Preliminary Findings of Inflight Icing Field Test to support Icing Remote Sensing Technology Assessment

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Presentation Overview

• Background

• Icing remote sensing systems
  – NASA Icing Remote Sensing System
  – NASA Terminal Area Icing Remote Sensing System

• In-situ atmospheric sounding systems
  – Weather Balloon Systems
  – Anasphere SLWC Sensor
  – SLWC Calculation

• Selected winter 2015 system comparisons
  – Forecasting and Release Decision Criteria
  – March 17, 2015
  – March 20, 2015
  – March 26, 2015

• Summary
Background

- Icing accidents continue to occur despite advances in all aspects of icing related technologies
- The spatial and temporal variability of icing severity is a major challenge to providing pilots and controllers with actionable icing hazard information
- The need for direct detection and measurement of hazardous icing conditions is still significant despite improvements to weather models over the past decade
- NASA has teamed with NCAR for the last 10 years to develop a ground-based remote icing hazard detection algorithm test bed to address this need
- The result of this effort is the NASA Icing Remote Sensing System (NIRSS)
- NASA carried out a weather balloon campaign during winter 2015 using a new supercooled liquid water (SLWC) sensor to generate the database necessary to validate NIRSS
Icing Remote Sensing Systems:  
*NASA Icing Remote Sensing System (NIRSS)*

- The NIRSS remotely detects hazardous icing conditions using ground based meteorological instrumentation
  - Vertical icing condition severity product is derived from calculated supercooled liquid water content estimated by the NIRSS algorithm
  - Includes 3 vertically pointing instruments: a Radiometrics Radiometer, a Vaisala Ceilometer and a METEK Ka-Band Cloud Radar System
  - System shown to agree well with the Aviation Weather Center (AWC) Current Icing Product (CIP) and Pilot Reports (PIREP)

- An acknowledged shortcoming of NIRSS is that it only produces a vertical profile of the icing conditions
  - To help fully protect a terminal area and provide information that accounts for the temporal and spatial variability of icing conditions, a volumetric remote measurement capability is required


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Icing Remote Sensing Systems:

NASA Terminal Area Icing Remote Sensing System

• The terminal area system was developed to address the shortcomings of NIRSS
  – Produces icing condition severity classification along defined airport approach and departure paths every minute based on most recent measurements
  – Icing hazard is output in 9 boxes centered along each runway approach path, from the airport center to 25 Km out

• Terminal Area System builds upon the existing capability of NIRSS
  – Includes NIRSS instrumentation, an additional pointable radiometer and ingests NEXRAD radar data
  – In addition to NIRSS vertical condition fields, the system ingests:
    • Radiometer slant elevation ILW measurements along airport runway headings
    • NEXRAD reflectivity and ground surface wind data to advect the measured fields into the 3-D volume

In-situ Atmospheric Sounding Systems: Weather Balloon Systems

- Weather balloons used to obtain in-situ measurements characterizing conditions aloft
  - Instrument package carried specialized, disposable sensor to measure supercooled liquid water content in addition to standard meteorological radiosonde

- Weather balloon operations were carried out from the NASA Glenn Research Center hangar ramp
  - Balloon release location is 0.25 Km from ground instrumentation and within 1 Km of airport center
  - Coordination with Cleveland Hopkins Airport Air Traffic Control established to ensure safe operations

- 24 instrumented balloons released for 12 different icing events between Jan. 22 and Apr. 23, 2015
In-situ Atmospheric Sounding Systems:
Supercooled Water Content Sensor

• Balloon-borne SLWC sensor
  – Anasphere, Inc., through a NASA contract, developed a new, prototype sensor based on
    work by Hill and Woffinden
    • Hill & Woffinden, “A Balloon-borne Instrument for the Measurement of Vertical Profiles of
      Supercooled Liquid Water Concentration,” Journal of Applied Meteorology, 1980

• Measurement principle is based on the reduction in natural vibration frequency of a wire due to
  ice accretion
  – Natural frequency decreases with increasing ice accretion along the wire
  – SLWC is calculated using time history of natural frequency

• Frequency measurements obtained every 3 seconds, nominally
  – Wire is periodically perturbed by magnet attached to a servomotor
  – Natural vibration frequency determined using Fast Fourier Transform
SLWC Calculation

\[ SLWC = \frac{C}{\varepsilon D \omega} \frac{df}{dt} \]


- **SLWC** is calculated using the frequency profile
  - The time derivative of the frequency, \( df/dt \), is the driving term
  - The coefficient \( C \) is model, assumption specific
  - The terms \( \varepsilon, D \) and \( \omega \) are collection efficiency, wire diameter and ascent speed, respectively

- Outliers in the frequency are removed and the profile is smoothed prior to calculation
  - Robust local regression using weighted linear least squares and a second degree polynomial (Matlab: LOESS)

March 17, 2015, Balloon 002 frequency profile showing characteristic frequency depression due to ice accretion on wire
Case Studies:
Forecasting and Release Decision Criteria

• Long-Range Forecast
  – Long-range icing forecasting was provided by NCAR
    • Weather systems of interest identified in advance

• Next-Day Forecast
  – NCAR provided next-day forecast specifying period of interest
    • Notice to Airmen (NOTAM) submitted for forecast specified period of time
    • Coordination with NASA GRC Hangar personnel

• Short-Range Forecast
  – Coordination with NCAR on conditions during period of interest for release decision
  – Radiometer-derived ILW used as final release decision criterion
    • ILW > 0.3mm
  – Coordination with Cleveland Air Traffic Control for permission to release
    • Class B Airspace
Case Studies:
March 17, 2015 (Remote Sensing and PIREP)

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Time [UTC]</th>
<th>Flight Level [Ft]</th>
<th>Icing Report</th>
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<tbody>
<tr>
<td>E145</td>
<td>1423</td>
<td>5200-6000</td>
<td>Light Clear</td>
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<tr>
<td>B712</td>
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<td>B712</td>
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PIREP Summary for March 17, 2015 for period of interest

NIRSS icing severity product output for March 17, 2015
[Note: Markers only indicate corresponding time and altitude and do not represent transection of aircraft with the NIRSS sample volume]
Case Studies:
March 17, 2015 Balloon 002 (Comparison)

Skew-T, Log-P Diagram (left), Frequency Profile (middle), and SLWC Profile (right) for March 17, 2015, 1447 UTC

ILW = \frac{1}{\rho_{H,0} \omega_0} \int_{z_0}^{z} SLWC \, dz
No icing PIREPs were issued within 90 Km of CLE during the period of interest (1300 to 1800 UTC) on March 20, 2015
Case Studies:
March 20, 2015 Balloon 001 (Comparison)

Skew-T, Log-P Diagram (left), Frequency Profile (middle), and SLWC Profile (right) for March 20, 2015, 1500 UTC
Case Studies:
March 26, 2015 (Remote Sensing and PIREP)

NIRSS icing severity product output for March 26, 2015
[Note: Markers only indicate corresponding time and altitude and do not represent transection of aircraft with the NIRSS sample volume]
Case Studies:
March 26, 2015 Balloon 003 (Comparison)

Skew-T, Log-P Diagram (left), Frequency Profile (middle), and SLWC Profile (right) for March 26, 2015, 1659 UTC
Summary

• A successful weather balloon campaign utilizing a new SLWC sensor was conducted out of NASA Glenn Research Center from Jan. 22 to Apr. 23, 2015
  – A database of 24 balloon soundings for 12 different icing weather events was generated that can be used to validate and improve the NIRSS and Terminal Area Systems

• Initial results between the remote sensing and in-situ systems show agreement in several cases
  – The altitude of significant SLWC and general distribution SLWC aloft agree in several cases
  – The ILW between NIRSS and the weather balloon soundings agree in several cases
  – Disagreement between NIRSS and the weather balloons system may be attributed to spatial and temporal sampling differences