

Special Project

Status of Inflight Icing Forecasting Products and Plans for Future Development

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Special Project Report

Status of Inflight Icing Forecasting Products and Plans for Future Development

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Abstract

The three papers in this Special Project Report were presented at the AIAA Atmospheric and Space Environments Conference in August 2010. They provide the current status of automated inflight icing diagnosis and forecast algorithms, and describe steps for improvement: new data inputs, improved logic, development of human-over-the-loop production methods, and expansion of the domain to cover the globe.

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Contents

Foreword iv

Potential Upgrades to the Current and Forecast Icing Algorithms 1

The Global Forecast Icing Product 11

Using Icing Algorithm Output to Create AIRMETs 19

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Foreword

Inflight icing has been a strong component of the Atmospheric and Space Environment Technical Committee of AIAA. For the most part, inflight icing studies presented at AIAA conferences tend to focus on the effects of the atmospheric environment on the performance of aircraft. However, descriptions of the icing environment, and of forecasting or diagnosing icing conditions, have also had a place in the presentations. This intermingling of related disciplines with a common goal—reducing icing-related accidents—has stimulated discussions and encouraged collaborations that otherwise would not likely have come to pass.

Three papers were presented at the 2010 Atmospheric and Space Environments Conference, held in Toronto, Ontario, Canada describing state-of-the-art automated forecasts and paths to future versions. At the time of the 2010 Conference, products available for inflight icing forecasting included the following:

- Airmen's Meteorological Bulletin (AIRMET): An advisory for widespread moderate or greater structural icing covering a 6-h forecast period, which may be amended.
- Significant Meteorological Information (SIGMET): A weather advisory for severe icing over a 3000-mi² or 7800 km² area.
- Current Icing Product (CIP): An hourly diagnosis of inflight icing environmental conditions over the continental United States (CONUS). The product includes probability of encountering icing in any of the 20-km/1000-ft grid boxes, expected severity, and likelihood of supercooled large drop (SLD; drops with diameters exceeding 50 microns, which is outside of the certification conditions). The CIP algorithm combines numerical weather prediction (NWP) model output with observations such as geostationary satellite imagery, NexRad radar reflectivity, surface weather observations, and the national lightning network.
- Forecast Icing Product (FIP): An output updated hourly for each hour up to 12 hours forward in time. FIP is similar to CIP but it uses NWP model surrogates for the observations ingested by CIP.

The automated CIP and FIP do very well at what they are called to do: provide a medium-scale resolution product with a broad-brushed icing severity estimation over the CONUS. The intended user is an aviation meteorologist, dispatcher, or pilot looking for strategic information for flight planning. Graphical depiction, both format and content, is extremely important to these users.

Consider a future air transportation system where aviation weather products are fully integrated into a seamless weather-to-aircraft process. The products will incorporate various components including weather observations, NWP models, algorithms to interpret and combine information, human-over-the-loop methods, communications protocols, and flight planning and control systems. User needs for displays will be taken into account, but for the most part the forecaster, dispatcher, or pilot is not the end-user so much as automated aircraft and ground-based systems that plan for and monitor the many aircraft in the air.

This publication, which comprises three presented papers, offers ideas for extending the existing suite of inflight icing products into new geographic domains, with richer information content and opportunities for forecasters to add additional skill and insight gained from experience and knowledge of the atmosphere. This research, which is underway, forms a solid basis for automated aircraft icing diagnosis and forecasting, which offers the reader a glimpse into future products.

Potential Upgrades to the Current and Forecast Icing Algorithms

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The Current and Forecast Icing Product algorithms generate icing diagnoses and forecasts across the CONUS. These have been approved for use in operational decision-making in aviation. However, there is both a desire and need for upgrades to improve accuracy through use of new or improved weather prediction models or observations. This paper describes the upgrades planned at this time and outlines the reasoning behind choosing new candidate information for those upgrades. Two products under consideration for addition to CIP, images from the Advanced Satellite Aviation-Weather Program and grids from the 3-D NexRad radar mosaic produced by the National Severe Storms Laboratory, are described in more detail.

I. Introduction

IT is not difficult to provide an automated icing forecast. Looking for moist air in the appropriate temperature range will give a fairly good forecast of icing – this was the basis behind the Schultz-Politovich algorithm¹, which was based on temperature and relative humidity fields from the Nested Grid Model in the early 1990s. If the user is only looking for a broad-based forecast of where icing conditions are likely, this fills the niche very nicely.

However, that's not the entire picture. As the user demands more details such as severity (especially moderate or greater), conditions outside Appendix C (including SLD, supercooled large drops with diameters exceeding 50 microns), higher resolution in time and space (especially vertically) and expanded geographic coverage, the forecast process becomes increasingly more complex. There are many areas in seemingly favorable temperature and humidity ranges that do not include icing conditions.

This paper will describe planned upgrades to the Current and Forecast Icing Products, and how upgrade data and process candidates are chosen. The development and operational transfer of icing products are closely linked to NextGen schedules and requirements; however this paper will focus on technical aspects of the upgrade process.

II. Algorithm Basics

The Current Icing Product² (CIP) provides an hourly diagnosis of icing conditions. The CIP algorithm examines model outputs and observations, and extracts clues about the icing environment from these information sources. The process is straightforward and traceable. It's relatively easy to assess the impact of humidity fields or satellite-derived cloud top temperatures on the final product. The forecast version, FIP, is purely model-based and uses models outputs as surrogates for most of the observations.

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CIP is based on the following principles:

- There is no one numerical weather prediction model or observational platform that provides all the information on the icing environment needed to make good flight decisions.
- Clues to where icing is and is not, and its attributes, can be obtained from a variety of Numerical Weather Prediction (NWP) models and observations. There's a lot of information out there. Why limit yourself to one source?
- Model outputs and observations have inherent uncertainties, biases, and shortcomings which must be accounted for in the algorithm.
- As much as possible is based on physical principles to insure the algorithm is robust.

Current versions of CIP and FIP in operations at the Aviation Weather Center (AWC) ingest Rapid Update Cycle (RUC) model data, Geostationary Operational Environmental Satellite (GOES) visible, short- and long-wavelength infrared imagery, a NexRad radar reflectivity mosaic, National Lightning Data Network (NLDN) lightning information, METARs, and voice pilot reports (PIREPs) as input. They provide 20 km x 20 km x 1000 ft output fields of expected icing severity, probability of encounter, and potential for SLD icing over the CONUS (Fig. 1). Resolution is 20-km horizontal and 1000-ft vertical, from the surface to FL300. The algorithms are run hourly; FIP calculates

1, 2, 3, 6, 9, and 12-h forecast windows.

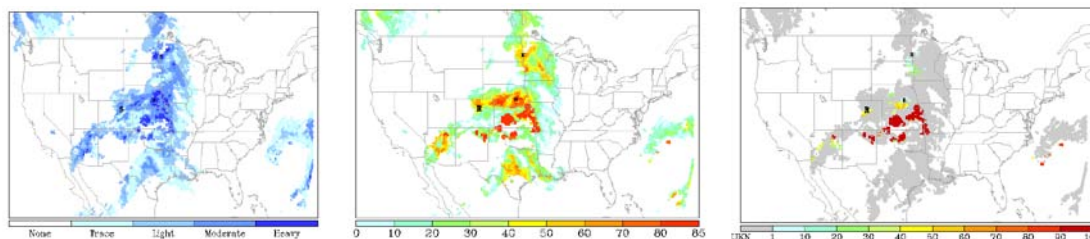


Figure 1. Examples of CIP severity, probability and SLD fields. Figures are composites showing the highest value in a vertical column.

The processes used in CIP and FIP are discussed below.

A. Gridding

Data are mapped to a grid based on that of the NWP model being used. Since the observational data are available at different resolutions, they must be mapped using various techniques. For those data sets with higher resolution data such as satellite or radar, the whole field of data contained within one horizontal grid footprint is utilized by finding percentiles of the distribution of parameter values in that area. Usually, 25th, 50th, and 75th percentiles are extracted and carried through the analysis rather than one value to characterize the entire grid. This way, the variation of those values can be used to assess the uniformity of the icing environment. For point values with coarser resolution than the underlying grid (and generally available at non-uniform spacing, such as METARs), a system is used by which each grid point seeks the “best” information by comparing information at various radii from the point. Depending on the parameter, the meaning of “best” changes, depending on the impact of the parameter on the icing condition – for example, there is a hierarchy of precipitation types that infer increasingly hazardous conditions aloft. Also during the gridding procedure, locations without cloud or precipitation are flagged as no-icing and further calculations are not applied which saves considerable computing time.

B. Decision Tree

Vertical columns of NWP model output are used to determine the type of cloud present which, in turn, influences how data are interpreted and combined downstream. A shallow, non-precipitating stratiform cloud has different physical processes at work than does a deep convective storm. Once a decision is made on a cloud type it is carried through that column – in the future, this may also be “fuzzified” (see below) to account for uncertainties in or combinations of conditions.

C. Fuzzy Logic

The fuzzy logic techniques used in CIP/FIP are simple but powerful. Information from diverse sources is mapped to a scale of -1 (completely negates) to +1 (completely supports) depending on how “interested” the algorithm is in using that information to determine icing and its characteristics. Zero means the information has no effect on consideration of icing conditions. Interest maps are created from all relevant parameters, then weighted according to their significance, given a confidence value depending on source and time of day (for example, the satellite information is less reliable near the terminator), and a final number is produced for each grid point. Separate fuzzy logic calculations are performed for icing probability, severity, and SLD potential.

III. Upgrades

Without introducing a discussion of “how good is good” we always strive for improvement in the algorithms. Our biggest problem at this time is overforecasting of icing conditions and we believe that is mainly due to an inability to diagnose glaciated cloud conditions. Some upgrades are forced on us, for example, when the National Center for Environmental Prediction (NCEP) makes changes in NWP models or when aging satellites are replaced and the detected radiation wavelengths differ slightly with the new instruments. Other upgrades represent changes in algorithm logic as we learn more about atmospheric processes and how to use observations more intelligently. Additional upgrades are pursued as new instruments are developed with a potential for becoming operational platforms. Our guidelines for considering upgrade candidates are these:

- New NWP models and instruments
 - No choice (model changes made at NCEP, new GOES, etc.)
 - They add new information not available elsewhere
 - They confirm other information and/or serve as backups in case of data loss
 - They form a basis for the future (i.e., at current temporal and spatial resolution they may not seem to add much but they could make a potentially huge difference in the future)
- Logistical
 - Increased domain – Alaska, global
 - Increased spatial resolution – high resolution NWP models, radar and satellite data enhancing coarser model output
 - More frequent update – limitations in computational speed, human comprehension. What is too fast an update rate? What can a human handle, and what makes sense in terms of how fast atmospheric processes are changing? What are the relevant scales?
- Algorithmic
 - Improved microphysics in models – weights change in the algorithm
 - Improved logic for extracting and combining information
 - Changes in interest maps to accommodate model changes

Planned upgrades for CIP/FIP are scheduled for early 2011, coincident with the transition from RUC to the Weather Research and Forecast Rapid-Refresh model (WRF-RR), and for 2013. Beyond that time, we anticipate major changes in input data sets, both from observational platforms and NWP models. Minor upgrades due to model and instrument changes, or for bug-fixes, can be implemented as needed.

Prior to implementation, upgrades are incorporated into test versions of FIP and CIP at NCAR and run for several weeks to allow scientists to gage their performance. Statistical comparisons with baseline versions of the algorithms, and with pilot reports of icing, are used to quantify improvements. When the scientists are satisfied that the upgrade provides improvement (or, at the least, does not degrade the product), and has no unexpected downstream effects, engineers code the upgrades into the algorithm for further testing, verification, and implementation. The evaluation and verification processes to approve operational versions of the products is rigorous and is undergoing changes to comply with NextGen requirements; they will not be discussed here.

For the 2011 upgrade (Table 1), most of the work consists of bug-fixes, slight changes to fuzzy logic interest maps to accommodate changes in the model output, and some upgrades to bring the CIP up to date with FIP. (The current and forecast algorithms had been on different update cycles and some of the logic in FIP had been upgraded with no concurrent change in CIP.) The overall goal is to increase the Probability of Detection (POD) while not increasing false alarms or overwarning. Currently we have no reliable means to routinely assess false alarm rate, so we compare volume covered or use data from research aircraft in case studies. No new data input sets are planned for the 2011 upgrade. Output will remain the same: 20 km x 20 km x 1000 ft, hourly updates, severity, probability, and SLD potential fields. However, forecasts will infill the 12-h forecast period to provide hourly predictions rather than the 2, 3, 6, 9 and 12-h forecasts now issued.

The 2013 upgrades (Table 2) are more substantial. Products from the NASA Langley Research Center's Advanced Satellite Aviation-weather Program (ASAP) will be incorporated into CIP to improve identification of cloud tops and characteristics. For example, the cloud phase product has been found useful to help establish the content of the cloud through its depth (see Section VI for more details). Other upgrades are planned to further help in determination of cloud locations, especially cloudy and intervening clear layers. The output will consist of the same fields (severity, probability and SLD potential) but will be provided at 13-km horizontal resolution. Update rate will remain hourly but the forecast lead time will be extended to 18h. We also will apply results of studies of regional differences in icing into the algorithm, focusing mainly on differences between continental and maritime environments and their effect on cloud characteristics³.

In the outyears (2015 and beyond, Table 3) we will incorporate three new data sources: the WRF High Resolution Rapid Refresh model (WRF-HRRR); the NSSL 3D radar mosaic (see Section VII), and dual-polarized NexRad data. The WRF-HRRR will provide 4-km resolution and will be updated more frequently than hourly (rate TBD) and should thus provide the attributes needed for tactical weather decisions in the cockpit. We also anticipate improvements in the NWP model predictions of parameters needed to assess icing severity for individual aircraft (temperature, liquid water content and drop size) to a point where a flight-planning tool incorporating an ice accretion and performance model may be applied along a planned flight path to predict aircraft response. All new information sources will be thoroughly tested prior to appearing in the operationally-available products.

Table 1. CIP-FIP upgrades for 2011

Upgrade	Description	Justification	Datasets	Effect
Higher resolution	13x13 km horizontal resolution, forecasts every 1h to 12 h	Make use of native NWP model resolution.	WRF-RR	Increase resolution and granularity
Radar reflectivity	Replace VIP with reflectivity	VIP was an artifact from previous vendor mosaic, dBZ is now available, why not use it?	Vendor or NSSL 2D radar mosaic (composite or lowest layer)	Minimal – but lays a foundation for future upgrades
SLD upgrade	Add SLD diagnosis for conditions aloft (not just near-surface)	Identify SLD aloft	NWP model, satellite, PIREPs	Improve SLD likelihood
Night severity	Recalibrate probability and severity thresholds to match daytime severity	Make nighttime probability and severity fields consistent with higher-accuracy daytime fields (due to availability of vis channel during daylight hours)	CIP output files to run regressions on	Increase POD and improve severity estimates
Cloud top height	Add cloud top height (CTZ) fuzzy-logic algorithm to CIP -- already implemented in FIP	Improve estimation of cloud top height; decrease overforecasting of cloud volume	GOES, METARs, NWP model	Decrease volume warned while retaining high POD