Comparison of Integrated Digital Radiometer with Concurrent Water Vapor Radiometer using the Alphasat Receivers in Milan, Italy

Propagation Experimental Methods and Campaigns (S P01)

Michael Zemba[1], James Nessel[1], Lorenzo Luini[2], Carlo Riva[2]

[1] NASA Glenn Research Center, Advanced High Frequency Branch
[2] Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria

Presented by Michael Zemba
+1.216.433.5357
michael.j.zemba@nasa.gov

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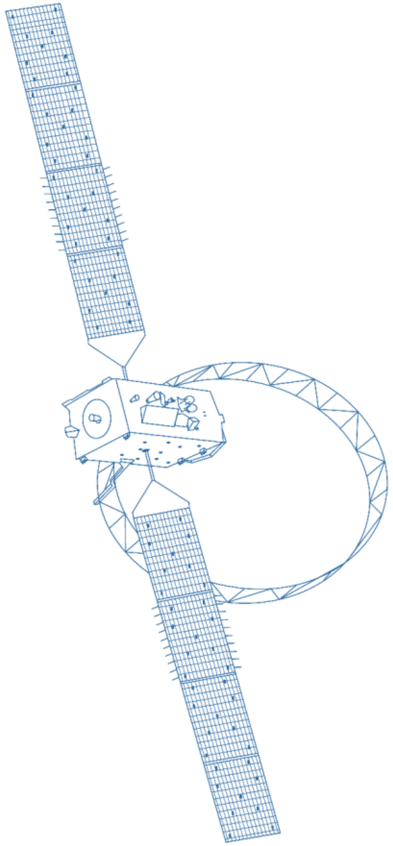
Presentation Overview

Alphasat in Ariane 5 fairing.
(Photo: ESA)

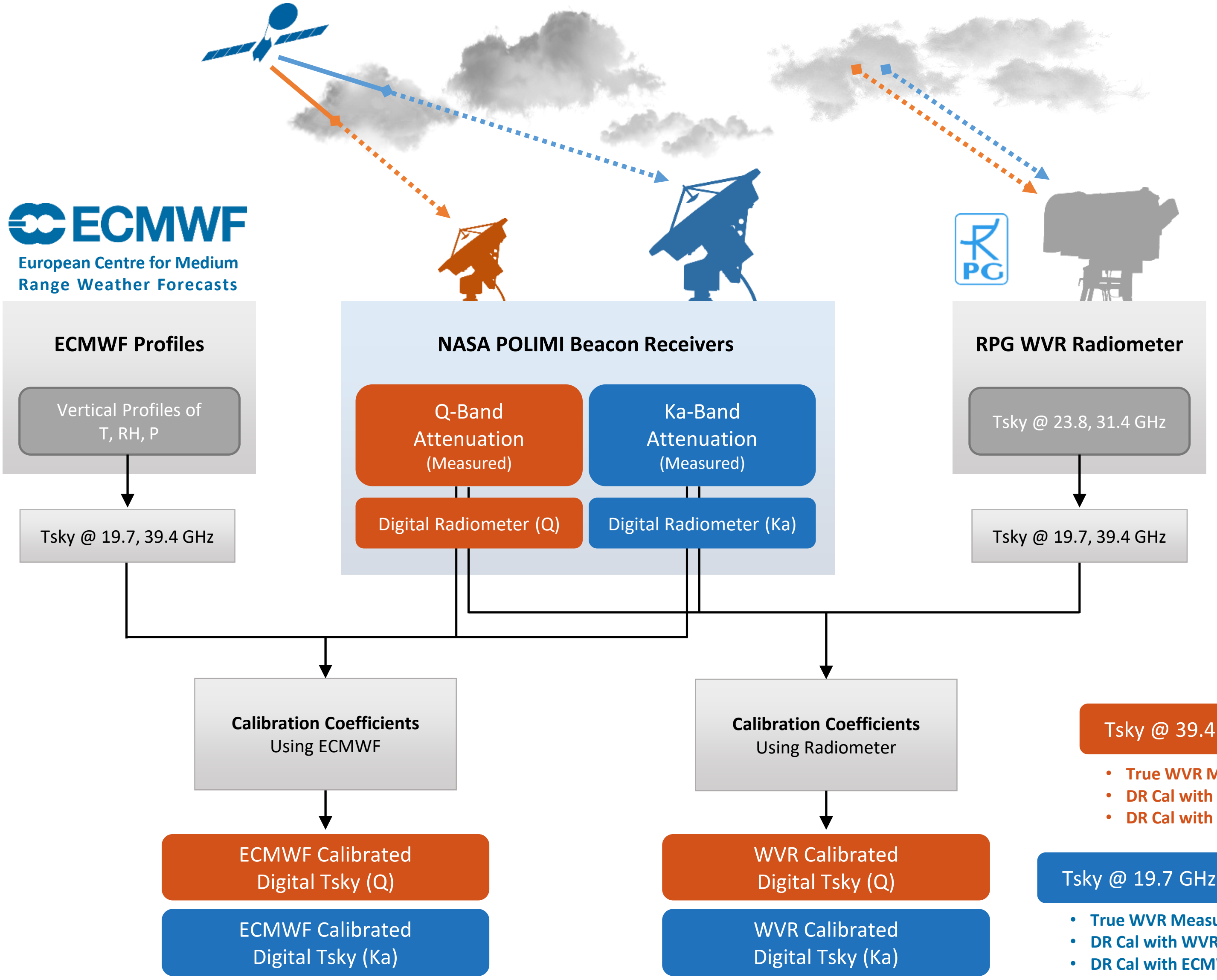
1. Motivation & Goals
2. Site of Study
3. Instrumentation
4. Beacon Receiver Design
5. Digital Radiometer Implementation
6. Calibration of Digital Radiometer
7. Results & Analysis
8. Concluding Remarks

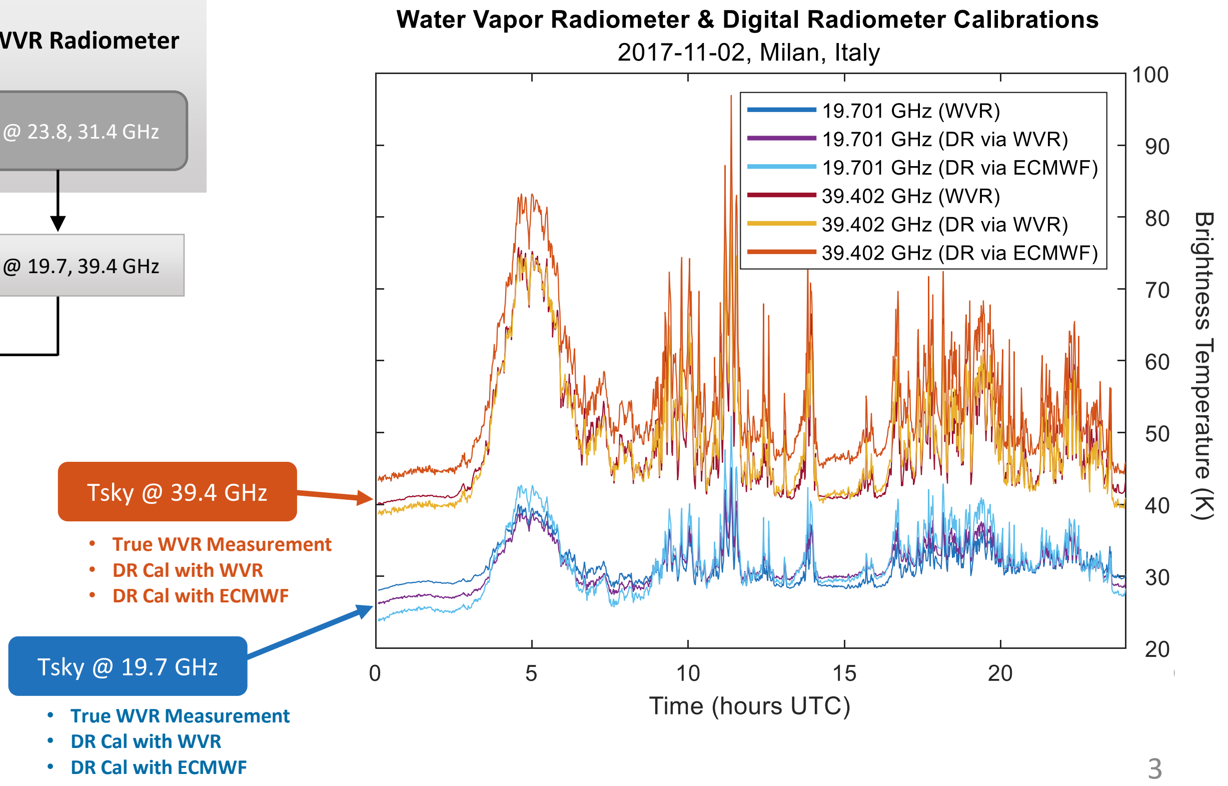


Alphasat wireframe model (deployed).
(Photo: ESA)

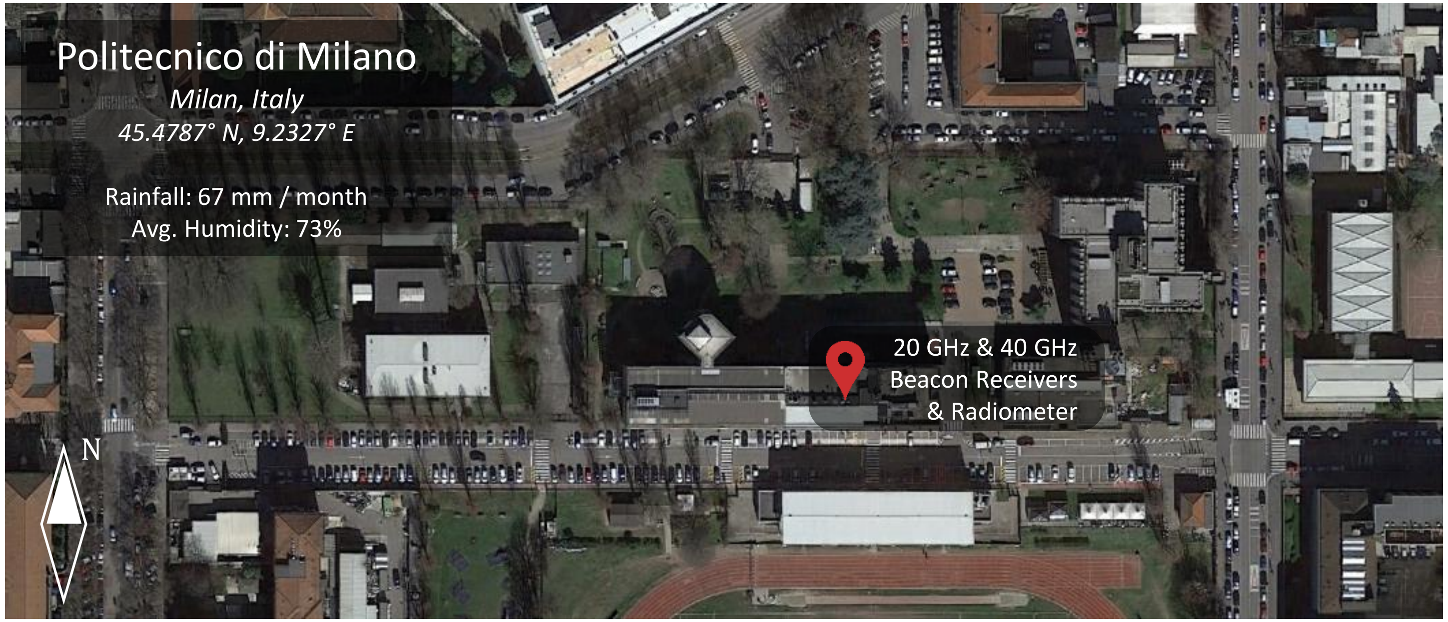
Motivation & Goals

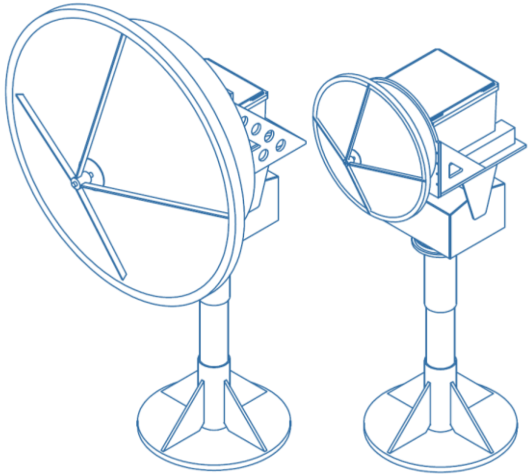
Implementation of a digital radiometer offers the opportunity to calibrate beacon measurements to a clear-sky reference level in the absence of a costly radiometer, but the digital measurement must be calibrated accurately. Given the presence of both the digital radiometer and water vapor radiometer at POLIMI, such calibration techniques can be readily assessed.



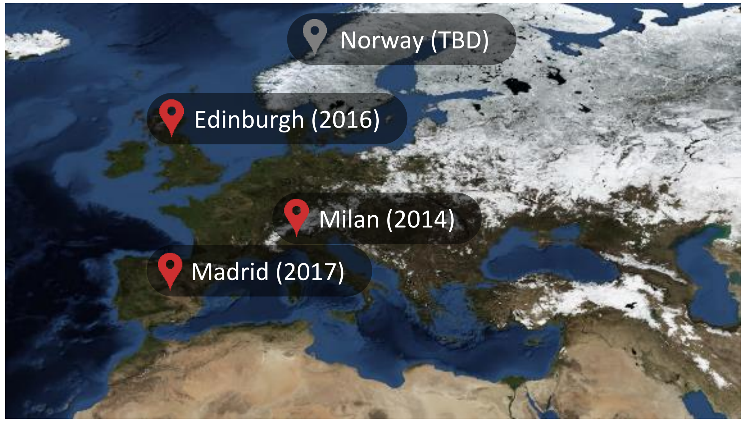


Site of Study





		Milan, Italy
Ground Station	**Installation Date**	April 2014
	Latitude	45.4787° N
	Longitude	9.2327° E
	Altitude	138 m
Satellite	**Name**	Alphasat
	Nom. Elevation	35°
	Nom. Azimuth	158°
	Beacon Freqs.	19.701 GHz 39.402 GHz



NASA Alphasat Stations

Beacon Receivers, Disdrometer, and Weather Station at the POLIMI DEIB Building

Instrumentation

Beacon Receivers

Water Vapor Radiometer

Optical Disdrometer

Weather Instrumentation

Anemometer:
Young 05178A

Temp/RH Sensor:
Young 41382VC

Pressure Sensor:
Young BPV3000

Tipping Bucket:
Young 52203

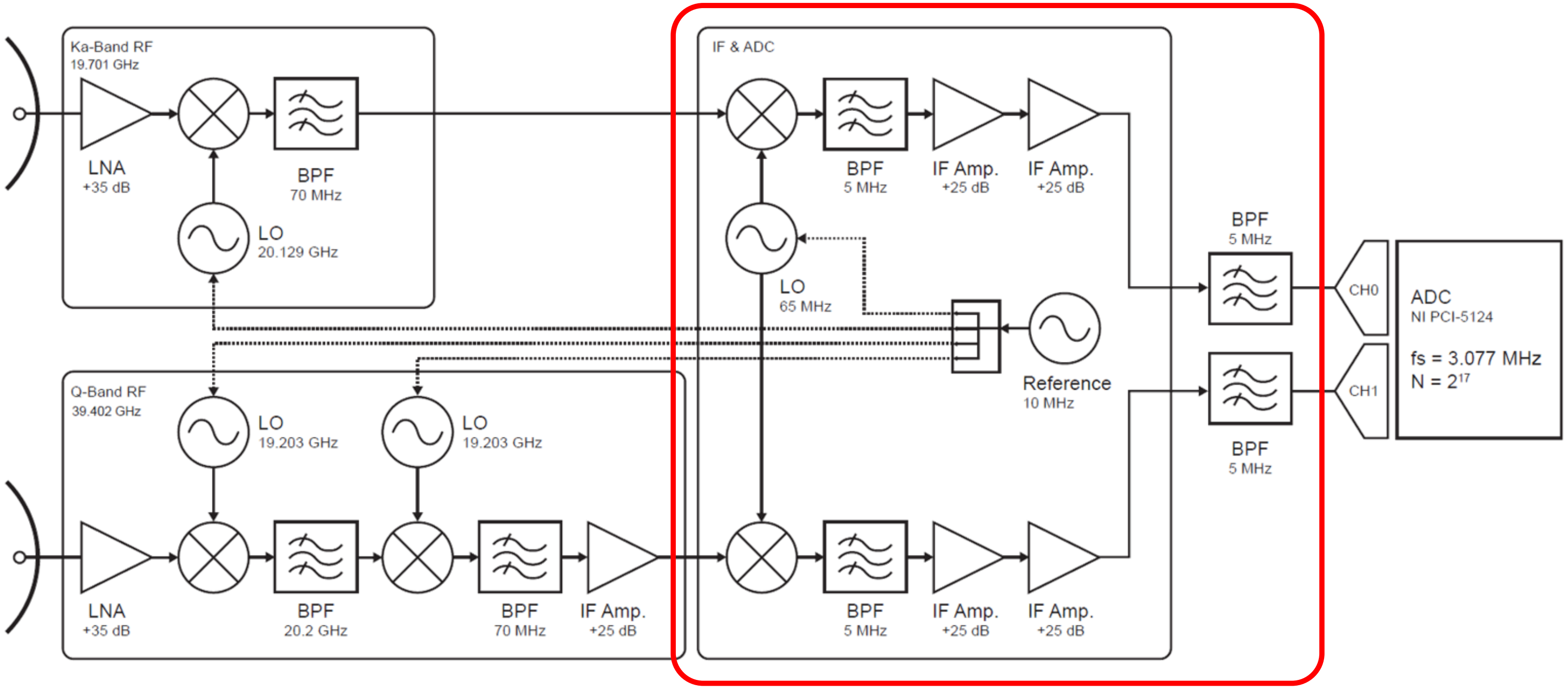
Antenna Gain	45.6 dBi
Antenna Beamwidth	0.9 deg
Antenna Tracking Resolution	0.01°
LNA Gain	33 dB
LNA Noise Figure	2.5 dB
Beacon Frequencies	19.701 GHz / 39.402 GHz
Final IF Frequency	5 MHz

Measurement Rate (RF)	8 Hz and 1 Hz
Dynamic Range	38 dB
Temperature Control	0.01 °C (plate) / 0.1 °C (LNA) / 2 °C (air)
Weather Station	RM Young
Disdrometer	Thies Clima 5.4110
Radiometer	RPG LWP-U72+82
Radiometer Channels	23.8, 31.4, 72.5, 82.5 GHz

Beacon Receiver Design

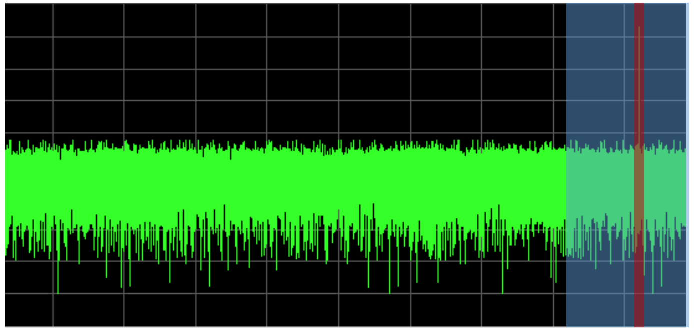
Beacon Receiver Specifications	
Downconversion (Ka)	2-step down to 5 MHz
Downconversion (Q)	3-step down to 5 MHz
System Noise Temperature	504 K (Ka-band) 720 K (Q-band)
Dynamic Range	38 dB (Ka-band) 40 dB (Q-band)
ADC Sampling Rate	3.077 MHz
ADC # of Samples	2^{17}
Time Series Output Rate	8 Hz / 1 Hz (averaged)

Reconfigured in November 2017 for Digital Radiometer Implementation

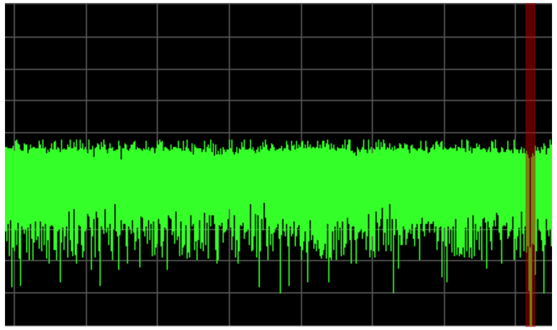


The beacons are downconverted from 19.701 GHz and 39.402 GHz to 70 MHz in at the feed. The Q channel is converted in two stages, first to 20.199 GHz, then to 70 MHz. The signal is run a short distance (< 5m) over shielded coaxial cable fiber to the final downconversion stage (5 MHz) and then another coaxial run (< 30m) before digitization. All LOs are referenced to a common ultra-stable 10 MHz reference oscillator.

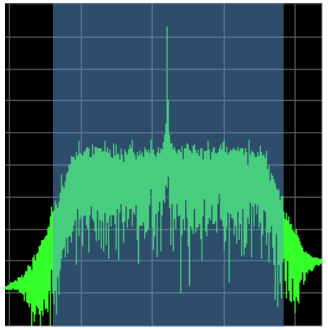
Digital Radiometer Implementation



Nyquist Sampled Spectrum
($f_s/2$ = 1.55 MHz)



Noise Power Spectrum
Notch Filter @ Beacon Frequency → Integrate Noise Power



Signal Spectrum
BPF @ Beacon Frequency → Decimate / Undersample → Estimate Frequency (QNF) → Calculate Signal Power

- **Added to Milan Terminal November 2017**
- Co-located Radiometer Physics GmbH (RPG) Radiometer LWP-U72+82 for Calibration & Validation

Digital radiometer implementation:

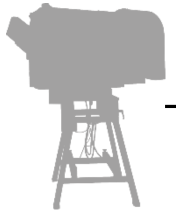
Noise Power - The full bandwidth output from the final-stage filter is Nyquist sampled to obtain the noise power measurement. A digital notch filter is applied, centered on a moving average of past beacon frequency estimates, to remove the signal power. The remaining noise power is then integrated to produce the noise power measurement.

Signal Power - The signal power is obtained by applying a digital band-pass sampling around the beacon frequency, then decimating to reduce the computational demand of the FFT / frequency estimators used to estimate signal power.

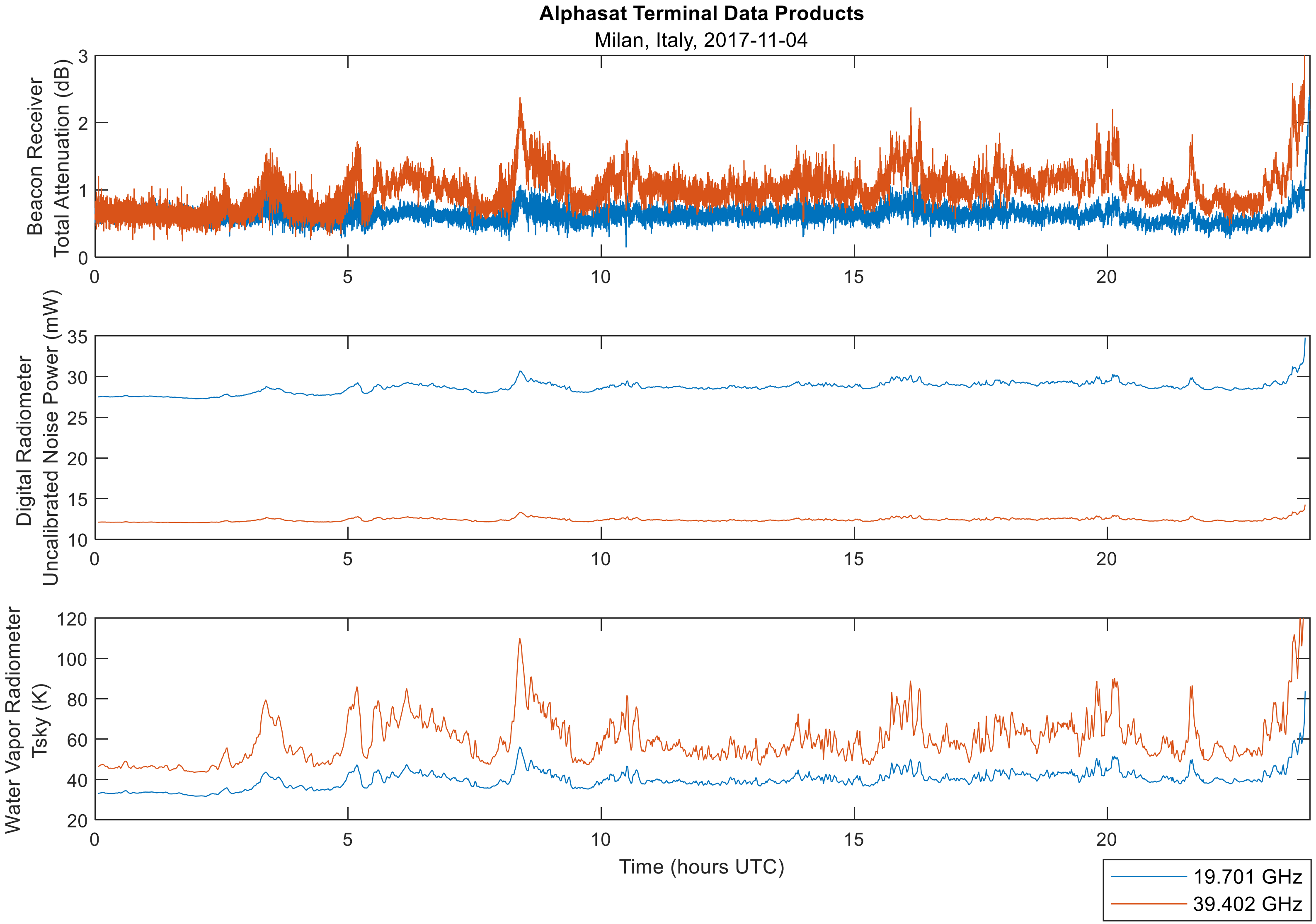
fs	3.1 MHz
N	2^{17} (113,072)
Decimation	2^5 (32)
BPF Bandwidth	0.888 MHz
Notch Bandwidth	25 kHz

Alphasat Terminal Data Products

Beacon Receivers

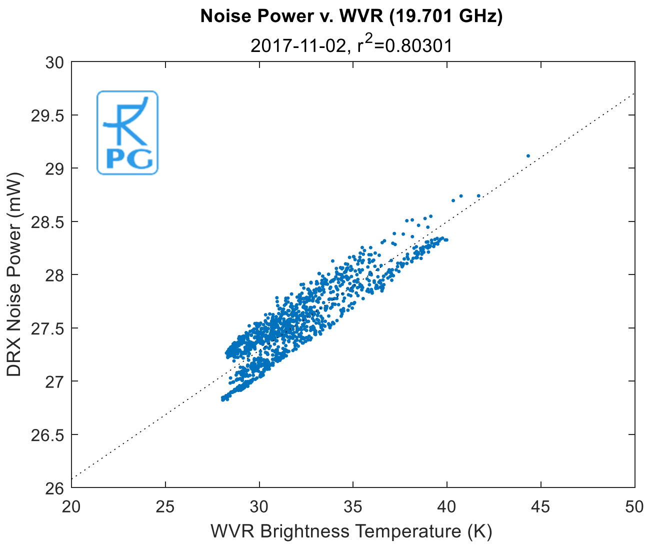


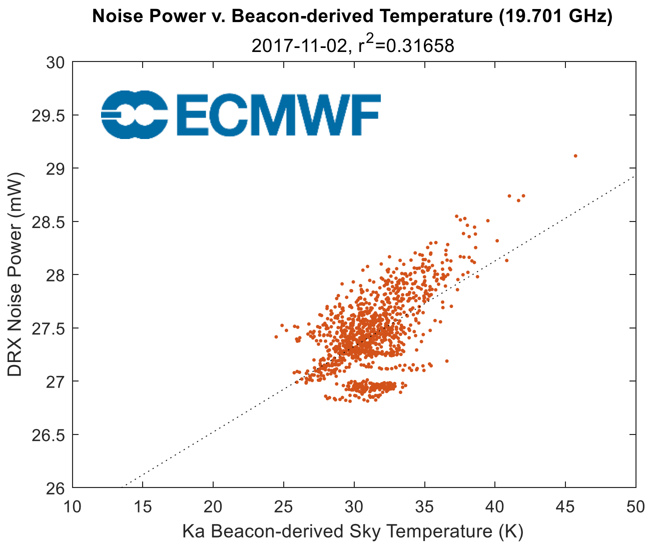
Water Vapor Radiometer

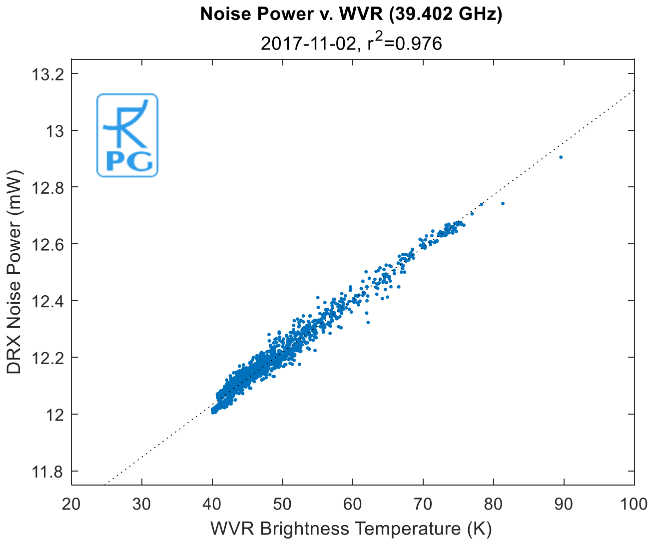


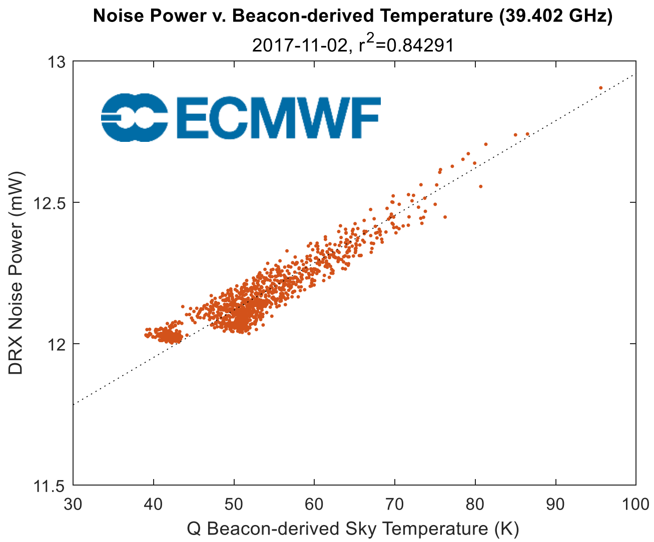
Can this digital radiometer approach be suitably calibrated to approximate water vapor radiometer data?

Calibration of Digital Radiometer Data





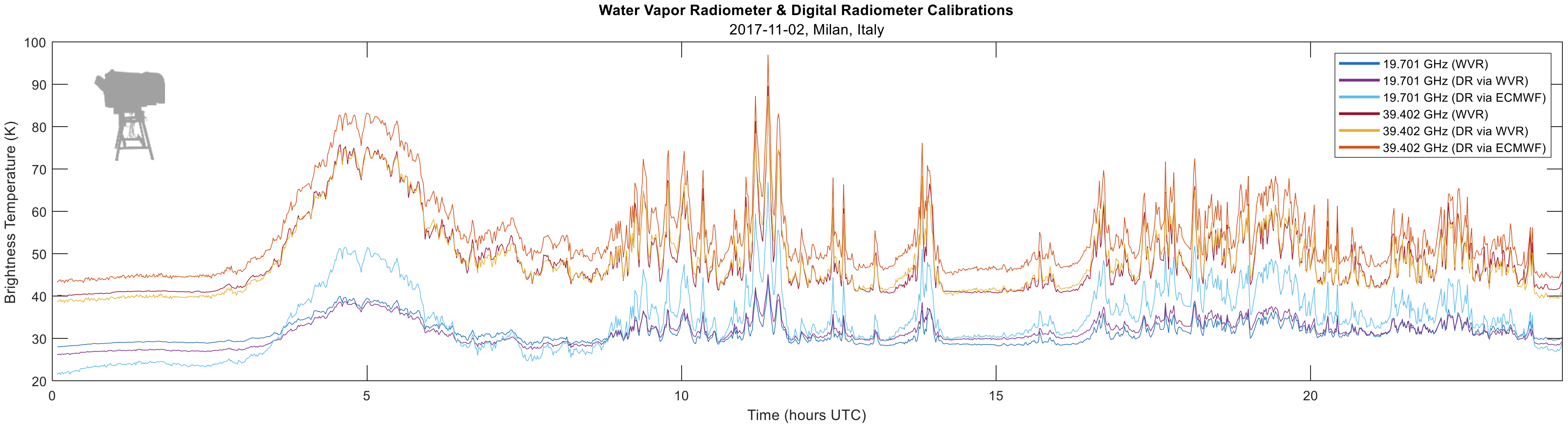




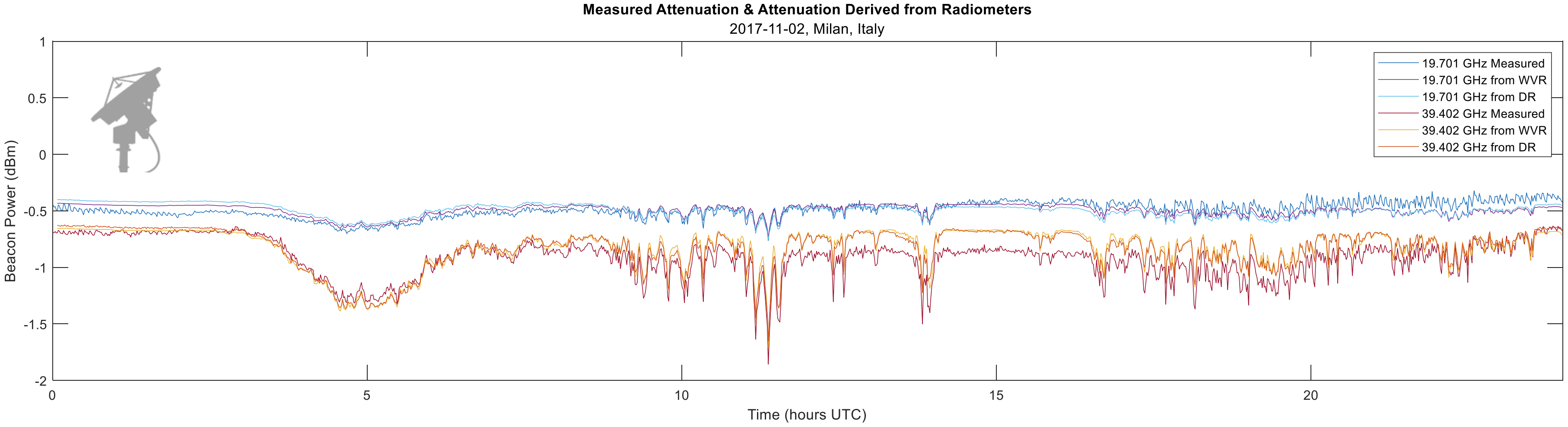
- **WVR Calibration –** The DR measurement is referenced to the WVR sky brightness through a linear fit to relate the noise power to sky brightness.
  - **8.3 K/mW slope** and **-195 K offset** for the Ka channel and **54.1 K/mW slope** and **-611.0 K offset** for the Q channel with r^2 of 0.80 and 0.98, respectively.
- **ECMWF Calibration** – The beacon data is converted to a sky temperature using ECMWF vertical profiles, and this beacon-derived sky temperature is used as the reference to calibrate the DR noise power.
  - **12.5 K/mW slope** and **-310 K offset** for the Ka channel and **59.7 K/mW slope** and **-674 K offset** for the Q channel with r^2 of 0.32 and 0.84, respectively.
- Preferable days for calibration are days with a good amount of low-level attenuation, but no rain. Perfectly clear days will make it difficult to get an accurate linear fit (especially with for Ka ECMWF).
- For example, one clear sky day per month could be used to derive calibration coefficients to apply for calibration of the rest of the month's noise power measurements, or to derive a singular clear-sky attenuation offset applied to the rest of the monthly beacon measurements.

Example Sky Brightness & Attenuation

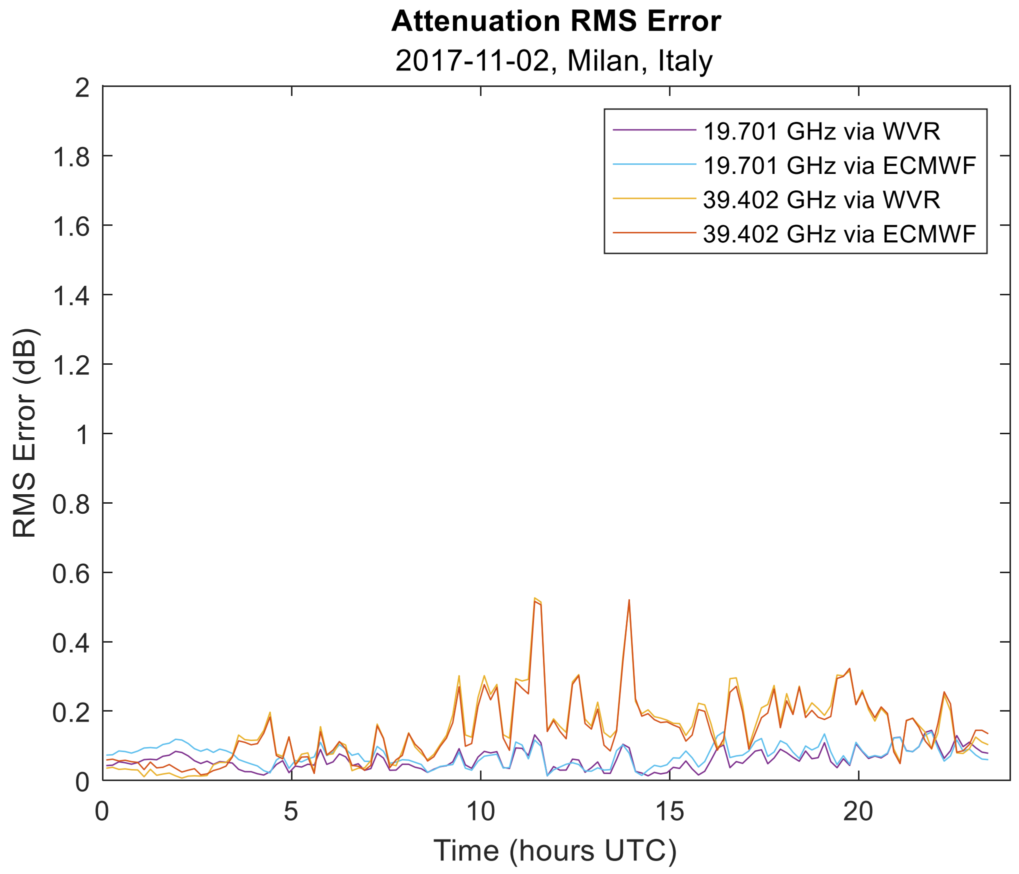
Calibrated Digital Radiometer compared to Water Vapor Radiometer (Tsky)



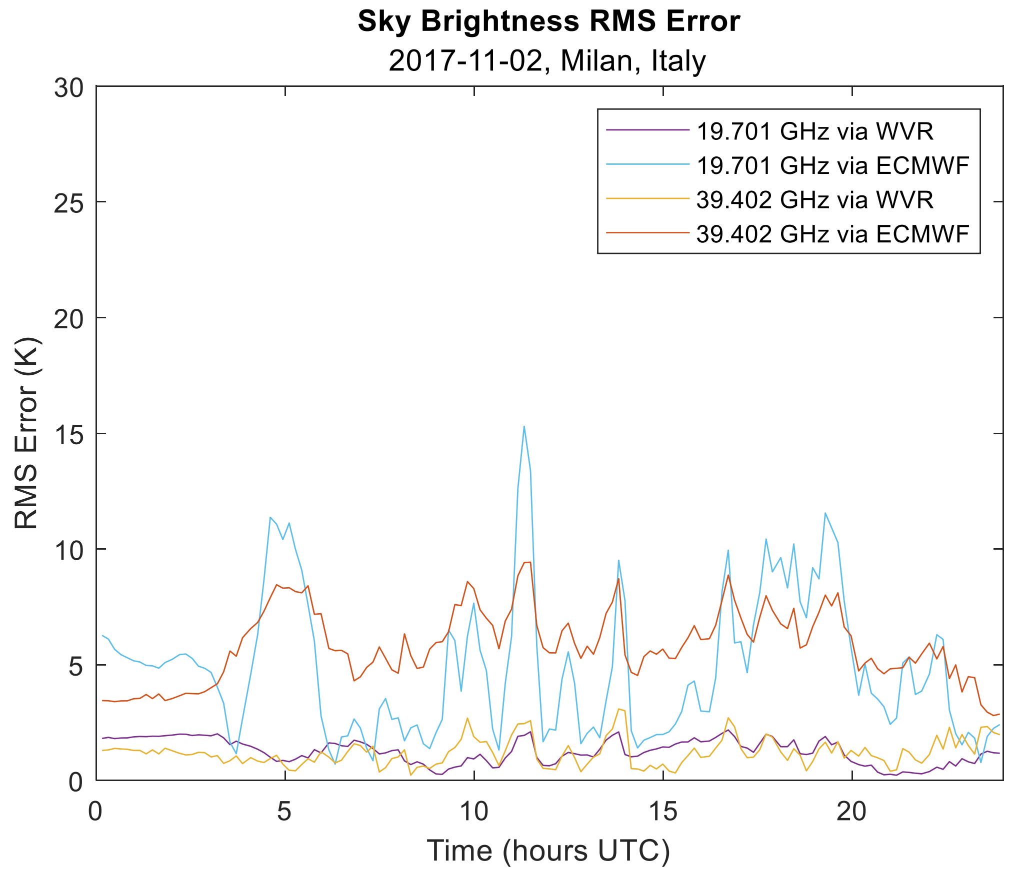
Calibrated Digital Radiometer translated to attenuation and compared with Beacon Receiver Measurement (dB)



RMSE, Attenuation and Sky Brightness

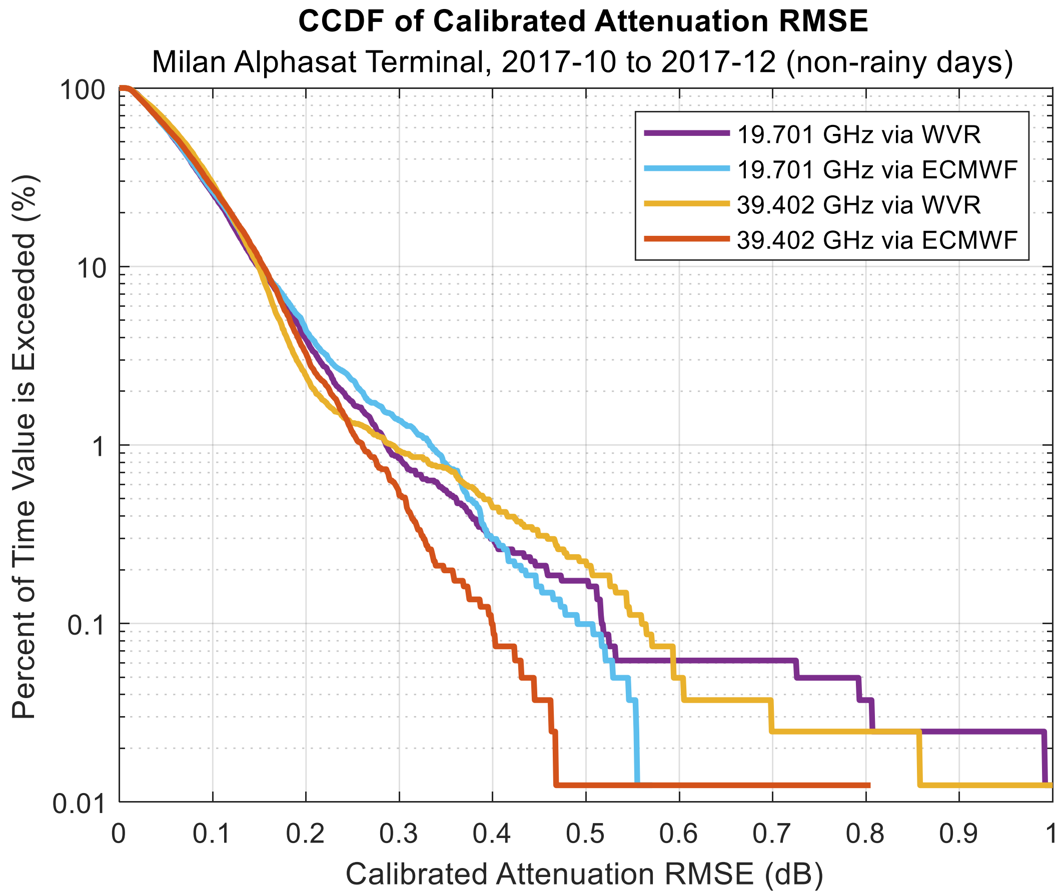


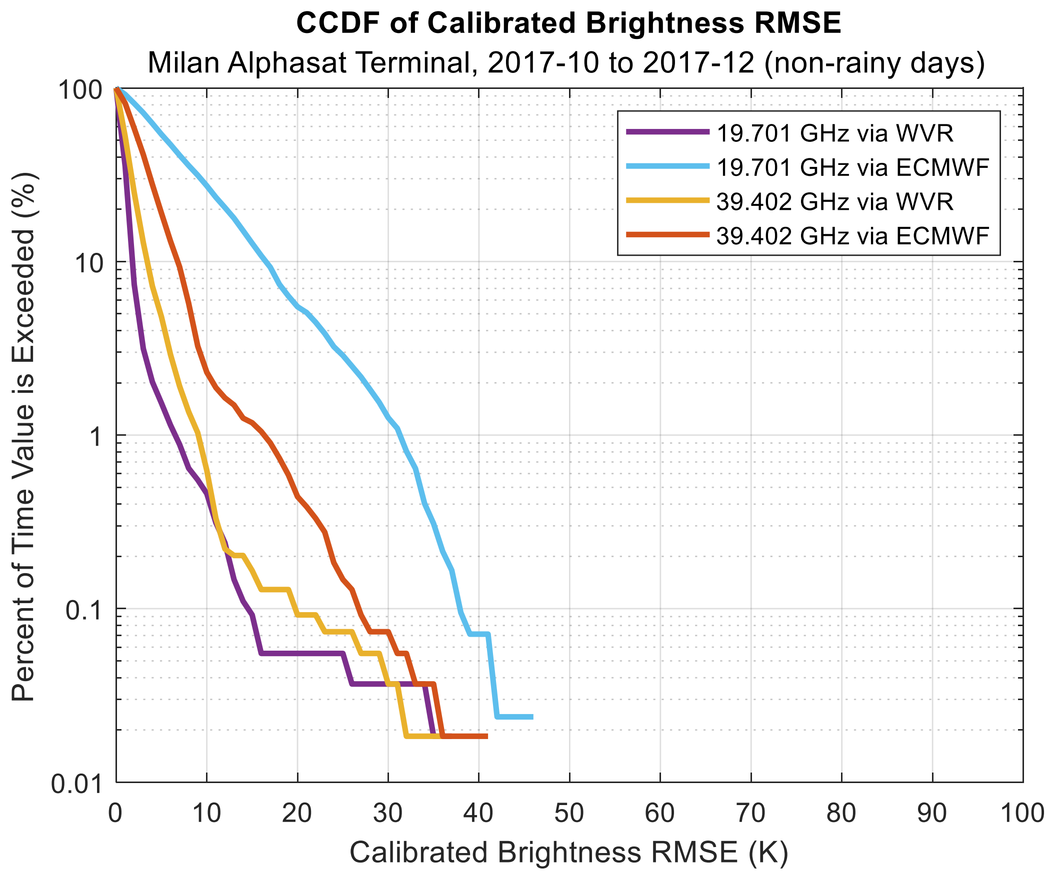
Calibrated Digital Radiometer RMSE as compared with Beacon Receiver Measurement (dB), after conversion from brightness to attenuation.



Calibrated Digital Radiometer RMSE as compared to Water Vapor Radiometer Measurement (Tsky)

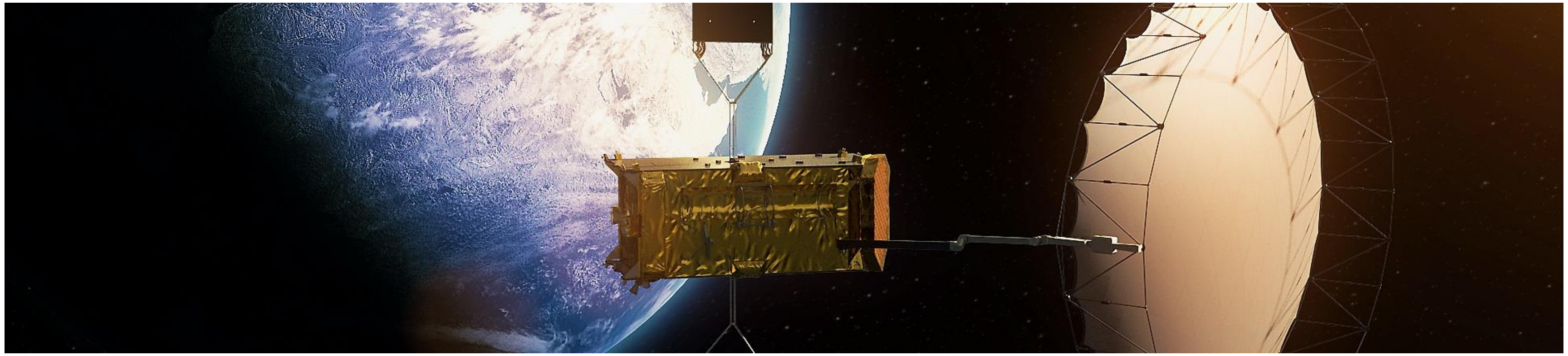
Statistical Analysis of Calibration RMSE





Statistical Analysis of Generally Clear, Non-Rainy Days from November through December 2017 (64 out of 92, 69.5%)

Concluding Remarks

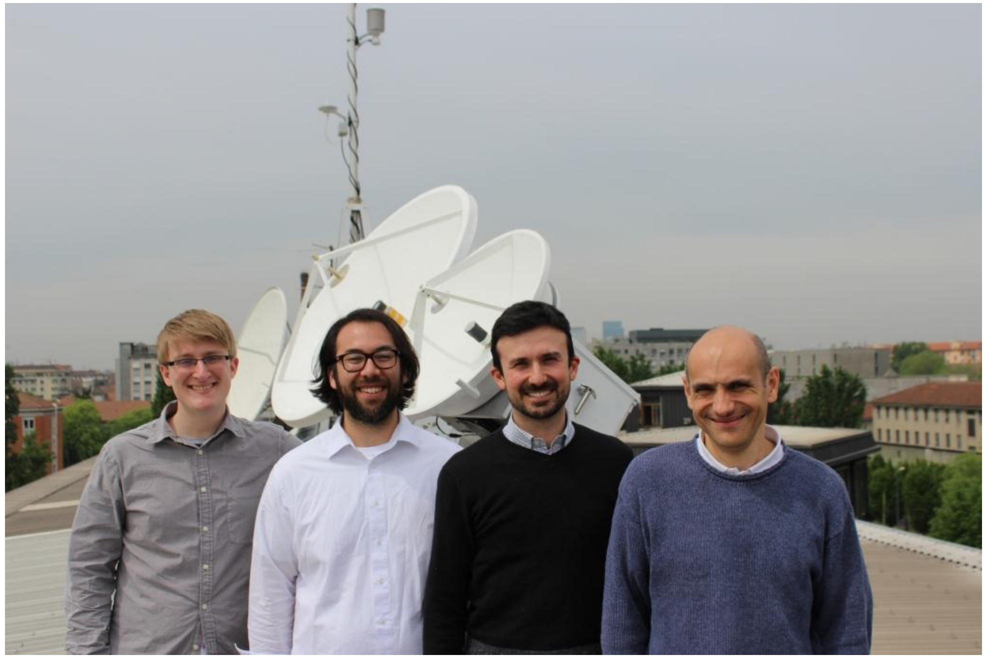


Conclusions:

- The Alphasat Propagation Terminal in Milan has operated reliably since May 2014 with maintenance and upgrades in November 2017 to add a digital radiometer measurement. A co-located water-vapor radiometer allows for validation & characterization of the digital radiometer technique.
- Looking at a 3 month period with 64 clear days suitable for calibration, errors less than 20 K of brightness temperature and less than 0.5 dB of attenuation can be achieved for 99% of clear days when calibrating the digital radiometer with either a MWR or ECMWF profiles.
- Calibration of the Ka channel with the ECMWF is least accurate, because smaller variations in brightness/attenuation make it challenging to accurately obtain a linear fit between noise power and brightness. However, this can be accommodated by an appropriate calibration schedule as a good calibration day may only be required once every 2 – 4 weeks.

Future Work:

- Continued validation of digital radiometer with water vapor radiometer data over a larger data set.
- Characterization of calibration accuracy as time increases from the day the calibration coefficients are derived.



Thank you!

Appendix Charts

Contact Information

NASA Glenn Research Center
21000 Brookpark Rd. MS 54-1
Cleveland, Ohio 44135, USA

Michael Zemba

Principal Investigator, RF Propagation Task

216.433.5357

michael.j.zemba@nasa.gov

Peter Schemmel

Researcher, Advanced High Frequency Branch

216.433.6677

peter.j.schemmel@nasa.gov

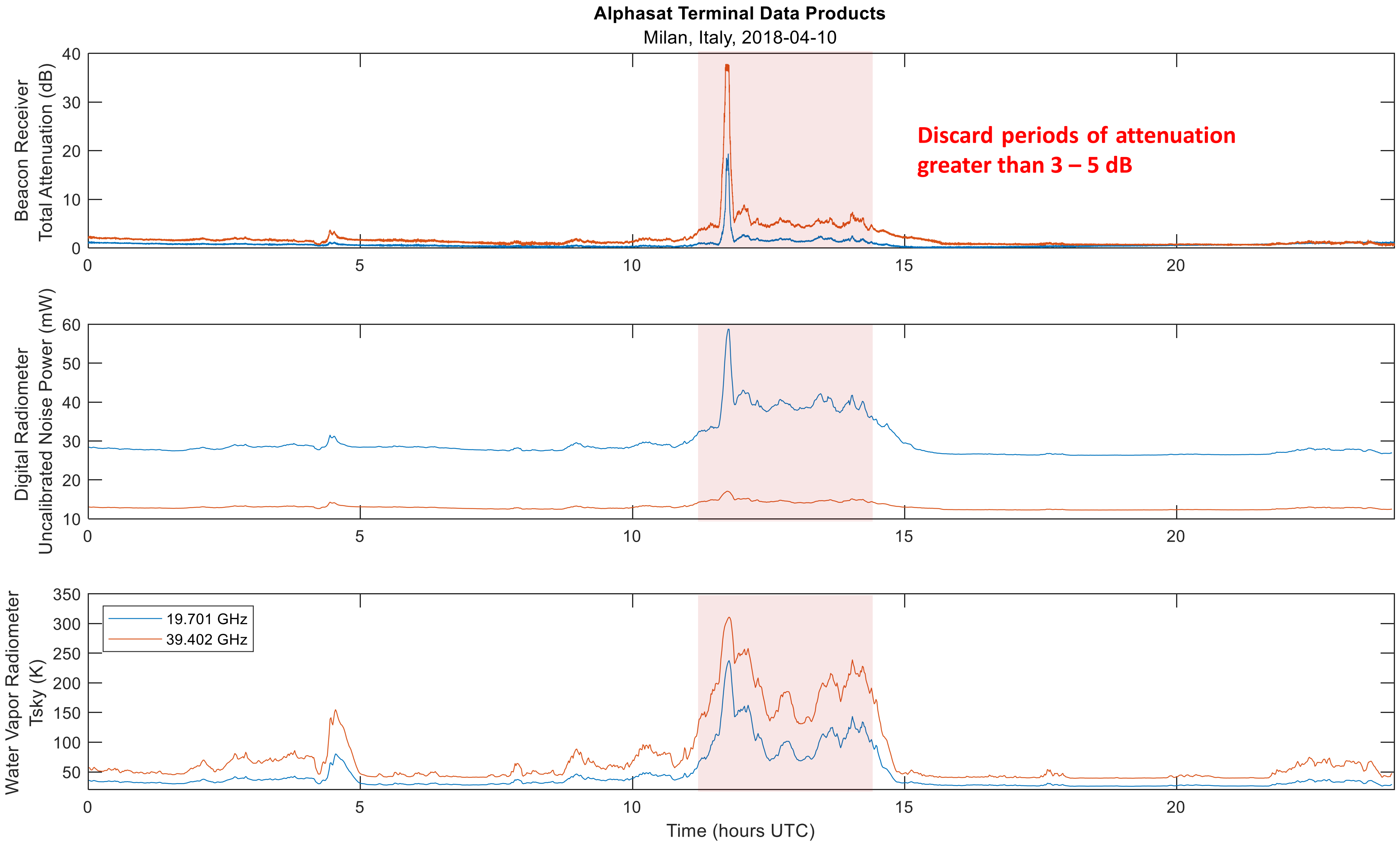
James Nessel

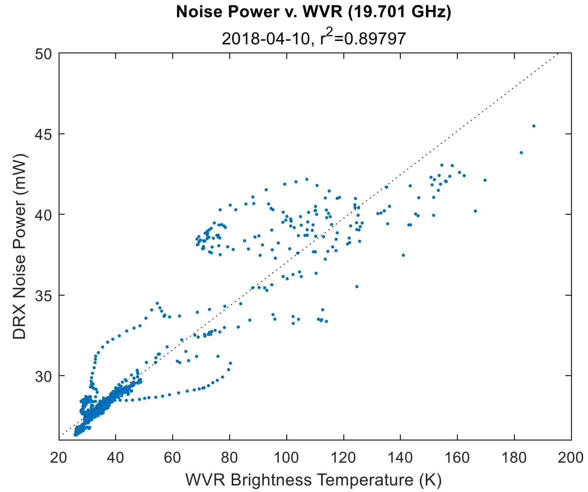
Chief, Advanced High Frequency Branch

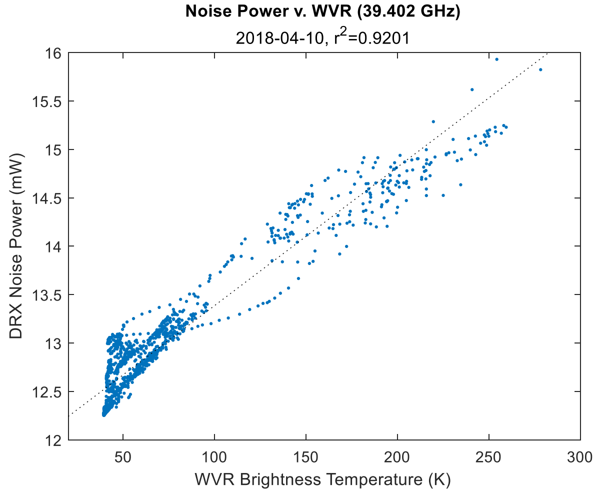
216.433.2546

james.a.nessel@nasa.gov

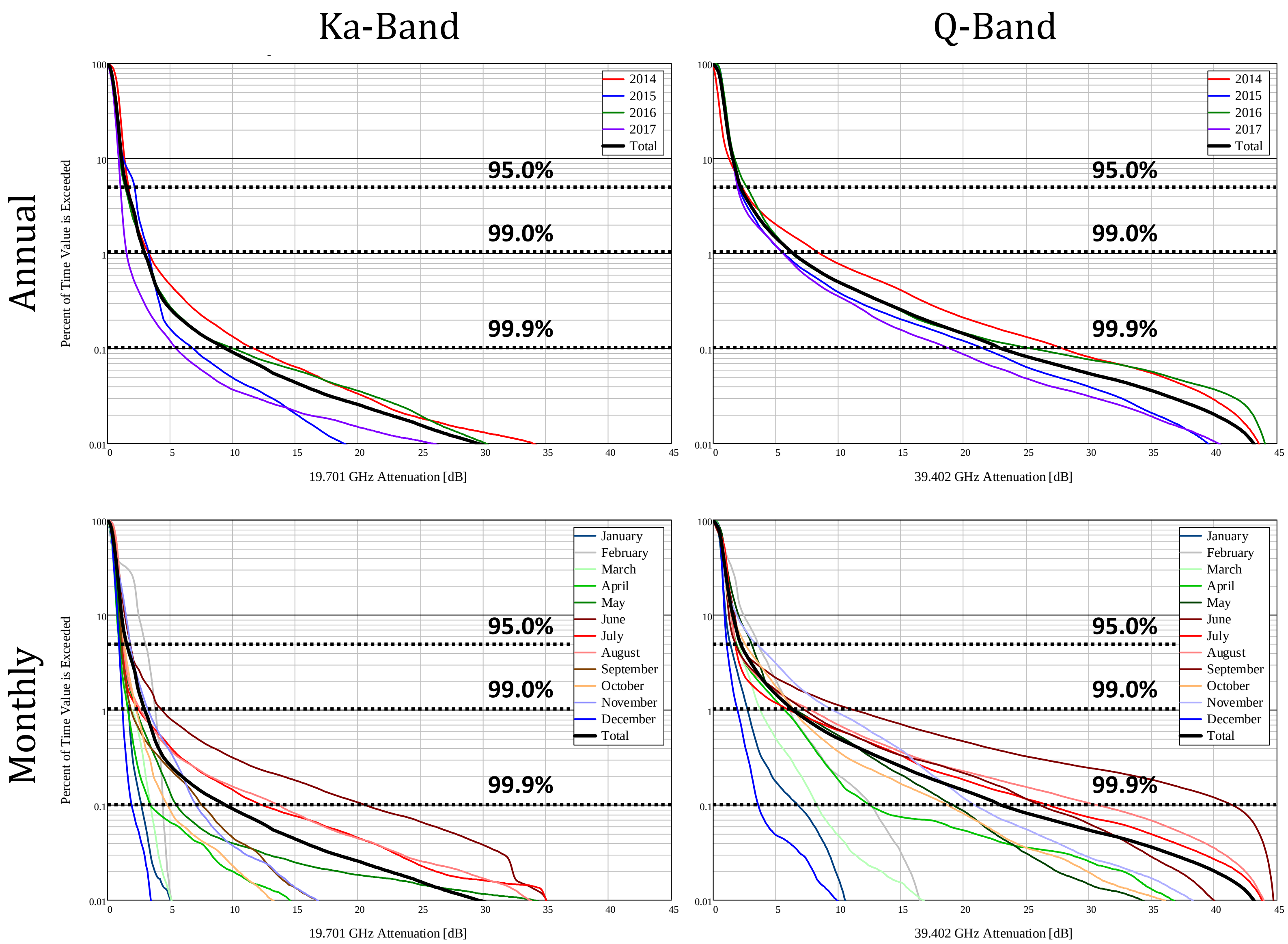
Rain Example







Attenuation Statistics (2014 - 2017)



		Ka-Band			Q-Band		
		95%	99%	99.9%	95%	99%	99.9%
Monthly Averages	January	1.26	1.69	2.72	1.36	2.76	6.76
	February	3.03	3.82	4.45	3.59	6.14	12.64
	March	0.89	1.95	3.44	2.12	3.77	8.29
	April	0.96	1.64	3.45	1.85	5.71	12.52
	May	1.05	2.33	5.51	3.07	6.55	19.19
	June	1.82	4.36	20.61	2.25	11.25	41.50
	July	1.22	2.52	12.34	1.77	6.08	26.78
	August	1.29	2.65	13.66	1.80	7.79	30.67
	September	1.15	1.89	7.53	1.79	7.32	26.13
	October	1.34	2.31	4.80	2.54	6.44	18.75
	November	1.81	3.26	7.09	3.43	9.54	20.90
	December	0.93	1.22	1.94	1.09	1.95	3.61
Annual	2014	1.69	3.31	11.69	2.30	8.50	27.93
	2015	2.17	3.31	6.83	2.06	5.65	21.60
	2016	1.42	3.01	10.05	2.70	6.31	25.40
	2017	1.05	1.54	5.49	1.95	5.58	18.88
	Total	1.53	2.98	9.44	2.19	6.39	22.99

For 99% availability, the associated link margin was 2.98 dB (Ka-band) and 6.39 dB (Q-band).

On a monthly basis, the highest attenuation was observed in the wetter summer and fall months (July, August, September) and the smallest attenuation in the drier winter months (December, January, February).

Reference Attenuation Level

Due to the absence of a radiometer the attenuation reference level is calculated using radiosonde observations and National Weather Prediction products. The total attenuation is them calculated using: