PLANET ICE

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YVON CHOUINARD * GINO CASASSA * RICHARD ALLEY * IAN STIRLING NICK JANS * BROUGHTON COBURN GRETEL EHRLICH

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LETTERS FROM THE SKY

FROM SNOWFLAKES TO ICE

Gino Casasa

Snow and ice can evoke supreme joy in some people. Think delicious ice cream, cool iced drinks on hot summer days, skiing dream slopes of powder, heavenly glacier landscapes, or surreal snow and ice festivals. Other people associate snow and ice with suffering: bitterly cold weather, freezing pipes, exhausting shoveling to clear the front door, deadly avalanches. But beyond these associations, should we really be worried about how a warming planet affects snow and ice? Are snow and ice so important?

The answer to both is, uncategorically, yes.

Snow and ice are unique and critical components of our planet. We all know that water is essential for life and that ice is simply the frozen phase of water. It is also clear that the climate controls the amount of snow and ice on earth. What is less known is that many of the earth's characteristics, such as its climate, are governed to a large extent by the relative abundance of ice and water.

Snow and ice have probably existed on Earth as far back as 2.7 billion years ago, during the so-called Huronian Ice Age when an ice sheet covered a major portion of North America. That is quite early in Earth's history, considering that our planet is 4.5 Billion years old. The controversial "snowball Earth" idea proposes that the Earth was completely covered by snow and ice 850 million to 630 million

GINO CASASSA, a senior scientist at Centro de Estudios Sientificos in Valdivia, southern Chile, is a Chilean glaciologist with a degree in hydraulics engineering and a Ph.D. in glaciology. Early on, he became an active mountaineer and developed great interest in frozen water. He has published more than sixty peer-reviewed papers and more than ten book chapters about glaciology. He holds leading positions in several national and international committees, including vice president of the International Association of Cryosphere Sciences. He was awarded a Guggenheim Fellowship in 2005 and was lead coordinating author of Working Group II of the Intergovernmental Panel on Climate Change, which was co-awarded a Nobel Peace Prize with Al Gore in 2007.

Climbers approach the summit of Mt. Margarita in the Ruwenzori Range, the highest peak in the fabled Mountains of the Moon.

years ago. There is indeed evidence that ice sheets have covered large portions of several continents during past ice ages, but there is no evidence that all of the continents were ice covered at any given time.

Human beings started to appear on Earth during the last few hundred thousand years, at the time when the Earth was experiencing cold glacial periods followed by warm interglacials. The most recent ice age ended about 18,000 years ago. The present inter-glacial is known as the Holocene.

Snow and ice on earth now take the form of ice sheets and ice shelves, glaciers, seasonal snow cover, frozen ground, sea ice, and lake and river ice. What is happening to this cold and frozen world has broad implications for human and non-human life on this planet.

PROPERTIES OF ICE AND SNOW

Ice and snow begin with water and its close interaction with air temperature and the sun. Sunshine is essentially white, being formed by equal amounts of blue, green and red frequencies. The water molecule H_2O absorbs six times more of the red frequencies of the spectrum than the blue component, thus preferentially reflecting blue light. Blue ice is particularly obvious under diffuse light, when the sky is overcast. If ice contains large numbers of air bubbles, it will appear white due to multiple reflections of incidental light produced on the rough surface of the bubbles (which also explains why beer foam is white, even in the case of delicious dark ales).

When frozen—that is, below 0° Celsius (32° F) at sea-level pressure—the H_2O molecule expands by more than eight percent. This behavior is quite uncommon in nature and is not at all obvious from water's chemical composition, which is one of the simplest in chemistry. This happens because water molecules are linked by weak chemical forces known as hydrogen bonds, connecting the hydrogen atoms of one molecule and the oxygen atom of the neighboring molecule.

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At 4° ~~C~~ (39° F), water achieves its maximum density, expanding at lower temperatures due to changes in these hydrogen bonds; just the opposite is expected from normal fluids and materials in general, which expand at higher temperatures. Therefore, ice can float in a glass of Scotch, the same way that icebergs and sea ice float on the ocean. While this is bad news for ship traffic in polar regions (for example, the *Titanic*) and for pipes (which tend to burst in cold winters), it is good news for polar bears, which depend on sea ice for survival. The lower density of ice compared to water favors the existence of marine and freshwater ecosystems, which can develop under very low atmospheric temperatures because of the ther-mal isolation of the floating layer of ice.

Depending on its temperature and pressure, ice exhibits ~~fifteen~~ different crystalline structures, plus ~~three~~ amorphous phases. The crystalline structures are known as *ice I* through *ice XV*, of which only *ice I* occurs naturally on Earth; all the others exist at much lower temperatures and higher pressures than found on Earth. Fortunately, Kurt Vonnegut's *ice IX*, which "crystallized all water on Earth" as described in his novel *Cat's Cradle*, symbolizing the involuntary self-destruction of humankind, is a fiction. The real *ice IX* is not stable at the temperatures and pressures found on our planet. Amorphous ice is formed only artificially and perhaps also in outer space at extremely rapid cooling rates, which prevent the formation of a crystal lattice. *Ice Ih*, where *h* denotes the hexagonal structure of the ice crystal (which, incidentally, is the reason why all snowflakes have ~~six~~ points), occurs naturally on Earth. Some speculate that other ice structures might be found deep in the Earth's interior under high pressures, but if they exist, they remain undiscovered. *Ice IC*, that is, cubic ice, is normally formed from vapor condensation at very low temperatures and may be found in the upper atmosphere.

The deepest-occurring natural ice on Earth is at a depth of nearly 5 kilometers (3.1 mi) at the base of the Antarctic Ice Sheet, where the pressure is nearly 500 times larger than atmospheric pressure at sea level, but still less than a quarter of the pressure needed to transform *ice Ih* to other crystalline ices. At that depth, the melting temperature of ice (also known as the pressure melting point) is about ~~minus~~ 3.3° Celsius (26° F). The pressure melting effect is also a direct consequence of the nature of the hydrogen bonds that cause frozen water to expand. Pressure melting will allow, for example, the classic experiment of a fine wire hanging with weights attached to it to cut through an ice cube, thus melting its way down, with the ice refreezing (called *regelation*) on the upper side where the pressure on the wire is reduced.

Snow is essentially a mixture of ice, air, impurities, and also water if temperatures are at or above the freezing point. Snowflakes are truly "letters from the sky," as beautifully described by Japanese physicist Ukichiro Nakaya, who in the 1930's was the first to reproduce snow crystals in the laboratory. If snow undergoes sufficient compaction, as occurs on a glacier due to periodic snow accumulation, it will eventually transform into ice.

In atmospheric sciences, *accretion* is the technical term that describes the growth of snow and ice from water vapor. Accretion by formation of ice from vapor condensation or from freezing rain can be very destructive for such things as aircraft, polar ships, power lines and road traffic. Accretion also results from growth of solid forms of snow and ice, as with snowballs, particularly those made with wet snow (which is much stickier than dry snow). Think of the rapid growth of a snowball rolling down a slope.

Ice is one of the planet's most fascinating crystalline structures

Snow and ice have a very low surface friction, which allows