Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2017-25-AC2, 2017

Atmospheric Measurement Techniques Discussions

Interactive comment on "The sensitivity of snowfall to weather states over Sweden" *by* Lars Norin et al.

Lars Norin et al.

lars.norin@smhi.se

Received and published: 28 June 2017

We thank the referee for the time and effort spent to review the manuscript as well as for the very constructive comments and suggestions. Below, please find a point-by-point reply to the comments (reproduced in italics).

General comments

1. Previous research has identified the 8 states the paper analyzes. While investigating snowfall relative to these states is appropriate, I think the authors should note that these states are not independent from one another. I would like to know how many events comprise each category, and if individual dates can be included in

multiple categories.

A table listing the number of days containing the different weather states (as well as how many other other weather states occurred for those days) has been added to the manuscript.

2. Are there no snowfall observations over Sweden that can be used to further validate the remotely sensed data? At times the authors refer to "snowfall accumulation". As I understand the analysis performed, no statements can be made about snowfall accumulation, as the duration of the snowfall events does not appear to be considered.

We agree that no quantitative statements can be made about snowfall accumulation. To find a qualitative estimation of the relative contribution of the different weather states to the total snowfall amount, the average snowfall intensities were multiplied with the number of days for each weather state. The text in Section 4.3 has been adjusted in the revised manuscript.

3. Figures 1 and 2 — are these composites (means) of all events? Or individual events that are representative of the composites?

These are individual events, representative of the composites. This has now been clarified in the manuscript.

4. On the use of CloudSat — As you discuss, data represents a "snapshot" taken once or twice per day. Is snowfall occurring during all of these snapshots? How many snapshots are there per event? I am concerned about how representative these snapshots are for the events analyzed using the other more frequent data sources, as comparisons are made between them.

Yes, only passes during which CloudSat detected snowfall over Sweden were

used in the analysis. The number of data points with identified snowfall per pass varied from 1 up to 1007. It is true that measurements from the ground-based radars are more frequent as well as made over spatially smaller areas. However, only CloudSat can provide a detailed vertical structure of the snowfall. The impact of CloudSat's lower temporal and spatial resolution is now discussed in the manuscript.

5. I would like to know more about how the wind directions were defined. The NAO is straightforward and I can see how identifying the presence of a pressure center over land is tractable. But wind direction can be highly variable over the domains shown in the figures.

The method for identifying the weather states was presented in a paper by Thomas and Devasthale (Atmos. Chem. Phys., 14, 11545—11555, 2014). The wind directions were determined by analysing the average wind direction over an area near the centre of Sweden. For this reason wind direction can be different when far from this area (e.g. in the northernmost part of the country). The description of this method has now been expanded in the manuscript. The area in which the weather states were calculated has been added to figures 1 and 2.

6. I think it would be useful to the reader to see figures that show the radar coverages referred to in the text (48–82 km from a Swedish radar station), so we can have an idea of how representative the data is with respect to the entire country.

We thank the referee for the suggestion. The radar coverages used in the analysis have now been added to figure 3 and 10.

7. Related to the above comment, were the intensities for each event defined by averages over each radar volume? How many times were used in each event?

Yes, for each radar composite the average snowfall intensity was determined using all radar cells detecting snowfall. All snowfall measurements detected during each day (24 h) with an identified weather state were used.

8. I see that Norin et al. (2015) describes how the snowfall product is generated. Given the fact that your conclusions are heavily dependent upon the quality of the data that results from the methods used to define the product, I think it would be worthwhile to further discuss the limitations of the radar-based data.

A paragraph discussing the limitations of the radar-based snowfall product has been added to the revised manuscript.

9. Section 4.2, line 15. I see what you are referring to in Figure 9a and b, but I am not sure how this resolves the apparent paradox discussed in the previous paragraph. Perhaps you could be more explicit.

Fig. 2a shows that during High MSLP conditions, anticyclonic winds coming from Northern Europe further pick up moisture from the North Sea before making precipitation over western coast of Norway and southern parts of Sweden. This leads to increase in specific humidity over these regions (Figs. 7a and 8a). These snowfall events, whenever they do occur, also seem to be well vertically developed as evident in Fig. 9a. However, during low MSLP conditions, the location of low pressure (Fig. 2b) is such that more northerly, colder winds result in lower specific humidity anomalies (Fig. 8b). Notice however that over the southernmost tip of Sweden, humidity anomalies are slightly positive during low MSLP conditions due to warmer southwesterly winds. Since the centre of low pressure is slightly northward (compared to the centre of high pressure), the occurrence of snowfall events with differing intensities, over northern and southern regions of Sweden leads to more broader vertical distribution of snowfall as observed by CloudSat (Fig. 9b).

Minor comments

1. In line 5, it is stated that the NAO correlates strongly with precipitation, but explains only 32 to 54% of precipitation variability locally (Busuioc et al. 2001). In line 17, Linderson (2001) further observes a robust correspondence between local precipitation and large-scale circulation during winter months over southern Sweden. As written, it seems these results are contradictory. If this is the case, it should be highlighted as motivation for this study. If this isn't the case, perhaps the text could more clearly explain the differences in the studies.

We agree that the current formulation of these sentences is confusing. They are therefore clarified in the revised manuscript. During winter months, NAO can explain a significant part of precipitation variability. But in a year as a whole, the other circulation types, such as cyclonic systems, persistent westerly winds and even anticyclonic systems, can be more important, especially over the southern parts of Sweden.

2. Line 22 — Such a characterization also provides guidance concerning the performance of NWP models by quantifying their strengths and limitations in wintertime regimes — could you state more clearly how your work relates to NWP verification?

This rather abstract sentence is also rephrased in the revised manuscript. Our intention was to point out the fact that NWP models need to show similar response of snow to weather states as we have presented in this study, in order to capture snowfall events realistically. Therefore, the observationally based results from our study can be used for process oriented evaluation of NWP models to test the fidelity of NWP models.

3. Line 30 — snowfall distribution and frequency is very inhomogeneous meridionally across Sweden. How does it vary?

The snowfall distribution across Sweden is shown in Fig. 1 below. The southern parts of Sweden receives the smallest amounts of snow. The snow depth increases steadily with increasing latitudes but the largest snow depths are found in the mountains to the west, along the border to Norway. This description has been added to the manuscript.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-25, 2017.

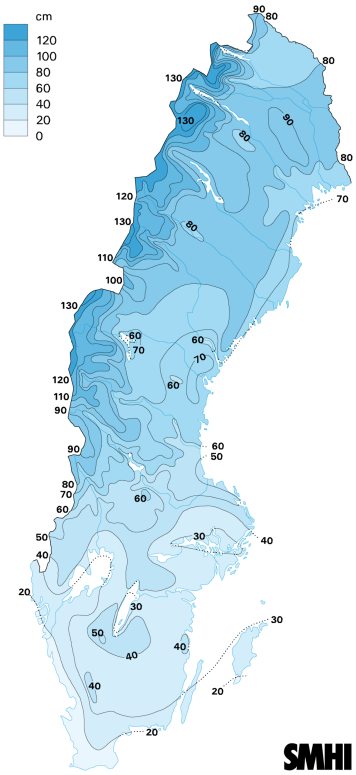

Fig. 1. Average largest snow depth during the period 1961–1990.