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EVALUATION OF A GLOBAL SNOW DEPTH ANALYSIS BASED ON OPTIMAL INTERPOLATION

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ABSTRACT

Assimilation of snowpack observations into Numerical Weather Prediction (NWP) models represents a key component that impacts the accuracy of predicted meteorological parameters. NOAA's National Centers for Environmental Prediction (NCEP) operational NWP models routinely assimilate observations of snow depth and snow cover area to improve snow model initializations. A new snow depth analysis based on optimal interpolation method has been developed with improved spatial resolution compared to the existing analysis and the capability to assimilate both satellite and station snow depth. An essential component and assumption of the analysis are the spatial correlation functions and scales of snow depth distribution with respect to horizontal distance and elevation. Based on these correlation functions and the predetermined data errors, snow depth from the surrounding stations are weighted to compute an analysis snow depth estimate. This study presents an accuracy assessment of the analysis over North America that uses correlation scales currently adopted in operational snow analysis at world's major weather and climate prediction centers: an e-folding scale of 120 km for horizontal distance and an e-folding scale of 800 m for elevation. Snow depth data to drive and evaluate the analysis are obtained from the Global Historical Climatology Network (GHCN) during the 2016-2017 winter season. Snow depth from NOAA's Global Forecast System (GFS) was used as first guess. It was found that a range of 600 km is sufficient for a near complete coverage of analysis over North America in areas with sparse in-situ measurements available for interpolation. The analysis improves first guess estimates substantially over relatively flat areas. However, improvements are smaller, and the accuracy is much lower over high-elevation terrain, mainly attributed to inaccurate e-folding scales used for interpolation.

Key words: evaluation, global snow depth, analysis optimal interpolation, NOAA

INTRODUCTION

Operational snow depth analysis has become a component of numerical weather prediction (NWP) models, providing consistent snow depth observations for updating modeled snow states. Routine in-situ snow depth measurements are considered the gold standard and therefore heavily relied upon in snow analyses, owing to their high local accuracy, but their distribution is sparse and inadequate in many remote areas (Figure 1). In contrast, satellite remote sensing offers excellent spatial coverage and temporal frequency ideal for large area monitoring (e.g., Figure 2), but snow depth estimated from satellite data has an absolute accuracy inferior to that of in-situ measurements.

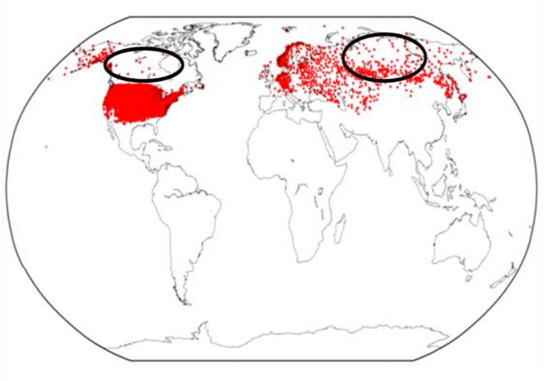

Figure 1. Distribution of in-situ snow depth from Global Historical Climatology Network (GHCN-Daily). Noted are areas of low station density over Alaska and Siberia.

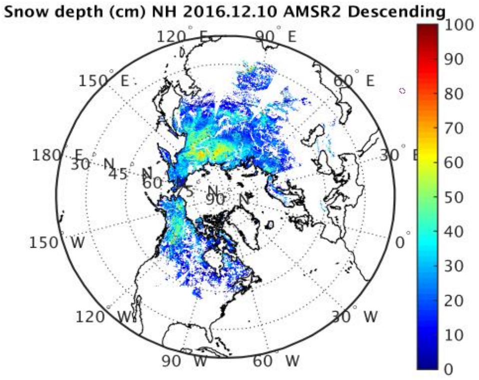

Figure 2. Example of AMSR2 snow depth (in cm) over Northern Hemisphere from NOAA's operational processing system.

A viable strategy for improving the accuracy of satellite-based snow depth, while retaining the benefit of its global spatial coverage and high temporal frequency, is to combine it with in-situ measured snow depth from available ground stations. One blending approach is optimal statistical interpolation, whereby satellite estimates are updated by blending it with snow depth from surrounding ground stations. Spatial weights are computed from spatial correlation functions of snow depth daily increments with respect to horizontal distance and elevation between pairs of snow depth observations. This technique was introduced in operational snow analysis for numerical weather prediction by Brasnett, 1999. An application of the technique to satellite and in-situ snow depth over selected regions of western US and Alaska is described in Liu et al., 2013; 2015. Here, the satellite estimate is used as first guess and updated by blending it with in-situ snow depth from surrounding stations.

In this paper, we use a similar blending approach to demonstrate its large-scale operational applicability for improving the mapping of satellite-based snow depth. To this end, the technique is applied to global satellite and in-situ data, and its output is evaluated over North America during one typical winter season using different blending strategies with respect to the number of in situ stations considered for updating satellite estimates.

MATERIAL AND METHODS

Data

Input and testing data were assembled for January–February 2017 period over North America. Satellite snow data were obtained from NOAA's suite of passive microwave snow products—snow cover, snow depth and Snow Water Equivalent (SWE)—which utilizes brightness temperatures at specific window frequencies from AMSR2 onboard the GCOM-W1 (Global Change Observation Mission – Water) satellite (https://www.ospo.noaa.gov/Products/atmosphere/gpds/about_amsr2.html). A detailed description of the NOAA's snow cover and snow depth algorithms is found in Lee et al., 2015. Figure 2 displays an example of AMSR2 snow depth over the Northern hemisphere.

In-situ station data for snow depth and elevation were extracted from the Global Historical Climatology Network (GHCN-Daily) available at NOAA's National Center for Environmental Information (NCEI, https://www.ncdc.noaa.gov). This is a large dataset that includes synoptic and other snow recording stations. Additional snow depth data were obtained from the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS). The GFS surface flux files containing snow depth fields were obtained from NOAA's National Operational Model Archive and Distribution System (NOMADS). The downloaded model data have various resolutions. The GFS surface data used in this study were available at approximately 12 km resolution on a Gaussian grid.

Elevation information is critical to the technique and is needed at every grid cell over the analysis domain. Static gridded elevation data at the analysis resolution of 12 km were constructed from the global 1-km raster data product called GTOPO30 (US Geological Survey; https://www.usgs.gov).

Methods

The overall blending snow depth algorithm is presented in Figure 3.

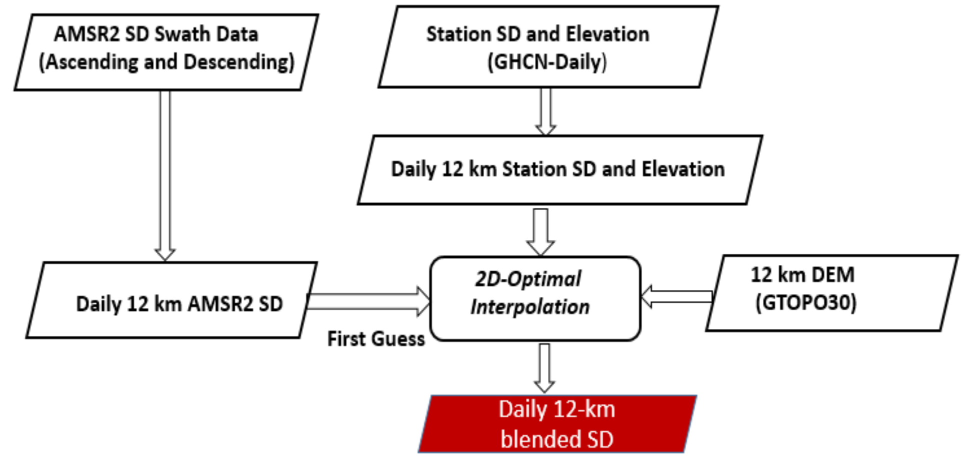

Figure 3. Flow diagram of the snow depth (SD) analysis application using two-dimensional (2D) optimal interpolation. “2D-Optimal Interpolation” refers to the interpolation over two dimensions: distance and elevation.

The input and ancillary data are averaged on a daily basis over a common regular grid at 12-km spatial resolution. For AMSR2, this spatial resolution is a reasonable approximation to the native resolution of brightness temperatures used to estimate snow depth. Given the relative coarse spatial distribution of in-situ data, averaging yields only one value per grid cell for the majority of the grid cells considered.

Satellite snow depth from AMSR2 is used as a first guess and as a snow mask to constrain the analysis, i.e., analysis is performed only over satellite snow cover grid cells. Only station-averaged snow depth (at 12 km) within a fixed range centered at each grid cell were considered. Correlation scales are the ones currently adopted in operational snow analysis at world’s major weather and climate prediction centers: an e-folding scale of 120 km for horizontal distance and an e-folding scale of 800 m for elevation. Implementation of the analysis over North America during the evaluation period indicated that a radius of influence of 600 km centered at each (satellite snow cover) grid cell would be adequate to have at least two in-situ observations available for blending with the first guess satellite estimate. Therefore, a 600-km maximum distance from each analysis grid point was set to screen in-situ data for consideration (in addition to the maximum number of observations). Note that in well-monitored areas, the actual range (the most distant snow depth observation considered) is on average much smaller. For example, over the continental US, the median range during the period of investigation was about 260 km. In contrast, over Canada and Alaska, the median range was about 580 km, and the median number of observations considered was only 21. This means that a radius of influence much smaller than 600 km would negatively impact the analysis over poorly monitored areas.

RESULTS

Figure 4 displays time series of the average daily bias in snow depth during the January-February 2017 evaluation period from the blended (satellite/in-situ) analysis using different maximum number of in-situ stations surrounding the satellite footprint. For low elevation (top panel), the bias from analysis using 5 and 50 maximum number of stations for blending is close. However, for high elevation (bottom panel), the bias increases as the maximum number of stations increases to 50. A minimum number of surrounding stations (5) is shown to result in the lowest bias.

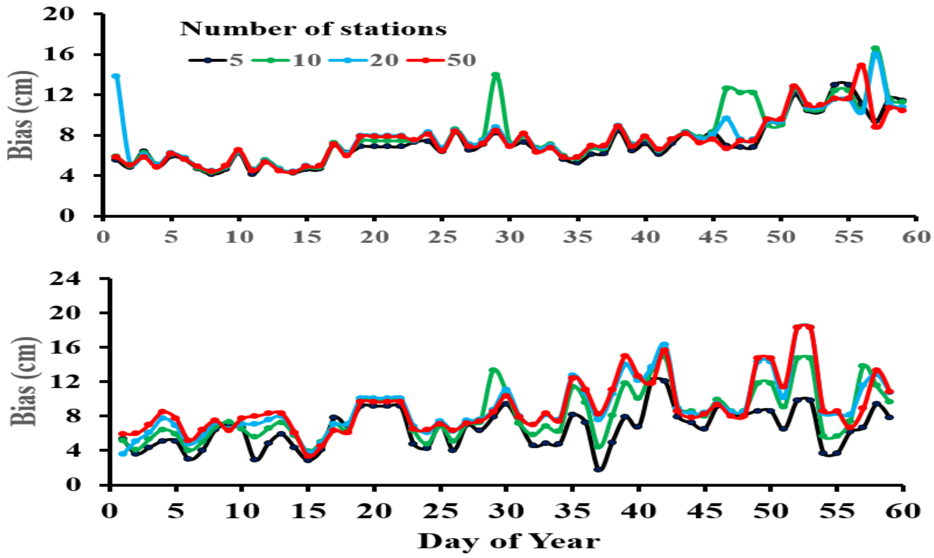

Figure 4. Time series of daily bias computed from application of analysis during January-February, 2017, for low elevation (top panel, less than or equl to 800 m) and high elevation (bottom panel, above 800 m) grid points.

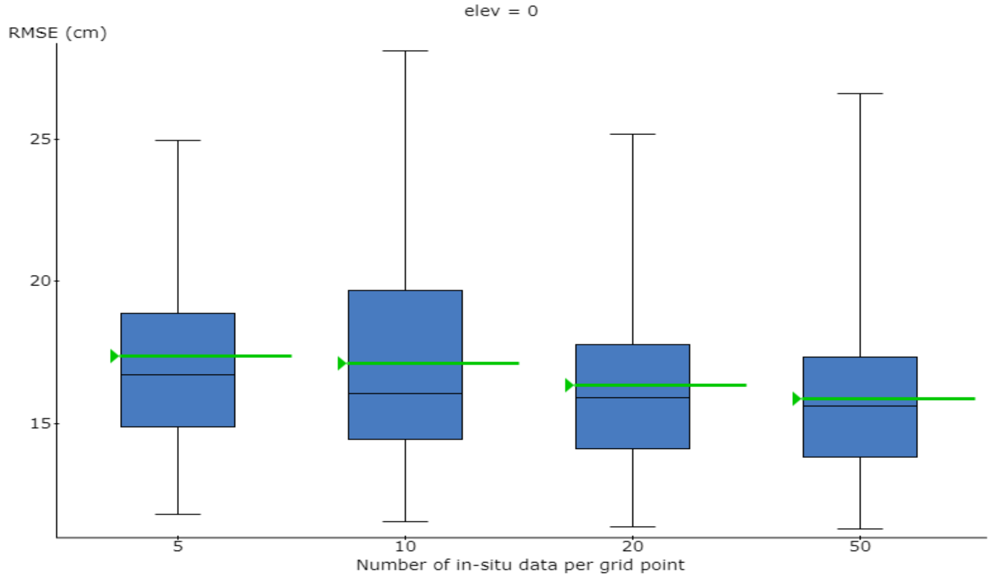

Figure 5. Boxplots of summary statistics for snow depth RMSE as a function of the maximum number of in situ stations used for blending over low elevation (less than or equal to 800 m)

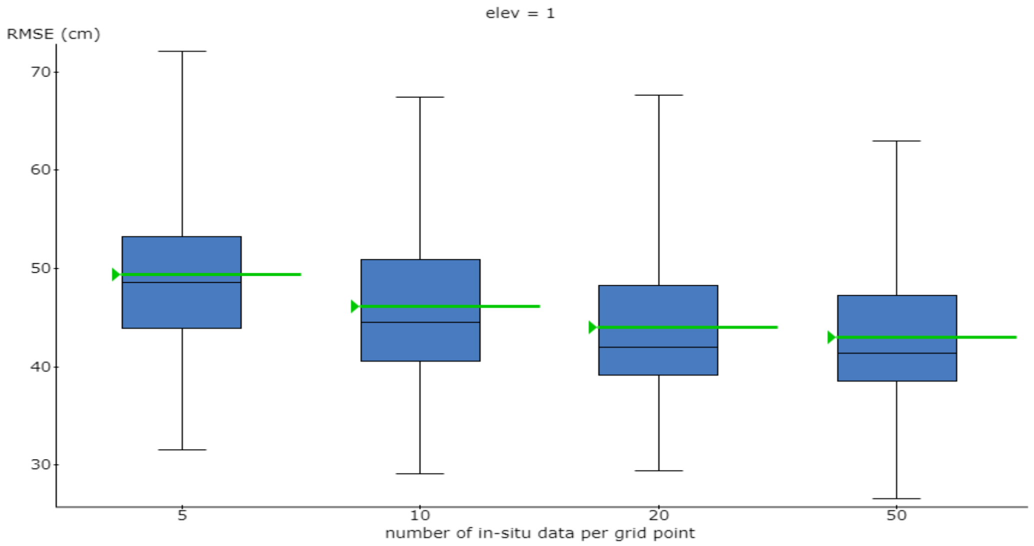

Figure 6. Boxplots of summary statistics for the snow depth RMSE as a function of the maximum number of in situ stations used for blending over high elevation (above 800 m)

Figures 5 and 6 display boxplots (minimum, 25th percentile, median, mean, 75th percentile and maximum) of Root Mean Square Error (RMSE) in snow depth from analysis over low and high elevation grid points. Results show that RMSE improves consistently over both low and high elevation grid cells as the maximum number of in-situ stations for blending increases from 5 to 50. However, RMSE for high elevation is substantially larger than for low elevation terrain, due to a) larger and more spatially variable snow depth accumulations and b) possible inaccuracies in spatial correlation models and correlation scales used.

CONCLUSIONS

The objective of the study is to test the large-scale applicability of the two-dimensional optimal interpolation method in improving satellite snow depth by combining AMSR2 satellite estimates with in-situ station snow depth data obtained from NOAA’s Global Historical Climatology Network. Evaluation of the snow depth analysis over North America during one winter season showed that a large range of up to 600 km is adequate for blending in-situ station data with that of the satellite, to provide adequate and improved analysis over poorly monitored areas. Increasing the number of snow depth measurements from 5 to 50 reduces snow depth analysis RMSE consistently over both low and high elevation terrain, although the accuracy over high elevation areas is much lower. On the other hand, while the bias remains generally low, increasing the number of stations from 5 to 50 increases the bias over high elevation grid cells, whereas over low elevation the bias is minimally impacted.

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