Cayenne-2015 Data set status, NRC CV580 – NAWX radar and Pilot`s radar

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HAIC-HIWC Science Team Meeting, 16-19 May 2016

National Research Council Canada | Conseil national de recherches Canada | Environment Canada | Environnement Canada | Canada

Outline

- **In-situ data**
  - Updated quality control data
  - Netcdf format
  - Examples
- **The NRC W-band and X-band radars (NAWX)**
  - System
  - Reflectivity calibration
  - Doppler corrections/de-aliasing
- **Convair 580 pilot weather radar**
- **Apenglow elastic lidar**
- **Summary**

List of available measurements and sensor for Cayenne, May 2015

Parameters	Sensors	Availability date
Time	**GPS (Honeywell, IRIDGB, …)**	**10, 12, 13, 14, 15, 16(a/b), 20, 23, 25, 26(a/b), 27(a/b)**
Atmospheric state (Temp, Rh, Ps, Pd, Wind_n, Wind_e, Wind_speed, Wind_dir,)	**AIMMS, POK,**	**10, 12, 13, 14, 15, 16(a/b), 20, 23, 25, 26(a/b), 27(a/b)**
Air data (P alpha, P beta)	**AIMMS**	**10, 12, 13, 14, 15, 16(a/b), 20, 23, 25, 26(a/b), 27(a/b)**
Aircraft state (pitch, roll, heading/yaw, lat, lon, alt, Gs, track, Q, P, R, Ax, Ay, Az, NS_Vel, EW_Vel, V_Vel)	**Honeywell, POK, Litton, Flex, Pro**	**10, 12, 13, 14, 15, 16(a/b), 20, 23, 25, 26(a/b), 27(a/b)**

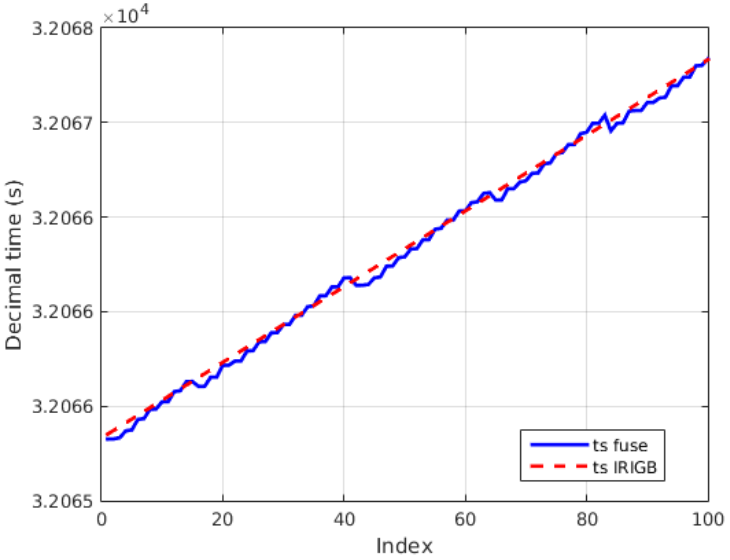
Cayenne Aircraft In-situ Data

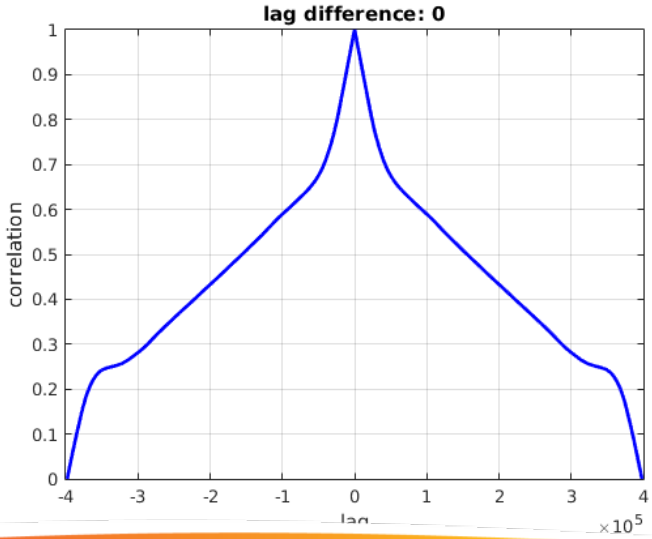
❖ Quality control procedure (Updated)

- IRIGB Hg (Honeywell) is set as the main clock. Resolved the nonmonotonic timing issue (fig., next slide) and all data are mapped to the main clock.
- All parameters except Licor 840A are decimated to 4Hz rate. Licor 840A data is at 1Hz (as collected). From our analysis, the data are sync correctly.
- Recalculated Ps, Pd (scalar, 858) with updated calibration factors.
- Ts at scalar boom and port wing are not available for data before May 20 thus used Ts from AIMMS.
- Recalculated TAS (scalar and 858).
- Remove outlier samples by thresholding its gradient. If the outlier percentage is less than a pre-set threshold, remaining data points are interpolated.
- Monitor data consistency (across sensors) and detect for faulty data segments by standard statistical methods (local correlation, local standard deviation and gradient).
- Export QC data to netcdf files.

Examples of data QC actions

Nonmonotic timing issue with fuse data (also) but not with IRIGB, thus data are sorted, decimated and then mapped to the IRIGB clock.





Example of a typical cross-correlation function of data from different sensors (e.g. Ps from scalar and 858) shows that the data are synchronized in time.

Netcdf file

Netcdf header

```
dimensions:
        Time4Hz = 49718 ;
        Time1Hz = 12430 ;
variables:
        int time(Time4Hz) ;
                time:long_name = "Decimal time at 4Hz" ;
                time:units = "seconds" ;
                time:fill_values = "-9999" ;
                time:DataQuality = "good" ;
                time:Categories = "A/C state." ;
                time:comments = "seconds since midnight" ;
        int time_licor840A(Time1Hz) ;
                time_licor840A:long_name = "Decimal time at 1Hz for Licor 840A Dew Point measurements" ;
                time_licor840A:units = "seconds" ;
                time_licor840A:fill_values = "-9999" ;
                time_licor840A:DataQuality = "good" ;
                time_licor840A:Categories = "A/C state." ;
                time_licor840A:comments = "seconds since midnight" ;
        float longitude(Time4Hz) ;
                longitude:long_name = "Longitude" ;
                longitude:units = "degrees east" ;
                longitude:fill_values = "-9999" ;
                longitude:DataQuality = "good" ;
                longitude:Categories = "A/C state." ;
                longitude:comments = "longitude of the aircraft" ;
                        ⋮
        float tas_spol_858(Time4Hz) ;
                tas_spol_858:long_name = "Local True Air Speed from RM858" ;
                tas_spol_858:units = "m/s" ;
                tas_spol_858:fill_values = "-9999" ;
                tas_spol_858:DataQuality = "good" ;
                tas_spol_858:Categories = "Atmos." ;
                tas_spol_858:comments = "with measured 858 Ps, Pd" ;

// global attributes:
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                :Aircraft = "NRC Convair-580" ;
                :Sensors = "Fuselage, AIMMS, Scalar, 858" ;
                :Project = "CHIWC Cayenne May 2015" ;
                :Categories = "Position, Aircraft State, Atmos." ;
                :Contact = "mengistu.wolde@nrc-cnrc.gc.ca / cuong.nguyen@nrc-cnrc.gc.ca" ;
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Available NRC CV580 aircraft in-situ data

dimensions:

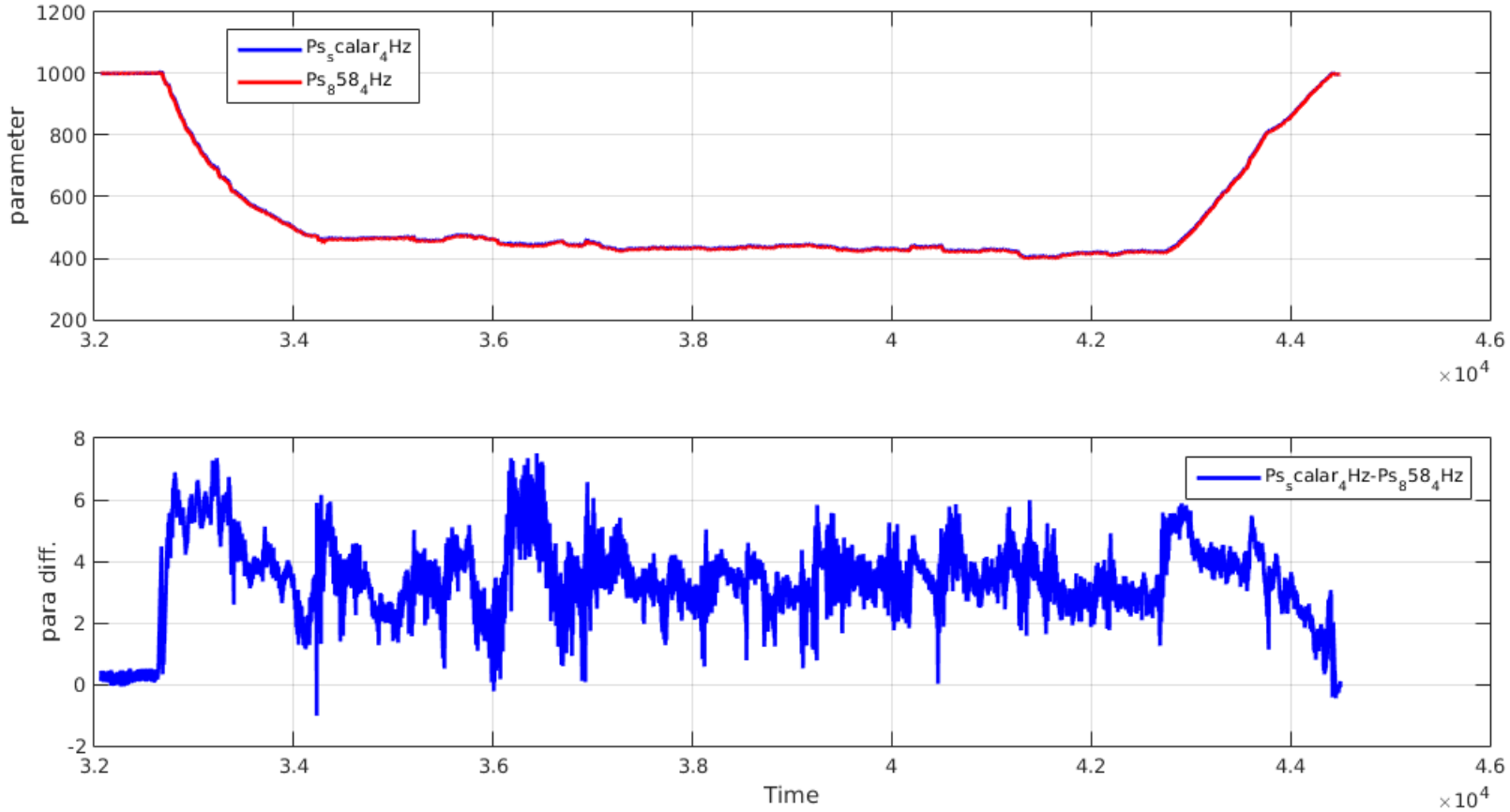
Time4Hz = 49718 ;
Time1Hz = 12430 ;

variables:

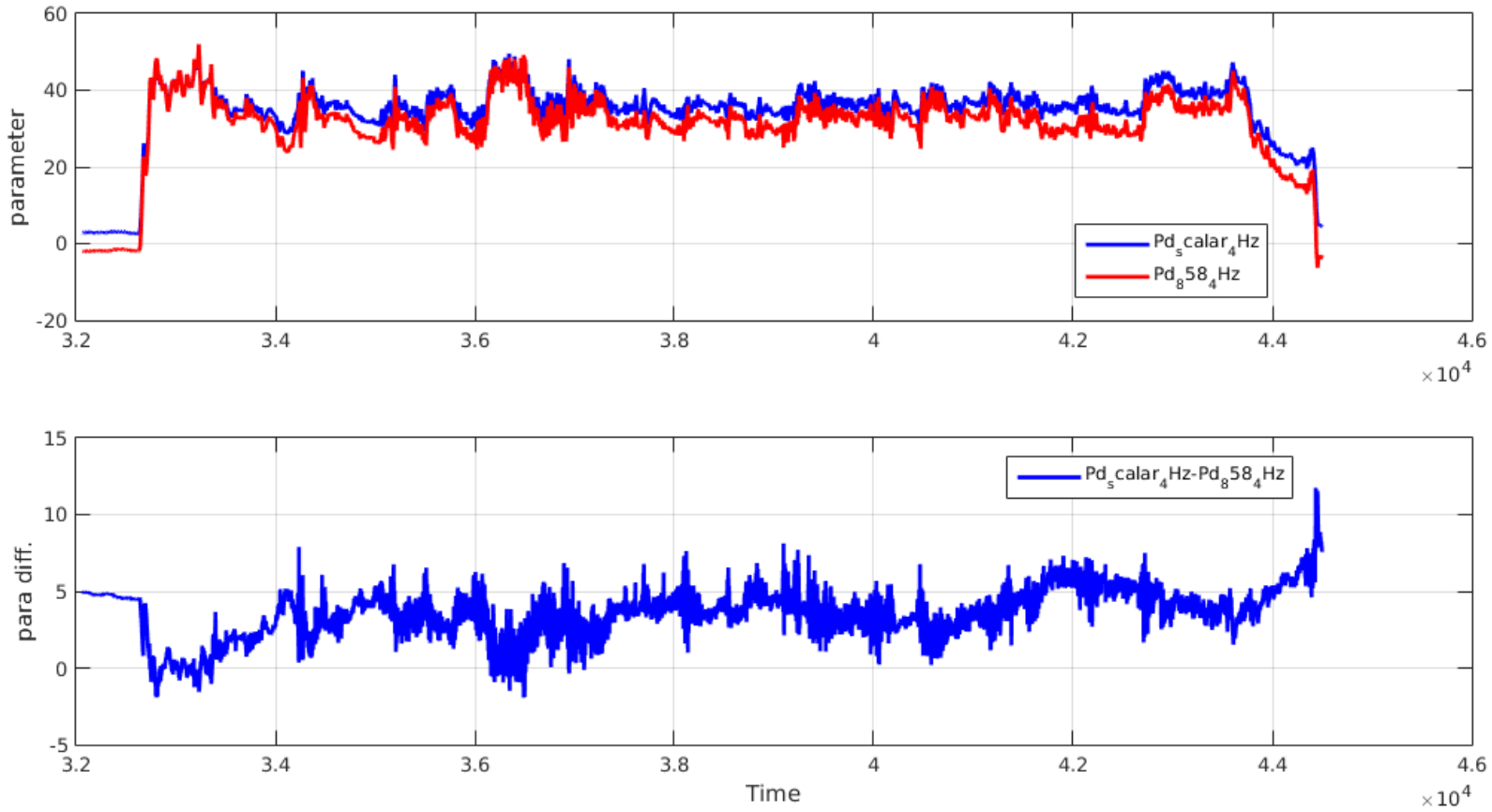
int time(Time4Hz) ;
int time_licor840A(Time1Hz) ;
float longitude(Time4Hz) ;
float latitude(Time4Hz) ;
float altitude(Time4Hz) ;
float ts_swt_AIMMS(Time4Hz) ;
float rh_swt_AIMMS(Time4Hz) ;
float ps_swt_AIMMS(Time4Hz) ;
float hwspd_swt_AIMMS(Time4Hz) ;
float hwdir_swt_AIMMS(Time4Hz) ;
float vwind_swt_AIMMS(Time4Hz) ;
float tas_swt_AIMMS(Time4Hz) ;
float psc_f(Time4Hz) ;
float pdc_f(Time4Hz) ;
float ts_ssb(Time4Hz) ;
float vwnd_spol_858Hg(Time4Hz) ;
float hwsd_spol_858Hg(Time4Hz) ;
float hwdir_spol_858Hg(Time4Hz) ;
float ps_ssb(Time4Hz) ;
float ps_spol_858(Time4Hz) ;
float pd_ssb(Time4Hz) ;
float pd_spol_858(Time4Hz) ;
float td_c_CM(Time4Hz) ;
float td_c_Licor840A(Time1Hz) ;
float C2Oppm_c_Licor840A(Time1Hz) ;
float H2Oppt_c_Licor840A(Time1Hz) ;
float tcell_c_Licor840A(Time1Hz) ;
float pcell_c_Licor840A(Time1Hz) ;
float tas_f(Time4Hz) ;
float tas_ssb(Time4H

Examples of QC data

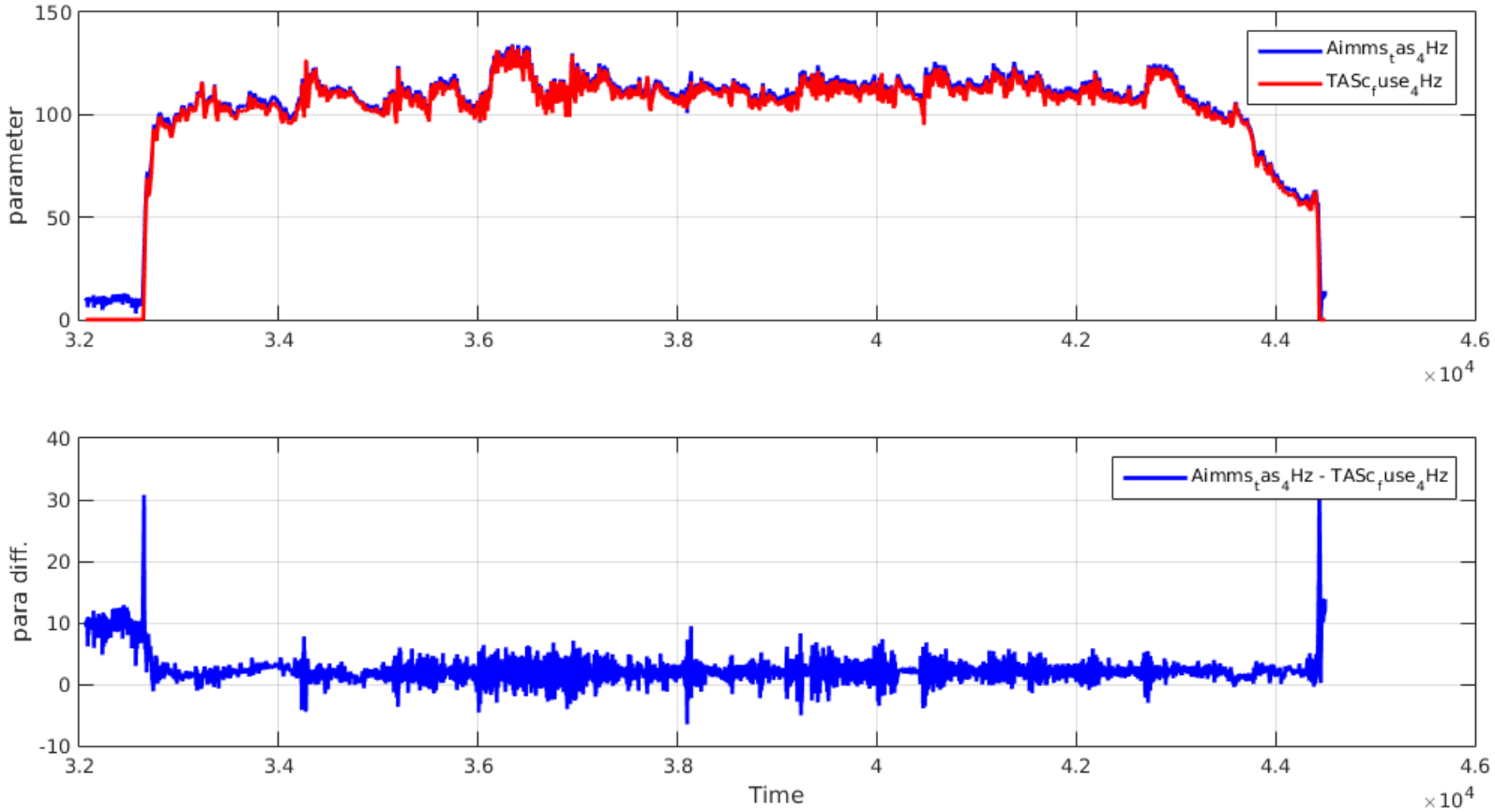
Static Pressure (May 20, 2015)



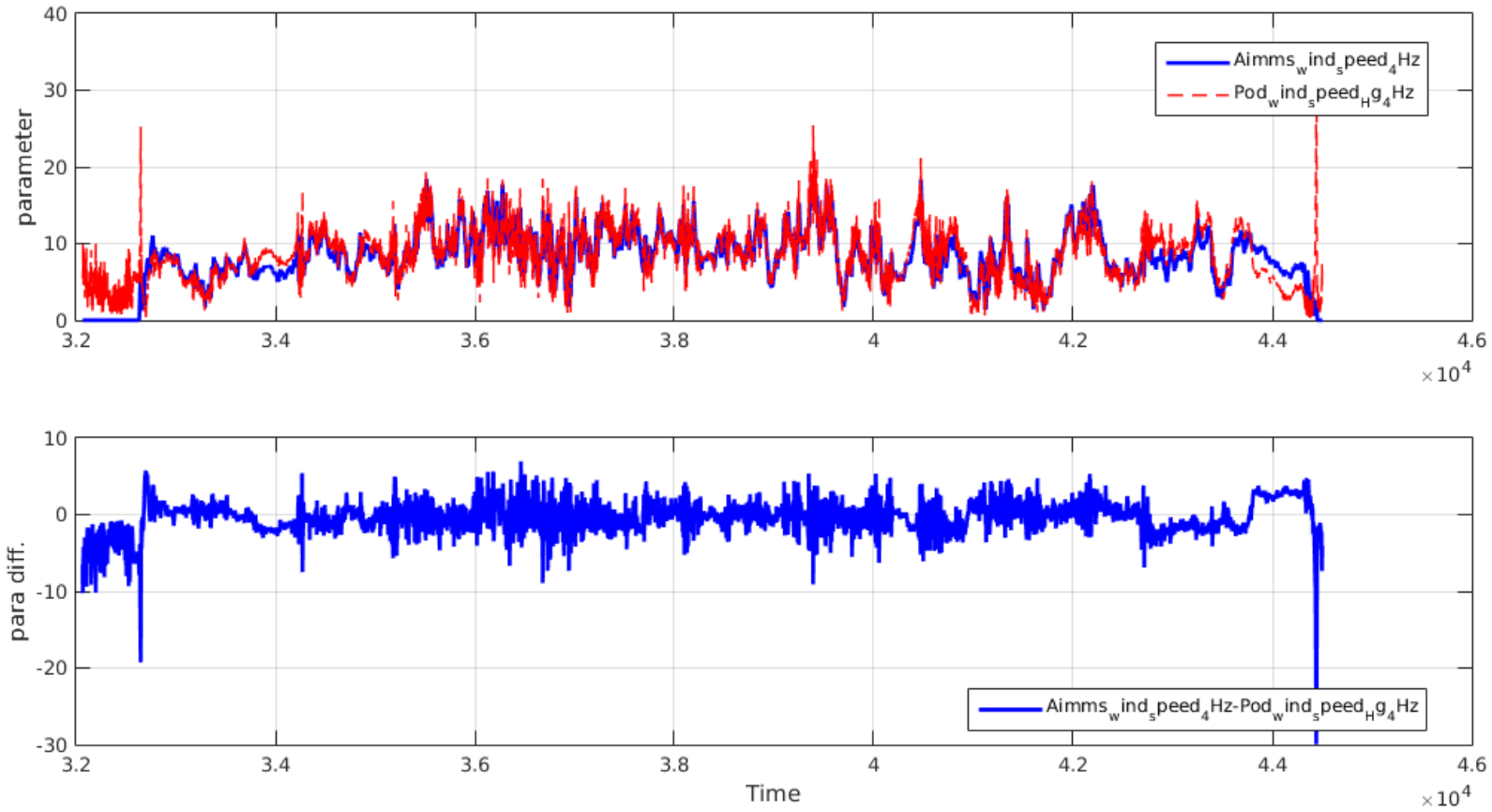
Dynamic Pressure (May 20, 2015)



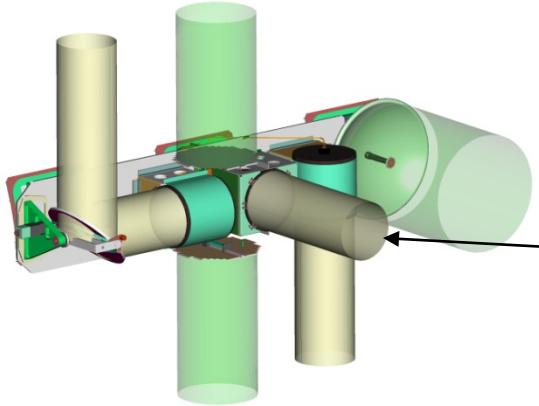
True Air Speed (May 20, 2015)

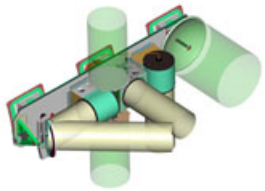


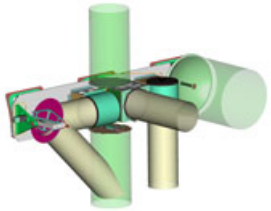
Wind Speed (May 20, 2015)



*N*RC *A*irborne *W* and *X*-bands radar (NAWX)



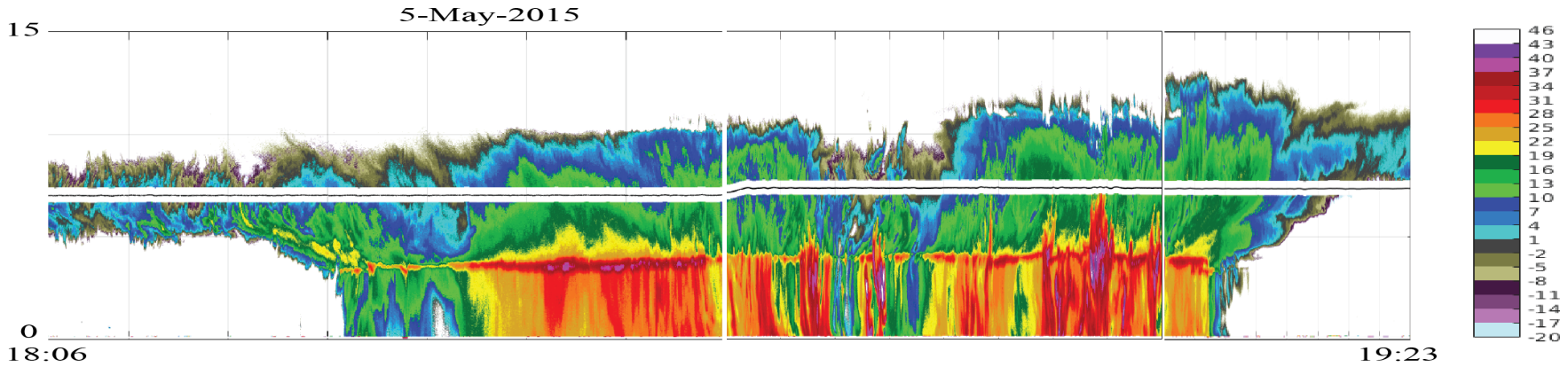




NAWX	W-band	X-band
Transmitted Frequency (GHz)	94.05	9.41
Peak Tx Power (KW)	1.7 - typical	25 (split b/n two ports)
Polarization	Co and Cross	Simultaneous H and V
Doppler	Pulse Pair and FFT	Pulse Pair and FFT
Pulse Duration (μs)	0.1 - 10	0.11-1
Max PRF (KHz)	20	5
Ant. 3 dB BW (°)	0.75	3.5
Antenna ports	5	4
View direction	Up, down and side	Up, down and side

Convair Radar Performance

Date May	10	12	14	15	16	16	20	23	23	25	26	26	27
Flt #	7	8	9	10	11	12	13	14	15	16	17	18	19
X													
W													
K_a													
Pilot													

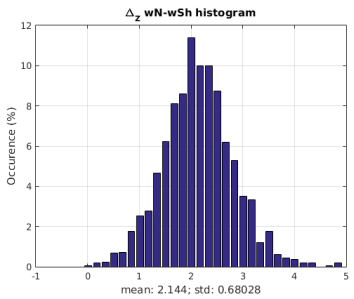


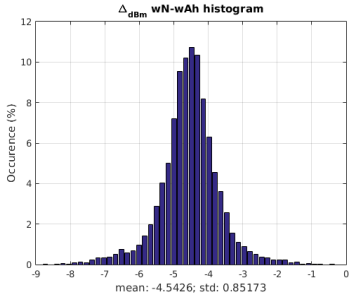
X – Very good; W: Good, but data gap; Ka – Marginal – only nadir data; Pilot X - Good

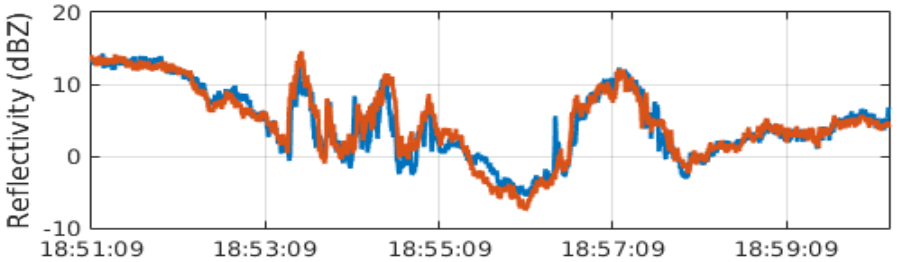
NAWX calibration using corner reflector

- Corner reflect calibration of Aft antenna
- Drizzle / small ice crystal Z from W is used for determination of calibration constant for X-band

- NAW power measurements





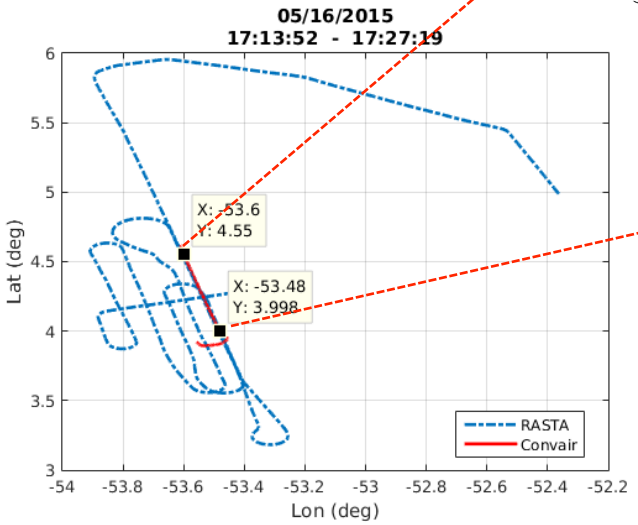


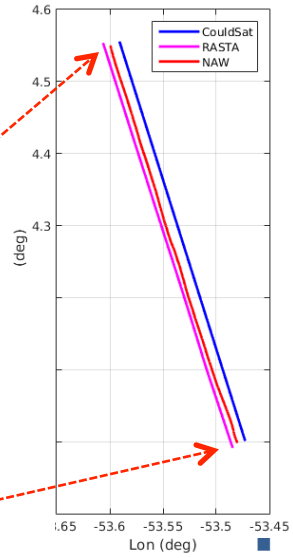
Environment Canada Environnement Canada

NRC·CNRC

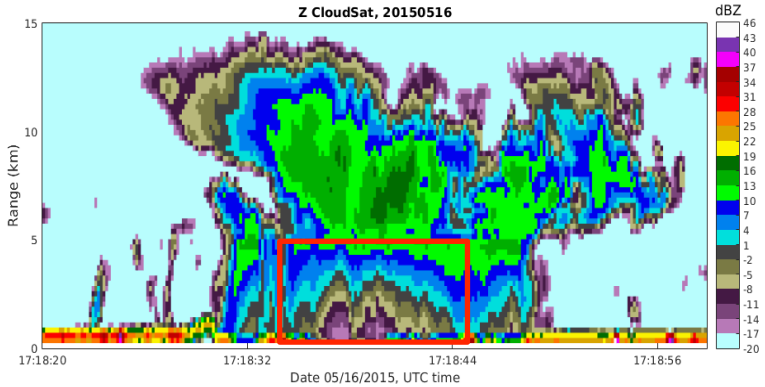
Reflectivity calibration: NAW-RASTA-CloudSat

Convair and RASTA track





CloudSat overpass

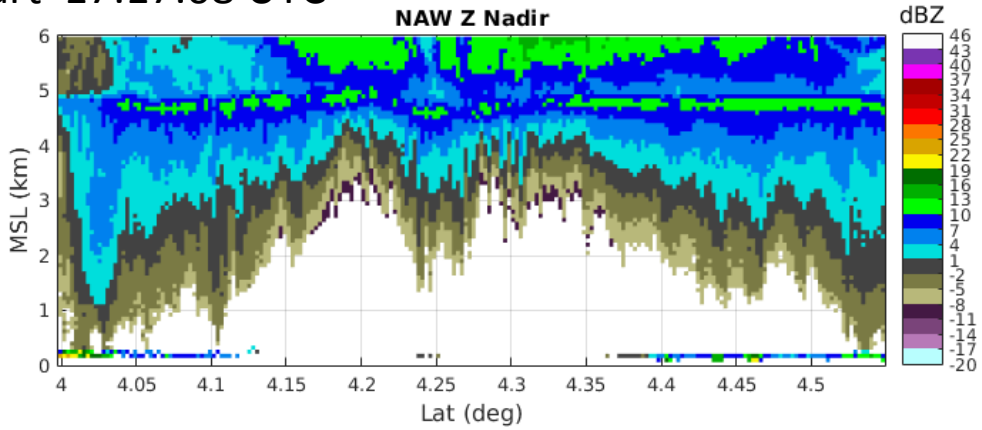


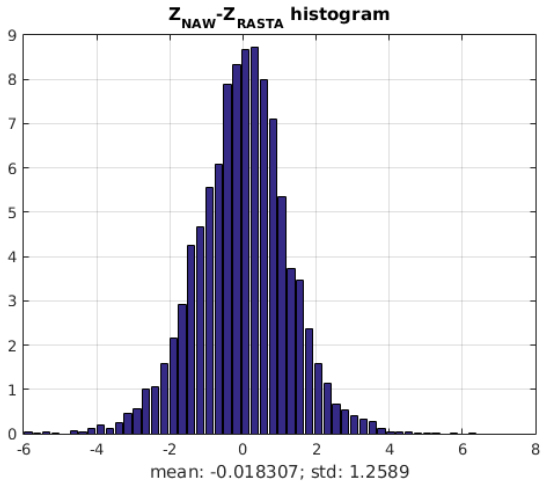
- Select an overlap segment of the flight track when the temporal and spatial differences between the three platforms are minimum
- NAW has a higher resolution than CloudSat and RASTA data used in the comparison
- Comparison are done with NAW data was “downsampled” and re-gridded to match with RASTA and CloudSat resolutions

Minor offset in Convair, F20 and CloudSat tracks

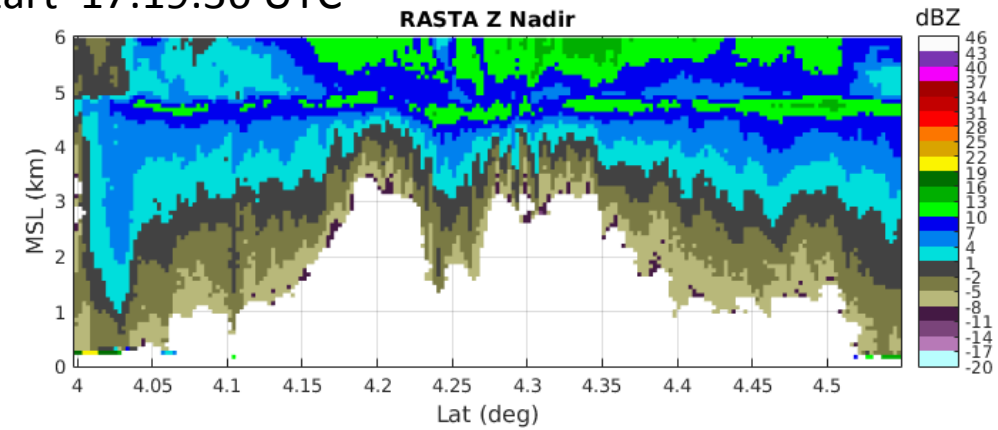
NAW-RASTA

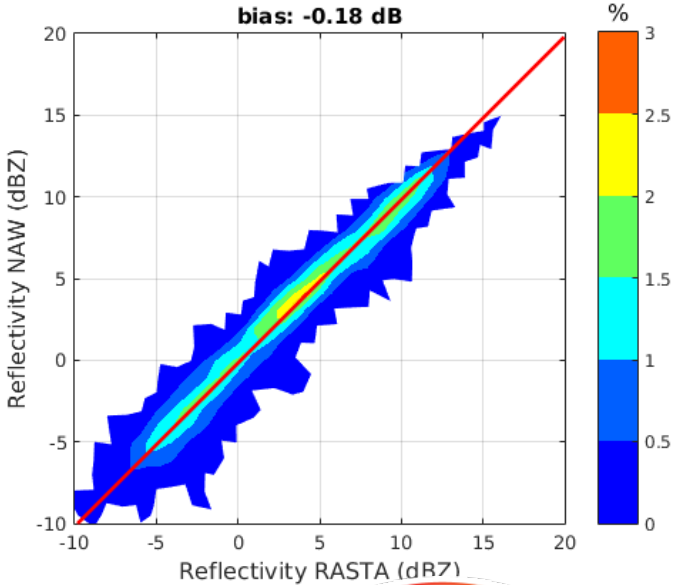
Start 17:17:08 UTC





Start 17:19:36 UTC

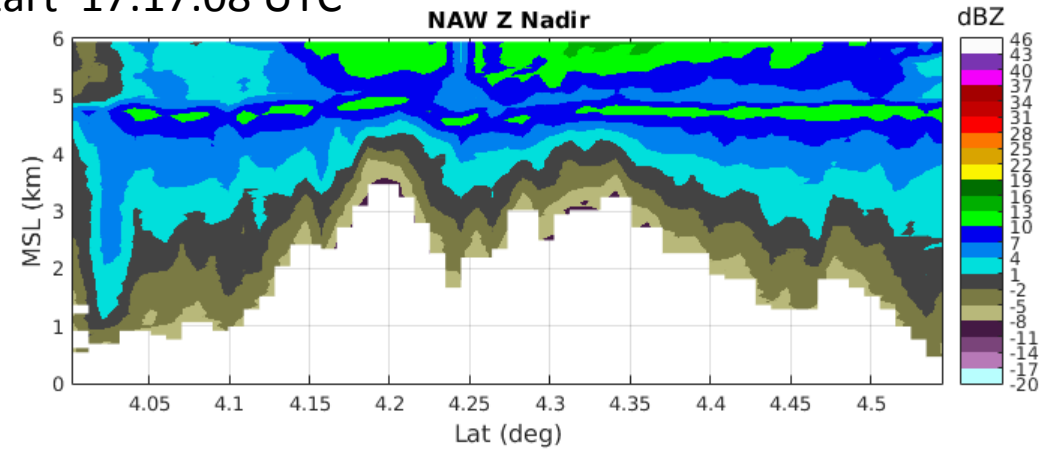




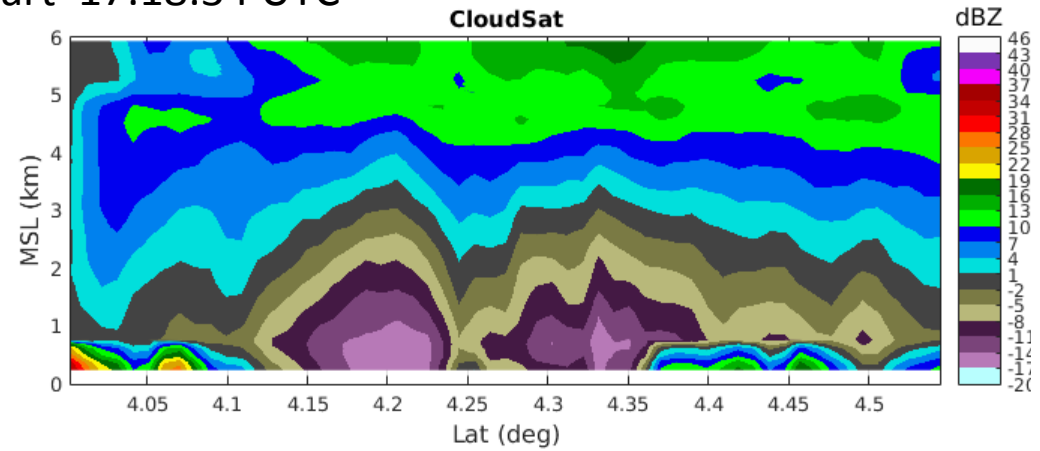
Excellent agreement b/n RASTA and NAW

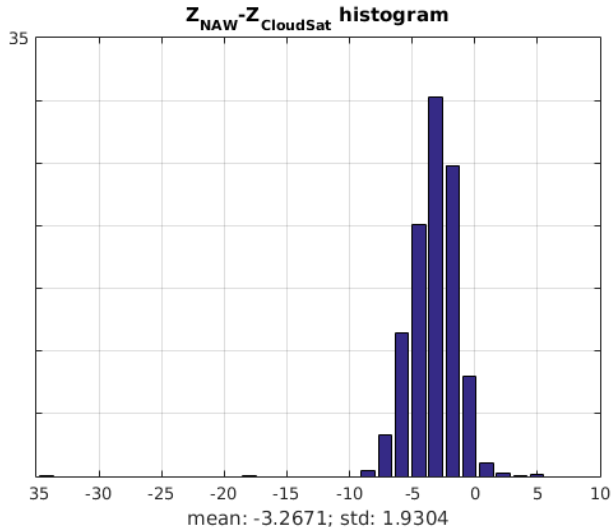
NAW-CloudSat

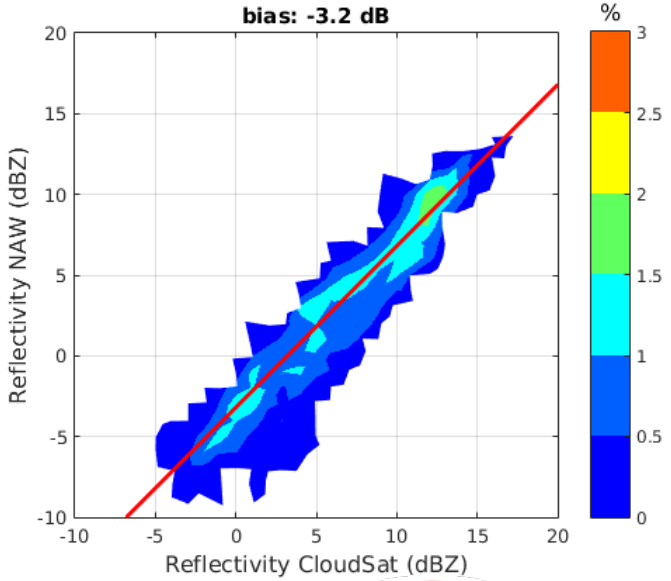
Start 17:17:08 UTC



Start 17:18:34 UTC

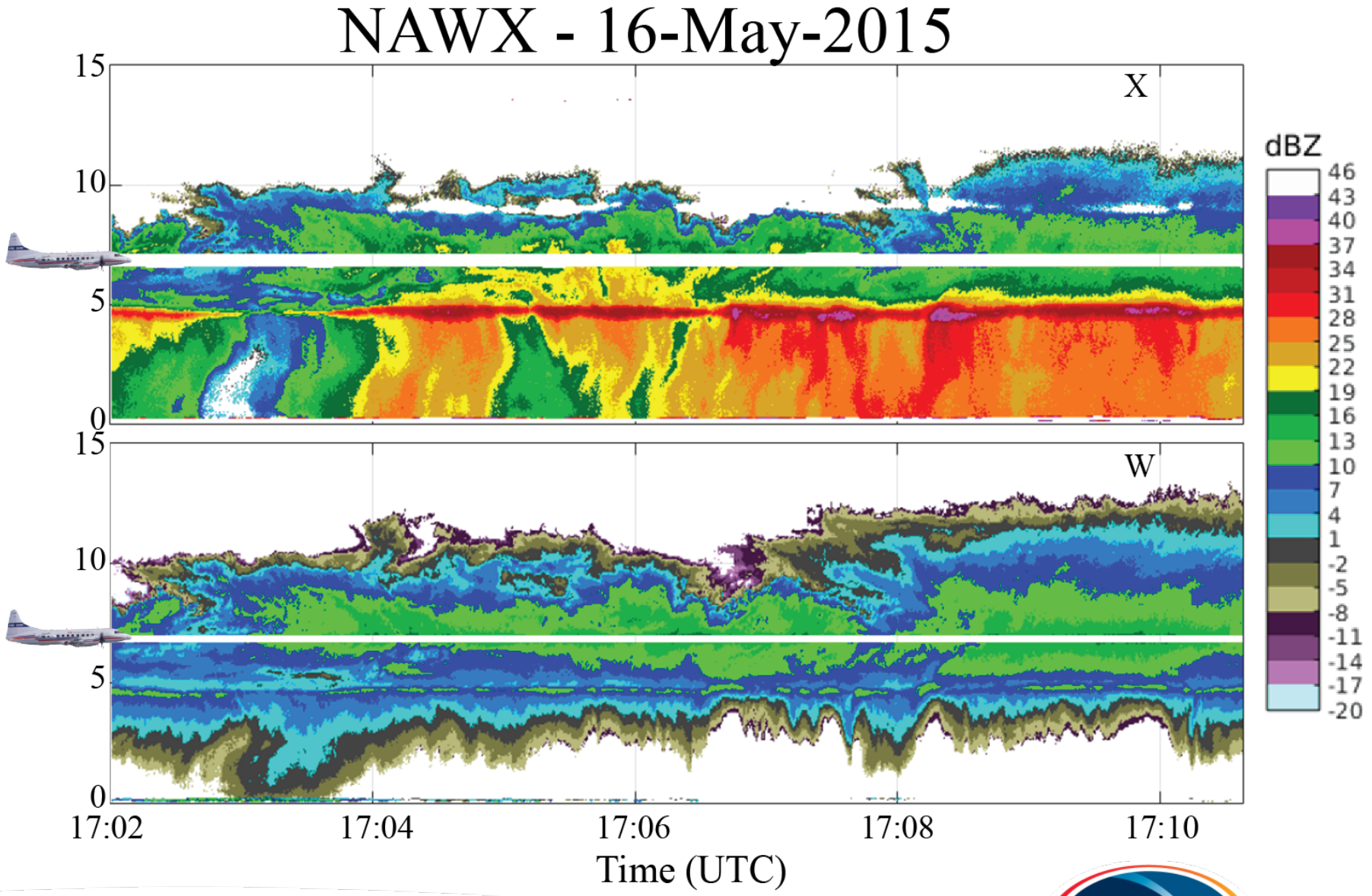






NAW/RASTA Z 3.2 dB lower than CloudSat

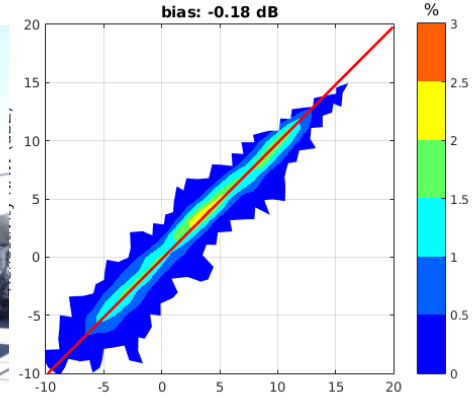
Comparison of W-band and X-band vertical reflectivity profiles

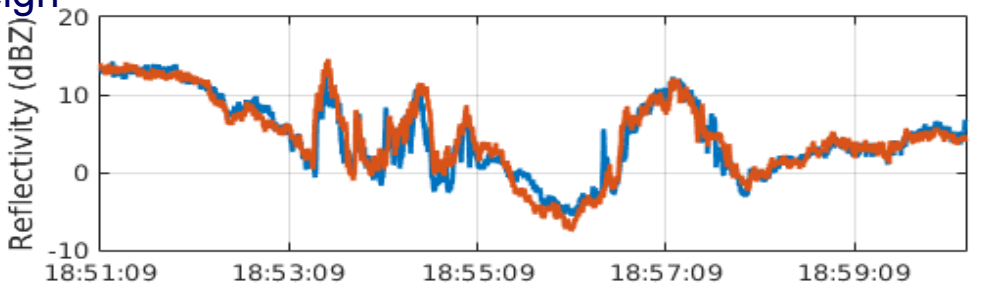


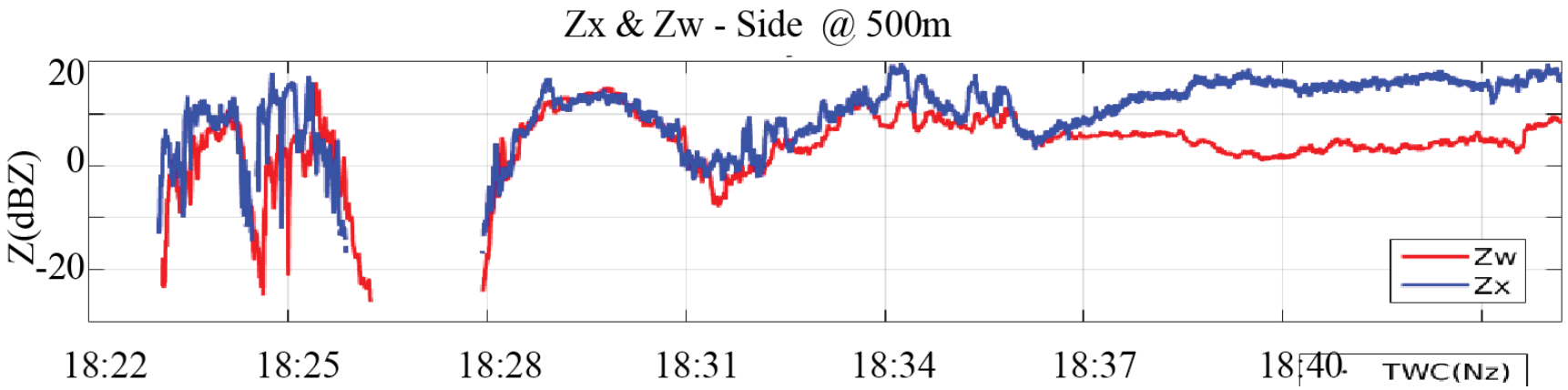
DFR – Attenuation, Mie, Rayleigh scattering, artifact

Calibration & consistency of W and X-bands data

- Calibration
  - Corner reflector
  - Relative calibration - consistency
    - First few usable range gates
    - Drizzle – small ice crystals – Rayleigh
    - Cloudsat
    - RASTA
    - Water surface

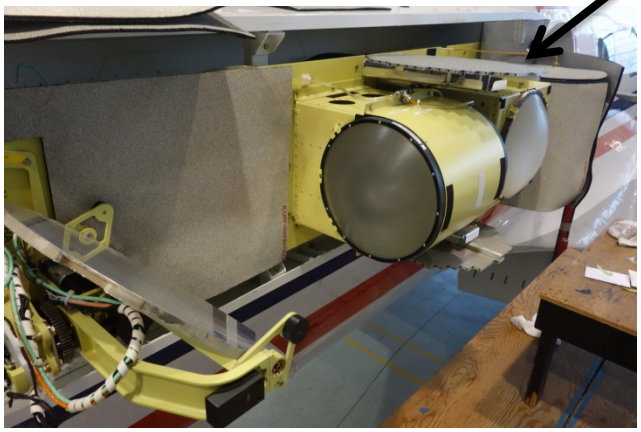


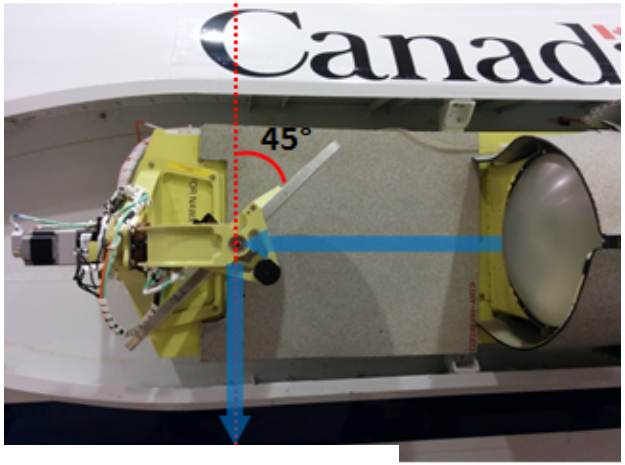


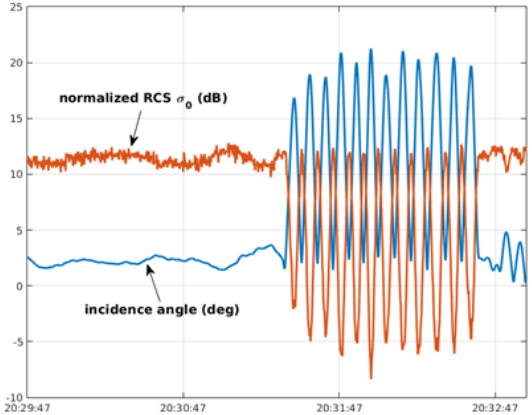


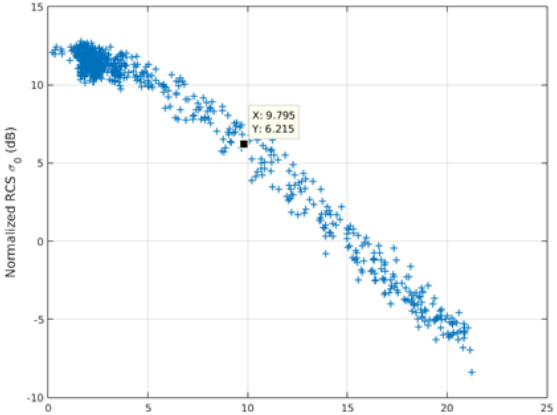
Consistent dataset with of multiple antennae and frequency

NRC W-band Radar (NAW)









Analyzed limited ocean surface calibration data

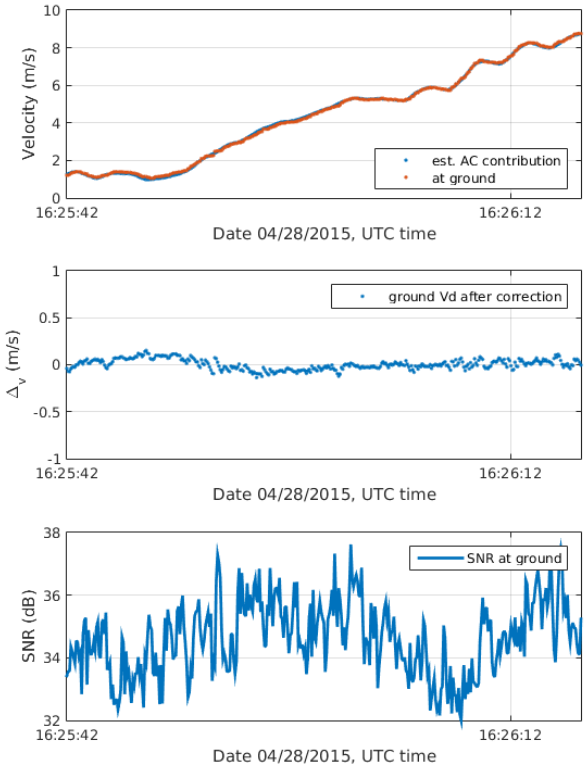
V_d-Processing – Removal of a/c motion

Radar measured Doppler: $v = \mathbf{b} \cdot (\mathbf{V}_s + \mathbf{V}_d' + \boldsymbol{\omega} \times \mathbf{R})$

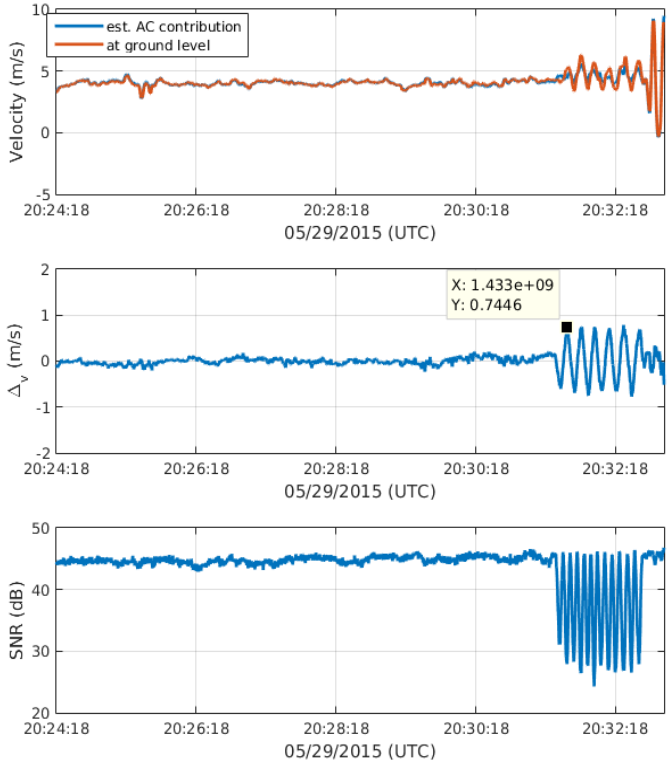
At ground: $v_{obj} = 0$

MMSE beam vector estimation: $\mathbf{b} = [b_x \; b_y \; b_z]^T$ (MMSE) $\mathbf{b} = \min_{\mathbf{b}} \{tr((\mathbf{V} - \mathbf{V}_{obj})(\mathbf{V} - \mathbf{V}_{obj}$

Example 1: Convair over land with increasing roll angle



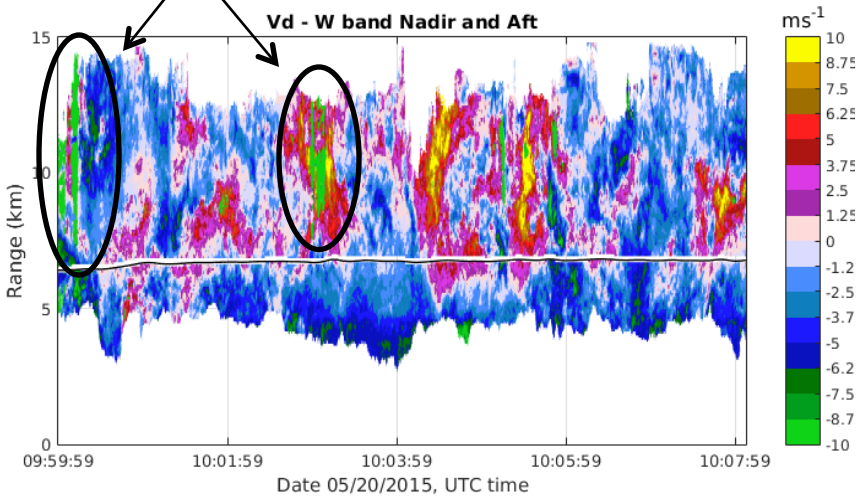
Example 2: Convair over ocean with periodic roll angle



Aircraft motion removal – V_d accuracy < 0.1 m/s

NAW Doppler un-folding using staggered PRT

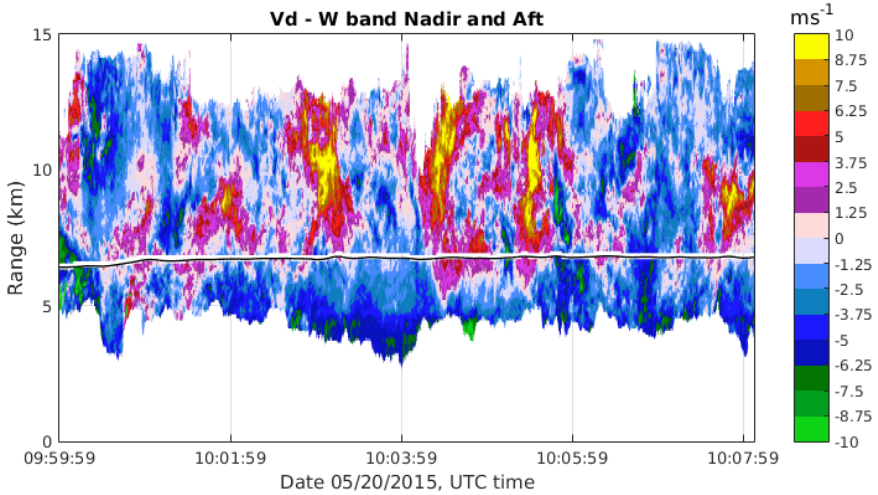
Velocity folding at W-band

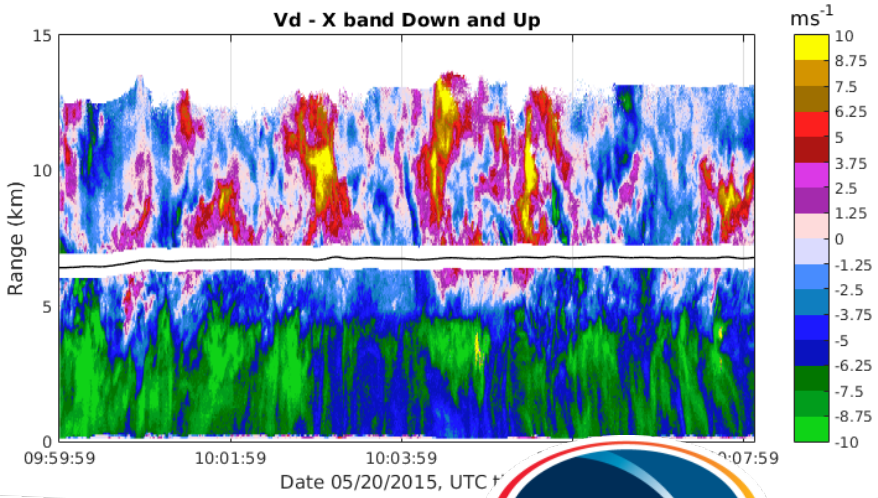


V_d at Aft H, v_a = 13.29 m/s

V_d at X-band, v_a = 20 m/s

Corrected V_d using Aft H and Aft V (v_a = 19.93 m/s)



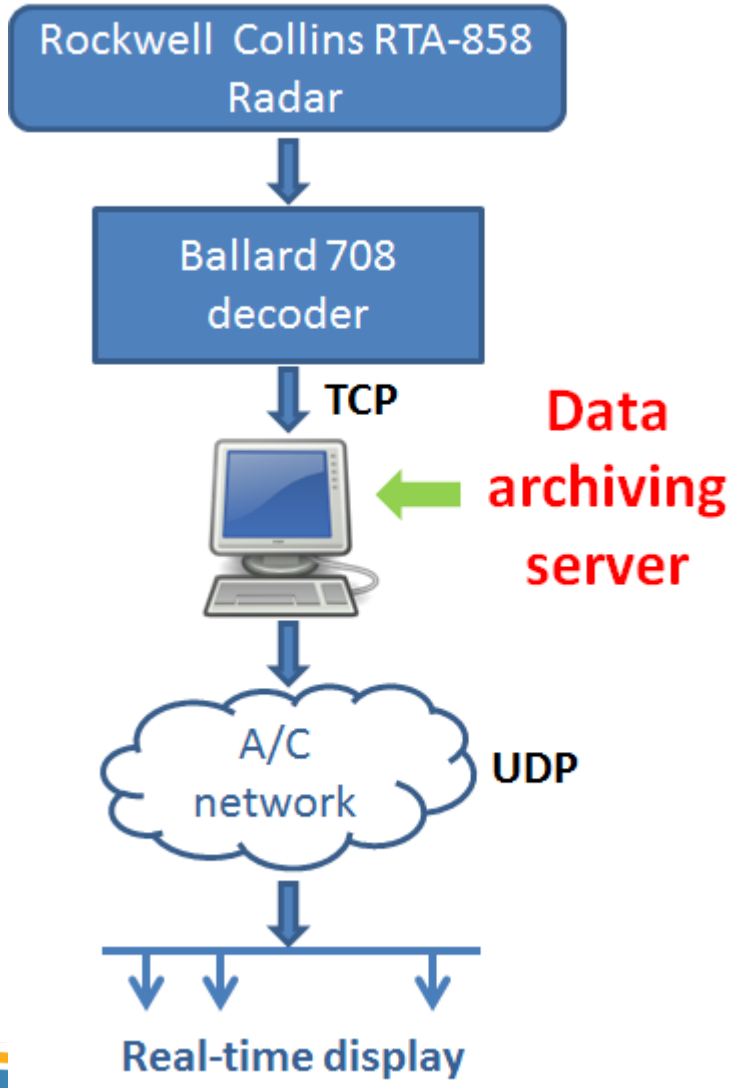


Aircraft motion removal and un-folding - completed

NRC CV580 – Pilot`s radar

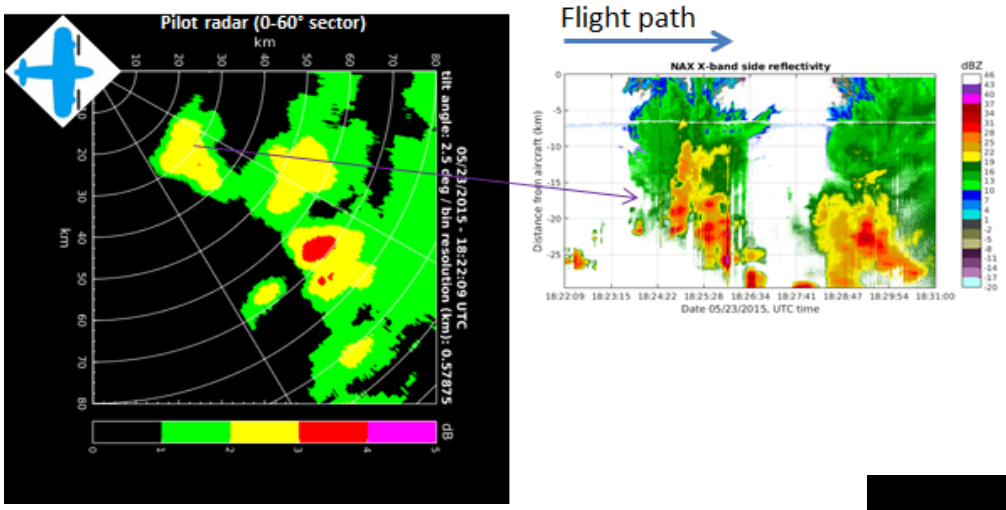
Convair Pilot Radar and Data Archiving System

- Rockwell Collins WX RTA -858 Receiver 622-8441-004
- Data (binary format) is captured using Ballard Technology OmniBusBox
- Needs an operator to record the data
- Recorded for most of the flight segments when the aircraft was in cloud
- 64-bit floating double precision time stamps were added for later analysis

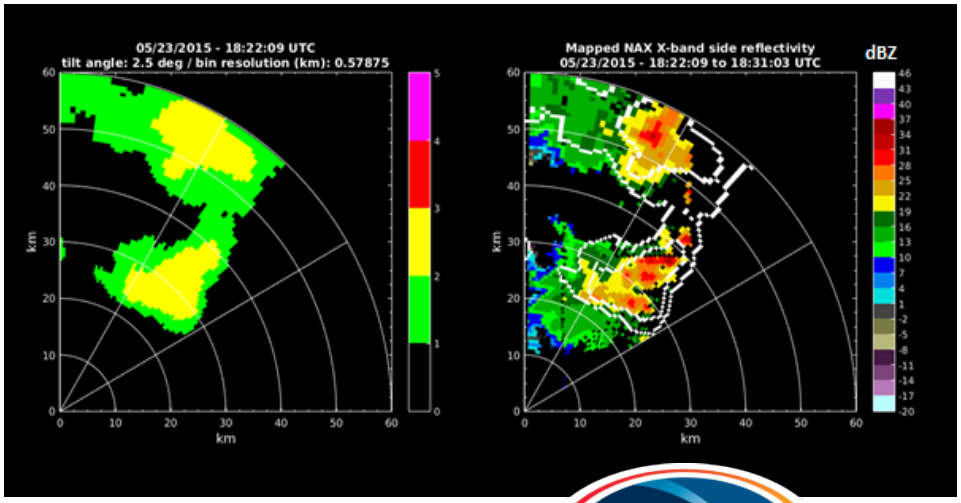


Mapping PWR data to NAX data

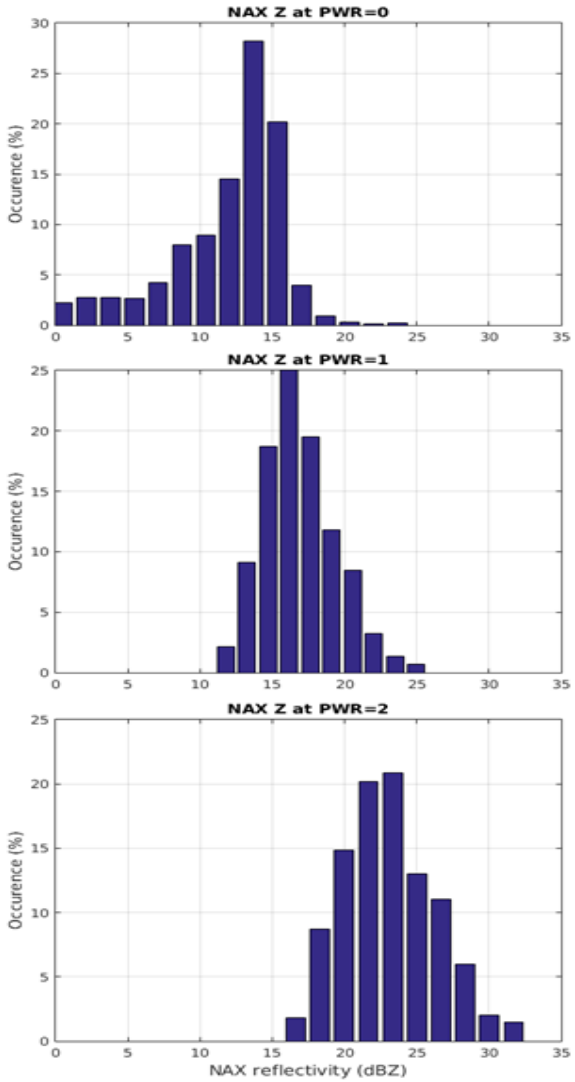
The spatial and temporal distributions of measurements by the two radars:
Pilot weather radar display for a sector of 0°-60° (left) and NAX side-looking reflectivity (right)



Pilot radar observation at 18:22:09 UTC (left) and the corresponding reflectivity field obtained from NAX measurements between 18:22:09 and 18:31:03 UTC



Characterization the Convair PWR sensitivity



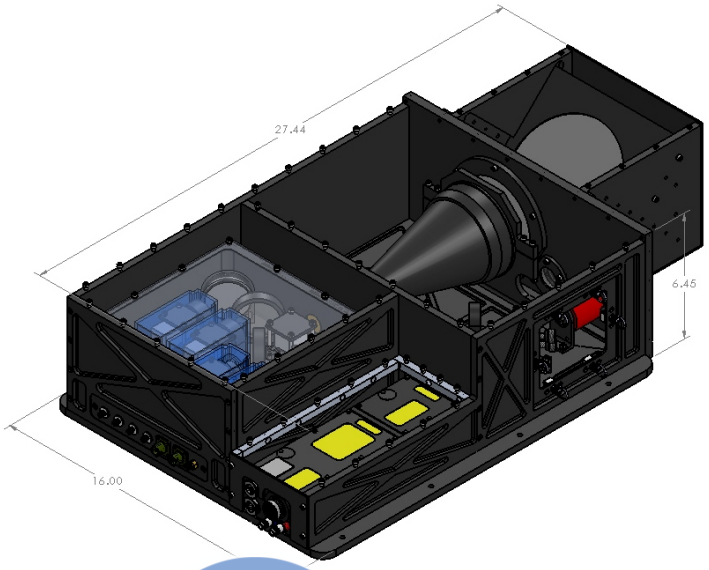
Pixel value (3 bits)	Weather Condition	Corresponding NAX reflectivity (dBZ), mean/std
0	no precipitation	11.96/3.96
1	light precipitation	16.92/2.53
2	moderate precipitation	23.08/3.21

- NAWX:
  - Z and Vd processing completed
  - Processed data in netcdf format

- Pilot`s Radar
  - Developed methodology for mapping of NAX into Pilot`s radar display
  - Relative calibration of pilot`s radar scales to Z

- Ka-band – limited data and not analyzed yet

Convair Lidars



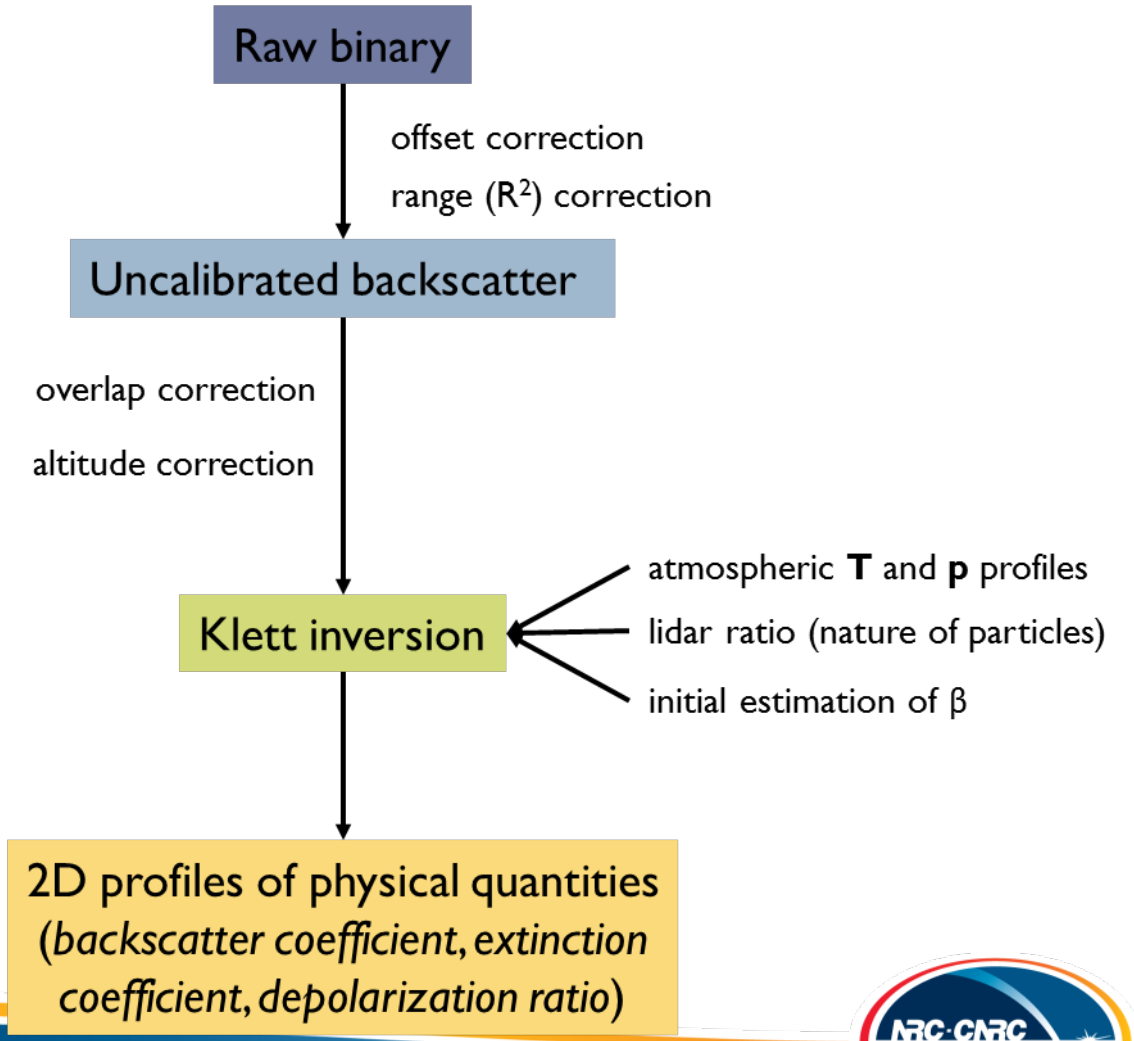
ALPENGLOW INSTRUMENTS

- 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

Zenith orientation

Lidar data processing



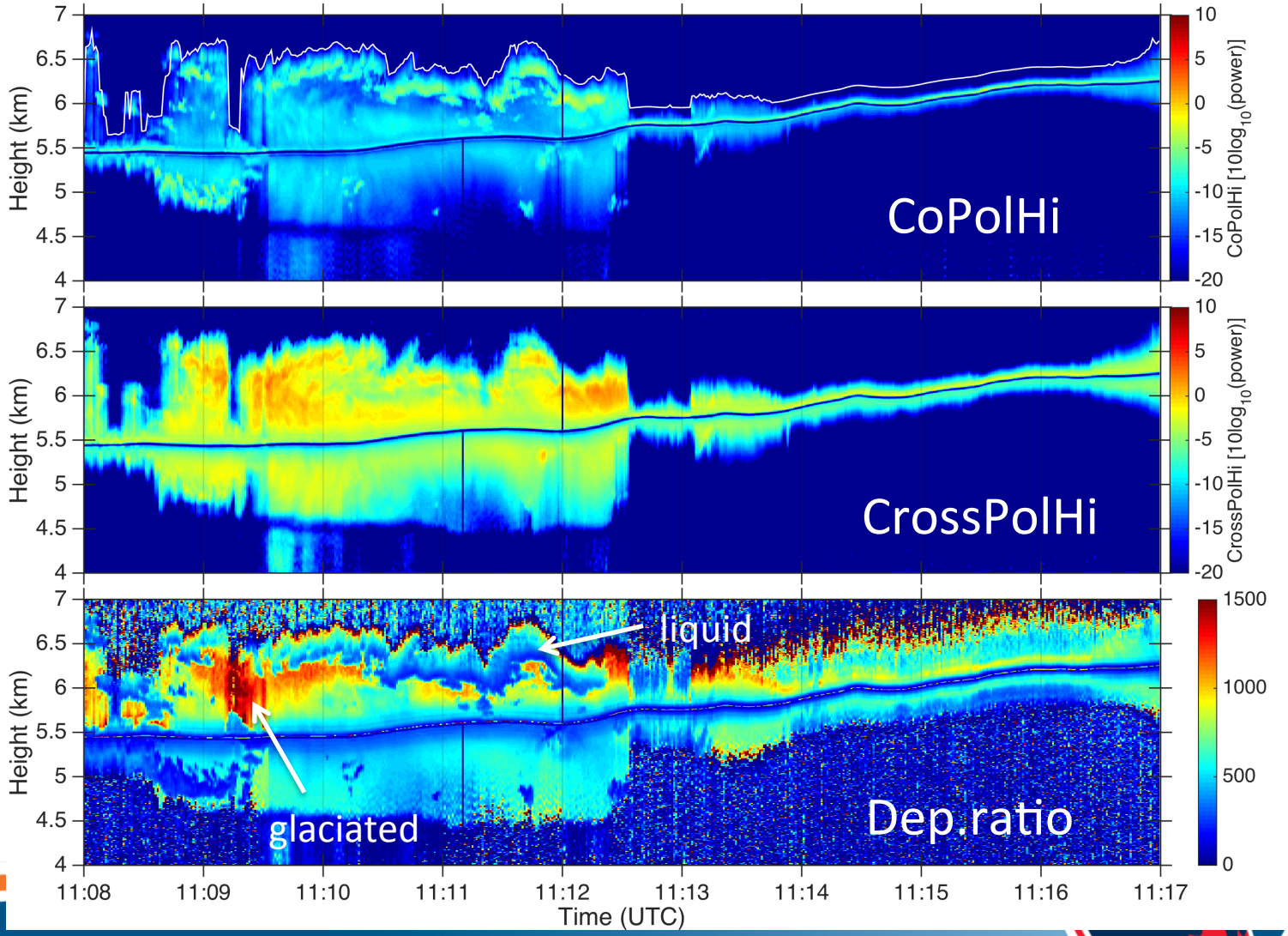
Cayenne lidar data availability

AM flight	PM flight

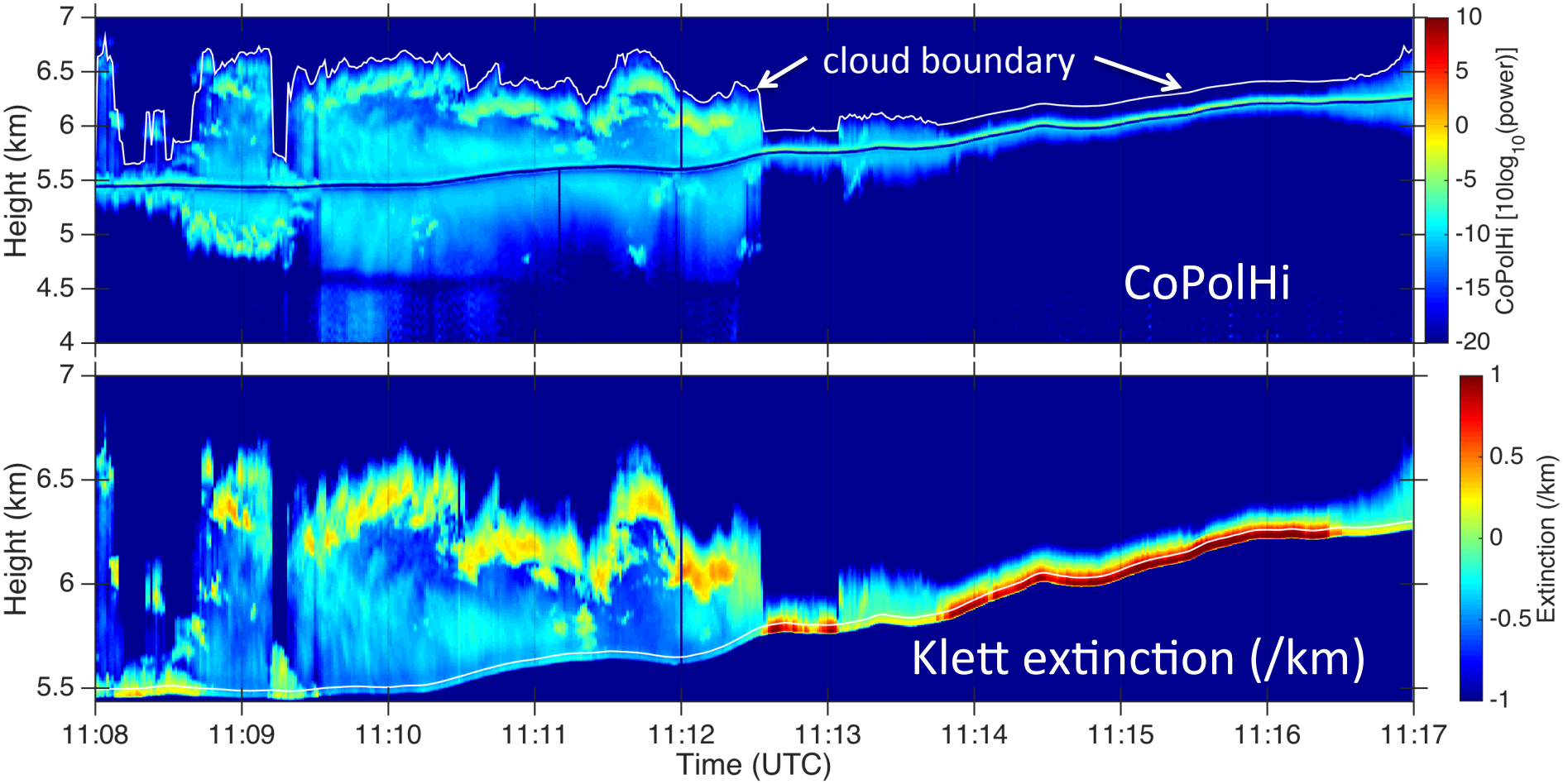
Flight	Date	From	To	Hours
1	10-May-16	16:04	17:42	1.63
2	12-May-16	19:23	21:19	1.93
3	14-May-16	13:33	16:52	3.32
4	15-May-16	8:59	12:50	3.85
5	16-May-15	8:33	12:11	3.63
6		16:21	18:07	1.77
7	20-May-15	9:07	12:12	3.08
8	23-May-15	9:04	12:32	3.47
9		16:03	19:19	3.27
10	25-May-15	18:40	22:06	3.43
11	26-May-15	9:38	12:18	2.67
12		14:14	16:54	2.67
13	27-May-15	8:51	12:18	3.45
14		14:51	15:35	0.73
			Total hours:	38.90

Elements of AECL data analysis

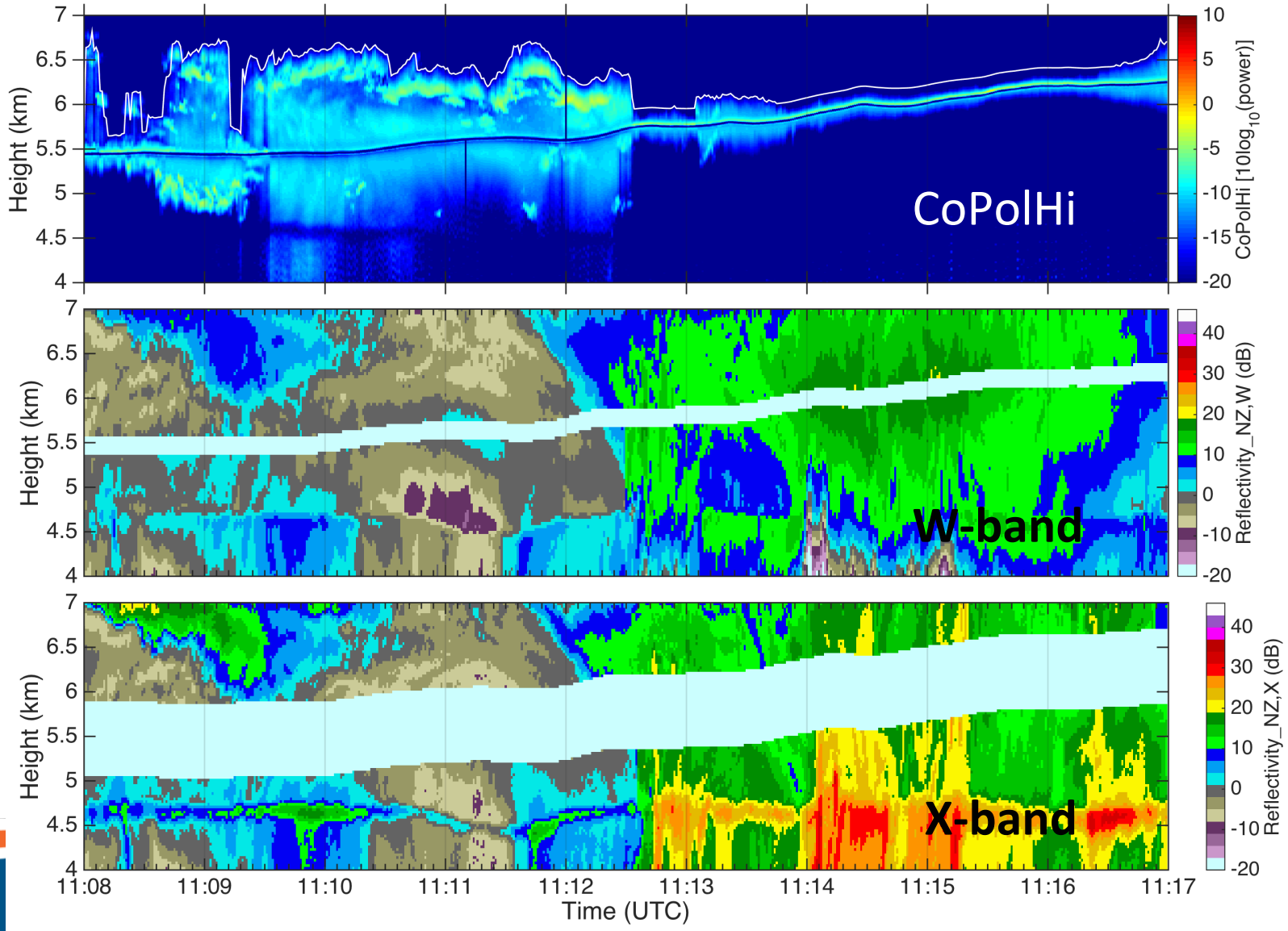
Co- and cross-polarization channels



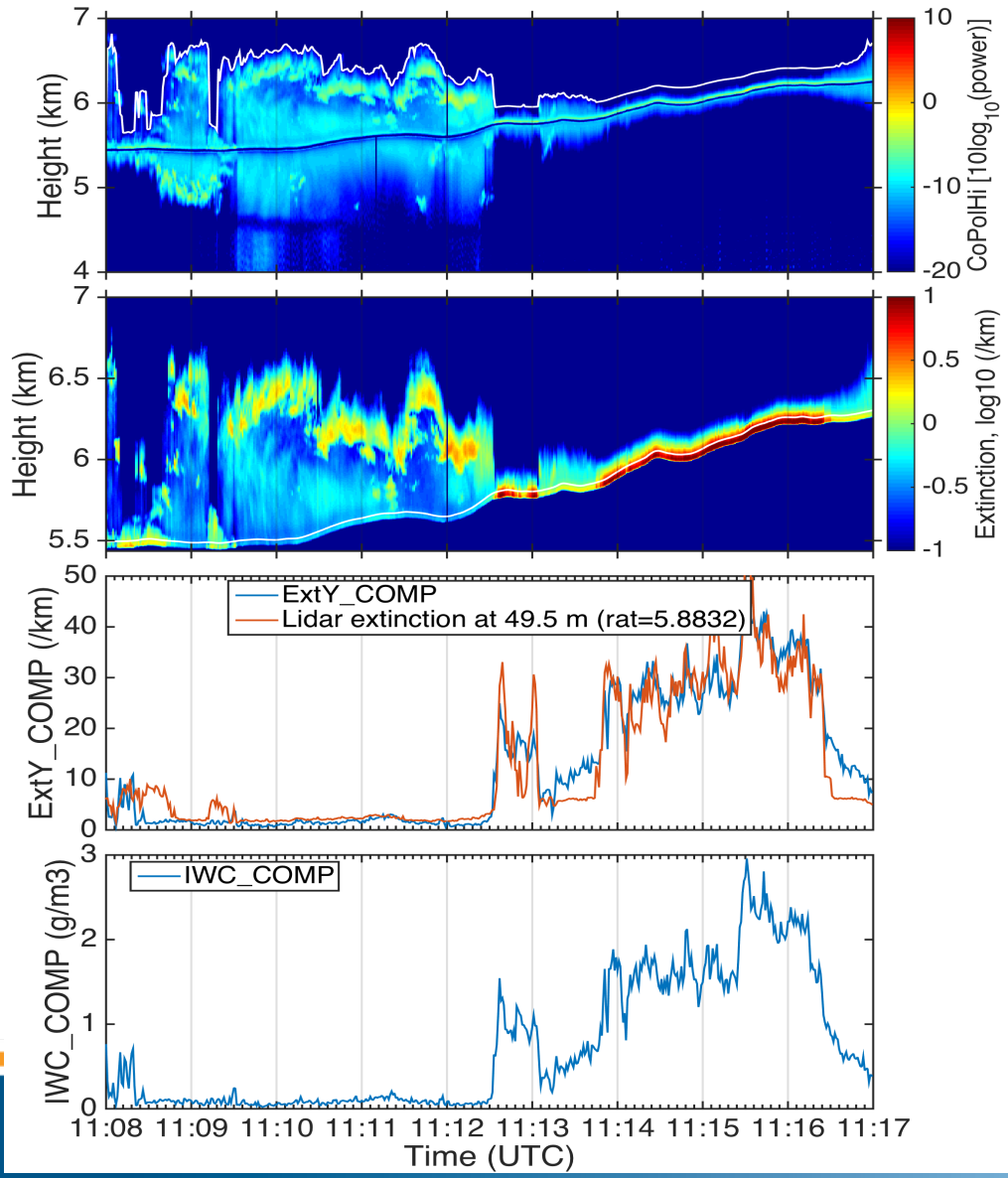
Extinction retrievals (Klett inversions)



Coherency with radar data



Coherency with in-situ data



Lidar progress (May 12, 2016)

Overlap correction

Klett inversions in the zenith direction

Test case analysis

High Ice Water Content (HIWC) Program