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The Cryosphere
Discussions

Interactive comment on "Investigating the dynamics of bulk snow density in dry and moist conditions using a one-dimensional model" *by* C. De Michele et al.

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Dear Dr. Richard Essery

Thank you for the comments to our manuscript. Your observations are really useful and interesting as well the very recent and pertinent reference. All these points will be fully considered in the revised version of the manuscript.

Here, we would like to make clear that:

1. The model's novelty resides in modeling with a simple and height-integrated approach the relation between liquid water content and snowpack density during all the

year. In this way, it is possible to follow the dynamics of the snow density during dry and wet conditions. We agree with you that Eq.(9) in our paper, or variants of it, has been used in many energy-balance snow models, however it provides only a partial information about the density of snowpack. In our model, in fact, we consider as state variables in addition to the dry snow density (eq.9) also the liquid water content, and the height of snowpack. In this way it is possible to appreciate the differences between the density of the ice structure (dry snow density) and that of the whole domain (snowpack density). We think that this work contributes to 1) furnish a simple tool which is both simple (to predict snowpack mass dynamics for hydrological purposes in poorly instrumented areas) and physical based describing mechanical and hydraulic processes in the snowpack (which is needed to reply to forcings changes); 2) identify key variables to be monitored systematically like the liquid water content which is still poor investigated;

2. Concerning the applications, the model could be easily adopted to make future predictions of snow water equivalent starting from climatic scenarios, according to the type of model developed: mechanistic physically based. Besides, it can be directly used for snow density predictions, which are useful for civil engineering and hydrologic purposes, and to interpret snow hydrology and remote sensing data.

3. The "temperature filter" has been adopted to remove small fluctuations existing in snow depth data and due to temperature oscillations (flutter). In fact, since snow depth data are derived from the measure of the travel time of a ultrasonic signal in the air (which is sent by a sensor, reflected by snow surface and then received by the sensor itself), and since the speed of the signal in air is strongly temperature-dependent, snow depth data at the hourly scale can vary quickly with temperatures (even of some inches), without real snow events occurring. The instrument does measure air temperature and correct the speed of the signal, but turn out to be inefficient with quick variations. As a consequence, since every positive increment of snow depth is considered in the model as a solid event, it is necessary to distinguish between real hourly

events and noise. The filter is based on the assumption that temperature fluctuations and recorded snow depth oscillations are related. We are preparing a new contribution that will specifically focus on this issue and on the extension of the analysis on many other SNOTEL stations, anyway we will make clear this point in the revised version of the manuscript.

4. We agree with your observation about mass variables units, and we will fix the misconception. From the general point of view, we prefer to describe mathematically the phenomenon considering firstly the volumetric variables and then passing to heights.

5. As for the difference between h and hS, it is important to note that "h" is the height of the volume domain (at any time), while "hS" is the height of the ice structure. As a consequence, they coincide, except for the last few hours (or days) of the melting season, during which the ice component completely melts. In this situation, pores saturate and the ice structure collapses, forcing bulk density to increase. As a borderline case, the outflow term can accumulate a little "delay" which corresponds to the instant in which the last elements of ice are disappearing, creating a liquid water domain, a pool, doomed to a quick direct outflow. This distinction is necessary to model the conceptual transition from ice to liquid water. The insert of the Maculay brackets are needed to interpret these last instants of the season without returning incorrect domain densities, and to let the model to be completely general (since it is therefore not forced by any existence condition);

6. As for snow temperature, the at coefficient has been directly derived from the slope of Kondo and Yamazaki (1990) Figure A3.

7. As for the Bartelt and Lehning (2002) quotation, we did want to stress the importance of snow hydrology, with reference to many "reduced" models which considered a rigid or dry snowpack. In the revised version we will clarify this point.

8. SWE overestimations in Figure 3 are mainly due to a problem of the snow depth input data, as visible in panel c). In fact, solid contributions are derived from snow depth

measured and edited increments, while the liquid ones depend on possible positive differences between cumulative precipitation data series and solid precipitations data series (in mm of equivalent water). As a consequence, if a precipitation event presents a measured contribution, which cannot be completely fulfilled by the solid contribution (this is the case of a mixed event), the surplus (which is consider as rain) is inserted in the domain. A simple 0°C threshold is imposed to these surpluses: if they occur with negative temperatures, they are considered as erroneous. As a consequence, this "editing" threshold does not represent a direct threshold to the separation of solid and liquid events, and has no effect on snow events detection. As for the underestimations of Figure 2, the degree-hour parameter has been obtained by a numerical calibration. We think that the quality of the simulation could be improved by adopting different temperature thresholds during the melting season.

9. In the revised version of the manuscript, we will fix in figures 2 and 3, labels and axis range.

Interactive comment on The Cryosphere Discuss., 6, 2305, 2012.