

The Moving Tropic of Capricorn

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Abstract

Curiosity about the placing of the monument marking the Tropic of Capricorn on Botswana's A1 road between Mahalapye and Gaborone reveals that: it is actually some 7 kilometre south of the correct position, that the line of the True Tropic is constantly moving; that it moves through a range of 267 kilometres and that Gaborone city misses inclusion in 'the tropics' by a bare 10 kilometres!

As one drives north along the A1 main road from Gaborone to Mahalapye, a road sign draws your attention to a monument on the east side of the road at the turn off to Buffels Drift, which marks the Tropic of Capricorn. The monument is a cement block with a short length of pipe supported vertically over its upper surface. On a brass plaque on the north side of the block is the following legend:

"This point is on the Tropic of Capricorn, which is the most southerly latitude reached by the Sun. Here the Sun will be at the zenith each year on Midsummer Day at mid-day local apparent time which is on 22 December at approximately 12 minutes past 12 O'clock noon. At the above time the Sun will shine directly down the tube above this notice." (Note 1, below)

The plaque on the south side displays the same information in Setswana.

I have never managed to be at this place on the day in question but have often wondered about the monument itself. This interest grew when I noticed that, during re-alignment and upgrading of the road, it had been moved to a temporary position at one side and was later relocated but in a totally different position on the opposite side of the road.

I wondered: "Why was it not put back in the same place" and, since it was in a different position, "how accurate was the new position, and, if they were different, which of the two had been 'wrong'?" The enquiry led to some rather interesting insights about our Earth and the manner in which it orbits about our Sun.

As we remember from our school geography, the Earth is one of eight planets that orbit the Sun, each at increasing distances from it. They all orbit in the same plane but a number rotate around an axis that is NOT at right angles to that plane. Earth, for example, is off-set by 23.5 degrees and this rather extraordinary fact accounts for the passage of the seasons. Were it not so, every place on Earth would have, essentially a 'fixed' climate, one that hardly varied at all through the year: there would be no winter, no summer, no seasons and much less habitable earth for humans to occupy.

In addition to being at an angle to the plane of the ecliptic, the Earth does not spin flawlessly on its axis, but displays a very slight 'wobble'.

In the 1920's, a mathematical scholar named Milutin Milanković, a Serbian geophysicist and astronomer, studied this and other very small inconsistencies in the Earth's orbit and rotation and as a result he was able to establish that the 'wobble' causes the angle of the Earth's tilt towards the Sun to vary between 22.1° and 24.5° degrees (a total of 2.4°) over a period of 41,000 years. This calculation has many times been confirmed.

In geography we learnt that the so-called 'Tropics' are imaginary lines that circle the earth and are defined by the most northerly (Cancer) and southerly (Capricorn) points on the Earth's surface where the Sun can still be vertically overhead at the mid-point of summer (June in the north and December in the south). We also learnt that these lines were located at 23.5° north and south of the equator.

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Following Milanković's observations we know that, because of the Earth's 'wobble', the angle of the Earth to the Sun drifts from the generally accepted 23.5° north or south of the equator, and so too, therefore, must the position of the Tropics alter in the same manner. As that drift ranges through 2.4°, obviously the Tropics must move north and south by that same amount and they do it, according to Milanković, over the time span of 41,000 years.

From their most southerly position, for example, they move north over a distance of 2.4° in the course of 20,500 years and then move back south over the same distance in the next 20,500 years, completing the whole cycle in 41, 000 years. In this essay, I refer to these moving Tropic lines, as the 'True' Tropics. At the moment, the angle is at 23.44° and is decreasing¹ (in other words, the line of the True Tropic is moving north).

The distance of 2.4° over the Earth's surface in Botswana's part of the world (the Earth is not an exact sphere so there are slight differences, depending on where you are) is calculated as follows:

$$\begin{array}{l} \text{Circumference of the Earth along a north-south} \\ \text{meridian beside the AI road in Botswana} \end{array} = 40,075.16 \text{ kilometres}^2$$

$$\text{This is equal to } 40,075 \times 1000 \text{ metres thus} = 40,075,160.00 \text{ metres}$$

If we divide this number by 360 – being the number of degrees in a circle we get:

$$\frac{40,075,160 \text{ metres}}{360 \text{ degrees}} = 111,319.88 \text{ metres per degree}$$

We know from Milankovic that the line of the True Tropic is going to move and cover a range of 2.4° over the Earth's surface in the course of 20,500 years, so we can say that, in that time, it will move a total of 111,319.88 metres/degree x 2.4° which is:

$$111,319.88 \times 2.4 = 267167.71 \text{ metres}$$

or

$$267.17 \text{ kilometres in 20,500 years}$$

Thus, we can say the line of the True Tropic will move 267 kilometres in that time and that this equates to approximately:

$$\frac{267,167.71 \text{ metres}}{20,500 \text{ years}} = 13.03 \text{ metres a year or a little over a metre a month! (Note 2)}$$

It is quite extraordinary to think that the Tropics move as much as they do.

This means, for people in Botswana, for example, that Mahalapye will, one day, be ‘out’ of the Tropics and that Phakalane, a residential suburb a little to the north of Gaborone will, one day, be ‘in’ the Tropics!

With an understanding of how the Tropics move, I became curious to know where, exactly, the original monument was placed and whether or not it had been placed on the True Tropic or on the ‘Geographical’ Tropic.

It was in October 1970 that Mr J.W. Bate of the then Department of Surveys and Lands, at the request of the Roads Department, calculated the position of the Tropic of Capricorn and had it marked with the monument on the A1 north.

In those days, there was no Global Positioning System (GPS) and whilst today one would simply use a GPS to determine where the line of Tropic lay, and refine that position more precisely from there, in 1970 that was not quite so easy.

Bate had to first find his position on the Earth’s surface: obviously he tried to get as close to where he thought the Tropic was and chose a base station from which to work. By measuring the positions of seven pairs of North/South meridian stars and working with chronometer corrections taken from a radio time station, his results show that the point from which he started was at 23° 30' 03.8" South, and from here he calculated that the Tropic lay 383' (feet) north of his base station. This calculation was, he claimed, accurate to the nearest imperial foot (i.e. with an accuracy of 304.8mm)³. And it was at this calculated position that the monument was erected.

It took me some time to realise that Bate was not seeking to locate the then True Tropic: he was seeking rather to mark on the ground the ‘Geographical’ position of that feature. He was trying to pinpoint 23° 30' 00" South – and he did this with remarkable accuracy and that is where the monument was first placed in October 1970.

So the answer to my first question: “Where was the monument originally placed?” is that it was placed by John Bate on the line of the Geographical Tropic, i.e. at a point 23° 30' 00" South of the equator.

In 2004 rehabilitation of the A1 north was begun. It became clear that the re-aligned road would overlay the 1970 position of the monument and for this reason it was to be moved. The task was the responsibility of the contractors and they engaged a Mr Faan Potgieter, a South African surveyor, to undertake the task⁴.

Potgieter first established the exact position of the Bate monument and marked a new position for its re-erection on the East side of the new carriageway (it had originally been on the west side of the ‘old’ road).

He reported the positions as follows⁵:

<i>“The existing position of the Tropic of Capricorn</i>	
<i>Y 39513.02</i>	<i>X 2599669.71</i>
<i>The relocated position of the Tropic of Capricorn”</i>	
<i>Y 39473.02</i>	<i>X 2599669.71</i>

(The above co-ordinates are typically those used by surveyors. They represent a metricated rectangular system of co-ordinates (Projection: Gaus Conformal, Datum: Cape South Africa also known as Universal Transverse Mercator) and are employed simply because calculations are easier than the otherwise identical Geographical System based on Degrees, Minutes and Seconds. Conversion from one to the other is a very simple exercise.)

The reader will notice that the two ‘X’ co-ordinates are the same. This shows that the two positions are on the same latitude and if one deducts the ‘Y’ co-ordinates it is seen that the new position is 40 metres to the east of the original position.

Potgieter merely re-located the monument to a safe position on the opposite side of the new road, 40 m away but on the same latitude as that used by Bate.

I had now established the reason why the monument was not back in its original position, after the road had been re-aligned. It was on the opposite side of the road because its original position was under the new road. I had also established that the 1970 and the 2006 monument positions were on exactly the same latitude, thus the accuracy of the original placement has been perfectly preserved. It had also been verified that both locations of the monument were on the Geographical Tropic and NOT the True Tropic.

These conclusions suggested several new questions: “As the monument is not on the True Tropic, how far is it out of position and in which direction does the True Tropic lie?”

What is of further interest is to calculate how much the Tropic has moved in the 42 years since the monument was first put in place.

We know that it was located at 23° 30' 00” South in 1970 and that it is still on that latitude today.

By reference to astronomical tables it can be ascertained as follows^{6,7}:

Table 1: Actual true position of the Tropic of Capricorn

(Note: these figures neglect nutation - an additional but separate ‘wobble’ in the Earth’s rotation about its axis. Nutation has a 19 year cycle and, if it is included in the calculations the 2012 error amounts to 1007.46 m in 42 years or an average of 23 m/year. This is a significant difference but its inclusion or exclusion is a matter for specialists to decide, see Note 2 below.)

Date	Position of ‘True’ Tropic calculated from astronomical dat	Monument position	Total lapse of years	Distance from 1970 position in minutes & seconds of arc	Distance between Monument and ‘True’ Tropic
<i>1970, 15th October</i>	<i>23° 26’ 35.123”</i>	<i>23° 30’ 00”</i>		<i>3’ 24.877”</i>	<i>6302.85 metres</i>
<i>2012, 23rd October</i>	<i>23° 26’ 15.452”</i>	<i>23° 30’ 00”</i>	<i>42</i>	<i>3’ 44.548”</i>	<i>6907.56 metres</i>

From this table we can see that the ‘True’ Tropic has moved from 23° 26' 35.123” which is where it was in 1970 to 23° 26' 15.452” in 2013, a total distance of 604.71 metres. Clearly, it is moving north. We can also observe that when the original monument was placed in 1970 on the line of the Geographical Tropic is was already 6303 metres south of the True Tropic.

This means that the monument to mark the Tropic of Capricorn in Botswana is technically wrongly placed and is now, in 2013, some 7 km south of where it should be.

From this table we can also calculate the rate at which the True Tropic moves:

Total years:	42
Total Distance:	604.71 metres
Distance per year:	14.397 metres per year

And we can see in this instance, that the True Tropic moves at about 14.5 metres per year (or, again, a little over a metre a month). This is very close to the theoretical figure mentioned above (again refer to Note 2 below).

- There are several interesting conclusions from these foregoing:
- Even if there is dispute over the rate of change it is clear that the True Tropics do move and that no monument can ever be and remain ‘exactly’ on the actual line of the Tropic. Wherever it is placed, like a stopped watch, the monument can only ever be absolutely correctly placed twice in 41,000 years!
- It is tempting to think that the Equator must also move in ‘lockstep’ with the Tropics: but this is wrong. If it were defined as the point half-way between the two True Tropics then, indeed, it would so move. However, it is defined as the point half-way between the Poles and so the moving Tropics approach it and withdraw from it but the Equator itself does not move.
- The location, in Botswana of the monument on latitude 23o 30' 00” South is sound sense.
- Gaborone, near the most southerly reach of the Tropic’s travel, misses being labelled a ‘tropical destination, by only ten kilometres!

Notes:

Note 1.

This is variable, and may be part of the effect that you see. The time when the Sun reaches its most southerly declination will, in general, not be at local noon, because of the non-integer number of days in a year. Some years the solstice may be closer at noon on 21 December. This year (2013) the solstice will be at 12:11 on 21 December. By noon on 22 December, the Sun will have moved slightly north of its most southerly declination. That can be calculated to first order with a sine wave ⁸.

Note 2.

For the sake of simplicity, I have treated these calculations as linear whereas, in fact, the motion will be, to first order, sinusoidal. The effect will be that reality may vary somewhat from my figures throughout the full cycle with the greatest variation occurring at the extremes of the wave. This linear calculation is therefore not absolutely correct so it is better understood as an order of magnitude: a useful and interesting guide! ⁹

1. *Loaring, Nicola:* *Personal communication, South African Astronomical Observatory, Cape Town, South Africa.*

2. *Wikipedia* *Internet: diameter of the Earth*

3. *Bate, John:* *Placement of Tropic Beacon, Surveys and Mapping Department, Internal memorandum, Government of Botswana, Gaborone 1970.*

4. *Potgieter, F:* *Personal communication*

5. *Horn, C:* *Letter to Department of Survey and Mapping from Buka Projects, containing the report of F. Potgieter on the relocation of the Tropic of Capricorn Monument. Surveys and Mapping Department, Government of Botswana, Gaborone 22.06.2006.*

6. *[http://www.neoprogrammics.com/obliquity of the ecliptic/](http://www.neoprogrammics.com/obliquity_of_the_ecliptic/)*

7. *Loaring, Nicola:* *Personal communication, South African Astronomical Observatory, Cape Town, South Africa.*

8. *D. Kurtz, Prof.:* *Personal communication, Preston University, United Kingdom*

9. *D. Kurtz, Prof.:* *Personal communication, Preston University, United Kingdom*