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

- 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

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


Radiometrics Radiometer on top of IRT roof with NEXRAD radar and KCLE airport in background
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

- **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, \( \frac{df}{dt} \), 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>
</tr>
</thead>
<tbody>
<tr>
<td>E145</td>
<td>1423</td>
<td>5200-6000</td>
<td>Light Clear</td>
</tr>
<tr>
<td>B712</td>
<td>1520</td>
<td>4000</td>
<td>Light Rime</td>
</tr>
<tr>
<td>B712</td>
<td>1552</td>
<td>4000</td>
<td>Mod. Rime</td>
</tr>
</tbody>
</table>

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

\[ ILW = \frac{1}{\rho_{H,0} z_s} \int_{z_s}^{\infty} SLWC \, dz \]
Case Studies:
March 20, 2015 (Remote Sensing & PIREP)

- No icing PIREPs were issued within 90 Km of CLE during the period of interest (1300 to 1800 UTC) on March 20, 2015
Skew-T, Log-P Diagram (left), Frequency Profile (middle), and SLWC Profile (right) for March 20, 2015, 1500 UTC

ILW−NIRSS = 0.27
ILW−Sonde = 0.25
Case Studies:
March 26, 2015 (Remote Sensing and PIREP)

PIREP Map for March 26, 2015

PIREP Summary for March 26, 2015 for period of interest

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Time [UTC]</th>
<th>Flight Level [Ft]</th>
<th>Icing Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 E145</td>
<td>1428</td>
<td>12000</td>
<td>No Icing Below 12000 Ft</td>
</tr>
<tr>
<td>2 E145</td>
<td>1439</td>
<td>13000</td>
<td>Mod. Rime</td>
</tr>
<tr>
<td>3 C525</td>
<td>1650</td>
<td>14000</td>
<td>Light Rime</td>
</tr>
<tr>
<td>4 C56X</td>
<td>1836</td>
<td>10500</td>
<td>No Icing</td>
</tr>
<tr>
<td>5 C510</td>
<td>1910</td>
<td>15500</td>
<td>Light Mixed</td>
</tr>
</tbody>
</table>

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

ILW–NIRSS = 0.89
ILW–Sonde = 0.37
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