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REAL TIME AVIATION FORECASTING AT WSI

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1. INTRODUCTION

The paradigm for providing weather forecast information to the United States aviation industry is continuing to evolve. Historically, the US government has provided the lion's share of weather information in formats useful to air traffic controllers, commercial and private pilots, flight dispatchers and recreational aviators. Though governmental weather sources offer a suite of meteorological products that do meet the minimum requirements to operate aircraft domestically and internationally, a need still exists for products and services that are tuned to meet specific needs of the aviation community.

Starting in the late 1990's the Weather Services International (WSI) Corporation expanded its weather services business to include forecasting products and services. This began with the Energy and Media sectors, with further expansion earlier this year into the aviation sector. The motivation and opportunity for this expansion came from the fact that, since 2001, the airlines have been under extreme pressure to reduce costs while maintaining or improving upon their existing level of meteorological services.

This preprint article describes some of the aviation weather forecasting activities that are being conducted currently at WSI. Commercial real-time aviation forecasting activities at WSI range from providing human-generated short-term Terminal Area Forecasts (TAFS) at specific sites across the US four times a day to making WRF-based 24 hr turbulence forecasts over the Atlantic Ocean every six hours.

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2. MODELING SUPPORT

The latest version of The Weather Research and Forecast Model WRF (version 2.0.3) is run locally to support the gamut of aviation forecasting activities at WSI. More information on the WRF model can be found in Michalakes et al. (2001) and Skamarock et al. (2001).

Figure 1 illustrates the domains for which aviation forecasts are currently being generated and the grid separation distance (GSD) for each. A 36 km GSD grid is run over the North Atlantic Ocean (ATLANTIC) four times daily, a 16 km GSD grid is run over Europe (EUROPE) four times daily, and a 12 km GSD grid is run over the Continental US (CONUS) eight times daily. A floating domain (FLOATER) is also run at 12 km GSD. As the name implies, the FLOATER may be placed in different locations on a daily basis depending on the weather of interest. A domain spanning the North Pacific Ocean (PACIFIC) at 36 km GSD will soon be added.

All the forecasts are run on a cluster of 40 IBM dual processor 3.06 and 3.20 GHz machines. A 48 hour forecast over the CONUS takes 100 minutes. In contrast, a 24 hour forecast over the ATLANTIC (including 1/3 of the eastern US) takes 15 minutes. The model output is evaluated by forecasters at WSI and it is also used as input to a suite of post-processing algorithms that generate forecasts for severe weather, ceiling height and visibility, atmospheric turbulence, and forecast icing potential.

The CONUS run is initialized 30-60 minutes after the hour using analyses from the Rapid Update Cycle (RUC) model. Boundary conditions are provided from the latest available run from the Global Forecast System (GFS). All non-CONUS runs are initialized using one-degree output from the GFS. This procedure causes a significant delay and provides a major constraint on providing realtime forecasts for very short-term

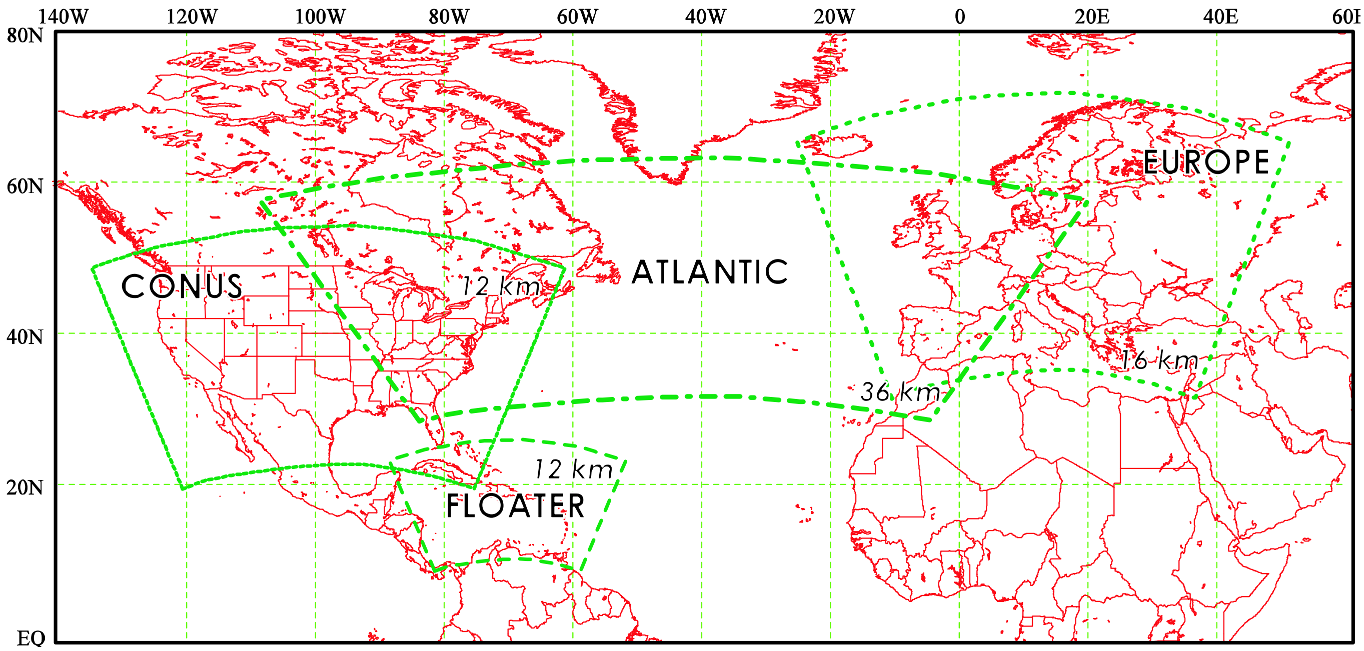

FIG. 1. *Domains used for aviation forecasts as shown by areas enclosed by dashed lines.*

operations. Further constraints - although much less severe - are also present because of the many other operational forecasts that are being run. For example, output from the 0000 UTC GFS run is not available until approximately 0430 UTC. However, a 48 hr 0300 UTC CONUS 12 km GSD forecast is not completed until just before 0530 UTC. Thus, the 0000 UTC ATLANTIC 36 km GSD forecast does not begin until around 0530 UTC. A 24 hour forecast takes less than 10 minutes. The speed with which the forecast is completed over such a large domain after nearly a five-hour delay waiting for boundary conditions is tantamount to the utility of the forecast in the 6 to 12 hour time-frame. More information on realtime forecasting at WSI is available in Hutchinson et al. (2005).

The raw model output is then fed through a series of post-processing routines to create additional aviation forecast parameters and to generate graphics. Most of the algorithms used for the post processing currently are adapted from those developed at NCAR or FSL and which are used to generate RUC-based aviation forecasts. Two important reasons for developing the capability in house to provide WRF-based aviation forecasts are a) in some instances (e.g., non-CONUS domains) these forecasts provide the only model-based guidance of its kind, and 2) evaluating the performance of these forecasts will allow future improvements to be made to the WSI-versions of the algorithms. With respect to aviation-specific interests, post-processing is currently available and used to provide WRF based forecasts for turbulence, precipitation type, ceiling and visibility, and icing potential. While the WRF-based forecasts over the CONUS domain are certainly useful to the WSI forecasters for the CONUS domain, they are even more valuable for the non-CONUS domains because in most instances they provide the only (high-resolution) NWP-based forecast of that type. Details of the various types of WRF-based aviation forecasts are provided below.

3. FORECAST OPERATIONS

Forecast operations range from providing Terminal Forecasts…to providing EnRoute Forecasts…to providing Irregular Operations Support…to providing Ancillary Support. The Terminal Forecast products and services include WSI Hubcast, Level I, II, and III **T**erminal **A**rea **F**orecast (TAF), Hub airport discussions, Load Planning temperature forecasts, Deicing forecasts, Daily Airline System Outlooks, and Briefings/consultations as necessary or scheduled. The EnRoute Forecasts include Turbulence, Thunderstorm location/coverage/intensity, Icing, Volcanic ash, Dust/sand storm, and Area forecasts. During special situations such as severe convective events, major winter storms, or hurricanes, more detailed forecasts are provided. Finally, WSI provides on an as-needed basis Incident/Accident reports, Expert witnesses, Climatological studies, Training, and Data/forecast archiving. More detailed information on selected activities and products is provided below.

3.1 Hubcasts

The WSI Hubcast is a good example of a Terminal Forecast product. The purpose of the Hubcast product is to provide hourly forecasts and alerts of critical parameters impacting capacity at key airports resulting in explicit predictions of Airport Arrival Rates (AAR). The Hubcasts are provided via a secure web page for customer-specific airports, both domestic and international, out to 8 hours and updated every hour. Forecast granularity is every 1 hour. Forecast information includes ceiling, visibility, wind speed and direction, wind gust speed, weather, and thunderstorm probabilities. A sample of Hubcast output is shown in Fig. 2. Customers have access to a wide range of recent observations including satellite and radar loops, as well as short term forecast information and 5-day outlooks. A detailed view of the last few preceding hours shows forecasted vs. observed information to allow customers to identify any forecast biases that may exist. The color-coding indicates safe and dangerous levels, which depend on the specific forecast parameter. The last row shows forecasted and validated airport acceptance rates (AARs) for user-selected runways.

Preparation of each Hubcast involves inspection of a wealth of observations and forecast information. Forecast information from the WRF (as well as from other models) and current observations are subjectively assimilated to modify a first-guess forecast. Of the necessary Hubcast parameters, only wind speed and direction, and quantitative precipitation are directly output by the WRF. The WRF-based forecast information for ceiling and visibility, wind gust, and precipitation type forecasts is provided via post-processing algorithms.

The ceiling and visibility algorithms are modeled after the Stoelinga-Warner algorithm (Stoelinga and Warner, 1999) that relies on light attenuation from various hydrometeor types, and an empirical algorithm developed at the Forecast Systems Laboratory (FSL) that relies on relative humidity and dew-point depression. For the visibility algorithm, the Stoelinga-Warner algorithm is used where precipitation is occurring and the FSL algorithm is used in non-precipitating regions. The ceiling algorithm is based entirely on the Stoelinga-Warner algorithm.

Wind gust forecasts are also generated from the WRF model output. Both convective and non-convective wind gusts forecasts are generated using a simple vertical mixing algorithm for non-convective situations and the NIMROD algorithm (Hand 2000) for convective situations. A convective mask is applied to blend the results from both algorithms. Information from the individual algorithms is available to the forecasters as well – in situations where they decide to override the convective mask.

The Weather parameter that is forecast is based on expected precipitation type and intensity. The (liquid equivalent) intensity from the WRF is a direct model output. Precipitation type forecasts from the WRF are generated using two different algorithms. The BTC algorithm is modeled after Baldwin et al. (1994), and the Bourgouin algorithm is modeled after Bourgouin (1994). The algorithms are similar from the standpoint that they both identify melting and freezing layers that a hydrometeor experiences on its descent – however they differ on how the layers are identified. More information on the algorithms and how they are implemented, and how well they perform within the WRF framework can be found in Sousounis and Hutchinson (2005).

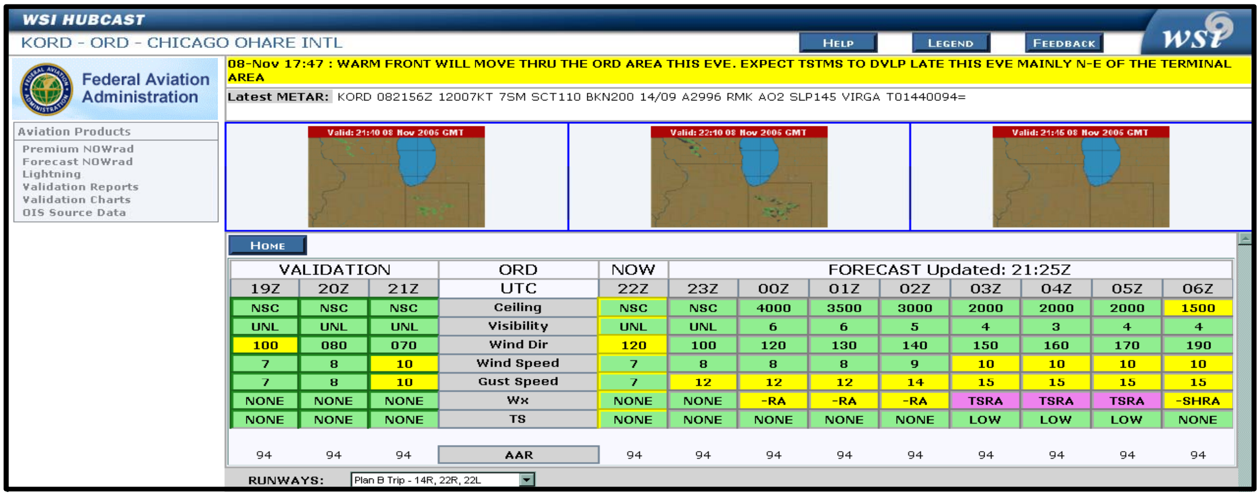

FIG. 2. *Sample Hubcast output. See text for explanation.*

3.2 Turbulence Forecasting

Turbulence forecasts are provided for customer-specific airspace out to 24 hours and updated every 3 hours. The product itself (not shown) is provided in a format similar to that provided by the Aviation Weather Center (AWC). Polygons indicate the expected severity of the turbulence for a 3 hr period as well as the affected flight levels. Forecasters hand-draw the polygons based on available information. A variety of freely available information is used to assist with the preparation of these forecasts. Over the Continental US, the Graphical Turbulence Guidance (GTG) from the Rapid Update Cycle (RUC) model provides detailed information on forecasted turbulence intensity. However, over many other regions of the world for which forecast responsibilities exist, and for those forecast periods beyond 12 hours over the Continental US, there is no freely available forecast product that is comparable to the RUC-GTG in terms of precision and accuracy.

Towards addressing the information void, WSI has developed its own WRF-based turbulence forecast product. The product is based on a suite of algorithms that are very similar to those used in the RUC-based GTG to provide support for turbulence forecasts for the domains shown in Fig. 1. The turbulence algorithms were chosen based on published performance and how easily they could be implemented. Interpretation of the published literature (e.g., Sharman et al. 2004) suggests that the performance characteristics of many of the individual algorithms are more or less similar to one another and that it is the way the results from the individual algorithms are combined that is more important. That said, given the fact that other NWP based turbulence forecast information was not available to WSI and given a one-month time constraint to produce WRF-based turbulence forecasts, the initial version of the suite of algorithms was rather simple. More information on the actual algorithms is provided in Sousounis (2005).

The WRF-based turbulence forecasts from the various algorithms are scaled in terms of an index from 1-10, which are color-coded to represent conditions from smooth (0-1) to severe (9-10). Forecast information is provided as 3 hr averages at select pressure levels from 500 to 150 mb. A sample of the graphical output for the ATLANTIC domain is shown in Fig. 3. In addition to the graphical output, the information is provided internally to WSI aviation forecasters in grib format for additional viewing, manipulation, etc. The GTG algorithms have only recently been added to the CONUS domain and hence no statistically meaningful

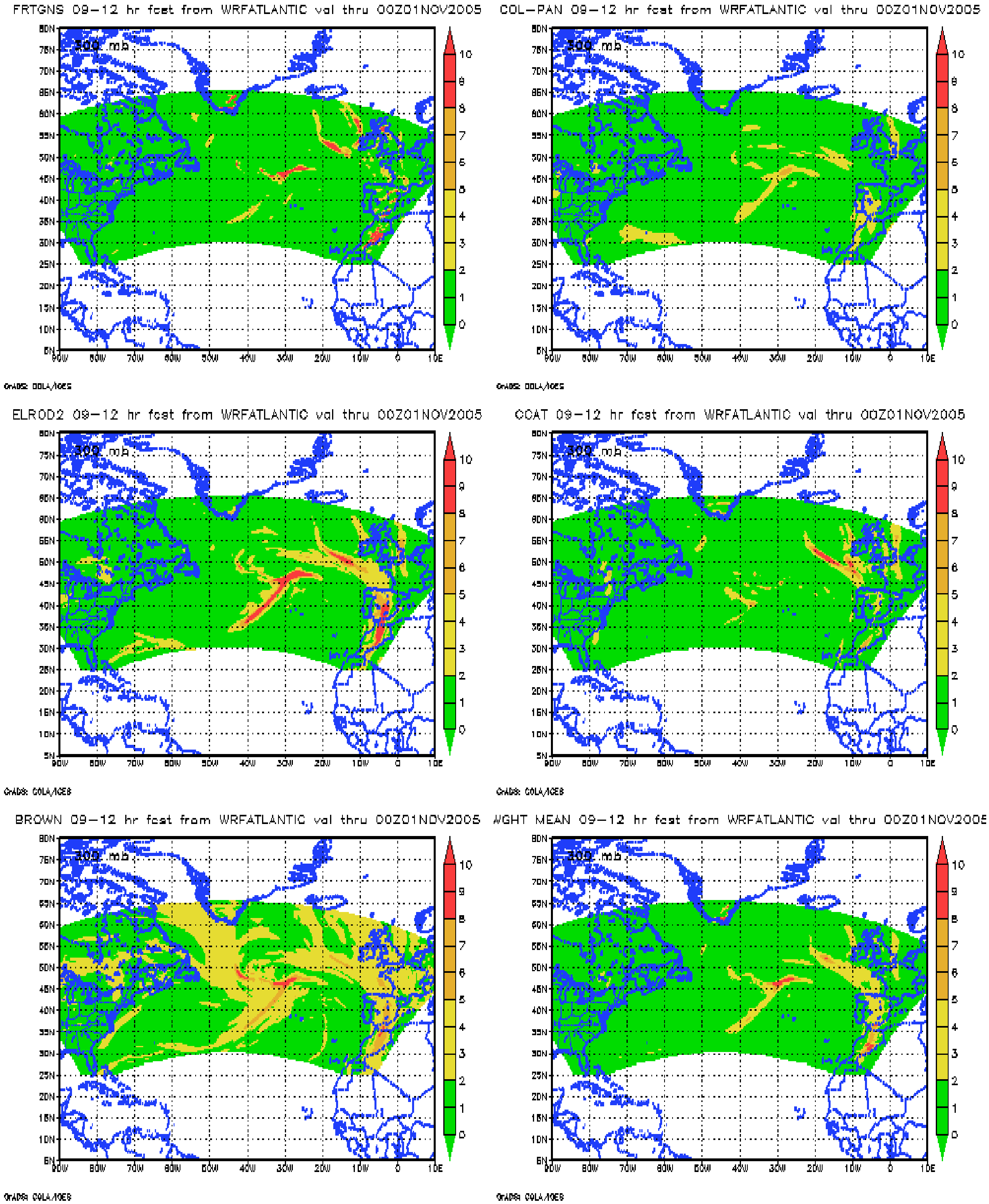

FIG. 3*. Sample WSI-GTG output. See text for explanation.*

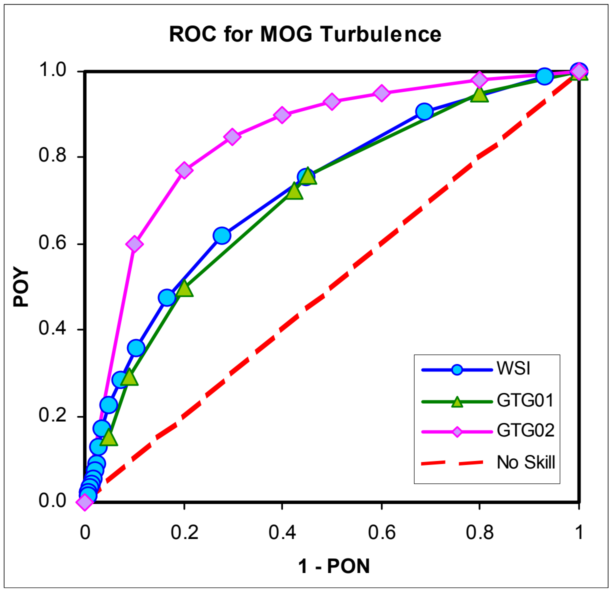

***FIG. 4**. Relative operating Characteristic (ROC) curve for WSI GTG algorithm for 09-12 h forecast period. Also shown are sample GTG01 and GTG02 curves for 6 h lead time (adapted from Sharman et al 2004).*

performance numbers are available yet. However, over the ATLANTIC domain, performance is comparable to the RUC-GTG.

The absence of an operational forecast product for North Atlantic turbulence forecasting provided the original motivation for developing the WSI algorithms. The absence of such a product however also makes comparison to similar forecast products difficult. Because the ATLANTIC domain does overlap with the Rapid Update Cycle (RUC) domain over the eastern third of the CONUS, albeit at lower horizontal resolution, it is appropriate to compare performance of the WSI turbulence forecast to the Graphical Turbulence Guidance (GTG) products that are supported by model output from the RUC. Figure 4 shows the relative operating characteristic curves for WSI, GTG01 and GTG02. The ordinate shows the probability of detection for YES forecasts (POY), and the abscissa shows 1 - the probability of detection for NO forecasts (PON). The WSI curve is based on 09-12 h forecasts over the entire ATLANTIC domain for moderate or greater (MOG) turbulence values (e.g., 3 or higher). The GTG01 is currently operational, while the GTG02 is still only experimental. Both are considerably more sophisticated than the WSI turbulence forecast product. Specifically, a dynamical weighting - or scaling - is applied at each forecast cycle. That is, algorithms that generate 00 h forecast values that correlate well with pilot-reported turbulence are given more weight for future forecast hours. Despite the more sophisticated approach, the WSI turbulence forecast product shows comparable skill at least to GTG01. The GTG02 product that is still under development shows considerably more skill than GTG01 or WSI.

3.3 Forecast Icing Potential

Icing potential forecasts are similar in format to the turbulence forecasts. The challenges for producing the forecasts are also similar. For example, over non-CONUS domains, there is little information comparable to the RUC based Forecast Icing Potential that is freely available.

Again, towards addressing the information void, WSI has developed its own WRF-based forecast icing potential product. The Forecast Icing Potential (FIP) algorithm on which the product is based is very similar to that used in the RUC-based FIP (McDonough et al, 2004). Slight differences exist in the way the interest maps are combined. Forecasts are provided as 3-hr averages out to 24 hr on selected pressure surfaces.

A sample of the graphical output from the EUROPE domain is shown in Fig. 5. The current version of WSI-FIP includes ancillary information supporting the actual FIP values (FIPXINTR - shown in the lower right panel). For example, for the particular forecast shown, the interest function for temperature (TEMPINTR), relative humidity (RELHINTR), and supercooled liquid cloud water (SCLWINTR) at 700 mb (FL 10,000 ft) seem to be responsible for the high FIP values over portions of France.

While formal verification is not yet in place as of the preparation of this preprint, subjective comparison to existing PIREPS and to the RUC-FIP shows good

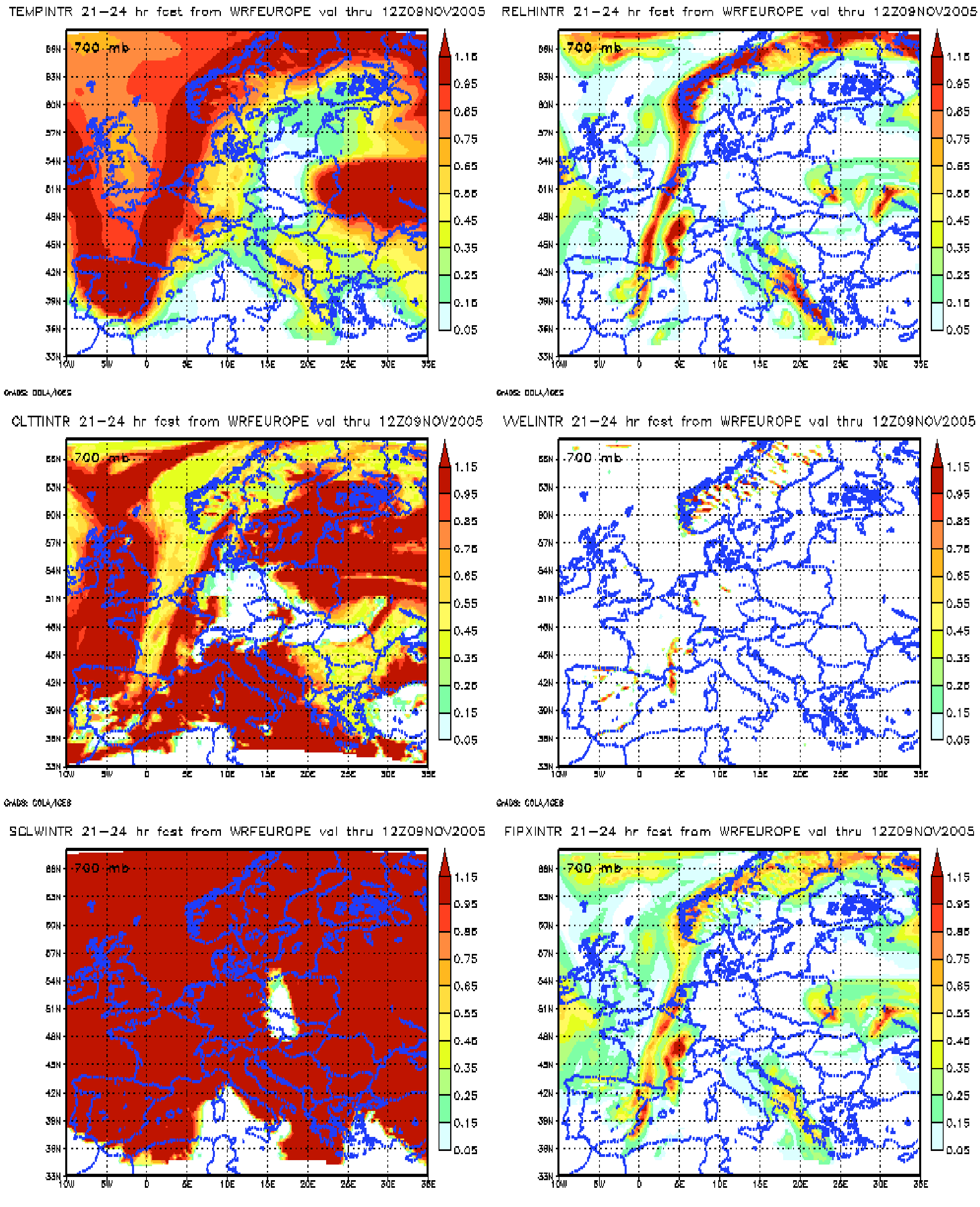

Fig. 5. *Sample WSI-FIP output. See text for explanation.*

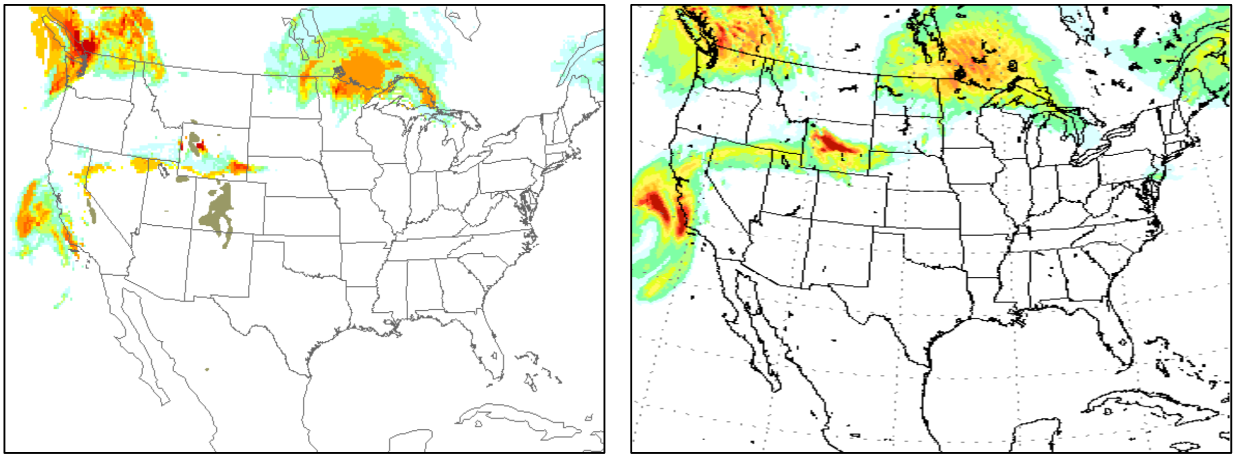

***Fig. 6**. Comparison of 12hr forecast of RUC-based FIP (left) and WSI-FIP (right) valid 06 UTC 9 NOV 2005.*

agreement.[1] For example, Fig. 6 reflects the forecasted icing potential from RUC-based FIP and the WSI version based on WRF.

In addition to the graphical output, the information is provided internally to WSI aviation forecasters in grib format for additional viewing, manipulation, etc.

4. CLOSING REMARKS

The WSI Corporation has recently begun providing customized aviation forecast information to meet the needs of the commercial aviation industry. Realtime forecast operations include providing Terminal and EnRoute Forecasts several times daily for selected sites and regions both domestically and internationally.

The latest version of the Weather Research and Forecast model is run locally at WSI several times per day over several different domains in support of the aviation forecast operations. Additional post-processing algorithms have been developed to provide forecasts of parameters not directly output by WRF – such as ceiling and visibility, convective wind gusts, winter precipitation type, turbulence, and forecast icing potential.

A verification system is currently being developed to objectively evaluate performance of the various algorithms - as well as of the human forecaster generated products. Once a more complete picture of forecast performance is formulated, improvements to the current system can and will be made…in order to assist decision-makers, such as dispatchers and pilots, to better determine if certain aircraft can safely fly while meeting the Minimum Equipment List (MEL) requirements. Some of the more obvious improvements may be to simply re-scale algorithms within the current suite. Other improvements may include the addition of new algorithms (and possibly the modification and/or removal of existing ones). Still other refinements may come from increasing the resolution of the WRF simulations. Finally, creating a dynamical system in a way similar to how the GTG01 and GTG02 products are created may be a future activity.

In closing, it is safe to say at this point that because the WSI aviation forecasting operation is still very much in its infancy, additional refinements to it will yield additional forecast skill.

[1] A realtime verification system for FIP has only recently been put in place. Unfortunately there is not yet enough information to provide statistically useful feedback on how well the FIP algorithm is performing.

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