MULTI-PLATFORM DATA FUSION FOR MORE ACCURATE SPATIAL ESTIMATION OF THE SIERRA NEVADA SNOW

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ABSTRACT

Over 100 wireless sensors for monitoring realtime snow conditions were deployed in ten clusters distributed across the headwaters of the American River Basin of the Sierra Nevada. The sensors are strategically placed to measure snow depth, temperature, relative humidity, solar radiation, and soil moisture across elevation gradient, heterogeneous slope, aspect and canopy-covered montane regions. Meanwhile, time series of snow water equivalent (SWE) maps were reconstructed using National Land Data Assimilation Systems (NLDAS) data and fractional Snow Coverage Area (fSCA) from MODIS for 2001-2014 snowmelt seasons using energy-balance model (Guan et. al., 2013) and the maps would be reconstructed every year after the snow melt-out date. Both data sources are spatially blended using k-nearest neighbors algorithm for extrapolating the current snow conditions from the sensor-networks data. (KEYWORDS: Sierra Nevada, snowpack, SWE, wireless sensors, American River)

INTRODUCTION

The snowdepth and snow water equivalent (SWE) in the Sierra Nevada is found to be affected by orographic, topographic and vegetation effects (Zheng et. al., 2016). The snow observatory stations managed by state, federal and local agencies are sparsely located over the Sierra Nevada mountain range and for most situations each station is only instrumented by one sensor node. Considering the snowdepth variability versus the current instrumentation strategy, it may not be able to provide representative data on catchment scale and also capture orographic, topographic and vegetation effects across the entire basin. For snow courses conducted by the department of Water Resources and local agencies, although its grid-sampling strategy will provide better information on local representative snowdepth and variability, the 1-month temporal resolution is too small to capture most storming events before the snow peak season. As a key water sources of Sacramento, the headwaters of American River Basin (Figure 1) are covered by snowpack over the winter season and the surface water released by snowmelt over the spring season will be confluence in North, Middle and South forks of the American River and finally feed into Folsom Lake. To better inform the water resources institutions and decision-makers of California, ten clusters of novel wireless sensor networks, with over 100 wireless sensor nodes, were strategically deployed across the headwaters of the American River Basin in 2013 and have been on telemetry and providing snowpack information for almost three years. Each sensor network is comprised of 10-11 sensor nodes, which monitor snowdepth, temperature, relative humidity and soil moisture, and samples these variables every 15 minutes as well as transmitting these data immediately to the server at Berkeley. Therefore, the wireless sensor networks have better spatial coverage than the current meteorological stations and better temporal resolution than snow courses.

Most decision-makings for water resources managements are based on the current condition and historic observations. By searching a nearest neighbor in historic observations to present condition, the decisions and strategic plans used in before could be borrowed and applied on current scenarios. As analogy to this, the snowdepth/SWE spatial estimation on a relatively high resolution (500 meter) could be achieved by a similar strategy. By utilizing the daily historic SWE reconstruction (Guan et. al., 2013) computed from MODIS fractional snow coverage area and National Land Data Assimilation Systems (NLDAS) energy forcings, a near real-time SWE map could be generated from the 15-min wireless sensor networks data and using k-nearest-neighbor algorithms to

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find historic best match candidates from the reconstruction SWE. The objective of this paper is to present a data management and interpolation framework for estimating the snow water equivalent of the American River Basin in near real-time.

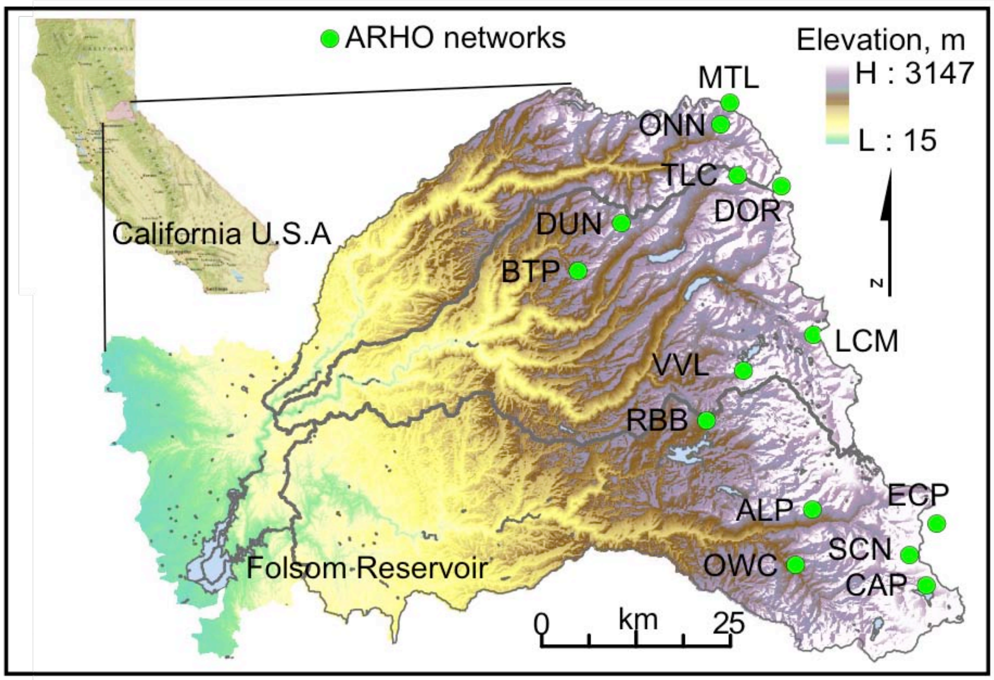

Figure 1. American River Basin and the locations of the wireless-sensor-network clusters

WIRELESS SENSOR NETWORKS DATA MANAGEMENT AND QA/QC

The wireless sensor networks data is transmitted wirelessly through satellite or cell services from the base stations of the networks at each site to the Linux server at UC Berkeley. To better manage the data and enable easier access to the public, all data are stored in a MySQL relational database. The framework of the database is shown as Figure 2. The metadata of each site and each node could be easily added when new site or new sensor node is installed. And metadata is also intelligently linked to the level_0 and level_1 data tables. Since the data could also be downloaded manually from the SD card embedded on the microcontroller of each sensor node, there is a web interface (Figure 3) for field-work staff to upload the SD card data to the server.

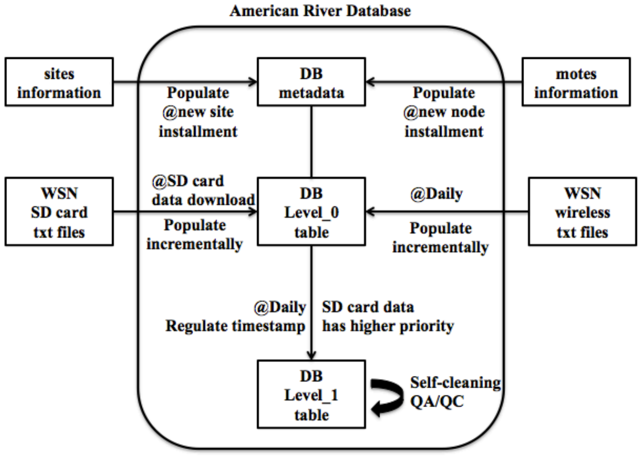

Figure 2. Structure of tables in the MySQL database and data flow

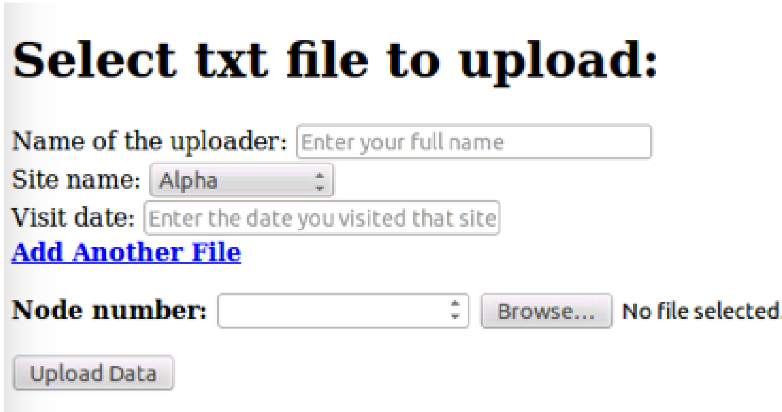

Figure 3. Web-interface for uploading the SD card data

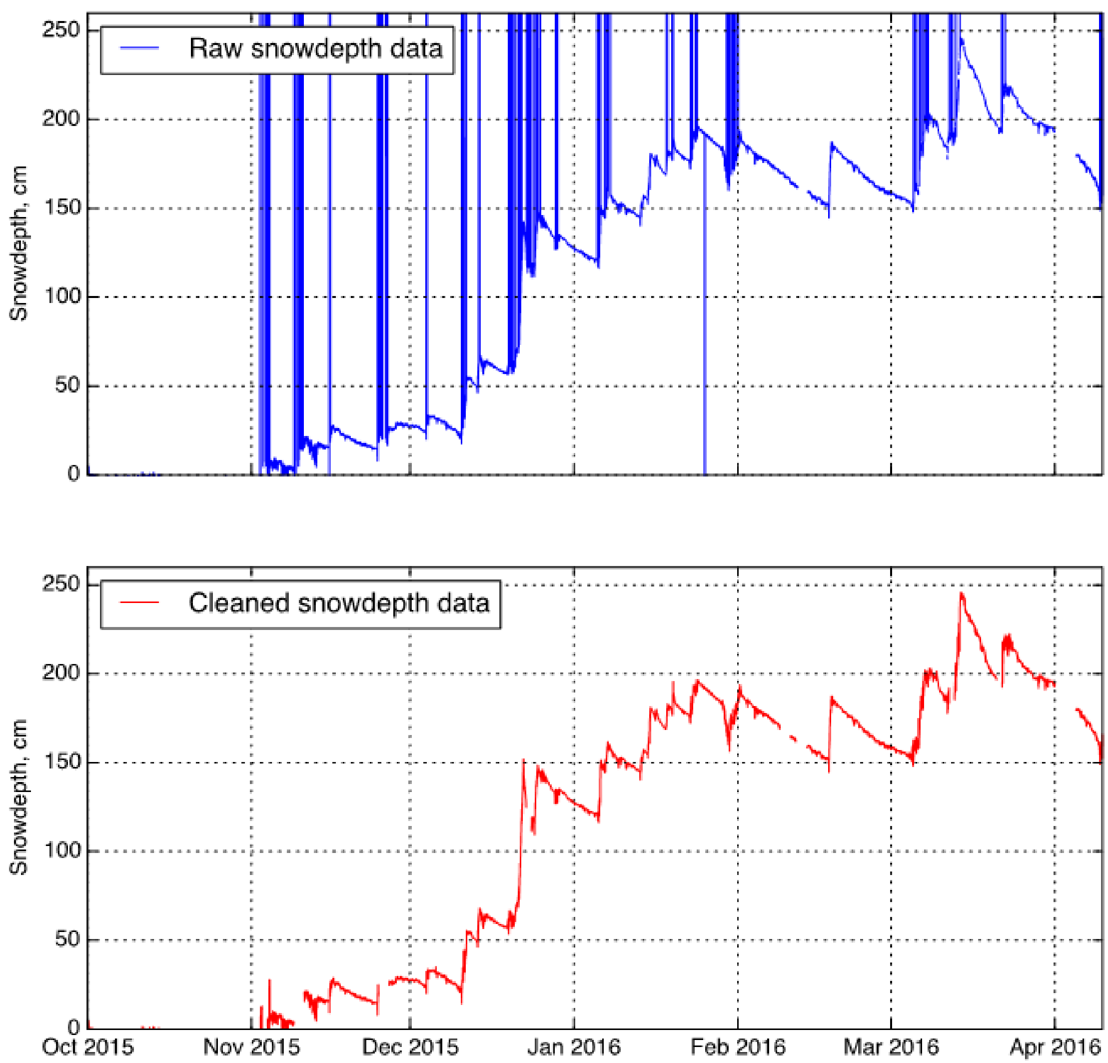

Figure 4. Raw snowdepth data and cleaned snowdepth data using SVD

The data uploaded each day will automatically be merged from level_0 to level_1 table with timestamps regulated and SD card data having a higher priority to be merged, all controlled by the data management Python script running in the background. And the level_1 snowdepth data will be further cleaned and then gap-filled by Singular Value Decomposition, the equation of which is shown as Eqn 1-3. The result of cleaned data is shown in Figure 4.

$$A = USV^T \quad [1]$$

$$p_u = U_u\sqrt{S}^T \quad [2]$$

$$q_i = \sqrt{S}V_i^T \quad [3]$$

K-NEAREST NEIGHBOR INTERPOLATION MODEL

As the near real-time ground measurements transmitting over the Internet, we could use a *k*-nearest neighbor algorithm to search for the closest SWE condition spatially across the American River Basin from the historic SWE reconstruction data online. The value of *k* needs to be tuned considering the bias-variance trade-off. Figure 5 shows a spatial example of the interpolation results across the basin. In order to validate the performance of the interpolation results, a Lidar survey was conducted on April 1st 2016 and the data from which will be used as ground truth to compare with the algorithmic results.

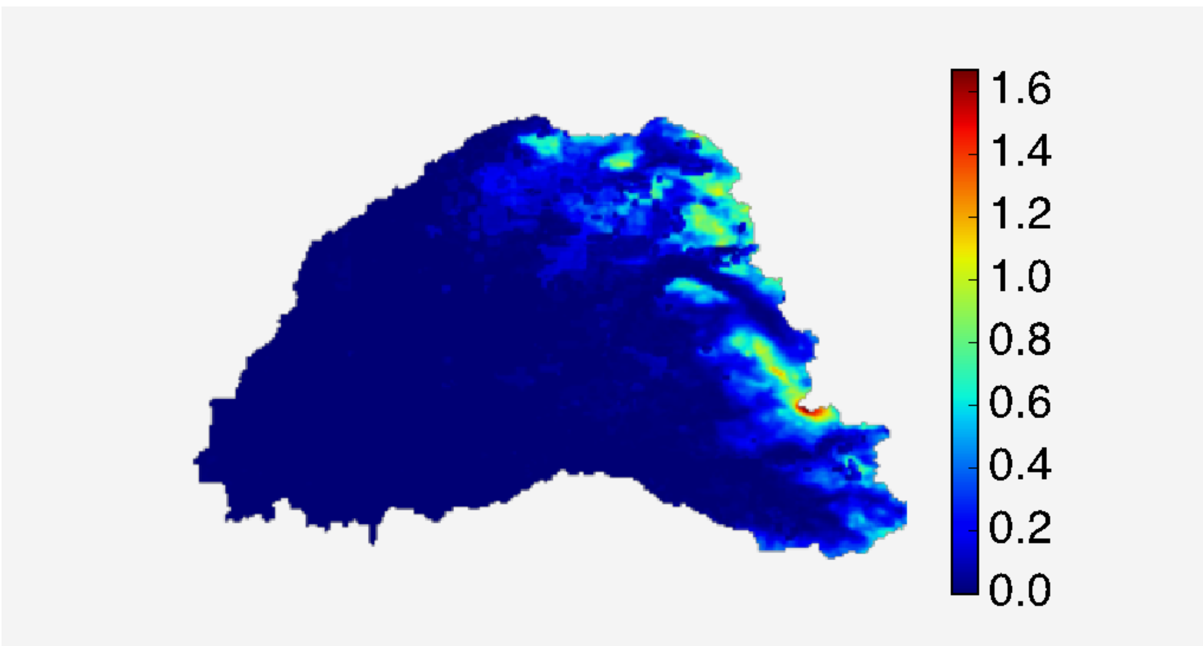

Figure 5. Interpolation results using k-nearest neighbor algorithm

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