SLD Instrumentation in IWTs – Investigation Overview

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Session Lineup & Outline

No	SLD Instrumentation Session Topics	Presenter
1	**SLD Instrumentation Collaboration Overview**	**J. Van Zante**
2	Comparison of PSD and MVD measurements at NRC AIWT	A. Korolev
3	IKP TWC Measurements in SLD at NASA IRT	T. Ratvasky
4	Inter-Facility LWC Differences in SLD due to Calibration Instruments	L. King-Steen
5	Causes of MW Bias During SLD Testing in the IRT	L. King-Steen
6	SEA Ice Crystal Detector (ICD) in SLD at NASA IRT	L. Lilie

- Motivation & Goals
- Facilities
- Instrumentation
- Test Matrix
- Future Work

Team Members

NASA:	Judith Van Zante, Tom Ratvasky, Laura King-Steen, Emily Timko, Mark Potapczuk, Mary Wadel, Jack Oldenburg
NRCC:	David Orchard, Catherine Clark, Gislain Chevrette
CIRA:	Biagio Esposito
ECCC:	Alexei Korolev, Ivan Heckman, Jason Iwachow, Mike Harwood
FAA:	Tom Bond, Jim Riley, John Fisher, Chris Dumont
Met Analytics:	Walter Strapp

With support from probe manufacturers

Artium:	Will Bachalo
SEA:	Lyle Lilie

Nomenclature

National Agencies

CIRA = Centro Italiano Ricerche Aerospaziali SCpA (IT)
ECCC = Environment and Climate Change Canada (CA)
FAA = Federal Aviation Administration (US)
NASA = National Aeronautics and Space Administration (US)
NRCC = National Research Council Canada (CA)

Facilities

AIWT = Altitude Icing Wind Tunnel (NRCC)
IRT = Icing Research Tunnel (NASA)
IWT = Icing Wind Tunnel (CIRA)

Cloud

LWC = Liquid Water Content (g/m^3)
MVD = Median Volumetric Diameter (um)
PSD = Particle Size Distribution
SLD = Supercooled Large Drop

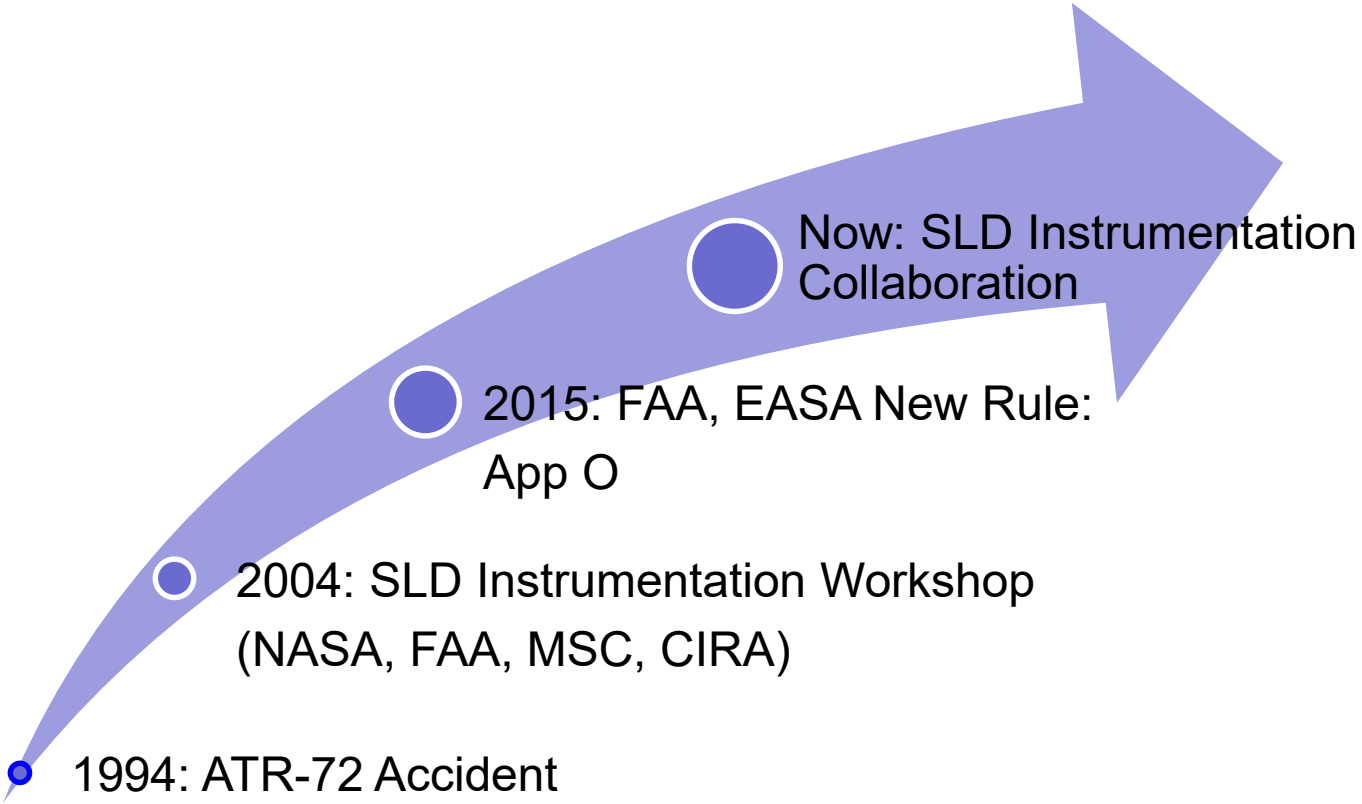
Probes – Water Content

ICD = Ice Crystal Detector (SEA)
IKP = Iso-Kinetic Probe (SEA/NRCC)
MW = Multi-Wire, or Multi-Element (SEA)

Probes – Sizing

2D-S = Two Dimensional Stereo (SPEC)
ADA = Airborne Droplet Analyser (Aerometrics)
CDP = Cloud Droplet Probe (DMT)
HSI = High Speed Imaging (Artium)
OAP = Optical Array Probe (PMS)
PDI = Phase Doppler Interferometer (Artium)

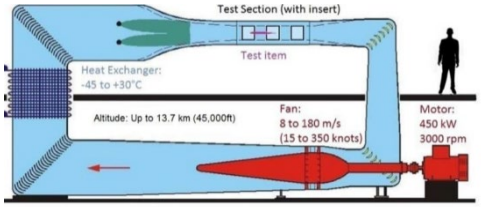
Background

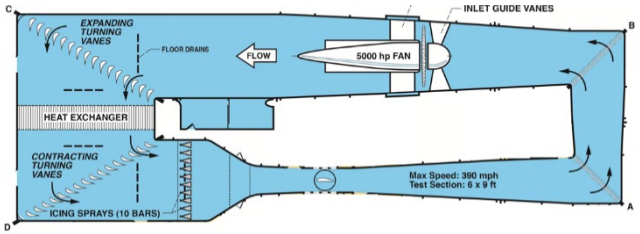

Now: SLD Instrumentation Collaboration
2015: FAA, EASA New Rule: App O
2004: SLD Instrumentation Workshop (NASA, FAA, MSC, CIRA)
1994: ATR-72 Accident

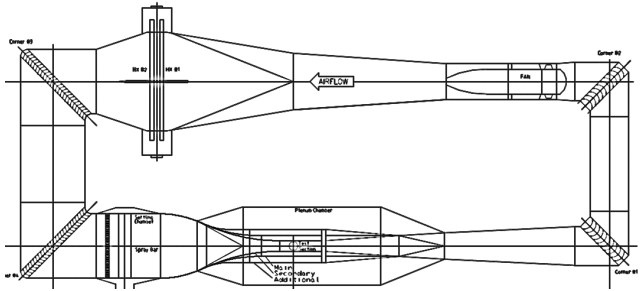
Motivation & Goals

1. Better understand cloud characterization probes and data processing algorithms in SLD conditions.
   - PSD, Particle Size Distribution probes
   - LWC, Liquid Water Content probes
2. Better understand ability to simulate SLD conditions in several facilities.
   - NRCC's AIWT, Altitude Icing Wind Tunnel
   - NASA's IRT, Icing Research Tunnel
   - CIRA's IWT, Icing Wind Tunnel
3. Assess potential for inter-facility bias in SLD simulations due to choice of instrumentation.

Facility Information







NRCC's AIWT, Altitude Icing Wind Tunnel

- 0.57 x 0.57 m^2, 6:1
- PSD: Malvern
- LWC: Rotating Cylinder

NASA's IRT, Icing Research Tunnel

- 1.83 x 2.74 m^2, 14:1
- PSD: CDP, OAP-230X, OAP-230Y
- LWC: MW, Icing Blade

CIRA's IWT, Icing Wind Tunnel

- 2.35 x 2.25 m^2, 10:1
- PSD: ADAs, OAP-2D-GA2
- LWC: Icing Blade, Robust Probe

Instrumentation Considerations

Team selected Probes from current and emerging technologies.

The Team enlisted support from manufacturers Artium Technologies, Inc. and Science Engineering Associates, Inc. to ensure the best quality data from the newer technologies being evaluated at the tunnels.

Statement regarding choice of Common Reference Probes:

- Should not be interpreted that the Team believes these probes provide the “most accurate” measurement.
- Chosen because of good reputation within the community, familiarity with the probes and data processing schemes AND practical reasons – with in Team is ability to transport, operate and analyze their data in a consistent manner.

Instrumentation (Common)

PSD Probes	Full Name	Range (um)	Manufacturer	Owner (Sponsor)
CDP-2	Cloud Droplet Probe	2 – 50	DMT	ECCC
2D-S	2Dimensional Stereo	10 – 1280 (2560)	SPEC	ECCC
PDI-FPDR-2	Phase Doppler Interferometer	Small: 1 – 130	Artium	Artium (ECCC)
PDI-4D		Large: 7 – 1000	Artium	CIRA
HSI-FPDR	High Speed Imaging	5 – 1500	Artium	ECCC
HSI w/ trigger		5 – 1800	Artium	CIRA

LWC Probes	Full Name	Manufacturer	Owner
MW	Multi-wire	SEA	NASA
IKP-2	Iso-Kinetic Probe	SEA, NRCC	NASA
ICD	Ice Crystal Detector	SEA	SEA (FAA)
NACA-0012	Airfoil		Facility

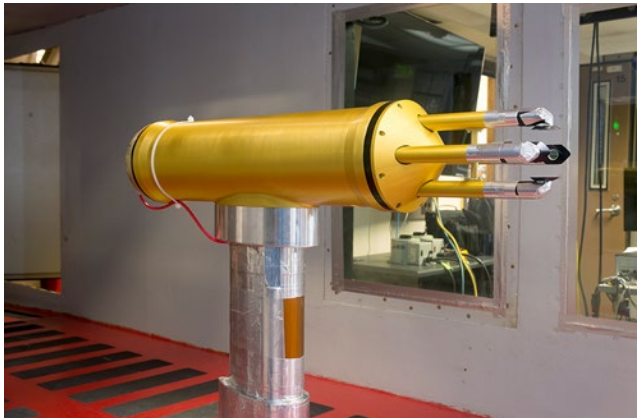
Bold denotes *Common Reference Probes* used for interfacility comparison

Instrumentation – Common Reference

Common Reference Probes

- PSD: CDP-2 + 2D-S w/ common processing algorithm
- LWC: Multi-wire (MW)

CDP-2 (ECCC)
light intensity



2D-S (ECCC)
optical array probe

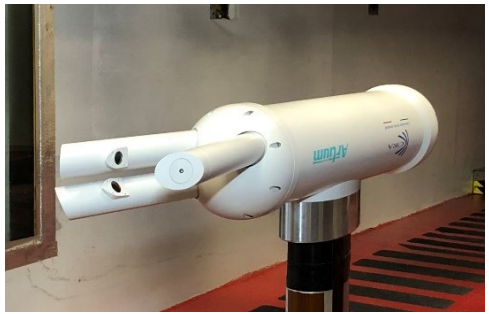
MW (NASA)
heated elements

Instrumentation – Additional PSD

PDI-FPDR
(ECCC-Artium)

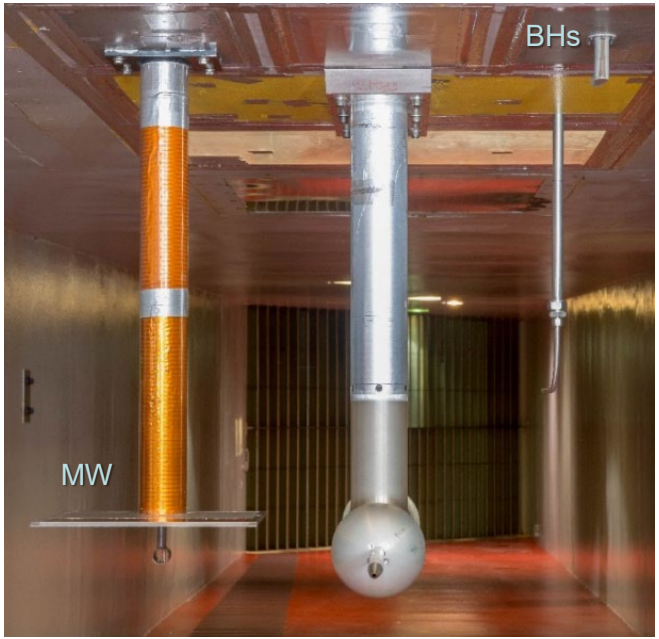
HSI-FPDR
(ECCC)

PDI-4D
(CIRA)



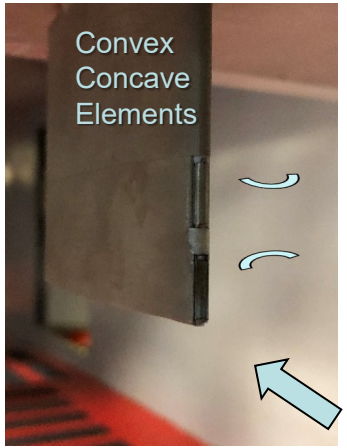
HSI with trigger
(CIRA)

Instrumentation – Additional LWC



IKP-2 (NASA)
MW & Background Hum.

Tunnel IKP (NRCC)



ICD (NASA)

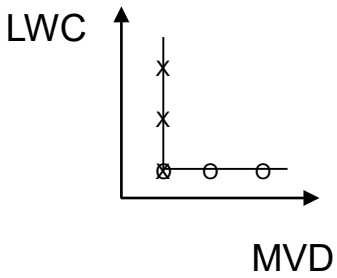
Common Test Matrix – Target

Derived from overlap region from each Facility's stated capabilities.

- Primary test points: LWC sweep for LWC probes & MVD Sweep for PSD probes
- Airspeed at 80 m/s or 150 kts (77.2 m/s)

Conditions set in each facility per native calibration with native probes

LWC Sweep (x)			*MVD Sweep (o)*	
LWC (g/m^3)	**MVD (um)**		**LWC (g/m^3)**	**MVD (um)**
0.5	20		0.5	20
1.0	20		0.5	50
1.5	20		0.5	100
2.0	20		0.5	150
2.5	20		0.5	200
3.0	20		0.5	250



Test Matrix – Actual

- NRCC met targets via native cal curves
- NASA & CIRA selected calibrated points
  - Allowing non-sweep parameter to vary
- Two facilities added bimodal and
- Two facilities added higher speed LWC sweeps.
- NASA added LWC sweep at MVD =140 um.

Note: CIRA recently installed new SLD nozzles, and conducted a full cal. In June 2021, prior to their SLD Instrumentation test.

NRC			
Test point	VTAS (m/s)	LWC (g/m3)	MVD (μm)
AIWT LWC Sweep			
AIWT-2	80	0.35	20
AIWT-3	80	0.5	20
AIWT-4	80	0.9	20
AIWT-5	80	1.0	20
AIWT-6	80	1.4	20
AIWT-7	80	1.5	20
AIWT-8	80	2.0	20
AIWT-9	80	2.5	20
AIWT-10	80	3.0	20
AIWT MVD Sweep			
AIWT-21	80	0.5	15
AIWT-23	80	0.5	28
AIWT-24	80	0.5	40
AIWT-25	80	0.5	45
AIWT-26	80	0.5	60
AIWT-27	80	0.5	76
AIWT-28	80	0.5	116
AIWT-29	80	0.5	178
AIWT-30	80	0.5	199
AIWT-31	80	0.5	227
AIWT-32	80	0.5	262
AIWT BiModal			
AIWT-51	80	0.5	< 40
AIWT-52	80	0.5	> 40

NASA			
Test point	VTAS (m/s)	LWC (g/m3)	MVD (μm)
IRT LWC sweep			
IRT-1	77.2	0.42	14.5
IRT-1a	77.2	0.47	19.8
IRT-2a	77.2	0.97	22.2
IRT-3	77.2	1.57	20.0
IRT-4a	77.2	1.98	19.7
IRT-5	77.2	2.64	22.8
IRT-6b	77.2	3.02	20.3
IRT MVD Sweep			
IRT-21c	77.2	0.42	14.9
IRT-22	77.2	0.57	30
IRT-23	77.2	0.50	46
IRT-24	77.2	0.54	60
IRT-25	77.2	0.51	108
IRT-26a	77.2	0.45	142
IRT-26	77.2	0.60	169
IRT-27	77.2	0.71	208
IRT-28	77.2	0.91	275
IRT-29	77.2	1.36	460
IRT BiModal			
IRT-51	77.2	2.00	< 40
LWC sweep, 129 m/s			
IRT-11	128.6	0.61	20.0
IRT-12	128.6	1.17	19.7
IRT-13	128.6	2.00	25.6
LWC sweep, MVD = 140 um			
IRT-81	77.2	0.45	142
IRT-82	77.2	0.56	140
IRT-83	77.2	0.62	138
IRT-84	77.2	0.75	138
IRT-85	77.2	0.87	139

CIRA			
Test point	VTAS (m/s)	LWC (g/m3)	MVD (μm)
IWT LWC sweep			
IWT-1	80	0.35	20
IWT-2	80	0.89	23
IWT-3	80	1.4	20
IWT-4	80	2.0	20
IWT-5	80	2.5	20
IWT-6	80	3.0	20
IWT MVD sweep			
IWT-21	80	0.40	15
IWT-22	80	0.65	25
IWT-23	80	0.65	40
IWT-24	80	0.68	60
IWT-25	80	0.89	90
IWT-26	80	0.83	145
IWT-27	80	0.89	160
IWT-28	80	higher	300
IWT LWC sweep, 140 m/s			
IWT-11	140	0.44	25
IWT-12	140	1.38	20
IWT-13	140	2.00	20

Test Procedure

1. Each facility set conditions according to their native calibration.
2. Probes acquired data according to established practices
    a. ECCC operated the CDP-2 and 2D-S and analyzed data according to their algorithms
    b. NASA operated the MW and analyzed data according to their algorithm
        i. except using native MVD (instead of PSD) to determine the MW concave element collision efficiency

Accomplishments to Date; Future Work

- NRCC completed 15 days testing, 2017-18
- NASA completed 15 days testing, 2017-18
- ECCC completed analysis on CDP-2 and 2D-S data
- NASA completed analysis on MW data

- Difficulties with PSD results will lead to more testing (5-d at NRCC and 5-d at NASA) and investigating additional data analysis tools.
- Begin CIRA tests in Spring 2022

Acknowledgements

- NASA AETC-CA
  (Aerosciences Evaluation and Test Capabilities – Capability Advancement)
- FAA Technical Center
- NRCC Aerodynamics Laboratory
- ECCC Atmospheric Science and Technology Branch
- CIRA SLD-FZDZ program

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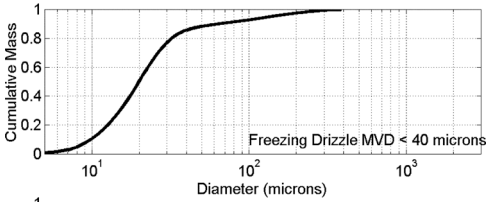
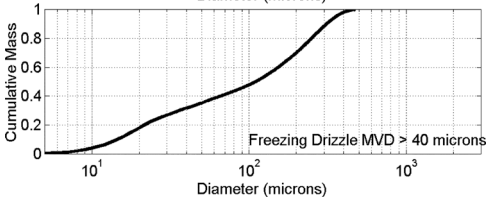
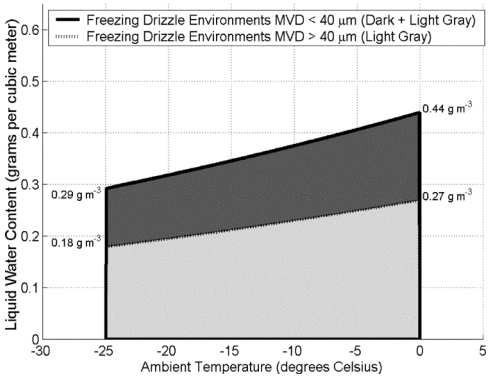
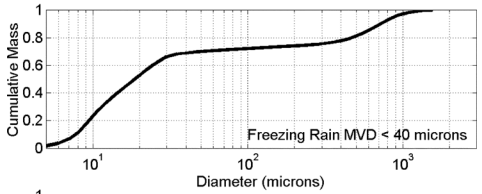
FAA & EASA Appendix O (SLD)

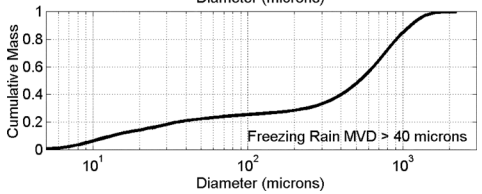
Freezing Drizzle (d_max < 500 um)

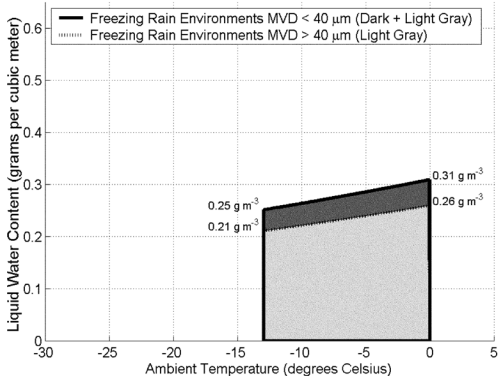












Freezing Rain (d_max > 500 um)