DUST-ON-SNOW EFFECTS ON COLORADO HYDROGRAPHS

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ABSTRACT

Desert dust emitted from the greater Colorado Plateau and deposited onto the Colorado Mountain system has increased in frequency and intensity over recent decades. The consequent dust-induced reductions in snow albedo are affecting Colorado snowmelt hydrographs by accelerating snowmelt rates, when dust is exposed at or near the snowcover surface. A combination of dust intensity per storm, depth of dust layers, and spring weather patterns affect how dust influences the change in spring snowmelt and runoff patterns. These factors can be used to calculate melt forcing from dust, and this information can be used regionally to inprove runoff forecasting. (Annotated selection of PowerPoint slides from the presentation at the 2014 Western Snow Conference by Landry, additional editing by Proceedings Editor) (KEYWORDS: dust on snow, albedo, runoff, Colorado, CODOS)

INTRODUCTION

The Center for Snow and Avalanche Studies (CSAS), in Silverton, CO, has been collecting comprehensive hourly weather and water cycle data from its study area high in the San Juan Mountains of southwestern Colorado, near Red Mountain Pass.

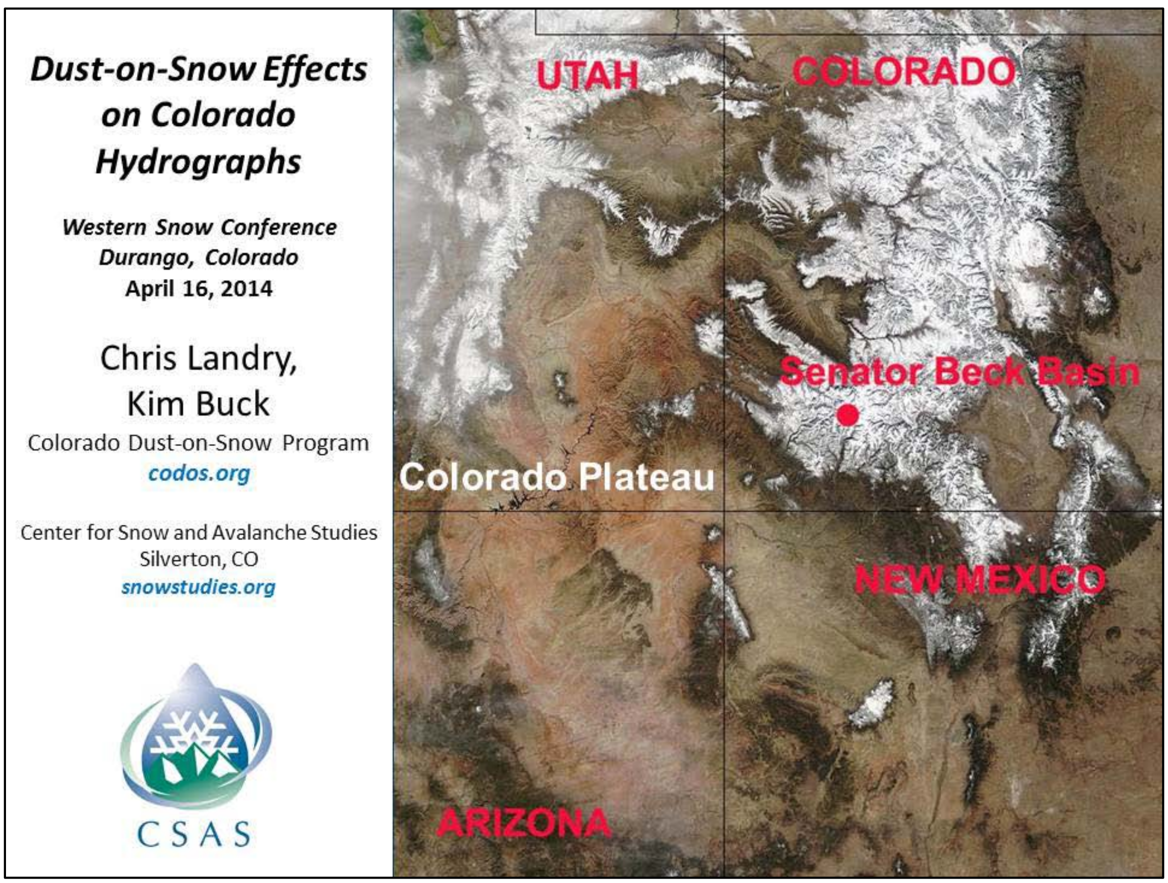

Figure 1. Map of dust source area, the Colorado Plateau, and the Senator Beck Basin in the Colorado Rockies.

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DUST AND SNOWMELT

Snow melts due to a variety of energy fluxes, and as shown in Figure 2, the bulk of the melt is caused by shortwave solar radiation and reflected long-wave radiation. The effect of bright sunshine is much stronger than the effect of warm temperature in terms of the rate and quantity of melt. The lower-left panel in Figure 2 presents the difference in albedo, or snow reflectivity across the shortwave and near-infrared spectrum. Visible light and considerable energy is found in the .4 to .9 micrometer wavelength. Reflective snow with a high albedo (clean snow) reflects more than 80% of the incoming solar radiation, but dust-covered snow can have albedo less than 0.5, meaning that up to half of the incoming solar radiation is absorbed and causes snowmelt.

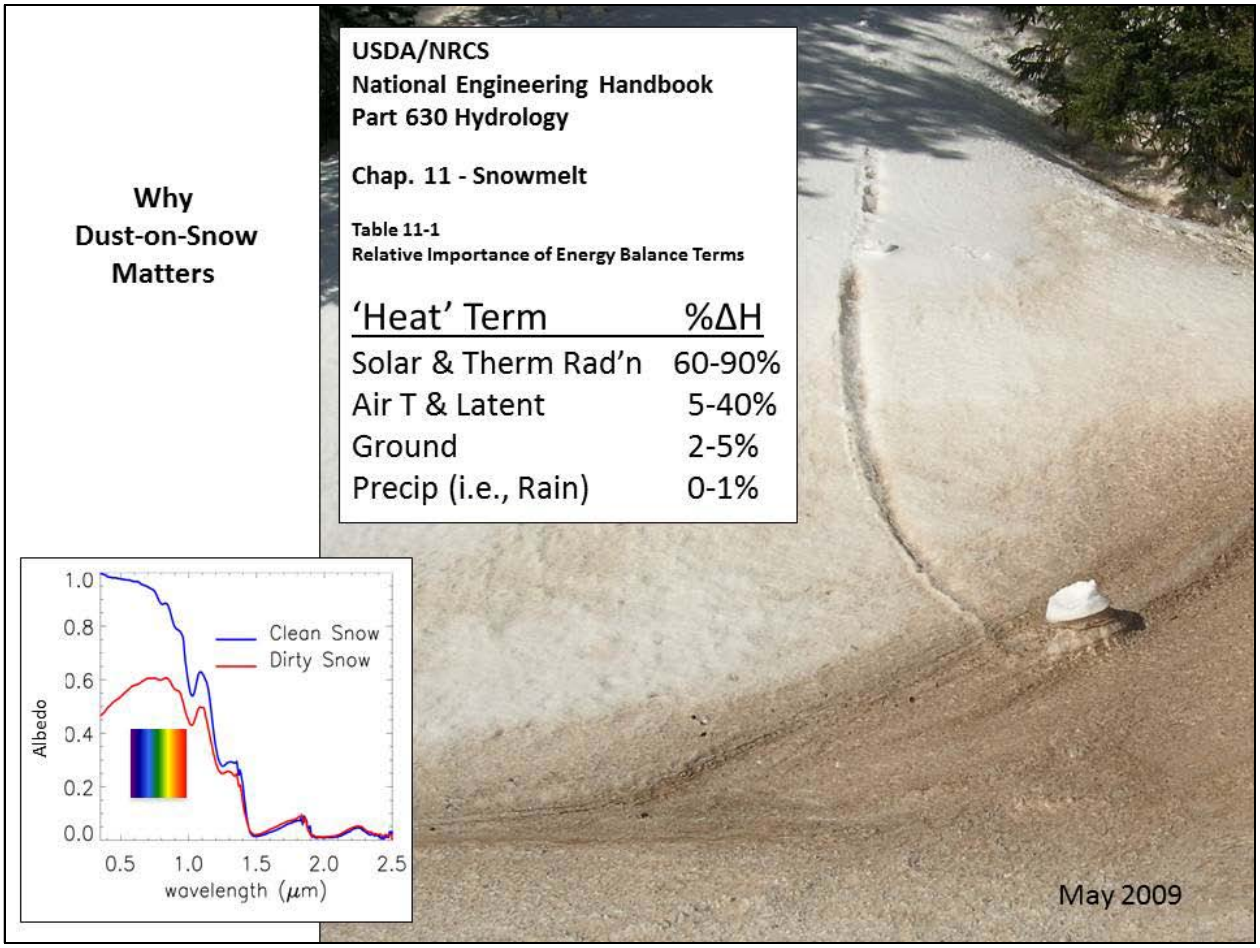

Figure 2. Dust-induced reductions in snow albedo, and the increased absorption of solar radiation (largely in the visible wavelengths), add considerable additional energy to a dust-contaminated snow surface, as compared to a 'clean' snowcover. Among the sources of snowmelt energy, dust increases the relative importance of solar radiation.

Dust Deposition Timing

Almost all dust-on-snow events in Colorado are deposited during March, April, and May. Dust is either deposited 'wet', in conjunction with new snow, or 'dry', without any accompanying precipitation. Wet deposition of dust generally results in a layer of clean new snow overlying the new dust layer, thereby minimizing the initial impacts of that new dust on snow albedo. Dry dust deposition causes an immediate reduction in snow albedo. As dust layers are exposed over the course of the spring snowmelt season, they merge and progressively decrease albedo. Broadband albedo during the spring of 2013 fell to 0.33 at the Senator Beck Basin Study Area at Red Mountain Pass, San Juan Mountains, as layers D8 (April 15-17), D7 (April 13/14), and D6 (April 8), and four subsequent layers, met and merged at the snowpack surface.

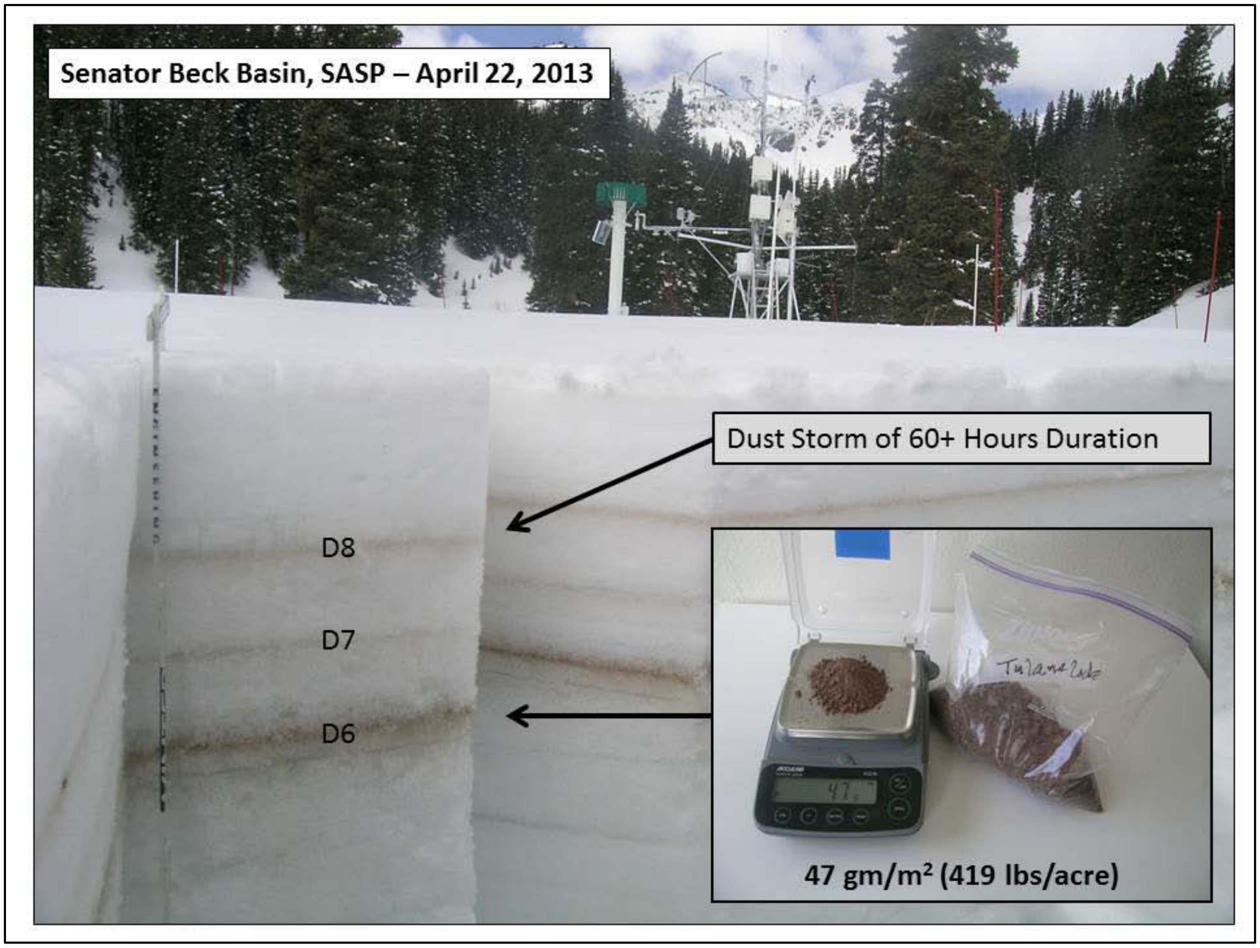

Figure 3. A snow pit dug at Senator Beck Basin study site showing three dust layers in the top of the snowpack.

Dust occurs multiple times through the winter, and the thickness of the layer depends on factors such as magnitude and length of the storm, wind direction, and origin of the source air mass. While dust can be deposited in almost any month, most events occur during March, April, and May. Different years have different proportions of wet vs. dry events, as shown in Figure 4.

CODOS Event Log – by Season

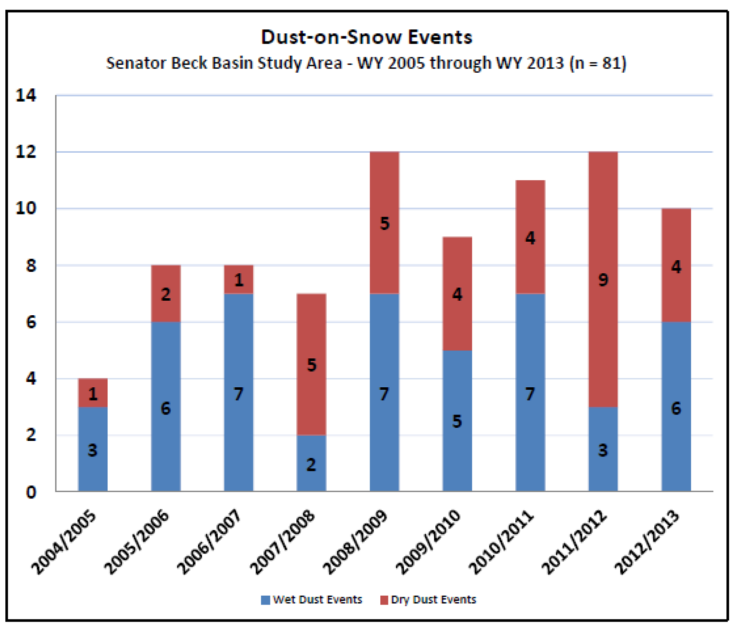

Figure 4. Dry and wet dust events by month

RUNOFF TIMING CHANGES

While dust has a strong effect on melt due to changes in albedo, the amount of dust changes from year to year, as does the timing of snow deposition and the temperature pattern between April and June. Figure 5 defines some of the combinations of these factors, and lists the outcome in terms of runoff timing and magnitued.

'Flat' Typology of Snowmelt Runoff Patterns

in spring weather context(s)

	Min/No Dust: Spring Weather Drives Runoff Hydrograph Shape	"Moderate" Dust: Spring Weather & Dust Timing Govern Hydrograph Shape	Heavy Dust: Max Radiative Forcing Drives Runoff to Possible 'Extreme' Hydrograph
Low Mar 1 SWE	Dry Spring + Min Dust = Early, Low Yield, Shorter Duration Runoff to Drought Flows	Dry Spring + Mod Dust = Early Surging to Early, Low Peak, Rapid Descending Limb to Drought Flows	Dry Spring + Heavy Dust = Very Early and Rapid Surge to Early and Below/Near Average Peak followed by Steep Descending Limb to Extreme Drought Flows
Average Mar 1 SWE	Avg Spring + Min Dust = "Median" Hydrograph	Avg Spring + Mod Dust = Erratic Ascending Limb, Flash to Above Average Peak, Rapid Descending Limb to Below Average Flows	Avg Spring + Heavy Dust = Possible Early Onset, Surging to Possible Early and High Peak, Rapid Descending Limb to Drought-Level June Flows
High Mar 1 SWE	Wet Spring + Min Dust = High Amplitude, Delayed, Long Duration Runoff	Wet Spring + Mod Dust = Erratic, Flashy, Surging Runoff to High Peak, Possible Delayed Descending limb	Wet Spring + Heavy Dust = Potential for Delayed, Rapid Surge to Extreme Peak Flows and High Amplitude Descending Limb

Figure 5. Runoff results from differing amounts of dust and March 1 snow water equivalent.

In southwest Colorado and the San Juan Mountains, spring 2013 was a case study in the combined effects of poor snowcover formation (below average SWE as of March 1), very heavy dust-on-snow, and 'average' spring weather. This 'flat' typology is constrained to depicting SWE and dust intensity and does not fully capture the interactions of snowpack (SWE), dust intensity and, very importantly, a full range of spring weather conditions. The 2013 runoff pattern had a delayed onset of runoff, a near-normal but early peak, high-amplitude peaks, an early center of mass timing, and a quick recession.

However, in addition to the dust magnitude and the March SWE, a third dimension, representing March/April/May precipitation (snowfall) is needed to more full account for the remaining factors affecting runoff magnitude and timing. Spring precipitation can vary significantly in the San Juan mountains, and these differences can be portrayed via Figure 6. This 3x3x3, dust-enhanced snowmelt runoff 'space' does capture the interactions of spring weather, dust intensity, and available snowcover on March 1. Sustained periods of dust exposure and low albedo, during a dry spring, tend to advance the timing of dust effects and shift a hydrograph toward earlier runoff. Frequent restoration of high albedo by spring snowfalls tend to disrupt and delay dust effects and can result in a prolonged, albeit erratic, runoff cycle that may mirror more 'normal' timing of ascending, peak, and descending flows. This typology is useful for characterizing past behaviors, but may not be particularly practical as a forecasting tool.

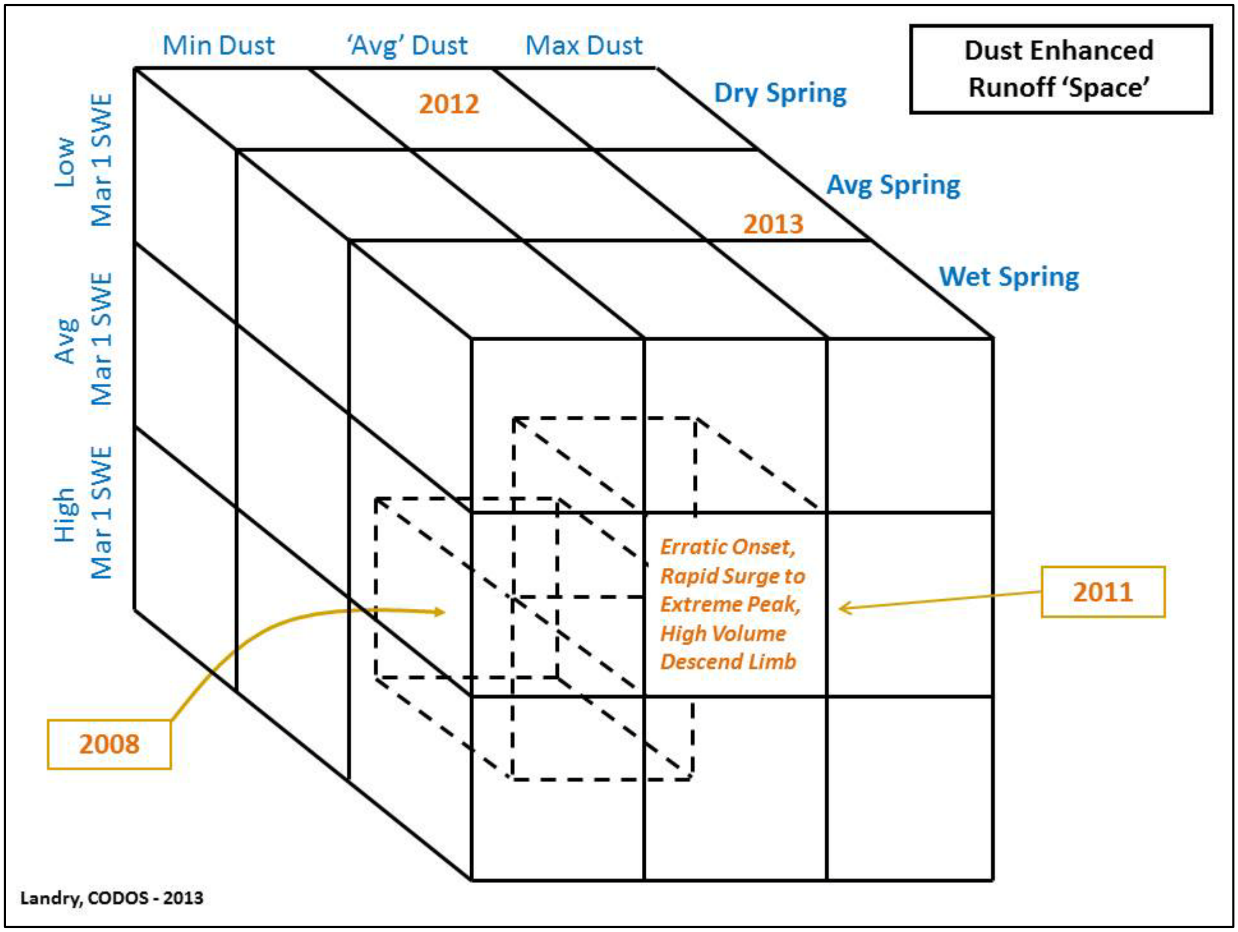

Figure 6. A 3x3x3 dust enhanced runoff space.

RADIATIVE FORCING OF SNOMELT BY DUST

For the sake of discussion, assume that snow albedo (i.e., rate of solar radiation absorption) is the dominant driver of snowmelt timing and rates – a simplistic assumption given the important role of thermal (longwave) radiation during darkness, particular in forested snowcover. The process interactions that dust introduces into snowmelt runoff forecasting are illustrated in this "semi-formalism" and illustrated in Figure 7. The challenge during a snowmelt cycle subject to dust-on-snow effects involves predicting or detecting (in a 'nowcasting' setting) the timing and spatial extent of dust layer emergence, or the burial of exposed dust by clean snow, 'resetting' snow albedo. Then, applying spatially and temporally variable potential solar energy flux 'intensity' and duration to estimate snowmelt rates and timing, during both high and low albedo periods, until the snowcover is consumed to "snow all gone" (SAG). Radiative forcing processes operate on a diurnal time scale, albedo fluctuations are episodic, driven be weather events, and solar intensity follows a seasonal time scale but interacts with weather at multiple time scales. Agencies responsible for spring snowmelt runoff forecasts in Colorado are faced with a very difficult new (dust) factor. Proxy approaches to estimating snowmelt energy budgets, using air temperatures for instance, are challenged when dust has reduced snow albedo.

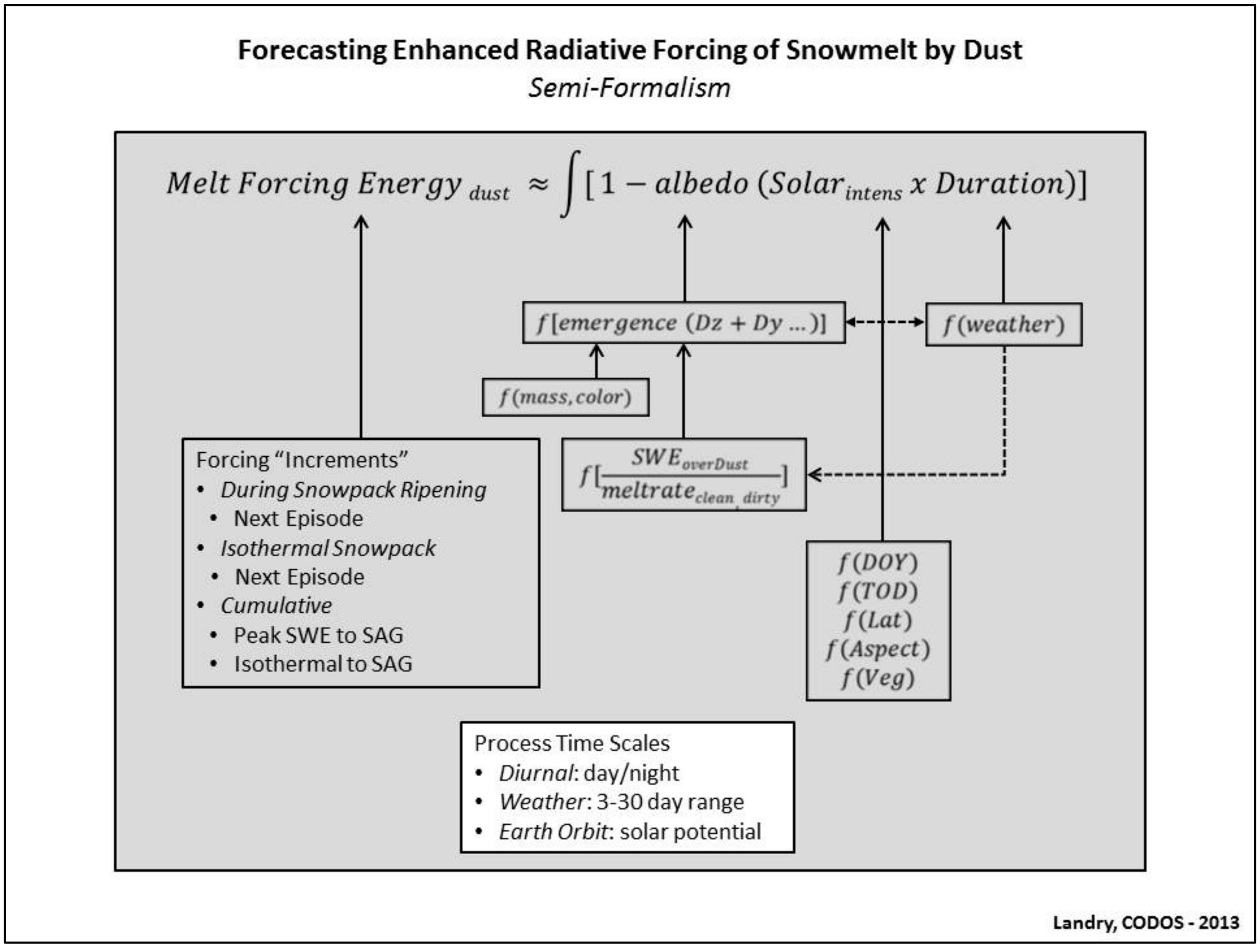

Figure 7. The timing and duration of dust effects on albedo have a cumulative effect on energy available to melt snow. Depending on dust magnitude, exposure timing and duration, and other factors, estimates of melt forcing energy can be calculated and used to adjust river forecasting models in improve forecasts.

CONCLUSIONS

Colorado has recognized the importance of dust from the Colorado Plateau to the south east by instituting a state-wide dust monitoring program. Dust occurs primarily during March, April, and May as both wet and dry storm events, but can occur in other months as well. The effects of snowmelt exposing a buried dust layer can be significant. Due to the significant decrease in albedo, much more sunlight is converted into heat and melts the snow very fast. The change in snowmelt rates has been shown to change the pattern of snowmelt in Colorado rivers. River forecasters are now incorporating the effects of dust to modify their runoff forecast models and to improve their runoff forecasts.