In-Cloud ICing and Large-drop Experiment

Stephanie DiVito, FAA

October 13, 2020

New FAA Flight program: ICICLE

In-Cloud ICing and Large-drop Experiment

LEA Leading Edge Atmospherics

FEDERAL AVIATION ADMINISTRATION

National Research Council Canada

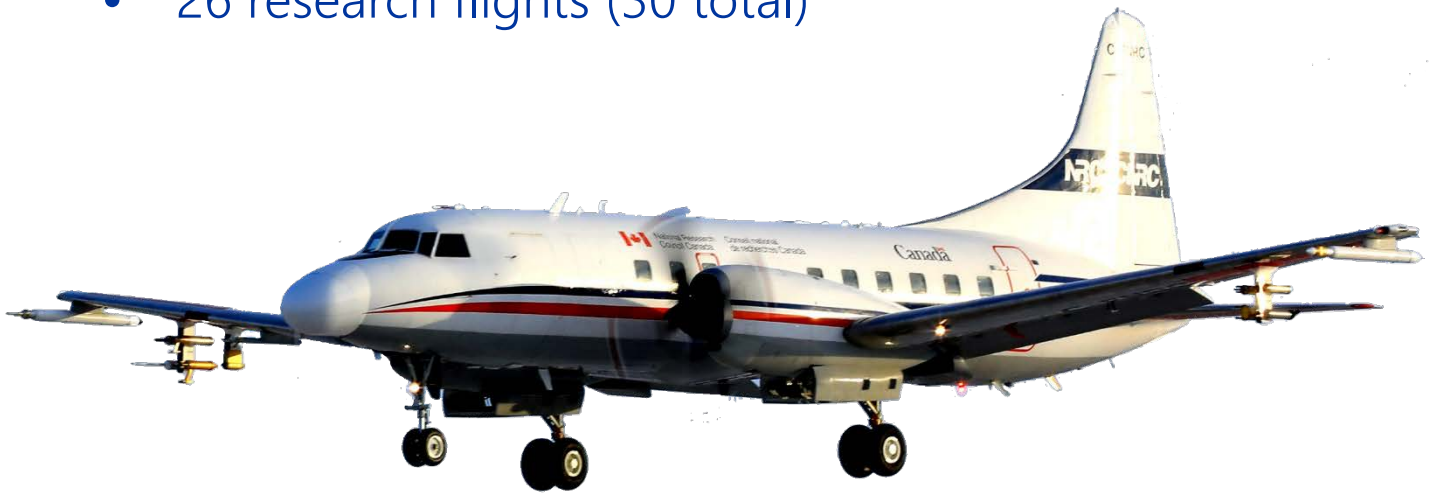
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

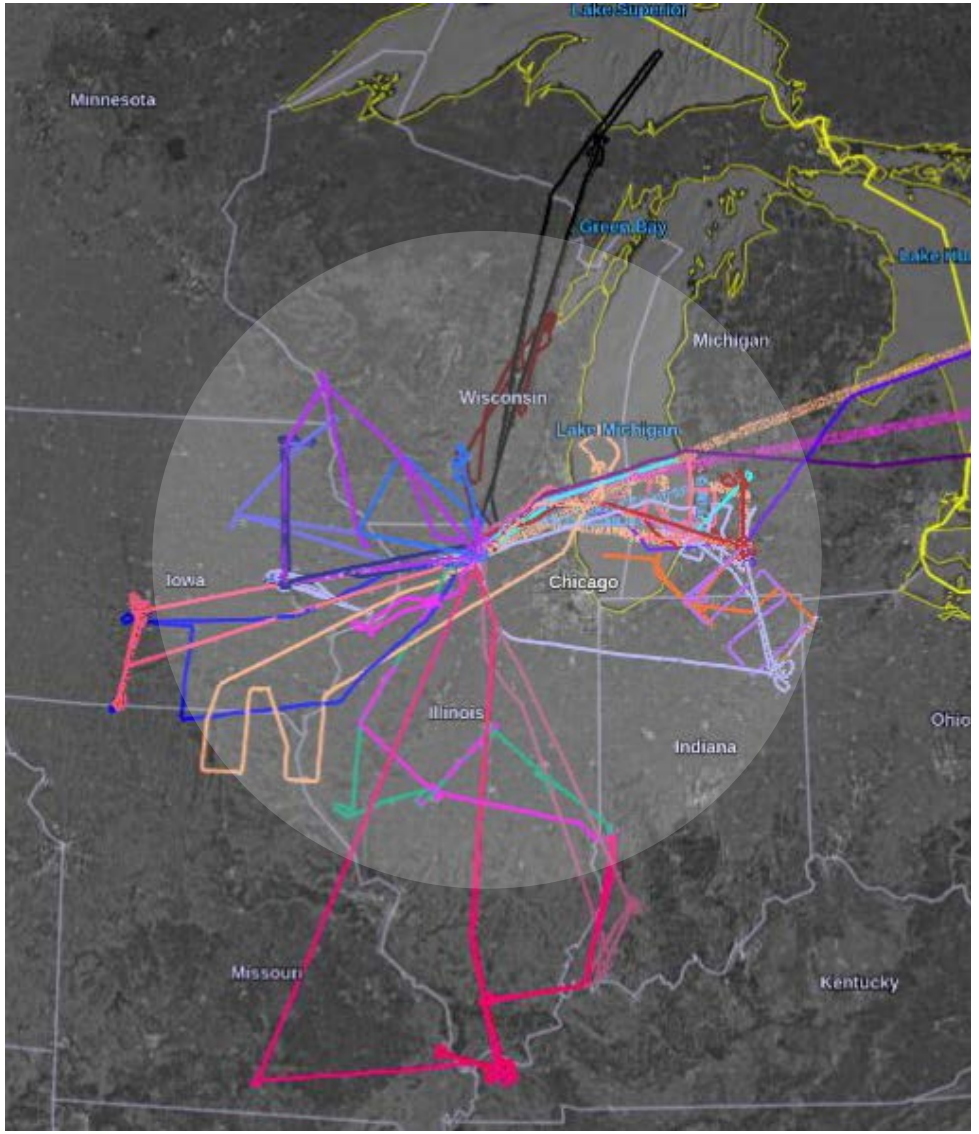
Environment and Climate Change Canada

Other Participants: Desert Research Institute (DRI), National Oceanic and Atmospheric Association (NOAA) Earth System Research Laboratory (ESRL), National Aeronautics and Space Administration (NASA) Langley Research Center, Meteo-France, UK Met Office, Deutscher Wetterdienst (German Meteorological Office), Northern Illinois University, Iowa State University, University of Illinois at Urbana-Champaign, and Valparaiso University

Flight Program Overview

- January 27 – March 8, 2019
- Operations Base: Rockford, Illinois
  - Domain: 200 nmi radius
- NRC Convair-580 aircraft
  - Owned and operated by NRC Flight Research Laboratory
  - Jointly instrumented by NRC and ECCC
  - Extensively used in icing research for over 25 years
- 120 flight hours (110 for research)
- 26 research flights (30 total)





Scientific & Technical Objectives

- Observe, document, and further characterize a variety of in-flight and surface-level icing conditions
  - Environmental parameters and particle size distribution for:
    - Small-drop icing, FZDZ and FZRA
  - Transitions between those environments & non-icing environments
  - Synoptic, mesoscale & local effects

- Assess ability of operational data, icing tools and products to diagnose and forecast those features
  - Satellite – GOES-16
  - Radar – Individual NEXRADs, MRMS
  - Surface based – ASOS, AWOS, etc.
  - Numerical Weather Prediction (NWP) models
  - Microphysical parameterizations, TLE, etc.
  - Icing Products - CIP, FIP, other icing tools

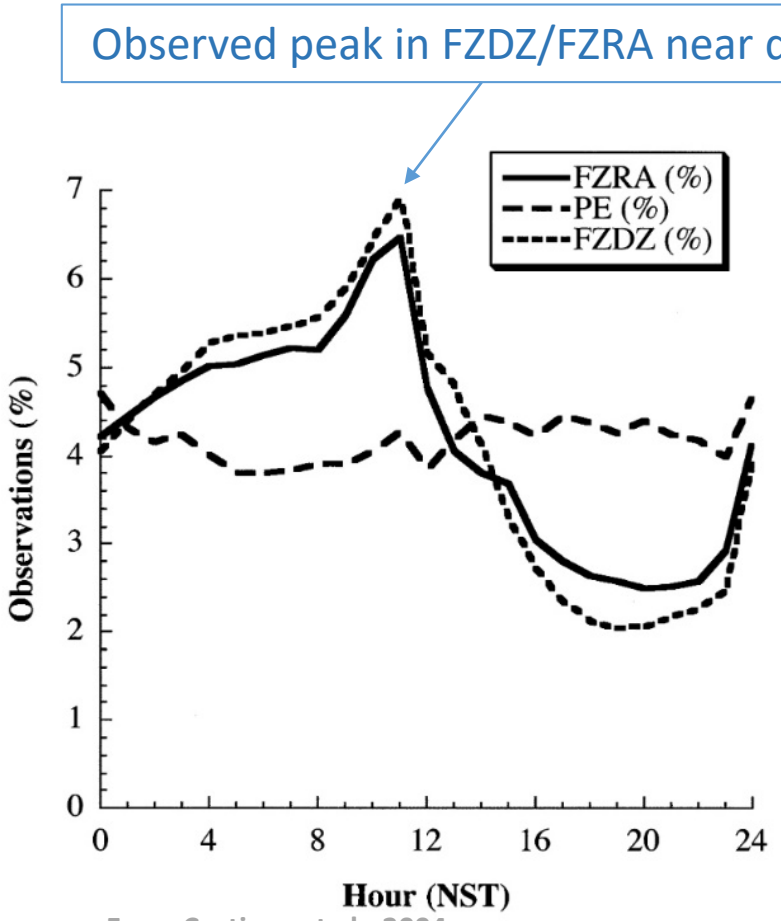
Sampling Objectives (1/2)

- Collect data in a wide variety of icing and non-icing conditions
  - Small-drop and large-drop
    - Including those with (& without) FZDZ and FZRA
  - Null icing environments
    - Clear-air, glaciated, T>0°C

Event type (across) Parameter (down)	FZDZ aloft down to sfc	FZDZ aloft only	FZDZ Seed-Feeder	FZRA	Classical PL	Deep Glaciated	Shallow StCu	High LWC / MVD 30-40 mic	Typical App C	Clear Air
Priority	1	2	3	4	5	6	7	8	9	10
% flight hr	15	10-15	10	15	5	5	10-15	5-10	5-10	5
Time (hr)	18	12-18	12	18	6	9	12-18	6-12	6-12	9
Frequency (1-10)	5	5	4	3	2	9	6	3/1	9	10
Sampling Diff. (1-10)	5	5	6	8 (Z vs MEA)	9 (narrow)	1	3 (Z vs MEA)	7 (small) / 9 (rare)	2	1
Tmin range (°C)	-5 to -13	-5 to -13	-5 to -13 / -20	-2 to -10	-2 to -12	-30	-5 to -20	-4 to -13	-5 to -20	0 to -30
Dominated by	Liquid	Liquid	Liquid/SN mix	Varies	Mixed PCP	Snow	Liquid	Liquid	Liquid/Mix	None
LWC (gm^{-3})	0.1-0.4	0.1-0.4	0.1-0.4	0.1-0.3	0.1-0.2 (FZRA)	0-0.2	0.2-0.8	>1.0 / 0.1-0.4	0.1-0.4	0.0
MVD (mic)	20-250	20-250	20-250	20-2500	20-2500	10-20	10-25	12-20 / 30-40	15-25	N/A
Dmax (mic) Liquid	200-500	200-500	200-500	>500	>500	20-30	15-30	15-25 / 35-60	20-30	N/A
Depth (kft)	1-5	1-5	1-5	0.2-1.0	0.3-1.5 (FZRA)	3-40	1-3	2-6 / 1-5	1-5	N/A
Length (nm)	10-200	10-200	10-200	10-100	5-50	20-100+	20-200	5-25 / 10-100	20-500	5-100+
Width (nm)	10-200	10-200	10-200	50-250	50-250	20-100+	20-200	5-50 / 10-100	20-500	5-100+
Duration (h)	2-10+	2-10+	2-10+	2-24+	2-24+	2-24+	2-24+	0.5-3 / 2-24+	4-24+	2-24+
Sfc Wx Type	FZDZ	DZ/-SN/None	FZDZ/-SN	FZRA, PL, RA	FZRA, PL, RA	SN, RA	None/-SN	SHRA / Varies	None	None

Sampling Objectives (2/2)

- Sample at all times of day
- Sample full vertical extent of cloud(s) and precipitation
  - Including sub-cloud layer, and clear air immediately above cloud top
  - Most of the sampling done in cloud (IFR)
  - Prolonged periods, multiple passes & altitudes
  - Missed approaches
- Collect photography of ice accretion, cloud(s) above, below, and in the vicinity, and other phenomena



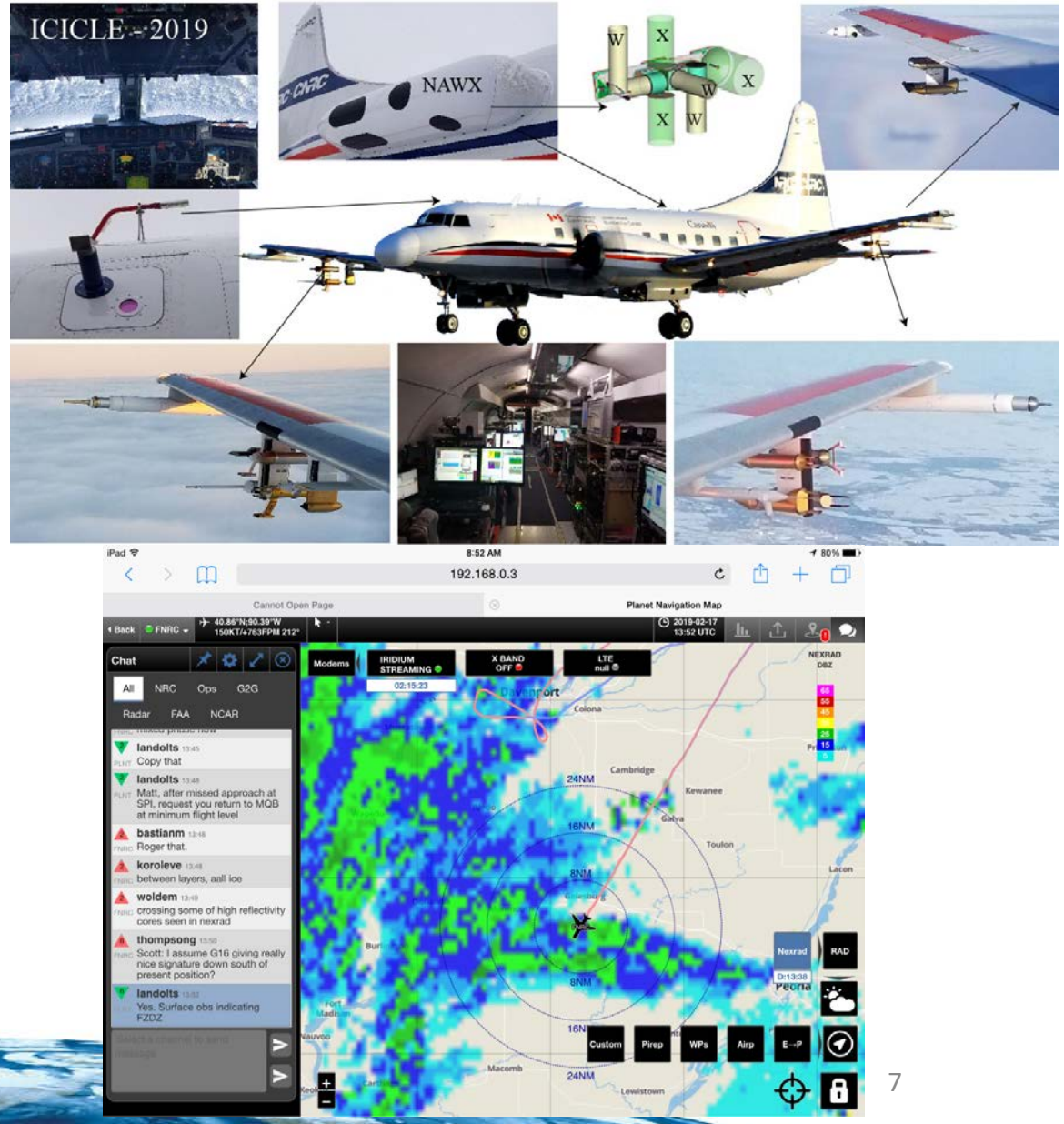
From Cortinas et al., 2004

Convair-580 Instrumentation

- Extensive in-situ and remote sensing systems and ground-aircraft data exchange tool (PLANET)

Parameters	Sensors
Aircraft state	Inertial Navigation Systems (4), and GPS (2)
Atmospheric state	Rosemount Temperature Sensors (4), Licors (2) – Dew point, Chilled Mirror, Multiple pressure transducers including 3 5-hole probes
Aerosol (size and concentrations)	UHSAS, SP2, CCN Counter, CPC
Bulk microphysical measurements (IWC, LWC)	Nevzorov (2), SAE Icing Detector
Icing	Goodrich Icing Detector (3)
Cloud Particles (Size and concentrations)	FCDP, CDP and FSSP

Parameters	Sensors
Cloud Imaging Probes	2D-S (2), 2D-C, CPI
Precipitation Imaging Probes	PIP, HVPS
Radars	NRC Airborne W and X (NAWX) radar, Pilot X-band Radar Ka-band Precipitation Radar
Radiometer	183 GH-z G-band Water Vapor Radiometer (GVR)
Lidar	355 nm - Nadir and Zenith
Communication	PLANET – Ground – Aircraft data exchange and flight coordination

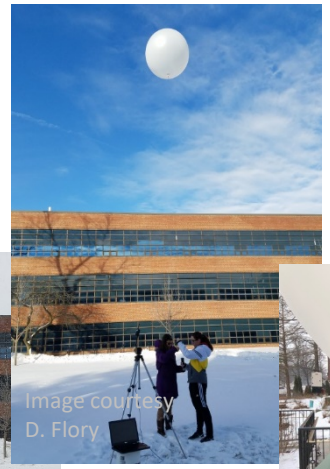


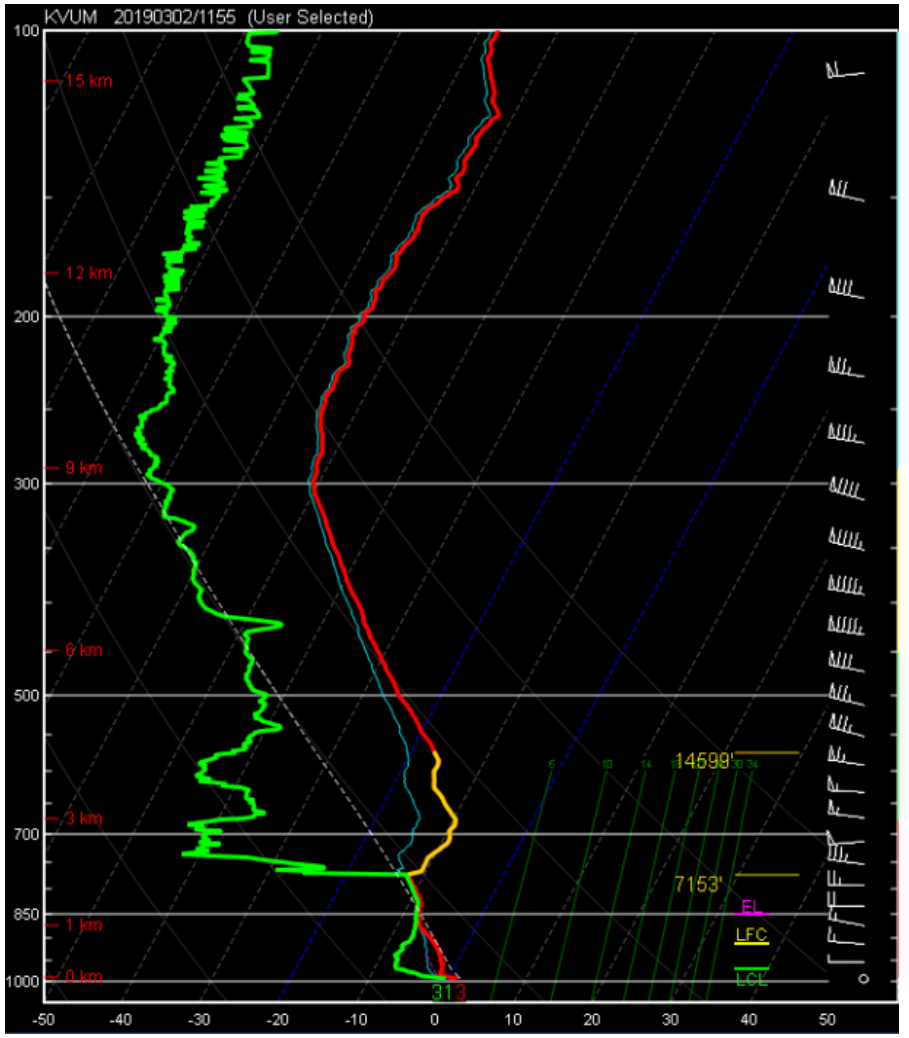
Sensor Suites: Surface Stations

1 Present weather sensor, icing sensor, disdrometer, precipitation gauge w/ shield, state parameter sensor.
2 Same as (1) plus a ceilometer.

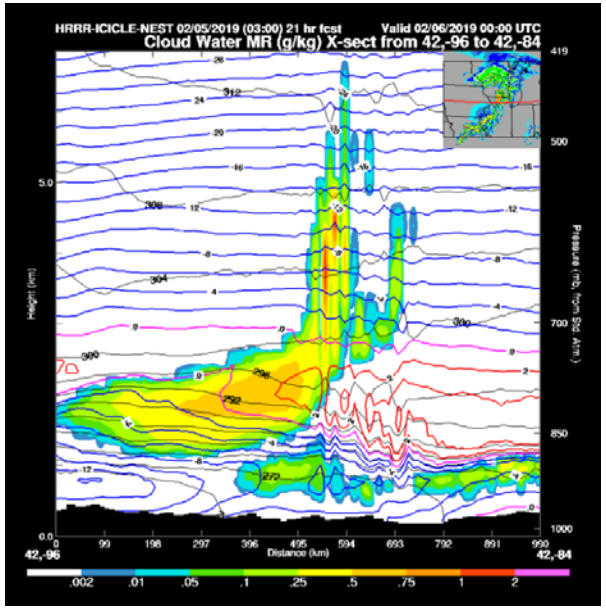
Sensor Suites: Supplemental Soundings

- 27 weather balloon launches
- Partnerships with Universities
  - Valparaiso University (4)
  - University of Illinois – Urbana Champaign (5)
  - Northern Illinois University (11)
  - Iowa State University (7)

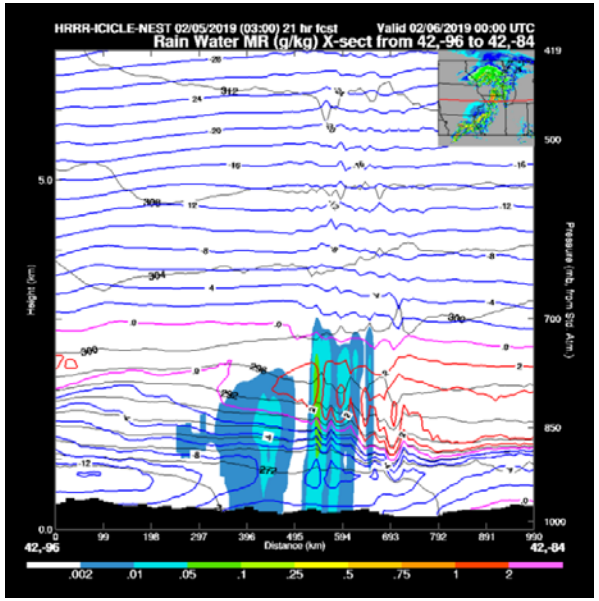


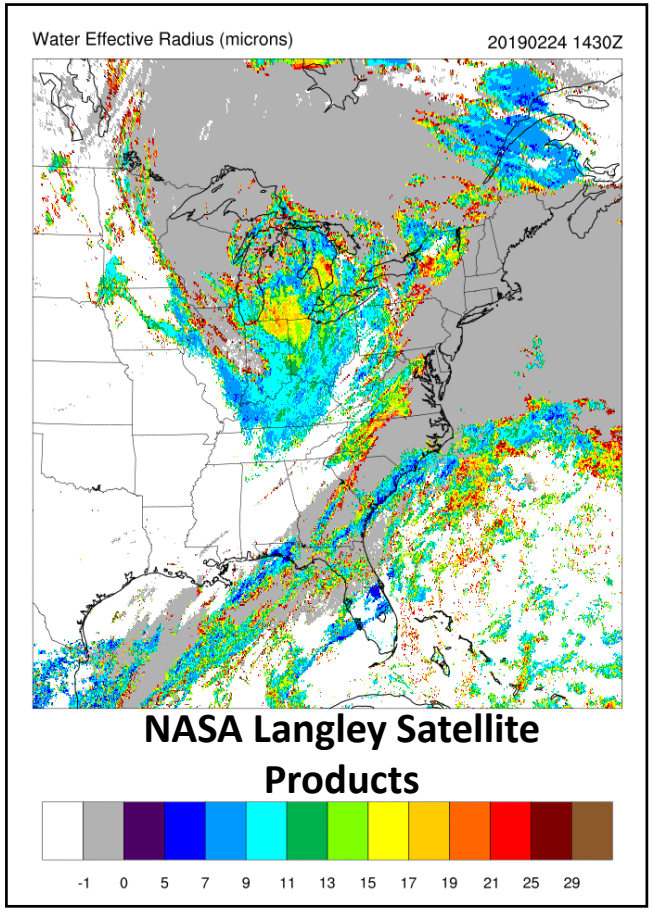


Collaborative Tools

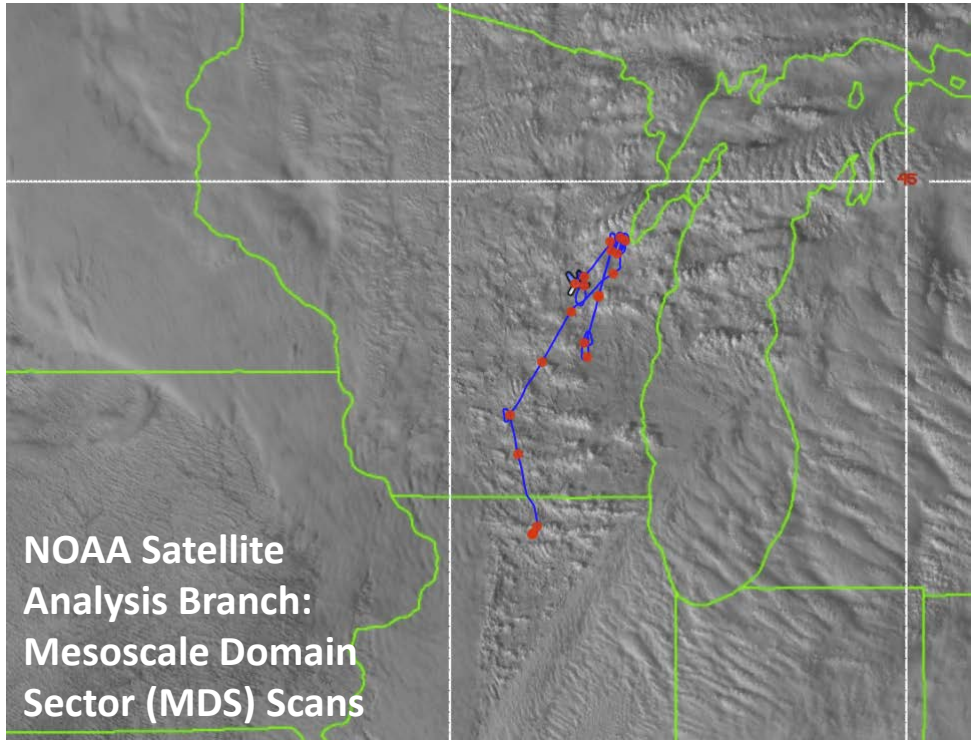


NOAA GSD ESRL 1km-HRRR nest (cross sections, shown)

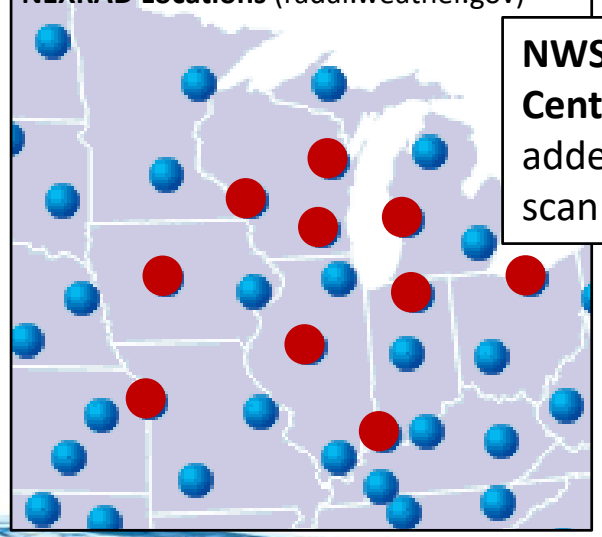




NASA Langley Satellite Products



NEXRAD Locations (radar.weather.gov)



NWS Radar Operations Center: VCP35 Modification; added 19.5 elevation angle scan to 10 radars (red)

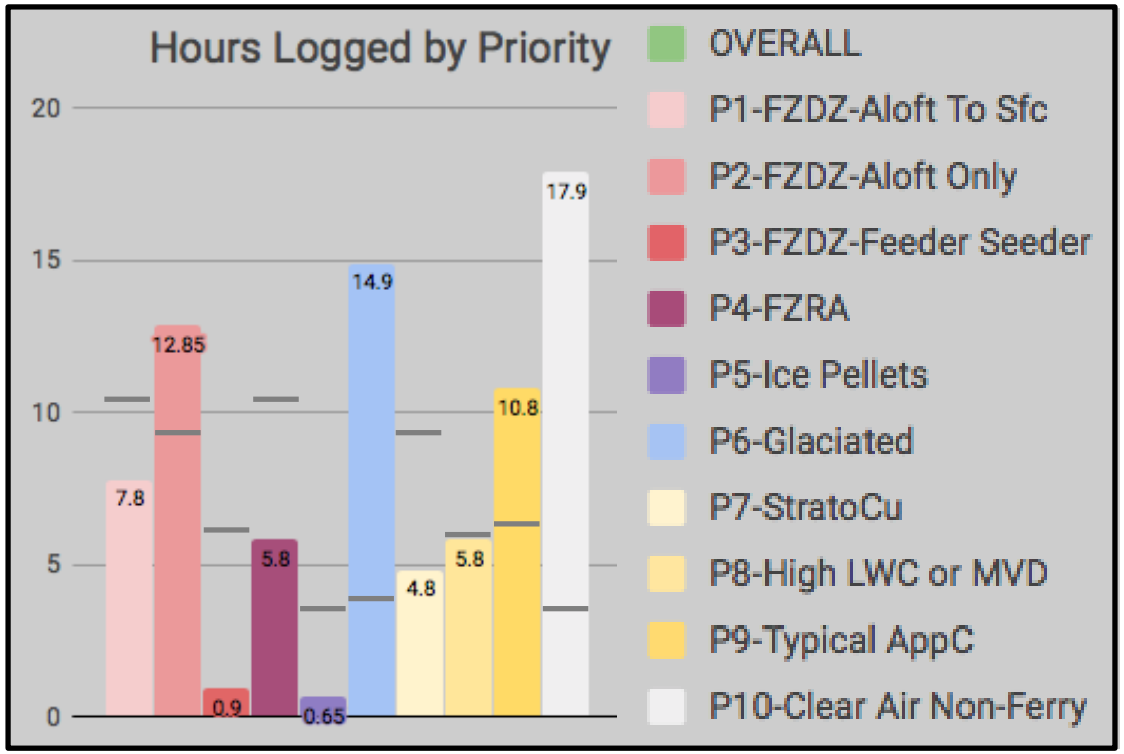
Outcome (1/4)

- Achieved overall target of ~110 hr in 5.5 weeks
  - ~83 hours of actual sampling

~49 hours of flight in icing

- >20 hours in "small-drop" conditions
- >20 hours in FZDZ *(a lot!)*
  - Much of FZDZ found aloft only
    - Less than half appearing to reach the surface
- ~6 hours in FZRA *(also a lot!)*
  - Most FZRA *did* extend to the surface
    - As expected – low altitude phenomenon

- FZDZ and FZRA with & without small drops
  - App O sub-categories
  - Significant amount was in mixed phase



— = approximate targets for each category.
These were aggressive targets, worth pursuing.
Did very well, overall.

Outcome (2/4)

- Collect data in a wide variety of icing and non-icing conditions

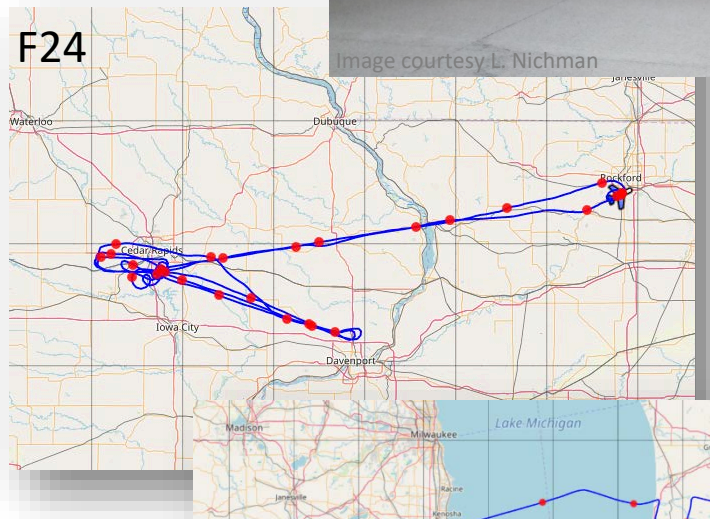

Image courtesy L. Nichman

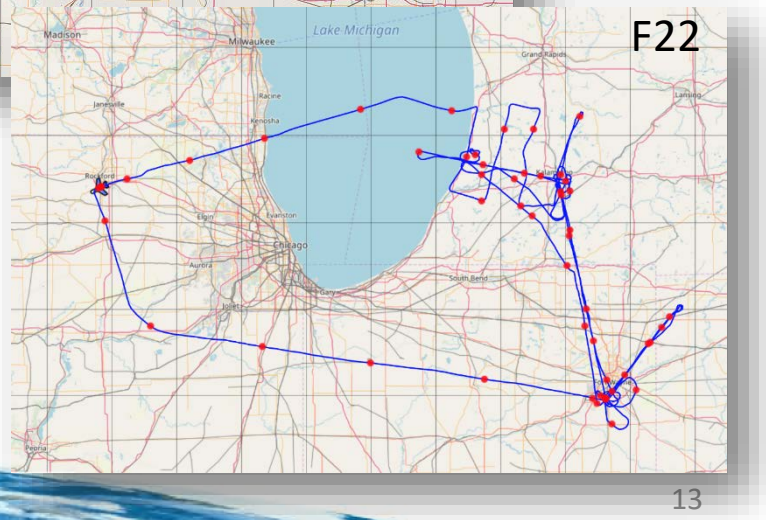

Image courtesy S. Landolt

Outcome (3/4)


Image courtesy L. Nichman

- Altitudes: Surface to 23,000 ft
- Good variety of Temperature, LWC, drop size
  - -25°C < SAT < 0°C – Small drop icing
  - -20°C < SAT < 0°C – FZDZ
  - -13°C < SAT < 0°C – FZRA
- Time of day: 4:30 a.m. to 11:45 p.m. (local time)
  - Typical duration ~4 hrs
  - One-flight and two-flight days
- Variety of patterns flown
  - Straight line, lawnmower, stacking, repeating



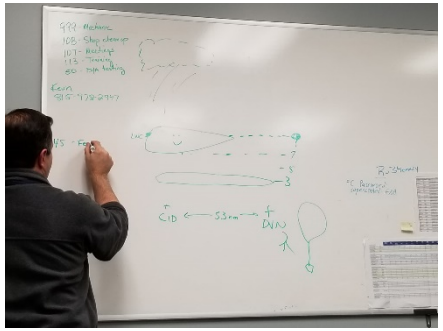


Outcome (4/4)

- Vertical profiles
  - >100 "deep" vertical profiles
  - 48 missed approaches
  - Done during FZDZ, FZRA, SN, precipitation-free, layers, clear skies
- Photography

Daily Schedule Template

Single-flight Day:
0130 : *Forecaster A shift begins* / Sounding launch, if possible
0300 : Weather briefing
0330 : Message to pilots go/delay/no-go [pilot duty starts]
0330 : Operations planning meeting (Ops director, forecaster, others as needed)
0430 : Operations decision for the day; pilots arrive
0430-0500 : Brief pilots on plans
0630 : Takeoff
0630-0715: [FLIGHT] Transit to sampling location
0715-0945 : [FLIGHT] Sampling
0800 : Forecaster B shift begins
0945-1030: [FLIGHT] Transit back to KRFD
1030 : Landing [4hr flight]
1100 : Debrief morning flight (get pilots perspective first, project objectives second, then cover instrumentation, data)
1130 : Forecaster A shift ends
1130 : Weather outlook for tomorrow (1-3 day); Provide estimated Takeoff Time and Number of flights (1 or 2) for tomorrow
*1200 – pilot duty ends **[8.5 hours duty]***
["break" aka disassemble temporarily]
1330 : Forecaster B weather outlook (long range; 1-7 day outlook - Ops Director and Forecaster B required, others as needed]
1400 : Send out email/message with times for tomorrow; END OF DAY



Note: All times local

Ongoing and Planned Research

FAA ICICLE research focused on:

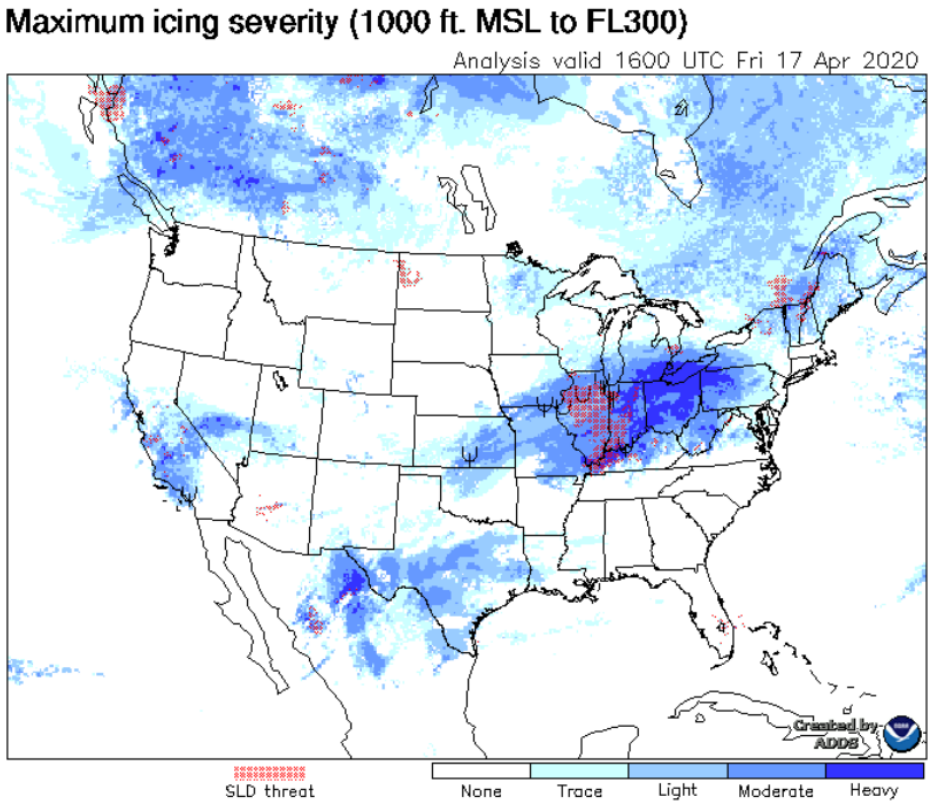
- In-Flight Icing (IFI)
  - POC: Danny Sims (danny.sims@faa.gov)

- Terminal Area Icing Weather Information for NextGen (TAIWIN)
  - POC: Stephanie DiVito (stephanie.divito@faa.gov)

In-Flight Icing (IFI)

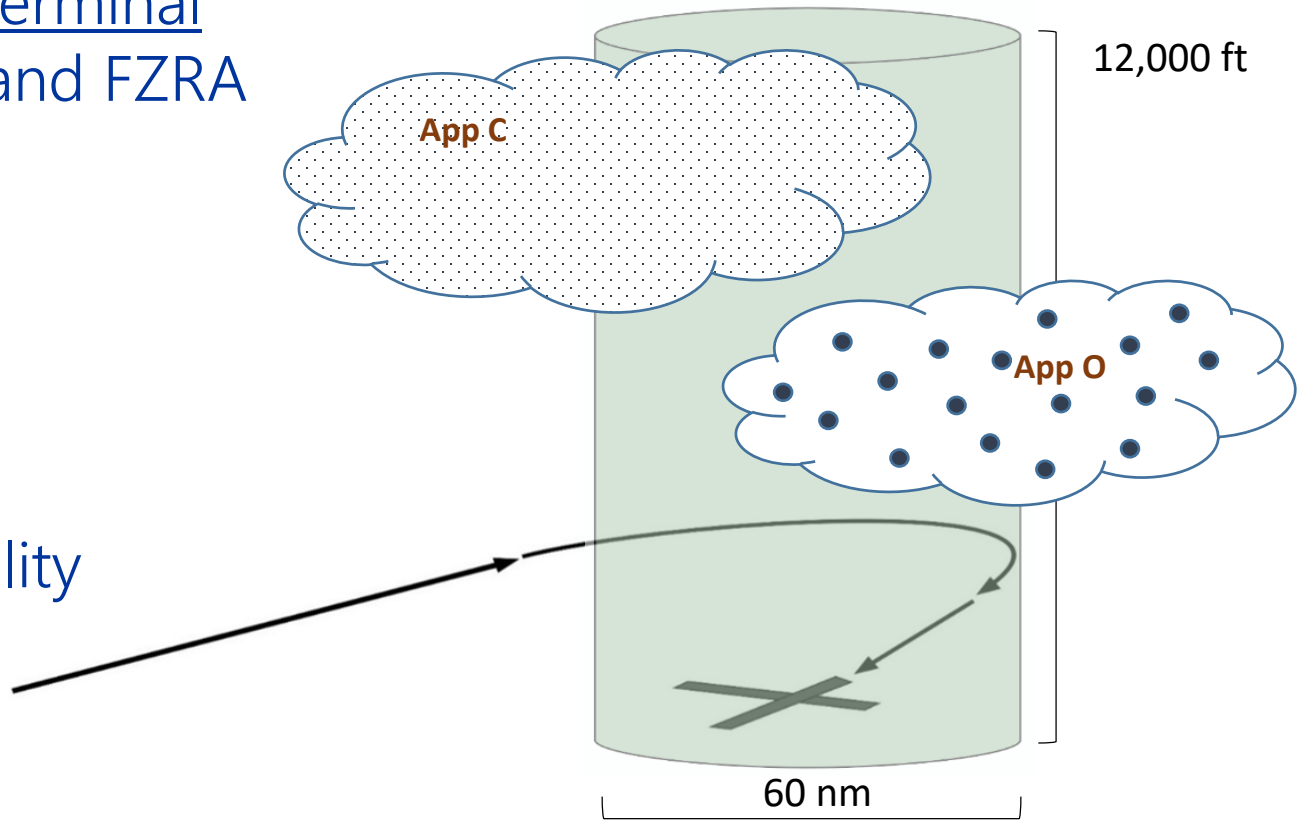
- Goal is to enhance automated diagnostic and forecast capabilities (CIP and FIP) to address inflight icing safety hazards and updated regulation and certificate changes (Appendix C and O)
- Improve CIP and FIP by incorporating enhancements in weather models, satellites, and radar
- Evolve from current forecasts of icing severity to Appendix C and O drop-size information

Current Icing Product (CIP) Severity



Terminal Area Icing Weather Information for NextGen (TAIWIN)

- Goal is to develop a capability for icing diagnosis and forecasting in the terminal area, with an emphasis on FZDZ and FZRA identification
  - Diagnosis updates every 5-15 mins
  - Forecasts 0-12 hours
  - High resolution grid spacing
    - ~1 nm horizontal; <500 ft vertical
- Developing first version of capability



ICICLE Related Research: TAIWIN and/or IFI

- Particle Size and Type Investigation
  - Surface vs aloft conditions in the terminal area
- Ceilometer
  - Examining raw backscatter profile as well as it's relationships with particle size/number information
- GOES-16/17
  - High-resolution and icing environment detection
  - Evaluating cloud properties, including additional spectral information
- NEXRAD dual-pol capabilities
  - Detecting presence of SLW
  - Multi-Radar Multi-Sensor (MRMS)
    - Hydrometeor classification and drop size research
    - Better differentiating between ground clutter and light precipitation
- Satellite and Radar Feature Tracking
  - Using fog product and feature tracking algorithm; looking into other fields
- Time-Lagged Ensemble forecasts
  - Evaluation and verification
- Numerical weather prediction forecast models
  - Evaluating cloud phase, maximum drop diameter, and LWC
  - Improving cloud microphysics schemes
- TAIWIN capability development
- Evaluating CIP and FIP new versions
- Applying research results from CIP and FIP to Icing Product Alaska (IPA)
- Targeting CIP and FIP operational enhancements in 2023
  - Drop-size output will be a future enhancement

ICICLE Current Status and Next Steps

- Data processing for most datasets complete
  - Remaining datasets to be delivered by end of October 2020

- Planned publications
  - Complete FAA Technical Document: ICICLE Science and Operations Plan
  - Submit an AMS BAMS article
  - January 2020: AMS presentations
  - Among others…

- Group meetings
  - *February 2020: Workshop #1 – Data Processing*
  - October 2020: Workshop #2 – Data Update
  - December 2020: Technical Interchange Meeting
  - Late Spring 2021: Workshop #3 – Research Review

Thank you!

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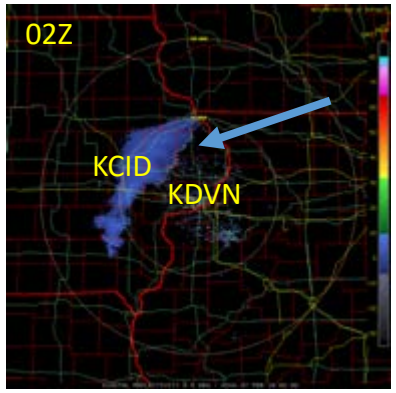
This research has been done in response to requirements and funding by the Federal Aviation Administration (FAA). The views expressed are those of the authors and do not necessarily represent the official policy or position of the FAA.

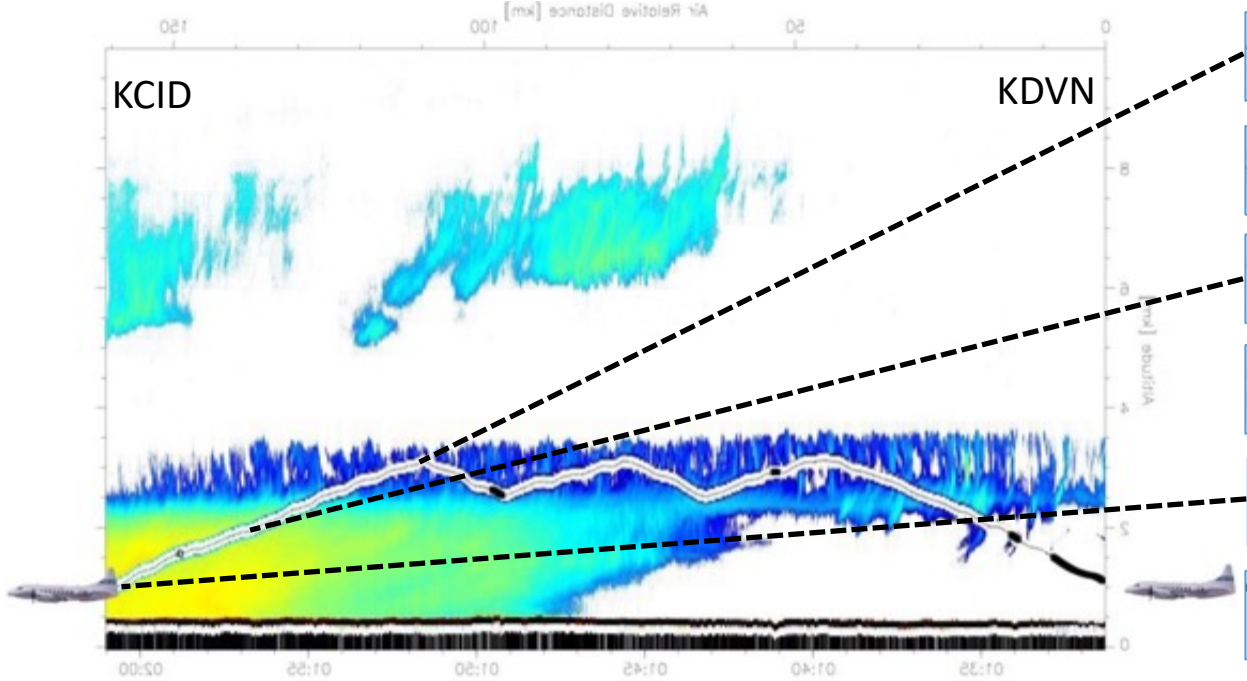
Backup

Some Sample Flight Data

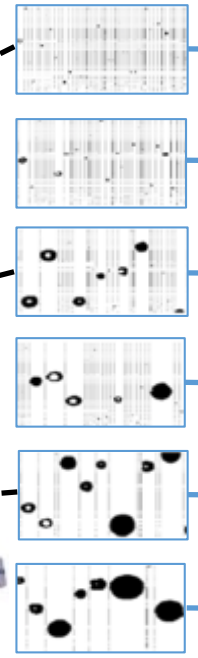
- Flight 24: Feb 26/27



NRC Airborne W-Band Radar



NOTE: Image flipped horizontally for spatial referencing; station locations are approximate



2D-S

KCID Profile C: 0151-0207 UTC