The amount of aqueous vapor actually present in the air may be exprest either by the expansive force or pressure that it exerts or by its weight in grains in a cubic foot of space. In the above example it is stated in terms of its expansive force, or barometric pressure, in inches of mercury. Whether exprest in terms of weight or pressure, the amount of vapor actually present is sometimes called the absolute humidity. It is very important to distinguish between the absolute humidity and the relative humidity, sometimes referred to merely as the humidity. The relative humidity is the ratio of the amount of vapor actually present to that which might be present at the existing temperature if fully saturated: Example from Death Valley, June, 1891, temperature of dry bulb, 108° F., wet bulb, 68° F., whence is obtained from hygrometric tables: dew-point, 39° F., relative humidity, 10 per cent. A relative humidity of 10 per cent or less is not at all infrequent in desert regions. The observation quoted means, first, that in order to condense any of the moisture present into dew or rain the temperature would have to fall 69° (from 108° to 39° F.), or the amount of moisture then in the air would have to be increased ten fold. This point can not be emphasized too strongly. At the temperatures which exist in the Colorado Desert, and under the general conditions of aridity which prevail, the atmosphere takes up vapor as a sponge absorbs water. It should be remembered, moreover, that the capacity of the air for vapor is vastly greater at high than at low temperatures; the problem in the Southwest, therefore, so far as the production of rain is concerned, is not essentially one of increasing the vapor contents of the air but rather of diminishing the temperature to the point at which condensation takes place. There is sufficient moisture in the air to produce abundant precipitation if means of cooling it were at hand. The absolute humidity at Yuma is slightly greater than that of St. Louis, and only a little less than that of Vicksburg, both of which points have, in general, an abundance of rain and a so-called moist atmosphere.

The amount of vapor taken into the air over Salton Sea must be considerable in the course of a year, but to adduce definite and satisfactory proof that it has increased the rainfall is a very difficult problem. That it has increased the relative humidity in a slight measure, is undoubtedly true. Aqueous vapor in the absence of a strong wind circulation is diffused very slowly thruout the atmosphere. It is, therefore, improbable that any considerable portion of the local supply of vapor ever passes beyond the immediate confines of the desert. The writer knows of but one case where there is a reasonable presumption that the local evaporation has increased the rainfall, and the increase in this case amounts to but two or three inches annually over the immediate area whence the evaporation proceeds.

CHANGES OF LATITUDE AND CLIMATE.

It is well known that shortly after Mr. Chandler's convincing demonstration that the axis of rotation of the earth is changing its position within the earth in an irregular way not previously recognized, many astronomers suggested various explanations of the phenomenon in the search after the forces that brought it about. The memoir that seems to have had the greatest acceptance was that of Prof. Simon Newcomb, appearing in 1892, and showing in the first place that a periodic term of 306 days proper to a strictly rigid earth, as deduced by Euler and called the Eulerian period, would be increased if there were any elastic yielding of the earth under the great stresses to which it is subjected. Hough (1895) showed that an elastic steel globe would have a "free" period of 428 days in its axis of rotation as one of the terms in the nutation due to the action of the sun and moon on our globe. Newcomb also showed that a displacement of material on the earth's surface, such as the annual transportation of rain and snow between the poles and the equator, and possibly other meteorological phenomena, recurring year after year, would maintain such a variable annual disturbance of the regular 428-day term as to produce the change in latitude discovered by Chandler, since these phenomena produce a variable moment of inertia and are not symmetrical with regard to the earth's axis. The influences of changes of load have been most exhaustively studied by Prof. R. S. Woodward.

In a recent memoir by Prof. J. Larmor and Maj. F. Hills, published in the Monthly Notices of the British Royal Astronomical Society,[1] the authors have analyzed the movements of the North Pole, as most exactly determined since 1900 by Albrecht, and less exactly before that time. They have computed by graphical process from a map showing the path of the North Pole day by day, another map showing the departure from the 428-day period, thence the hodograph, and thence the torque that must be acting in order to produce that motion of the pole, whence we may infer something as to the displacements of atmospheric material, oceanic sediments, and continental material that must be taking place in order to produce this torque. By considering individual meridians the locations of the changes in the torques in the direction of the equator and of the meridians, respectively, can be determined approximately. If such changes are mainly due to displacements of surface material by any action of the atmosphere or solar heat they should show seasonal recurrences. Those which are not seasonal may prove to be due to subpermanent changes of masses of water or air as shown by changes in the level of the ocean or in the pressure of the atmosphere. Larmor and Hills show that a surface depression of one foot over a square mile of land, in latitude 45°, extending downward and diminishing to zero at a depth of 30 miles, that is to say, an average displacement of one foot down to 15 miles, would displace the polar axis thru a fraction of a second of arc represented by 3×10^{-13}. Sir G. Darwin showed that one per cent of the area of Africa moving ten feet vertically would alter the polar axis of a perfectly rigid globe by 0.2 seconds of arc. This direct effect upon the motion of the pole is so slight that an ordinary earthquake would have no influence, but observation seems to show that, within several years past, sharp curvatures in the movement of the pole appear to be, on the whole, concomitant with earthquakes. Possibly, therefore, earthquakes are promoted by those changes of the load carried by the earth that are the main cause of the irregular motion of the pole, so that the connection between earthquakes and change of latitude is a secondary one. Now a change of load that could cause an earthquake must, to a great extent, be due to transfer of ocean water, melting of polar ice, monsoonal flooding of large regions, like India, the deposition of mud in deltas, and other periodical matters that belong to meteorology. In fact the mere motion of ocean currents from the polar region, where water has but little angular momentum, to the middle latitudes where it has a great moment of inertia, must have an appreciable influence. The authors figure that if a mass of water representing a layer one foot deep over a region 4000 miles square were to move from the pole to latitude 45° it would displace the pole of rotation in the earth by something like two seconds of arc.

Of course any such movement is ordinarily counterbalanced by an equivalent circulation in the opposite direction; but frequently cases occur in which the equilibrium is not restored for six months or a year, as for instance in the case of an antarctic earthquake when 1000 square miles of ice floe is suddenly dislodged and floats northward, thus diminishing the moment of inertia of that continent until an equivalent amount of glacial snow and ice can again accumulate. A periodic change of this sort always occurs when the southeast trade breaks

[1] Presented at the meeting of the society in London, Nov. 9, 1906.

across the Indian Ocean and becomes the southwest monsoon, driving a great mass of surface water before it from equatorial into northern latitudes, while at the same time depositing two or three feet of rain water along the Asiatic coasts.

A study by Larmor and Hills of the curve of torque seems to them to point preponderantly toward the Pacific Ocean as the source of the disturbances, as tho there were a simultaneous accumulation or diminution of load in the neighborhood of the meridians that are perpendicular to the center of that ocean, namely 90° east and west of Greenwich. The procedure adopted in their memoir has been to eliminate the uniform precession and nutation of the ellipsoid of revolution in order to bring out prominently the irregular shifts due to the torques produced by the irregular redistribution of material. Altho they do not distinctly allude to the fact, yet it may be worth mentioning that the meridians perpendicular to the center of the Pacific correspond to those on which are located the North American and especially the Asiatic regions of winter high pressure and summer low pressure, and it is worth inquiring whether the annual variation in distribution of rain, snow, wind, or pressure can possibly have produced the torques of whose causes we are in search.

While the above-mentioned investigation has great interest in its relation to the current state of the globe it is of still greater interest in connection with the question of the variation of climate in past geological ages. Among the numerous hypotheses that have been put forward to explain the occurrence of glacial epochs a change in latitude has often been urged; but our authors show that this is mechanically impossible without, indeed, such an upturning of the earth's surface as is thoroly inconsistent with the horizontal stratification that has been going on since Archean times. The amplitude of the oscillations of the earth's pole will always be kept small by the internal friction or viscosity of the soft interior, so that the axis of rotation will always be near the principal axis of inertia, and can never wander farther from its original position than the latter does.

I have never felt certain that we need to assume great heat in the interior of the earth. The small amount of heat conducted outward annually thru the outer crust may be supplied, not by conduction from a molten center, but by the slow chemical, physical, and crystallizing processes going on within the crust, and especially by the mechanical crushing, sliding, and faulting that accompany the tidal strains produced by the attraction of the sun and moon combined with the diurnal rotation of the earth.[2] By these tidal strains the gravitational work—at least a small fraction of it—is converted into internal heat thus supplying that which is conducted both outward and inward, so that the interior never can cool to absolute zero. If the daily or annual conduction outward is just equivalent to the daily or annual development of heat by the crushing due to tidal strain, then we can reckon the corresponding amount of work done or the force that does it.

The theory of isostasy advocates the idea that continents are the tops of intrinsically lighter masses floating on a liquid or viscous material. But such canyons as those of the Congo and Hudson, as well as the stratified geological formations, show that continents have risen and fallen relatively to ocean levels so frequently and so much that they are not continents by reason of a small density, but for other reasons that can be reduced to shrinkage and tidal strain, as indeed was expounded by me in 1880.

When the sun and moon are simultaneously nearest the earth and in the same geocentric declination and right ascension they produce the maximum interior tidal strain; this was also true in past ages. The strain is greatest when the solar and lunar declinations have their maximum values, i. e., 23° and 28°, respectively; and then the two halves of the earth's crust will buckle and slide over each other at points along a line of weakness most nearly coinciding with the great circle that is perpendicular to the line joining the earth and sun, and therefore tangent to the Arctic and Antarctic circles. This process will be repeated with every conjunction or opposition, and most intensely with every perigee of moon or sun, so that great faults must develop, especially along a system of *great circles tangent to the Arctic and Antarctic circles.* Thus the earliest granitic shell of the globe was broken up into the systems of faults or bends that define the general outlines of our continents and mountain ranges. The greatest fault is that which incloses the Pacific Ocean; the changes which have occurred in the floor of this ocean have determined the general level of the other oceans, while the continental half of the globe has preserved its general elevation above the oceanic. The deprest half of the crust became so and has remained so by virtue of the crushing due to early tidal strains, and isostasy has had only a minor influence on the relative altitudes.

The researches of geologists have shown that there have been several glacial epochs, the latest addition to the subject being an article by Prof. William M. Davis,[3] where he has shown that there is remarkably clear evidence of glaciation during Permian times, and that, too, of a general continental type, over a large area in the interior of Africa just south of the Torrid Zone, due to the flow of ice from the northward, namely, from a region nearer the equator. Professor Davis thinks that this occurred at a time when that continent had about the same altitude and winds that now prevail, and adds that *no conceivable arrangement of continents and ocean currents* could have produced an abundant snowfall in latitude 25° south so long as the general temperature of the atmosphere preserved its present value.

We think it must be allowed that glaciations have taken place in various parts of the world during very different geological epochs, and that the conditions which made these local glaciers possible were themselves local, and were not general changes of latitude or solar radiation. We attach most importance to actions that we know have been going on as recorded geologically and historically—e. g., the simple rising and falling of continents, and the changes in the distribution of land and water—and we must pursue an exhaustive study of the possibilities in this line before we feel driven to try hypotheses that can not be reconciled with what we know of the simpler ordinary methods of nature. It is true that a variation in solar radiation is made plausible by considering the variations in brightness of the variable stars, but we shall not need to appeal to that hypothesis until we are convinced that the earth and atmosphere do not possess within themselves the possibility of producing alternate glacial epochs, dry epochs, and moist epochs.

We need not inquire whether orographic changes are due to earthquakes, or loading, or secular cooling and shrinkage of the nucleus; it suffices to recognize that they have always been going on. We are especially imprest by facts pointing to the conclusion that there have been temporary continuous connections between North America and Europe where the Atlantic now rests, and temporary islands, if not whole continents, in the Pacific, which are now represented by small islands and submerged banks. The great gorges of the Hudson and the Congo rivers extend many miles off the American and African coasts, being recognizable at depths of five thousand feet, and these deep canyons show that in some former time those rivers flowed thru dry land, so that the Atlantic was then far smaller and shallower than at present. The mountain ranges, with their earthquake centers,

[2] See Bull. Phil. Soc., Washington, April 13, 1889, vol. XI, pp. 533–536.

[3] Bulletin of the Geological Society of America, vol. 17, 1906, pp. 377–450.

extending from Patagonia to Alaska and from Kamchatka far down along the Pacific coast of Asia, have long been recognized as showing that we have here a part of a great circle around the Pacific representing a belt that is unable to withstand the great strain produced by the tidal action of the sun and moon. The strata of this belt have, therefore, for a long time been gradually crumpling, while the bed of the Pacific has been alternately rising and falling as it rested on the viscous interior of our globe. These oscillations of the Pacific Ocean must have affected the level of the Atlantic. They could change the axis of rotation of the globe only a very few degrees, but affect local climates directly, causing great oscillations in altitude, temperature, and moisture, with only small changes in the general circulation of the atmosphere. The conditions that now produce glaciation in New Zealand, Greenland, Alaska, Switzerland, and Iceland appear to have once prevailed in the Himalayas, the North American Lake region, central Africa, and Scandinavia during the many changes that have been taking place in the orography of the earth's surface. The fundamental condition producing glaciation is simply the ratio between the snowfall of the cold season of the year and the heat, wind, evaporation, and rainfall of the warm season. If the latter agencies are sufficient to melt the winter's snow, then no glacier occurs. As illustrative of this point, it may be well for some one to construct maps of the globe analogous to that which was prepared by me for a lecture in Baltimore in 1898, showing the average total snowfall during the winter seasons of 1884-1895, divided by the average total rainfall of the year. Of course one must take into account the temperature of the rain water and the evaporation from a dry snow surface, as well as the melting of the snow in the sunshine. Our map therefore gives only the crude elements of the problem, but practically the coefficients must be determined meteorologically, by studying the actual records of snow on ground in regions where glaciers now occur.

As concerns the changes of climate in Asia Mr. Ellsworth Huntington, who has been studying in person the physiography of that continent, has discovered what he believes to be conclusive evidence of great changes in the direction of dessication during the last two thousand years. He has brought together conclusive data showing the drying up of rivers and lakes and the retreat of their shores to distances of fifty or a hundred miles. The great caravan routes from China westward have also been changed from time to time owing to the necessity of following the water routes. The area of dessication extends from the Caspian Sea eastward for over twenty-five hundred miles. Mr. Huntington, in fact, seems to maintain that there have been alterations of dry and wet centuries, three such alternations since the year 800, with a long period of abundant rain previous to that. Without discussing his definite epochs we may in general conclude that in the present state of the globe and the atmosphere, and without any change in latitude or altitude, moisture or sunshine, it is perfectly possible for such combinations of winds to occur as to give us in one century conditions favorable for rain, snow, and glaciers, but in another distant century drought, sand, and desert. These alternations depend essentially upon extreme variations in what is called the general circulation of the atmosphere; they are perturbations produced solely by its own internal mechanism. We are familiar with such alternations every six, eight, or ten years in most countries. Brückner has submitted arguments in favor of changes at irregular intervals, averaging thirty-five years, in Europe, while Russell maintains a periodicity of nineteen years in Australia. But the motions of the atmosphere are too irregular to be properly styled periodic; a combination that will occasionally recur so as to give a drought in the United States may do so at very irregular intervals, and no matter whether the average interval is seven, nine, or thirty-five years, it should not be spoken of as periodic. The main point for us to remember is that where now we have droughts once there was abundant rain; where now we have arable land once there were glaciers; and these climatic changes are recurring without any notable change in surrounding conditions. They are the result of the innumerable combinations that may arise, some favorable and some unfavorable; and they will be exactly explained when we fully understand the mechanics of the atmosphere as it now is.—*C. A.*

TORNADOES OF JUNE 6, 1906, IN MINNESOTA AND WISCONSIN.

Referring to page 274 of the MONTHLY WEATHER REVIEW for June, 1906, the Editor has received a report written by the late Mr. T. S. Outram, in which he gives some account of the tornadoes which occurred on June 6, 1906. The following brief extracts are sufficient to locate these tornadoes, but many details are given in the manuscript:

Late in the afternoon of June 6 tornado conditions were evident at many places in eastern and southeastern Minnesota and western Wisconsin, with actual tornadoes occurring in Houston and Chisago counties, Minn., and La Crosse, Monroe, and Vernon counties, Wis.

The Chisago tornado evidently developed between Forest Lake and Wyoming, and moved nearly northward some 35 miles to near Harris. The width of the track of greatest destruction varied from 50 feet to about a quarter of a mile.

The effects of the Houston tornado[1] were felt over a wide area, but the storm was most severe between Freeburg and Reno, a distance of about six miles. From Reno the storm seems to have past over the Mississippi River to near Stoddard, Wis., but from Stoddard to Leon, a distance of about fifteen miles, the great force of the tornado was again exerted.

In both these storms the funnel-shaped cloud was present; it was very black, showed a violent whirl in which there was much débris, and toward which the clouds seemed to rush from all directions; the lower end of the funnel whipt about, destroying everything it came in contact with. The wreckage of the buildings and timber seemed to be thrown in all directions, but a few persons thought they noticed that the whirl of the storm was in a direction opposite to that of the hands of a watch. There were heavy rains after the passage of both tornadoes, and in places there were very large hailstones. The noises are said to have been very distinct, resembling the rumbling or roar of a long train of cars.

The characteristic freaks or strange happenings so common in tornadoes were present in these storms also, and a few may be mentioned. A kitchen cupboard, filled with china, standing in a house which was completely torn to pieces, was carried four rods and set down so gently that not a piece of the china was broken. When the storm struck the Inglett place Mr. Inglett, sr., was sitting in the kitchen with a child on his lap; the house was completely demolished, even to the carrying away of nearly all the floor but that on which the man was still sitting uninjured after the storm past. Articles of furniture were carried 4½ miles from their starting point. The rung of a chair was driven thru a large tree, so that its ends projected from each side.

MR T. S. OUTRAM.

Mr. Thomas S. Outram, in charge of the Minnesota Section of the Climatological Service of the Weather Bureau, died at his post of duty, in Minneapolis, Minn., December 5, 1906.

Mr. Outram was born at Elmira, N. Y., May 26, 1856. His education in public and private schools at Easton, Md., was supplemented by an attendance of eighteen months at Cornell University. He entered the weather service of the Government (Signal Corps) in March, 1879. After serving for five years he severed his connection with the service, but reentered on September 30, 1891, and continued therewith until his death.

Always a capable, energetic, and conscientious public servant, Mr. Outram continued to discharge his duties with accustomed fidelity and exceptional courage long after his physical condition clearly foreshadowed his death. By his demise the Bureau has lost a valuable official, whose integrity and earnestness of purpose justly gave him an enviable standing in the community that he served. His pleasing personality greatly endeared him to his fellow workers and his death will be sincerely mourned.—*J. B.*

[1] This "Houston tornado" is evidently the storm described by Mr. G. A. Oberholzer in the June Review.—EDITOR.