AN ANCIENT CHINESE FLAT EARTH COSMOLOGY

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(This is the text of a paper read at the London Ancient Science Conference, February 17, 2016.
Disclaimer: in this paper I only present the main features of the *gai tian* system as an extraordinary intellectual effort, leaving out many details, such as numerous calculations, several problems that are inherent to the system, the usual interpretation of the sunlight as a cone, the different number of the radius of the area of sunlight, the flat heavens represented as a Chinese hat, and so on. A fuller account will appear in March 2016 in the second volume of the *Tsinghua Journal of Western Philosophy*, and an even more extensive one in my forthcoming book *When the Earth Was Flat*).

In all civilizations, people believed that the earth is flat, until in ancient Greece the idea of a spherical earth emerged. In China the belief in a flat earth lasted until the end of the sixteenth century, when catholic monks told them the new world picture, albeit not that of Copernicus, but that of Aristotle. Almost all Presocratic cosmologists, too, conceived of the earth as flat, although perhaps somewhat concave. The usual picture was that of the dome of a hemispherical or spherical heaven over or around the flat earth. Not surprisingly, this conception yielded some difficulties that were hard to cope with. Here I will only mention two of them, as they are the most relevant in the context of this paper. In the first place, on a flat earth it is always everywhere the same time. When the sun rises, it rises over the surface of the entire flat earth, and when the sun sets it gets dark all over the flat earth. Or, in the words of Ptolemy: "if the earth were flat, the stars would rise and set for all people together and at the same time".[1] That at least some of the Presocratics were aware of this problem is clear from an otherwise enigmatic report on Archelaus, who pleads for a concave earth, because "the sun does not rise and set at the same time for all men, as would inevitably happen if the earth were flat".[2] The second problem was the tilt of the celestial axis. The heavenly bodies seem to orbit around an apparently arbitrary fixed point in the northern heavens. In Presocratic Greek cosmology, the tilt of the heavens was a recurrent topic. As Furley writes: "they commonly explained this by the *ad hoc* assumption that the heavens tilted somehow, after the formation of the earth".[3]

In the centuries before the beginning of the Christian era, Chinese astronomers developed a very ingenious flat earth cosmological system, called *gai tian*, which resulted in a conception of heaven and earth fundamentally different from the ancient Greek one, and in which both problems found an elegant solution. Next to some additional sources, the main source of our knowledge of the system is a book called *Zhou bi* ('gnomon at Zhou'), brilliantly translated and commented by Christopher Cullen.[4]

In the *gai tian* model, the heaven is thought to be a flat disk, parallel to the flat square earth. In due time the *gai tian* was replaced by the rivaling system called *hun tian*, which was more like the ancient Greek cosmology. Nevertheless, as a whole the *gai tian* was an intellectual achievement of the first rank and by far more powerful in producing

[1] Ptolemy, *Almagest* I.4, transl. R. Catesby Taliferro 1952.

[2] Hippolytus, *Ref.* 1.9.4 = DK 60A4. It has been often noted that a concave earth would lead to phenomena contradictory to simple observation. Ptolemy (*Almagest* I.4) already remarked: "if the earth were concave, the rising stars would appear first to people towards the occident" Dmitri Panchenko (1999) has ingeniously argued that what Archelaus must have meant is that the earth was concave at the bottom, and thus convex at the upper side, just like Achilles' shield can be called both concave and convex.

[3] D. Furley 1989, 12 n.32.

[4] C. Cullen 1996.

calculations than the ancient Greek flat earth cosmology. In this paper I can only offer an impression of its basics, the main outlines and some details. A fuller account will appear in an article in a Chinese journal and in my forthcoming book *When the Earth Was Flat*.

The words *gai tian* mean 'canopy heaven'.

Figure 1 A wooden horse-drawn chariot unearthed from a Han dynasty tomb

Already an ancient source, from about 300 BC, uses the simile of the chariot and its canopy: "The squareness of the chariot is to represent Earth; the roundness of the canopy is to represent Heaven". In the *gai tian* model the celestial bodies turn around the celestial pole in daily orbits in a plane parallel to the earth's surface. The celestial axis stands perpendicular upon the earth, just like the stick of the canopy on the chariot in Figure 1, and not slanted as in Presocratic Greek cosmology.

The argument behind this is probably something like the following: there must be a place on earth where an observer, if he were able to reach that point, would be right under the pole of the heavens. The Chinese astronomers imagined what an observer at the sub-polar point would see: sun, moon and stars orbiting overhead in circles. This image was the starting point for their conception of the heavens

Figure 2 A time exposure photo of the stars circling around the pole

In the *gai tian* model, for an observer anywhere on earth the direction of 'north' is always from the observer to the pole, and 'south' is the opposite direction. As a consequence of this, the four cardinal directions (north, south, east, west) are not absolute, but depend on the position of the observer. Actually, although 'north' is always the direction towards the pole, each place on earth has its own north-south and east-west coordinates, as is shown in the next picture for three at random placed observers (the three little squares). However, although going north and south is moving in a straight line to and from the pole, going east and west is moving in a circle around the pole. This is how the model explains why we see new stars when going south, therewith demonstrating the insufficiency of this phenomenon as an argument for the sphericity of the earth (as in Aristotle's *De Caelo*).

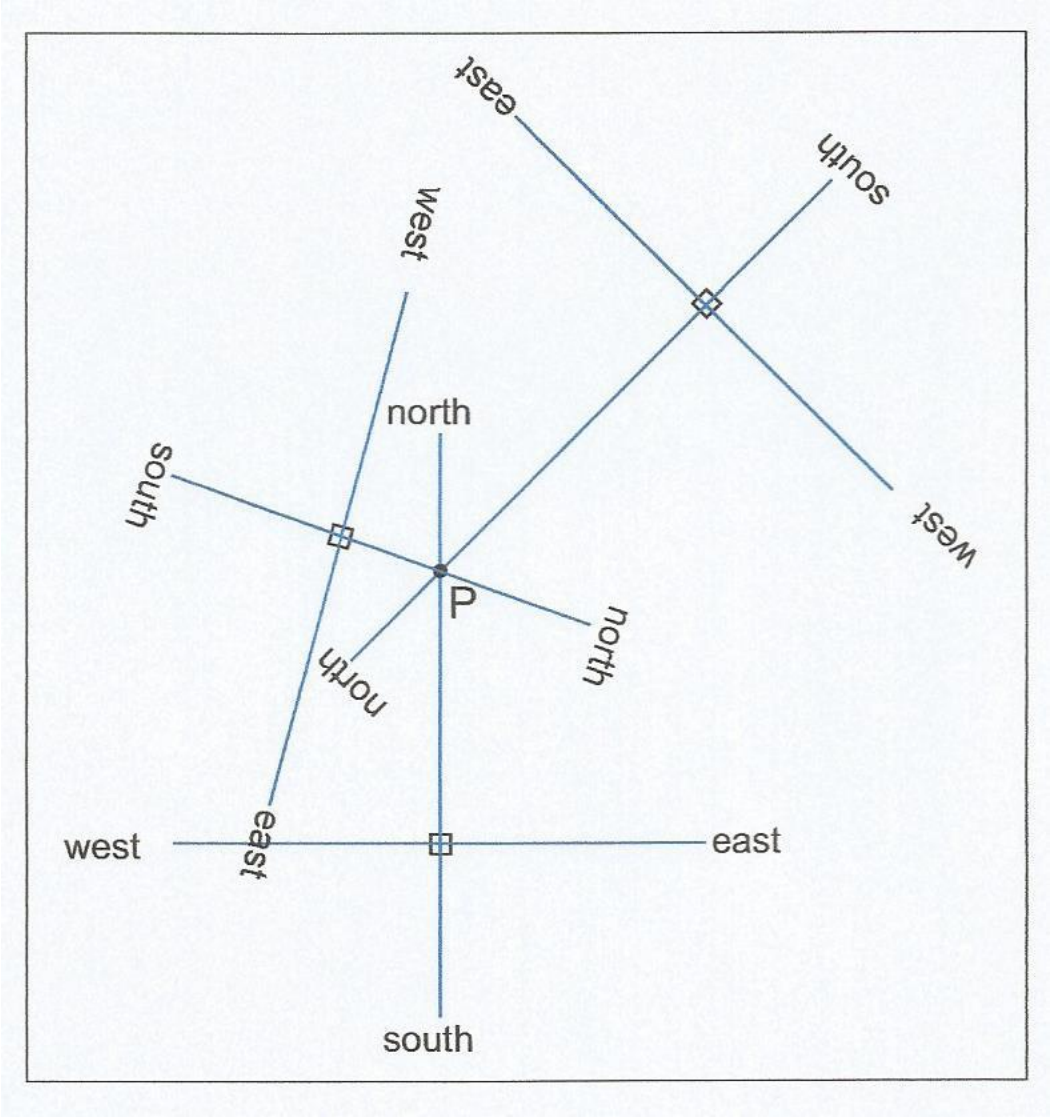

Figure 3 The four cardinal directions for three different observers (plan view)

The model pays special attention to the movements of the sun, making the width of its orbit around the pole vary with the seasons. Because the pole around which the sun rotates has its counterpart on earth right underneath it in the subpolar point, the circles described by the sun also have their counterparts on earth. This means that the tropics and the equator are not only circles in the flat sky, but also circles on the flat earth.

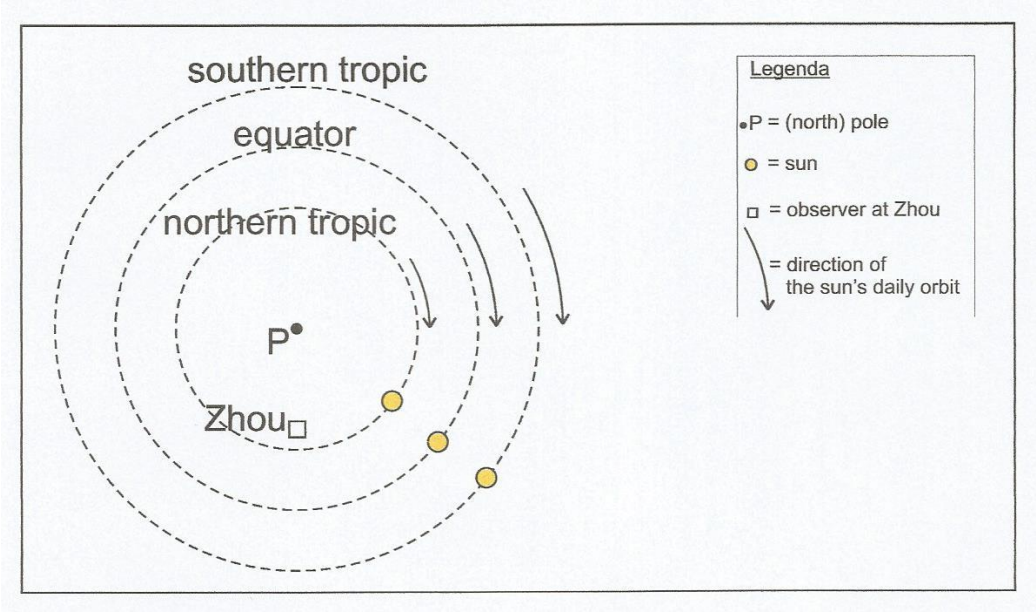

Figure 4 The *gai tian* model of the heaven according to the *Zhou bi* (plan view)

In this picture also the dimensions of the tropics and the equator, as well as the distance from the pole to Zhou are rendered. I will return later to the method used for these calculations.

Another important element of the model, not explicitly mentioned in the *Zhou bi* but in other sources, is that the horizon, where heaven and earth seem to meet each other, is an optical illusion: in *gai tian* reality earth and heaven are two planes at a certain distance from each other. Accordingly, the phenomena of sunrise and sunset (and the risings and settings of the other heavenly bodies) are optical illusions as well. In reality the sun does not set, but disappears out of sight, just like a man with a torch walking away from us. So there must be some gradual decline by which the sun is seen lowering and attaining the horizon, although in the *gai tian* reality it is always at the same distance from the surface of the earth.

In order to understand the full impact of this, we must discuss two interrelated notions: the range of visibility and the area of sunlight.
When I am in a room without windows, my vision is limited physically by the four walls around me, the ceiling above my head, and the floor under my feet. In the *gai tian* model, my vision is limited again, by the ground under my feet and by the heaven above my head; but around me my vision is also limited, even though there are no physical walls. My power of vision does not extend infinitely, but has an absolute limit beyond which I cannot see. This limit shows itself where the two planes of earth and heaven come together at the horizon. The horizon defines the limit of my range of visibility, which in the *Zhou bi* is called 'the distance to which human vision extends'. If there were not the flat earth underneath me and the flat heaven above me, the complete shape of my range of visibility would be a sphere around me.

We get the actual extent of the range of visibility when we draw between the earth and the heaven a part of a sphere with the observer in the center and with a radius that equals the distance between the observer and his horizon. The resulting slice of a sphere is the actual range of visibility. The limits of the range of visibility also determine where we see the heavens as an optical illusion.

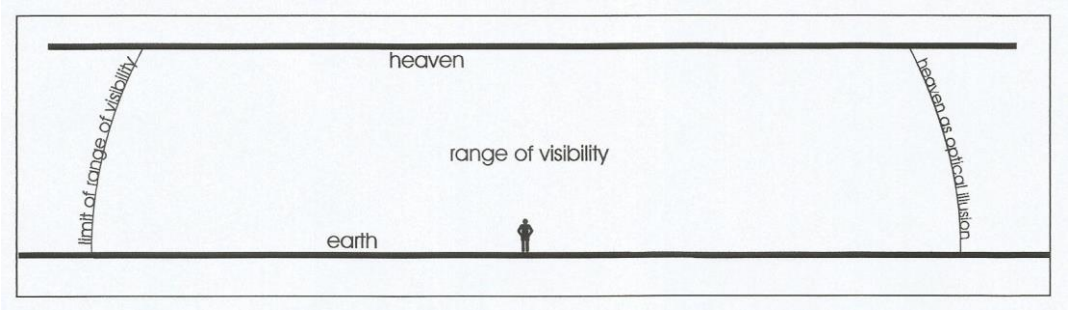

Figure 5 The limited range of visibility and the horizon as an optical illusion (elevation view)

Similar bounds hold for the sun: the light of the sun, like any other light, has a limit beyond which it cannot reach. The best way to imagine this is a sphere of light all around the sun. Outside the sphere of light it is dark. This sphere is also cut off above by the plane of the heaven and below by the earth's surface, which results in a slice-of-a-sphere shaped range of sunlight between heaven and earth, throwing a circular area of sunlight on the surface of the flat earth.

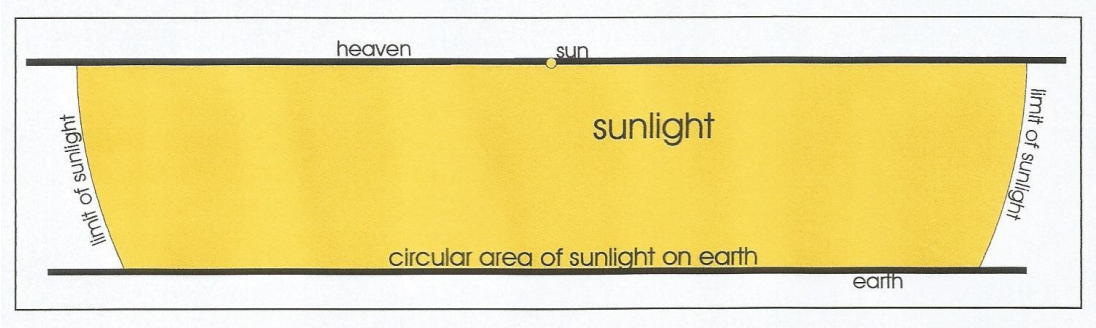

Figure 6 The limited reach of the light of the sun and the circular area of sunlight on earth (elevation view)

According to the *Zhou bi* the range of visibility is identical in size with the area of sunlight, which is logical when you think about it. This is shown in the next picture, in which the interrelation of range of visibility and area of sunlight is visualized.

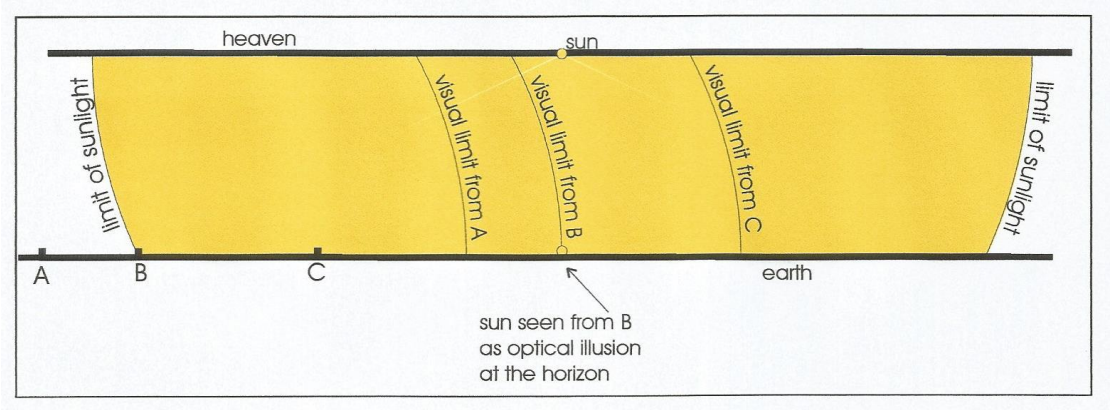

Figure 7 The interrelation of range of visibility and area of sunlight (elevation view)

An observer at A, standing outside the area of sunlight will not see the sun. His range of visibility does not reach unto the sun, and the light of the sun does not reach him; for him it is night. When he approaches the rim of the area of sunlight (or when the area of sunlight approaches him), as in B, he will see the sun (albeit as an optical illusion) at the horizon. Accordingly, the radius of his range of visibility equals the radius of the area of

sunlight. When he further enters the area of sunlight, he will stand in broad daylight, as in C, and if he would go further southwards, he could even come at a subsolar place, where the sun is right above his head.

When we draw this in plan view, we see that the sun throws a circular area of light upon the earth. Inside that circle it is day, outside that circle it is night. In Figure 8 it is sunrise at Zhou.

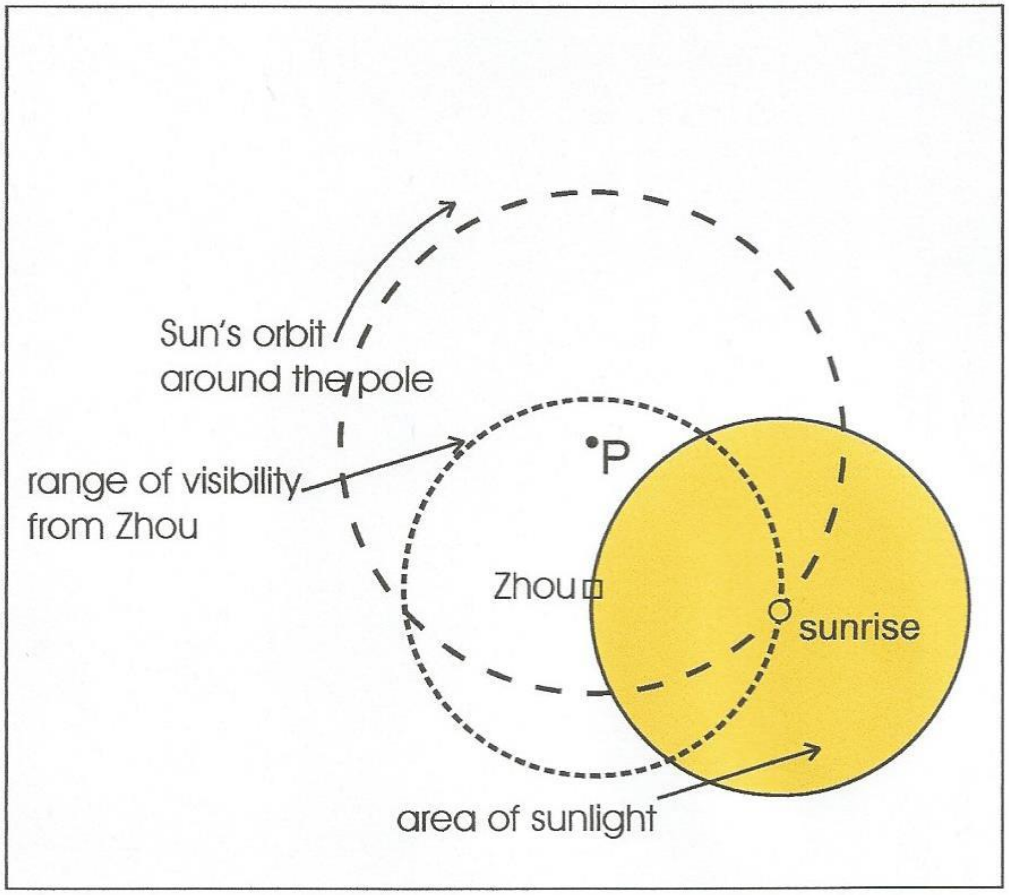

Figure 8 The circles of the area of sunlight and the range of visibility in plan view; sunrise at Zhou

This picture shows most clearly the elegant way the *gai tian*, with its combined concepts of the area of sunlight and range of visibility, solves the problem of time differences on earth. Whereas in the Presocratic flat earth system with its (hemi)spherical heaven the sun rises and sets at the same time all over the earth and it is always everywhere the same time, in the *gai tian* system every place has its own time; when the sun rises at Zhou, it sets at another place, and at yet another place it is night. In the next picture it is noon at Zhou.

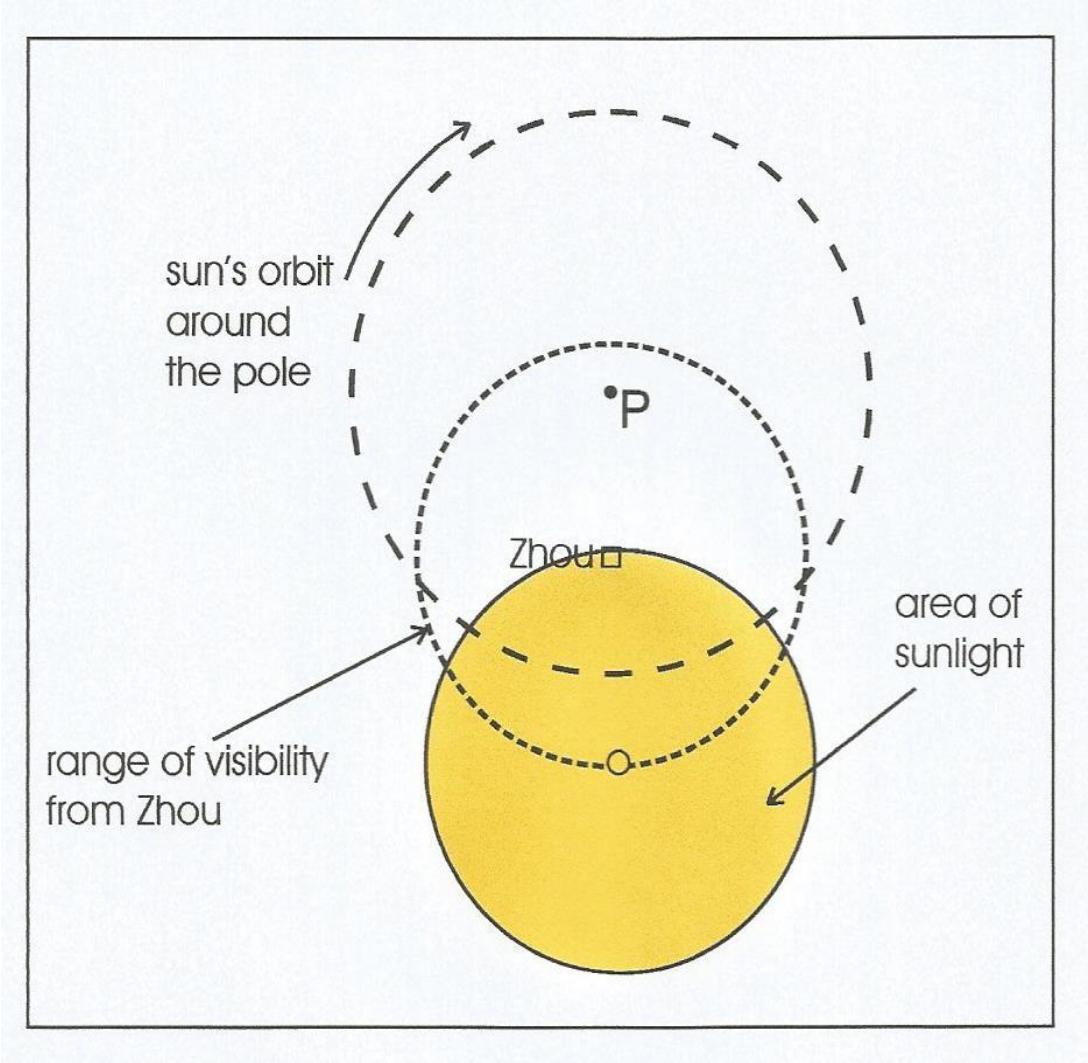

Figure 9 The circles of the area of sunlight and the range of visibility in plan view; noon at Zhou

And in the next one it is sunset at Zhou.

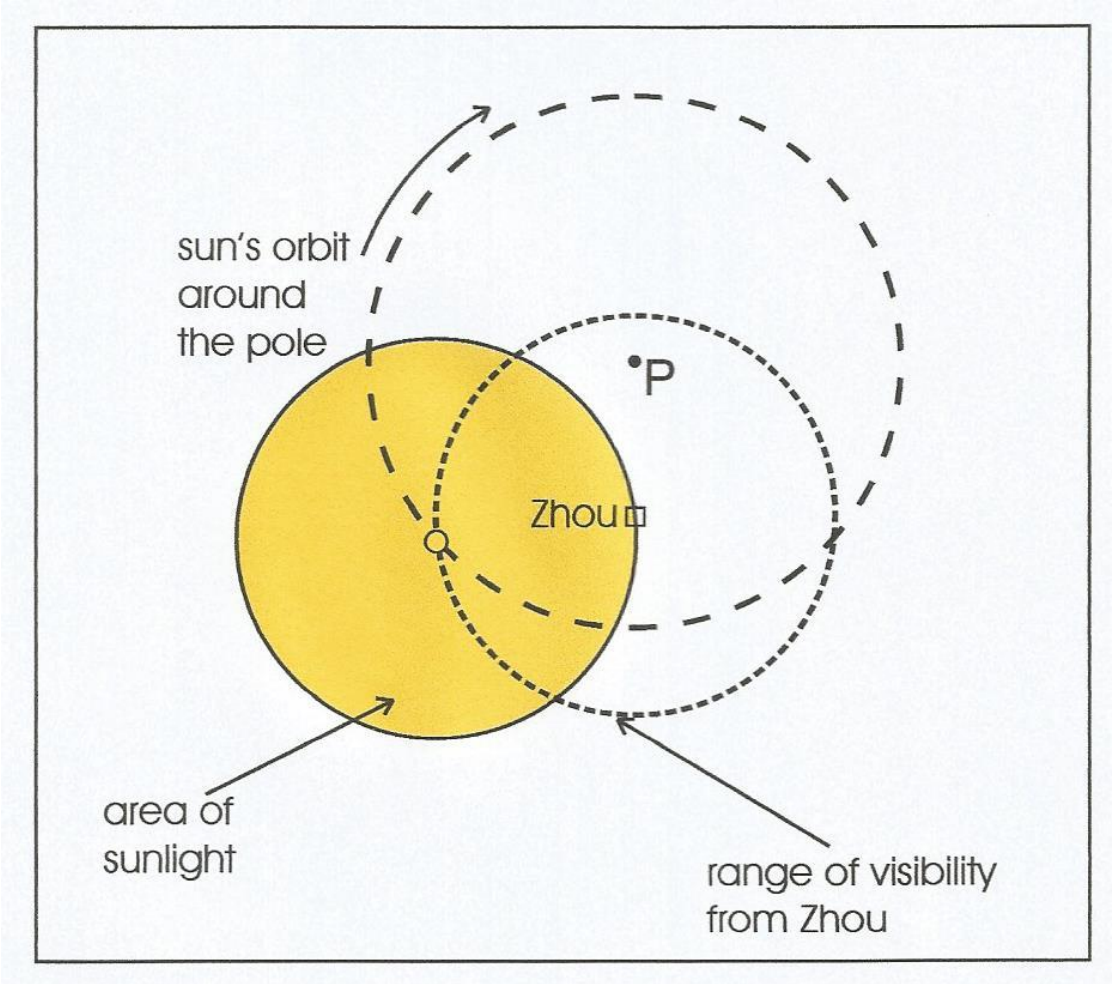

Figure 10 The circles of the area of sunlight and the range of visibility in plan view; sunset at Zhou

And finally it is night at Zhou.

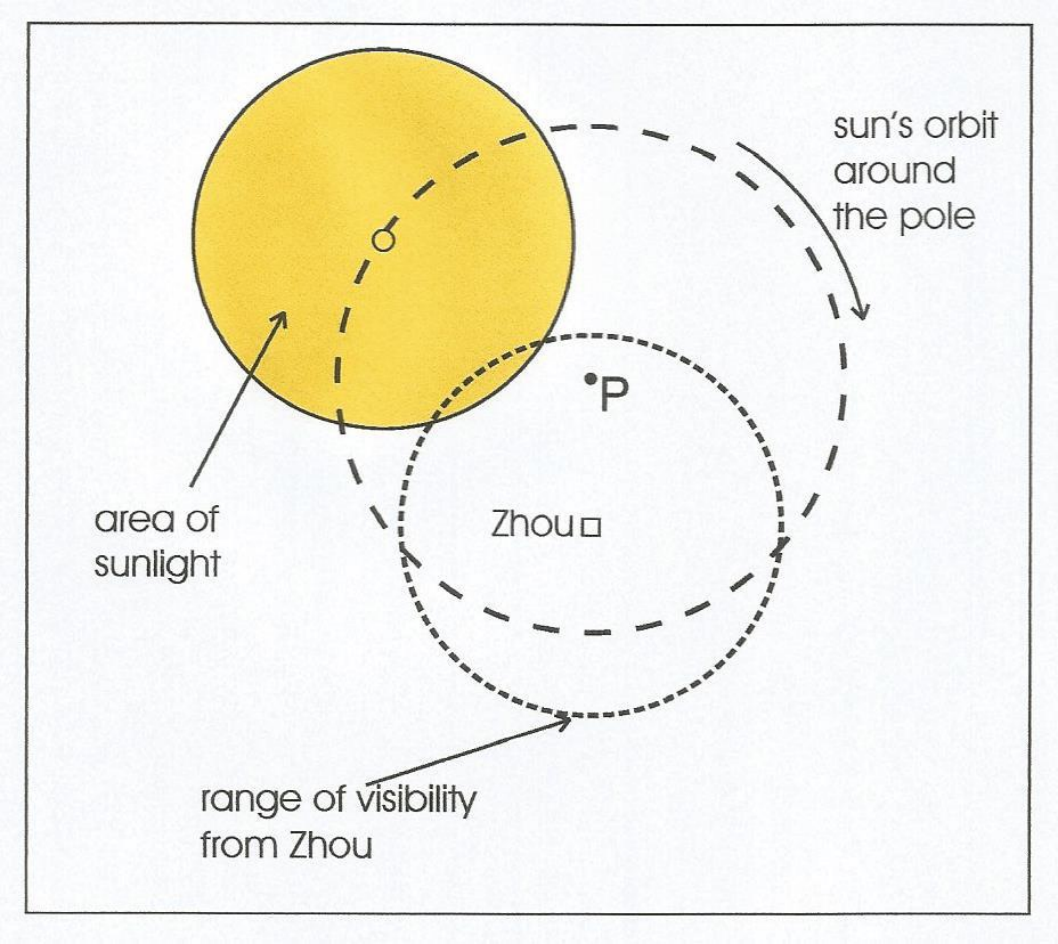

Figure 11 The circles of the area of sunlight and the range of visibility in plan view; night at Zhou

In the next picture we see a three-dimensional image of the *gai tian* model with the blue circle of the heaven over the green square of the earth, and the yellow area of sunlight in between. It is night at Zhou.

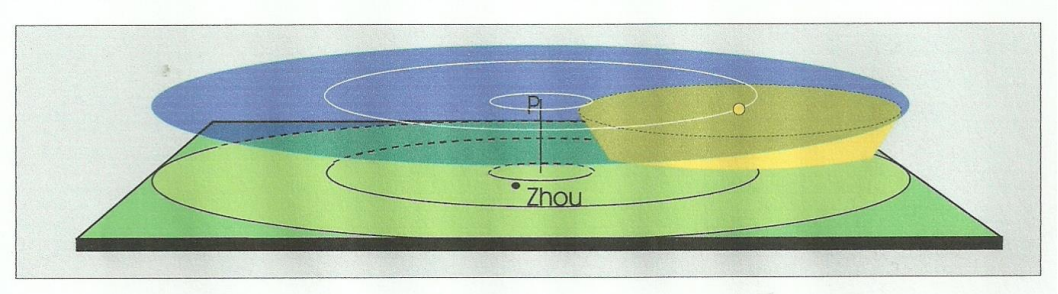

Figure 12 The *gai tian* conception of heaven and earth; it is night in Zhou (three-dimensional view)

Thus far we have seen three equations: the range of visibility is equal to the area of sunlight and to the distance of the observer to the horizon. There is, however, a fourth equality. For an observer at the subpolar point, at the equinoxes the sun circles around the horizon. This is the case on our spherical earth but also on the flat *gai tian* earth. Obviously, the Chinese astronomers had discovered that at noon at the equinox the angle between the celestial pole, the observer, and the sun equals 90°.

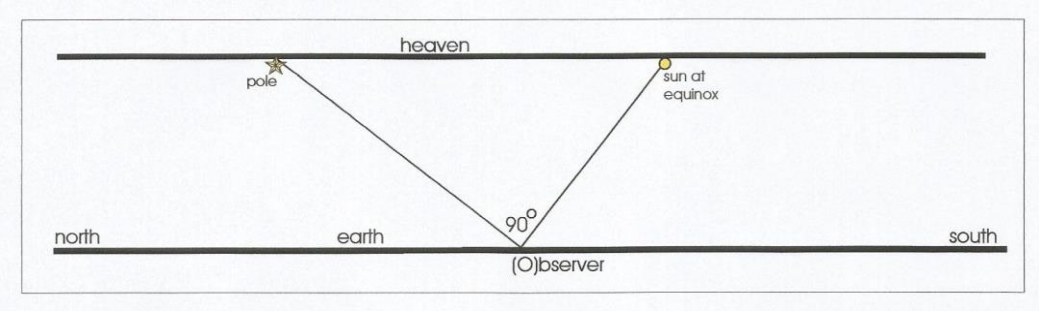

Figure 13 The angle between the pole and the sun at noon at the equinox

This means that for an observer right under the pole, at the equinox the sun is at the horizon, and since the sun turns in a circle around the pole, the sun must remain all day at the horizon. In other words, all three distances mentioned are equal to the radius of the circle of the equinox (or the equator).

For the fringes of the earth the *Zhou bi* uses the expression "the four poles" as an indication of the ultimate limit of solar light on earth. Obviously the idea is that there exists not only the one central pole, but also four peripheral poles. This is somewhat confusing and has to do with the conception of the earth as a square. Taking into account that for every observer, wherever on earth, the direction to the central pole is 'north' and the opposite direction 'south', it is less confusing to speak of one circular south pole instead of 'the four poles'.

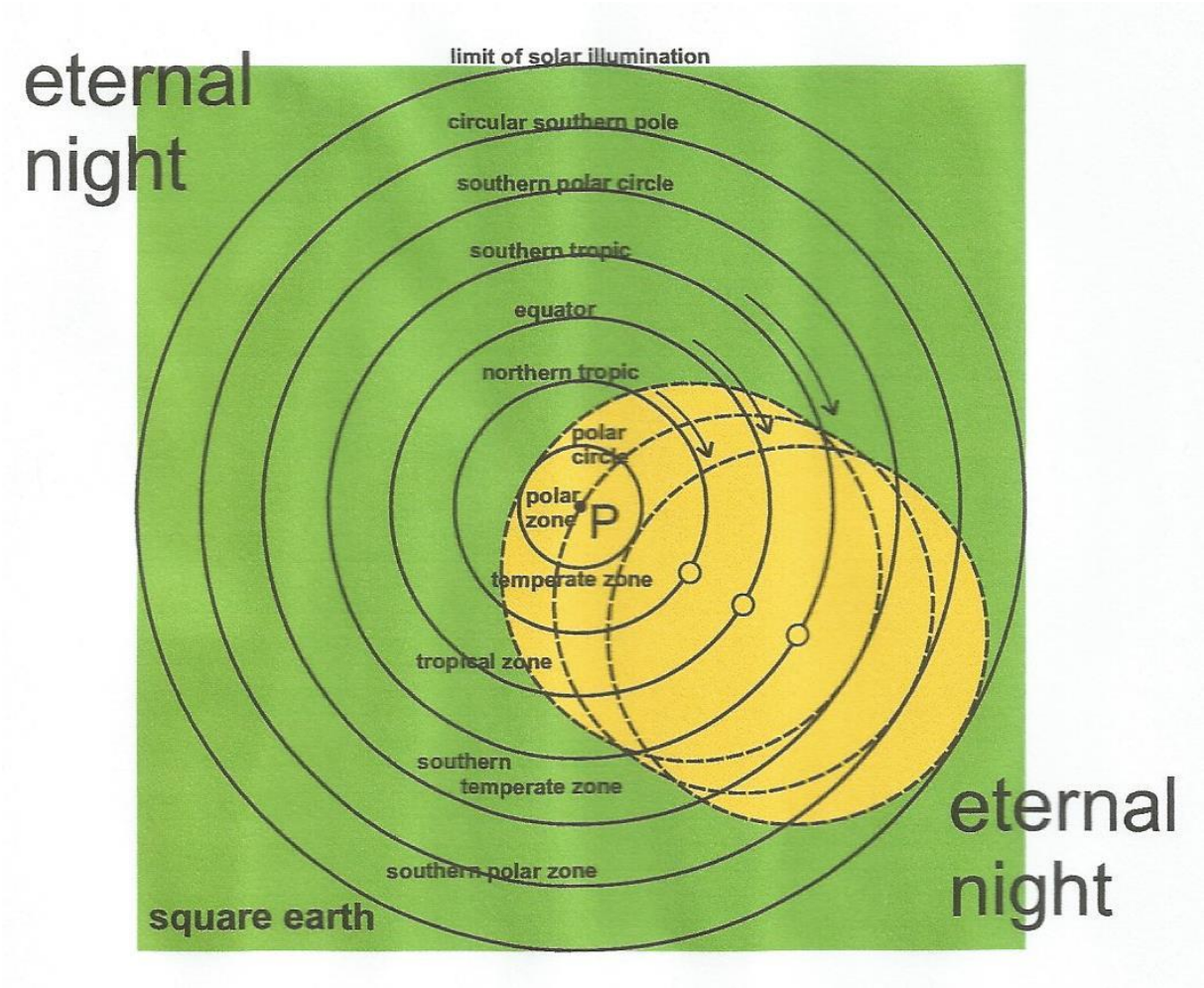

Figure 13 The area of sunlight through the seasons, the climatological zones and the circular south pole (plan view)

Between the circular south pole and the equator we can draw the southern tropic and the southern polar circle, as in Figure 13. Outside the ultimate circle of where the sunlight can reach it is eternally night. Or, as it is said lapidarily in the *Zhou bi*: “Nobody knows what is beyond this”.

The central north pole and the circular south pole are features that can be compared with those on a map of the spherical earth in a polar azimuthal equidistant projection, although here it is an effect of mapmaking, whereas in the *gai tian* it is the result of the conception of heaven and earth.

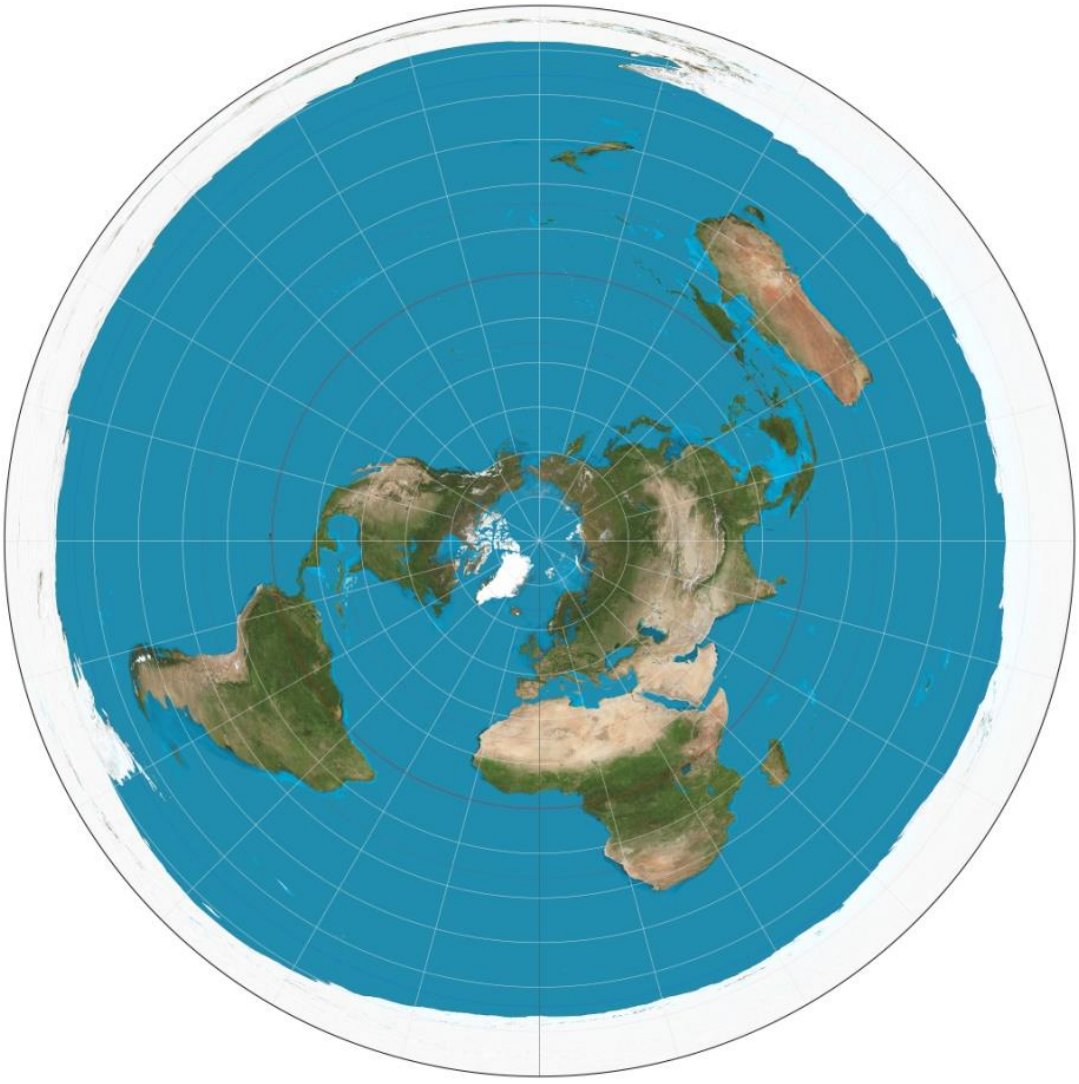

Figure 14 A polar azimuthal equidistant projection of the spherical earth

How big was my surprise when I discovered that the same kind of projection is used in the emblem of the United Nations.

The *gai tian* astronomers would have loved it.

Figure 15 The emblem of the United Nations

The ancient Greek cosmologists, who also believed that the earth is flat, were not able to calculate the dimensions of the cosmos. The figures mentioned by Anaximander for the distances of the celestial bodies were purely symbolic. The only real calculation we know of was made by Anaxagoras, who compared the size of the sun with the Peloponnesus, which must have implied some indicative idea of its distance.[5]

In the *Zhou bi*, on the other hand, the dimensions of the cosmos can be calculated. The *Zhou bi* contains many calculations, but the measurement of the distance to the sun is the basis of all others. Having observed that the farther one goes towards the south, the higher the sun at noon stands, they argued that there must be a place on earth where the sun stands in the zenith. Actually, they used a method very similar to that by which Thales is said to have measured the height of a pyramid. Let us look at this picture of a pyramid and the sun at noon

[5] See Couprie 2011, chapter 16: “The Sun is as Big as the Peloponnesus”.

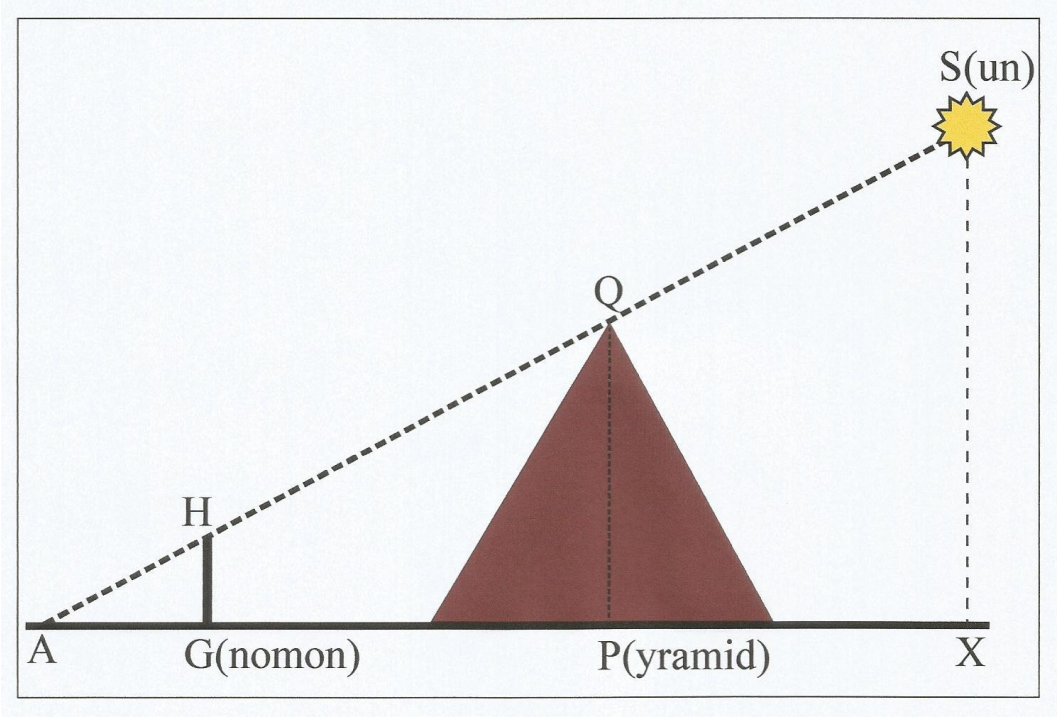

Figure 16 How Thales measured the height of a pyramid

Thales argued that the triangles AHG and AQP were similar, so when he knew the length of the gnomon HG, the length of its shadow AG, and the distance AP, he could easily calculate the height of the pyramid PQ. This method almost invites you to draw the perpendicular line SX. If you would know the distance AX, you would also be able to calculate the distance SX, which is the distance between the sun and the flat earth.

To measure the distance AX, which is the distance from the observer to the place on earth where the sun stands in the zenith, the Chinese used the so called 'shadow rule'. This rule sounds: "When you use a gnomon (*bi*) of 8 *chi* long, the decrease or increase of the shadow is one *cun* for a thousand *li*". One *cun* is 0.1 *chi*. The Chinese astronomers started their calculations with a shadow length of 6 *chi*, so that they got a triangle with a hypotenuse (from the top of the gnomon to the end of the shadow) of 10 *chi*.

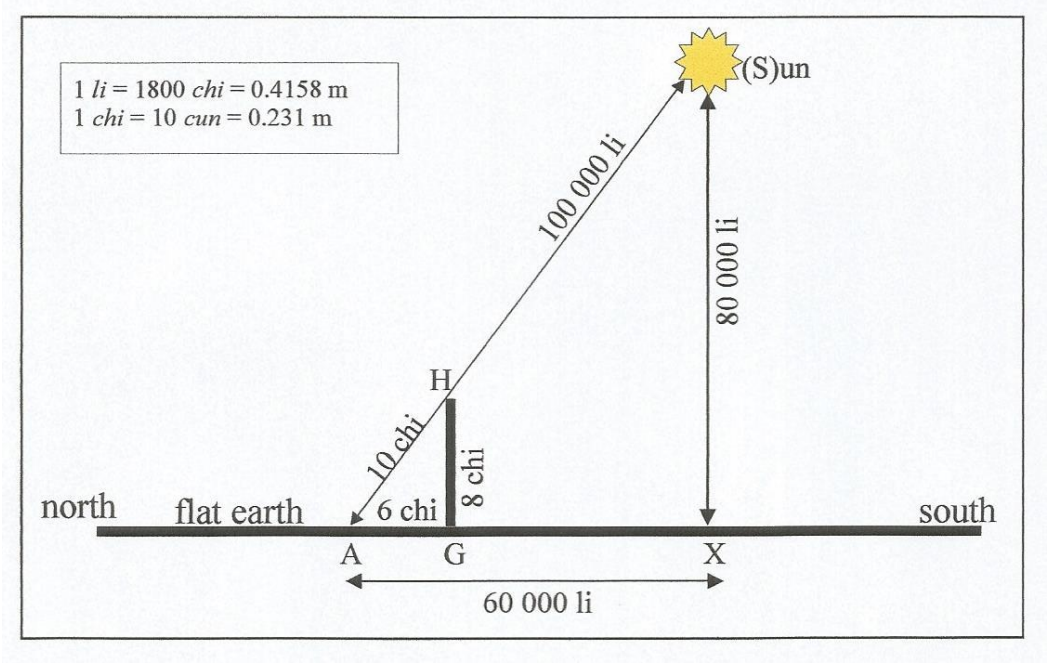

Figure 17 Measuring the distance between the flat earth and the sun at a subsolar point at 60 000 *li* distance from Zhou

According to the shadow rule, the distance AX (which is the distance between Zhou and a subsolar point on earth) is 60 000 *li* and, accordingly, the distance SX of the sun above the earth is 80 000 *li*.

[[In the Han measurement system one *chi* equals 0.231 meters, so the Chinese astronomers used a gnomon of about 1.85 meters long. One *li* = 1800 *chi*, so one *li* equals 415.8 meters. One *chi* = 10 *cun*, so one cun is 0.0231 meters]]

At first sight the shadow rule looks like based upon observation, until one realizes that something is wrong. This is best illustrated by the calculation of the distance from Zhou to the northern tropic at the summer solstice, which is also given in the *Zhou bi*. On the day of the summer solstice the noon shadow at Zhou is one *chi* and six *cun*, or 16 *cun*. So the rule says that 1000 *li* due south the shadow is one *chi* and five *cun*, or 15 *cun.* This means that the distance AX (which is the distance from Zhou to the northern tropic) equals 16 000 *li*. The distance SX is again 8000 *li*, as can be seen on this picture, which is, of course, again not to scale:

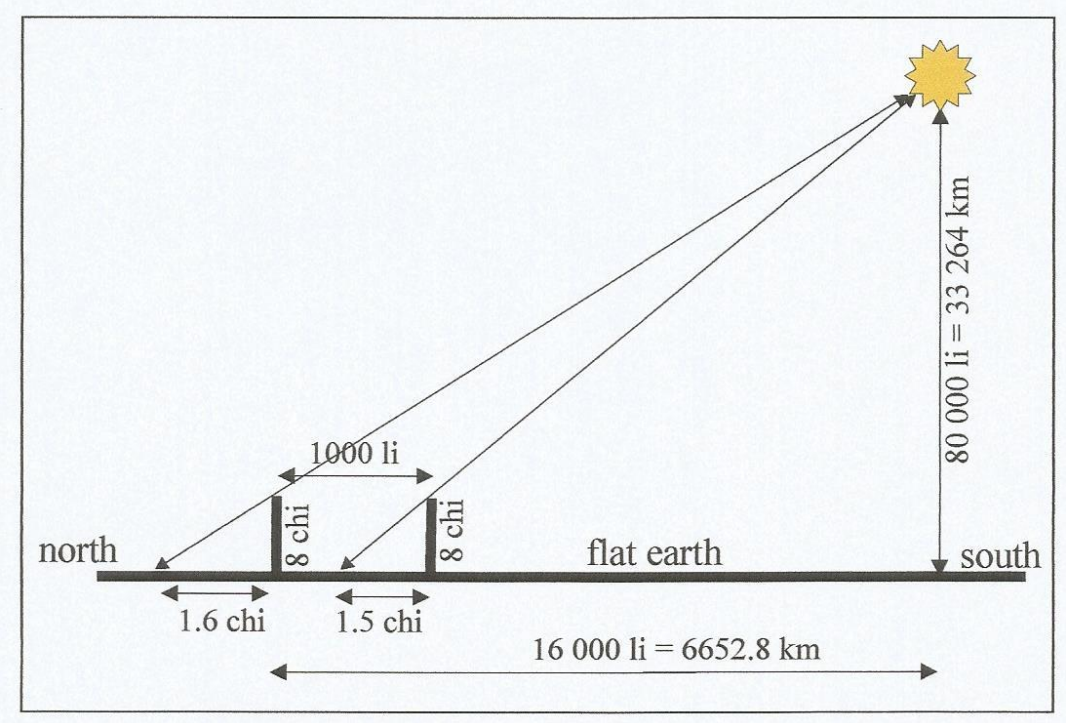

Figure 18 measuring the distance between Zhou and the northern tropic at noon at the summer solstice

The distance from Zhou, the abode of the observers, to the place where the sun at the summer solstice stands in the zenith thus equals 6652.8 kilometers, and the distance between sun and earth 33 264 kilometers.

This method is correct in principle for measuring heights on a flat earth, as Thales' example shows. However, the Tropic of Cancer is only about 1200 kilometers south of Zhou (which is, by the way, in the southern part of China), and thus the height of the sun in figure 18 should be about 6000 instead of 33 264 kilometers. The reason for this

discrepancy is that the shadow rule is wrong. Cullen remarks: "The most striking fact about the rule is how completely wrong it is".[6]

[[The origin of the shadow rule's being mistaken can hardly lie in the difficulty to measure distances over the surface of the earth, because for that the discrepancies are too big. Dmitri Panchenko has put forward the intriguing suggestion that "the shadow rule was established somewhere outside of China (meaning Greece, DLC) and that, in the process of the transmission, the Chinese *li* was substituted for a foreign measure".[7] I think, however, that there is an easier and more natural explanation: The ancient Chinese astronomers were beforehand convinced of the enormous size of both earth and heaven. They started with the standard triangle of a 6:8:10 ratio, because that gave a ratio of 3:4:5 with which it was easy to calculate. Then they deliberately chose the numbers of the shadow rule so as to produce a huge triangle of similar numbers: 60 000, 80 000, and 100 000 *li*. And the other calculations were made according to the 'rule' thus found. In other words, the shadow rule was not based on observation but construed for the sake of easy calculating. The authors of the *Zhou bi* were more interested in a rule that was able to produce always the same distance between earth and heaven than in the real distances on earth.[8]]]

However this may be, since the other calculations depend on this fundamental one they all suffer from the same mistake. Nevertheless, it is impressive to see how many calculations the Chinese astronomers were able to make on the basis of this one measurement.

The distance between Zhou and the northern tropic equals 16 000 *li*, as we saw. In a similar way the distance from Zhou to the subpolar point was measured at night. The instruction in the *Zhou bi* says: "Tie a cord to the top of the gnomon and look along the cord at the pole. Lead the cord down to the ground and note the distance between the point where the cord touches the ground and the foot of the gnomon. This is 10 *chi* and 3 *cun* from the gnomon, and therefore the center of heaven is 103 000 *li* from Zhou. The radius of the northern tropic is thus: 103 000 + 16 000 = 119 000 *li*".

[6] Cullen 1996, 113.

[7] Panchenko 2002, 252.

[8] One might compare this obstinate sticking to a wrong idea with the stubbornness with which the Presocratic flat earth cosmologists stuck to the tilt of the celestial axis, although they could have noticed that that tilt was less when they went towards the north, and that it must be zero right under the celestial pole.

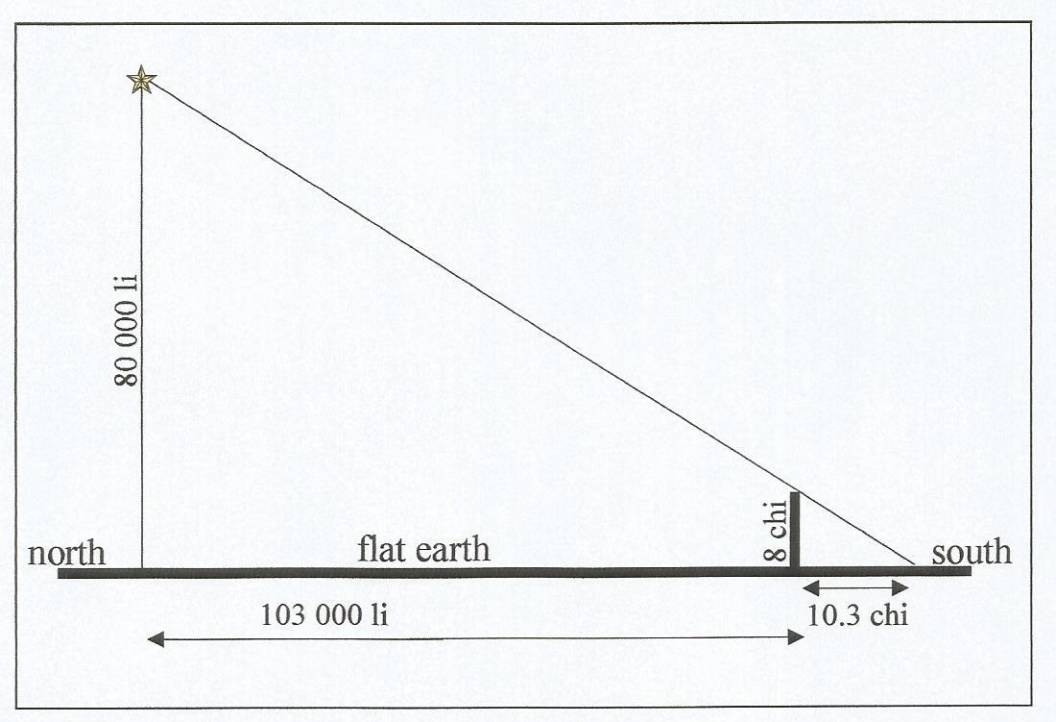

Figure 19 Measuring the distance from Zhou to the subpolar point

In a similar way the radii of the equator and the northern tropic were calculated. The results are shown in a picture we saw earlier.

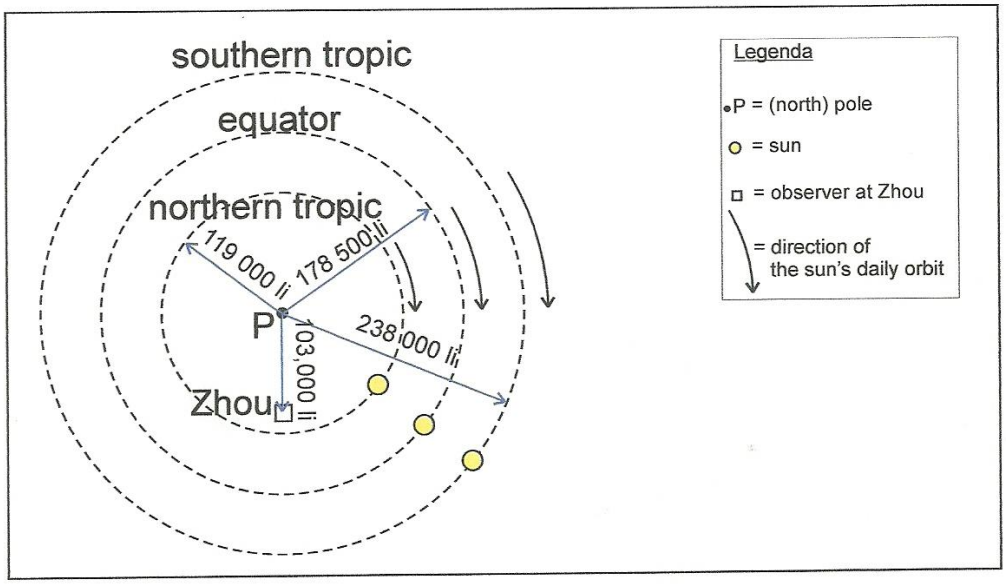

Figure 20 The *gai tian* model of the heaven according to the *Zhou bi* (plan view)

Usually, of the many calculations in the *Zhou bi* only the outcome is given. I have made the calculations and drawn the planimetric drawings that belong to them. Here I will give only one example, namely the distance from Zhou to the subsolar point due east of Zhou at the winter solstice.

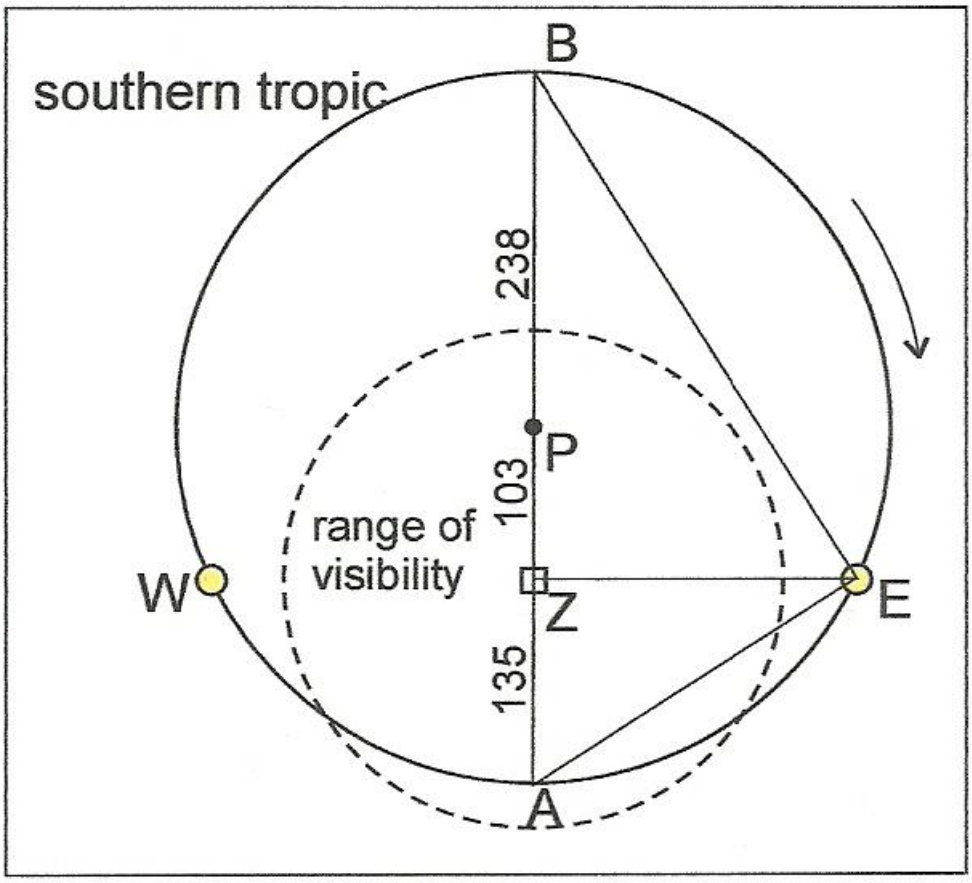

Figure 21 The measurement of the distance from Zhou to the subsolar point due east of Zhou at the winter solstice

The distance from Zhou to the southern tropic is 238 000 – 103 000 = 135 000 li, as follows from Figure 21. AEB, AZE and BZE are similar triangels. The calculation goes as follows: AZ : EZ = EZ : BZ → ZE^2 = AZ × BZ → ZE^2 = 46 035 → ZE = 214.557 684 6 (× 1000). The number as given in the Zhou bi is 214 557½ *li*. As one can see in the picture, the sun due east of Z (Zhou) lies outside the range of visibility of an observer at Zhou, just as the *Zhou bi* says. I will spare you the many other calculations.

Instead I will ask your attention for a remarkable revival of this cosmological system in recent times. In 1872 AD the second edition appeared of a book called *Zetetic Astronomy: The Earth not a Globe*, written by a man who called himself "Parallax" (his real name was Samuel Birley Rowbotham). He re-invented the *gai tian* system, without any knowledge of his Chinese predecessors. I will show you some pictures from this remarkable book.

On the first you see the area of sunlight circling over the disk of the flat earth with the north pole in the center and the circular south pole at the periphery.

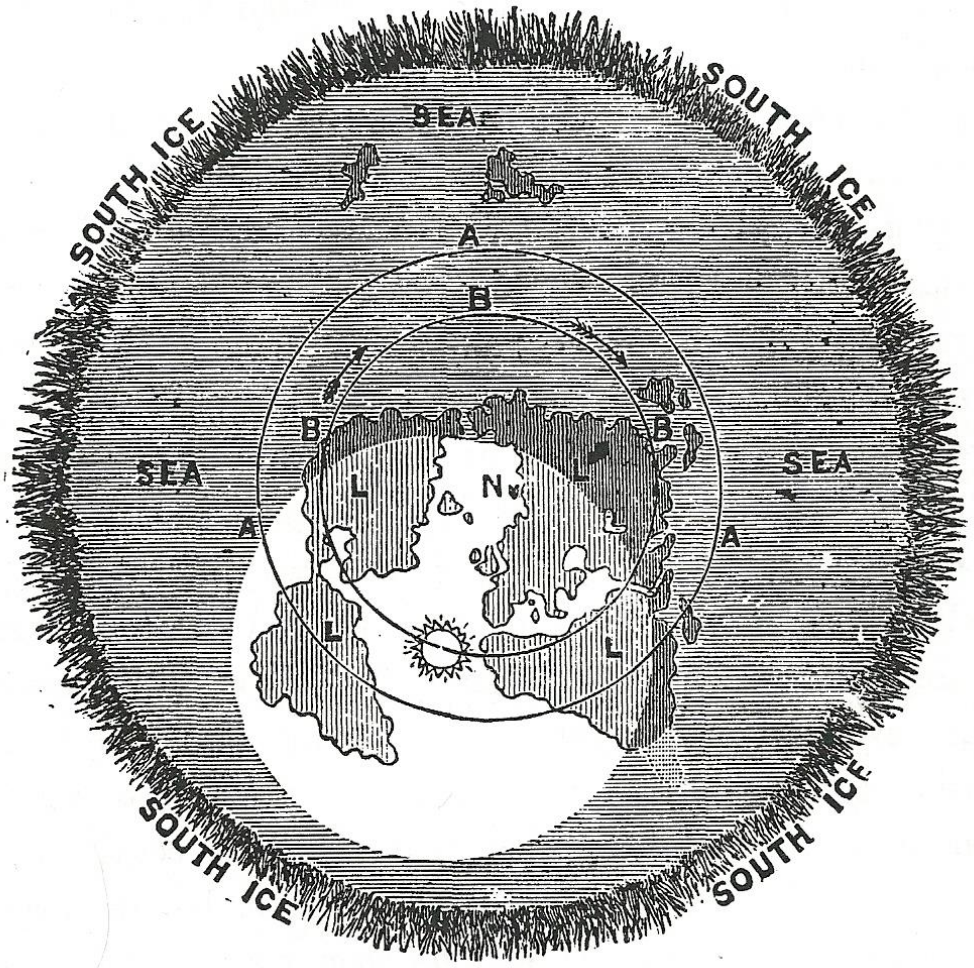

Figure 22 "Parallax's" version of the flat earth with the are of sunlight

This book has become the bible of the modern Flat Earth Society, of which can be found several intriguing sites on the Internet, with animations of suns circling over the flat earth. What at the beginnings of our era was an intellectual effort of the first rank is in its modern shape rather ridiculous. The death blow to the ideas of the modern Flat Earthers results when one realizes that they suffer from what I call the Northern Hemisphere Bias. People living on the southern hemisphere, like in Australia or Argentina, could easily imagine a counterpart of the world of mr. Parallax, by means of another polar azimuthal equidistant projection of the spherical earth, but now with the south pole at the center and a circular north pole at the periphery.

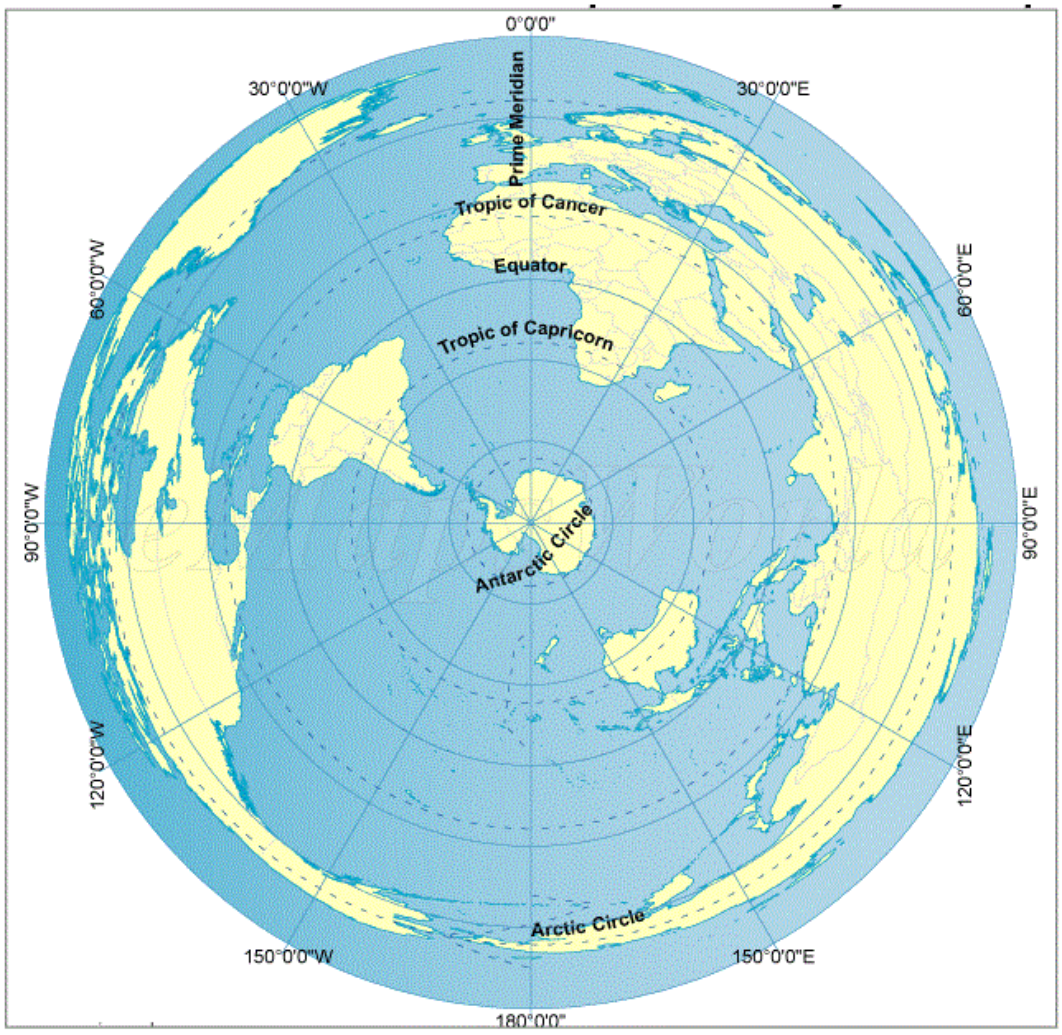

Figure 25 A southern polar azimuthal equidistant projection of the spherical earth

Perhaps the Russians would welcome this projection, since it supports their claim on the north pole, their country bordering at almost half of it.

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