J1.6 AN INFERRED ICING CLIMATOLOGY - PART II: APPLYING A VERSION OF IIDA TO 14-YEARS OF COINCIDENT SOUNDINGS AND SURFACE OBSERVATIONS

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1. INTRODUCTION

A commonly asked question about in-flight icing is how frequently it occurs, where and at what time of the year. A lack of regular, unbiased, direct measurements of the presence and absence of icing conditions makes this very difficult to answer. Pilot reports (PIREPs) of in-flight icing are strongly biased by traffic frequency, time of day and are subjective in nature (Young et al 2002). Research aircraft provide the only other in-situ observations of in-flight icing, but the sample set is small and can be biased by the purpose of the flight program (i.e. to find icing). Thus, other techniques must be used to infer the presence of icing conditions from past observations to create more unbiased climatologies.

In this study, an icing climatology for the winter and late-fall months (November to March) is inferred using regularly observed data from 14 years of coincident, 12-hourly US and Canadian surface weather reports and balloon-borne soundings. Although these datasets do not provide direct observations of icing conditions aloft, when properly combined they can be used to identify where icing is likely to be present and absent (as in Bernstein 2001).

2. DATASETS AND ANALYSIS TECHNIQUE

2.1 Soundings

Sounding data were derived from a NCDC database of quality controlled balloon-borne soundings taken at ~120 sites across North America. The NCDC database included soundings from 1946 to 1992, but those made before 1977 (and at selected sites during parts of the 1980s) were eliminated due to known problems with the hygristor (Wade 1995), while those after 1990 were eliminated to match the surface observations dataset available (see next subsection). The data were QC'd beyond NCDC standards to only include those that had good temperature and moisture data up to at least T=-35C, reached 400mb and had at least 25 levels in the file. This limited the database to those soundings that were both of good quality, adequate resolution and were deep enough to reach temperatures where ice-dominated cloud tops could exist.

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Soundings were launched at 1100 and 2300 (all times UTC). The 14-year dataset resulted in ~4,200 soundings per site and ~5 million, total. Horizontal coverage is fairly uniform across North America (Fig. 1), eliminating most of the geographic bias from the climatology. Interpolation of results between sites is reasonable for all but areas where local effects are important, such as the Rocky Mountains and, to some extent, the Appalachians and around large water bodies. Local maxima and minima are likely to exist in these areas and will not be captured here.

2.2. Surface Observations

Surface Airways Observations (SAOs) were derived from the NOAA Techniques Development Laboratory (TDL) and NCDC "SAMSON" archives. Both datasets spanned the period of interest (1977-1990) and were combined to eliminate completely or partially missing SAOs in each dataset.

Surface observations were applied to the soundings essentially in the same manner that they are applied to RUC grid points in the Integrated Icing Diagnosis Algorithm (IIDA; McDonough and Bernstein 1999, hereafter MB99). At each sounding site, all observations made within a 100km radius were considered if the elevations of the stations were

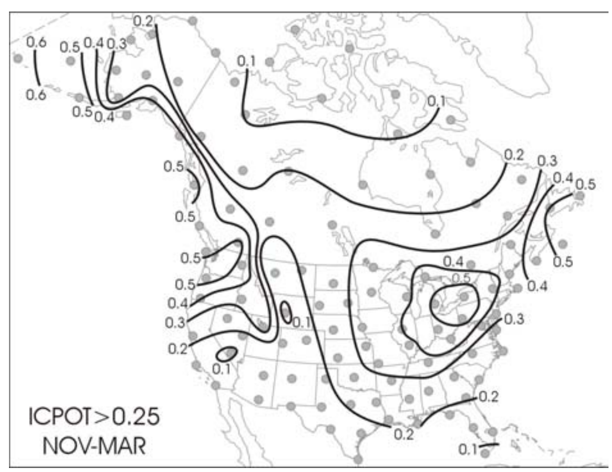

Fig. 1. Map of the percentage of soundings with 0.25 or greater ICPOT at any level for November to March. Sounding sites are indicated with gray dots. Contours shown at 0.1 (10%) intervals.

no more than 609m different from that of the sounding site. The number of stations available varied from site to site, with several stations having only one station (e.g Inuvik, NWT), while others had ten or more (e.g. Sterling VA, Oakland CA). If all of the surface observations reported sky cover that was either "clear" or "scattered", then it was considered to be a "cloud free" sounding for icing purposes. Bernstein et al (1997) showed that nearly all icing occurs in places where at least "broken" sky cover is reported. If any of the stations within the 100km radius reported "broken", "overcast" or "obscured" sky cover, then the ceiling height was set to the height of the lowest deck that met these criteria. Precipitation observations were checked for the presence of the following precipitation types: any, freezing (including ice pellets) and snow-only.

For both ceiling and precipitation reports, data from the time of the launch (11 or 23) were used when available, and data from the next hour (12 or 00) were used if the 11/23 data were not present.

2.3 The "sounding IIDA"

To diagnose the potential for in-flight icing conditions to exist (ICPOT), a special version of the IIDA was applied to the matched surface and sounding data. IIDA is normally applied to real-time satellite, radar mosaic and surface observations matched to Rapid Update Cycle model output. The determination of ICPOT is rather complex, so the reader is referred to MB99 for complete details. In short, if a grid point is determined to be "cloudy" via satellite and surface observations, then the range of altitudes where clouds and/or precipitation are present are examined for their ICPOT. Between cloud top and cloud/precipitation base, the physical situation is identified (e.g. single-layer, non-precipitating cloud). The observations and model output are then run through interest maps and combined appropriately for the situation to determine the potential for supercooled liquid water to be present at sufficiently cold temperatures to form icing on a typical prop-aircraft. The sounding IIDA is used to calculate ICPOT at each altitude where data are available. Values are on a scale of 0.0 (no icing) to 1.0 (icing very likely). Results for an example sounding are shown in Fig. 2.

The sounding IIDA has some key differences from the RUC-based IIDA. They are as follows:

- "Cloudiness" is determined exclusively from surface observations of sky cover
- In "cloudy" situations, the cloud top is set to the highest altitude where RH_i or RH_w exceeds 87% (similar to Wang and Rossow 1985). Cloud top temperature (CTT) is set to T at cloud top.
- No radar data was used, as it was not available. Radar plays only a minor role in the IIDA.
- Identification of "dry layers" that separate cloud decks was made using dew point or frost point depression, depending upon temperature, rather than relative humidity. A layer had to be adequately thick and dry (>2000C*m) to clearly separate two cloud layers.
- The relative humidity and temperature interest maps are much more stringent that that applied to the RUC model profiles, since sounding measurements are more reliable (especially RH).
- When thunder is present in the SAOs, a special icing potential is calculated for deep convection, allowing icing to extend to much colder temperatures. CTT and RH interest maps are not applied in this case, since CTT does not relate well to icing in deep convection, and the sounding may not have passed through small-scale convective clouds and thus, high RH.

2.4 An independent dataset, including PIREPs

A 5-year set of matched soundings and surface observations from 1997-2001 was created to test the ability of the sounding IIDA to detect icing PIREPs. Sounding locations were essentially the same during these years. In-flight icing PIREPs made within 40km of the sounding sites and during the time of the balloon ascent (1100-1159 and 2300-2359) were compared with the soundings and the resultant icing diagnoses. Verification was done for all sounding levels within one level of the reported icing altitude(s), and was performed both on "positive" and "negative" (no-icing) reports.

Overall, the sounding IIDA had a POD_y of 0.75 and a POD_n of 0.94, using ICPOT=0.01. Higher (lower) thresholds had lower (higher) probabilities of detection, and were more (less) efficient predictors of icing conditions. Of all positive icing reports, 99% occurred where at least "broken" sky cover was reported, and 89.3% occurred between cloud top and cloud/precipitation base (INCLD). The remaining PIREPs were reported at altitudes either above the highest cloud top (7.3%), below the lowest cloud/precipitation base (2.4%; below cloud base when no precipitation is present) or where only clear skies or scattered clouds were observed (1.0%). Of the INCLD PIREPs, 3.3% and 2.3% were reported to be at altitudes with $T>0^oC$ and both RHw and RHi<50%, respectively. Overall, roughly ~16.6% of all positive icing PIREPs occurred either outside of clouds/precipitation or at a T or RH where icing is very unlikely to be present. Such errors are frequently due to misreported locations, and mistakes in encoding and/or decoding. A good example of this is when a pilot calls in a report after climbing through an icing layer, where the altitude of the icing is miscoded as at the altitude where the report was called in rather than where it actually occurred (e.g. 9,000ft instead of 5,000-7,000ft).

IIDA would always indicate ICPOT=0.0 in the cloud free, very warm and/or dry situations described above. Overall, IIDA captured ~90% of all PIREPs that appeared to be of good quality.

3. CLIMATOLOGY TECHNIQUE

To infer the frequency of occurrence of in-flight icing conditions, each sounding was examined for ICPOT values of 0.25 or greater at any level. If these conditions were met, then the sounding was considered to have at least a marginal potential for icing. The 0.25 threshold was chosen because it compared well with icing AIRMETs in past studies (Fowler et al 2002). The more stringent T and RH matches used in the sounding IIDA point toward the use of 0.15 as a more appropriate threshold, based on having PODy statistics more comparable to AIRMETs. However, icing becomes increasingly less common at the lower thresholds, and the algorithm is less efficient in this range. The reverse is true at higher thresholds (e.g. 0.75). Regardless of threshold choice, the geographic patterns for icing occurrence are essentially unchanged. Maps will show the percentage of time that ICPOT of 0.25 or greater was present at any level.

4. RESULTS

Figure 1 shows the results for the months of November to March (winter and late fall) and infers that icing is most common along the northern Pacific Coast, with the highest frequencies along the Aleutian Islands. The northwest maximum is essentially constrained to west of the continental divide. A notable maximum extends from Oregon southeastward to Salt Lake City, Utah. The other primary maximum extends from the eastern Canadian provinces (especially Newfoundland) southwestward to the Great Lakes and central Plains states. Both of the maxima are located where stratiform clouds and precipitation are quite common. Aleutian, Gulf of Alaska and Washington/Oregon coastal lows are quite common during these months, and frequently bring such conditions inland. The eastern maximum is associated with a wider variety of weather situations, including widespread stratus in the wake of cold fronts, and overrunning clouds as lows track along the cold front and bring moist air over preexisting cold air masses.

Icing was at a minimum along and just east of the Rocky Mountains, in the Southwest, portions of the deep South and in the Arctic. The Rockies, Southwest and Gulf Coast are more frequently cloud-free during November to March. While clouds and icing do impact these regions on occasion, their frequency is lower. Though upslope conditions on the eastern slope of the Rocky Mountains can cause quite significant icing events, clear skies are quite common in this area as the jet stream often brings winds with a westerly (downslope) component to the area. Common storm tracks do not often bring strong cold air to the deep South, but good lift and moisture are often present near and in the advance of lows as they pass along and pick up moisture from the Gulf of Mexico. Note the significant gradient in icing running northwestward from the western end of the Gulf of Mexico. Relatively dry and cloud-free conditions tend to exist to the west of this line. The Arctic is simply too cold during these months to have many clouds at temperatures warm enough to sustain supercooled liquid water. Icing in the Arctic peaks during the summer months (not shown).

Month-by-month results for November to March (Fig. 3) show some deviations from the overall “winter” pattern. The eastern maximum migrates southward as fall transitions to winter, then back northward as spring approaches. The northern end of the eastern maximum moves south from Hudson’s Bay to southern Ontario and Quebec, while the southern end moves from Tennessee and Missouri to

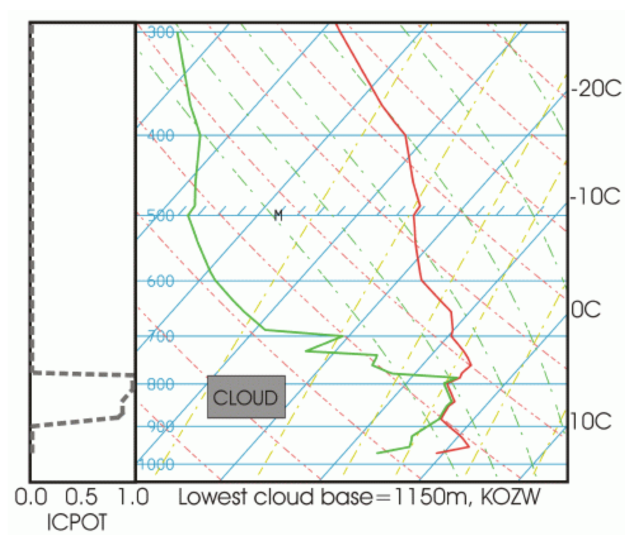

Fig. 2. Example sounding and icing potentials (dashed line) for a single-layer cloud structure observed at Detroit on 20 March 1997. Lowest cloud base reported within 100km was 1150m, from Howell MI. The cloud layer diagnosed by IIDA is indicated as a gray box.

the Gulf Coast. This reflects the southward migration of the storm track and its subsequent retreat, bringing clouds at the best icing temperatures (-15C to -5C) briefly to the deep South.

5. SUMMARY

Using the IIDA sounding technique, it is possible to infer the climatology of icing across North America. This technique could be applied to other parts of the world, and even be used in real-time, as long as good quality sounding and surface observations are available.

Distinct geographic in-flight icing maxima and minima are quite evident during the months of November through March. These are likely linked to a combination of frequency of cloud cover and the location of temperatures that are particularly conducive to the formation of supercooled liquid water. Results shown here compare well to those found in parts I and III of this series. A discussion of the comparison is included in Part III (Fowler et al 2002).

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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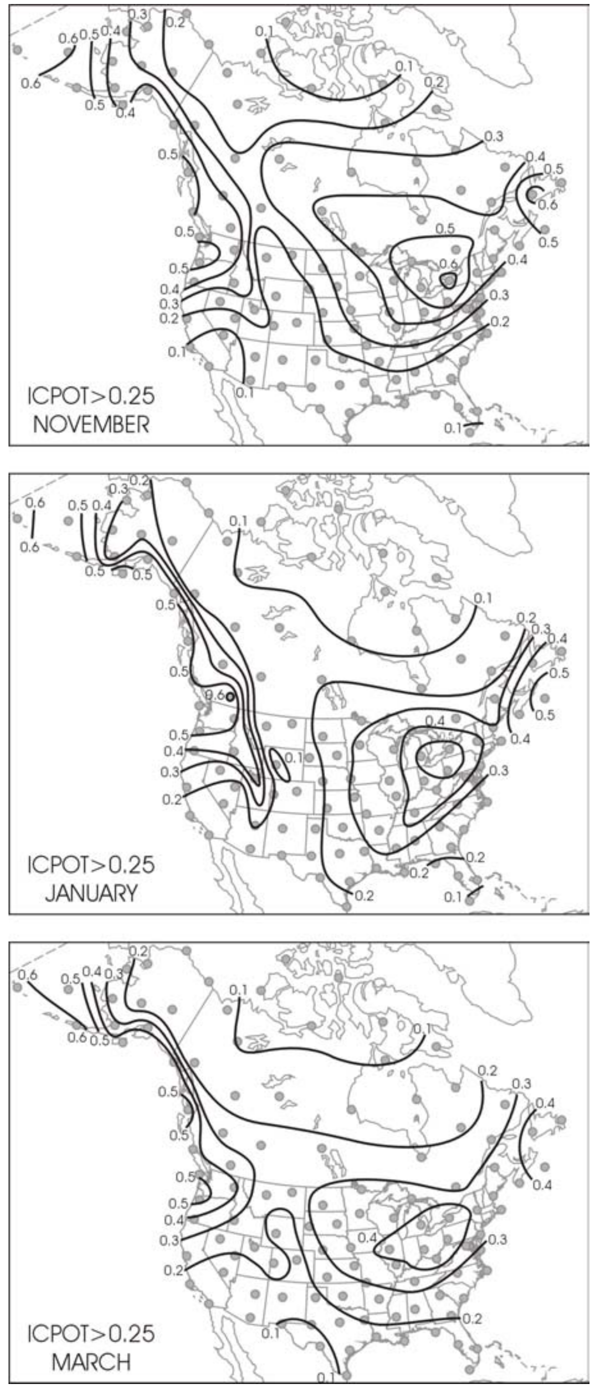

Fig. 3. Same as Fig. 1, but for individual months of November, January and March.