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Geoscientific
Model Development
Discussions

Interactive comment on "TOPMELT 1.0: A topography-based distribution function approach to snowmelt simulation for hydrological modelling at basin scale" *by* Mattia Zaramella et al.

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Our point-to-point response is reported below. Reviewer's Comments are reproduced in italics; the Authors' Responses are given directly afterward. All reviewer comments are identified using the code RXCY, where X is the reviewer number and Y is the reviewer comment number (for example R1C3 means Reviewer 1 Comment 3). Line numbers in authors' responses refer to the original manuscript unless otherwise stated.

The following answers are an integration to the answers given with comment **SC1**. Re-organisation of the answers was necessary after a revision of the manuscript accounting for all the reviewers' comments. We apologise for any repetition.

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Answers to main comments

R1C1: LUMPED or SEMI DISTRIBUTED. Here is the definition of lumped very broad and actually the implementation with elevation bands and radiation index classes heavily reminds me the definition of hydrological response units, also a semi-distributed approach. I think your approach is much more semi-distributed than lumped.

In the manuscript, we characterised TOPMELT as ‘lumped’ in order to make very clear the differences with a spatially distributed approach. However, we agree with the Reviewer that the model can be considered as ‘semi-distributed’, as this class of models do not make calculations for every point in the catchment but for a distribution function of characteristics. TOPMELT has the feature that the snow predictions can be mapped back into space for comparison with any observations of the snow properties. We substituted ‘lumped’ with ‘semi-distributed’ in the revised version.

R1C2: INPUT PRECIPITATION Please expand on the techniques declared at page 4.

With the sentence at line 13, page 4, we mean that precipitation can be calculated by using a range of methods (Thiessen Polygons, multi-quadratic and Kriging), on the condition that the model input is an areal precipitation estimated starting from any of these techniques. The interpolation and averaging code of precipitation is not included in the version of TOPMELT illustrated in this manuscript, but it is included in the complete hydrological model code. For the case study of the paper, we used the Thiessen polygons to calculate an areal precipitation over the whole basin. We clarified this issue in the revised version of the paper.

R1C3: LIST OF VARIABLES I would welcome a Table with a list of the used abbreviations.

A table with model parameters and variables is reported here below and is included in the revised version of the paper.

R1C4: "DYNAMIC" RADIATION AREA AND INDEX: If you had static radiation regions

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instead of radiation classes you would not need the supplementary workaround for updating the states with a "migration". Can you better justify your choice, or, even better, compare your results to a version with static radiation sub areas selected using elevation, aspect and/or slope?

TOPMELT accounts for the seasonality of sun declination and for the visible horizon, therefore including both the effects of the temporal variability of the incident radiation angle and of shadowing. This makes the spatial distribution of radiation variable over time, which requires the updating of the snow states and represents a key feature of the model. The use of topographic variables, like aspect, elevation and slope as a surrogate for radiation is similarly subject to arbitrariness and lack of generality. For instance, during winter months in Norther Hemisphere, portions of north-facing slopes may remain shaded throughout the day due to the low angle of the sun. This causes snow on north-facing slopes to melt slower than on south-facing ones. The scenario is just the opposite for slopes in the Southern Hemisphere, where north-facing slopes receive more sunlight and are consequently warmer. Near the Equator, north- and south-facing slopes receive roughly the same amount of sunlight because the sun is almost directly overhead. At the Poles, north and south slopes tend to be either shrouded in darkness all winter long, or bathed in sunlight all summer long, with only slight variation between the slopes in spring and fall. All this, shows that using radiation instead of topographic variables leads to a better generalization of model application and evaluation. The paper already includes an analysis of the impact of decreasing the frequency of the snow state updating. This can be seen in Figure 8 of the submitted paper, left panel, which shows the impact of updating the radiation distribution at decreasing frequency. The frequency ranges from 1 week, which is chosen as the reference temporal aggregation, to 2 weeks, 4 weeks, 8 weeks and 12 weeks. Figure 1 below shows the scatter plots corresponding to the pixel-by-pixel comparison summarised in Figure 8 of the submitted paper, in terms of snow water equivalent (w.e.). The scatter reported in Figure 1 indicates that the impact of the decreasing frequency may have important consequences when the w.e. spatial distribution is sought.

Specific comments

R1C5: Page 1, line 10: Similar topic was addressed in Klok et al, 2001, where Hock model has been implemented in a fully distributed and in a semi distributed model. Klok, L., K. Jasper, K. Roelofsma, A. Badoux, J. Gurtz (2001) Distributed hydrological modelling of a glaciated Alpine river basin. Hydrol. Sci. J. 46: 553-570.

Reference added (see marked-up manuscript).

R1C6: Page 1, line23: Zappa M, Pos F, Strasser U, Warmerdam P, Gurtz J. 2003. Seasonal water balance of an Alpine catchment as evaluated by different methods for spatially distributed snowmelt modelling. Nordic Hydrology 34: 179-202.

Reference added (see marked-up manuscript).

R1C7: Page 2, line 24: Here is the definition of lumped very broad and actually the implementation with elevation bands and radiation index classes heavily reminds me the definition of hydrological response units, also a semi-distributed approach.

Please see our response to R1C1.

R1C8: Page 2, line 28: A priori statement, not yet supported by results and/or references. The comment refers to the sentence: 'This is a potentially significant advantage when parameter sensitivity and uncertainty estimation procedures are carried out'.

We have rephrased as follows: 'This is a potentially significant advantage when several model simulation runs should be carried out, such as in Monte Carlo based parameter sensitivity and uncertainty estimation procedures.'

R1C9: Page 3, line 3: Making this a semi-distributed approach ....

We agree on this comment, which underlines the need to term 'semi-distributed' the TOPMELT modelling approach.

R1C10: Page 4, line 8: single for the whole basin and a specific day or single for the

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whole computation period?

We thank the Reviewer for the opportunity to better specify here: ‘Air temperature data are used to estimate an unique hourly vertical lapse rate for the whole basin’ (revised Section 2.2, first paragraph).

R1C11: Page 4, line 13: Reference(s)? This is the only place where you declare how P is interpolated, but it seems to me quite strange to declare a "range of techniques" used .... Did you use now Kriging or Thiessen?

See our response to comment R1C2. We modified the original text as follows: ‘The model permits use of several techniques ranging from Thiessen’s polygons to multi-quadratic (Borga and Vizzaccaro, 1997) for the estimation of basin mean areal precipitation values. For the analyses reported in this work, the Thiessen method was used’ (revised Section 2.2, first paragraph).

R1C12: Page 5, line 8: Rerference(s)?

Reference was added (Anderson, 1976).

R1C12: Page 5, line 10: A table provided as supplementary material listing all variable and units might be a good addon.

Please see our response to R1C3

R1C13: Figure 1: You define for each time and elevation band 10 sub-regions with equal area after sorting them according to RI. Why 10 areas? Why not discriminate them according to slope and aspect (which seems dominant to me).

‘Why 10 areas?’ The impact of using different subdivisions is examined in Figure 8b of the submitted paper, where the number of classes ranges from 1 to 20, showing that the gain in reproducing the snow water equivalent spatial distribution is very limited when more than ten classes are used. See our response to R1C4 for the comment concerning the use of topographic information to discriminate between local areas. We revised Figure 1 changing the colour scale (see below).

R1C14: Page 6, line 14: If you had static radiation regions instead of radiation classes you would not need this supplementary workaround for updating the states. Can you better justify your choice, or, even better, compare you results to a version with static radiation sub areas selected using aspect and/or slope?

See our response to R1C4 for the comment concerning the use of topographic information to discriminate between local areas.

R1C15: Page 8, line 17: What is suitable in your opinion?

We used 10 mm as a threshold value in this analysis. The revised version has been updated accordingly and a reference supporting the choice was added (Parajka and Blöschl, 2008).

R1C16: Page 10, line 3: Thanks, this replies one of my previous points.

Thanks.

R1C17: Page 10, line 20: For nc1 there should not be any migration, isn't?

Yes, when using just one class there is no need to update the snow water equivalent.

R1C18: Page 10, line 20: With static radiation classes you should not have any migration but exploiting the potential of ERI, isn't?

The Reviewer is right in this remark, but we note that solar radiation is inherently variable in time. Thus, taking this variability into account should at least be attempted in a model which aims to use both temperature and radiation for snowmelt modelling.

R1C19: Page 12, line 20: Zappa M. 2008. Objective quantitative spatial verification of distributed snow cover simulations – an experiment for entire Switzerland. Hydrological Sciences Journal, 53(1): 179–191. DOI: 10.1623/hysj.53.1.179.

We added this reference.

R1C20: Page 13, line 2: Still W4-C10?

Yes, we put a note on this in the revised text (see marked-up manuscript).

R1C21: Figure 6: I would be interested to see a "spaghetti plot" sorted by C and W.

Whereas the sensitivity of the modelled snow water equivalent to variation of number of classes (C) and number of updates (W) is quite remarkable, the sensitivity of the modelled runoff is much less (actually, dispersion in the spaghetti plot cannot be recognised). This is due to the size of the study basin and the branching nature of the river network; both provide a powerful way in averaging out the heterogeneity of snowmelt processes, as shown by Comola et al. (2015). In order to illustrate this point, we reported values of the Nash-Sutcliffe index for different model simulations obtained by using different values of C and W (see Table 2 of the revised paper, reported below). In the revised version, we also examined the control exerted by the catchment size on runoff simulations. We subdivided the study basin into a number of sub-basins characterised by different drainage areas. We isolated 5 basins with mean drainage of 20 km^2, 10 basins with mean drainage area of 10 km^2, and 20 basins with mean drainage area of 5 km^2. Results are reported in the new Section 3.4 of the revised version (see Table 3, reported below, for a summary).

R1C22: Figure 8: Why not using same scale of y-axis in the left and right graphs? So you could easily see that W is less sensitive than C

In the revised version of the paper we used the same scale.

R1C23: Page 15, line 5 (it is fig 8).

Corrected.

References

Borga M. and Vizzaccaro A.: On the interpolation of hydrologic variables: formal equivalence of multiquadratic surface fitting and kriging, J. Hydrol., vol. 195, no. 1–4, pp.

160–171, doi:10.1016/S0022-1694(96)03250-7, 1997.

Comola, F., B. Schaefli, P. Da Ronco, G. Botter, M. Bavay, A. Rinaldo, and M. Lehning: Scale-dependent effects of solar radiation patterns on the snow-dominated hydrologic response, Geophys. Res. Lett., 42, 3895–3902, doi:10.1002/2015, 2015.

Parajka, J., and Blöschl, G.: Spatio-temporal combination of MODIS images - potential for snow cover mapping, Water Resour. Res., 44, W03406, doi:10.1029/2007WR006204, 2008.

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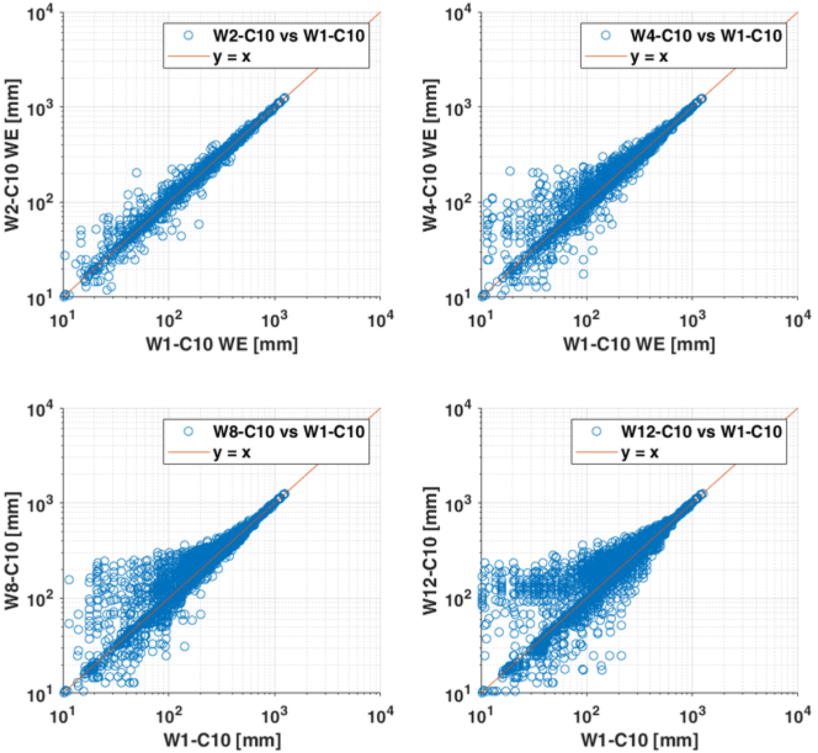

Fig. 1: Scatter plot of the pixel-by-pixel comparison of w.e., obtained by updating the w.e. classes at decreasing frequency ranging from 2 weeks to 12 weeks. The updating frequency of 1 week is used as reference. The study period is from October 1 2010 to June 30 2011.

Fig. 1. Additional figure

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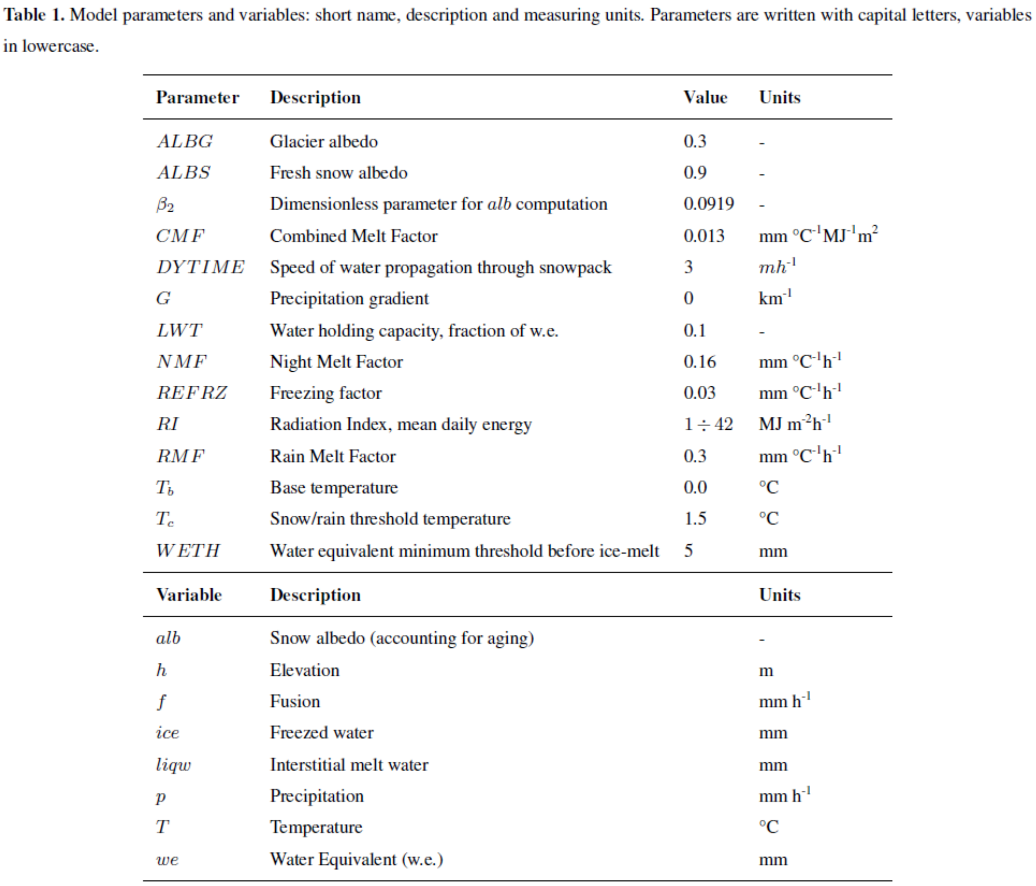

Table 1. Model parameters and variables: short name, description and measuring units. Parameters are written with capital letters, variables in lowercase.

Parameter	Description	Value	Units
$ALBG$	Glacier albedo	0.3	-
$ALBS$	Fresh snow albedo	0.9	-
β_2	Dimensionless parameter for alb computation	0.0919	-
CMF	Combined Melt Factor	0.013	mm °C^{-1}MJ^{-1}m^{2}
$DYTIME$	Speed of water propagation through snowpack	3	mh^{-1}
G	Precipitation gradient	0	km^{-1}
LWT	Water holding capacity, fraction of w.e.	0.1	-
NMF	Night Melt Factor	0.16	mm °C^{-1}h^{-1}
$REFRZ$	Freezing factor	0.03	mm °C^{-1}h^{-1}
RI	Radiation Index, mean daily energy	$1 \div 42$	MJ m^{-2}h^{-1}
RMF	Rain Melt Factor	0.3	mm °C^{-1}h^{-1}
T_b	Base temperature	0.0	°C
T_c	Snow/rain threshold temperature	1.5	°C
$WETH$	Water equivalent minimum threshold before ice-melt	5	mm

Variable	Description	Units
alb	Snow albedo (accounting for aging)	-
h	Elevation	m
f	Fusion	mm h^{-1}
ice	Freezed water	mm
$liqw$	Interstitial melt water	mm
p	Precipitation	mm h^{-1}
T	Temperature	°C
we	Water Equivalent (w.e.)	mm

Fig. 2. Table 1, revised paper.

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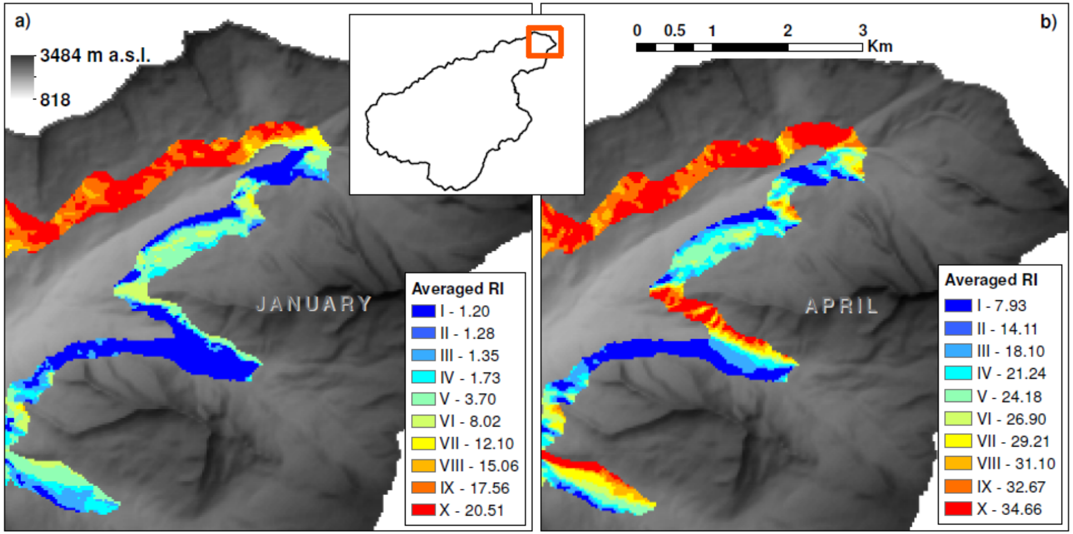

Figure 1. Comparison between radiation index distribution over the 2000-2200 m elevation band of the Aurino basin for a) January 1st and b) April 1st (ten classes subdivision). The figures show the north-eastern portion of the basin and report the average radiation index [J m^{-2}], with the corresponding radiation class identified by a roman number.

Fig. 3. Figure 1, revised paper.

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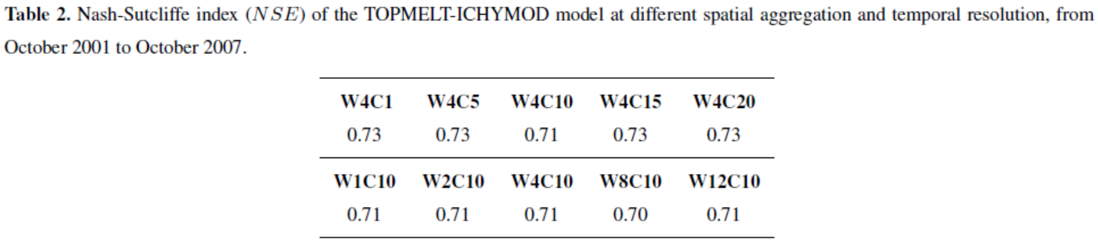

Table 2. Nash-Sutcliffe index (NSE) of the TOPMELT-ICHYMOD model at different spatial aggregation and temporal resolution, from October 2001 to October 2007.

W4C1	W4C5	W4C10	W4C15	W4C20
0.73	0.73	0.71	0.73	0.73
W1C10	**W2C10**	**W4C10**	**W8C10**	**W12C10**
0.71	0.71	0.71	0.70	0.71

Fig. 4. Table 2, revised paper.

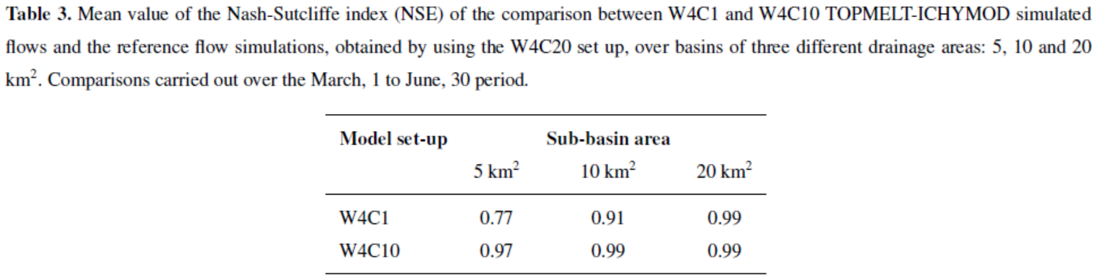

Table 3. Mean value of the Nash-Sutcliffe index (NSE) of the comparison between W4C1 and W4C10 TOPMELT-ICHYMOD simulated flows and the reference flow simulations, obtained by using the W4C20 set up, over basins of three different drainage areas: 5, 10 and 20 km^2. Comparisons carried out over the March, 1 to June, 30 period.

Model set-up	**Sub-basin area**		
	5 km^2	10 km^2	20 km^2
W4C1	0.77	0.91	0.99
W4C10	0.97	0.99	0.99

Fig. 5. Table 3, revised paper