Blue Snow and Green Ice

Under the right conditions, snow and ice can take on unexpected colors

By IVARS PETERSON

Snow presents more than just a uniformly white face. Holes in snow reveal a deep blue color that is more pure than the color of the bluest sky. Crevasses in glaciers and tunnels in snow, too, appear eerily blue.

Anyone who knows what to look for can see this vivid snow color, says meteorologist Craig F. Bohren of Pennsylvania State University. Missed more frequently is the subtle bluish-green or green tinge of ice in frozen waterfalls or icebergs. Bohren says the explanation for both color effects lies in the way snow grains (agglomerated snowflakes or ice crystals) or ice-trapped air bubbles scatter and absorb light. He described his observations and findings at a recent conference on optical engineering in cold environments.

Pure ice absorbs more red light than blue light, but it takes many meters of ice before transmitted light appears noticeably blue. "You can observe blue light transmitted in very large blocks of pure, homogeneous ice," says Bohren, "but you see it in snow at much smaller depths because of multiple scattering."

The ice grains that make up snow scatter most of the incoming light. This scattering increases the distance light travels, as it bounces from grain to grain, before the light reaches a certain depth. This longer path length allows more absorption to occur.

Polar region explorers and mountaineers are familiar with snow's blue face. Researcher G. H. Liljequist, a member of the Joint Norwegian-British-Swedish Antarctic Expedition of 1949-1952, wrote of his experiences in the Antarctic: "From the pits and tunnels at Maudheim my impression of the blue color of the penetrating light is vivid. Sometimes we used to pierce the ceiling of a tunnel ... in order to come out into the open air. As one approached the surface, the hole took on a beautiful deep-blue color. ... In the small tunnels, where we made our measurements, we noticed this filtering effect of the snow. In the uppermost tunnels the light was bluish-white, to become deep blue at 0.5-to-1-meter depth."

Bohren has seen the effect when he has walked up a snow-covered mountain. "Every time I punch holes in the snow with my ice axe, I leave these little blue holes behind me," Bohren remembers. "They're rather eerie."

Early in March, at a remote site near Schefferville, Quebec, Bohren photographed the effect. He punched a narrow, meter-deep hole into clean, deep snow in which no melting had occurred. The camera lens fitted snugly into the hole's opening so that outside light was excluded. The resulting pictures clearly showed the blue color of the light that penetrated into the snow.

Even a subtle color shift is apparent along the sides of the hole, says Bohren. The transmitted light near the opening is yellowish. As the depth increases, the color becomes yellowish-green, bluish-green and then vivid blue. Finally, if the hole is deep enough, the color and light disappear completely when all the light is absorbed. The colors seen also depend on the snow grain size and snow density.

Bohren says some people mistakenly ascribe the blue color to the same kind of scattering that gives the sky its color. Molecules and very small dust particles in the atmosphere tend to scatter blue light more than red light. Thus, the sky looks blue except in the direction of the sun (particularly when the sun is near the horizon, and blue light is scattered out of the sunlight, leaving the red color of sunrises and sunsets).

If this type of scattering also occurred in snow, argues Bohren, then the transmitted light ought to be red rather than blue. Instead, because of the large size of snow grains, all wavelengths of visible light are scattered equally, and the color is due to absorption of red light.

"Unfortunately, there's a tendency to assume that nature has only one recipe for making this blue color," comments Bohren.

Other people have claimed that a snow hole's blue color is simply a reflection of the surrounding sky. "Rubbish," says Bohren. He has calculated that the blue color in a snow hole is more pure than the sky's blue. He also notes that when he took his photographs the hole appeared vivid blue in color while the surrounding sky was a "faded bluish-gray."

"Now, there is a subtle point here," says Bohren. "Have you ever noticed that often when artists depict snow scenes, in the shadows the snow will be somewhat bluish?" In that case, no direct sunlight reaches the shadow's area, and reflected skylight gives a faint bluish tinge to the shadow. However, this has nothing to do with why the transmitted light deep in a snow hole is blue, says Bohren.

The more subtle coloring seen in light reflected from "bubbly" ice in frozen waterfalls and icebergs is also due to light scattering, but this time air bubbles trapped in the ice scatter the light. The effect is seen most easily when there is a sharp contrast between bright, white snow and the dark, pale bluish-green ice.

Bohren says, "I have often observed frozen waterfalls along road cuts while driving during the winter. Such waterfalls exhibit two characteristics: they are not nearly as bright as surrounding snow, and they are slightly green or bluish-green."

When Bohren first noticed the color in roadside frozen waterfalls, he thought he was imagining things. Later, he derived mathematical expressions that modeled the behavior of light in bubbly ice. Instead of considering ice particles in air, as he did for snow, he adapted the equations to apply to air bubbles in ice. The calculations predicted that reflected light from such ice would have a low-purity, greenish tinge.

"I've never heard anybody talk about the color of frozen waterfalls," says Bohren, "but I have a sneaking suspicion that people might well attribute it to impurities. I tend to shy away from that. 'Impurities' can be a sort of catchall for something you don't understand."

Icebergs are also composed of bubbly ice. Although Bohren has never seen a green iceberg, he has found accounts of such observations. In 1859, Robert M. Ballantyne, in his book *Hudson's Bay: Or Every-Day Life in the Wilds of North America,* wrote:

"Ice now began to surround us in all directions, and soon after this I saw, for the first time, that monster of the Polar Seas, an iceberg. It was a noble sight. We passed quite close, and had a fine opportunity of observing it. Though not so large as they are frequently seen, it was beautifully and fantastically formed. High peaks rose from it on various places, and down its sides streams of water and miniature cataracts flowed in torrents. The whole mass was of a delicate greenish-white color, and its lofty pinnacles sparkled in the moonbeams as it floated past, bending majestically in the swell of the ocean."

The reflected color of ice can be used to estimate the strength of ice and even how long it has been frozen. Ice formed on the Arctic Ocean, for example, is white in its first year because it is full of bubbles, giving it the same sparkling appearance as snow. In this case, there are so many bubbles that light travels only a short distance before it is scattered out of the ice. Little light absorption occurs.

During the summer, the ice surface melts, and later, new, overlying ice layers compress the remaining air bubbles. Now, any light that enters the ice travels a longer distance within the ice before it emerges. This reflected light appears blue-green or blue. Thus blue ice, with fewer bubbles, tends to be older and stronger than white ice. Arctic researchers have learned that floating camps built on blue ice will last longer. Mountain climbers, too, feel safer on blue ice. □

Craig F. Bohren

The greenish color of frozen waterfalls contrasts with white light reflected from overlying snow.

"It was a noble sight... The whole mass was of a delicate greenish-white color, and its lofty pinnacles sparkled in the moonlight as it floated past..."

Captain John Ross, *Exploring Baffin's Bay*, 1819

Arctic explorers have reported the green or bluish-green color of icebergs.