

Nowcasting Airport Winter Weather

Presentation by

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Acknowledgements

- **Monika Bailey, Stewart Cober, Norman Donaldson, Ismail Gultepe, Norbert Driedger, David Hudak, Anna Glazer, Janti Reid, Peter Rodriguez, and J. Walter Strapp**
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Problems Associated with Airport Winter Weather

- **Ice forming on wings of aircraft requiring de-icing**
- **Reduced visibility**
- **Low ceilings**
- **Runway icing and snow removal**
- **In-flight icing during takeoff and landing**
- **Extreme cold temperatures**

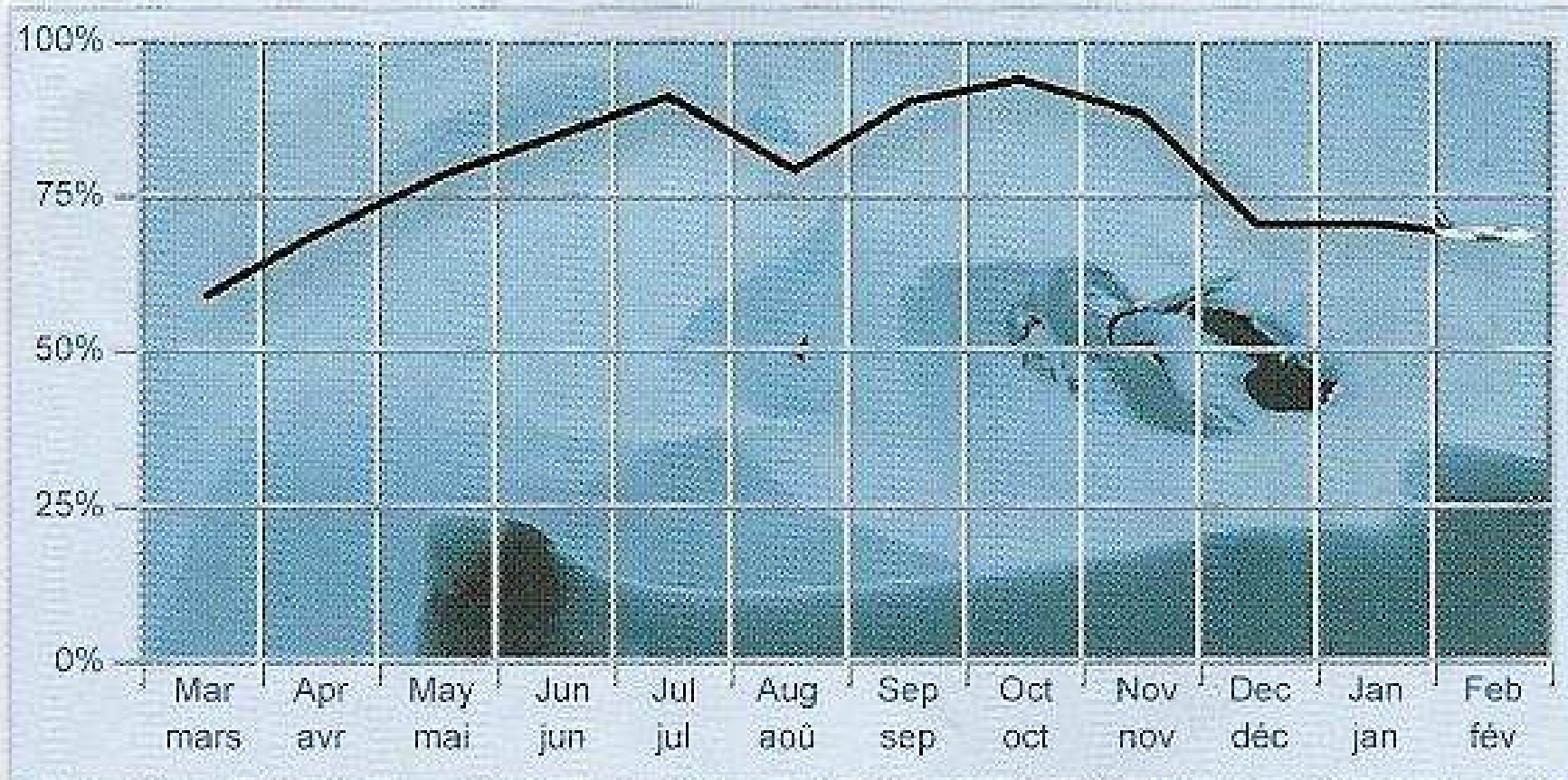
Large Airport Statistics

Airport	Montreal Trudeau	Toronto Pearson	Vancouver International
Destinations	85**	110	90
Passengers per Day	24,500**	78,300*	43,100*
Takeoff and Landings per Day	562*	1108*	862*
Airport Employees	52,000	70,000	28,000

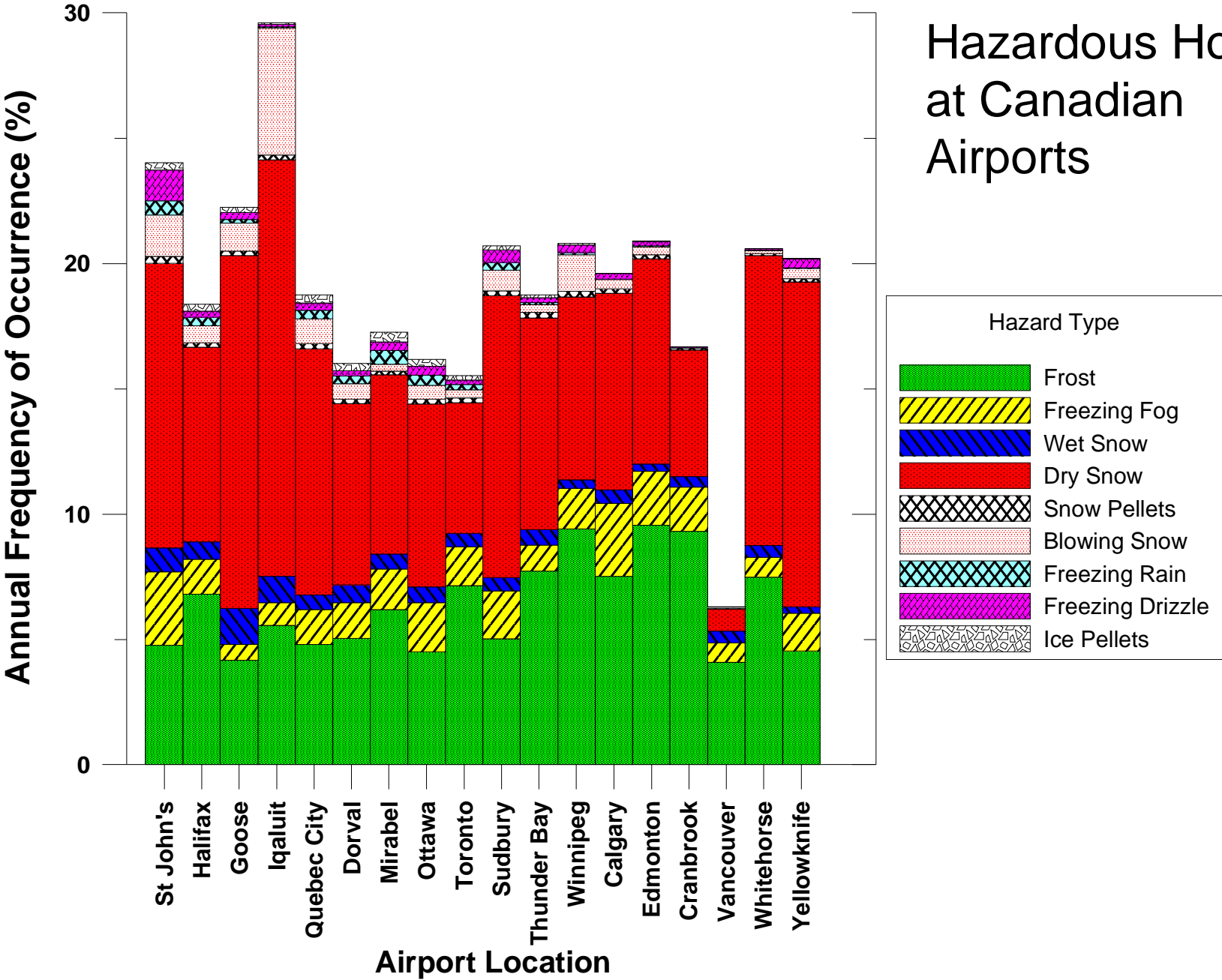
*from 2004 statistics for year; **from 2003 statistics

CanJet Flight Delays

SmartTimes © CanJet Airlines



Hazardous Hours at Canadian Airports



HOT for SAE Type I Fluid

TABLE 1

SAE TYPE I⁵ FLUID HOLDOVER GUIDELINES FOR WINTER 2004-2005

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Approximate Holdover Times Under Various Weather Conditions (minutes)								
°C	°F	Frost ²	Freezing Fog	Very Light Snow ¹	Light Snow ¹	Moderate Snow ¹	Freezing Drizzle ³	Light Freezing Rain	Rain on Cold Soaked Wing	Other ⁴
-3 and above	27 and above	45	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	CAUTION: No holdover time guidelines exist
below -3 to -6	below 27 to 21	45	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6		
below -6 to -10	below 21 to 14	45	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
below -10	below 14	45	5 – 9	7	4 – 7	2 – 4				

°C = Degrees Celsius

°F = Degrees Fahrenheit

OAT = Outside Air Temperature

FP = Freezing Point

HOT for SAE Type II Fluid

TABLE 2-Generic

SAE TYPE II FLUID HOLDOVER GUIDELINES FOR WINTER 2004-2005¹

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Type II Fluid Concentration Neat Fluid/Water (Vol% / Vol%)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
°C	°F		Frost ²	Freezing Fog	Snow ⁶	Freezing Drizzle ⁴	Light Freezing Rain	Rain on Cold Soaked Wing	Other ⁵
above 0	above 32	100/0	12:00	0:35 – 1:30	0:20 – 0:55	0:30 – 0:55	0:15 – 0:30	0:05 – 0:40	CAUTION: No holdover time guidelines exist
		75/25	6:00	0:25 – 1:00	0:15 – 0:40	0:20 – 0:45	0:10 – 0:25	0:05 – 0:25	
		50/50	4:00	0:15 – 0:30	0:05 – 0:15	0:05 – 0:15	0:05 – 0:10		
0 to -3	32 to 27	100/0	8:00	0:35 – 1:30	0:20 – 0:45	0:30 – 0:55	0:15 – 0:30		
		75/25	5:00	0:25 – 1:00	0:15 – 0:30	0:20 – 0:45	0:10 – 0:25		
		50/50	3:00	0:15 – 0:30	0:05 – 0:15	0:05 – 0:15	0:05 – 0:10		
below -3 to -14	below 27 to 7	100/0	8:00	0:20 – 1:05	0:15 – 0:35	0:15 – 0:45 ³	0:10 – 0:25 ³		
		75/25	5:00	0:20 – 0:55	0:15 – 0:25	0:15 – 0:30 ³	0:10 – 0:20 ³		
below -14 to -25	below 7 to -13	100/0	8:00 ⁷	0:15 – 0:20 ⁷	0:15 – 0:30 ⁷				
below -25	below -13	100/0	Type II fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the OAT and the aerodynamic acceptance criteria are met. Consider use of Type I when Type II fluid cannot be used.						

¹C = Degrees Celsius

²F = Degrees Fahrenheit

OAT = Outside Air Temperature

Vol = Volume

Thresholds for Surface Precipitation

- Freezing Rain (ZR) Thresholds

Light: less than 2.5 mm/hr

Heavy: greater than 7.5 mm/hr

Moderate: between light and heavy

- Freezing Drizzle (ZL) Thresholds

Light: less than 0.2 mm/hr (or 0.1 inch/hr)

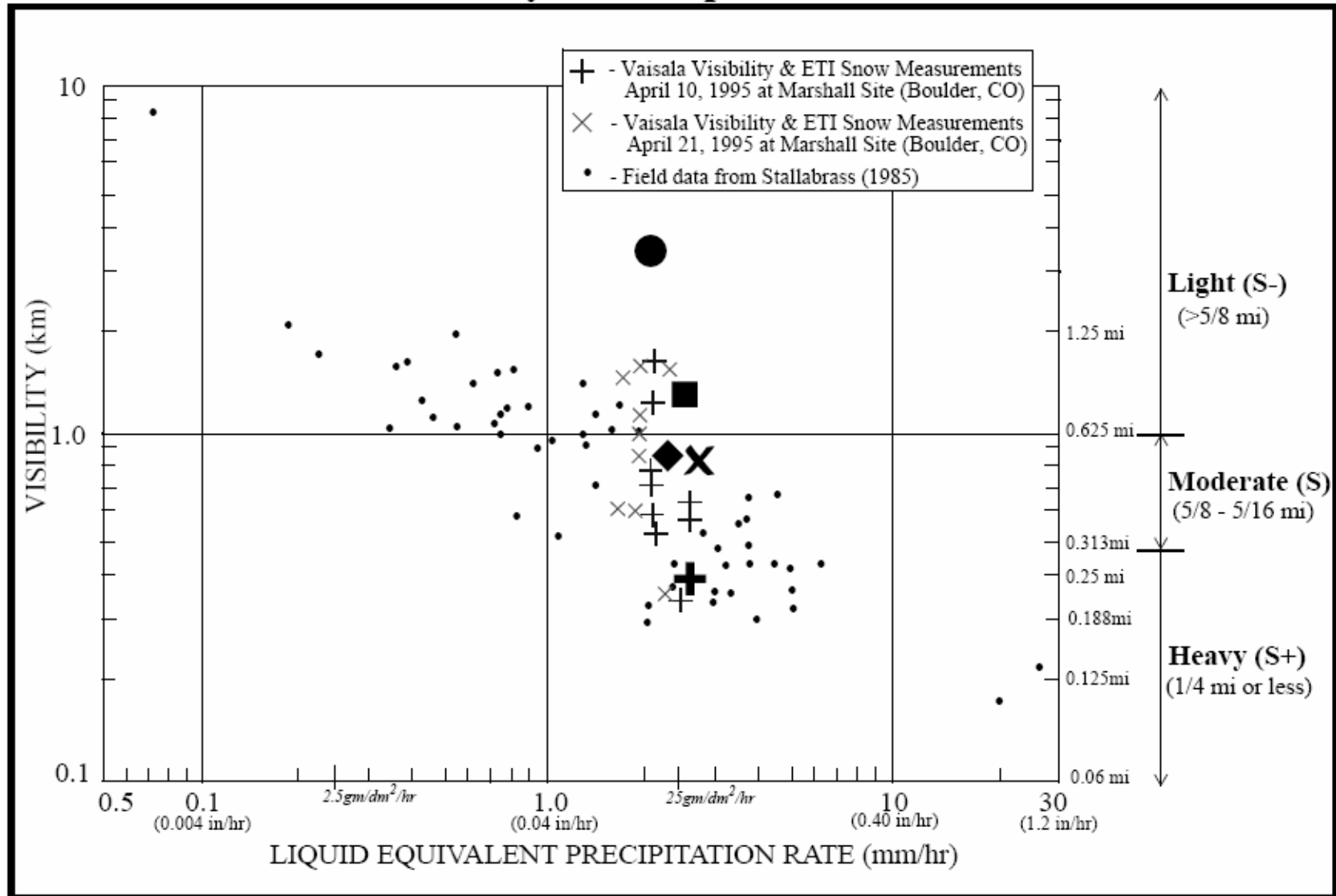
Heavy: greater than 0.4 mm/hr (or 0.2 inch/hr)

Moderate: between light and heavy

Snowfall Rate Information

- Light: Visibility $> 3/4$ mile (1.2 km) NWS
Visibility $> 5/8$ mile ManObs
- Moderate: Visibility $1/2$ mile (0.8 km) NWS
Visibility $1/2$ or $3/8$ mile ManObs
- Heavy: Visibility $< 1/4$ mile (0.4 km) NWS
Visibility $1/4$, $1/8$ or 0 miles ManObs
- No definitions for mm/hr. However, SAE G12 use 1-2.5 mm/hr (water equivalent) as definition of moderate snow (private communication – Barry Myers)

Visibility vs Precipitation Rate



Rasmussen, R.M. et al, 1999: The estimation of snowfall rate using visibility. J. Appl. Meteor., 38, 1542-1563.

TABLE 8
 VISIBILITY IN SNOW VS. SNOWFALL INTENSITY CHART¹

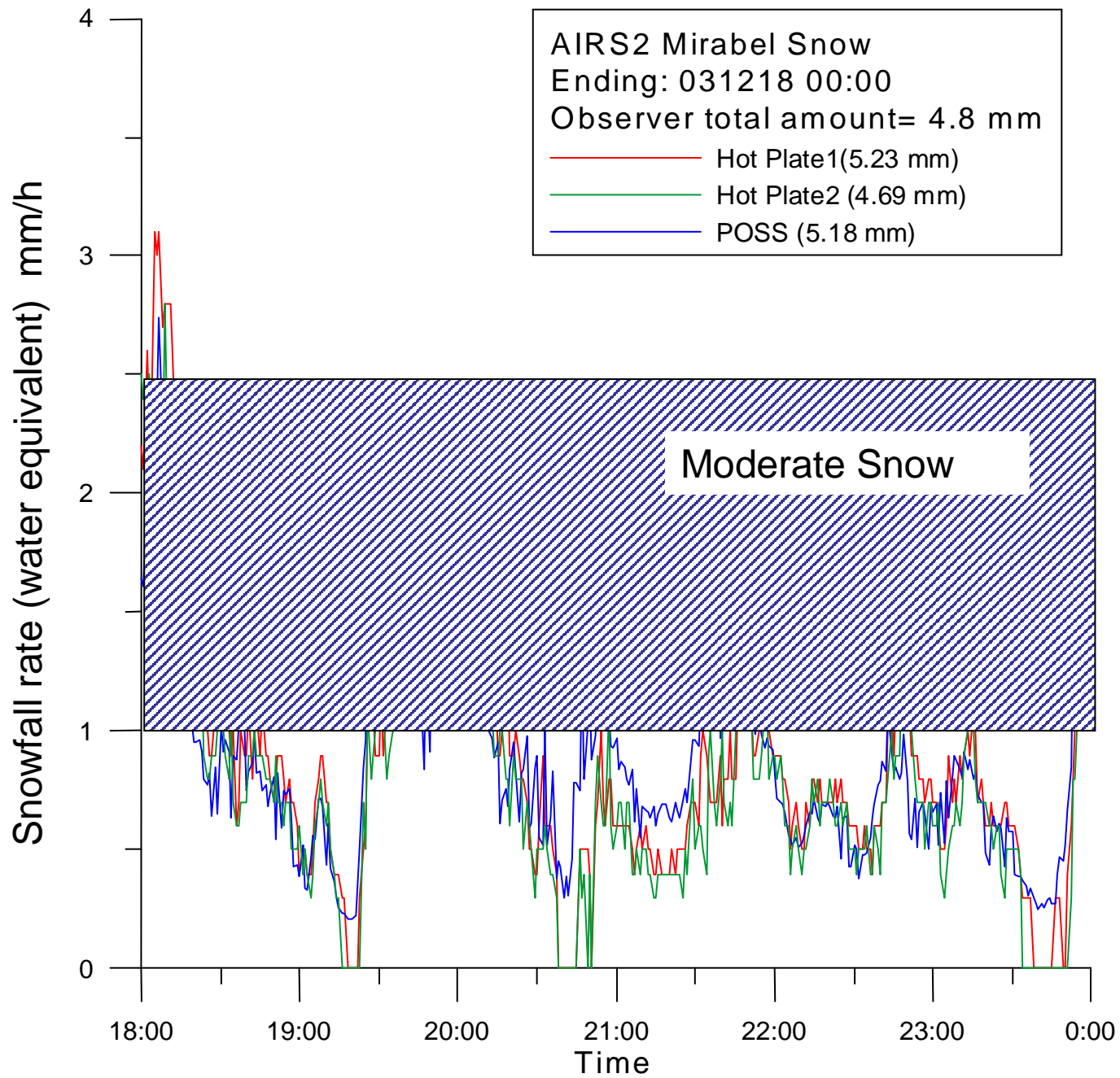
Lighting	Temperature Range		Visibility in Snow (Statute Miles)			
	°C	°F	Heavy	Moderate	Light	Very Light
Darkness	-1 and above	30 and above	≤1	>1 to 2½	>2½ to 4	>4
	Below -1	Below 30	≤¾	>¾ to 1½	>1½ to 3	>3
Daylight	-1 and above	30 and above	≤½	>½ to 1½	>1½ to 3	>3
	Below -1	Below 30	≤¾	>¾ to 7/8	>7/8 to 2	>2

1 Based on: *Relationship between Visibility and Snowfall Intensity* (TP 14151E), Transportation Development Centre, Transport Canada, November 2003; and *Theoretical Considerations in the Estimation of Snowfall Rate Using Visibility* (TP 12893E), Transportation Development Centre, Transport Canada, November 1998.

Transport Canada Analysis of MSC Surface Data

(from Barry Myers, TC)

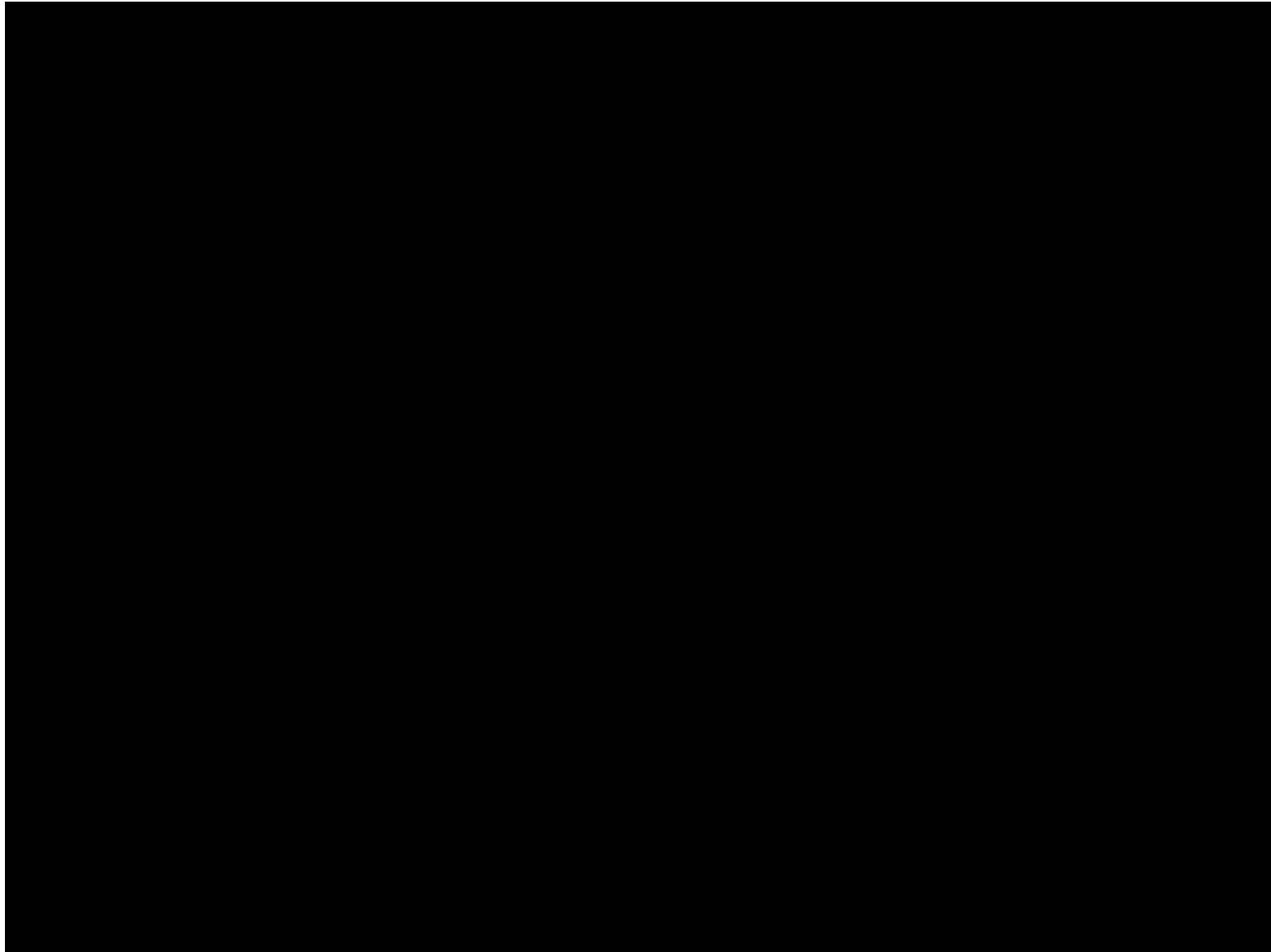
		50%	75%	95%	99.0%	99.9%
#min		Precipitation Rate mm/hr (water equivalent)				
338151	Snow	~0.3	~1.0	2.0	3.9	7.0



Characterize Accretion of Ice



**031130F1 NASA Twin Otter
18 minute icing encounter
over YOW with FZDZ**



Movie Showing Clear Ice Shed from Twin Otter
During YOW Approach during AIRS II

Major Accidents: In-flight Icing

§ 1994 Roselawn, IN, ATR-72 Turboprop, 68 fatal

- Holding in Severe Icing / SLD
- 4 ATR icing incidents prior to accident
- Generated several recommendations to FAA regarding icing certification

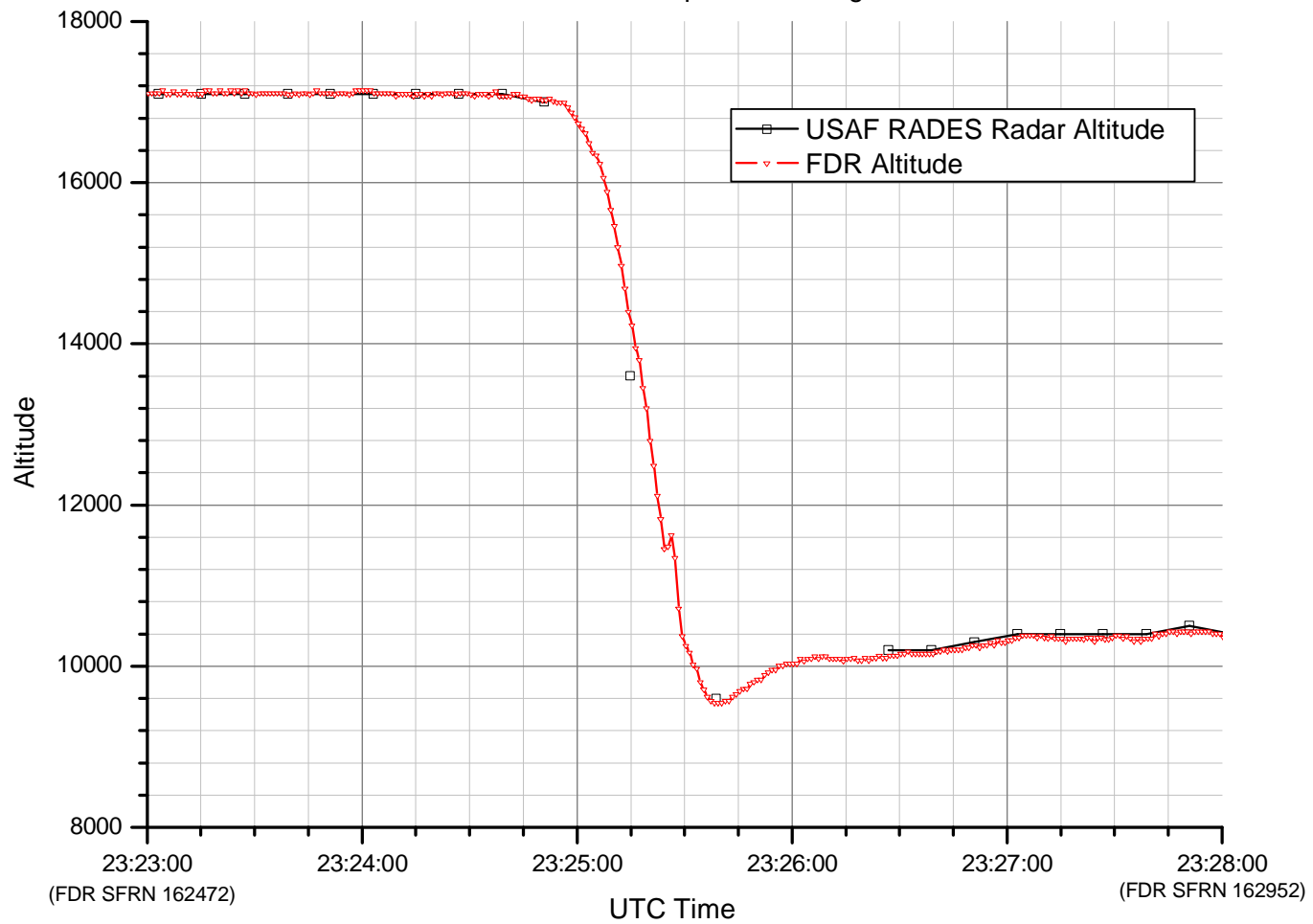
§ 1997 Monroe, MI, Comair 3272, EMB-120 Turboprop, 39 fatal

- Encountered icing conditions while on approach
- Deice boots not activated
- 6 EMB-120 icing incidents prior to accident
- Generated additional icing certification recommendations to FAA

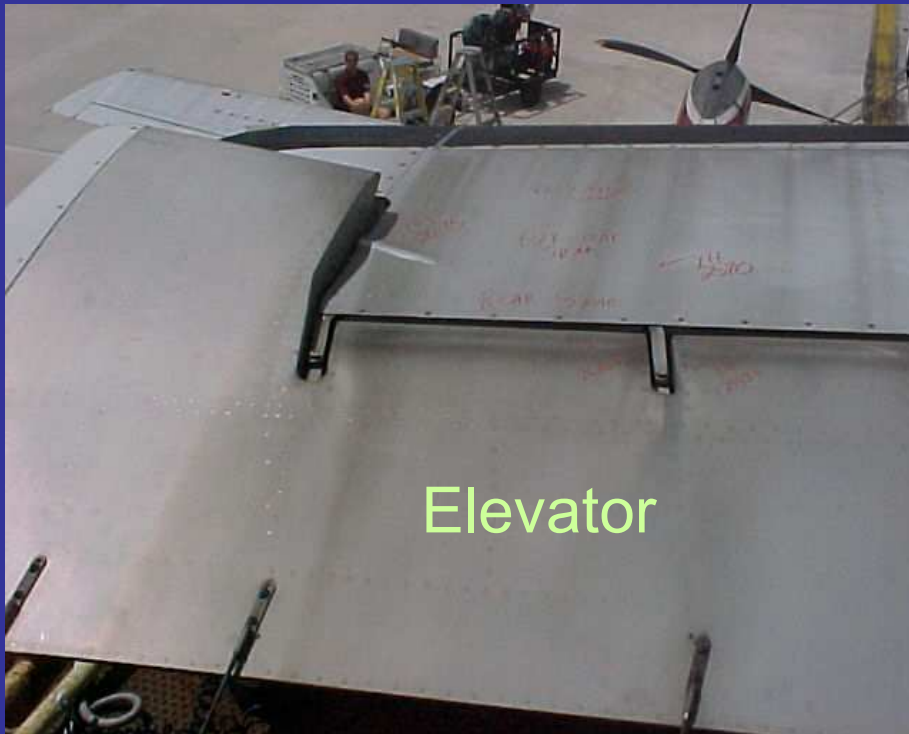
March 19 2001
Comair Flight 5054 EMB-120 Incident
West Palm Beach, FL

- § 8000 ft altitude loss, structural damage to horizontal tail and elevator
- § Pilots reported using de-icing boots (3 minute activation cycle) and seeing some remnants of ice on boots after boot activation
- § Indications from FDR, CVR Ice Detector was active Possible SLD conditions (SAT – 4 Deg C)

Comair 5054 - March 19, 2001
FDR/Radar Altitude Comparison During Event



View from above Horizontal Stabilizer



Airframe Structural Icing:

Bombardier Challenger CL-600
Birmingham, England – Jan. 4, 2002



- § 5 fatalities
- § Crashed During Takeoff
- § Was not de-iced prior to takeoff
- § UK AAIB finding: “Frost contamination of aircraft lifting surfaces was present when the aircraft took-off.”

Under Investigation:

Bombardier Challenger CL-600

Montrose, CO – November 29, 2004



- § 3 fatalities, 3 seriously injured
- § Crashed During Takeoff
- § Atmospheric conditions conducive to upper wing surface ice accumulation
- § Upper wing ice contamination is being investigated

Airframe Structural Icing

Cessna 208 Caravan:



- § Single-engine turboprop airplane
- § Seat 10 pax, or haul freight
- § Successfully passed current FAA icing certification, and additional review of icing concerns
- § Eight icing-related fatal accidents in last 4 years
- § Subject of current special assessment by staff

Cessna 208B Suspected Icing Accidents: 2001-2004

- ✂ April 28, 2001 – Argentina (*10 fatal*)
- ✂ May 5, 2001 – Steamboat Springs, CO (*1 fatal*)
- ✂ Oct.10, 2001 – Dillingham, AK (*10 fatal*)
- ✂ March 6, 2002 – Barrow, AK (*5 seriously injured*)
- ✂ March 15, 2002 – Alma, WS (*1 fatal*)
- ✂ Nov. 8, 2002 – Parks, AZ (*4 fatal*)
- ✂ October 29, 2003 – Cody, WY (*1 fatal*)
- ✂ January 18, 2004 – Pelee Island, Ontario (*10 fatal*)
(*Under Investigation – TSB Canada*)
- ✂ December 6, 2004 - Bellevue, ID (*2 fatal*)
(*Under Investigation – NTSB*)

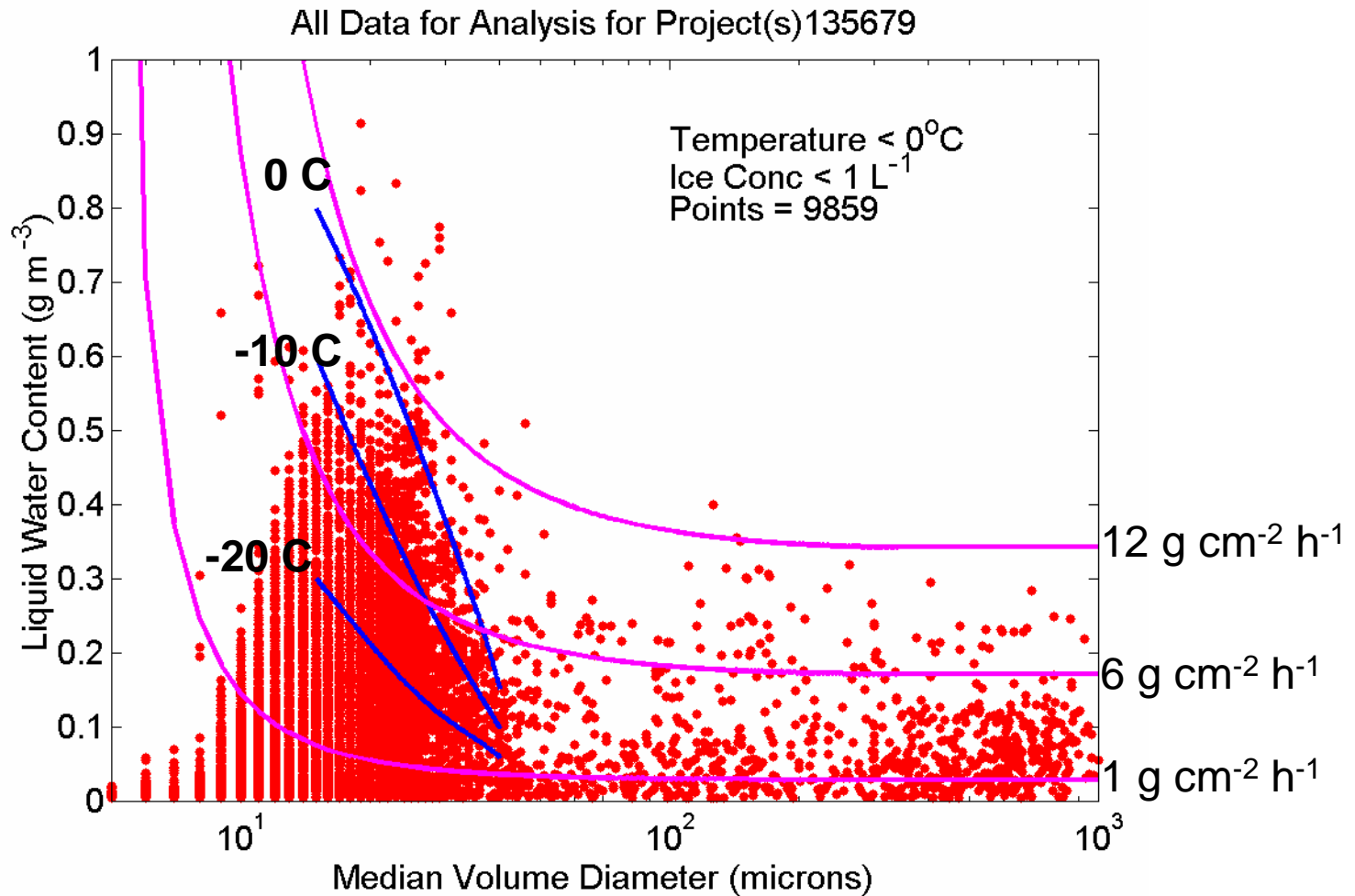
Summary of the Data

Definition	MSC	NASA	Total
Projects	4	3	7
Flights	81	53	134
Hours	311	91	402
Distance (km)	112068	22984	135052
30-s Points	37356	10945	48301

Summary of In-Cloud Conditions

Definition	30-s Points	Characteristics
In-Flight	48301	
In-Cloud	27497 (57%)	TWC > 0.005 g m ⁻³
In-Cloud Cold	22267 (46%)	+ Ta ≤ 0°C
In-Icing	14206 (29%)	+ L/M Phase
In-Spectra	10135 (21%)	+ Ice ≤ 1 L ⁻¹
In-SLD	2497 (5%)	+ Dmax ≥ 100 μm

Characterizing Icing Environment for New Certification Rules



Each data point represents a 30-s (3-km) MedVD LWC observation.

Freezing Precipitation Estimate Comparison

		50%	75%	95%	99.0%	99.9%
Method	Type	Precipitation Rate mm/hr				
In-Flight	ZL	0.03	0.07	0.26	0.60	1.13
POSS	ZL	~0.1	~0.2	0.4	0.65	??
In-Flight	ZR	0.50	1.1	2.1	3.2	4.5
POSS	ZR	0.65	1.2	3.0	7.9	??
Gauge	ZR	0.67	1.7	3.3	4.5	6.2

An extreme value analysis, similar to what was done for the in-flight and Gauge data, needs to be done for POSS data.

Alliance Icing Research Study II

- A large international research program (participants from 25 organizations from N.A. and Europe, gov't and university sectors)
- Lead by MSC
- Conducted in the Ottawa-Mirabel region 3 Nov 2003 to 13 Feb 2004
- Focus on aviation meteorology research, nowcasting, aircraft icing, cloud processes
- Web site <http://airs-icing.org/> (Science Plan, Data access, publications, etc)
- Endorsed by Aircraft Icing Research Alliance (AIRA) and WWRP Aircraft In-Flight Icing Project (AIFI)
- Five (5) research aircraft involved
- Three (3) different Nowcasting systems (MSC, NASA, NCAR/NOAA)
- Data currently being quality controlled and archived
- Project Workshop was conducted at Mt. Tremblant, 9-10 November
- Special Session at AIAA in Reno in January/05



Surface Instrumentation at Mirabel



Participating Research Aircraft



NASA ER-2



NRC Convair-580



NCAR C-130



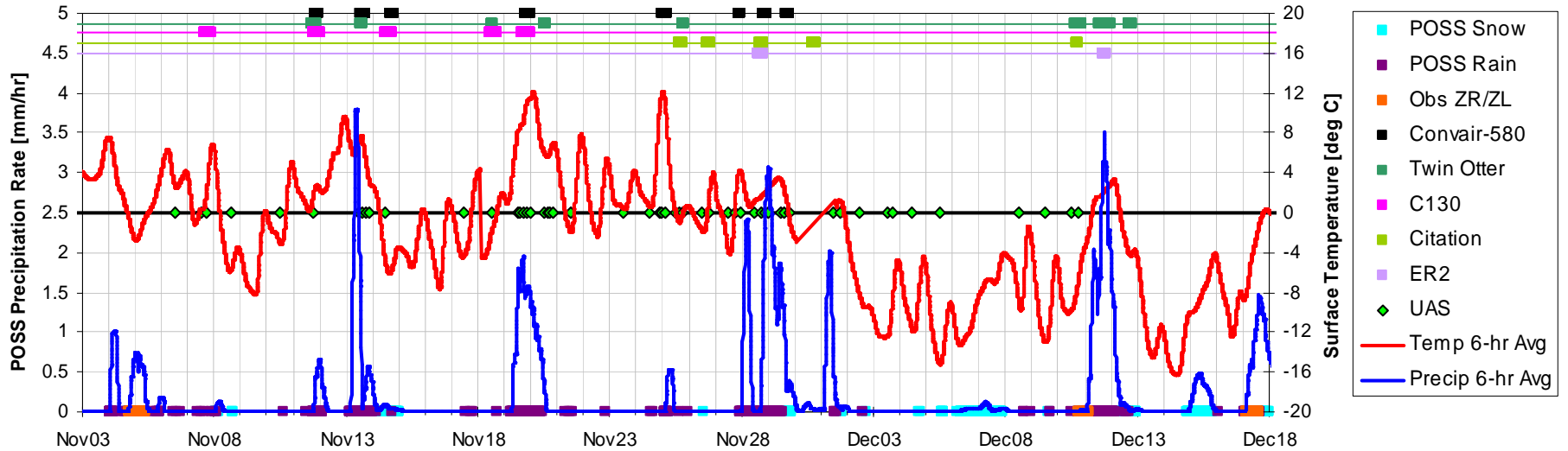
UND Citation



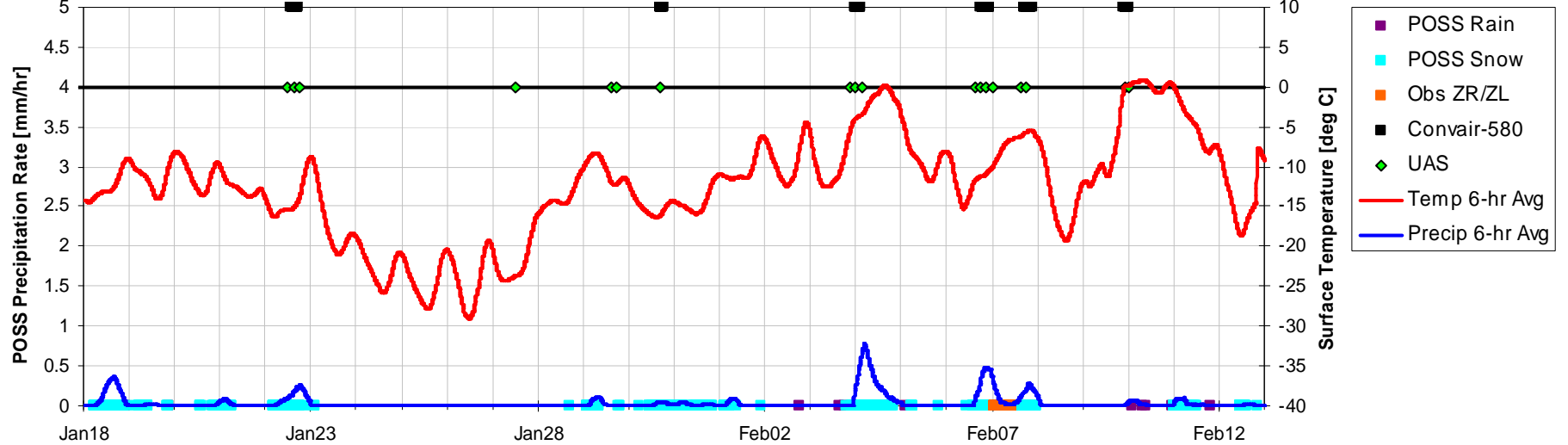
NASA Twin Otter

AIRS II Precipitation & Flight Summary over Mirabel

IOP1

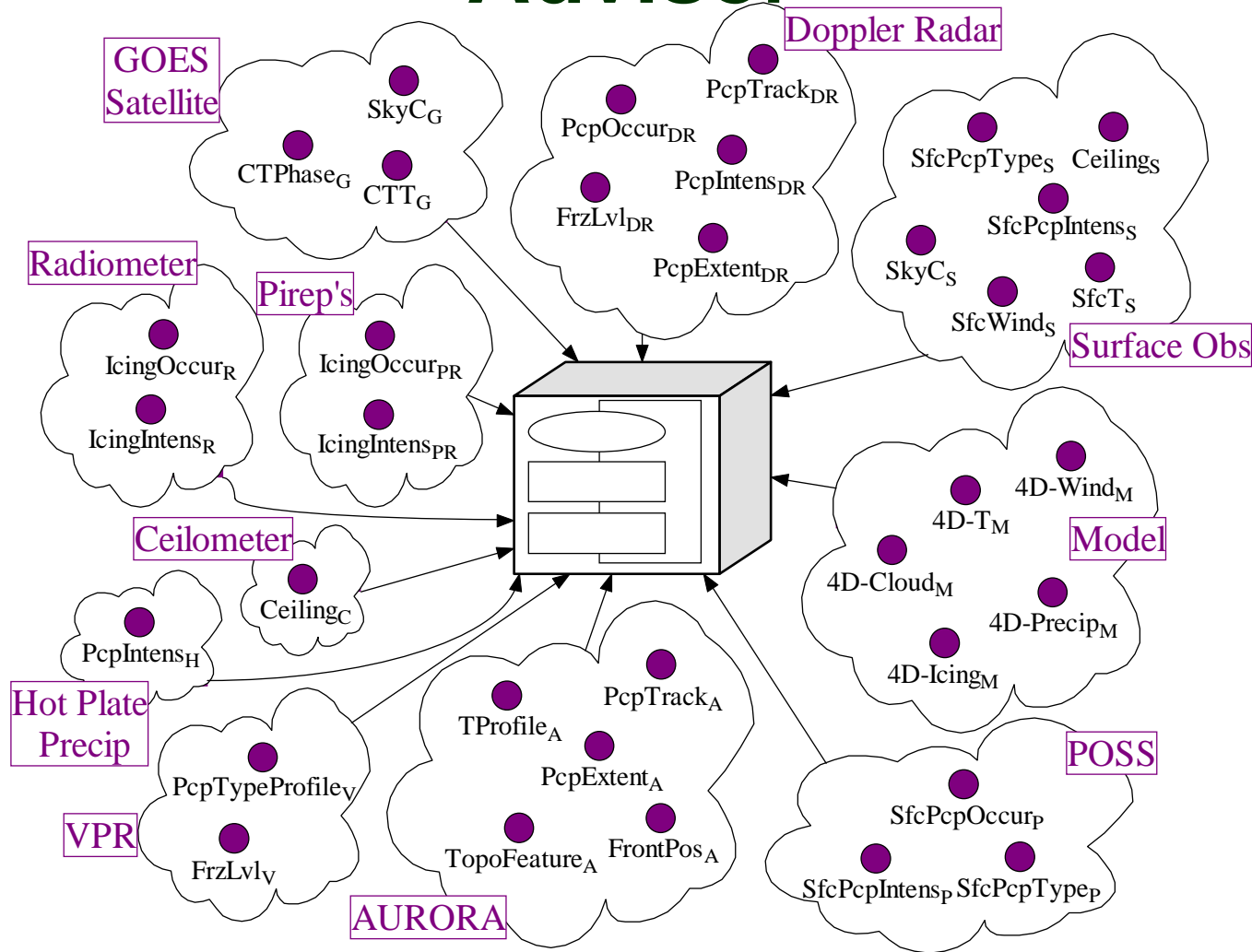


IOP2



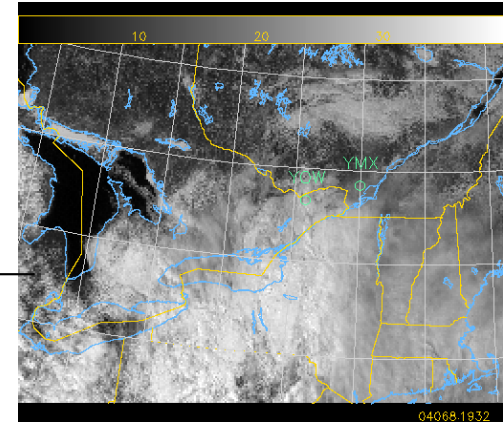
MSC-AVISA

Airport Vicinity Icing and Snow Advisor

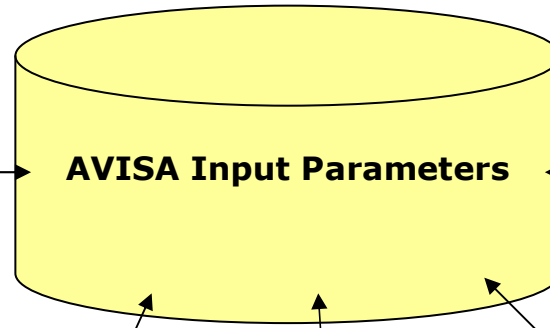
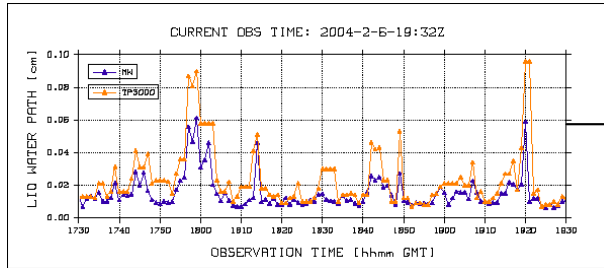


AVISA Algorithm - Input

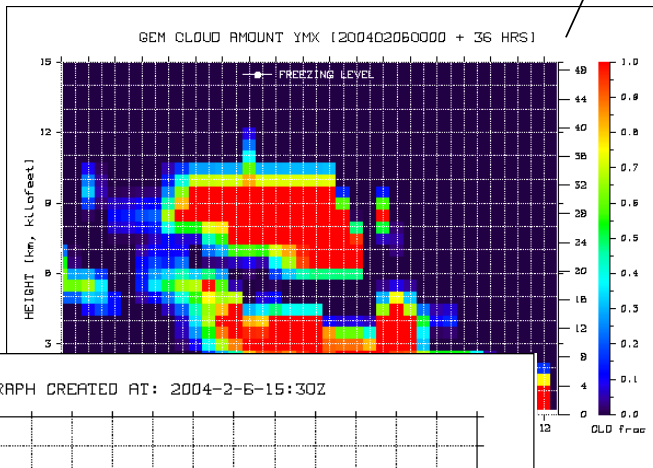
GOES Satellite



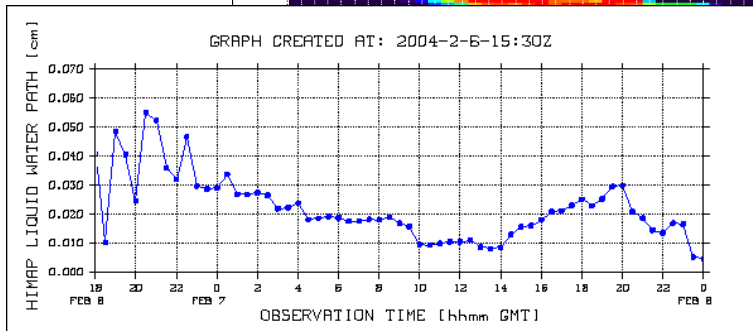
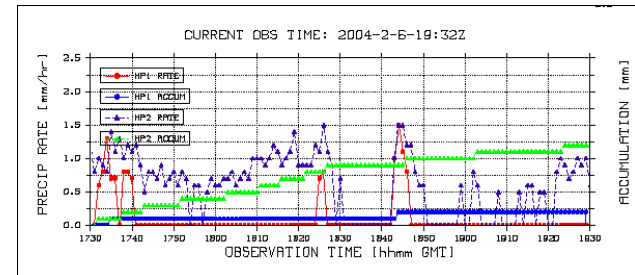
Radiometers



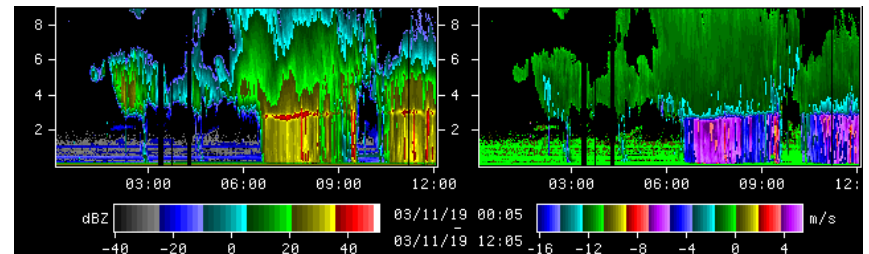
HIMAP & GEM Models



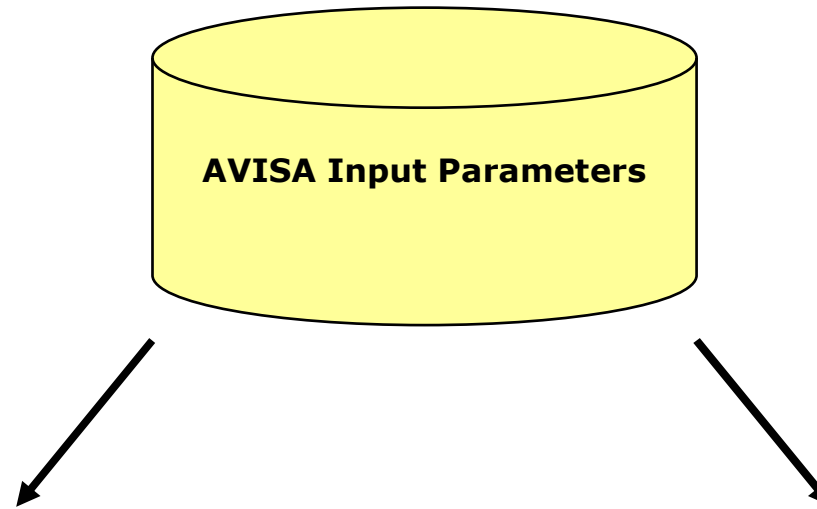
POSS, HP and Met Station



Doppler Radar & VPR



AVISA Algorithm – SLW and SLD



Derive SLW for current conditions & forecast

- From radiometer, cloud base and top
- From GOES icing satellite techniques
- From HIMAP or GEM models
- FROM VPR LWC & particle typing

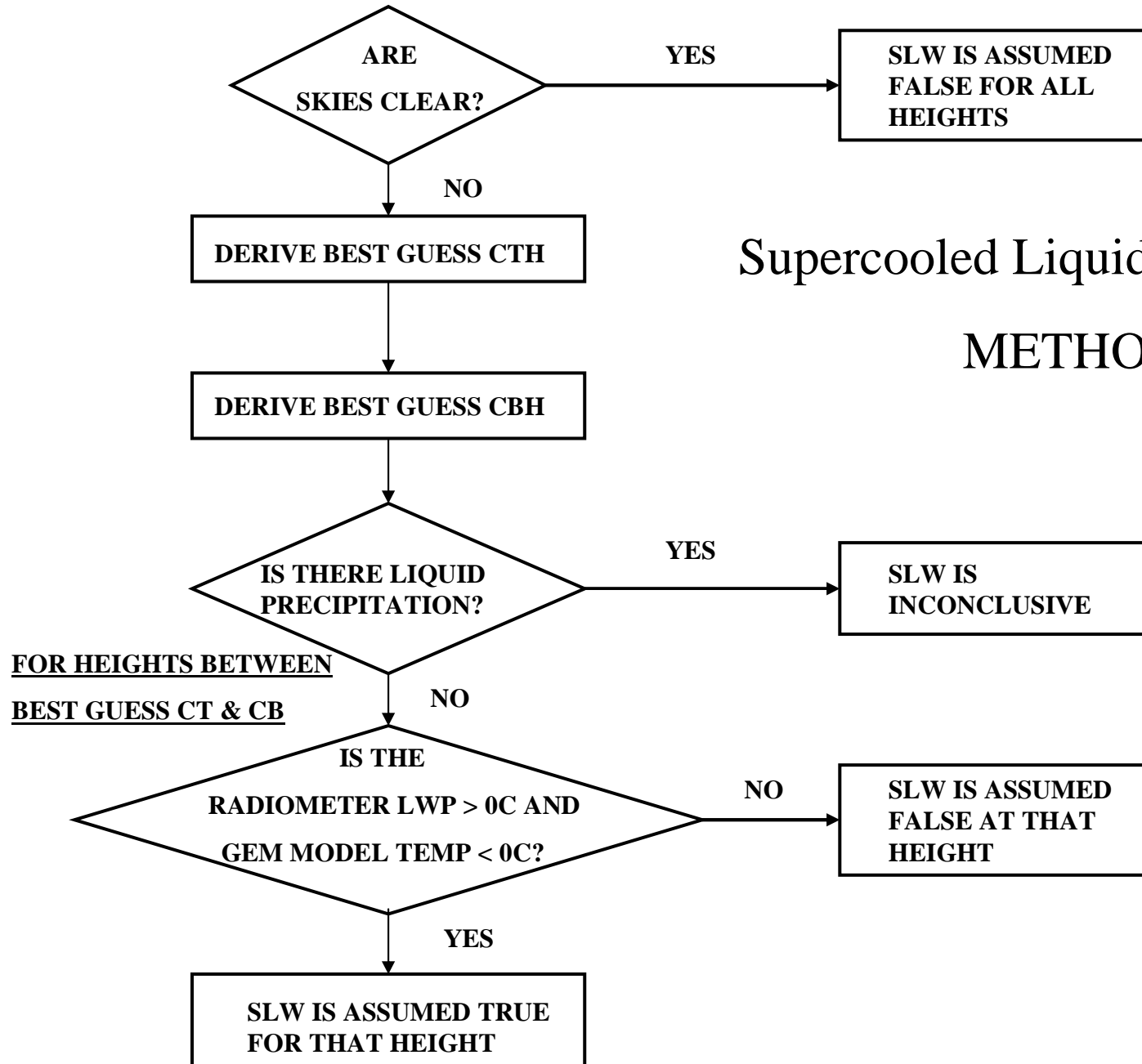
Derive SLD for current conditions & forecast

- From VPR LWC & particle typing
- From POSS typing & surface obs

SLW - Supercooled Liquid Water, SLD - Supercooled Large Drops (> 50 μ m)

Supercooled Liquid Water (SLW)

METHOD 1



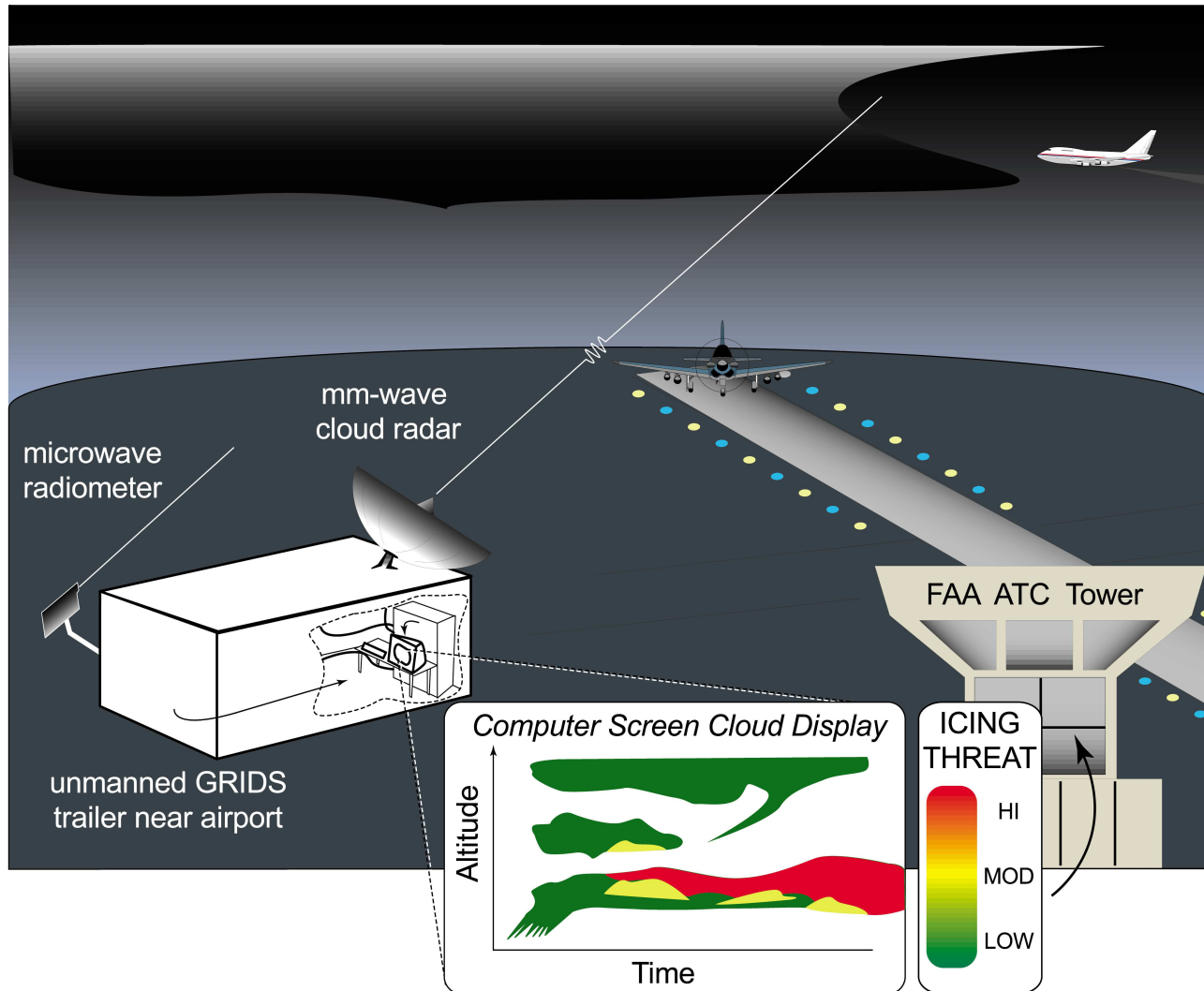
Other Nowcasting Systems

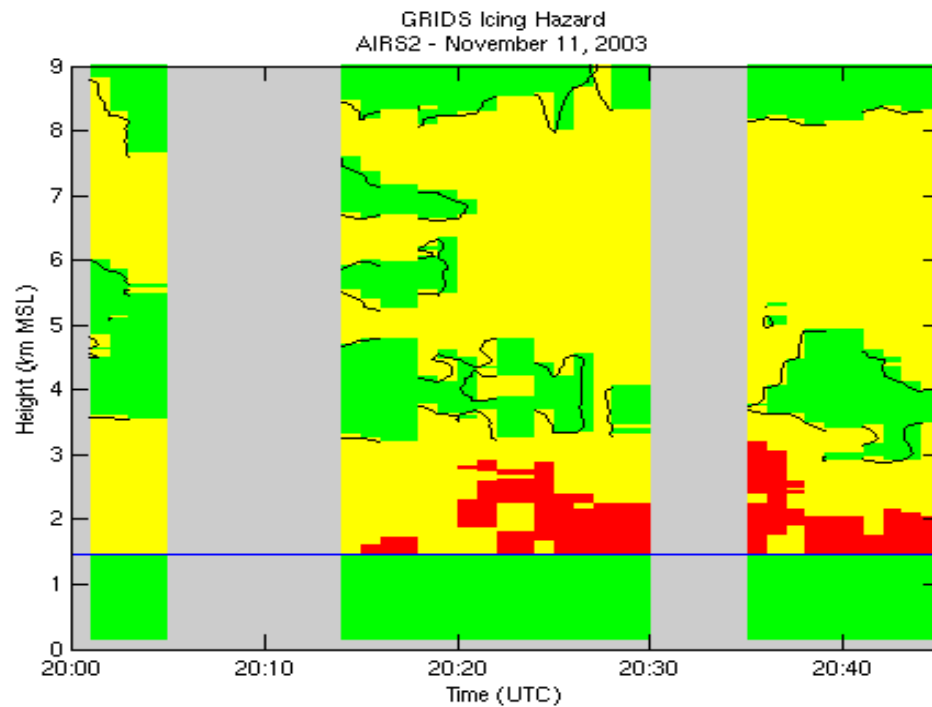
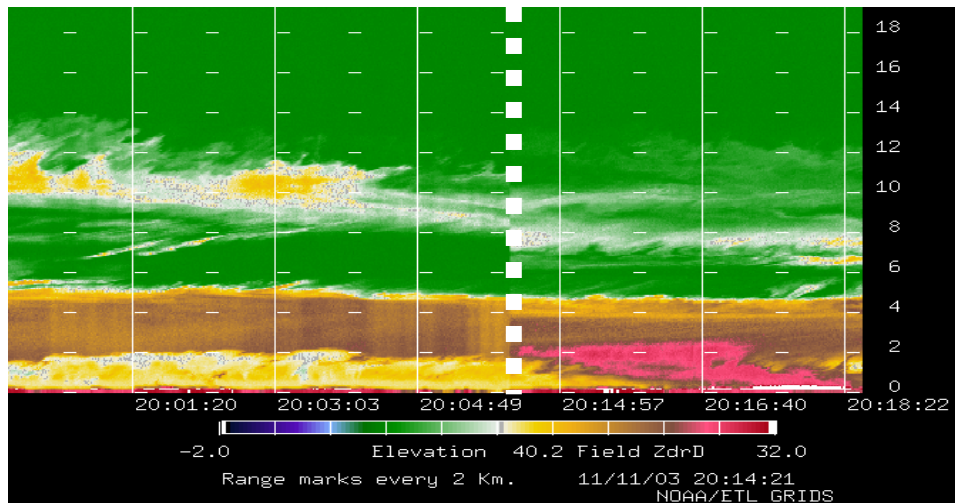
NOAA Ground Based Icing Detection System (GRIDS) integrates a Ka-band dual-polarized radar, a microwave radiometer, local surface meteorological measurements, and information from a numerical weather forecast model (the U.S. National Center for Environmental Prediction's Rapid Update Cycle Model, or RUC) ingested via the Internet to produce icing forecasts in the vicinity of an airport.

NASA Icing Remote Sensing System (NIRSS) combines a vertically staring dual band (X and Ka) radar, a multifrequency microwave radiometer, and a ceilometer (Reehorst and Koenig, 2001). The goal of this development effort is to demonstrate a relatively low cost, stand-alone icing condition detection system in the airport (terminal) environment.

NCAR Weather Support to Deicing Decision Making (WSDDM) Winter weather airport nowcasting system with emphasis on ground deicing problems and weather. Uses NEXRAD radar and surface sensors. (see Rasmussen et al. 2001: Bulletin AMS)

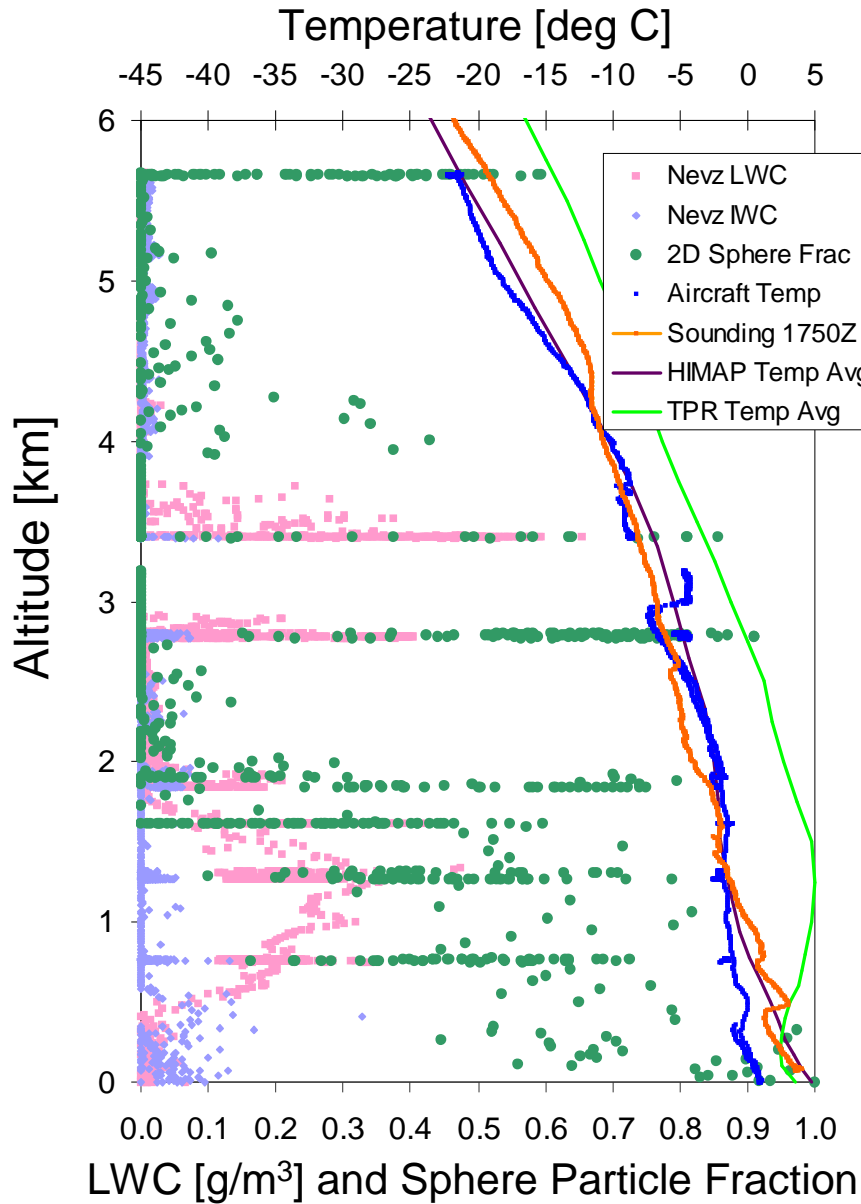
The NOAA-ETL Ground-based Remote Icing Detection System



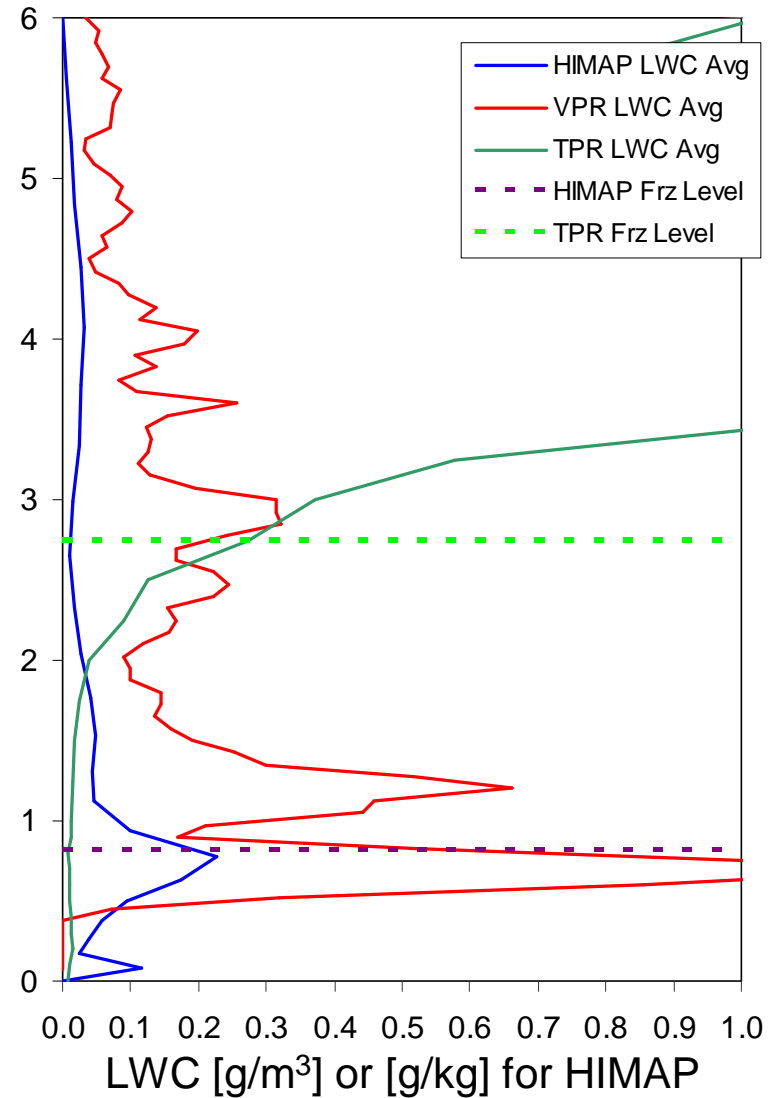


Sample Products from
Ground-based
Remote Icing
Detection System
(GRIDS)

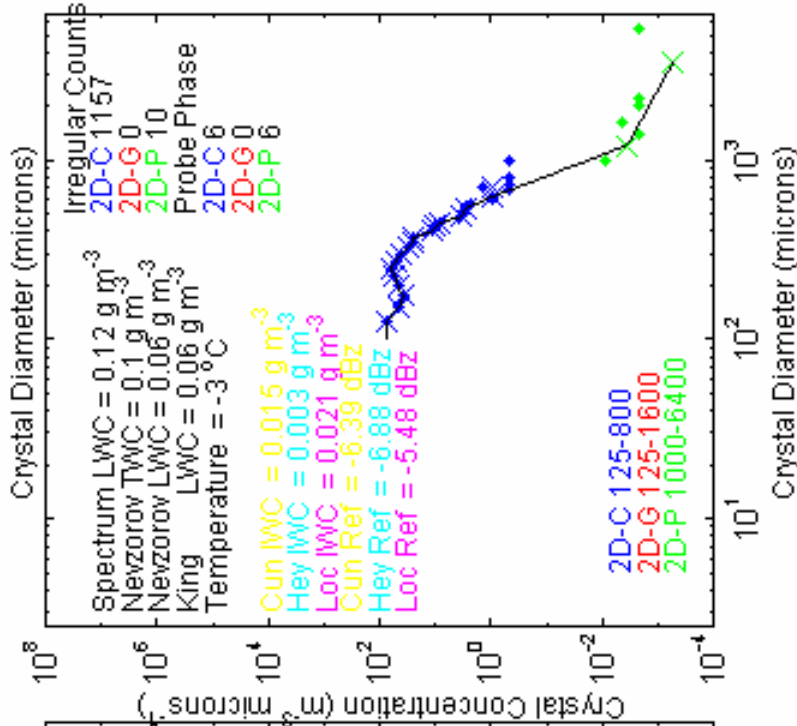
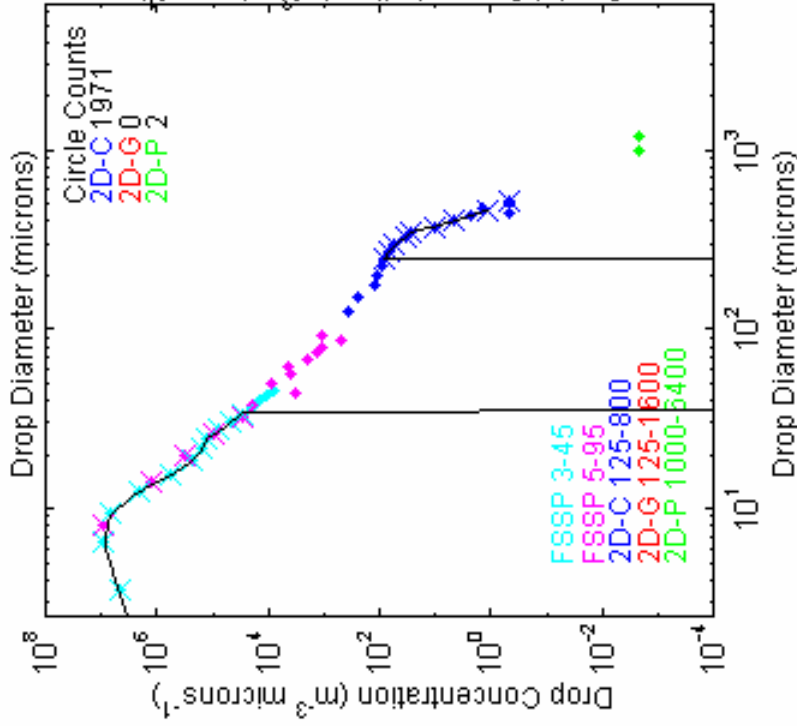
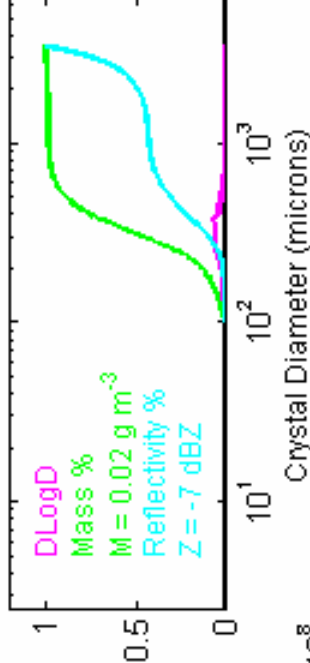
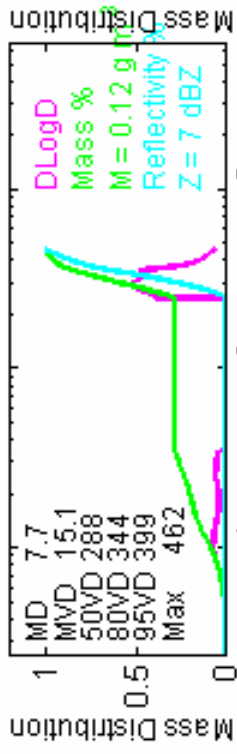
Case Study: November 11, 2003 1940-2210 UTC



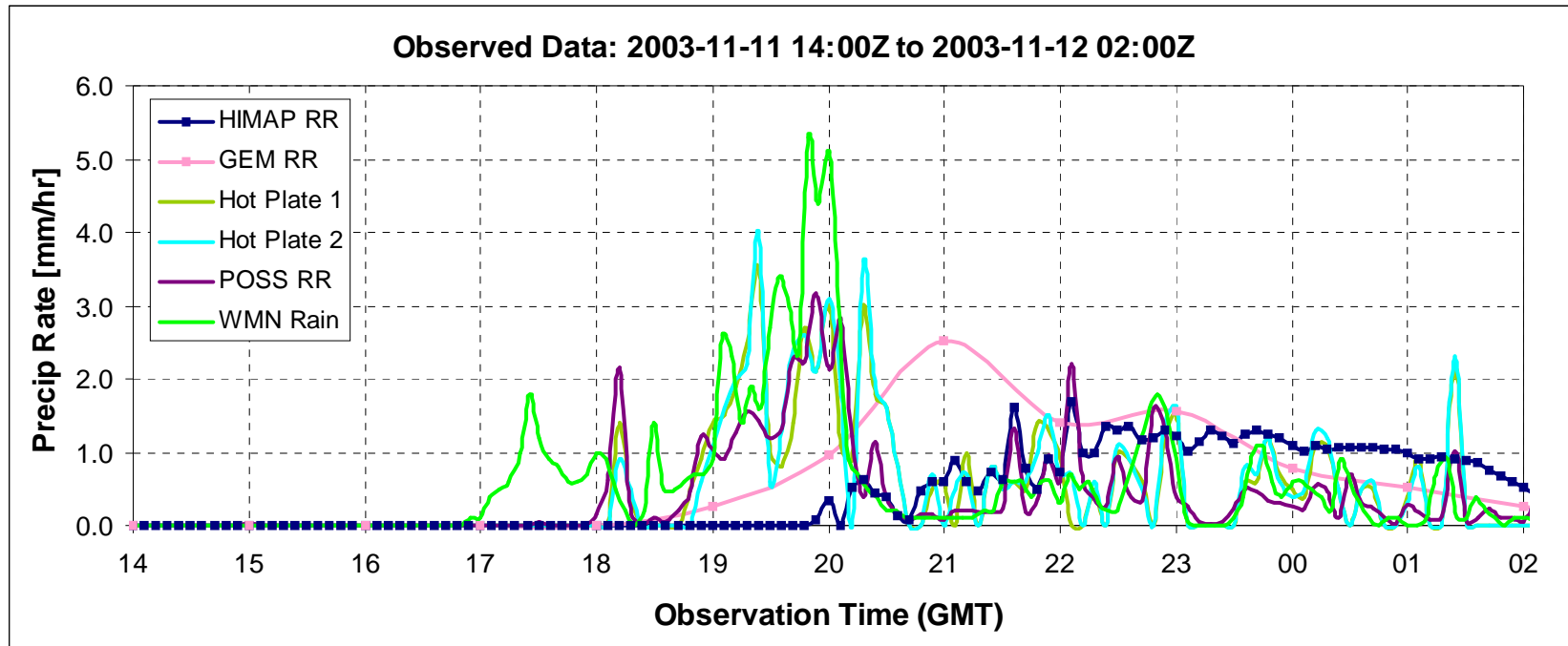
L+M Icing



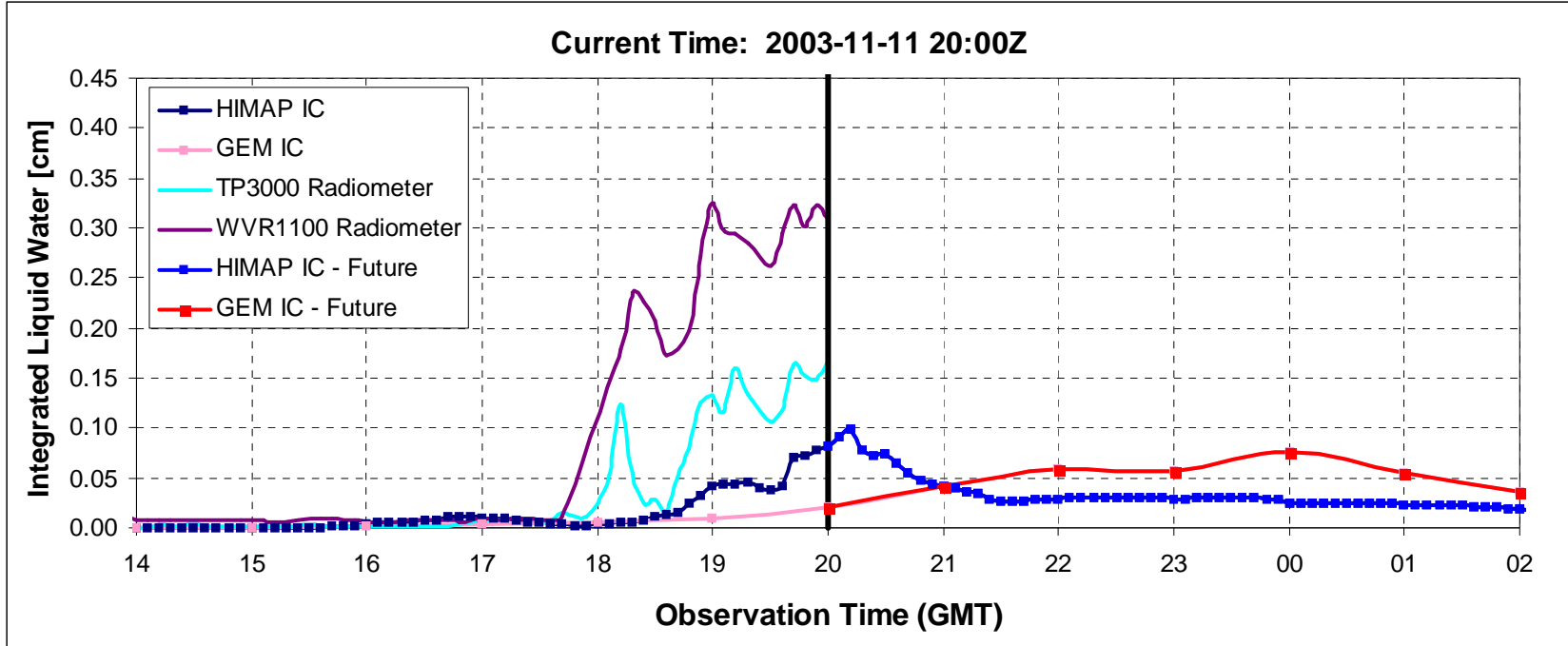
Flight 059 11-Nov-03 Time 210400 Cloud-Pt 166Phase 6 Flight-Pt 201



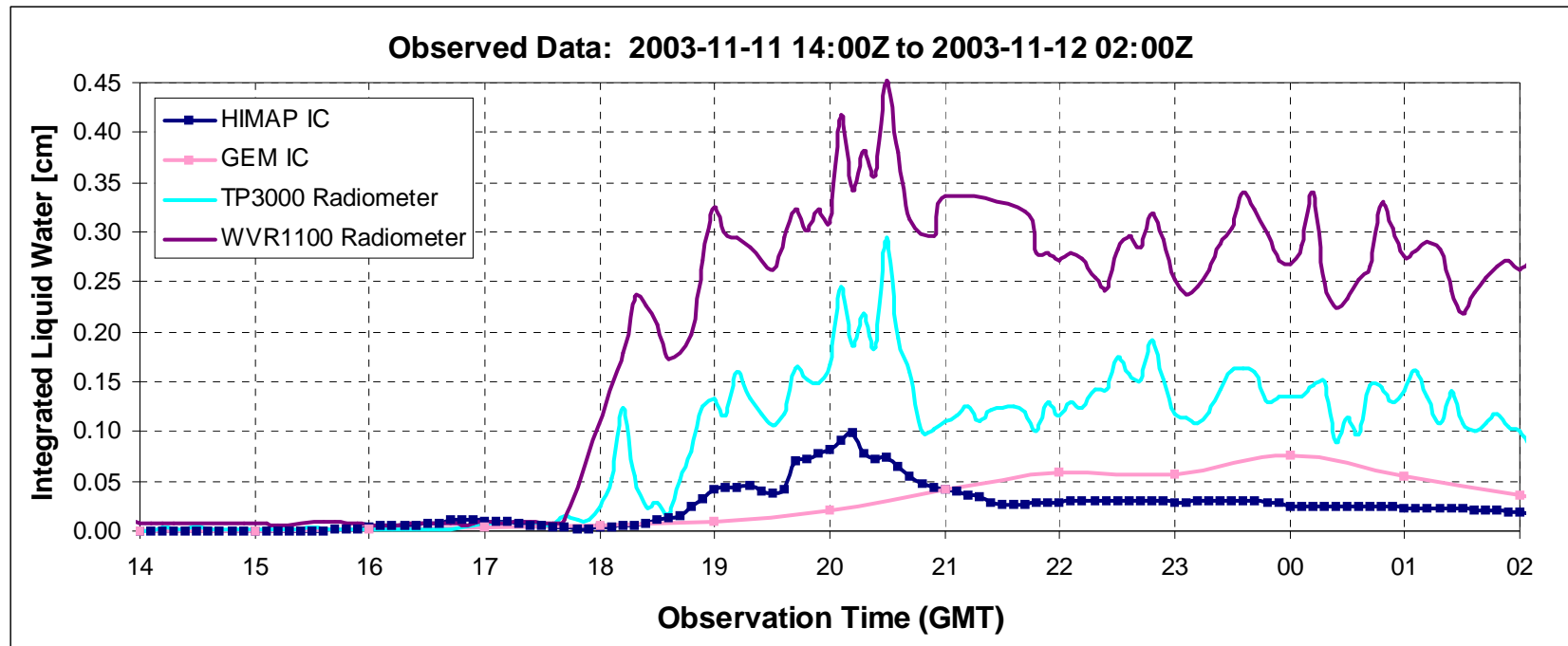
AVISA Precipitation – Observed Data for November 11, 2003 – Same 12 Hour Period



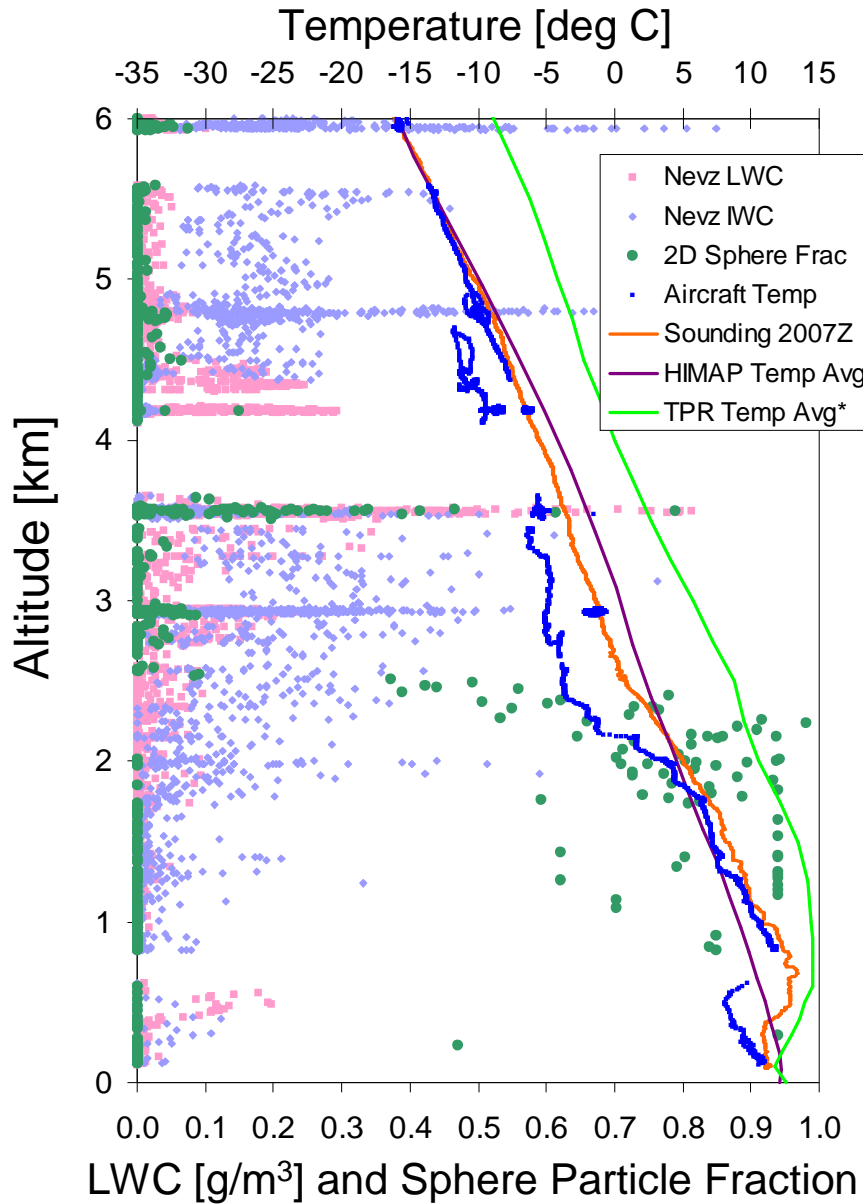
AVISA Liquid Water Path Forecast Display for November 11, 2003 at 20 UTC



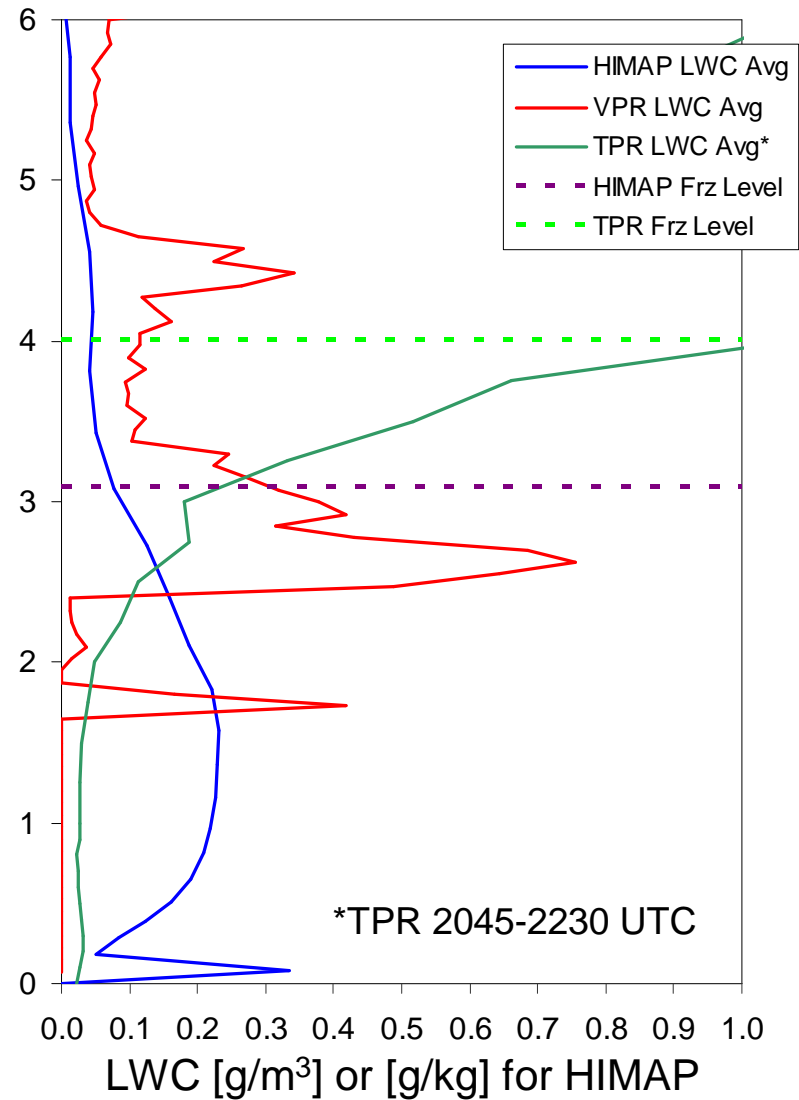
AVISA Liquid Water Path – Observed Data for November 11, 2003 – Same 12 Hour Period



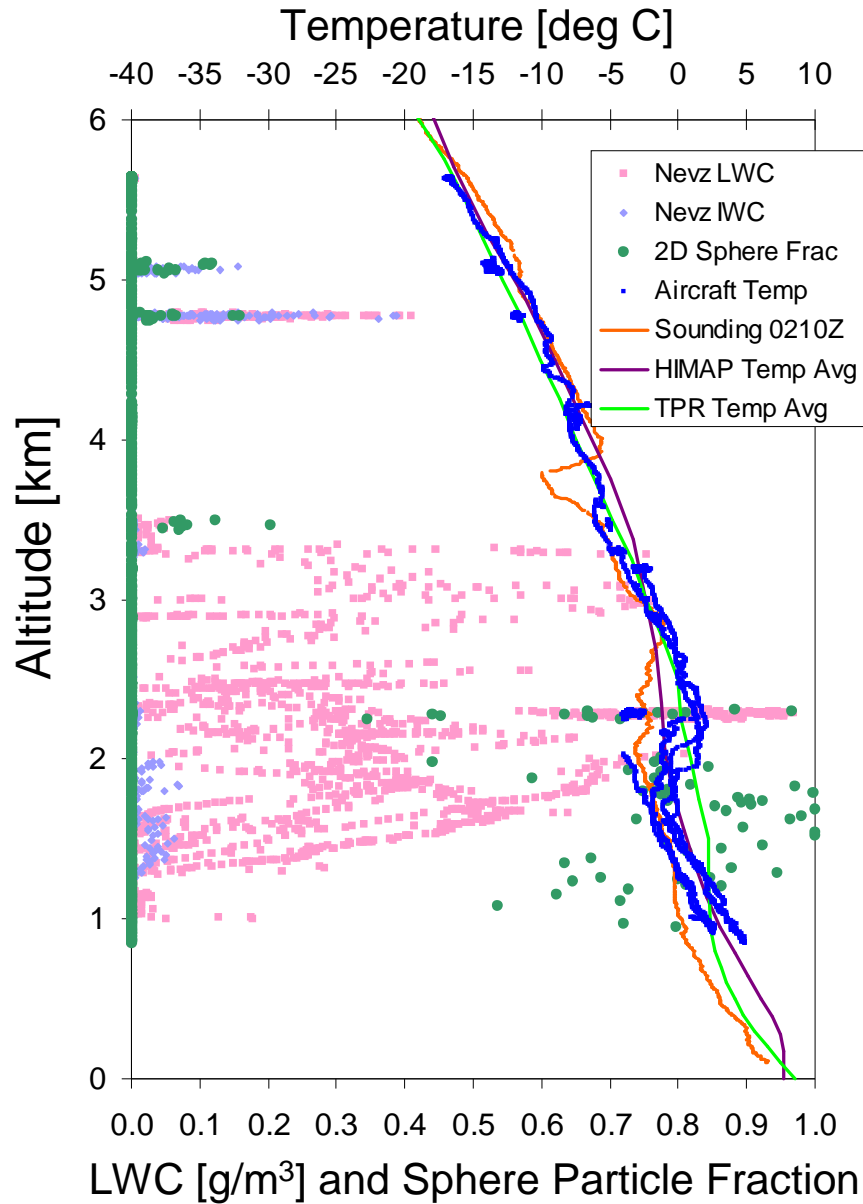
Case Study: November 19, 2003 2045-2345 UTC



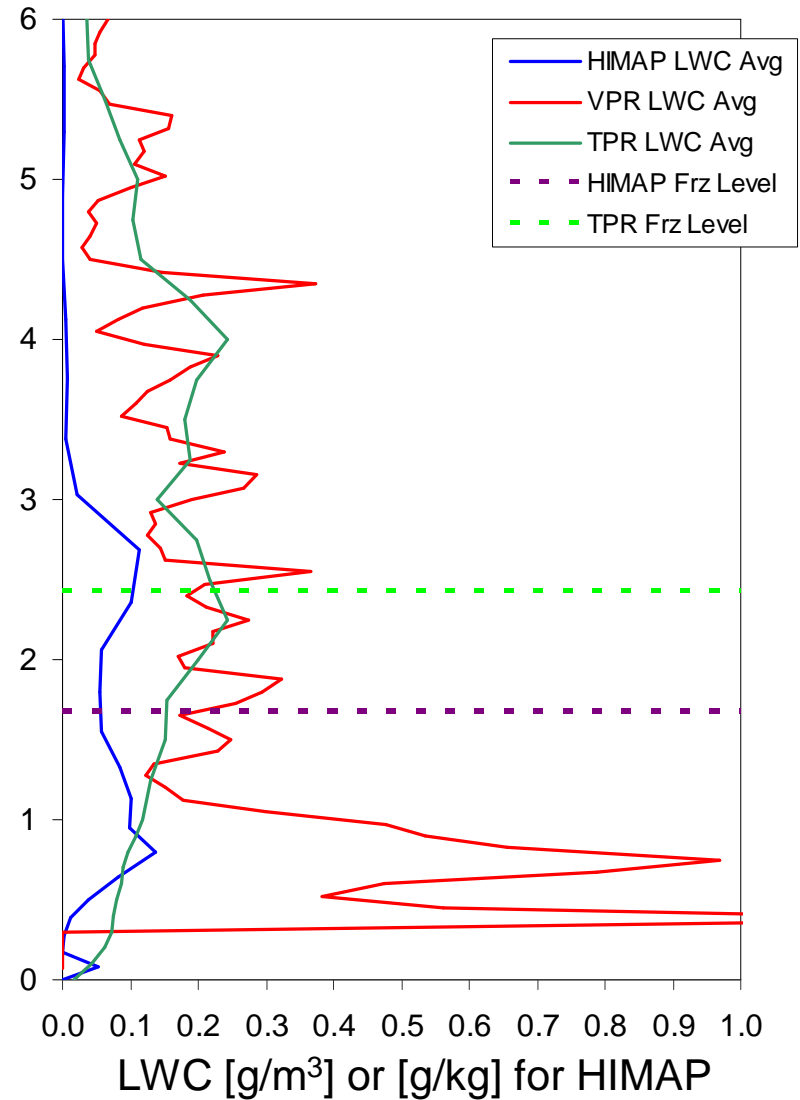
M+S Icing



Case Study: November 25, 2003 0025-0345 UTC

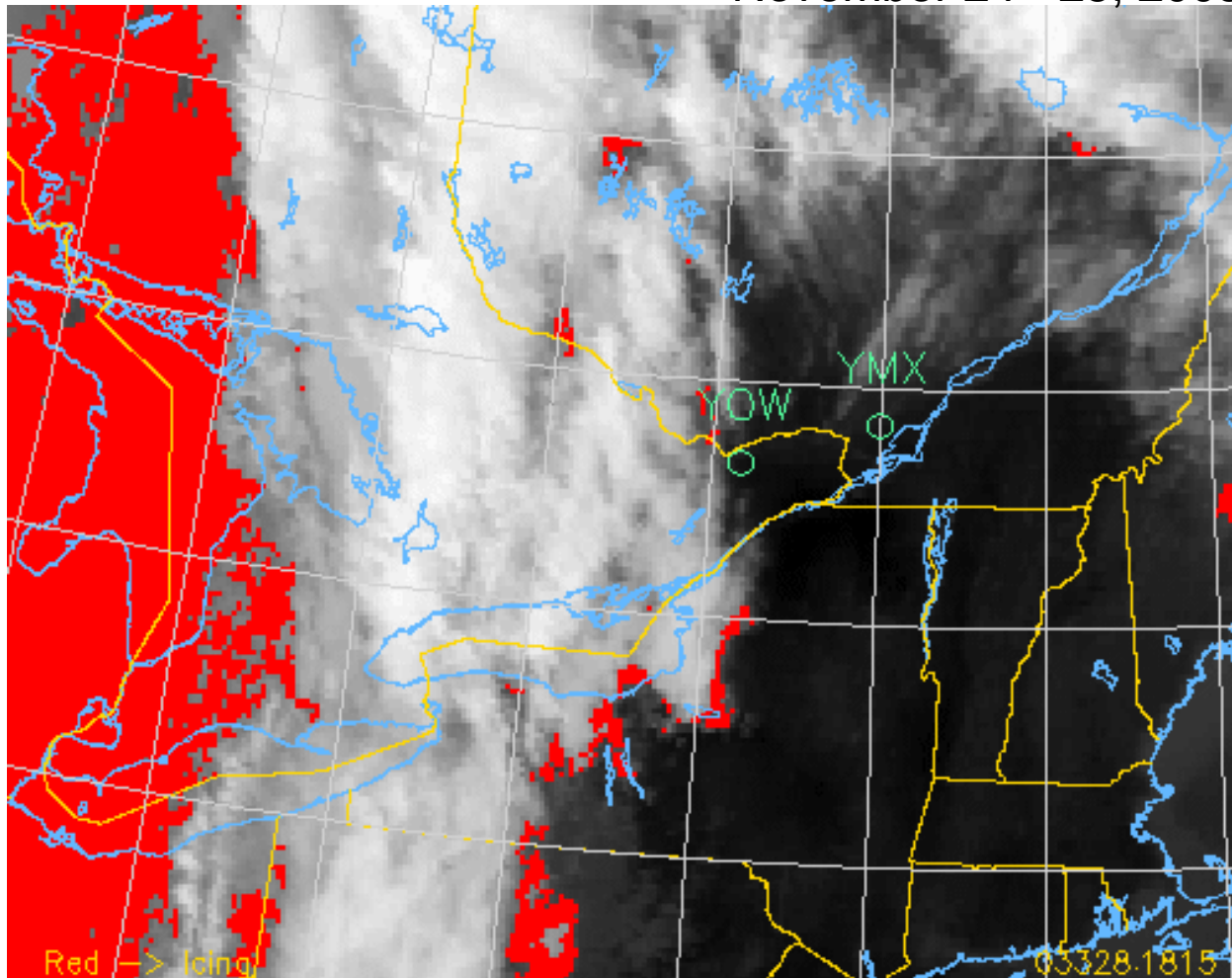


L+M Icing

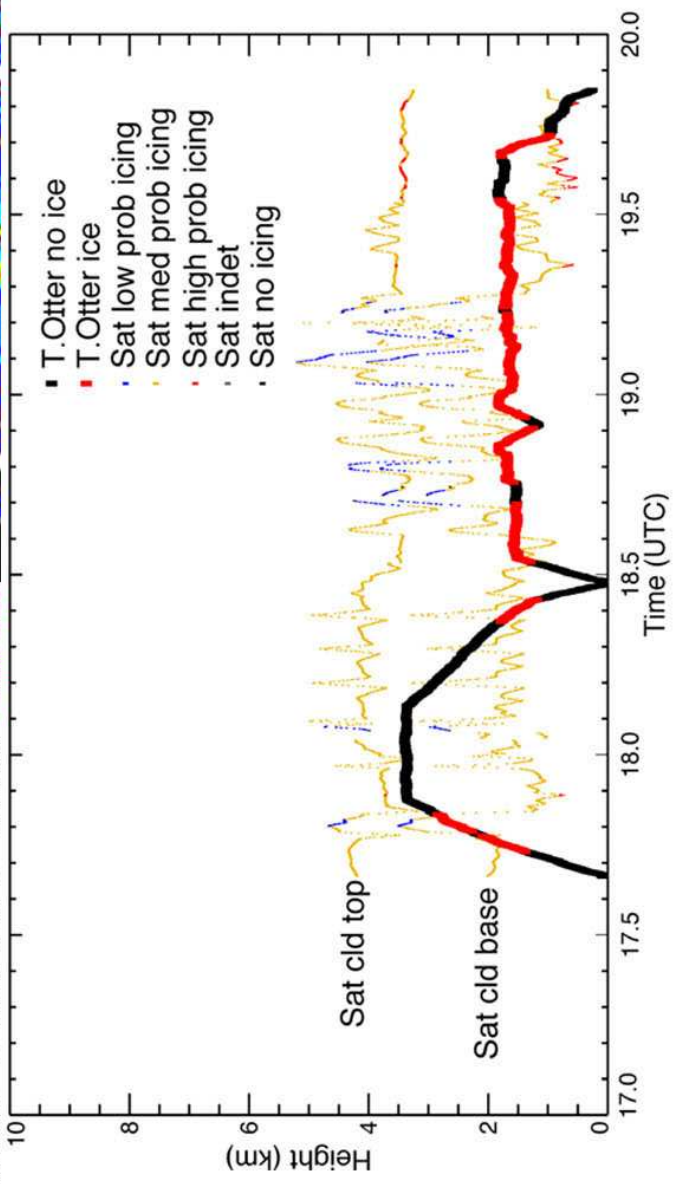
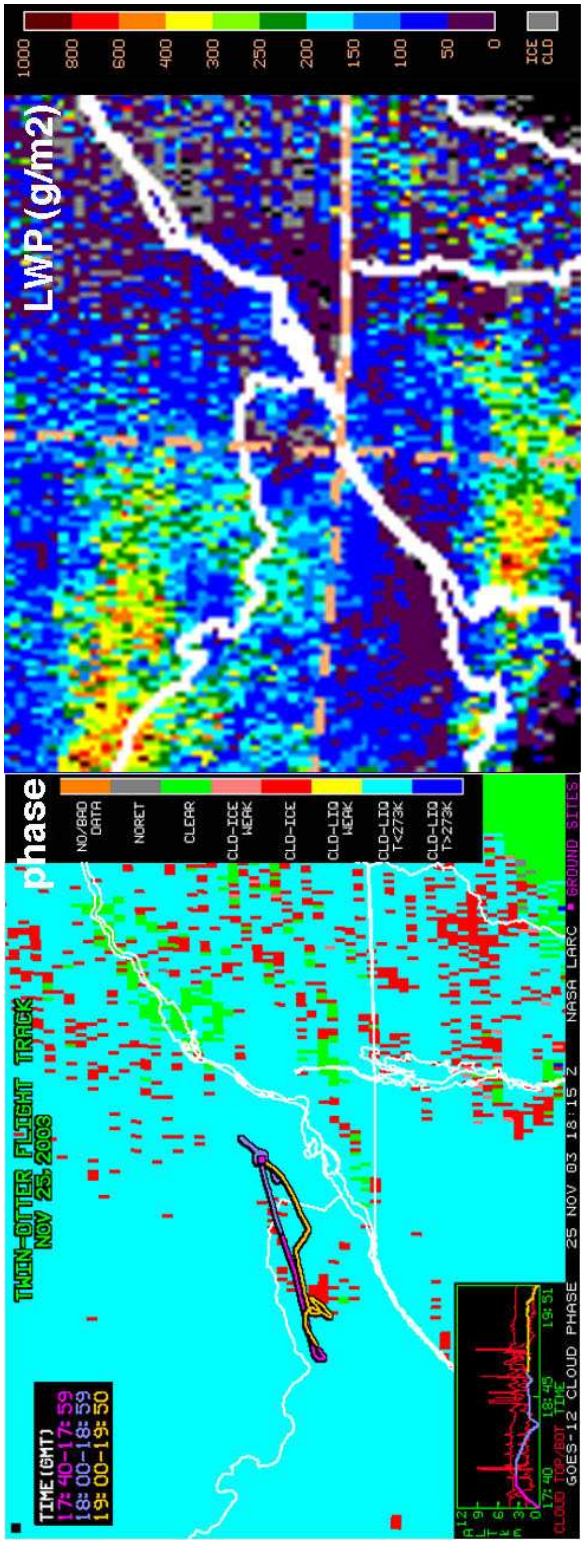


Satellite Based Icing Predictions

November 24 - 25, 2003

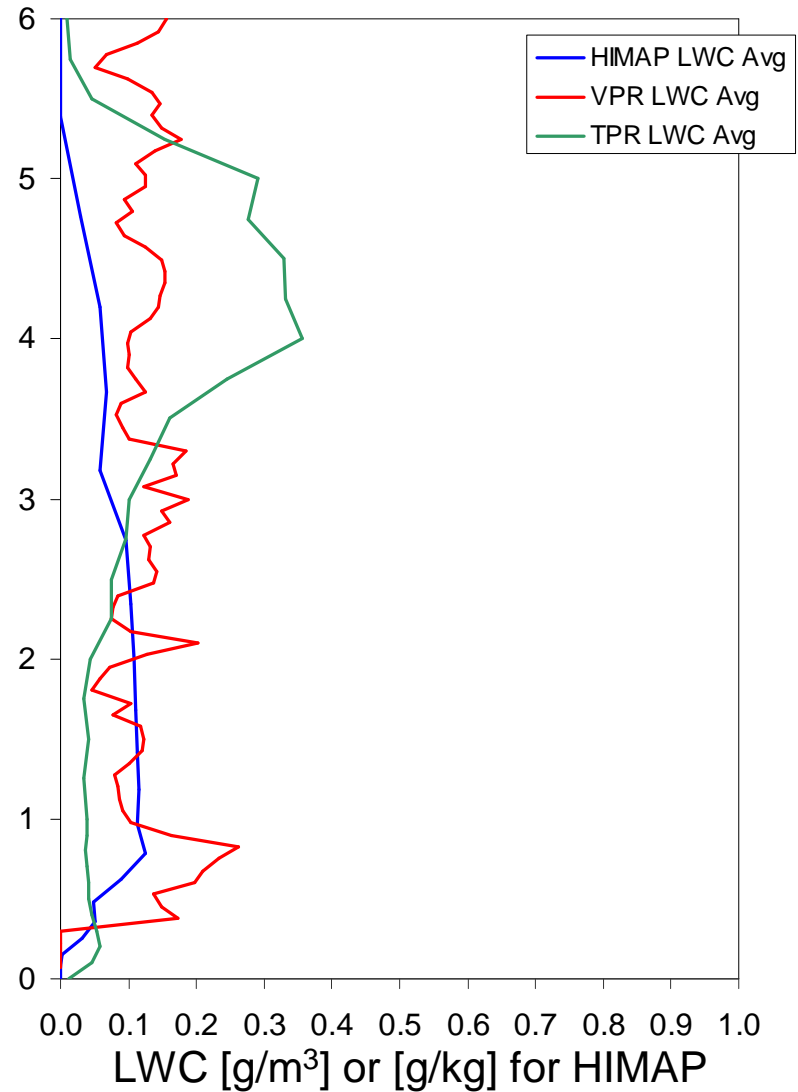
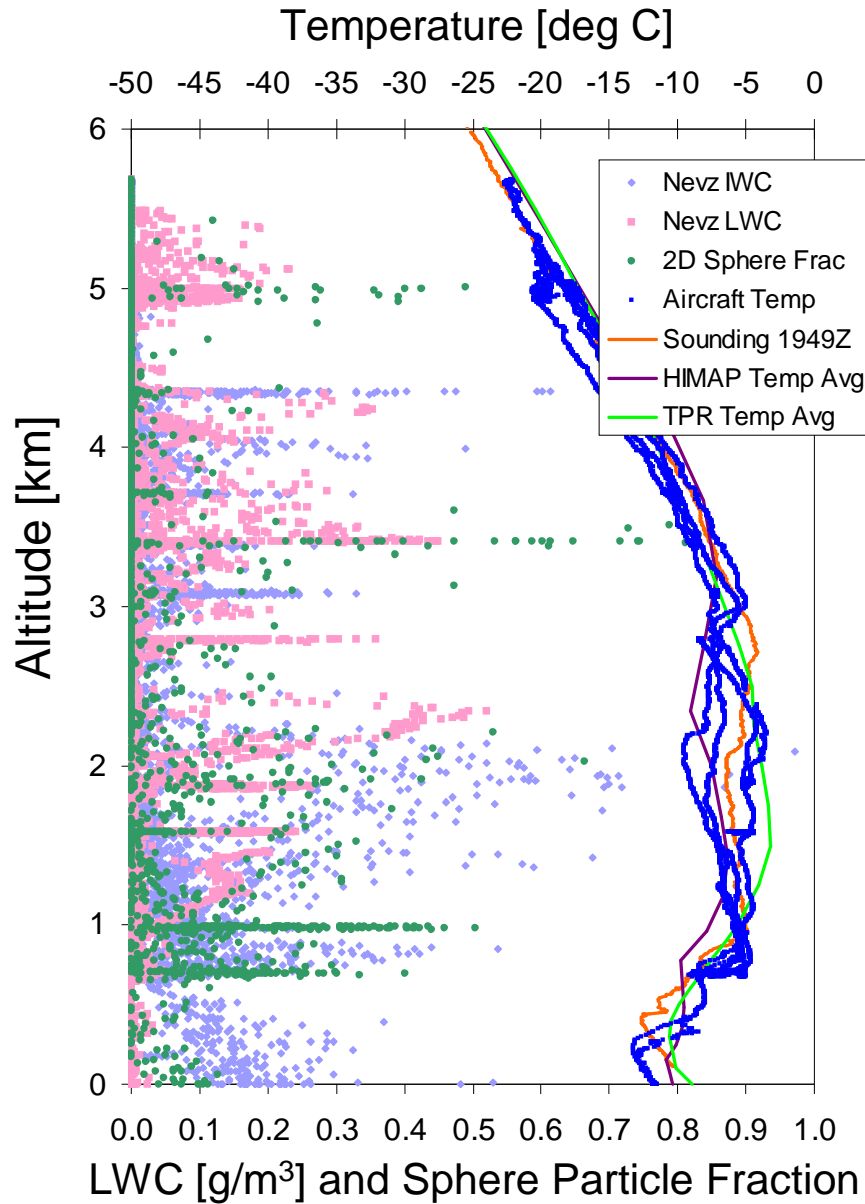


MSC icing product using GOES-12 data. Icing is marked in red. In this case the cloud on the right was high level and glaciated, but behind the system was a low level stratiform deck with icing predicted. The Convair found severe icing in the low level cloud, confirming the prediction in this case, and there were many other pilot reports. The Citation, flying over Lake Ontario, did not find significant icing.



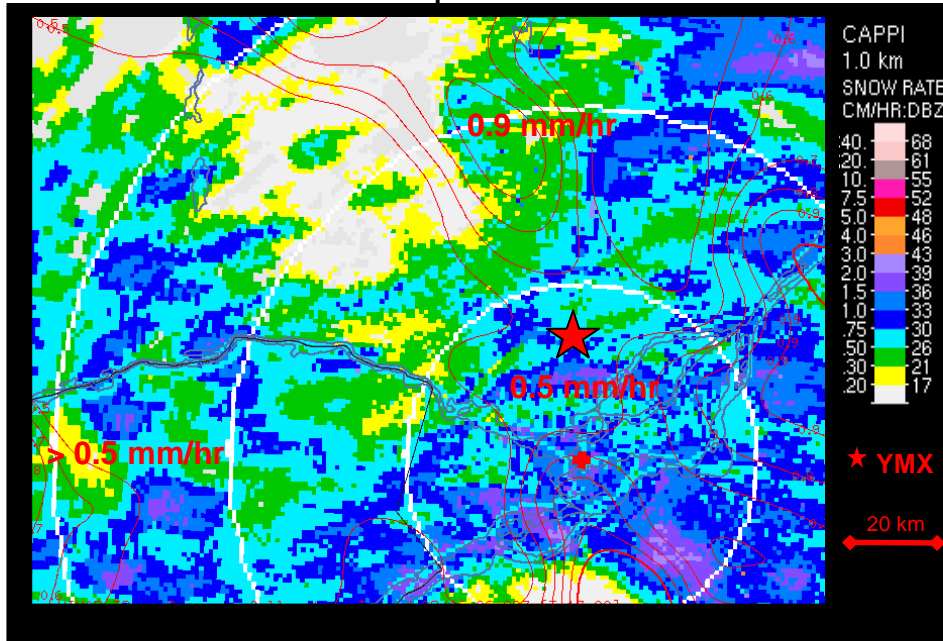
Case Study: February 6, 2004 1900-2210 UTC

M+S Icing

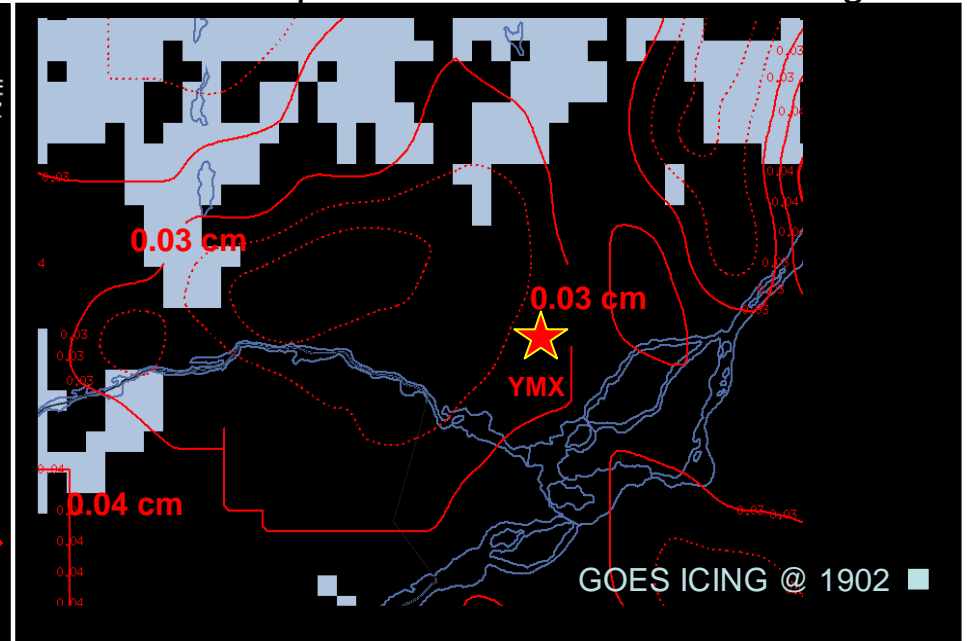


February 6, 2004 - 19 UTC in the vicinity of YMX

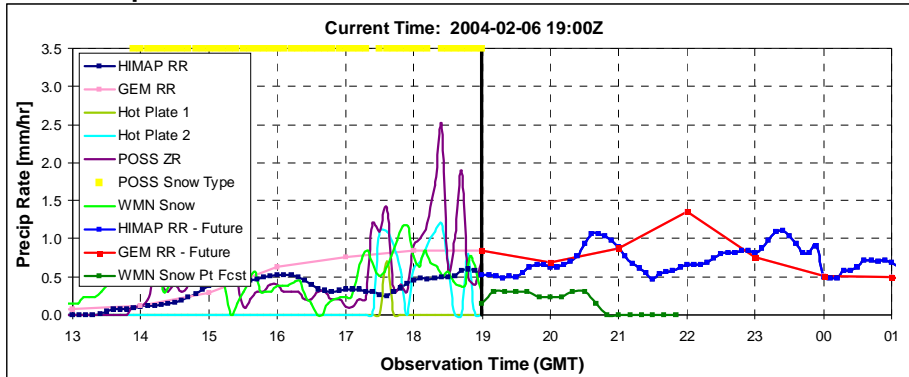
HIMAP Total Precipitation Rate and Radar



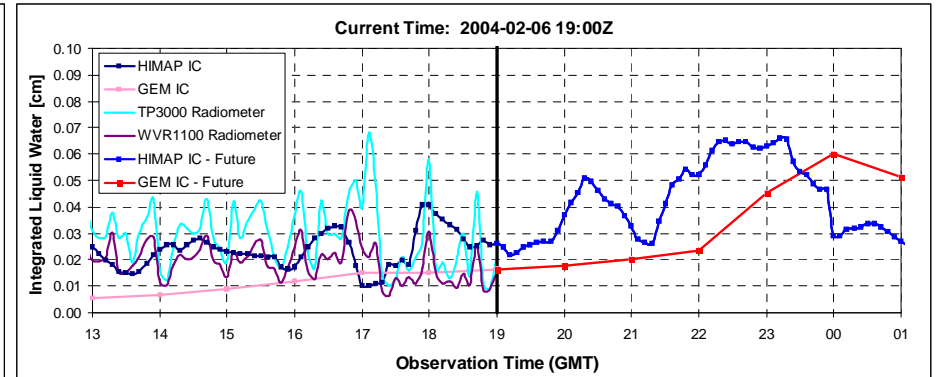
HIMAP Supercooled LWP & GOES Icing



Precipitation Observations & Forecast at YMX

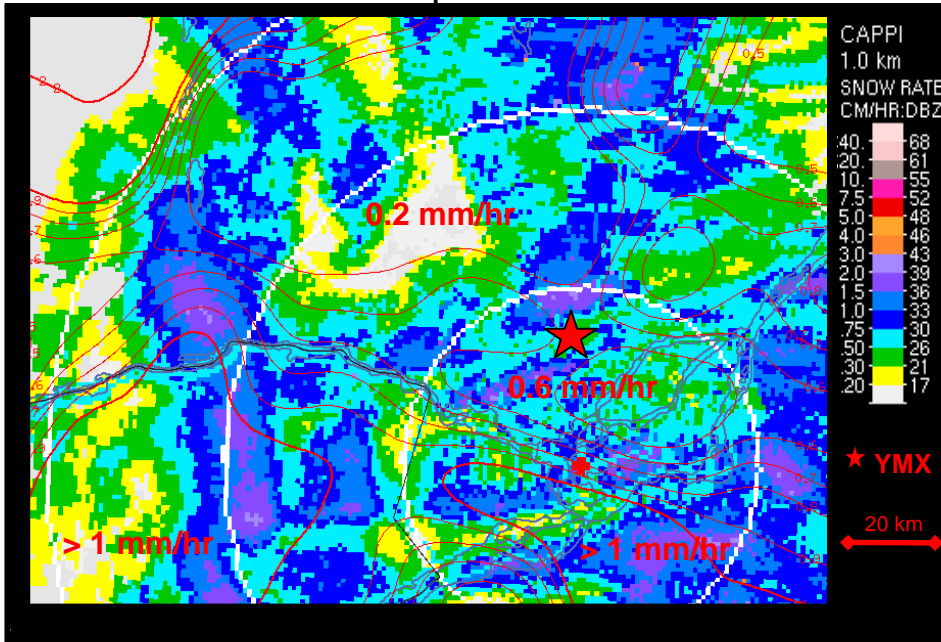


LWP Observations & Forecast at YMX

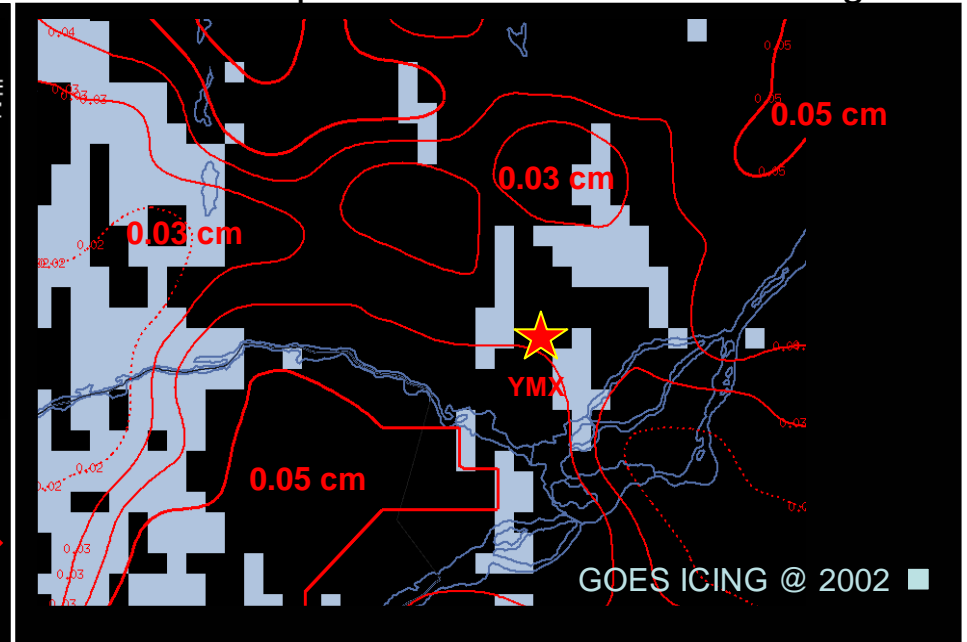


February 6, 2004 - 20 UTC in the vicinity of YMX

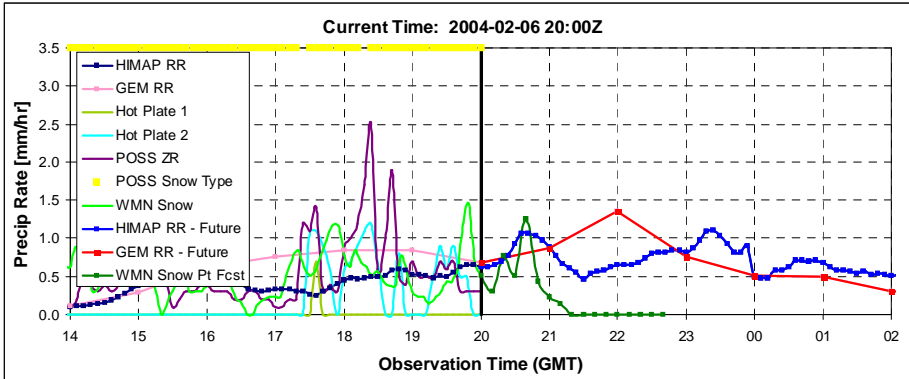
HIMAP Total Precipitation Rate and Radar



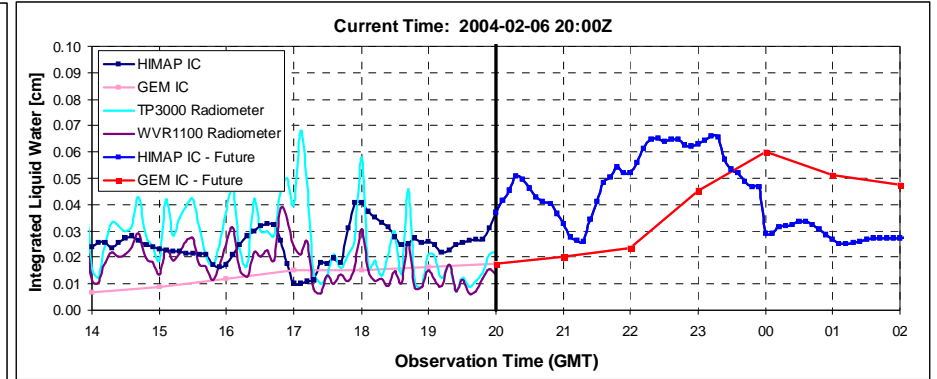
HIMAP Supercooled LWP & GOES Icing



Precipitation Observations & Forecast at YMX

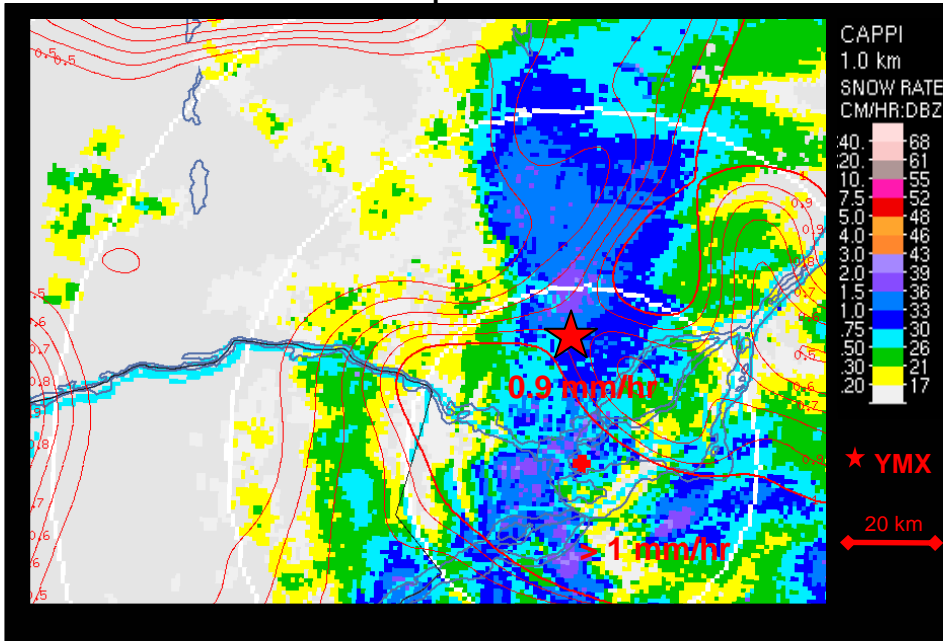


LWP Observations & Forecast at YMX

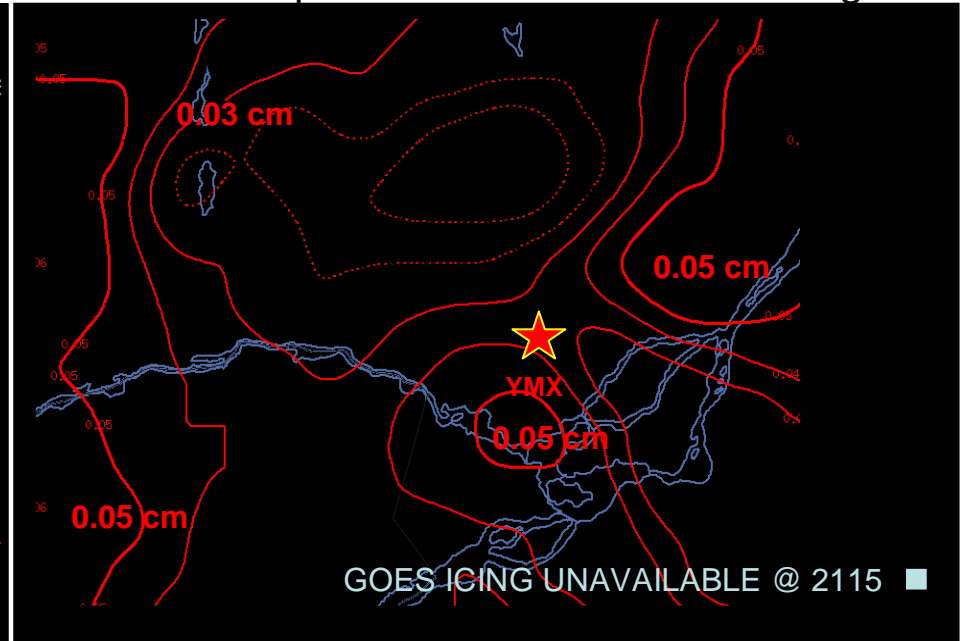


February 6, 2004 - 21 UTC in the vicinity of YMX

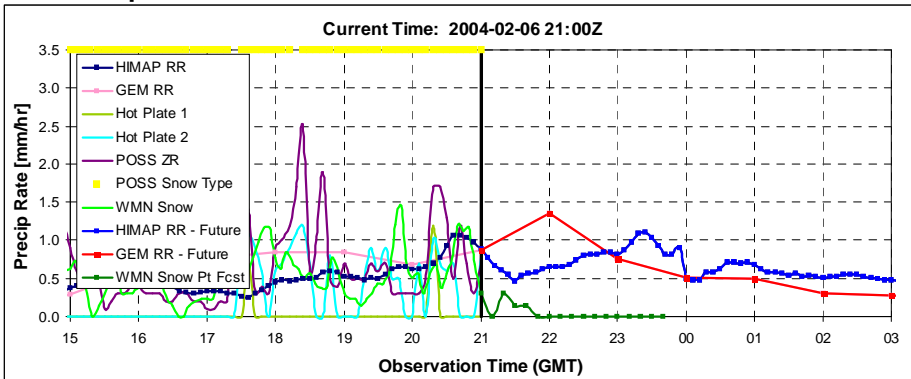
HIMAP Total Precipitation Rate and Radar



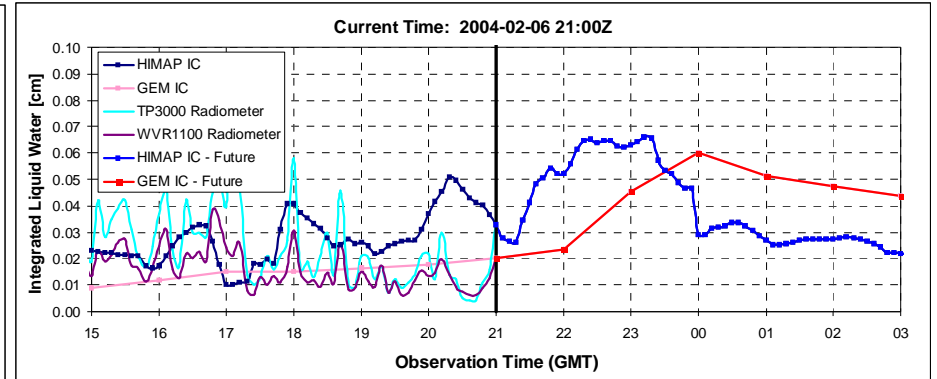
HIMAP Supercooled LWP & GOES Icing



Precipitation Observations & Forecast at YMX



LWP Observations & Forecast at YMX

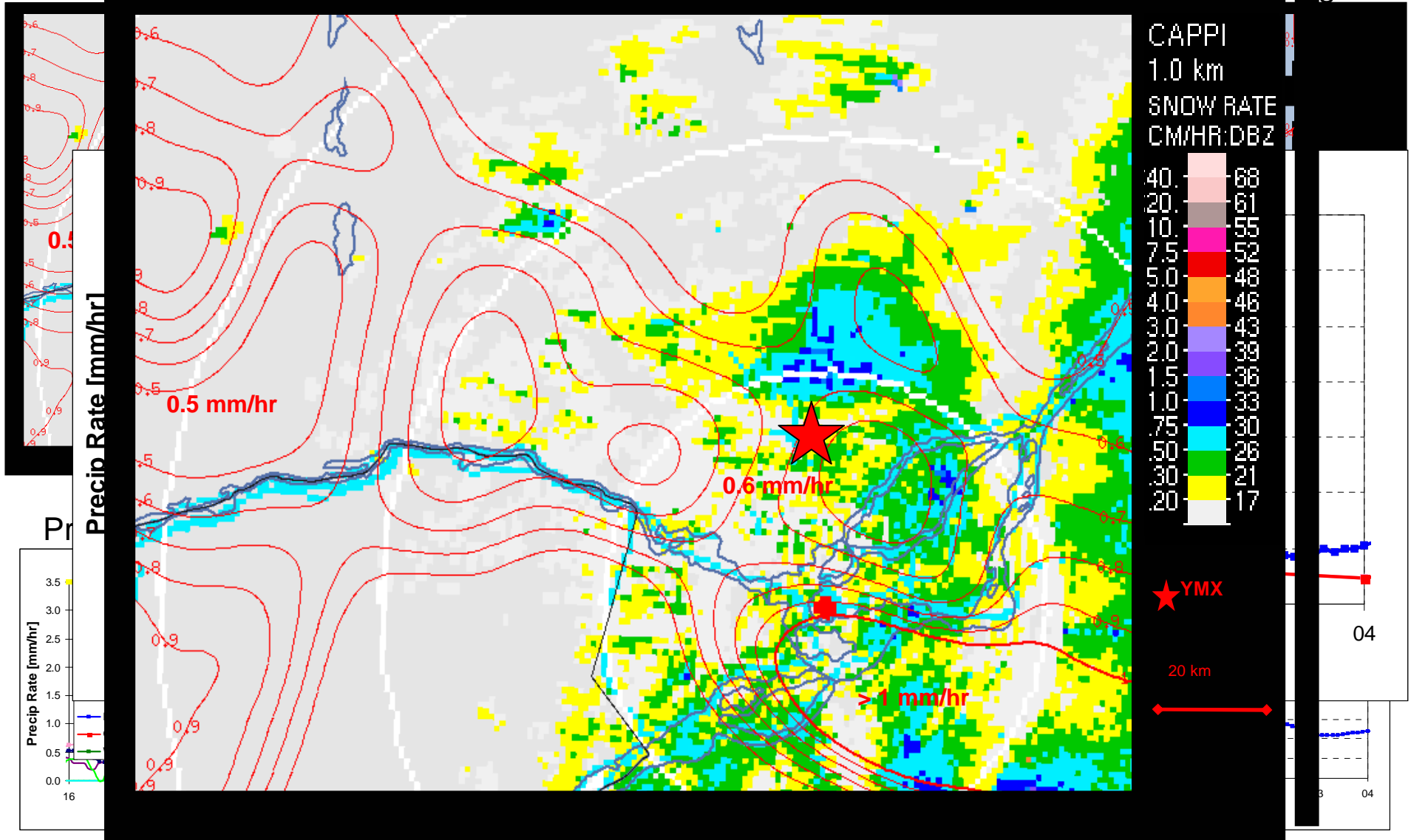


February 6, 2004 - 22 UTC in the vicinity of YMX

HIMAP Total Precipitation Rate and Radar

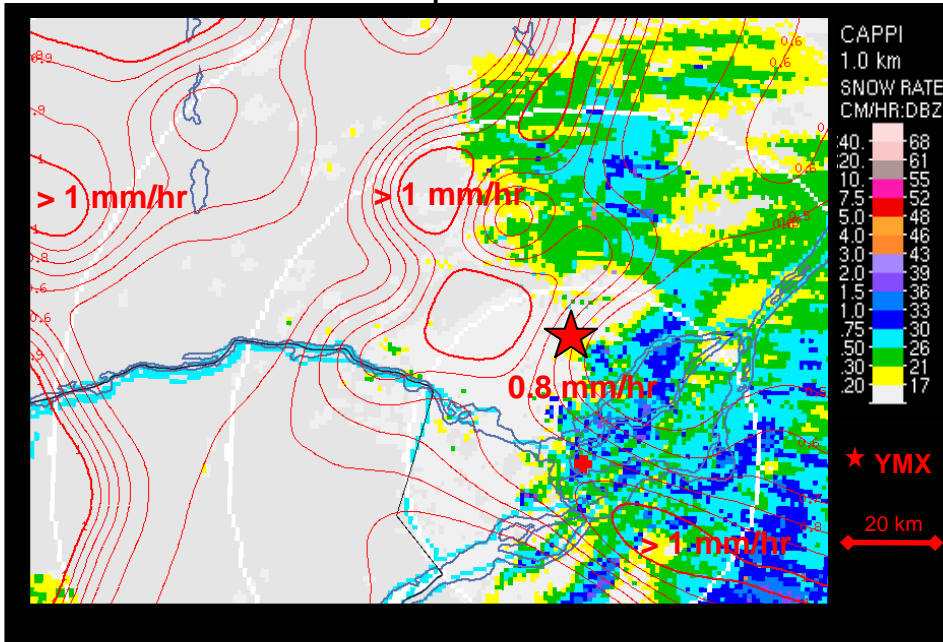
HIMAP Total Precipitation Rate and Radar

HIMAP Supercooled LWP & GOES Icing

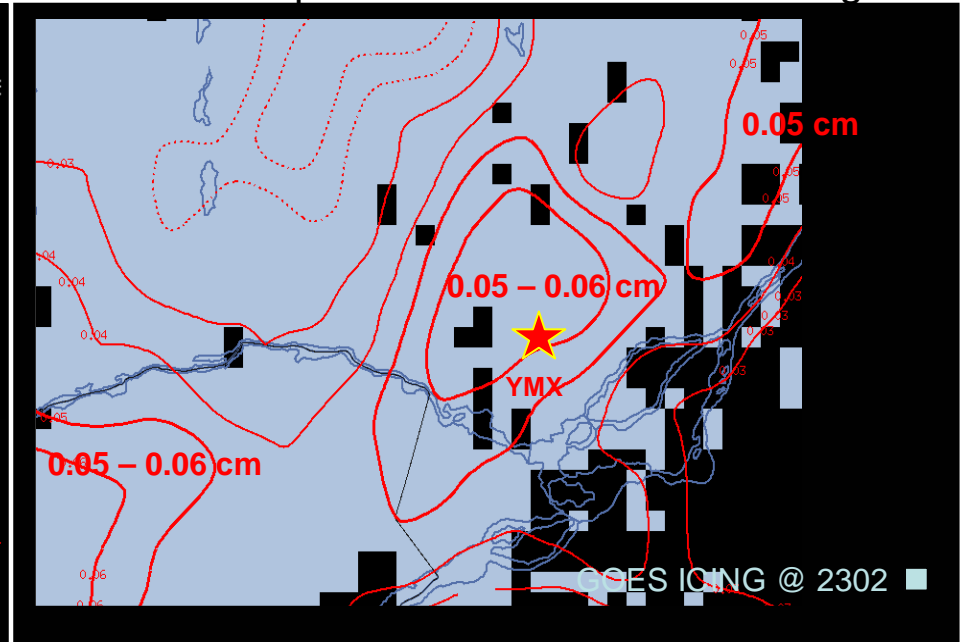


February 6, 2004 - 23 UTC in the vicinity of YMX

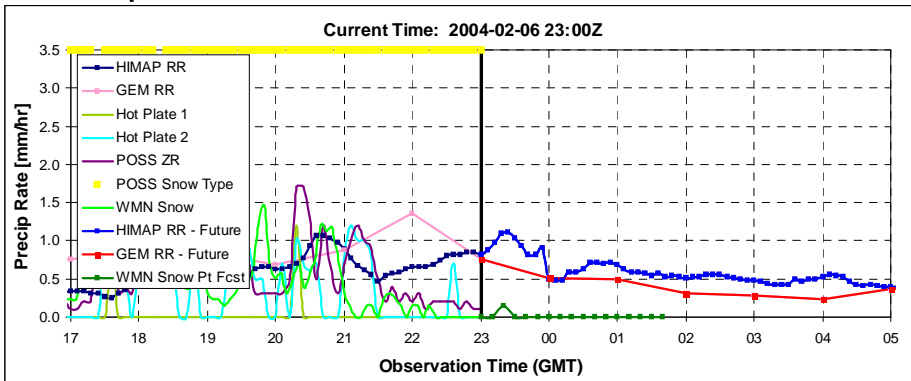
HIMAP Total Precipitation Rate and Radar



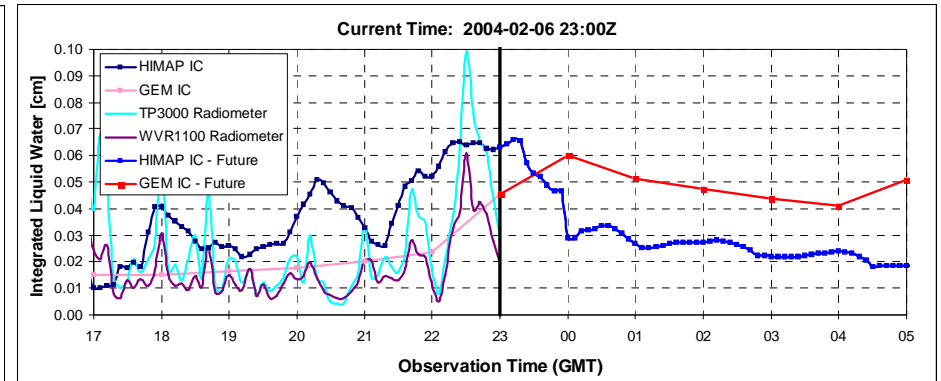
HIMAP Supercooled LWP & GOES Icing



Precipitation Observations & Forecast at YMX

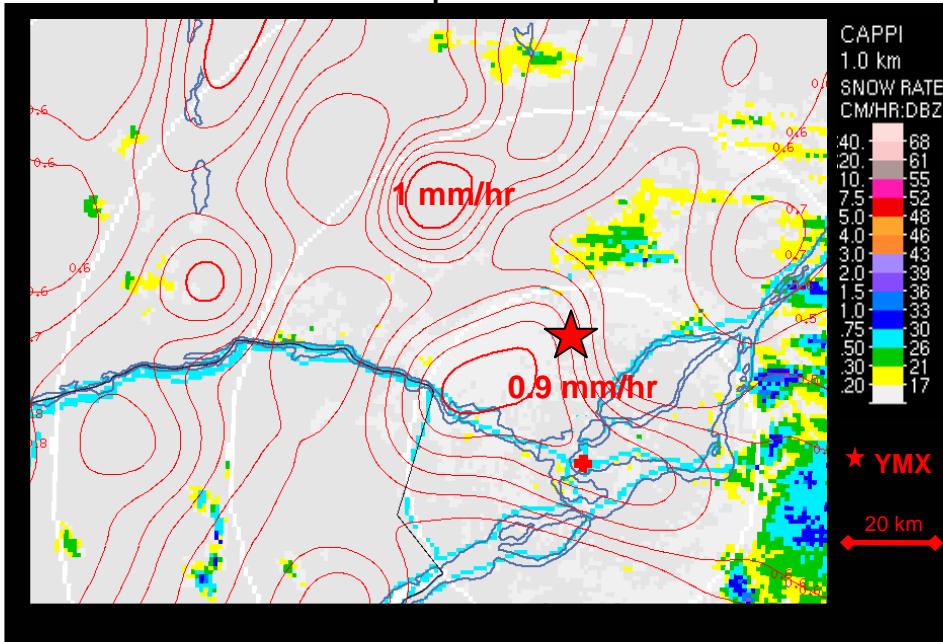


LWP Observations & Forecast at YMX

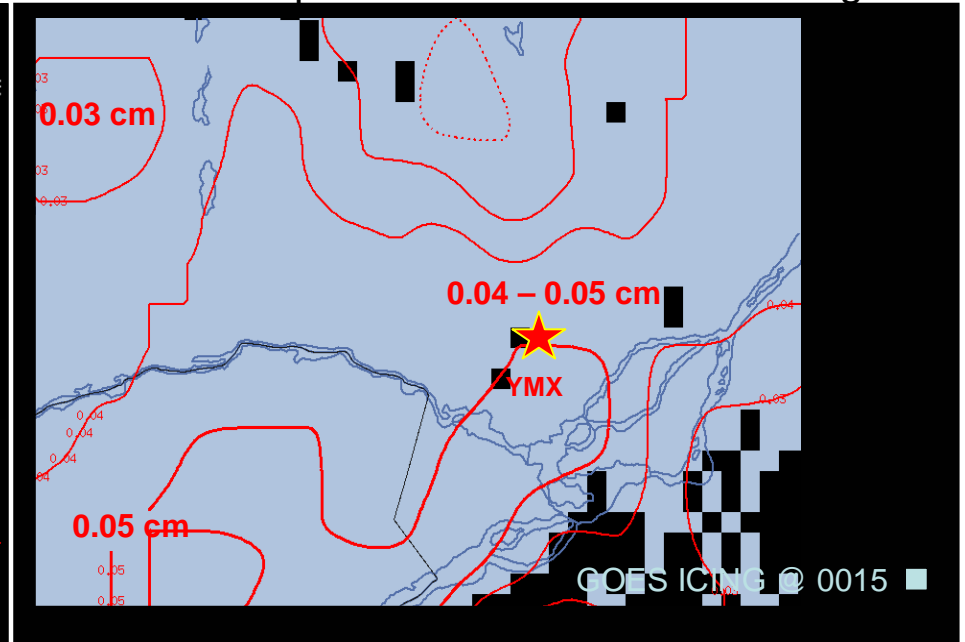


February 7, 2004 - 00 UTC in the vicinity of YMX

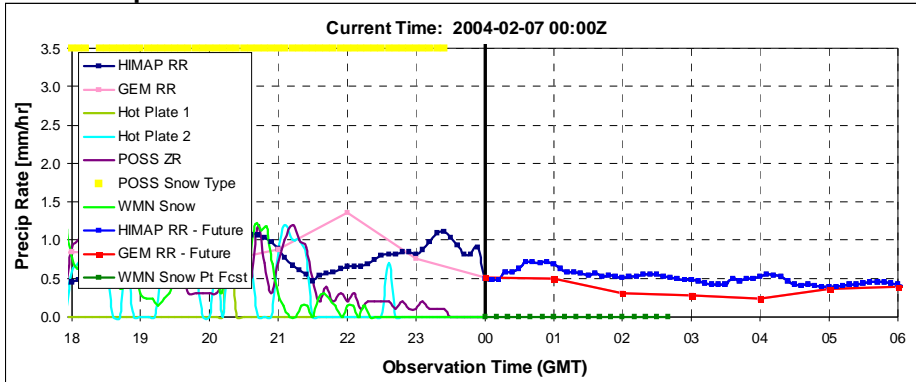
HIMAP Total Precipitation Rate and Radar



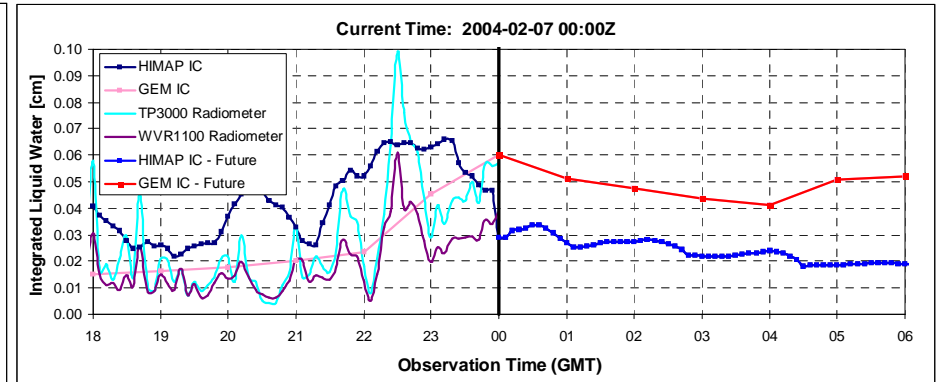
HIMAP Supercooled LWP & GOES Icing



Precipitation Observations & Forecast at YMX

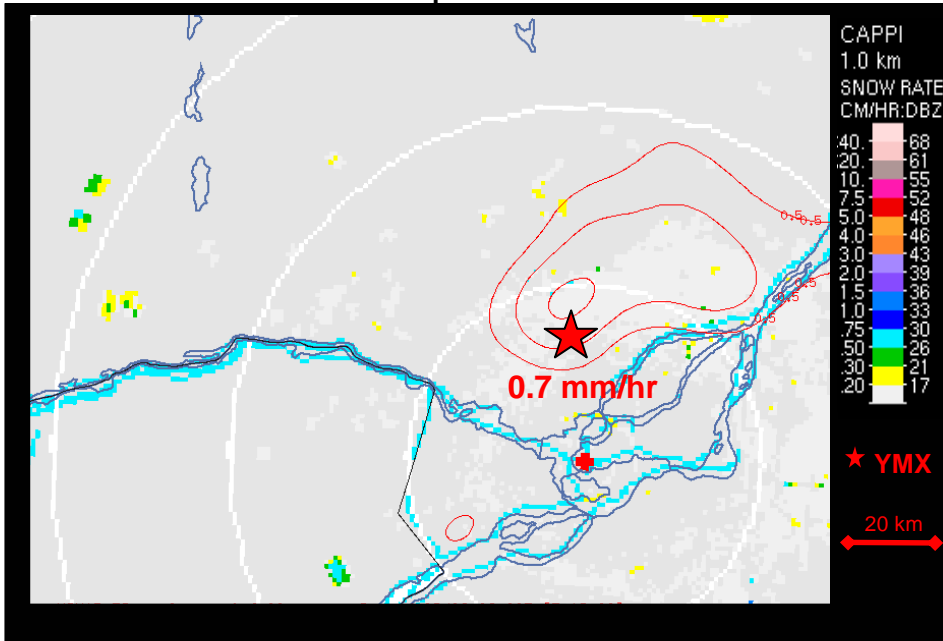


LWP Observations & Forecast at YMX

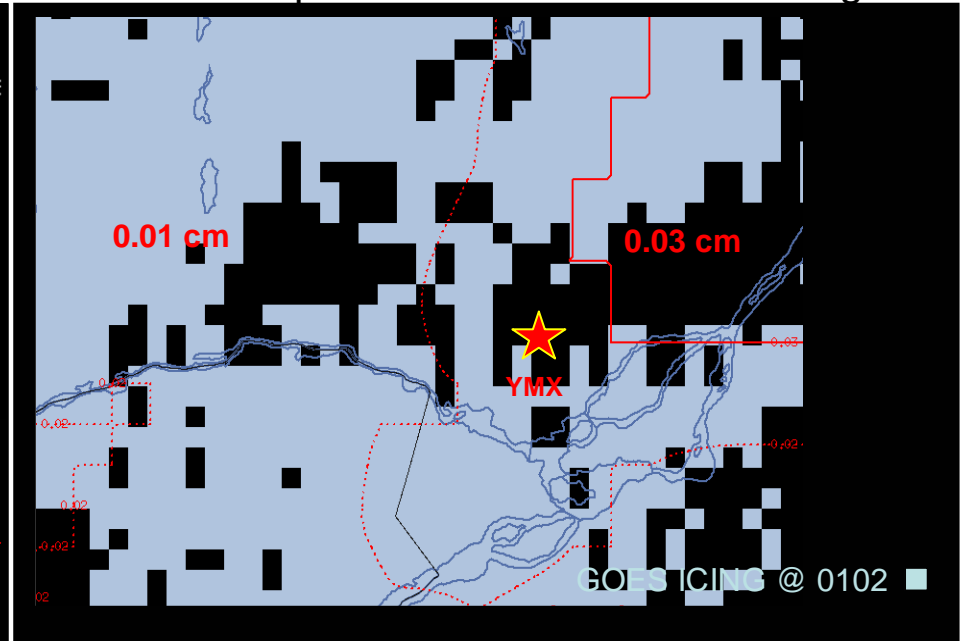


February 7, 2004 - 01 UTC in the vicinity of YMX

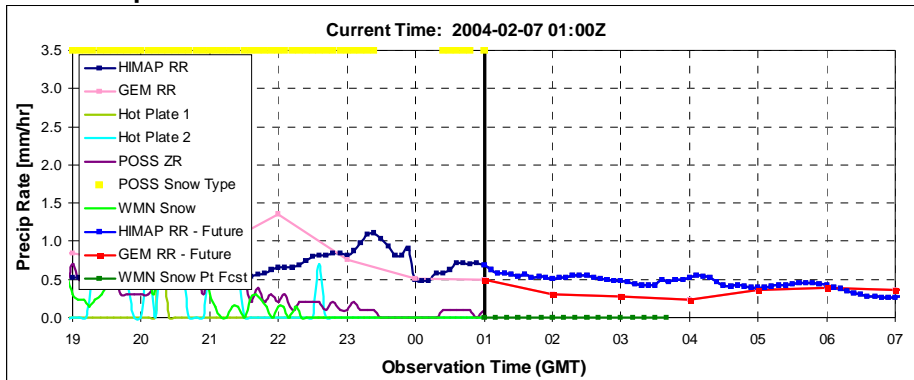
HIMAP Total Precipitation Rate and Radar



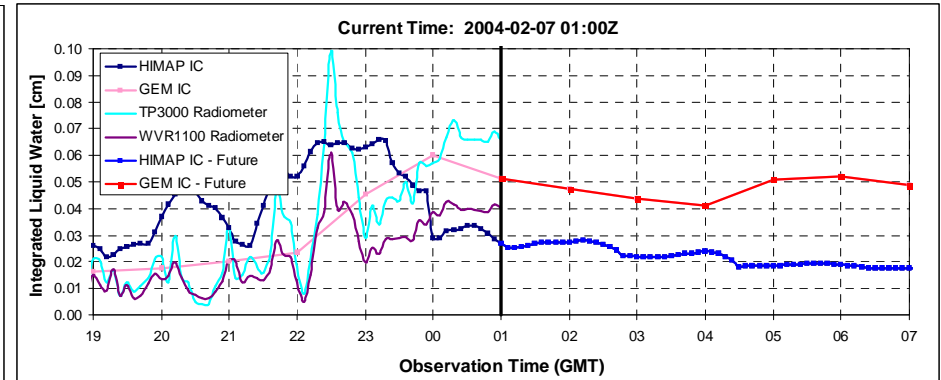
HIMAP Supercooled LWP & GOES Icing



Precipitation Observations & Forecast at YMX

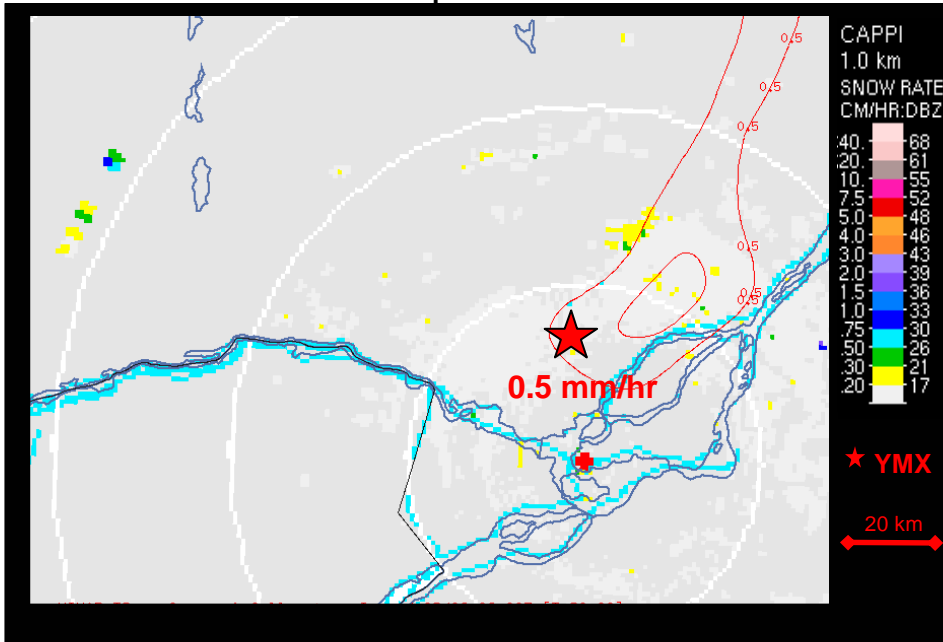


LWP Observations & Forecast at YMX

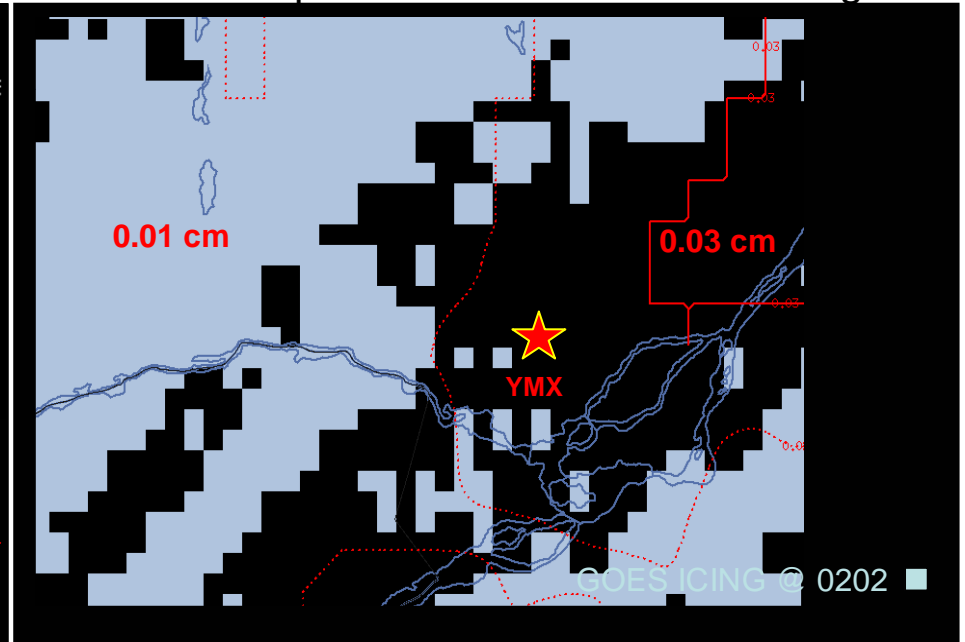


February 7, 2004 - 02 UTC in the vicinity of YMX

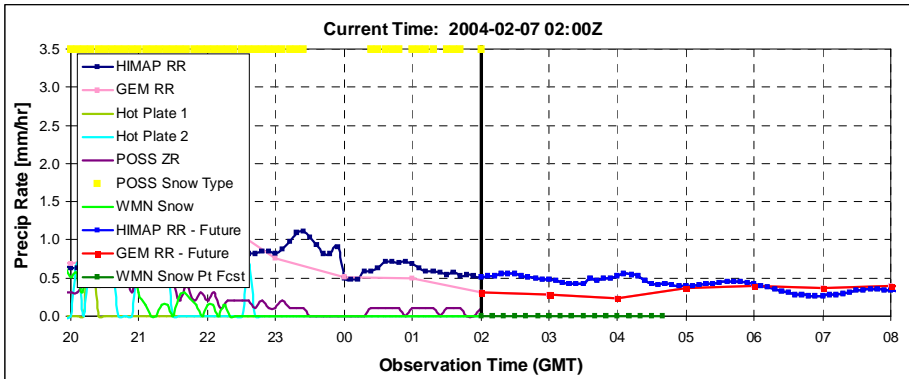
HIMAP Total Precipitation Rate and Radar



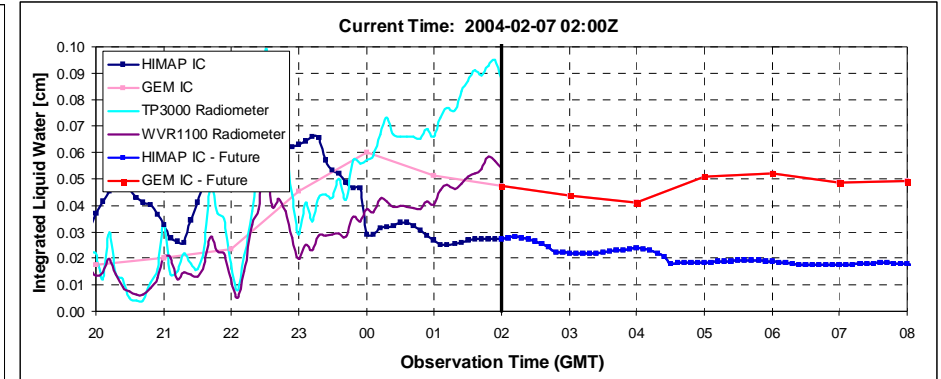
HIMAP Supercooled LWP & GOES Icing



Precipitation Observations & Forecast at YMX

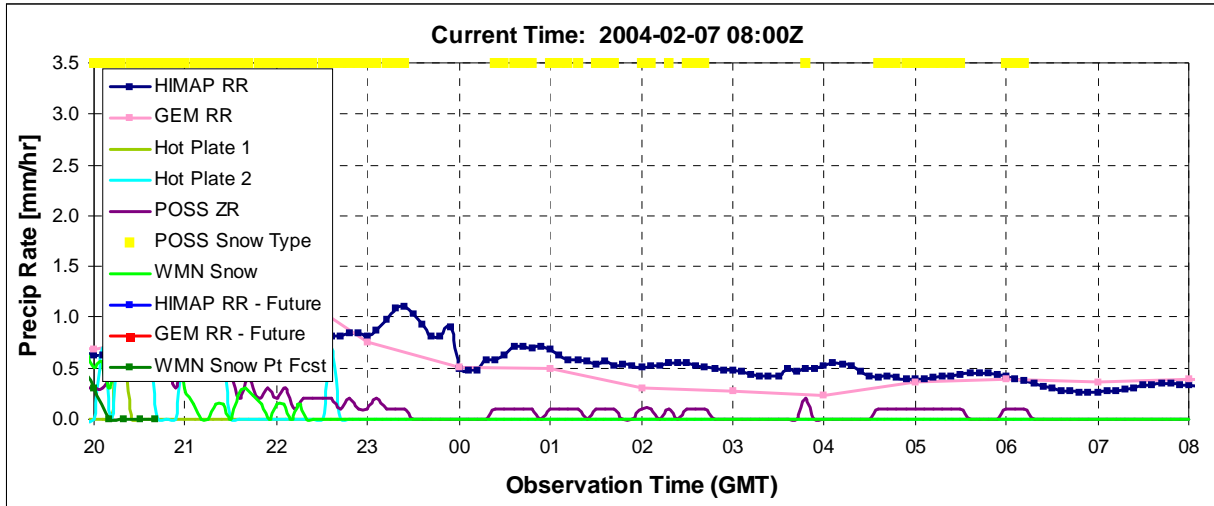


LWP Observations & Forecast at YMX



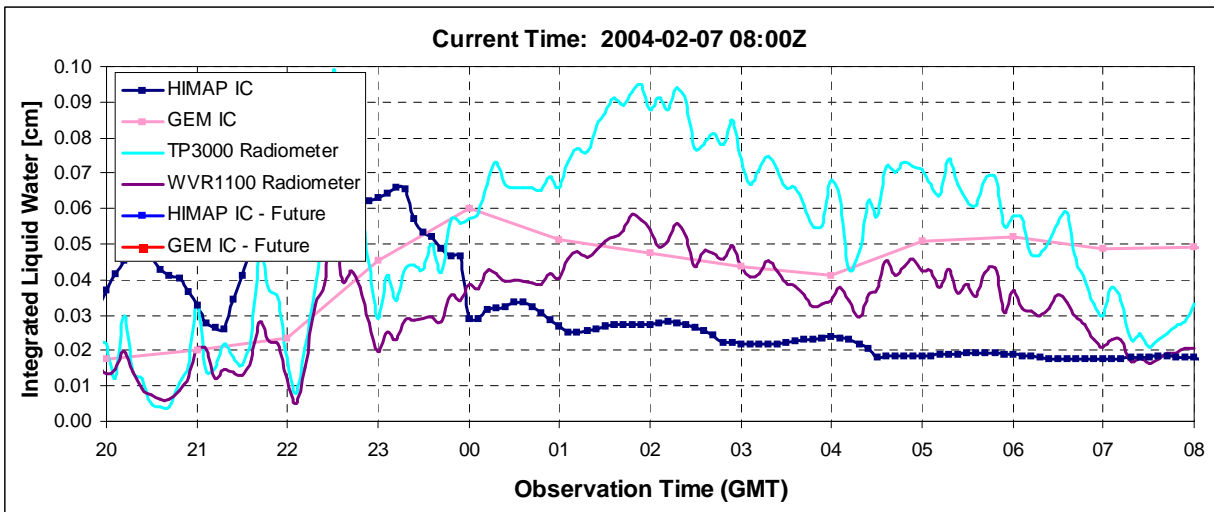
February 7, 2004 – Until 08 UTC

Precipitation Observations at YMX



Only intermittent light snow (≤ 0.1 mm/hr) fell at YMX. Models continued to forecast a higher rate.

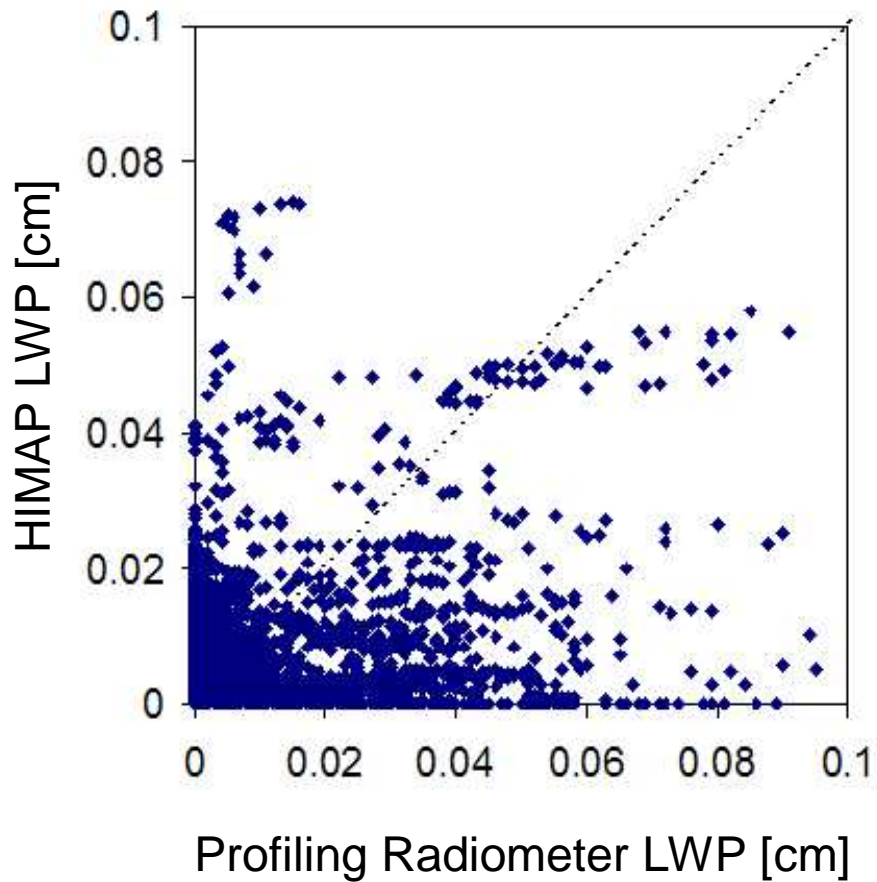
LWP Observations at YMX



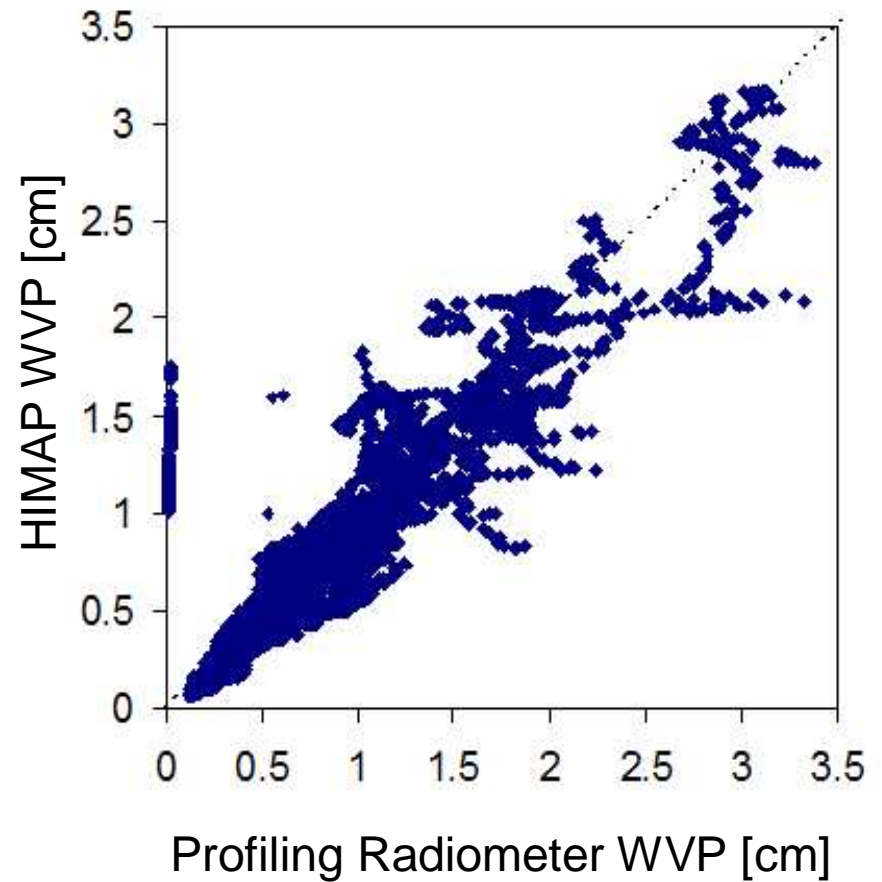
Microwave radiometers continued to report significant LWP (> 0.2 mm until $\sim 7Z$)

Model/Radiometer Comparison

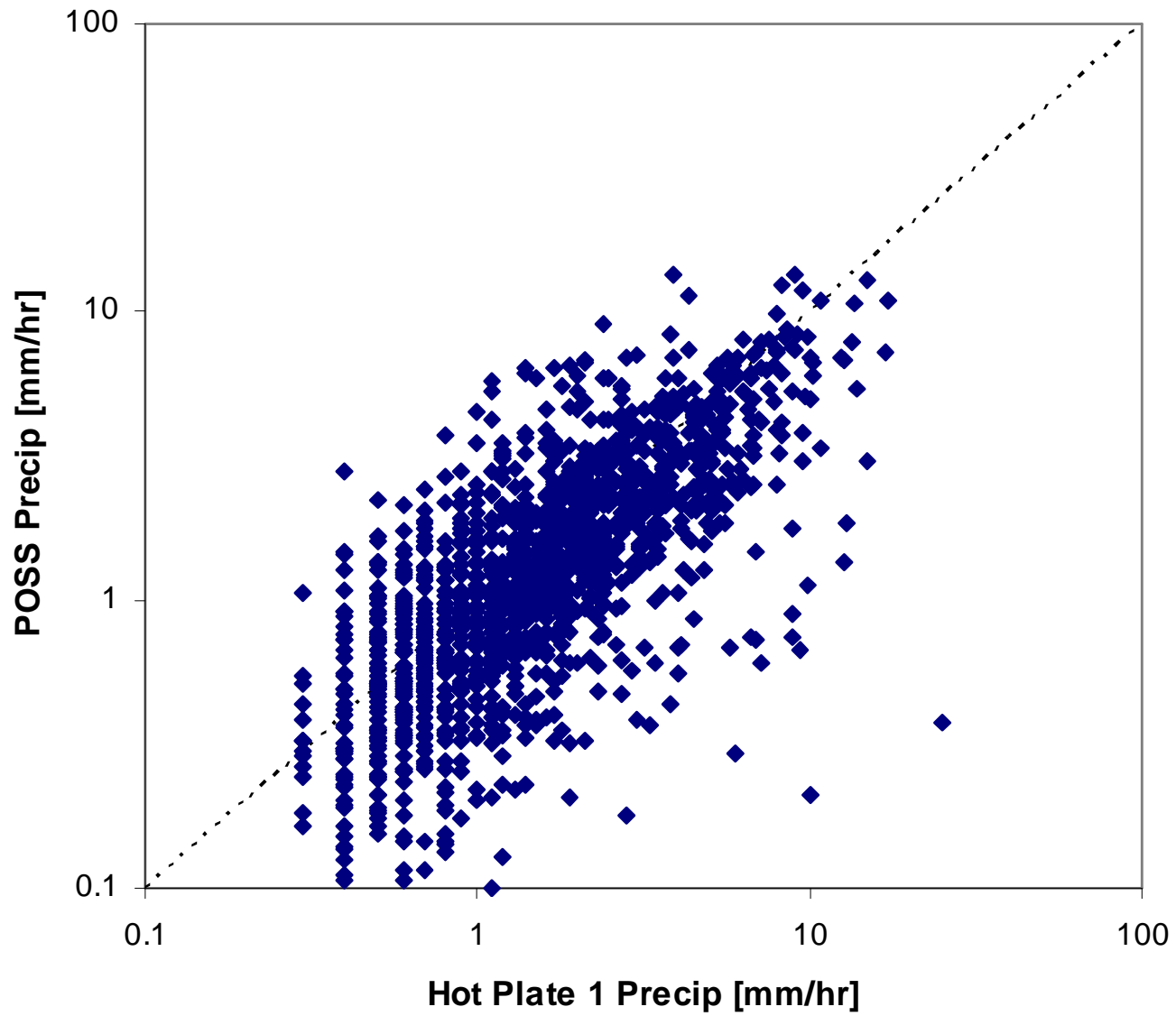
Liquid Water Paths



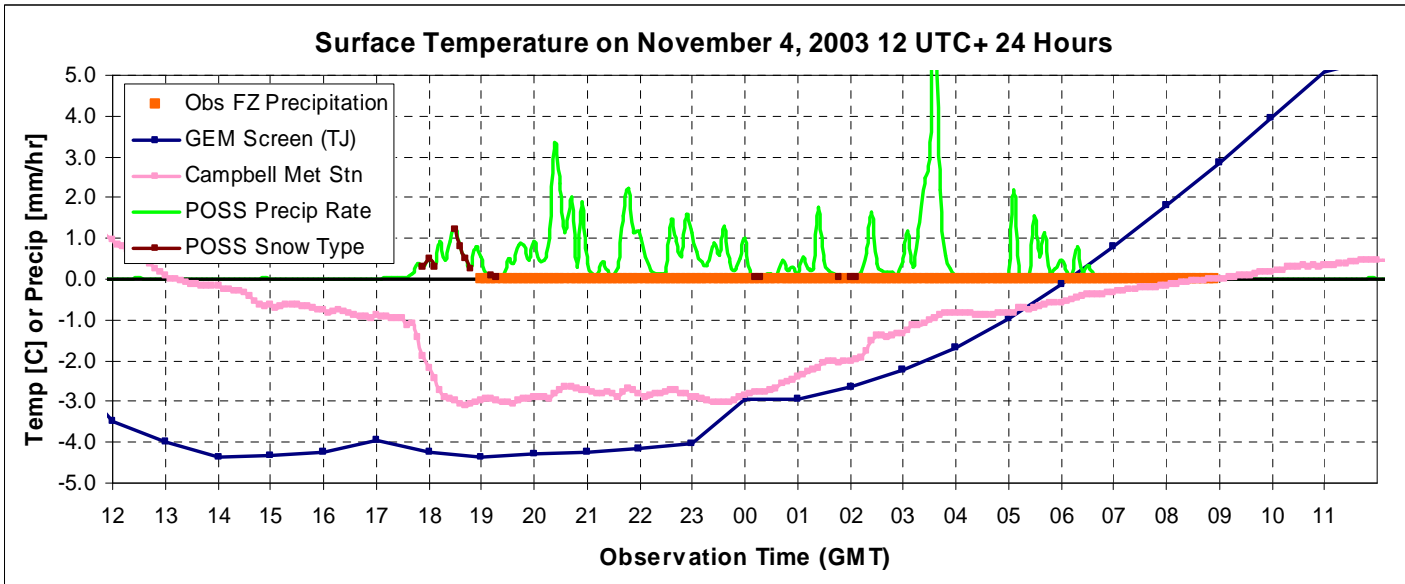
Water Vapour Paths



Precipitation Sensor Comparison



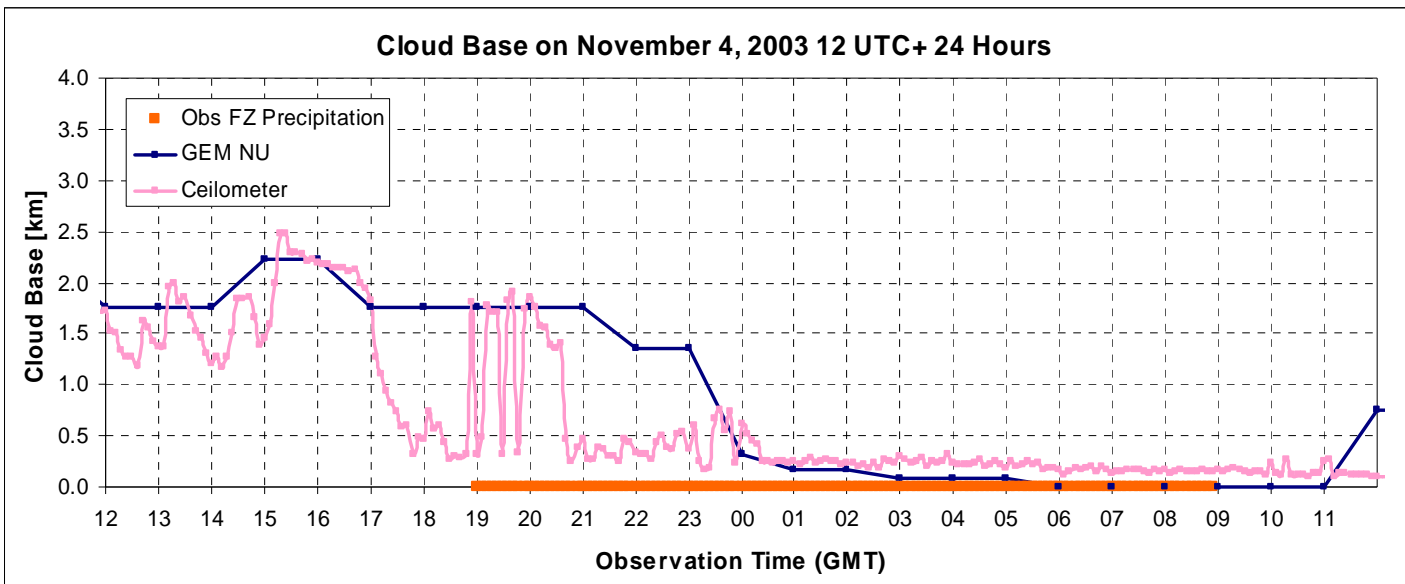
November 4-5, 2003: Freezing Rain Event



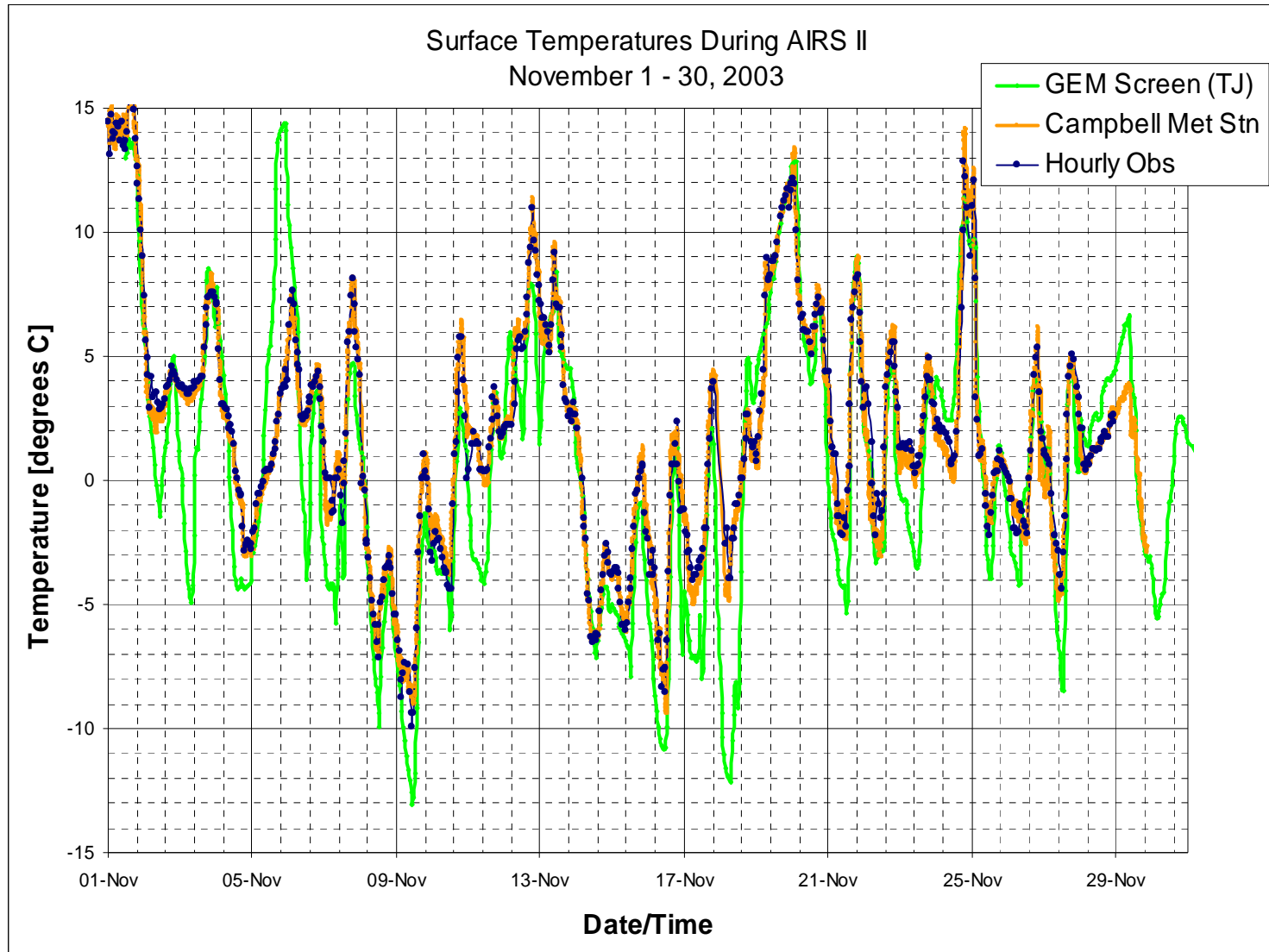
Orange marks when the YMX observer reported ZR

Time series data contain a change in model runs at 00 Z

POSS reports mainly rain type Wx

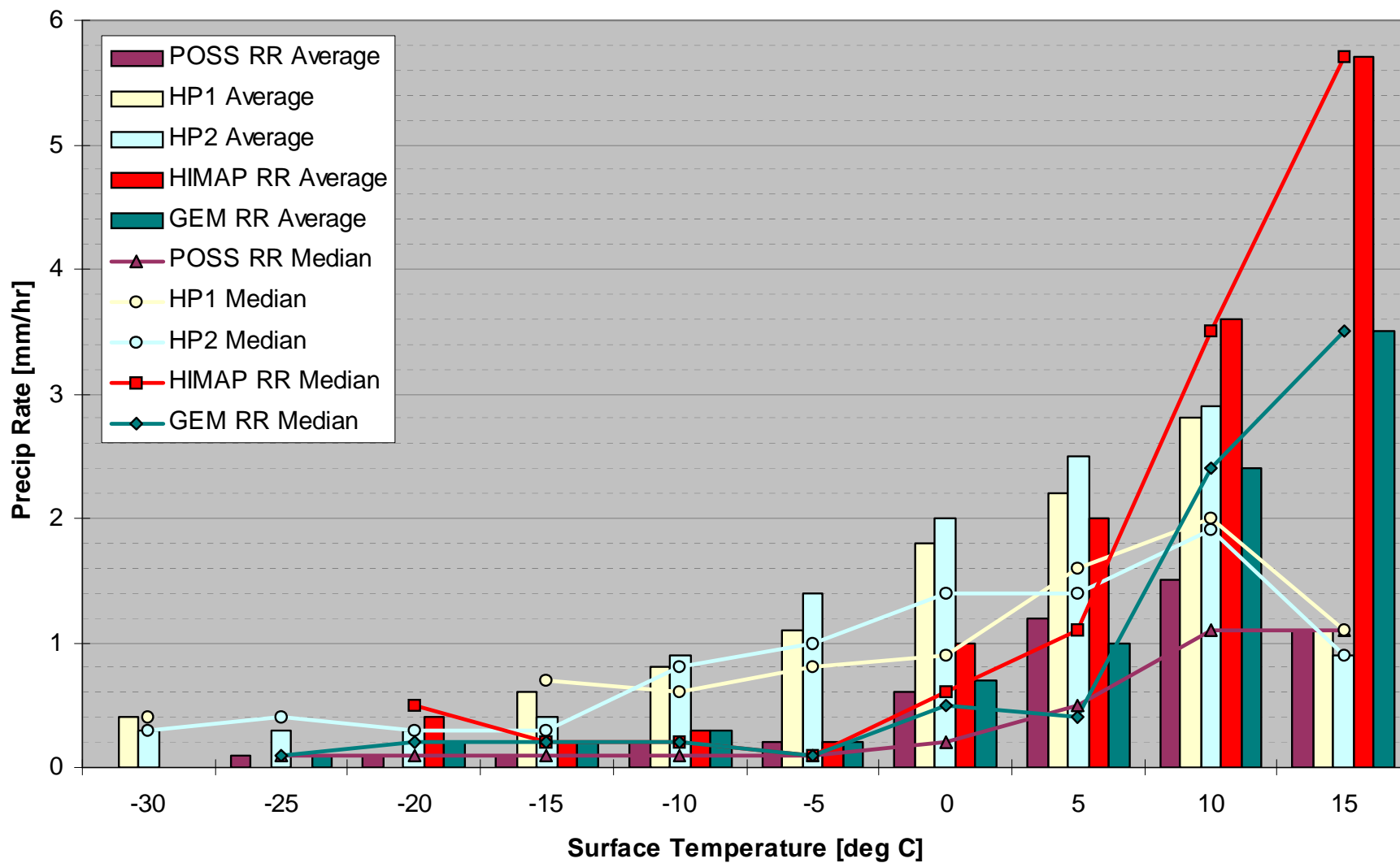


Surface Temperatures in November 2003: GEM vs. Observed



Poor minimum temperature predictions reflect on ability to predict frost or fog

Precipitation Rate vs. Surface Temperature During AIRS-2



Preliminary Comparison with HIMAP During AIRS II

Parameter	Instrument		Hit Rate	FAR	TSS
Liquid Water Path	Profiling Radiometer	HIMAP	0.54	0.11	0.43
Cloud Occurrence	Ceilometer	HIMAP	0.96	0.69	0.27
Precipitation > 0 mm/hr	Hot Plate 1	HIMAP	0.78	0.17	0.61
Precipitation > 2 mm/hr	Hot Plate 1	HIMAP	0.42	0.01	0.41

Data not fully quality controlled

Summary of SLW Algorithms for Mirabel Flights During AIRS-II

	Flight Date	Time over YMX [UTC]	Icing	Precip	MWR	HIMAP	TPR	GOES	VPR
1	2003-11-11	1940-2210	L+M	RA	INC	YES	YES	N/A	YES
2	2003-11-13	1425-1705	L	RA	INC	YES	YES	NO	YES
3	2003-11-14	1745-1930	L	RA,SN	NO	NO	YES-	NO	YES
4	2003-11-19	2045-2345	M+S	RA	INC	YES	YES	NO	YES
5	2003-11-25	0025-0345	L+M	RA,SN	YES	YES	YES	YES	YES
6	2003-11-27	2100-2315	None	RA	NO	YES-	YES-	NO	NO
7	2003-11-28	2025-2245	L	RA	INC	YES	YES	NO	YES
8	2003-11-29	1620-1910	L+M	IP,SN	NO	YES	YES	NO	YES
9	2004-01-22	1425-1655	L	SN	NO	YES	YES-	NO	N/A
10	2004-01-30	1655-1805	None	SN	NO	YES-	NO	NO	YES
11	2004-02-03	0015-0155 (04)	L+M	SN	NO	YES	YES	NO	YES
12	2004-02-06	1900-2220	M+S	SN	YES	YES	YES	YES	YES
13	2004-02-07	1735-2035	M+S	SN	YES+NO	YES	YES	NO	YES
14	2004-02-09	2220-2350	L	SN	INC	YES	YES	YES	YES

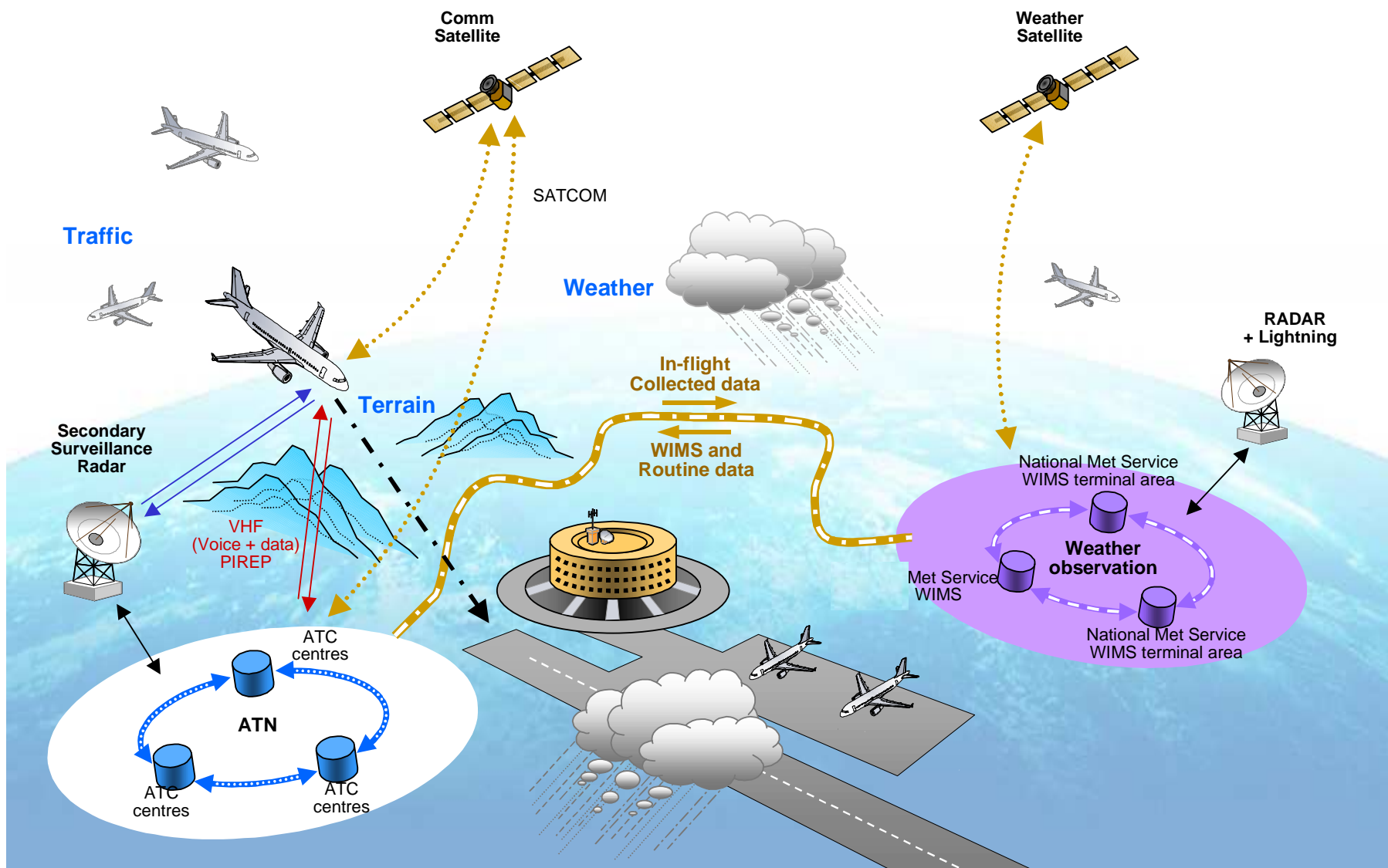
YES- = SLW deduced but either low LWC amounts or limited to a thin layer

Conclusions

- AIRS II produced an excellent data set to develop and test airport systems to detect winter weather, with emphasis on icing and snow.
- Although weaknesses in some sensors and models were documented, a good system will use the strengths from various potential input components to produce reliable and accurate detection and forecast methods.
- Other aspects such as SLD formation, aircraft response to icing, and cloud characterization measurements also studied but not reported here.

Future Airport Nowcasting

- There is a need to consult with users regarding the effective presentation of data. (Proposal to SAR not funded but will be attempted again)
- Emphasis so far on improved safety but there are large financial savings with improved winter forecasting at airports
- Who will operate an airport nowcast system? MSC, NavCan, airport authority, airline, or private company.
- AIRS III, FlySafe or a U.S. based experiment



53 M € over 4 years from European Community

Collaboration through World Weather Research Program



Suggestions for Model Development/Verification

- **Nowcasting needs forecast models that are initialized more frequently than every 12 hours.**
- **Recommend at least every 3 hours**
- **Specially instrumented ground sites could be very useful tools for validation and development of small scale models**
- **Recommend sites across country: west coast, prairie, central, Arctic, and east coast.**

Questions?

