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Atmospheric Measurement Techniques Discussions

Interactive comment on "A sun-tracking method to improve the pointing accuracy of weather radar" *by* X. Muth et al.

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We would like to thank the reviewers for their constructive and helpful comments. The following sections provide our detailed answers to the reviewers' questions and comments. Please note that we have provided all our responses to all reviewer's comments to the three reviewers so that they have access to all responses.

Reviewer 1

1. *In page 5577, the authors mentioned that when collecting sun measurements "the scanning procedure has to be accurately synchronized in time to avoid additional uncertainty". Can the authors give an indication of the expected error due to timing errors (e.g. from 1sec to 1min)?*
   In order to get an accuracy of 0.01 deg in the estimated position of the sun (derived from the apparent sun velocity), an accuracy in time of about 2.2 s in azimuth and 5 s in elevation is required (for mid-latitudes). So an accuracy of about 1 s is enough for all conditions. This has been added in the text (see l.173).

2. *The authors use DEM as a reference to validate the corrections. However, there are no comments regarding the grid resolution of the DEM data. Will this have an effect in the comparisons? Also, what's the vertical resolution of the DEM? Will the vertical resolution influence the comparisons?*
   The horizontal resolution of the DEM is 25 m, with an uncertainty of at most $\pm$5 m in the study area. All the details are provided in (*Swisstopo*, 2004). The resolution of the DEM will have an influence on the spread of the distribution of the residuals between the reference DEM and the radar-derived DEM (see Figures 8 and 9). Increasing the resolution of the reference DEM would decrease this spread (quantified by the standard deviation for instance), until the reference DEM resolution is similar to the radar resolution (in range and azimuth). The impact on the mean of the residuals is expected to be lower (given the large sample). Overall, the 25-m resolution appears to be high enough to demonstrate the significant improvement due to the pointing correction proposed.

3. *In page 5579, it was mentioned that 'the recorded profiles which have hit the ground are detected by using a threshold which takes the decrease of radar power density with distance into account' and then this power is somehow translated into ground elevation*

and position. However, in order to do this, the propagation of the radar beam and the beam power profile have to be defined and this will influence the calculations. Can you comment on this? Can you include this uncertainty in your model?
The uncertainty in the exact beam position is very difficult to quantify because it requires a complete knowledge of the 3D field of refractive index in the considered region of the atmosphere, which means knowing the air temperature, moisture, and pressure. Accurately estimating these fields could be achieved using a very high resolution numerical weather model, but would require a lot of work for a limited gain. The errors between the reference and the radar-derived DEM using a standard atmosphere are reasonable (standard deviation about 35 m, see Figures 8 and 9), so we do not think it is necessary to conduct such complex modeling studies.

4. *Where is the dotted line in figure 8?*
   Figure 8 has been changed to improve its readability. Position 1 is now figured by the red curves and Position 2 by the blue curves.

Reviewer 2

1. *The introduction of Position 1 and Position 2 in Section 2.1 is rather hidden. A more prominent explanation of these two positions that are very relevant for this work is needed.*
   Figure 1 has been modified to better illustrate and explain the 2 antenna positions.

2. *The fundamental assumption of the analysis method is that Positions 1 and 2 are exactly opposite. In previous studies on antenna alignment I have seen that the elevation and azimuth scales can have a non linearity of tenths of degrees.*

How would is impact your method?
Such non-linearities in the azimuth and elevation scales have been assumed negligible in the present study. Significant differences in the supposedly same elevation at the 2 antenna positions would affect the estimation of C_{V_0} according to Eq.8. The azimuth scale is the same in both antenna positions, and its rigorous modeling would require to use a variable A_0 which would depend on the azimuth. The very good agreement between the radar-derived and the reference DEM is in our view a strong indication that these non-linearities are indeed negligible in our case.

3. *In Section 2.3 did you consider measuring the actual surface refractivity via pressure, temperature, and humidity and input that in your refraction correction?*
   Following *Huuskonen and Holleman* (2007), we have assumed that the correction of the atmospheric refraction based on the standard atmosphere is accurate enough. Radar sun echoes were collected at elevation angle of at least a few degrees, and the difference in the refraction between summer and winter is rather limited at such elevation (less than 0.1 deg), as illustrated in Figure 2. Moreover, the small-scale variability of the temperature and humidity field would require dense networks of station to adequately monitor them or very high resolution simulations from a numerical weather model. This is in general difficult to achieve. See also our response 3 to Reviewer 1.

4. *In Section 3.1 you mention "alternatively in both positions of the antenna (see Fig. 3)" but this figure does not help me understand the nature of both positions*
   Figure 3 does not illustrate the 2 antenna positions. The text has been modified to avoid this confusion (see l.112). In addition, the modified Figure 1 now clearly explains the 2 antenna positions.

5. *In Section 3.2 the model for fitting the sun tracking results is described. If I understand it correctly it consists of a two step approach: first data from a number of sun tracking experiments are analyzed using the model contained in Equations 1-6 for each experiment individually. Subsequently the extracted biases (x0,y0) for each experiment at different elevations/azimuths are interpreted using the additional model in Equations 7 and 8. If this is indeed the case I suggest that the authors rewrite this Section to make it much more clear. In addition the description of Equations 7 and 8 and the symbols therein should be improved as none of the symbols in these equations are introduced properly (and Figure 1 with some of these symbols is also not very clear).*
   This section has been modified to better convey the message. An appendix in which the detailed derivation of Eq.2-6 is presented has been added. Finally, Figure 1 has been modified to better illustrate the different error terms.

6. *Sections 3.3 starts with details about the equations for getting the sun position up to 0.003 deg, that seems much more accurate than required for this application. What kind of requirement does this put on your timing? I think an accuracy of a few hundredths of a degree is sufficient.*
   The reviewer is right, we need an accuracy of about 0.01 deg in the input to be able to achieve a positioning with an accuracy of about 0.1 deg. The idea here is to show that even for high accuracy like 0.003 deg, the required geographic position accuracy is easily reachable with a standard GPS beacon. The text has been changed to be more clear (see l.161).

7. *Section 3.4, how accurate synchronization in time is needed?*
   An accuracy in time in the order of 1 s is enough. This is now mentioned in the text (see l.173). See also our response 1 to Reviewer 1.

8. *Figure 8 could be improved. The data are fine but the display is confusing.*
   Figure 8 has been improved.

9. *What is the added value of Figure 9 after the discussion of Figure 8?*
   With respect to Figure 8, Figure 9 provides another "view" of the error between the reference and the radar-derived DEM. Figure 8 shows that the distribution of this error is closer to 0 mean and more narrow after correction, but it does not provide any information about the possible spatial correlation of this error. This is precisely what is provided in Figure 9, by plotting the variogram of this error before and after correction, which shows that there is much less structure after correction, with errors almost randomly distributed over the domain. We think that this is a relevant information which is worth to be provided to the reader.

10. *Conclusions (last lines): the application of the method maybe difficult for operational weather radar as it is difficult to take them of the network for a whole day. Probably the method will be more used for (mobile) research radars.*
    The proposed method is indeed primarily intended for mobile research radar systems with no operational constraints. But an operational radar with (relatively) high elevation angles in its scanning protocol could still benefit from this method by sampling the sun signature at different periods during one day.

Reviewer 3

1. *Page 5573: the index error E0 should be explained to the reader. It is just said that it has to be distinguished from CV. It is possible to understand this with some thinking, but the reader should be helped*

Figure 1 has been improved to better illustrate the different error terms.

2. *Page 5573: Notation CV and CH seems clumsy. What about CV and CH?*
The notation has been changed: CH_0 now reads C_{A_0} and CV_0 now reads C_{A_0}.

3. *Page 5576: Egs.7 and 8 use symbols which were introduced on page 5573. It would be helpful to repeat some definitions here, unless the work is restructured so that these two parts are combined. It is now demanding to understand the equations as no description of the symbols are given. It may be that some of the comments below are caused by misunderstanding because of this.*
To help the reader, we have added a reference to a newly introduced Table 1 which lists the different terms involved in these equations (see l.77-78).

4. *Page 5576: Are Ei and Ai the elevation and azimuth observations? The symbols are explained on page 5572 which is faraway.*
Yes they are. The text has been modified to clarify this issue (see l.146).

5. *Page 5576: Are the formulas original or taken from literature? In the latter case a reference need to be given. I assume that the angle between vertical electrical and mechanical pointing is always small. This is assumed, as the angle appears as such without any trigonometric functions. It appears to me that the formulas as limited to small values of Ei and Ai, because second term of Eg.(7) goes to infinity, as Ei approaches 90 deg. There is a similar problem with tan(Ei). The limits of validity have to discussed. Measurements up to 60 deg of elevation are shown in Fig. 1.*
These are "standard" formulas, and a reference has been added. The instrumental errors are assumed to be small (and this is used for approximations) but these

formulas are valid for all elevation and azimuth angles. The azimuthal error given in Eq.7 indeed increases with elevation (and tends to infinity at $E = 90$ deg): $\tan(E) \simeq 5.7$ and $1/\cos(E) \simeq 5.8$ when $E = 80$ deg (but note that $\beta_0 \simeq 0.008$ deg and $C_{A_0} \simeq 0.006$ deg in our case). The text has been modified to mention that the instrumental error terms β_0, C_{A_0}, C_{E_0} are considered small (see l.147-148).

6. *Page 5578: States that collimation errors cannot be estimated with earlier methods. This is true is a sense. However, for radar applications the electrical pointing is what matters, and hence the antenna is pointed using e.g. the sun. The elevation collimation error is then easy to check by measuring the antenna orientation by e.g. using plumb line. But the horizontal collimation error is difficult to determine with earlier methods.*
We agree with the reviewer. However, the method presented in this paper allows an automatic estimation of all these terms and do not require manual experiment. The word "automatically" has been added in the text to better highlight the added value with respect to previous methods. In addition, the automatic estimation of C_{E_0} and E_0 can be useful for diagnosis/maintenance purposes.

References

Huuskonen, A., and I. Holleman (2007), Determining weather radar antenna pointing using signals detected from the sun at low antenna elevations, *J. Atmos. Oceanic Technol.*, *24*(3), 476–483.

Swisstopo (2004), DHM25, the digital height model of Switzerland, *Tech. rep.*, Swisstopo.

Interactive comment on Atmos. Meas. Tech. Discuss., 4, 5569, 2011.