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A PERFORMANCE ASSESSMENT OF GRIDDED SNOW PRODUCTS IN THE UPPER EUPHRATES

ESTEBAN ALONSO-GONZÁLEZ*[1], J. IGNACIO LÓPEZ-MORENO[2], M. CANSARAN ERTAŞ[3], AYNUR ŞENSOY[4], ALI ARDA ŞORMAN[4]

[1] *Centre d'Etudes Spatiales de la Biosphère, CESBIO, Univ. Toulouse, CNES/CNRS/INRAE/IRD/UPS, Toulouse, France.*

[2] *Instituto Pirenaico de Ecología, CSIC, Zaragoza, Spain.*

[3] *Erzurum Technical University, Faculty of Engineering, Department of Civil Engineering, Erzurum, Turkey.*

[4] *Eskisehir Technical University, Faculty of Engineering, Department of Civil Engineering, Eskisehir, Turkey.*

ABSTRACT. Snow observations are important in many mountain areas to quantify the water stored in snowpacks and to predicting runoff during the melting period. In this study we compare the performance of five different regional-scale gridded snow products to reproduce snow water equivalent (SWE) in the Upper Euphrates region (Karasu Basin, 10,275 km^2), with observations from automatic weather stations in the catchment through Taylor diagrams. The products compared are the ERA5, ERA5-Land, MERRA-2, snow data from a dynamical downscaling of ERA-5 (period 2000-2018) and SWE generated from microwave satellite data (SWE-E(H13) period 2013-2015 product of the EUMETSAT H SAF project). The H13 product presented deficiencies in terms of not being able to reproduce the spatial and temporal variability of the snowpack. ERA-5 and, in particular, ERA-Land products, at 30 and 9 km grid size, respectively, showed good performance in reproducing snow evolution compared to four available observation sites. MERRA2 at 50 km resolution showed lower skills compared to the above-mentioned products. Resulting snow data from WRF at 10 km resolution did not show any improvement with respect to the global datasets. The impossibility of testing different configurations due to the lack of observations to compare and the computational constraints to test different parametrizations may be the reasons to explain the low performance although they remain speculative. All the gridded datasets showed good performance in reproducing snow duration over the basin, compared to remotely sensed data. Results highlight ERA-Land dataset as a very promising tool for regional snow studies in mountainous regions with limited observations, in a cost-effective way.

Evaluación de productos de nieve en cuadrícula en el Alto Eúfrates

RESUMEN. La observación del manto de nieve es importante para cuantificar el agua almacenada y predecir la escorrentía durante el período de deshielo. En este trabajo comparamos el rendimiento de cinco productos de nieve en rejilla a escala regional diferentes para reproducir el equivalente de agua de nieve (SWE) en la región del Alto Éufrates (Cuenca de Karasu, 10.275 km^2), con observaciones de estaciones meteorológicas automáticas en la cuenca a través de diagramas de Taylor. Los productos comparados han sido ERA5, ERA5-Land, MERRA-2, un *downscaling* dinámico de ERA-5 (período 2000-2018) e información del SWE generado a partir de datos satelitales de microondas (SWE-E(H13) período 2013-2015 resultado del proyecto EUMETSAT H SAF). El producto H13 presentó deficiencias en cuanto a no poder reproducir la variabilidad espacial y temporal de la capa de nieve. ERA-5 y, en particular, los productos ERA-Land, con un tamaño de cuadrícula de 30 y 9 km, respectivamente, mostraron un buen rendimiento en la reproducción de la evolución de la nieve en comparación con cuatro sitios de observación disponibles. MERRA2 con una resolución de 50 km mostró un menor rendimiento en comparación con los productos mencionados anteriormente. Los datos de nieve resultantes de WRF a una resolución de 10 km no mostraron ninguna mejora con respecto a los conjuntos de datos globales. La imposibilidad de probar diferentes configuraciones debido a la falta de observaciones para comparar y las limitaciones computacionales, explican el bajo rendimiento del *downscaling* que precisa de una configuración especifica. Todos los productos procedentes de simulaciones numéricas mostraron un buen rendimiento en la reproducción de la duración de la nieve sobre la cuenca, en comparación con los datos de detección remota. Los resultados destacan el conjunto de datos ERA-Land como una herramienta muy prometedora para los estudios regionales de nieve en regiones montañosas con observaciones limitadas.

Key words: Snow water equivalent, snow gridded datasets, reanalysis products, microwave remote sensing, Euphrates Basin.

Palabras clave: Equivalente de agua de nieve, conjuntos de datos de nieve en rejilla, productos de reanálisis, teledetección por microondas, cuenca del Éufrates.

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***Corresponding author:** Esteban Alonso González, Centre d'Etudes Spatiales de la Biosphère, CESBIO, Univ. Toulouse, CNES/CNRS/INRAE/IRD/UPS, Toulose, France. E-mail address: e.alonsoglz@gmail.com

1. Introduction

Snow water equivalent (SWE), as an essential climate variable, must be monitored (Bojinski *et al.*, 2014) because it controls the hydrology and the seasonal cycles of the ecosystems (phenology of plants and animals) of mountain regions of mid and high latitudes (Musselman *et al.*, 2021). In addition, its occurrence, quantity, and spatial and temporal variability have important implications for land management and economy of these areas. It plays a major role in water resources and food production systems (Qin *et al.*, 2020), transportation and hazard management associated mostly to heavy snowfall events, avalanches, and floods from rain-on-snow events (Haeberli and Whiteman, 2021). In the last decades, winter tourism has become one of the main economic industries for mountain territories, and this is highly dependent on the strong interannual snow fluctuations (Steiger *et al.*, 2019).

Despite the inherent interest of properly quantifying water stored as snow in mountain areas, monitoring of the snowpack is still a challenging task due to the economical and technical difficulties of deploying ground based sensors (Dozier *et al.*, 2016; Margulis *et al.*, 2016). In addition, the high spatial variability and the very dynamical nature of a snowpack, subject to fast changes during both the accumulation and melting periods, poses great difficulty in interpolating those measurements over complex topography, hence, quantifying the volume of water stored in a snowpack which will be available during the melting period (López-Moreno *et al.*, 2013; López-Moreno and Nogués-Bravo, 2006; Sexstone *et al.*, 2021). Many efforts have been made to create snow products that properly characterize the spatial and temporal fluctuations of snowpacks at the regional scale (Wrzesien *et al.*, 2017), remote sensing products, and the combination of atmospheric simulations with snow energy balance models being two of the most promising approaches (Alonso-González *et al.*, 2017). Remote sensing made a noticeable advance in mapping snow cover area, snow cover fraction and even snow water equivalent from microwave radiometry (Andreas *et al.*, 2012). When the variable of interest is only snow cover, it can be inferred using spatial sensors such as MODIS or Sentinel-2. Such products have proved to be consistent with in situ observations (Aalstad *et al.,* 2020). The high resolution of the currently available snow cover products has been used to generate snow climatology over large areas, especially in regions with relatively deep snowpacks and sparse forests (Gascoin *et al.*, 2015 and 2020; Saavedra *et al.*, 2017). For moderate spatial resolution (~5 km grid), there are products such as SE-E-SEVIRI(H10) (EUMETSAT H SAF product) that generate daily operational snow extent from visible (VIS) and infrared (IR) radiometry. Despite the recognized limitations of passive microwave satellites for SWE estimation over complex topography and wet snow (Frei *et al.*, 2012), it has been used to successfully characterize snow dynamics for large areas (Bormann *et al.*, 2018; Derksen *et al.*, 2005).

Atmospheric reanalysis has also been used to extract long-term (multidecadal) climatological and snow information at low resolution for large and global scales (e.g., Wegmann *et al.*, 2017; Wu *et al.*, 2018). The initial problems of resolution have been partially overcome by increasing the resolution of the state-of-the-art atmospheric reanalysis (Nogueira 2020), i.e., the ~ 30 and 50 km resolution of ERA-5 and MERRA2, respectively. However, downscaling such products is mandatory in order to infer the spatial variability of the snow in complex terrain. Thus, the resolution of ERA-5 has been enhanced by correcting the air temperature, air humidity and pressure surface meteorological fields of ERA5 with elevation into a finer grid. The newly generated variables are used to force the ERA-5 land surface model, which generates the ERAS-Land product at 9 km resolution (Muñoz-Sabater *et al.*, 2021).Alternatively it is possible to apply dynamical downscaling techniques to outperform statistically gridded products; mesoscale fully dynamical meteorological models have successfully reproduced snow cover patterns over rugged topography (Alonso-González *et al.*, 2021; Rasmussen *et al.*, 2014). However, the computational cost of generating such products is often prohibitive and requires an appropriate setup. Therefore, it is necessary to assess the added value of performing these costly simulations compared to the moderate resolution products already available. The main objective of this study is to compare the performance of different gridded snow products of different nature over a sparse data region. In this study we compare different gridded snow water equivalent (SWE) products at moderate resolution (between 50-9 km of grid size) in the Upper Euphrates (Karasu) Basin in Eastern Turkey using the SWE-E H13, MERRA-2, ERA-5, ERA-LAND and a dynamical downscaling WRF simulation performed by the authors for the current study. We use for the comparison of products automatic weather stations and snow measurements for reference.

2. Study area

The River Euphrates, the longest in southwest Asia (2700 km), is formed by the union of two major tributaries - the Karasu, which rises in the highlands of eastern Turkey, and the Murat, which originates north of Lake Van (Cullen and Menocal, 2000). This area is key for water management and supply to the vulnerable and politically sensitive regions of the Fertile Crescent, and it highly depends on water coming from snowmelt (Kelley *et al.*, 2015; Tekeli *et al.*, 2005). The Euphrates Basin is largely fed from snow precipitation over the uplands of northern and eastern Turkey. About two-thirds of the precipitation occurs in winter, during which all precipitation falls as snow which may remain on the ground half of the year (Tekeli *et al.*, 2005). This is followed by a sustained period of high flows during the spring, resulting from melting of the snowpack (Yilmaz and Imteaz, 2014). Karasu Basin, a sub-basin of the River Euphrates, is the test basin for this study. The region is mountainous and, according to long-term analysis of the hydrographs, snowmelt constitutes 60-70% of total annual streamflow volume (Tekeli *et al.*, 2005). Most of the water that originates from snowmelt contributes to large reservoirs located on the River Euphrates in Turkey. The study area is basically the headwaters of Karasu Basin, represented by the drainage area of stream gauging station E21A019. The selected study area is located within the longitudes 38°58′E to 41°39′E and latitudes 39°23′N to 40°25′N. It has a drainage area of 10,275 km2 and ranges in altitudes from 1125 to 3485 m (Fig. 1). The main land cover types are pasture, agriculture and bare land.

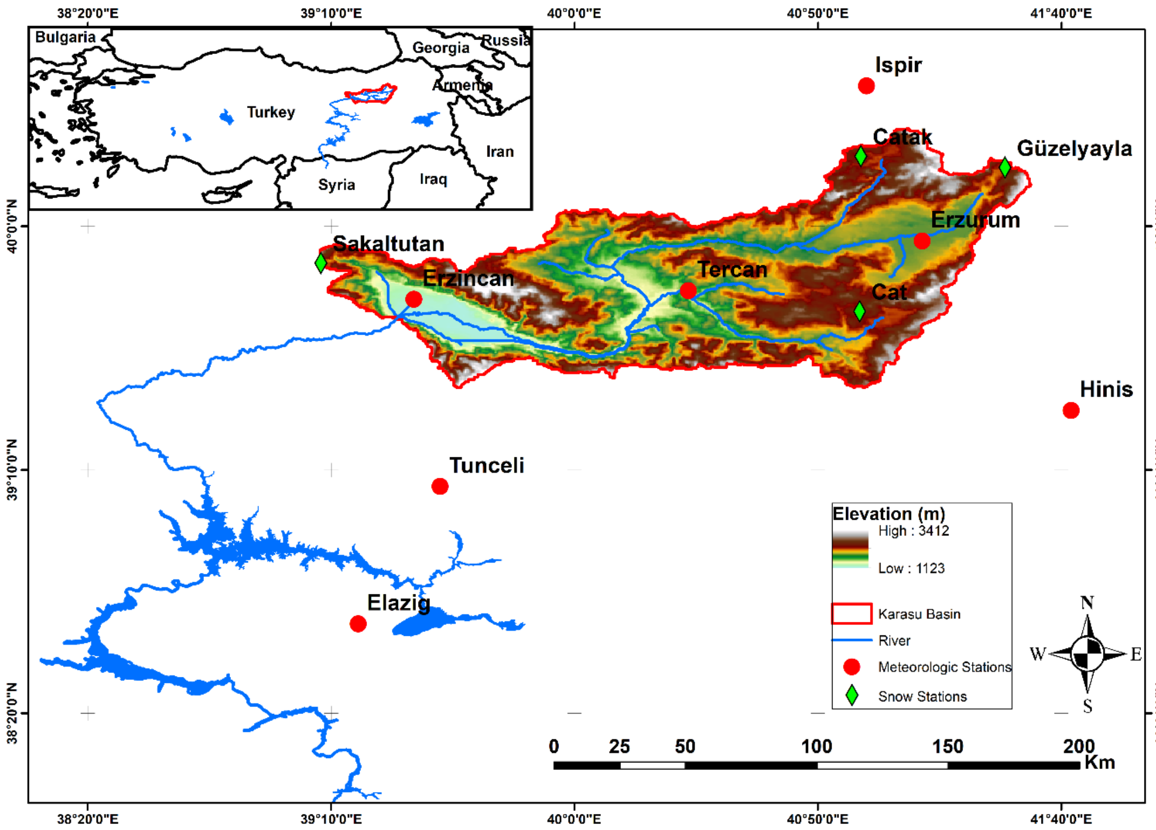

Figure 1. The pilot basin area and observation network (meteorological and snow stations) used in the study.

3. Data and methods

3.1. Gridded snow water equivalent datasets

In this study, we used various SWE products of different nature at moderate resolutions. These products represent a sample of the most widely used possibilities to develop multi-year snow studies, including atmospheric reanalyses, passive microwave remote sensing and dynamical downscaling. These products are summarized in Table 1.

Table 1. Datasets used to derive gridded snow products in this study and main characteristics.

Product	Spatial resolution	Temporal resolution	Origin
SWE-E(H13)	25 km	Daily	Satellite remote sensing
ERA5	30 km	Hourly	Atmospheric reanalyses
ERA5-Land	9 km	Hourly	Land surface reanalyses
MERRA-2	50 x 60 km	Hourly	Atmospheric reanalyses
WRF	10 km	Hourly	Dynamical downscaling
SE-E-SEVIRI(H10)* *Snow cover only	5 km	Daily	Satellite remote sensing

3.1.1. SWE-E(H13)

The daily SWE-E(H13) (https://hsaf.meteoam.it/Products/Detail?prod=H13) product is produced by an assimilation technique utilizing the modified Helsinki University of Technology (HUT) snow emission model (Pulliainen *et al.*, 1999). The gridded brightness temperature values of AMSR-E

(Advanced Microwave Scanning Radiometer - Earth Observing System Sensor on the NASA Aqua Satellite, https://nsidc.org/data/amsre) were produced by the National Snow and Ice Data Centre (NSIDC) and are available in EASE-Grid projections at 25 km spatial resolution. The spatial coverage of these products covers nearly the entire earth and the temporal resolution is daily. AMSR-E on NASA's EOS Aqua spacecraft stopped rotating on Oct 4, 2011. Therefore, the H13 snow product started production, using SSMI/S data (Special Sensor Microwave Imager Sounder, https://www.ncdc.noaa.gov/ssmi) in real time on April 10, 2012 (Beşer, 2011; Şorman and Beşer, 2013). Recent results of product validation are given in Piazzi *et. al*., (2019).

3.1.2. ERA5

ERA5 is a global atmospheric reanalysis, developed in the supercomputing facilities of the European Centre for Medium-Range Weather Forecasts (ECMWF). It replaces the previous ERA-Interim reanalysis, with improved spatiotemporal resolution (Hersbach *et al.*, 2020). ERA5 has a horizontal resolution of 30 km, with an hourly output compared with the 80km horizontal resolution and 3-hourly outputs of its predecessor. In addition, it offers uncertainty estimations from an ensemble of simulations. ERA5 is continuously generated, with close to real time outputs (preliminary updates of ERA5 are available with a delay of 5 days) expanding from 1950. ERA5 is developed by means of the operational version of the Integrated Forecast system (IFS), the ECMWF atmospheric model. ERA5 assimilates a massive amount of historical observations, including satellite retrieval of the state of the atmosphere and surface and in-situ observations from the main meteorological networks of the World Meteorological Organization, which include radar, radiosondes or land stations, among many others. The SWE is computed by the land surface component of the IFS using a physically based energy and mass balance model, where snow density is computed representing compaction, overburden and thermal metamorphism.

3.1.3. ERA5-Land

ERA5-Land is a dataset generated by running the land surface scheme of ERA5, using the atmospheric component of ERA5 as forcing (Muñoz-Sabater *et al.*, 2021). Unlike ERA5, there is no data assimilation in ERA5-Land; however, data assimilation has an indirect influence on it, due to the effect that it has in ERA5. So far, ERA5-Land expands from 1981 until three months before the present. It has enhanced spatial resolution, compared with ERA5, with 9km. To reach such high resolution, the atmospheric forcing is corrected with the elevation. More specifically, the air humidity, temperature and pressure are modified as a function of the elevation difference between the cell of ERA5 and the higher resolution of the ERA5-Land geometries.

3.1.4. MERRA-2

MERRA-2 dataset is the second version of the Modern-Era Retrospective Analysis for Research and Applications (Gelaro *et al.*, 2017), being the latest global atmospheric reanalysis of NASA's Global Modelling and Assimilation Office (GMAO). This version has significant improvements in the assimilation system, being able to assimilate hyperspectral radiance and microwave observations and GPS-Radio Occultation or space-based observations of aerosols, among others. Despite its enhanced capabilities in the assimilation system, the spatial resolution remains similar to its previous version, 50km in the latitudinal dimension and over 60km in the longitudinal dimension. In addition to the assimilation scheme, it takes advantage of the evolution of the Goddard Earth Observing System (GEOS), including a better representation of the cryospheric processes.

3.1.5. Dynamically downscaled products

The Weather Research and Forecast model (WRF; Skamarock *et al.*, 2008) is a non-hydrostatic mesoatmospheric numerical model designed for both atmospheric research and operational forecasting applications. It is widely used as a dynamical downscaling and data assimilation tool. To provide the WRF model with the initial and boundary conditions, we downloaded the ERA5 reanalysis data (Hersbach *et al.*, 2019). The data was downloaded from the Climate Data Store (CDS) infrastructure at an hourly time step.

The WRF simulation was configured following previous experiments, where the model has proven to provide reliable simulation of winter precipitation over complex terrain (E Alonso-González *et al.*, 2021; Ikeda *et al.*, 2010; Rasmussen *et al.*, 2014). Thus, the parametrization schemes used in the WRF simulation include the following: the Thompson cloud microphysics scheme (Thompson *et al.* 2008); the NCAR Community Atmosphere Model (CAM) (Collins *et al.*, 2004) scheme for both shortwave and longwave radiation; the Noah-MP Niu, G.-Y. *et al.* (2011) scheme to solve land surface physics; the Mellor-Yamada-Janjic (Janjic, 2002) scheme for the planetary boundary layer; and the Betts-Miller-Janjic (Janjic 1994) scheme for deep and shallow convection. TheNoah-MP scheme for land surface physics is particularly relevant in this study. It has more realistic snow physics compared with other land surface models, including a thin surface layer, liquid water retention and refreezing, snowpack densification, sublimation, and turbulent and radiative heat flux exchanges to and from the snowpack with soil and plant canopy interactions. The domain configuration was designed with the center at the 38ºN, 42ºE coordinates with 220 cells in the West-East axis and 150 cells in the North-South axis. The spatial resolution was set to 10km in a Lambert conformal projection (Fig. 2).

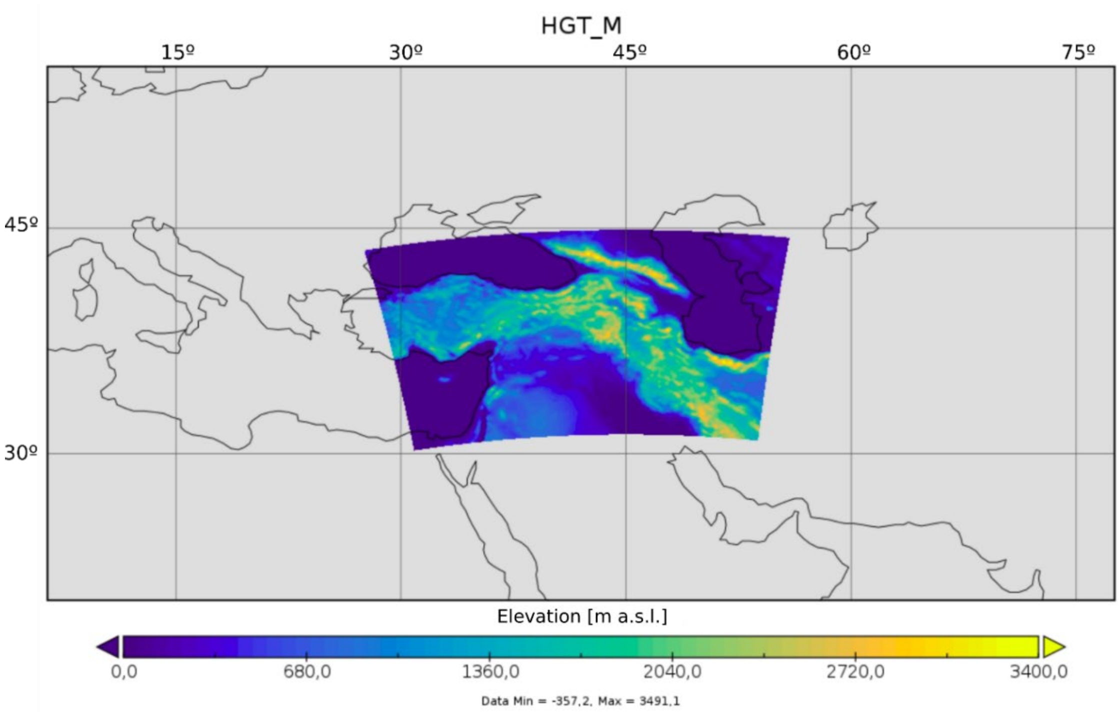

Figure 2. WRF simulation 10 km resolution domain and its digital elevation model. The domain spans from 42º to 36ºN (latitude) and from 25º to 47ºE (longitude).

3.1.6. SE-E-SEVIRI(H10)

Snow cover over the Karasu basin was also monitored with the satellite product SE-E-SEVIRI(H10) (https://hsaf.meteoam.it/Products/Detail?prod=H10), a daily operational product of snow cover, at 5 km resolution generated from visible (VIS) and infrared (IR) radiometry of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) instrument on board the geostationary Meteosat Second Generation (MSG) satellites. The high temporal resolution and wide aerial coverage of SEVIRI imagery make it highly suitable for snow-cover mapping, since cloud cover is continuously monitored (Piazzi *et al.*, 2019). It was selected for this study because the resolution is close to or higher than the compared snow products, and its usability has already been tested for this region (Piazzi *et al*., 2019). It has shown advantages in snow detection compared to other satellite products such as MODIS (Sürer *et al.*, 2013).

3.2. Evaluation

Eight stations with daily average temperature and total precipitation covering the period 1999-2018 where continuous data is available within or near the Karasu Basin (Fig. 1) are used in the evaluation analysis. The stations have an elevation range spanning from 981 to 1759 m a.s.l., and the precipitation is measured with wind protected, tipping bucket rain gauges. These data were contrasted with outputs from atmospheric models to see how two main drivers (temperature and precipitation) of snow seasonality are reproduced in the study area. The comparison was made considering the period from December to the end of April, as these months record most of the snow accumulation and melting over the study area. In addition, four stations ranging from 2070 to 2300 m a.s.l. where regular in-situ observations are manually taken for snow water equivalent measurements are used in the evaluation analysis (Fig. 1). The available dataset covers the period 2000-2015 and the comparison was performed following the same methodology as for the temperature and precipitation. There are between six and eight measurements at each site for each year.

A prior consideration in the performed comparison, as shown in other comparisons of gridded products (Alonso-González *et al.*, 2021; Revuelto *et al.*, 2018; Wrzesien *et al.*, 2017) , is the obvious mismatch in resolution between point-scale measurements and coarse spatial grids (Blöschl, 1999), especially as topographic complexity and terrain roughness increase (López-Moreno *et al.*, 2015). This problem has been addressed using accuracy indicators based on capturing the interannual variability of the variable of interest rather than their absolute values, over a value obtained by interpolating the 4 closest cells to each station. This has been done using Taylor´s diagrams, which are generally used to quantify the degree of correspondence between the modeled and observed behaviour in terms of three statistics: the Pearson correlation coefficient, the root-mean-square error (RMSE), and the standard deviation (Taylor, 2001). In addition, the temporal comparison of aggregated values of SWE and snow cover (H10) over the Karasu basin provides a sound estimate of the ability of the different snow products to reproduce the snow dynamics over the study area.

4. Results

4.1. Capacity of reanalysis products to reproduce precipitation and temperature

All compared reanalysis products properly reproduced the observed temperature (from December to April) at the eight available meteorological stations covering the period 1999-2018 (Fig. 3A). Pearson´s correlation coefficient is always above 0.9 for all products and sites, with values often exceeding 0.95. The standard deviations of the gridded products and observations also show a high agreement. RMSE is generally below 2.5 °K, indicating that the absolute values are also well reproduced but, as expected, this score worsens as the spatial resolution of the gridded datasets decrease.

The error estimators for precipitation from December to April (Fig. 3B) clearly shows a much lower performance of the reanalysis products to reproduce this variable. It also shows a much larger dispersion between sites and products. In general, Pearson´s coefficients range between 0.4 and 0.7 as previous studies have reported in mountainous terrain (Zandler *et al.,* 2019). The standard deviation is underestimated for most of the sites and products. The RMSE also shows noticeable biases in the total amount of precipitation but, in this case, the values are not only influenced by the spatial resolution of the products but also by the very important differences in precipitation amounts recorded among the eight observation sites. It is interesting to note that the WRF simulation exhibits, in most cases and sites, the lowest accuracy in reproducing precipitation amounts and their variability, while the other products reproduced precipitation better, showing very similar scores for the different observation sites.

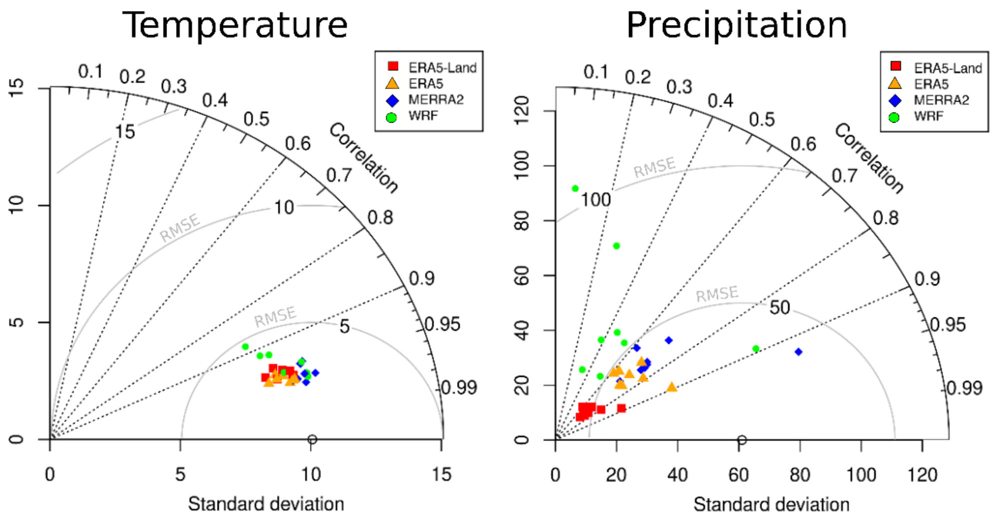

Figure 3. Taylor´s diagram showing the standard deviation, correlation and root-mean-square error (inner circles) for December to April temperature (left panel) and precipitation (right panel) at the available meteorological stations from MERRA 2, ERA-5, ERA-LAND and WRF.

4.2. Comparison of snow products

The four reanalysis products exhibit logical differences among them but have a clear similar pattern, while the microwave product H13 exhibits a different temporal pattern of SWE (Fig. 4). Thus, it seems that H13 saturates at some threshold that makes that average SWE for the basin not exceed a certain limit, close to 140 mm value over the years. The other snow products show annual maximum SWE values that exceed 200 mm for the higher resolution products and values around 50 mm for the coarser reanalyses. Both reanalyses (ERA5 and MERRA-2) showed the lower values of the series, due to the combined effect of a low resolution and a high spatial variability, in contrast to the high averaged value of H13, consequence of spatially constant values.

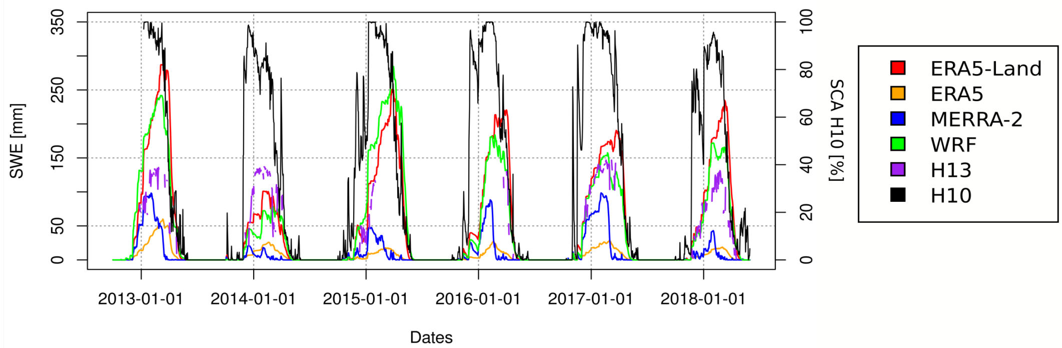

Figure 4. Temporal evolution of basin average snow water equivalent from MERRA 2, ERA-5, ERA-LAND and WRF and SE-E-SEVIRI(H10) and SWE-E(H13) between 2013-2018.

The snow duration provided by all snow products (including H13) is very similar and it highly matches with the snow cover area provided by H10 product. The largest differences were observed during isolated melting events that occurred during the accumulation period (i.e., 2015-16 and 2016-17). Such deviations are likely associated with the different resolution of the two products, and also to isolated snowfall events that are not properly captured by WRF, or they are captured but with a biased snowline. These events do not affect the overall estimation of the annual duration of the snowpack.

The unrealistic representation of snow based on H13 can be also observed with the spatially distributed SWE for different selected days (Fig. 5). The comparison of WRF and H13 shows how the latter neglects most of the spatial variability that can be expected in both accumulation and ablation periods in mountainous terrain such as Karasu basin, and therefore discarded in the following analyses.

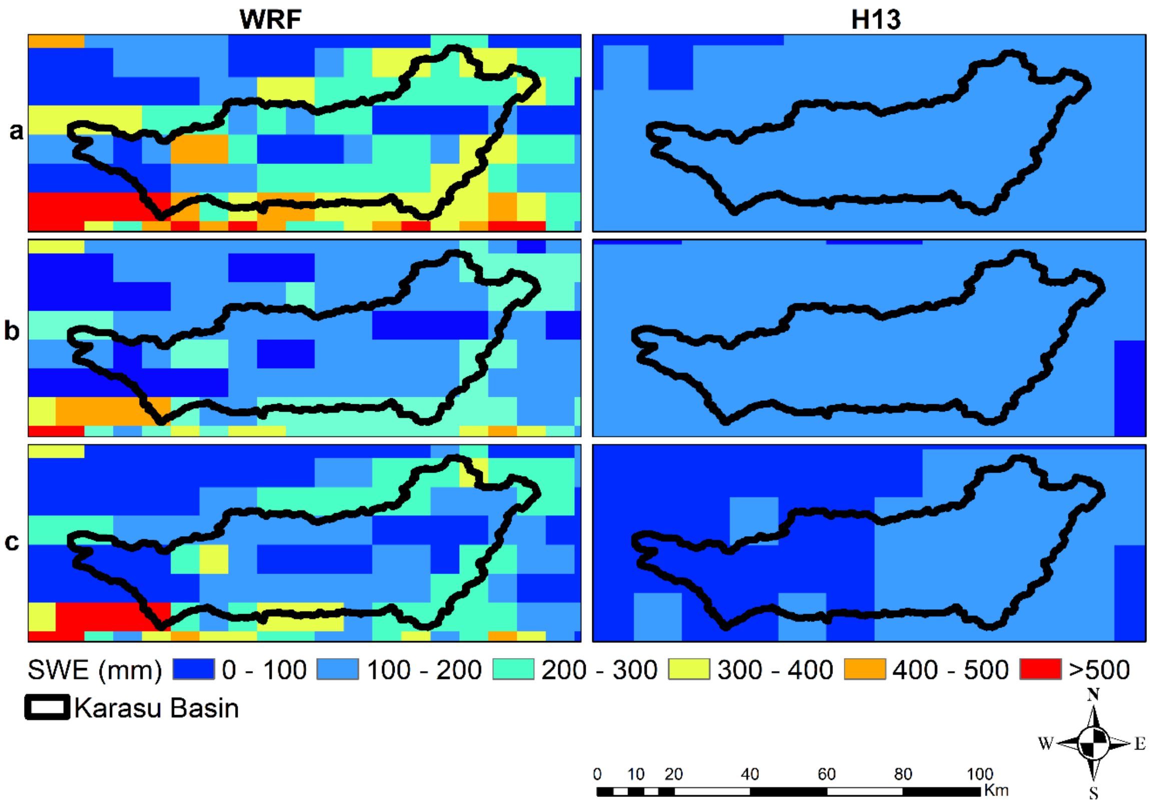

Figure 5. Comparison of SWE derived from WRF (left panels) and H13 (right panels) for Karasu basin, a) 09 Mar 2015, b) 25 Feb 2017, c) 01 Feb 2018.

Once H13 is discarded, the rest of the reanalysis snow products show better ability to reproduce the temporal and spatial SWE variability over the Karasu basin, while some deficiencies were found (Fig. 6). It is interesting to note that, at each site with ground measurements, different models show different accuracy. In general, ERA-Land showed the highest Pearson´s coefficient most often (often exceeding 0.8), followed by ERA 5 (with values over 0.7 and 0.8). However, the standard deviation of the ERA5-Land product is closer to the deviation of in-situ observations, perhaps as a consequence of its higher resolution, which is able to better represent the natural variability of the snowpack. MERRA 2 and WRF simulation showed lower Pearson´s coefficient values and very high variability among the four sites of observation. This may be caused by the fact that WRF is not directly assimilating any data, while ERA5 assimilates different products, including snow cover information. In the case of MERRA2, we hypothesize that its coarser resolution is preventing proper matching of its snow simulations with in situ observations.

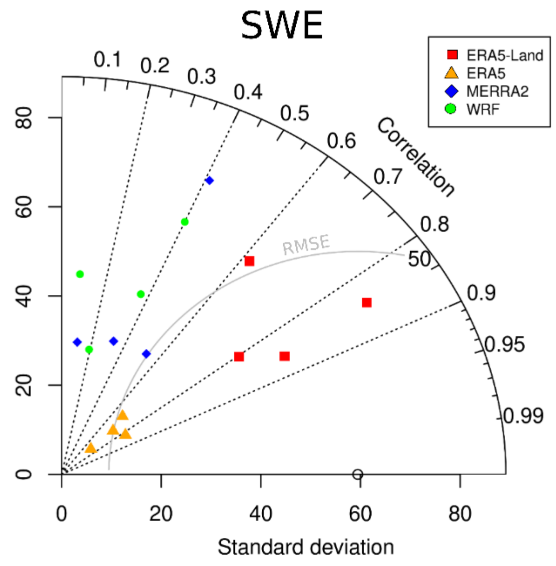

Figure 6. Taylor´s diagram showing the standard deviation, correlation and root-mean-square error (inner circles) between reanalysis snow products and observed SWE at four observation sites.

5. Discussion and conclusions

Results show that the existing gridded snow products may give reasonable information on snow amounts and their spatial distribution over large areas, similarly to testing done by Wrzesien *et al.* (2017) for the Californian Sierra Nevada or Bien *et al.* (2022) over the Tibetan plateau. However, results based on microwave satellite sensor H13 over the Karasu basin seems problematic, especially at seasonal maximum SWE, confirming previous studies highlighting the limitations of passive microwave products in reproduce the spatial patterns of the snow (Mortimer *et al.*, 2020). Snow duration from the H13 SWE series are similar to those obtained with WRF and H10 products. However, there is a threshold close to 140 mm from which H13 saturates or simply is assigned when snowpack is present, making that retrieved maximum annual SWE almost identical every year of the study period (2013-2018). At the same time, the distributed values exhibit little variability, with relatively less response to elevation variation over the basin. Independent validation and identification of these limitations should be considered for the subsequent development of new products and future estimates of SWE values for complex topographies. This is valuable for water resources management with a scarce observation network or, alternatively, to identify for which environments the SWE estimates are most reliable or uncertain.

Snow products based on atmospheric reanalysis have shown promising performance for use in areas with limited observations. Snow products reached better accuracy scores than the precipitation for December to April. There are two reasons for this. First, measured winter precipitation in a cold environment such as Karasu basin is far to be the ground truth due to undercatch (Buisán *et al.*, 2017) and, in some cases, atmospheric simulations can outperform observational networks (Lundquist *et al.*, 2019). The second reason is that atmospheric reanalysis assimilates snowpack information retrieved from both remote sensing and in-situ observations, noticeably improving the final results on the snow product (Largeron *et al.*, 2020). Lack of snow data assimilation and the computational limitations preventing to search for an optimal parametrization when conducting the dynamical downscaling of ERA5 using WRF are the most likely explanation of the poor performance shown by the WRF product. Applying dynamical downscaling to obtain long-term series involves very high computing requirements that often are too complicated to be used by most research teams, even with occasional access to super-computing facilities (Gutmann *et al.*, 2016), even considering new emerging more efficient options (Powers *et al.*, 2021). This computational effort often limits testing model codes and configurations to be better suited to specific meteorological conditions for a given study site. Under such limitation, the 9 km ERA-land product has been raised as a promising dataset covering the emerged part of the earth hourly since 1981, including its snow product, which has obtained the best scores in this work. When higher resolution is required, pseudo-physical downscaling approaches (Esteban Alonso-González *et al.*, 2017; Liston and Elder, 2006) may be successfully applied over this dataset to run offset snow models from finer interpolated input data.

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