Statistical Analysis of a Radar-based Icing Hazard Algorithm

Christopher Johnston [a], David Serke [a], David Albo [a], Andrew Weekley [a], Daniel Adriaansen [a], Marcia Politovich [a], Scott Ellis [b], John Hubbert [b], Andrew Reehorst [c] and Kim Elmore [d]

a National Center for Atmospheric Research, Research Applications Laboratory, Boulder, Colorado

b National Center for Atmospheric Research, Environmental Observation Laboratory, Boulder, Colorado

c NASA Glenn Research Center, Cleveland, Ohio

d Cooperative Institute for Mesoscale Meteorological Studies, Norman, Oklahoma

NCAR

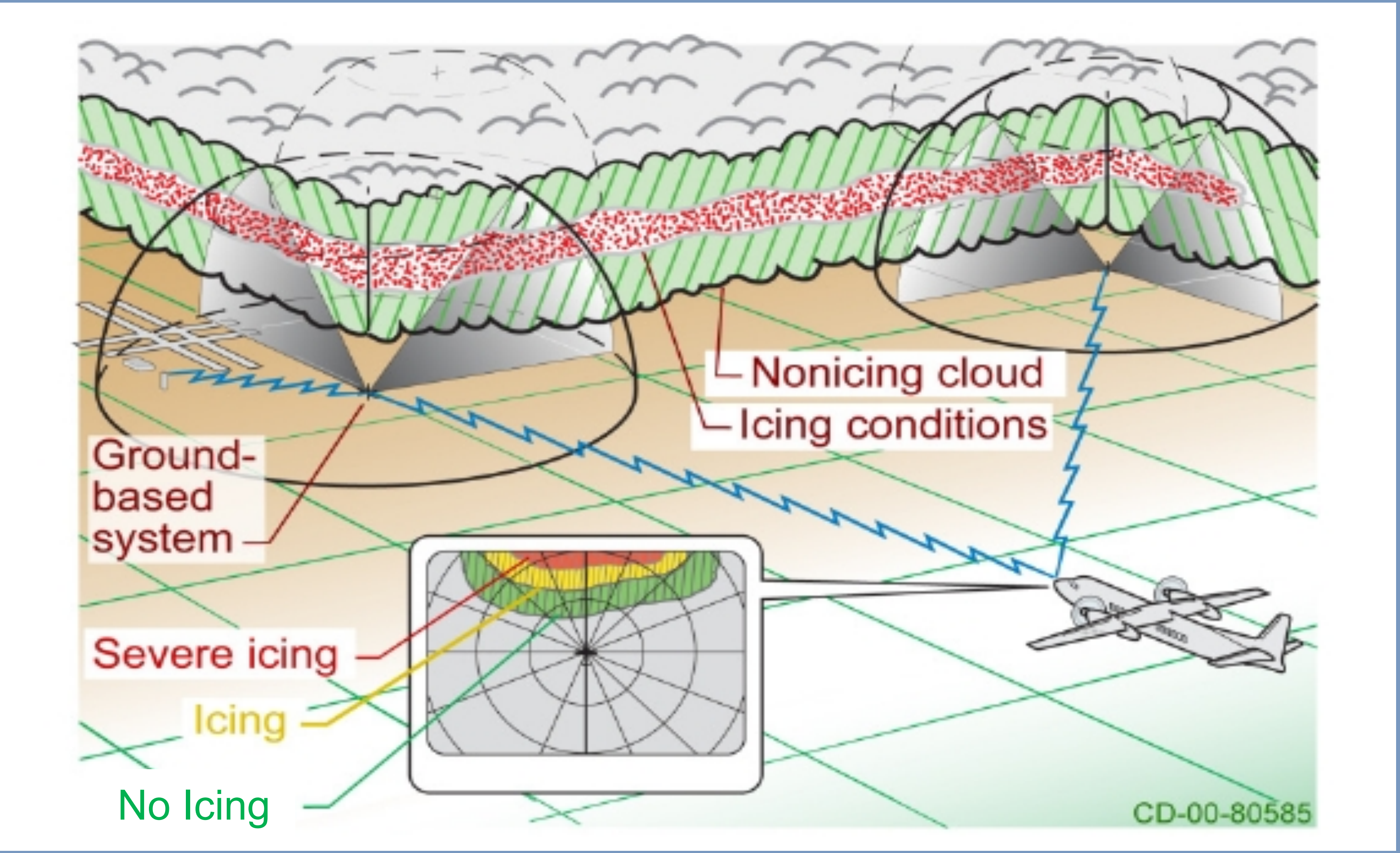
Presentation Overview

- In-flight Icing Background
- Ground Based Remote Sensing
- Past Research
- The Icing Hazard Algorithm
- Methodology
- Case Studies
- Statistical Analysis
- Summary

In-flight Icing Background

- Supercooled liquid water (SLW) instantly freezes to leading edges of aircraft
- Changes the lift and drag characteristics
- Contributing factor to many 'uncontrolled descents'
- FAA, airlines and science partners interested in SLW detection

Ground-based remote sensing goal:



NASA Icing Remote Sensing System (NIRSS)

Image of NIRSS hardware located at the NASA Glenn Research Center in Cleveland, Ohio 250 meters away from KCLE NEXRAD radar

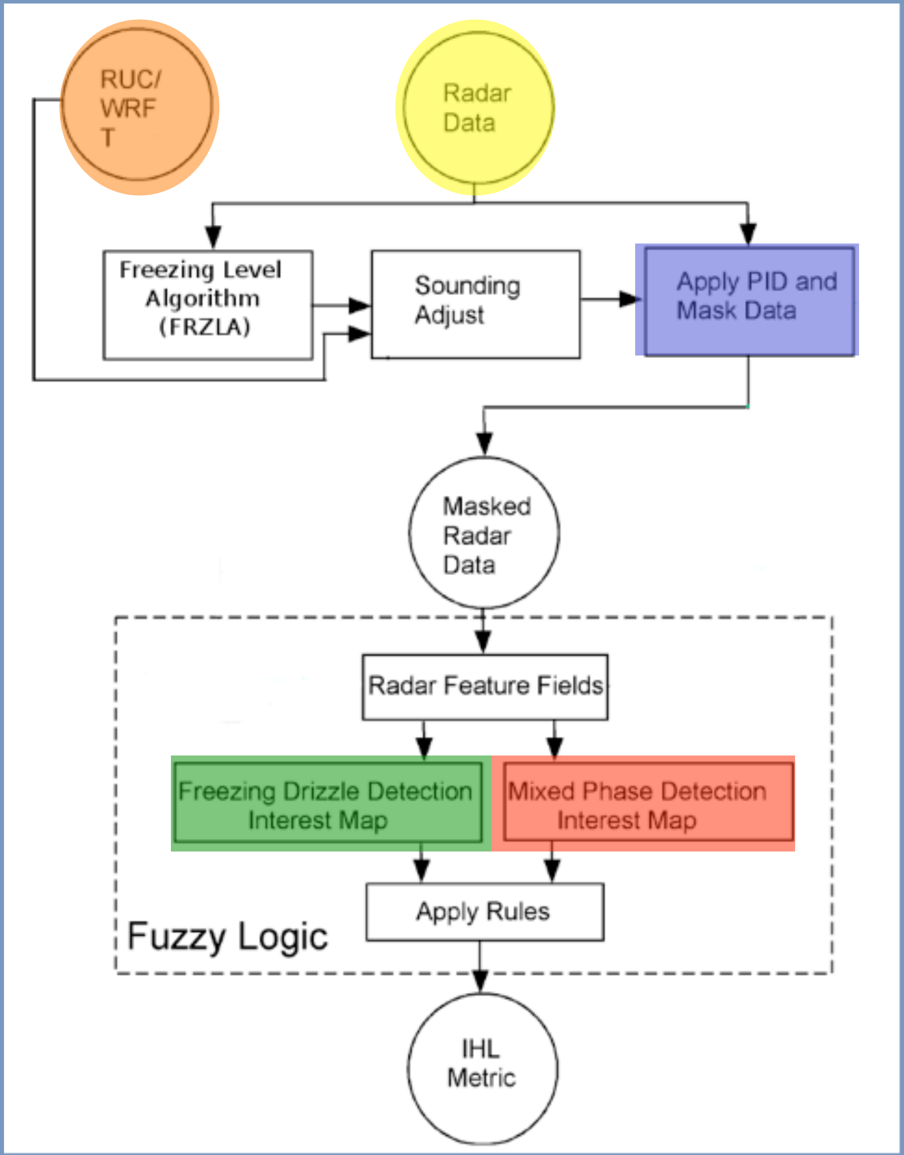
- Integrates 3 vertically pointing sensors
  1. Vaisala Laser Ceilometer
     - Defines cloud base heights
  2. Metek Ka-band Radar
     - Delineate cloud top and base heights
     - Produces Radar Reflectivity
  3. Radiometrics Corporation 23-channel radiometer
     - Derives integrated liquid water (ILW)
     - Atmospheric water vapor
     - Atmospheric temperature profiles

Past Research

NCAR

- Vivekanandan et al.1999, Ikeda et al. 2008, and Plummer et al. 2010 strongly suggested that the use of dual-polarization radar moment fields could provide better real-time diagnosis of in-flight icing conditions
- Dual-polarization radar measurements provide information on the shape of the hydrometeor
- If the shape is known, inferences can be made about the potential of the sensed cloud or precipitation to produce icing conditions

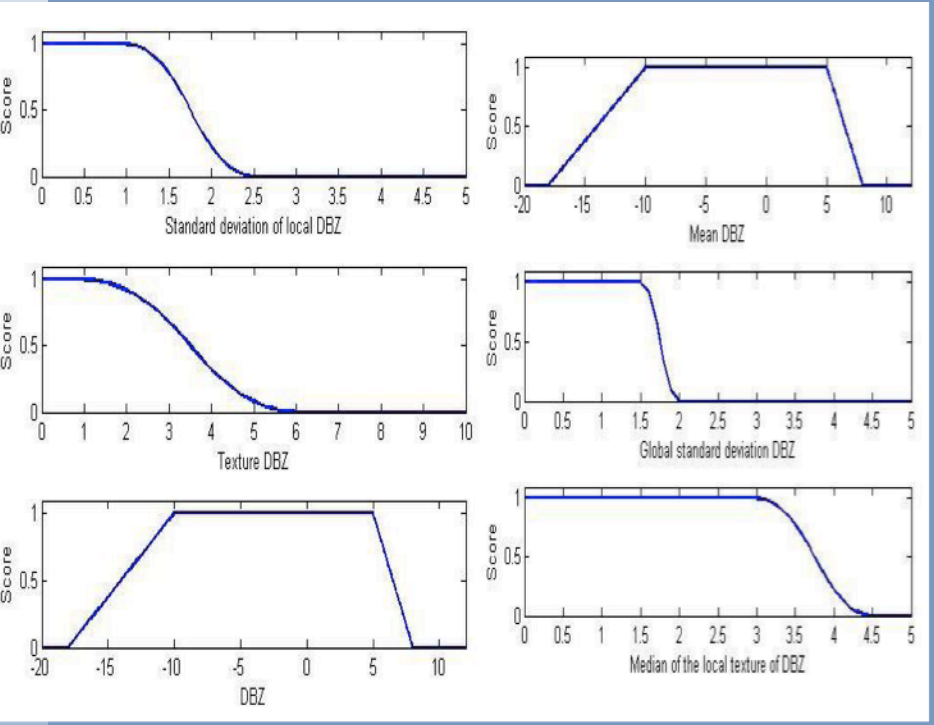
Brief Icing Hazard Level (IHLA) Overview

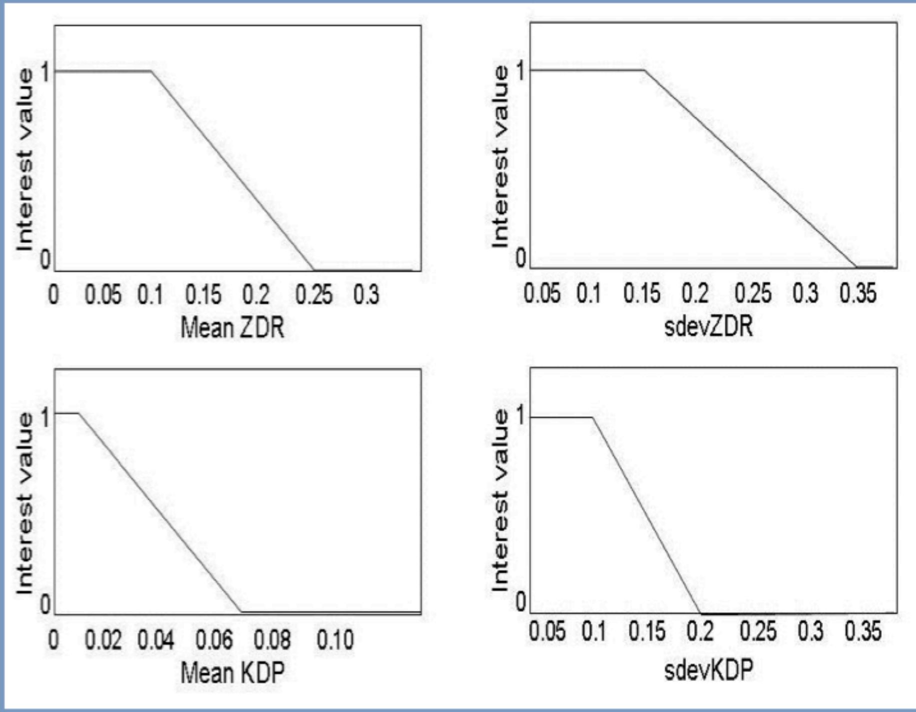


- Icing detection with radar difficult
  - SLW overlaps with ice
  - Ice dominates mixed phase
  - Dual-pol gate-by-gate values not enough
- Inputs to IHLA are dual-polarized radar volume scans and Numerical Weather Prediction model data from the WRF-RR
- Uses basic form of Vivikanandan et al. 1999 PID
- Spatial Statistical Properties
  - FRZDRZ detect Ikeda et al. 2008
  - SLW detect Plummer et al. 2010
- Uses Fuzzy logic to output an IHL Metric

IHLA Overview

NCAR





Membership Functions: FRZDRZ (Ikeda et al., 2009, on Left), SLW (Plummer et al., 2010, on right)

Category	Name	Description	Value	Icing
1	High SLW	SLWA output >0.55	1.0	Yes
2	High FZDZ	MNDDA output >0.70	0.7	Yes
3	Both high	Category 1 and 2 apply	0.8	Yes
4	Both low	SLWA and MNDDA output both <0.45	0.0	No
5	Below SNR	When mean dBZ < -31 dBZ	-0.1	Unknown
6	Both medium	Not categories 1 through 5	0.5	Maybe

Methodology

- Looked at a series of icing and non-icing cases based upon PIlot REPorts (PIREPs) inside a 50 km radius of Cleveland, Ohio's dual-polarized radar (KCLE) from 27 January 2012 to 26 February 2012
  - 17 non-icing cases
  - 14 icing cases
- Ran IHLA for all cases
- Looked at 2 case studies
- Polarimetric radar volume analysis statistics
  - Total number of radar pixels for each of the IHLA output fields per volume were divided by the total pixels in the volume that had returned power above the signal-to-noise level
- NASA Icing Remote Sensing System comparison analysis statistics
  - Matched all the representative icing and non-icing mean radar volume percentages for IHLA 'yes icing' for each individual case to 5-minute mean ILW values of NIRSS

Case Studies

- Moderate PIREP Case:
  1408 UTC 02 February 2012
  - Dassault Falcon 900
  - Located to the 20 SM east-northeast of KCLE
  - FL 060

- Null PIREP Case:
  1721 UTC 12 February 2012
  - Embraer ERJ-145
  - Located to the 5 SM southeast of KCLE
  - FL 040

Moderate PIREP Case – 1408 UTC 02 February 2012

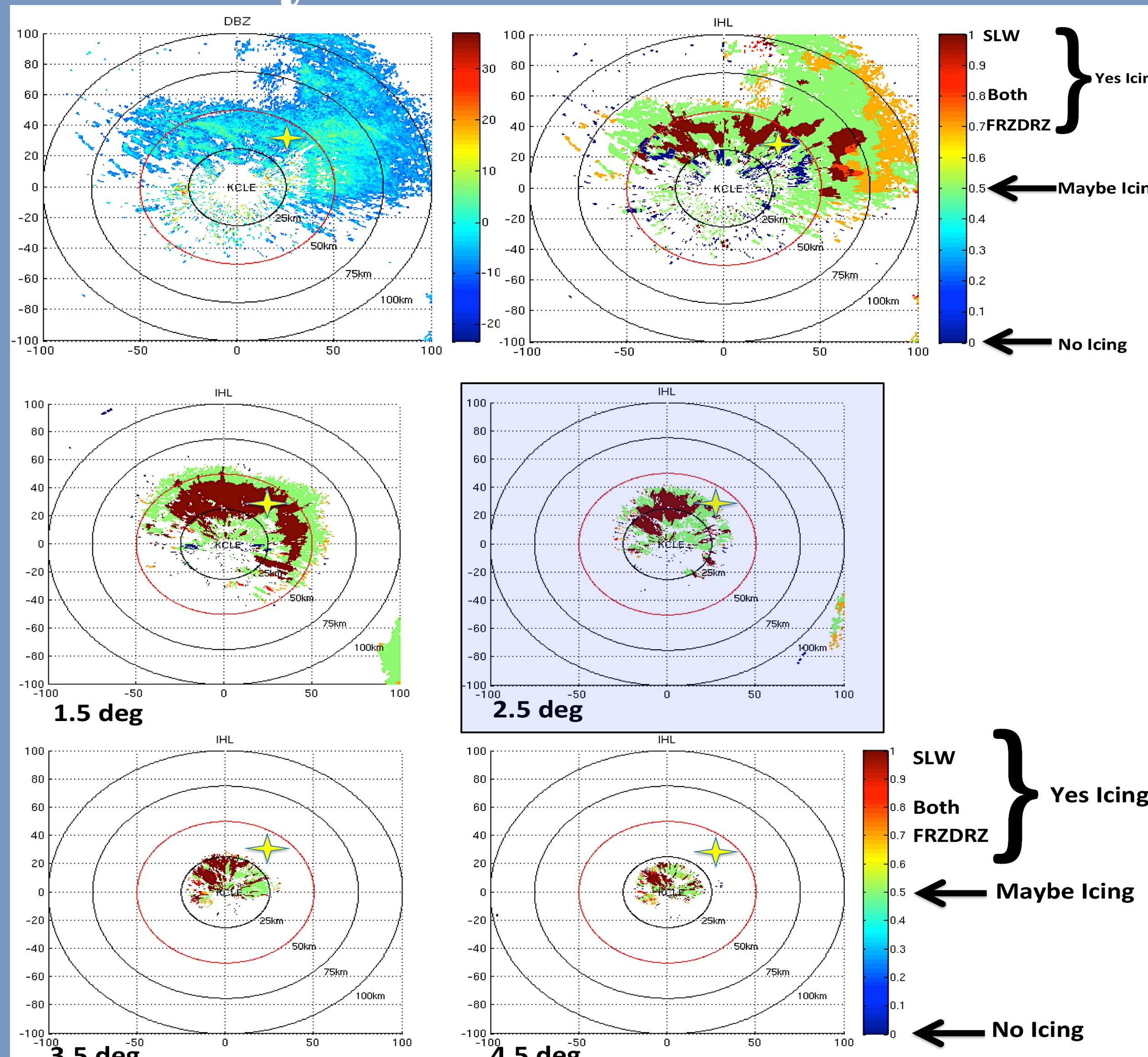
- Total number of radar pixels for each of the IHLA output fields per volume were divided by the total pixels in the volume that had returned power above the signal-to-noise level

- Created mean volume percentages

- Mean volume percentages of :

  ‘yes icing’ = 44.7 %
  ‘SLW yes’ = 31.5 %
  ‘FRZDRZ yes’ = 13.2 %
  ‘maybe icing’ = 49.7 %
  ‘no icing’ = 5.60 %

- The PIREP was in 2.5 degree scan
- IHLA did a good job classifying the icing area



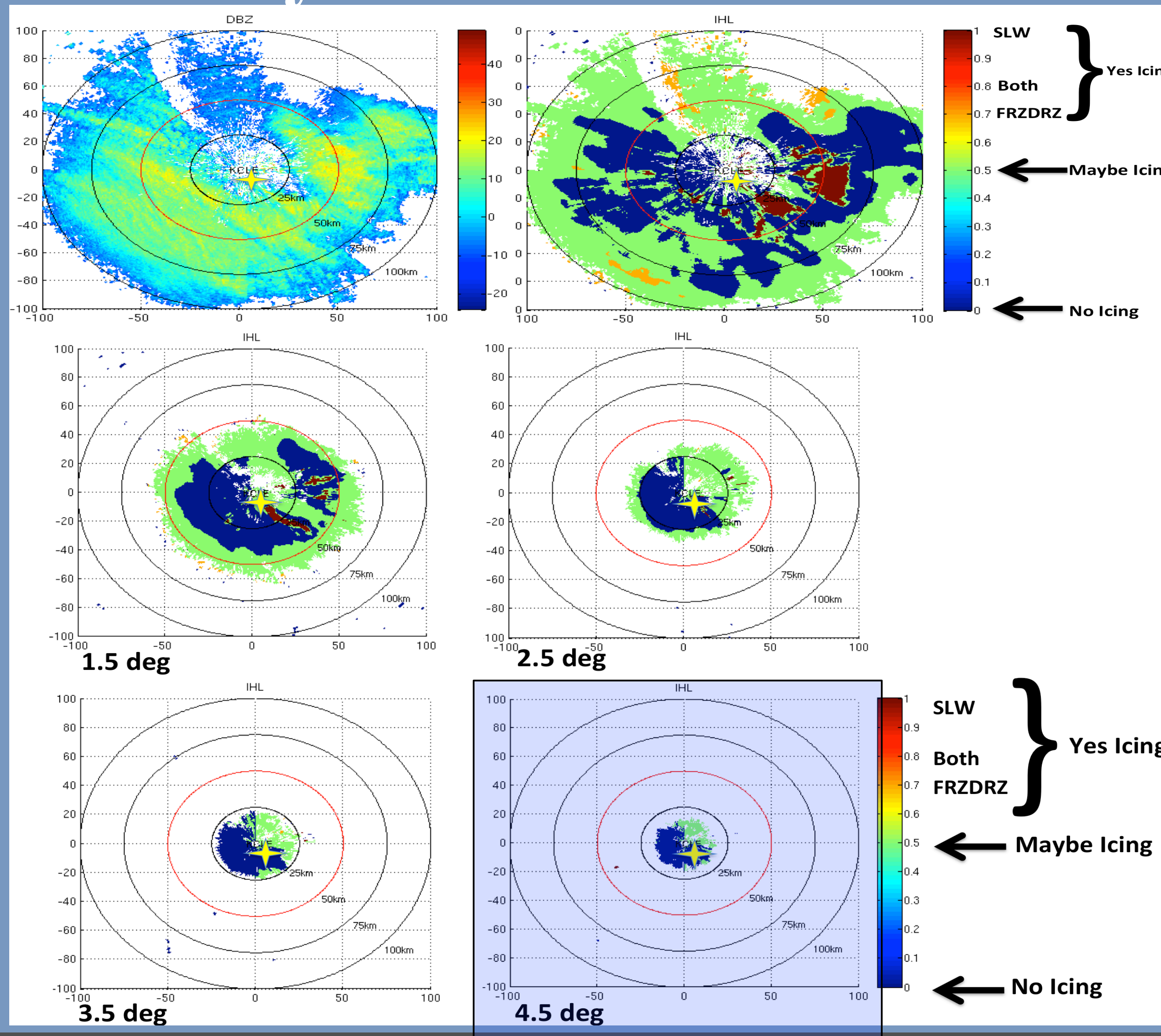
Null PIREP Case – 1721 UTC 12 February 2012

NCAR

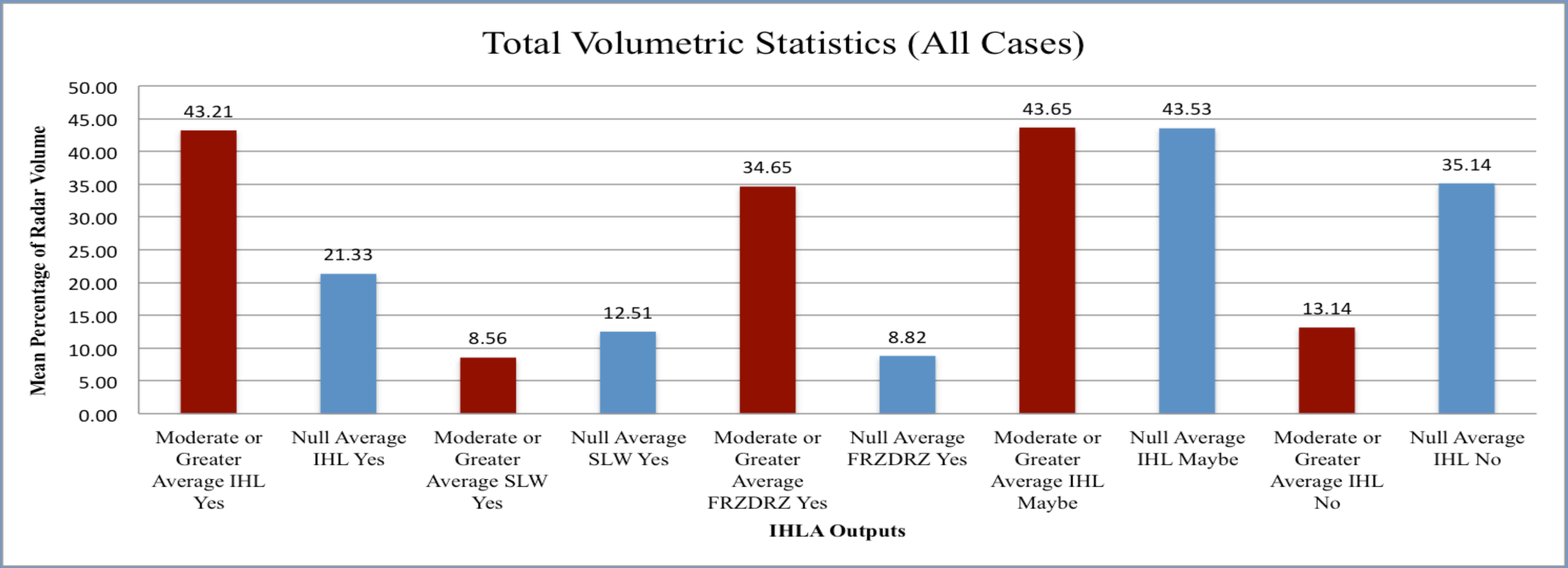
- Mean volume percentages of :
  ‘yes icing’ = 4.20 %
  ‘SLW yes’ = 3.14 %
  ‘FRZDRZ yes’ = 1.06 %
  ‘maybe icing’ = 45.8 %
  ‘no icing’ = 50.0 %

- The PIREP was in 4.5 degree scan

- IHLA did a great job classifying the the no icing area

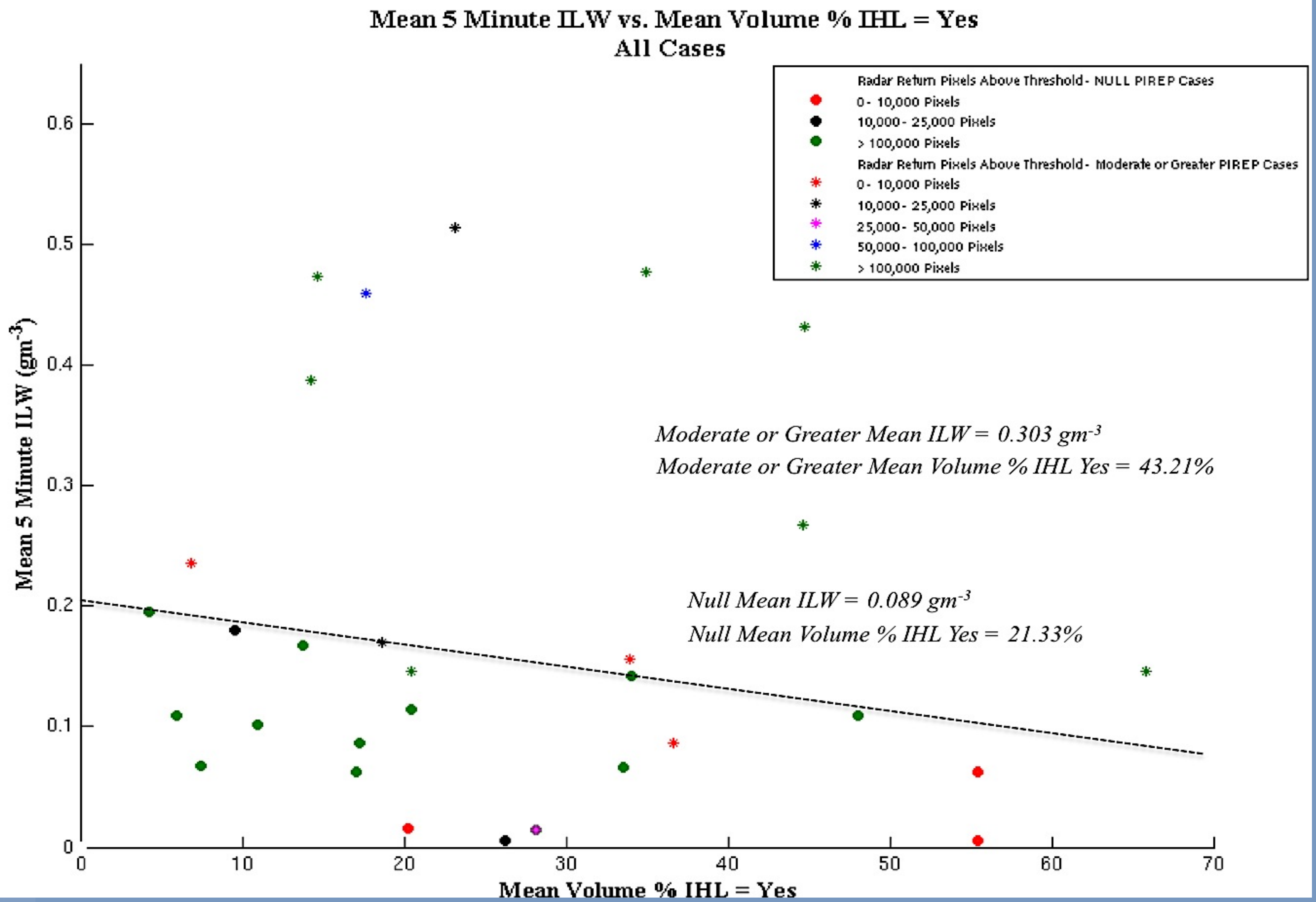


Warning Volume Statistics



- In the moderate or greater cases, the majority of the detected icing was from the FRZDRZ algorithm, but for the null icing cases, the majority of the detected icing pixels were from the SLW algorithm
- An earlier study by Serke et al. 2012 showed the opposite result
- The result indicates that there is a need for further analysis to possibly tune the FRZDRZ and SLW algorithms and specifically analyze each case in real time over several radar volume scans
- Overall, these statistics displayed that the IHLA was effective in detecting the known icing conditions, and shows promise for the operational polarized S-band algorithm. In addition to analyzing each case from this study, further case analysis will be performed during the next winter season

NIRSS Mean ILW Comparisons to IHLA Volumetric Statistics



Both NIRSS and the IHLA did detect these cases reasonably well, but the scale of the SLW features aloft can quickly change over the vertically pointing system, thus causing the severity of NIRSS to not match certain cases

Summary

- IHLA output near the location of PIREPs and mean warning volume percentages corresponded well with the known icing conditions

- There is a need for further analysis to tune the FRZDRZ and SLW algorithms, needs mitigation for canted particles

- IHLA does well detecting MOST in-flight icing → Misses small drop cases

- Optimal solution? Merge NIRSS and S-band icing algorithms
  - Interpolate volumetric cloud layers from S to K-bands
  - Independent volumetric in-flight icing measures made

Acknowledgements

- This research is sponsored by the NASA Aviation Safety Program under the Atmospheric Environment Safety Technologies (AEST) project. The views expressed are those of the authors and do not necessarily represent the official policy or position of the NASA.
- This work was also sponsored by the Federal Aviation Administration under Air Force Contract No. FA8721-05-C- 0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.
- Many thanks to my colleagues: Dave Serke, Dan Adriaansen and Marcia Politovich

Future Work

- Continue conversion to airport volumetric coverage with NIRSS

Thank you!
Questions?