10A.4 THE NOAA AVIATION FORECAST PROCESS IN THE NEXTGEN ERA

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Abstract
To support the Next Generation Air Transportation System (NextGen) requirements for weather information, The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) must consider changes to its existing forecast processes and procedures. This paper provides an overview of the NextGen weather paradigm, highlights the strengths and weaknesses of the existing aviation forecast process, and then introduces approaches under development to meet these new requirements Finally a high level look at the most complicated, yet intriguing, challenges will identified for the road ahead.

1. INTRODUCTION

With demand for air transportation expected to double or triple between now and 2025, the Air transportation system is under stress. The current system is not able to accommodate this growth, especially since its optimal design is built around the "fair weather" assumption. As Figure 1 shows, even without considering weather, a doubled demand for airspace greatly exceeds available airspace using the 2002 baseline system, implying a commensurate increase in flight delays based on congestion alone. Add low ceilings and visibility or unfavorable winds impacting one key airport or thunderstorms at a key intercontinental route and the results are even more delay. In fact, flight delays during the summer of 2007 reached an all time high. In its May 2008 report the Congressional Joint Economic Committee (2008) quantified the total cost of air traffic delays for 2007 at $41B.

FAA records indicate that on average, weather is a factor in 70 percent of delays and estimates about 2/3 of those delays may be avoided with better weather information (REDAC, 2007). It is important to note what is meant by saying "better weather," both improved, more accurate, timely and consistent information produced by NOAA as well as better integration of the weather information by the Federal Aviation Administration (FAA) into their Air Traffic Management (ATM) Decision Support Systems

In 2003, the President signed legislation establishing the Joint Planning and Development Office (JPDO). JPDO is a multi-agency office consisting of members from the FAA, Department of Transportation (DoT), Department of Defense (DoD), Department of Commerce (DoC), National Aeronautics and Space Administration (NASA) and private industry. JPDO has been tasked to develop the Next Generation Air Transportation System (NextGen) to enable the National Airspace System (NAS) to accommodate the expected growth in demand for air traffic services without degradation to safety. A key component of NextGen is the reduction of weather impacts by transforming the manner in which weather-related information is collected, managed, disseminated, and utilized in decision-making.

The NextGen weather vision is described in the NextGen Concept of Operations (2007), the NextGen Weather Concept of Operations (2006) and other documents produced by the JPDO. These concepts are further refined by the FAA's NextGen Implementation Plan (2008), formerly called the Operational Evolution Partnership. Running throughout this vision are the concepts of trajectory based aircraft operations, network-enabled operations and the integration of weather information into decision making. In the NextGen Vision, aircraft trajectories are managed by automated systems that will route air traffic around areas of hazardous weather.

The key to this proposed concept is establishment of a four-dimensional database (three spatial dimensions and time), or virtual cube, of weather information (e.g., observations, analyses, forecasts) made available in a network-enabled, digital format. In 2008, the multi-agency NextGen Integrated Work Plan (IWP) assigned NOAA as the Office of Primary Responsibility (OPR) for building and deploying an initial 4D Weather Data Cube, also known as the Weather Information Database (WIDB) internally in NOAA. The requirements the 4-D weather data cube must meet are contained in the IWP and in the overall JPDO NextGen Weather Concept of Operations and include:

- Observations, analyses, and forecasts with improved time and spatial resolution that meet NextGen Functional and Performance Requirement specifications
- Consistency across spatial and temporal scales
- More accurate and timely weather information
- Automated generation of legacy aviation products (e.g., Significant Meteorological Information Bulletins (SIGMETs)), Terminal Aerodrome Forecast (TAFs), Airmen's Meteorological Bulletin (AIRMETs) from the 4-D weather data cube
- Capability for meteorologist intervention in the forecast process

2. CURRENT NWS AVIATION FORECAST STRUCTURE

Today, the NWS generates a variety of aviation products, ranging from text bulletins to graphics. This weather information is presented to NAS decision-makers, who incorporate it with other information for use

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in formulating control and planning decisions. Many products require subjective interpretation, while others products, such as TAFs and SIGMETs, are more objective. Aviation weather products are produced by NWS using a three-tier system: National scale products at the Aviation Weather Center (AWC) and the Alaska Aviation Weather Unit (AAWU), regional products at the Center Weather Service Units (CWSU) and local products at the Weather Forecast Offices (WFO). The primary text-based aviation product issued by WFOs is the TAF, disseminated on set schedules with amendments sent, as needed, between issuance times. The CWSUs disseminate the Center Weather Advisory and the Meteorological Impact Statement, and AWC and the AAWU issues SIGMETs, AIRMETs and Area Forecasts for their respective areas. In addition, AWC creates a suite of supplementary graphic products that address a range of aviation needs, from short-duration, low-level general aviation to long-duration, high-level international flight. These products, developed in conjunction with the National Center for Atmospheric Research (NCAR), include the Graphical Turbulence Guidance (GTG), Current Icing Product (CIP), and the Forecast Icing Potential (FIP). However, today's generation of these digital, automated products do not include meteorologists' oversight and are not suitable as a replacement for the legacy products mentioned above.

Underlying the text and graphic products are good quality, and continuously improving, numerical weather prediction (NWP) models, such as the North American Model (NAM), the Global Forecast System (GFS) model, and the Rapid Update Cycle (RUC) model. National Weather Service (NWS) field meteorologists use these models to add value in the short-term forecast (0-12 hours) of several aviation elements by assessing output from multiple NWP models in the development of deterministic forecasts.

The NextGen paradigm requires a consistent set of weather products. However, the current state of operations does not ensure or encourage consistency and can lead to inconsistent or conflicting information from NWS offices. A major challenge of transitioning from today's service structure to the vision enabled by NextGen will be improving information consistency.

3. NEXTGEN WEATHER REQUIREMENTS

In June 2007, the JPDO's Cabinet level governing body, the Senior Policy Committee (SPC), approved a request for agency resources to form a JPDO Weather Working Group-sponsored study team to perform a functional requirements analysis. This initial, living document, entitled *Four Dimensional Weather Functional Requirements for Air Traffic Management,* was released in early 2008 and begins to indentify the challenges the NWS will face when meeting NextGen requirements. For example, the document states:

> *NextGen clearly requires a change in the way weather is collected, analyzed, predicted, tailored, and integrated into aviation decision-making. Although the recent advances in meteorology have been astounding, today's weather information is designed for today's requirements. In the NextGen era, the primary role of weather information is to enable the identification of optimal trajectories that meet the safety, comfort, schedule, efficiency, and environmental impact requirements of the user and the system. The character of weather information today falls short. It has neither the temporal nor spatial resolution required, nor is it updated frequently enough, and it contains inconsistencies (e.g., multiple different convective forecasts).*

More specifically the purpose of this report was to identify and document in greater detail NextGen aviation transportation system weather information functional capability requirements (delivered through a 4-D cube concept) as envisioned in the NextGen Concept of Operations, including data attributes (e.g., resolution [spatial and temporal], data latency, refresh, reliability, integrity, and information content). The report then provided the necessary functional and limited performance NextGen weather requirements to support NextGen operations.

Currently, additional multi-agency study teams are further decomposing these initial functional requirements into more detailed performance requirements (i.e. "how good is good enough"). The NWS will consider these detailed requirements as it develops strategies to support NextGen weather needs.

4. HOW WILL NOAA/NWS MEET NEXTGEN REQUIREMENTS?

Weather products generated by the NWS have undergone a revolution over the last 10 years with the transformation of traditional weather forecast production into the digital age through the use of the Interactive Forecast Preparation System (IFPS) application on the Advanced Weather Interactive Processing System (AWIPS) used at Weather Forecast Offices. Digital data in the form of gridded and graphical displays of official NWS products are provided via the National Digital Forecast Database (NDFD). Selected NWS forecasts, in the form of text and graphics, are now produced interactively from meteorologist-developed grids of surface weather information. Aviation weather products are not yet provided digitally via the NDFD in part because many current FAA systems cannot yet interpret digital weather information.

As NOAA and NWS move toward meeting NextGen requirements, two issues must be addressed. First, aviation weather information must be meteorologically consistent across NWS products. Second, for rapidly updated, automatically generated information to be accepted by the user, meteorologists must have the ability to correct or adjust the final product to improve its accuracy. This paper will address these issues by highlighting some of the processes and procedures the NWS and its research partners are involved with today. While these areas are important, the evolving data attribute requirements (resolution, latency, reliability, etc…) cannot be ignored.

The three tiered system used by the NWS today to produce aviation forecasts often results in inconsistent weather information for NAS decision-makers. Addressing this inconsistency requires a shift in the meteorologist's role from manually creating products (e.g., charts, text bulletins, TAFs, etc.) to modifying a 4D weather data cube of gridded weather analysis and forecast data. In this forecast process, meteorologists add value to automated products to produce accurate, timely forecasts. Many of the traditional manual products could then be automatically generated from the 4D weather data cube. These "value-added" processes can be classified as either Meteorologist In the Loop (MITL) or Meteorologist Over the Loop (MOTL):

4.1 *MITL:*

The Meteorologist in the Loop (MITL) process is one where meteorologists interactively add value inside an automatic forecast process. This concept contrasts to a completely automated forecast process where meteorologists have no input. For example, in the MITL modifications envisioned for 4D weather data field, a meteorologist would modify the gridded data using robust, user-friendly, man-machine interface software tools prior to its publication in the 4D cube. This process will allow the operational staff to compensate for some of the inaccuracies found in NWP guidance forecasts or automated post-processing systems.

4.2 *MOTL.*

The Meteorologist over the Loop (MOTL) concept refers to forecaster involvement at the front end of a forecast process, such as providing convergence boundary locations to a convection algorithm. NWP models will then be "re-processed" or "re-run" with this enhanced or modified input data. The resulting output is then released without the need for further human interaction.

The NWS is working with its research partners to develop and test new MITL and MOTL technologies as well as improving and enhancing existing capabilities to meet NextGen requirements. Some of these projects or processes are detailed below and include:

- Interactive Calibration of Aviation Grids in 4 Dimensions (IC4D)
- Auto-nowcaster (ANC)
- Localized Aviation MOS Program (LAMP)
- The NWS Storm Prediction Center Short-Range Ensemble Forecast (SREF)

4.3 *IC4D*

The NWS Meteorological Development Laboratory (MDL) has created a software prototype to support the MITL process with capabilities provided in the Interactive Calibration of Aviation Grids in 4 Dimensions or (IC4D) The IC4D approach relies on forecaster experience to validate and adjust automated guidance as necessary. Adjustments include the compensation for known biases and situational limitations of the NWP models, as well as "nudging" the digital forecast to reflect the latest available observations.

The IC4D encompasses a broad range of functionality, providing forecasters with a highly configurable graphical user interface (GUI) as demonstrated in Figure 2 to display and make adjustments to the digital guidance. The initial software was developed based upon an existing package of applications currently implemented at NWS Weather Forecast Offices (WFOs) known as the Graphical Forecast Editor (GFE).

An operational test and evaluation of the IC4D began in September 2007 at the NWS Alaska Aviation Weather Unit (AAWU). Additional testing is now being done at NWS Honolulu Weather Forecast Office in Hawaii and is planned for transition to AWC in 2009. More detailed information can be found at http://www.nws.noaa.gov/mdl/pubs/Documents/Papers/Uhlenhake2008Developing.pdf

4.4 *Auto-nowcaster (ANC)*

The NWS, in cooperation with the National Center for Atmospheric Research (NCAR), is testing and validating ANC, which allows the forecaster to provide value-added enhancements to automated, gridded convective forecasts. The overarching goal is to improve the consistency, reliability, and accuracy of 0-2 hour convective forecast products for automated aviation weather digital products for the NAS.

The ANC system provides combined 1 hour deterministic forecasts of storm extrapolation and evolution and the likelihood for convection initiation every 5 min (Fig. 3). Previous demonstrations of the ANC system for FAA activities have shown that forecaster input into the ANC process added consistency, reliability and accuracy to the 0-1 hr short term, time and location specific thunderstorm nowcasts. This improved performance was achieved when forecasters, using an interactive display tool, entered into the ANC system the locations of surface convergence boundaries (e.g., the yellow and magenta polylines in Fig. 3) observed in radar, surface station and satellite data. These boundaries play a key role in the formation and evolution of future convective storms.

This tool is currently being prototyped at the Dallas/Fort Worth Forecast Office. The system allows the forecaster to select from a variety of synoptic regimes to enable the system to better model the prevalent conditions in the area. After using a GUI interface to input the positions of convergence boundaries, the system will automatically generate the thunderstorm “nowcasts” every five minutes. Over the past year, the ANC toolset has been integrated into the AWIPS, the primary forecast system used by NWS meteorologists. In coming years, the ANC program will be focusing on expanding the system to better handle the elevated convection regime, and producing probabilistic instead of the current deterministic output.

4.5 *LAMP*

The NextGen Weather Concept of Operations specifically documents the requirement of probabilistic weather information needed for integration into decision support tools. For years the NWS has been producing objective statistical guidance in the form of Model Output Statistics (MOS) which contain many probabilistic attributes. Continuous enhancement and improvement of LAMP is consistent with NextGen weather requirements and goals. The GFS LAMP guidance is running operationally at NCEP and is now available on an hourly basis. Much more detailed information on LAMP is available on the LAMP web page: http://www.nws.noaa.gov/mdl/lamp/index.shtml

4.6 *SREF*

From the NWS SPC SREF web page: http://www.spc.noaa.gov/exper/sref/

> *The SPC Short-Range Ensemble Forecast (SREF) is constructed by post-processing all 21 members of the NCEP SREF plus the 3-hour time lagged, operational WRF-NAM (for a total of 22 members) each 6 hours (03, 09, 15, and 21 UTC). Output is available at 3h intervals through 87 hours. The SPC ensemble post-processing focuses on diagnostics relevant to the prediction of SPC mission-critical high-impact, mesoscale weather including: thunderstorms and severe thunderstorms, large scale critical fire weather conditions, and mesoscale areas of hazardous winter weather*

This focus on the mesoscale includes several aviation specific probabilistic forecasts including convective cloud tops (see Figure 4), precipitation types and wind shear.

As with the LAMP guidance, the SREF probabilistic suite of products are consistent with the type of forecasts required for integration into the next generation of flight planning and flight decision support tools developed for the NextGen paradigm.

By no means are IC4D, ANC, LAMP, and SPC SREF the only products in development or even in use today that will support a 4D weather data cube or other NextGen weather requirements. NextGen requirements are still being developed and additional refinements are likely. The NWS feels strongly that no single automated solution will meet NextGen accuracy requirements for years to come. Therefore a continuation of improving both model driven products and development of processes to allow the meteorologist to add quantifiable value are needed.

5. THE CHALLENGES AHEAD

Many complicated challenges lie ahead in any transition or modification of the NWS forecast process. Aviation weather is one of many critical missions the NWS supports and the NWS will be very cognizant of any impacts changes in the aviation forecast process have on these other missions. Considering that many of the changes already discussed should assist all NWS missions (e.g. improving convective model resolution for aviation needs would certainly improve the severe weather warning mission), this risk seems minimal.

The most significant challenges ahead include:

- *Consistency* – Development of methodologies to ensure that not only all aviation products are consistent, but also NWS aviation products are consistent with other NWS public and marine forecast products.

- *Temporal and spatial requirements – Some of the requirements highlighted in the Four-Dimensional Weather Functional Requirements for NextGen Air Traffic Management stretch state of the science limits. Will model researchers and developers have the resources available to meet these requirements?*

- *Observational requirements – The same challenges that exist with the modeling resolution requirements above will likely be levied on observations. Additional challenges include meeting accuracy and certification requirements that are likely in years to come.*

- *Developing a Net-Centric Capability - Though not discussed in much detail in this paper, the ability for NWS weather systems and the 4D Weather Data Cube to be compatible with developing FAA standards and protocols is complicated and quite different from today's data exchange models between government agencies.*

6. SUMMARY

NextGen requirements will drive changes to the NWS forecast process for aviation weather. The details of such a change are the subject of R&D at this time. It is certain changes will need strong involvement from NWS field forecasters at all levels (CSWU, WFO, AWC/AAWU) as well as with the science officers at the local and regional level.

In working toward meeting NextGen weather requirements, NWS is developing and testing tools that facilitate forecaster interaction with gridded data.

Workload becomes an issue as the update rate increases, so research is being conducted at NCAR, MDL, and GSD to evaluate these tools and to quantify where the human can add the most value. This research is necessary to demonstrate the utility of human expertise in an increasingly automated environment and to posture NWS for aviation weather support in the future

The challenges the NWS faces to transition to a new forecast process for NextGen are significant. The NWS, in partnership with its government, industry, and research partners, will work to develop a forecast process which meets mature and validated NextGen requirements.

7. REFERENCES

Concept of Operations for the Next Generation Air Transportation System, v2.0, 2007: Joint Planning and Development Office, 1500 K St. NW, Suite 500, Washington, DC

Congressional Joint Economic Committee (JEC) Report, 2008: Your Flight Has Been Delayed Again.

FAA, 2008: FAA's NextGen Implementation Plan (formerly Operational Evolution Partnership).

Four-Dimensional Weather Functional Requirements for NextGen Air Traffic Management, 2008: Joint Planning and Development Office, 1500 K St. NW, Suite 500, Washington, DC.

Integrated Work Plan (IWP), 2008: Joint Planning and Development Office, 1500 K St. NW, Suite 500, Washington DC.

Research, Engineering and Development Advisory Committee (REDAC), 2007: Report of the Weather—ATM Working Group.

Uhlenhake, H., T. Boyer, and D. Ruth, 2008: Developing tools for calibrating four-dimensional aviation weather forecasts, *13th Conf. on Aviation, Range, and Aerospace Meteorology,* New Orleans, LA, Amer. Meteor. Soc., P1.10.

Weather Concept of Operations, v1.0, 2006: Joint Planning and Development Office, 1500 K St. NW, Suite 500, Washington, DC.

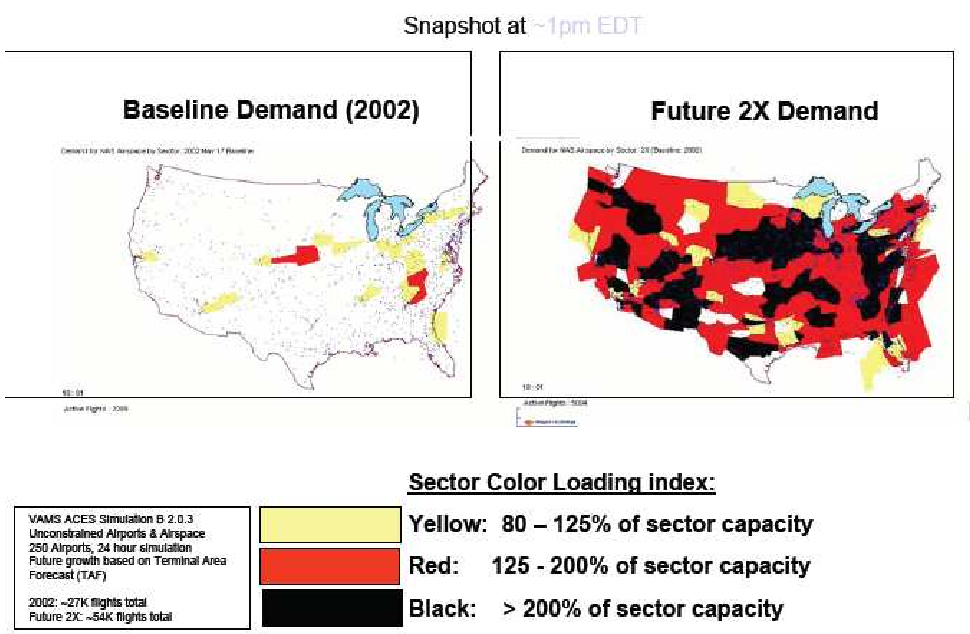

Figure 1. Airspace Loading: Midday Demand for Airspace

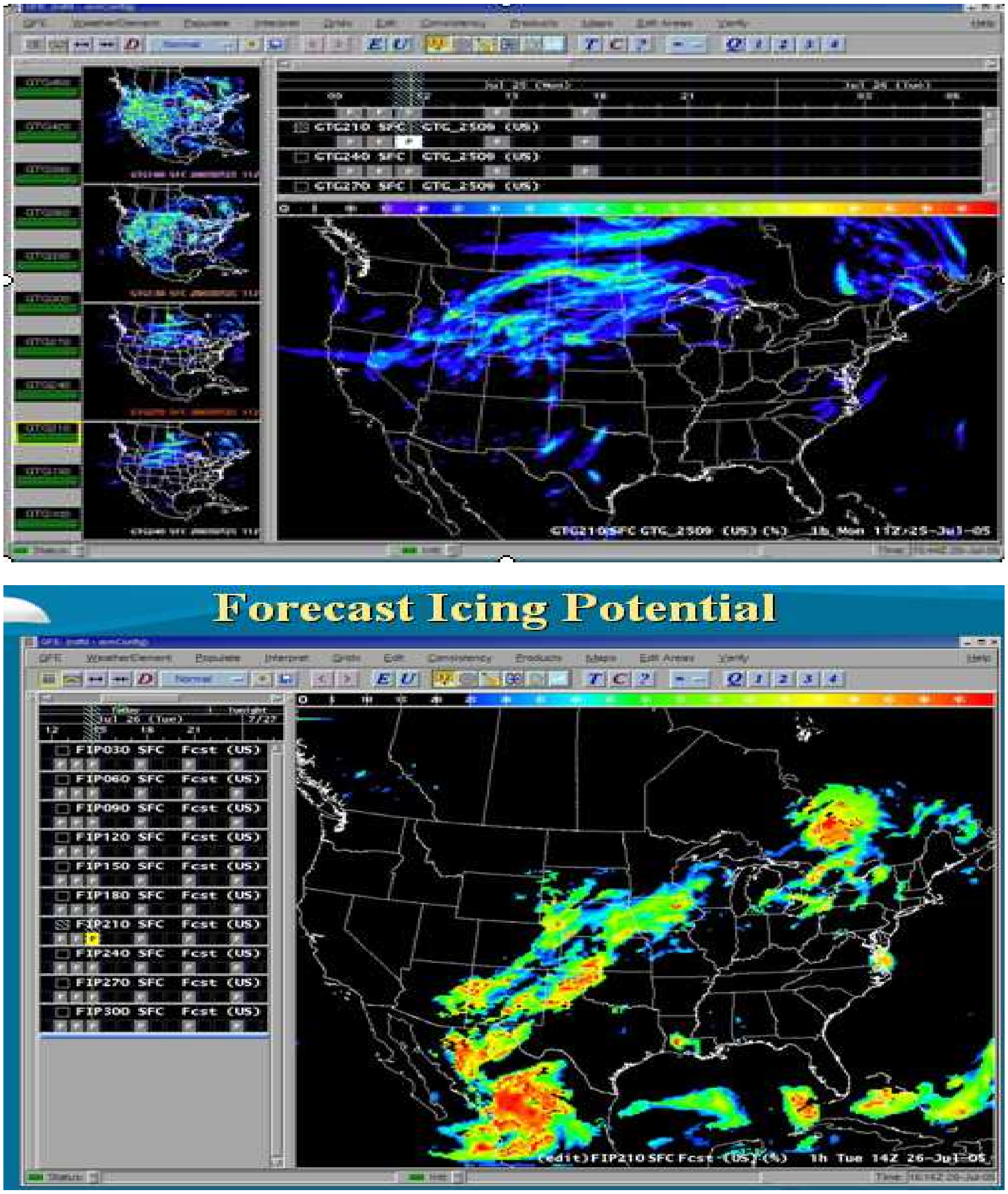

Figure 2. Example of IC4D graphical user interface.

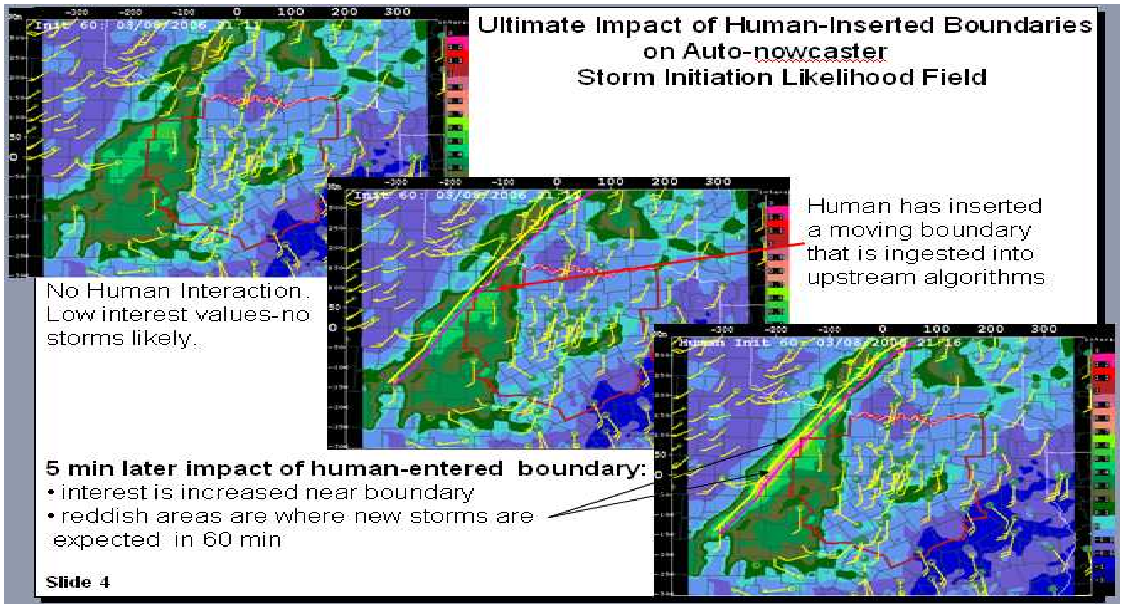

Figure 3. Example of meteorologist-over-the-loop value-added for convective initiation.

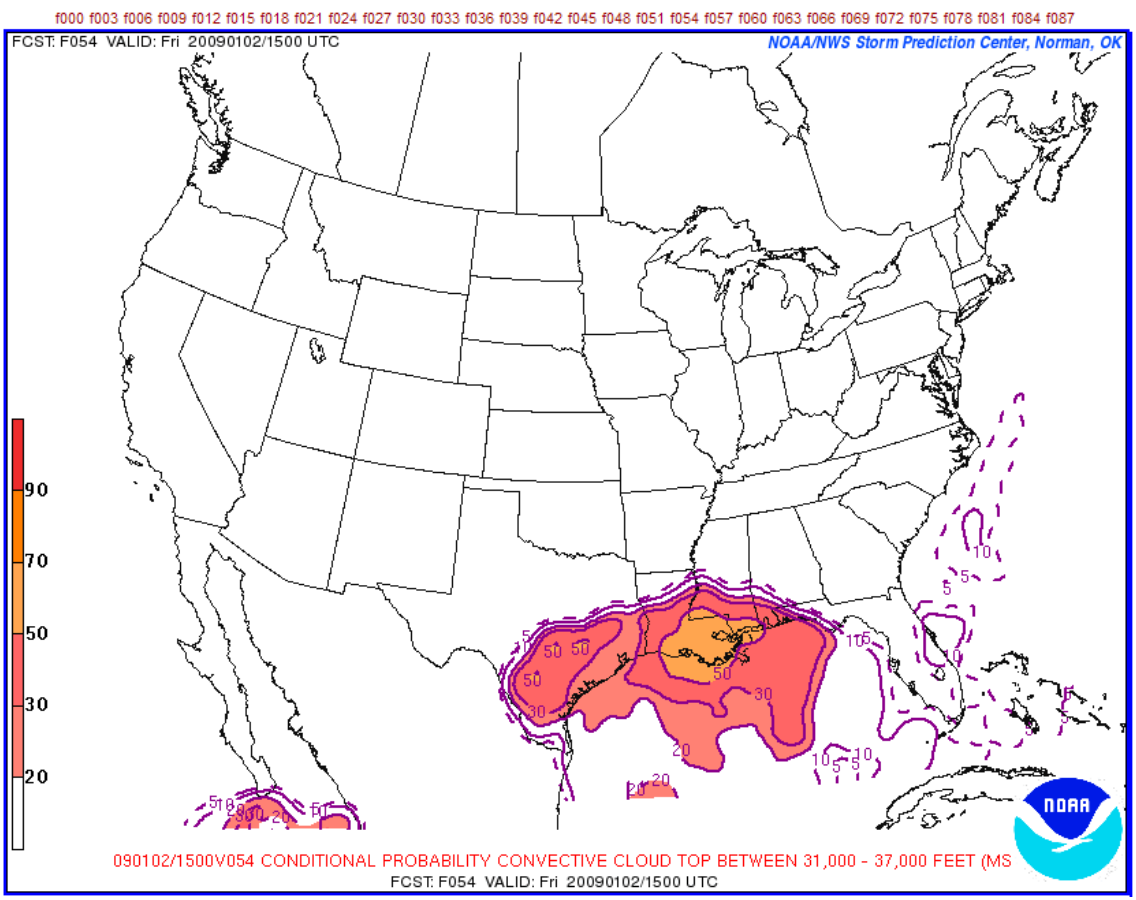

Figure 4. SPC Short-range ensemble forecast of convective cloud tops. Conditional probability interpretation: If thunderstorms do occur, probabilities of cloud tops between 31,000 and 37,000 feet are indicated by contours and shading.