# An operational radar monitoring tool

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**Abstract**

For many applications it is vital that radars are well-calibrated and that they are in operation continuously. This requires that the radar is frequently calibrated, but also that its performance is monitored. Because there are many parts of a radar system that can cause either miscalibration or malfunction, it is necessary to monitor several variables in order to be able to determine which of these parts is causing this. A suite of tools that provides information about multiple variables related to radar performance is presented. This suite includes (1) solar monitoring, (2) transmitted power monitoring, (3) monitoring of stable clutter returns, (4) short-range anomaly monitoring, and (5) effectivity of clutter filter monitoring. Typical cases of malfunctioning radar components are presented to show the usefulness of this monitoring tool.

## 1. Introduction

Monitoring of radar performance on a day-to-day basis is very important in an operational setting. Early detection of system performance degradation and subsequent corrective maintenance can help in preventing the radar being taken out of operation or to avoid long-term sub-optimal radar performance. Furthermore, information on radar performance can also be used as radar data quality information. This is particularly relevant for the OPERA (Operational Programme for the Exchange of weather RAdar information; see Huuskonen et al., 2010) programme, which can use this information for both harmonization and for producing data quality information. Several useful ways to monitor operational weather radars were presented by Donaldson (2010), but these require expert judgment for operational monitoring. Here, we develop easy to monitor variables that can be easily checked on a day-to-day basis.

In this paper we describe a suite of radar monitoring variables that can be used to monitor the performance of several parts of the radar. Examples of how these variables could have prevented serious degradation of performance for the two radars operated by KNMI are given to illustrate the usefulness of these variables. Some of these variables are based on long-term statistics of reflectivities in each pixel, which are discussed in Section 2 along with the radar settings in the Netherlands. The different monitoring variables are discussed in Section 3, and conclusions are drawn in Section 4.

## 2. Radar data and statistics

KNMI operates two identical SELEX-SI C-band Doppler weather radars, one in De Bilt (5.17834E 52.10168N) and one in Den Helder (4.78997E 52.95334N). The radars perform a 14-elevation scan every 5 minutes, yielding four moments (uncorrected reflectivity (Z), clutter-corrected reflectivity (Z), mean Doppler velocity (V), and Doppler spread (W)). Signal processing (i.e. Doppler clutter filtering and moment calculation) is carried out at each radar, and product generation is carried out centrally at the KNMI main office. In order to extend the dynamic range of the radar receiver the reception chain, the signal is split into an attenuated and an unattenuated channel before digitization. High-power signals are digitized in the attenuated channel, and low-power signals are digitized in the unattenuated channel. More details about the radars can be found in Beekhuis and Holleman (2008).

Histograms of the values of all moments are operationally generated for each pixel in the radar volume. These statistics are stored for periods of one month and one year. This means that for a given pixel in the radar volume it is easy to determine e.g. the mean, mode, or 25$^{th}$ percentile of the uncorrected reflectivity over a given month or year. More details about these statistics can be found in Donaldson (2010). Changes in these statistics are of course related to the weather, but can also be related to radar performance. In this paper we show that these changes yield useful information.

## 3. Monitoring variables

### 3.1 Sun power and location

We use the methods described by Huuskonen and Holleman (2007) and Holleman et al. (2010) to monitor the antenna pointing angle and the receiving chain, respectively. Both of these methods employ the solar signals that are present in the operational volume data accumulated over a day. The number of sun "hits" depends on the radar location, its sensitivity, the season, and the scan strategy. In The Netherlands this number varies between approximately 40 and 80. Four variables are currently operationally monitored: (1) the number of "hits", (2) the solar power at C-band, (3) the deviation of the azimuth angle from the commanded angle, and (4) the deviation of the elevation angle from the commanded angle. The number of

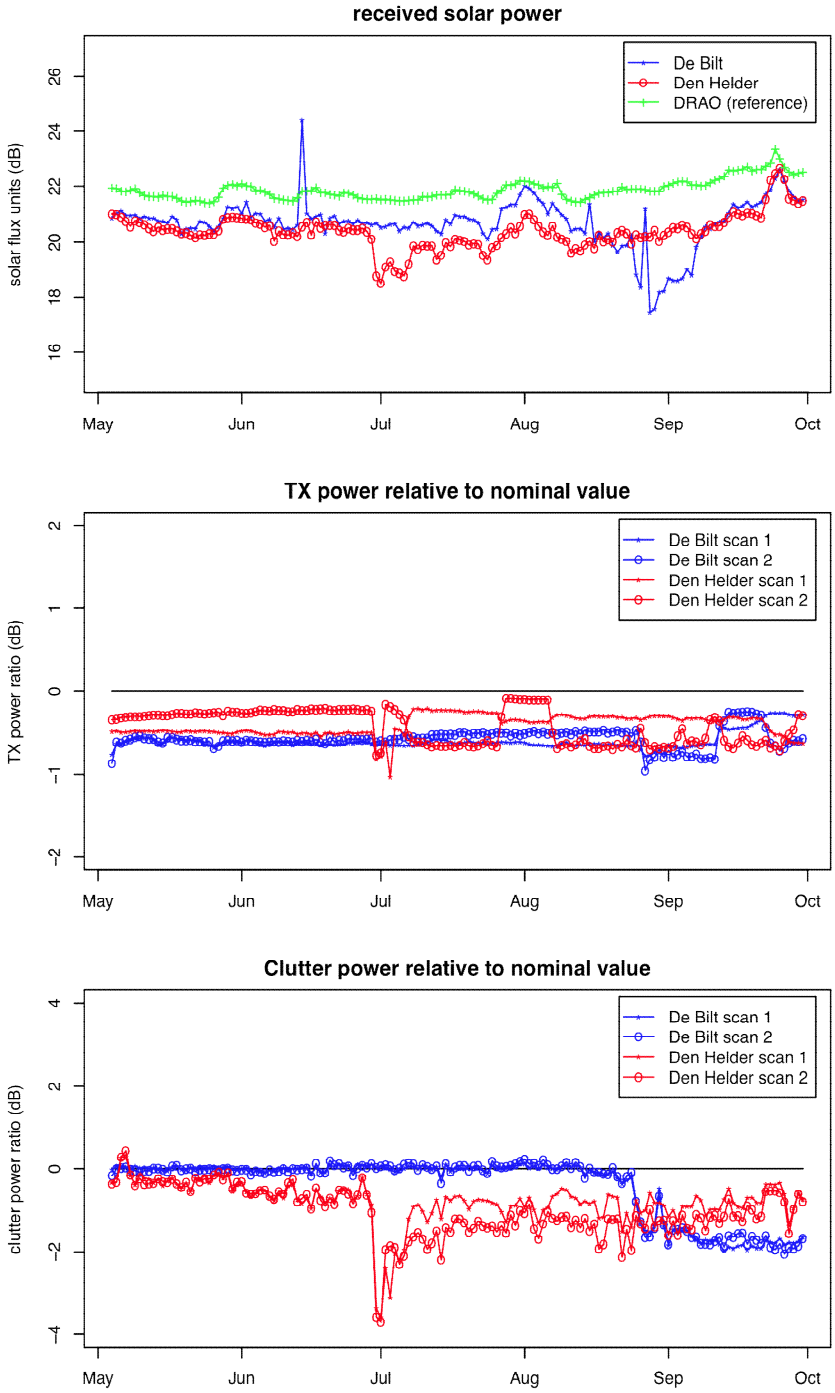



*Fig. 1 Time series (2011) of the solar flux, the TX power, and the power from stable clutter targets measured by the two KNMI radars in De Bilt and Den Helder.*

"hits" can be used to detect loss of sensitivity, and the measured solar power is compared to that measured by a reference in order to monitor the receiving chain (see Holleman et al., 2010). It should be noted that changes in the received solar power relative to the reference signal are attributed to the unattenuated receive channel (see Section 2).

### 3.2 Transmitted power

The transmitted power is measured operationally in the wave guide. This measurement complements the information collected about the receive chain inferred from the measured solar power (see Section 3.1). The variable that is monitored is the ratio of the nominal (commanded) transmitted power and that actually measured. In interpreting this signal it should be noted that anomalies can be caused by the transmit chain as well as the reception of this transmitted signal.

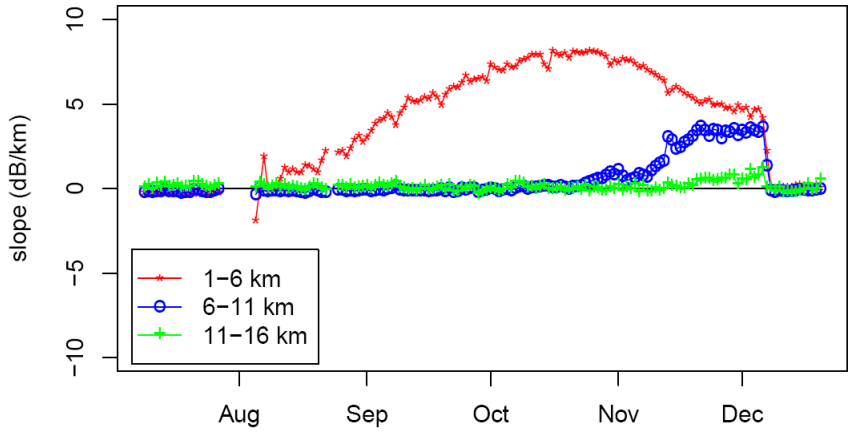



*Fig.2 Time series (2009) of the slope of the difference of mean dBZ values in De Bilt for three range intervals.*

3.3 Fixed clutter target returns

Fixed ground clutter returns can provide information about the entire transmit/receive chain. This can then be linked to the information about the receive (see Section 3.1) and transmit (see Section 3.2) chains. For this purpose, several clutter pixels are selected based on the statistics of uncorrected reflectivity over the previous year (see Section 2). The criteria for a pixel to be selected are that the average returned power is high enough (>60 dBZ for De Bilt and >50 dBZ for Den Helder), and that the standard deviation of the reflectivity values throughout the year is limited (<1 dBZ for De Bilt and <2 dBZ for Den Helder). The averaged dBZ values over the entire year for the selected pixels are used as reference levels. The variable that is monitored is the average of the difference between the reference levels and the daily-averaged uncorrected dBZ values for all selected pixels. When using strong stable clutter returns quantitatively, it should be noted that clutter returns may saturate the receiver, so that a decrease in signal strength is underestimated and only recorded when this decrease is strong enough. It should also be noted that changes in the clutter power are attributed to the attenuated receive channel (Section 2).

In Figure 1, we present an example of the power monitoring variables as measured by the two KNMI radars for the summer of 2011. Around the end of June 2011 the solar signal, the TX power, and the stable clutter returns all drop significantly for the Den Helder radar. This event is linked to a failure of the air conditioning unit at the radar site. Through monitoring the solar power we were quickly able to send a maintenance crew to the radar, which promptly determined that the cause was a malfunctioning air conditioning unit. On another occasion at the end of August 2011 all power monitoring signals for the De Bilt radar are seen to drop significantly. Alerted by this, we were able to determine the cause of the problem, which was a faulty IF-downconverter, a fault which otherwise could have gone unnoticed for a long time. The continued degraded performance after September 15, 2011 as seen from the clutter power graph is not visible in the TX power or the solar power graphs. This is likely due to the fact that the solar signal is related to the unattenuated receive channel, and the clutter signal is related to the attenuated receive channel. Such an analysis of these graphs can help localize the problem.

3.4 Short-range anomalies

The T/R limiter ensures that the transmitted signal does not enter the receiver unattenuated. However, it should quickly recover after having strongly attenuated the transmitted pulse. It is known that ageing of T/R limiters can deteriorate their recovery time. The performance of T/R limiters can be monitored by examining the difference between the azimuth-averaged uncorrected reflectivity over given day and a reference. The idea behind this is that degradation of the T/R limiter starts close to the radar. This can be detected by inspection of close-range echoes, under the assumption that there are always enough clutter returns close to the radar to dominate the average reflectivity. This is especially the case for the lowest elevations. The reference is taken to be the azimuth-averaged uncorrected reflectivity averaged over the previous year. It is hence assumed that in the largest part of this reference period the T/R limiter was functioning properly.

In the case of a properly functioning T/R limiter it is expected that the difference between the reference and the daily average is constant with range (it is zero if the calibration of the radar is also the same as in the reference period). When the T/R limiter starts to degrades, it is expected that this difference becomes negative at close ranges and returns to zero at further ranges. Hence, the local range derivative of this difference becomes positive. The variables that are monitored are the range derivatives over the ranges 1-6 km, 6-11 km, and 11-15 km. These slopes are determined by linear regression.

Figure 2 shows time series of these variables for the second half of 2009. It is clear that the T/R limiter starts to degrade from the beginning of August 2009. This continues unnoticed for several months until not only the first 6 km are affected but also ranges between 6 and 11 km (October 2009), and finally also the ranges between 11 and 16 km (November 2009). It was finally discovered on November 27, 2009 that the T/R limiter was malfunctioning, with subsequent replacement on December 6 (which can also be clearly seen in Fig. 3). If this monitoring tool had been in place, the deterioration of the T/R limiter could have been noticed several months earlier.

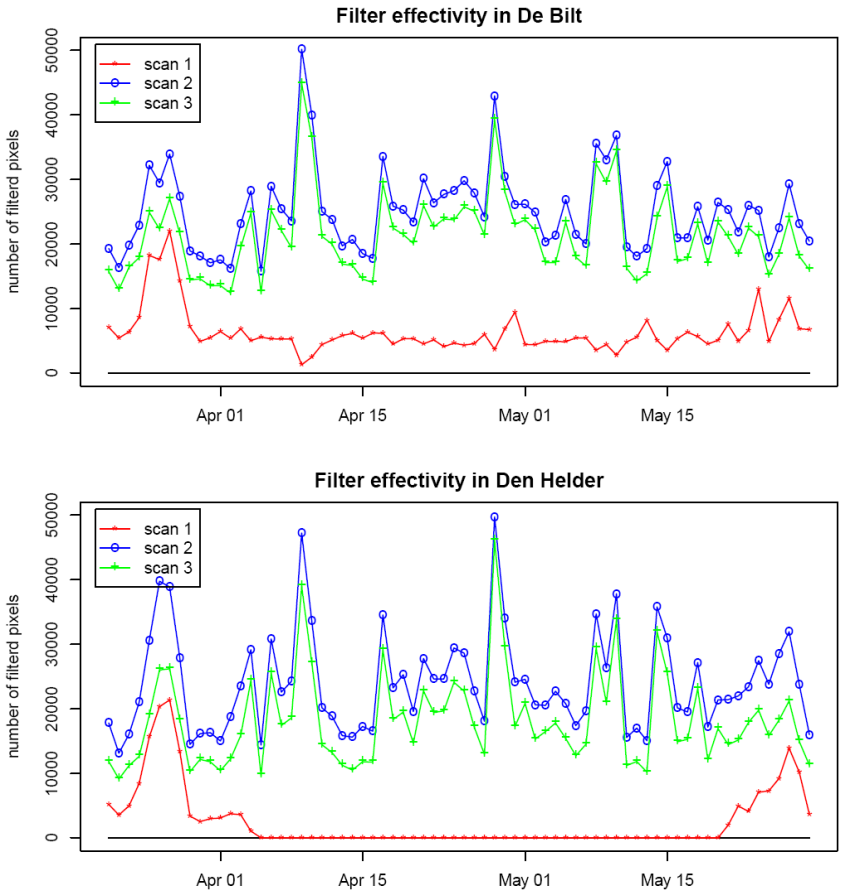



*Fig.3 Time series (2012) of the number of pixels affected by clutter filters for different scans for both radars.*

3.5 Effectivity of clutter filter

To assess the effectivity of a clutter filter, the number of pixels affected by the filter can be displayed. The variable that is monitored is the average number of pixels where the uncorrected reflectivity is higher than the corrected reflectivity. This is done for a selection of scans, as the clutter filter applied may vary per scan. The number is of affected pixels is expected to fluctuate depending on the weather, but there will always be pixels that are affected. Figure 3 shows a recent time series of this number. It is clear that for the Den Helder radar the clutter filter was inadvertently turned off at the beginning of April of 2012. Had this filter effectivity monitoring tool been available, this would have been noticed. This would have prevented 1.5 months of severe contamination of radar data by clutter.

## 4. Conclusions and discussion

Several radar monitoring variables have been presented, and their usefulness has been demonstrated. The combination of solar interference, TX power measurement, and stable clutter returns provides a powerful way of detecting and localizing malfunctioning of the radar. The functioning of the T/R limiter can be monitored by comparing the range-dependence of the azimuth-averaged reflectivity to that over a reference period (the previous year). It is shown that monitoring this can prevent several months of data being affected by an ageing T/R limiter. A very simple method is used to monitor clutter filter effectivity. A recent example shows that this can be highly effective.

Several of the proposed monitoring variables rely heavily on the availability of statistics of radar data over a previous period. This shows the usefulness of operationally storing such statistics (Donaldson, 2010).

The monitoring variables presented here provide insight into how the radar is functioning. The graphs presented can be quickly analyzed on a day-to-day basis so that maintenance can be performed as quickly as possible when needed. However, in countries with many radars, analysis of such graphs becomes tedious. The next step would therefore be to build an automated radar monitoring system that issues a warning when radar malfunctioning is suspected. This requires defining thresholds for each variable above (or below) which such a warning would be issued. The graphs should be stored, so that they can help in assessing and localizing the problem.

## Acknowledgment

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