

**Part I**  
**Boundary Conditions for Microbial Life**  
**at Low Temperatures**



# Chapter 1

## The Climate of Snow and Ice as Boundary Condition for Microbial Life

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Contents	
1.1 The source of energy: solar radiation.....	3
1.2 Distribution of energy: the energy balance of snow and ice.....	5
1.3 Air temperature: effects of altitude and latitude .....	6
1.4 Atmospheric humidity and precipitation .....	8
1.5 The cryosphere: a matrix for life .....	9
1.6 Liquid water in the cryosphere .....	11
1.7 Hot spots in the ice.....	13
1.8 Conclusions.....	14
References.....	14

### 1.1 The source of energy: solar radiation

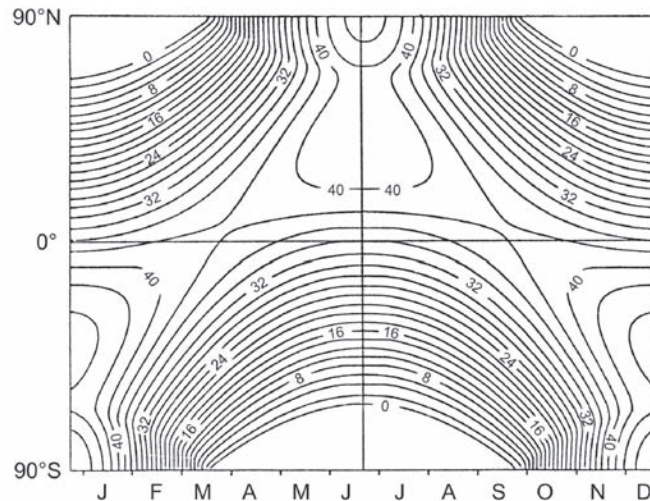
The Earth's surface is the place where the biosphere, the atmosphere, the hydrosphere and the lithosphere interact most extensively. In mountains and polar regions, the cryosphere adds more facets to this multiple interaction. The biogeochemical cycles at the Earth's surface are driven by the vertical exchange of energy and water locally, and by the horizontal motion of air and water in the global circulation. The energy absorbed from the incident solar radiation is used to heat the ground, snow, or water, which in turn heat the overlying air by turbulent convection; to evaporate water, melt or sublimate ice; and in part is re-emitted as infrared radiation.

Solar radiation, the prime energy source of all climatic and biotic processes, has a strong daily and seasonal variation in mid and high latitudes. This is best illustrated by its reference value, the extraterrestrial irradiance, the amount of energy that would be received if there were no atmospheric extinction. Daily sums of extraterrestrial irradiance are displayed in Fig. 1.1 in response to geographical latitude and time of the year. While the tropics have the highest annual sums, the two polar regions reach the highest daily totals in their respective summers, with Antarctica receiving more than the Arctic since the Earth is closest to the Sun in the Austral summer.

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**Fig. 1.1** Daily sums of extraterrestrial solar irradiance, the reference amount of energy that would be received without atmospheric extinction. Values are given in  $\text{MJ m}^{-2} \text{ day}^{-1}$  computed for a solar constant of  $1,368 \text{ W m}^{-2}$

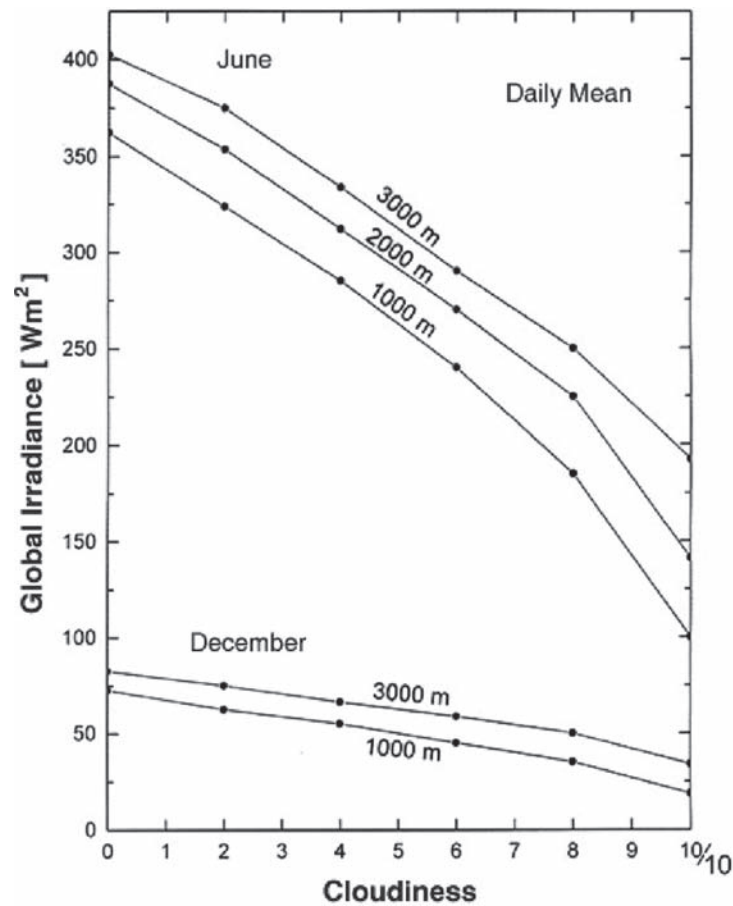
Extinction by the air and its trace gases and by clouds and aerosols gives it a change with altitude as well. Global irradiance, the sum of direct and diffuse solar irradiance, was compiled from records at Austrian stations in Fig. 1.2, as a function of cloudiness and altitude. There is an increase of global irradiance of the order of 1% per 100 m altitude at mean cloudiness, and a decrease by 50% when comparing cloudless and cloud covered sky at an altitude of 3,000 m.

The maximum daily average of  $400 \text{ W m}^{-2}$  in Fig. 1.2 is associated with an instantaneous maximum of ca.  $1,000 \text{ W m}^{-2}$  at noon.  $400 \text{ W m}^{-2}$  is identical to the maximum mean daily irradiance reached in the Dry Valleys of Antarctica, close to sea level, although the solar geometry at that high latitude is very different from that of the Alps. This daily average amounts to 83% of the extraterrestrial irradiance in alpine conditions, a fraction that is nearly identical to the 85% found in the central Antarctic at the time of summer solstice. It is obvious from Figs. 1.1 and 1.2 that this fraction decreases at lower solar elevations.

A large part of this incident solar radiation is reflected back to the atmosphere. The broad band albedo of dry alpine or polar snow exceeds 80%, reaching 90% in the visible and UV parts of the spectrum and dropping to less than 20% in the near infrared; in the thermal infrared, snow is essentially a black body with an emissivity close to 0.98.

At low angles of solar elevation, as typical for polar regions, forward scattering in the snow increases albedo to values >90%. The albedo of snow and ice decreases with increasing grain size and increasing liquid water content so that clean alpine snow that survives into summer displays albedo values between 60 and 70%. The presence of dust or other admixtures reduces the albedo further.

The albedo of ice depends largely on the presence of cracks and air bubbles: typical clean ice of alpine glaciers would reflect about 40%, dust and dirt covered ice may reflect



**Fig. 1.2** Daily averages of global irradiance at eastern alpine stations, according to altitude and cloudiness, based on data by Dirmhirn (1964)

as little as the surrounding rocks, i.e. 15–20%. The so-called blue ice of Antarctica has emerged to the surface after having been subjected to very high pressure in the deepest part of its trajectory: 1,100m of ice exert a hydrostatic pressure of 100 bars (100 atmospheres), a pressure under which air bubbles become dissolved in the crystal lattice of the ice. This bubble free, blue ice has the darkest appearance of any naturally occurring ice.

## 1.2 Distribution of energy: the energy balance of snow and ice

Solar radiation is the prime source of energy for planet Earth. It supplies a global, annual average of  $240 \text{ W m}^{-2}$ . Geothermal heat supplied by the hot interior of the Earth and by radioactive decay amounts to only  $60 \text{ mW m}^{-2}$ , negligible compared

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