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Evaluation of Precipitation Scaling Using the Observed Snow Cover Disappearance Date for Snow Models

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Abstract

Precipitation measurements of snowfall are sparse in mountainous areas. Snowfall at an ungauged point must be estimated by rescaling precipitation measured some distance away. This study evaluates a method for scaling precipitation based on the snow disappearance date. The method is evaluated over 8 years at 144 surface stations. The method performs well and underestimates seasonal SWE volume by 10-16% and peak seasonal SWE by only 8-16%. It has potential application in mid-elevation ranges.

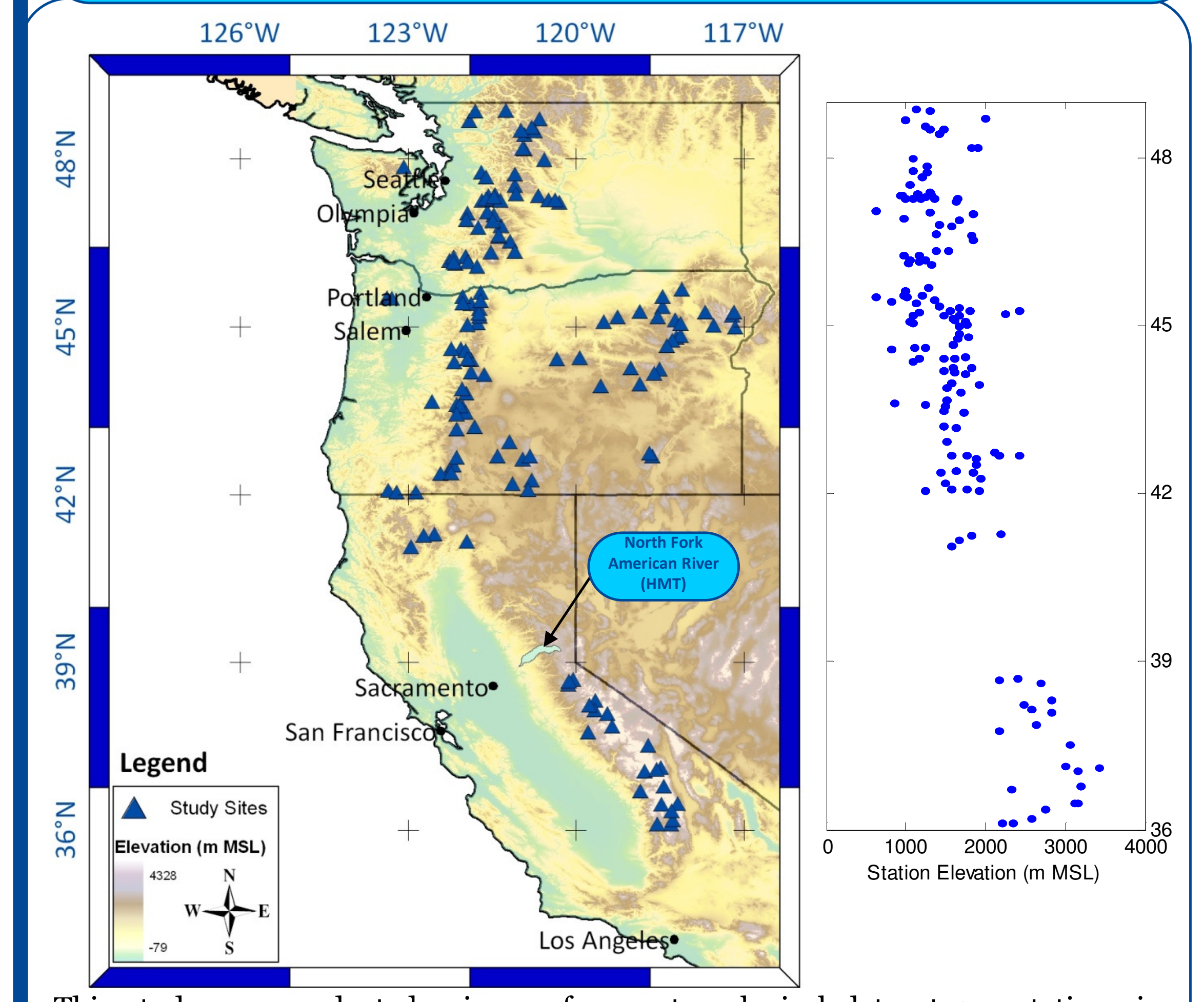
I. Background & Purpose

National Oceanic and Atmospheric Administration
Hydrometeorology Testbed Program

This study is a part of the Hydrometeorology Testbed Program (HMT) of the National Oceanic and Atmospheric Administration (NOAA). The general purpose of the HMT project is to analyze data from a dense network of intensive surface and radar measurements to provide the river forecasting community with improved knowledge for hydrologic modeling. The HMT study area is the American River Basin in California, just west of Lake Tahoe and upstream of Sacramento.

Because precipitation data are essential to running hydrologic models but are sparse in many basins, it is critical that a robust method is available to scale precipitation for realistic estimations. This study has emerged to address the need of scaling precipitation for a distributed snow model in the American River Basin. The snow disappearance date can be obtained (see Applications & Implications section) at any point in a basin and thus a method that scales winter precipitation based on that date may be useful to hydrologic modeling in the American River Basin.

II. Study Areas



This study was conducted using surface meteorological data at 144 stations in Washington, Oregon, and California from water years 1996 – 2004. The above figures show the latitude and elevation of the stations, and the table below provides information specific to each region.

	# of Stations Used	Elevation Range (m MSL)	Study Period (Water Years)	Operator
Washington	47	610 -1981	1997 - 2004	NRCS* (SNOTEL)
Oregon	72	610 - 2411	1997 - 2004	NRCS* (SNOTEL)
California	25	1555 - 3414	1996 - 1998	Varies (CDEC**)

* NRCS – Natural Resources Conservation Service

** CDEC – California Data Exchange Center (through California Department of Water Resources)

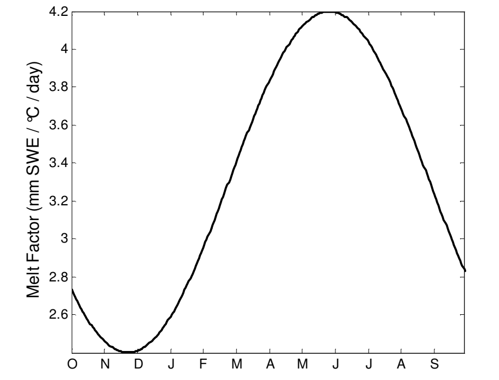
III. Data & QA/QC

Example layout of a surface meteorological station with locations of measuring devices denoted by letter.

Observed daily mean air temperature, cumulative precipitation, and snow water equivalent (SWE) data were obtained for each SNOTEL study site in Washington and Oregon. Precipitation data were not available for the California CDEC sites, and accordingly the incremental magnitude of accumulated observed SWE was used as a surrogate estimation. Surface meteorological measurements from remote mountain stations are notorious for missing and erroneous values, especially during extreme weather events. An automated algorithm for detecting suspect values at a single station was developed based off the framework suggested by Meek and Hatfield (1994). This algorithm was expanded to use data from a network of observation stations to flag jumps in observed precipitation and SWE. The limits used in the QA/QC are displayed in the table below. Analysis was not conducted on sites when more than 3 days of missing or erroneous temperature or precipitation data were found during each observed snow season. SWE records with an unmeasured snow disappearance date were rejected.

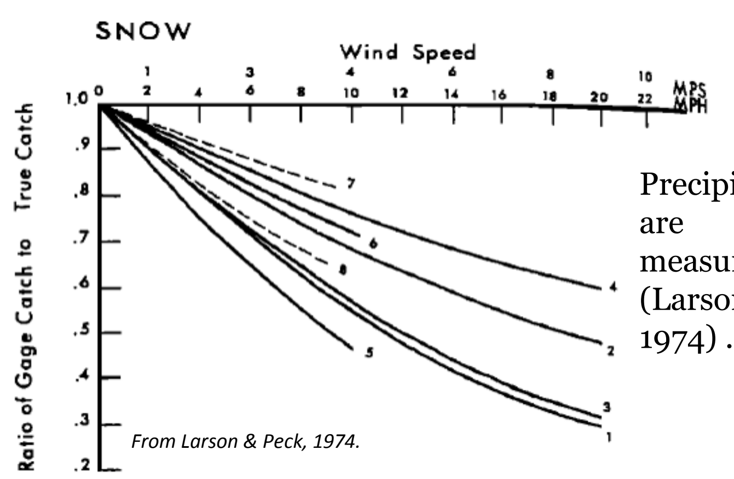
	Lower Limit	Upper Limit	Constant Limit (days)	Jump Limit
Air Temperature (° C)	-25	40	3	25
Precipitation (mm/day)	0	200	3	N/A
SWE (total mm)	0	3300	10	300

IV. Snow-17 Model



Snow-17 (Anderson 1976) is a conceptual temperature-indexing model that requires temperature and precipitation records to simulate the accumulation and ablation of snowpack. This study uses Snow-17 at the daily time step data (see Data section) to scale precipitation. Snow accumulation in Snow-17 is a function of air temperature since temperature dictates whether precipitation is occurring as rain or snow. Ablation is also driven by temperature in the model according to a seasonally dependent melt factor (figure, left). Snow-17 accounts for the heating and melting of snow pack through a heat deficit system that requires a ripe snowpack with zero heat deficit.

V. Precipitation Scaling Method



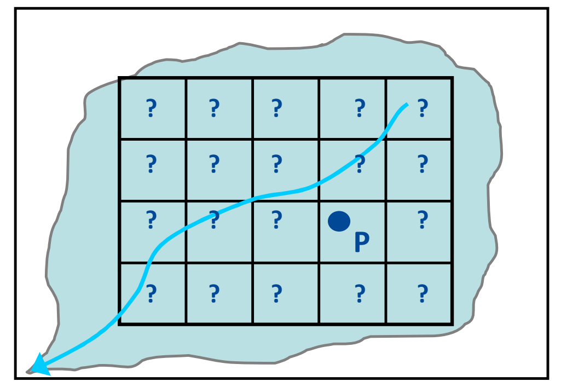
From Larson & Peck, 1974.

Problem #1

Precipitation gauges are deficient at measuring snowfall (Larson & Peck, 1974).

Problem #2

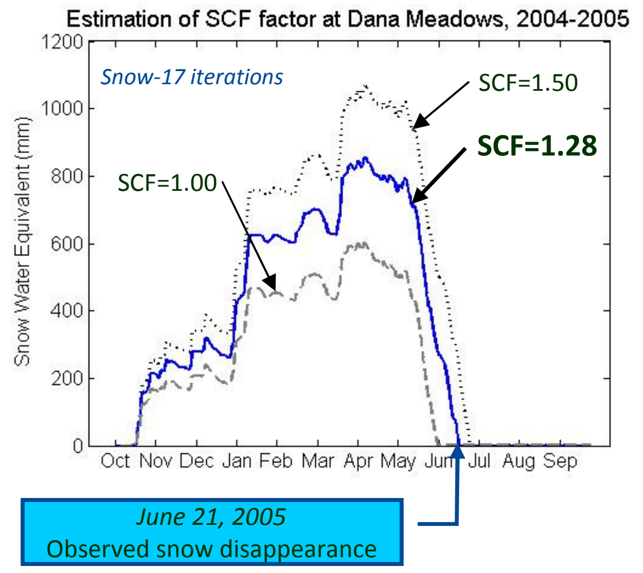
Precipitation observations are not abundant in mountainous regions.



Gridded basin showing cell with precipitation gauge (P) and ungauged cells (?).

Solution to #1 & #2

If the snow disappearance date is known, a snow model can be run iteratively by adjusting the precipitation under-catch correction factor until the modeled and observed snow disappearance dates align. This provides a simulation of SWE based on disappearance date (Liston, 1999; Molotch and Bales, 2005) and a new precipitation scaling factor (SCF) that combines the scale factors used in Problems #1 & #2.



VI. Results & Discussion

Performance Metrics

Two primary metrics (below) were used to quantitatively assess the accuracy of this precipitation scaling method. A perfectly simulated snow pack will score unity in the Volume Ratio and Peak Ratio metrics. Temporal metrics were also used to evaluate the timing differences. Due to the non-linearity of Snow-17, exact convergence at the snow disappearance date could only be attained in 52.1% of the realizations while 85.2% of all realizations closed within 1 day. All closures greater than 2 days were discarded.

1. Volume Ratio

$$V_{ratio} = \frac{\int_{t_1}^{t_2} SWE_M}{\int_{t_1}^{t_2} SWE_O}$$

Where:

SWE_M=Modeled SWE (mm)
SWE_O=Observed SWE (mm)
t_1=start date of snow cover
t_2=end date of snow cover

2. Peak Ratio

$$P_{ratio} = \frac{\max(SWE_M)}{\max(SWE_O)}$$

Where:

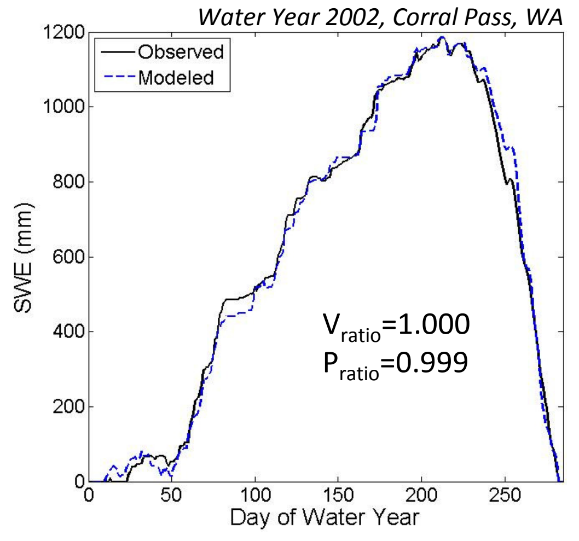
SWE_M=Modeled SWE (mm)
SWE_O=Observed SWE (mm)

Temporal Metrics

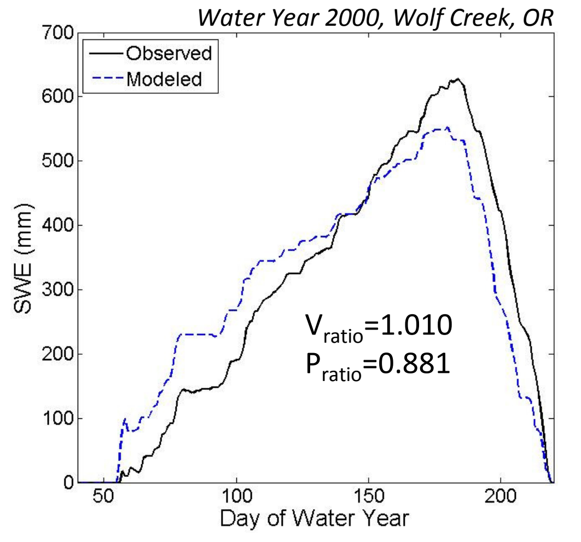
ΔT_{peak} = difference (days) in observed peak SWE and modeled peak SWE

ΔT_{end} = difference (days) in observed and modeled snow disappearance date

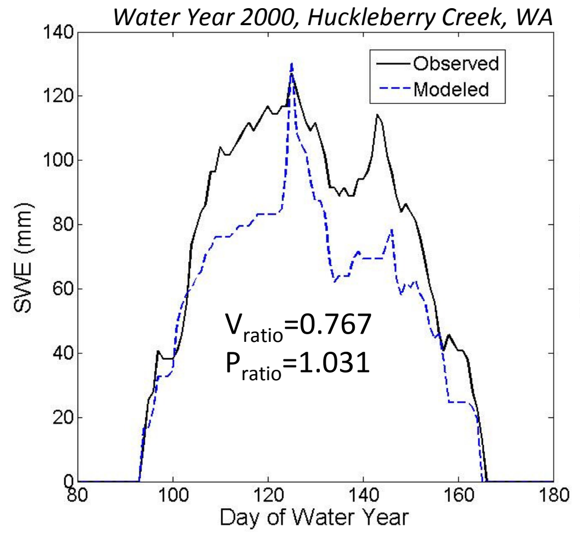
Range of Results



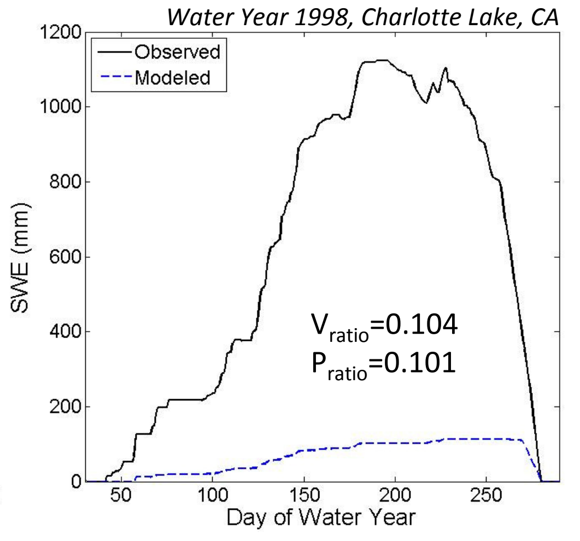
Model matches observed SWE volume and peak SWE



Model matches total observed SWE volume but predicts too much SWE early and too little SWE later. Model underestimates peak SWE

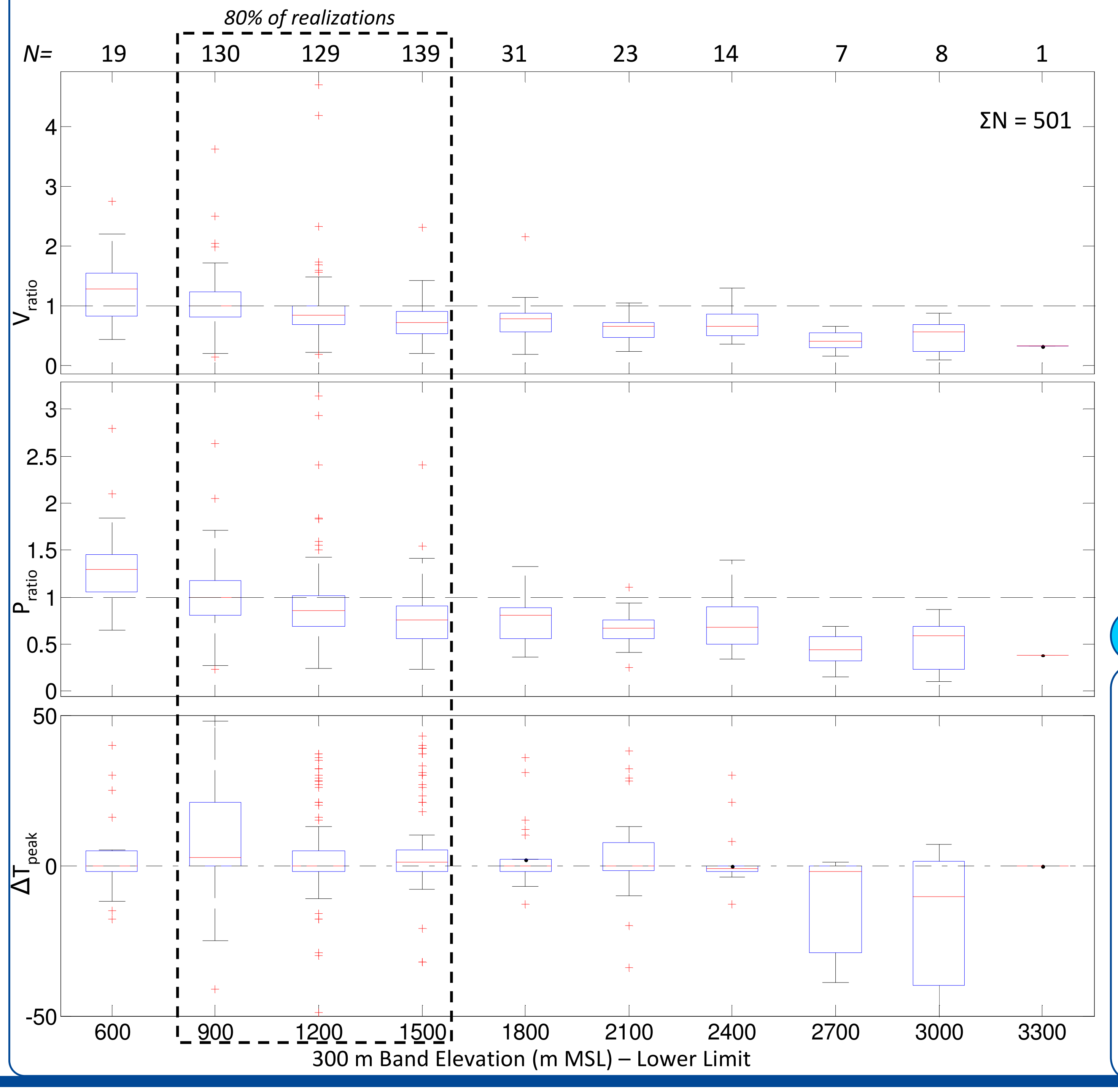


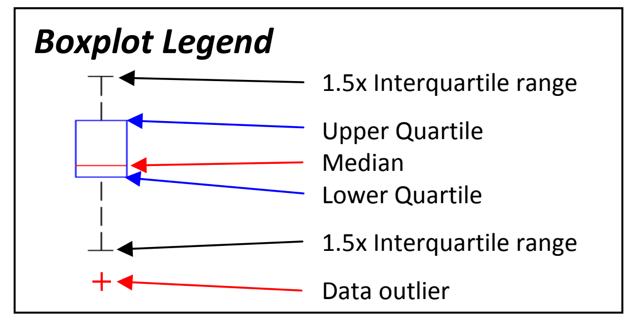
Model matches observed SWE peak SWE but otherwise underestimates the SWE volume



Model underestimates SWE volume and peak by a large magnitude

Performance Across Elevation Bands





$\pm\Delta T_{end}$ (days)	0	1	2
Realizations	261	427	501
Mean* V_{ratio}	0.8678 ± 0.0407	0.8714 ± 0.0342	**0.8702** **± 0.0325**
Median V_{ratio}	0.8494	0.8466	**0.8416**
Mean* P_{ratio}	0.8796 ± 0.0510	0.8796 ± 0.0432	**0.8775** **± 0.0395**
Median P_{ratio}	0.8467	0.8364	**0.8302**
Mean* ΔT_{peak} (days)	6.0 ± 2.3	6.2 ± 2.1	**6.0** **± 1.9**
Median ΔT_{peak} (days)	1	1	**1**

*95 % confidence limits included

VII. Conclusions

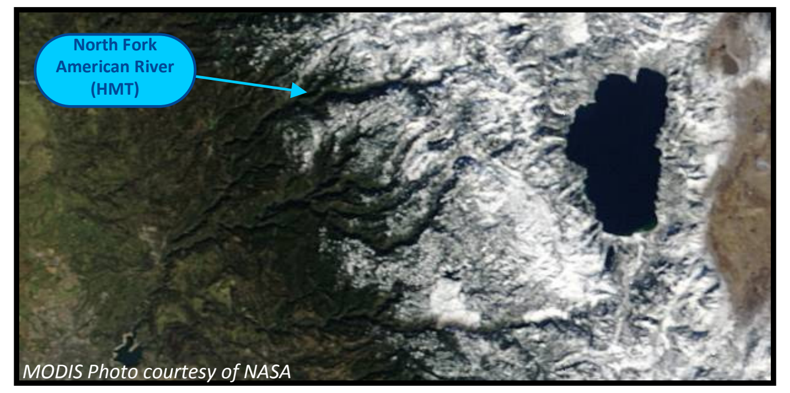
- •Precipitation scaling using observed snow disappearance date underestimates seasonal SWE volume by 10-16% and peak SWE by 8-16%. On average, the method estimates the peak SWE 6 days earlier than observed.
- •Modeled snow pack can disappear within 2 days of the actual date without significantly changing the results of this method.
- •Lower elevation stations tend to overestimate SWE volume and peak SWE.
- •Underestimations of SWE volume and peak SWE are greatest at higher elevation stations.

VIII. Applications & Implications

How can we obtain and use snow cover disappearance dates for scaling precipitation to grid cells in a distributed model?

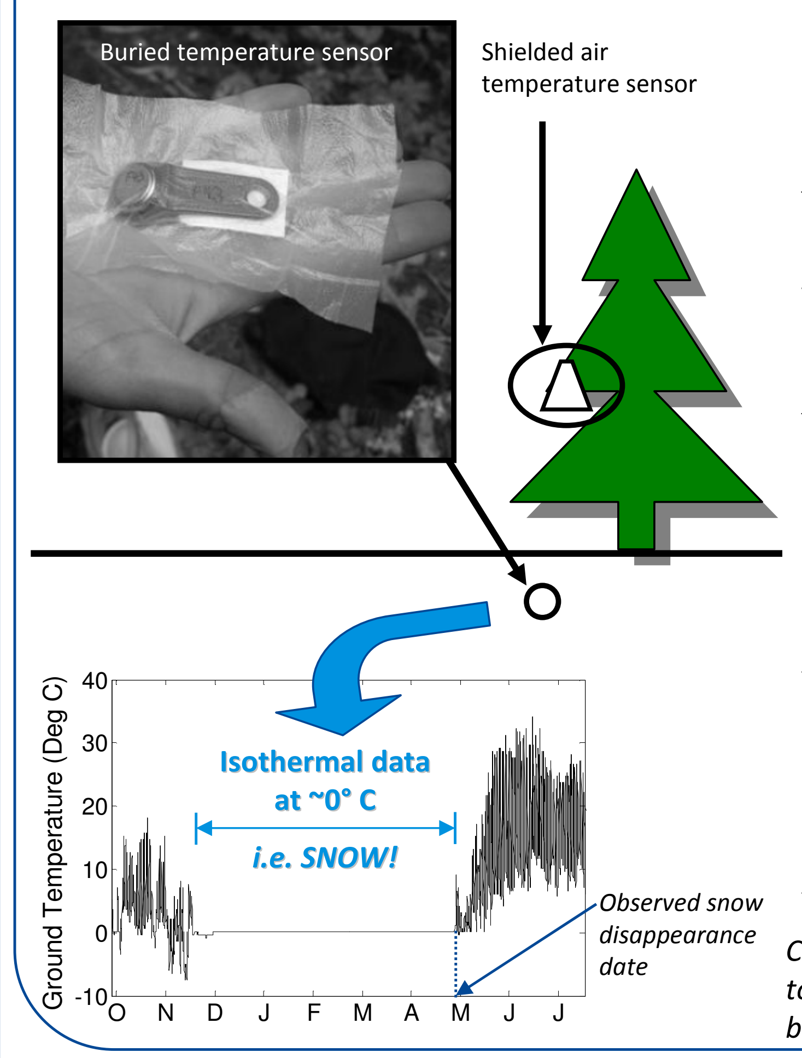
A) MODIS Satellite Imagery

- •NASA MODIS satellite images (figure, right) observe snow covered area over the entire earth on a 1-2 day time scale, and remotely measure the date when snow disappears at each grid cell.
- •Using lapsed meteorological data, the method evaluated here can be implemented to find the precipitation scaling factor based on the observed MODIS snow disappearance date (Molotch and Bales, 2005).



MODIS Photo courtesy of NASA

Challenges: There is inherent uncertainty in the MODIS observed snow disappearance date due to variability of snow covered area within each grid cell. Additionally, MODIS has difficulty observing snow covered areas in topographically complex areas, such as steep valleys (North Fork American River).



B) Buried Temperature Sensors Paired with Distributed Air Temperature Sensors

- •Snow has low thermal conductivity and insulates the ground from temperature variations in the air.
- •In the presence of persistent snowpack, temperature measurements in the upper layer of the soil are isothermal near 0° C.
- •Small, inexpensive temperature sensors buried in the upper soil can provide an indication of the snow disappearance date once diurnal temperature fluctuations resume (see figure, left). (Lundquist & Lott, 2008).
- •A paired temperature sensor can be installed in an adjacent tree with a radiation shield, and these data can be combined with the observed snow disappearance date and nearby precipitation data to scale precipitation for distributed snow modeling. This method is particularly useful in that sensors may be distributed in complex terrain where MODIS has difficulty observing snow covered area.

Challenges: This method requires annual field work to collect data and reprogram sensors. You have to be able to find your buried sensors!

IX. Future Work

- •Evaluate this method with more stations especially those at higher and lower elevations.
- •Demonstrate application of this method in the American River Basin using two years of data from over 30 paired air temperature and ground temperature sensors.

X. References

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