Lecture 27—Snow Hydrology

Well, we've spent an entire semester explaining that a) it rains, and b) some of the water that rains flows downhill and out through rivers. What we spent that time worrying about was how *long* it took to get from a to b so that we could worry about things like if there'd be enough water for drinking this year, or if we'd be flooded out of town. In all that time, however, we never once mentioned that it also *snows*. Snow is actually a fairly minor contributor to overall precipitation (only 13% of U.S. precipitation), but in some parts of the U.S. (namely some western states), it is the primary source of drinking water for the whole year. For western cities like Seattle (and many Californian cities), the snowpack is vital for water the entire year. In parts of the upper Midwest, melting snow causes one of the larger floods of the year. So how's it all work?

The trouble with snow is that it acts as sort of a water storage facility, but it's one we don't have a lot of control over. Trying to understand what controls snowmelt is fairly complex, but we'll try to work through some of it today.

How much water is in snow?

This *ought* to be a fairly simple question. We're taught that "eight inches of snow equal one inch of rain" from, like, *birth*, but turns out it's not exactly the case. One problem is that the density of newly fallen snow is about 100 kg/m^3 (compare with liquid water's 1000 kg/m^3), but as we all know snow's density increases with compression and aging so that it can reach nearly a density of 500 kg/m^3. As a result, hydrologists use an equation to approximate the amount of water in snow:

$$SWE = 0.01 d_s \rho_s$$

where SWE is the *Snow Water Equivalent* in mm, d_s is the depth of snow in cm, and ρ_s is the snow density in kg/m^3. In order to estimate the total storage of water in a snowpack, then, we need data on the density of the snow and its depth. This is commonly done with surveys using snow cores. The corer determines the depth of the snow, and returns the cores to a lab to determine density and depth

so that an overall density can be assigned. Trust me, in Ohio it seems silly, but in California, this is big business.

So what does it take to melt snow?

Basically, it takes heat. No duh, right? Ok, well, if snow is at 0°C, it takes 80 cal/g of heat to melt the snow. Where does that energy come from? One place is rain—falling rain is often warmer than 0°C, so the excess heat contributes either to raising the snow temperature to 0°C, or to melting the snow. Another place is solar radiation—incoming ultraviolet radiation can increase the total heat in snow and melt it. However! This process is controlled by how much light the snow reflects, or the *albedo* of the snow. Standing water reflects about 5 to 10% of the incoming ultraviolet radiation, but newly fallen snow reflects up to about 80%. This figure changes with time, though—old snow may have an albedo of less than 50%. Also, snow radiates heat as a black body—longwave ultraviolet radiation is returned to the atmosphere, but trapping of that radiation in the atmosphere can lead to re-radiation to the snowpack (the infamous greenhouse effect). So how do we keep track of it all? With a heat budget, of course:

$$\Delta H = Q_N + Q_g + Q_c + Q_e + Q_p$$

where ΔH is the change in heat storage in snow, Q_N is the net ultraviolet radiation, Q_g is conduction of heat to snowpack from the ground, Q_c is convective transport of heat from the air to the snow, Q_e is the release of latent heat of vaporization by condensation of water vapor onto the snow, and Q_p is the advection of heat to the snow by rain. Whew! Several of these are a pain, but some go away quickly—unless you live in Iceland, Qg is not a terribly important term because the snow is considered to have been in contact with the ground surface for enough time that the ground surface temperature and the snow temperature have reached equilibrium. Three of the others (Q_c, Q_e, and Q_p) are diffusive processes, and are therefore controlled by the temperature difference between either air and snow, or rain and snow.

Ok, so directly computing the elements of the snow heat budget is something of a pain in the butt, but most of the contributors are

effectively controlled by the temperature difference between snow and air, we *could* just make an empirical relationship between the air temperature and the snowmelt for various locations and work from that. {graph}. Note that these are regression lines and are therefore subject to all the regression issues we talked about earlier. Also note that they chose not to show us the range of data here. Ever wonder why?

What happens to melted snow?

The last thing we have to worry about is what happens to the meltwater that forms from the snow. How does it get out of the snowpack? Turns out this is a process like groundwater flow. The water has to percolate down to the ground layer, where it infiltrates the soil. It's only when the infiltration rate has been exceeded that liquid water begins to run through the snow, forming a saturated snow-water mix we lovingly refer to as *slush*. Slush flows relatively slowly (10-60 cm/min), but like any water drainage system, slush drainage becomes channelized under the snowpack, which increases the velocity by quite a bit. From there, it's out in the world. In Western states, this is a relatively gradual process, and snowmelt continues basically for the entire summer—therefore, drought conditions in California, Oregon, and Washington, are typically known the winter before. If you didn't get enough snow in the winter, you won't get enough snowmelt in the summer. Because El Niño controls a lot of where the storms track on the west coast, it is also quite intertwined with drought conditions in the west (basically, El Niño equals wet, La Niña equals dry for the west coast). In the upper Midwest, though, snowmelt is more a flood issue than a water supply issue. Here spring breaks quickly, so large temperature differences between snow and air occur, causing a lot of snowmelt quickly. Infiltration rates into frozen soil are exceeded, and water comes flooding over the landscape. This reaches an obvious extreme in volcanic areas (remember how I mentioned Iceland?), where volcanic activity under the snowpack can lead to very high snowmelt that becomes trapped behind unmelted snow and ice downslope of the volcanic vent. If enough pressure from melted water builds up, the ice barrier collapses and a very large flood wave sweeps downstream. This is known by its Icelandic name as a *jökulhlaup*.