National Aeronautics and Space Administration

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

Background

- In 1996 at the FAA Phase III Icing Conference, Chuck Ryerson of US Army CRREL gave a presentation on the potential of Icing Remote Sensing (“Remote Detection and Avoidance of Inflight Icing”, DOT/FAA/AR-96/81,II,pgs179-190, 1996).
- 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.

Background

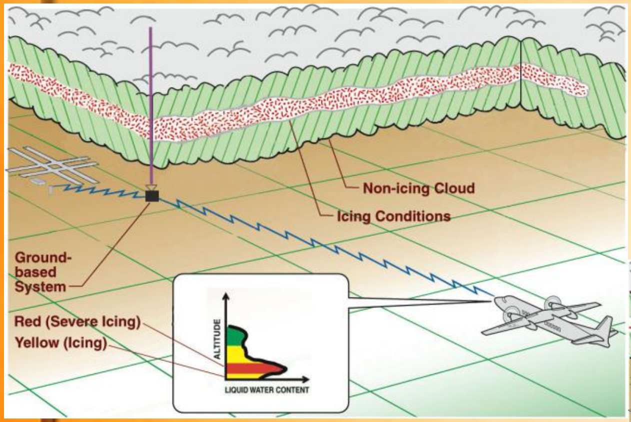
- And at the 1996 AIAA Aerospace Sciences Meeting, Steve Green contrasted our lack of operational knowledge in the icing environment to our knowledge of the thunderstorm environment
- Unlike thunderstorms, when dealing with icing (in 1996)
  - The pilot didn’t have forecasts of future icing conditions 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

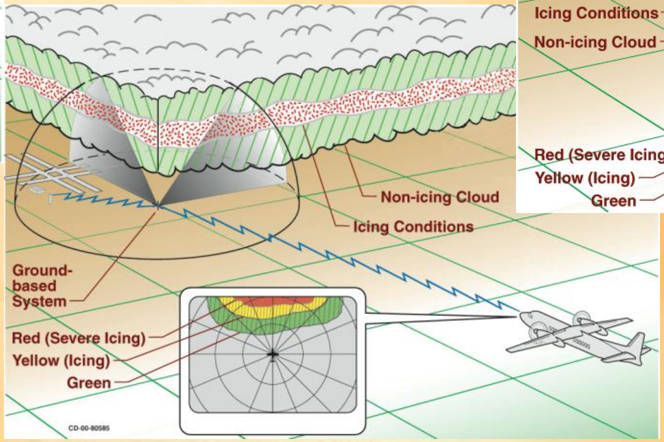
- Since 1996 a great deal of work has been expended working on the forecasting and nowcasting of icing conditions
  - Model improvements are tightening up the icing forecasts
  - Integrated Icing Diagnosis Algorithm (IIDA), now called the Current Icing Product (CIP), has been developed to provide operationally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

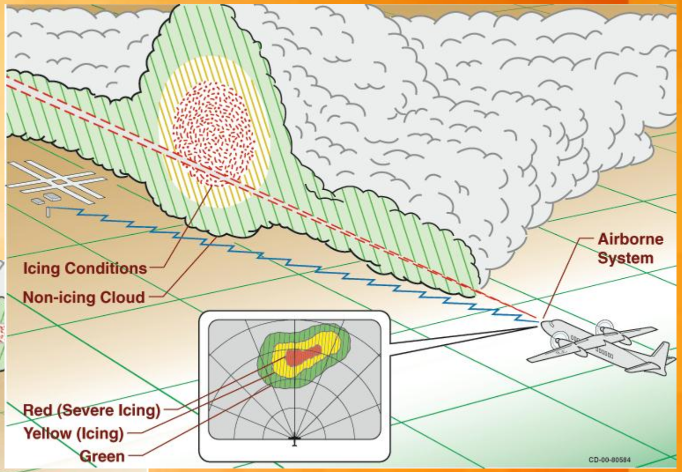
Develop technologies that will enable terminal area sensing and airborne sensing. Implement through incremental development starting at ground-based vertical staring.



Current Capability



Ground-based goal

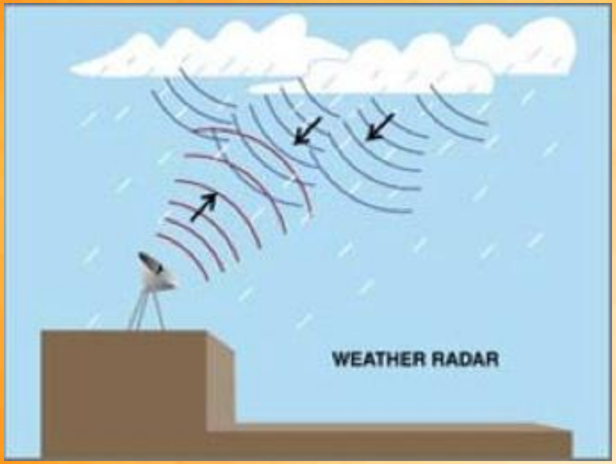


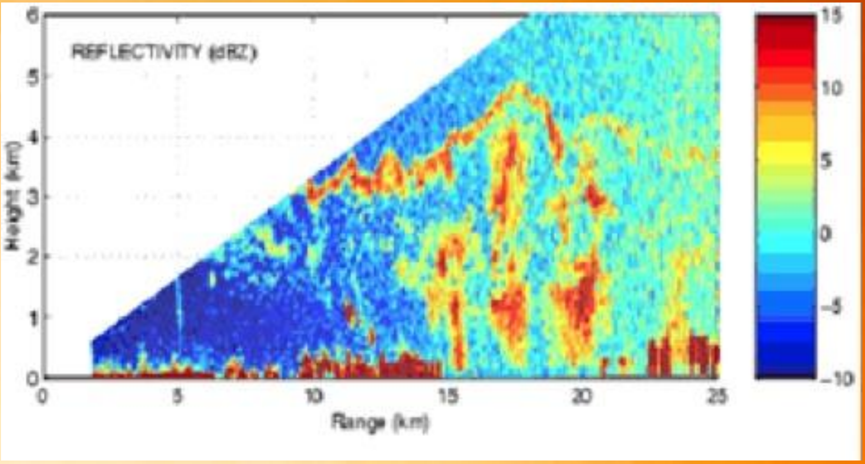
Airborne goal

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

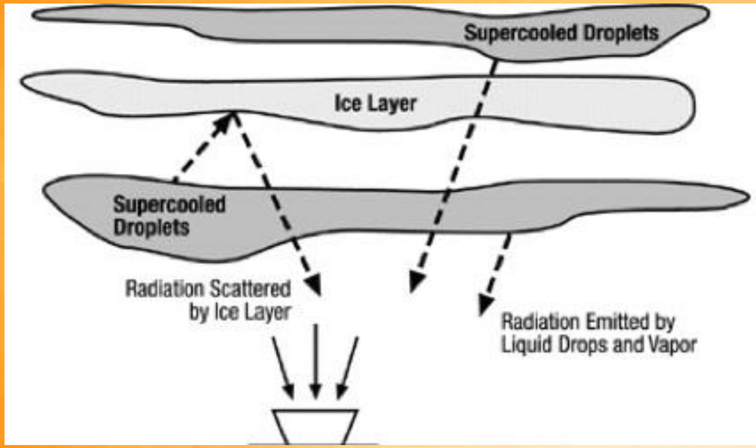
Icing R-S 101: Radar capability

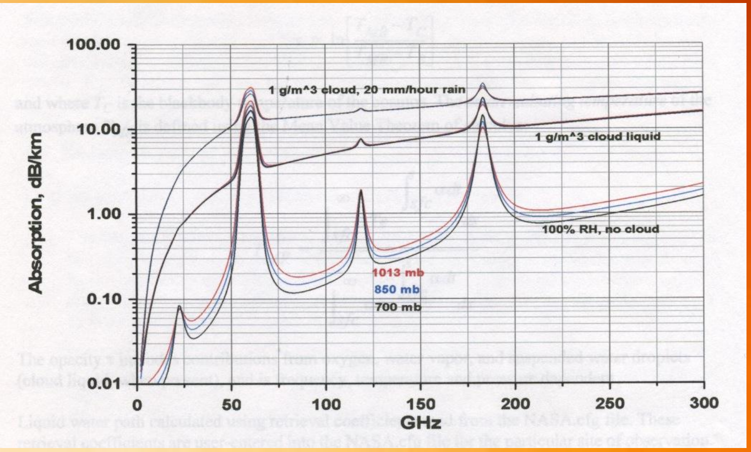




- Active (pulse and listen)
- Ranged data
- Measures reflectivity (dBZ)
  - dependant on number of targets and their size
  - i.e., both cloud liquid water content and cloud droplet size
- If a Doppler radar, measures velocity
  - (radial velocity relative to radar)

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

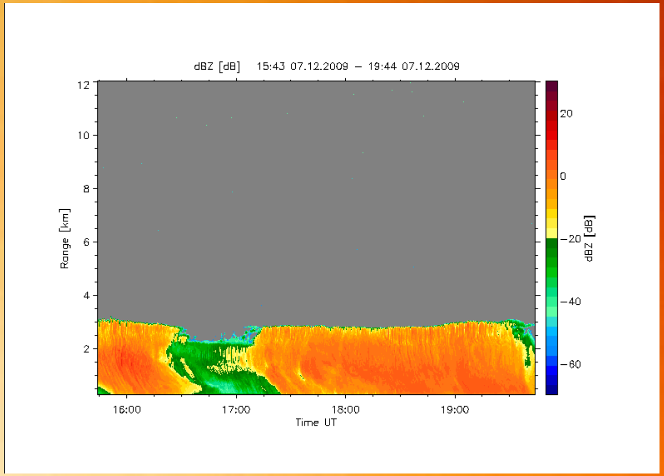
- Prior to FY 06: Part of original AvSP's Icing Project (focusing on enabling icing information)
- FY 06-10: Part of AvSP II's Integrated Intelligent Flight Deck (IIFD) Project (focusing on enabling airborne systems)
  - External Hazards Detection element (FY 06 – FY 08)
  - Enabling Avionics Technologies 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.

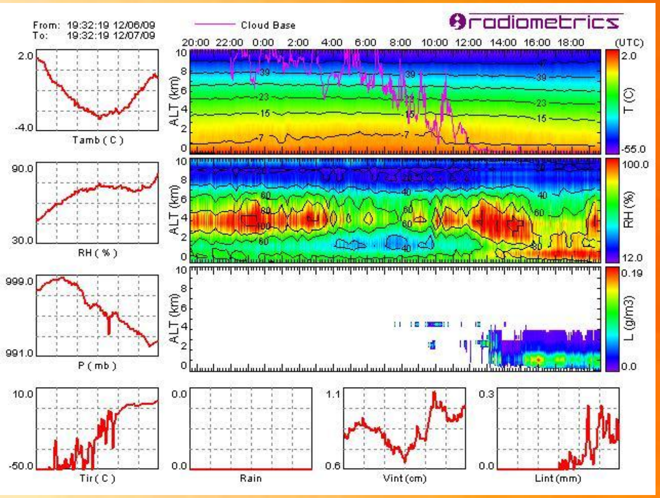
Major Safety Program Activities & Deliverables

- 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)
- On-line Icing Remote Sensing Product (2007) (http://icebox.grc.nasa.gov/RSData)
- Assessment of feasibility and benefit of scanning, narrow-beam radiometer (2010-ongoing)

Current vertical-pointing Icing R-S

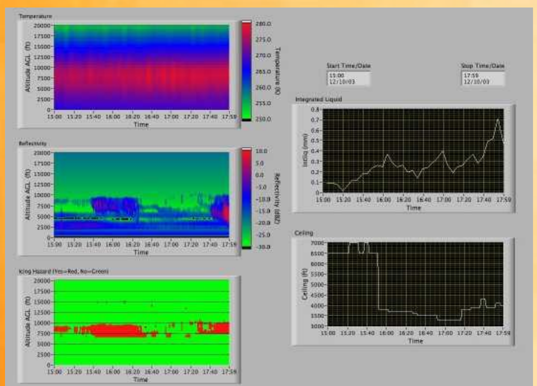
- NASA Icing Remote Sensing System (NIRSS) Technologies
  - Radar
    - Provides cloud boundaries
  - Multi-frequency Microwave Radiometer
    - Provides Temperature Profile
    - Provides Integrated Water Content
  - Ceilometer
    - Refines cloud base boundary



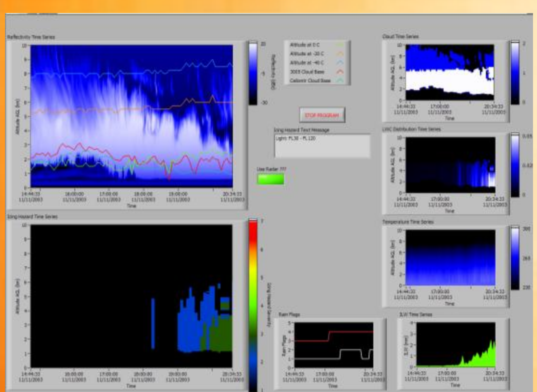


Current vertical-pointing Icing R-S

- R&D status - <u>Fusion Program evolution</u>

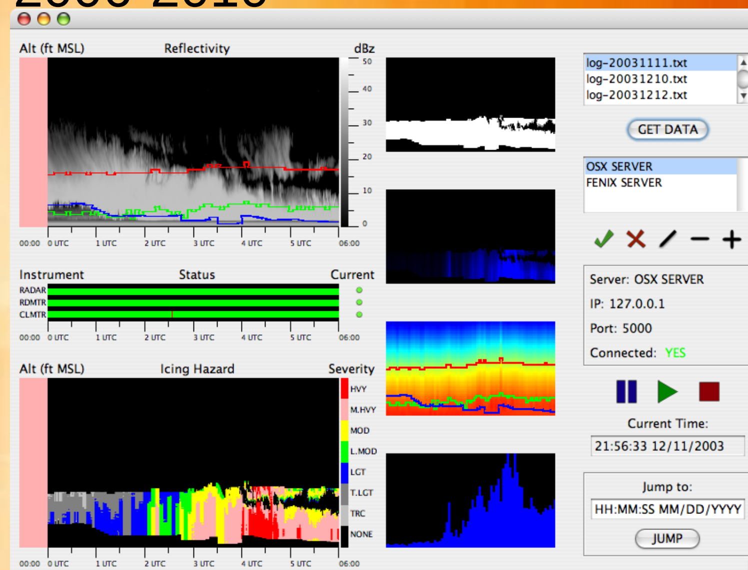


Original Reehorst Version 1, LabVIEW-based 2004



NCAR Version 2, LabVIEW-based **Realtime** 2005

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



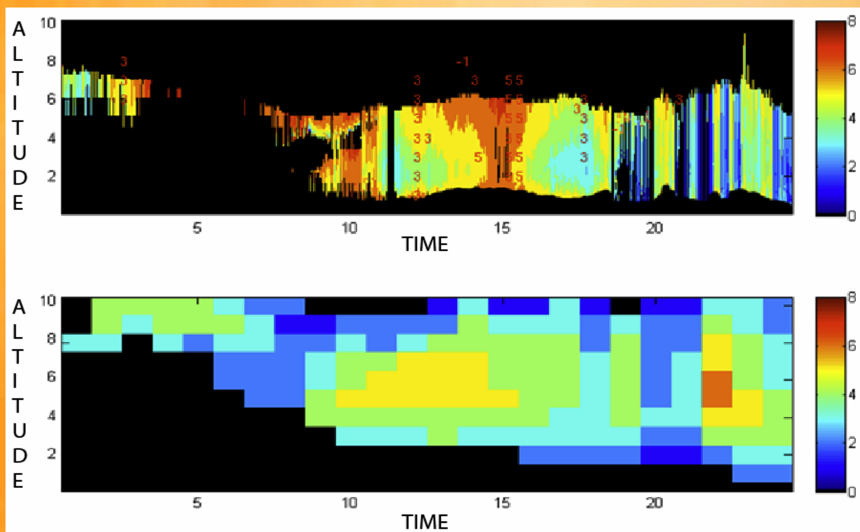
NCAR Version 4
Modularized, updated algorithms
2010-present

Current vertical-pointing Icing R-S

- 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 $REFL^{0.5}$)
     – Based on Bernstein et al, "Current Icing Potential: Algorithm Description and Comparison with Aircraft Observations. J. Appl. Meteor., 2005.
  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

	N vs. P	C vs. P
POD_y	0.78	0.90
POD_n	0.71	0.29

NIRSS (left) and CIP (right) Probability of Detection (POD) (positive and negative) compared to PIREPS.

“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.”

From: Johnston, C.J., et al, “In-flight icing hazards: Comparison of ground, model, and pilot in-situ based severity products”. AMS 15th Symp of IOAS-AOLS, paper 10.2, Jan 2011. - **SEE POSTER**

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.

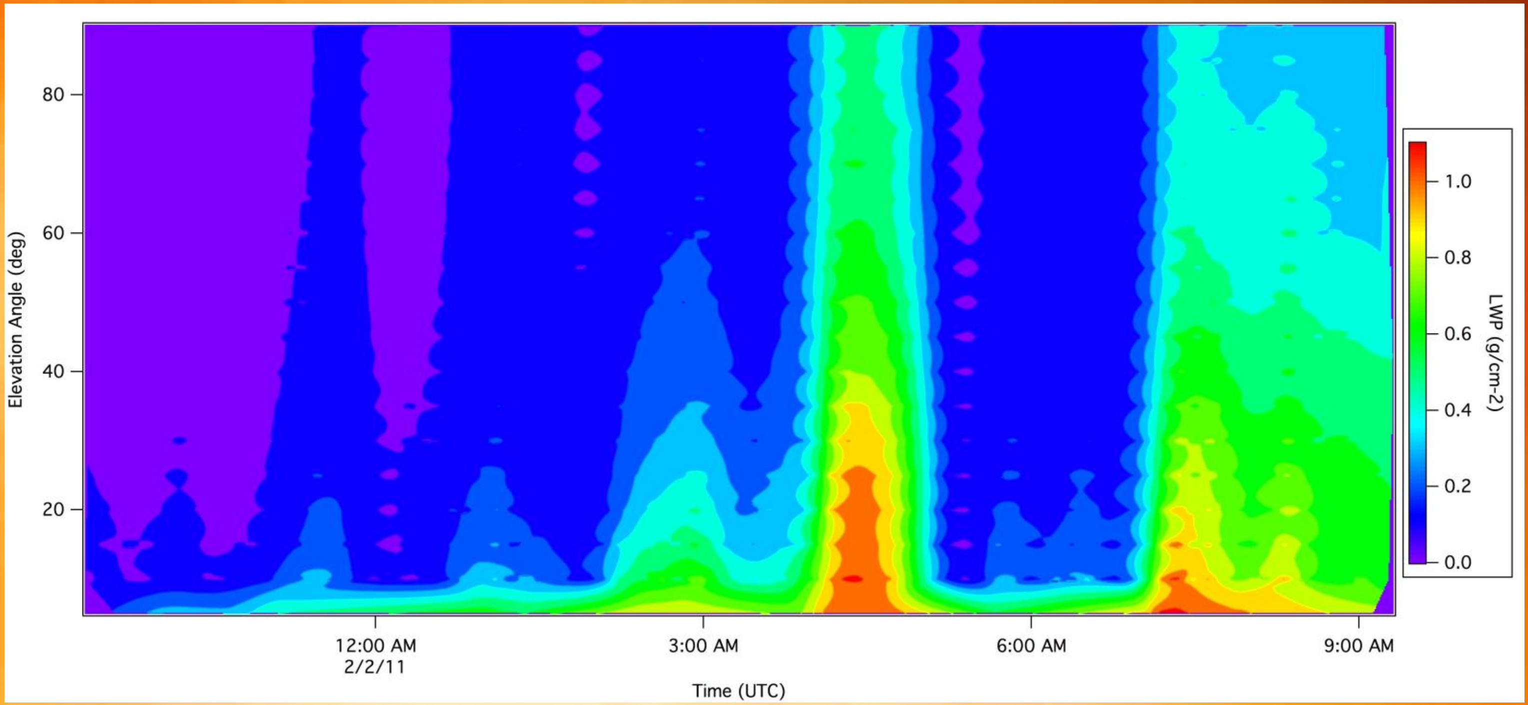
ACCOMPLISHMENTS

- 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

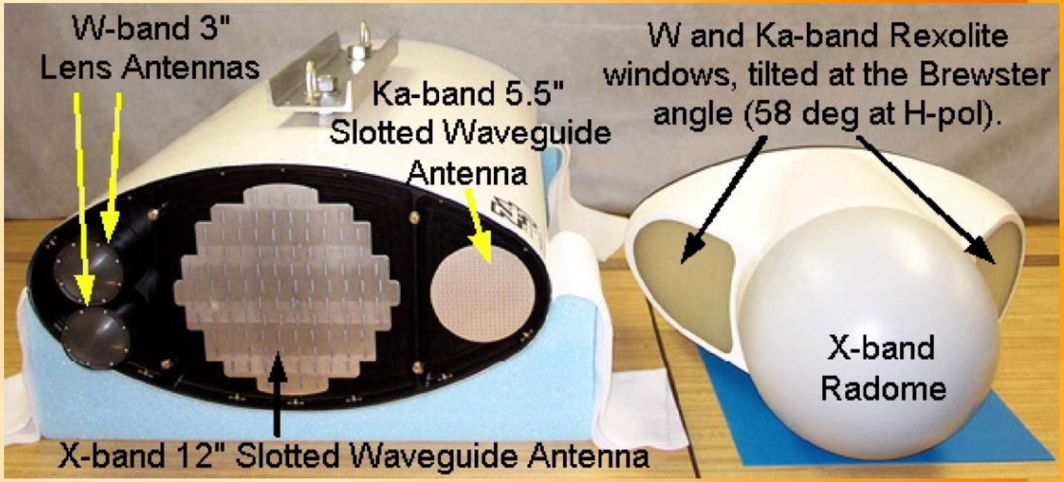


Conditions:	S-	S-	OVC	OVC	ZR-	ZR-	ZR-	ZR-	ZR-	ZR-	ZR-	R-	R-	OVC
Visibility:	4	6	9	10	3	3	1.8	4	5	9	10	5	10	10

- 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.

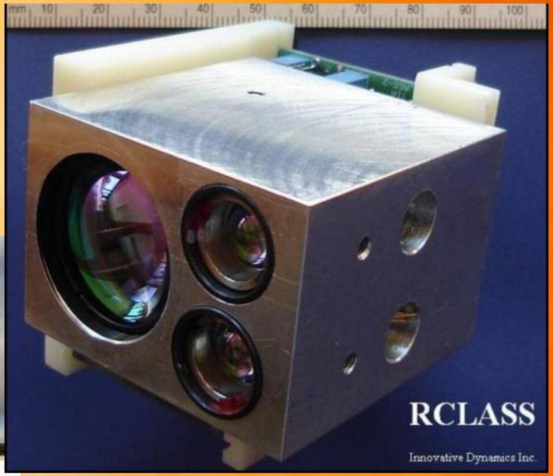
Long Term Development: Airborne Multi-Frequency Radar

- 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
- Completed SBIR Phase I, II and III contracts with Innovative Dynamic, Inc. of Ithaca, NY for optical LWC probe. Awaiting test window for IRT version to assess accuracies.
- 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)