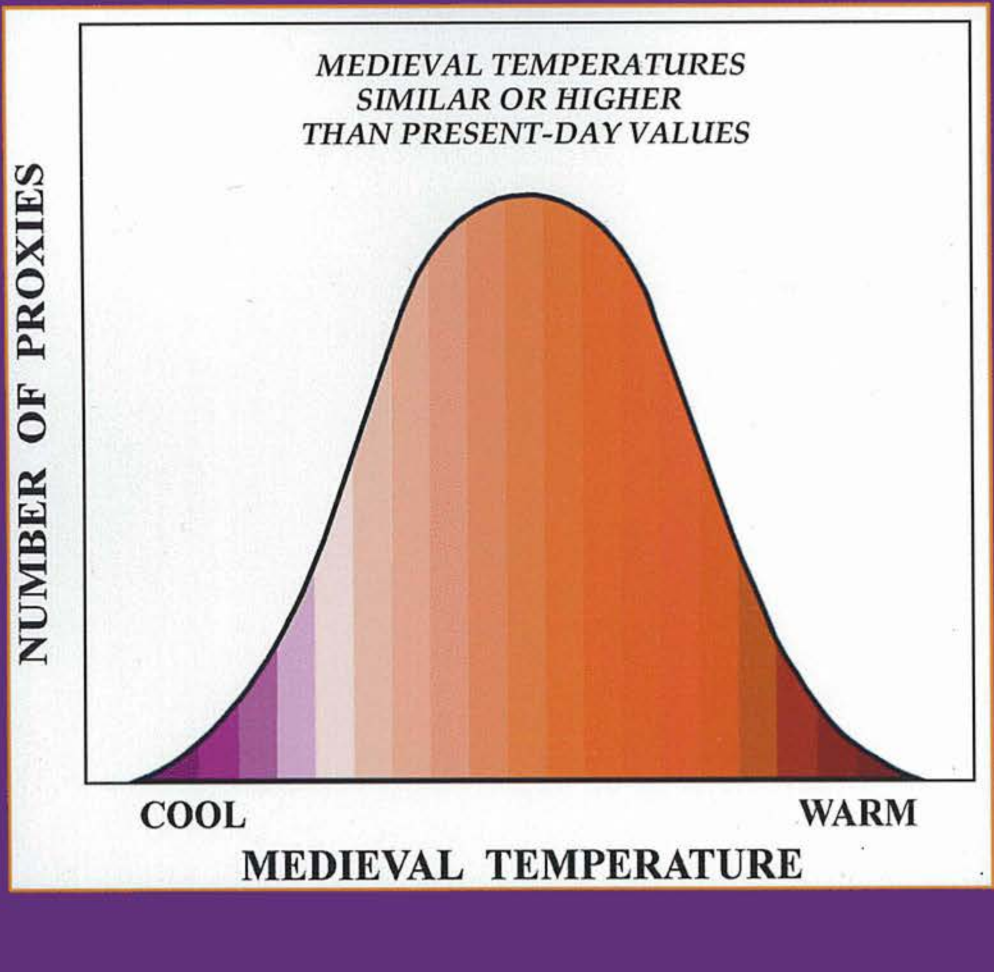
Miroslav Kutílek & Donald R. Nielsen

FACTS ABOUT GLOBAL WARMING

Rational or Emotional Issue?



Essays in GeoEcology

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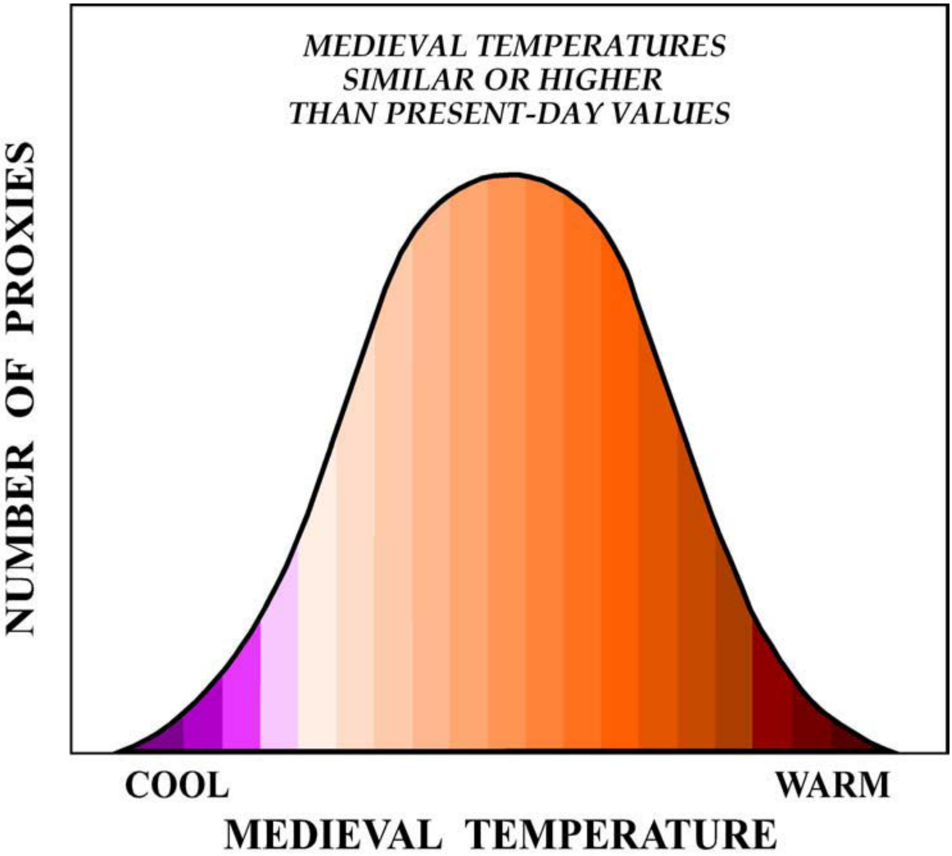

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1. Soil scientist and climatology

Our friends used to ask us: Why do you butt into the affairs of climatology when your own subject is soil science and mainly soil physics and soil hydrology?

Answering them, we always say that we have at least three good reasons. The first one, and for us the most important, are the statements and announcements of many climatologists made public by alarmists repeatedly in the media with dramatic scenarios. Media are prosperous when they deal with catastrophes – the more intense and richly colored, the higher is the rating of the radio, TV or newspaper, and thus profits of the owners are escalated. With principles of the market being inexorable, the various media submit themselves to such statements and announcements with great pleasure. It is astonishing to recognize how simple it has been for journalists to become producers of articles of merchandise, and how easy it is now for them to forget the slogan that journalists are vanguards of truth and justice. With the world not being black and white, there are newspapers and TV channels that do not pursue strict market requirements and rewards, but unfortunately, they belong to the minority.

Climatological alarmists offered two very attractive scenarios to media. Scenario number 1: A hypothesis on global warming caused by human activity. Scenario number 2: This warming may lead to a catastrophe never experienced before by humans. The main cause of the catastrophic change is the burning of fossil fuels by the industrial society to produce energy. This burning is linked to the emission of carbon dioxide CO_2 that is the root of global warming through its greenhouse effect.

The logic of the hypothesis is simple. Carbon accumulated in coal, oil and gas during millions of years was released as CO_2 in the very short time interval of two-and-a-half centuries. During this short time, the content of CO_2 in the atmosphere increased by approximately 40%. The content of CO_2 in the atmosphere is usually expressed in parts per million, abbreviated as ppm. Let us imagine 1 ppm of CO_2 – that concentration is one molecule of carbon dioxide in one million of air molecules. Before the industrial revolution, the CO_2 content in atmosphere ranged between 250 to 280 ppm. Today, the CO_2 content has increased to about 388 ppm. Luckily enough, CO_2 is not toxic for us even in much higher concentrations, nor does it cause allergic illnesses. Indeed, researchers conducting experiments in greenhouses deliberately increase its concentration by 100 to 400%, which surprisingly to some, causes an increase of crop yields. Plant physiologists refer to this beneficial practice as fertilizing with CO_2. However, CO_2 belongs to greenhouse gases that cause global warming. This single effect is described by media as a catastrophe, and apparently entirely socially and scientifically adequate to label CO_2 as a gas dangerous to the public.

It may happen in winter after we have had a couple of days with heavy snowing – the media informs everybody that it was the result of global warming. Nobody explains how the snowing is related to warming. If it is so stated in the TV, it means it must be so! The same happens when a wave of above-average tropical temperatures comes in summer. There is no need for explanation. Humid, tropical temperatures in central Europe or in Midwest of USA are linked with global warming – everybody believes it – just look at all of the sweaty, wet shirts as proof! Global warming is also a simple explanation for heavy soil erosion that floods villages with mud. And, forest fires are the consequence of warming. Similarly, the degradation of our environment and its accompanying decreased diversity are explained by the unfortunate, unnecessary steps of our society. The principal culprits according to alarmists are the greenhouse gases, mainly CO_2 emitted into the atmosphere by burning oil, coal or natural gas. The alarmists asked the politicians to introduce appropriate measures against the warming in compliance with their hypothesis. They asked for a strong reduction of CO_2 emissions into the atmosphere, i.e. a reduction of burned oil, coal and natural gas. We believe that such a practice would reduce, instead of develop, the economy with the net result being a decreased standard of life. Considering all of its consequences, the original theoretical problem of climatology is now a matter of the entire human society.

Climatological alarmists and those in international and intergovernmental institutions propagating their closely knitted views object to opinions of non-climatologists. They ask, "How can you dare to discuss the problems of climatology, a subject you are not qualified to study in detail?" The answer is that we are not engaged in the details of a purely scientific problem because climatologists transferred their own views, those far beyond the details of their own discipline, upon the public and to the political level. Their recommendation for the solution of "the crisis due to global warming" has a general political and globally economic character. Considering this latter aspect, everybody should have the right to a legitimate opportunity for expressing rational criticism. When we say everybody, we mean that this right and opportunity should be available to not only scientists in branches closely related to climatology, but to all other disciplines as well as economists, politicians and those in all other sectors of society. Accepting the alarmists' recommendation on restrictions of CO_2 emissions means an overwhelming interference in global economics, which cannot be promulgated or globally obeyed without viable national and international political decisions.

With global warming not being their exclusive domain, climatologists will have to get used to others butting in to express their views and scientific rationale on the subject. With this sentence we are ending the first reason for our writing on global warming.

The second reason for our meddling into climatology is our profession. We are engaged in soil science, sometimes called pedology – the word originating from the Greek (*pedon* = soil, plain, earth and *logos* = word, notion). When we consider the origin and time of soil evolution on a scale of a human life, we refer to a very long time. If we use the geological time scale, soils emerge and develop very quickly during hundreds and thousands of years only. These times for soil genesis appear very brief compared with tens of million years characterizing for example, either of the Cambrian or Jurassic geological periods.

Today, there are many different kinds of soil existing within the various landscapes of each continent. They differ because several factors influencing their genetic evolution are not the same within regions or across continents. Materials of soil origin are more or less weathered rocks and accumulated organic matter. These materials are also the products of earlier physical and biological transformations of rocks. We denote them all as parent material and as one of the soil-forming factors. Most soil properties are conditioned by the nature of the parent material. Hence, it should be clear to everybody that heavy clays cannot originate from sandstone. Because chemical and physical weathering, transport of matter within a soil and type of vegetation all depend upon climate, it is considered another soil formation factor. With climate long being defined as the principal soil-forming factor, all soils were earlier classified into two main groups: the climatogenic soils (i.e. soils influenced by the climate), sometimes called zonal soils, and the aclimatogenic soils (i.e. soils not dominantly influenced by climate), also called azonal soils. Since that time, soil classification systems are more complex without accentuating climate as the most important and decisive factor of soil genesis. A third soil formation factor are plants together with soil microflora and fauna, denoted collectively as soil organisms. The topography, a fourth factor, modifies the impact of the local climate and regulates and partitions hydrologic pathways on and below the soil surface. Nowadays, we frequently add human activity to the list of factors involved in soil genesis.

Let us give important examples of how climate influences soil-forming processes. In the arid environment of deserts and semi-deserts, physical weathering is a dominant transformation process easily recognized on coarse-grained igneous rocks like granite. Granite is composed essentially of three minerals – quartz, feldspar and mica. The distinctive color of each of these minerals allows them to be accurately recognized by eye.

The arid climate typically has cool nights and very hot days. The fluctuating temperatures of these three minerals are not the same due to their different absorptions of solar radiation, which primarily depend upon their individual colors. Owing to their unequal specific thermal expansivities, the volume of each mineral uniquely changes according to its own time-dependent temperature and expansion coefficient. As the volume of the three minerals differentially change during sequences of day-night temperatures, powerful stresses cause them to be mechanically separated. Because the thickness of the separating cracks is microscopic and not perceptible by the eye, the granite still appears as a solid rock. However, if we rake our hand over its eroded surface, we separate all of the individual minerals in a similar way as if we had raked the surface of individual sand particles. The minerals are crumbled out and easily separated because they are no longer fixed together as ingredients of the solid, uneroded granitic rock. This crumbliness reaches depths of tens of centimeters below the original unweathered rock surface. Desert foxes and small animals dig out holes in this material to hide and seek comfort inside of their dens during the hot days and the cold nights.

I (the first author, MK) took my students of the Khartoum University to an excursion to the north to visit the landscape of the sixth Nile cataract. The students sat on the bed of the truck while I sat next to the local driver with one of the students as an interpreter. During the first half-hour we drove in the direction of rutty wheel tracks. When there were no more tracks nor any obvious trail to follow, we continued to take an unmarked route roughly to the north, which only the driver knew that eventually led to the Nile cataract. The driver's name, translated from Arabic, was Crocodile. Since I knew that animals have a better instinct for direction, I trusted the driver mainly because of his name from the animal kingdom. The students and I had hiking boots while the driver Crocodile was wearing homemade sandals with soles cut from an old tire. I decided to stop close to an apparently unweathered granite rock. Visual teaching is the most effective. I walked to the rock where I swung my right foot to the rear and then I kicked with all my force as if I were kicking a penalty during a football game. The students were silent for a second and then they exploded in a cheerful ovation when they saw that my entire boot penetrated into the "rock" like in a heap of sand. Everybody tried the kick, even the driver Crocodile. He did it with less force – his foot was in a sandal. My explanation on physical weathering of coarse-grained rocks followed in English. I also did not forget to mention that fine-grained rocks do not all weather in the same way. In the dry hot climate, they are sometimes covered by a compact glassy coating as we had the chance to see later on at the Nile cataract. All of my "lecture" was in English. With the driver knowing only a couple of

English words, he definitely never heard nor even understood terms like weathering and glassy compact coating.

We continued on our drive to the cataract where the Nile valley narrowed and the stream was very swift and filled with rapids as its water flowed with difficulty around the obstacle of a large, fine-grained igneous rock. Here we stopped again, and even before I could say a single word through the interpreter, the driver Crocodile, smiling with pride, quickly ran to the rock to be the first to kick it. He kicked with all his might, but the solid glassy rock did not budge and left his foot bleeding and swelling with excruciating pain. I had to drive on our return to the university, with the driver Crocodile only being able to navigate me with the help of my student interpreter. I am absolutely confident that those students kept in mind for the rest of their entire lives that vivid lesson on physical weathering, and on the role of climate, which is modified by the specific nature of weathering rock. And the driver Crocodile is still probably thinking that the white "khavadia" is not worth trusting.

Physical weathering in cool climate is mainly caused by volumetric changes of water and ice. Water infiltrating into the pores of a rock start freezing at temperature below zero (Celsius) and as its volume increases; the ice acts like a wedge. When the process is repeated many times, the rock eventually cracks with small stones, and sometimes even coarse sand, separated from the rock.

Chemical weathering occurs in the presence of water, which dissolves the binding materials of sedimentary rocks. The crystal lattices of minerals as well as that of other primary and secondary soil constituents are also gradually destroyed in the presence of water. We can depict or model the mineral crystal lattice in our imagination as a construction of tubular scaffolding. The bonds between atoms or ions are represented by tubes and the atoms or ions are joints and blocks holding individual tubes together. The distribution and thickness of tubes are variable in order to represent various energies of bonding when the atoms – or our fixing blocks – are not the same. Chemical weathering may be realized in our imagination by a strong gusty wind that causes a vibration sufficient to collapse the entire construction. On the ground, we find all of the products of chemical weathering – individual fixing blocks, broken tubes and parts of the tubular scaffolding. The individual blocks as well as two blocks bound together with one tube of our model are, in the reality of mineral chemical weathering, the simple chemical compounds of soluble salts, which are readily transported by flowing water. Other compounds, for example, those of iron or aluminum, are soluble only if conditions are favorable and are usually transported slowly for relatively short distances. Some compounds remain as coating of soil mineral grains. The broken whole parts of the deformed tubular scaffolding represent the residuals of weathering – most frequently the clay minerals. Even though it may not seem reasonable, we now know that pure clay is composed of a relatively small number of unique minerals. They are very tiny, not visible in a simple microscope and usually only translocated small distances within the soil.

Summarizing, we know that chemical weathering produces three different groups of materials: readily soluble salts (including even ordinary table salt), slightly soluble compounds and clay minerals. All of the various clays we find in nature, including those in kaolin (or china clay) used for producing porcelain, are all products of earlier stages of chemical weathering. Clay minerals are not all the same. They differ in their crystal lattice and in their physical and chemical properties. In contrast to kaolin, some shrink as they dry and swell as they wet. All of their diversity depends upon many factors with climate being the most important.

As we mentioned earlier, some of the products of chemical weathering are readily transported through a soil by flowing water, some are transported only small distances and others are essentially not transportable. Their transport depends upon local conditions dominated by the climate. If there is sufficient rainfall, readily soluble inorganic salts are leached out of the topsoil and into the ground water. The leaching of soluble salts occurs when rainfall is greater than evaporation, and is one of the principal reasons why ground water is "hard". If the climate is characterized by low precipitation and high evaporation in hot dry climate, the dominant direction of water flow in the topsoil is upward with salts being shifted to the soil surface. Under such climatic conditions, soils are salinized and sometimes to such an extent that salts may even form a whitish blanket on their surface. In regions of mild climate where downward rainwater flow in soil exceeds evaporation, clay particles are moved downward by depths of tens of centimeters. A similar translocation of iron oxides occurs in acid soils. Hence, soils are commonly classified according to the impact of local climatic conditions on specific soil transport and accumulation processes.

Dead parts of plants as well as the dead remains of soil microorganisms are the parent material for the formation of the soil humic substances. They cause topsoils to have dark brown and black colors. The process is called humification with the organic parts and remains being partly decomposed to inorganic substances, which subsequently serve as important plant nutrients. The organic parts and remains are also decomposed to simpler organic substances. The transformation process continues as a new synthesis and polymerization to eventually form humic substances that exist either individually or as a coating of mineral particles. The decomposition is accompanied by the release of carbon dioxide CO_2 into the air contained in soil pores, and from there the released CO_2 moves out of the soil and escapes into the atmosphere first by gaseous diffusion. We denote this process as soil breathing – a term frequently used in scientific literature. Soil breathing is the last segment of small CO_2 cycles. The first segment begins with atmospheric CO_2 entering into the plant through the stomatal pores of its leaves. There it is chemically transformed into organic compounds by the active contribution of solar radiation commonly known as photosynthesis. Because carbon is a basic element in living organisms, it occurs in plants, soil fauna, soil microbes and their products. Part of the carbon stays in decomposed roots and in humic substances while only part of the CO_2 originally entering plants is released by soil breathing. In other words, the soil acts as a bank to save and conserve a certain portion of the CO_2 used by plants and other living organisms. Hence, soil carbon is a very important controlling portion of the total global balance of CO_2 and its dynamics in the atmosphere. Therefore, it should not be surprising to anyone why soil scientists have an intense interest in hypotheses about global climate change – those related to warming or cooling occurring in the past, now or in the future.

The intensity of soil breathing, or of the CO_2 release into the atmosphere depends upon the water content and temperature of the soil. Both of them influence the microbial activity and intensity of humification provided that there is enough transformable organic material. And least and not last, soil breathing requires the soil to contain a sufficient volume of air, since transport of carbon dioxide through the soil takes place by diffusion through continuous paths of air within soil pores to the atmosphere. When soils are too wet, diffusion is impeded and soil breathing virtually stops. A long-lasting soil water logging leads to the reduction of the decomposition rate and even the nature of the organic matter transformation is changed.

We have mentioned that as soil scientists we study climatology in order to understand what are the environmental conditions for the origin of soils. We are equally interested and have long studied the reverse situation. When we find the remnants of an old fossil soil that has remained intact from an earlier time period (e.g., from the last interglacial period existing on our planet 120,000 years ago), we can deduce the climatic conditions during the origin and existence of this soil type. The study of old and buried soils is the theme of paleopedology (Greek *palaios,* old), and one of the products of paleopedologic studies is the characterization of ancient climates. Indeed, paleoclimatology utilizes the results of paleopedology. Because recent soils originating on old soils frequently keep some of the properties of the previous soils, we must admit that separating the result of the earlier time periods from the product of recent environmental conditions is a very difficult task. A few examples of such separation procedures have recently been provided by Sauer (2008). We have to repeat emphatically that the study of climate is not an idle curiosity, but an unconditional necessity for a soil scientist.

The third reason for a soil scientist to study climatology is its relationship to research in soil physics and in soil hydrology. When rainwater first meets the topsoil of a landscape, a portion of the precipitation infiltrates into the soil profile where it is temporarily stored for the future use of plants. It flows into the roots and up through the plant to its leaves where it evaporates. This evaporation is commonly known as transpiration. A portion of the infiltrated water may flow below the roots and deeper into the ground water, or it may flow below the soil surface to a creek or to a river. Except when it evaporates, water transports dissolved inorganic salts and organic compounds through the soil to the groundwater or eventually to the sea contributing to its salinity.

That portion of rainwater, which does not infiltrate or evaporate as it flows across soil surfaces eventually reaches riverbeds. This water running across soil surfaces usually carries soil particles and causes water erosion of soils. Water flowing either inside a soil or on its surface may contain dissolved pollutants, which act harmfully upon water resources and generally damage the quality of the environment.

Soil scientists and hydrologists are able to describe a multitude of transport processes by deriving and solving simultaneous sets of differential equations. We are able to predict the time required for a prescribed quantity of water to reach a groundwater aquifer. And with that same prediction, we can accurately assess the extent to which that valuable water in the aquifer shall be polluted by water flowing downward with its dissolved contaminants. We have models for predicting surface runoff and erosion hazards. We can reliably compute the rate of water evaporation from the soil and that from its vegetation. The process, called evapotranspiration, is an obvious combination of evaporation and transpiration. To derive and solve the great majority of models, we have to know the appropriate boundary conditions. In other words, we have to insert quantitative values for rain intensity, air temperature and its humidity, the direction and velocity of the wind, etc. that prevail in the atmosphere just above the soil surface. Collectively, we refer to the meteorological conditions typical for the region we wish to examine. Such weather data most frequently available are usually related to the local climate. And in order to deal mainly with typical weather situations, we must consider climatic conditions in our quantitative models.

We have used the words meteorology and climate. What is the difference? Weather is studied and described by meteorology. A meteorological station is located two meters above the ground and contains instruments for measuring the temperature, air pressure, air humidity, wind direction and velocity, length of solar radiation and other variables. Similar instruments are also in meteorological balloons. Using those measurements, meteorologists study atmospheric processes. Nowadays, the most popular process is the weather forecast obtained by inserting data from many meteorological stations into computer models. The climatologist uses statistical methods for evaluating meteorological records of previous data in order to estimate average values for a particular region. The aim of his activity is to classify the climate of different regions in order to predict future values for each region within a prescribed level of probability. If he deals with the entire planet earth, he estimates the average global climate and its variation in time. With simplification, we say that climate is an averaged weather over large time, usually at least 30 years, but frequently even over a much longer time span. Because the climatic characteristics depend on the size of a region as well as on its prevailing vegetation, we distinguish between local, regional and global climates.

It is foolish to judge a climatic change from this year's winter or from last year's frequency of tornadoes. When we read in the Old Testament about seven fat years and seven lean years, it does not mean that the climate was changing. The sentence demonstrates what we have since learned about the clustering tendency of extreme meteorological or hydrological events – only the vocabulary has changed. When the climate during a time span of several hundred years is evaluated, long-term differences in the otherwise prevailing climate with durations of tens to hundreds of years are frequently manifested. Without a comprehensive knowledge to adequately explain all of their specific causes, such variations have been denoted as stochastic oscillations or random anomalies of the climate.

Summarizing this chapter, we believe that global climate is a highly familiar, well-known scientific topic for a soil scientist. Our ambition to discuss its change without the vocal intensity of alarmists, the media and their converts is realized in the chapters that follow.

2. Global warming

2.1. Reports on global warming

We begin this chapter with four excerpts quoted from the report Climate Change 2007: The Physical Science Basis. Summary for Policymakers written by the Intergovernmental Panel on Climate Change (IPCC, 2007).

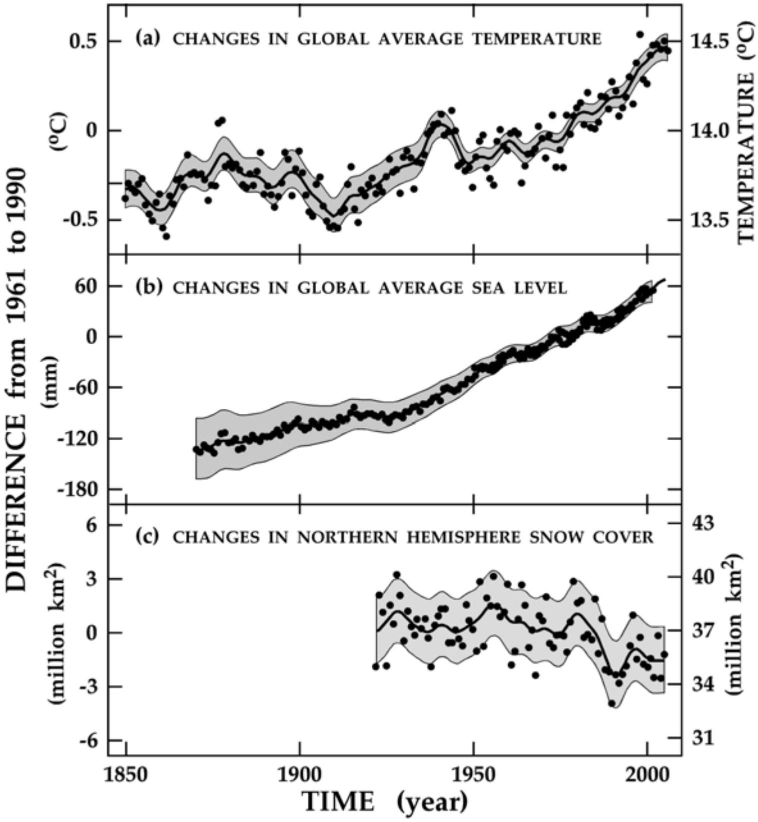

Fig. 1: Changes of global average temperature (a), global average sea level (b), Northern Hemisphere snow cover (c), in the last 150 years according to IPCC (2007a) when the averages from 1961 through 1990 are taken as comparative values equal to zero.

> *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.*

> *The total temperature increase from 1850 – 1899 to 2001 – 2005 is 0.76 [0.57 to 0.95]°C. Eleven of the last twelve years (1995 - 2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). The updated 100-year linear trend (1906 – 2005) of 0.74 [0.56 to 0.92]°C is therefore larger than the corresponding trend for 1901 - 2000 of 0.6 [0.4 to 0.8]°C. Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been absorbing more than 80% of the heat added to the climate system.*
>
> *Such warming causes seawater to expand, contributing to sea level rise. Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The total 20th century rise is estimated to be 0.17 [0.12 to 0.22] m.*
>
> *At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones."* We are referring to Figure 1 where all three phenomena are presented graphically.

During the last 28 years, we have used instrumentation in satellites to measure the Earth's global surface temperature. Although these methods of measurement are considered by meteorologists to be the most objective proof of global warming, they have also been criticized from various points of view. In spite of such criticism, let us assume that the IPCC statement on global warming is based upon a serious evaluation of the measured data and that it provides an objective, quantitative proof of global warming.

The reported rise of the global temperature by 0.74°C does not mean that the temperature rose uniformly over the Earth. This same value would not have been obtained everywhere that the temperature was measured locally during the past 100 years. Indeed, observed warming has been greater over land than that over the oceans, owing to the smaller thermal capacity of the land. There was a tendency for a higher temperature rise in the northern hemisphere than in the southern hemisphere (Trenberth et al., 2007, IPCC). Values of average temperature rise also differ according to differences in climate of various regions. The rise is very small in the equatorial regions and increases with the distance from the equator to the poles; in other words, it increases with the latitudes, both north and south. This dependence on latitude is only one of many factors that relate to average temperatures. The average temperature rise depends upon its particular geographical location on a continent. Values differ for inland climates compared with those influenced by a nearby ocean. In central Europe the average temperature increased between 1.1 to 1.3°C in 100 years, while in Northern Ireland at Armagh Observatory the increase was only 1.2°C in 200 years, i.e. from 1796 to 2002. Within the Arctic Circle at latitudes between 70 and 90°, the average temperature rise was 2.1°C in the period 1880-2004 (Trenberth et al., 2007, IPCC, from their Fig. 3.7). During the first 60 years of that 124-year period, the average temperature increased, then decreased for the next 20 years, and subsequently increased for the following 44 years. In that 124-year period the average temperature rise rates were higher in 1920 to 1940 than they are today.

Although warming has been extensive, significant warming has not been measured at about 20% of all locations monitored. *"Warming is strongest over the continental interiors of Asia and northwestern North America and over some mid-latitude ocean regions of the southern hemisphere as well as southeastern Brazil. In the recent period, some regions have warmed substantially while a few have cooled slightly on an annual basis"* (Trenberth et al., 2007, IPCC, p. 250). These few examples enable us to imagine how difficult it is to estimate the global temperature and its rise merely from the data obtained from any number or all meteorological stations. *"No single location follows the global average, and the only way to monitor the globe with any confidence is to include observations from as many diverse places as possible"* (Trenberth et al., 2007, IPCC, p.250).

The Climate Change 2007 report of the Intergovernmental Panel gave examples from Solomon et al. (2007) on Alpine glacier thawing and the decrease of the volume of ice in the Arctic. During the past decade, the area covered by ice decreased by 2.7%. Starting from 1980, the temperature of permafrost (permanently frozen soil) increased by approximately 3°C. And since 1900, the area of seasonally frozen soil decreased by 7%. In contrast to these data from the Arctic, no reduction in the ice volume of the Antarctic glacier was apparent. The unlike conditions are caused mainly by the nature of ice formation and different precipitation in those two regions. Glacier is dominantly formed on the continent in the southern polar region while in the northern region ice covers the ocean and a relatively small area of land. The IPCC report also states that during 1900 to 2005, annual precipitation increased in many regions – North and South America, northern Europe and Asia. But during that same period, areas of drought-threatened soils increased.

Global warming can also be deduced from indirect evidence of nature. In the northern hemisphere during the last century, the vegetation period was extended on the average by 12 days with fluctuations of 4 to 29 days. However, in northern Russia during the same time, the vegetation period was shortened (Linderholm, 2006). With extensions of vegetation periods not linearly dependent upon the average year temperature increase, it is obvious once again that climatic change depends upon many factors. Hence, a measured change of only one factor does not allow an accurate prediction of the extent and rate of climate change.

Living organisms react to changes of global temperature. The northern boundary at which some types of insects exist is shifted further to the north on the Northern Hemisphere. The earlier the germination and sprouting of buds, the earlier are the arrivals and egg laying of migrant birds. Ornithologists have observed cranes over winter in Germany instead of migrating earlier to Spain and Portugal. Pocket gophers and hedgehogs wake up earlier from their winter sleep. The fishing location for cod has shifted in Alaska. The retreat of Alpine glaciers causes a movement of entire fauna and flora populations to higher elevations. They do not become extinct – they simply are not found where they were 50 and 100 years ago. In a detailed study on two types of butterflies in the Rocky Mountains, DeChaine and Martin (2005) discovered a regular migration of fauna in the direction of the retreat of a glacier during interglacial (between two glacial periods) periods. When the glacier increases and extends its area during a glacial period, the migration runs towards the valley in the direction of lower elevations.

Geologists assume that our most recent geological epoch, called the Holocene, which began about 11,500 years ago, will end and be followed by a new glacial period. During the Pleistocene epoch that started about 1,800,000 years ago, long glacial periods lasting about 100,000 years were regularly interrupted by short interglacial periods usually lasting about 12,000 years. Those regular changes are more expressed in the last 400,000 years. Because of these regular oscillations of cool and mild periods, we believe that we are now living in an interglacial period of time. Moreover, DeChaine and Martin (2005) and Petit et al. (1999) consider that we are living in an interglacial period that is relatively cool. Hence, the earlier mentioned migration of butterflies is slower than it was in the last interglacial period that occurred 130,000 to 115,000 years ago. We shall reconsider these butterfly migrations later on when we discuss the rate of recent global warming.

When we summarize all the examples selected from many other observations, we conclude that global warming is without a doubt, presently occurring. This long-term trend is probably interrupted by the cooling tendency in the last ten years and its duration is not easily predicted as we discuss it in Chapter 4.1.2. However, the recent 150 years of warming does not mean that an ecologic catastrophe is occurring or imminent.

Similar warming situations existed on our planet Earth in the not-to-distant past in the middle ages and a little bit earlier during interglacial periods. We shall speak about them in more detail in Chapter 2.4.

2.2. How temperature is measured with and without thermometers

In 1653 organized measurements of air temperature began in northern Italy with the first international meteorological network initiated in Tuscany. Such a network depended on the production of accurate thermometers having detailed, reliable scales of measurement. Unfortunately, at that time, they were not yet available. Series of temperature data also exist in England from 1659 (Horton et al., 2001, quoted according to Lomborg, 2007) but we meet the same problem with comparable instruments for the early data like that in Tuscany. The development of thermometers, which began during the 17th century is linked with names of many scientific inventors. In 1714, the mercury thermometer was ultimately provided with a reliable, physically based scale named after its German inventor Gabriel Daniel Fahrenheit (1686-1736). Subsequently in 1742, still another scale established by the Swedish astronomer and physicist Anders Celsius (1701-1744) was eventually modified and accepted. Both scales remain in use today. Starting from about 1720 the air temperature was measured in Germany. Shortly afterwards, other developed countries determined its value.

In 1755, the order of Jesuits in Prague initiated and sustained the first successful regularly observed temperature measurements in central Europe. From that time until now, a continuously documented record of daily air temperatures exists. The founder of the "observatory" was Josef Stepling, ordained as a Jesuit monk in 1745, and later was a professor at Prague University. Temperatures were measured three times a day at 7:00, 14:00 and 21:00 consistent with the Mannheim time zone. Since the temperature was not measured during the night, the average day temperature was calculated from four values – those measured at 7:00 and 14:00, and two values identical to that measured at 21:00. It is worth noting that even today, if the night temperature is not directly measured, the average day temperature is approximated in this same way.

With the advent of reliable thermometers and other weather-related instruments, attempts to develop national and international meteorological networks grew rapidly and are more than adequately documented throughout the world. Here, only a few examples below illustrate their development. The first meteorological observations in Lithuania were conducted at Vilnius University in 1770. Soon after his arrival to America in 1771, the Scottish born scientist William Dunbar began making the first recorded meteorological observations in the Mississippi Valley. The first meteorological observations in southern Alaska (Sitka at 57°N) were made in 1828. In 1855 the first meteorological observations were made in West Africa where about a dozen stations were established in Dakar. In 1870, the U.S. Weather Bureau made its first meteorological observations using reports gathered by telegraph from 24 locations.

In the Netherlands at the beginning of the 18th century, Petrus van Musschenbroek may be considered the founder of the first meteorological network. Near the end of that century the British and French Royal Society made numerous unsuccessful attempts to collect weather data from around Europe. The initial development of meteorological networks was mainly driven by scientific curiosity. But national economic institutions and custom bureaus quickly discovered the advantage of knowing and predicting weather conditions to improve estimations of agronomic yields for purposes of national taxation and international embargo policies. As a result, federal financing was everywhere abundantly available and fostered the development and maintenance of new meteonets – an acronym for meteorological networks. And soon, the exploitation of data from meteonets for weather forecast became commonplace and appreciated by virtually everyone. Military leaders recognized this information as an important factor for a strategy during times of war. Many great battles were lost because of unexpected, changing weather conditions. If a number of heavy showers came and the battlefield changed into deep slimy mud, the horsemen in armor sank into sludge transforming a quick, victorious surprise attack into a catastrophic defeat. With governments becoming fully aware of the importance of weather forecasts, meteorological data became a top secret at the beginning of the First World War.

Today, the number of observation stations in meteorological networks continues to increase according to the general rule – the more wealthy is a region or country, the greater is the number or density of stations in meteonets. And since their density is not the same on the Earth, we are confronted with difficulties when we try to estimate the Earth´s global temperature. Whenever two bodies having different temperatures are connected, heat is transported from the warmer to the cooler body. At the earth's surface, there is a transport of heat between mutually different bodies or systems that are interconnected. Each of the systems is strongly heterogeneous and usually composed of several subsystems. In some of the subsystems the temperature is measured, in some of them not. The estimate or interpolate temperatures between them is definitely not linear and its realization is rather complicated.

Let us imagine that at a location *K* we measured a temperature of 16°C. And at the same time we measured a temperature of 20°C at location *M* several hundred kilometers from location *K*. Also at the same time we measured a temperature of 19°C at a third location *L* halfway between locations *K* and *M*. A couple of days later we measured temperatures of 18°C at *K* and 22°C at *M*. Is it correct to assume that at *L* the temperature would be 21°C? No. Indeed, we measured 19°C at *L*. Such "irregularities", or differences are caused by the action of many factors influencing the temperature. The factors are neither consistent nor constant with the passing of time because they react differently to changes in radiation, conduction, convection and other processes associated with landscape properties. We know that the properties of individual components of systems are not constant in time. Let us assume that we derive the temperature of one region without measurement from the measured temperatures of neighboring regions according to a complicated method for a dry summer. We know in advance that the same method is not applicable for a wet spring.

The more distant is the location from the meteorological station, the more difficult it is to estimate its temperature. The use of simple statistics for estimating the average global temperature within prescribed negligible limits of error is impossible for such a complicated system where the subsystems and factors influencing the temperature are mutually linked and variable in space and time. Today, an abundance of complex statistical methods exists and even more are continually being developed without rigorous, universally accepted standards to judge their worthiness to estimate global temperatures. Hence, it should be no surprise to anyone that estimates of global temperature made by individual research teams and institutions differ and their divergence cannot be satisfactorily explained.

Starting in 1978 the use of satellites to measure the temperature in the troposphere simplified the assessment of the global temperature. Troposphere is the lowest part of the atmosphere with the stratosphere above it. The height of the troposphere is the greatest in the belt around the equator where it reaches to 16 and up to 18 km above the Earth surface. It is lower in the mild zone, about 11 km and lowest at the poles where its top boundary is at 7 to 9 km. The air is "mixed" in the troposphere (Greek: *tropos* for mixing), the winds are blowing and a great majority of meteorological processes occur there. We find in the literature that the temperature measured by satellites is given with the accuracy of 0.03°C. The measurement is not performed with classical thermometers. Values of temperature, derived from an analysis of the wavelengths of radiation data, are evaluated and checked by two independent procedures. The most frequently, but not universally used procedures are the remote sensing system, RSS (see Fig. 2), and that developed by the University of Alabama, Huntsville, UAH. Some institutions rely on still other procedures. The UAH procedure indicates a slightly smaller global warming than that from the RSS. It is not surprising or unusual that the temperatures evaluated according UAH and RSS are not identical – the paths for exploring nature are not straight, well-lighted highways where the driver or scientist can safely travel at a high speed.

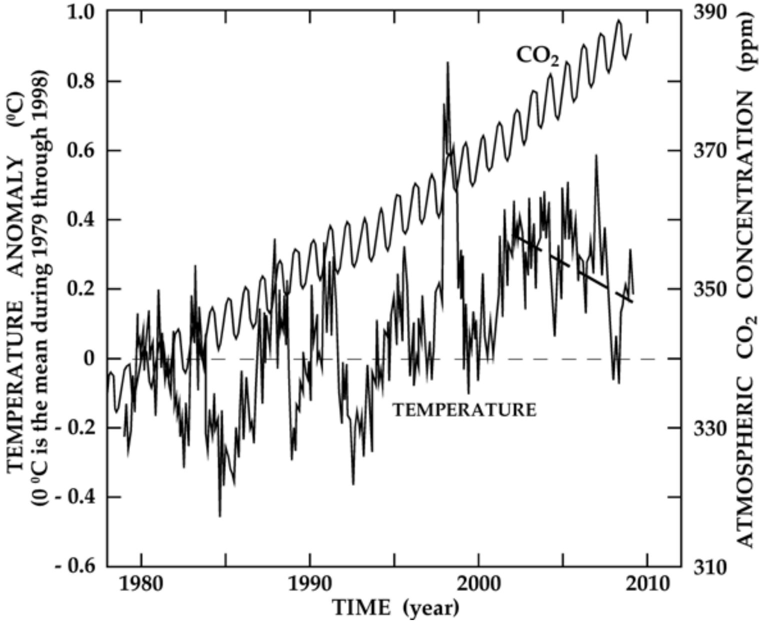

Fig. 2: Graphical presentation of the temperature change in the lower troposphere (from the earth surface to the height about 8 km) for 30 years (1979 to 2009) determined by satellite measurements and evaluated with the remote sensing system, RSS. The rising and regularly oscillating curve represents the increase of CO_2 concentration as measured at Mauna Loa Hawaii. Starting from the year 2000, the temperature change has a slightly decreasing tendency. More about it in Chapter 4.1.2. Source: http://www.friendsofscience.org/

It is quite opposite – paths exploring nature are crooked and narrow with a lot of blind streets and intersections. There is no navigation system available to allow the scientist to drive quickly through the many crossings as he strives to unravel and understand the intricacies of our environment. Our parable is also valid for the estimation of the most accurate method of global temperature. If somebody states, in the heat of discussion, that his method is the best and most accurate to provide the only exact data of global temperature, we must be cautious to not fully accept what he says at that moment.

Because directly measured temperatures during the immediate past two and three centuries do not reveal earlier temperatures and more generally, cannot identify or characterize the climate in the ancient past, other methods must be used to learn the reality of those ancient climates. Arguments saying there is no need to study ancient climates to predict future global climate change are not acceptable for two reasons. First, because climate is never constant, we must develop a better knowledge of its changing, variable manner. Second, with the past climate being the only experiment performed by nature, we have to use that unique reality for testing theories, hypotheses and eventually models to reliably predict our climate in the future. There are many natural experiments in the past available for testing of our hypothesis and prediction procedures.

Some sources of information are chronicles rich with documentation about plant yields, floods and unusual weather starting from the Middle Ages. Regarding climate, reports from ancient civilizations are much less rich and contain only meager information. Fortunately, both handwritten chronicles and scarce reports in cuneiform writing inform us about events that could be related to climate and its change. However those sentences are difficult, and often impossible to transcribe into the kind of quantitative data we need.

Frequently, we ascertain the temperature from other measured data, and since temperature is indirectly and approximately estimated, we use the word *proxy*. It stems from the Latin *propis, proprior, proximus* – near, nearer, nearest. *Proximus* also means very similar. The most frequently used proxy data are deduced from the following measurements and analyses:

1. The analysis of concentration changes of isotopes of oxygen and hydrogen in deep core drillings removed from glaciers provides estimates of temperature change.
2. The concentration change of the isotope beryllium 10 (^{10}Be) in either sediments or ice indicates temperature as well as solar activity.
3. Pollen analysis (palynology) offers information on the dominant plants, which infer past climatic conditions.
4. Tree-ring width and density records (dendrochronology) estimate temperature change and age of trees.
5. Isotopic ratios and chemical composition of corals estimate surface sea temperature.
6. Change found in annual lake sediments called varves provides information on temperature and age.
7. Change in growth of stalagmites in karst caverns and isotopic ratios indicate climatic change.
8. The size of lichens offers information on age and climate.

9. The pedogenesis of fossil and buried soils reflects the climate at the time of their origin.

That branch of climatology, which investigates past climates based on these proxy data is called paleoclimatology (Greek *palaios,* old, ancient, past). It is advisable to calibrate proxies against directly measured temperature for specific periods of time. Some proxies are typical for one year, while others reflect temperature for long-term periods. This characteristic time length has to be respected when the data are analyzed. It is also important to evaluate more than one type of proxy and to carry out research using a combination of different proxy types. Unfortunately, authors of scientific papers seldom respect this latter principle.

2.2.1. Proxy – stable isotopes and the geologic thermometer

The term isotope is derived from the Greek *at the same place,* meaning the position in the Periodic Table of chemical elements. Isotopes (or nuclides) of a certain chemical element differ one from the other by their atomic mass (mass number). The different number of neutrons in the nucleus causes their atomic mass to differ, while the number of protons is constant for all isotopes of one chemical element. Since the mass of a proton and that of neutron are nearly the same and since the mass of electrons is negligible when compared to protons, the mass of a certain isotope equals the sum of mass of all protons and neutrons in the nucleus.

Inasmuch as the isotopes of a certain chemical element have the same number of protons and electrons, we could assume that their chemical and physical properties are the same – but it is not that simple. Isotopes of a given chemical element manifest small physical differences that are measurable, as e.g. their mass, melting point, boiling point, diffusion rate etc. The impact of their different masses causing the rates of their chemical reactions to differ is called the kinetic isotope effect (KIE). Owing to their larger masses, heavier isotopes tend to react somewhat more slowly than lighter isotopes of the same element. Its efficacy is inversely proportional to the mass of the isotope.

Isotopes of hydrogen H manifest the strongest KIE. The most common isotope of hydrogen denoted by ^{1}H has no neutrons at all and its nucleus contains only one proton. When we deal with isotopes, the name of ^{1}H is protium – a word derived from the Greek *proton*, the first. If hydrogen also contains one neutron, its weight is doubled. We denote it ^{2}H since it has one proton plus one neutron in its nucleus. We call it deuterium from Greek *deuteron,* the second, and also denote it by D. When the hydrogen isotope has two neutrons in its nucleus, it is ^{3}H with the name tritium from Greek *triton,* the third, and also denoted by T. Why do these isotopes of hydrogen exist on Earth and how long have they been constituents of our environment? It is recognized that the presence of protium originated with the formation of the Earth. The advent of deuterium is still debated, but it has been generally accepted that its relative abundance has not changed for at least 13 billion years. On the other hand, tritium is constantly being created and destroyed. Tritium occurs naturally due to cosmic rays interacting with atmospheric gases, and with a radioactive half-life of about 12.32 years, tritium decays naturally to helium. Until it was produced in nuclear reactors and released in large amounts to the atmosphere by testing of nuclear weapons, its natural abundance was negligible and did not accumulate over geologic time scales.

A water molecule containing the most abundant isotope protium is considered ordinary water and designated by ^1H_2O or simply H_2O. Water highly enriched in deuterium and even by as much as 100% is considered heavy water and designated by ^2H_2O or D_2O and one containing mainly tritium is called tritiated water and designated as ^3H_2O or T_2O. The water molecule ^3H_2O is heavier than ^2H_2O, and ^2H_2O is heavier than "normal ordinary" water ^1H_2O. All three types of water exist on our Earth planet.

The concentration of ^2H in our planetary oceans is 154 ppm (parts per million) i.e., the ratio $^2H/^1H = 154/10^6$ or 154/1,000,000. The use of the term "heavy water" usually refers to water containing a higher proportion of the isotope deuterium than "normal standard" water in the form of deuterium oxide, D_2O (^2H_2O), or deuterium protium oxide, HDO ($^1H^2HO$). Heavy water containing as much as 100% D_2O has a density that is 10.6% higher than that of "normal" water ^1H_2O. Ice made from such heavy water sinks in normal water. When we compare evaporation from heavy water with that from normal water, we recognize that the heavier ^2H_2O molecules find it more difficult to jump out of the liquid water into the air due to their larger mass. Because heavy water is more "lazy" during evaporation, water vapor existing in the air above liquid water contains a smaller fraction of heavy water than that in the liquid water. The ratio of $^2H/^1H$ is denoted by the symbol δ and since heavy hydrogen is involved we write δ^2H. Condensation of water vapor is an opposite process and the heavy molecules are caught easier on the solid phase of condensation nuclei. Concentration of heavy water in micro-drops of water in clouds is higher than concentration of heavy water in seawater. The values of δ^2H (δD) in water vapor and in rainwater are found by isotopic analysis.

Since evaporation increases as the temperature increases, the value of δ^2H is dependent upon the temperature and is preserved in ice. When researchers measure δ^2H in a thin layer of ice, they are able to derive the temperature of the medium at the time when the ice originated. The same principle is applied when the isotopes of oxygen are determined, see the