MARINE FOG

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Definition of fog

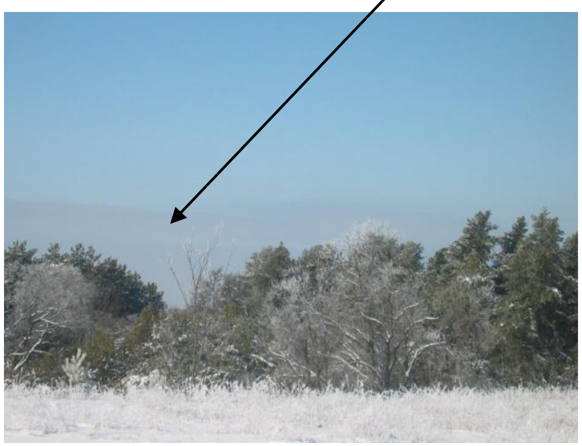
Warm fog → RHw~100% and Vis<1 km

Cold fog →

- **Freezing fog:** Tg<=0C; RHw~100%; Ta~0C (freezing at surface)
- **Frozen fog:** -10C<Ta<=0C; RHw~100% (freezing happens in the air)
- **Ice fog:** Ta<-10C; RHi>100% (Depositional nucleation)

Fog and Precip VIS

$$Vis=f(V_{rh};V_{mix};V_{liquidfog};V_{icefog};V_{drizzle};V_{rain};V_{snow};V_{blows})$$

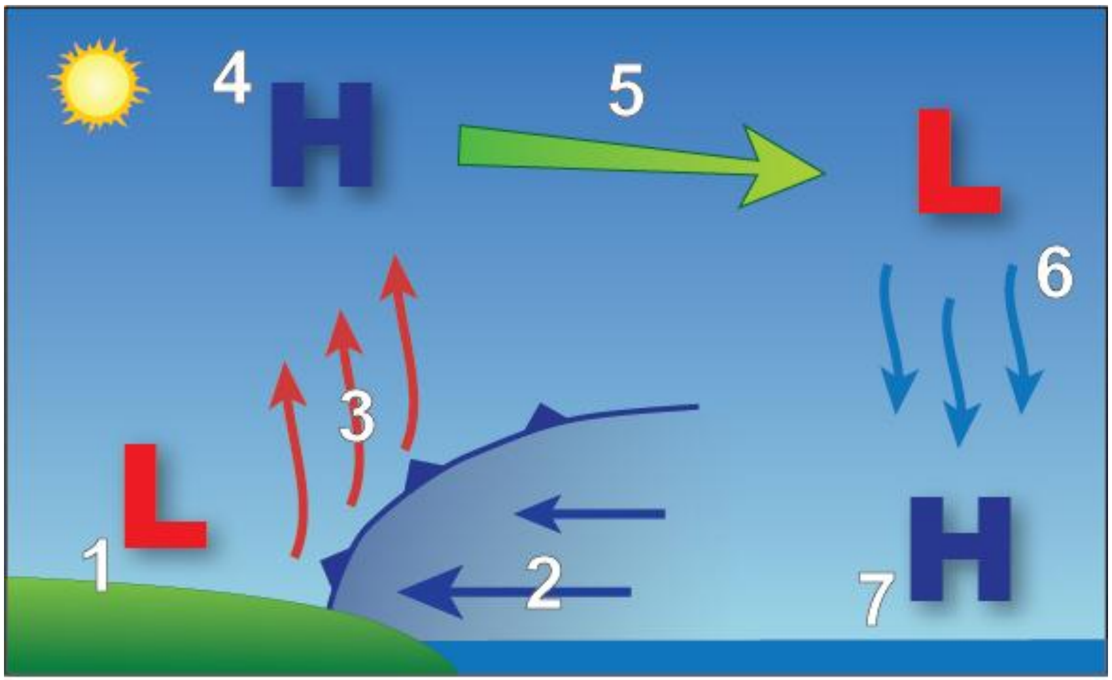


MARINE FOG

Goals

- 1) its formation
- 2) its development and dissipation
- 3) Its impact on environment
- 4) Its prediction and numerical models
- 5) Remote sensing applications

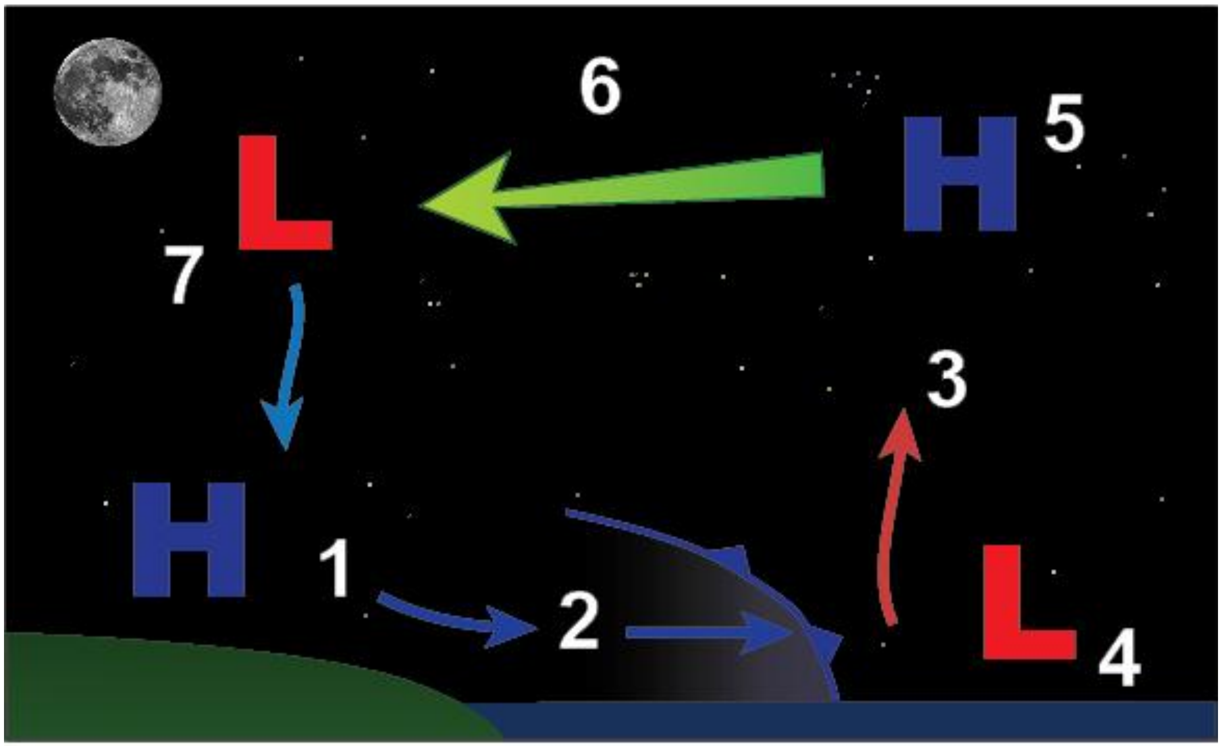
SEA BREEZE OVER DAY TIME



The sea breeze circulation is composed of two opposing flows; one at the surface (called the sea breeze) and one aloft (which is a return flow). These two flows are a result of the difference in air density between the land and sea caused by the sun's heating.

http://www.srh.noaa.gov/jetstream/ocean/seabreezes.htm

OVER NIGHT

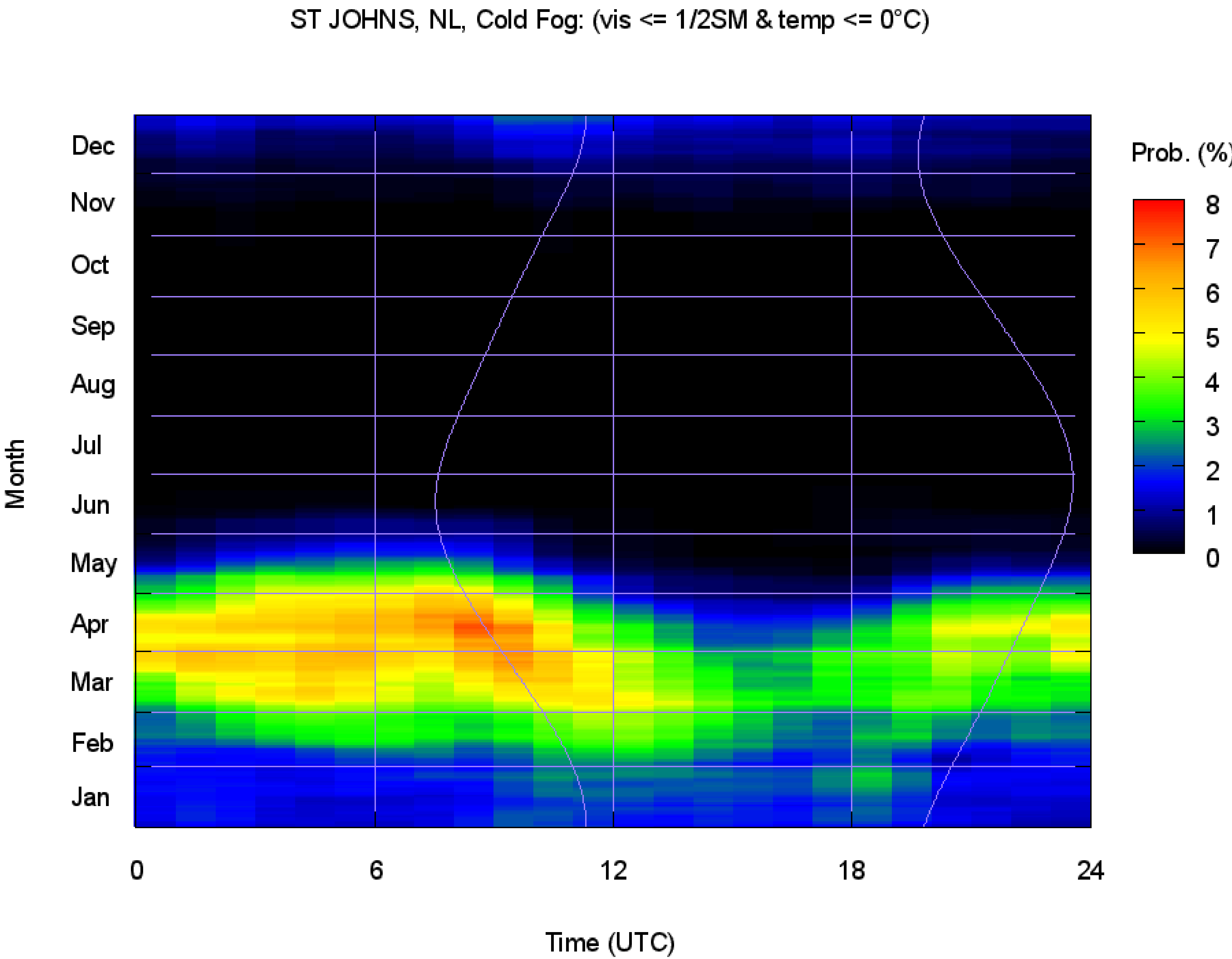


As the air warms, its density decreases creating a weak low pressure area called a "thermal low" (1).

Over the adjacent water the cooler, more dense air, being pull down by gravity, begins to spread inland (2).

This inland push of air from the ocean undercuts the less dense air over land forcing it to rise (3).

A sharp boundary develops due to the large difference between the air temperature over land and over water. This boundary, called a sea breeze front, acts in the same manner as the cold front we typically experience.


ST JOHNS, NL, Cold Fog: (vis <= 1/2SM & temp <= 0°C)
Month
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
0
6
12
18
24
Time (UTC)
Prob. (%)
8
7
6
5
4
3
2
1
0

FORMATION
Warm air advection

- Marine fog forms due to large scale warm and moisture air advection from ocean over the colder ocean and land surfaces.

- Ta >Ts

- Ta-Td~<2C

- Existence of CCN

DEVELOPMENT

- Marine fog intensity (Vis) decreases in early morning because of radiative cooling over land
- Calm air/less turbulence
- Strong advection from warm/moist air regions
- Available CCN (sea salt particles)

DISSIPATION

- 1) Radiative heating
- 2) Wind circulation opposite to conditions occurred during development
- 3) Turbulence/Mixing

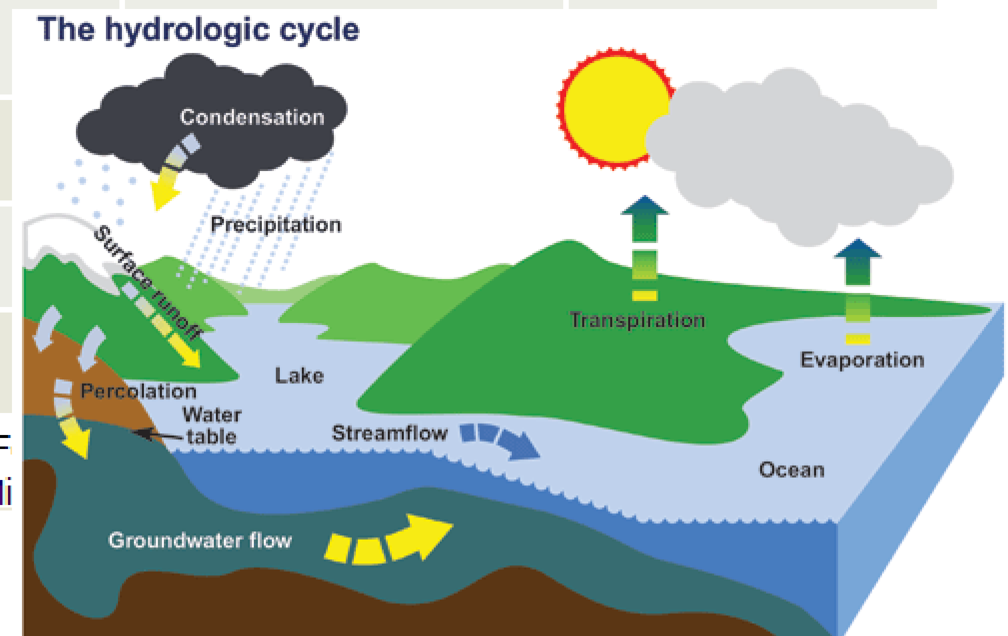
3. ITS IMPACT ON ENVIRONENMENT

- i. Hydrological cycle
- ii. Plant and vegetation
- iii. Aviation and transportation
- iv. Energy

i) Hydrological cycle

	Intensity inches/hour (cm/hour)	Median diameter (millimeters)	Velocity of fall feet/second (meters/second)	Drops per second per square foot (square meter)
Fog	0.005 (0.013)	0.01	0.01 (0.003)	6,264,000 (67,425,000)
Mist	.002 (.005)	.1	.7 (.21)	2,510 (27,000)
Drizzle	.01 (.025)	.96	13.5 (4.1)	14(151)
Light rain	.04 (1.02)	1.24	15.7 (4.8)	26 (280)
Moderate rain	.15 (.38)	1.60		
Heavy rain	.60 (1.52)	2.05		
Excessive rain	1.60 (4.06)	2.40		
Cloudburst	4.00 (10.2)	2.85		

Source: Lull, H.W., 1959, Soil Compaction on F
Forestry Service, Mi



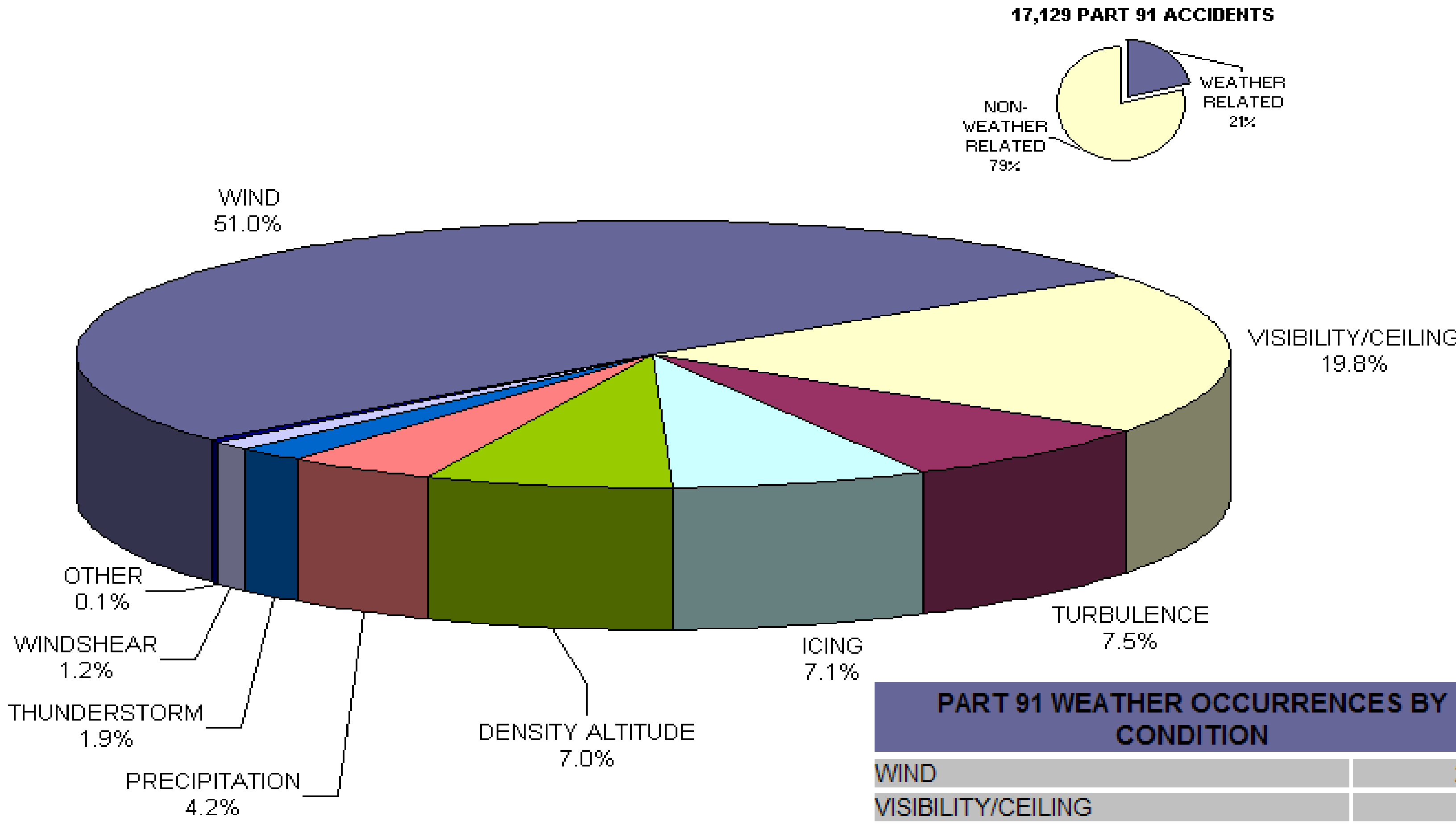
ii) Plant and Vegetation

- Plants need water to survive and some trees need more than others
- In their growth season, they use their body cells (Leaves) absorbing the water droplets
- Longer the contact with fog, they can process chemicals found in the fog
- Keep the soil moisture in the certain level

iii) Aviation and Transportation

- Visibility affects aviation and transportation
- Approximately 30-40% of aviation accidents related to weather conditions
- ~60 people dies in Canada because of fog related accidents per year
- This number increases up 600-1000 people per year in US (assuming same rate)
- 30 Million dollars per day costs to the aviation industry if a large airport stops the commercial flights.

PART 91 NTSB WEATHER RELATED ACCIDENTS BY WEATHER CONDITION 1994-2003



PART 91 WEATHER OCCURRENCES BY CONDITION	
WIND	2514
VISIBILITY/CEILING	977
TURBULENCE	371
ICING	350
DENSITY ALTITUDE	347
PRECIPITATION	208
THUNDERSTORM	94
WINDSHEAR	59
OTHER	7
TOTAL	**4927**

Between 1994 and 2003, there were 19,562† aircraft accidents, involving 19,823 aircraft, of which 17,129 were cor in 3,617 of the Part 91accidents. This chart identifies the breakout of Part 91 weather related accidents according to

† Accidents include final reports only where causal factors were identified.

§ A single accident may involve multiple weather conditions.

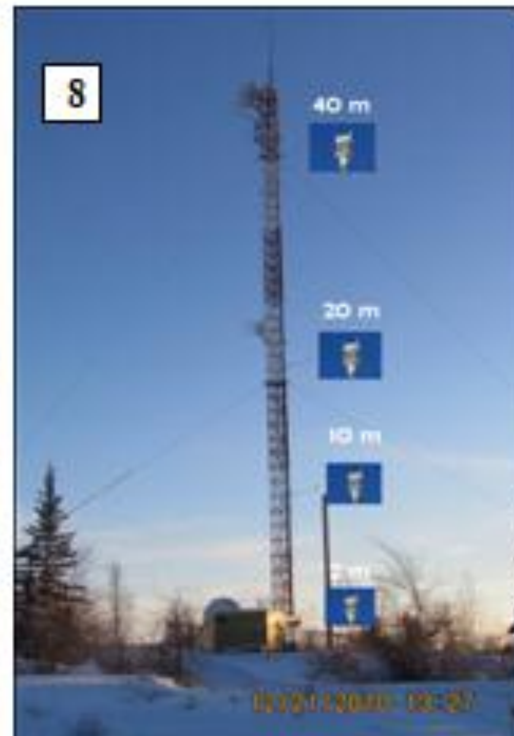
iv) Energy

- Fog affects surface air temperature (also heat) significantly
- This effect can be about 100 W m-2 depending on fog microphysics and optical thickness
- It also affects power lines because of freezing fog conditions.
- Its effect on climate change assessment is very limited/even unknown

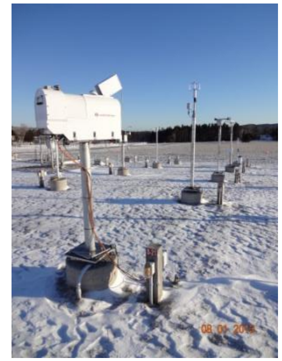
FOG PREDICTION

- FRAM Projects have been done over various regions of the world.
- Observations for some cases were collected nearby the ocean
- Microphysical observations were done using FMD (DMT fog device)
- All weather sensors were used for Vis meas.
- Remote sensing platforms were utilized

FOG SENSORS 2010-2011

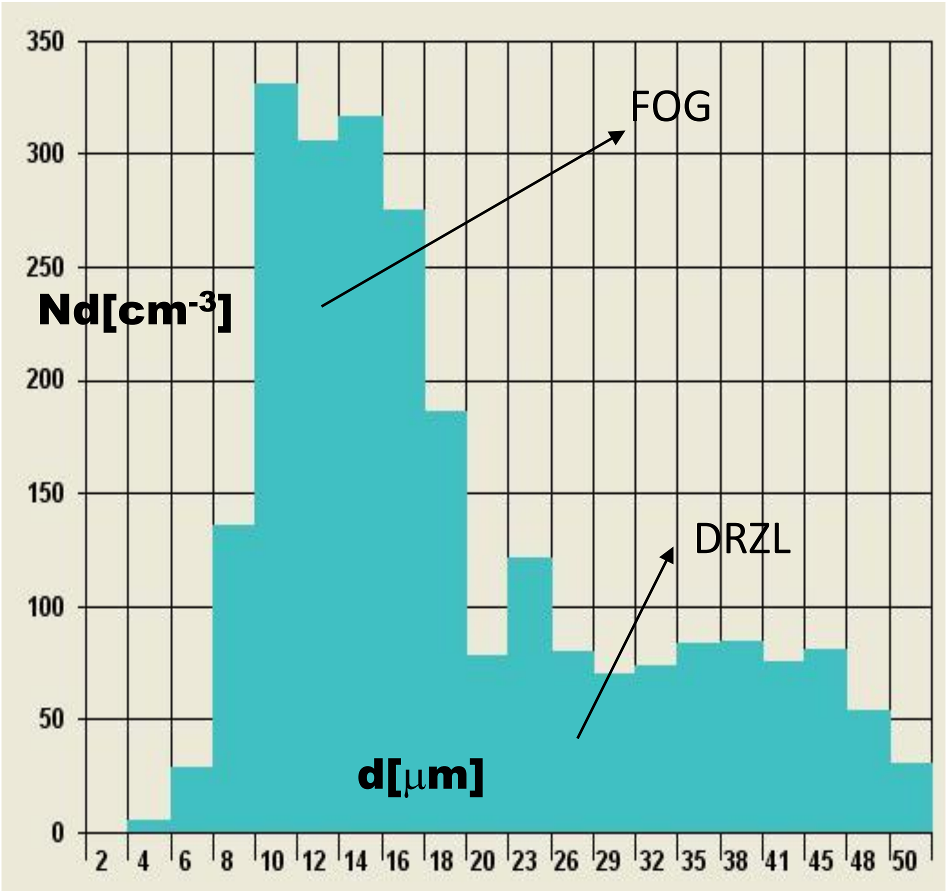


ICE FOG
WINTER 2014

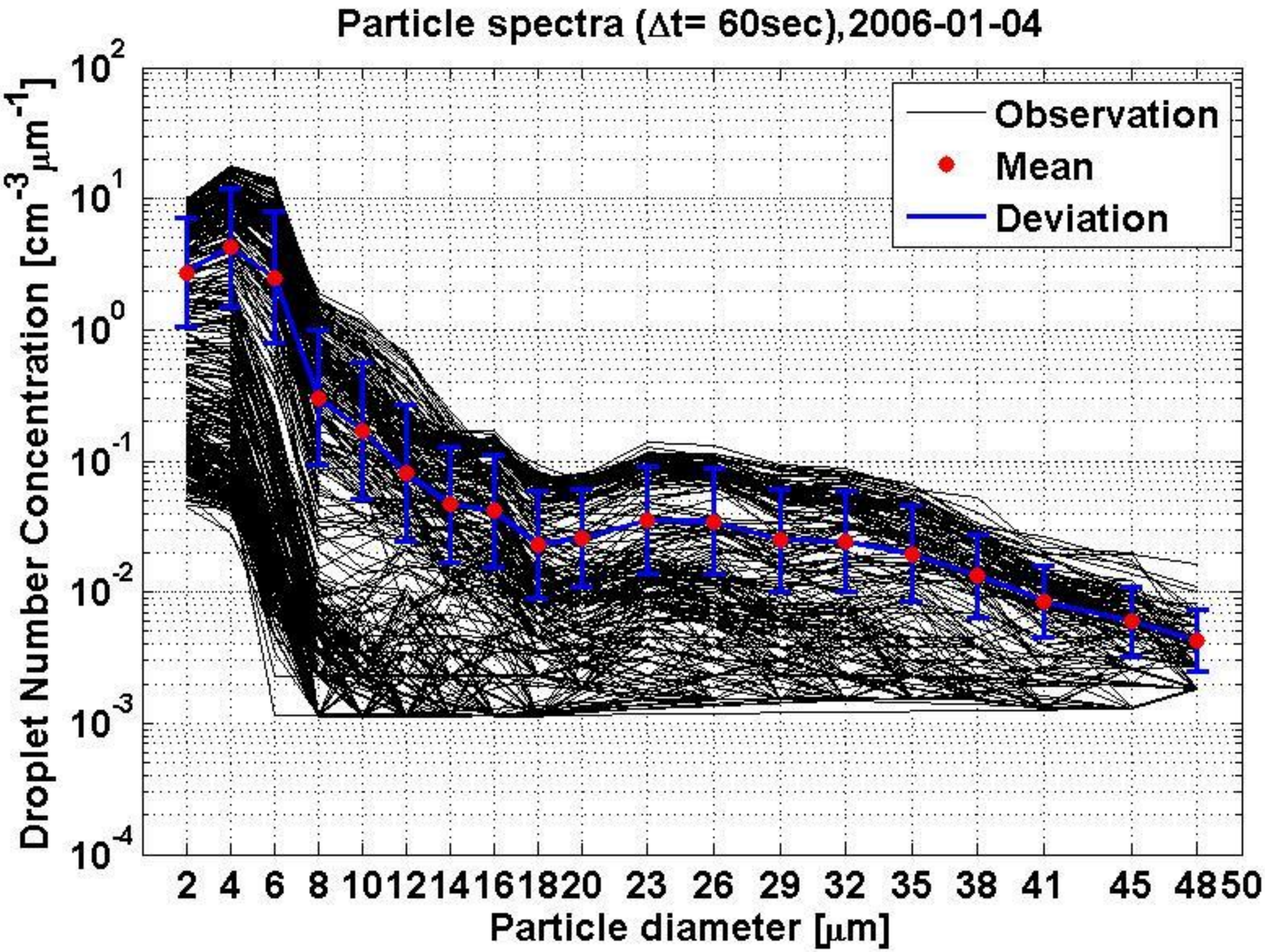


FMD (fog measuring device)

FOG +DRIZZLE DROPLET SPECTRA AT 10 AM LST.

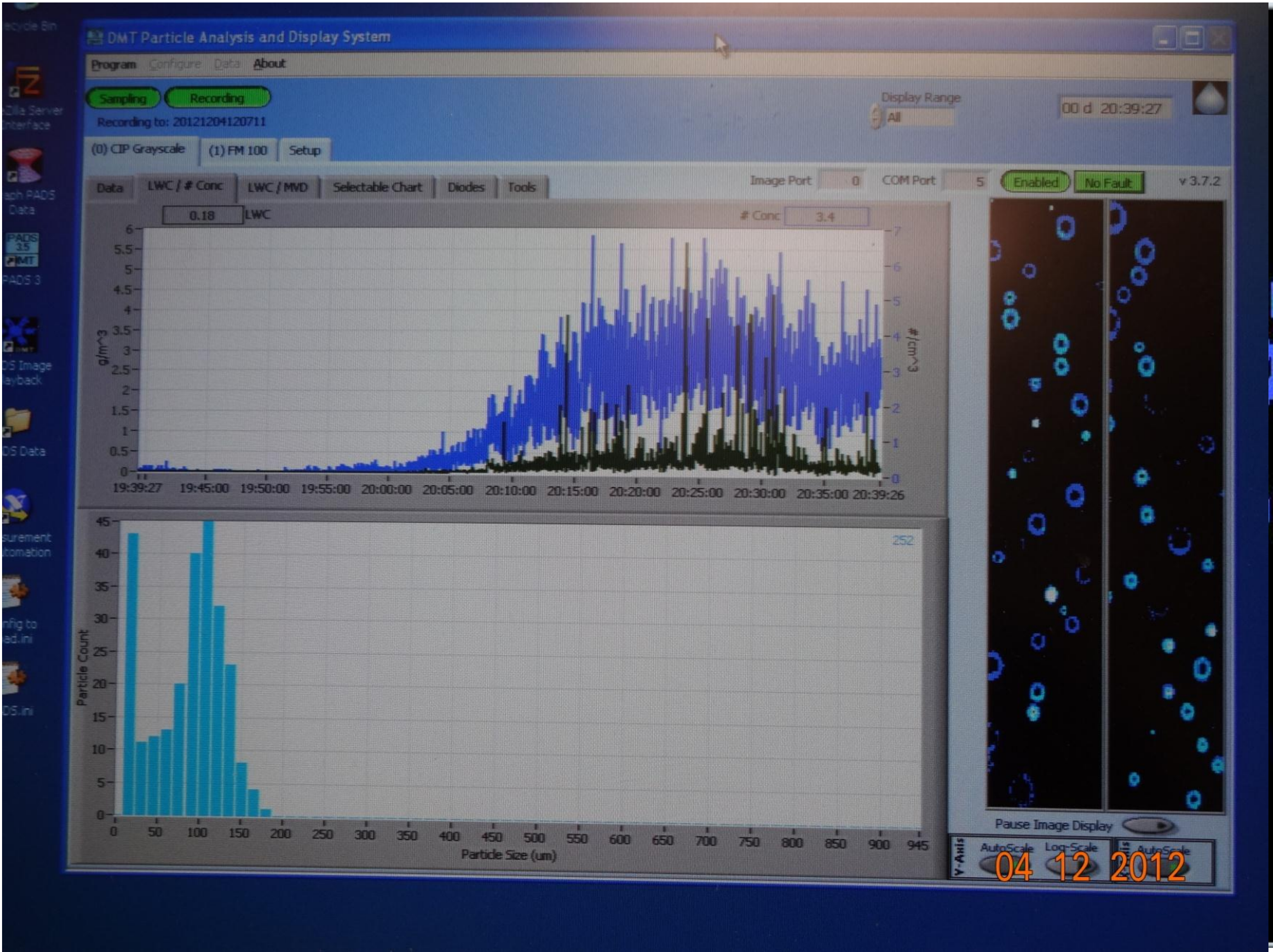


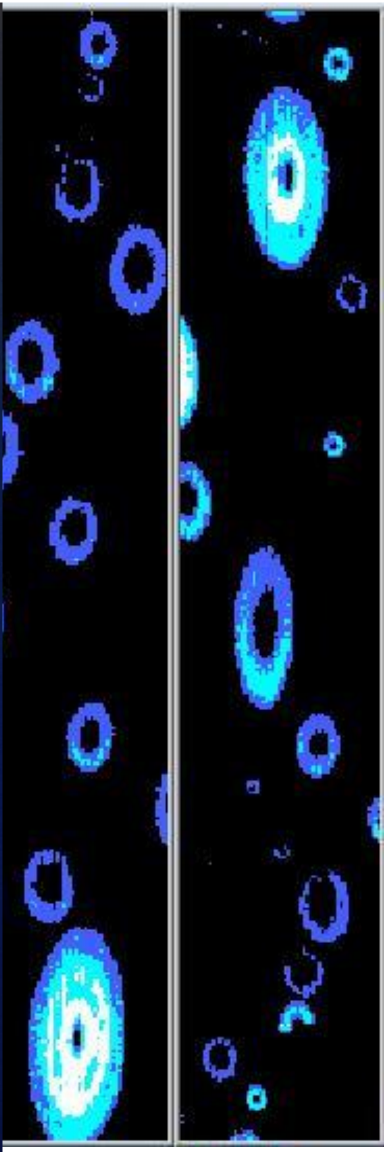
FOG SPECTRA

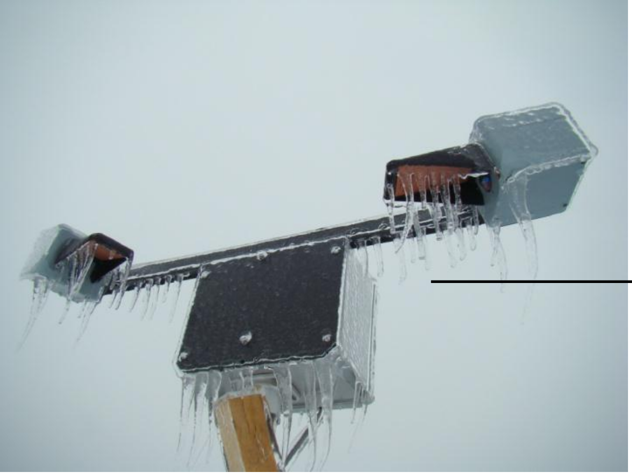


Particle spectra (Δt= 60sec),2006-01-04
Droplet Number Concentration [cm^-3 μm^-1]
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
Observation
Mean
Deviation
2 4 6 8 10 12 14 16 18 20 23 26 29 32 35 38 41 45 48 50
Particle diameter [μm]

GCIP MEASUREMENTS







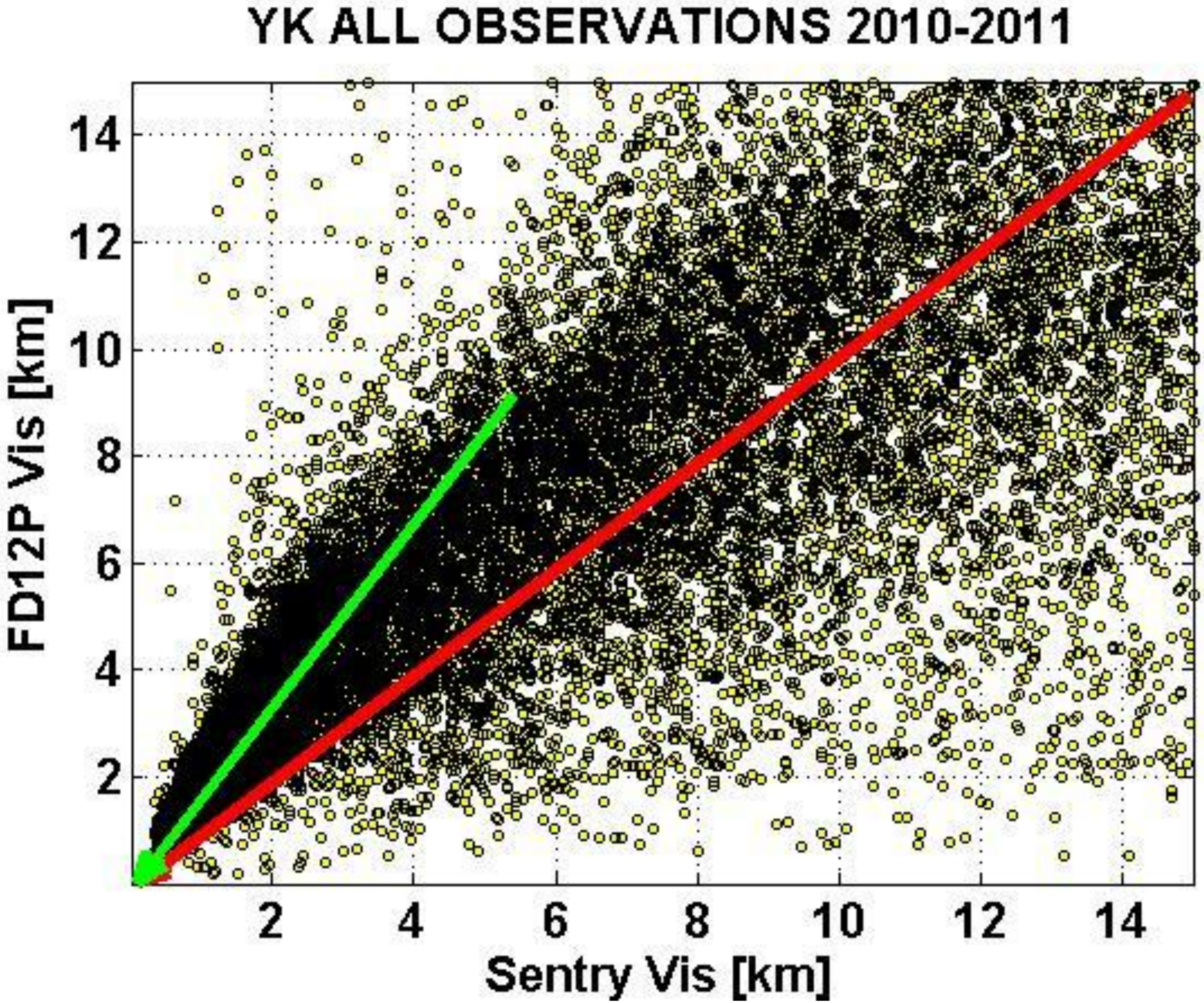
Sentry Vis

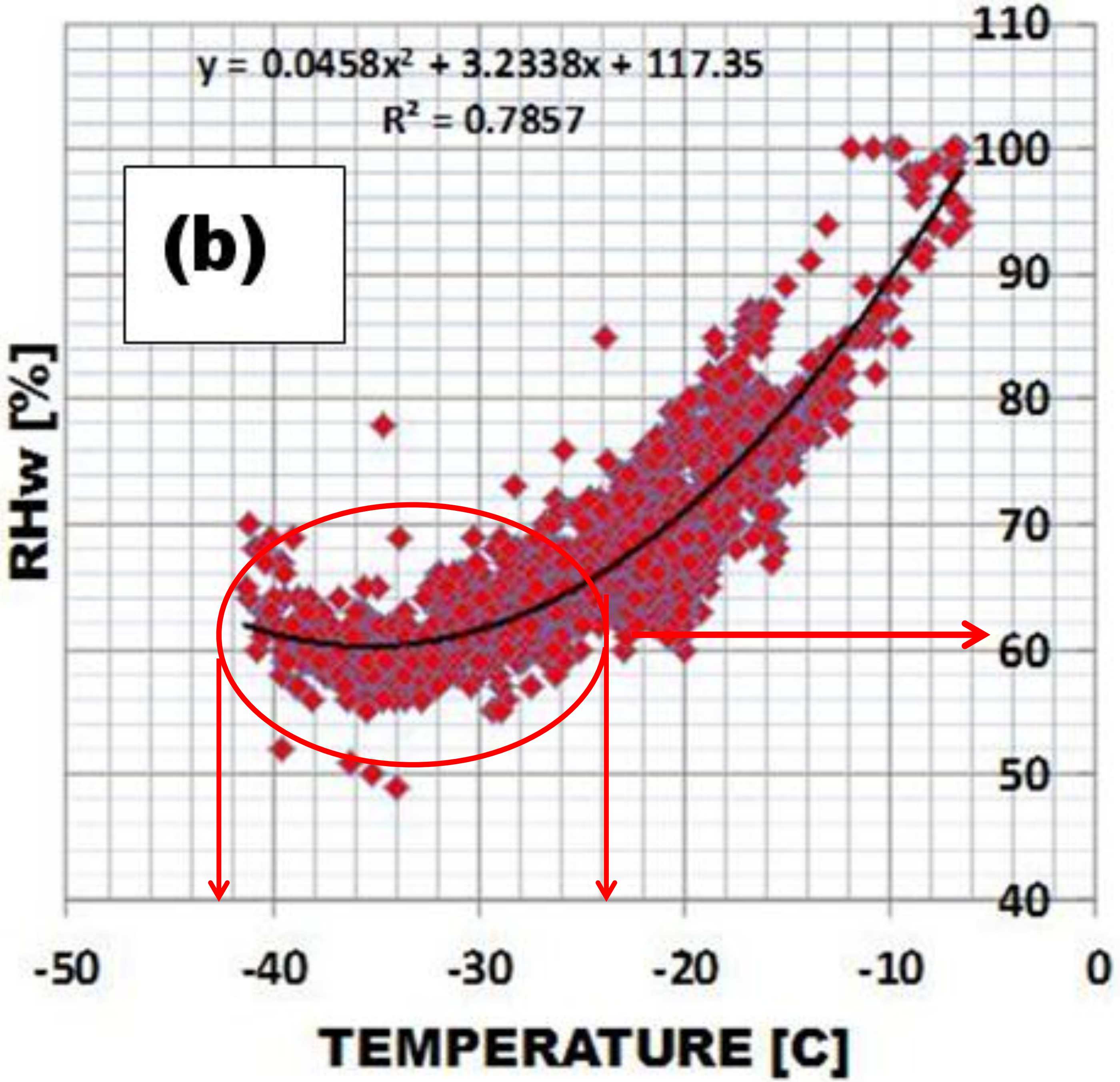
PWD12

Belfort Vis

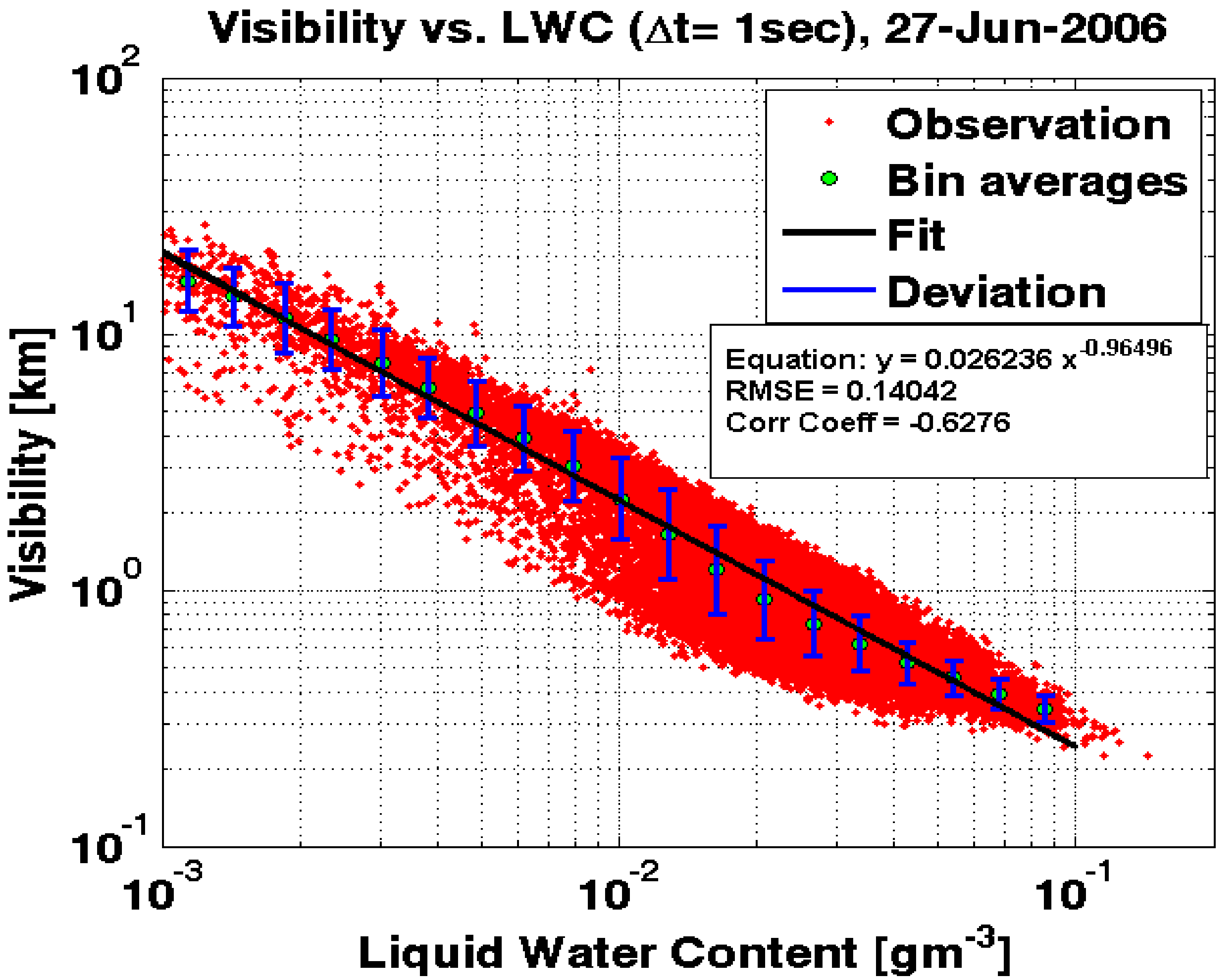
FD12P

HSS

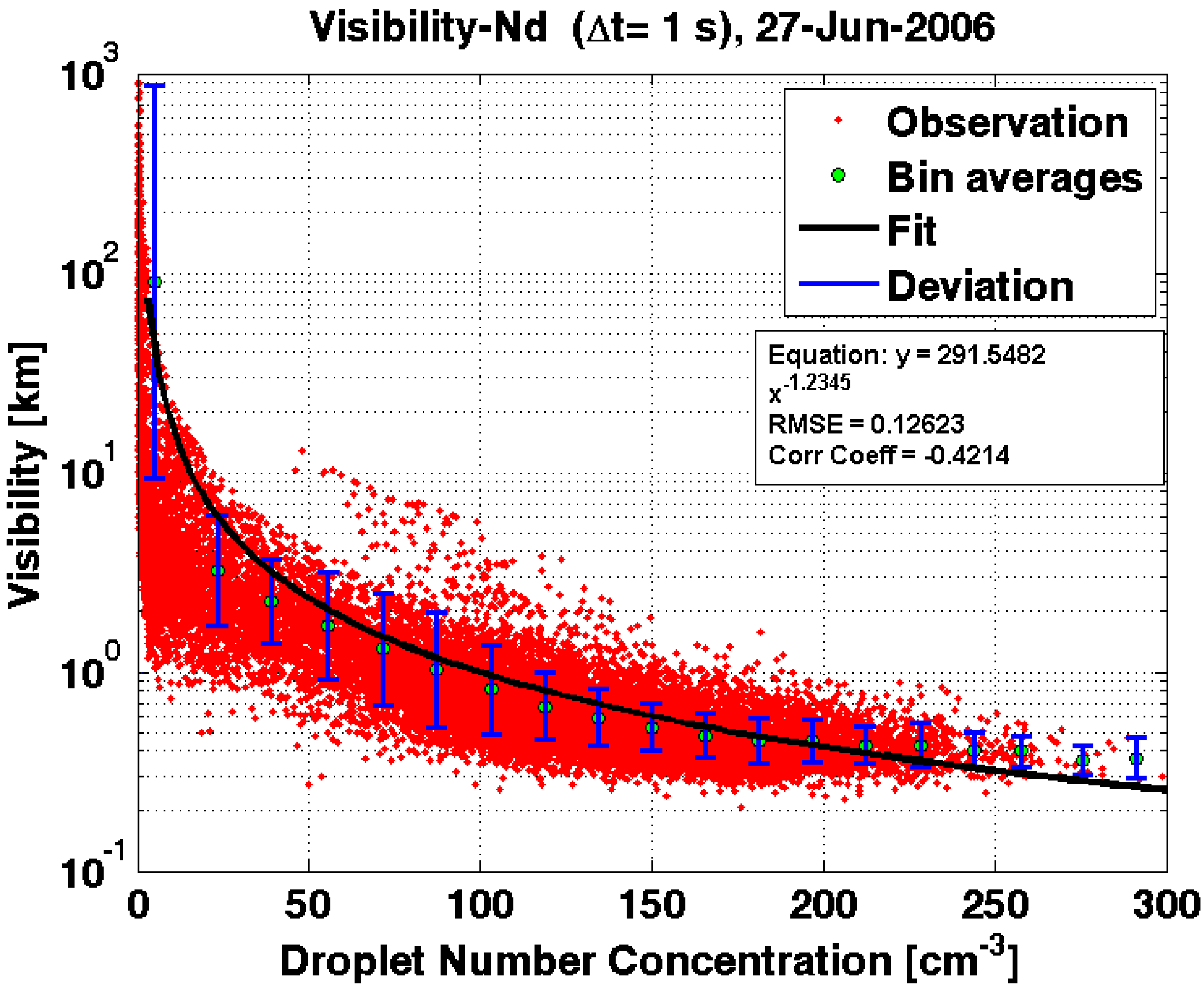

YK ALL OBSERVATIONS 2010-2011
FD12P Vis [km]
Sentry Vis [km]
2
4
6
8
10
12
14
2
4
6
8
10
12
14



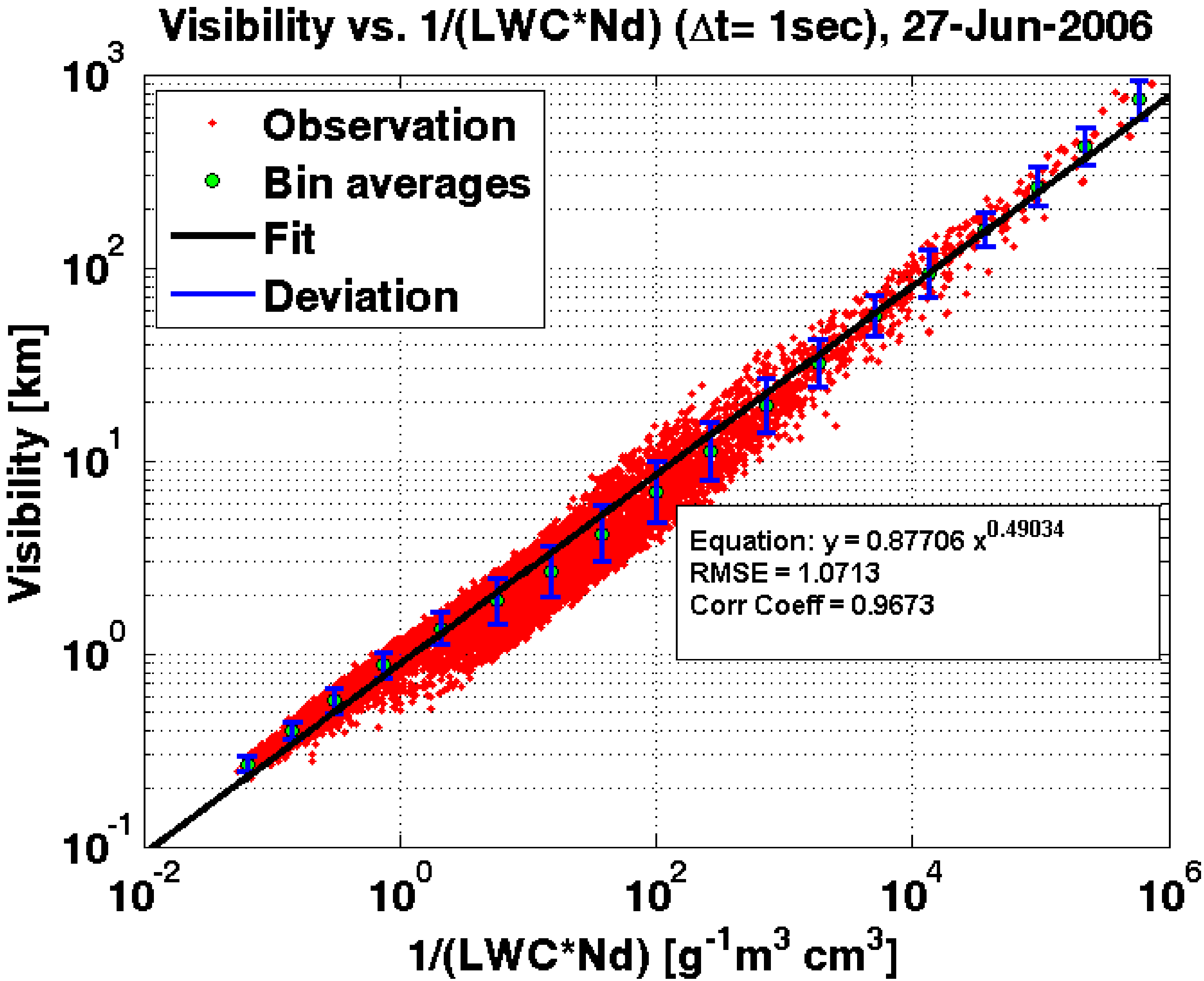
y = 0.0458x² + 3.2338x + 117.35
R² = 0.7857
(b)
RHw [%]
TEMPERATURE [C]
110
100
90
80
70
60
50
40
-50
-40
-30
-20
-10
0



Visibility vs. LWC (Δt= 1sec), 27-Jun-2006
Observation
Bin averages
Fit
Deviation
Equation: y = 0.026236 x^-0.96496
RMSE = 0.14042
Corr Coeff = -0.6276
Visibility [km]
Liquid Water Content [gm^-3]
10^2
10^1
10^0
10^-1
10^-3
10^-2
10^-1



Visibility-Nd (Δt= 1 s), 27-Jun-2006
Observation
Bin averages
Fit
Deviation
Equation: y = 291.5482 x^-1.2345
RMSE = 0.12623
Corr Coeff = -0.4214
Visibility [km]
Droplet Number Concentration [cm^-3]
10^3
10^2
10^1
10^0
10^-1
0
50
100
150
200
250
300



Visibility vs. 1/(LWC*Nd) (Δt= 1sec), 27-Jun-2006
Observation
Bin averages
Fit
Deviation
Equation: y = 0.87706 x^0.49034
RMSE = 1.0713
Corr Coeff = 0.9673
Visibility [km]
1/(LWC*Nd) [g^-1 m^3 cm^3]
10^-1
10^0
10^1
10^2
10^3
10^-2
10^0
10^2
10^4
10^6

FOG FORECASTING

Issues

- **Microphysical algorithms**
- Boundary layer characteristics
- Horizontal and vertical time/space resolutions
- 2D versus 3D models
- Validation of numerical forecast model simulations

INTEGRATED VISIBILITY

$$\beta_{ext} = \sum Q_{ext} n(r) \pi r^2 dr$$

$$\beta_{\text{int}} = \beta_{RHw} + \beta_{LWC;IWC} + \beta_{R;S}$$

$$Vis = -\ln(0.02) / \beta_{ext}$$

$$V_n = 1.8507 V_d^{\,0.814}$$

Daytime Vis versus nighttime Vis

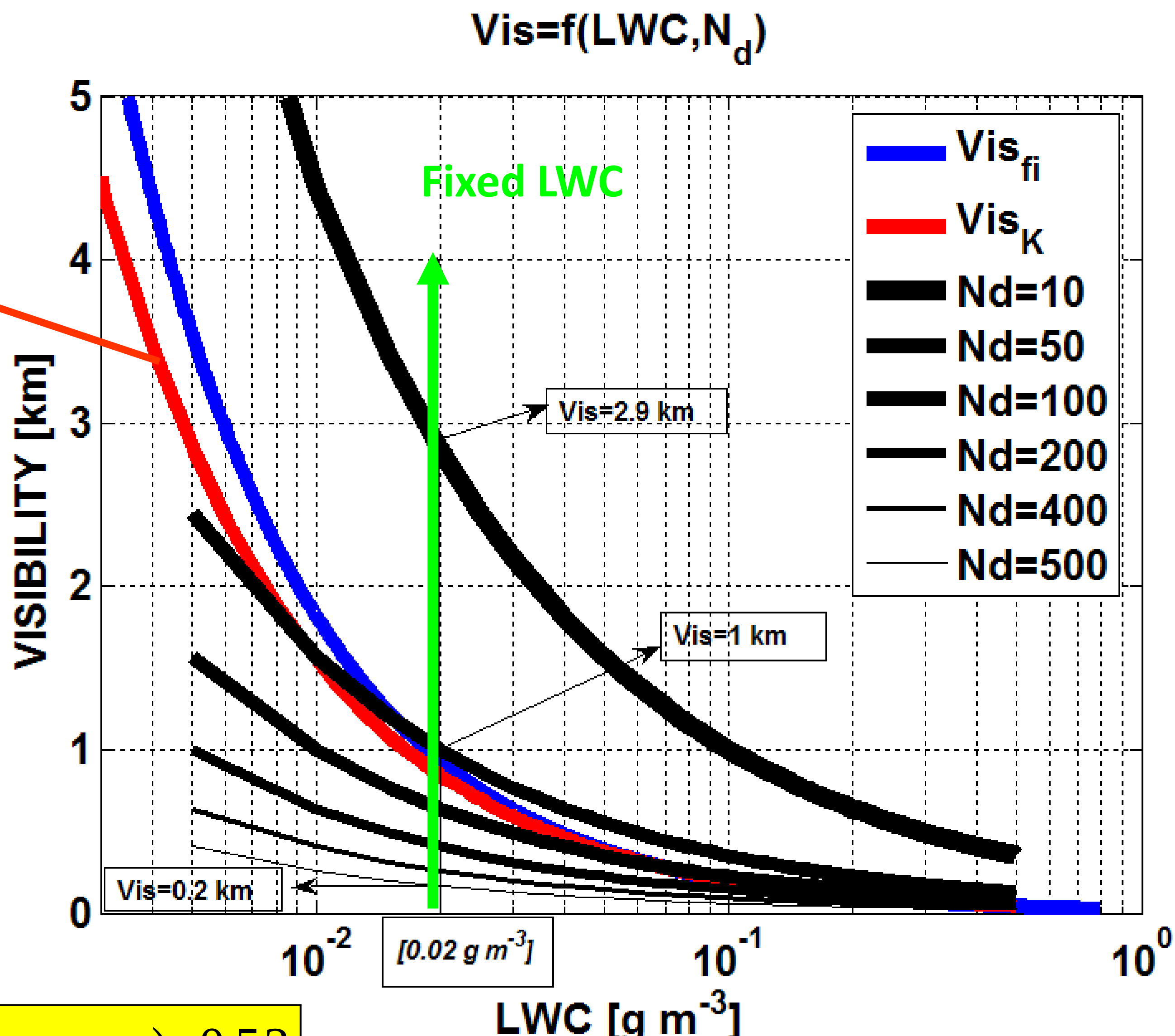
Vis=f(XWC); neglected N_d

TABLE 1. Relationships between the mass concentration (C, g m^{-3}) and the extinction coefficient (β, km^{-1}).

Hydrometeor	Relationship
Cloud liquid water, fog	$\beta = 144.7\ C^{0.88}$
Rain	$\beta = 1.1\ C^{0.75}$
Cloud ice	$\beta = 163.9\ C^{1.00}$
Snow	$\beta = 10.4\ C^{0.78}$

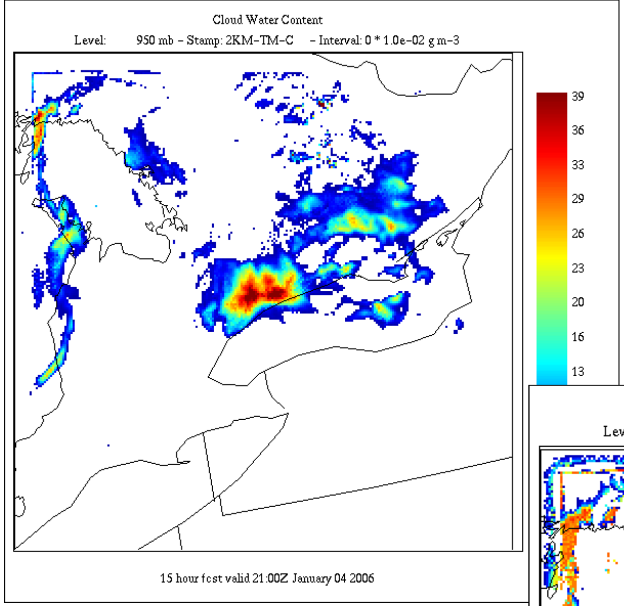
FOG Vis parameterization

RUC Vis

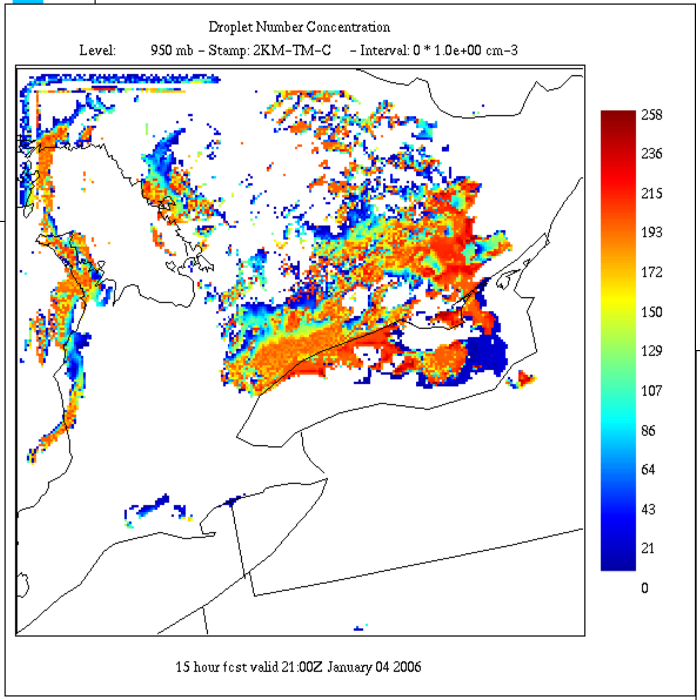


$$vis = 1.02\left(LWCxN_d\right)^{-0.52}$$

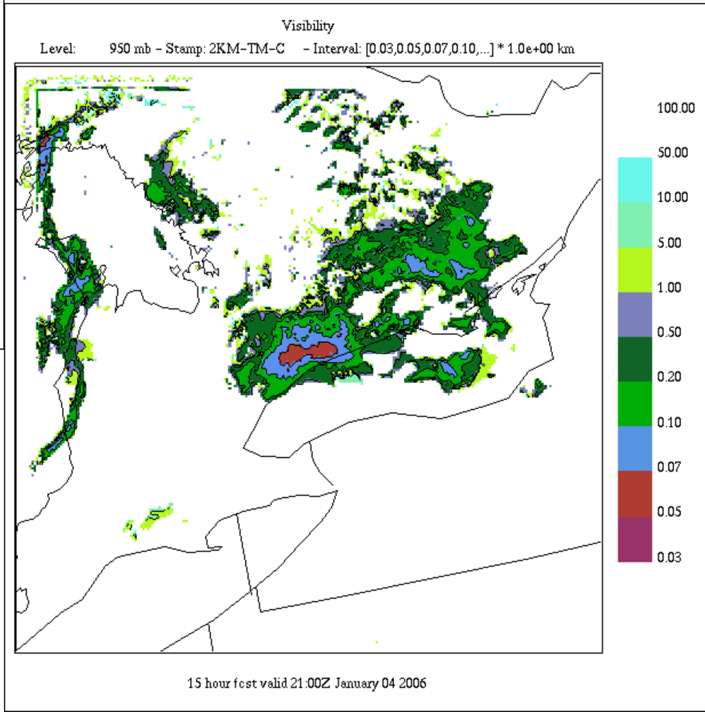
LWC, Nd, VIS



Cloud Water Content
Level: 950 mb - Stamp: 2KM-TM-C - Interval: 0 * 1.0e-02 g m-3
39
36
33
29
26
23
20
16
13
15 hour fcst valid 21:00Z January 04 2006

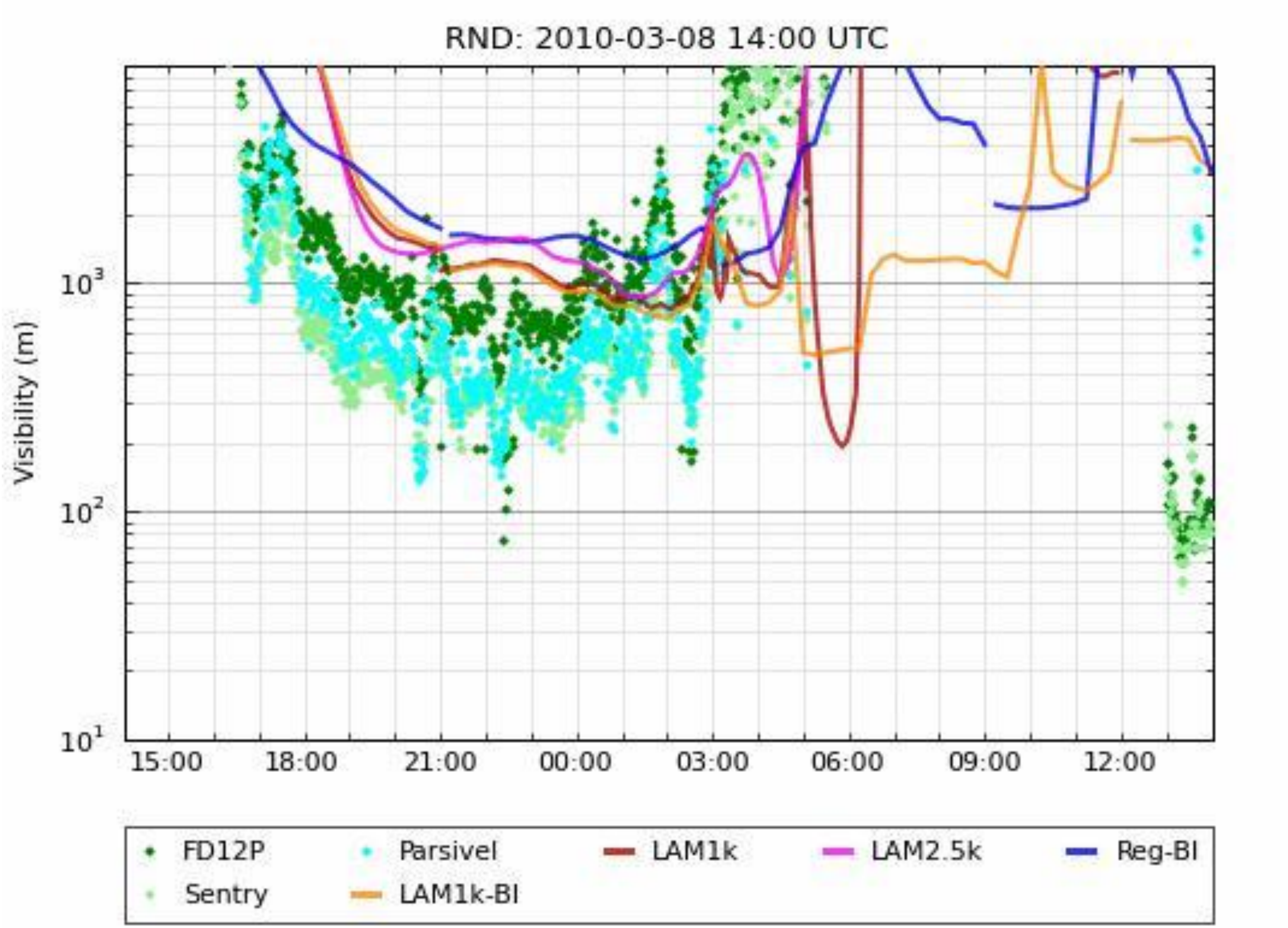


Droplet Number Concentration
Level: 950 mb - Stamp: 2KM-TM-C - Interval: 0 * 1.0e+00 cm-3
258
236
215
193
172
150
129
107
86
64
43
21
0
15 hour fcst valid 21:00Z January 04 2006

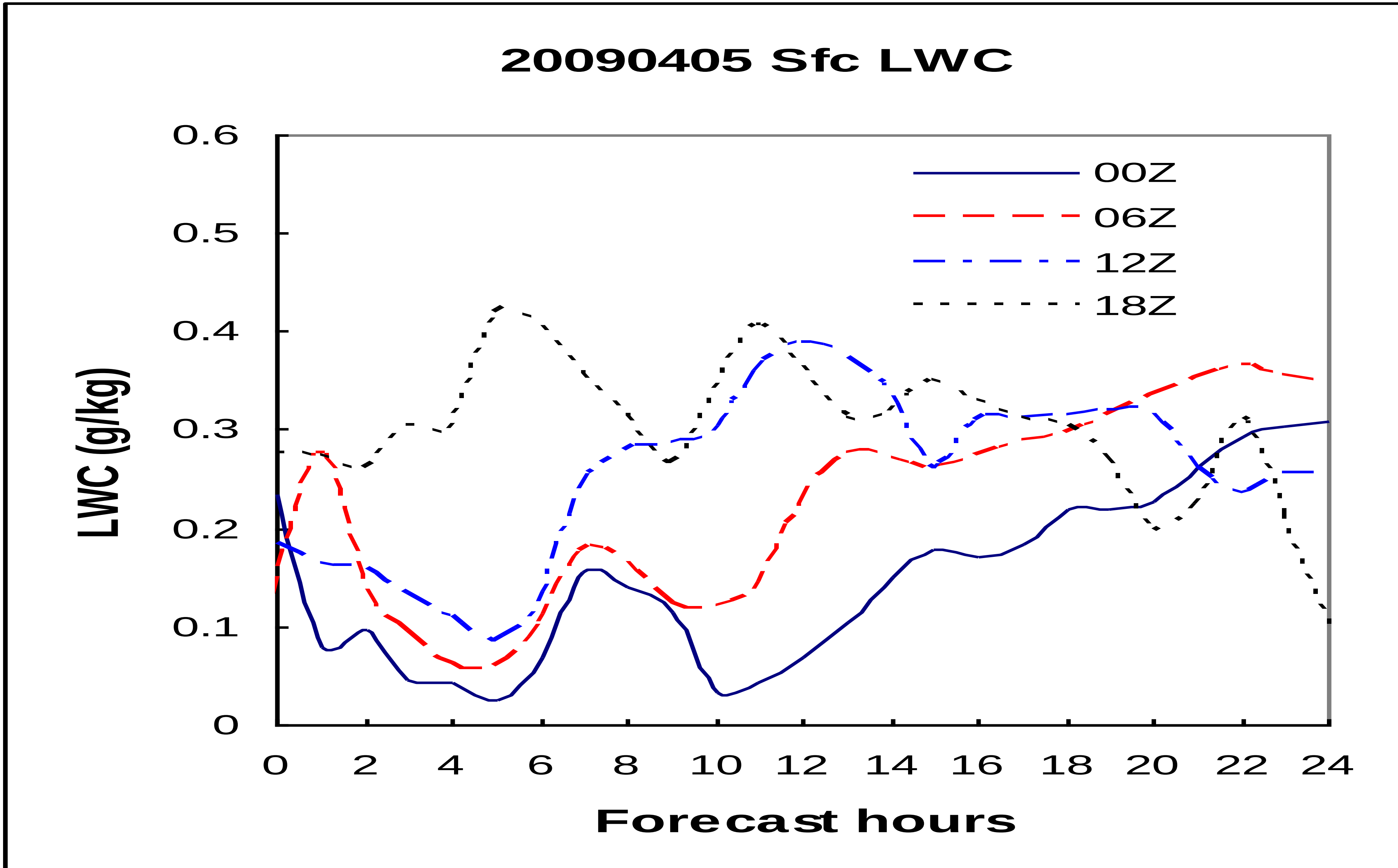


Visibility
Level: 950 mb - Stamp: 2KM-TM-C - Interval: [0.03,0.05,0.07,0.10,...] * 1.0e+00 km
100.00
50.00
10.00
5.00
1.00
0.50
0.20
0.10
0.07
0.05
0.03
15 hour fcst valid 21:00Z January 04 2006

VIS VERSUS TIME
RND station



LWC comparisons at various forecast hours (NCEP-NAM)



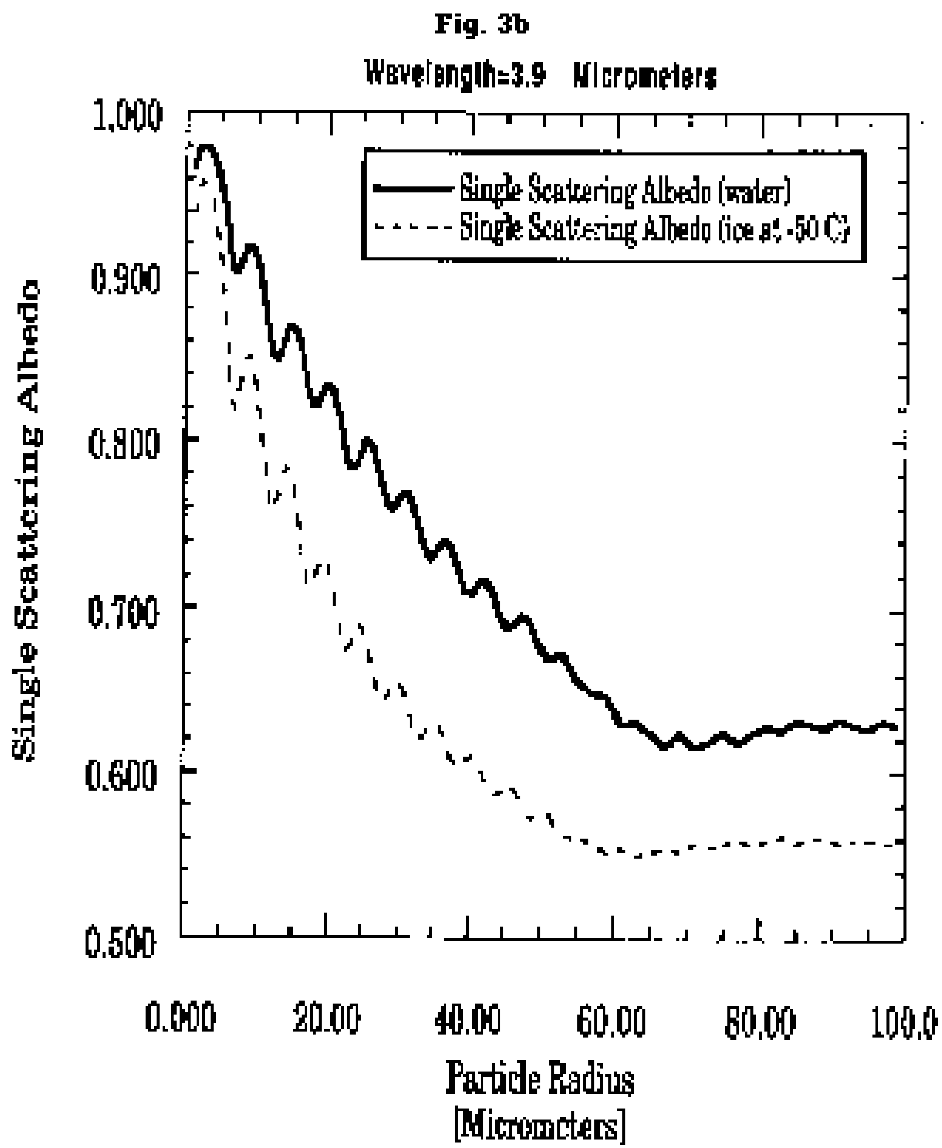
GOES-R ABI Bands

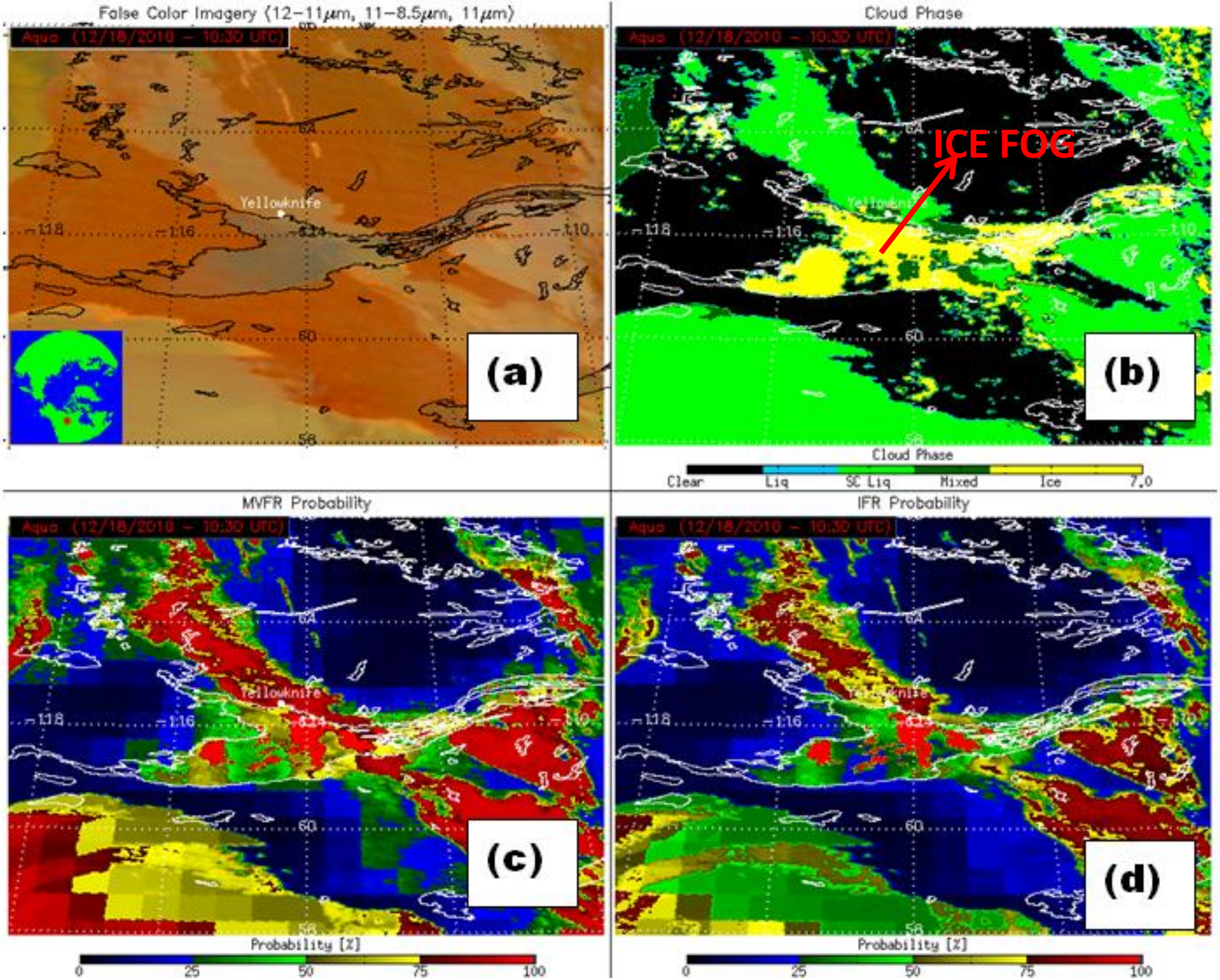
Future GOES Imager (ABI) Band	Wavelength Range (µm)	Central Wavelength (µm)	Sample Objective(s)
1	0.45-0.49	**0.47**	Daytime aerosol-over-land, Color imagery
2	0.59-0.69	**0.64**	Daytime clouds fog, insolation, winds
3	0.846-0.885	**0.865**	Daytime vegetation & aerosol-over-water, winds
4	1.371-1.386	**1.378**	Daytime cirrus cloud
5	1.58-1.64	**1.61**	Daytime cloud water, snow
6	2.225 - 2.275	**2.25**	Day land/cloud properties, particle size, vegetation
7	3.80-4.00	**3.90**	Sfc. & cloud/fog at night, fire
8	5.77-6.6	**6.19**	High-level atmospheric water vapor, winds, rainfall
9	6.75-7.15	**6.95**	Mid-level atmospheric water vapor, winds, rainfall
10	7.24-7.44	**7.34**	Lower-level water vapor, winds & SO_2
11	8.3-8.7	**8.5**	Total water for stability, cloud phase, dust, SO_2
12	9.42-9.8	**9.61**	Total ozone, turbulence, winds
13	10.1-10.6	**10.35**	Surface properties, low-level moisture & cloud
14	10.8-11.6	**11.2**	Total water for SST, clouds, rainfall
15	11.8-12.8	**12.3**	Total water & ash, SST
16	13.0-13.6	**13.3**	Air temp & cloud heights and amounts

Based on experience from:

Current GOES Imagers

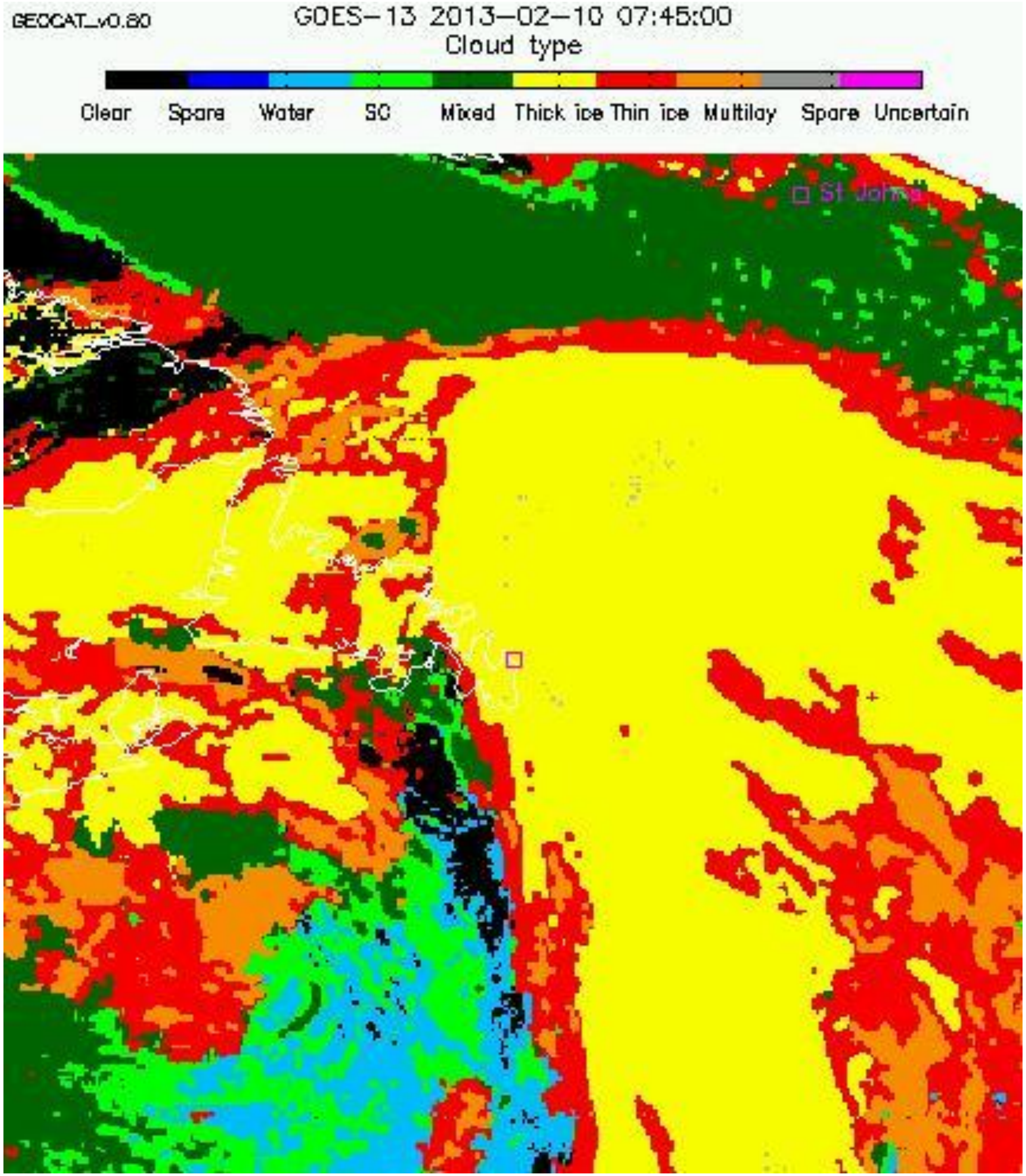
SSA versus Reff at 3.9 micron for liquid and ice particles



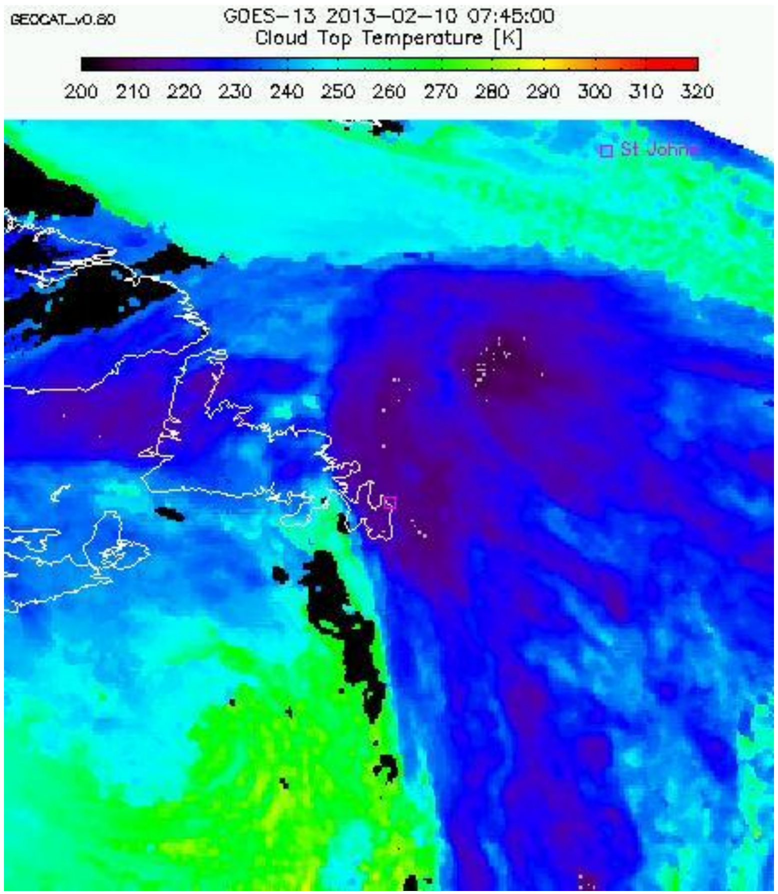


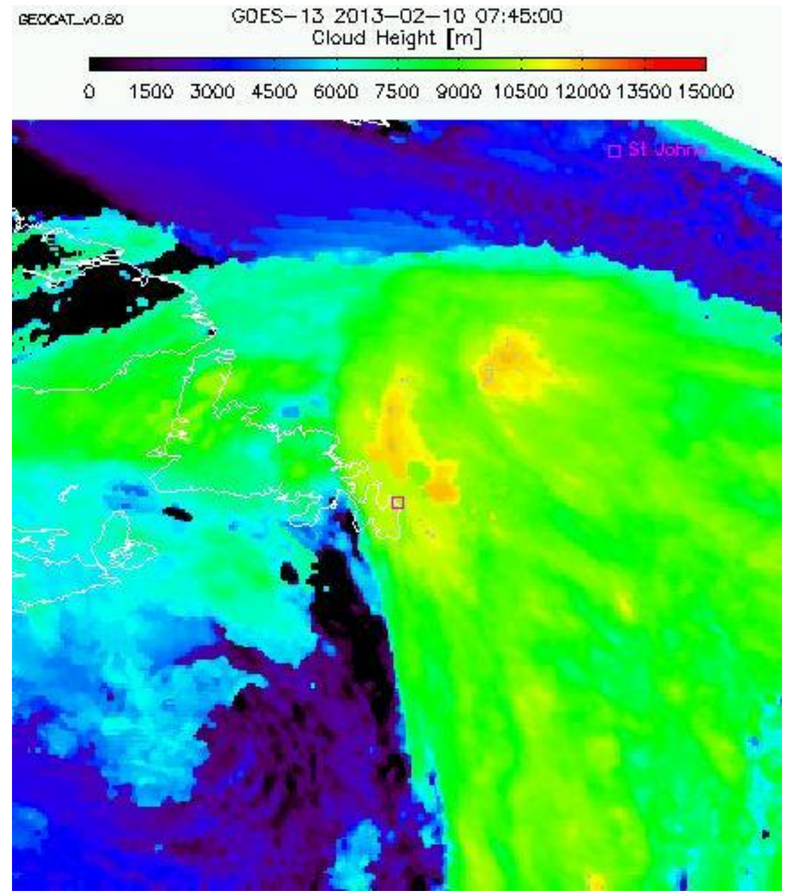
False Color Imagery (12-11µm, 11-8.5µm, 11µm)
Cloud Phase
ICE FOG
Yellowknife
(a)
(b)
Cloud Phase
Clear
Liq
SC Liq
Mixed
Ice
7.0
MVFR Probability
IFR Probability
(c)
(d)
Probability [%]
0
25
50
75
100

CLOUD TYPE

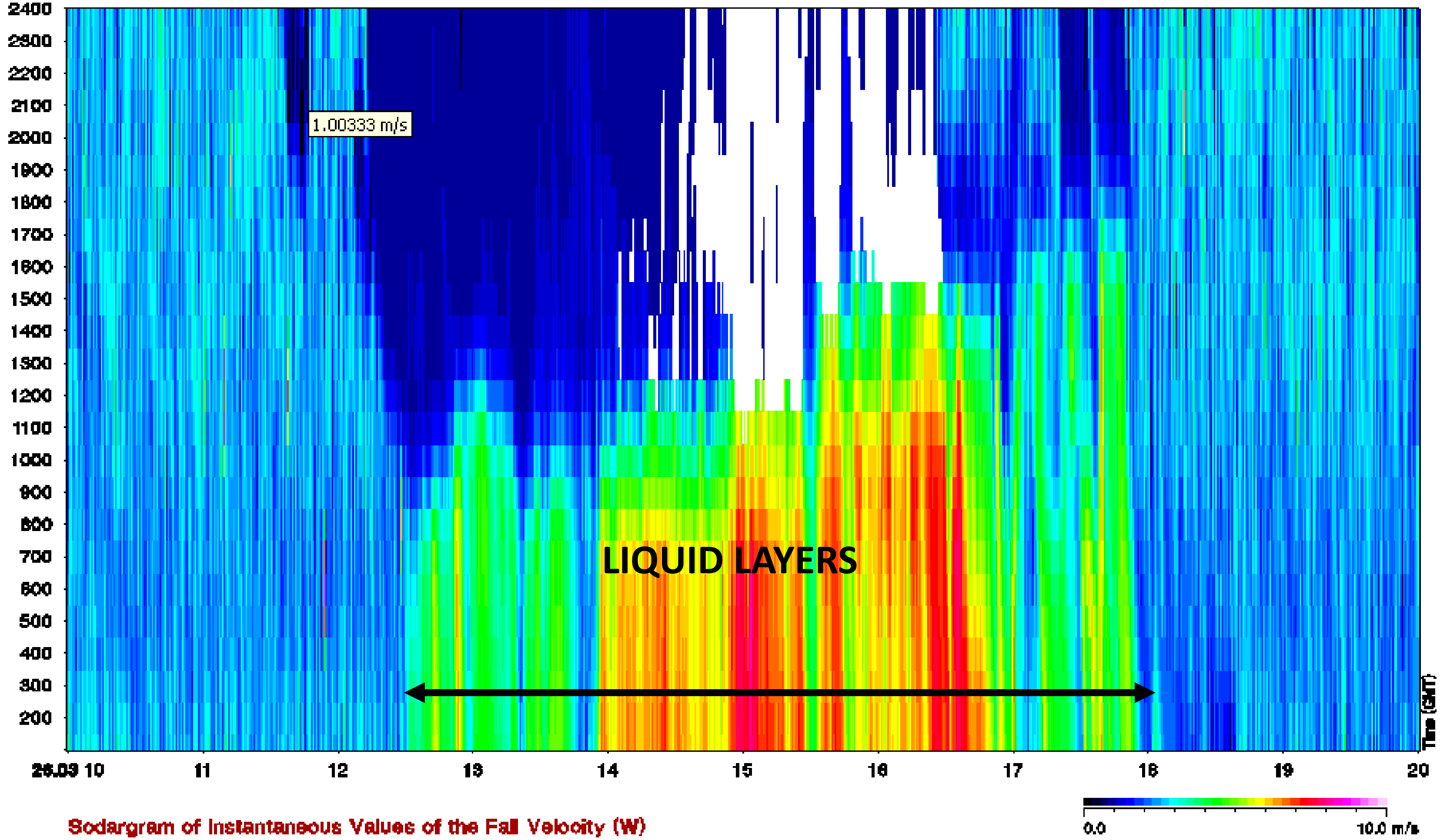

GEOCAT_v0.80
GOES-13 2013-02-10 07:45:00
Cloud type
Clear
Spare
Water
SC
Mixed
Thick ice
Thin ice
Multilay
Spare
Uncertain
St Johns

CLOUD TOP T AND HEIGHT



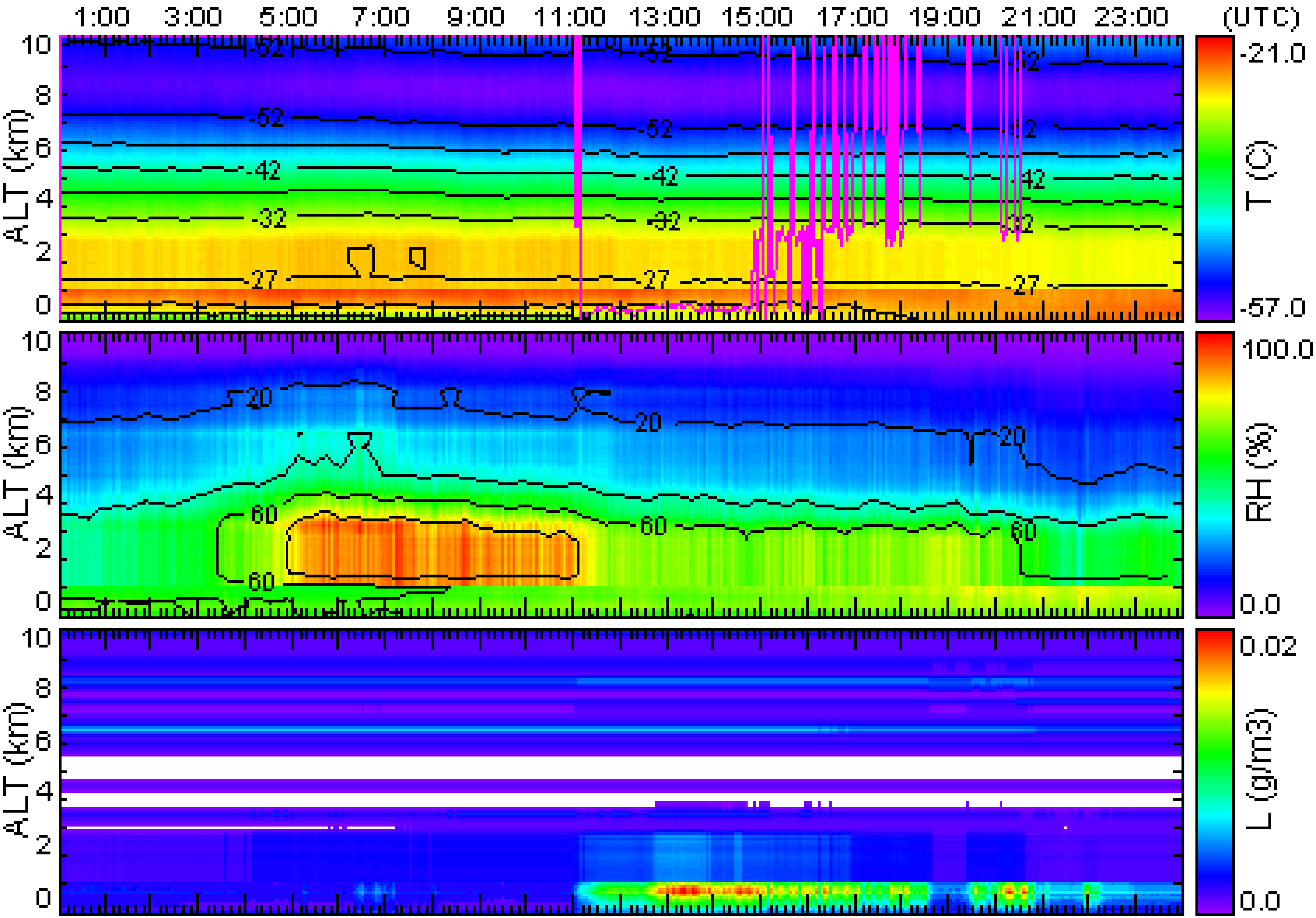


MRR Vd



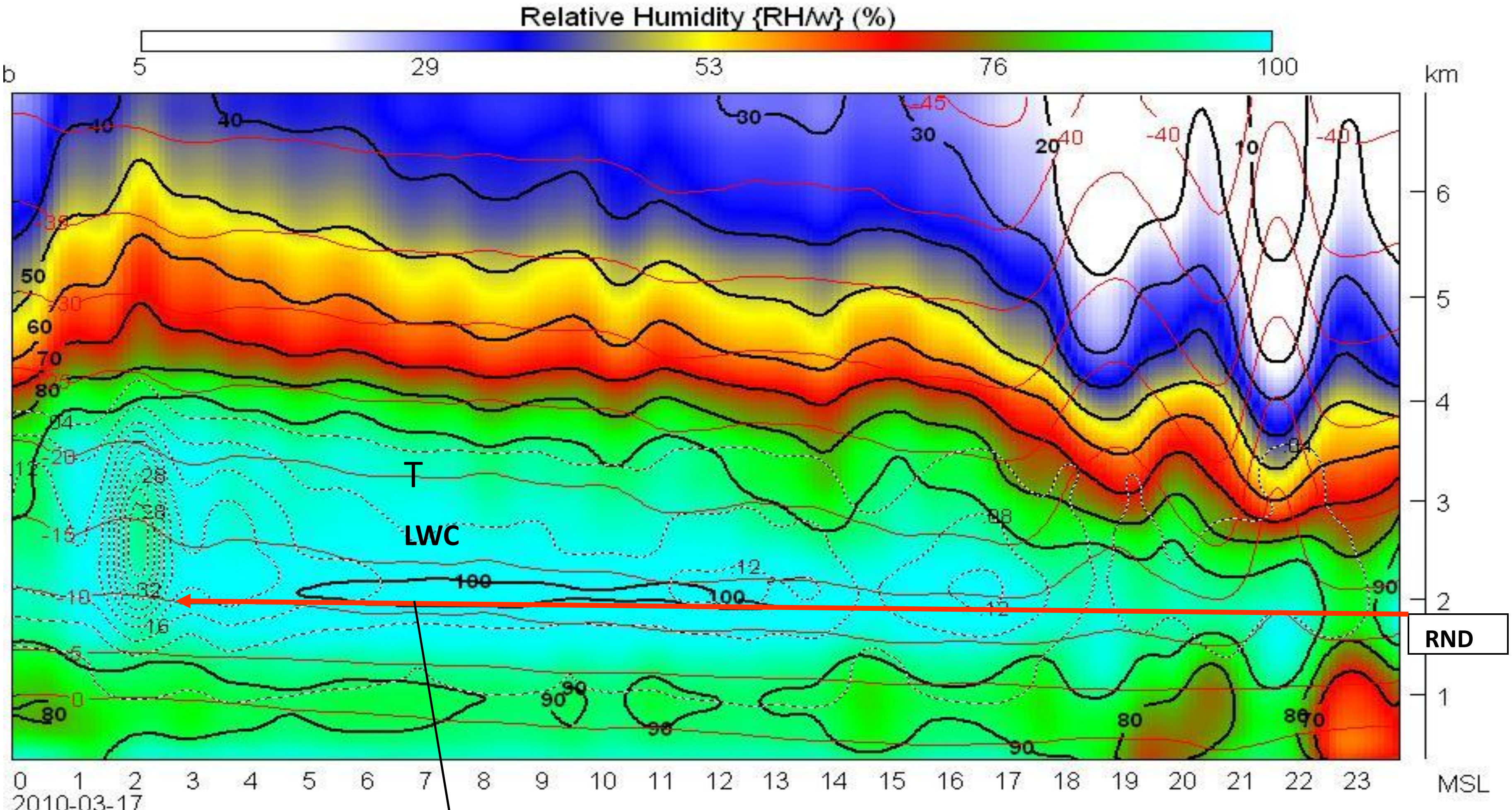
The MRR particle fall velocities [m s^{-1}] versus height from 1000 UTC to 2000 UTC, 26 March 2009. The red color represents fall velocities greater than 7 m s^{-1}.

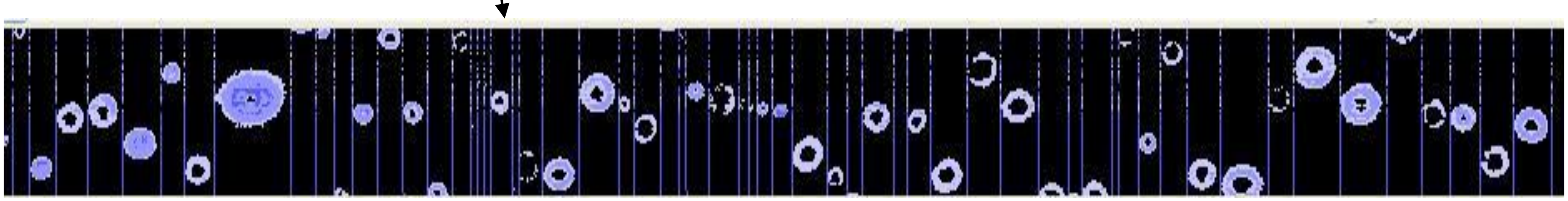
Jan 13 PMWR


Cloud Base
radiometrics
1:00
3:00
5:00
7:00
9:00
11:00
13:00
15:00
17:00
19:00
21:00
23:00
(UTC)
ALT (km)
0
2
4
6
8
10
-52
-42
-32
-27
T (C)
-21.0
-57.0
20
60
RH (%)
100.0
0.0
L (g/m3)
0.02
0.0

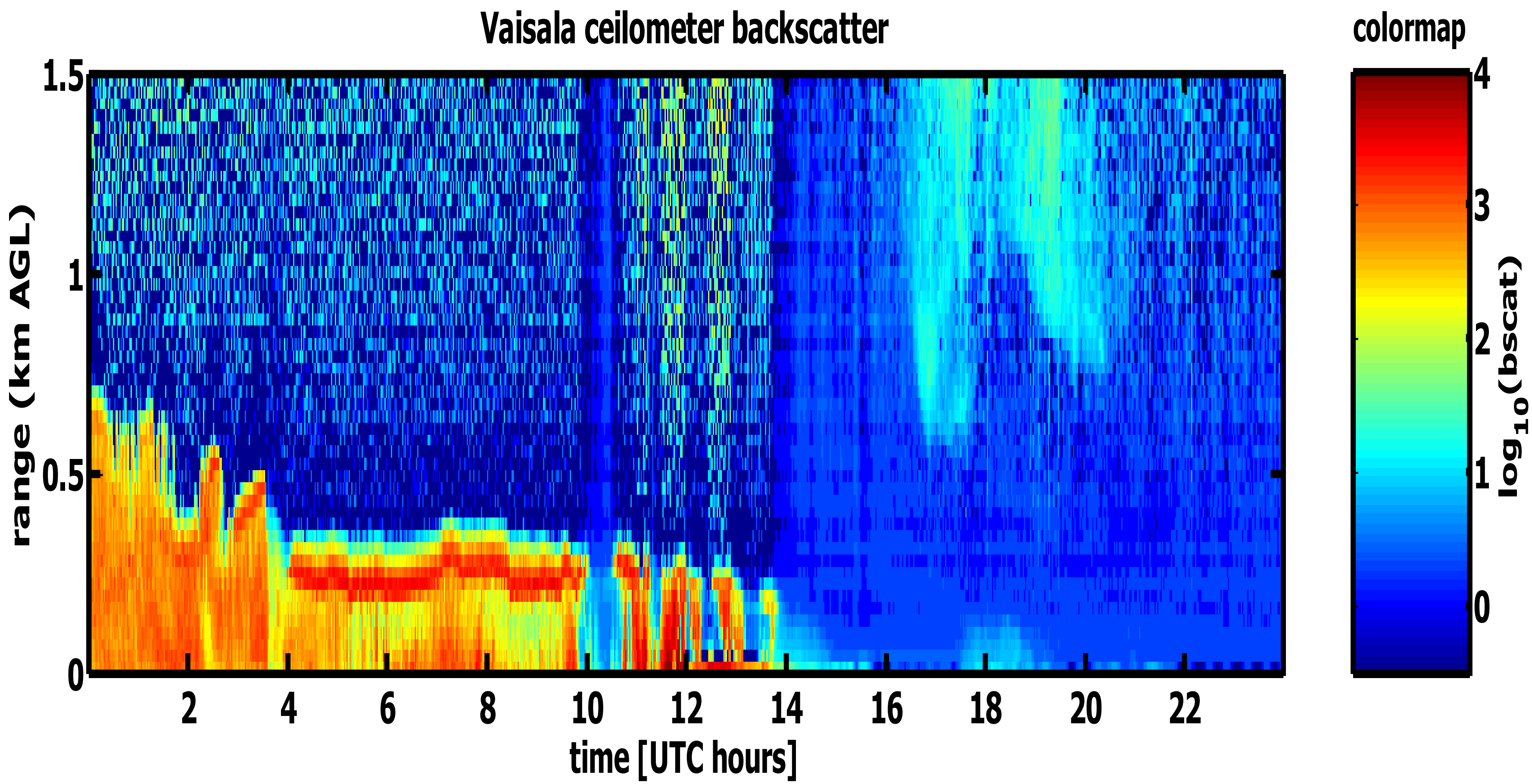
LWC DETECTION BY PMWR

Gultepe et al 2012





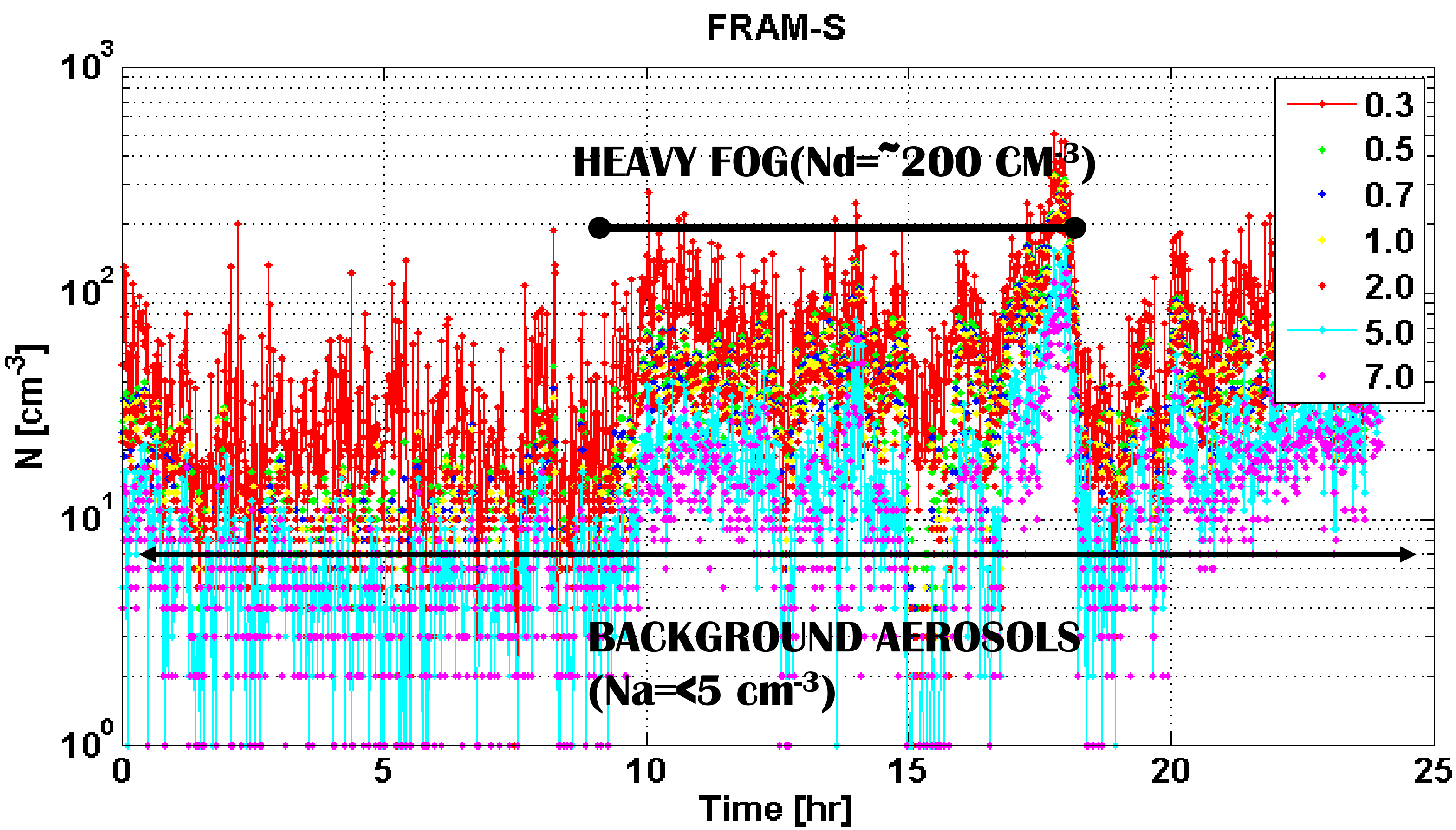
CEILOMETER APPLICATIONS



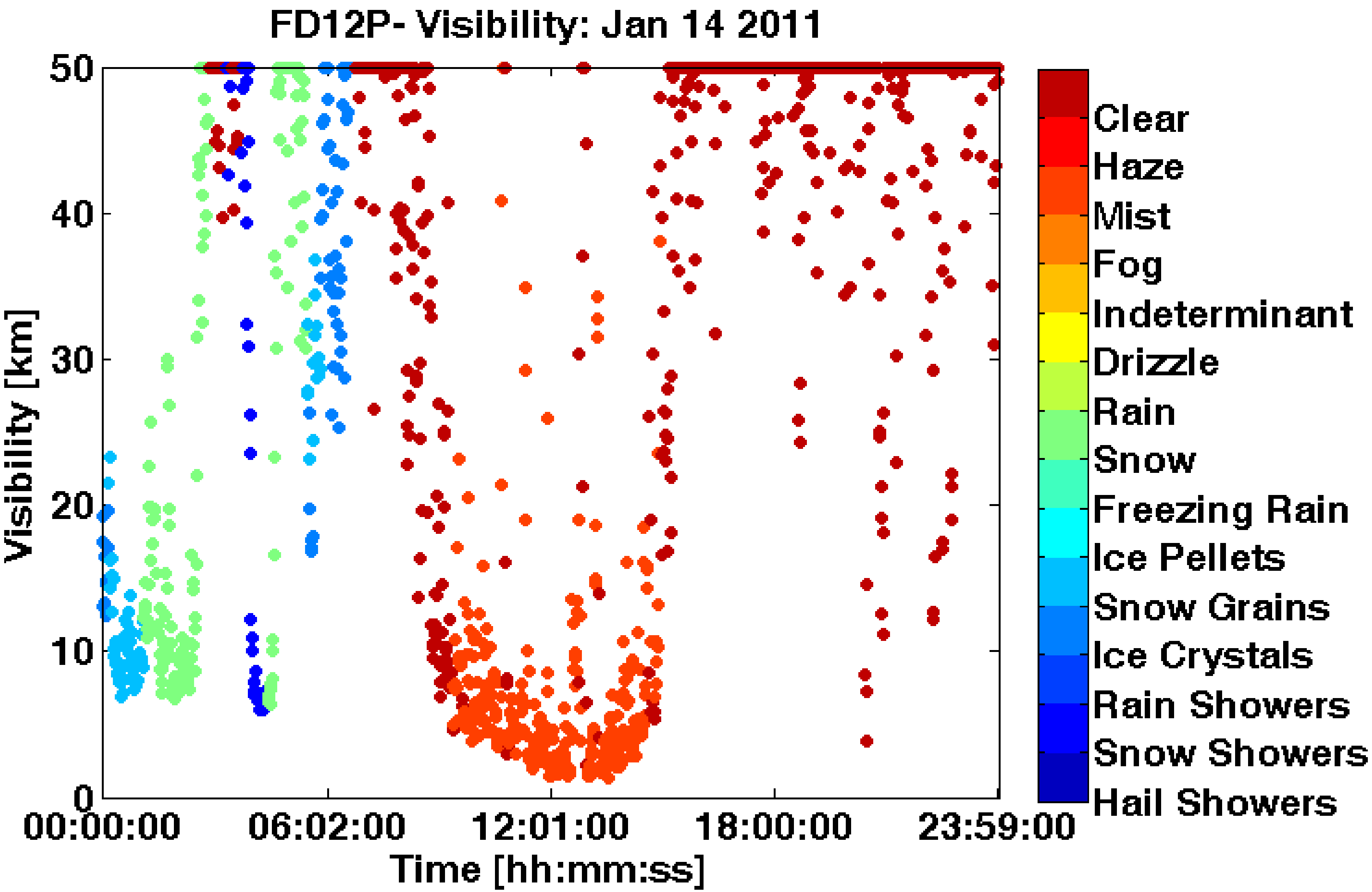
AEROSOLS/ACTIVATED AEROSOLS (CCN)

CAP (Climatronics Aerosol Profiler)sensor

(7 channels between >0.3 …….7 micron)



Jan 14


FD12P- Visibility: Jan 14 2011
Visibility [km]
0
10
20
30
40
50
00:00:00
06:02:00
12:01:00
18:00:00
23:59:00
Time [hh:mm:ss]
Clear
Haze
Mist
Fog
Indeterminant
Drizzle
Rain
Snow
Freezing Rain
Ice Pellets
Snow Grains
Ice Crystals
Rain Showers
Snow Showers
Hail Showers

CONCLUSIONS

- **Rule Based Marine fog predictions need measurements of T, Td, Ts, wind speed and direction, and LWC.**

- **3D numerical forecasting needs better prediction of LWC, Nd, RHw, and PR to simulate Vis**

- **Remote sensing platforms e.g. mm radar, ceilometer, and satellites should be used for fog related parameters when surface observations do not exist**

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