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

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Presentation Overview

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- In-situ atmospheric sounding systems
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- Summary

Background

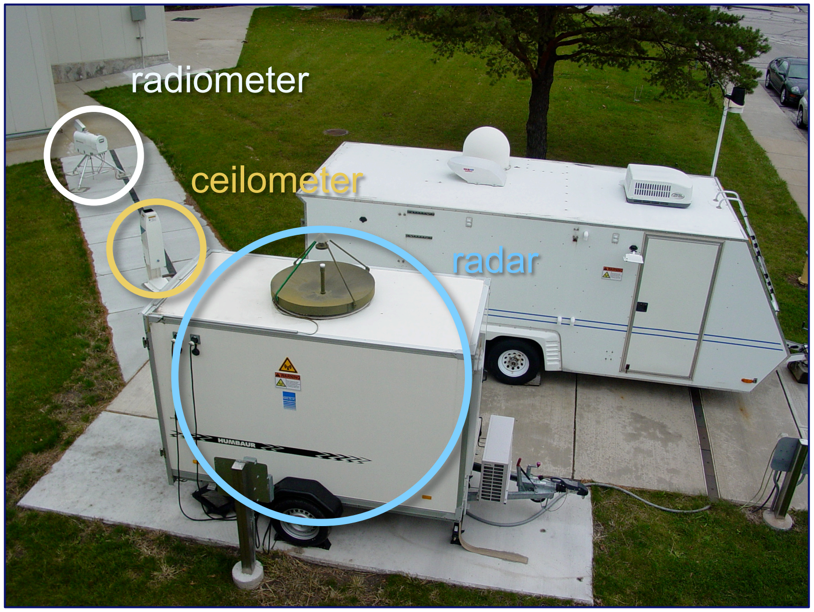
- Icing accidents continue to occur despite advances in all aspects of icing related technologies
- The spatial and temporal variability of icing severity is a major challenge to providing pilots and controllers with actionable icing hazard information
- The need for direct detection and measurement 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)
    - Johnston, Christopher J., et al., "Comparison of In-Situ, Model and Ground Based In-Flight Icing Severity", NASA/TM—2011-217141, Dec. 2011

- 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

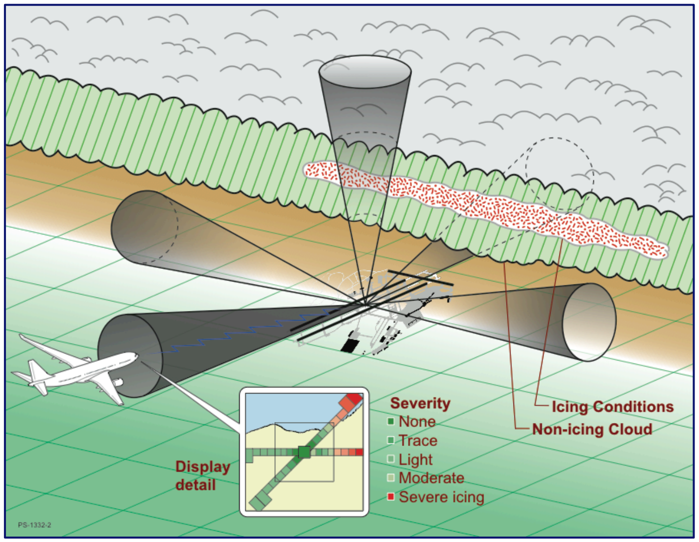


Reehorst & Serke, "A Terminal Area Icing Remote Sensing System", NASA/TM-2014-218417, Nov 2014

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



Reehorst & Serke, "A Terminal Area Icing Remote Sensing System", NASA/TM-2014-218417, Nov 2014

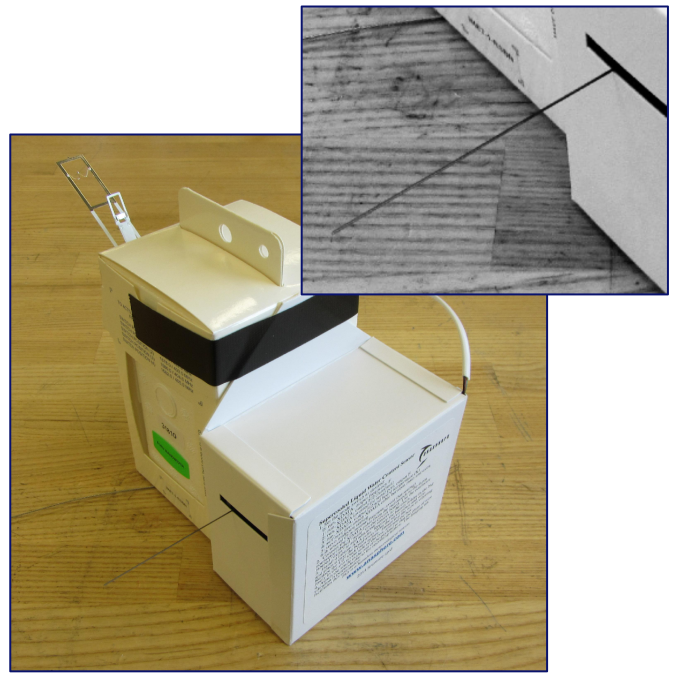
- Terminal Area System builds upon the existing capability of NIRSS
  - Includes NIRSS instrumentation, an additional point-able radiometer and ingests NEXRAD radar data
  - In addition to NIRSS vertical condition fields, the system ingests :
    - Radiometer slant elevation ILW measurements along airport 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



Instrument Package: InterMet iMet-1-RSNB Radiosonde and Anasphere SLWC Sensor

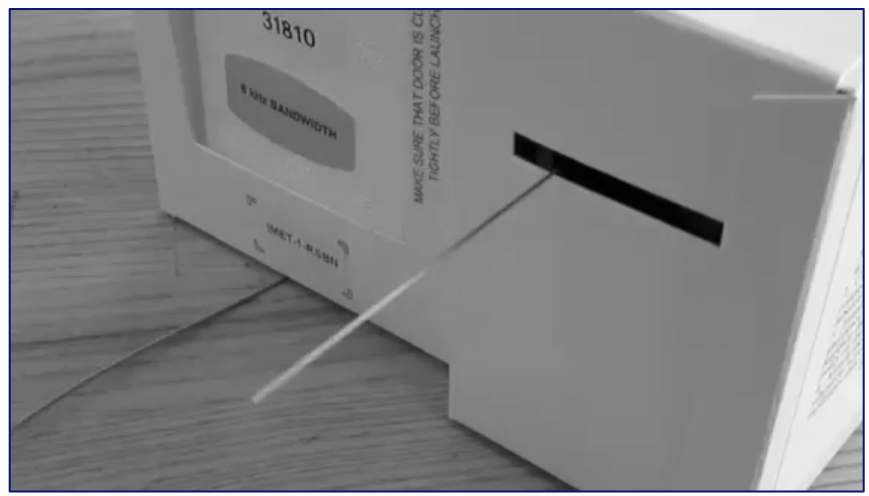
In-situ Atmospheric Sounding Systems:

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

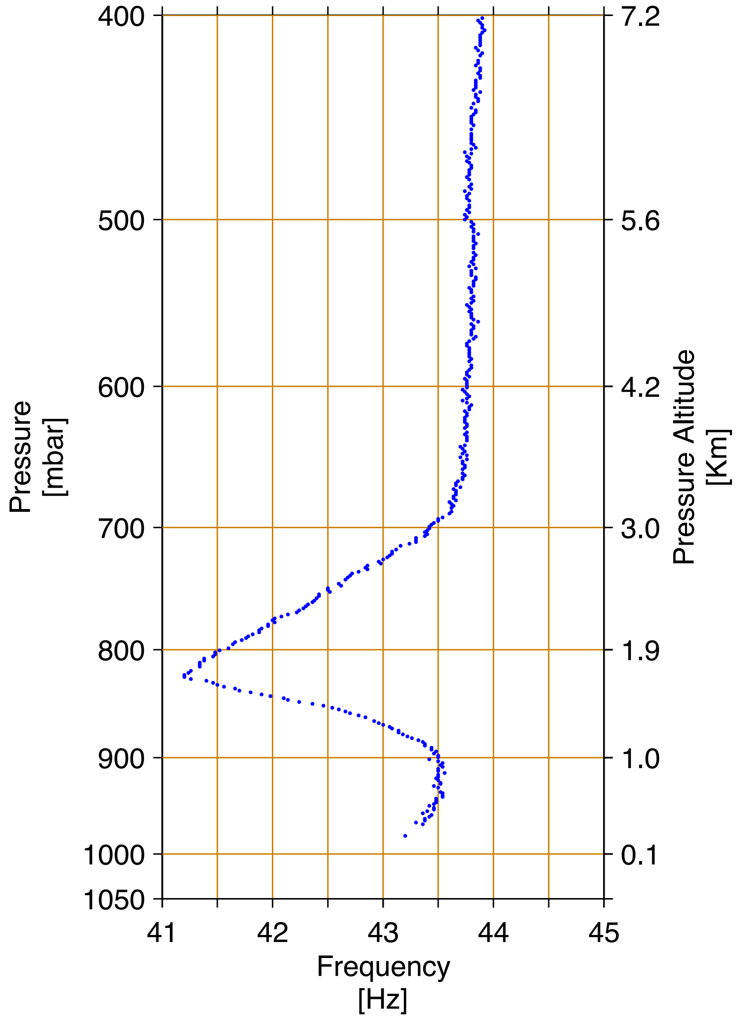
- Measurement principle is based on the reduction in natural vibration frequency of a wire due to ice accretion
  - Natural frequency decreases with increasing ice accretion along the wire
  - SLWC is calculated using time history of natural frequency

- 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



Anasphere, Inc. SLWC Sensor: Wire Vibration Video Loop

SLWC Calculation



March 17, 2015, Balloon 002 frequency profile showing characteristic frequency depression due to ice accretion on wire

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

General form of the equation to calculate SLWC from Hill, "Analysis of Supercooled Liquid Water Measurements Using Microwave Radiometer and Vibrating Wire Devices," J. Atmo. & Oceanic Tec., Vol. 6, 1989.

- ***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 ***ε***, ***D*** and ***ω*** 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)

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

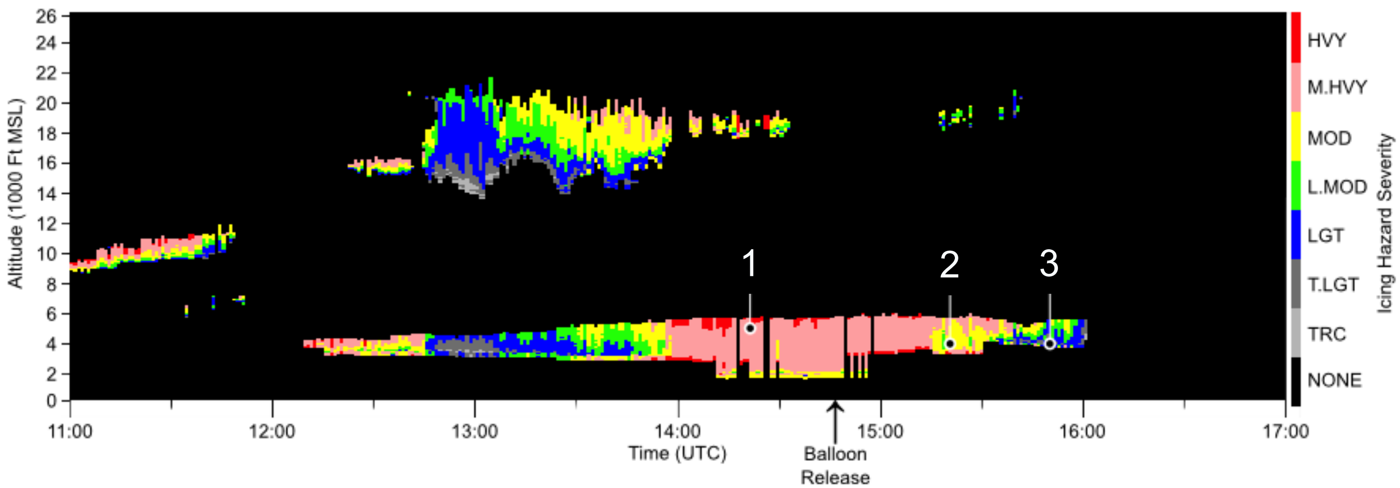
Case Studies:

March 17, 2015 (Remote Sensing and PIREP)

PIREP Map for March 17, 2015

	Aircraft Type	Time [UTC]	Flight Level [Ft]	Icing Report
1	E145	1423	5200-6000	Light Clear
2	B712	1520	4000	Light Rime
3	B712	1552	4000	Mod. Rime

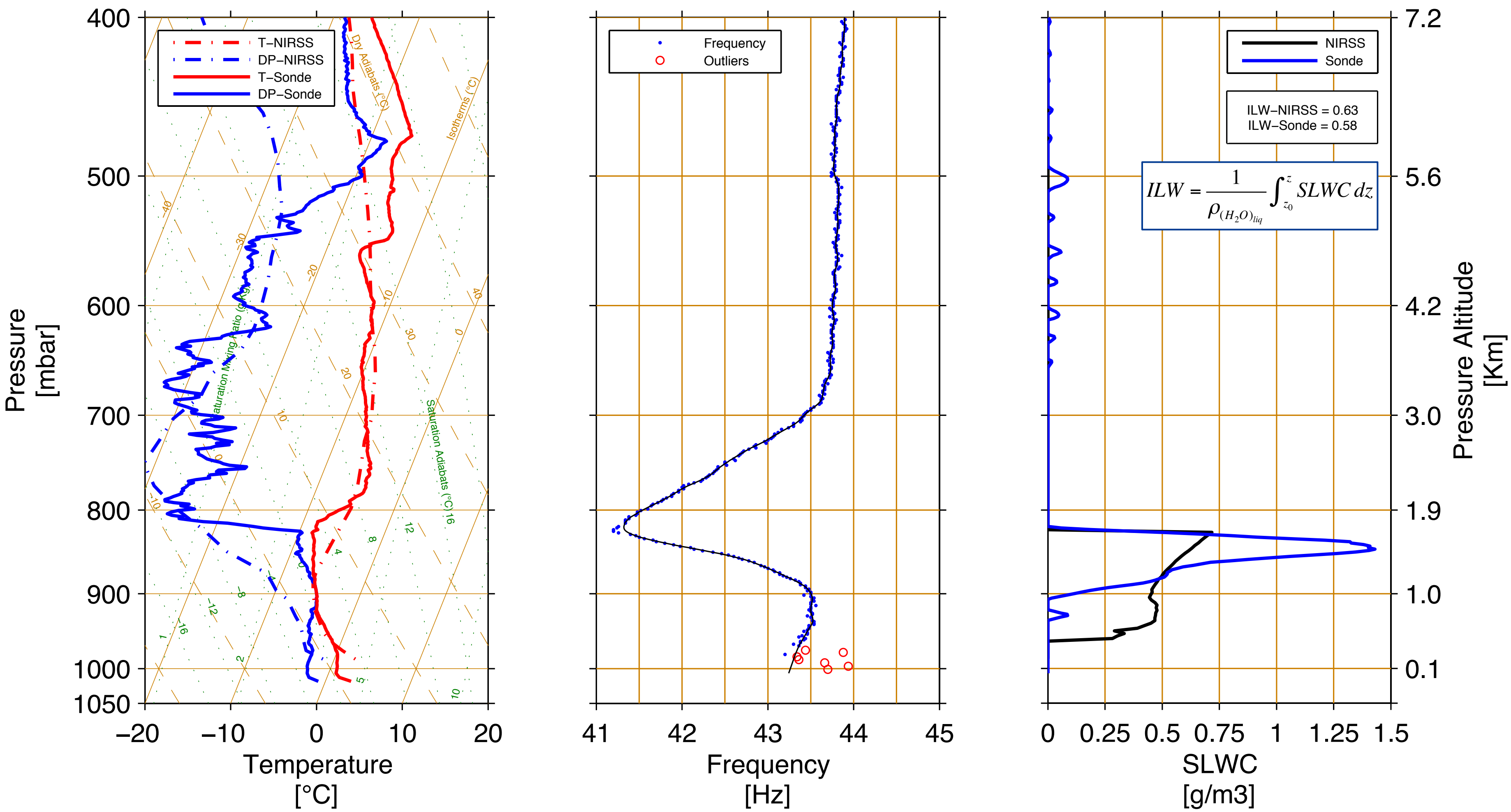
PIREP Summary for March 17, 2015 for period of interest



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:

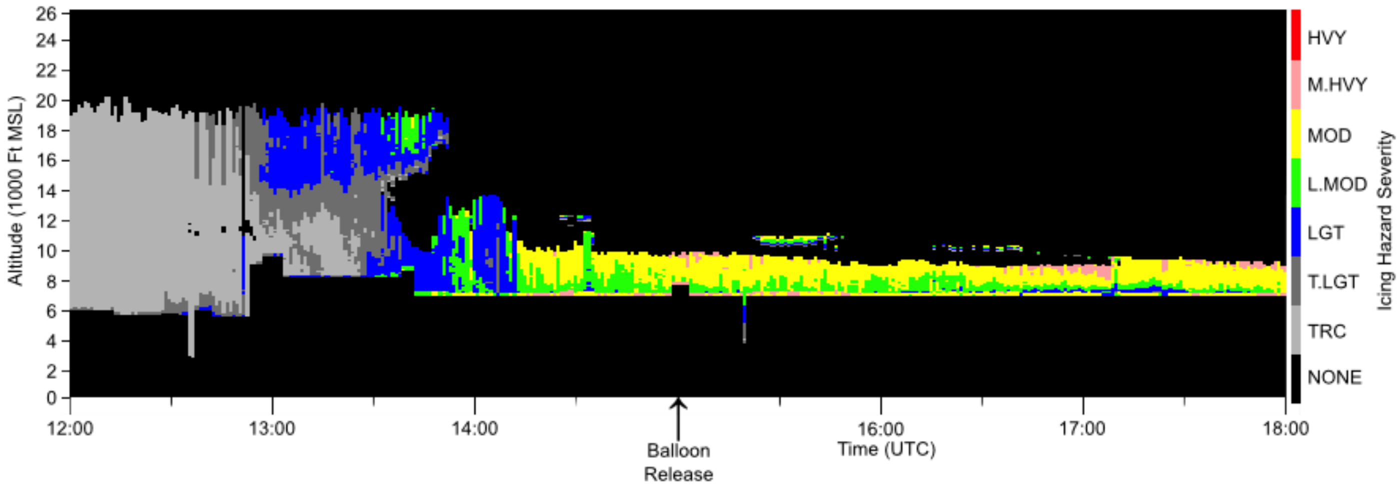
March 17, 2015 Balloon 002 (Comparison)



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

Case Studies:

March 20, 2015 (Remote Sensing & PIREP)

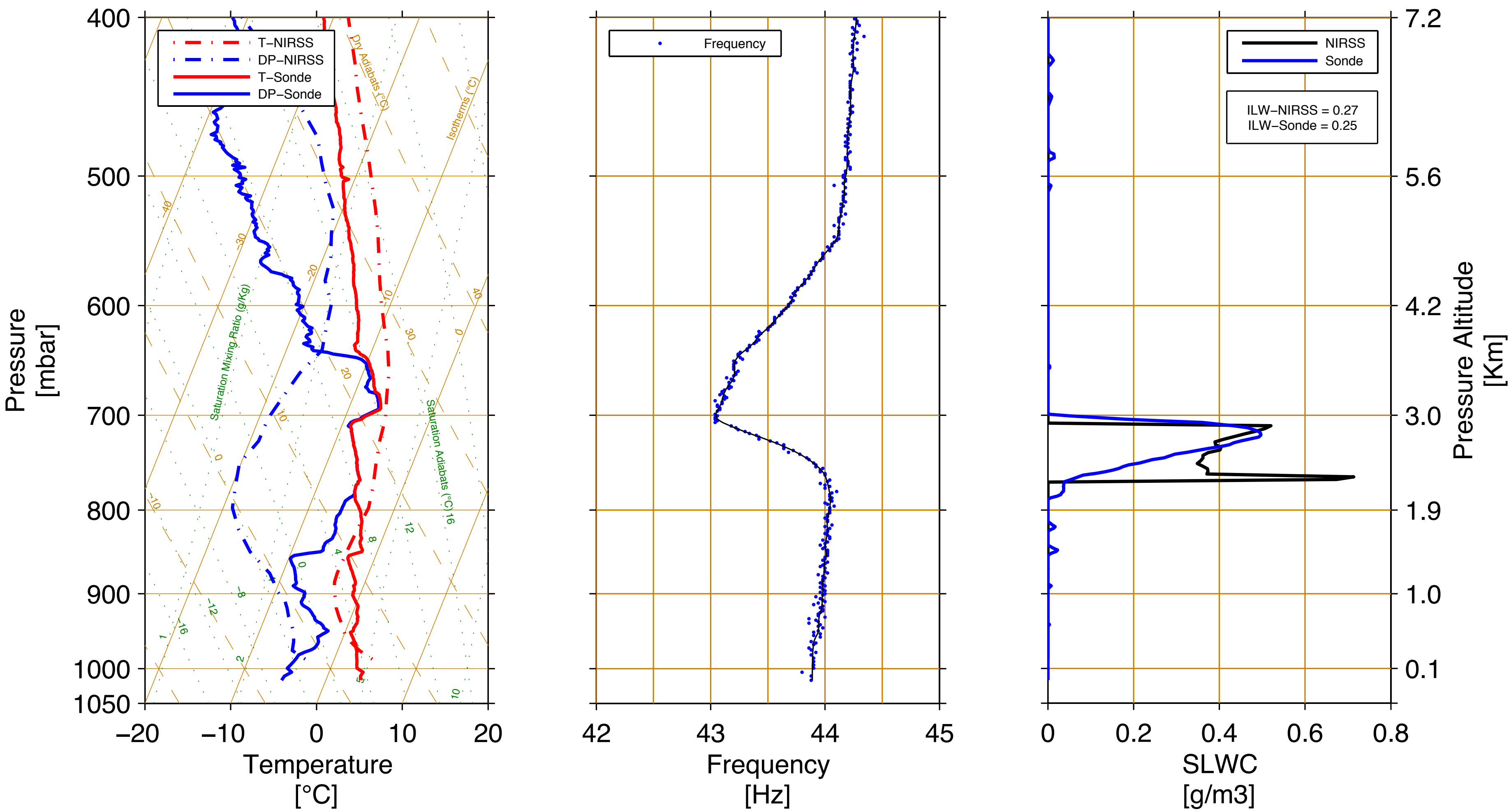


NIRSS icing severity product output for March 20, 2015

- 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

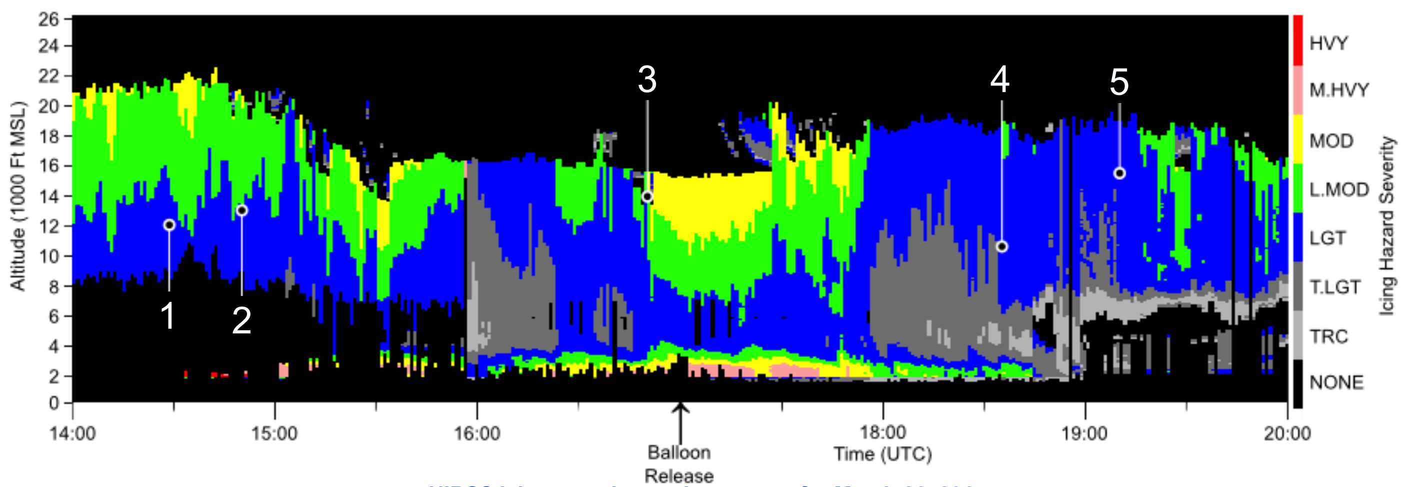
Case Studies:

March 26, 2015 (Remote Sensing and PIREP)

PIREP Map for March 26, 2015

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

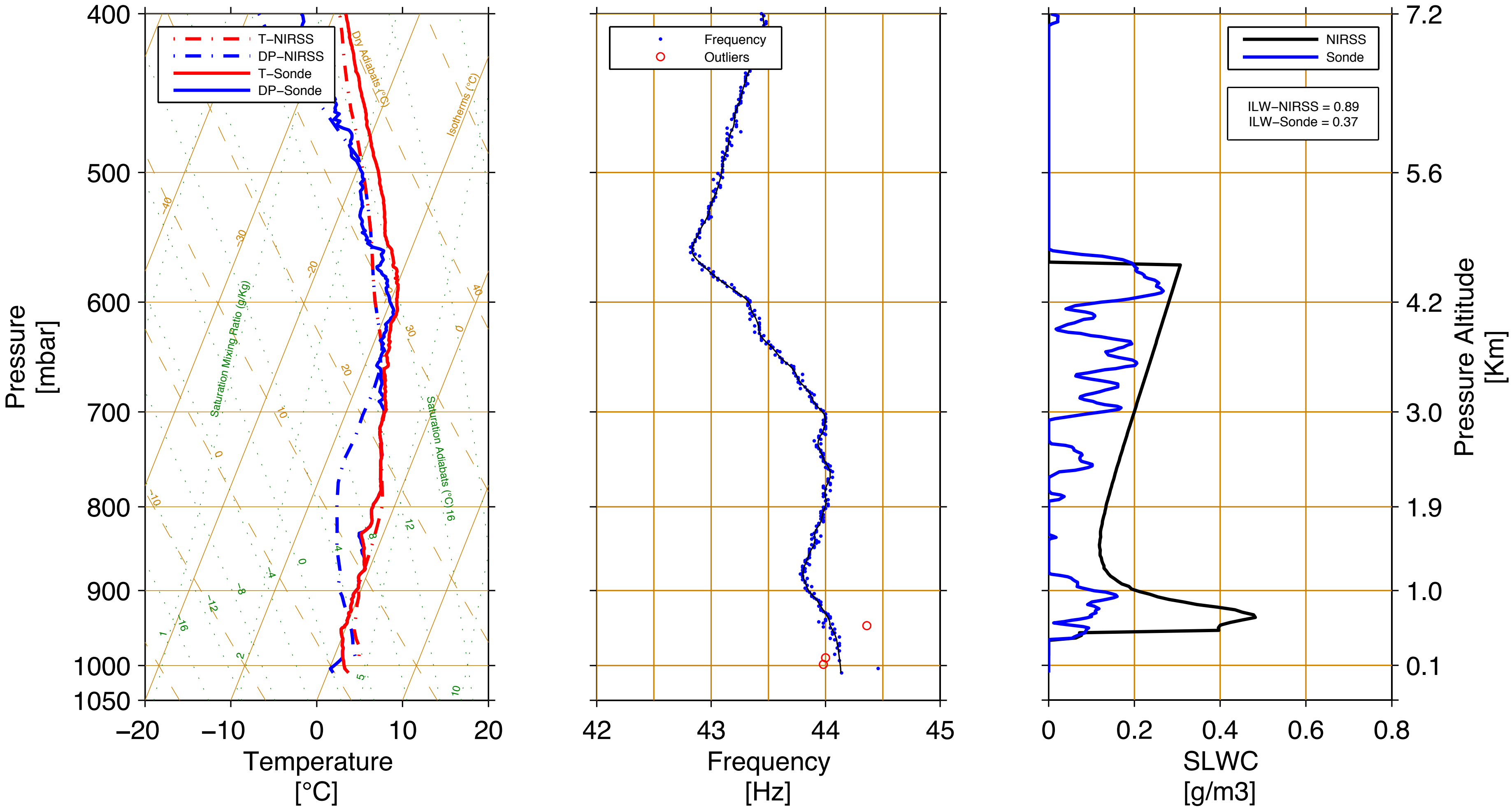
PIREP Summary for March 26, 2015 for period of interest



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