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*VARIATION OF LATITUDE.**

THE question is frequently asked, "How can latitude change?" There are two ways obviously. First, we may imagine that a portion of the earth slips on the surface of the globe, due say to earthquake shock. Then if the movement of the mass has been toward the equator the latitude of that place is decreased; if toward the pole of the earth the latitude is increased. But suppose that some forces at work on the earth cause it to revolve about a new axis, then we have at once a new equator, and the latitudes of *all* points on the earth's surface change except at those places where the old and new equator intersect.

If, for example, the earth's axis of revolution should be changed so as to pass through this hall, the latitude would be changed from a little over 40 degrees, as it now is, to 90 degrees. There are changes no doubt produced by the slipping of portions of the earth's strata, but we know that these causes are insignificant and local. The only way that latitudes could be made to change *throughout the world* would be by changes in the axis of rotation of the earth, thus changing the position of the equator.

Are there any undisputed evidences of a variation in the latitude of a place and is it large?

To-day the evidence is overwhelming, but the amount is small, so small, in fact, that only the refined instruments of the present day have been able to discover it; though now, that it is discovered, older observations show it.

La Place, in his Mécanique Céleste (Tome V., p. 22), says "All astronomy depends upon the invariability of the earth's

* From a lecture before the New York Academy of Sciences, April 29, 1895.

axis of rotation and upon the uniformity of this rotation."

He considered that down to the beginning of this century astronomical instruments had not been able to show any variation of latitudes. There were differences, but these he thought could be accounted for as errors of observation.*

To-day, however, we feel certain that small variations in latitude are taking place, but so small that practically, in map making, for example, and in navigation, they are of no importance, though scientifically very important.

It might also, in this connection, be stated that there are theoretical reasons which seem to indicate that the earth's *rotation time* is not only changing, but also is not altogether uniform. The effect of the tide-wave as it moves west over the earth is to act as a friction-brake on the revolving earth, and so slow up the rotation time, and as this tide effect is not always the same the retarding effects differ, and theoretically produce a non-uniformity in the rotation time. But the shrinkage of the earth, due to loss of heat, would tend to make it revolve more rapidly. These effects may work against each other. However, observations and calculations to-day do not furnish us with any certain evidence that the rotation time is longer or shorter than it was ten centuries ago.

It no doubt will happen that, when observations and instruments are much improved, astronomers will discover these slight changes in rotation time that theory seems to require.

The idea that the latitudes of places change is not a new one.

Down to about the time that the telescope was invented there were many learned persons who believed that the latitudes of places changed several degrees in the course of centuries. These ideas were based on a comparison of maps made at different times.

A disciple of the illustrious Copernicus considered that the evidence was conclusive, and was satisfied that the pole of the earth was changing its position in a *progressive* manner; he considered that in time the torrid and frigid zones would change places.

However, these views of Dominique Maria de Ferrare were founded on poor data. The latitudes of a few places had been determined, by very imperfect means, in the best way they had, viz., from the shadow cast by a gnomon; but the latitudes of many places on the maps were put in from the accounts of travelers, the time it took to travel from one point to another being used as the basis of calculation.

Even in these enlightened days, as we like to consider them, there is no good map of our own Empire State. The latitudes of a few points only in New York State have been determined with accuracy. But there are many places in the State whose positions are not known within more than a mile.

In the latter part of the 16th century Tycho Brahe, of Denmark, improved the instruments in use (without the telescope), and later, about 1610, the telescope was discovered and applied to astronomical instruments. Then new and more accurate methods were used to determine latitude, and the large discrepancies disappeared. Some observers found differences between latitudes determined in winter and in summer, and they supposed those differences to be due to changes of the pole.

In the latter part of the 17th century J. D. Cassini summed up the state of the problem in his day, and arrived at the conclusion that, notwithstanding the apparent variations in the latitudes, the pole of the

* The writer is much indebted to the paper by Professor Doolittle on 'Variations of Latitude' read before the A. A. A. S., at Madison, Wis., August, 1893.

earth did not change to any *large extent*; that most of the apparent changes in latitude were due to errors of observation and defects in theory, but he thought it probable that *small* changes did occur in the position of the pole; he thought the changes were *periodic*, and did not amount to more than two minutes of arc equal to about 12,000 feet. "Thus, instead of several degrees which were conceded by the astronomers of of previous centuries, but a paltry two minutes was now allowed; but with improved instruments, with the discovery of aberration and nutation and the perfection of the theory of refraction, even this modest allowance was gradually reduced to a vanishing quantity."

The geologists, in their investigations, have found fossil remains in the cold regions of the north, belonging to the Miocene, Upper and lower Cretaceous, Jurassic and other geological periods, which seem to indicate a former temperature much higher than the present. In 1876 Dr. John Evans, then President of the British Geological Society, discussed the problem, and concluded that the amount of polar light and heat in the past must have been much greater than it is now. He invited the attention of the mathematicians to this problem, and asked: Would a considerable elevation and depression of the sea bottoms and continents produce a 'change of 15 degrees to 20 degrees in the position of the pole?'

Sir William Thomson discussed this problem and gave his conclusions in 1876 to the British Association for Advancement of Science. He said: "Consider the great facts of the Himalayas and Andes and Africa, and the depths of the Atlantic, and America and the depths of the Pacific, and Australia; and consider further the ellipticity of the equatorial section of the sea level, estimated by Colonel Clarke at about one-tenth of the mean ellipticity of the meridianal sections of the sea level.

"We need no brush from a comet's tail to account for a change in the earth's axis; we need no violent convulsions producing a sudden distortion on a great scale, with change of axis of maximum moment of inertia, followed by gigantic deluges; and we may not merely admit, but assert as highly probable, that the axis of maximum inertia and the axis of rotation, always near one another, may have been in ancient times very far from their present geographical position, and may have gradually shifted through ten, twenty, thirty or forty or more degrees without at any time any perceptible sudden disturbance of either land or water."

Sir William Thomson gave no account of the calculations made by him as the basis of these conclusions.

In 1877 Mr. G. H. Darwin made a careful and elaborate mathematical discussion of the problem. He showed that, in a *perfectly rigid* globe, the pole could not have wandered more than 3 degrees from its original position, as the result of the continents and oceans changing places. "If, however, the earth is sufficiently plastic to admit of readjustment to new forms of equilibrium, by earthquakes and otherwise, possible changes of ten or fifteen degrees may have occurred. This would require, however, such a complete changing about of the continents and oceans, with maximum elevations and depressions in precisely the most favorable places, as has certainly never occurred in geologic times."

The evidence indicates, in fact, that the continental areas have always occupied about the same positions as now.

Thus it would seem that the geologists must abandon the hypothesis of *great* changes in latitude as a factor in the earth's development, unless a new cause can be found that will move the pole to the extent required by the geologists.

In an address made before Section A, of the British Association in 1892, Professor

Shuster stated that he believed the evidence at hand was in favor of the view that there was sufficient matter in interplanetary space to make it a conductor of electricity. This conductivity, however, must be small, for if it were not, he said, the earth would gradually set itself to revolve about its magnetic poles. However, changes in the position of the magnetic poles would tend to prevent this result. Perhaps the investigator in the near future, working on the suggestion of Dr. Shuster, may find some connection between the earth's magnetism, rotation time and position of rotation axis.

The evidence, then, at this phase of the discussion, is in favor of the view that there is no adequate reason for believing that any *large changes* of latitude, amounting to several degrees, have occurred in geologic times. The evidence shows, however, that there are small changes. Are they *progressive;* does the north pole of the earth wander slowly but surely further and further away from its positions of ages gone by?

At the International Geodetic Congress held in 1883 at Rome, Sig. Fergola, of the Royal Observatory Cappodimonti, Naples, gave a tabular statement which seemed to show that small but *progressive* changes *had* taken place in Europe and America. This table showed, for example, that the latitude of Washington, D. C., had decreased from 1845 to 1865, 0.47″; at Paris, from 1825 to 1853, the decrease was 1.8″; at Milan in 60 years, 1.5″; at Rome during 56 years, 0.17″; at Naples in 51 years, 0.22″; at Königsberg in 23 years, 0.15″; at Greenwich in 19 years, 0.51″. Fergola, at the Congress mentioned, suggested a plan for making systematic observations, and he pointed out the favorable location of several observatories that were on nearly the same circle of latitude, but differing widely in longitude. Unfortunately this suggestion of Fergola's was not carried out in any way until 1892, when the Columbia College Observatory arranged to work in conjunction with the Naples Observatory on the problem. This series of observations was begun in the spring of 1893, and will be continued several years.

The data given by Fergola at Rome in 1883 showed a diminution of latitude in every case; other data showed a similar diminution; however there were exceptions, where the latitudes seemed to increase.

The investigations that have been going on since 1883 throw doubt on the *progressive* changes in latitude, or at least such changes are masked by proved *periodic changes*.

For a long time, since 1765, periodic changes have been looked for, because the theory of a rotating earth, an earth having the form of a sphere flattened at the poles, or, more accurately, an ellipsoid of revolution, demanded such changes; but the theory did not furnish any clue to the amount of changes, except that they must be very small. This theory shows that if the earth was *absolutely rigid* and revolved about its shortest axis (called the axis of figure) at any time it would continue to revolve about such axis forever, unless disturbed by some outside force. If so disturbed, then the axis of rotation would no longer coincide with the axis of figure—the axis of rotation would intersect the earth's surface at points away from the points where the axis of figure comes out. But the theory also showed that the new axis of rotation would revolve about the old one in a period of 304.8 days. This period comes from the knowledge of the magnitude of precession and nutation, and is known very accurately.

We would expect therefore that changes in latitude would show this 305-day period.

Several attempts have been made to determine the distance between the two axes (figure and rotation axis) from changes in latitudes.

The celebrated astronomer Bessel made

the first attempt, and was unsuccessful, it was supposed until recently.*

Observations were also made at Pulkova, Russia, Greenwich and Washington. The Washington observations were made between 1862 and '67, and included six complete periods of 305 days each. A rigorous discussion by Newcomb gave the separation of the axes as 3 feet, or 0.03″.

C. A. F. Peters, of Pulkova, had in 1842, obtained ″.079 = 8 feet.

These figures are small, but fairly accordant. A reinvestigation, however, showed that the various calculations did not agree in showing the same displacement at the same time. This made the whole result doubtful, so that Newcomb (in 1892, March, Mon. Not. R. A. S.) remarked that "the observations showed beyond doubt there could be no inequality of the kind looked for."

It was while investigations of this kind, to determine the separation of the axis of rotation and axis of figure, were going on that Sir Wm. Thomson (now Lord Kelvin) announced, at the Congress of the British Association at Glasgow in 1874, that the meteorological phenomena, the fall of rain and snow, the changes which occur in the circulation of the air and of the sea waters would modify a little the mechanical constitution of the globe, and displace a little the *axis of figure*, *i. e.*, the form of the earth would be changed by the causes mentioned, and so a new shortest axis would be made. The effect of this would be to produce a change in the latitudes of places, evidently. He thought that it might amount to ″.50, which would correspond to a movement of the old axis (at the pole) of 50 feet on the earth's surface. Sir W. Thomson did not publish his calculation, but the authority of the great English mathematician and physicist was such as to make scientific men give the statement great attention. These meteorologic phenomena of which Sir William Thomson spoke are annual in character. When this annual period is combined with the 305-day or ten-month period of Euler we see that complexity results. This was the state of the investigation when Dr. Küstner, of the Berlin Observatory, published the results of his observations made in 1884–1885. Dr. Küstner undertook some observations for the trial of a new method for the determination of the constant of aberration. On reducing his observations he obtained results which were not at all satisfactory. A careful examination of his work led him to make the announcement that the unsatisfactory value for the aberration constant was due to a comparatively rapid, though very small, change in the latitude of the Berlin Observatory—"that from August to November, 1884, the latitude of Berlin had been from ″.2 to ″.3 *greater* than from March to May in 1884 and 1885."

* Tisserand says in Ann. Bur. Long. '95 (P. 42, B. 11) that there is a letter of April 7, 1846, in which Humboldt replies to Gauss that Bessel had told him in 1844 that his observations showed that his latitude had decreased 0. 3″ in two years. Bessel attributed this variation to changes accomplished in the interior of the globe. See also Hagan's letter in Astr. Nach., September, 1894.

In this connection it ought to be noted also that Prof. J. C. Maxwell read a paper April 20, 1857, before the Royal Society of Edinburgh (see Transactions Roy. Soc. Edinburgh, Vol. XXI., Part iv., pp. 559–571), 'On a Dynamical Top for exhibiting the phenomena of the motion of a system of invariable form about a fixed point, with some suggestions as to the earth's motion.' He deduced a period of 325.6 solar days. He examined the observations of *Polaris* made with the Greenwich Transit Circle in the years 1851–54. He found the apparent co-latitude of Greenwich for each month of the four years specified.

"There appeared a very slight indication of a maximum belonging to the set of months, March, '51; February, '52; December, '52; November, '53; September, '54." This result, he says, "is to be regarded as very doubtful, as there did not appear to be evidence for any variation exceeding half a second of space and more observations would be required to establish the existence of so small a variation at all."

This would indicate that from August to November, 1884, the pole of the earth had approached Berlin more closely by 20 to 30 feet than in the time from March to May.

This conclusion was fortified by the examination of other data, obtained from the observations made at Pulkova by Nyrén.

Here, then, was evidence of a comparatively rapid change in latitude. New observations were undertaken at Berlin, Potsdam, Prague, and Bethlehem, Penn. (all by Talcott's method), and all agreed in showing plus and minus changes in latitude for the years 1888–'90.

There were still some doubters. Moreover it was decided to critically test the matter by sending an expedition to the Sandwich Islands, which is 180 degrees (nearly) in longitude from Berlin. If it was known the latitude of Berlin increased, then a point in the northern hemisphere 180 degrees away from Berlin should simultaneously show a decrease in latitude, for if the pole moves toward Berlin it must move from the point on the other side of the earth.

Our own Government joined in the effort. Marcuse of Berlin and Preston of Washington spent more than a year on the Sandwich Islands observing for latitude, while at the same time observations were continued at Berlin, Prague and Strassburg in Europe, and at Rockville, Bethlehem and San Francisco in the United States. The results of all these observations have been published, and show, without a chance of error, that the earth's axis is moving, that the latitudes at the Sandwhich Islands increased when the latitudes in Germany diminished and *vice versa*.

The law of the change was eagerly and industriously sought for by some of the ablest mathematical astronomers of the world. They first worked on the idea that the changes must conform to the 305-day period of Euler, combined with an annual change due to causes set forth by Sir W. Thomson, and which I have previously mentioned. None of these investigations have given a satisfactory formula for the prediction of the latitude of any place.

In 1891 Dr. S. C. Chandler, of Cambridge, Mass., began his investigation of the problem. He remarks:

"I deliberately put aside all teaching of theory, because it seemed to me high time that the facts should be examined by a purely inductive process; that the nugatory results of all attempts to detect the existence of the Eulerian period (of 305 days) probably arose from a defect of the theory itself, and that the entangled condition of the whole subject required that it should be examined afresh by processes unfettered by any preconceived notions whatever. The problem which I therefore proposed to myself was to see whether it would not be possible to lay the numerous ghosts in the shape of various discordant, residual phenomena pertaining to determinations of aberration, parallaxes, latitudes and the like, which have heretofore flitted elusively about the astronomy of precision during the century, or to reduce them to some tangible form by some simple consistent hypothesis. It was thought that if this could be done a study of the nature of the forces as thus indicated, by which the earth's rotation is influenced, might tend to a physical explanation of them."

Dr. Chandler proceeded to examine his own work with the Almucantar at Cambridge, the observations of Küstner, Gyldén, Nyrén, the Washington observations and others. He found that they all seemed to indicate that the pole of the rotation axis was moving from west to east about the axis of figure of the earth in a period of 427 days. Other observations did not seem to confirm this period. Finally he made an elaborate analysis of 33,000 observations between 1837 and 1891, and the result was an empirical law which can be announced as follows:

The pole of the rotation axis of the earth moved with its greatest velocity about the pole of the axis of figure about the year 1774; the period then was 348 days. The velocity has diminished with an accelerated rate since then. In 1890 the period was 443 days. The distance of one pole from the other was about 22 feet = 0.22″.

Further elaborate examination of this material developed the exceedingly important and interesting result that the changes in latitude were the sum of *two periodic* fluctuations superposed on each other. One had a period of about 427 days and an amplitude of 0.12″ The second had a period of a year with an amplitude that was variable between .04″ and .20″

Sometimes these two fluctuations worked together, giving a total range of .33″, and at times they conspired against each other, reducing the range to a minimum of a few hundredths of a second. He compared his theory with the observations, and the result was in the main exceedingly satisfactory.

His conclusions were attacked as to the 427-day term. The annual term could be explained as due to meteorologic causes.

Professor Newcomb, however, in March, 1892, explained in a paper communicated to the Monthly Notices of the Royal Astronomical Society that in deducing the Eulerian period of 305 days the earth, as we have remarked, was considered *absolutely rigid;* that when the effect of the mobility of the oceans and of the lack of perfect rigidity of the earth were taken into account, the mathematics required a time of rotation of the true pole about the axis of figure longer than the previously accepted 305 days. Making certain assumptions Newcomb obtained a period of 443 days.*

An additional interesting conclusion which Dr. Chandler has lately published is that the fluctuation with a period of 427–428 days is a circular one, as theory seems to demand, while the annual fluctuations appear elliptical in character.

An exceedingly interesting and important confirmation of the Chandlerian period of 427 days, or about 14 months, was lately announced by M. Tisserand. Examination has been made of the tide records of the Helder in Holland. These are kept with great accuracy. It has been found that between 1851 and 1893 these tide records show a variation in the average sea level indicating a 14-month period. The greatest divergencies are very small, only 14 mm.= ½ inch about, but they appear unmistakably and are what theory would demand.

In a letter recently received from Dr. Chandler he states that he finds that the annual part of the polar motion is an ellipse three or four times as long as broad, and he expresses the law of the motion of the pole in this ellipse as that the areas described from the centre are proportional to the times.

We can conclude safely, therefore, that no large changes of latitude have taken place for many thousands of years; in fact, in geologic times, that there is no adequate proof of *progressive* changes in the latitude of any place; but finally that very small periodic changes have occurred, and they are such as can be and are observed.

The feeling is growing in the minds of those who have given the subject close attention that we shall find that many and various causes enter into the problem of determining the law of changes. It will, no doubt, take many years of careful observation to obtain the data necessary to fully test Dr. Chandler's or any other hypothesis.

The scientific men abroad are discussing the advisability of establishing several observatories at various places on the earth's surface, for the purpose of collecting the data.

* Professor R. S. Woodward has lately obtained by a new discussion of the theoretical problem a formula that seems to indicate the correctness of Chandler's empirical formula.

Ultimately Dr. Chandler's formula, or a slight modification of it, may be proved correct, and with it we may be able to state what the latitude of any place will be at any time.

The lecture was followed by some illustrations showing that revolving bodies preferred to revolve about their shortest axis or around the axis about which the moment of inertia was a maximum.

Charts and diagrams were exhibited showing the results of observations made at Pulkova, Prague, Berlin, Strassburg, Bethlehem and the Sandwich Islands, etc.

These results were compared with the deductions from Chandler's formula and shown to agree therewith to a remarkable extent.

The preliminary results of the observations made at Columbia College from May, '93, to July, '94, were exhibited.

The lecturer threw on the screen illustrations of several forms of Zenith Telescopes and described the new form made by Wanschaff, of Berlin.

J. K. REES.

COLUMBIA COLLEGE.

CURRENT NOTES ON PHYSIOGRAPHY (VII.).

AREA OF LAND AND WATER.

PROFESSOR H. WAGNER, of Göttingen, contributes to the April number of the Scottish Geographical Magazine an abstract of his recent studies on the land and water areas of the globe for successive latitude belts. He contends that Murray's figures, published in the same magazine for 1886 and 1888 and based on Bartholemew's maps, are inaccurate to a significant extent. Wagner's measures of the better known lands between 80° north and 60° south latitude is 51,147,100, against Murray's 51,298,400 square miles. Taking 250,000 for lands yet undiscovered in the Arctic regions, and 3,500,000 for Antarctic lands, the total land area of the globe would be 55,814,000 square miles. Wagner finds confirmation of his figures in the results independently obtained by K. Karstens, who has recently made a new reckoning of the area and mean depth of the oceans.

THE 'FLY-BELT' IN AFRICA.

THE remarkable control over the occupation of Africa, exercised by the little tse-tse fly, whose bite is fatal to horses and cattle, leads to the introduction of cheaply constructed narrow-gauge railways across the belt of country dominated by this pest. The Portuguese district, next south of the Zambesi river on the east coast, with its capital at the little settlement of Beira, attains some commercial importance from its relation to Mashonaland and the gold district of the interior; but in order to connect the two, a railway a hundred and twenty miles long has been made 'to bridge the fly-belt.' The coast exhibits a combination of equatorial and tropical rainfall, having high temperature and heavy rain from October to April, but from June to September 'the weather is almost pleasant.' At Beira the scarcity of water in the dry season threatened a few years ago to be a serious question, as a supply had to be brought from the upper course of the rivers at a considerable cost; but "in 1893 a Scotch plumber was imported, and all anxiety on this score came to an end," as he made galvanized iron tanks in which rain water could be gathered and stored from the roofs (Scot. Geogr. Mag., April, '95).

COLD AND SNOWFALL IN ARABIA.

THE ordinary association of heat with the dryness of deserts tends to give the impression that Arabia has no cold weather. Nolde's account of his expedition into the Nefud desert of the Arabian interior, latitude 28 north, altitude 3,000 feet, tells of the severe cold that he experienced there in