Answers to reviewers: TC-2021-281

Temporal stability of long-term satellite and reanalysis products to monitor snow cover trends

Ruben Urraca and Nadine Gobron

REFEREE #2 – Alvaro Ayala

Urraca and Gobron investigate the long-term temporal stability of snow-related variables produced by two global climate reanalysis products (ERA5 and ERA5-Land) for the period 1950-2020 (1980-2020 in the case of ERA5-Land) and the weekly Snow Cover Extent (SCE) charts produced by NOAA Climate Data Records (CDR) for the period 1966-2020. The authors compare these products against a set of 470 ground stations over the Northern Hemisphere. Temporal stability is investigated by calculating the bias in snow depth and snow cover duration of the products at each ground station. The authors found that the assimilation of new observations and satellite products improves the accuracy of snow variables of the reanalysis at the expense of introducing step discontinuities in the long-term time series, or, in the case of NOAA CDR, producing an artificial positive trend since 1990. Finally, the authors also use the ground stations data to update snow trends over the North Hemisphere.

I think that this a very good article, the research questions are clear and interesting for the scientific community and The Cryosphere. Results are well presented, and a clear message is provided in the Conclusions. The paper is a bit difficult to follow because it uses several data sets and methods, but overall, I think that the authors did a very good job in organizing the text. My recommendation is to accept the article with minor revisions. I have several short comments that could help for improving clarity.

COMMENTS

1) Temporal stability. I have some suggestions to improve the use of this key term:

1.1) I think that adding the word "temporal" would make the title more informative "Temporal stability of long-term satellite…".

Answer: We have added the word 'temporal' to the title:

"Temporal stability of long-term satellite and reanalysis products for snow trend analysis"

1.2) Please provide a formal definition of temporal stability in the Introduction. Paragraph 5 could be a good option. In the glossary of GCOS (2016): "Stability may be thought of as the extent to which the uncertainty of measurement remains constant with time. In this publication, values in Annex A under "stability" refer to the maximum acceptable change in systematic error, usually per decade." The thresholds defined by GCOS could be written next to the chosen definition.

Answer: We have included the definition given in GCOS (2016) in the introduction:

"Stability is defined by GCOS as the extent to which the uncertainty of measurement remains constant with time (GCOS, 2016). GCOS stability requirements for snow cover are 10 mm/decade for SD and SWE, and

4%/decade for SCE. These requirements refer to the maximum acceptable change in systematic error per decade."

2) As the authors don't use data from Canada it might be good to comment about the limitations of the analyses of snow trends in the Northern Hemisphere.

Answer: Following the reviewers' suggestions, we have added Canadian in-situ data to the study. We have processed all the stations available in the Canadian Historical Daily Snow Depth Database. Out of them, 57 passed our selection criteria for trend/stability analysis, and 34 were classified as representative for the validation of gridded datasets.

SUGGESTED TECHNICAL CORRECTIONS

2: The acronym EO is not used again in the article. I would remove the parenthesis.

Answer: We have removed the acronym.

3: "Temporal stability is essential but…" Essential for what?

Answer: We have rephrased the sentence as follows:

"Monitoring snow cover to infer climate change impacts is now feasible using Earth Observation data together with reanalysis products (derived from earth system model and data assimilation). Temporal stability becomes essential when these products are used to monitor snow cover changes over time. The stability of satellite products can be altered when multiple sensors are combined into a single product, and due to the degradation and orbital drifts in each individual sensor."

5: "some longest satellite and reanalysis products" but NOAA CDR was not originally a satellite product, or yes? Maybe you can find a more general term than satellite?

Answer: Before 1999, NOAA CDR was derived manually by trained scientists from optical satellite data. Since then, NOAA CDR assimilates the IMS satellite product. So, despite the manual processing of data, NOAA-CDR has always used satellite images as inputs.

11: lack of direct data assimilation

and

11: at the expense of

Answer: We have rephrased as follows:

"By contrast, ERA5-Land is more stable because it does not assimilate directly snow observations, but this leads to a worse accuracy despite having a finer spatial resolution"

14-15: This sentence is a bit confusing. I would suggest using here the "trade-off" sentence of the conclusions.

Answer: Rephrased as follows:

"Reanalysis datasets face a trade-off between accuracy and stability when assimilating new data to improve their estimations."

25: What variable would be "snow-albedo feedback" with units W m-2 K-1? Can you be more specific?

Answer: This is the definition of climate feedback given by IPCC:

"Changes of the net energy budget at the top of atmosphere (TOA) in response to a change in the Global Surface Air Temperature (GSAT)"

The IPPC AR reference is included at the end of the sentence for clarification.

32: What do you mean by "changing vegetation"? Do you mean seasonal changes? Does it affect the spatial representativity of ground stations?

Answer: The spatial representativeness of the stations, regarding snow cover variables, is reduced in stations surrounded by a heterogeneous land cover. We have rephrased as follows:

"Ground stations provide the most accurate snow measurements, but their spatial representativeness is very limited in mountain regions or places with heterogeneous land cover"

34: What is the source for the 11 long-term stations in the Southern Hemisphere? In Chile and Argentina there are several snow stations with long-term data, although not with a very high frequency (Masiokas et al., 2006).

Answer: The statement was extracted from IPCC AR5:

"Measurement challenges are particularly acute in the Southern Hemisphere (SH), where only about 11 long-duration in situ records continue to recent times: seven in the central Andes and four in southeast Australia."

We have included the corresponding reference. Nevertheless, we have relaxed the sentence as follows:

"Long-term snow measurements are particularly limited in the Southern Hemisphere (SH) (Stocker et al., 2013)."

46: On the other hand, microwave-based…

Answer: Done

74-75: Please explain what data are used to update the trends.

Answer: We have added the following clarification:

"The study also updates the snow cover trends in the Northern Hemisphere from 1955 to 2015. Snow depth and snow cover trends are evaluated with in-situ data due to the discontinuities and trends found in gridded datasets. Snow cover extent could be only evaluated by inter-comparing the three gridded datasets."

98: "consistent with" wouldn't be more precise "derived from"?

Answer: Rephrased as follows:

"ERA5-Land is a replay of the land component of the ERA5 climate reanalysis, forced by meteorological fields from ERA5"

101-102: "but snow…" can be deleted as is a repetition from the previous paragraph.

Answer: Done.

141: series.

Answer: Corrected.

159: "The course products evaluated" this is a bit unclear as it seems that you are evaluating the reanalysis. Please replace by something like: "The coarse pixels correspond to that of ERA5 and ERA5-Land"

Answer: We are indeed evaluating the quality of reanalysis products, so the interpretation is correct.

160: Why did you choose 2015?

Answer: We chose 2015 because it is the first full year provided by IMS 1km. We believe that one year of data is enough to evaluate the spatial representativeness of the stations, since we are covering all the snow cover patterns throughout the year.

184: 50 or 5%?

Answer: SCF = 50%. We have modified Fig. 2 x-axis (previously it was in 0-10 scale) to be consistent with numbers in the text.

185: in the middle of these values

Answer: Done.

226: affected by the station removal.

Answer: Added.

233: SSE<=4.01

Answer: Corrected

252: RIHMI instead of RIHIMI. There might be more typos with this acronym, please revise.

Answer: Thanks. We have revised the manuscript accordingly.

257: lack of direct data assimilation

Answer: Thanks. Added.

274: In what figure can we see the positive trend?

Answer: Fig A6 (fall) and Fig A7 (winter). We have specified the exact figures in the text.

282: Delta bias was not defined as percentual. Please add the word "percentual" or similar. What would be the base for that percentage? Bias before?

Answer: We have added the definition of both absolute and relative delta bias in the Methods section.

361: …1950-2020 using data from the ground stations.

Answer: Done.

424: The acronym NWP has not been introduced

Answer: We have defined it.

Figure 2: Please add Snow Cover Fraction and Snow Depth in the caption.

Answer: Thanks for the comment. We have added both.

Figure 7: Why not showing the map of MAM in b?

Answer: Because the number of significant trends in that season is smaller, and the few stations showing significant trends have diverging signs. Boxplots in Fig. A8 also evidence the lack of artificial trends globally in MAM.

We have clarified why we did not include this map in the figure caption.

Figure 9: Please add in the caption that the trends are computed with the ground data.

Answer: Done:

"(a) Annual and (b) seasonal decadal trends in snow depth (SD) and snow cover duration (SCD) from 1955 to 2015 based on in-situ measurements"

Sometimes supplementary figures are named AX and sometimes SX.

Answer: We have renamed all supplementary figures consistently.

Figure A2: Is panel b RIHMI-NOAA CDR correct? It seems that there are very few valid observations. These data the same as those used in Figure 7a, aren't they?

Answer: Yes. Panel b (SCD bias in winter, new Fig. A7) seems to be empty because the SCD bias is zero or close to zero in most RHIMI stations during winter. This is because most RIHMI stations are covered by snow during the whole winter period.

Table 2: According to line 170, the units of SSE and SSB should be days/year.

Answer: Yes. We have updated it accordingly.