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THE ICE AGE PROBLEM

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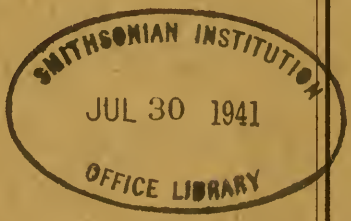

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In a paper entitled "Ice Ages"[1] Sir George Simpson argues, in opposition to the hypothesis that a decrease of radiation would produce an ice age, that, on the contrary, an increase of radiation would produce such an effect. Simpson explains this paradox clearly in a few printed pages. It seems that Simpson did not know of a brief essay by the present writer,[2] who advanced a similar opinion. The writer, however, finds the ice age question rather more complicated, and concludes that ice ages may by no means be set parallel with pluvial ages, and furthermore, that ice ages are possible by warming as well as by cooling. H. H. Clayton also made the same suggestion.[3] From this it follows that a simultaneous ice age for the whole earth is not admissible.

Let us briefly consider as an example possible situations in the Cordilleras of the western coast of South America (Chile) up to the Antarctic. If we suppose, in illustration, an average warming everywhere of 5° C. above the present normal year temperatures, the following situation would probably result: the actual temperature of approximately 18° C. at sea level in the Tropics would rise by our hypothesis to 23° C. The decrease of temperature with increasing altitude may be 0.5° C. for every 100 meters. In this case we should find 0° C. at a 4,600-meter altitude. In the Southern Hemisphere even altitudes of 6,000 meters in the Tropics (Puna de Atacama) are free from eternal snow; and only south of the Tropic of Capricorn do we find light formations of firn which lead to a strong glaciation in the Aconcagua Massif. But with the assumed temperature increase the insignificant precipitation of our days would give place, according to the arguments

[1] Simpson, Sir George, Ice ages. Ann. Rep. Smithsonian Inst. for 1938, pp. 289-302, 1939.

[2] Knoche, Walter, Eiszeit durch Erwaermung der Erde. Deutsch-chilenische Monatshefte, vol. 11, Santiago de Chile, 1932.

[3] Clayton, Henry Helm, Solar activity and long-period weather changes. Smithsonian Misc. Coll., vol. 78, No. 4, p. 6, 1926.

of Simpson as well as of Knoche, to an increase of precipitation, above all in the High Cordillera. Such increase of precipitation would be near the Equator in summer (confines of Argentina-Chile-Bolivia) but farther south (latitude Valparaiso-Santiago) in winter. However, in altitudes above 4,600 meters the precipitation would fall as snow. In the peak region of the high volcanoes or high mountain chains of the Chilean-Argentine Atacama, little hanging glaciers would probably be formed, while, for example, the glacier tongues of the Aconcagua Massif would advance up to the central Chilean longitudinal valley.

In the indicated regions we ought to consider, moreover, that radiation would be diminished under the influence of increased cloudiness (see Knoche and Simpson) and therefore also the process of melting away would be more or less strongly hindered. Passing over now to West Patagonia, we have at a certain latitude average annual temperatures of 6° to 9° C., which, with a general temperature increase, according to the above-mentioned hypothesis, would give 11° to 14° C. So we should find the 0° C.-isotherm at 2,200 to 2,800 meters. Today, the firn region in northern Patagonia descends in the south to 1,600 to 1,200 meters and in Fuegia to 1,000 meters or less. The inland ice is to be found, taking no account of several mountain massifs (Cerro San Valentin), in altitudes which lie below 2,800 meters. Under the actual temperature conditions, the precipitation falls as snow even in northern West Patagonia only in altitudes above 1,600 meters, in the south above 1,200 meters, in Fuegia above 1,000 meters. With the supposed warming, the firn region of present times would receive only rain, perhaps more than the actually measured amounts. This increase is not certain because it is doubtful if the west-to-east circulation on which the West Patagonia precipitation depends would be preserved in the same strength. If the west-to-east circulation decreased, a local diminution of rainfall might occur even in a generally pluvial age.

The almost total cloudiness, which is today between 8 and 9, and consequently also the radiation, can hardly experience any essential change. The "Patagonian" conditions of West Patagonia, Fuegia, or similar regions of the earth (for example, New Zealand), are very special ones, marked by cool summers and warm winters. At the mouth of the Straits of Magellan the annual average minimum of temperature is hardly below 5° C., and snowfall at sea level is the rare exception. However, the glaciers descend to the sea owing to the colossal firn masses, and this in a latitude corresponding to that of the northern Adriatic. The glacier tongues lie in the middle of a nearly tropical, seemingly virgin forest with tree ferns, bamboo

grasses, fuchsias, and evergreen beeches. Under our assumed conditions this thick forest type would cover Fuegia to the extreme south, owing to the temperature rise and, after the disappearance of the firn, occupy also the heights of the Cordilleras in West Patagonia.[4] The arguments about West Patagonia refer naturally to the western as well as to the eastern side of the Andes, as the glaciers of the two flanks have their origin in the so-called inland ice. An increase of 5° C. in the average temperature of West Patagonia seems by no means exaggerated when we consider that at the lighthouse of Evangelista (western mouth of the Strait of Magellan) the annual average was 5.6° C. in the year 1925, and the average minimum 3.6° C. In the year 1934, however, these values were 8.4° and 7.7° C., respectively.

Simpson and Knoche are surely right in supposing that with a warming, combined with increased evaporation, cloudiness, and precipitation, the average annual temperatures of the polar regions, Arctic as well as Antarctic, would remain under all circumstances far below 0° C., even with a general warming of more than 5° C., so that the ice masses in the polar and subpolar regions would have to increase. Both authors argue that the contrast, Tropics-Poles, would be greatly enhanced. Owing to geographical differences between the northern and southern polar regions, we ought to expect with warmer conditions an extended ice covering in the Northern Hemisphere with its deep Arctic sea (compare fig. 5 in Simpson's paper), while in the Antarctic continent there would only be an extension in the dimensions of the firn region a little more northward. As contrasted with the north polar region, where in consequence of the increased ice masses up to relatively great distances, advancing glaciation would be plausible, such an intense cooling by the southern ice mass, in spite of its growing, would be hardly conceivable on a great scale. Of course, the pack-ice belt would extend itself, and the icebergs would increase in quantity and dimension, but they would also begin to melt away faster in the oceans of the then warmer climate of the tropical and subtropical zone. As today on a small scale at sea level

[4] Prof. F. Reichert, who at the beginning of 1940 crossed the Cordilleras of West Patagonia in the region of Mount Valentin in the middle of the inland ice, told me that during the last 20 years there was formed in a little "sierra" a rich vegetation of *Nothofagus*. Rats and some kinds of birds have come there, and there exists also a small lake not in a frozen state. Twenty years ago the same "sierra" was a complete desert with the exception of one kind of lichen. This proves a change of climate in West Patagonia with an inclination to warmer conditions. Therefore the inland ice may be actually considered as a sort of "fossil" ice.

the virgin forest embraces the glacier tongues of West Patagonia, so the pack ice, in the assumed case of a planetary warming, would lie out at sea before the virgin forests of Fuegia. Even if the increase of 5° C. for Fuegia would be diminished a little by the Antarctic ice belt, the conditions could not be essentially changed. It is conceivable, as indicated above, that the general warming of 5° C. would be exceeded in Fuegia. For South Fuegia there is at present an average annual temperature of 5° to 5.5° C., and the minimum lies indeed at nearly 1° C. In the mountains of this group of islands, a temperature increase of 2° to 3° C. would be sufficient to cause the glaciers to decrease or even disappear through decrease or disappearance of firn region.

A cooling would have a reverse effect. As through lack of precipitation no firn zone exists today in the most arid Puna regions, no change would be produced by increased lack of precipitation; the desert steppe of the Puna would be transformed with all its elevations into a desert. Where little firn zones with hanging glaciers or peak glaciers exist today, these would disappear owing to the diminution of precipitation. Such glaciers now appear only in altitudes above 5,000 meters, where even today the precipitation falls in solid form. They would retreat as in the Aconcagua region.

What effect would a cooling then have in the region of the West Patagonian Cordilleras? We have here, according to isolated existing observations, even at sea level total precipitations of 2½ to 6 meters per annum, which for certain elevations may surely be doubled. It is quite possible that at some time precipitations will be found there which will equal the highest observed anywhere in the world, if indeed they will not surpass them. Let us suppose, although it is not absolutely sure, that with the then existing circulation conditions, precipitation suffers a decline, so that, contrary to the situation today, it will prevalently fall in solid form with a decline of 5° C. of the average temperature. This we suggest in Fuegia at sea level, and at nearly a 500-meter altitude above sea level in the north of the West Patagonian Cordillera. Under these conditions we must admit an ice age in Patagonia. In the polar regions, and therefore also in the Antarctic, there would be produced a decrease of the glaciation. For here only solid condensation would fall just as in our times, but in decreased quantity over the planet as a whole because of decrease of evaporation and cloudiness. The radiation in the region of the central Andes of Chile and Argentina with diminished cloudiness further tend to accelerate the decline of the glaciers. In the south an increase of the radiation could scarcely be expected, because here, owing to the

geographical conditions and to the prevailing winds, a sensible decrease of the cloud amount, which now reaches in the peak region nearly 10, is out of the question.

Summing up our considerations, it follows that the question of ice ages is a 0° question; that is, it depends on whether the precipitation, on an average, falls as snow or rain. The 0° C.-isotherm depends, however (disregarding regional and local conditions) on latitude and altitude. The latitude (neglecting the altitude) is above all decisive for the polar caps, the altitude (neglecting the latitude) for mountains—supposing that certain general morphological conditions exist, as, for example, the arid regions, windward flanks, etc.

From these examples we come to the conclusion that in certain regions of the earth, according to given conditions, at moderate altitudes with sufficient quantities of precipitation and an equilibrium between snow and rain, cooling could produce an increase of glaciers or an ice age by augmentation of solid condensation. In other zones, i. e., in very great heights with more or less solar radiation for other reasons, even in relatively adjoining regions the contrary process must be caused. In these zones, as a consequence of general warming, firn and glaciers will be formed when the "cordillera" reaches such a great altitude that solid condensations predominate. A period of warming, on the other hand, would be generally identical to a pluvial age; as we mentioned before, ascending temperature augments evaporation, cloudiness, and precipitation. According to the arguments, a pluvial age is identical with an ice age, and in certain zones, with warming. Moreover, the cooling that may cause the "West Patagonian" ice age is combined with a general reduction of precipitation; thus, not all ice ages correspond to pluvial periods.

It is furthermore probable that in some mountains the glaciers of closely adjoining peak regions can advance or retreat, according to their height and situation, either with a general decrease or with a general increase of the temperature of the earth's atmosphere. In every case, one should take care not to consider the ice ages in the north of the Northern Hemisphere as generally valid for all regions of the earth.