DIP AS A MEANS OF GEOIDAL RESEARCH IN PACIFIC OCEAN ISLANDS

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IMPORTANCE OF DEFLECTIONS OF THE VERTICAL IN PACIFIC OCEAN ISLANDS

Many islands in the Pacific, which emerge from depths often attaining several thousand metres and have steep slopes and no continental shelf, pose a delicate problem for geodesists.

Such islands, sometimes taking the shape of atolls and at other times formed as high mountain ranges, are in fact supported by submarine cones, the existence of which causes a slight swelling of the geoid in relation to the terrestrial ellipsoid. Although this swelling is inconsiderable and of no more than a few metres in extent, it suffices owing to the small size of the islands to create an appreciable slope at the island's circumference, and to deflect proportionally (sometimes by as much as several tenths of a second of arc) the direction of the plumb line with respect to the normal to the ellipsoid.

A major disadvantage of this phenomenon is the inability to adopt observed astronomical positions as such for the control of local triangulation and charting. Since the islands are impenetrable whenever the interior is mountainous, or whenever occupied in the case of atolls by lagoons often devoid of rocky islets, astronomical observations are taken near the sea edge, where there is considerable deflection of the vertical, rather than near the centre of the island in localities where the plane tangent to the geoid is nearly parallel with that tangent to the ellipsoid.

These strong deflections of the vertical moreover give rise to errors in astronomical azimuth, and even in the horizontal angles that are measured on the geoid, and must be referred to the ellipsoidal horizon for calculation of the triangulation.

No geodetic operations of a certain accuracy can therefore be carried out without an adequate knowledge of deflections of the vertical, i.e. of the shape of the geoid in the area concerned.

Staff Captain RIBOURT was well aware of these facts over a century ago, when between 1845 and 1850 he carried out geodetic work in Tahiti. By latitude observations and triangulation, he showed a deflection northwards of 33.5″ on the north side of the island, and deflection southwards of 25.3″ on the south side, at a latitude range of 17′ between the two points considered.

In more recent times, Lieutenants NAY and VALLAUX, operating between 1947 and 1953 in Tahiti and in numerous atolls or islands of the Tuamotu group mainly for the purpose of fixing their geographical position, saw fit to apply corrections systematically to the geographical coordinates deriving from their shore-based astronomical observations.

METHODS OF DETERMINING DEFLECTIONS OF THE VERTICAL

The conventional method for obtaining these corrections consists in taking several astronomical stations on the same island and in connecting them by triangulation. But this is a considerable task, which was carried out by NAY and VALLAUX on a dozen islands, and which fortunately enabled them to deduce two linear laws between the amount of deflection of the vertical and the area of the island : one for the high-rising islands and the other for the atolls. They took judicious advantage of these laws to correct the major portion of their astronomical observations.

But in islands where deflection of the vertical is considerable, there is a relatively simple method of ascertaining it with apparently acceptable accuracy. This is by measuring the dip of the sea horizon. The method is not new, since RIBOURT used it on the west coast of Tahiti. He discovered a difference of 18.5″ between sights of the horizon taken first parallel to the coast and then perpendicularly, that is by turning his back appreciably towards the island's centre. By this method he could determine deflection, at points where it is approximately in an east-west direction, without measuring differences in longitude, an invariably delicate and rather inaccurate operation for the period. He planned to check his results by longitude differences obtained by light signals, but seems to have been unable to carry out this project.

The use of dip of the horizon appears to be particularly interesting in the case of islands of high elevation, as at a certain altitude the sea horizon is some tens of kilometres away, yet remains fairly distinct. Surface disturbances of the sea, swell and waves are then usually inconsiderable, except during periods of very heavy weather. At this range the sea surface, which represents the geoid, is practically undistorted by the land on which operations are being carried out and in actual practice coincides with the terrestrial ellipsoid. The method hence leads to a deflection of the vertical which may be qualified as absolute and which is exactly the one sought, since it enables passing at the observation point from the normal to the geoid to the normal to the ellipsoid.

In practice operations must be carried out at a certain height, say between 50 and 100 metres, and a theodolite of high accuracy should be used to measure, at every 20° of azimuth over the entire visible horizon, the zenith distance of the sea horizon.

GRAPHIC TREATMENT OF DIP OBSERVATIONS

When dip is measured at a certain number of well-distributed azimuths, deflection of the vertical at the station point may be deduced with scarcely any computations, by a graphic method similar to the one used in the analysis of equal-altitude observations.

Let ε be the theoretical value of dip at the observation point; the zenith distance of the horizon would be $90° + \varepsilon$ in all directions in the absence of deflection of the vertical. But if this be not true, a measurement ζ of the zenith distance of the sea horizon, taken at azimuth Z, corresponds to a difference of $\Delta\zeta = 90° + \varepsilon - \zeta$, by means of which a locus of the geoidal zenith may be plotted on a large-scale graph. The locus takes the shape of a straight line, is similar to a position line, perpendicular to azimuth Z, and passes at a distance $\Delta\zeta$ from an origin representing the ellipsoidal zenith, provided we assume, as stated, that the ellipsoid coincides with the undistorted geoid defined by the sea horizon.

The straight lines supplied by the various observations in principle should converge at a point whose position in relation to the origin of the graph gives the deflection of the vertical in terms of both magnitude and direction.

But it is also possible to disregard the dip ε and plot the straight lines with the intercept $\Delta\zeta = 90° - \zeta$; these should then envelop a circumference having its centre at the previous point of convergence and of radius ε.

For convenience in plotting, an identical arbitrary quantity may of course be added algebraically to values of $\Delta\zeta$ and later subtracted from the radius of the circumference to obtain the value of ε.

This artifice may moreover be used in the case indicated earlier and for which the intercept $\Delta\zeta = 90° + \varepsilon - \zeta$ is taken. The straight lines, instead of converging, must then be tangent to a circle with a radius equivalent to the arbitrary quantity added to the values of $\Delta\zeta$.

EXAMPLE

We have processed by this graphic method observations taken at point Maraa, on the west coast of Tahiti, by Lieutenant BONZON, Lieutenant VALLAUX's successor as head of the Tuamotu geodetic survey.

Observation data were as follows :

Readings of horizontal limb	*Zenith distance ζ of sea horizon*
180°	90°20′34″
200°	31
220°	20
240°	13
260°	11
280°	6
300°	6
320°	22
340°	
360°	49

With an azimuth of 325° for the zero of the horizontal limb and a constant value of 24′ arbitrarily selected so that the circle enveloping the position lines would have an appropriate radius at the adopted scale, the following data were obtained in plotting the position lines :

Azimuth Z	$\Delta\zeta = 90°24' - \zeta$
145	206″
165	209
185	220
205	227
225	229
245	234
265	234
285	218
305	
325	191

The graph reproduced herewith was plotted on the scale of 1 mm = 4″. The following results may immediately be deduced :

Deflection of vertical : magnitude 41″, azimuth 224°.

Dip of horizon : 20′45″.

This dip value shows that the station was appreciably 136 metres high and that the sea horizon was distant by about 25 miles.

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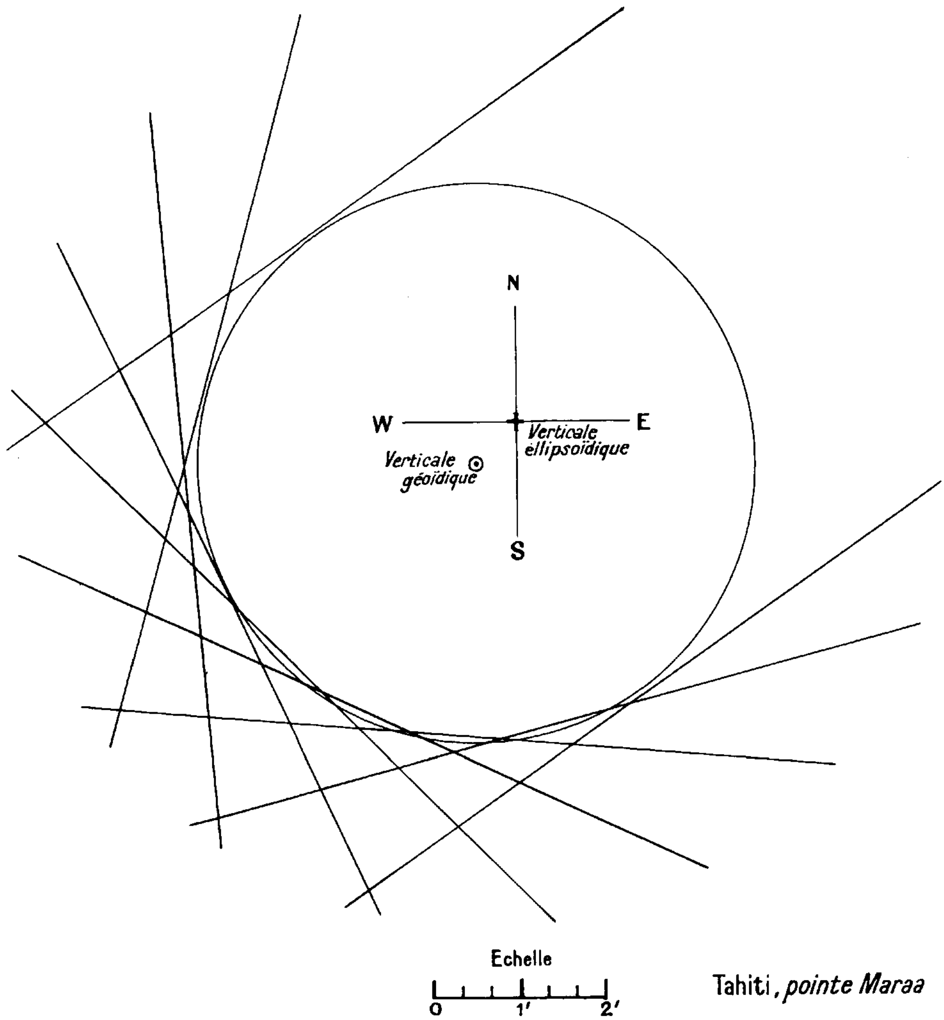

Tahiti, *pointe Maraa*