# From LaCaille to Gill and the start of the Arc of the 30th Meridian

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## SUMMARY

If one looks at a map of European arcs of meridian and parallel at the beginning of the 20th century there will be seen to be a plethora them. Turning to Africa there was the complete opposite. Other than the arcs of Eratosthenes (c 300 BC) and the short arcs by LaCaille (1752) and Maclear (1841-48) the continent was empty. It was in 1879 that David Gill had the idea for a Cape to Cairo meridian arc but 1954 before it was completed.

This presentation summaries the work of LaCaille and Maclear and then concentrates on a description of the 30th Meridian Arc in East Africa. The only other comparable arcs at the time were that through the centre of India by Lambton and Everest observed between 1800 and 1843; the Struve arc of 1816 to 1852 and the various arcs in France during the 18th century. The usefulness of such arcs was highlighted in 2005 with the inscription by UNESCO of the Struve Geodetic Arc on the World Heritage Monument list. A practical extension to the Struve Arc Monument is the 30th Meridian Arc since there is a connection between the two.

At an ICA Symposium in Cape Town, 2003, Lindsay Braun gave a presentation that detailed the political machinations of the history of the 30th Arc; here it is hoped to fill in other aspects of this work including some facts and figures since that is what surveyors thrive upon.

The Indian Arc took 43 years to complete but the African Arc took 75 years. The 125th anniversary of the inception of the 30th Arc and the 50th anniversary of its completion, were both celebrated in 2005. Plaques were unveiled in 2004 and 2005 respectively at the southern and northern terminals. Such long-term projects illustrate the dedication of the participants in striving towards goals, the fruits of which, they possibly would not live to see.

In a paper such as this, of restricted length, it is only possible to scratch the surface of such a large topic and material is still being gathered as part of the research project to compile as complete a picture as possible of the efforts of numerous surveyors over 75 years.

Any readers with detailed knowledge of any part of the arc are encouraged to contact the author so that their input can form part of the larger picture.

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## 1. 1752 LACAILLE AND THE ARC AT THE CAPE OF GOOD HOPE

The triangulation for the first arc of a Meridian to be measured in Southern Africa was observed between Klipfontein and Cape Town as early as 1752. The French astronomer, Abbé de LaCaille, had gone to the Cape to make a study of the stars of the Southern Hemisphere but, like many astronomers of his time, he was also greatly interested in the burning scientific issue of whether the shape of the earth to the South of the Equator mirrored that to the North. Lacaille's work, which covered little more than a degree in latitude, suggested that the length of a degree of latitude at the Cape was *longer* than that of a degree at the Equator. [10]

Why his interest in surveying when there was no mention of an arc measurement in his aims when he went to the Cape? This was a point that Maclear raised later when he quoted the memoir from the French Academy of Sciences to the Dutch Ambassador, setting forth the observations which LaCaille proposed to make in the Cape. [11]

As with his interests generally, so again there were really two attractions that lured him to southern parts. He had compiled a huge catalogue of northern stars and thus had a good case to want to repeat the exercise in the southern hemisphere. Additionally he had been involved in considerable arc measurement in France with the Cassinis. Whilst he, LaCaille, was convinced that Newton's theory was the correct one, it had not, at that time been proved in the southern hemisphere further south than 3º. One way to possibly confirm this was to measure an arc at the Cape of Good Hope.

Perhaps it was not thought wise to mention his geodetic arc ideas before he reached the Cape, since the Dutch Government was inclined to be rather suspicious, and permission might have been withheld if the word "survey", or "triangulation" had been seen. Or perhaps LaCaille genuinely thought there would not be time to even contemplate such an exercise.

By the time LaCaille went to the Cape geodesy was well established, particularly in France, and as a result of the expeditions to Peru and Lapland, so Italy, Denmark and Holland had some crude values resulting from early attempts at triangulation. When LaCaille was observing in the Cape so Boscovich was similarly occupied in Italy. The only arc in England at that time -by Norwood- had not been measured by triangulation. In effect Norwood took a retrograde step and in 1633-34 had measured from London to York with a 99 ft. (= 6 poles each of 16½ft) chain. The astronomical observations in London and York were with a sextant of 5 feet radius.
Triangulation, which was fundamental to accurate measurements of arc length, was introduced in the early 17th century probably by Mercator although Snellius and Frisius in

Holland generally get the credit of first putting it into practice although Tycho Brahe had attempted it in 1578.

Up until then all arc measurements, from the time of Aristotle (350 BC) and Eratosthenes (230 BC), had been executed by physically measuring a distance equivalent to many tens of miles, and then astronomically determining the angle subtended by that arc at the centre of the earth.

Triangulation allowed the replacement of such a long linear measure with one, accurate, but much shorter, baseline and a series of triangles. Still the same principle, but with improving techniques, was used until the advent of surveying by satellite.

Soon after the introduction of triangulation the problem was made more difficult by the contention that the earth was not a true sphere. If this were so, it could only be proved and quantified by measuring more than one arc, as far separated from one another as possible, and determined to a high degree of accuracy.

As it was to turn out, the difference between the major axes of the earth only accounted for around 22 km in the radius. Or average variations in the length from one degree to the next of less that 20m where a degree is around 111 km. In the early years this was of the same magnitude as the "noise" in the system, i.e. the instruments and techniques could give errors of this magnitude so that they would not be recognised as legitimate variations in the length of a degree. This almost certainly contributed to the erroneous view held for many years by the Cassini family in France that the longer radius was in the N-S direction rather than the E-W direction, giving a prolate rather than an oblate spheroid.

LaCaille sailed from France on the 21st November 1750 and by mid April 1751 he reached the Cape. Since he had travelled specifically to make astronomical observations he was recommended to lodge at the house of a Mr Bestbier, a cavalry captain, in Strand Street, Cape Town where it was thought possible to construct an observatory. It was only a 12 ft x 12 ft observatory, and contained but two six-foot radius sectors, a pendulum clock, quadrant and various telescopes. Considerable detail about the location and construction of the observatory can be found in various of the references.

Although LaCaille had initially made no mention of an arc, by 6 September 1751 he wrote that he had found an area near Groene-Clof (Groen Kloof), 12 leagues north of the Cape, that would be suitable for a baseline measure.

Thus it was that LaCaille surveyed by triangulation, a meridian arc of just over 1º in extent and included in this a baseline of 8 miles length. LaCaille recorded mention of this in his *Journal* [9] but he specifically omitted details on survey calculations or investigations of an astronomical character so that for such technical information recourse had to be made to various of the *Paris Memoires*, particularly that for 1751 published in 1755, and later to the work *Grandeur et Figure de la Terre* of 1912.

Delambre [4] remarked that LaCaille did not have such good instruments as Bradley, as he took with him those which he had used in France. But he was accompanied by a mathematical instrument maker named Poitevin so that it was possible to make modifications, verifications and check adjustments and even build on the spot any instruments or accessories needed.

For instrumentation LaCaille had the same sector that he had used 12 years previously and referred to as that of Cassini de Thury. It was of six pieds radius (where 1 pied or Paris foot = 12.785 English inches.) and with a limb graduated to 51º 20'.

La Caille described the verification of the graduated limb, where marks were set out on a tangent line at a little over 343 toises from the instrument. Corrections running to 5.4" seem very reasonable for the instruments of that time.

He also had a sextant of 6 pieds radius made by Langlois. This had two fixed telescopes, one of 6½ pieds focal length was adjusted parallel to the radius through the zero of the limb, and this was used for observing zenith distances to 64º.

The second telescope of 5½ pieds, was fixed at right angles to the first. This telescope could be adjusted to the horizon either by reversing the instrument, or by using a star visible with the first telescope, each had a micrometer. LaCaille's third instrument was a quadrant of 3 pieds radius with which he made all the triangulation observations. This had been constructed by Langlois in 1743 and used by LaCaille at the Collège Mazarin. The telescope of the quadrant was shortened from 5 pieds to 3½ pieds.

The reconnaissance was made in Aug 1752 and LaCaille left the Cape for the northern terminal on Sept 9th. The four triangles which he formed had all their angles measured, and sides were up to 41000t, (80 km) long. Airy [1] says that the signals were fires, rocks and the like.

The azimuth observations were made at the eastern corner of the observatory at the Cape using 17 altitudes of the rising sun at elevations between 45' and 4º 25" and LaCaille consequently found Kapoc Berg declined from the north towards the west by 2º 26' 24" with regard to the eastern corner of the observatory.

The angles by 3 ft quadrant were reduced to centre and to the horizontal plane since the quadrant gives the inclined angle and the triangular misclosures of 21", 15", 8" and 19" were distributed in proportion to the size of the angles, which was common practice then.

Amplitude

For determination of the difference of latitude as a prelude to finding the amplitude of the arc he used a six foot radius sector during September 14-24 1752. [1]. At his northern terminal of Klyp Fonteyn he placed the instrument in a barn. He manipulated the instrument such that it was parallel to a string stretched in the meridian, and then observed during six nights in a

clear and calm sky the zenith distances of 16 stars; 8 of these stars passed to the north of the zenith, and 8 to the south.
He compared the observed zenith distances of the chosen 16 stars at his Strand St Observatory and at Klyp Fontein and the differences of latitude between the two were found to give 1º 13' 17.3" for the celestial arc. The latitude of his observatory was recorded as 33º 55' 15" and the obliquity of the ecliptic as 23º 28' 21.2"

## 1.1 Accepted Amplitude 1º 13' 17.3"

### 1.1.1 Baseline

The base on the Zwartland Plain was measured 17-21 October 1752. LaCaille had the iron standard toise, and his wooden copy, against which to compare his wooden field rods. LaCaille had four perches or rods of fir each of 18 pieds length, (i.e. 3t = 5.847m), 3 pouces (literally thumb, but used as the name for the French inch) broad and 2 pouces thick; fitted at the ends with iron tips and given two coats of oil paint. The rods were compared with the standard four times a day, at the beginning and end both of the morning and afternoon spells of measurement. Pickets were set 120t apart and the intervals between them were measured first going, and then immediately, in returning. LaCaille himself placed the rods in contact, apparently on the ground. The base was thus measured in sections, each section twice.
So in total he effectively measured the base in both directions. The two totals differed by only 8 pouce. He took the mean and after applying various corrections accepted 6467.25t (NB 0.25t = 1pi 6p) = 38803.50 Paris.ft. Maclear later equated this to 41355.44 English ft.

### 1.1. 2 Unit of Measure

The iron toise used as standard had been made by Langlois who had constructed the previous toises for La Condamine and Maupertuis. It was brought from Paris and conformed to that of the Toise du Peru. From this LaCaille set off a wooden toise shod with metal plates that he had made at the Cape. [1]

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### 1.1.3 Arc Length

It was not straightforward to determine the length of the arc between the terminals as it was computed by parallels and perpendiculars rather than through a coordinate system. So we read that: "the picket at Klyp Fonteyn was 2604t E of the meridian of the Observatory and 69 668.6t N of the east corner of the same Observatory. 0.9t was added on account of the departure of the parallel of Klyp Fonteyn from the perpendicular let fall upon the meridian. 0.4t was deducted as being the amount by which the East corner of the Observatory was more southerly than the sector pillar". Summarising his result:-

### 1.1.4 Accepted Arc Length 69 669.1 Toises

Value of 1º
Airy, [1] said of LaCaille's arc that it presented a remarkable anomaly. He quoted 1º 13' 17.3" and 69 669.1 t to give 1º = 57 037 t. He gave the base length as 6467 t. According to this measure a degree in the Southern hemisphere whose mean latitude was 33º 20', was equal to a degree in the Northern hemisphere whose mean latitude was about 45º. The known ability of the observer almost forbade the supposition of an error in the observations, and there were no grounds for conjecturing the cause of such a deviation from the law which seemed to apply to other arcs.

Delambre studied all the original observations at the Paris Observatory and concluded that one must think that the plumb of LaCaille had been deranged by Table Mountain.

### 1.1.5 Accepted Result 1º = 57 037 t.

LaCaille expressed his surprise at the result for the length of a degree. He was unable to find any weak point in his work despite re-measurement and re-computation.

## 2. 1820 EVEREST

The reason for the apparent discrepancy in LaCaille’s work was not confirmed until George Everest visited the Cape. On 1st October 1820 he left his post in India for a period of sick leave at the Cape of Good Hope and was there recuperating for almost a year. Prior to leaving India he had been in discussions with his superior, William Lambton, regarding the apparent inconsistency between the arc measure at the Cape by LaCaille when compared with the results from various other measures around the world. Briefly the overall pictured looked thus:-

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|---|---|---|---|
| 66º N (Lapland) | 1º = 57 438t; | 45º N (France) | = 57 074 |
| 1º 33' S (Peru) | = 56 748; | 33º 08'S (Cape) | = 57 037 |

This suggested that a degree at 33º S was almost equal to a degree at 45º N. or, in other words, the earth was more flattened towards the South Pole than towards the North Pole.

Everest and Lambton had considerable experience in India on the Great Arc and were familiar with observing in the vicinity of large mountain masses. They knew also of the experiments of Pierre Bouguer who went on the Peruvian Survey Expedition of 1735. In discussions before Everest left for the Cape it was agreed that, assuming Everest was sufficiently fit, he would investigate the possible causes of the LaCaille anomaly.
Soon after arriving in the Cape Everest "...immediately ... commenced my inquiries..." [5] but he could not make any progress since there was no copy of LaCaille's Journal [9] to be found in the Cape and Everest had to send to Europe for one. That could not be achieved in a few days; it was July 1821 before he had any documentation to aid his research. Unfortunately Everest had no access to, or perhaps even knowledge of, LaCaille's papers in the *Memoires* of

the Paris Academy, and hence had little numerical data to go in. Thus it can be seen that there are some seven months unaccounted for.

R S Webb, when describing LaCaille's Journal said "In this little volume ... very few pages contain anything directly concerned with the measurement of the arc of meridian....[it] cannot be recommended as an historical account of the geodetic operations." [14]. This is all that Everest had to work with. However he was able to set out to recover as many of LaCaille's station positions as possible. In addition to the two terminals of the base there were four major stations connected in two triangles. The celestial observations had been made at the two vertices of these triangles- namely Klip Fontein and Cap - the location of LaCaille's observatory at Cape Town. The two central stations were at Capocberg and Riebecks Castel

### 2.1 Deflection of the Plumb Line

Studying the topography in the vicinity of both Klip Fontein and the Cap, Everest considered that rather than any effect at these stations cancelling out it was likely that the reverse would have occurred. In which case the arc would have been too great by the combined effects of the mountains at each end of the arc.

So that he might quantify this Everest inter-compared the results of the arcs of Bouguer & La Condamine in Peru 1738; of Cassini in France in 1740 and LaCaille's results. From these he determined that LaCaille’s value for 1º should have been about 56 919 t. or 190 t shorter.

### 2.2 Perpetuating a Mistake

In taking this to its final stage Everest quoted the LaCaille arc value from “a very old edition” of Hutton's *Philosophical Dictionary* of 1795, as most of his reference works were still in India, and he perpetuated a transcription error. The figure of 410 814 feet (Note that here it is Paris feet that are used not English) quoted by Hutton – and perpetuated in Grant's *History of Physical Astronomy* of 1852 should read 418 014 feet to agree with the measure quoted by LaCaille of 69 669.1 toise. The value is then erroneously turned back to toise as 68 469 - the value used by Everest. How easy it is to perpetuate mistakes! [12]. It would seem that Hutton (as he was earlier than Grant) had the misprint value of the arc in feet and the length of a degree as 57 037 toise.

Combining these gave a value (again erroneous) for the arc of 1º 12' 01.55".
Luckily the effect of the error hardly changes Everest's conclusion. Where the figures he used resulted in a difference of 8.99" to attribute to attraction, the figure should have been 9.15". From this Everest calculated a need to increase the amplitude of LaCaille's arc by 8.99" in order to compensate for the possible effect of local attraction. If this were done the arc would fall into harmony with an ellipticity of 1/300. This figure of 1/300, deduced by Everest 180 years ago, is only about ½ % different from the accepted value today of about 298.256.

## 3. 1837-1847 MACLEAR

Verification of Everest’s findings came in 1841-1847 when Sir Thomas Maclear, Her Majesty’s Astronomer at the Cape, carried out further observations. He extended the triangulation south to Cape Point and north to Koeberg in latitude 29º 44′ so that the Arc was 4º 37′ in extent. In doing so he established that the astronomical amplitude of LaCaille’s arc was very nearly correct but a deviation of some 8" in the direction of the vertical at Klipfontein was responsible for much of the LaCaille disagreement.[7], [10], [15].

Full details of Maclear's work are found in *Verification and Extension of LaCaille's Arc of Meridian at the Cape of Good Hope* 2 vols. 4º 1866 by Sir Thomas Maclear [12]. The work was edited by Airy.
In addition to a Bradley zenith sector with 12½ ft telescope and scale arc of 12½º graduated to 5' by means of golden plugs set in a steel limb and observed by micrometer, he also had a theodolite by Thomas Jones, called the Fuller theodolite after the MP who donated it to the RAS; and the Beaufort theodolite by Reichenbach & Ertel, was lent to Maclear by Sir Francis Beaufort. A repeating instrument by Dolland was used for zenith distances.

### 3.1 Astronomical Amplitude

Lacaille's astronomical amplitude was found to differ from Maclear’s revised value of 1º 13’ 17.12” by only 0.38"; a remarkable proof of the extraordinary ability of LaCaille. It followed from this that Maclear was obliged to seek for an explanation of the anomaly in the terrestrial measure.

### 3.2 Baseline

Between Oct 30th 1840 and Apr 5th 1841 a baseline 8½ miles long was measured in Zwartland (now Malmesbury) using Colby bars. 88 days were occupied in making the measurement. The greatest length in any one day was 787.5 ft in 11½ hours. One measure of the base only, was recorded, but it was verified by dividing the base into six unequal sections connected by a triangulation scheme. The final accepted length was 42819.06533 ft of $O_1$ at 62º F

### 3.3 Standard of Measure

Maclear used the Cape 10 ft standard bar A. It was a rectangular iron bar 122.22 inch x 1.46 inch (64.5 mm) deep by 2.6 inch (38mm) broad supported at 1/4 and 3/4 of its length on brass rollers. For 2 inches (50 mm) from each end it was cut down to half height exposing two plane rectangular surfaces coincident with the neutral axis. In the centre of each of these was a circular surface of gold with a small dot which were meant to define the 10 ft British Imperial standard. A spirit level of 9½ inch length was attached to the middle of the upper surface of the bar.

All except about two inches at each end was enclosed in a wooden box. Gill later asked Troughton and Simms to replace the indistinct dots with fine lines. It was calibrated at Breteuil by Benoit. [6]

**3.4 Calculation of Revised Arc Length**

Maclear's revised value for LaCaille's arc was 445 361.5 ft (= 111 133 m per degree). This differed from LaCaille's value by 13.586 ft or 2.1245 t.

**3.5 Value of 1º**

For his extended arc Maclear obtained 1º in lat 35º (sic) 43' 20" S = 56 932.5 t (= 110.961 km per degree). (This latitude position is in the sea. Is it a misprint for 32º?) A value 47 t less than the French found for a degree at 40ºN.
La Caille's determination of the value of 1º was 57 037 toises, equivalent to 364 728.4 English feet: (=111.164 km using a conversion of 0.3048)

The 'modern' base (i.e.1841) applied to LaCaille's recorded triangles gives 1º = 364 593.9 Eng.ft. 111.128 km
The distance between Kapoc Berg and Riebeek's Kasteel was 135 765.7 ft and the meridional length 144 feet shorter than LaCaille's recorded determination. [11]

Using the meridional distance between the stations of Bradley's Sector at Rogge Bay Guard House and Klip Fontein.

With the celestial arc of 1º 13' 14.56". gave 1º = 364 557.3 ft. (=111.117 km)

The meridional distance between the stations of Bradley's Sector, at the Royal
gave 1º = 364 439.0 English feet. (=111.081 km)

The difference between the two values of 364 557.3 and 364 439.0 = 118 feet, is an index to the relative influence of Table Mountain on the Cape Town and Royal Observatory stations. Maclear then demonstrated that the principal part of the deflection of the plumbline on LaCaille's arc was at the north end, where the mountain masses run north-west beyond Klip Fontein. The total effect on the arc was about 8.55" with -1.36" in the south at Rogge Bay and +7.19" in the north at Klip Fontein Sector station, and verifies the wisdom of extending the operation.

From Maclear's verification it would appear that LaCaille's base was too long by over 2t. in a length of 6 467.25t. (See [13] for more details). This seems almost inconceivable in the light of the precautions he took and considering that he even re-measured it with a 30t cord to check for gross errors.

One must conclude that perhaps the measuring bars of 18 ft each were in error by an amount which, to cover the suggested discrepancy, would be about 0.08 inches per bar length. Thus the possibility could be of an accumulative effect of 0.08 inches (2 mm) each time the bars were put in contact or since each bar was compared to a toise standard of one third this length, the standard used may have been 0.08/3 inch (or 0.7 mm) different to that used by Maclear. Or it could be that LaCaille applied or ignored different sources of error equating to this magnitude.

### 3.6 Extension of the Arc

Hence Maclear decided on a 3º- 4º arc with terminal stations well away from any likely attraction. After many hardships he succeeded in this operation completing it during 1848. This set of values would give an arc of 4º 36' 48.60" and 1 678 375.7 ft or 1º = 363 796.62 ft or approximately 56 891.82 toise. This does not tally with the value quoted above of 56 932.5 t (But what feet - toise conversion was used? Remember French feet are to English feet as 1351.12 to 1440) and Maclear used Cape 10 ft standard bar A

*Accepted Amplitude* *4º 36' 48.60"*

*Accepted arc length* *1 678 375.7 ft*

*Accepted result* *1º approx. 56 892 toise*

## 4. 1859 BAILEY

Nothing further by way of systematic and accurate triangulation was done in South Africa until 1859 when a triangulation of the southern east coast of Cape Colony and what was then known as British Kaffraria was begun.[7]. This was to stretch for some 500 miles from Mossel Bay, Port Elizabeth and East London to the then Kei River Frontier of the Colony.

### 4.1 The Requirement for Geodetic Survey

Mapping an area the size of Africa presented very practical problems. McCaw illustrated this by showing that at Mpange at the northern extremity of the South African Arc (09º 41′ S) the discrepancy in latitude between the astronomical and computed or (A-G) amounted to +8.8 seconds of Arc when the chain was computed on the Clarke 1880 spheroid. If recomputed on a spheroid which best fits the South African Arc, it would decrease to +3.1 secs. The difference of 6 seconds amounts to a shortfall of some 200 metres. How should this be absorbed at the Tanganyika border?

If it were not absorbed, the error would get worse and positions further north would bear little relation to their actual positions on the earth. But this is not the whole problem.

McCaw listed the following practical uses of geodetic triangulation:
To prevent embarrassing accumulation of errors; to unify and coordinate all disparate surveys; to give them one origin and to combine them into one harmonious whole to avoid boundary disputes; to facilitate and cheapen topographical, cadastral, boundary, engineering, mining and geological surveys; to establish a feeling of public confidence and security in land tenure and to furnish perpetual points for the use of posterity.

## 5. 1879 - GILL AND FIRST WORK ON THE 30$^{TH}$ ARC

Circa 1875 F Orpen, formerly Surveyor-General of Griqualand West commented to A de Smidt -then Surveyor-General of the Colony of the Cape of Good Hope- that by determining the position of Douglas he found that in the maps current at that time, the whole of Griqualand was about a degree out of its true position. This fact was of sufficient importance for Smidt to put it in his Official Report of 1876 when stressing the necessity for a Trigonometrical Survey of the Colony on geodetic principles. He strongly stressed that Maclear's meridional arc survey and the Trigonometrical Survey by Captain Bailey should be extended. He was further able to illustrate the irreconcilability of the mapping of the time by referring to Colesberg, among other places, "…jostled about by successive compilers, in an erratic orbit of some 20 miles radius.

It was soon after this that David Gill entered upon the survey scene. As LaCaille and Maclear before him, Gill was a devoted astronomer. In 1874 he participated in an expedition to Mauritius to observe the transit of Venus and in 1877 he went to Ascension Island to observe the near approach of Mars to determine its distance. As a result he was well aware that a better knowledge of the figure of the earth would improve the results of the determination of the scale of the solar system.

During 1874-1876 Gill was in Cairo where he measured a 1 km baseline for the Survey of Egypt and also surveyed the Great Pyramid, apparently measuring its height and base to the nearest mm. He refers to the baseline he measured as "I myself measured the first base line intended as a commencement of the operation". Gill made this statement to Lord Lindsay in May 1875. By this he probably meant the start of the Survey of Egypt but he also expected that to later form part of the 30th Arc. Arising from this the Khedive invited Gill to become Director of Surveys but this offer was later withdrawn and Gill returned to London. It was then that he obtained the Cape Colony Observatory appointment.

Gill's interest in the arc measurement was thus mainly technical and scientific. In order, however, to fulfil his aspirations and to initiate this project he had to obtain the interest of the different governments and their financial support. There was then in South Africa a need to have all land surveys based on a principal triangulation. The benefits of establishing a continuous chain of measured triangles were fully realised. In this way the isolated surveys could be brought to a common basis which would prevent discontinuity of the various mapping and survey systems. Just before Gill's arrival at the Cape a big controversy was raging in the Cape Colony about the inadequacy of the existing system to control the survey of land and to ensure the reliability of surveyors' diagrams. A special Survey Commission was formed in 1878 which recommended that the geodetic chains established by Maclear and Bailey be extended and a secondary triangulation connected to them.

David Gill arrived in South Africa 25th May 1879 and brought with him a great interest in the shape of the earth as well as a passionate belief in the value of establishing, as quickly as possible in any developing country, a sound framework of geodetic triangulation on which to base any future topographical or cadastral work. In his Report of 1896 Gill said that

> *Soon after my appointment as Her Majesty's Astronomer at the Cape in 1879 I began to study the general question of the Geodetic Survey of South Africa. The tradition of my office appeared not only to justify but to demand that some portion of my time and attention should be devoted to this work.* [6] .

Gill continued:-

> *Sir Bartle Frere was then Governor of the Cape Colony and High Commissioner for South Africa. From his experience in Indian administration His Excellency thoroughly realized the advantages and the necessity for accurate survey, and the true economy of basing all future surveys upon a Principal Triangulation of such accuracy that its results might be considered definitive for all future time, and he gave my recommendations his strongest and most cordial support.*
>
> *These recommendations embraced a plan for a gridiron system of chains of principal triangulation extending over the Cape Colony, the Orange Free State, Natal and the Transvaal.*

Some of this enthusiasm could have been generated by his friendship with Otto Struve who had an interest in carrying on the work of his father F G W Struve whose name was given to the Struve Geodetic Arc. We know that between the transits of Venus of 1874 and 1882 Otto got to know David Gill. In addition Gill, in preparation for his new post in the Cape made a tour of the major European Observatories including Pulkovo where Struve worked. It is also apparent that Struve and Gill corresponded on a fairly regular basis certainly between 1881 and 1897. [3]

On 26th September 1879 Gill sent a memorandum to the Governor giving in great detail his grand scheme of principal triangulation. He commented on the good work of Maclear and of Bailey indicating that they were the only existing trigonometrical operations of any worth. He then put forward various recommendations for the future triangulation of South Africa. These included

> *A plan of value in a geodetic sense as contributing to our knowledge of the form and dimensions of the earth. The general principle of which is that upon which the Great Trigonometrical Survey of India is founded, viz the construction of chains of triangles in meridian and longitude series, and along coast and boundary lines.* [2]

This was accompanied by a map setting out the existing and possible nine new chains of triangulation. He defined and named the several meridian and longitude series of triangles, and indicated the whereabouts of the base lines which must be measured. He set out in clear and forcible terms the practical advantages to be gained from the triangulation survey, and also the scientific aspects of it. Among the chains he recommended was

> *The Meridian Series along the 30th parallel (sic) of E. Longitude, I look upon as the first step in a chain of triangles which ultimately will connect Natal with the Mediterranean and Alexandria.*
> *This is no exaggerated statement:*
> *The survey of Egypt along the Nile must come as a matter of necessity in course of time. … This chain of triangles could be carried without difficulty along the Nile to Lakes Albert and Victoria Nyanza. Thence the chain would have to be connected with Lake Tanganyiki and southwards to meet the Natal and Transvaal triangles at the Limpopo. … Perhaps the present generation will not live to see its completion, but it is a great work, that I believe will yet be performed if kept steadily in view.* [2]

Looking to Gill as basically an astronomer, such a well measured and long line was probably foreseen as a baseline for determining distances to such bodies as the moon, although he probably realised that this would only be a dream in his lifetime.

For the actual survey work on the various chains he recommended recruitment of persons who had experience with the Royal Engineers, the Survey of India or with the Ordnance Survey. Both of which latter organisations were apparently reducing staff. All to be under the direction of Her Majesty's Astronomer at the Cape with the organisation's central office at the Royal Observatory. Indirectly all this work was to be the foundation of the cadastral system of South Africa but rather like George Everest in India, Gill seemed far more interested in Geodesy than cadastral work. He saw the second and lower order work coming under a separate Surveyor-General's Department.

In a letter to Gill, General Walker of the Survey of India offered for free, one of the great theodolites and other equipment. Gill naturally followed this comment with a recommendation that application should be made to the Indian Government for whatever instruments could be spared. [2]

That the Great Theodolite of 36 inch diameter did arrive in South Africa is certain since it appeared on an inventory of the Observatory for 1902 and today resides in the Museum of the Chief Directorate of Surveys & Mapping in Cape Town. What is not known is how and when it arrived and for what tasks, if any, it was used. [8]

The Geodetic Survey started in 1883 and we also read that it was the same year that a detachment of British Royal Engineers arrived in Durban under the command of Captain Morris. They measured the Pietermaritzburg baseline using five Troughton & Simms ten foot wood-encased steel bars. The theodolite used by Morris was an 18 inch one which, with stand, weighed 260 lbs. So Gill had success in this direction as well.

Between 1895 and 1900 steps were taken to extend the geodetic framework from South Africa, largely into Rhodesia under the general direction of David Gill, but little topographic mapping was achieved other than by boundary commissions.
At the first South African meeting of the British Association in 1905, Gill gave a paper *On the Origin and Progress of Geodetic Survey in South Africa and of the African Arc of Meridian.* In reporting this Van der Sterr said, after brief comments on LaCaille and Maclear, that the real foundations for the geodetic survey of South Africa were laid by David Gill, H.M.Astronomer at the Cape from 1879 to 1907. The country owes him a big debt of gratitude. It is to his indomitable perseverance that we are now placed in possession of an accurate gridiron system of geodetic chains covering well nigh the whole of the Union and joining up with the Rhodesian triangulation. Much of the survey work was carried out by Col.William Morris.

Gill designed the gridiron network of trigonometrical chains to cover the then four states of South Africa: the Cape Colony, Orange River Colony, Natal and Transvaal. The triangles were of sides averaging 50-80 km in length. The scheme was prepared with the view of incorporating Maclear's and Bailey's triangulations within a network. As McCaw commented no one with a moderate knowledge of the writings of Sir David Gill could fail to be struck with the stress he laid upon the economic factor in Geodetic Survey. Though he could not overlook the scientific aspect he was much too interested in the development of South Africa to put forward, wittingly, a scheme opposed to the progress of the Sub-Continent. He realised that it was true economy to base all future surveys on a principal triangulation. It was he also who promoted the fundamental principle that survey should proceed from the whole to the part whilst others, who he described as short-sighted, supported and even advocated the contrary principle. He was also well aware that the comments above applied not only to S Africa but to all those countries through which the 30$^{th}$ Arc would go.

McCaw cited how the Arc was the basis of control in S Rhodesia; in N Rhodesia it formed the starting point for all Boundary and Topographical Surveys within reach of it; in Uganda, extensions from the Arc were being actively pursued in the 1930s; in Egypt it was the foundation of the whole system of survey, cadastral and topographic. In the Sudan at that time (early 1930s) the necessity for such control had passed beyond the realm of discussion and in Tanganyika the need was rapidly becoming obvious.

Gill knew that this great chain would be of the highest value to the science. It would contribute to a better knowledge of the form and dimension of the earth. Such a long arc would be a base for the calculation of parameters of a new ellipsoid best fitted for the whole African continent.

*On the immense importance of the proposed work as a geodetic operation it is unnecessary to dwell - the measurement of an arc of Meridian 65° in amplitude would be a gain to Geodesy so vastly important as alone to justify its inception*

To begin with, the African Arc took Gill a lot of effort and three years of correspondence with many governments and institutions. To obtain their interest and financial support in such a project, and to secure co-operation between them, was a difficult task as Winterbotham and Macleod were also to find, some 50 years later.
The proposed Meridian series along the 30th Meridian of East longitude, was an ambitious and daunting proposal. Travel was still by horse or on foot except where the occasional railway or river and lake steamers could be used. Gill would have to persuade the home or colonial governments to fund large sections of the work. The surveyors would be exposed to malaria, sleeping sickness and bilharzia. There is no doubt that Gill's own enthusiasm was the fundamental inspiration for the whole project.[10]

Gill eventually succeeded in gaining approval from the Governors in the Cape Colony and in Natal to undertake the principal triangulation of both colonies as a joint work and this was commenced in 1883 by a party of Royal Engineers under the command of Captain Morris and completed in 1892. The geodetic survey of South Africa could now proceed, thanks to Sir David Gill, its promoter, inspirer and scientific adviser. It meant that the survey of the Arc of the 30th Meridian of the East Longitude was also initiated - a huge project which was completed 70 years later:
Natal proved to be a less than enthusiastic partner and several times threatened to withdraw support but Gill and Morris always succeeded in pressing their case. In his report of 1896, Gill continued to enthuse about the ultimate aim, which he now saw as even farther north.

On the centenary of Gill's birth Whittingdale, Director of Trig Svy said:

*... he virtually assumed the position of Honorary Director of Geodetic Survey for the African sub-continent and untrammelled by Service regulations and normal administrative control, he dealt directly with governors and administrators, ordered his own equipment, appointed the staff for the work on his own terms of service and generally got work done in a way that would be quite impossible for the most competent salaried official to do in any one of the seven different governments he had dealings with in the course of his amazing career.*

Future researchers will find that much has been written about the Arc of the 30th Meridian. There are many publications, papers and technical reports relating to this huge project. The geodetic survey of Southern Africa has been scrupulously documented in six volumes from 1896 to 1933. Various other reports give details with regard to the technical aspects of the surveys or to its history.

*He agitated for the measurement of an arc of the 30th meridian crossing all of Africa. The total length of this arc would be around 66 degrees. But it could yet be much augmented, when by a triangulation in the Levant one could join the measures made in Africa, to the grand arc of Struve which extends from the North Cape in Norway as far as the southern frontiers of Russia.* The total length of* *this arc would be 104 degrees; it is the greatest arc of the meridian that one could possibly measure on the earth's surface. This project of Sir David Gill was presented to the XIIIth International Conference for Geodesy held in Paris in 1900.*

* At that time the "southern borders of Russia" coincided with the River Prut i.e. the western boundary of the modern Moldova where it meets Bulgaria. However this was a very flexible boundary and depends on just what Gill understood by the "frontier of Russia" which could have been the frontier of Russian influence.

> *… the gratitude not only of the Colony, but of all of whatever nationality who take an interest in the scientific delineation of the form and features of the earth's surface, is due to the eminent Astronomer, Mr. David Gill, … for the conspicuous ability displayed throughout, and for his unwearying devotion to this noble cause, and for the successful results achieved in the Geodetic Survey in conjunction with Colonel Morris, … upon whom the chief part of the execution of the survey devolved, …*
>
> *… the confident forecast of H.M. Astronomer at the Cape, that at no distant date the Geodetic Survey of South Africa will be extended northwards through the Continent, … to the Mediterranean.*

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## BIOGRAPHICAL NOTES

**J.R.(Jim) Smith** began his career as a surveyor in local government in UK, then in Western Nigeria and in 1964 he joined Military Survey as a civilian. In 1968 he became a lecturer in surveying to Civil Engineers at the University of Portsmouth. After some 20 years there he was principal lecturer at the time he took early retirement. He is currently the Editor of *Survey Review* and Hon. Sec. of the History section within the International Federation of Surveyors (FIG). He was active for many years in both the Royal Institution of Chartered Surveyors and the Institution of Civil Engineering Surveyors; and was involved in both British Standards and International Standards. He has written several technical books on surveying topics including

1986. *From Plane to Spheroid. Determining the Figure of the Earth from 3000 BC to the 18$^{th}$ Century Lapland and Peruvian survey expeditions.*1986

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From 1994 to 2005 he was involved with others in the preparation of a submission to UNESCO seeking recognition of the Struve Geodetic Arc as a World Heritage Monument. This was achieved in July 2005.

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