Assimilation of MODIS Snow Cover Data into the SAC-HT/SNOW17 Model over the Western US

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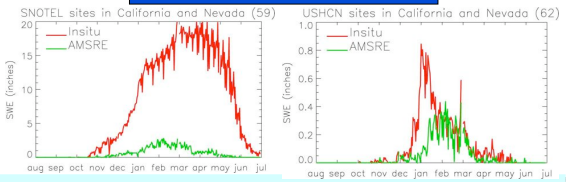
Snow and Meteorological Data

1. **Satellite Observations:**
   Terra-MODIS Level 3 500m SCA data (MOD10A1)
   Terra-MODIS Level 3 1km LST data (MOD11A1)
2. **In-situ Observations:**
   U. S. Historical Climatology Network (USHCN) Daily Temperature, and Snow Depth Data (62 sites)
   SNOTEL Daily Temperature and Snow Water Equivalent Data (59 sites)

AMRE SWE vs Insitu SWE

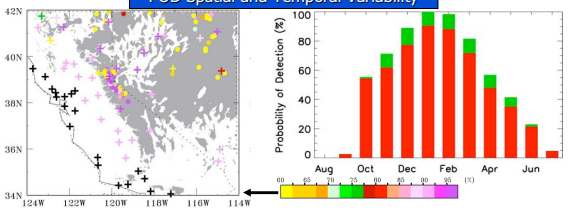


Methodology: The quality of MODIS-retrieved SCA relative to the in-situ observations is evaluated using common statistical verification measures, an error matrix, including the probability of detection (POD) and false alarm ratio (FAR). The POD measures the fraction of observed snow cover presence that were correctly detected in MODIS, and FAR measures the fraction of observed snow-free land (SFL) that were incorrectly detected as snow cover in MODIS.

$$POD = \frac{SS}{SS + NS} \qquad FAR = \frac{SN}{SN + NN}$$

		In-situ	
		SCA	SFL
MODIS	SCA	SS	SN
	SFL	NS	NN

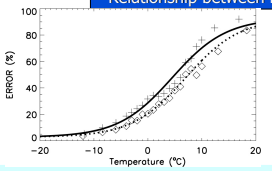
POD Spatial and Temporal Variability



(LEFT) The POD of MODIS SCA retrievals with coincident ground truth station data for snow season (October to June) from February 2000 to December 2005 in California/Nevada. (RIGHT) The POD and FAR in each month from February 2000 to December 2005.

For the study area, the MODIS SCA product demonstrates strong ability in detecting the presence of snow cover (83%). However, significant spatial and temporal variations in accuracy (from 75% in high roughness to 86% in low roughness region and 44% in October to 97.5% in February), suggest that a proxy is required to adequately predict the expected errors in MODIS SCA retrievals. The FAR is below 10% all year round.

Relationship between POD and Temperature



MODIS SCA retrieval error relative to in-situ daily mean air temperature (pluses) and MODIS LST (diamonds) over all in-situ sites in Colorado. The cumulative double exponential distribution function is used to construct the nonlinear relationship between the errors and in-situ air temperature (solid line) and MODIS LST (dotted line).

There is a nonlinear relationship between the MODIS retrieval error and temperature. The cumulative double exponential distribution function is used to construct the nonlinear relationship of the errors as a function of temperature in MODIS snow cover retrievals.

$$err = 1 - POD = e + \frac{90}{1 + e^{-(t - t_f)/b}}$$

	T_f	b
In-situ Temp	4.5	5.0
MODIS LST	7.0	5.0

Where e is the base of the natural logarithm, T_f is the reference temperature as a location parameter, and b is a scale parameter. We obtained the parameters based on least square fitting.

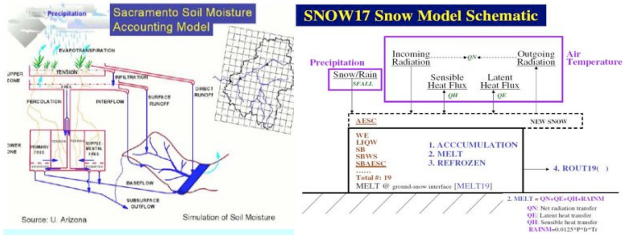
Abstract

As both the model predictions and passive microwave snow water equivalent (SWE) observations contain large errors due to land surface complexities and temporally frequent snowmelt processes in the western United States, the 500m daily MODIS snow cover area (SCA) product has been used in this study as an important constraint on snowpack processes in land surface and hydrological models. The uncertainty in MODIS SCA product has been assessed over the study basin, and quality control will be applied to the MODIS SCA product before assimilated into SNOW17 model.

In this study, we assimilate the MODIS derived snow cover fraction into the SNOW17 model operating on the HRAP (Hydrologic Rainfall Analysis Project) grid at 4.7625KM resolution over DMIP II Carson River Basin domain. We update the snow cover fraction values at pixels which feature less than 50% cloud coverage. Because the change of snow cover fraction makes no change to the amount of snow water equivalent in SNOW17, we had to develop a new scheme to account for the effect of change in snow cover fraction to total snow water equivalent. We selected the traditional bisection method to study this inverse problem. The iterations will depend on the defined error tolerance, which was arbitrarily set to 0.001. Our initial sensitivity experiments show most results converged after 10-15 iterations with this error tolerance, and the computational burden is not large. The assimilation results has been evaluated by SNOTEL SWE (in-situ measurements).

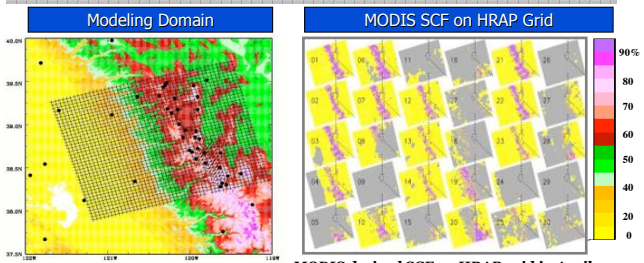
Models

The models used in this study include: SAC-HT version of SAC and SNOW17 under the NASA LIS (Land Information System) frame work for land modeling. The study area is in Sierra-Nevada Basin on HRAP grid, and the forcing (temperature and precipitation) is from DMIP II.



MODIS Derived SCF on HRAP Grid

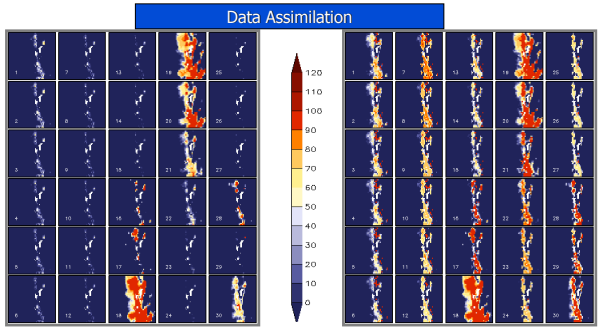
Terra-MODIS Level 3 500m Daily Snow Cover Area Data were aggregated onto HRAP grid at 4.7625KM resolution to generate the snow cover fraction data. The HRAP grid is treated as cloud covered when the cloud cover fraction is above 50%.



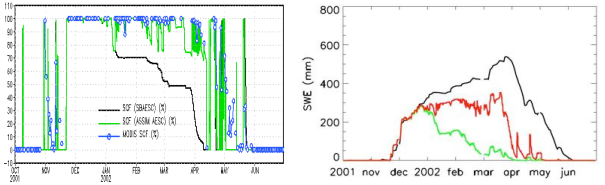
MODIS derived SCF on HRAP grid in April 2002.

We perform two runs in parallel. One is without using assimilation, and the other is applying the data assimilation. At this time, we just apply the direct insertion algorithm in our assimilation. The LIS SAC-HT/SNOW17 model is operating from October 1, 2001 to September 30, 2002. We assimilate the above MODIS derived snow cover fraction into the SNOW17 model on the HRAP (Hydrologic Rainfall Analysis Project) grid at 4.7625KM resolution over DMIP II Sierra-Nevada Basin domain. We are going to update the snow cover fraction values daily at 10:30 am local time and at pixels which feature less than 50% cloud coverage.

Data Assimilation

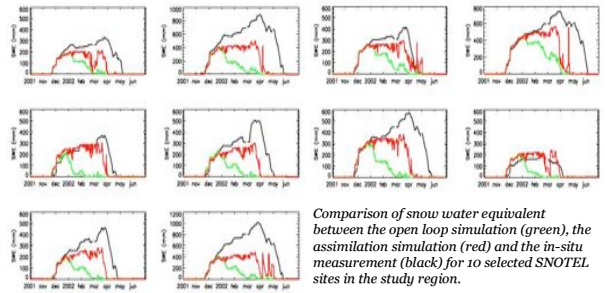


The above figures show the daily snow cover fraction in April 2002 from two simulations: (LEFT) The open loop simulation; (RIGHT) Data assimilation simulation.



LEFT: Comparison of snow cover fraction between the MODIS, the open loop simulation and the assimilation simulation.

RIGHT: Comparison of snow water equivalent between the open loop simulation (green), the assimilation simulation (red) and the in-situ measurement (black) averaged over all SNOTEL sites in the study region.



Comparison of snow water equivalent between the open loop simulation (green), the assimilation simulation (red) and the in-situ measurement (black) for 10 selected SNOTEL sites in the study region.

SUMMARY

This study has investigated remotely-sensed MODIS snow cover estimation uncertainty. For cloud-free pixels, the MODIS SCA retrieval errors can be quantitatively predicted by temperature with regional calibrated parameters.

The preliminary experiments show that the snow cover fraction after assimilation shows close agreement to the MODIS SCF observations. Comparison at an individual grid between open loop and assimilation simulations shows that the snow water equivalent is also improved through assimilation of MODIS SCF.

Future Plan

- **We will apply the statistical equation to depict the uncertainty in MODIS snow cover fraction, and further to apply the ensemble Kalman Filter (EnKF) in our data assimilation scheme.**
- **We will couple SAC-HT/SNOW17 to a stream flow module in order to use station stream flow measurements as additional method to verify the performance of our assimilation.**