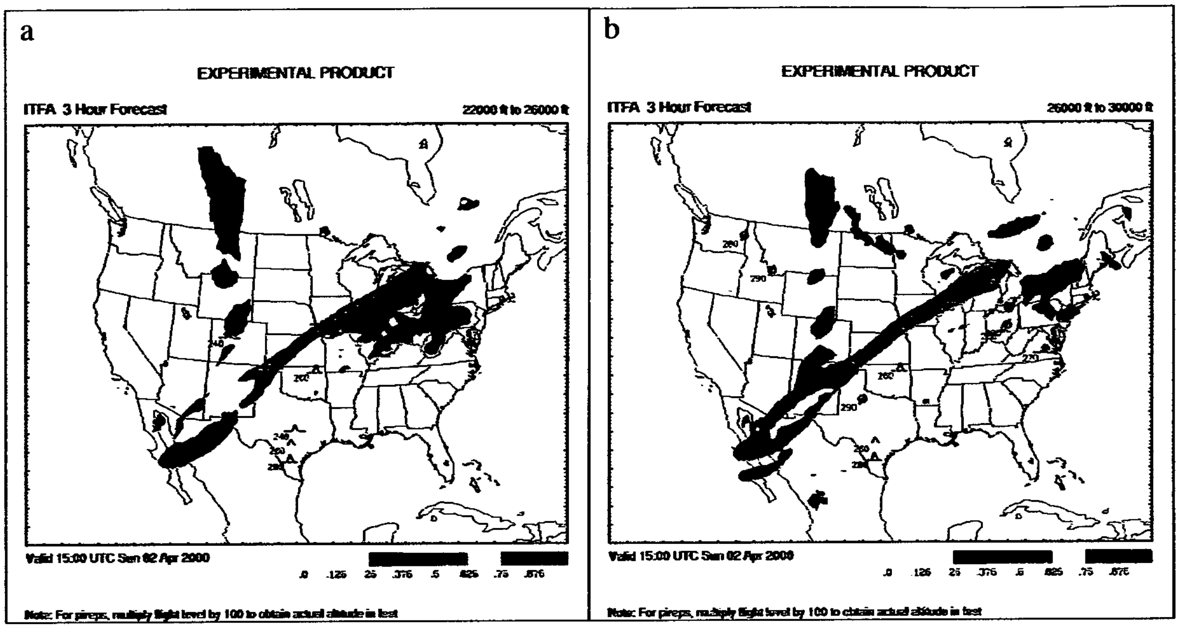

FIGURE 13A-B. FROM EVENT 11, ITFA PRODUCTS VALID 1500 UTC, FOR 22,000-26,000 FT (A) AND 26,000-30,000 FT (B), PRODUCED AT 1200 UTC

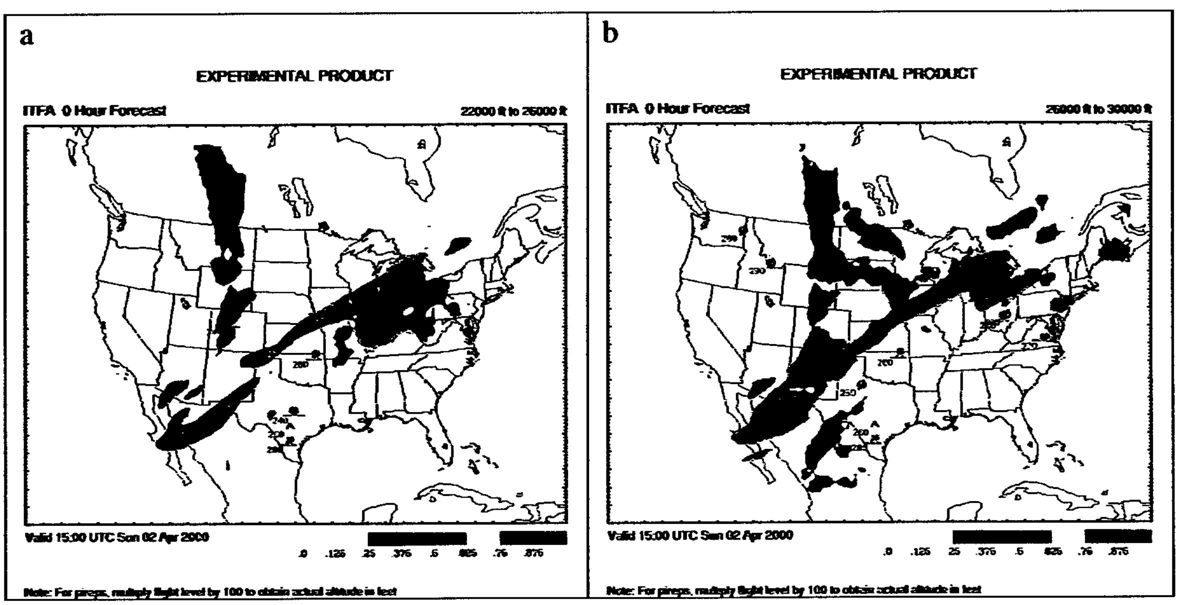

FIGURE 14A-B. FROM EVENT 11, ITFA PRODUCTS VALID 1500 UTC, FOR 22,000-26,000 FT (A) AND 26,000-30,000 FT (B), PRODUCED AT 1500 UTC

5.3.2 Meteorological Correlation.

The turbulence events identified during this evaluation were associated with upper troughs and the directional and speed shear associated with these systems. A common observation was that significant turbulence tended to occur along and ahead of an approaching trough axis, with turbulence being reported both in regions of considerable directional shear, found along and just ahead of the trough axis, and regions of considerable speed shear found downstream of the trough axis. Correlating data from the meteorological analysis with the ITFA output, it was observed that ITFA tended to identify areas of significant turbulence associated with regions of speed shear better than turbulence associated with regions of directional shear. Information from Event 6 is presented below as an example of this observation.

5.3.2.1 Event 6 - Speed Shear vs. Directional Shear.

On March 3, 2000 AWC issued a series of SIGMETs for occasional severe turbulence over the Midwest between 24,000 and 32,000 feet due to wind shear that was associated with an upper level trough and jet stream. Figures 15a and 15b show the initial and amended SIGMETs that were issued at 1030 UTC and 1430 UTC, respectively. Figures 15c and 15d are the 1200 UTC 500 and 300 mb analyses, respectively, from March 3, 2000 and comparing this information to figures 15a and 15b reveals that the advisory area identified by the SIGMETs fall in regions of considerable directional and speed shear.

ITFA zero-hour forecasts produced at 1200 UTC and 1500 UTC are presented as figure 16a-d. As seen in these figures, ITFA produced forecasts up to .625 for the Ohio portion of the advisory area, an area that was associated with speed shear along the backside of the negative-tilt trough over the Northeast. However, for the majority of the advisory area (Illinois and Indiana) ITFA provided little or no forecast of turbulence potential. Analysis of the upper air data provided in figures 15c and 15d indicate that this region was under a col, where considerable directional shear existed between the low-pressure center over Kansas and the low-pressure center off the coast of Maine. Thus, the ITFA forecasts were better correlated with regions of predominate speed shear than directional shear.

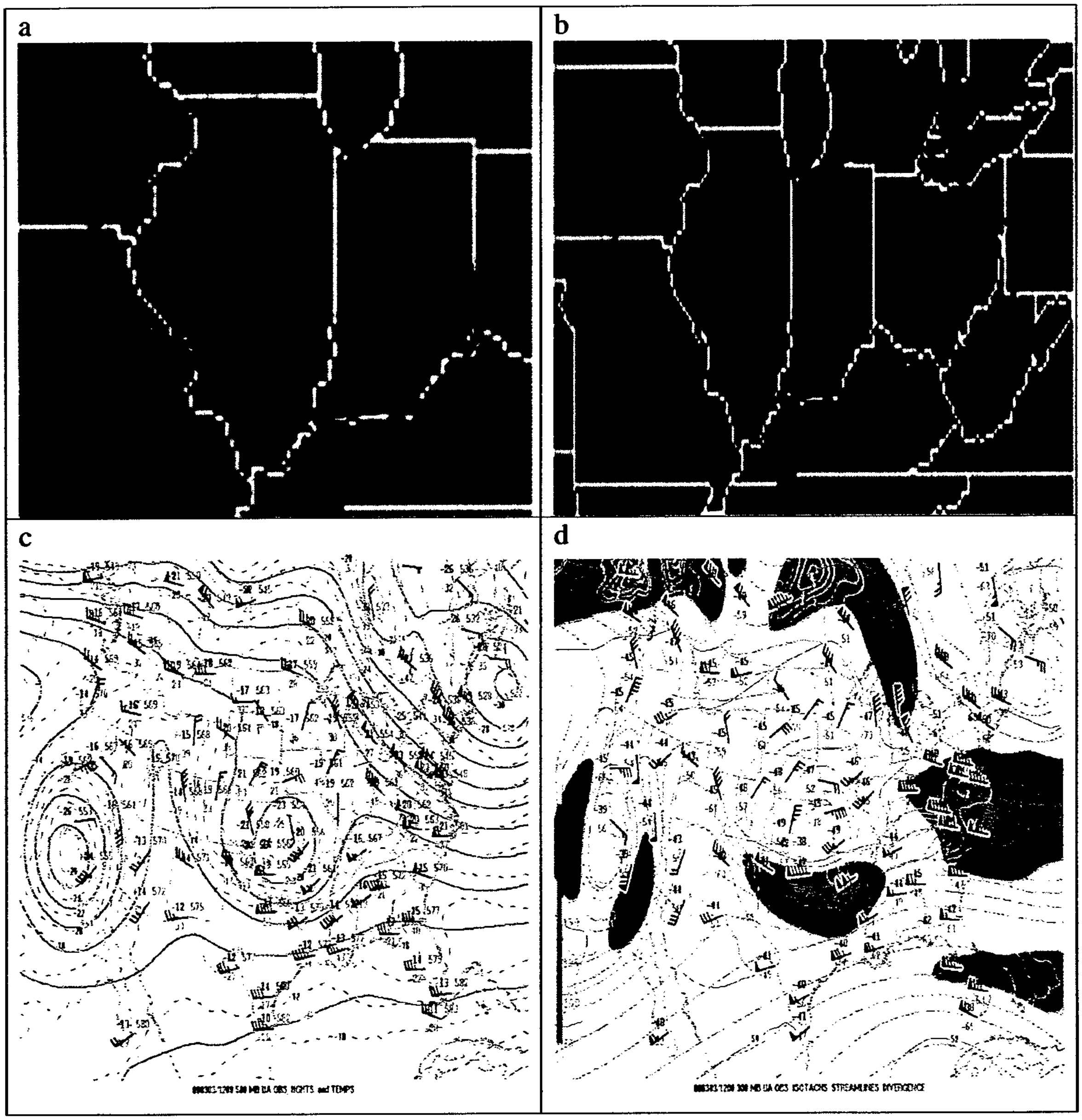

FIGURE 15A-D. FROM EVENT 6, BOUNDARIES FROM THE INITIAL (A) AND AMENDED (B) SIGMETS ISSUED AT 1030 UTC AND 1430 UTC AND THE 1200 UTC 500 MB (C) AND 300 MB (D) UPPER-AIR ANALYSES

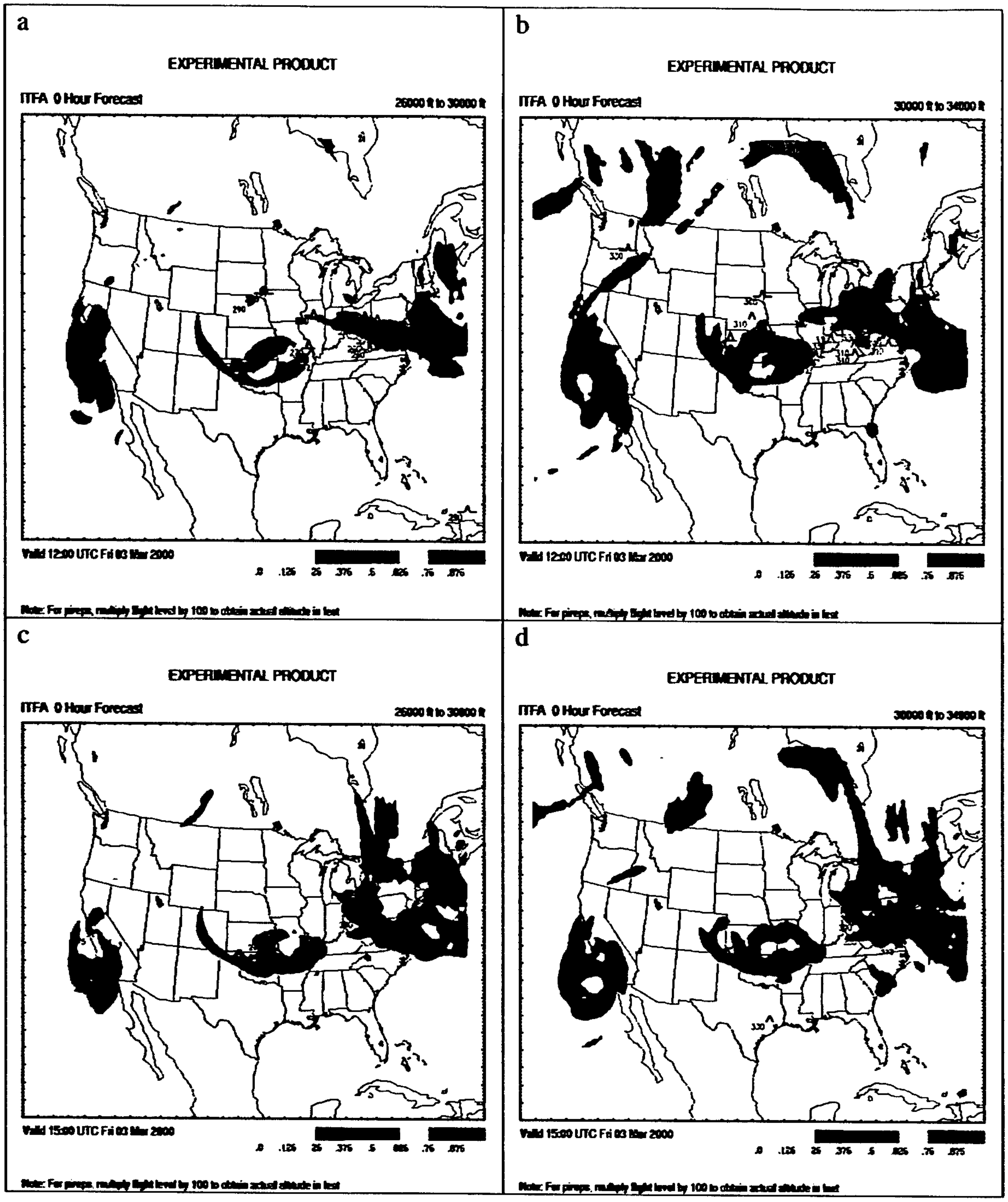

FIGURE 16A-D. ITFA ZERO-HOUR FORECASTS FOR 26,000-30,000 FT AND 30,000-34,000 FT, VALID 1200 UTC (A AND B) AND 1500 UTC (C AND D)

5.3.3 PIREP Processing.

Determining the impact of ingested PIREPs on the ITFA products was another focus of this evaluation. Observations throughout the evaluation period indicated that PIREPs ingested by ITFA were represented and processed differently, and this inconsistency had an effect on both the zero hour and forecast products. The differences involved the display of turbulence symbols that resulted from a processed PIREP and the associated override or lack of override of the algorithm output that was evident on the ITFA products. Examples of these differences are presented in the following sub-sections. In addition, there were cases where moderate to severe turbulence PIREPs were identified in the PIREP database, but were not identifiable on ITFA products. Since it is assumed these PIREPs simply did not make it into ITFA, examples are not presented.

For observations where displayed PIREPs were associated with the override of ITFA output, discussions with NCAR revealed that how long a turbulence PIREP influences future output (up to six hours) depends on the origin of the PIREP and when it was received for processing. In addition, for cases where no algorithm override was observed for a displayed PIREP, NCAR will need to address how to maximize the use of all available turbulence reports in the ITFA processing.

5.3.3.1 Event 11 - PIREP Display/Override.

ITFA zero-, three-, six-, and nine-hour forecasts valid for 1800 UTC and 2100 UTC April 2, 2000, and 0000 UTC and 0300 UTC April 3, 2000, are presented as figure 17a -d, respectively. This data was collected during the analysis of Event 11, which was a turbulence event over the Midwest and Great Lakes region previously described in section 5.3.1.2. In figure 17a, two severe turbulence PIREPs are identified in the advisory area, one over southeast Wisconsin and the other over southwest Michigan. Also apparent in figure 17a is how ITFA processed these two PIREPs, with locally higher forecast values being displayed in conjunction with the placement of the turbulence symbols. This is an example of ITFA using actual turbulence reports to override the original algorithm output. Similar relationships are also evident with the other PIREPs on this image, such as the PIREP in northwest Georgia.

In addition to ITFA using the turbulence reports to override algorithm output in the 1800 UTC zero-hour product, the turbulence reports are seen to continue in the 1800 UTC ITFA three- and six-hour forecast products, which are presented as figures 17b-c, respectively. As seen in figure 17d, the PIREP influence does not occur beyond the six hour forecast period.

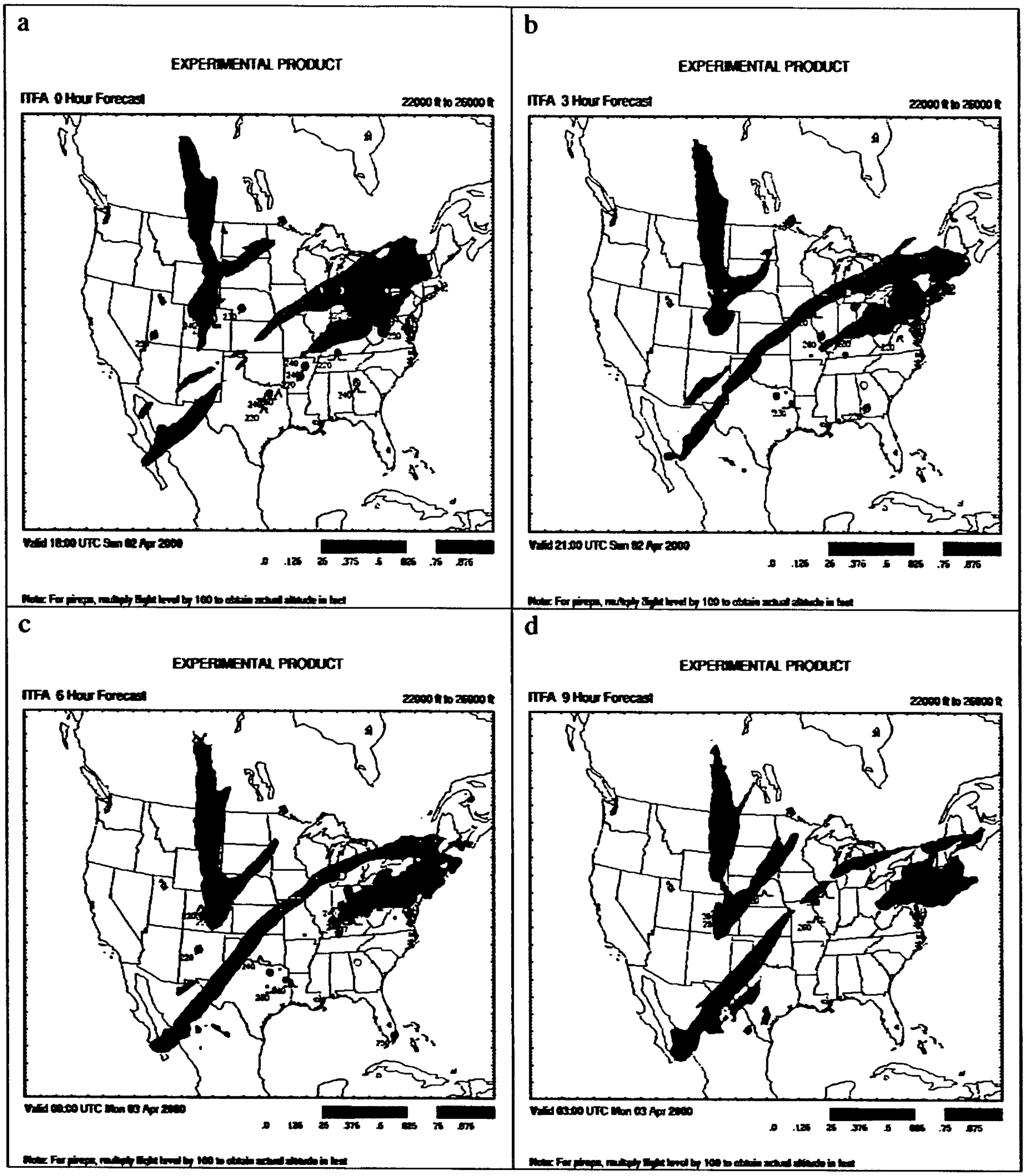

FIGURE 17A-D. FROM EVENT 11, ITFA 1800 UTC 22,000-26,000 FT ZERO- (A), THREE- (B), SIX- (C), AND NINE- (D) HOUR FORECASTS PRODUCTS

5.3.3.2 Event 8 - PIREP Display/No Override.

ITFA zero- and three-hour forecasts valid for 0000 UTC and 0300 UTC March 5, 2000 are presented as figure18a -b, respectively. This data was collected during the analysis of Event 8, which was a turbulence event over central and southern California. In figure 18a, three severe turbulence PIREPs are identified and plotted over central California. Also apparent in figure 18a is that ITFA shows no locally higher forecast values being displayed in conjunction with the placement of the turbulence symbols. This is an example of ITFA displaying actual turbulence reports but not using the reports to override the original algorithm output. As seen in figure 18b, not only did ITFA not override algorithm output in the 0000 UTC zero hour product, the turbulence reports had no influence on the 0000 UTC forecast products.

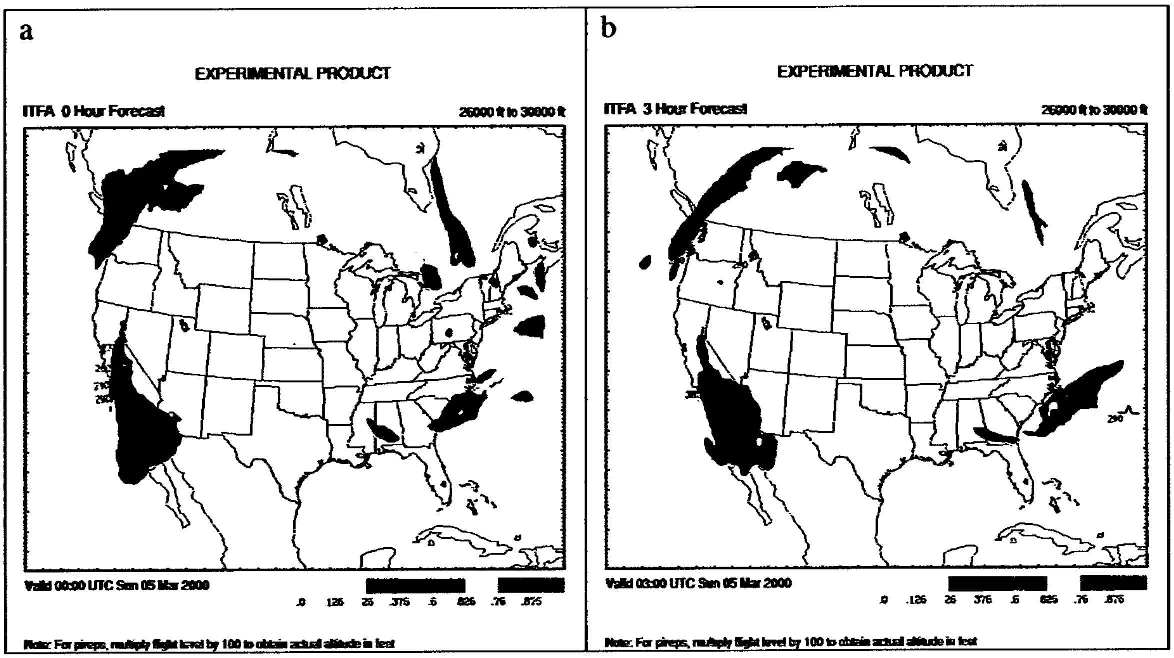

FIGURE 18A-B. FROM EVENT 8, ITFA 0000 UTC 26,000-30,000 FT ZERO-(A) AND THREE-(B) HOUR FORECASTS PRODUCTS

6. CONCLUSIONS.

The FAA AWRP has provided funding to the NCAR/RAP to develop a forecasting tool that mitigates the dangers to commercial and general aviation aircraft from unexpected, hazardous, clear-air turbulence. In response to the direction provided, the NCAR/RAP developed the Integrated Turbulence Forecasting Algorithm (ITFA), which produces turbulence forecasts for the contiguous United States. In support of this development the Weather Branch at the FAA William J. Hughes Technical Center performed an event-driven meteorological evaluation of the ITFA. The evaluation was conducted from January to August 2000 and focused on providing a subjective assessment of the performance, characteristics, and trends of ITFA before and during significant turbulence events.

Rather than focus on purely statistical measurements of algorithm performance, the objective of the ITFA Meteorological Evaluation was to provide a subjective assessment of ITFA performance and to document characteristics and trends of the ITFA before and during significant turbulence events. ITFA performance issues that were evaluated included lead-time, end-time, forecast vs. observed conditions, and geographical biases. Characteristics and trends of the ITFA identified during the evaluation included intra-event consistency, meteorological correlations, and PIREP processing impacts.

Overall results of this meteorological evaluation indicate that ITFA has the potential to be an effective forecasting tool. Conclusions addressing the ITFA performance issues, characteristics and trends documented in this report are presented in the following sections.

6.1 PERFORMANCE ISSUES.

6.1.1 Lead Time.

ITFA lead times ranged from zero to 12 hours. In cases with zero lead-time, either the ITFA algorithms and/or the incorporation of actual turbulence observations resulted in at least a partial identification of the turbulent region. In contrast, the human-produced SIGMET product failed to provide any lead-time for each event identified in this evaluation, which may be a reflection of the conservative nature of human forecasters issuing SIGMETs, but also illustrates that ITFA has some value in alerting forecasters to the potential for jet stream/wind shear induced upper-level turbulence prior to onset.

6.1.2 End Time.

Throughout the evaluation period ITFA generally agreed with the event end-time as deduced from the SIGMET/PIREP analyses. However, there were cases where ITFA indicated an event might be continuing beyond the expiration of the associated SIGMET. For these cases either the turbulence was moving away from United States' airspace or a lack of substantiating PIREPs (usually into the overnight hours) prompted the AWC to either cancel the SIGMET or allow it to expire. Thus, it is possible, but not confirmed, that ITFA was correct in continuing an event.

6.1.3 Forecast vs. Observed Conditions.

While observations of severe turbulence were associated with each turbulence event, the analysis of the ITFA forecast values found no forecasts above .75 (yellow) were produced before or during any of the identified events. In addition, ITFA forecasts of .625 to .75 (yellow) were generally only produced in response to the PIREP override function of the ITFA, which causes a pre-determined value for a received light, moderate or severe turbulence PIREP to override the result of the ITFA processing. Typical ITFA forecasts for detected events were blues and greens (.375 to .625).

6.1.4 Geographical Biases.

Though turbulence events from throughout the United States were evaluated in this study, the cases did not comprise an adequate sampling to determine whether or not ITFA performs better or worse in any particular region of the Nation.

6.2 CHARACTERISTICS AND TRENDS.

6.2.1 Intra-Event Consistency.

ITFA products created prior and during each event were compared to each other 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 the onset, evolution and end of the event generally being resolved with greater accuracy with each successive ITFA run. However, observations were made of ITFA products produced at 1200 UTC that contained forecasts with decreased spatial resolution and/or lower forecast values than those products valid for the same time produced at 0900 and 1500 UTC. While the ITFA 1200 UTC products are not generated in a manner different from other runs, it is possible that the RUC fields that are input to ITFA at 1200 UTC may be the cause of the observed discrepancy.

6.2.2 Meteorological Correlation.

The turbulence events identified during this evaluation were associated with upper troughs and the directional and speed shear associated with these systems. A common observation was that significant turbulence tended to occur along and ahead of an approaching trough axis, with turbulence being reported both in regions of considerable directional shear, found along and just ahead of the trough axis, and regions of considerable speed shear found downstream of the trough axis. Correlating data from the meteorological analysis with the ITFA output, it was observed that ITFA tended to identify areas of significant turbulence associated with regions of speed shear better than turbulence associated with regions of directional shear.

6.2.3 PIREP Processing.

Observations throughout the evaluation period indicated that PIREPs ingested by ITFA were represented and processed differently, and this inconsistency had an effect on both the zero hour and forecast products. The differences involved the display of turbulence symbols that resulted from a processed PIREP and the associated override or lack of override of the algorithm output that was evident on the ITFA products. In addition, there were cases where moderate to severe turbulence PIREPs were identified in the PIREP database, but were not identifiable on ITFA products.

For observations where displayed PIREPs were associated with the override of ITFA output, discussions with NCAR revealed that how long a turbulence PIREP influences future output (up to six hours) depends on the origin of the PIREP and when it was received for processing.

Additional research is needed to determine how to incorporate all relevant PIREPs into the ITFA.

7. RECOMMENDATIONS.

The meteorological evaluation of the ITFA demonstrated that ITFA has the potential to be an effective forecasting tool for detecting and forecasting upper level turbulence. ACT-320 recommends AWRP continue to providing funding and direction for future development of the ITFA. Further development should specifically include the following:

a. NCAR should continue to refine the mapping of the ITFA diagnostics to turbulence potential. Improvement in this area will allow ITFA to better discriminate between light, moderate and severe turbulence potential that will result in a closer correlation between forecast and observed turbulent conditions.

b. Additional data collection over several seasons is required to determine if ITFA performs better or worse in different regions of the Nation.

c. NCAR should investigate why some ITFA 1200 UTC products studied during this evaluation under forecasted turbulence potential when compared to 0900 and 1500 UTC products and whether or not this bias occurs at other times of day.

d. NCAR should investigate the incorporation of additional indices that are designed to identify regions of directional shear in upper levels of the atmosphere into ITFA's processing. This addition should allow ITFA to better resolve regions of turbulence potential associated with weather systems that produce areas of both strong directional and strong speed shear.

e. NCAR should investigate methods for better incorporating actual turbulence reports into the ITFA. This effort should include determining how to incorporate and display all relevant PIREPs in a consistent manner as well as determining a more accurate methodology for how long a PIREP should influence or override output on ITFA forecast products.

8. ACRONYMS.

ACARS	Aircraft Communications Addressing and Reporting System
ARINC	Aeronautical Radio, Inc.
AVARS	Aircraft Vertical Accelerometer Reports
AWC	Aviation Weather Center
AWRP	Aviation Weather Research Program
CAT	Clear Air Turbulence
FAA	Federal Aviation Administration
FBWTG	FAA Bulk Weather Telecommunications Gateway
FSL	Forecast Systems Laboratory
GIF	Graphics Interchange Format

GrADS	Grid Analysis and Display System
GRIB	Gridded Binary
ITFA	Integrated Turbulence Forecasting Algorithm
MDCRS	Meteorological Data Collection and Reporting System
NADIN	National Airspace Data Interchange Network
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
NWSTG	National Weather Service Telecommunications Gateway
PDT	Product Development Team
PIREPs	Pilot Reports
RAP	Research Applications Program
RTVS	Real Time Verification System
RUC	Rapid Update Cycle
SIGMET	Significant Meteorological Information
SPC	Storm Prediction Center
TAR	Tape Archive Utility
U.S.	United States
UTC	Universal Coordinated Time
WMO	World Meteorological Organization