

Review of: 'ESOLIP – estimate of solid and liquid precipitation at sub-daily time resolution by combining snow height and rain gauge measurements' by E. Mair, G. Bertoldi, G. Leitinger, S. Della Chiesa, G. Niedrist, and U. Tappeiner

General comments:

This paper propose a method for calculating hourly total precipitation in mountain areas from unheated rain gauge measurements, snow height measurements by ultrasonic rangers and micrometeorological data gathered by automatic weather stations, based on the increasing number of such recording devices operated at high altitudes for various purposes. The measurement or estimation of total precipitation in mountain areas is a key issue for many practical and scientific applications, therefore any contribution aimed at better understanding the processes and/or at improving precipitation estimates in these areas could have significant impacts. The ESOLIP procedure proposed by the authors could be valid, in principle, for sites equipped with similar instrumentation. However, in my opinion, the manuscripts has many deficiencies, both conceptual and formal.

From the conceptual point of view, the authors do not provide adequate description of the instrument characteristics and, most importantly, they do not discuss error sources and uncertainties in measurements (e.g. the effect of wind redistribution on the readings of snow pillows and ultrasonic rangers), which are relevant because the ESOLIP approach makes use of many meteorological sensors (temperature, relative humidity, solar radiation, wind speed, snow height, rainfall), each of which has its own uncertainty. In addition, the choice of case studies looks unfortunate, because they are peculiar (e.g. too small precipitation events, not representative of typical winter or spring precipitation), affected by likely instrumentation failure (e.g. the heated rain gauge undercatch reaches 78%, which is much larger than errors reported in literature for such instruments), and use of inappropriate measurements (e.g. the snow pillow for estimating total precipitation) for testing the hypotheses. The authors do not adequately discuss the problems stemming from these choices, which significantly impact the obtained results. In many cases it is unclear how the authors optimize the threshold values, filtering methods and calculation methods for fresh snow density, to be used in ESOLIP. Insufficient elements are presented in support of the drawn conclusions. For example it is not obvious how have been established the relative humidity and global radiation thresholds, to be used for assessing the precipitation possibility, because it is not clear how did the authors assessed into which hours there was precipitation (circular reasoning), and how were these threshold combined, for example during night when the global radiation is zero.

From a formal point of view, the paper is rather long and in some cases its reading is difficult. The use of synonyms does not help the reader and a higher consistency throughout the paper would be desirable. Many concepts are implicit and should be clarified (see details in the specific comments). Moreover, it is not always understandable what has been done, with which chronological sequence and into which of the two presented study areas. Many concepts are repeated in various parts of the paper and in some cases they are not in the right part of the manuscript (e.g. methods in the results or vice versa) and need to be re-organized. Finally, an English proofreading is recommended.

To conclude I would say that this paper is not acceptable as is, and that it requires a major revision before being reconsidered for publication in this journal.

Specific comments:

Page 8684, line 3: consider to substitute 'themes' (maybe too generic) with 'applications' or 'research themes'

Page 8684, line 8: I think that the separation of precipitation into solid and liquid phases would be more clear than speaking about a generic winter precipitation. Try also to be consistent throughout the paper

Page 8684, line 9: there 'is' an increasing number...

Page 8684, line 12 and following: in my opinion here the author should better clarify how the ESOLIP approach works, e.g. by stating more clearly that it is based on unheated precipitation data, for example just after 'is proposed', at line 12.

Page 8684, line 13: careful filtering of snow eight 'data' (or measurements)

Page 8684, line 16: comparing 'the' results...

Page 8684, line 16: do you mean 'solid', by using 'winter'? Or maybe solid plus liquid? Try to be more specific, also in the following of the paper

Page 8685, line 6: also the increased frequency of solid precipitation is a limit at higher altitudes

Page 8685, line 15: which are usually installed

Page 8685, line 18: 40% is not a correction factor, I guess you meant 1.40. However I think that you could write 'because underestimates may exceed 40-50%', after 'empirical factors'. Add also further references, e.g. WMO intercomparisons

Page 8685, line 19: add some references in support to this statement

Page 8685, line 22: why are these data more available than in the past? Maybe you can also mention here the higher time frequency of these newly available data

Page 8685, line 20 and following: in my opinion this period should be re-arranged. Firstly, I would talk about the limitations (undercatch, costs, time etc...), then I would talk about the newly available technologies and higher frequency data, which provide new opportunities and so on...

Page 8685, line 27: consider substituting 'less detailed' with 'lower'

Page 8686, line 1: snow pillows also have technical problems, e.g. they tend to misread when ice layers form inside the snow pack. And what about snow redistribution by wind?

Page 8686, line 3: consider replacing 'correspondingly' with 'proportionally'

Page 8686, line 7-10: please, try to improve this sentence, e.g. by moving the water budget concept at the beginning of the sentence. Try also to avoid the excessive repetition of 'especially', and add few references at the end of the period.

Page 8686, line 10: to calculate 'the' snow....

Page 8686, line 11: and therefore 'to' derive...

Page 8686, line 13: these approaches 'were' not validated

Page 8686, line 14: across the 'entire' hydrological year (remove yet)

Page 8686, line 16: I think that this period should be completed explaining why these approaches are applied at a seasonal resolution, rather than at event- or day-scale.

Page 8686, line 17 (and in the following of the paper): In order to calculate 'the' SWE; an accurate estimate of 'the' snow density...

Page 8686, line 18: is 'generally' assumed

Page 8686, line 21: that the new snow density may vary

Page 8686, line 23-26: this sentence overloads the Introduction and in my opinion it should be moved in the Methods section

Page 8687, line 1-12: this part also overloads the Introduction, try to synthesize

Page 8687, line 13: for measuring, or to measure

Page 8687, line 14-15: snow redistribution by wind is another important source of error for ultrasonic snow height measurements

Page 8687, line 18: what do you mean with 'vice versa'? Snow removal by wind and/or melt?

Page 8687, line 22-26: please, rewrite to improve English and clarity. Maybe better also to use 'solid' and 'liquid', rather than snowfall and rainfall, and to be consistent throughout the paper.

Page 8687, line 27: I think that you should explain here, even shortly, in what consists the ESOLIP procedure. Are the following methods (precipitation occurrence, density, filtering etc...) part of ESOLIP? Try to better link the sentences and the different concepts

Page 8687, line 28-29: what is 'precipitation possibility'? Maybe you meant precipitation occurrence? What's the difference between meteorological data and meteorological information?

Page 8688, line 3-5: do the tested snow height filtering routine and the indicators for possible precipitation make part of the ESOLIP? If so, why not saying (generally) that the ESOLIP was tested in two different locations?

Page 8688, line 9: I would avoid starting the sentence with 'in addition'. Otherwise, I would write 'The experimental site is equipped with a meteorological station, which includes the following sensors... A snow pillow also operates at Kaserstattalm....'

Page 8688, line 14: it is unclear if the mentioned working period is referred to the snow pillow or to the entire instrumental setup (meteorological station and snow pillow)

Page 8688, line 14-15: I would skip mentioning here the filtering routine and the indicators for possible precipitation (maybe better indicators of precipitation occurrence, also in the following of the paper). You should simply introduce the other experimental site of Matsch Valley. And add a figure with the geographical setting of both sites!

Page 8688, line 20: at a distance of 3 km

Page 8688, line 22: what are the purposes of these manual measurements? Are they operational observations e.g. in the framework of hydropower production? Provide some details on how these measurements were carried out (e.g. measurements include snow height and fresh snow or only snow height?)

Page 8688, line 24-25: where they considered or used? Here you restart speaking about the automatic weather stations, why not completing their description before talking about manual observations? Do you refer to all the sensors or to a specific (i.e. snow height) sensor?

Page 8689, line 4: add 'as' after 'data'

Page 8689, line 9: add 'actual' after 'related to'

Page 8689, line 13: here 'additional data' is not so clear. It obliges a re-reading of the preceding sentence. Try to clarify what is additional data in the preceding sentence

Page 8689, line 17: please be more specific when you say 'meteorological data'

Page 8689, line 18: avoid reference to a figure in the heading of a section

Page 8689, line 20-21: how was this carried out? Did you compare the rain gauge data with nearby weather stations? If not, how did you establish which data were outliers and which were not?

Page 8690, line 4: but 'it' does not

Page 8690, line 5: try to explain why there is this residual error in snow height measurements. Is it dependent on the solar radiation? Additional errors affect the snow height measurements by sonic rangars, such as sudden spikes during precipitation events and wind redistribution/preferential deposition. Did you correct also these errors?

Page 8690, line 8: in my opinion one should not apply moving averages when aiming at obtaining hourly data

Page 8690, line 15: remove the parentheses and 'which was'

Page 8690, line 16-19: reading the following sentences, it seems that a two-step procedure is implemented: i) check of metadata to exclude periods without precipitation, and ii) automatic exclusion of erroneous precipitation data, based on hourly measurements of relative humidity and solar radiation. If this is true, then clarify (also in Figure 1)

Page 8690, line 19: remove 'from further analysis'

Page 8690, line 19-20: these are results rather than methods

Page 8690, line 20-22: what do you mean with 'describe the general weather conditions'? Be more specific. And what do you mean with 'allow further reduction of periods to investigate'? Maybe additional filtering, or exclusion of erroneous precipitation data from the final data series? Clarify and try to be consistent throughout the manuscript

Page 8690, line 23-27: how did you establish these maximum % errors?

Page 8691, line 2-3: do these authors use meteorological data with the same time steps, i.e. hourly data (also for global radiation)?

Page 8691, line 3-5: how did you assess 'real' precipitation?

Page 8691, line 8: 'snowpack' in capital letters

Page 8691, line 6-15: here the authors present a fixed threshold value for global radiation, to be used for excluding erroneous precipitation recordings. However the clear-sky global radiation varies during the day, and it also varies during the year. Therefore, in my opinion, the authors should explain why did they not used a normalized threshold, e.g. a given fraction of the clear-sky global radiation. And what about the night hours? Maybe they used the relative humidity data alone? It is not clear how they used the radiation data in combination with the relative humidity data, which is however reported in Table 1

Page 8691, line 21-23: here the authors introduce the use of the air temperature as an additional variable to distinguish between presence/absence of precipitation, but it is not clear how do they used it, i.e. in a qualitative or quantitative way, for example using fixed thresholds and/or in combination with global radiation. Moreover, how was managed the case of actual rainfall melting the snow accumulated at the rain gauge orifice?

Page 8692, line 2: snowline has a precise meaning in glaciology (i.e. *a set of points forming the lower limit of a snow-covered area*. see e.g. Cogley et al., 2010). Use snowfall limit instead, for example, or give a definition. However, in my opinion, the air temperature, or wet bulb temperature or dew point temperature say little about the position of the snowfall limit (i.e. they only could say if it is above, at, or below the elevation of the automatic weather station). Therefore I would prefer to use the term 'precipitation phase' (solid or liquid), or 'precipitation status', in this case.

Cogley, J.G., Hock, R., Rasmussen, L.A., Arendt, A.A., Bauder, A., Braithwaite, R.J., Jansson, P., Kaser, G., Möller, M., Nicholson, L. and Zemp, M., 2010, Glossary of Glacier Mass Balance and Related Terms. IHP-VII Technical Documents in Hydrology No. 86, IACS Contribution No. 2, UNESCO-IHP, Paris. 114 pp.

Page 8692, line 5: why does it work better than other methods? Give a short explanation

Page 8692, line 6: why is it considered less suitable?

Page 8692, line 8-9: this is a quite low limit. Does it derive from the technical specifications of the snow height sensors? Or maybe from your tests? And what about short-term fluctuations and reading errors?

Page 8692, line 22: variation of what?

Page 8692, line 23: the threshold is = 1°C, not < 1°C

Page 8693, line 5-26: try to improve the description of the whole section 4, in particular how it is structured and divided in sub-sections, to improve readability

Page 8693, line 7-14: in my opinion this part could be improved by better specifying what has been done and where, and looking after the time sequence of calculations/assessments. This could be better specified also in the methods

Page 8693, line 19: remove comma after 'allowed'

Page 8693, line 19-20: the accuracy and errors of snow pillow readings should be better analyzed. Why do the authors assume that the evaluations from relative humidity and global radiation are better indicators of precipitation occurrence than the snow pillows reading? Did the authors account for possible errors in the snow pillow reading coming from snow redistribution by wind?

Page 8693, line 23: are you sure of this? Theoretically, heated rain gauges should melt precipitation *during* the events, not *after* them. Errors of heated rain gauges mainly stem from wind-induced undercatch (there is much literature on that), and more rarely they get occluded from intense snowfalls. Therefore the authors should better justify why they did not use heated rainfall data.

Page 8694, line 8: according to previous statements, ultrasonic range disturbances mainly stem from air temperature fluctuations and solar radiation. However, both are low during precipitation events. In addition, there is not enough information on the magnitude of these errors and on the frequency of their occurrence and/or relationship with air temperature and solar radiation. Here it seems that the authors account for these errors using simple moving averages, but this choice should be better justified providing adequate information on sensor errors magnitude and occurrence

Page 8694, line 9: Figure 3

Page 8694, line 12: do you mean 'notable', 'remarkable'?

Page 8694, line 14: remove 'however' and start a new paragraph

Page 8694, line 16-18: please rephrase, unclear and difficult to read

Page 8694, line 18: add 'for these two events' after 'were found' to improve clarity

Page 8694, line 21: snow height or fresh snow height? New snow height? Be consistent

Page 8694, line 21-23: is this magnitude estimate based on authors experience, literature, data of this study, or what?

Page 8694, line 23-24: how was this carried out? Was the above-mentioned underestimation taken into account in some way?

Page 8694, line 26: define 'close to reality'

Page 8694, line 20-28: is this part concerning the two-events analysis or the entire period of observations? Try to clarify

Page 8695, line 10: what means 'resp.'?

Page 8695, line 17-18: did you mean 'a reduction of the same magnitude'?

Page 8695, line 18-19: which reasons (better 'these')? The correspondence between the two sites is totally insufficient in supporting the choice of the 5 h moving average

Page 8696, line 22-23: which are 'the requirements for SWE calculation of single events'. Not clear (also at lines 1-2 and 6-7, page 8697).

Page 8697, line 1-2: please, provide additional information (e.g. statistics, or a figure, or a reference to results presented in the following of the paper) because Figure 4 does not support this assessment

Page 8697, line 4: provide a more complete description of the test sites, also concerning the local topography and the presence of nearby obstacles, in Section 2. Additionally, discuss the low importance of wind in density calculations, based on site characteristics

Page 8697, line 9-19: consider to completely remove this part

Page 8697, line 24: why did you select a winter event with such a small precipitation amount? It's not representative of typical precipitation events during winter, I guess

Page 8698, line 1-3: these considerations should be moved at the end of the sub-section, after the discussion of both events, taken individually

Page 8698, line 8: and 'later' end?

Page 8698, line 19-21: this sentence is unclear, maybe 'approach' at line 20 has to be replaced with 'snow pillow'?

Page 8698, line 21-22: this sentence contradicts the previous one, because you don't have enough data to assess the error of the heated rain gauge (i.e. you say that the initial rain was not registered by the snow pillow). Line 22, do you mean 'air' temperatures? 2 m air temperature should be added in Figures 5 and 6. Overall, the analyzed events seem to be unfortunate choices and the conclusions which were drawn seem not to be supported by the data. In the first event, the authors should report also the precipitation recorded by the heated rain gauge after 14:00 of 28/01/2010, because it's clear that the heating system of the rain gauge was not working properly (this issue should be anticipated in the Section 2 and more properly discussed in Section 4). In the second event ESOLIP estimates cannot be compared to snow pillow recordings because, as the authors say, rainfall at the start of the event was not registered as the snow pillow was not covered by snow. Also in this case it is not clear if the heated rain gauge recorded precipitation data after the sunrise of 16/01/2010. If this event should be characteristic of spring conditions, why the authors did not present a spring event?

Page 8698, line 27-28: also underestimates, because the final values are quite similar

Page 8699, line 1: also in this case, both overestimates and underestimates are visible in the diagram of Figure 7

Page 8699, line 4: I would not talk about 'underestimation' in this case, because it is clear that the heated rain gauge was malfunctioning (see e.g. the completely missed events during the winter).

Underestimation here reach about 75%, which would require a correction factor of about four, hardly found in the literature for average seasonal or annual precipitation amounts.

Page 8699, line 5: the authors have not discussed one of the main issues in comparing 'total' precipitation estimates by means of ESOLIP with snow pillows measurements. The latest, indeed, do not record liquid precipitation occurring without snow cover, or percolating through the snow. Maybe the authors in this case included only solid precipitation events, but this is not clearly explained. In my opinion this should be detailed well upfront here and in the methods section.

Page 8699, line 14-15: please, discuss the magnitude of the instrument error and compare it to the errors reported in the literature for rain gauges with similar characteristics. There is also a lack of a discussion of the difference among different seasons, which is large (Table 4)

Page 8699, line 15-18: I think that a more careful analysis of data would confirm this hypothesis, thus the word 'probably' should be avoided

Page 8699, line 17: considering the snow pillow as the reference in all season is a bit problematic, because it cannot measure liquid precipitation. How did you face with this issue?

Page 8699, line 17-24: these conclusions are questionable, because of the above-mentioned problems of using the snow pillow as a reference. A certain overestimation of total precipitation by ESOLIP is desirable, indeed, to account for the underestimations of total precipitation obtained by only snow pillow readings

Page 8700, line 2-4: the determination of precipitation possibility has been assessed using relative humidity and global radiation data. Therefore, what is the link with the differentiation between rainfall and snowfall?

Page 8700, line 8-11: in my opinion this conclusion is not adequately supported by the data and the results provided in the paper

Table 1: explain e.g. in the caption the reason of the different values presented in the table (i.e. taken in the literature and compared to the present work)

Table 2: two precipitation events are presented, not just one (modify in the caption). Try to avoid repetition of 'data' in the second line of the caption. The second column does not report snow height increments (which are reported in columns 3 to 6, instead)

Figure 1: step 2, there is also a third case, which is precipitation possible but not recorded (e.g. rain falling over a rain gauge which is obstructed by snow, or rain gauge malfunction). Did you accounted also for this possibility?

Figures 2 and 3: original data are poorly visible in the diagrams. Give an explanation of why moving averages are interrupted (in the captions)

Figure 4: replace 'tested' with 'calculated' in the caption. Clarify the duration of the analyzed precipitation events (hourly data?)

Figure 5 and 6: add air temperature data

