Monitoring of weather radar receivers using solar signals detected in operational scan data

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I. Introduction

When operating a network of weather radars for monitoring of (severe) precipitation and (strong) wind, data quality and network homogeneity are of crucial importance. Using sun for offline calibration of the antenna alignment is a well-established method and tools for this are included in the software packages provided by the radar manufacturers. This offline calibration is typically performed during radar maintenance. Solar signals can, however, be detected automatically in polar reflectivity data produced operationally by a weather radar.

Recently we have published a method to determine the angular biases of the radar antenna using solar signals observed by a scanning weather radar (Huuskonen and Holleman, 2007). Data recorded at low elevations, where atmospheric refraction has a significant effect on the propagation of radio waves, are used and a method to take the effect of the refraction into account in the analysis was presented. Using a linear model the detected solar signals can be analyzed quantitatively, and the azimuth and elevation biases of the antenna reading are obtained. The method is applied to datasets based on operational measurements at FMI and KNMI.

Here we present an extension of the online method towards monitoring of the weather radar receivers (Holleman et al, 2008). The solar monitoring method can be used for monitoring of the day-to-day stability of a single receiver, for monitoring of the network homogeneity, and for checking the absolute calibration. For this the maximum power of the sun signals detected by a radar is converted to solar flux units and then compared to observations from the DRAO solar flux monitoring station in Canada. Here we introduce the online sun method and describe all conversion steps. In addition a comparison between online and offline sun monitoring results is discussed. Finally operational results from the FMI and KNMI radar networks are highlighted.

II. Sun signals in radar data

A method for monitoring radar antenna pointing and receiver calibration using sun signals detected in operational scan data is presented. Weather radars scanning at low elevation angles regularly detect signals from the sun. These signals are most usually seen around sun rise and sun set and they can be recognized in the images as spokes in the direction of the sun. In the radar raw polar volume data the artifacts are observed whenever the antenna points close to the direction of the sun. Details on the monitoring of antenna pointing can be found in Huuskonen and Holleman (2007). Examples of sun signatures in radar imagery and data are shown in Figures 1 and 2.

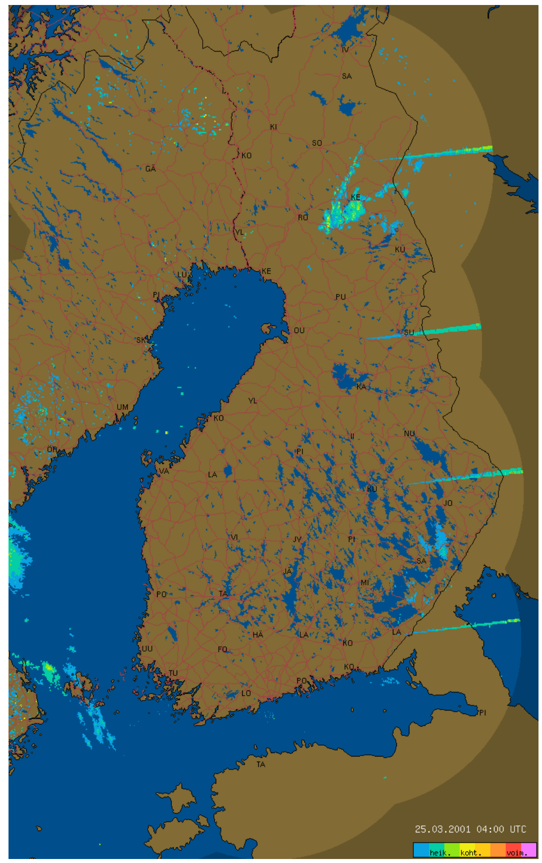

Fig. 1. Reflectivity conmposite from Finnish radar network with four sun signatures recorded during sunrise.

III. Conversion of reflectivity to solar flux

A consistent reflectivity signal, i.e., signal from a continuous source, at long ranges and high altitudes is searched ray-by-ray in the operational scan data. Depending on the hardware of the radar, the volume coverage pattern, the season, and the latitude

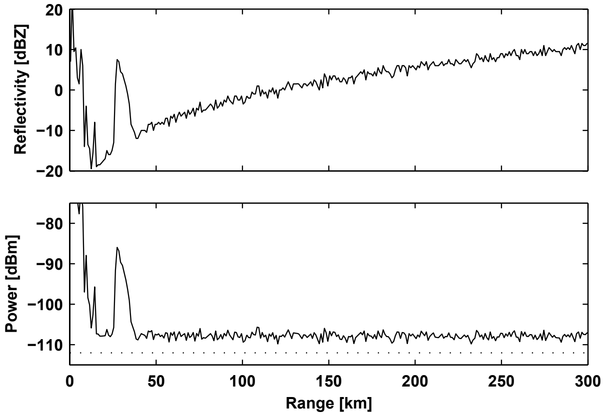

Fig. 2. Radar A-scope plot with uncorrected (top) and corrected (bottom) reflecitiy signals from the sun.

of the radar, several tens of sun signatures are typically found per day. The received solar spectral power at the antenna feed per MHz in dBm is calculated from reflectivity as function of range $Z(r)$:

$$P_f = Z(r) - 20\,{}^{10}\log r - 2ar - C_r + L_{RX} - 10\,{}^{10}\log \Delta f \quad (1)$$

where C_r is the radar constant, a the one-way gaseous attenuation, and Δf the receiver bandwidth. The mean solar power $\bar{P}_f$, power standard deviation, elevation, azimuth, date, and (accurate, $<$10 s) timestamp are stored for all rays where a sun signature is detected. Corrections for beamwidth and scanning losses and for attenuation must be made (See Figure 3).

IV. Correction for atmospheric refraction

For the analysis of the solar signatures we have to know the position of the sun. The position of the sun, without the effect of refraction, is obtained from standard formulas. The radiation of the sun is, however, refracted during its propagation through the atmosphere due to change of the refractivity with altitude. We are using radar data collected at very low elevations and, therefore, the refraction has to be taken into account. Equations for atmospheric refraction of radio frequency waves consistent with 4/3 earth's radius model have been derived.

V. Daily analysis of sun signatures

Figure 4 shows a scatter plot with the power and angular deviations for one month of sun signatures is shown. It is evident from the figure that the solar signals are scattered over roughly 1 deg in both elevation and azimuthal direction. The width in azimuth is slightly larger because the antenna scan in azimuth produces additional smoothing not present in the elevation. On a daily basis all detected sun signatures are analyzed by fitting the data to a linear model based on a two-dimensional Gaussian. After the fitting the retrieved maximum power is converted to sun flux using effective antenna area and by correcting for single-polarization reception.

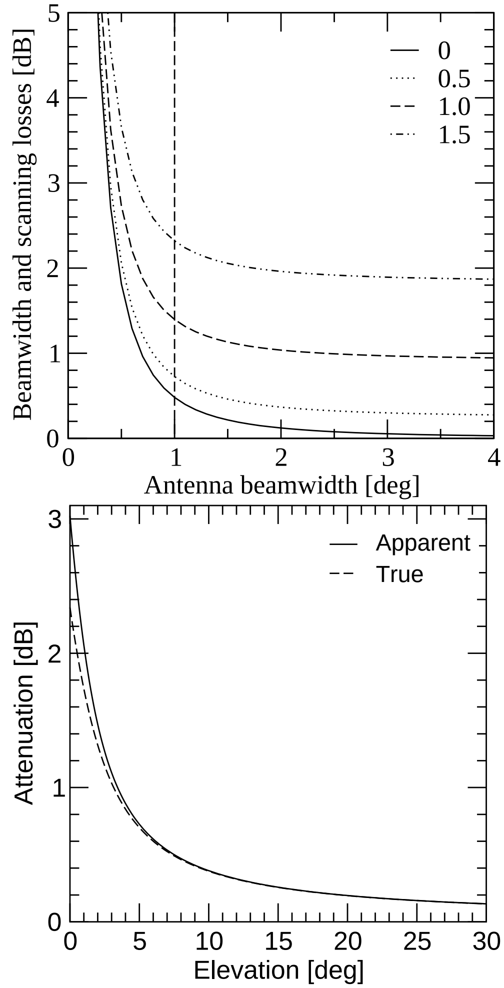

Fig. 3. The top frame shows the calculated correction for the beamwidth and the scanning losses as a function of the 3 dB width of the radar antenna. Curves for different ratios (0...1.5) of the azimuthal width of the processed rays and the 3 dB antenna beamwidth are shown.The bottom frame shows the calculated gaseous attenuation of the sun at radio frequency as a function of the apparent (solid) and true (dashed) elevation.

VI. Comparison of online and offline solar flux

The sun flux retrieved from online scan data has been validated with offline sun pointing experiments on 22 January 2008 in De Bilt (Figure 5). The sun flux observed by the weather radar in De Bilt is somewhat below the DRAO reference and for Den Helder a larger bias is seen. The bias of De Bilt with respect to DRAO is -0.38 dB during this period and the standard deviation is only 0.14 dB. For Den Helder a bias of -0.93 dB and a standard deviation of 0.17 dB are obtained.

VII. Example

Figure 6 shows an example how a gradual failure of radar components is seen in the daily sun flux data. The solar power is seen to diminish starting about 20 February 2008, and the number of sun hits also drops. The decrease in the power soon gets faster and on 4 March the recorded power is about 4 dB

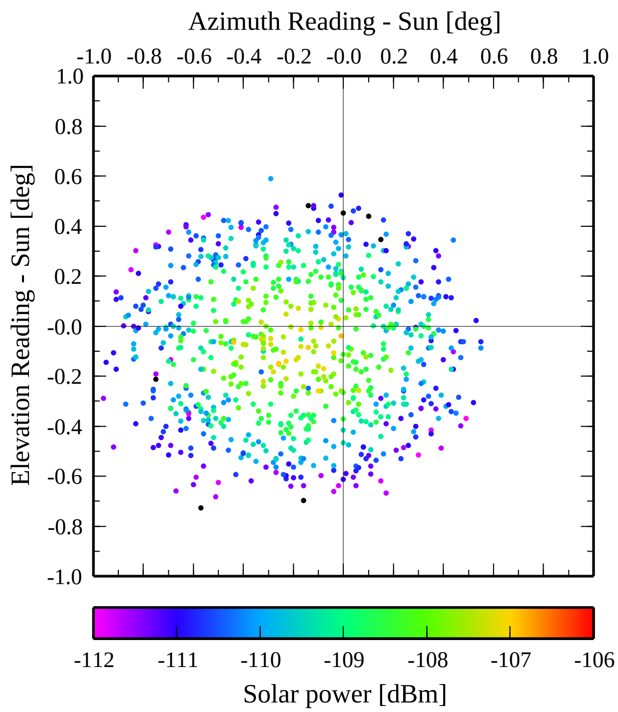

Fig. 4. A scatterplot of the solar signals collected by the weather radar in De Bilt during March 2004. The vertical axis gives the difference between the observed antenna elevation (reading) and the calculated elevation of the sun, and the horizontal axis the same for the azimuth.

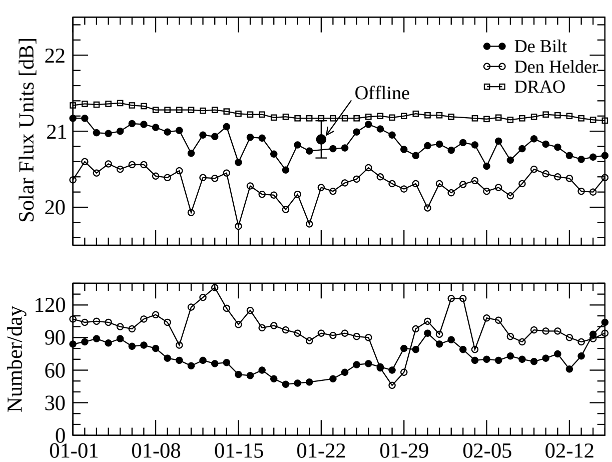

Fig. 5. Daily analysis of the sun signatures observed by the weather radars in De Bilt (filled circles) and Den Helder (open circles) from 1 January to 15 February 2008. For reference the observations from DRAO are plotted as well. The upper panel displays the solar flux and the lower panel shows the number of analyzed sun signatures per day. The result from the offline sun tracking in De Bilt on 22 January 2008 is also plotted.

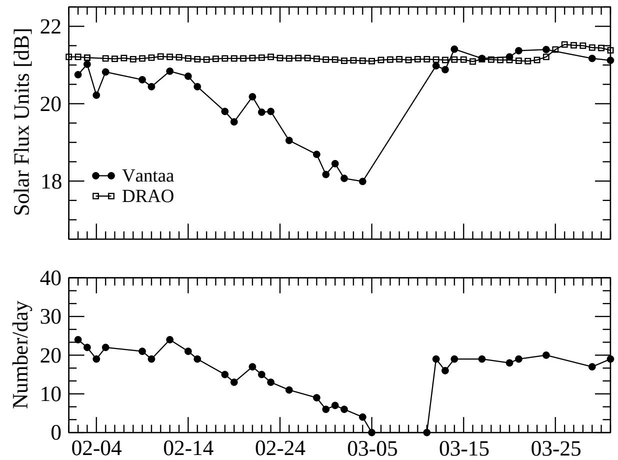

Fig. 6. Daily analysis of the sun signatures observed by the weather radar in Vantaa and the DRAO reference from 1 February to 31 March 2008. The upper panel shows the observed solar flux and the lower panel the number of analyzed sun signatures per day.

lower than normal, and the number of hits is down by a factor of five. At this point the cause of the power loss was found out, which appeared to be the harmonic filter in the waveguide. After replacement of the filter, the sun power and the number of sun hits returned to the typical values.

VIII. Conclusions

Results from a daily analysis of the sun signals in radar data can be used for monitoring the alignment of the radar antenna and the stability of the radar receiver system. In a national or international network of operational weather radars, differences in the effective antenna system gain, i.e., combination of antenna and receiver, can be brought to light. By comparison with the observations from a sun flux monitoring station even the absolute calibration of the effective antenna system can be checked. For a full calibration of a weather radar a calibration of the transmitter is also required. In the future this method can be extended to online monitoring of differential reflectivity and linear correlation data from polarimetric weather radars. The method presented in this paper has great potential for monitoring and cross-border harmonizing of the weather radars in an international network, e.g. the OPERA network in Europe (See TECO-2008 paper 01-09).

Ackowledgements

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