Evaluation and Verification of a Distributed Snow Model with Time, Space, and Elevation Variables

Jongkwan Kim[1,3] and Mike Smith[2]

[1]NOAA-National Weather Service, National Water Center, Tuscaloosa, Alabama, [2]NOAA-National Weather Service, National Water Center, Silver Spring, Maryland, [3]University Corporation for Atmospheric Research, Boulder, Colorado

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Abstract

In the mountainous western U.S., snow accumulation and melt are critical components of the water cycle. In this study, we compare simulated and observed snow variables using traditional and new spatial similarity measures. We use the SNOW17 model within the Hydrology Laboratory Research Distributed Hydrologic Model (HL-RDHM) developed by NOAA-National Weather Service (NWS) to simulate distributed snow water equivalent over the Durango River Basin in Colorado. The study basin is in the mountainous western U.S. area and consists of 108 Hydrologic Rainfall Analysis Project (HRAP, 4km*4km) grid cells.

Simulated snow information is produced on 4km HRAP grids with the temporal resolution of 1 hours for a 9-year period (Water Years 2003-2012) using a priori parameters provided by NOAA-NWS. Another simulated snow information is from Snow Data Assimilation System (SNODAS). In-situ snow observations include snow water equivalent data from 5 Snow Telemetry (SNOTEL) stations within the objective basin.

The main purpose of this research is to compare spatially distributed snow simulations with various observations considering time, space, and elevation variables. For the consideration of spatial patterns, both traditional measurements and similarity functions are employed to calculate errors between snow simulations and in-situ observations. We use the Hausdorff Distance (HAUS) and Earth Mover's Distance (EMD) for the analysis of spatial patterns. HAUS considers various factors such as time, location, and elevation. EMD measures the volume that must be displaced to make one gridded field equal to another.

The purpose of this work is to illustrate the utility of HAUS and EMD similarity error functions for evaluating spatially distributed snow models.

Motivation

- Snow variables are closely related to spatial variables; especially, the location as well as elevation variables need to be included in the process of error calculation.
- For the distributed snow models, better comparison methods should be employed to improve comparisons.
- For this reason we explore the use of spatial similarity functions for evaluation of the distributed snow variables.

Methodology

For better spatial pattern representation, two different similarity functions are employed within the process of error calculation between distributed snow simulations and observations. The time-series comparison, spatial pattern comparison, and both time and spatial comparisons are conducted with time, spatial, or both time and spatial variables. Various comparisons are conducted such as one SNOTEL observation vs. one grid cell simulation including the SNOTEL station, 5 SNOTEL observations vs. 5 grid cell simulations corresponding to the 5 SNOTEL stations, whole grid observations vs. whole grid simulations, and so on.

Data Sources & Study Area

Simulations

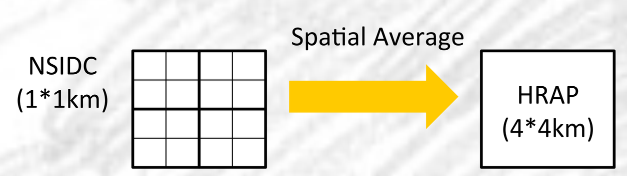
- Gridded snow water equivalent simulations from SNOW17 within the HL-RDHM framework
- Gridded snow water equivalent simulations from SNODAS available via National Snow and Ice Data Center (NSIDC)
- A priori parameter set for SNOW17 provided by NOAA-NWS

Observations

- Snow water equivalent from 5 SNOTEL sites
- Distributed fields of precipitation and temperature from NLDAS2 to run SNOW17

Data Processing

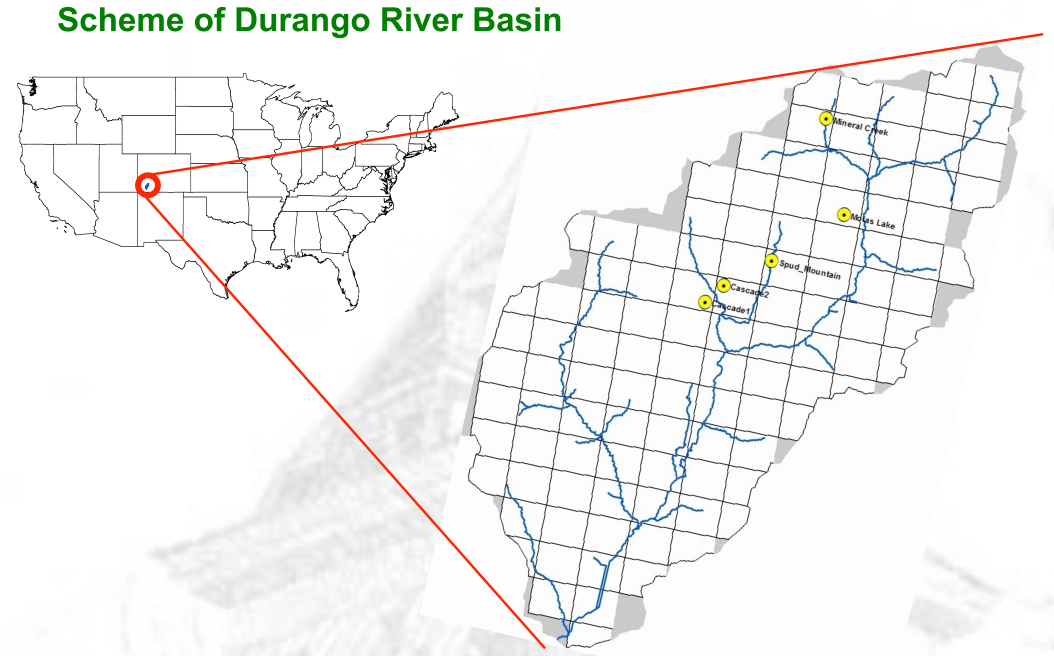
- All data sets are normalized based on the minimum and maximum of observations
- Matching up the different spatial resolution between SNOW17 (4km HRAP) and SNODAS (1km Lat/Lon)



Durango River Basin in Colorado

- Snow Dominated Basin
- 108 HRAP (4*4km) Grids
- 5 SNOTEL Stations

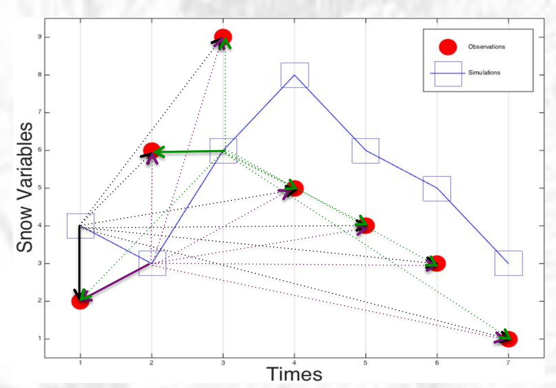
Scheme of Durango River Basin



Time-Series Comparison

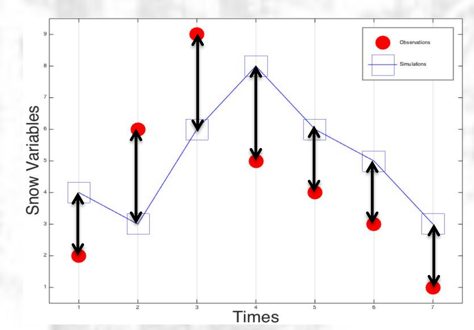
Traditional Measurements

- RMSE, Bias, NSE, R-Squared .....
- Compare only 1 vs. 1 for each time step



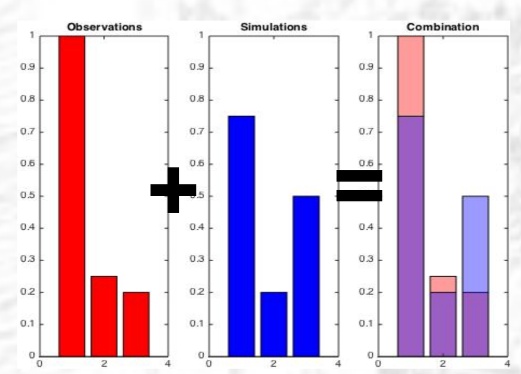
Hausdorff Distance

- Compare all the points on time-series



Earth Mover's Distance

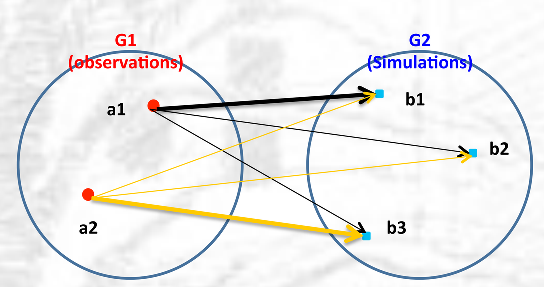
- Considering moved amount and distance



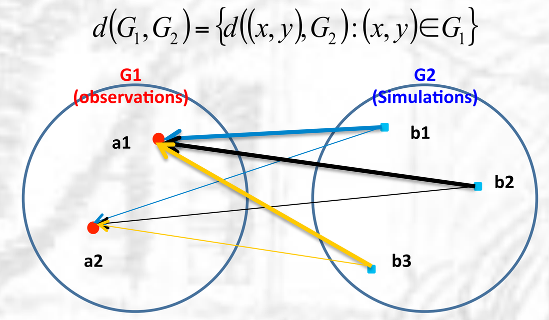
Spatial only or Time & Spatial Comparisons

Hausdorff Distance

$$Hausdorff = \max\{\sup(d(G_1,G_2)), \sup(d(G_2,G_1))\}$$

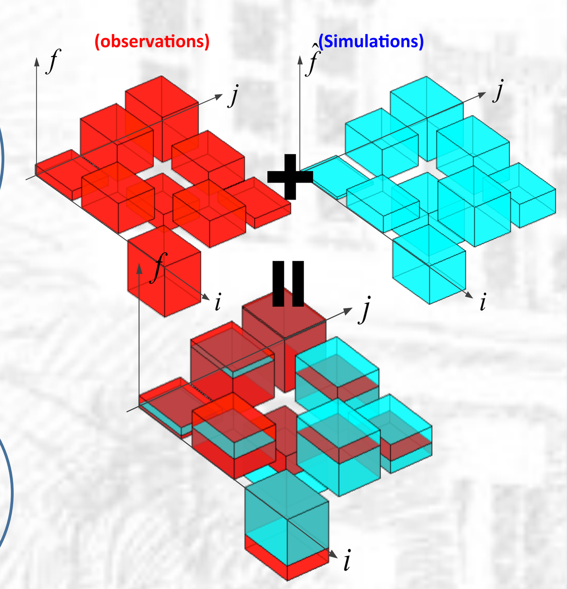


$$d(G_1,G_2) = \{d((x,y),G_2) : (x,y) \in G_1\}$$



Earth Mover's Distance

$$EMD(P,Q) = \min_{\{f_{ij}\}} \frac{\sum_{i,j} f_{ij} d_{ij}}{\sum_{i,j} f_{ij}}$$



From J. Kim et al., AGU 2013 Annual Meeting, San Francisco, CA

Results

Time-Series Comparisons

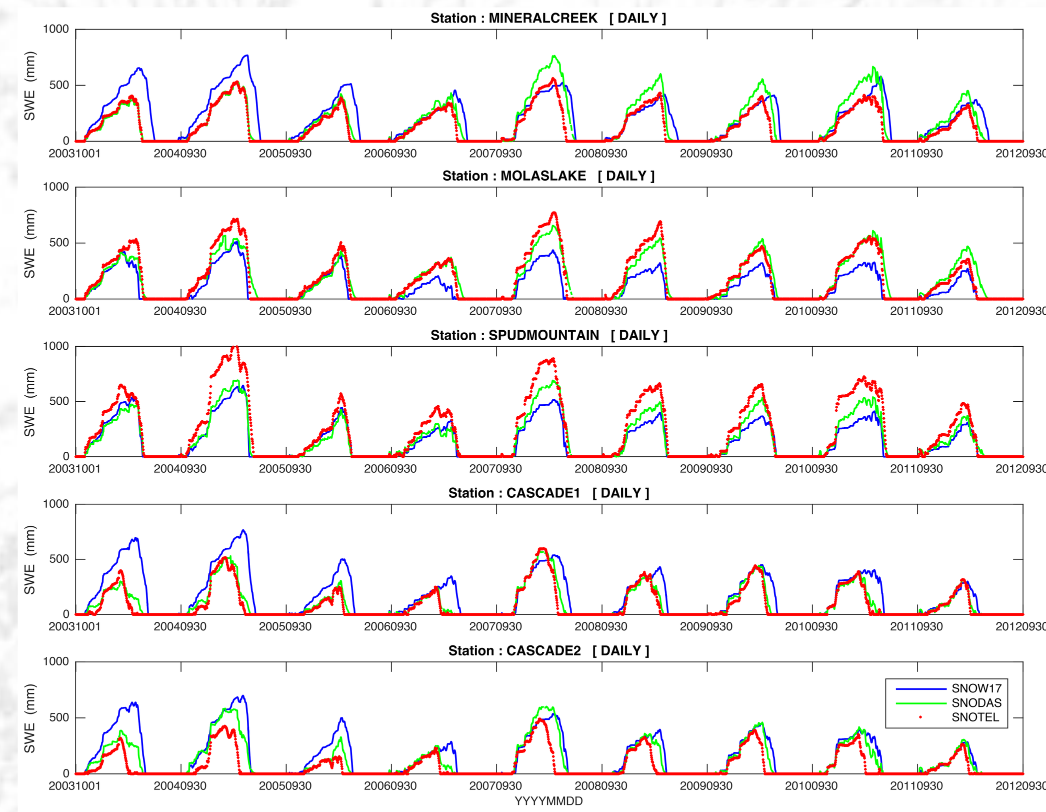


Figure 1. The time-series of observations from 5 SNOTEL stations and simulations from HRAP (4km) grid cells containing the 5 SNOTEL stations.

Calculate Errors

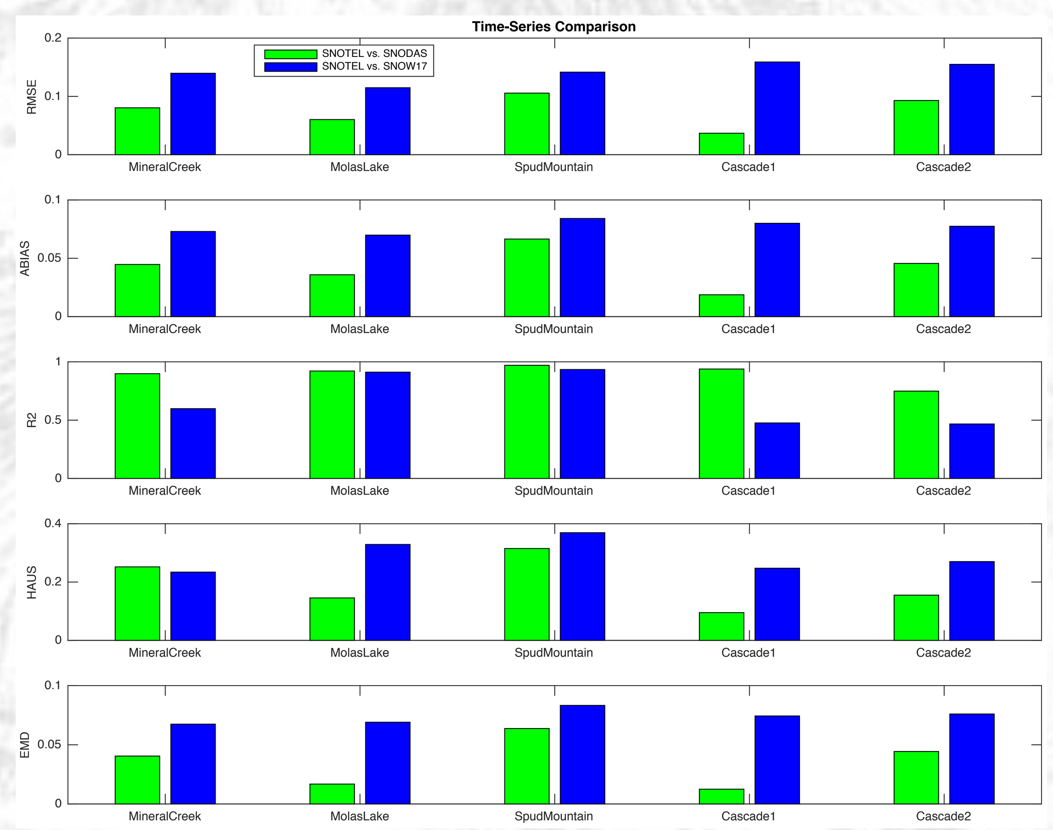
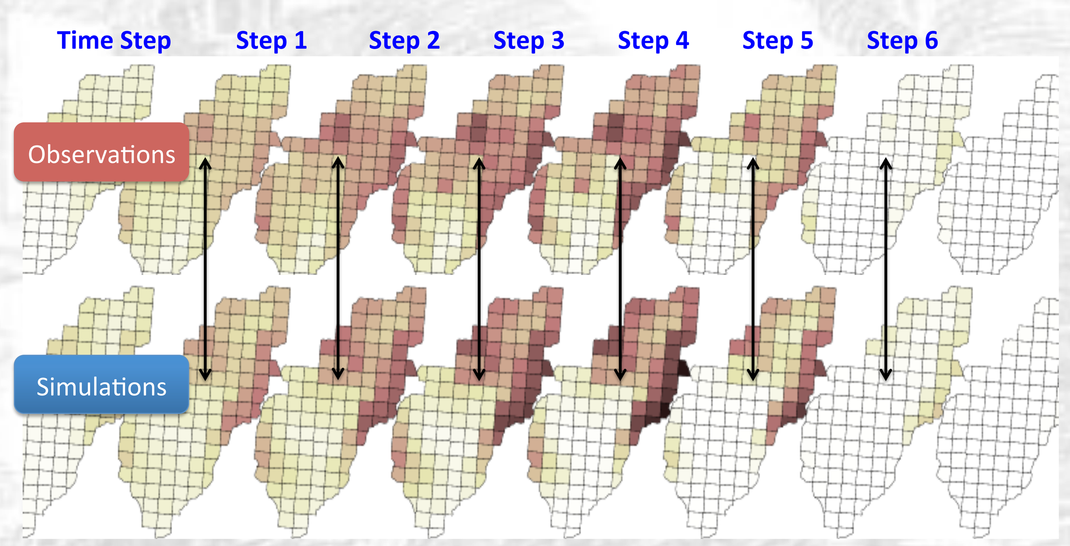


Figure 2. Error values with traditional (RMSE, Absolute Bias, and R_squared) and new similarity functions (HAUS and EMD) between Snow Water Equivalent observations from 5 SNOTEL stations and simulations from SNODAS and SNOW17 grid cells containing the 5 SNOTEL stations.

Spatial Comparisons



- Compare day by day

SNODAS vs. SNOW17

- Compare SWE simulations of 108 HRAP (4km) grids from SNODAS with SWE simulations of 108 HRAP (4km) grids from SNOW17 using EMD and HAUS functions. EMD uses spatial comparison and HAUS function uses longitude, latitude, and elevation variables.

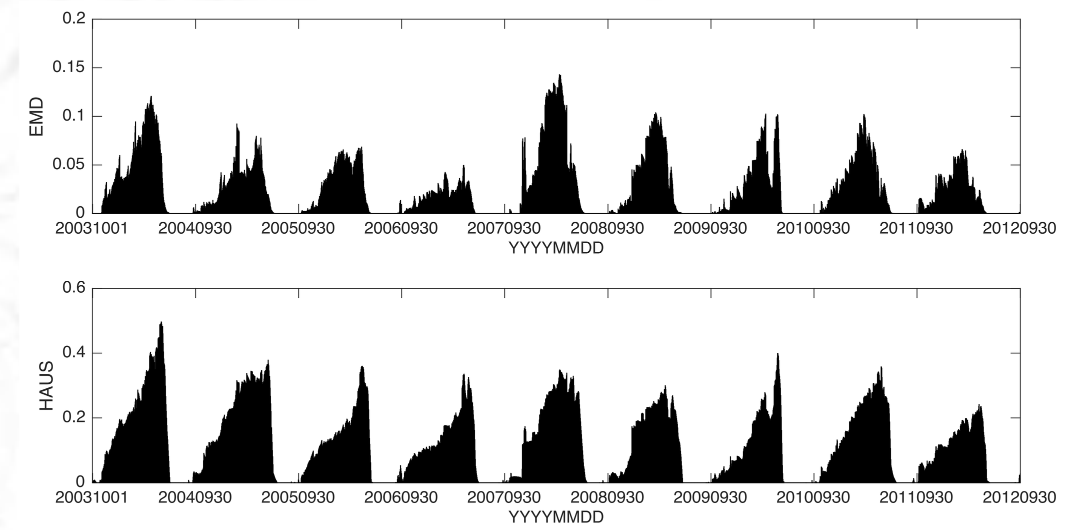


Figure 3. EMD and HAUS error values for each daily time step between SNODAS and SNOW17

Table 1. The Minimum, Maximum, and Average values of EMD and HAUS error functions for each daily time step between SNODAS and SNOW17

	Min.	Max.	Aver.
EMD	0.000	0.143	0.026
HAUS	0.000	0.496	0.123

5 SNOTEL points vs. SNOW17 or SNODAS 5 points

- Use HAUS to compare SWE observations at 5 SNOTEL stations to grid-cell SWE simulations from SNOW17 and SNODAS. HAUS includes longitude, latitude, and elevation variables.

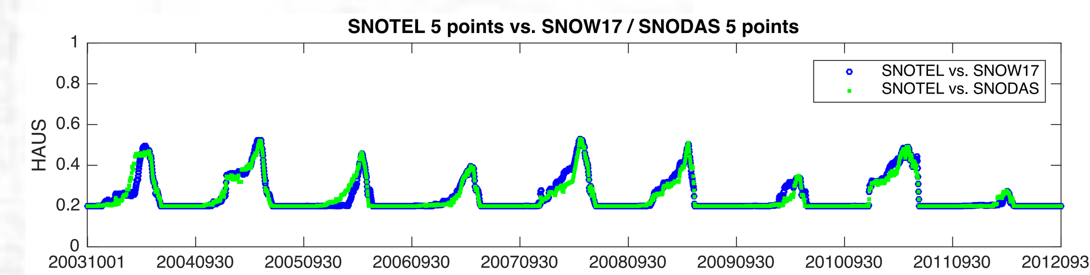


Figure 4. HAUS Error values for each daily time step between SWE observations from 5 SNOTEL stations and SWE simulations of 5 HRAP (4km) grids containing 5 SNOTEL stations from SNOW17 and SNODAS.

5 SNOTEL points vs. SNOW17 or SNODAS 108 points

- Compare SWE observations from 5 SNOTEL stations with SWE simulations of 108 HRAP (4km) grids (entire Durango River Basin) from SNOW17 and SNODAS using HAUS function.

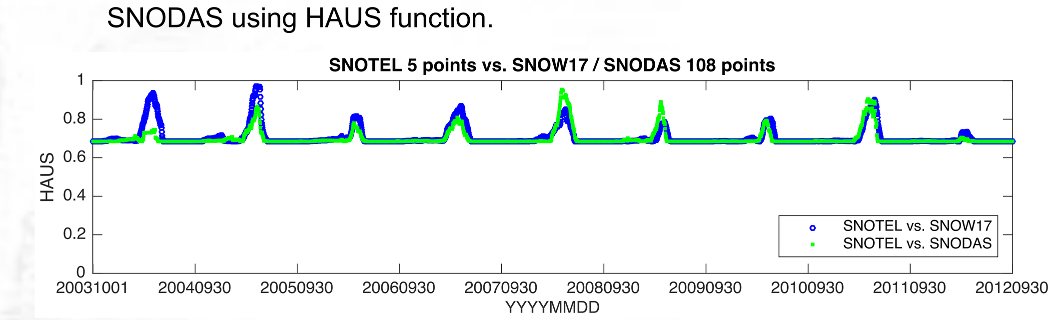


Figure 5. HAUS Error values between SWE observations at 5 SNOTEL stations and SWE simulations of the entire Durango River Basin HRAP (4km) grids from SNOW17 and SNODAS (Daily time step).

Table 2. The Minimum, Maximum, and Average values of HAUS error functions for each daily time step between 5 SNOTEL stations and SNOW17 / SNODAS

	5 SNOTEL points vs. SNOW17 5points	5 SNOTEL points vs. SNODAS 5points	5 SNOTEL points vs. SNOW17 108points	5 SNOTEL points vs. SNODAS 108points
Min.	0.1997	0.1997	0.6847	0.6847
Max.	0.5290	0.5294	0.9712	0.9536
Aver.	0.2488	0.2467	0.7065	0.7001

Each SNOTEL point vs. SNOW17 or SNODAS 108 points

- Compare SWE observations from each SNOTEL station with SWE simulations of 108 HRAP (4km) grids (entire Durango River Basin) from SNOW17 and SNODAS using HAUS function.

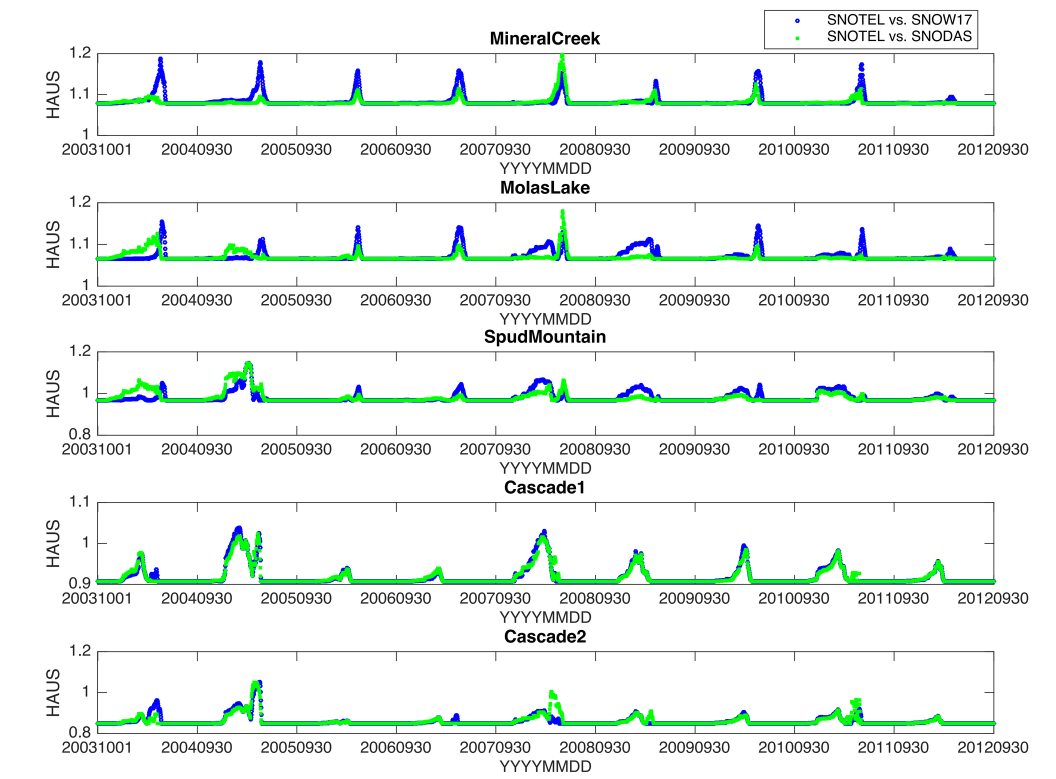
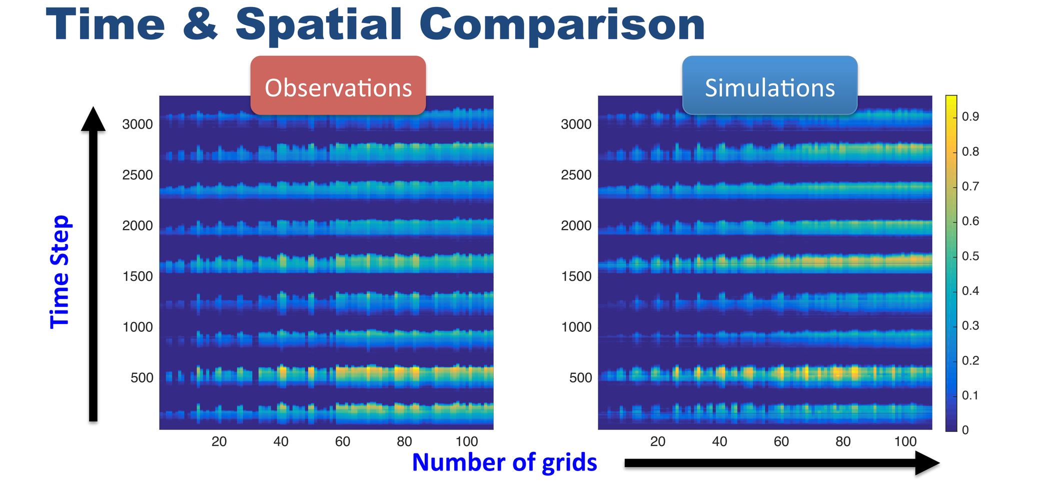


Figure 5. HAUS Error values between SWE observations at each SNOTEL and SWE simulations of the entire Durango River Basin HRAP (4km) grids from SNOW17 and SNODAS (Daily time step).

Time & Spatial Comparison



- Compare SWE observations with SWE simulations using EMD and HAUS function. EMD considers both time and spatial variables. HAUS includes time, longitude, latitude, and elevation variables simultaneously.
- SNODAS vs. SNOW17
- 5 SNOTEL stations vs. SNODAS
- 5 SNOTEL stations vs. SNOW17

Table 3. EMD and HAUS Error values with both time and spatial variables

EF	Comparisons	Error Values
EMD	SNODAS vs. SNOW17	0.0079
HAUS	SNODAS vs. SNOW17	0.9821
	5 SNOTEL points vs. SNOW17 5points	0.3923
	5 SNOTEL points vs. SNODAS 5points	0.3319
	5 SNOTEL points vs. SNOW17 Entire Basin	0.7294
	5 SNOTEL points vs. SNODAS Entire Basin	0.7130

Conclusions

- The EMD and HAUS functions complement the traditional functions such as RMSE, Bias, and R_squared for SWE time-series.
- With EMD and HAUS, comparisons including both time and spatial variables are possible.
- With HAUS, a variety of spatial factors, especially elevation, are available for the process of error calculation.
- The use of similarity measurements is very proper for the evaluation and verification of distributed snow models.
- In this illustration, SNODAS shows better performances than SNOW17 with time and spatial variables.

Further studies

- This study could be extended to larger regions containing SNOTEL stations to investigate overall error values.
- Other comparisons of snow models could include the EMD and HAUS functions.

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Jongkwan.kim@noaa.gov

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