Reconstructing the Space-time Variability of California Snow Water Equivalent (SWE)

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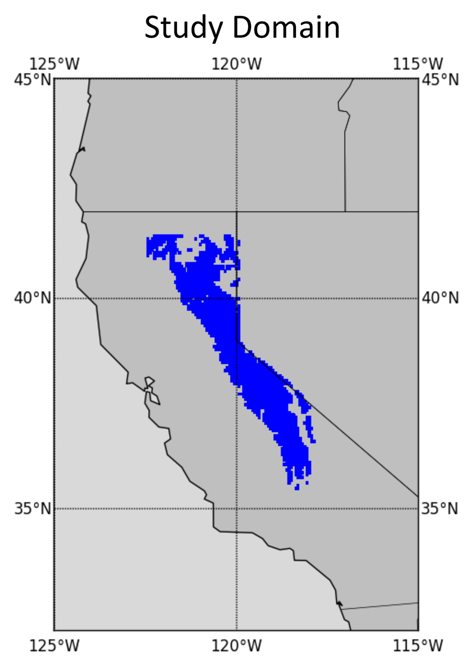
1. Background

Given the magnitude of the California economy and its dependence on water, there has been great interest in water stored seasonally in the Sierra-Nevada Snow Region's Snow Water Equivalent (SWE). We compare estimates of SWE over the period 2004-2014 from three sources: a model-based estimate from the Variable Infiltration Capacity (VIC) land surface model, NOAA's SNODAS data (based on a combination of model-based estimates and point observations), and an estimate based on remote sensing (RS). We find that in general, the RS estimate is higher than either VIC or SNODAS (by 53-69 percent over the 2004-2014 period), but during drought year 2014, the estimates were more similar.



The study domain consists of the 1/16th degree latitude-longitude grid cells in California for which Mao et al. (2014) found that long-term average Apr 1 SWE exceeded 10 mm.

2. Data Set Description

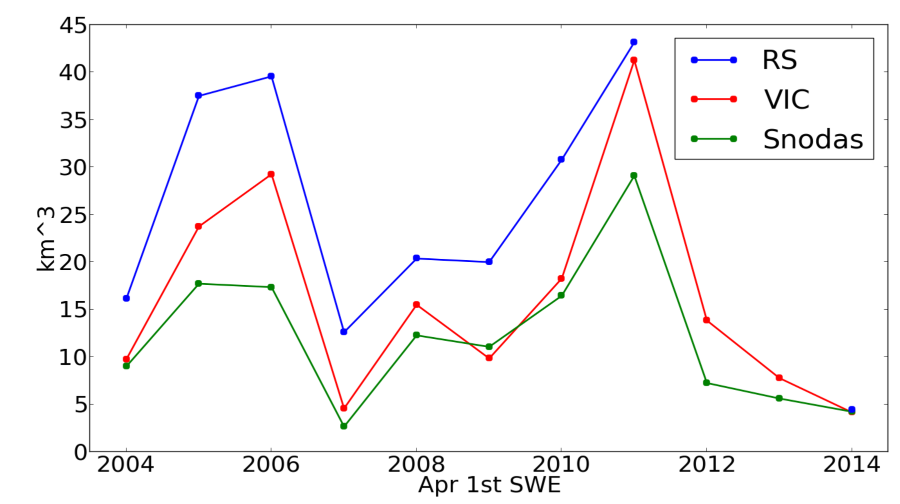
The Variable Infiltration Capacity (VIC) land surface model (Liang et al 1994) has been applied in many hydrological studies that include the estimation of mountain snowpacks. Mao et al. (2014) describe SWE reconstructions using the model over California for the period 1920-2014 at 1/16th degree spatial resolution. Our VIC estimates of California SWE (and our study domain) are taken from that paper.

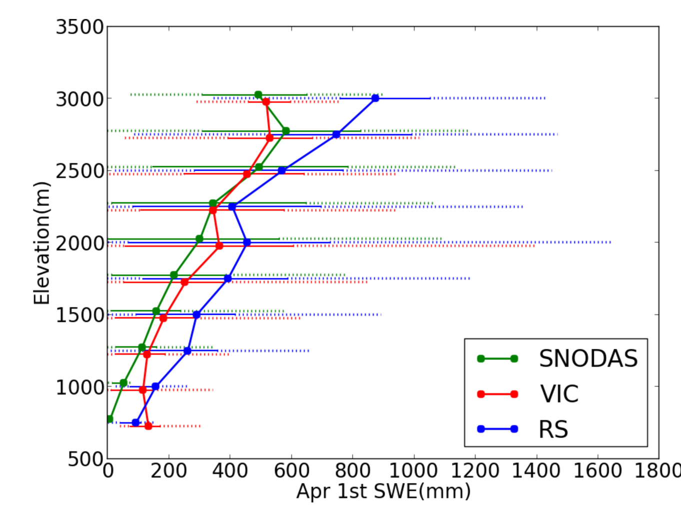
The SNOw Data Assimilation System (SNODAS) was developed by NOAA's National Operational Hydrological Remote Sensing Center (NOHRSC). It is produces estimates of SWE that are a combination of model-based quantities adjusted by assimilation of satellite and aircraft SWE estimates as well as surface SWE observations (we believe that over the Sierra Nevada, the primary and possibly only assimilated data are surface SWE from snow pillows). The modeling core for SNODAS is the NOHRSC Snow Model, details of which are unavailable in the refereed literature, but which is stated online to be "a physically based, spatially distributed, energy-balance and mass-balance snow model."

The UCSB remote sensing reconstruction is based on the energy required to melt SWE during the ablation season. For each pixel, from the time of peak SWE through the disappearance of snow in a satellite image, the reconstruction accumulates SWE backwards in time using melt energy taken from the North American Land Data Assimilation System (NLDAS).

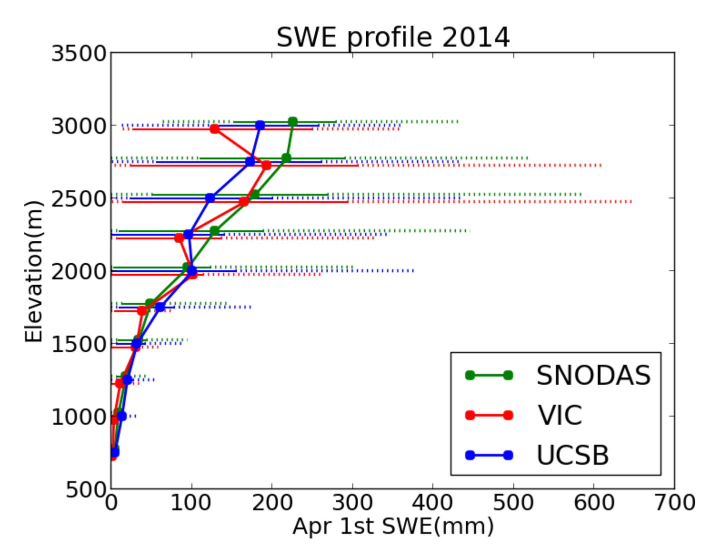
3. Time series and elevation profiles

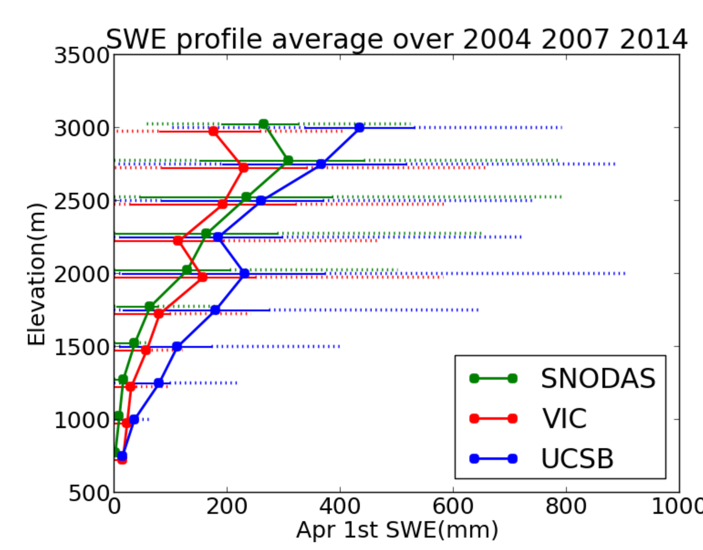
We aggregated the SNODAS and RS estimates to the 1/16th degree VIC spatial resolution over the same domain. We show below the aggregate SWE on Apr 1 over the model domain from each source (note that RS is not available for 2012 and 2013), and by elevation.





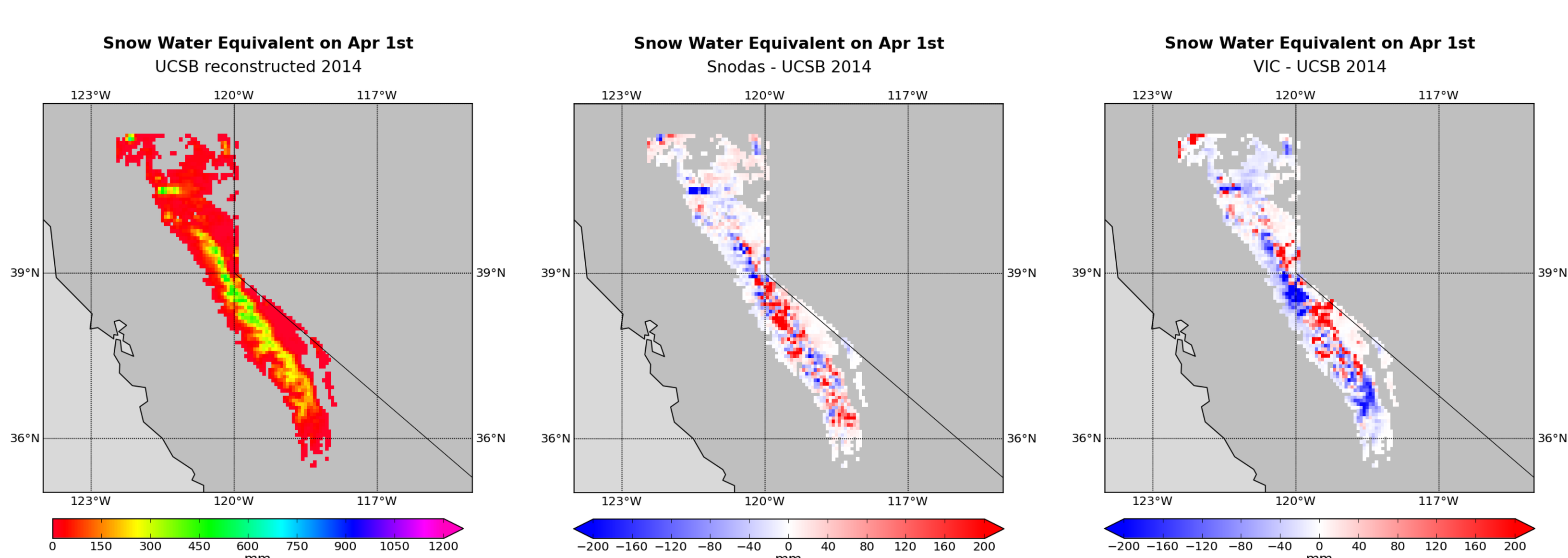
We show below elevation profiles for drought year 2014, and averaged over the three lowest SWE years (2004, 2007 and 2014) for which estimates are available from all three sources. The profiles are more similar for 2014 than they are on average over all years, however the averages for the three lowest years are similar (aside from magnitudes) to the averages over all years.

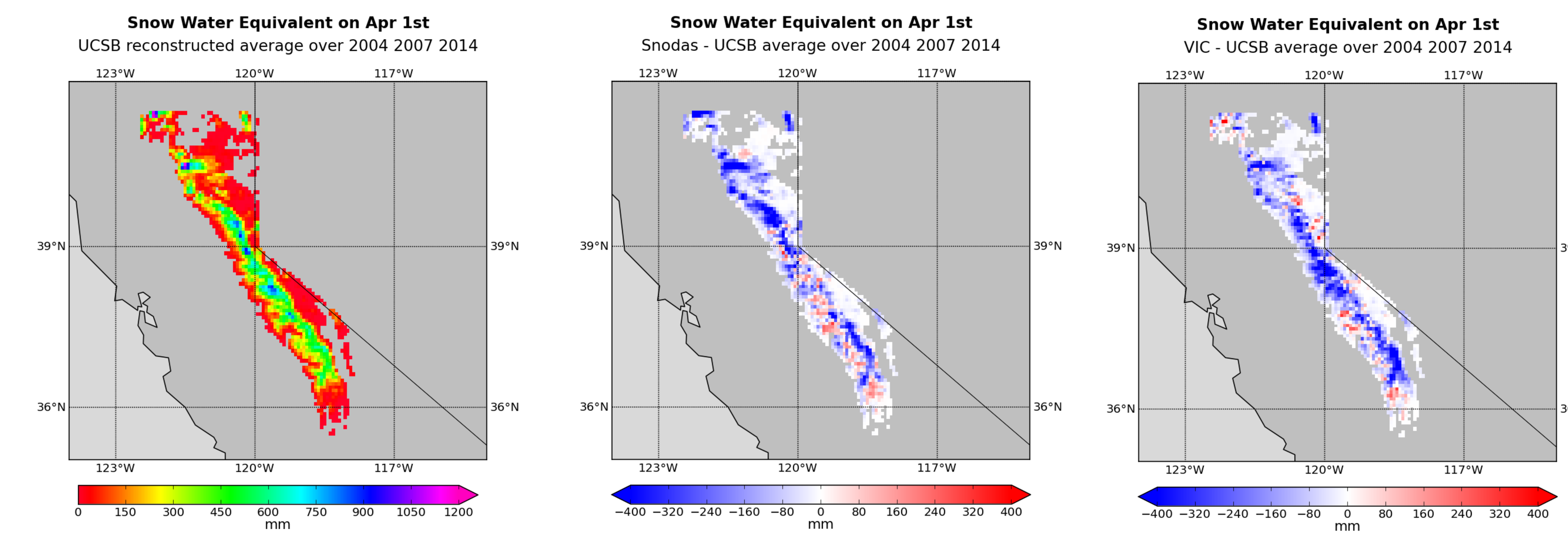




4. Spatial variations between Datasets

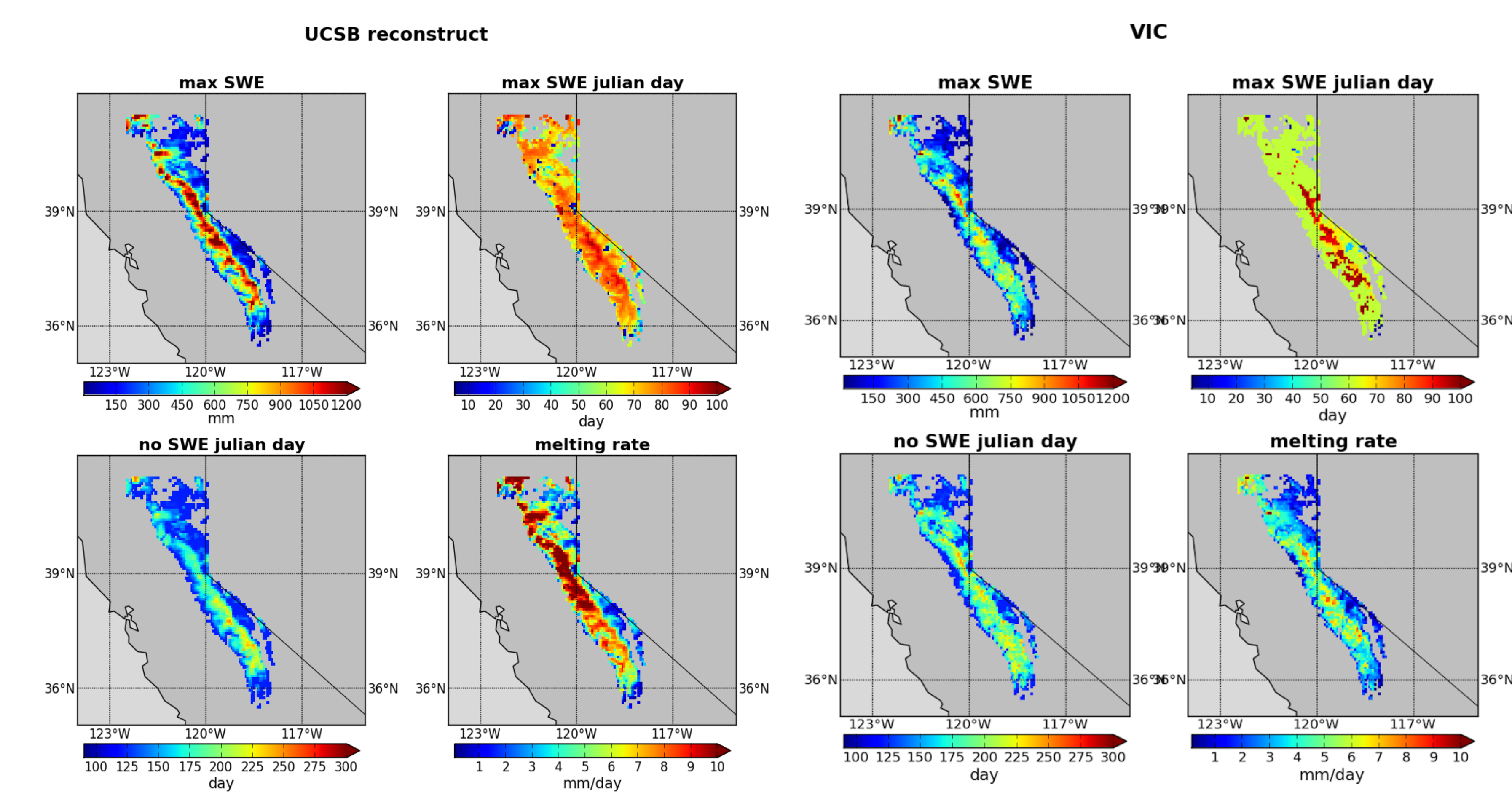
Next the spatial distribution of SWE on Apr 1st for the selected dry years and the difference between these datasets are shown. In year 2014, the three datasets are close and thus the difference plots are somewhere positive and somewhere negative. RS data is higher than the other two in 2004 and 2007, blue(<0) dominates the plots.





The last figure shows the maximum SWE during water-year, the max SWE ordinal day, time of last SWE and the melting rate of RS and VIC data. The Peak SWE time is around April 1st and many grid cells' the last SWE day is between July and September. We calculated the melt rate as Max SWE/(Max SWE day – Last SWE day).

The RS reconstructed Maximum SWE is generally higher than VIC and the no SWE days are similar, therefore melt rates for RS are generally higher than for VIC.



5. Summary

1. The UCSB reconstruction estimates have higher SWE (by 53% relative to VIC, and 69% relative to SNODAS averaged over 2004-14); however the estimates are more similar in drought year 2014).
2. UCSB estimates on average have later dates of maximum snow accumulation relative to VIC (by 6 days on average), and earlier days of last snow (by 14 days on average).
3. As a result, UCSB melt rates are on average about 41% higher than VIC's. Part of this difference results from UCSB's representation of fractional snow coverage, which VIC does not in the model version that was applied.

Reference

National Operational Hydrologic Remote Sensing Center, 2004: Snow Data Assimilation System (SNODAS) Data Products at NSIDC. [indicate subset used]. Boulder, Colorado USA: National Snow and Ice Data Center

Liang, X., et al., 1994: "A simple hydrologically based model of land surface water and energy fluxes for general circulation models." Journal of Geophysical Research: Atmospheres 99, 14415-14428.

Mao, Y., B. Nijssen, and D.P. Lettenmaier, 2015: "Is climate change implicated in the 2013–2014 California drought? A hydrologic perspective." Geophysical Research Letters 42, doi:10.1002/2015GL063456.