NRC Research Update

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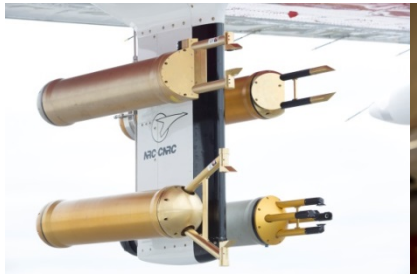
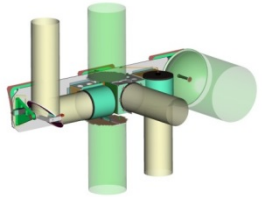
HAIC-HIWC Science Team Meeting, 05-09 Dec, 2016, Capua, Italy

Outline

- NRC Convair instrumentation and Flights during the 2015 HAIC-HIWC Cayenne Flights
- IWC from radar
  - Near-coincident measurement
    - within few hundred meters from the aircraft radar and in-situ
    - Attenuation
  - Reflectivity based
  - Multi-frequency and multi-parameter
- Lidar in HIWC
- GVR in HIWC

NRC Convair-580 Instrumentation during the HAIC-HIWC 2015 Cayenne mission



- Over 40 **in-situ** and remote sensing (**radars**, LIDARs and radiometer) systems were integrated on the NRC Convair-580 for the mission – allowing unprecedented dataset for characterization of high altitude icing environment that is being used for regulatory as well as science objectives

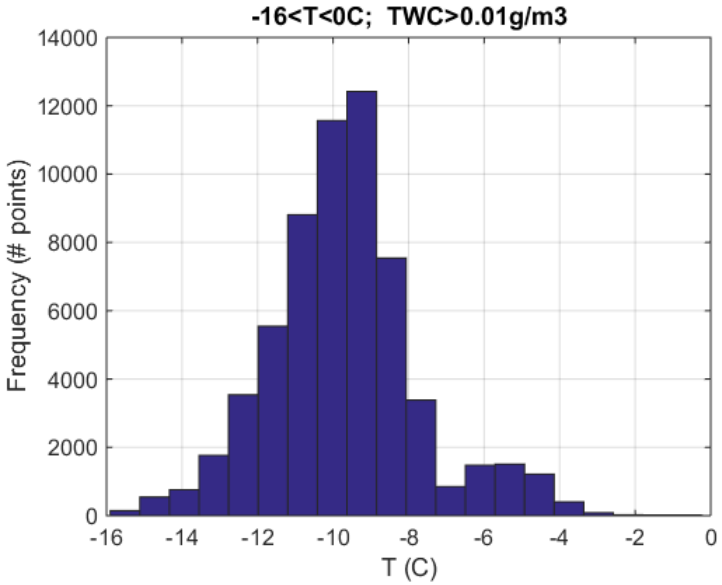
Environment Canada Environnement Canada

Over 30 NRC and EC staff were involved in system integration and flight test

NRC·CNRC

NRC Convair-580 flights during the HAIC-HIWC 2015 Cayenne mission

- Conducted 14 flights inside MCSs - in both continental and maritime convective systems
- In-situ sampling at -17 °C< T < -3°C, with mostly conducted horizontal transects at ~ -10° C.



Environment Canada Environnement Canada

Over 30 NRC and EC staff were involved in system integration and flight test

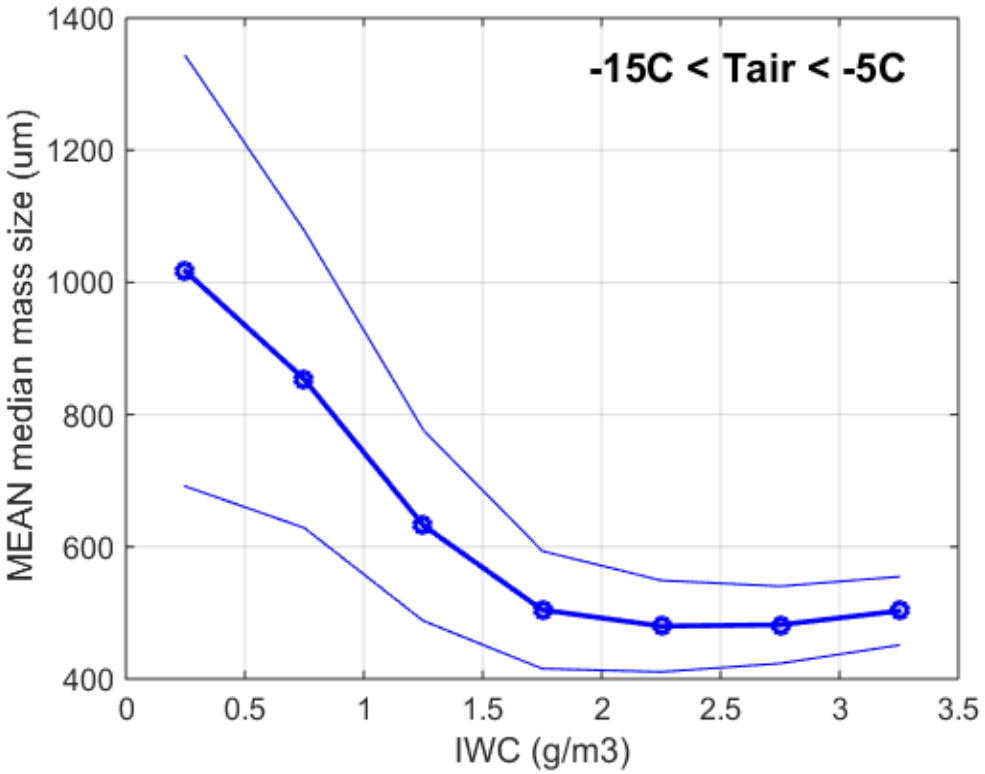
NRC·CNRC

Convair-580 Flights - In-situ cloud microphysics data summary

Environment Canada Environnement Canada

NRC·CNRC

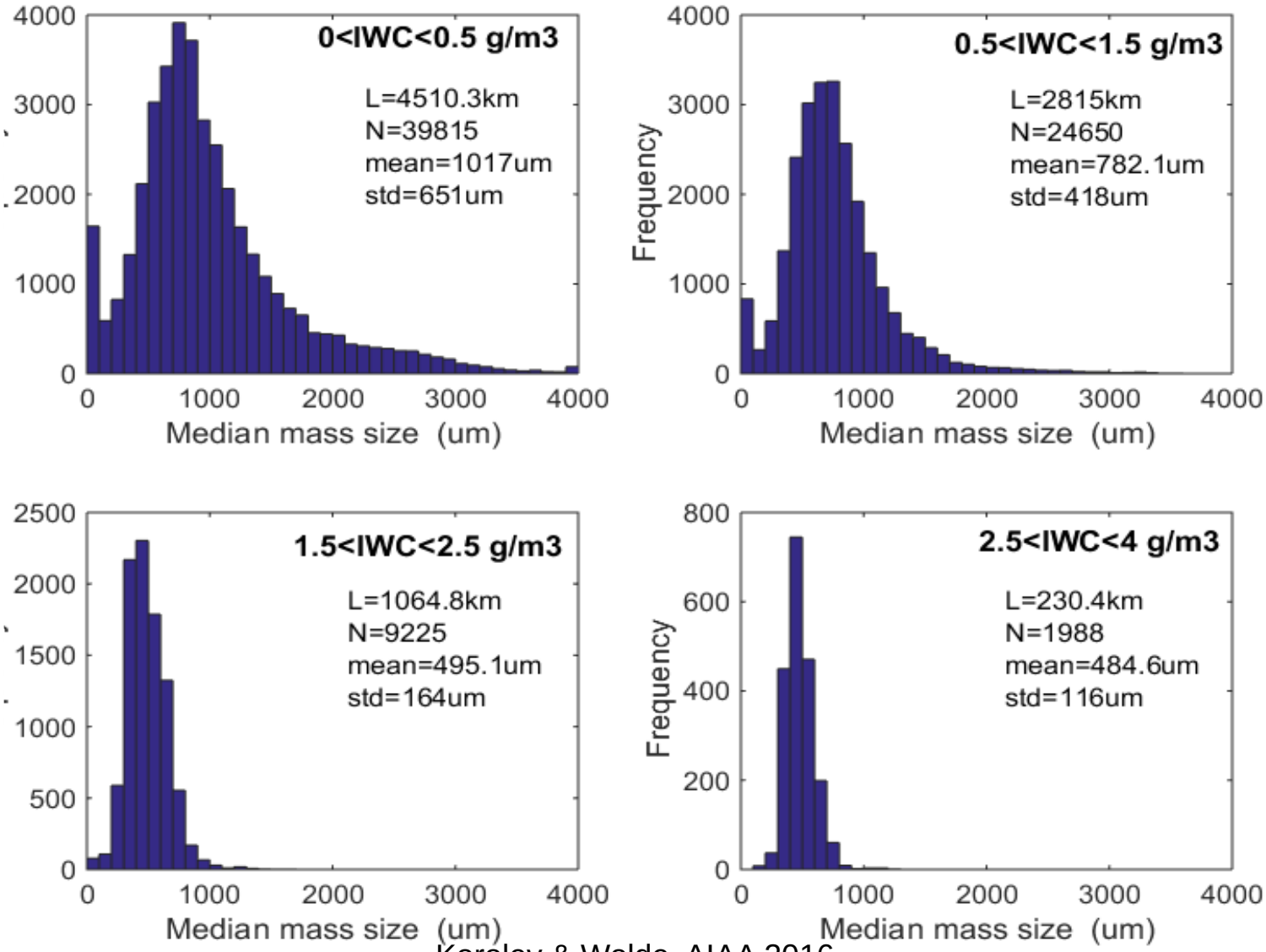
Median mass size vs. IWC



Median mass size decreases with increase of IWC approaching to MMD~500μm and IWC>1.5g/m^3

Korolev & Wolde, AIAA 2016

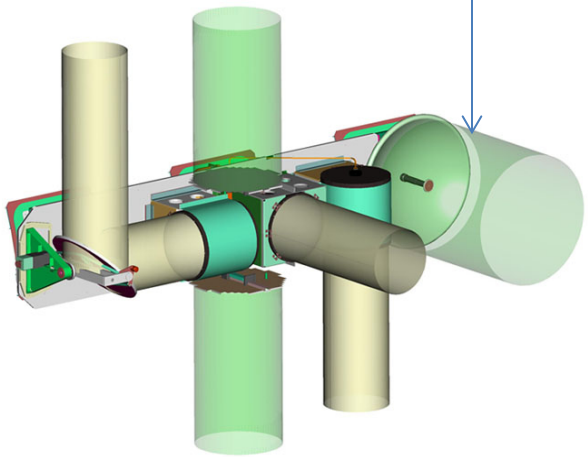
Distribution of MMD in different IWC ranges
-15C < T < -5C



Korolev & Wolde, AIAA 2016

Dual-Pol - NAWX

X-band dual-pol antenna

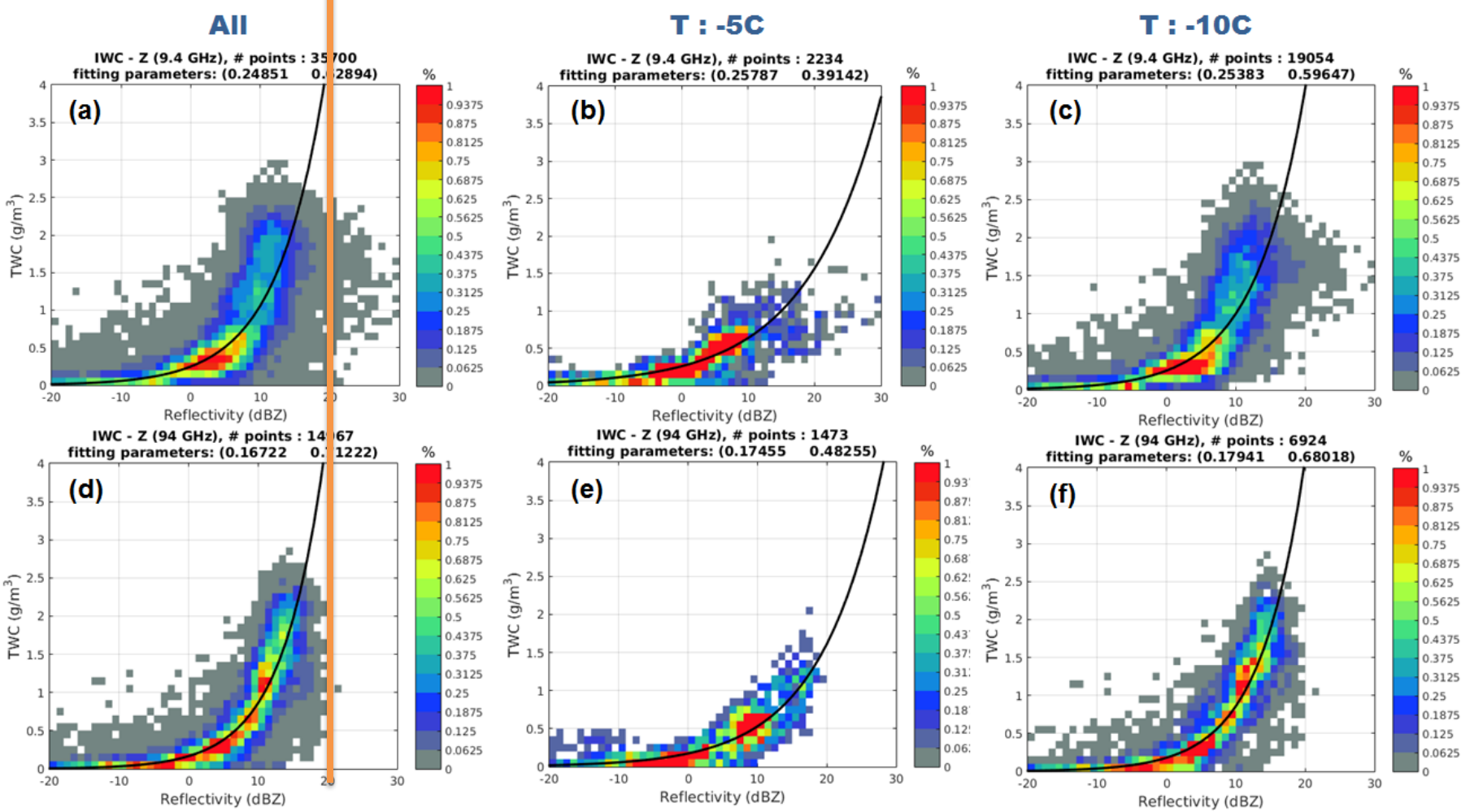


W band: pale yellow

X-band: green

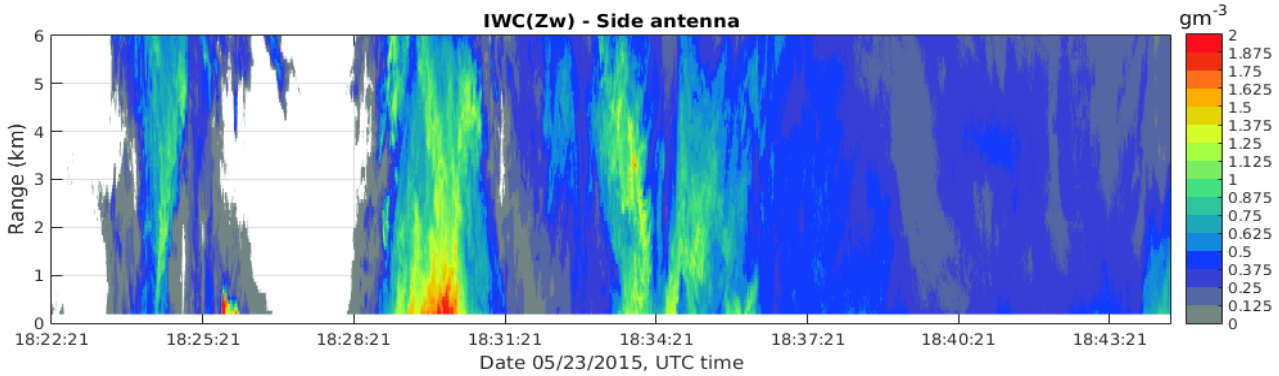
	X-band	W-band
RF output frequency	9.41 GHz +/- 30 MHz	94.05 GHz
Peak transmit power	25 kW magnetron split between two ports	1.7 kW typical
Transmit polarization	H and V	H or V
Maximum Pulse Repetition Rate	5 kHz	15 kHz
Antennas	**Side: 1 x 26" dual-pol** Nadir/Zenith: 2 x 18" single-pol	**Side/Aft: 2 x 12" dual-pol** Nadir/Zenith: 1 x 12" single-pol

NAWX - IWC vs. Z_e

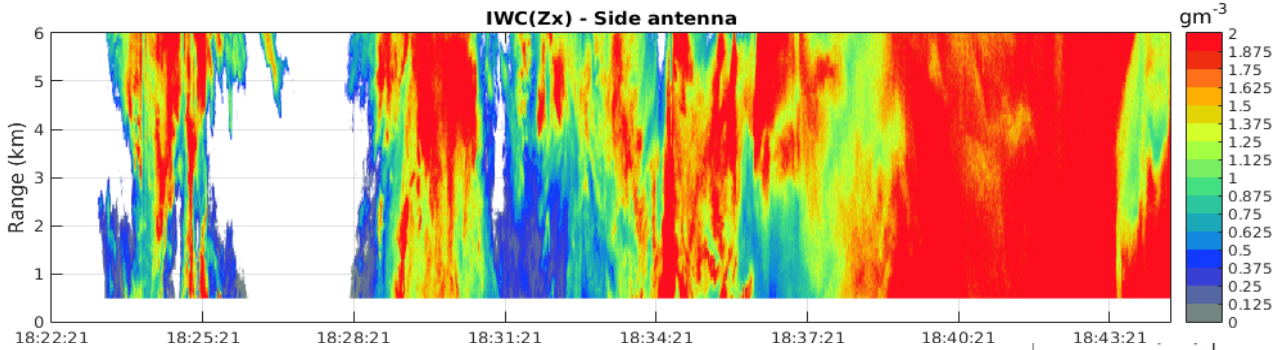


X-band – IWC < 2 g m^{-3} for Z > 20 dBZ – bifurcation in IWC vs. Z

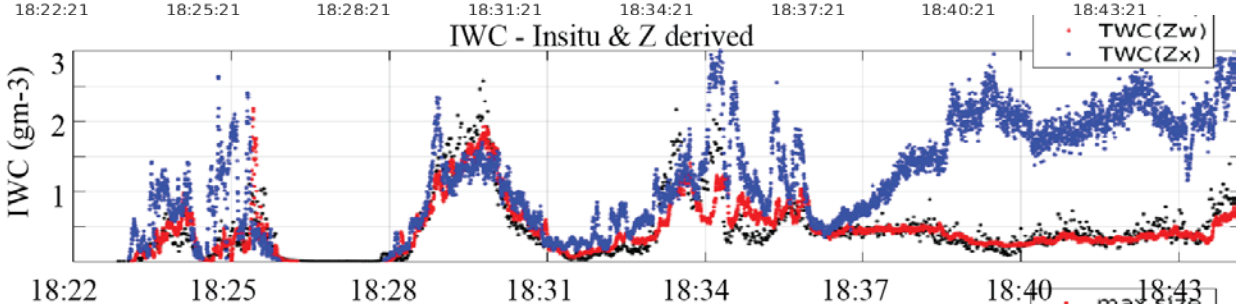
May 23 - IWC from Z_e



Side-looking W-band

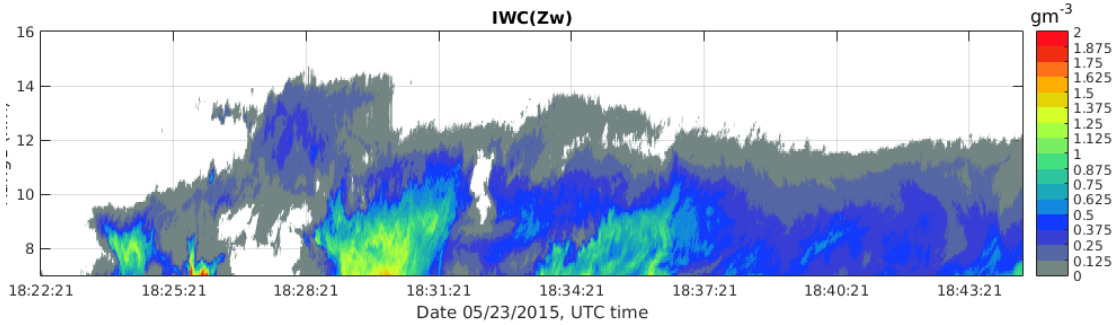


Side-looking X-band

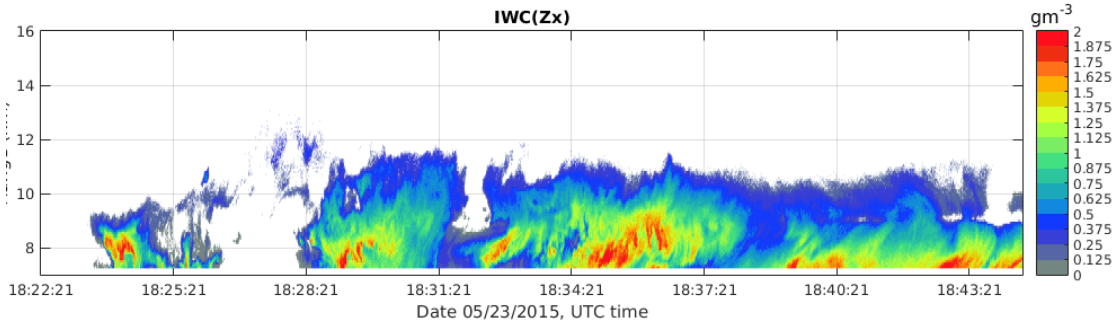


Flight level – in-situ vs. IWC from Z_e

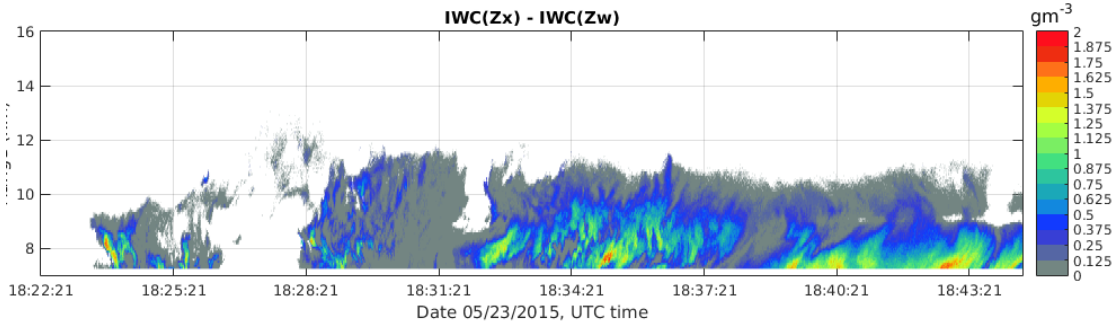
May 23 - IWC from Z_e



IWC from W-band Z_e



IWC from X-band Z_e

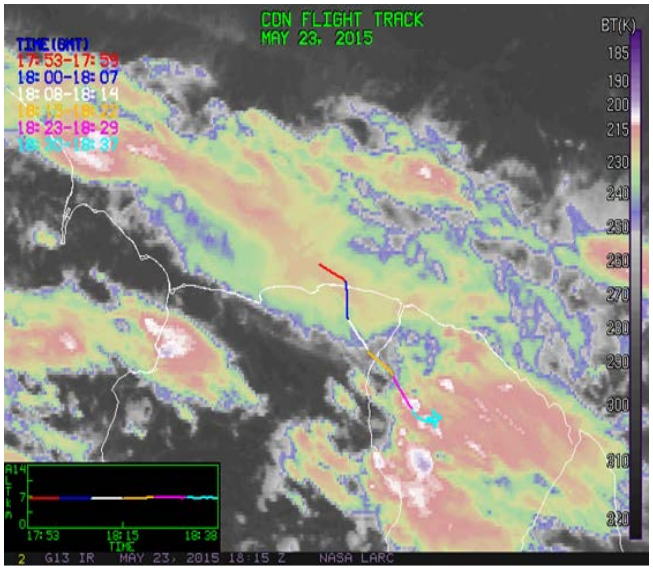


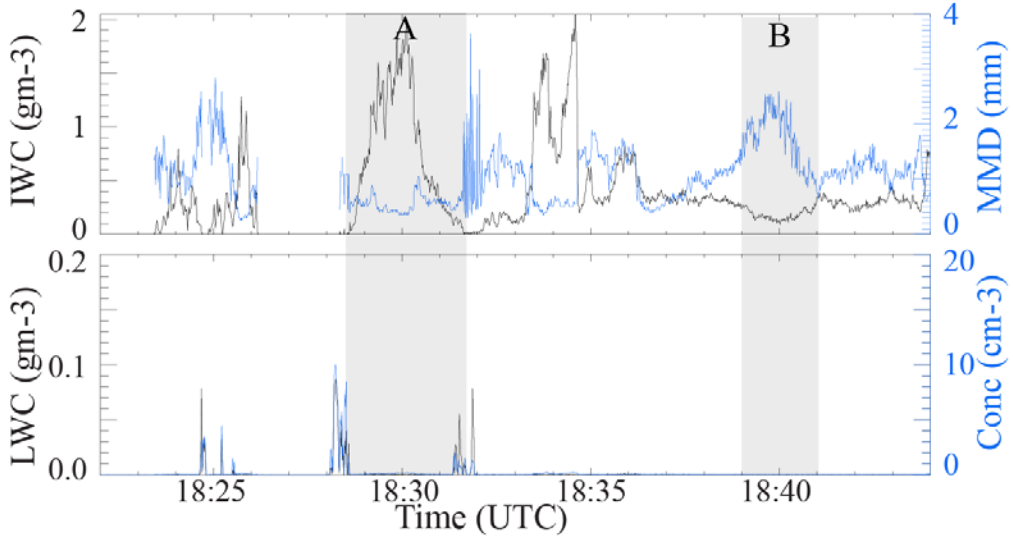
IWC_x - IWC_w

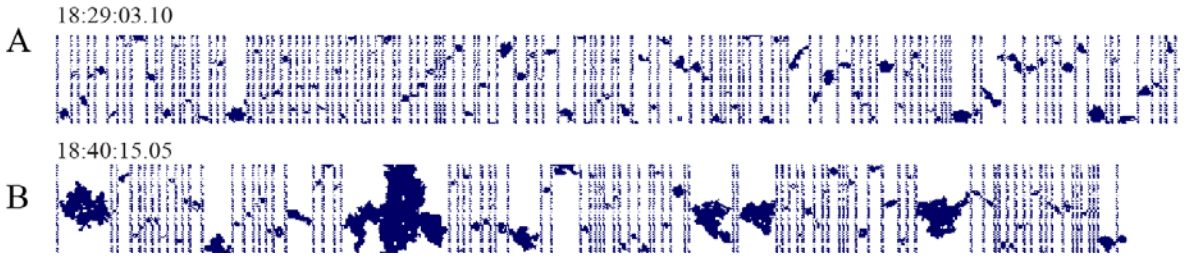
Case Study – May 23

- Correlate in-situ cloud microphysics data with radar responses (both dual frequency research radar and pilot weather radar)
- Horizontal and vertical reflectivity variabilities

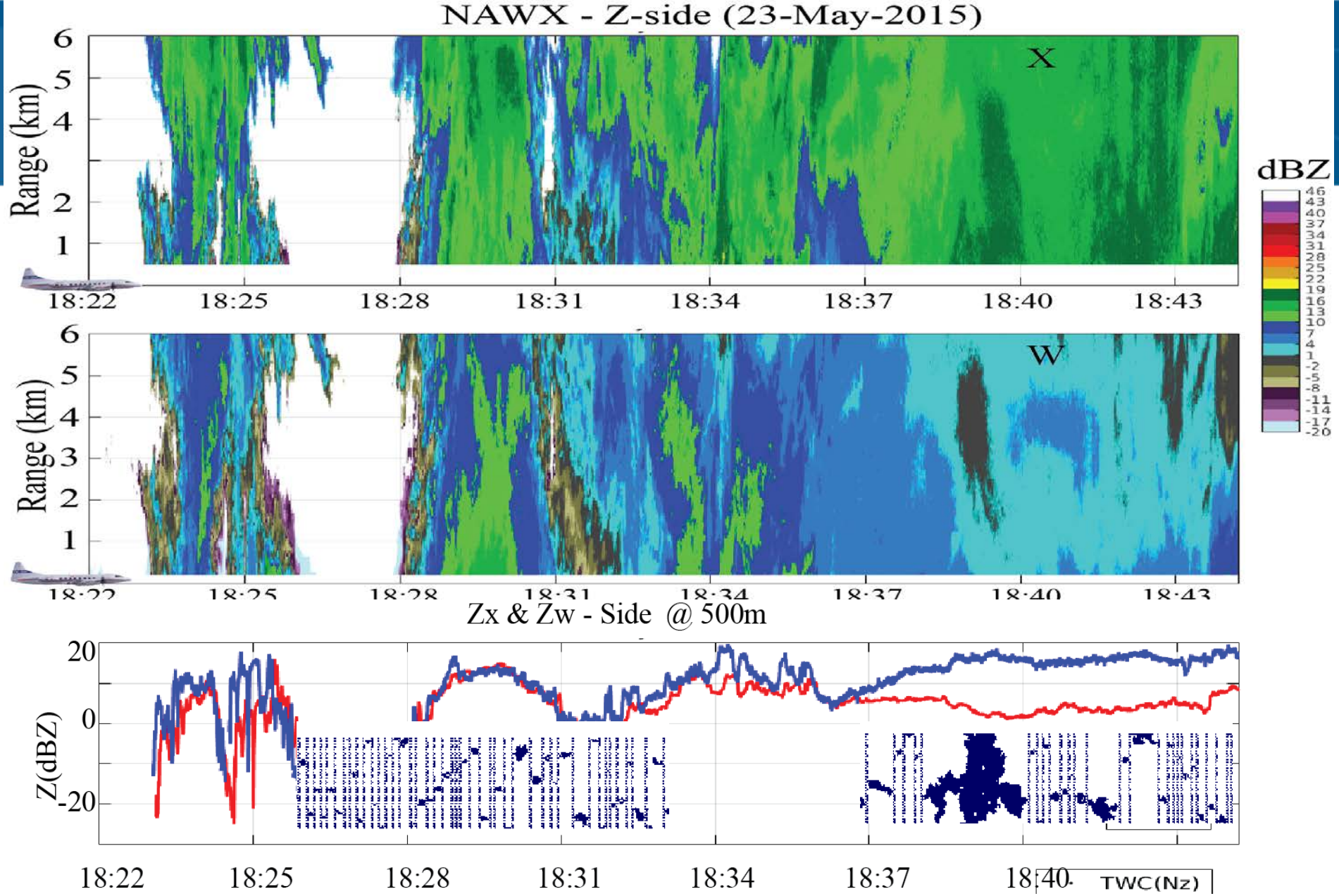
23-May 2015 Flight



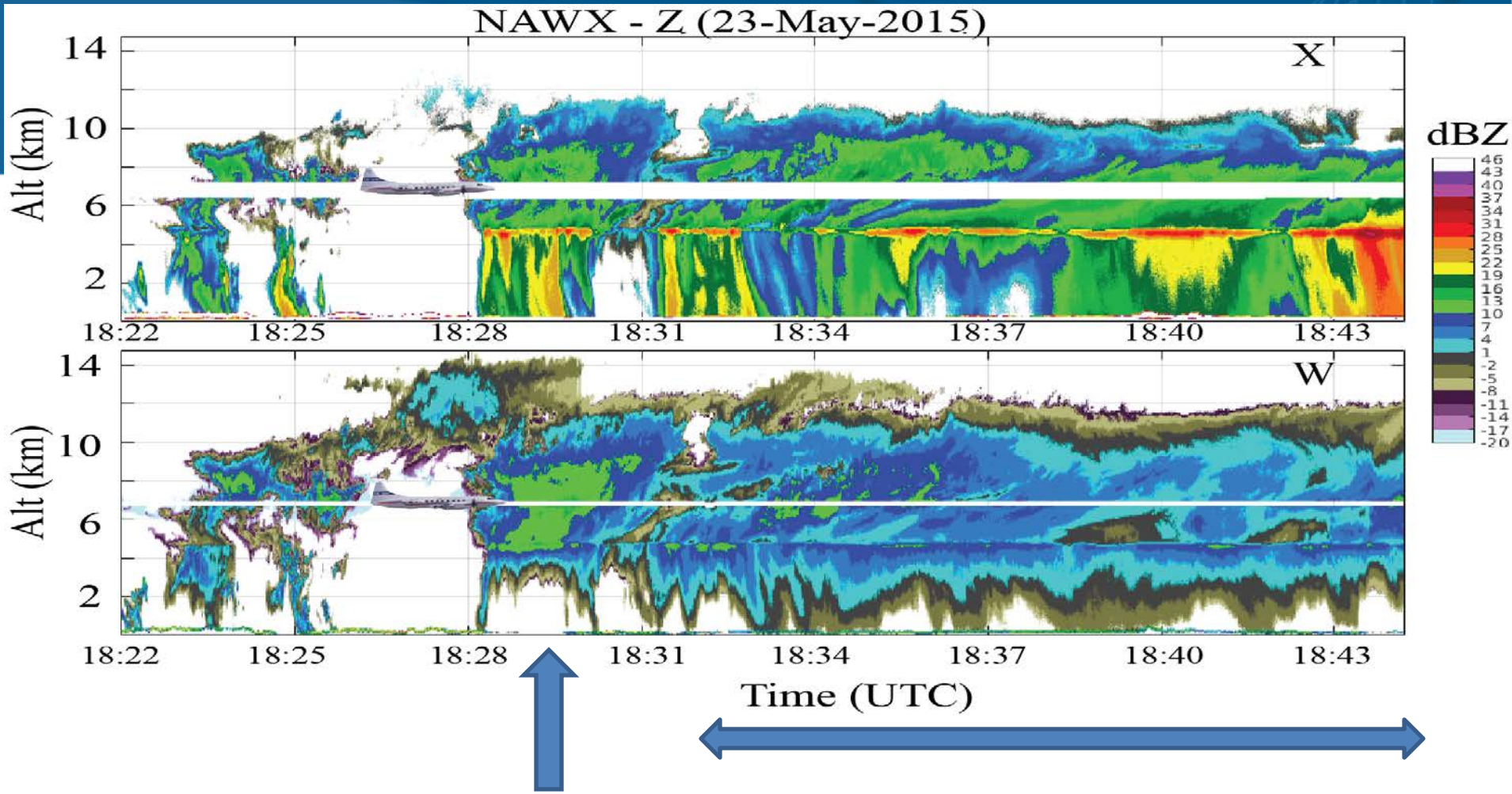




- HIWC in segments with MMD < 500 µm (A)
- IWC < 0.5 g m-3 in cloud segments with MMD > 1 mm (B)



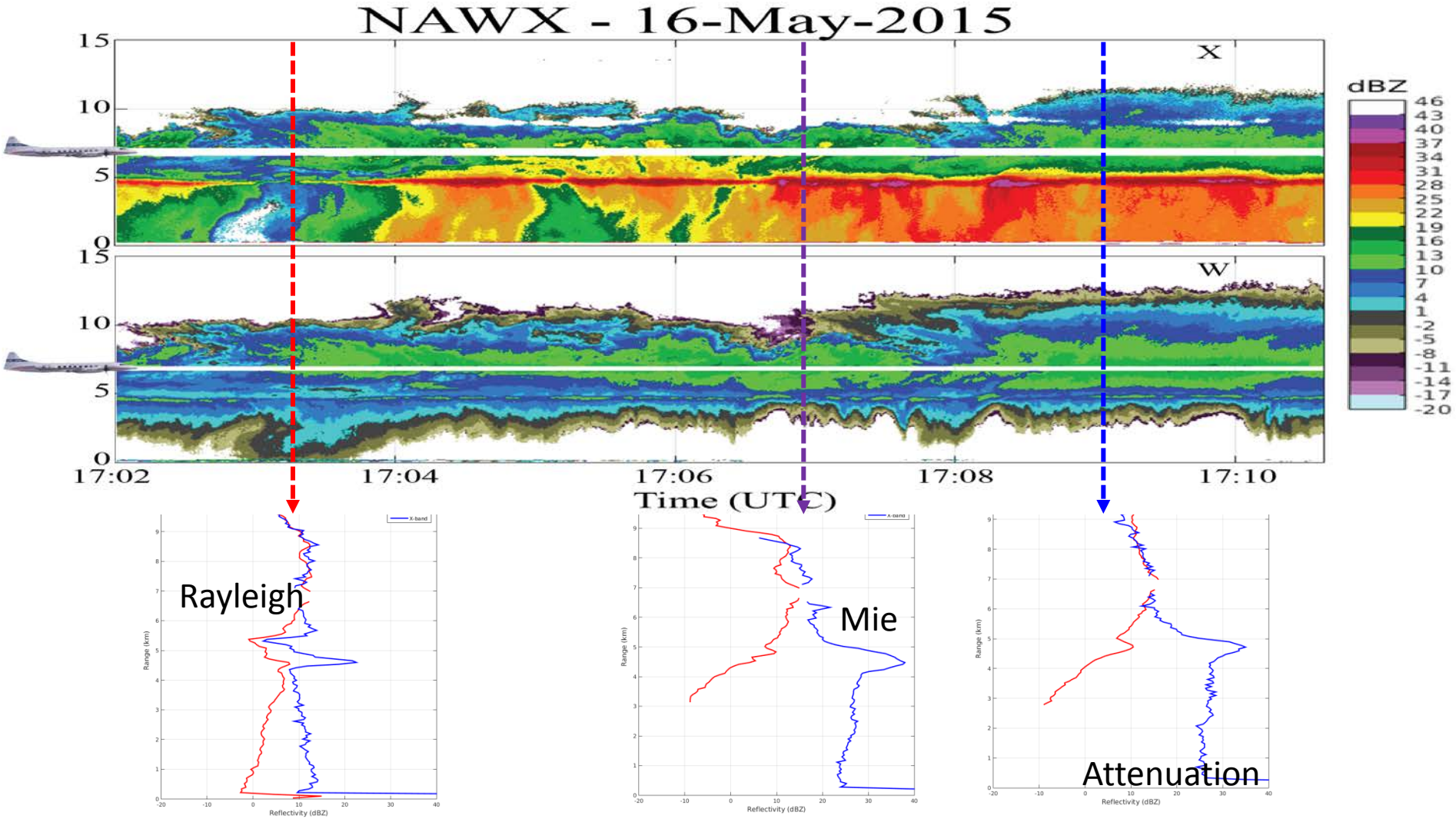
DFR: **~ 0 dB at max IWC** **Aggregates up to 10 dB**



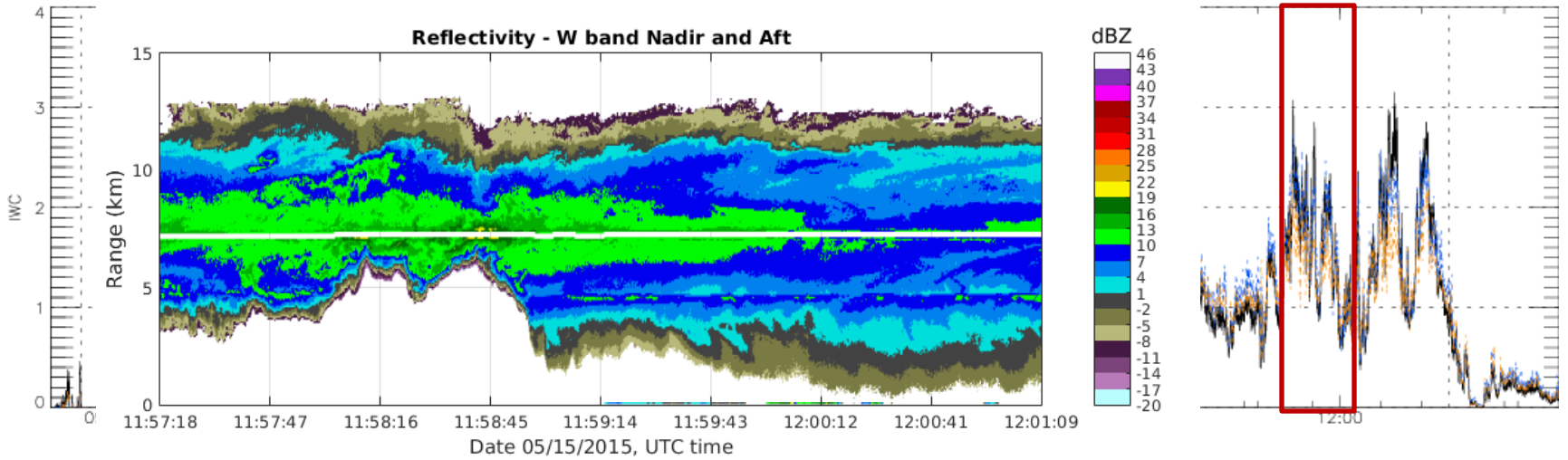
In rain – W-band heavy attenuation
At flight level – good agreement b/n X and W

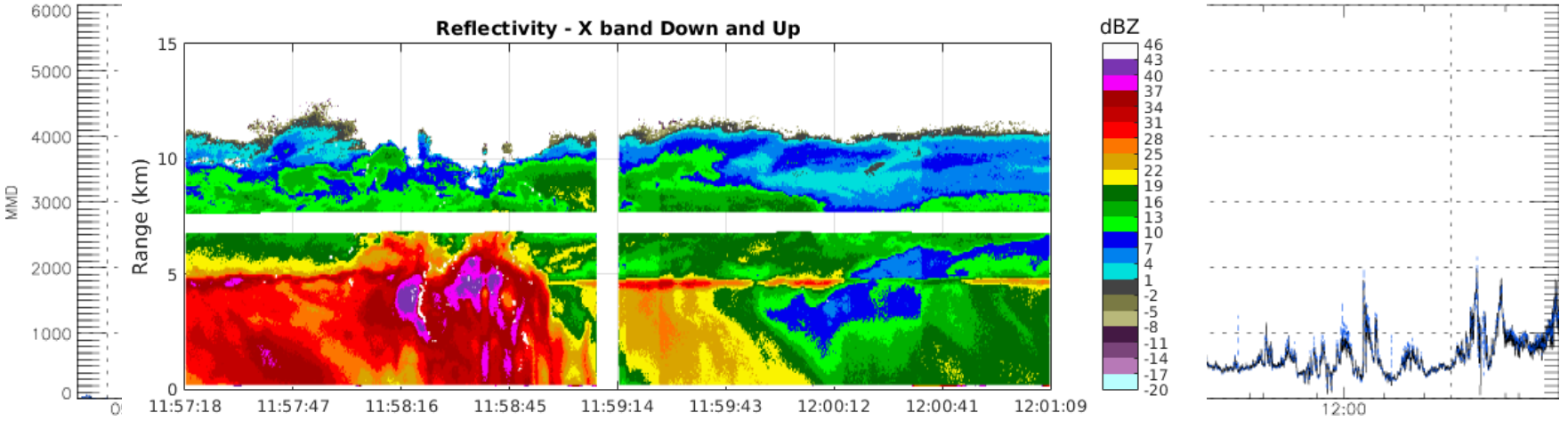
Flight level – Mie effect – large crystals

Attenuation and different scattering regimes at W-band in HIWC conditions

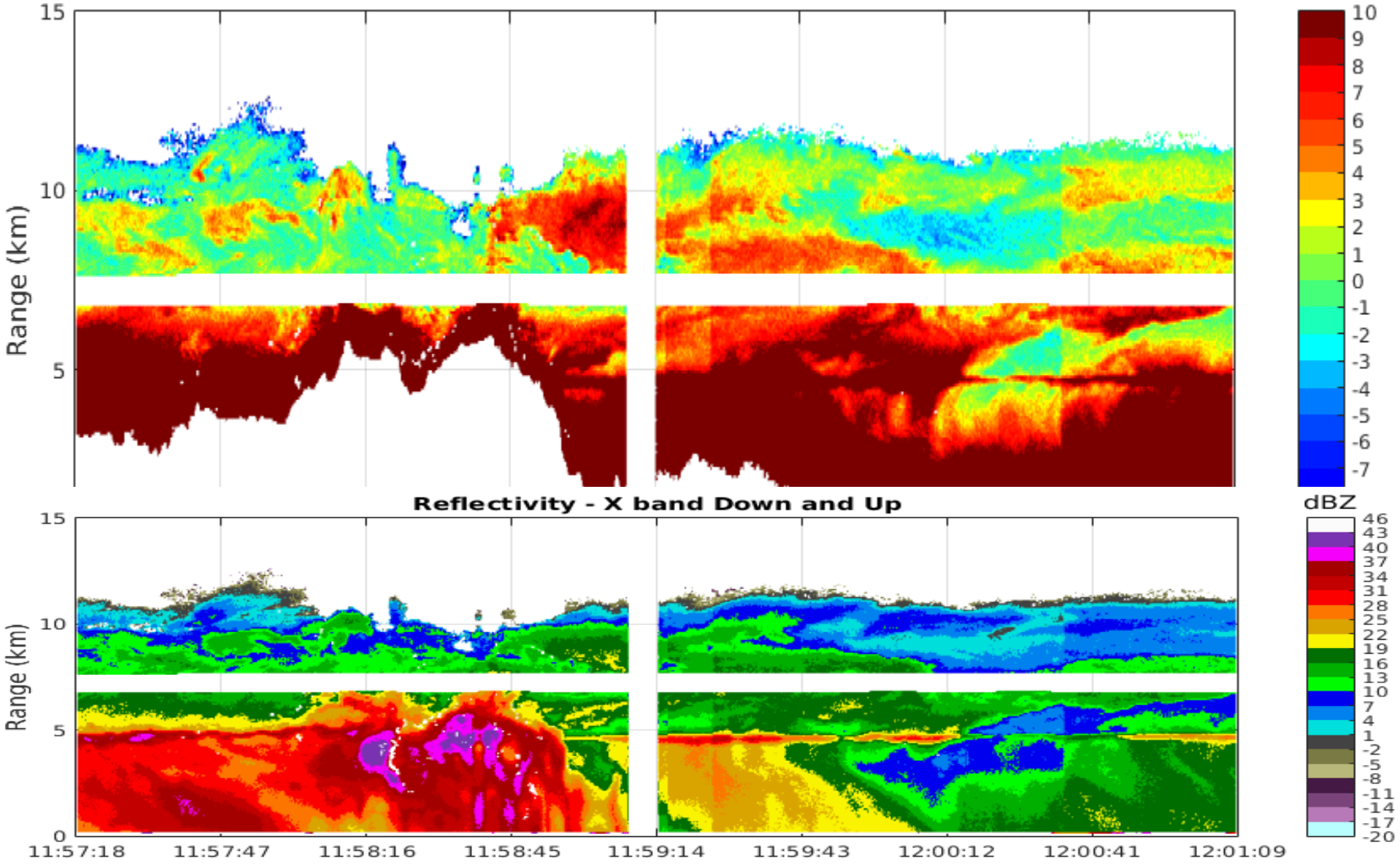


DFR – 15-May Flight



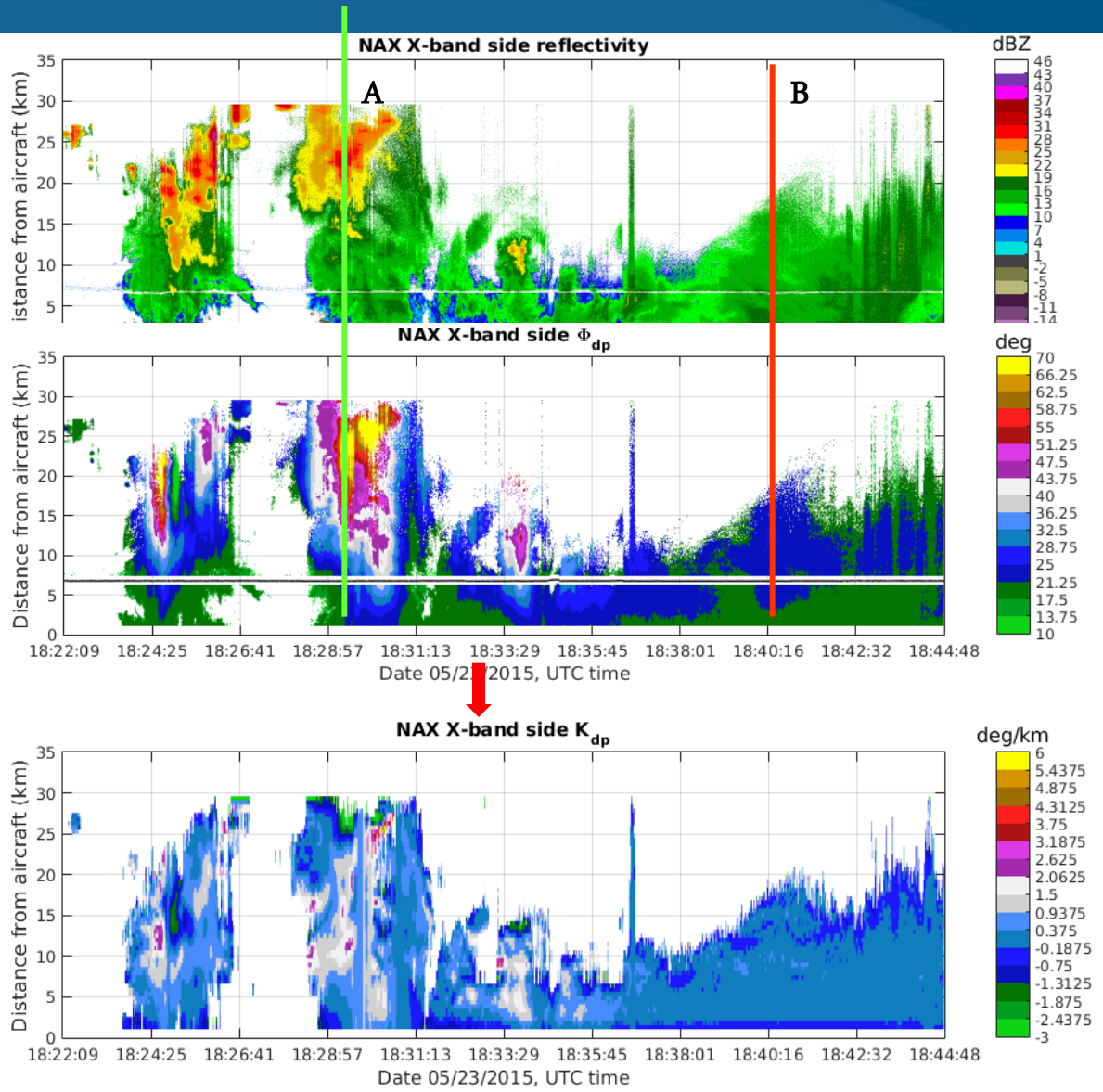


DFR – 15-May Flight

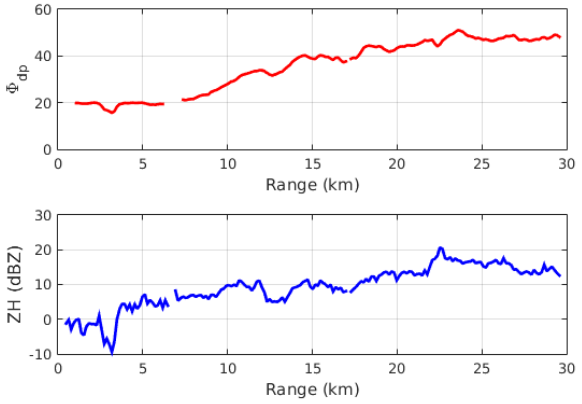


Polarimetric method for IWC retrieval

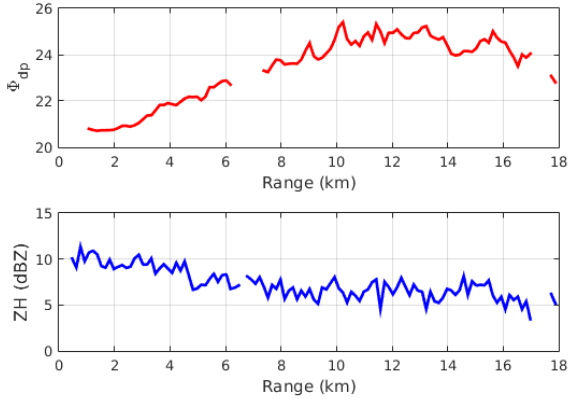
Method for estimation of K_{dp}



A

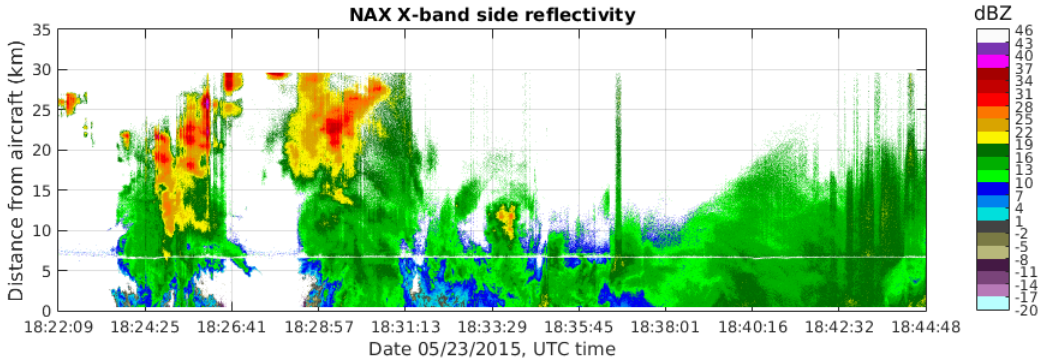


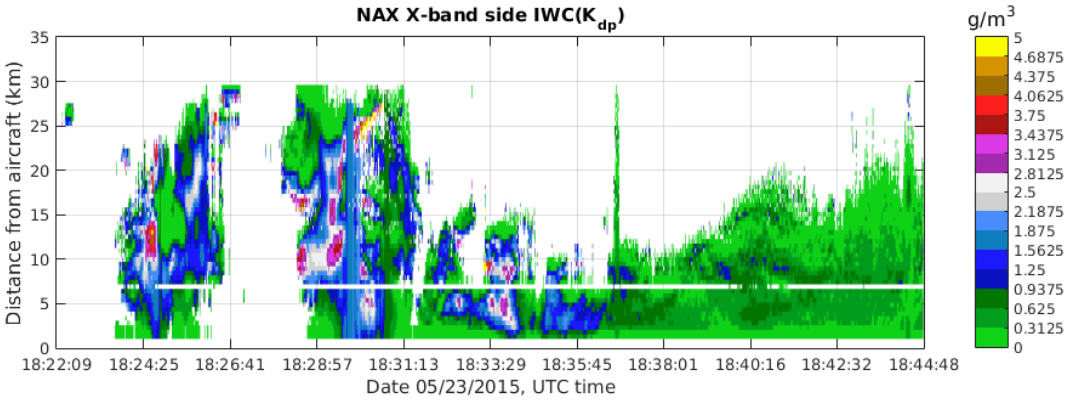
B

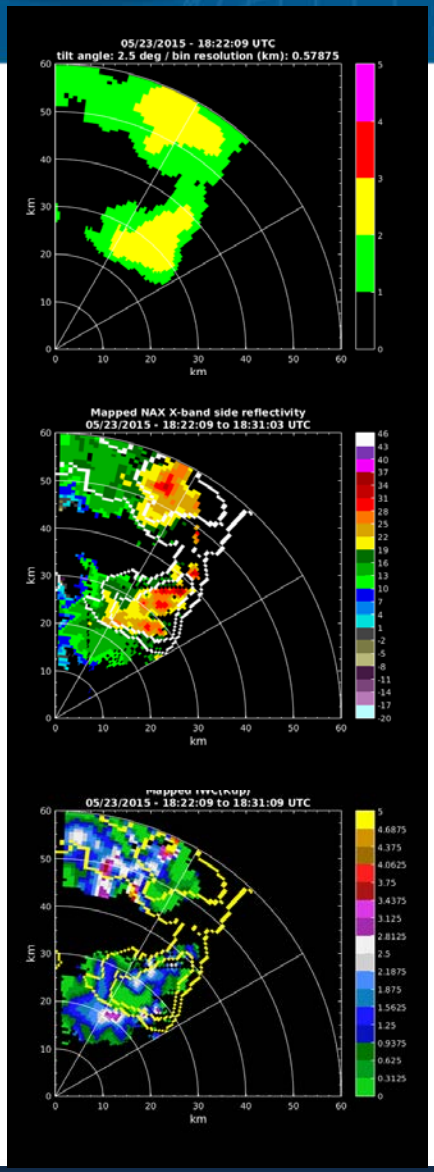


IWC retrieval from X-band side reflectivity

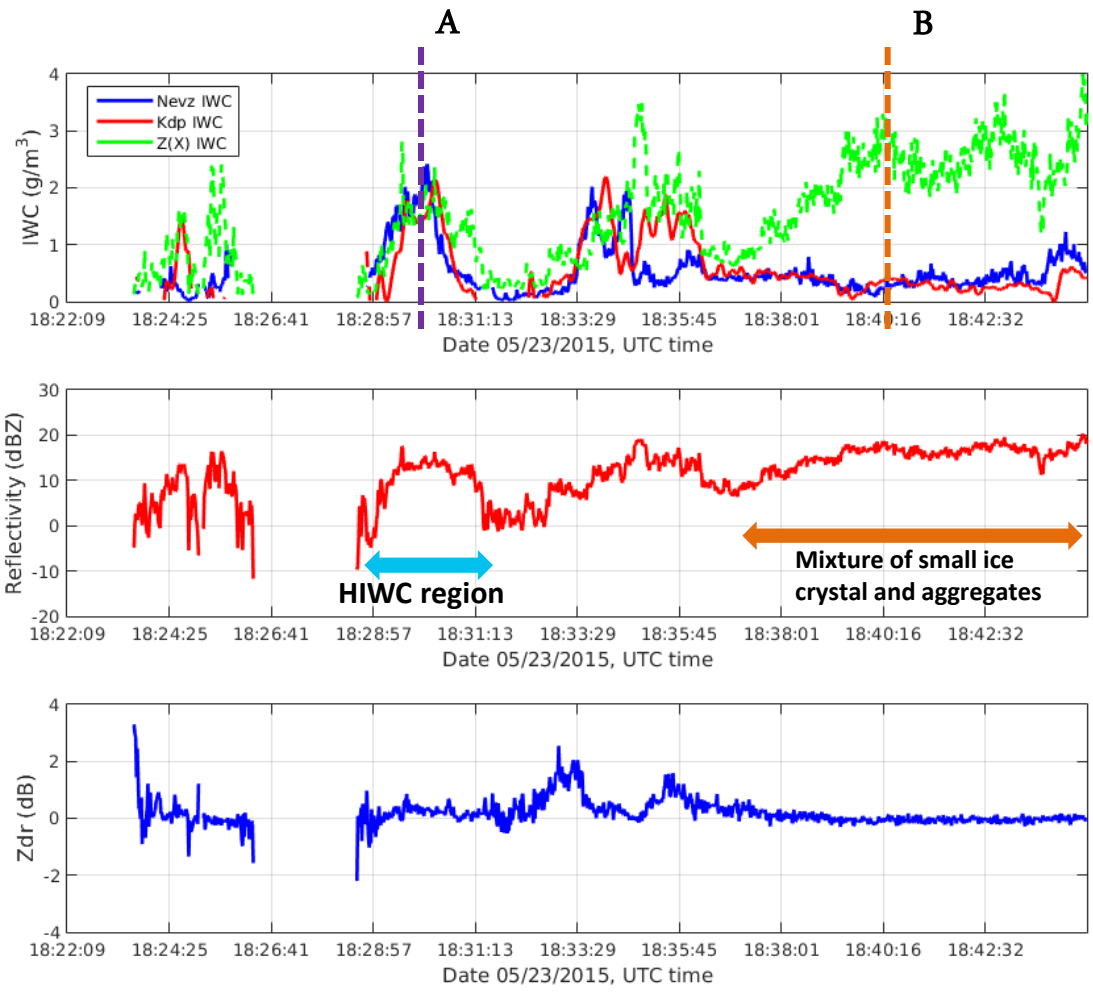
Mapping Zx and IWC(Kdp) to PWR

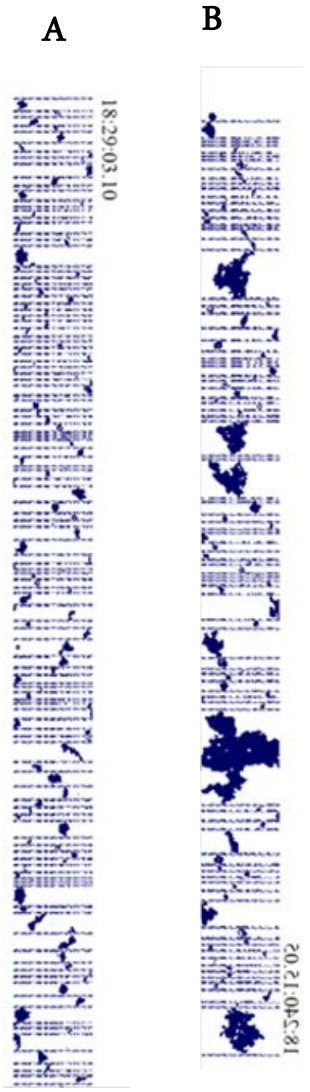






IWC(K_{dp}) for X-band, May 23 case

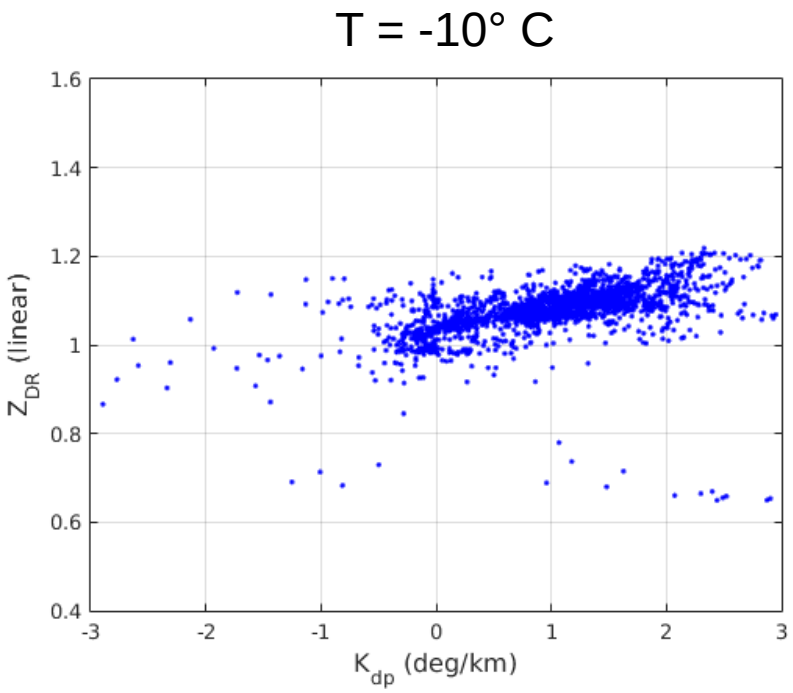




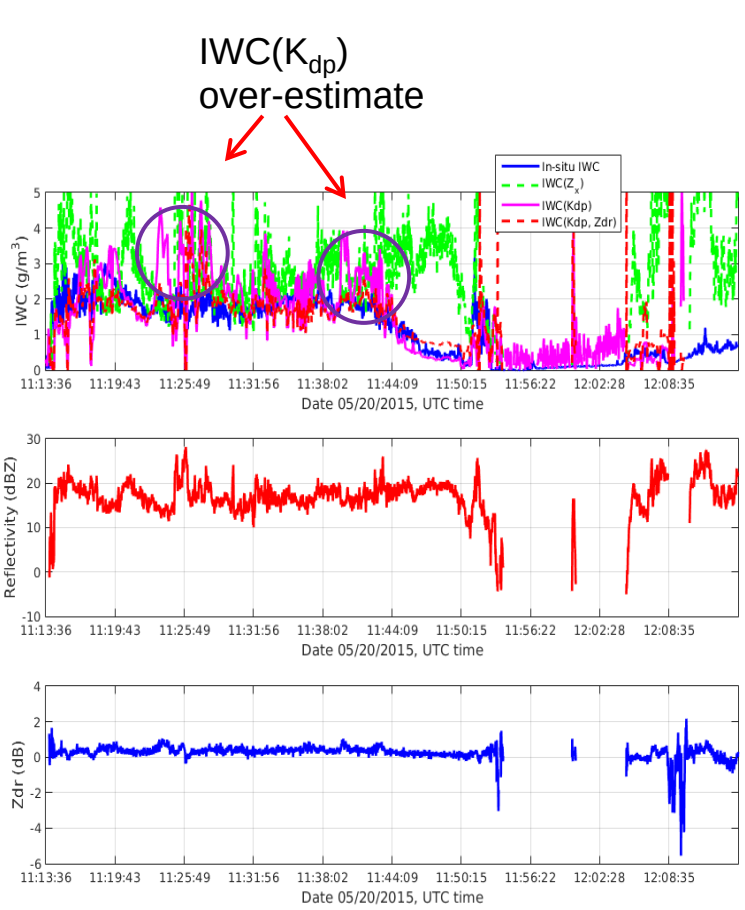
K_{dp} and Z_{dr} relationship in HIWC environment

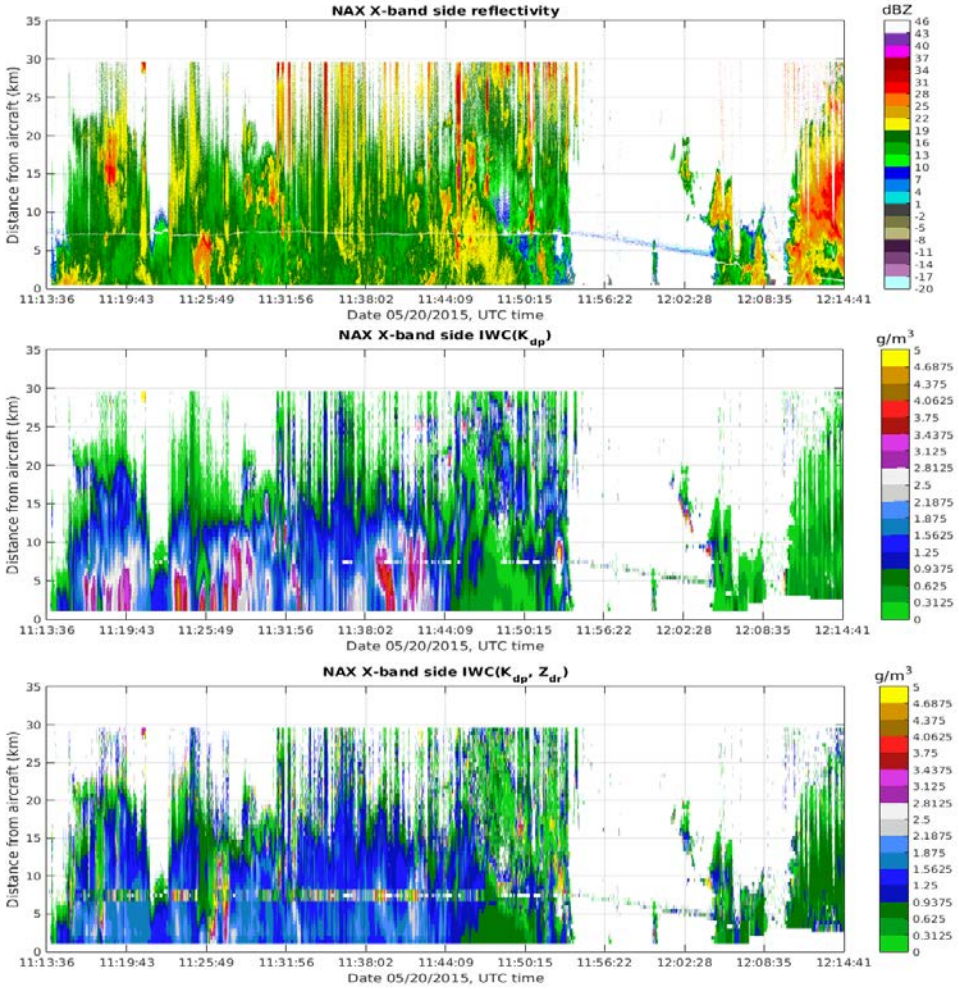
Approximation:

- **K_{dp} and Z_{dr} highly depend on the particle shape whereas at low temperature their ratio does not an is determined only by the mass of t particle.**

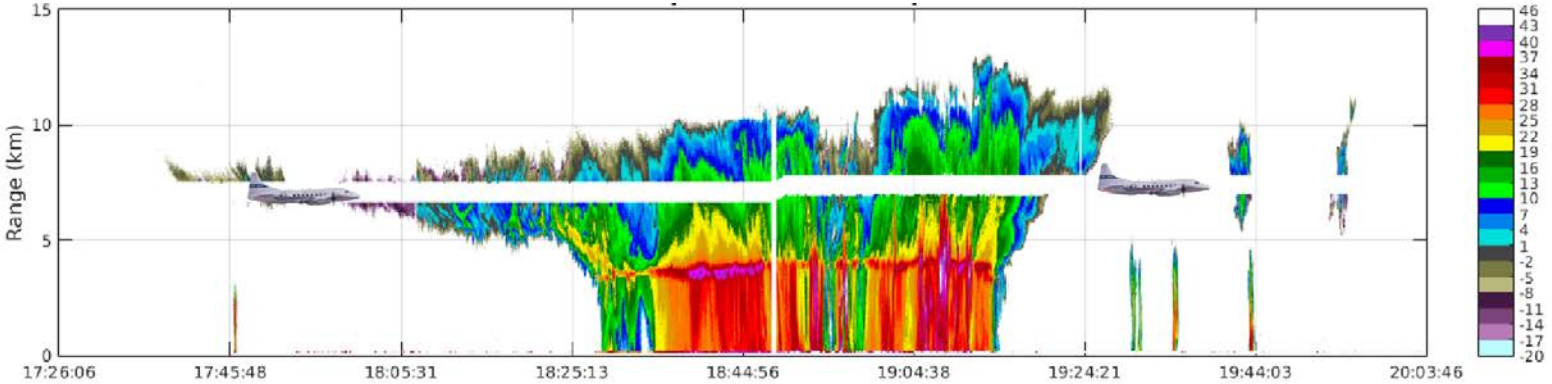


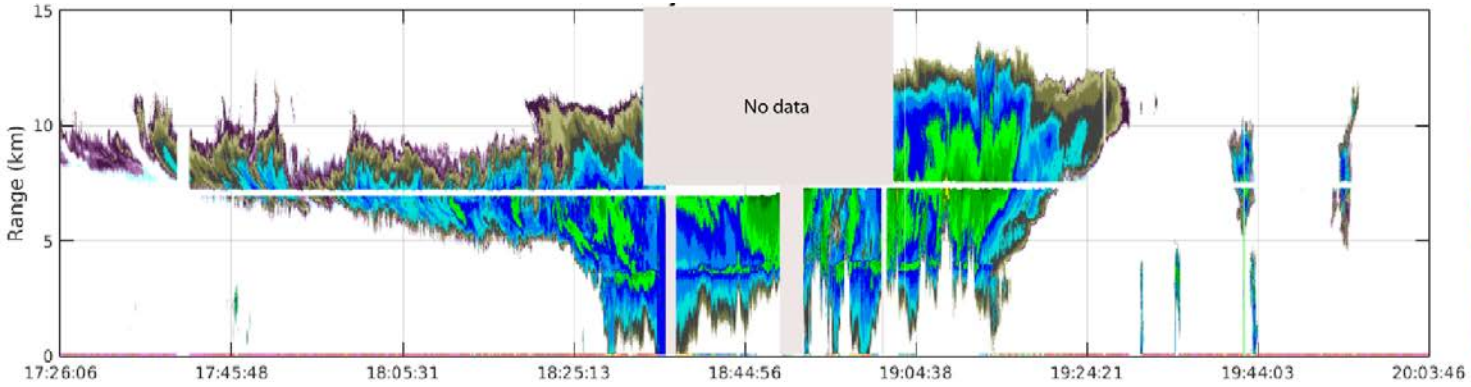
IWC(K_{dp}, Z_{dr}) for X-band, May 20 case

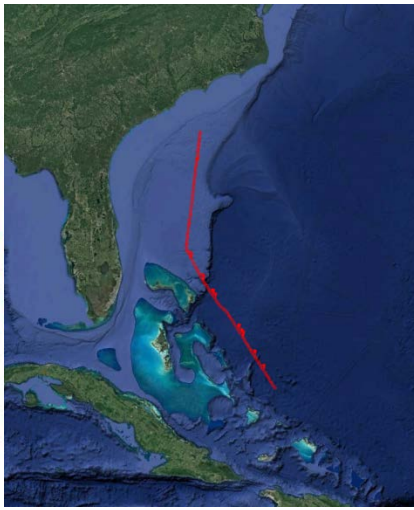




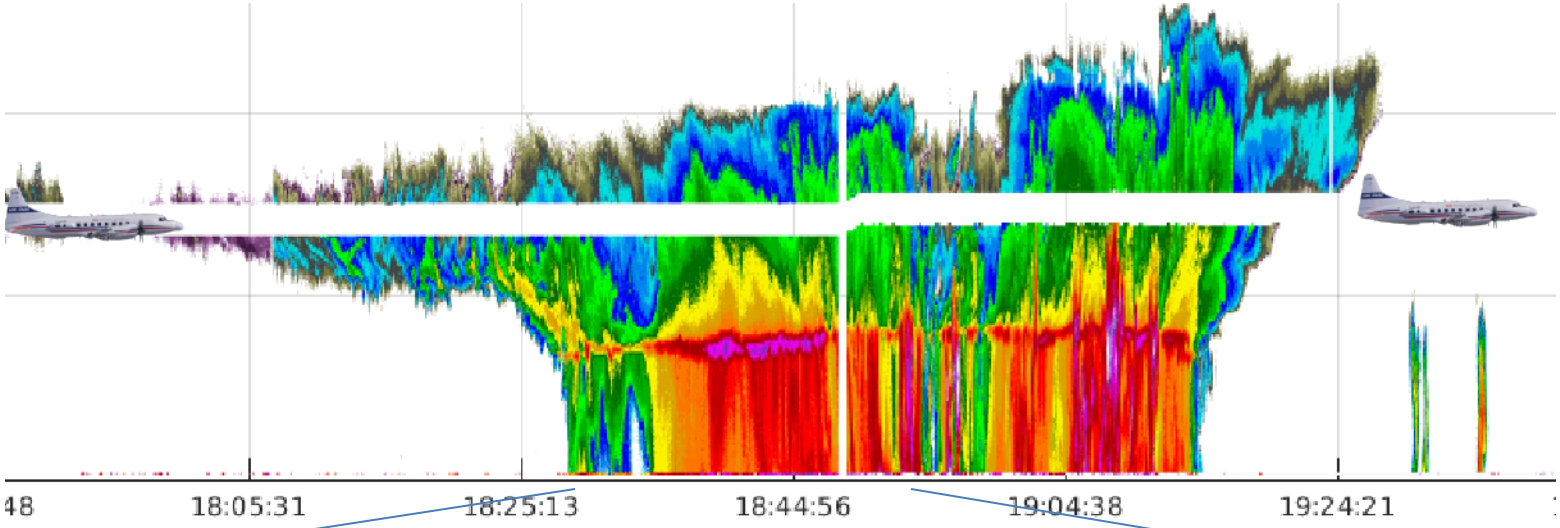
May 05 – Convair Transit Flight

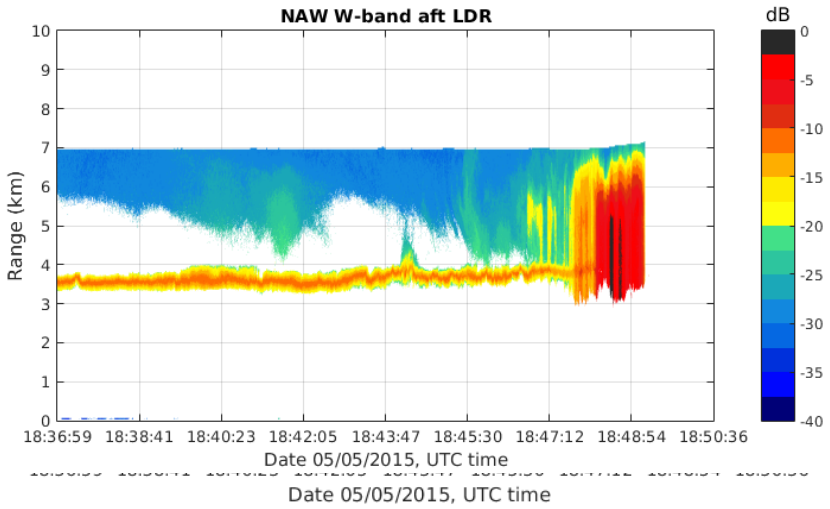


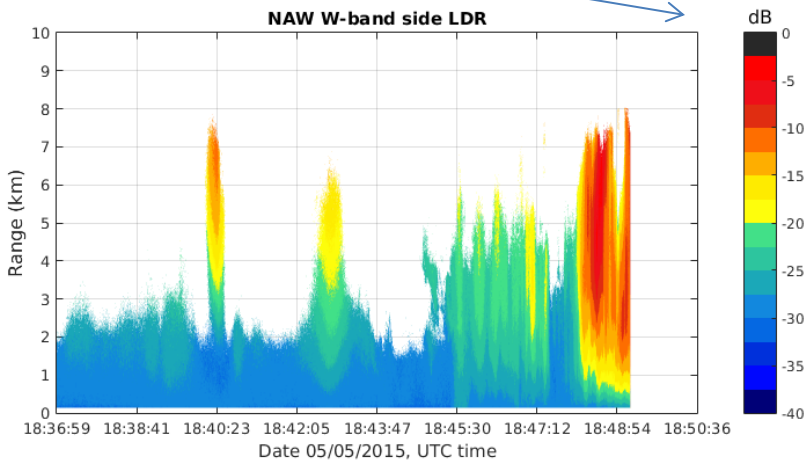


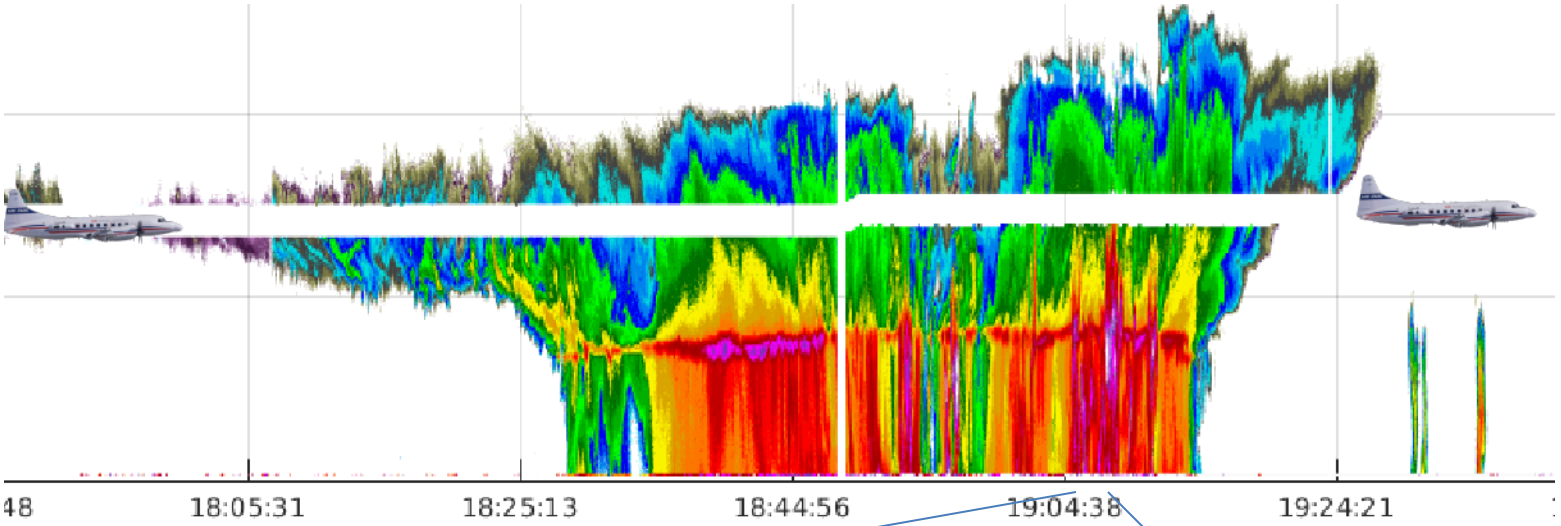


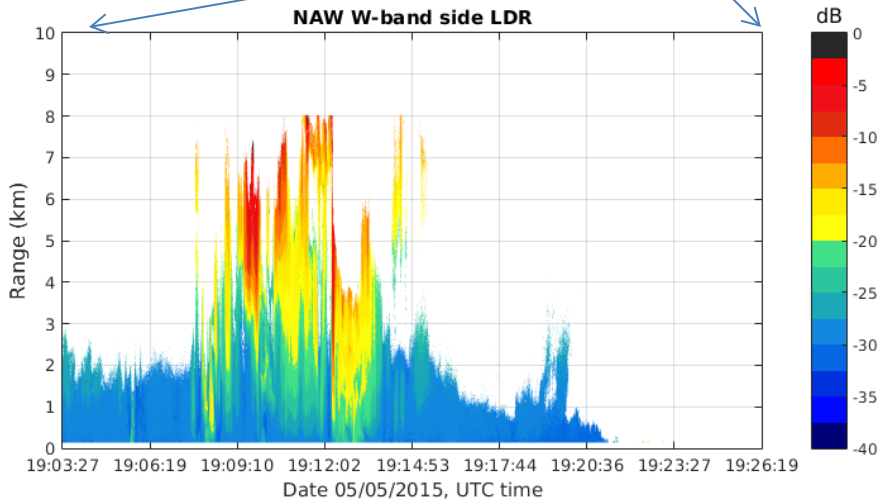
May 05 – NAW LDR

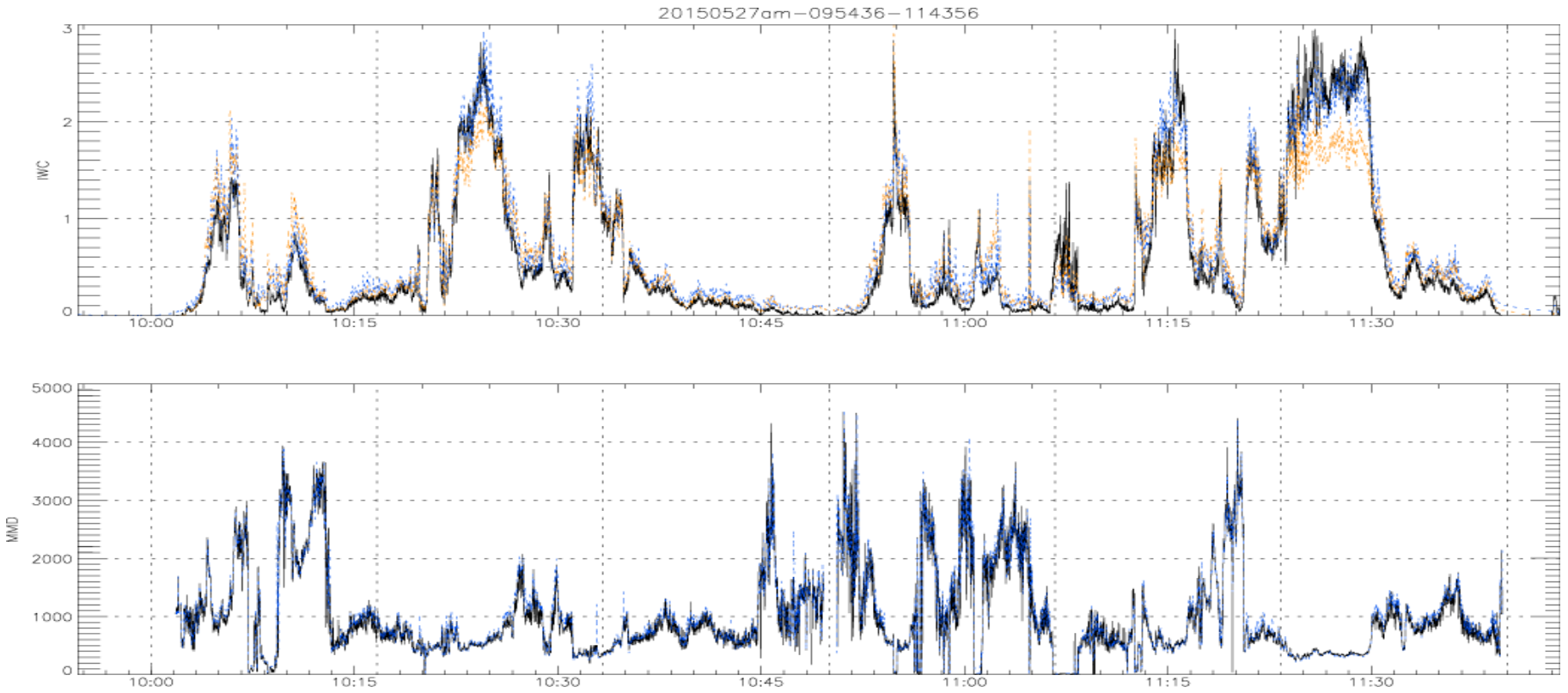


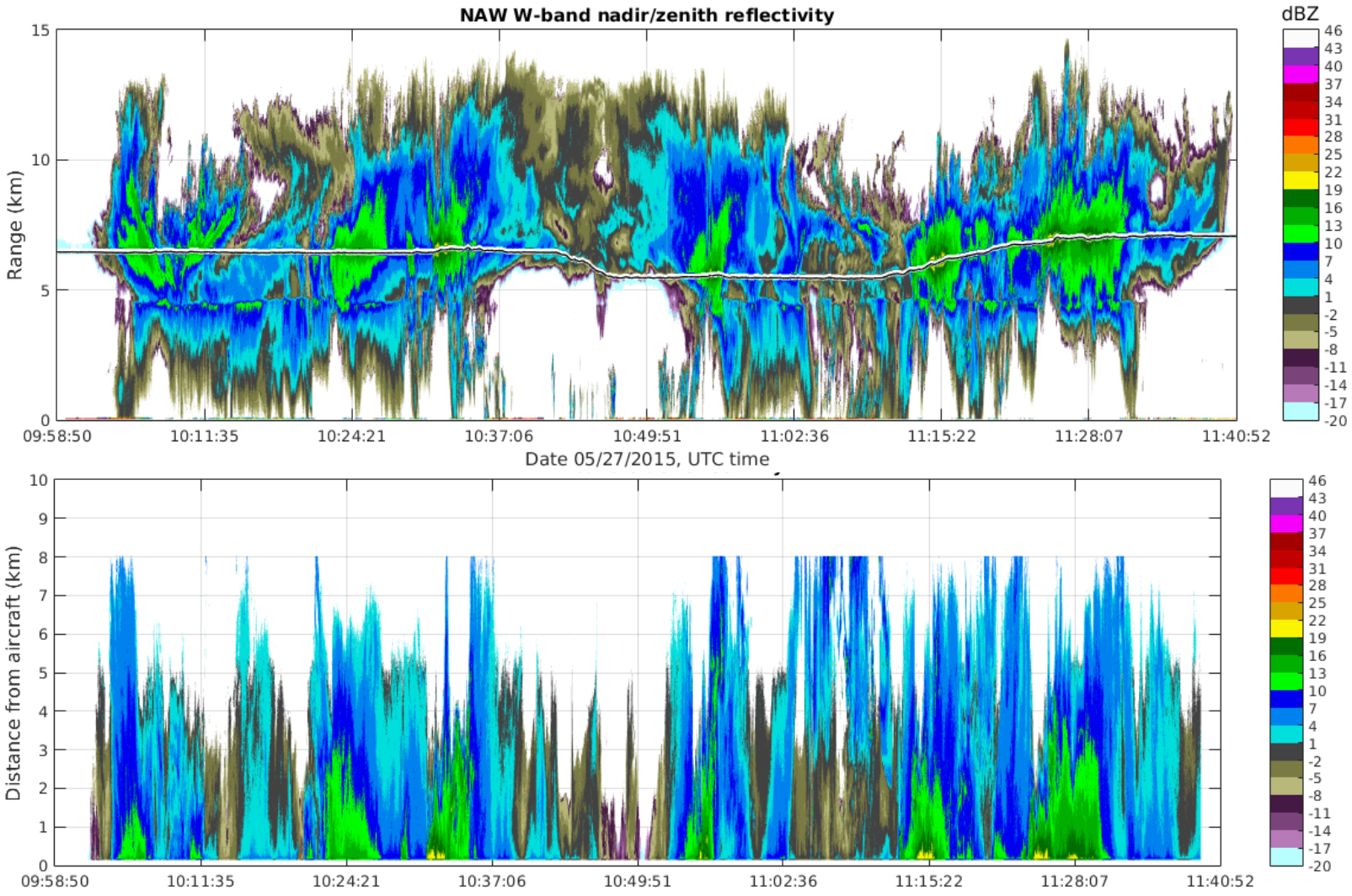


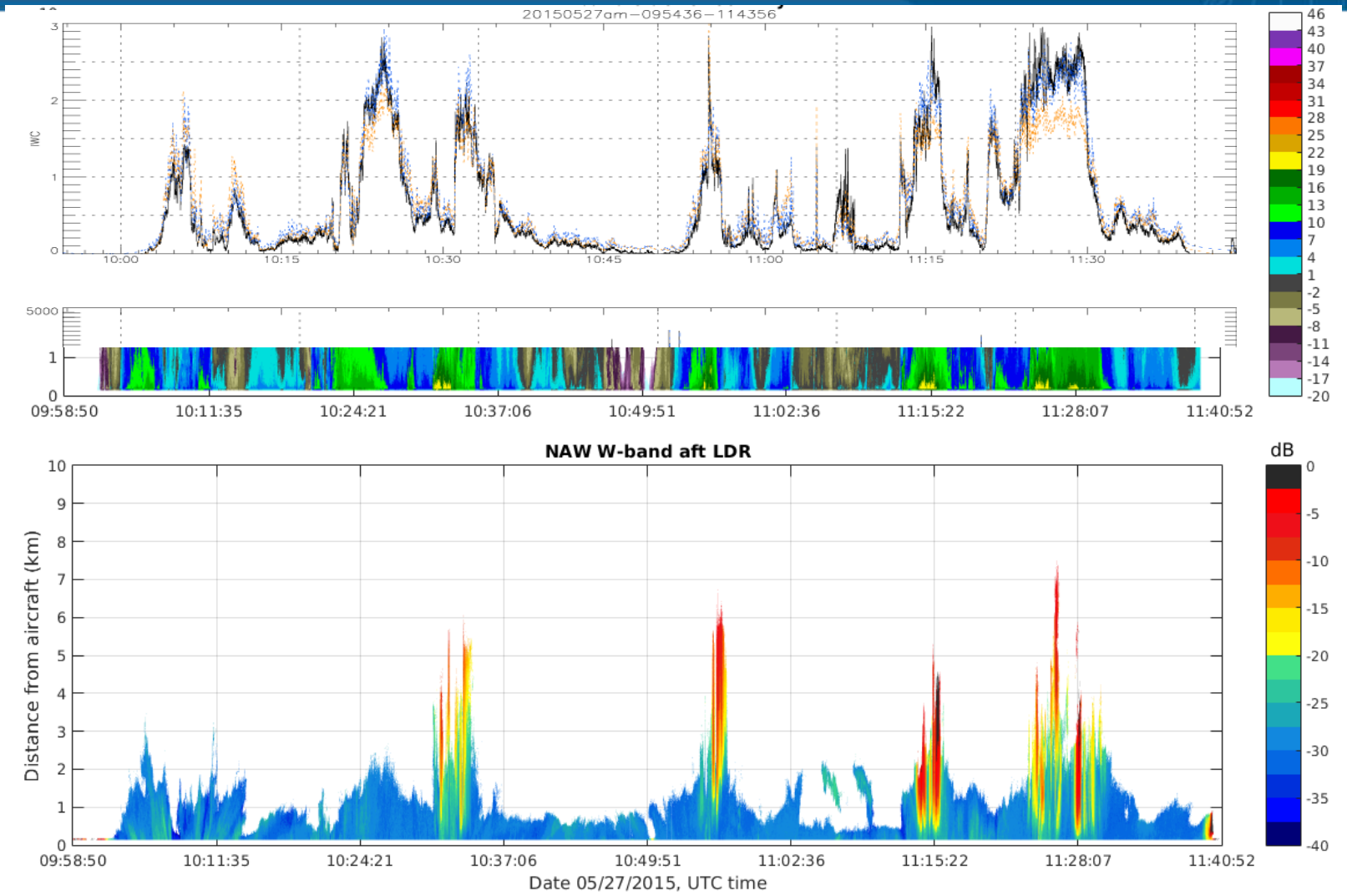



48
18:05:31
18:25:13
18:44:56
19:04:38
19:24:21


NAW W-band side LDR
dB
0
-5
-10
-15
-20
-25
-30
-35
-40
Range (km)
0
1
2
3
4
5
6
7
8
9
10
19:03:27
19:06:19
19:09:10
19:12:02
19:14:53
19:17:44
19:20:36
19:23:27
19:26:19
Date 05/05/2015, UTC time


20150527am-095436-114356
IWC
0
1
2
3
10:00
10:15
10:30
10:45
11:00
11:15
11:30
MMD
0
1000
2000
3000
4000
5000
10:00
10:15
10:30
10:45
11:00
11:15
11:30


NAW W-band nadir/zenith reflectivity
dBZ
46
43
40
37
34
31
28
25
22
19
16
13
10
7
4
1
-2
-5
-8
-11
-14
-17
-20
Range (km)
15
10
5
0
09:58:50
10:11:35
10:24:21
10:37:06
10:49:51
11:02:36
11:15:22
11:28:07
11:40:52
Date 05/27/2015, UTC time
Distance from aircraft (km)
10
9
8
7
6
5
4
3
2
1
0

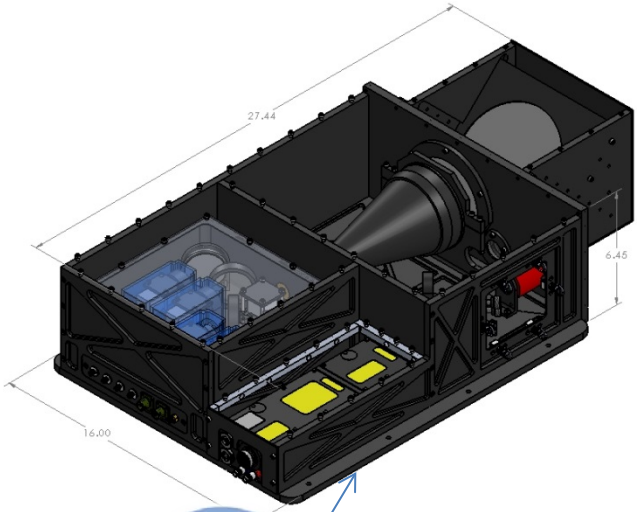

20150527am-095436-114356
IWC
10:00
10:15
10:30
10:45
11:00
11:15
11:30
09:58:50
10:11:35
10:24:21
10:37:06
10:49:51
11:02:36
11:15:22
11:28:07
11:40:52
NAW W-band aft LDR
dB
Distance from aircraft (km)
Date 05/27/2015, UTC time

Ongoing work

- Improve Kdp estimates.
- IWC (Kdp, Zdr) and IWC (Kdp, Zdr, T).
- W-band polarimetric radar signatures of HIWC environment.
- Dual-frequency (X and W-band) analysis.
- Feasibility study of IWC detection and estimation algorithm for real-time application.

LIDAR in HIWC

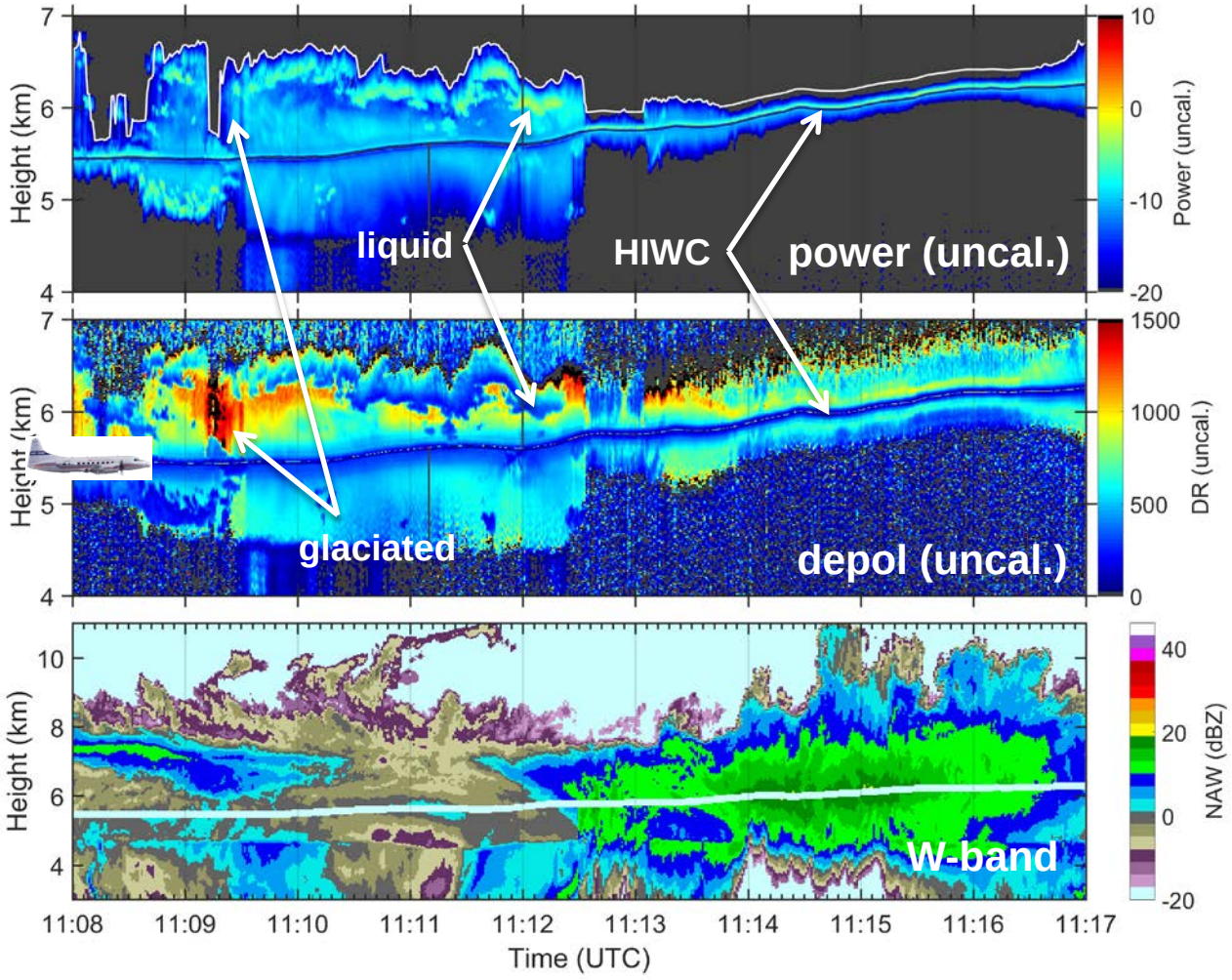
Convair Lidars



- Wavelength: 355 nm, for eye safe operation.
- Horizontal resolution: 20 profile per second.
- Vertical resolution: up to 0.75 m (200MHz sampling rate).
- Depolarization measurements: supercooled water and ice separation.
- High and low gain channels to avoid in cloud signal saturation.
- Measurements extend close to aircraft.

- Zenith and Nadir-looking
- Two independent systems

Test case May 27, 2015 – Entering into a HIWC cloud

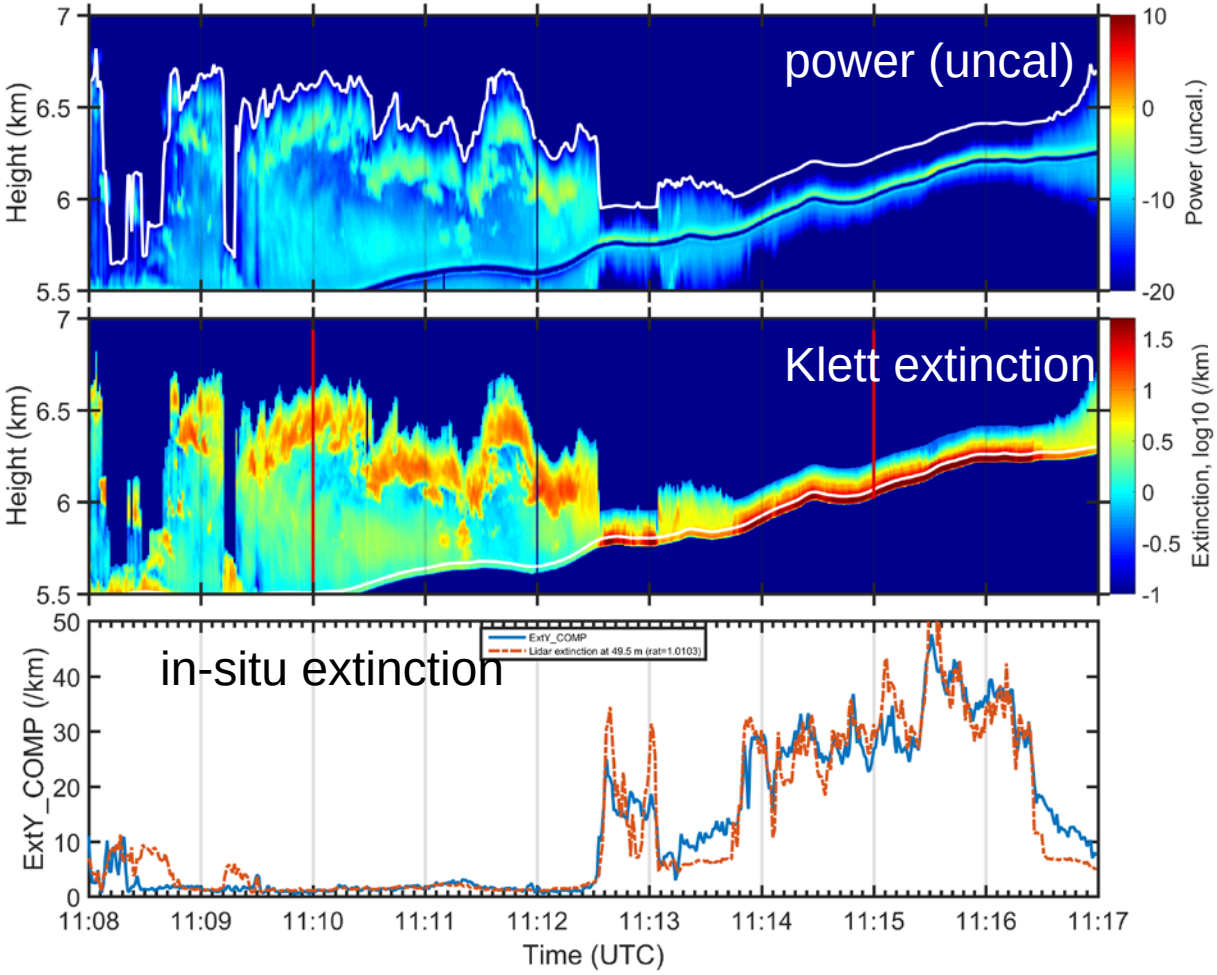


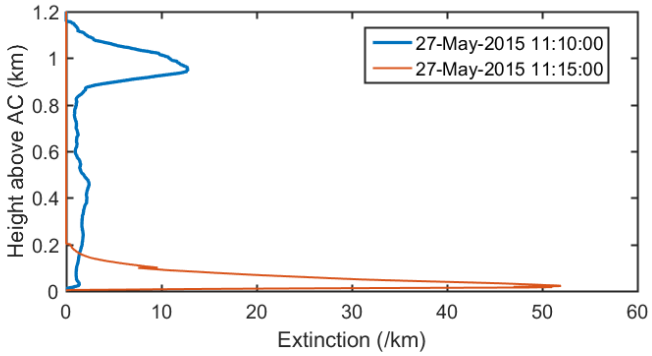
AECL backscatter and depolarization signatures allow to identify liquid and glaciated layers

In HIWC AECL signal is mostly extinguished in the first 200m

NAW shows a melting layer at 4.5 km. Maximum reflectivity (~18 dBZ) is achieved in HIWC region (~11:14-11:15) above the melting layer

Test case May 27, 2015 – Lidar vs in-situ extinction





AECL extinction profiles were retrieved using Klett inversions (LR = 20)

AECL extinction values taken at 50m and scaled by ~4 show an excellent agreement with in-situ measurements

Lidar-based estimations of IWC

- **Lidar-only** retrievals from extinction (κ) parametrization (e.g. Heymsfield et al, 2005, 2014)

$$IWC = a\kappa^b$$

a,b - constants

- **Lidar-radar** retrievals (e.g. Wang and Sassen, 2002)

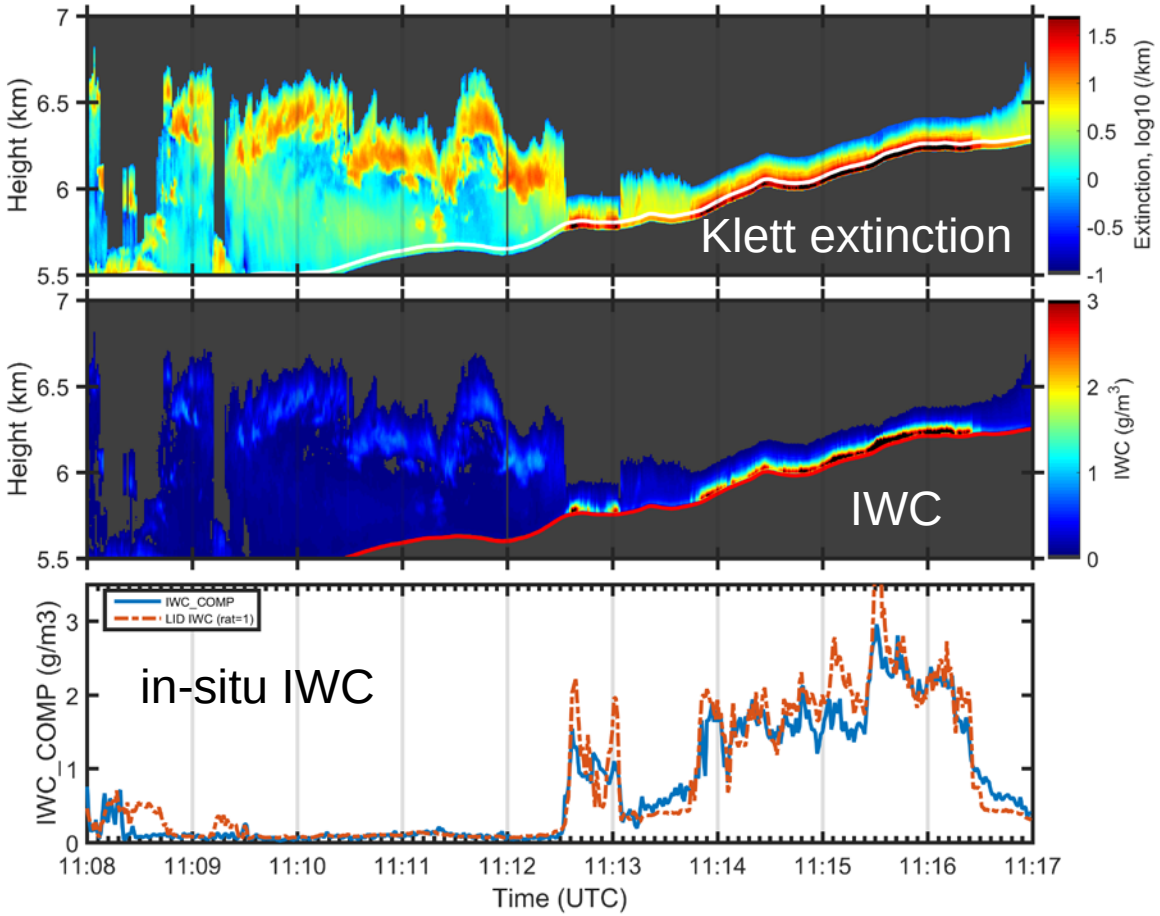
$$IWC = \left(\frac{Z_e}{C'}\right)^{1/(b+1)} \left(\frac{\kappa}{a_1}\right)^{1/(b+1)}$$

Z_e – radar reflectivity, C', b, a_1 - constants

- **Lidar-radar-radiometry** (e.g. Delanoë and Hogan, 2008)

Variational scheme

Test case May 27, 2015 – IWC profiles (lidar only)

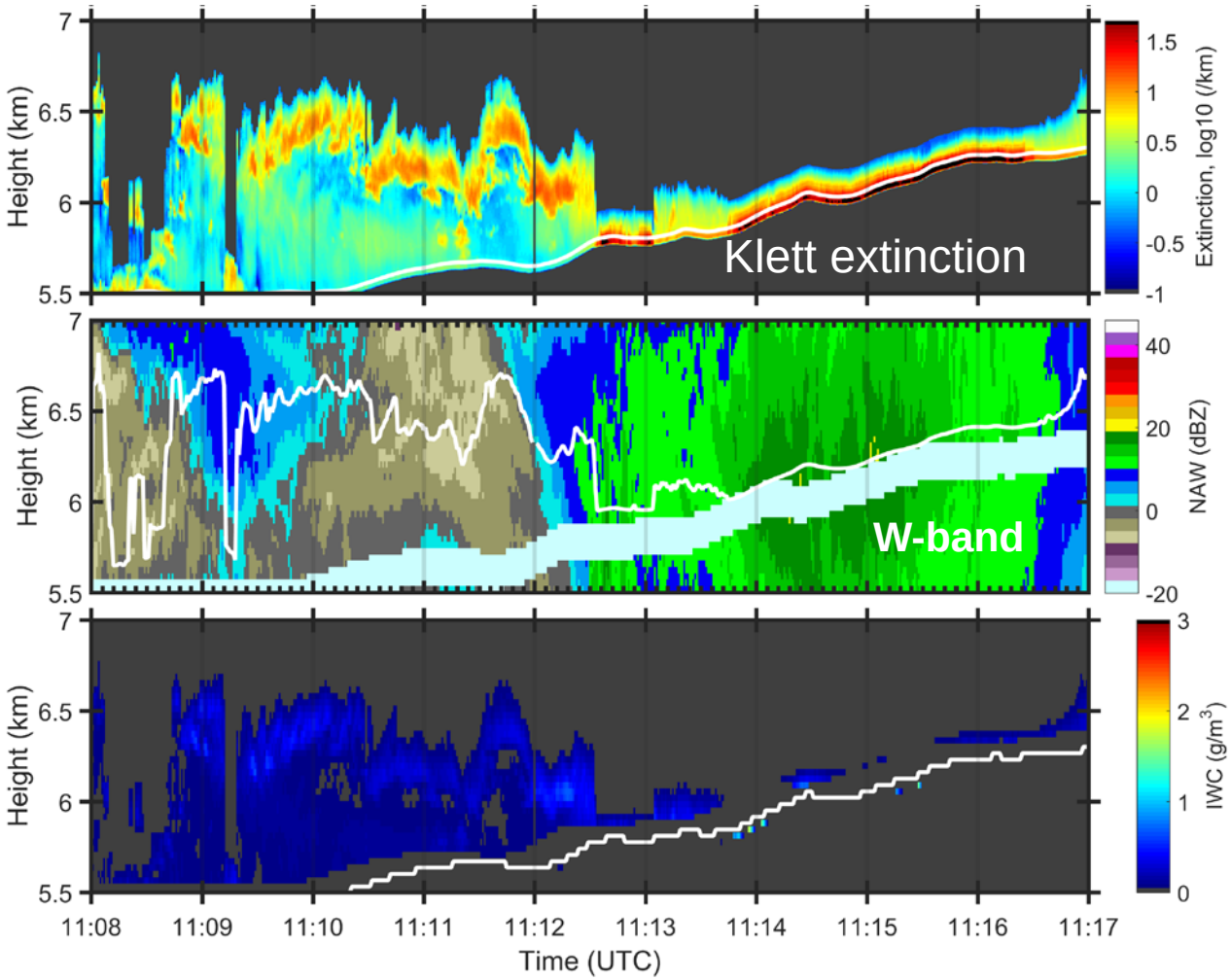


after Heymsfield et al., 2014

IWC content values can reach >3.5 g/m^3 in the HIWC region.

In general, good agreement between in-situ and extinction-based IWC values

Test case May 27, 2015 – IWC profiles (lidar-radar)



after Wang and Sassen, 2002

No reliable radar data in the near-range to compare with in-situ

GVR in HIWC

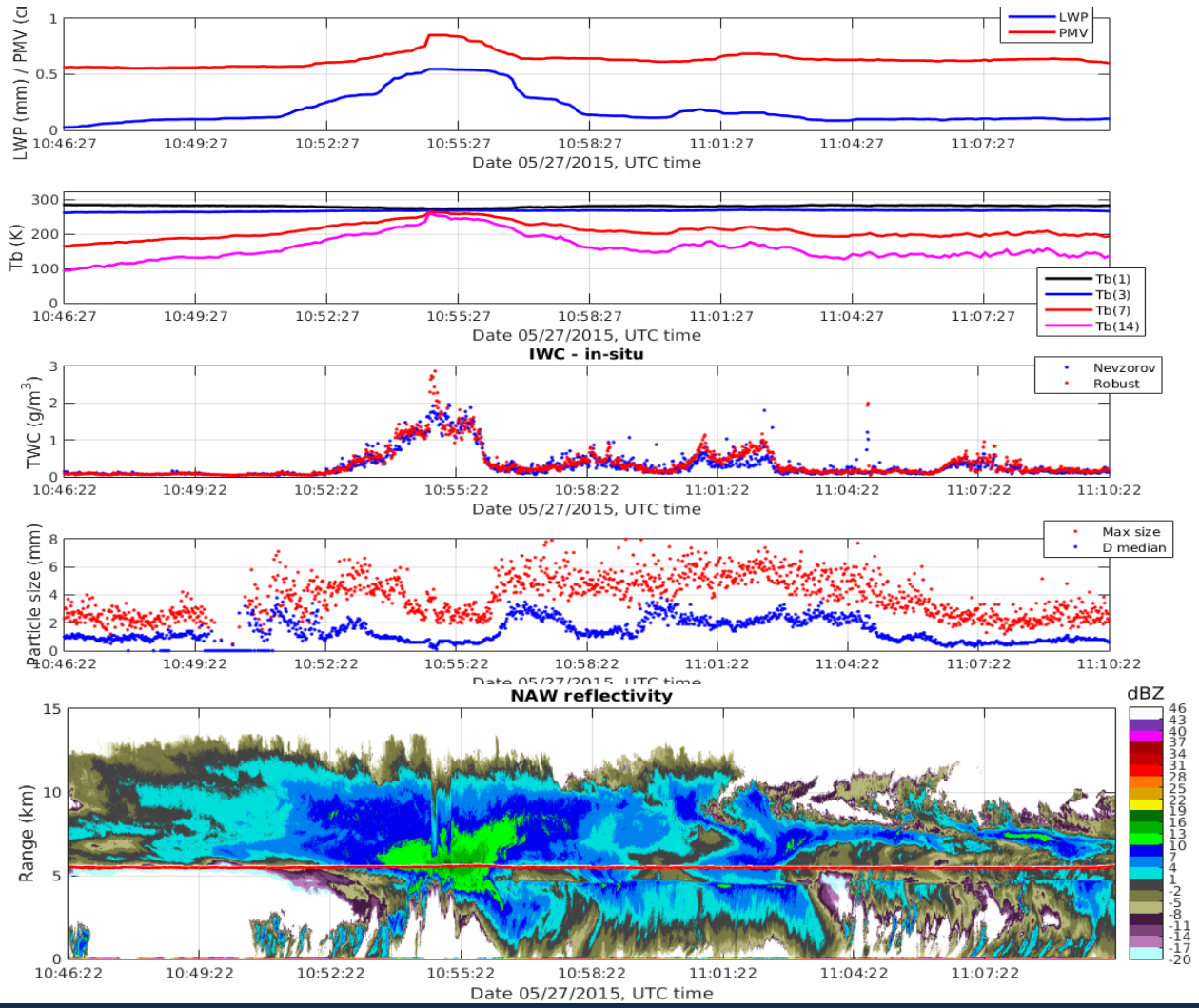
G-band (183 GHz) water Vapor Radiometer (GVR)

- Developed by ProSensing Inc. and first airborne installation on Convair in 2007 (Pazmany & Wolde, 2009)

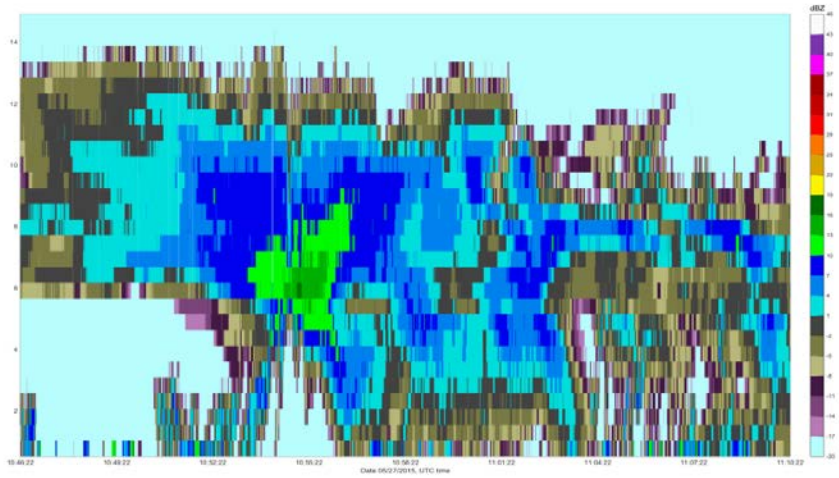
- Measures brightness temperature at 183.31 ±1, ±3, ±7 and ± 14 GHz

- **Neural Network Retrievals of PWV and LWP from GVR brightness temperature (Pazmany, 2009; Cadeddu et. al., 2009)**

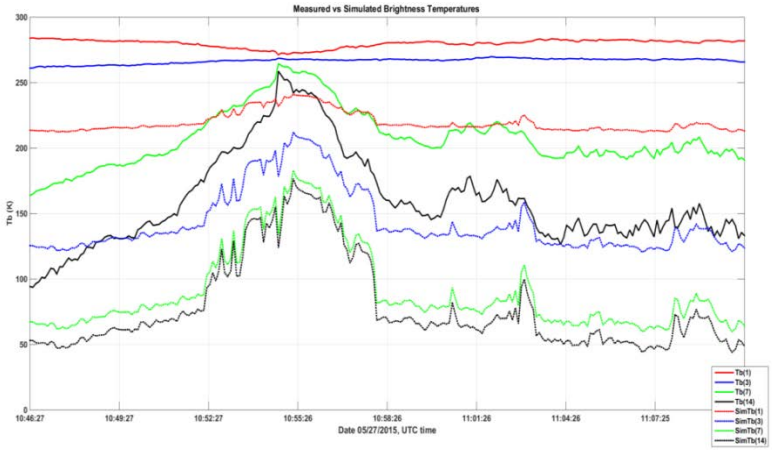
GVR Response in ICI environment – Cayenne 2015



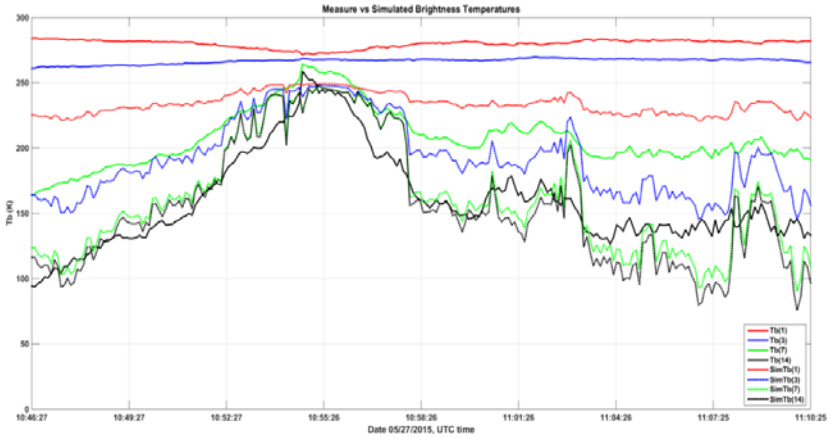
Simulated Brightness Temperatures Along the Flight Path



Averaged cloud, consisting of 29 layers.



Brightness temperature measurements compared to simulations**.** Time interval is 6.0 seconds, or 239 measurements.



As above (right panel) but with the cloud optical depth multiplied everywhere by a factor of five.

Results of radiative transfer simulations are In broad qualitative agreement with observations, considering the absence of the thermodynamic structure of the atmosphere and the PSD within the cloud.

Summary

- Preliminary analysis of responses and signatures of NAWX in HIWC environment:
  - IWC-Z follow a power-law fit for Z < 20 dBZ and depends on temperature at W-band.
  - For X-band, the IWC-Z relationship in aggregates with Z > 20 dBZ is different from IWC-Z relationship in HIWC regions. Polarization (Kdp) based IWC estimation shows a better result than Ze based IWC at X-band
  - Close to the aircraft (<500 m range), there is no difference between W and X-band reflectivity values in HIWC region
- High Lidar extinction in HIWC
- At G-band, the 183±7GHz and 183±14GHz channels show higher responses to HIWC conditions.

Ongoing work

- IWC (Kdp, Zdr) and IWC (Kdp, Zdr, T).
- W-band polarimetric radar signatures of HIWC environment.
- Dual-frequency (X and W-band) analysis.
- IWC detection and estimation algorithm for real-time application
- Lidar-Radar based HIWC reterivals
- Modeling of HIWC Tb responses at 183 GHz

- US-Honeywell Boeing 757
- NRC Convair
- French Falcon-20

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High Ice Water Content (HIWC) Program

Environment Canada Environnement Canada

NRC·CNRC

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Thank you

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