NM WRRI Student Water Research Grant Progress Report Form
FINAL REPORT

Project title

Evaluating the impacts of particulate matter deposition on snow melt processes in the Upper Rio Grande, NM

Student Researcher

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Faculty Advisor

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Description of research problem and research objectives.

Problem:
Dust deposition on snowpack in NM's mountains may be leading to earlier onset of snowmelt by decreasing reflectivity of snow and increasing energy absorption in snowpack. This is associated with higher water losses from evaporation.

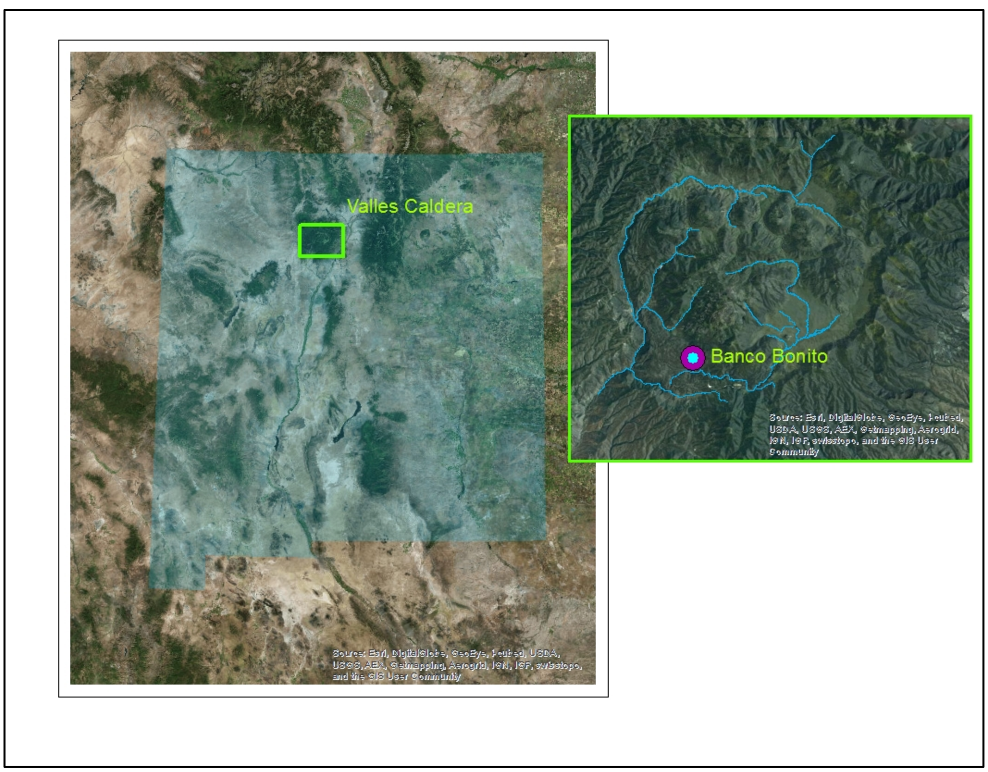
Objectives:

- *Determine if albedo conditions in situ are significantly different than theoretical albedo.*
- *Evaluate how much dust deposition impacts time to melt*
- *Model snow melt to understand hydrological processes at work.*

Description of methodology employed.

Data Collection
This research was conducted within the Valles Caldera National Preserve in the area known as Banco Bonito, see Figure 1. One weather station was deployed in an area cleared of trees referenced as the "cleared site" for this paper. The evaluation of changes in albedo was completed with the collection of meteorological data, data analysis, and snow melt modeling with the snow energy balance model (SNOBAL).

Figure 1: Location map of Banco Bonito



The weather station was equipped to measure precipitation, temperature, barometric pressure, solar radiation, wind speed/direction, and snow depth. Measurements were taken every 15 minutes and stored by a data logger. For the purposes of this study, focus was placed on the cleared site because radiative forcing under clear sky conditions are most easily interpreted with the existing literature on spectral albedo and energy balance. The weather station was deployed in early January and data are presented for the period of January 17 to March 16. Snow events after March 16 were sporadic, and snow accumulations quickly melted due to high radiative forcing and warm temperatures.

In addition to the collection of data at the weather station, field measurements on an established snow course were taken to track changes in the snow pack. The snow course was 30 meters in length with snow depth measured every three meters and snow water equivalent (SWE) measured every six meters. Snow depth and SWE were measured using a Mt. Rose sampler, metric ruler and kitchen scale. Visits to the cleared site occurred on 1/16/2015, 1/23/2015, 2/2/2015, 2/23/2015, 3/2/2015, and 3/16/2015 (most snow melted on this visit). A field spectrometer was used on 1/16/2015, and 2/2/2015 to measure reflectivity of snow in the cleared site. The field spectrometer was unavailable for use after this because the optical cord broke.

The presence of dust on snow was evaluated through exploratory data analysis of albedo measurements and comparison of field measurements of snow depth with a snow energy balance model (SNOBAL) run driven by data collected at the installed weather station. Meteorological data was checked for accuracy and corrected. Albedo from the net radiometer was evaluated at the cleared site and fit with an exponential function. It was determined grain growth of snow particles closely followed that of pure snow and that no measurable effect from dust was found to contribute to melting on snow. Albedo was measured with the field spectrometer on two occasions and compared with albedo measurements taken with the net radiometer; these matched the albedo from the net radiometer and there was no signal in the visible spectrum that indicated the presence of dust. The project contributed to my knowledge of snowmelt dynamics in New Mexico.

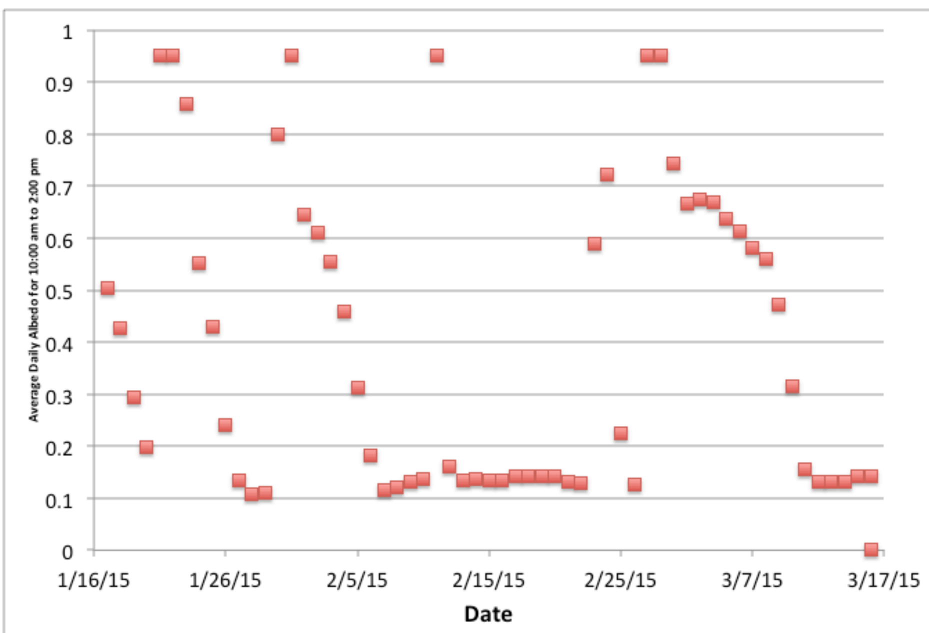
Data Processing

SNOBAL requires the following inputs: time step, total precipitation, fraction of snow, snow density, precipitation temperature, net solar radiation, incoming thermal radiation, air temperature, vapor pressure, wind speed, and soil temperature (Marks and Dozier, 1992).

SNOBAL was run with one-hour time steps. As mentioned, meteorological data were collected at 15 minute intervals and were filtered dependent on whether the data were stochastic or continuous Missing data and outliers (very few present) were removed and linearly interpolated. Wind speed, net solar radiation, air temperature were averaged for each time step. Soil temperature was not collected this year due to frozen ground conditions at the time of weather instrument installation and was set to a value of – 10° C for the full duration at which the model was run. Although the soil temperature was colder than one would expect, it has been shown that some mid-latitude sites in the rain-snow transition zone have colder ground conditions due to a lack of insulation from snow. More work will be completed in the 2015-2016 winter period to evaluate the importance of ground heat flux on energy balance. Vapor pressure was calculated using relative humidity, temperature and the Clausius-Clapeyron relationship and averaged for each hourly time step. Precipitation was corrected for wind related undercatch using the methods presented by Goodison et al. (1998), and further corrected to remove false precipitation events using wind speed, incoming shortwave radiation and relative humidity. The sum of precipitation was taken for every one-hour time step. Precipitation temperature was assumed to be equal to dew point temperature. Fraction of snow falling during a precipitation event was dependent on dew point temperature, and was always equal to 1 for the period of record. Snow density was needed for new snow only and was set between 100 kg/m^3 and 150 kg/m^3- agreeing with snow densities collected in situ.

Albedo from the net radiometer was evaluated independently of the SNOBAL model to look at trends in reflectivity. The net radiometer measures incoming and outgoing solar radiation independently of one another and albedo was calculated by dividing the outgoing solar radiation by the incoming radiation. Theoretical values of albedo for new snow are between 0.85 and 0.95. Albedo follows a pattern of exponential decay most reliably related to time in days and is inversely proportional to grain size growth (Warren and Wiscombe, 1980). For new snow, particle sizes range between 50 µm and 100 µm and grow to a size of 1000 µm. I subset albedo daily for the period of 10:00 am to 2:00 pm, and took the average albedo as the daily direct albedo. Outliers, were present on days when there was cloud cover and were apparent with values ranging between 0.95 and 3, these were replaced by a linearly interpolated value of albedo.

Figure 2: Corrected Albedo



The field spectrometer was used on two occasions (1/23 and 2/2) to measure the reflectivity of snow and was collected between 10:00 am and 2:00 pm. Reflectivity was in line with the albedo measurements collected with the net radiometer for each measurement.

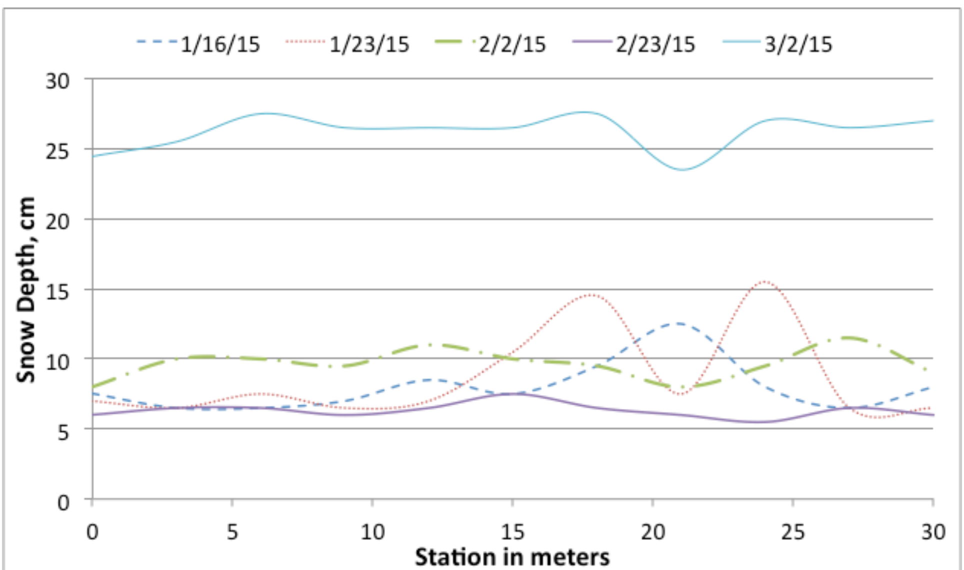
SNOBAL Model Run

SNOBAL model runs were completed for the period of January 17 to March 16 using the meteorological data discussed above. The model results are discussed in greater detail below.

Description of results; include findings, conclusions, and recommendations for further research.

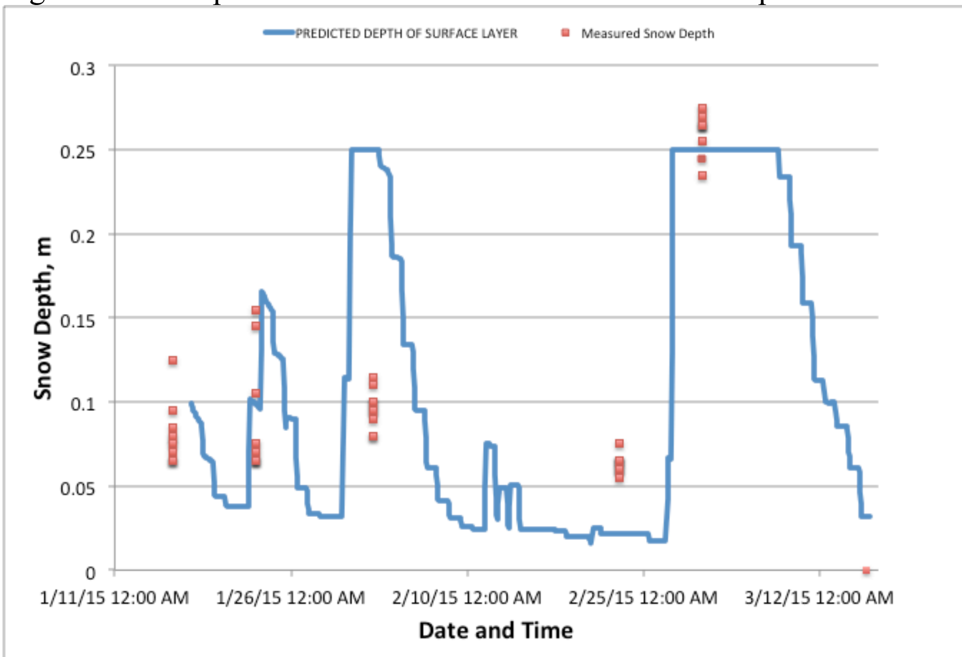
Snow depths for the snow course are shown in Figure 3 and ranged between 0 cm and 27 cm for the period of January 17 to March 16 (no snow on 3/16). Total precipitation for the period of measurement was 7.6 cm. Albedo followed a theoretical decay and the presence of dust was not apparent in either the spectral data collected with the field spectrometer or the albedo collected with the net radiometer. Albedo quickly decayed after each snow event and was clearly impacted by large radiative forcings and vegetation in shallow snow, see Figure 3.

Figure 3: Snow depths on snow course by date- Banco Bonito for winter 2015



Initial SNOBAL model runs roughly capture trends in snowmelt at the Banco Bonito site with the exception of the period between 2/10 and 2/25 as seen in Figure 3. Earlier model runs appeared to include a systematic error that I thought was due to a relatively small snowpack and large radiative fluxes which was true. The model was improved by front-loading each snow event at the beginning of the storm with maximum snowfalls of 5 kg/m^2 for each hourly time step. The error between actual and modeled snowmelt is reasonable considering the existing literature on the subject of snowmelt modeling with SNOBAL (suggests that it is not uncommon to have errors of several centimeters). In the future, I will complete a sensitivity analysis to see how responsive the model is to modified precipitation events. It should be noted that many snowmelt models were developed for colder continental climates with greater snow depths and therefore may not be well suited to capture snowmelt dynamics in New Mexico.

Figure 4: A comparison of measured and modeled snow depth at Banco Bonito for winter 2015



The Banco Bonito cleared site was situated at an elevation of 8200 ft above mean sea level (MSL) and was heavily influenced by short-wave radiation, vegetation and topographic effects. Although snow was present during most of the January-March period, snowmelt following a precipitation event occurred quickly and snow depths were often less than 10 cm in depth. While this data suggested that dust deposition does not lead to an earlier onset of snowmelt at this particular site, I am cautious to say that it is not an issue at all in throughout parts of the Rio Grande basin lying within New Mexico. Mountainous regions of higher elevation and greater topographic complexity in this region are likely to have greater time to melt with deeper snowpacks. The extension of the snow season in higher elevation regions may make these snowpacks more susceptible to dust on snow events as spring winds increase. Based on this experience, all future research will be completed at elevations above 9000 ft MSL and will have a strong north facing aspect.

This research provided a strong foundation for understanding the hydrological processes of snowmelt in a mid-latitude, subalpine site. Increasing water supply while simultaneously improving forest health has potential within the context of water management in New Mexico. Lundquist et al. (2013) found that time to melt could potentially be improved by decreasing canopy density. A number of studies have been conducted in Arizona since 1970's, including the most recent Four Forest Restoration Initative (Robles, 2014) that have shown water yield could be increased by thinning. Therefore, one plausible option for increasing water supply is the treatment of our forests and it should be researched. An apparent gap in the current state of knowledge is the translation of observed hydrological processes in field studies to snowmelt models with canopy. As such, I plan to undertake the improvement of snowmelt models as a component of my dissertation.

Additionally, ground heat flux played a significant role in the snowpack energy balance and therefore will be researched in greater detail in the upcoming winter. I will deploy a series of soil temperature sensors with at least one weather station to understand how ground heat fluxes moderate snowmelt processes dependent on climate forcings, vegetation density and elevation.

Provide a paragraph on who will benefit from your research results. Include any water agency that could use your results.

This research will contribute to knowledge of federal and state agencies who seek to maximize water yield by providing a basis for estimating spectral characteristics in NM's watersheds. This research will also contribute to stakeholder (ie. Irrigation districts) knowledge of hydrological and meteorological processes affecting the quantity of water available for consumption.

Describe how you have spent your grant funds and your budget balance

Grant funds from NMWRRI were used to purchase a net radiometer from Cambell Scientific, snow pit measurement kit, soil temperature sensors for continuing research and reimburse travel costs associated with seven field trips. The snow pit kit and soil temperature sensors will be used this upcoming winter to conduct a detailed study in the Valles Caldera of ground heat flux moderation on snow pack and the influence of thinning treatments on snow accumulation.

The current balance is*: $0.00*

List presentations you have made related to the project.

Jemez Mountains CFLRP, March 2015
NMWRRI poster presentation, November 2014

List publications or reports, if any, that you are preparing. Remember to acknowledge the NM WRRI funding in any presentation or report that you prepare.

Impacts of ecological restoration on snowmelt processes in semi-arid ponderosa pine forest (in preparation)

List any other students or faculty members who have assisted you with your project.

The people listed have assisted me in the collection of snow surveys and spectral data in the field. Chad Mickschl, Caitlin Lippitt, Ryan Morrison, Breana Chavez, Lauren Jaramillo.

Provide special recognition awards or notable achievements as a result of the research including any publicity such as newspaper articles, or similar.

NA

Citations

Goodison, B. E., Louie, P. Y. T., Yang, D., & World Meteorological Organization. (1998). WMO solid precipitation measurement intercomparison: Final report. Geneva, Switzerland: World Meteorological Organization.

Lundquist, J. D., Dickerson-Lange, S. E., Lutz, J. A., & Cristea, N. C. (October 01, 2013). Lower forest density enhances snow retention in regions with warmer winters: A global framework developed from plot-scale observations and modeling. Water Resources Research, 49, 10, 6356-6370.

Marks, D., Dozier, J., & Davis, R. E. (November 01, 1992). Climate and energy exchange at the snow surface in the Alpine Region of the Sierra Nevada: 1. Meteorological measurements and monitoring. Water Resources Research, 28, 11, 3029-3042.

Robles, M. D., Marshall, R. M., O'Donnell, F., Smith, E. B., Haney, J. A., & Gori, D. F. (January 01, 2014). Effects of climate variability and accelerated forest thinning on watershed-scale runoff in southwestern USA ponderosa pine forests. Plos One, 9, 10.)

Wiscombe, W. J., & Warren, S. G. (1980). A model for the spectral albedo of snow. I: Pure snow. *Journal of the Atmospheric Sciences*, *37*(12), 2712-2733.