

ART. LVIII.—*The influence of Convection on Glaciation*; by
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THE suggestion made by Captain Dutton,* that the increase of precipitation due to a higher sea-level temperature might conceivably be confined to regions below the isotherm of 0° C., is one of such extreme simplicity that I can scarcely believe it to have escaped the physicists and geologists who have written on glaciation. Some months since I ventured to contribute a few pages† to the discussion, which were not written, however, until I had carefully considered the possibility which my colleague has since brought forward. I arrived at the conclusion that though conceivable, it was inapplicable to terrestrial conditions; but before giving the reasons for this conclusion I beg leave to restate the problem as I understand it.

This can be done in two ways, of which the first and most usual is: Given a definite locality, the mean temperature of which is now compatible with the existence of glaciers, will an increase of temperature at sea-level tend within certain limits to increase the accumulation of ice upon it? In this form the question is one of great complexity, for it involves a knowledge of all the climatic changes which would accompany a change of sea-level temperature. A portion only of these are known with any sort of approximation, and the gaps must be filled with assumptions which every opponent is at liberty to deny.

The second method of stating the problem is as follows: If two periods of different sea-level temperature and correspondingly different permanent snow-lines are compared, which will show the greater accumulation of ice above its own snow-line under similar topographical conditions? This question, which is that to which I attempted to give an answer in my former paper, appears comparatively simple, for it does not compel any definite assumption as to the relation between elevation and temperature.

As I understand Captain Dutton, he would reply to this latter question that the accumulation in each period would be the same, the whole excess of moisture of the warmer period falling as rain below the snow-line. His statement might have been made somewhat more broadly, for the same argument shows that upon his suppositions the precipitation above any isotherm is independent of the temperature at sea-level. If, for example, the characteristic temperature at sea-level in the cooler period were 10° and in the warmer period 20° , then the entire excess of moisture evaporated during the warmer period would

* This Journal, vol. xxvii, p. 1.

† This Journal, vol. xxvii, p. 167.

be precipitated below the isothermal line or surface characterized during the same period by a temperature of 10° . His suppositions are two: that the atmosphere is saturated (unless special exception is made, which is not the case in his concluding remarks), and, as the results of a calculation that the difference in the velocity of the wind in the two periods is insignificant. Granting for the sake of argument the insignificance of the difference in the velocity of the wind,* it is certain that, if the supposed complete saturation of the atmosphere would produce no essential alteration in the problem, Captain Dutton's result is immediate and inevitable; but as complete saturation represents an extreme case, it seems desirable to examine its bearing on the results.

No one of course would think of denying that the mean saturation of the whole atmosphere is never complete nor even the mean saturation of the portion of it which is in immediate contact with the sea. All know, on the contrary, that descending currents of relatively dry air constantly mingle with the moist air at the sea-level, more or less reducing its vapor contents. A similar process goes on at every level, and all must, I think, admit not only that complete saturation of any entire stratum of the atmosphere has never been observed, but that such a phenomenon cannot have taken place at least during later geological epochs. At every level above the surface of the earth the rise of air bodies, and sometimes other causes, tend to chill the air below its dew-point, while at the same time the continual admixture of drier air from higher regions tends to dilute the vapor and to keep it in the gaseous form. Precipitation therefore must be, as it certainly is, a local phenomenon induced by circumstances which favor the chilling of the air while (absolutely or relatively) retarding the intermixture of dry air with the moist. Were it not for the constant return to the surface of desiccated currents, evaporation must evidently altogether cease. On the other hand so long as precipitation takes place, air must be more or less completely desiccated and the process of distillation must continue.

More or less completely saturated air from the surface mingled with dry air from above forms a mixture, the dew point of which is considerably below the temperature of sea-level, and such a mixture may of course rise to the isothermal surface corresponding to its own dew point without precipitation. The process of admixture however is in general continuous, taking place at all levels, and it cannot be asserted of any particular molecule of vapor that it may not reach the confines of the atmosphere unprecipitated.

*It appears to me improbable that the additional energy which a warmer climate would impart to the air currents would be distributed simply among existing currents.

If a comparison is made between a warmer and cooler period, the conditions otherwise being equal, it will not be denied by any one that the lower strata of the warmer atmosphere contain a greater absolute amount of moisture than the lower strata of the cooler atmosphere, but on Captain Dutton's suppositions this excess is confined entirely to the lower strata. Suppose this condition of things to exist at a given instant. Then if the descending dry currents come into play and the tendency of the warm, moist surface air to rise is taken into consideration, it appears that a portion of this excess will be carried upward by convection and be added to the moisture of higher strata as explained in the preceding paragraphs. And though a part of this additional moisture might and probably would be precipitated at various levels, I cannot avoid the conclusion that, by the continuous admixture of dry air, a part of the excess would be carried on indefinitely, or, in other words, that the absolute humidity at every isothermal surface, or the relative humidity of the whole atmosphere, would be greater during the warmer period than during the colder one. There would indeed be a very slight, as it seems to me insignificant, counteracting tendency. The humidity of the lower strata of the air could not be increased by descending currents, because a rise of temperature and an increased capacity for moisture would attend their compression in sinking,* but rain drops from upper levels fall through warmer air than that in which they form, and there must be a minute evaporation during their passage. It seems, however, hardly possible to maintain that this addition to the moisture of the atmosphere near the surface is comparable with the contrary tendency which has been enlarged upon.

It appears quite certain therefore, that the absolute humidity at what I have called the glacial isotherm (where the tendency to the accumulation of *névé* is a maximum, not far from 0°C.) or, what is exactly the same thing, the mean relative humidity of the air over the glacial zone, during a warmer period, will be greater than over the corresponding but not identical glacial zone during a cooler one. Precipitation at the glacial isotherm may most naturally be supposed to be simply proportional to the mean relative humidity. It is indeed conceivable that though the mean saturation during the warmer period at this isotherm would be greater, complete saturation might be more seldom attained; but I know of nothing tending to prove such a relation. On the other hand, as I showed in my former paper, the empirical inference from observations on the diminution of temperature with altitude along mountain slopes is, that the higher the sea-level temperature the more rapid would be the decrease of temperature at the glacial isotherm, a relation

* It is of course supposed here that the sea-level temperature remains constant.

which would tend to increase precipitation at this line independently of the relative humidity; so that if the relation between relative humidity and precipitation is not simple and direct, it is probable that precipitation at the glacial isotherm increases more rapidly rather than less rapidly than the relative humidity.

I must conclude therefore, as I did before, that "the rate of decrease of temperature and the mean saturation will probably be greater in the warmer period . . . near the glacial isotherm," and indeed on the same grounds, for I prepared a passage for my former paper presenting in a more condensed form precisely the arguments here offered, but omitted it as being manifest without special mention.

The argument here presented does not include all the important factors involved in the relations of temperature to glaciation, some of the others being sketched in my previous paper. That here offered, however, may serve to show the essential part which convection plays in the distribution of precipitation.

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