Abstract

Snow observations from space play an important role in hydrological and climatological studies. They are especially important in remote areas with low (or none) population and sparse conventional observations at the ground. At mid latitudes, it is expected improvement of snow melt models by assimilation of spatial distribution of snow water equivalent or snow depth derived from microwave satellite data. Also, other satellite products are interesting candidates for snow melt model inputs. Paper presents discussion on several problems with satellite derived snow observations focusing on selected products: GlobSnow, H-SAF and JAXA GCOM-W1. Benefits and disadvantages of those products were described. Problems with proper validation against "ground truth" were also highlighted. Alternative use of microwave data was also presented. Other parameters derived from satellites were shortly discussed focusing on their benefits for snow melt models.

INTRODUCTION

Snow melting is an important source of water contributing to such processes like: water supply, erosion and flooding, counting to 50-80% of annual runoff in many catchments at the mid latitudes. In many areas, snow melt is the primary source of water supply for energy production and irrigation. Proper reservoir control maintaining safety and production require detailed snow cover monitoring and snow melt forecasts. The physical processes within a snowpack and involved in snowmelt are highly complex, involving mass and energy balances as well as heat and mass transport. Radiative energy is the most important energy exchange mechanism for snowmelt. Proper modelling of snow melt processes require availability of several parameters, which are usually: snow water equivalent, actual snow cover extent, incoming short-wave and long-wave radiation, albedo, temperature, precipitation. In many cases, amount of inputs is limited due to lack of sufficient data source. The most frequently used models for snow melt are either physical requiring more detailed description of mass and energy balance or conceptual with limited number of parameters. Examples of frequently used models are: UEB, SRM, SNTHERM, SNOBAL and many others. Input data have different character, they are both point observations based on ground measurement and distributed ones, using remote sensing techniques. In this work, evaluation of usefulness of satellite derived parameters was described taking into account products retrieved from meteorological satellites, representing mainly: snow extent, snow water equivalent and snow depth. Other parameters like: radiation components, albedo, precipitation, cloud mapping, surface temperature were also mentioned with a comment. The benefits and weaknesses of mentioned parameters were discussed.

SNOW MELTING PROCESSES AND REQUIRED OBSERVATIONS

Why we need snow cover observations? The volume of water stored as snow and ice amounts to approx. 75% of the total freshwater capacity at our globe. Snowmelt processes have a large impact to river basins discharge. Snowmelt occurs in: diurnal, intra-seasonal, seasonal and long term cycles, also depending on latitude and altitude. This process has both positive impact - e.g. electricity production and may have negative impact - snowmelt floods. Poland is very interesting area for satellite snow cover products validation, due to variable snow cover during winter, relatively long snow season and repeated snow fall/snow melt periods during winter (Fig. 1).

Figure 1: Discharge in Warsaw on Wisła river (left) and Nowa Sól on Odra river (right) for the years: 2011, 2012 and winter/spring 2013. Snow melting periods cause substantial increase of discharge, in some cases resulting floods.
We need a satellite observations for snow cover evolution monitoring. There are many factors limiting accuracy and usefulness. Ground network of observations has still not enough density, especially in the areas with scarce human population (polar areas, high mountains). Detection of snow properties from space is not a trivial procedure. In the Table 1 are presented selected snowmelt models and required input data. Part of them can be adopted from satellite data.

<table>
<thead>
<tr>
<th>Snowmelt–Runoff Model</th>
<th>Precipitation amount, Air temperature, Cloudiness, Snow cover extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah Energy Balance</td>
<td>Precipitation amount, Air temperature, Air humidity, Wind speed, Cloudiness, Short Wave Radiation, Long Wave Radiation, Albedo, Air pressure</td>
</tr>
<tr>
<td>Snowmelt model used in PL (author E. Kupczyk)</td>
<td>Precipitation amount, Air temperature, Snow temperature, Air humidity, Wind speed, Cloudiness, Short Wave Radiation, Long Wave Radiation, Albedo, Air pressure, Snow cover extent</td>
</tr>
</tbody>
</table>

Table 1. Input data for selected snowmelt models – possible use of satellite derived products marked red.

What we actually have from satellite observations? The most interesting for monitoring of snow cover evolution are products representing: snow extent, snow water equivalent and/or snow depth. Analysis of selected snow cover extent satellite products was done in several papers. Such analysis for the area of Poland, typical for Central Europe climate was done by author (Struzik et.al., 2012).

This study focused on selected snow water equivalent and snow depth products, freely available and generated in operational regime. For deeper comparison were selected following products:


**H-SAF H13** – similar algorithm to GlobSnow. Merged two products: Flat/forested area (FMI) and Mountainous area (TSMS). Used AMSRE/AQUA satellite data, since 2012 SSMIS on DSMP. Spatial resolution 0.25 deg., regular grid (H-SAF, 2012).

**GCOM-W1 SND (snow depth)** – new satellite launched in 2012. Snow depth product generated instead of SWE (clarified by larger amount of this measurement important for validation). Uses AMSR2 Tb18V – Tb36V difference with corrections for dry/wet soil. Very good documentation available at JAXA web page. Product available in 0.1 deg and 0.25 deg resolution in regular grid covering whole globe or separate North and South Polar Stereographic projection. Also available calibrated and navigated temperatures in all channels of AMSR2 instrument (JAXA, 2012, 2013, Shibata 2002).

At the first eyeball verification of snow properties retrieved from microwave satellite data were done. Two products concerning snow water equivalent: GlobSnow SWE and H-SAF H-13 shown very large similarities. Main problems of those products are:

- Artificial structures not connected with snow presence – “snow-like” and “snow-dislike” areas through the whole winter. According to those products, large area of Poland has completely no snow during the whole last winter.
- High peaks of SWE (up to 350 mm), higher for GlobSnow product at the end of winter season (in April) with sharp border on snow coverage from 0 mm to several hundreds of mm between snow-like and snow-dislike areas.
- Declared combined use of Synop observations and satellite retrievals – it looks, that only part of stations is used.
- Poor resolution (20-25 km) – not acceptable for smaller catchments.
- GlobSnow – lack of mountainous area,
- H-SAF H13 – problems with mountain mask and merging of FMI and TSMS products

![GlobSnow SWE vs H-SAF H13 SWE comparison](image)

![GCOM-W1 SND Ascending Pass vs Descending Pass](image)

**Fig. 2. Comparison of satellite products concerning SWE and snow depth – 28.01.2013**

**GCOM-W1:**
- Better spatial representation of snow cover,
- Descending pass (at night) better than ascending (at day) – temperature and possible wet snow at daytime makes this difference,
- Problems at higher temperatures - melting snow,
- Lack of thin snow cover detection – minimal depth is 5 cm.

Selected satellite snow products were compared with ground measurements performed at Polish Synop stations. Snow water equivalent and snow depth were used for GlobSnow/H-SAF and GCOM-W1 data respectively. Taking into account the first winter of GCOM-W1, other products were also selected for the same period of 1 Oct. 2012 to 30 Apr. 2013. For GlobSnow SWE and H-SAF SWE, there are a few Synop stations which have quite good agreement between satellite and ground observations (out of snow melting periods). It is probably caused by assimilation of data from those individual stations to HUT model. Unfortunately at the end of season both products have artificial peak to SWE values of 200-300 mm, when snow cover completely disappeared. At this time spatial distribution of SWE shown gradient from 0 to 200-300 mm between neighbor pixels. Example of SWE from satellite and ground observations at the artificial “snow-like” area and for “snow-dislike” area are presented at Fig. 3 and 4. Correlation coefficients for individual Synop Stations are presented on Fig. 5. We can observe generally low agreement of satellite and ground observations, especially in Western and Central Poland.
Fig. 3. Example of Snow Water Content [mm] on 1.10.2012-30.04.2013 at Wlodawa Synop station – comparison to GlobSnow SWE and H-SAF SWE (H-13 product).

Fig. 4. Example of Snow Water Content on 1.10.2012-30.04.2013 at Koło Synop station – comparison to GlobSnow SWE and H-SAF SWE (H-13 product).

Fig. 5. Correlation Coefficient for H-SAF H13 and Synop SWE. JAXA GCOM-W1 snow depth product compared to individual Synop stations shown better agreement between satellite and ground observations at the night time (descending pass). Selected time series are presented at Fig 6. Problems with proper detection of melting snow are also expressed. For better clarification of problems concerning comparison of satellite derived parameters with ground observations is presented on Fig. 7. Average correlation coefficient for ascending passes is 0.32 and
for descending passes 0.38, but at several point it’s reaching value 0.6. Generally correlation is better than for presented earlier SWE satellite products. The problem of places with low correlation may be also connected with different factors: not representative for larger areas location of Synop station (to close to the cities), high vegetation (forest), complicated orography.

Fig. 6. Snow depth on 1.10.2012-30.04.2013 at Włodawa Synop station – comparison to GCOM-W1 Snow Depth Product.

Fig. 7. Validation of GCOM-W1 SND against Synop snow depth – Spatial distribution of correlation coefficient

Among the GCOM-W1 satellite products from JAXA are also available calibrated and navigated temperatures from all channels of AMSR2 instrument. They are interesting source for individual
experiments. As was mentioned before, some experiments with brightness temperatures from AMSR2 were performed. Two interesting reflections concerning area of Poland must be mentioned. The first is better correlation of Tb36V-Tb89V with snow depth measured at the ground, than GCOM-W1 SND product for majority of Synop stations (Fig. 8). Similar result can be obtained for Tb23V-Tb89V. Better correlation between Synop and GCOM-W1 Snow Depth product was obtained only for stations 45-63 located in South and South-East part of Poland where snow cover is thicker (mountains at South and more snow at South-East Poland in 2012/2013 winter). For shallow snow cover (Synop stations 1-44) better results were obtained using difference of AMSR2 channels: T36V-T89V.

The second interesting feature concern melting snow detection. For this purpose can be used temperature difference between channels of the same frequency but with vertical and horizontal polarization. This test is usually used for rainfall detection and rainfall intensity estimation. Melting snow is also a source of significant difference of those two temperatures. It is specially well expressed at low frequency channels (10 GHz, 18 GHz) but also exist at higher frequencies. Channel 18 GHz is a good compromise between spatial resolution and sensitivity to snow melting conditions. On Fig. 9 is presented snow depth measured at Kolo Synop station and related T18V-T18H difference. Intensive snow melting conditions are marked by boxes. They correlate well with peaks of T18V-T18H difference.

Spatial distribution of snow melting conditions are presented on Fig. XXX. High values of T18V-T18H difference are well correlated with areas of intensive snow melting resulting flood in this region. Usually higher values are observe at ascending pass (at daytime), then at descending pass (night time) due to more intensive melting at higher temperatures. Interpretation of such signatures must be careful due to both rainfall and snowmelt causing such a signatures. From the second hand both phenomena are a source of runoff from the catchments, especially in coincidence.
Satellite products useful for modeling of snow melting processes do not concern only snow water equivalent and snow depth. Other satellite parameters useful for snow melting models are:

- Snow cover extent – very important parameter, known limitations concerning mainly cloudiness and required Sun elevation.
- Short wave radiation reaching ground surface – very interesting parameter required by many snow melt models, Land SAF DSSF is an example of product with sufficient spatial (MSG/SEVIRI resolution) and temporal (30 min) resolutions and reasonable quality.
- Long wave radiation reaching ground surface – much smaller impact on radiation balance, example Land SAF DSLF.
- Surface albedo – several models require this parameter, example: Land SAF Albedo product updated daily with MSG/SEVIRI resolution.
- Land surface temperature – also required by hydrological snow models, problem with cloudiness, especially during winter, example: Land SAF LST updated every 15 min with MSG/SEVIRI resolution.
- Cloud mask – example NWC-SAF Cloud Mask updated every 15 min with MSG/SEVIRI resolution.
- Precipitation – at the moment is hard to recommend accurate satellite product performing well both for snowfall and rainfall at winter conditions, especially at mid latitudes, where precipitation phase (liquid, solid, mixed) is changing even during hours.

It’s necessary to emphasize required spatial and temporal resolutions. For the modeling purposes in typical catchments of 30-100 km$^2$ area, resolution of MSG/SEVIRI, NOAA/AVHRR and better MODIS or VIIRS are sufficient. Parameters changing relatively slowly, like: albedo, snow cover, snow water equivalent, type of land cover can be updated on daily basis. Parameters related to cloud cover: precipitation, cloudiness, SW/LW radiation require more frequent sampling (a few min to 1h).

CONCLUSIONS

There is still lack of satellite product which can satisfy hydrological expectations concerning snow water monitoring in temperate zone (e.g. Central Europe). Snow water equivalent is a crucial parameter for proper runoff modeling and warning at snow melt conditions. Interesting results were found in GCOM-W1 Snow Depth product. Most difficult estimation of water amount is at melting snow conditions, which are of high importance for hydrologists! More investigations on that problem is required. Also shallow snow cover is a challenge for satellite passive microwave observations. It looks, that for shallow snow cover, interesting results could be obtained from microwave temperature difference: Tb36V-Tb89V or Tb23V-Tb89V, then from usually used T18V-T36V. Big problem exist with representative ground measurements for validation of MW observation with pixel size of 10-30 km. Ground posts are frequently located in or close to the cities, where snow cover is melting more quickly.

REFERENCES

GCOM-W1 "SHIZUKU" Data Users Handbook (2013), JAXA.
Product User Manual (PUM) for product H13 – SN-OBS-4 - Snow water equivalent by MW radiometry (2012), H-SAF.