NASA Icing Remote Sensing

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NASA’s Icing Remote Sensing Activity

- Background
- Goals/Vision
- Icing Remote Sensing Fundamentals
- Past Safety Program Achievements
- Current Work
- Next Phases
- Supporting Work

And, the NASA AGATE program was advocating Icing Avoid and Exit Strategy to maintain safety while maximizing aircraft utility. However, no technology existed to allow avoidance strategies to be developed.
And at the 1996 AIAA Aerospace Sciences Meeting, Steve Green contrasted our lack of operational knowledge in the icing environment to our knowledge of the thunderstorm environment.

Unlike thunderstorms, when dealing with icing (in 1996):
- The pilot didn’t have forecasts of future icing conditions with a track record of being strategically useful for flight planning.
- The pilot couldn’t reference nowcasts of icing.
- The pilot had to actually enter icing conditions before he knew it was there.
- The pilot might not even be aware that his aircraft was in icing conditions (until it was too late!).
Background

- Since 1996 a great deal of work has been expended working on the forecasting and nowcasting of icing conditions
  - Model improvements are tightening up the icing forecasts
  - Integrated Icing Diagnosis Algorithm (IIDA), now called the Current Icing Product (CIP), has been developed to provide operationally valuable nowcasts

- Ice detector development and pilot training are helping to alert flightcrews entering icing conditions

- But we still can’t warn the pilot with sufficient spatial resolution if the current flight path will take the aircraft into icing conditions
  - And forecasts and nowcasts are initiated with sparse ground station data and tuned only with sparse and inconsistent-quality pirep data
Icing Remote Sensing Goals/Vision

Develop technologies that will enable terminal area sensing and airborne sensing. Implement through incremental development starting at ground-based vertical staring.

Current Capability

Airborne goal

Ground-based goal
Icing Remote Sensing Fundamentals (Icing R-S 101)

- Want measurement of icing hazard aloft
- Can measure remotely:
  - Liquid water content of the cloud
  - Size of the cloud droplets
  - Temperature
- No single remote sensing technology can do all this
- Need multi-sensor measurement system
- Key technologies include:
  - Radar
  - Microwave Radiometry
Icing R-S 101: Radar capability

- Active (pulse and listen)
- Ranged data
- Measures reflectivity (dBZ)
  - dependant on number of targets and their size
  - i.e., both cloud liquid water content and cloud droplet size
- If a Doppler radar, measures velocity
  - (radial velocity relative to radar)
Icing R-S 101: Microwave Radiometry capability

- Passive (receive only)
- Provides integrated, “path”, measurement of atmospheric radiation emissions
  - Brightness temperature
- Multiple frequencies allow solution of temperature and humidity profiles
- Multiple frequencies allow solution of integrated liquid water.
Icing R-S 101: Simplified Algorithm

- Radar provides cloud profile
- Radiometer provides temperature profile
- Radiometer provides integrated liquid water path
- Distribute liquid water over cloud extent for LWC
- Derive droplet size
  - Reflectivity is a function of both cloud droplet size and liquid water content
  - Can do this because our water content and radar reflectivity are independent measurements
- Use temperature, water content, droplet size to determine icing hazard
Remote Sensing’s AvSP History

- Prior to FY 06: Part of original AvSP’s Icing Project (focusing on enabling icing information)
- FY 06-10: Part of AvSP II’s Integrated Intelligent Flight Deck (IIFD) Project (focusing on enabling airborne systems)
  - External Hazards Detection element (FY 06 – FY 08)
  - Enabling Avionics Technologies and Functions element (FY 09 -10 )
- Current: Part of the Atmospheric Environment Safety Technology (AEST) Project
  - Atmospheric Hazard Sensing and Mitigation element
  - Focusing again on enabling icing information, specifically for the terminal area.
Major Safety Program Activities & Deliverables

- Component testing (MWISP, AIRS I) (1999-2000)
- Icing R-S Technology Downselect Document (2001)
- Inhouse vertical-pointing system build-up (2001-2008)
- Post-processed icing product (AIRS II) (2004)
- Real-time icing product (2005)
- Assessment of feasibility and benefit of scanning, narrow-beam radiometer (2010-ongoing)
Current vertical-pointing Icing R-S

- NASA Icing Remote Sensing System (NIRSS) Technologies
  - Radar
    - Provides cloud boundaries
  - Multi-frequency Microwave Radiometer
    - Provides Temperature Profile
    - Provides Integrated Water Content
  - Ceilometer
    - Refines cloud base boundary
Current vertical-pointing Icing R-S

- R&D status - Fusion Program evolution

Original Reehorst Version 1, LabVIEW-based 2004

NCAR Version 2, LabVIEW-based Realtime 2005

NCAR Version 3 C++ and Java-Based Version 2006-2010

NCAR Version 4 Modularized, updated algorithms 2010-present
R&D status - Current NIRSS Algorithm

1. Measure Temperature Profile and Integrated Liquid Water (ILW)
2. Combine radar and ceilometer data to determine cloud layer(s)
   - If reflectivity is greater than 1 dBZ above minimum detectable threshold for at least 200m, call it a cloud layer
   - Perform 5 minute smoothing to eliminate noise
3. Use fuzzy logic to determine liquid distribution in layer, based upon known depth of layer(s), ILW, temperature profile, and reflectivity. Calculate weighted distribution using:
   - Uniform distribution (LWC = constant)
   - Wedge distribution (LWC = 0 at base to max at top)
   - Temperature weighted distribution (LWC = less if cold, more if warm)
   - Reflectivity weighted distribution (LWC proportional to \( \text{REFL}^{0.5} \))
4. Determine ‘severity’ based upon mapping of LWC
   - Based on Politovich, ”Predicting In-Flight Aircraft Icing Intensity”, J. Aircraft, 2003.
5. Calculate droplet size using reflectivity/LWC relationship
Current vertical-pointing Icing R-S

- Recent comparison of NIRSS and CIP relative to PIREPS
  - Based upon 3 years of NIRSS data (operating at GRC)

Altitude/Time plots of NIRSS (top), PiReps (top, red numbers), and CIP (bottom)

**Note the larger warning band for CIP**

"NIRSS detected almost 80% of positive PIREPs and over 70% of negative PIREPs in a relatively smaller warning volume. CIP detected slightly more positive PIREPs than NIRSS but did fairly poor in detecting negative PIREPs."

Next Phase: Ground-Based Scanning

NASA Narrow-beam Multi-frequency Microwave Radiometer (NNMMR)

Developed by Radiometrics, Inc. of Boulder, CO under an SBIR contract

OBJECTIVE

• Beam widths matched with NOAA’s NEXRAD weather radars.
• Using recently derived algorithms from Dr. Ulrich Lohnert from the University of Cologne, can measure integrated liquid water.
• Elevation and azimuth scanning capability provides potential for terminal area icing detection and warning.

ACCOMPLISHMENTS

• System fabrication completed summer 2009
• Field test assessment performed cooperatively with NCAR at CSU radar site in Greeley CO - summer 2009.
• Operational assessment, located at NASA GRC - ongoing.

TECHNICAL SPECIFICATIONS

Freq/Channels: 21 in Ka-band (22-30 GHz)
2 in W-band (89V, 89H GHz)

Antenna Beam: 1°
Preliminary Scanning Radiometer Results

- Qualitatively, the NNMMR seems to agree well with ground observations and PIREPS.
- System has operated for several months in CO and OH and is stable and reliable.
- Moisture on the reflector does influence the data. Currently working on a reflector rain/dew mitigation system (hydrophobic coating and air blower).
- Combined with the recently purchased temperature profiling radiometer and a scanning radar, this technology shows good promise for extending the NIRSS methodology to provide terminal area coverage.
Long Term Development: Airborne Multi-Frequency Radar

- Objective is to determine cloud liquid water content and characteristic drop size estimates from the multi-frequency radar reflectivity profiles.
- Three band radar (X-, Ka-, & W-band) with two pulsed (X and Ka) and one continuous wave (W) radars.
- Antennas, magnetrons, transmitters, waveguides, power supplies located in pod designed to be wing mounted.
- Currently operating in ground-based, vertical staring mode for development studies and comparison with NIRSS.
- Most recent work included development and assessment of Neural-Net software package to extract LWC and cloud particle size info from radar reflectivity measurements.
- Airborne technology development is currently a lower priority than ground-based due to sensing limitations and cost/power/drag penalties of current technology.
Supporting work: Radiosonde Capability

- Desired to reduce cost of in-situ calibration/validation
- System used at AIRS II, currently installed at Glenn Hangar
- New SBIR Phase I contract with Anasphere, Inc, of Bozeman, MT for SLWC/MVD probe.
Icing Remote Sensing - Summary

- NASA’s Icing Remote Sensing development has 3 elements:
  - Ground-based, vertical pointing
    - Algorithm refinement (sensors are available)
    - Relatively mature, well regarded within the research community
  - Ground-based, scanning
    - Sensors still being refined
    - Limitations yet to be defined (e.g., lowest elevation angles)
    - Vertical pointing methodology appears applicable for combining radar and radiometer data for terminal area coverage
    - Field testing will be required to allow validation and algorithm tuning
  - Airborne
    - Least mature
    - Available sensors are not adequate
    - Radar-based methodology is theoretically understood
    - Practical algorithms development still required
    - Extensive field testing will be required to cover numerous flight scenarios
    - Current technology does not lend itself to fleet adoption (size, cost, drag penalties)