Topic 9

Calibrating a Snow Gauge

Introduction

The main source of water for Northern California comes from the Sierra Nevada mountains. To help monitor this water supply, the Forest Service of the United States Department of Agriculture (USDA) operates a gamma transmission snow gauge in the Central Sierra Nevada near Soda Springs, California. The gauge is used to determine a depth profile of snow density.

The snow gauge doest not disturb the snow in the measurement process, which means that the same snow-pack can be measured again and again. With these replicate measurements on the same volume of snow, researchers can study snow-pack settlement over the course of the winter season and the dynamics of rain on snow. When rain falls on snow, the snow absorbs the water up to a certain point, after which flooding occurs. The denser the snow-pack, the less water the snow can absorb. Analysis of the snow-pack profile may help with monitoring the water supply and flood management.

The gauge does not directly measure snow density. The density reading is converted from a measurement of gamma ray emissions. Due to instrument wear and radioactive source decay, there may be changes over the seasons in the function used to convert the measured values into density readings. To adjust the conversion method, a calibration run is made each year at the beginning of the winter season. In this project you will develop a procedure to calibrate the snow gauge.

The Data

The data are from a calibration run of the USDA Forest Service's snow gauge located in the Central Sierra Nevada mountain range near Soda Springs, California. The run consists of placing polyethylene blocks of known densities between the two poles of the snow gauge and taking reading on the blocks. The polyethylene blocks are used to simulate snow.

For each block of polyethylene, 30 measurements were taken. Only the middle 10, in the order taken, are reported here. The measurements recorded by the gauge are an amplified version of the gamma photon count made by the detector. We call the gauge measurements the "gain".

The data available for investigation consist of 10 measurements for each of 9 densities in grams per cubic centimeter (g/cm^3) of polyethylene. The data appear in Table 1.

Table 1. The measured gain for the middle 10 runs of 30 of the snow gauge, for each of 9 densities in grams per cubic centimeter of polyethylene blocks.

Density	Gain									
0.686	17.6	17.3	16.9	16.2	17.1	18.5	18.7	17.4	18.6	16.8
0.604	24.8	25.9	26.3	24.8	24.8	27.6	28.5	30.5	28.4	27.7
0.508	39.4	37.6	38.1	37.7	36.3	38.7	39.4	38.8	39.2	40.3
0.412	60.0	58.3	59.6	59.1	56.3	55.0	52.9	54.1	56.9	56.0
0.318	87.0	92.7	90.5	85.8	87.5	88.3	91.6	88.2	88.6	84.7
0.223	128	130	131	129	127	129	132	133	134	133
0.148	199	204	199	207	200	200	205	202	199	199
0.080	298	298	297	288	296	293	301	299	298	293
0.001	423	421	422	428	436	427	426	428	427	429

Background

Location

The snow gauge is a complex and expensive instrument. It is not feasible to establish a broad network of gauges in the watershed area in order to monitor the water supply. Instead, the gauge is primarily used as a research tool. The snow gauge has helped to study snow-pack settling, snow-melt runoff, avalanches, and rain-on-snow dynamics.

At one point, gauges were located on Mt. Baldy, Idaho, on Mt. Hood, Oregon, in the Red Mountain Pass, Colorado, on Mt. Alyeska, Alaska, and in the Central Sierra Nevada, California. The Central Sierra snow gauge provided the data to be analyzed in this project. It is located in the center of a forest opening that is roughly 62 meters in diameter. The laboratory site is at 2099 meters elevation and is subject to major high-altitude storms which regularly deposit 5–20 centimeters of wet snow. The snow-pack reaches an average depth of 4 meters each winter.

The Gauge

The snow gauge consists of a cesium-137 radioactive source and an energy detector, mounted on separate vertical poles approximately 70 centimeters apart. A lift mechanism

at the top of the poles raises and lowers the source and detector together. The radioactive source emits gamma photons, also called gamma rays, at 662 kilo-electron-volts (keV) in all directions. The detector contains a scintillation crystal which counts those photons passing through the 70-centimeter gap from the source to the detector crystal. The pulses generated by the photons that reach the detector crystal are transmitted by a cable to a preamplifier and then further amplified and transmitted via a buried coaxial cable to the lab. There the signal is stabilized, corrected for temperature drift, and converted to a measurement we have termed the "gain". It should be directly proportional to the emission rate.

The densities of the polyethylene blocks used in the calibration run range from 0.001 to 0.686 grams per cubic centimeter (g/cm^3). The snow-pack density is never actually as low as 0.001 or as high as 0.686. It typically ranges between 0.1 and 0.6 g/cm^3.

A Physical Model

The gamma rays that are emitted from the radioactive source are sent out in all directions. Those that are sent in the direction of the detector may be scattered or absorbed by the polyethylene molecules between the source and the detector. With denser polyethylene, fewer gamma rays will reach the detector. There are complex physical models for the relationship between the polyethylene density and the detector readings.

A simplified version of the model that may be workable for the calibration problem of interest is described here. A gamma ray on route to the detector passes a number of polyethylene molecules. The molecule may either absorb the gamma photon, bounce it out of the path to the detector, or allow it to pass. If each molecule acts independently, then the chance that a gamma ray successfully arrives at the detector is p^m, where p is the chance, a single molecule will neither absorb nor bounce the gamma ray, and m is the number of molecules in a straight-line path from the source to the detector. This probability can be re-expressed as

$$e^{m \log p} = e^{bx},$$

where x, the density, is proportional to m, the number of molecules. A polyethylene block of high density can be roughly considered to be composed of the same molecules as a block that is less dense. Simply, there are more molecules in the same volume of material because the denser material has smaller air pores. This means that it is reasonable to expect the coefficient b in the equation above to remain constant for various densities of polyethylene.

The true physical model is much more complex, and in practice snow will be between the radioactive source and the detector. However, it is expected that polyethylene is similar

enough to snow (with respect to gamma ray transmission) to serve as its substitute and that the model described here is adequate for our purposes.

Investigation

The goal of this project is to provide a procedure for converting gain into density when the gauge is in operation. Keep in mind that the experiment was conducted by varying density and measuring the responses in gain, but when the gauge is ultimately in use, the snow-pack density is to be estimated from the measured gain.

Project 5
(Due on Friday, April 6)

1. Include everything you are usually expected to include and arrange things properly.

2. Your report should **include a short instruction sheet** for a lab technician on how the snow gauge should be calibrated for use in the winter months (assuming that the technician knows how to adjust the gauge mechanically and electronically to meet your requirements).

3. You should **also include an easy-to-use graph** for determining snow density for a given gain.

4. In your analysis, provide both point and interval estimates of densities for given gains. Check how well your calibration procedure works using the given data.

5. If the densities of the polyethylene blocks used in the experiment are reported with error in the form of *truth = reported value + measurement error*, how might this affect your analysis?

6. Do a presentation focusing on: (1) What are your instructions for the technician to calibrate the snow gauge? (2) Your easy-to-use graph for determining snow density for a given gain. (3) Your answer to the question in item 5.