P159 WEATHER RADAR CALIBRATION AND TESTING USING THE MOON AS REFERENCE TARGET

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1 INTRODUCTION

The calibration and the validation or verification of the calibration of weather radar systems is a permanent subject of research and development. Since there is no “reference rain” a weather radar must be calibrated indirectly. Two methods are used so far: the ground truth method and the engineering calibration. The ground truth method uses an accurate ground sensor like a disdrometer (e.g. Thurai 2008) and relates the measurement of this sensor to the radar measurement of the volume above the sensor.

The results presented in this paper are related to the engineering calibration method. This method is based on the calibration of factors representing the features of radar subsystems in the meteorological radar equation. (Gekat 2010).

Since the accuracy of the calibration can be improved if as many factors as possible are calibrated as a product with one measurement (provided that the accuracy of this measurement is at least as accurate as the accuracy of the individual calibration of the factors) methods are investigated which allow the calibration of products of factors of the radar equation.

The most prominent of these methods is the calibration using the sun as reference target (e.g. Sirmans 2001). This method allows the measurement of the antenna beam width and the ZDR offset of the complete receive channel. If the actual sun radiation power measured by a sun observatory is used as reference even the gain of the receive channel including the antenna gain can be measured.

However the sun calibration has the drawback of not including the transmit path of the radar. Therefore other methods have been tried. The most promising methods are the passive target calibration and the balloon or sphere calibration.

During the passive target calibration a reference target is placed in the Fraunhofer zone of the antenna. The radar cross section of the target must be known with a high degree of accuracy. Since it is usually placed relatively close to the ground, multipath propagation and obstruction must be avoided (Martner 2003)

The balloon calibration avoids the problems related to ground reflections and obstructions because the reference target (which can be the balloon itself) is carried to a high elevation. But it is difficult to keep the target in a stable position which makes the measurement quite noisy. Moreover the logistic effort required to conduct such a calibration is enormous (Brunkow 2001).

In order to find a method which calibrates the complete system by avoiding the drawbacks of the known methods we studied the moon as a potential calibration target. The movement trajectories of the moon and the earth and its distance are exactly known which is important for calibration purposes. The radar signature of the moon and its polarimetric properties are also well known from studies conducted in the 60ties preparing the Apollo moon missions. Since the moon always turns the same side to earth its signature does not change.

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2 MEASUREMENT SETUP

For our measurements we used a METEOR 1600SDP10 radar. This is a fully coherent S-Band polarimetric Doppler weather radar with a klystron transmitter. The key figures of the radar are listed in Table 1

Parameter	Specification
Antenna Gain	45 dB
Antenna Beam Width	1°
Transmitter Peak Power	750 kW
Transmitter Pulse Width	2 µs
Receiver Noise Figure	2 dB
Receiver Noise Bandwidth	525 kHz
Dual Polarization Mode	Hybrid

Table 1: METEOR 1600SDP10 Specifications

During all measurement the antenna was stationary pointing at the moon. The antenna pointing angle can be calculated for the data provided by the US Naval Observatory (USNO 2011). The Right Ascension and Declination angles must be transformed into the antenna azimuth and elevation angles taking the parallax of the moon and the refractive index of the atmosphere into account (Meeus 2005).

3 RANGE MEASUREMENT

The geometry for moon measurements with radar is shown in Fig. 1. The symbols are explained in Table 2.

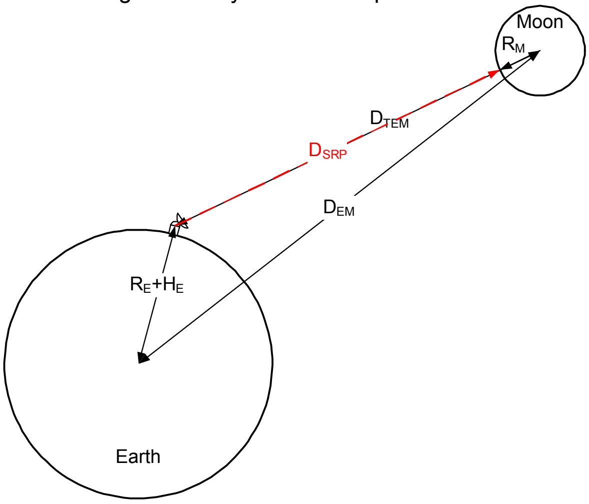

Fig. 1: Measurement Geometry

Symbol	Meaning	Value/Source
	Geographic Latitude	N 51°07'52"
	Geographic Longitude	E 6°44'09"
H_E	Height above Sea Level	55 m
R_E	Radius of Earth	R_E+H_E calculated by USNO
R_M	Radius of Moon	1738 km, (Williams 2010)
D_{TEM}	Topocentric Distance Earth-Moon	calculated by USNO
D_{SRP}	Distance Radar –Sub-Radar Point	D_{TEM}-R_M
D_{EM}	Geocentric Distance Earth-Moon	363300–405500 km (Williams 2010)

Table 2: Geographic and Astronomic Parameters of Radar Measurements

The measurement is validated by comparison with highly accurate data from the data base of the USNO.

In astronomy distances are usually defined between the centers of the respective objects (geocentric representation). Because the validation of the radar measurement requires the distance between the surfaces of the objects it is important to use topocentric data. Topocentric distances can be calculated if highly accurate algorithms describing the trajectories of the respective objects and their radii are available. Fortunately the USNO provides the topocentric distance from an arbitrary site on earth including the height to the center of the moon.

The distance measurement of the moon with a weather radar gives an ambiguous result since the distance is much larger than the unambiguous range r_{ua} of a weather radar:

$$r_{ua} = c/(2 f_{PRF}) \quad \textbf{Eq. 1}$$

The apparent range measured with an Ascope display r_{Asc} is:

$$r_{Asc} = \left(\frac{D_{SRP}}{r_{ua}} - \left\lfloor \frac{D_{SRP}}{r_{ua}} \right\rfloor \right) r_{ua} \quad \textbf{Eq. 2}$$

The brackets $\lfloor\rfloor$ are the mathematical annotation for rounding down to the next integer

Fig. 2 shows the Ascope display of one of our measurements. The relevant parameters are provided in Table 3.

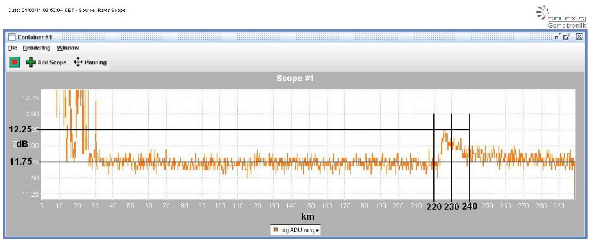

Fig. 2: Distance Measurement. Amplitude is normalized raw logarithmic power, without noise correction

Parameter	Figure
Date	01 March 2011
Start Time	08:50:00 UT
D_{TEM} @ Start Time	396488,764 km
End Time	08:50:09 UT
D_{TEM} @ End Time	396488,818 km
f_{PRF}	500 Hz
N_{ICS}	4096
Calculated r_{Asc}	223.125 km
Measured r_{Asc}	ca. 224 km

Table 3: Parameters and Results for Fig. 2. N_{ICS} is the number of incoherent integrated samples

In order test whether the observed signal really originates from the moon the antenna was slightly misaligned. As a result the signal disappeared.

The experiment was repeated with different pulse repetition frequencies. The measured distance always matched the calculated distance within ±3 km.

Due to the extremely large distance even small systematic errors in the range calibration of the radar would show up clearly.

4 REFLECTIVITY MEASUREMENTS

A large number of measurements have been carried out in order to measure the radar cross section of the moon (e.g. Hagfors 1968, Mathews 1988). Most of these studies were conducted with radars featuring long pulse durations (>11.2 ms) and wide-beam antennas (>0.5°) which allow the illumination of the complete lunar surface. The cross section for this sampling mode is $\sigma_0 = 0.07\pi R_M^2$. Unfortunately the calculation of the effective cross section for short pulse radars is quite cumbersome and not very accurate since the necessary scaling parameters for S-Band are missing. Moreover the accuracy of σ_0 is also not very high because the calibration of the radars used at that time was not very precise.

For these reasons and also because of the low SNR of all of our measurements we do not provide any measured cross section data here. But even if the moon is not suited for absolute calibration because accurate cross section data are missing it is well suited for relative calibration, i.e. the comparison of the calibration of different radars in a country-wide network, or even world wide. The peak power and the temporal signature of the signal scattered by the moon allow a very sensitive comparison of the radar calibration.

It must be pointed out that radar astronomical measurements are affected by Faraday rotation. This effect rotates the polarization of a linear polarized wave passing the Ionosphere. Therefore most of the measurements reported in the literature were using circular polarization.

5 DOPPLER MEASUREMENT

The measurement of the radial velocity of the moon will most likely also provide ambiguous results. The unambiguous radial velocity v_{ua} of a weather radar is:

$$v_{ua} = \pm c\, f_{PRF} / (4\,f) \qquad \textbf{Eq. 3}$$

The USNO provides data series in equidistant time steps for the topocentric distance which directly allow the calculation of the radial velocity of the moon v_M. The apparent radial velocity measured with an Ascope display v_{Asc} is:

$$v_{Asc} = (-2)\left\| \frac{v_M}{2v_{ua}} \right\| v_{ua} + v_M \qquad \textbf{Eq. 4}$$

The brackets $\| \ldots \|$ indicate rounding to the next integer.

Fig. 3 shows the Ascope display of a reflectivity and a velocity measurement. The velocity measurement is passed a quality threshold therefore only few data points are visible. The parameters of this measurement are given in Table 4.

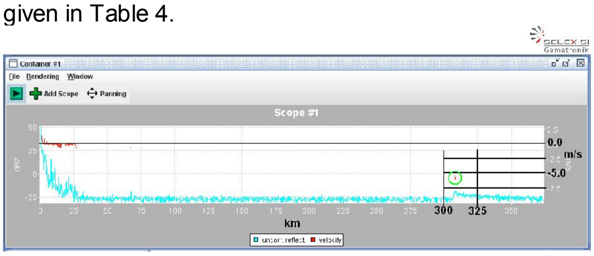

Fig. 3: Radial Velocity Measurement. Red = Velocity, Cyan = Reflectivity The red trace in the green circle represents the data which passed the quality threshold

Parameter	Figure
Date	01 March 2011
Start Time	09:52:37 UT
D_{TEM} @ Start Time	396645,054 km
End Time	09.53:24 UT
D_{TEM} @ End Time	396648,703 km
Moon Radial Velocity	+78 m/s
f_{PRF}	400 Hz
N_{ICS}	4096
Calculated v_{Asc}	-5.89 m/s
Measured v_{Asc}	ca. -5.5 m/s

Table 4: Parameters and Results for Fig. 3.

Within the confidence interval of this measurement it is a perfect coincidence. Moreover it is quite remarkable that the signal which returns after 2.6 s meets the receiver in a still coherent state. This is a phase stability test which is impossible with any other means.

6 POLARIMETRIC MEASUREMENTS

For the polarimetric measurements the system was operated in the hybrid mode, i.e. the H and V signals were simultaneously transmitted and received. Fig. 4 shows the Ascope of both signals. The parameters of the measurement are listed in Table 5.

Fig. 4: Polarimetric Ascope. Orange = H Reflectivity, Magenta = V Reflectivity. Amplitude is normalized raw logarithmic power, without noise correction

Parameter	Figure
Date	01 March 2011
Start Time	09:02:00 UT
D_{TEM} @ Start Time	396488,764 km
f_{PRF}	400 Hz
N_{ICS}	4096
N_H/N_V	0.75 dB
Calculated r_{Asc}	158.177 km
Measured r_{Asc}	ca. 160 km

Table 5: Parameters and Results for Fig. 4. N_H and N_V are the respective noise power levels

The moon signal is weaker than for the measurements with linear horizontal polarization. This is probably due to the 3 dB loss in the signal-to-noise ratio (SNR) of each channel caused by the splitting of the transmitter power. There is a salient difference in the noise powers of both channels. The reason is a receiver gain offset which can also be observed with a sun calibration.

For a ZDR offset calibration of the complete system the SNR is too low. Such a calibration can be performed based on the peak power of the moon signal in both channels. However before attempting such a calibration the impact of the Faraday rotation must be clarified.

It should be noted that the moon seems to have an LDR of about -12 – 14 dB (Hagfors 1967). Unfortunately the SNR of our setup was to small to reproduce this figure.

7 RADIOMETRIC MEASUREMENTS

For the radiometric measurement the transmitter was switched off. The antenna was pointing at the moon and the received power level was recorded. The result is shown in Fig. 5

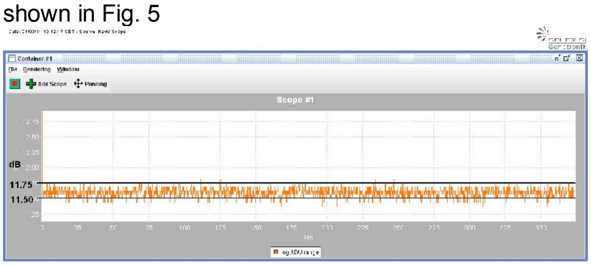

Fig. 5: Rel. Receiver Power Level. Transmitter is off, amplitude is normalized raw logarithmic power, without noise correction

Then the antenna was turned in azimuth to make sure that it is pointing away from the moon. The received power level from this measurement is shown in Fig. 6.

The parameters of both measurements are shown in Table 6.

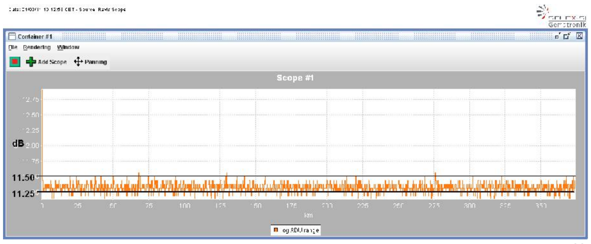

Fig. 6: Rel. Receiver Power Level, Transmitter is off, Antenna is 1° Azimuth off Target, amplitude is normalized raw logarithmic power, without noise correction

Parameter	Figure
Date	01 March 2011
Start Time Fig. 5	09:12:00 UT
Start Time Fig. 6	09:12:40 UT
Iluminated Fraction of the Moon	11 %
f_{PRF} (determin. total sampling time)	400 Hz
(Ant. On Target/Ant. off Target) Noise Power Ratio	0.25 dB
N_{ICS}	4096

Table 6: Parameters and Results for Fig. 5 and Fig. 6

A weak but noticeable difference of 0.25 dB can be observed. The origin could be sun radiation reflected from the moon. At the time the measurements were taken the moon was in its last quarter. Another possible source is blackbody radiation from the moon. In any case this is a strong indication for a high receiver sensitivity and a high antenna pointing accuracy.

8 CONCLUSIONS

We have shown that is possible to use the moon as a target for a weather radar. We got a clear power and also a Doppler signal.

The most promising application of moon measurement is the verification of basic radar measurements like range, velocity and probably polarimetric variables. Another interesting application could be the relative calibration of radars in a network.

For more accurate measurements a higher SNR is inevitable. The only way to increase the SNR is increasing the number of averaged samples, i.e. the incoherent integration gain. This will increase the total sampling period. The tangential movement of the moon during our measurement occurred at a rate of 0.02°/min in elevation and 0.25°/min in azimuth. Therefore a prolongation of the sampling period requires a tracking of the moon.

9 REFERENCES

Thurai, M., Bringi, V.N. 2008: Rain Microstructure from Polarimetric Radar and Advanced Disdrometers, in: Michaelides, S.C. (Ed.), Precipitation: Advances in Measurement, Estimation and Prediction, Springer

Gekat, F., Hille, M., Niese, H., Pool, M. 2010: Accuracy of the Engineering Calibration of Weather Radars , 2010 IEEE Int. Geoscience and Remote Sensing Symp. (IGARSS 2010), Honolulu, Hawaii, USA

Sirmans, D., Urell, B. 2001: On Measuring WSR-88D Antenna Gain Using Solar Flux, NEXRAD Radar Operations Center Report

Martner, B.E., Clark, K.A. and Bartram, B.W. 2003: Radar Calibration Using a Trihedral Corner Reflector, 31st Conf. Radar Meteorol., Seattle, Washington,

Brunkow, D. 2001: Sphere Calibrations, AMS Radar Calibration and Validation Speciality Meeting, Albuquerque, New Mexico

Mathews, J.D., Breakall, J.K., Sulzer, M.P. 1988: The Moon as Calibration Target of Convenience for VHF-UHF Radar Systems, Radio Sci. Vol. 23, No. 1, pp. 1-12

USNO 2011: http://aa.usno.navy.mil/data/docs/topocentric.php

Williams, D.R. 2010:Moon Fact Sheet http://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html,

Meeus, J. 2005: Astronomical Algorithms, Willmann-Bell, 2nd Ed.

Hagfors, T. 1967: A Study of the Depolarization of Lunar Radar Echoes, Radio Sci. Vol. 2, No. 5 pp. 445- 465

Hagfors, T., Evans, J.V. 1968: Radar Studies of the Moon, in: Hagfors, T., Evans, J.V. (Eds.) :Radar Astronomy, McGraw-Hill