Lecture 12: Snow Hydrology

Key Questions

1. How and where does snow form?
2. How is snow depth measured?
3. What is snow-water equivalent (SWE)?
4. What is a snow course?
5. What variables control snow metamorphosis?
6. What is a ripe snowpack
7. What controls snowmelt?
The Water Cycle: Snowmelt Runoff

If you live in Florida or on the French Riviera you might not wake up everyday wondering how melting snow contributes to the water cycle. But, in the world-wide scheme of the water cycle, runoff from snowmelt is a major component of the global movement of water. Of course, the importance of snowmelt varies greatly geographically, and in warmer climates it does not directly play a part in water availability. In the colder climates, though, much of the springtime runoff and streamflow in rivers is attributable to melting snow and ice.

Mountain snow fields act as natural reservoirs for many western United States water-supply systems, storing precipitation from the cool season, when most precipitation falls and forms snowpacks, until the warm season when most or all snowpacks melt and release water into rivers. As much as 75 percent of water supplies in the western states are derived from snowmelt.

During certain times of the year water from snowmelt can be responsible for almost all of the streamflow in a river. An example is the South Platte River in Colorado and Nebraska. Historically, the South Platte River was essentially "turned off" after the supply of water coming from melting snow was...
Snowmelt from winter accumulations in the high mountains is the source of about 75 percent of the region's water supply.

http://www.wcc.nrcs.usda.gov/factpub/wc_ss.html
Typically, irrigators and communities collect, store, and transport water to regulate quantity and ensure availability when and where it is required—there are over 219 dams in the Columbia basin.

Snow Formation

Snow forms due the same lifting and physical processes that generate rain—if the temperature drops to 32°F, vapor condenses to a solid.
Snow Formation

Orographic Effect

clouds expand as they rise

clouds cool when they expand

water vapor condenses when air cools, which produces snow
Snow Formation

Snow forms where the air temperature is cold.

1) high latitudes
2) high altitudes
Snow accumulation from a snow storm in November

The NRCS collects hydrologic data from the SNOTEL system, snow course network, and other climatological stations for water resource management purposes.
Measuring snow depth using a snow board.
NOAA: Mt. Baker snowfall  World record sticks (1140 inches)

Hydrologists are most interested in the Snow Water Equivalent of snow.

Example of Water Yield from a Volume of Snow

10 units x 20% = 2 units
Snow Water Equivalent (SWE) is a measure of the water content of the snow

\[ SWE = \frac{\rho_s}{\rho_w} h_s \]

\( \rho_s \) = snow density

\( \rho_w \) = water density

\( h_s \) = snow height

\( h_s \) = melted snow

\( \text{SWE} \) = Snow Water Equivalent
The density of new snow ranges from about 0.05 g/cm³ when the air is 14° F, to about 0.20 g/cm³ when the temperature is 32° F.

\[
\rho_s = \text{snow density}
\]

\[
\rho_w = \text{water density} = 1 \text{ g/cm}^3
\]

\[
SWE = \rho_s h_s
\]
Most snow that falls in the Cascade Mountains of Washington and Oregon tends to be higher density snow.
Most snow data comes from SNOTEL stations
SNOTEL = SNOwpack TELemetry

Telemetry is a technology that allows remote measurement and reporting of information.

The word is derived from Greek  tele = remote, and metron = measure.

Although the term commonly refers to wireless data transfer mechanisms (e.g. using radio or infrared systems), it also encompasses data transferred over other media, such as a telephone or computer network, optical link or other wired communications.

Wikipedia
SNOW PILLOWS:
FOUR STAINLESS STEEL PANELS ARE PLUMBED TOGETHER AND FILLED WITH AN ANTIFREEZE SOLUTION. THE WEIGHT OF THE WATER IN THE SNOW FORCES THE FLUID TO THE PRESSURE TRANSDUCER WHICH CONVERTS THE DATA TO A SIGNAL FOR TRANSMISSION.

snow pillows measure the weight of the snow
Ultrasonic snow-depth sensors measure the snow depth.

The NRCS uses Judd Communications Ultrasonic Depth Sensors to measure snow depth. The key component of the system is the ultrasonic transducer. The transducer is first used as a speaker to transmit an ultrasonic series of "clicks" down at the snow surface. The transducer then is used as a microphone to listen for clicks reflected back from the snow. By measuring the amount of time that it takes the clicks to travel from the transducer to the snow surface and back again, the distance to the snow can be calculated based on the speed of sound.

The **weight** from the snow pillow and **depth** from the ultrasonic sensor are used to estimate the SWE.
How is the SWE of the entire snowpack in a basin estimated?

snowpack is the total accumulated snow in the basin

point measurement
Field measurements along snow course
Hydrologists of the USDA NRCS measure the snow pack along a snow course.

- Soil corer for depth measurement and sample retrieval.
- Density estimate of snow in the core.

[Link to blog post: http://blog.oregonlive.com/weather/2008/01/snow_far_snow_good.html]
The Mt. Baker Ski Area reported 1,140 inches of snowfall for the 1998-99 snowfall season.
Snow Metamorphosis

time, heat, pressure, recrystallization

http://www.fsavalanche.org/Encyclopedia/cornsnow.htm
Gravitational Settling (pressure)

After a new layer of snow is added, the lower layers are compacted due to the added weight

older layers compact due to overlying weight – hence the surface subsides.
Heat Inputs

1) solar radiation is less significant than a lake because of the high albedo (reflectance) of the snow surface (i.e., glacier goggles).

2) Longwave and sensible heat inputs are more significant because the snow is colder (at least 32°F).
Tree cover in a basin will dramatically reduce solar inputs and reduce sensible heat input
Heat Inputs

heat input from **warm rain**
Heat Inputs

In the spring and summer $e_a > e_{sat}(T_{snow})$ as such molecules will diffuse from the air to the boundary layer (condensation) and heat input from condensing water vapor. A phase change from vapor to liquid (or solid) releases heat.
Heat Inputs

In the spring and summer $e_a > e_{sat}(T_{snow})$ as such molecules will diffuse from the air to the boundary layer (condensation).

1 cm of condensate will release enough heat to produce another 7.5 cm of water from melting snow (if the snowpack is at 32°F).
Snow Metamorphosis ([visit this link](#))

Heat inputs cause surface melting which percolates deeper into the snowpack and refreezes this changes the nature of the snow crystals.

\[
\text{time, heat, pressure, recrystallization}
\]
Snow Metamorphosis

The metamorphosis will continue until the snowpack becomes **ripe**

- grains become granular (like a coarse sand, i.e., corn snow)
- the snowpack is isothermal at 32°F (ready for a phase change)
- water exists between the grains (like pore water in a soil)
- the snow density is 40 to 50 % of water

[Diagram: Coarse Snow Grains and Free Water Between Grains]

http://www.fsavalanche.org/Encyclopedia/cornsnow.htm
In the Cascades, snowpack densities are around 20-30% in the winter to 30-50% in the spring. However, east of the Cascades, the snowpack density is much less. Typical values are 10-20% in the winter and 20-40% in the spring.
SWE as a function of time (2010 and 2011) at the MF Nooksack SNOTEL

MF NOOKSACK SNOTEL as of 02/07/2011

*** Provisional Data, Subject to Change ***

Date (mm/dd)

Index

0 5 10 15 20 25 30 35 40 45 50 55 60 65


SWE WY2010
SWE WY2011

MF Nooksack SNOTEL
After the snowpack reaches ripe conditions in the spring, all heat inputs produce meltwater (phase change from ice to water at 32°F)
Ripe snowpack, horizontal surface, measurement height = 2 m
Ground-heat input neglected

Specify conditions:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest cover, F</td>
<td>0.25</td>
</tr>
<tr>
<td>Clear-sky solar radiation, (K_{cs})</td>
<td>600.00 cal/cm²/day</td>
</tr>
<tr>
<td>Cloud cover, C</td>
<td>0.00</td>
</tr>
<tr>
<td>Albedo, (a)</td>
<td>0.65</td>
</tr>
<tr>
<td>Air temp, (T_a)</td>
<td>20.00°C</td>
</tr>
<tr>
<td>Relative humidity, (W_a)</td>
<td>0.75</td>
</tr>
<tr>
<td>Wind speed, (V_a)</td>
<td>2.50 m/s</td>
</tr>
<tr>
<td>Rain, (r)</td>
<td>0.00 cm/day</td>
</tr>
</tbody>
</table>

Computed Values (positive = heat input)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net solar radiation, (K)</td>
<td>81.78 cal/cm²/day</td>
<td>29,30,33</td>
</tr>
<tr>
<td>Vapor pressure, (ea)</td>
<td>17.58 mb</td>
<td></td>
</tr>
<tr>
<td>Atmospheric emissivity</td>
<td>0.85</td>
<td>40</td>
</tr>
<tr>
<td>Net long-wave radiation, (L)</td>
<td>190.05 cal/cm²/day</td>
<td>41b</td>
</tr>
<tr>
<td>Net radiation, (K + L)</td>
<td>271.83 cal/cm²/day</td>
<td>67.13%</td>
</tr>
<tr>
<td>Adjusted wind speed, (V_a)</td>
<td>2.00 m/s</td>
<td>45</td>
</tr>
<tr>
<td>Stability factor, (fs)</td>
<td>4.35</td>
<td>44</td>
</tr>
<tr>
<td>Net sensible-heat input, (H)</td>
<td>70.78 cal/cm²/day</td>
<td>17.48%</td>
</tr>
<tr>
<td>Net latent-heat input, (LE)</td>
<td>62.31 cal/cm²/day</td>
<td>15.39%</td>
</tr>
<tr>
<td>Evaporation/Condensation</td>
<td>0.57 cm/day</td>
<td>46/LE</td>
</tr>
<tr>
<td>Heat input from rain</td>
<td>0.00 cal/cm²/day</td>
<td>0.00%</td>
</tr>
<tr>
<td>Total heat input</td>
<td>404.92 cal/cm²/day</td>
<td>100.00%</td>
</tr>
<tr>
<td>Total water output</td>
<td>5.07 cm/day</td>
<td>26/LHF + rain</td>
</tr>
</tbody>
</table>
Remote Sensing is a technology that is used to assess snow conditions.
NOAA's Source for Snow Information

The National Operational Hydrologic Remote Sensing Center provides comprehensive snow observations, analyses, data sets and map products for the Nation.

- National Snow Observation Database
- Airborne Snow Surveys
- Satellite Snow Cover Mapping
- Snow Modeling and Data Assimilation
- Analyses, Maps, and Interactive Visualization Tools
- Integrated Snow Datasets for Geospatial Applications
- Applied Snow Research

NOHRSC products and services support a wide variety of government and private sector applications in water resources management, disaster emergency preparedness, weather and flood forecasting, agriculture, transportation and commerce.