Desert Dust Enhancement of Mountain Snowmelt

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Dust from the desert southwest of the U.S. is a common occurrence in the snow of the Colorado Rocky Mountains. Dust speeds up the rate of snowmelt because dust on the snow surface causes it to absorb more solar radiation. It is very likely that faster snowmelt and resulting shorter snow cover duration influence both the timing runoff and peak flows in the rivers that drain these mountains. An understanding of snowpack conditions and melt rates is necessary to accurately predict the seasonal volume of streamflows and the timing of streamflow peaks.

Since 2003, a collaborative "Dust on Snow" project among the Center for Snow and Avalanche Studies in Silverton, Colorado, the University of Colorado, and University of Utah. One objective of the project is to quantify the relationship between dust and snowmelt rates and timing with a view to providing improved streamflow forecasts. In this article we review dust deposition in mountains in the U.S. and worldwide, and the process by which dust impacts snowmelt. We present results from the Dust on Snow project from the San Juan Mountains of Colorado.

Mountain Dust Deposition

Dust is commonly found in the surface layers of late season snow in Colorado and other mountain ranges around the world. Dust layers have been observed in the Himalaya, the Japanese Alps and the European Alps. Dust layers in ice cores from the Himalaya indicate that dust has been deposited on snow and glaciers in that region each year throughout much of recent history. Also, the amount of dust deposition has increased over the last 100 years as a result of either increased aridity or land disturbance in dust source regions to the north and west of these mountains. In the western U.S., anecdotal evidence from backcountry rangers, avalanche professionals and citizens of mountain communities suggests that dusty snow is a frequent and common occurrence in most years.

Between 2003 and 2008, 4 to 8 dust deposition events have been observed annually by the Dust on Snow project team in the Senator Beck Basin Study Area in the San Juan Mountains (Figure 1a). Sampling by the project team during 2008 in central and northern Colorado indicates that many of these dust events occur over much of the State's snowpack. Evidence of one notable event in February 2006 was also found in snowpacks as far south as northern New Mexico, and as far north as northern Wyoming, suggesting that dust on snow is a regional phenomena.

The Source of Dust in the Colorado Rockies

Dust deposited in the San Juan Mountains comes from the deserts of the Colorado Plateau, which encompasses northeast Arizona, southeast Utah and northwest New Mexico. The number of dust events in each year depends both on weather conditions over the western United States and soil and moisture conditions on the Colorado Plateau. Dust transport from the Colorado Plateau occurs during periods of strong southwesterly flow that result from low pressure systems centered over western Colorado. However, dust transport and deposition events are not just linked to the frequency of these large-scale weather events. It appears that winter precipitation amounts, vegetation cover, and levels of soil disturbance play a large role in determining whether or not dust is mobilized. Soil disturbance appears to be a key factor. Dust particles are mobilized from disturbed soil surfaces at much lower wind speeds than from undisturbed surfaces. Concentrations of desert soils in sediment cores from mountain lakes indicate that dust deposition in the Colorado mountains increased significantly after increased settlement and expansion of agriculture of the Colorado Plateau in the 19th century. Understanding the interaction among weather and climate, vegetation dynamics, and soil disturbance is necessary before dust emissions can be predicted.

How Dust Enhances Snowmelt

Snow is the most reflective natural surface on Earth. Dust deposited on snow decreases reflectivity, causing snow to

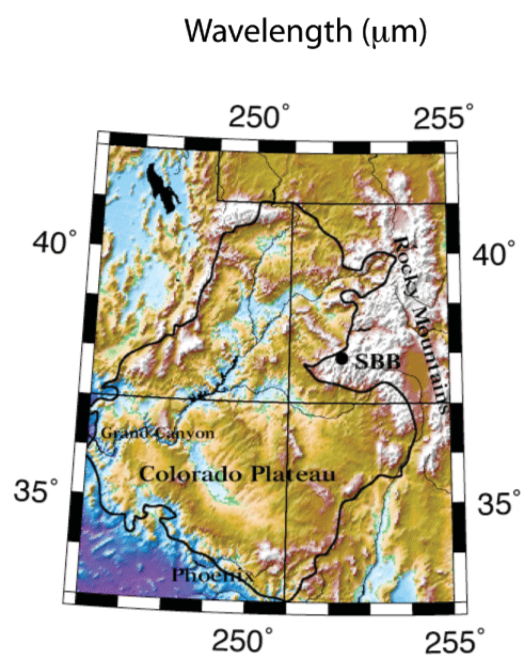

Figure 1a. The location of the Colorado Plateau, Colorado Rocky Mountains and Senator Beck Basin Study Area (SBB).

more solar radiation, warm-up to melting point faster and enhance rates of snowmelt. Albedo is a measure of reflectivity, and it is technically the ratio of reflected to incoming solar radiation expressed as a fraction. A surface that reflects all incoming solar radiation would have an albedo of 1.0. Radiation that is not reflected is absorbed. Albedo of clean, dry snow is between 0.8 and 0.97; less than 20% of incoming radiation is absorbed. Melting snow has slightly lower albedo (0.66 to 0.88). The impact of dust on snow surface conditions is quantified by measuring the change in albedo of the snow surface as a result of dust exposure. Measurements of the albedo of dust-covered snow made by the Dust on Snow project in the San Juan Mountains of Colorado were between 0.43 and 0.5; more than 50% of incoming solar radiation is absorbed. This extra energy from additional absorbed solar radiation either warms the snowpack to melting point or melts snow.

The Impact of Dust on Snowcover Duration

Although it is well known that dust enhances absorbed solar radiation and melt rates, these impacts have not been quantified in a natural setting. In two early studies, one of which made in 1913 at Wagon Wheel Gap, San Juan Mountains, Colorado, simple observations reported that dust deposited on snow may have shortened the duration of snow cover by as much as one month.

To quantify the impact of dust on snow melt rates and the duration of snowcover, we simulated snowmelt in 2005 and 2006. Two simulations of snowmelt were made: one represented the observed dust-covered snow conditions and the other represented estimated dust-free snow conditions. Based on these simulations, the occurrence of dust on snow caused melt-out to occur 22 to 35 days earlier (Figure 1b). Only 4 dust events occurred in 2005, while 8 events occurred in 2006. Snowmelt rates (measured in millimeters of melt per day) in 2006 were 40% faster than in 2005. The faster melt in 2006 can be attributed not only to a greater number of dust layers in the pack but also fewer snow storms and extended periods of cloud free days during spring, which maximized the exposure of dust at the snow surface and increased the amount of extra energy available for melting.

Outlook

Dust plays an important role in snowmelt in the Intermountain West, and its influence almost certainly extends to the timing of the onset of snowmelt runoff and peak streamflow. Results from our Dust on Snow project will improve the understanding of the interactions among changing weather conditions, dust deposition, and snowmelt timing, which have the potential to improve streamflow forecasts. This acquired knowledge should be combined with monitoring of dust deposition using satellite remote sensing as well as on-the-ground observations in order to improve data collection and analysis.

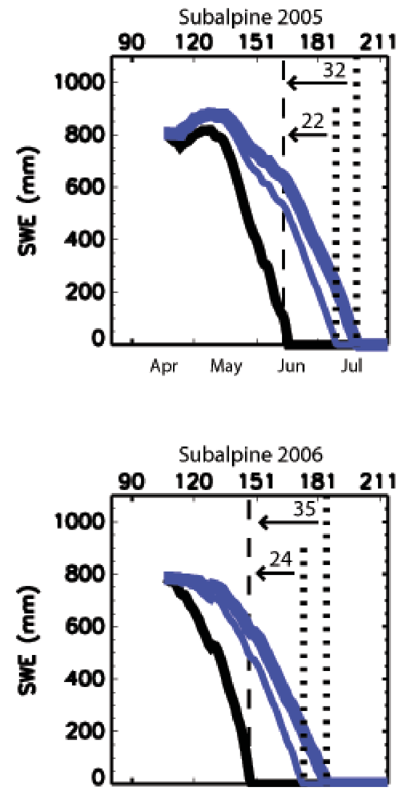

Figure 1b. Simulations of depleting snow water equivalent (SWE; 1" = 25.4 mm) for 2005 and 2006 for a subalpine site in the Senator Beck Basin Study Area. Black lines are depletion curves for observed dusty conditions. Blue lines are depletion curves for upper and lower estimates of dust-free snow albedo. Vertical dashed lines and numbers show melt out dates and differences in snowcover duration in days for dust and dust-free snow conditions.

Further Information

Some results from the Dust on Snow project are described in detail in a recent Geophysical Research Letters paper (Painter et al, 2008). An analysis of dust in lake sediment cores can be found in a recent Nature Geoscience paper (Neff et al, 2008). Information on the Center for Snow and Avalanche Center's Senator Beck Basin Study Area can be found at www.snowscience.org.

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