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PARTICIPATION OF BOSSCHA OBSERVATORY IN THE WORLD LONGITUDE DETERMINATION OF 1926 AND 1933

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Abstract: The 1923 establishment of Bosscha Observatory in Lembang, Indonesia, is frequently cited as the onset of ‘modern astronomy’ in Indonesia. This observatory has inspired the birth of several new generations of Indonesian astronomers as well as other observatories in Indonesia, including the Timau National Observatory which is currently under construction and in the completion stage. Double star astrometry has been one of the main programs since its founding. Nonetheless, records show that Bosscha Observatory was involved in research not only in astronomy but also in geodesy and geodynamics. This paper will discuss the participation of Bosscha Observatory in determining the most accurate longitudes of the Earth in the early days of its establishment. The World Longitude Determination of 1926 was the first global effort involving many of the world’s leading countries and institutions. It was proposed to determine the differences of longitude of many places with great accuracy. If this effort was repeated at intervals sufficiently separated in time, this might be used to test the possible change of their relative positions and possibilities as to the movement of the Earth’s crust as first hypothesized by Wegener. After a century of its existence, Bosscha Observatory looks to its future to continue its astrometry program and participate in determining a very accurate reference frame through the Very Long Baseline Interferometry (VLBI) technique in radio astronomy.

Keywords: Bosscha Observatory, Lembang, Netherlands East Indies, Indonesia, longitude determination, K.A.R. Bosscha, R.A. Kerkhoven, J.G.E.G. Voûte, F. A. Vening Meinesz

1 INTRODUCTION

Thanks to the dedication of Karel Albert Rudolf Bosscha (1865 –1928), Rudolf Adriaan Kerkhoven (1879 –1940), and Joan George Erardus Gijsbertus Voûte (1879 –1963), Bosscha Observatory, was established in Lembang, West Java, in 1923, after a relatively short, but intensive planning period, driven by these three people. The idea of establishing an observatory in Java was inseparable from the role of Jo-

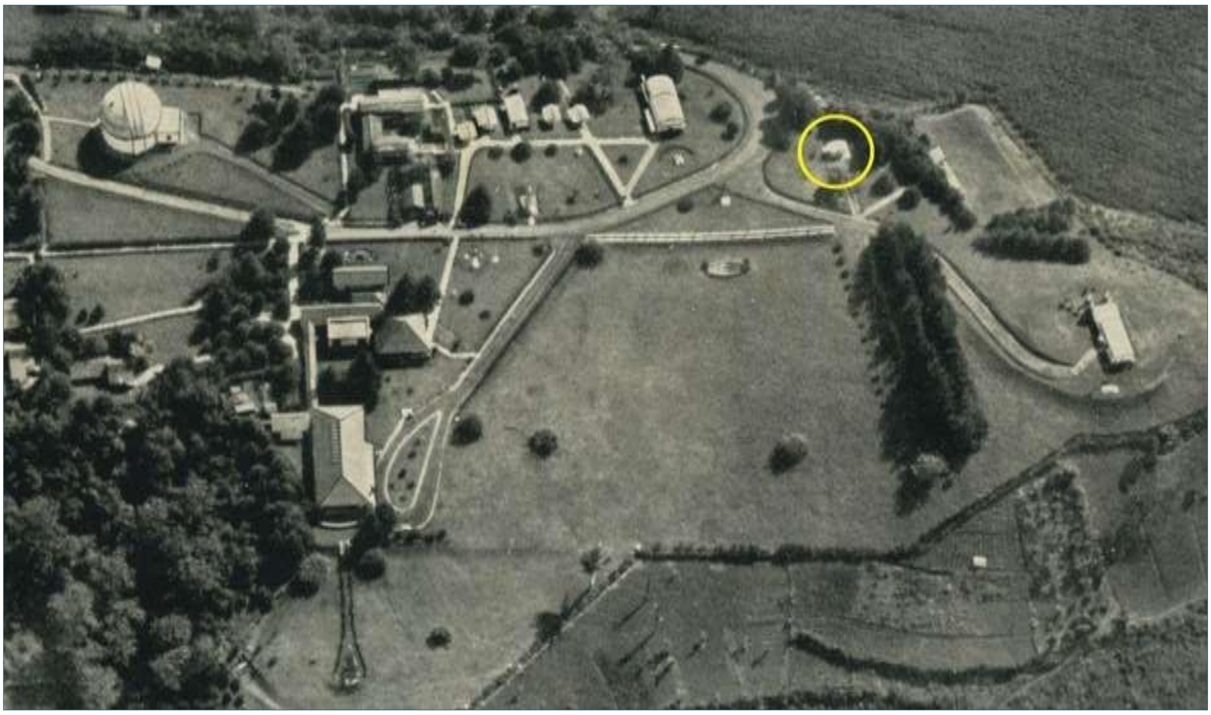

Figure 1: The main area of Bosscha Observatory circa 1932 (after Voûte, 1933). Most of the telescope buildings have a North-South orientation and were dedicated to observing the Southern sky. The yellow circle indicates the small building of the transit instruments described in the text (courtesy: Bosscha Observatory).

hannes Bosscha (1831–1911), a Professor of Physics at the Delft Institute of Technology, the father of K.A.R. Bosscha.[1] He raised this idea in 1902 with his son, when K.A.R. Bosscha, as a successful tea entrepreneur, was returning home for the first time to the Netherlands (Pyenson, 1989; van der Hucht and Kerkhoven, 1982). Thanks to his strong influence, on 12 September 1920, K.A.R. Bosscha succeeded in gathering many important officials and businessmen in Bandung and established an astronomical association, namely the *Nederlands Indische Sterrenkundige Vereniging* (NISV, Astronomical Association of The Netherlands Indies) which, among other things, aimed to establish and maintain an astronomical research observatory in the Netherlands Indies and promote astronomical science. By Government decree of 17 November 1920, the statutes of the NISV were approved. Then K.A.R. Bosscha was appointed as Chairman of the NISV, while R.A. Kerkhoven was appointed as Secretary–Treasurer. As is known, Kerkhoven was also a very enthusiastic amateur astronomer. Actually, the name Bosscha Observatory refers to Professor J. Bosscha (Pyenson, 1989; van der Hucht, 2025; van der Hucht and Kerkhoven, 1982) and at the official opening of Bosscha Observatory on 1 January 1923, Voûte was appointed as the first Director. The history of the Observatory is recounted in Hidayat et al., 2017; van den Heuvel, 2025.

Figure 1 shows the main area of Bosscha Observatory (Pannekoek, 1929; Voûte, 1933) after a decade of its establishment. Many telescope facilities are aligned along a North-South axis and are primarily used for observing the Southern Hemisphere. The area has remained largely unchanged compared to the current state, as can be easily verified using resources like Google Maps. Only a few new buildings have been added in more than a century. However, the surrounding area, Lembang, has changed significantly into a city with a population of more than 200,000 in 2024.

In 1915, shortly before the establishment of Bosscha Observatory, there were two very important scientific theories that were being promoted internationally. One was the General Theory of Relativity (Einstein, 1916), and the other was the hypothesis of continental drift by Alfred Wegener (1880 –1930), in his book *Die Entstehung der Kontinente und Ozeane* (Wegener, 1915) that could explain the evolution of various modification to the Earth's surface that we recognize today.[2] The General Theory of Relativity by Albert Einstein (1879 –1955) was immediately able to explain the problem of the apsidal motion of Mercury's perihelion, which had been a puzzle in astronomy for more than six decades (Le Verrier, 1859). Furthermore, this theory also obtained observational confirmation, through observations of the total solar eclipse on 29 May 1919 at Sobral (Brazil) and

Principe Island (Dyson et al., 1920), which proved that the trajectory of light rays are curved when they pass near a massive object—as predicted by general relativity. This effect is known as gravitational lensing.

Both major theories immediately became part of the research programs of the newly established Bosscha Observatory. Note that the Observatory participated in total solar eclipse expeditions to Christmas Island (21 September 1922), Bengkulu (14 January 1926) and Takengon, Aceh (9 May 1929), which among other things were to measure the effects of light-bending. Bosscha Observatory also had a rather important part to play in examining the continental drift hypothesis. In this paper, we will focus on this second topic.

Wegener theorized that the movement of continents occurred over an extended geological timeframe and is still ongoing today. He suggested that the movement might be measured using astronomical methods. Through these measurements at various locations, it should be possible to determine the rate of movement, and whether it is fast or slow. Therefore, repeated measurements need to be made, using astronomical methods, and over a relatively short period of time, in order to be able to detect this continental drift.

To test this hypothesis of continental movement, one of the things that had been done was to measure the world's longitudes with very high accuracy, involving many observing stations around the world. This was possible because there was new technology that could be applied, namely wireless telegraphy (see for example, Bobis and Lequeux, 2012; Cooke and Cooke, 1917; Ferrié, 1920; Kershaw, 2017; Knox-Shaw, 1922; Sampson, 1920). To do this, a large-scale international initiative was needed for this measurement of world longitude, which was finally carried out in 1926 and 1933, led by France (Chiat, 1956; de Roy, 1926; Ferrié, 1928; Verbandeert, 1931). The third initiative was carried out in 1958 on the occasion of the International Geophysical Year 1958. Bosscha Observatory participated in this initiative in 1926 and 1933, which we will discuss in the following Sections of this paper.

2 GEODETIC SURVEY

The Java triangulation was started in 1861 by Jean Abraham Chretien Oudemans (1827–1906), an astronomer who later became Director of the Utrecht Observatory (Orchiston et al., 2021; Pyenson, 1989). During his 18 years in the Netherlands East Indies, he successfully completed the triangulation of Java and most of the Nusantara Archipelago, which was published in a 6-volume report. Furthermore, the more complete Geodetic Survey in the Netherlands East Indies until the early twentieth century was carried out by the Topographical Services that was part of the Dutch Army. In carrying out its duties in the field, this service was divided into brigades and detachments, among others, a triangulation brigade and topographical surveying brigades, as well as detachment for land-revenue surveying (Schepers and Vening Meinez, 1929).

In triangulation measurements, the main stations are usually placed on mountain peaks forming a triangulation chain or system. The exact position of this system in latitude, longitude, and azimuth is determined by astronomical methods with an average error of ±0.10″. In the areas of Sumatra and Kalimantan, the position of the stations was determined through special astronomical expeditions, starting in 1886. Time correction was determined by observing the Eastern and Western stars near the main vertical or meridian, leading to longitude measurement, while latitude was determined by circum-meridian observations of the two northern stars and two southern stars.

For astronomical positioning measurements in the Netherlands East Indies, Johan Hildebrand George Schepers (1885 –1968), Head of the Geodetic Section of the Topographical Service, had assigned civil engineer, E.A. Scharpff, and assisted by J.D.C. Breyer as well as two native technicians, from January 1924 at Bosscha Observatory, Lembang, which was part of the Triangulation Brigade.[3] To carry out these tasks, the Brigade needed a transit telescope, astronomical clocks, and radio equipment. With the first two devices latitude determinations can be made; while the radio allowed the longitude to be measured. Shortly afterwards, two houses were built at the Western end of the Observatory grounds, where these officials stayed.

From then on they took care of the time service, helping the clocks with their teething problems and designed a suitable electrical system. Longitude was determined by means of radio time-signals from the Malabar radio station, controlled by the Royal Magnetical and Meteorological Observatory (now Indonesian Agency for Meteorological, Climatological and Geophysics, BMKG) in Weltevreden (now the Lapangan Banteng area, in Jakarta).[4] By the end of May 1924, 121 time determinations had been made. During September observations were made by radio time-signals with the help of the observatories in Leiden, Greenwich, Hamburg and Potsdam to determine the longitude of Lembang. Overall, it should be noted that Bosscha Observatory participated in these

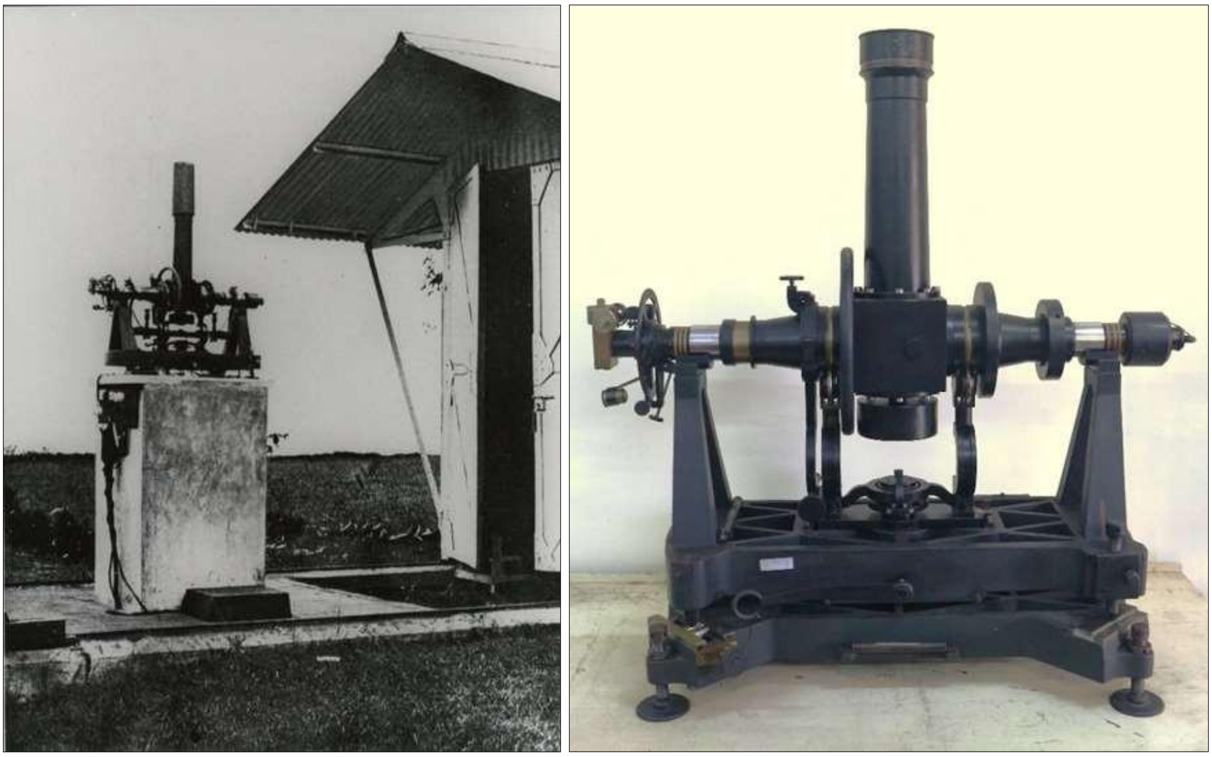

Figure 2: The transit telescope at Bosscha Observatory, utilized for the determination of geographic latitude and longitude in 1924 and the World Longitude Determination of 1926 was placed in a half-timbered building that could be moved in an East–West direction (left). This instrument is now displayed at the Bosscha Observatory Exhibition Room after being repaired for the World Longitude Determination of 1933 (photograph (right): the authors).

longitude determinations in 1924, 1925, and 1927 (Schepers and Vening Meinez, 1929), which also involved Sumatra and Kalimantan, with the Triangulation Brigade.

In December 1924 Voûte (1924) reported on the construction of the Zeiss 60-cm double refractor building located at 7^{h} 10^{m} 27.81^{s} E, 6° 49′ 29.1″ S, and an altitude of 1300 m, according to the results of the geodetic survey. Furthermore, in September 1924 Scharpff (1927) reported that the longitude of the broken-tube transit telescope at Bosscha Observatory (see Figure 2) was determined using wireless time-signals transmitted from Nauen (Germany) and Bordeaux–Lafayette (France). The transit telescope observations were carried out by Breyer and Scharpff, while the time-signals were recorded by Voûte, Scharpff and Breyer. Corrections to these time signals were provided by the Geodetic Institution at Potsdam and Hamburg Observatory. Meanwhile, the determination of latitude was carried out in July 1925 using a Hildebrand theodolite (see Figure 3) through observations of the zenith distance of several pairs of stars, one in the North and one in the South, at approximately the same zenith distance. Over six nights 65 pairs of stars were observed, and finally the following position of the Bosscha Observatory transit telescope was

Figure 3: The Hildebrand theodolite used in the early days for the geodetic surveys at Bosscha Observatory and currently displayed in the Exhibition Room at the Observatory (photograph: the authors).

derived: $7^h\ 10^m\ 27.73^s \pm 0.007^s$ E and 6° 49′ 32.93 ± 0.08″ S (Scharpff, 1927).

The Topographical Service has contributed a lot, which at that time was still limited to practical surveying and mapping work. These were certainly necessary for the interests of infrastructure development in the Netherlands East Indies. From these results, it is increasingly apparent that the Indonesian archipelago is also a very challenging area for geodetic, geophysical and geomorphological research. Bosscha Observatory's interest in this area began when Voûte, after attending the IAU General Assembly in July 1925 in Cambridge (UK), sent a letter dated 7 April 1926 to Professor Schepers, the Head of the Geodetic Section of the Topographical Service. Voûte raised the need for an expert staff member to ensure Bosscha Observatory's participation in the World Longitude Determination. Schepers anticipated that the corresponding tasks would be entrusted to the Geodetic Section, and in May 1926 he assigned the Triangulation Brigade to carry them out. Later, he assigned Pieter Hendrik Poldervaart (1896 –1948), a civil engineer, to be included in the Brigade.[5] Poldervaart (1930) practiced making observations using a micrometer attached to the transit telescope. Financial support from K.A.R. Bosscha once again played a vital role in the success of this project, while Voûte offered technical support.

Shortly later, on 10 May 1924, Professor Schepers also received a request via telegram from Felix Andries Vening Meinesz (1887–1966) who was conducting a series of maritime gravimetric survey on board a submarine (Poldervaart, 1930). This mission was pioneering work and one of the most important oceanic surveys at that time (Muller and Heuvelink, 1927). Vening Meinesz needed access to radio time-signals during this trip, which were then provided by the Netherlands East Indies Wireless Service and controlled by officers and engineers from the Triangulation Brigade at Bosscha Observatory. The results of this survey could also provide clues to test Wegener's hypothesis about continental drift.

In addition, the NISV had also invited the Topographical Services to participate in observing polar motion at Bosscha Observatory with the Observatory acting as an equatorial station in monitoring the movement (Schepers and Vening Meinez, 1929). Polar motion, also called the 'Chandler Wobble', was discovered by astronomer S.C. Chandler (1836 –1925) in 1891 and reported through a long series of papers, mainly in the *Astronomical Journal* (see, e.g., Chandler, 1902). We note that during 1899–1906 and 1915–1921 there were observations made at Leiden Observatory to determine variations in latitude caused by polar motion (van der Schraaf, 1979).

3 WORLD LONGITUDE DETERMINATION USING WIRELESS TELEGRAPHY

3.1 Wireless Telegraphy

In the early years of the twentieth century, there was significant progress in the transmission and reception of radio telegraphic signals over long distances, reinforced by the application of their precise reception using rhythmic signals, as well as their automatic recording by improved devices. General Gustave-Auguste Ferrié (1868 – 1932) was the leading French figure in the use of wireless telegraphy for military and scientific purposes. He was also a corresponding member of the French *Bureau des Longitudes* from 1911 (Kershaw, 2017). Through Ferrié's collaboration with Paris Observatory, on 23 May 1910 a radio time-signal was broadcast from the Eiffel Tower (*Station Radiotélégraphique de la Tour Eiffel*), conducting the so-called *Télégraphie Sans Fil* (T.S.F.), which was capable of providing a precision of 0.01s (Bobis and Lequeux, 2012). Previously, this comparison was carried out by transporting stopwatches and then by exchanging signals sent by wire or cable. Starting on 31 December 1910, this T.S.F method replaced sending signals via electric telegraph (*ibid.*). However, long distance radio time-signal exchanges showed that these signals could disagree by 1 to 2 seconds due to, among others, longitude errors with respect to the Greenwich meridian, errors in the positions of stars, or radio propagation time (Guinot, 2000). Therefore, a much better synchronization might be achieved using Universal Time (UT), as previously recommended by the International Meridian Conference in 1884. Following this progress in the radio transmission of time-signals, the need for a time scale as well as the creation of a body responsible for unifying time were recognized (Capitaine, 2022).

After hearing a report by Ferrié, the Bureau des Longitudes took the initiative to organize a *Conférence Internationale de l'Heure*, which was held in October 1912 at Paris Observatory. This conference was attended by representatives from 16 countries, and was chaired by Guillaume Bigourdan (1851–1932), President of the Bureau des Longitudes. This conference mandated the need to establish a permanent commission, the so-called *Commission Internationale de l'Heure*, and an executive body, the *Bureau International de l'Heure* (BIH), that was hosted by Paris Observatory. The BIH was entrusted with the task of coordinating the results, verifying and broadcasting Universal

Figure 4: Group photograph of the 2nd General Assembly of the International Astronomical Union, held in Cambridge, UK, 14 – 22 July 1925; photo source: Stearn & Sons (1925) Courtesy: Institute of Astronomy Library (http://www.dspace.cam.ac.uk/ handle/1810/238507).

Time (UT). It was followed by a second international conference on time, held in October 1913 at Paris Observatory, when eventually, a draft convention and statutes were set up.

Related to this attempt, finally a joint effort was proposed, called the World Longitude Determination. This was the decision of two major professional organizations in the world that were newly born after WWI, namely the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG), both of which were founded in 1919. Both organizations were keen in working together in this first global-scale project. It was soon decided that the BIH would be the executive body of the International Commission of Time, one of the commissions of the IAU. Then, in 1919 the BIH at Paris Observatory was responsible for coordinating the transmission of radio time signals. The BIH routinely published the differences between the time-signals broadcast by radio stations and astronomically determined time, which relied on telescopic observations of star transits. All this greatly facilitated the operation of the project and ensured the precision expected of it.

At the first General Assembly of the IAU and a meeting of the IUGG held in Rome in 1922 the strategy of longitude determination was intensively discussed and the IUGG became partially responsible for maintaining the Bureau. Subsequently, at the meeting in Madrid in 1924, the IUGG intended to undertake the World Longitude Determination. Moreover, at the 2nd IAU General Assembly meeting in Cambridge on 14 – 22 July 1925 (Anonymous, 1925a; 1925b), the IAU confirmed its participation in the World Longitude Determination (see Figure 4). Voûte was present at this meeting. The two bodies then agreed to form a joint commission, the so-called *Commission Internationale des Longitudes par T.S.F.*, headed by General Ferrié. Finally, at the IAU General Assembly, he reported that substantial preparations had been made (Anonymous, 1925a).

For this global effort with radio time-signals, the Commission invited many observatories around the world to participate and obtain results of great accuracy. This involved recording time signals as precisely as possible using the latest radiotelegraphy resources, and making precise astronomical observations (Anonymous, 1926; de Roy, 1926; Sampson, 1920; Verbaandert, 1931). First, it was necessary to select main stations which formed 'fundamental polygons', with all three stations in the 'polygon' situated at about the same latitude and separated by approximately 120° in longitude (so they were 8 hours apart). In this way a network on fundamental polygons was established around the world, ensuring rigorous verification of the results (Anonymous, 1926).

Therefore, it was decided that measuring the longitude differences between the 'fundamental polygon' stations could be used as the basis for verifying the accuracy of the results. At the same time, the three stations in a polygon would be involved in observations made at other stations, and these other stations should be selected and grouped to form a multitude of 'secondary polygons' between the 'fundamental polygons'. Moreover, these secondary stations should be linked to the fundamental polygon station as accurately as possible.

Subsequently, the observations were arranged so as to provide, for each polygon, an effective error of closure. This assumed that the two differences in longitude were entirely independent of each other. In other words, the time determinations and the radiotelegraphic comparisons recorded between each of the stations and the two nearest stations on either side were completely independent. If only one series of time observations were made at the intermediate station, the corresponding errors would have no influence on the difference in longitude of the two extreme stations. Similarly, if all the observatories located in the same polygon compared their clocks at the same time using the same signals, the error of closure of the polygon would necessarily be zero, whatever the errors affecting local time determinations. In this respect, polygons around the world would provide a more complete control where the sum of the individual differences in longitudes must be rigorously equal to 24 hours.

3.2 The 1926 Observations

Ultimately, the selected fundamental stations were at:

(1) the Naval Operating Base, San Diego, California (America);
(2) Algiers Observatory (Africa); and
(3) Zi-ka-wei (or Xujiahui) Observatory in Shanghai (Asia) (Ferrié, 1928; Wu, 2021).

The low latitude of these stations made it possible to set up time determinations on the passage of stars transiting not far from the zenith, in order to significantly reduce the influence of azimuthal error. Radio time-signals would be sent from the selected stations, and these signals had to be rhythmic signals, enabling the method of coincidences (Cooke and Cooke, 1917; Ferrié, 1920). Other stations that would play important roles in these longitude determinations were Greenwich, Paris, Potsdam, Pulkovo and Washington, which were selected to form 'secondary polygons'.

The observation period started on 1 October 1926 and ended on 1 December 1926. This was due to the relatively favourable weather in October and November in Europe that generally made it possible to carry out very complete observing programs. Later, for the second operation, in 1933, the same period was selected in order to eliminate the effect of systematic errors in the star positions. The stations involved recorded wireless signals and used micrometers on their transit telescopes. Stars drawn from the American Ephemeris were recommended (Hoogewerff et al., 1915), and clock stars were confined to the regions 20°– 25° North and South of the zenith.

It was decided that the radio telegraphic signals intended to allow a comparison of the clocks installed at the various observatories were emitted by seven stations, as listed in Table 1 (Anonymous, 1926). These were Paris, Bordeaux–Croix–d'Hins, Saigon (SE Asia),Honolulu (Hawaii Islands), Annapolis and Arlington (USA). Twenty radio signals, regulated according to a pre-determined plan, were to be broadcast in each 24-hour interval. Those observatories aiming solely to determine their longitude difference with Paris or Greenwich would be content with recording European signals, while those participating in the major fundamental operation would also attempt to record distant signals. Most of all, the three fundamental stations had to compare their clocks with the signals broadcast by all seven transmitting stations. The rhythmic signals were separated so that there would be 61 signals per minute for 5 minutes, resulting in 306 in all. They would be transmitted at three times during the day, according to the Greenwich times listed in Table 1 (Anonymous, 1926).

As previously stated, as many astronomical observatories as possible were encouraged to make time observations and receive signals, thereby allowing them to determine their longitudes relative to one or more reference points. The radio time-signals could be received automatically on a chronograph, a method that had some obvious advantages, or by ear, by the coincidence or other methods. Short-wave as well as long-wave signals were sent, as some observers reported better reception of the short waves especially at very distant stations, when there was not much daylight between the stations. These, in addition to the usual long-wave signals (2,650 to 18,900 meters), also emitted time-signals on short wavelengths: Arlington on 24.9 and 74.7 m, Saigon on 25 m, the Eiffel Tower on 32 m, and Honolulu on 36.8 m (Table 1). It was noted that thus far, Paris has received Annapolis and Saigon, but not Honolulu; Green-

Table 1: List of Transmitting Stations during WLD 1926.

Station	Wavelength (m)		Start–End Transmission Time (GMT)			
	Long-wave	Short-wave	h	m	h	m
Annapolis (USA)	17145		20	10	20	15
			03	10	03	15
			10	10	10	15
Arlington or Bellevue (USA)		74.7	20	20	20	25
(near Washington)		24.9	03	20	03	25
			10	20	10	25
Honolulu	11500		20	30	20	35
			03	30	03	35
			10	30	10	35
Honolulu		36.8	20	40	20	45
			03	40	03	45
			10	40	10	45
Saigon	17000	25	11	30	11	35
			19	00	19	05
Bordeaux	18900		08	01	08	06
Issy–Les-Moulineaux		32	20	01	20	06
(near Paris)			08	01	08	06
			20	01	20	06

wich had also received signals from Annapolis, but no short-wave signals have been satisfactorily recorded there.

Therefore, the World Longitude Determination represented a powerful project that united nations in a common interest. It involved a large number of observers working with uniform methods and spread around thirty countries. It would lead to a network of meridians over the entire surface of the Earth, making it possible to rectify a number of previous errors and increase the precision of all the ephemerides in which determinations of geographical positions were very important.

Eventually, there were 42 observing stations that took part, and 9 radio-telegraph stations providing 35 time-signal transmissions each day. Among the observing stations there were three groups of fundamental stations to which the others were attached:

1. Algiers, Zi-ka-wei and San Diego
2. Greenwich, Tokyo, Vancouver and Ottawa
3. Manila, Honolulu, San Diego and Washington

Many stations were linked to these fundamental stations, which themselves were linked to Greenwich, Paris, and Washington. Preliminary results were reported by Ferrié (1928).

4 IMPLEMENTATION OF THE WORLD LONGITUDE DETERMINATION AT BOSSCHA OBSERVATORY

In order to participate in the World Longitude Determination, Bosscha Observatory attempted to acquire all of the necessary equipment, while the associated staff were assisted by the Geodetic Section of the Topographical Service, led by Professor Schepers. The necessary instruments (Poldervaart, 1930) consisted of:

(1) a transit instrument equipped with a recording clock, and a housing for the instrument;
(2) high precision astronomical clocks;
(3) high precision chronographs;
(4) radio receivers; and
(5) radio transmitters.

We will now discuss these in more detail.

4.1 The Transit Telescope

The observations were made of meridian transits of stars chosen from the list in the *American Ephemeris* (Hoogewerff et al., 1915). A large number of observations were needed to obtain a reliable value. Moreover, a certain number of them had to be observed from at least two different stations. Accordingly, in each observing session at least 10 stars were observed. Some of the stars observed multiple times were α Draconis, β Centauri, θ Bootis, π Cephei and ε Octantis.

4.1.1 The Bamberg Meridian Telescope

Figure 2 shows the transit instrument at Bosscha Observatory, Bamberg Transit Telescope No. 14589, which was donated by R.A. Kerkhoven and ordered along with other large telescopes in 1921. This instrument consists of a mounting with three adjusting screws, above which is the telescope tube, supported so it can rotate about a horizontal axis. The telescope has an aperture of 90 mm and a focal length of 920 mm.

The instrument is equipped with three eyepieces, but only the eyepiece with a magnifying

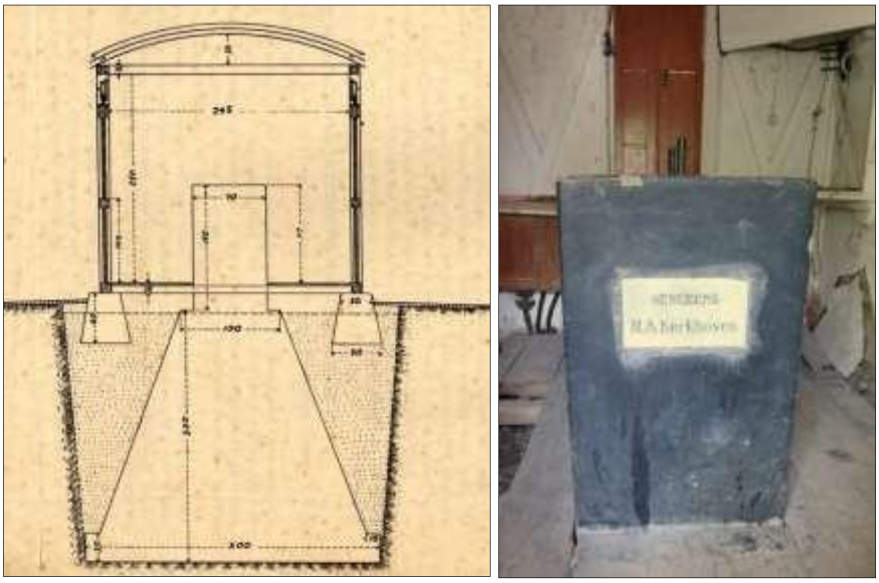

Figure 5: Cross section of the transit telescope building after it was made permanent (after Poldervaart,1930),with a sliding roof for the telescope (left). The concrete pillar that supported the transit telescope (right) was donated by R.A. Kerkhoven (photograph: the authors).

power of 90× was used during the longitude determinations. The transits were observed using an impersonal Repsold micrometer, which undoubtedly gave sufficiently precise results. The weak electrical current installation at Bosscha Observatory was designed by Scharpff in 1924. Later, for the 1933 observations, this transit telescope was improved to have better performance, and it is now displayed in the Exhibition Room at the Observatory (Figure 2, right).

4.1.2 The Transit Telescope Building

The transit instrument was placed in the Eastern part of Bosscha Observatory site in a small half-timbered building. In 1926, the building itself could be moved, as seen in Figure 2. However, in 1933, building was modified and made permanent (Figures 5 and 6), with the roof partially sliding off, thus providing a view of the sky about 75 centimeters wide towards the meridian. A larger opening was not recommended because quite severe dew at night caused condensation on the telescope lens (Poldervaart, 1930).

Although this transit telescope has never used again after the international project ended, the building has been preserved as one of the original Bosscha Observatory buildings (Figure 6), and we will continue to maintain it.

4.1.3 The Meridian Mark

The *Commission Internationale des Longitudes par T.S.F* requires at least one meridian mark, to pinpoint the meridian direction accurately (in addition to observing azimuth stars). For this reason, a meridian marker needs to be made and clearly visible from the transit telescope building. Figure 7 shows the South meridian mark.

The white line seen in Figure 7, was originally a 100-meter-long concrete footpath, at the end of which was a concrete pillar that functioned as a collimator. This pillar still exists today (see Figure 8), but the meridian line is no longer there, because it was later recognized that this meridian track was not very useful for observations made from locations like Bosscha Observatory located near the Equator.

In the opposite direction, on the mountain slope of Tangkuban Parahu at a distance of 3600 m from the transit instrument and at an altitude of 1440 m, they found a suitable location for the North meridian

Figure 6: Condition of the transit telescope building that has been preserved, even though the telescope is no longer there and is displayed in the Exhibition Room of Bosscha Observatory. The building is seen to the East (top), and to the North (bottom), with the sliding roof visible. There is an additional roof underneath that protects the walls from direct rain (photographs: the authors).

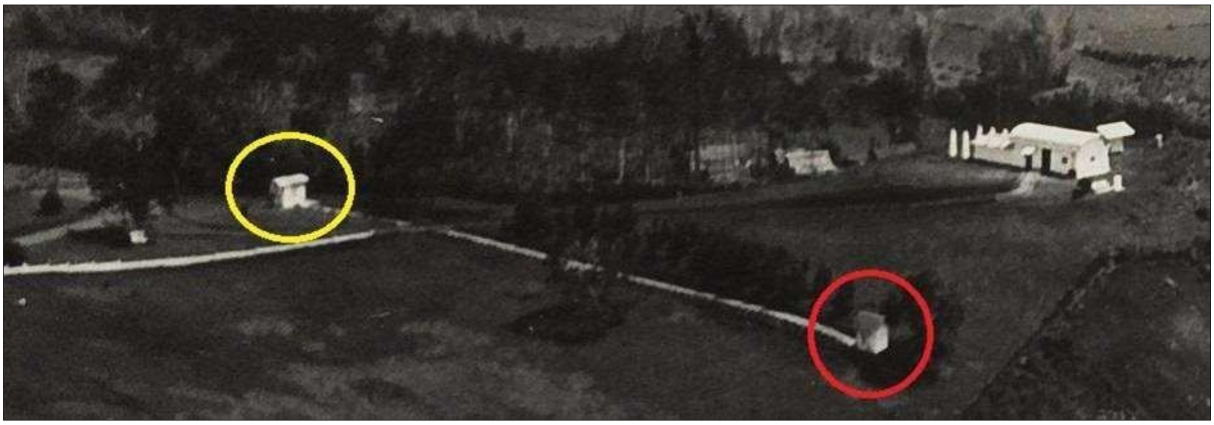

Figure 7: The transit telescope building with the white meridian track to the south, circa 1928. The yellow circle marks the transit telescope building, while the red circle marks the meridian pillar to the south, as a collimator. Above and to the right is the building for the Bamberg Astrophotographic Refractor with its sliding roof (courtesy: Leiden University Libraries, Luchtvaart Afdeeling Koninklijk Nederlandsch-Indische Leger, KITLV 38859, http://hdl.handle.net/1887.1/ item:910823).

mark. A small building was erected there with a window facing South, and at night a lamp was visible through the window to indicate true North. In fact, this North meridian marker has been lost due to urban development. We tried unsuccessfully to find it, but we have marked its estimated position in Figure 9 on Jayagiri Hill, at the following coordinates: $7^h\ 10^m\ 28.149^s$ E, 6° 47′ 32.952″ S, altitude 1440 m.

As already mentioned, at low latitude sites like Lembang, generally stars were chosen at almost the same zenith distances to the North and the South, so that the algebraic sum of their azimuth constants for a complete set was almost zero. Therefore, the influence of the transit instrument azimuth could be eliminated from the calculation of the clock correction. Consequently, determining the azimuth with the meridian mark is actually not necessary.

Figure 8: The meridian marker pillar to the south, about 100 m from the transit telescope building that still exists today. This pillar will be restored as one of the historical artifacts at Bosscha Observatory (photographs: the authors).

4.2 The Astronomical Clocks

Bosscha Observatory also acquired the following astronomical clocks:

1. Richter No. 110, which provided mean time (Figure 10, left);
2. Riefler No. 487, which provided sidereal time (Figure 10, right); and
3. de Casseres No. 3, which belonged to the Topographical Service and also provided sidereal time.

The three clocks were placed in a specially constructed room (see Figure 11, left), where the temperature was kept constant throughout the time. While the pressure in the room was not kept particularly constant, it was known that in tropical areas variations in atmospheric pressure were generally very small and therefore could be ignored.

In order to accommodate possible disturbances due to earthquakes the three clocks were placed in three different directions (see Figure 11, right). If an earthquake occurred, the three clocks would not experience the same vibration strength, so it was expected that they would not all stop at the same time. However, according to the records, after the magnitude 6.0 earthquake on 22 June 1924, all three clocks did stop (van der Hucht and Kerkhoven, 1982).[6] The epicenter of this earthquake was at Sukabumi, about 70 km in the Southwest of the Observatory.

The Riefler No. 487 was used as the standard pendulum clock and was fitted with two contact sprocket wheels on the seconds axis, one of which had 59 teeth. They were evenly distributed around the wheel at intervals equal to one-sixtieth of the circumference of the wheel. This was to indicate the minutes when one of the teeth was removed. The other wheel

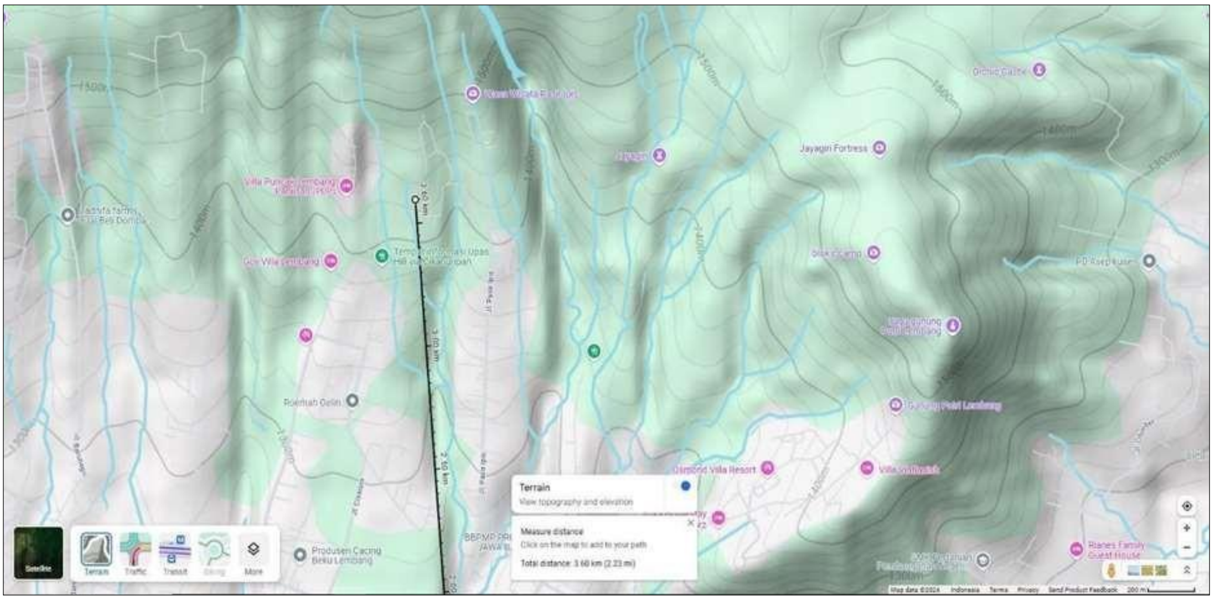

Figure 9: The estimated position of the meridian marker pillar is to the north, approximately 3600 m from the transit telescope building, and is at an altitude of 1440 on Jayagiri Hill, obtained using Google Maps (map: the authors).

had thirty teeth.

The Richter No. 110 clock was also donated by R.A. Kerkhoven, and was equipped with two contact sprocket wheels, both having 60 teeth. One of these was used to operate the first chronograph point in the same way as in the Riefler. On the other hand, the de Casseres No. 3 clock eventually was not used very often because of its less than satisfactory performance.

4.3 Time Recordings

4.3.1 The Coincidence Method

As mentioned earlier, the role of the T.S.F. in determining longitudes, was to provide instantaneous signals for those stations whose differences in longitude were to be determined. The precise moment at which the time on one's clock had to be noted in order to know the difference in the times noted at the other stations, and compared with the other timepieces at that precise moment. Its use was very advantageous, because it was important that the stations considered were within the range of the same radio-telegraph station, which, now, with the multiplicity of large existing T.S.F. stations, was more or less achieved for any point on the surface of the Earth (Ferrié, 1920).

Since the desired precision for this longitude determination was relatively high (i.e., of the order of a hundredth of a second), it was necessary to use much more exact processes to compare the clocks with the T.S.F. signals. Three different methods could be used: (1) Method of coincidences; (2) Method of series of the same period; and (3) Method of recording. These were explained in detail by Ferrié (1920). Among these three methods to receive time-signals, the method recommended by the International Commission was the coincidence one. Further details can be found in Cooke and Cooke (1917; 1920; 1923), and

Figure 10: The Richter clock (left) is used to keep a mean time, while the Riefler clock (right) is used to keep a sidereal time. Both clocks are now placed in the Exhibition Room of the Bosscha Observatory (photographs: the authors).

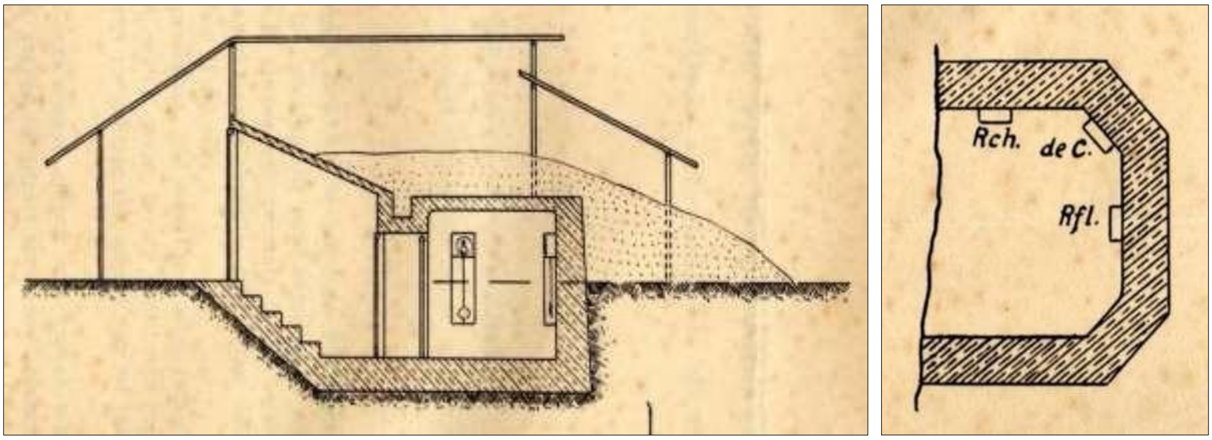

Figure 11: The clock storage room at Bosscha Observatory which is no longer in use. The temperature was kept constant for good clock performance (after Poldervaart, 1930).

Figure 12: Chronographs H. Frentzen and Nardin No. 1587 were used in the World Longitude Determination of 1933 at Bosscha Observatory. The Fuess chronometer used earlier no longer exists (photograph by the authors).

this method is also called the Cooke Method. Accordingly, Bosscha Observatory used this method.

Basically, between the two geographical points (say, A and B) for which the difference in longitude is to be determined, there is a large wireless station C that transmits a series of signals spaced apart by a certain time interval, to be detected and compared by A and B. The observers record the time indicated by the clocks at the instant when each of the coincidences occurs between the two series of beats, as well as the number of the wireless signals on which these coincidences occur. A variety of corrections also has to be made.

This method (first used in 1910), has already been used for a large number of measurements of differences in longitude, particularly of Paris–Washington in 1913 (Rines, 1916). This method was also used to determine numerous geographical positions in North Africa using the series of time-signals broadcast every night at 23:30 by the Eiffel Tower radio station.

4.3.2 The Chronograph

A chronograph was employed for time-recording at each station. In 1926, Bosscha Observatory used a Fuess Chronograph to record the transits of stars in conjunction with an astronomical clock. This chronograph could compare the three clocks with each other, and finally record a time-signal according to a given scheme.

The chronograph had three pins, which worked side by side on a recording tape, and were controlled by separate sets of electromagnets. However, there were many difficulties registering signals using Fuess' needle chronograph, and from 20 October 1926 coincidence hearing reception was solely used according to the Cooke method (Poldervaart, 1930). In 1933 the Fuess chronograph was replaced by a Frentzen chronograph (Figure 12), which was better.

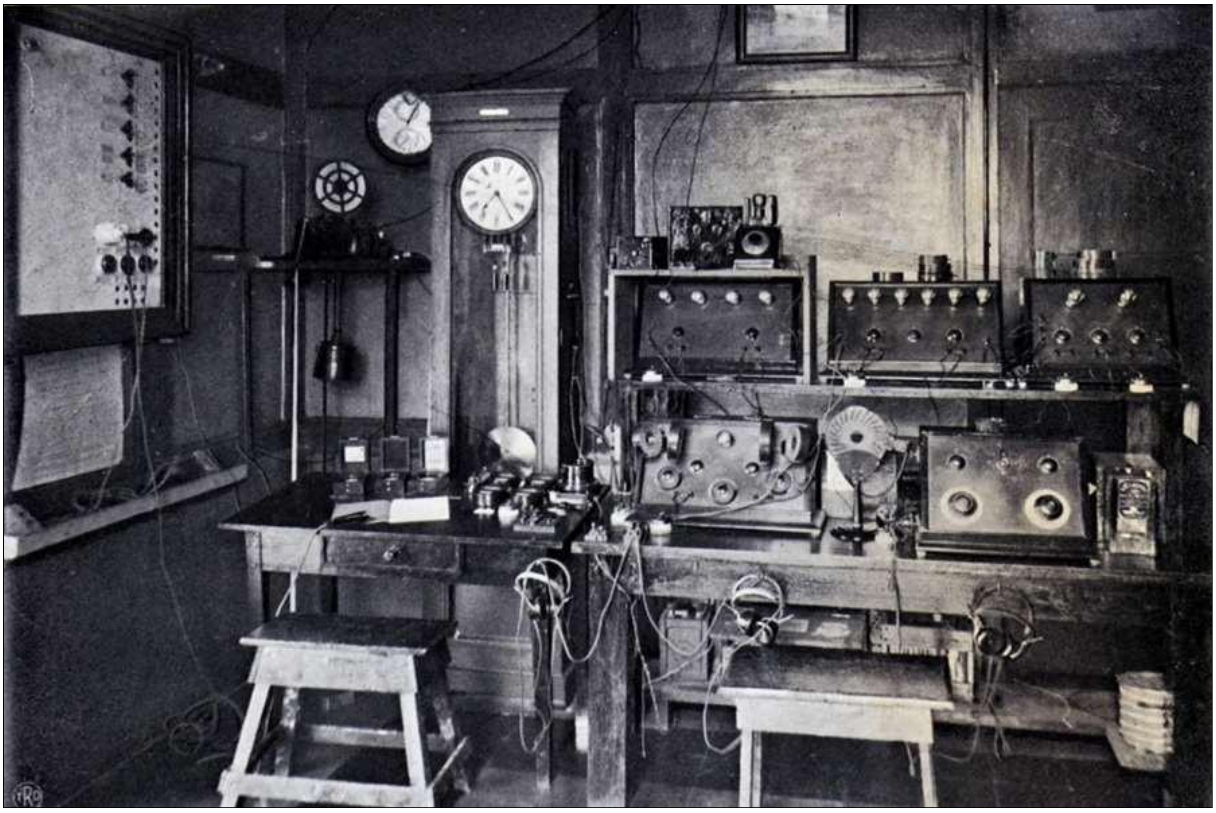

Figure 13: The radio control room which is no longer there at Bosscha Observatory; another Riefler clock is visible, which also can no longer be found (after Poldervaart, 1930).

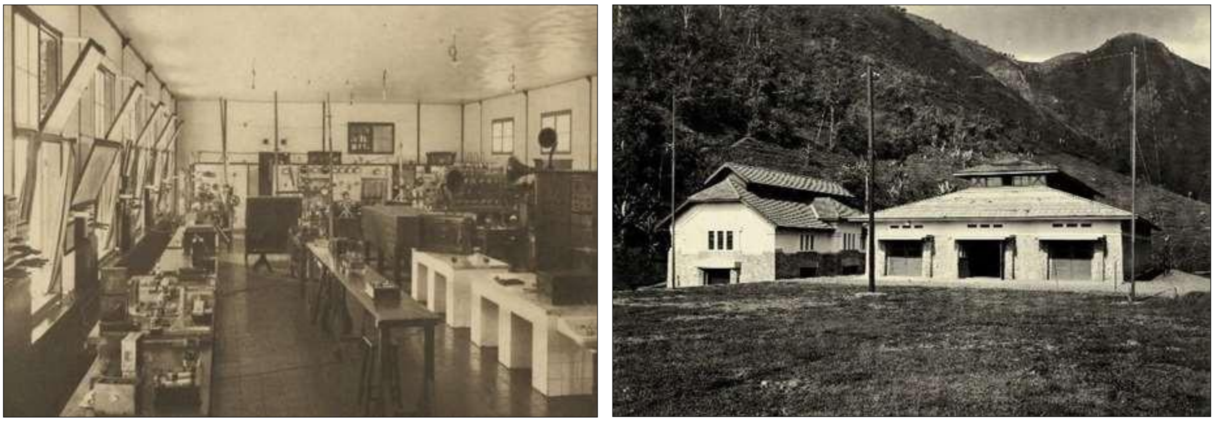

Figure 14: Bandung Radio Laboratory (left) and Cililin Radio station (right), a shortwave radio transmitter that fully supported the World Longitude Determination program at Bosscha Observatory (courtesy: Leiden University Libraries, http://hdl.handle.net/1887.1/item:928286; KITLV 107565).

4.4 Radio Receiving Equipment

Accordingly, receiving apparatus to detect time-signals was provided for Bosscha Observatory (Figure 13). In the network of these longitude determinations, Lembang was included in the first group of stations (see details in Section 5.3). Therefore, everything possible had to be done to ensure the best possible accuracy of the observations. In reality, the preparation period was very short, starting in early May 1926. Since observations had to begin in September 1926, it was not possible to bring in the necessary equipment from Europe. In this respect, the assistance and cooperation of various technical services in the Netherlands East Indies were very much relied upon, to provide scientific knowledge and staff in the Triangulation Brigade (Poldervaart, 1930). Finally, the Director of Bosscha Observatory ordered a set of receivers from the instrument-maker of the Radio Laboratory (Figure 14, left). However, it was soon discovered that some time signals could not be received in Lembang, partly because of their low power. After some adjustments, it could only be guaranteed that Bosscha

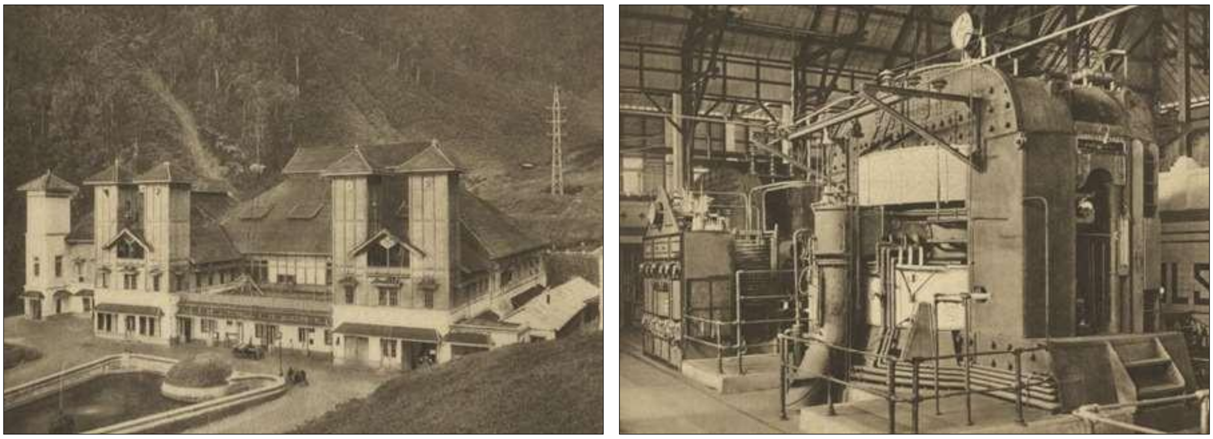

Figure 15: Malabar Radio station (left) and its transmitting hall (right) which fully support the World Longitude Determination program at Bosscha Observatory (Photo source: Leiden University Libraries, http://hdl.handle.net/1887.1/item: 928286; KITLV 107565).

Observatory could only pick up signals from Bordeaux and Saigon, while the problem of recording these signals had to be investigated further, especially because of the delay in the chronograph pin. At the time, there was no certainty that this recording would be successful.

The long wave receiving system in Lembang consisted of: (1) a T type antenna, that is, a monopole radio antenna comprising two 40-m long horizontal wires, suspended between two 12 m high supporting radio masts; (2) a heterodyne receiver; (3) a high frequency amplifier; (4) a low frequency amplifier; (5) a compensator; (6) a relay, which was connected to a chronograph for accurate timekeeping. In addition, a shortwave receiver was also built for Lembang. However, only the time-signals transmitted by Lembang itself via the Cililin shortwave station could be received (Figure 14). None of the shortwave time-signals mentioned in the program could be heard in Lembang. Several European stations could indeed be received, but unfortunately, they were not in the program.

4.5 The Radio Broadcasting Set

As concerned broadcasting the radio time-signals called upon by Vening Meinesz for his voyage of gravimetric survey on board the submarine K XIII, Bosscha Observatory has made some efforts to provide the appropriate means. For this purpose, which in the months of October and November 1926 also connected with the World Longitude Determination, the Observatory finally obtained a clock supplied by the firm of Van Arcken & Co., in Weltevreden. They also provided a contact device for giving signals, which, after special adjustment of the clock, could be received according to the coincidence method. These signals were sent directly to the Malabar radio station (Figure 15) through the cooperation with the Telephone Service and the Radio Company in Bandung. For sidereal time, nothing needed to be done inside the clock case. The clock was matched with a Riefler invar pendulum which was directly connected to the signal clock terminal via a telephone line to Lembang. Finally, these signals were transmitted to the Radio Exchange in Bandung and from there relays were used to transmit them to the radio broadcasting station in Malabar. Long-wave time-signals were broadcast from Malabar at $22^h\ 40^m$ GMT (see Figure 15), while short-wave time-signals were sent from Cililin at $10^h\ 40^m$ GMT (see Figure 14).

5 OBSERVATIONS, ANALYSES, AND RESULTS

5.1 Determination of Various Corrections

The Triangulation Brigade performed painstaking work to determine the various corrections necessary to obtain the exact local time. This consisted of determining the instrumental constant for the transit instrument, irregularity in the pendulum-contact, pen-lag, personal equations, etc. In addition, they also determined the corrections to be applied to the resulting computations of longitude that included lag by automatic recording of coincidence, as well as transmission times (Poldervaart, 1930).

We noted that only signals from Saigon, Bordeaux, and Malabar could be well detected from Lembang. For the calculations of longitude, transmission-times had to be adopted and applied. These are shown in Table 2, assuming the speed of radio waves is 300,000 km/s. It was found later that this assumption must be corrected.

So, to determine the difference of longitude from several locations to Lembang, corrections

Table 2: Transmission times for longitude calculations.

Between Stations	Time (s)
Saigon – Zi-ka-wei	0.009
Saigon – Lembang	0.006
Saigon – Paris	0.034
Saigon – Tokyo	0.015
Bordeaux – Zi-ka-wei	0.032
Bordeaux – Lembang	0.040
Bordeaux – Paris	0.002
Bordeaux – Tokyo	0.034
Bordeaux – Potsdam	0.003
Malabar – Lembang	0.000
Malabar – Tokyo	0.020

also had to be applied, as shown in Table 3.

Subsequently, the time-signals from the three sources detected in Lembang were summarized (Table 4).

Signals from Honolulu could not be detected by the Radio Service in Bandung. Similarly, signals from Annapolis failed to be detected in Bandung or Lembang.

5.2 Calculation of Longitude Difference with Other Observatories

To infer the accuracy obtained in Lembang, after receiving the results of reception at Paris and Zi-ka-wei, we can compute the difference in longitude between these stations, by comparing the corresponding times of reception. We consider only times of the signals from Bordeaux and Saigon, received at Paris and Zi-ka-wei. Then, the longitude difference between Lembang and Paris can be calculated (Table 5), and between Lembang and Zi-ka-wei (Table 6).

Time-signals from Bordeaux, Saigon, and Malabar were detected at Tokyo, and from their time-reception, the longitude could be calculated, yielding the results shown in Table 7.

Similarly, for Potsdam, only signals from Saigon were detected. From the corresponding reception-times at Potsdam, the longitude difference can be calculated (Table 8).

Table 3: Correction to be applied for longitude difference.

Signal From	Between Stations	Time Correction(s)
Saigon	Paris – Lembang	+ 0.028
Bordeaux	Paris – Lembang	– 0.038
Saigon	Zi-ka-wei – Lembang	+ 0.003
Bordeaux	Zi-ka-wei – Lembang	– 0.008
Saigon	Tokyo – Lembang	+ 0.009
Bordeaux	Tokyo – Lembang	– 0.006
Malabar	Tokyo – Lembang	+ 0.020
Bordeaux	Potsdam – Lembang	– 0.037

Table 4: Signal detected in Lembang.

Signal From	Wavelength (m)	Time of Transmission (GMT)
Bordeaux	28,900	$08^{h}\,01^{m}$
		$20^{h}\,01^{m}$ (1)
Saigon	15,800	$11^{h}\,30^{m}$
		$19^{h}\,00^{m}$
Malabar	15,600	$22^{h}\,40^{m}$
	39	$10^{h}\,40^{m}$

Note: (1) lost often by the strong air-disturbance.

Table 5: Longitude difference (Δλ) Lembang–Paris.

Signal From	Adopted Longitude	Mean Error
Bordeaux	$+7^{h}\,01^{m}\,6.849^{s}$	0.0035^{s}
Saigon	$+7^{h}\,01^{m}\,6.814^{s}$	0.0050^{s}
Mean	$+7^{h}\,01^{m}\,6.832^{s}$	
Δλ Paris – Greenwich	$+00^{h}\,09^{m}\,21.018^{s}$	(1)
Δλ Lembang – Greenwich	$+07^{h}\,10^{m}\,27.850^{s}$	

Note: (1) from World Longitude Determination.

We noticed that the mean errors in the calculated differences in longitude with Paris, Zi-Ka-Wei, Potsdam and Tokyo, calculated based on signals from the same transmitter, amounted

Table 6: Longitude difference (Δλ) Lembang – Zi-ka-wei.

Signal From		Mean Error
Bordeaux	$-0^{h}\,55^{m}\,15.052^{s}$	0.0050^{s}
Saigon	$-0^{h}\,55^{m}\,15.067^{s}$	0.0042^{s}
Mean	$-0^{h}\,55^{m}\,15.060^{s}$	
Δλ Zi-ka-wei – Greenwich	$+8^{h}\,05^{m}\,42.888^{s}$	(2)
Δλ Lembang – Greenwich	$+7^{h}\,10^{m}\,27.828^{s}$	

Note: (2) from World Longitude Determination.

Table 7: Longitude difference (Δλ) Lembang – Tokyo.

Signal From		Mean Error
Bordeaux	$-2^{h}\,07^{m}\,42.264^{s}$	0.0042^{s}
Saigon	$-2^{h}\,07^{m}\,42.277^{s}$	0.0030^{s}
Malabar	$-2^{h}\,07^{m}\,42.264^{s}$	0.0043^{s}
Mean	$-2^{h}\,07^{m}\,42.268^{s}$	
Δλ Tokyo – Greenwich	$+9^{h}\,08^{m}\,10.112^{s}$	(3)
Δλ Lembang – Greenwich	$+7^{h}\,10^{m}\,27.844^{s}$	

Note: (3) from World Longitude Determination.

Table 8: Longitude difference (Δλ) Lembang – Potsdam.

Signal From		Mean Error
Bordeaux	$+6^{h}\,18^{m}\,11.790^{s}$	0.0045^{s}
Δλ Potsdam – Greenwich	$+0^{h}\,52^{m}\,16.051^{s}$	(4)
Δλ Lembang – Greenwich	$+7^{h}\,10^{m}\,27.841^{s}$	

Note: (4) from Longitude Determination 1903.

to 0.0030 – 0.0050 s (Poldervaart, 1930). The differences between the values calculated for the same difference in longitude based on signals from different transmitters were in some cases somewhat larger than might be expected on the basis of these mean errors. For the longitude of the transit telescope at Lembang the following value could be assumed as a provisional value with respect to the Greenwich meridian: $7^h\ 10^m\ 27.840 \pm 0.003^s$.

Furthermore, the most probable value of the propagation velocity of radio waves was found to be 225,000 km/s, which deviated considerably from the theoretical value of 300,000 km/s. This phenomenon was also observed at other stations involved in determining longitude and can probably be partly explained by a shift in the starting points of the time signals, as a result of energy damping at large distances.

5.3 The 1933 Observations

There were many developments that were achieved after the 1926 Project, which was considered a great success (Lambert et al., 1938). In this respect, the General Assembly of the IAU held in Leiden in July 1928 adopted a resolution that the Longitude project in the form given to it in 1926 should be resumed.

The date set for its renewal, the exact time as well as its program would be determined by the *Commission Internationale des Longitudes* at the next IAU meeting. Until then, the observatories were invited to continue the determination of their longitudes in a more or less permanent way. This concerned the study of the systematic errors that the 1926 project was able to reveal, such as, the instantaneousness of the recording, the quality of the levels, time lost by the micrometer screw, and the personal equations of the observers. All the information thus collected would be brought to the attention of the Commission before its next meeting (*ibid.*).

Finally, on the occasion of the General Assembly of the IUGG held in in Stockholm in August 1930, the date of the second International Longitude Project was set for the autumn of 1933 by the Commission. When it was measured again, in 1933, a fundamental circle was added for the Southern Hemisphere, namely, Cape Town–Adelaide (or any other station in Australia)–Rio de Janeiro. To evaluate hypotheses regarding superficial deformation of the Earth's crust, whether due to Wegener's continental drift or submarine folds along the coasts as suspected by Vening Meinesz (see Section 6 below), the Commission recommended that combined stations, fully equipped with astronomical instruments and radio-telegraphic receivers, be established in the following regions: (1) Greenland and Scotland, (2) Madagascar and Mozambique, (3) the island of Ternate and Menado. However, missions in this third area could not be established by the authorities of the Netherlands East Indies (Lambert et al., 1938).

Nevertheless, during the NISV Board meeting on 23 – 24 December 1932 the question was raised about whether Bosscha Observatory would participate in this Project of 1933. Most members of the Board of Trustees were in favour of joining this project. This decision was made for the reasons that since the Dutch East Indies was such an important area of study in the geophysical field, and especially regarding plate movement, it would certainly cause great surprise in the scientific community if the few observatories in this area were to withdraw from this international determination of longitude. In addition, Bosscha Observatory was close to the Equator but was in the Southern Hemisphere, making it desirable that it participated in the Project of 1933—especially since more than 90 observatories internationally had already promised their cooperation. The only other station close to the Equator was Mogadishu in Africa (*ibid.*).

Thanks to the available funding estimated at 3000 guilders, a complete overhaul of the Observatory's Bamberg transit telescope could be carried out, as well as the purchase of a sensitive writing chronograph (Figure 12). The Richter and Riefler astronomical clocks at Observatory were also thoroughly overhauled before the start of the new longitude determination project. These clocks were provided with photo-electric contacts to avoid errors in mechanical contact wheels. Finally, long-wave time signals from Bordeaux, Nauen, Rugby, Saigon, Cavite and Malabar could be registered directly, while the delay of each signal could be determined with the receiving apparatus. The American long-wave stations still could not be recognized by ear, not even at the receiving stations of the Radio Service, while Tokyo was only recognizable by ear a few times under very favourable circumstances. Improved apparatus for determining personal errors in the determination of time was also adopted. The observations were carried out by Gsöllpointner and Scharpff from the Triangulation Brigade, kindly made available by the Head of the Topographical Service. For the local time correction, Lembang was placed in Group I, together with 20 other observatories. Group II comprised 30 observatories and Group III 20 observatories (*ibid.*).

It is also worth mentioning that, thanks to the goodwill of the head of the Radio Service,

Table 9: Variation of longitude relative to Greenwich.*

Continent	$\delta\lambda$ (s)	ε_v (s)	N	ε_{ext} (s)
Europe, Asia, Africa (AC)	+ 0.0116	± 0.0081	17	± 0.0230
North America (NA)	– 0.0020	± 0.0128	7	± 0.0221
Oceania, Australia, Japan (OJ)	+ 0.0053	± 0.0149	6	± 0.0236

* Where $\delta\lambda$ is variation of continent longitude between 1926 and 1933 relative to Greenwich, ε_v is error of the results, N is the number of stations, ε_{ext} is extrinsic error of longitude.

A.J.H. van Leeuwen, Bosscha Observatory was able to transmit powerful coincidence time-signals twice a day during the period 15 September –15 December 1933 via the large transmitter at Malabar. These Malabar time signals had been of the greatest importance for the World Longitude Determination of 1933 and especially for the Asia–America connection, as they compensated for the shortage of such powerful signals in the Pacific area. Lick Observatory reported that the Malabar time-signals were detected clearly during their measurements (Jeffers, 1934).

At Bosscha Observatory weather conditions were not ideal during this period, but 842 stars were observed during 55 complete time determinations. The number of registered long-wave time-signals was 400, while, in addition, 200 time signals were observed by means of coincidences in order to gain an insight into the relative differences between registration and hearing reception with coincidences. Eventually in 1934, in continuing the overview given in the previous annual report, the leader of the observations at Bosscha Observatory in September–October 1933, J.H.G. Schepers, compiled a concise report which he sent to the Bureau International de l'Heure in Paris, the receipt of which was reported on 5 December 1934.

5.4 Summary of the Results

The analyses of Dubois and Stoyko (1948) where they compared the longitudes of 1926 and 1933 from 71 stations showed that the deviations of the longitudes at the same station between these two projects were considerably greater than the errors of the longitudes calculated from all the results during the same project. The error of a longitude relative to Greenwich is equal to 0.0068 s taking all the stations into account except Canton. Moreover, comparison of the longitudes of 1926 with those of 1933 (from 33 common stations, excluding Voksenaasen) gave the average deviation of the results at ~0.0419 s. The error of a longitude relative to Greenwich was therefore equal to 0.0296 s, according to the comparison of the two world operations, neglecting the probable variations of the longitudes. This is an extrinsic error in the determination of the longitudes. The corresponding intrinsic error is equal to 0.0058 s, according to the error values, which thus is lower for those stations that participated in both projects than that (0.0068 s) of the stations that participated only in the 1933 project.

Furthermore, to infer continental drift, Dubois and Stoyko (1948) deduced the results summarized in Table 9, based on 30 fundamental stations.

Hence, for the movement of continents relative to each other, we obtain the results as shown in Table 10.

In any case, the uncertainties are larger than the values of the movement, so that the actual displacement, if any, cannot be deduced from these two operations with a seven-year interval. In addition, results from BIH's measurements spanning for more than 20 years indicated no appreciable secular shift in continents either (Dubois and Stoyko, 1948).

Moreover, we note that the longitude of Lembang was determined to be $7^{h}\,10^{m}\,27.773^{s}$ in 1926 and $7^{h}\,10^{m}\,27.840^{s}$ in 1933, so there is a difference of only 0.067 s (Lambert et al., 1938; Dubois and Stoyko, 1948). With reference to the position of the transit telescope, i.e., longitude $7^{h}\,10^{m}\,27.84^{s}$ E and latitude – 6° 49′ 32.93″, the positions of several instruments at Bosscha Observatory relative to the coordinates of the transit Instrument can be determined, as shown in Table 11 (Poldervaart, 1930; Voûte, 1933). The names in brackets are the names of the Telescope Building today. Table 11 also shows the positions based on Google Maps for a simple direct comparison after a century at Bosscha Observatory. It can be seen that there is an average difference of 0.38 s for longitude and a discrepancy of 3.49″ for latitude.[7]

6 GRAVITY ANOMALY MEASUREMENTS BY VENING MEINESZ

To obtain the figure of the Earth, it is essential to determine the direction as well as the inten-

Table 10: Relative continental movement.*

Between Continent	Relative Movement (s)	Uncertainties (s)
(OJ) – (AC)	– 0.0063	± 0.0170
(AC) – (NA)	+ 0.0136	± 0.0151
(NA) – (OJ)	– 0.0073	± 0.0196

* Where negative sign means receding continents and positive sign means approaching continents.

Table 11: Topographic measurements of instrument position at Bosscha Observatory.

Instrument	Topographic Measurement						Google Earth					
	Longitude (E)			Latitude (S)			Longitude (E)			Latitude (S)		
	h	m	s	°	′	″	h	m	s	°	′	″
Zeiss 60 cm double refractor (Kubah)	7	10	27.42	−6	49	31.8	7	10	27.81	−6	49	28.02
Comet-seeker (GAO-ITB)			27.62			32.2			28.00			28.86
Zeiss 13 cm Refractor (Stevia)			27.63			32.1			28.01			28.69
Secretan Refractor (Goto)			27.65			32.1			28.03			28.63
Pillar, for portable instrument (Surya)			27.68			32.2			28.06			28.75
Bamberg-Schmidt Refractor (Bamberg)			27.74			32.2			28.11			28.80
Transit Telescope (Transit)			27.84			32.93			28.20			29.40
Astrophotographic Refractor (Bima Sakti)			27.93			35.3			28.30			31.71

sity of the gravity. During the first General Conference of the European Arc-measurement, in Berlin 1864, pendulum observations were recommended. Measurements of local variation of the acceleration due to gravity could provide clues on mountain building and the properties of the Earth's crust. In 1870, Leiden Observatory conducted such observations during the determination of the longitude difference between Leiden and Bonn (van der Schraaf, 1979).

Figure 16: Geophysicist Felix A. Vening Meinesz (1887–1966), third from the right, seen here with several officers on the submarine K XII, on which he sailed to the Indies to conduct gravimetric surveys. The location of this 1928 Spaarnestad photograph is unknown (http://commons.wikimedia.org/).

In 1890, a subcommission, involving Johannes Bosscha and Hendricus Gerardus van de Sande Bakhuysen (1838 –1923), was set to make the necessary preparations to start these pendulum observations in the Netherlands.[8]

With the theory of continental drift it was believed that generally the crust floated on an underlying bed of molten lava and was in isostatic equilibrium. However, in tectonic regions strong forces were acting in the Earth's crust, and hence isostatic deviations could occur, resulting in isostatic anomalies. A positive anomaly on a gravity map implied overcompensation which led to a region that tended to sink, while, on the contrary, a negative anomaly revealed undercompensation, meaning that the area was likely to rise. Therefore, gravimetric measurements were indispensable. At this time, however, gravity survey for the oceans was quite limited, in contrast to continental surveys.

In this respect, the pioneering work of Felix Andries Vening Meinesz (1887–1966) in the field of gravity measurements at sea should be mentioned. He developed his own measuring techniques of swinging two pendulums in the same plane on the same support with equal amplitudes but in opposite phases, which allowed him to eliminate most disturbances of the pendulum movement. Between 1923 and 1938, he performed the famous oceanic gravity survey on board the following submarines: K II (1923), K XI (1925), K XIII (1926–1930), O 13 (1932), K 18 (1935), O 16 (1937), O 12 (1937), and O 13 (1938) (e.g., see Figure 16). These proved to be a complete success (Vening Meinesz, 1927; 1929; 1931; 1932; 1941; 1948; Vening Meinesz et al., 1934; van der Schraaf, 1979). The base observations were made at the Dutch Gravity Base Station De Bilt where the time-signals from Paris were used.

In autumn 1923, the submarine voyage was from Holland to Java (via Suez), and in 1925 from Holland to Alexandria, and subsequently in 1926 from Holland to Java, this time by way of the Panama Canal. These voyages provided a complete and continuous ring of gravity measurements, encircling the Earth. Furthermore, since the (Indonesian) Nusantara Archipelago was considered to be one of the most extensive regions of tectonic activity, special expeditions from the Netherlands East Indies were conducted to the Java Trench in February 1927, and in almost the whole of the archipelago from June 1929 until February 1930.

In the Atlantic Ocean, first the time-signals of Bordeaux, and later those of Annapolis, were recorded. The latter were usable up to halfway between San Francisco and Honolulu. When the voyagers reached the Pacific, the time-signals from Europe and America became increasingly more difficult to hear. In this respect, Bosscha Observatory gave substantial support during these surveys. The time-service was organized with the help of the Head of the Triangulation Brigade, J.H.G. Schepers, at Bosscha Observatory, who had also been in charge during the World Longitude Determination in 1926. Once a day a rythmic signal was sent out by Malabar radio station at a wavelength of 19,000 m. It was received and checked daily by means of astronomical observations owing to Poldervaart, Scharpf and Breyer at Bosscha Observatory. The radio signals were continually transmitted from July until the arrival of the submarine in Java in December 1926. Then they were taken up again twice daily for the trip across the Indian Ocean in February 1927. In the Western Pacific, radio signals from Saigon, and later also from Bordeaux, were audible.

For the three voyages in the archipelago in 1929 –1930, Vening Meinesz decided to establish a base-station at Bandung for his observations in Java, in addition to his base station at De Bilt in Holland. Hence, a complete series of base-observations were made at the base-station at Bandung, which was located in the Bosscha Laboratorium at the Technische Hogeschool (Figure 17). A cable connection with Bosscha Observatory at Lembang was available, and one of the shutters of the recording apparatus could be operated directly by one of the pendulum clocks at the Observatory. After completing the observations in Bandung, the apparatus was transported to Surabaya where the submarine expedition would start. When he stayed in Bandung and Batavia, Vening Meinesz gave lectures about how his gravimetric data could provide a crucial test of Wegener's continental drift theory (Pyenson, 1989). He was also an honoured visiting scholar at Bosscha Observatory.

Vening Meinesz found that the Netherlands East Indies exhibited great isostatic anomalies, especially during the last part of his voyage on board the Submarine K XIII in 1926. Moreover, they did not change when passing from an island chain to a deep part of the ocean or to a trench (Vening Meinesz, 1931). The results showed great disturbances of equilibrium in the Earth's crust, the meaning of which was not yet clear, and it was therefore desirable to continue this research. An extension of the research over the whole area would allow a study of the relationship between these disturbances and geological and topographical features, which might lead to a better understanding of their nature. In some ways, Vening Meinesz disagreed with Wegener's theory of continental drift. Consequently, more data about the magnitude and trend of the tectonic stresses working on the crust were needed so that a more in-depth study could—hopefully—reconcile these different viewpoints. To this end plans were worked out to cover the whole Archipelago with a large number of sea gravity stations and it was hoped that afterwards a land gravity survey would also be carried out (Vening Meinesz,1929; 1932; 1941; 1948).

Figure 17: The Bosscha Laboratorium at the Technische Hoogeschool. This laboratory was donated by K.A.R. Bosscha to what is now the ITB on 12 March 1922 (photograph: the authors).

Figure 18: VGOS Radio Telescope Construction Plan at Bosscha Observatory located near the transit instrument building, which is still preserved (courtesy: Bosscha Observatory).

7 RECONNECTING WITH ZI-KA-WEI: THE SHAO AND VGOS

As previously mentioned, Zi-ka-wei (Shanghai) played a role as one of fundamental stations for the World Longitude Determination both in 1926 and 1933. In fact, after more than a century, Bosscha Observatory recently reconnected with Shanghai Astronomical Observatory (SHAO) of the Chinese Academy of Sciences (CAS) thanks to a cooperative venture to build a radio telescope in Indonesia as part the network of the VLBI Global Observing System (VGOS). The CAS plans to build 10 VGOS stations, one of which will be at Bosscha Observatory. Six VGOS stations have already been operating in China: three at the National Time Service Center (NTSC), and three others, in Sheshan, Tianma and Urumqi (Li et al., 2019). In addition, one station in Chiang Mai, Thailand, currently is at the commissioning stage, in cooperation with NARIT. Three further stations are now under construction, at Lembang (Indonesia), Walailak University (Thailand), and in Nigeria.

The so-called VLBI Global Observing System is the realization of the next-generation VLBI system (Niell et al., 2006; Petrachenko et al., 2009; 2010), to achieve an accuracy of 1 mm in station position, and 0.1 mm/year in station velocity on a global scale. VGOS is also expected to perform continuous time-series measurements of station positions and Earth Orientation Parameters (EOP), which are crucial in geodesy and astrometry as they describe irregularities in the Earth’s rotation. Once in operation, they will post initial geodetic results <24 hours after completing the observations. The development of VGOS is an excellent example of symbiosis between geodesy and astronomy.

Over the last three decades, VLBI has contributed significantly to the International Terrestrial Reference Frame (ITRF, Altamimi et al., 2016; 2023), and uniquely to the realization of the International Celestial Reference System (ICRF; Charlot et al. 2020; Seidelmann and Kovalevsky, 2002). Moreover, VLBI uniquely provides a full set of self-consistent Earth Orientation Parameters that link the terrestrial and celestial frames and enable Earth positioning and space navigation (Bizouard, 2020).

Figure 18 shows the site plan for the construction of the VGOS station at Bosscha Observatory, which has been planned jointly with the SHAO since 2022. Figure 19 shows the progress with the construction as at January 2025. Once construction is completed, commissioning and preparation for operation will immediately be carried out. Placed in a position near the transit telescope, at coordinates 6° 49′ 29.85316″ ± 0.0002 (m) S and 107° 37′ 03.09318″ ± 0.0003 (m) E, and an altitude of 1324.1265 ± 0.0010 m, this VGOS antenna will be the one closest to the Equator in the

Southern Hemisphere and in a unique Eastern longitude region. Meanwhile, a new VGOS station currently is under construction very close to its antipodal point, at Eusébio, Fortaleza (Brazil), positioned at 3.8770° S and 38.4253° W. This location is even nearer to the Equator (da Silva et al., 2023) but is opposite Bosscha Observatory in terms of longitude, being on the Western side of the Earth. Obviously, this will make an important contribution to the distribution of VGOS station positions, which are, nonetheless, still predominantly in the Northern Hemisphere. Both new stations will be essential in contributing to UT1 measurements.

The presence of the new VGOS station at Bosscha Observatory marks the participation in and continuation of the Observatory in supporting research in astrometry and geodynamics which has now been carried out for more than a century. This effort also continues the Observatory's participation in global collaborations, reminiscent of the World Longitude Determination Efforts of 1926 and 1933. This

Figure 19: The VGOS telescope tower building (top) and its supporting building (bottom) under construction at Bosscha Observatory in January 2025 (photographs: the authors).

will also certainly help the growing VLBI network in Southeast Asia (Sugiyama et al., 2023).

8 DISCUSSION AND CONCLUDING REMARKS

Ancient astronomical knowledge in the Indonesian Archipelago was evident through ethno-astronomical practices in various regions, including the construction of temples throughout Indonesia (see for example, Fatima et al., 2021; Khairunnisa et al., 2021; Rasyid et al., 2021; Rodhiyah and Hidayat, 2019). However, despite some transient activities in the nineteenth century associated with total solar eclipses (Mumpuni et al., 2017; Pearson and Orchiston, 2017), it was not until the early twentieth century, with the establishment of Bosscha Observatory, that 'modern astronomy' found an institutional footing in Indonesia. In its century-long journey this Observatory has inspired the establishment of more than 30 small observatories in various universities in Indonesia, especially in Islamic State Universities. On a larger scale, the Timau National Observatory has now been established (Hidayat et al., 2012; Mumpuni et al., 2018), in order to continue the Bosscha Observatory legacy of sustaining astronomical and astrophysical research in Indonesia.[9]

Bosscha Observatory has also participated in international collaborative projects, as shown in its participation in the World Longitude Determination which was carried out in 1926 and 1933 under the auspices of the IAU and IUGG. At that time this project was intended to test Wegener's hypothesis of continental drift. By providing the necessary equipment, and with support from officers and engineers in the Geodetic Section of the Topographical Service and the Triangulation Brigade, Bosscha Observatory succeeded in contributing to this global effort (Poldervaart, 1930).

This global effort was considered a great success. The closing error of the primary triangle was just two thousandths of a second in time (or less than one metre, expressed in distance). Subsequently, this first World Longitude project was followed by one more, the International Geophysical Year (1957–1958). Whilst the later project became more international and less French in character, the fundamental techniques were unchanged. This continuity accentuates the historical relevance of Ferrié's 1919 memorandum to the Bureau des longitudes, which set forth the methods for precise longitude determination throughout the wireless era. These results have been thoroughly discussed, and their accuracy seems to have exceeded expectations.

Meanwhile, since 2008 Bosscha Observatory has embarked on a multi-wavelength program, that particularly emphasizes radio astronomy (Hidayat et al., 2013; 2014). Accordingly, with a VGOS radio telescope soon to be operational, Bosscha Observatory has affirmed its commitment to participate in various international geodetic and astrometric astronomy projects, in addition to on-going astrophysical research. Achieving an accuracy of 1 mm in positioning using the VLBI method marks a 1000-fold improvement over measurements taken nearly a century ago. Likewise, with VLBI, there are growing opportunities to participate in a range of related multi-disciplinary applications. As a result, Bosscha Observatory undoubtedly will be able to sustain its research tradition while embracing its multifaceted international character.

9 NOTES

1. He also served as Secretary of the Netherlands Geodetic Commission 1879 –1881 (van der Schraaf, 1979).
2. The first edition was published in 1915, the second in 1920, the third in 1922, and the fourth in 1929, which was a continuous update; the English edition of "The Origin of Continents and Oceans" was translated by John Biram (1966).
3. Schepers was appointed as the first Professor of Geodesy in 1922 at Technische Hoogeschool te Bandung (now Institut Teknologi Bandung, established on 3 July 1920). He was also an active member of the NISV management in the period 1923 – 1939. Returning to Holland, then he was member of the Netherlands Geodetic Commission until his death in 1968.
4. Located about 50 km to the south of Lembang, the Malabar radio station was built in 1917 and officially inaugurated on 5 May 1923.
5. In 1939, Poldervaart replaced Schepers as the Head of Triangulation Brigade and in 1941 he was appointed Professor of Geodesy at Technische Hoogeschool te Bandung.
6. As can be checked at URL: https://www.volcanodiscovery.com/earthquakes/quake-info/11528224/mag6quake-Jun-22-1924-Jawa.html (accessed on 2 February 2025).
7. Recently, the position of the transit telescope has been remeasured more accurately using the GNSS observations. It is found to be: Longitude = 107° 37′ 03.00614″ E ± 0.0004 (m) or $7^h\ 10^m\ 18.20041^s$ E ± 0.0004 (m); Latitude = 6° 49′ 29.40696″ S ± 0.0003 (m); Altitude:

1316.3022 ± 0.0009 m. Therefore, the estimation of positions using Google Maps is consistent with our last measurement.

8. Astronomer H.G. van de Sande Bakhuysen was Director of Leiden Observatory from 1872 to 1908, but he also served as President of the Netherlands Geodetic Commission from 1882 to 1923. The Library at Bosscha Observatory acquired its first collection when Sande Bakhuysen kindly donated his personal library to the Observatory.
9. The main telescope at the Timau National Observatory is identical to the Seimei Telescope at Kyoto University's Astronomical Observatory, which is located at the Okayama Observatory in Japan. It is a 3.8-meter diameter optical-infrared alt-azimuth-mounted telescope installed within the telescope dome that has been erected on Mount Timau in West Timor. As of January 2025, the secondary mirror has been successfully installed, but the primary mirror, which consists of eighteen petal-shaped segments, is still being prepared. Engineering first light is expected to be achieved in July this year. The telescope will be used for research on various transient phenomena, including outbursts and flares. It will also search for exoplanets using the transit and microlensing methods, study gamma-ray bursts (GRBs), and conduct asteroid surveys and patrols, among other projects.

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As a scientist, his main interest is in millimeter/submillimeter radio observations of planetary atmospheres. Recently, he has been very active in establishing the VGOS radio telescope at Bosscha Observatory, and developing VLBI in Southeast Asia. He has also joined a research group to study star-forming regions and the deep field environment of radio galaxies using ALMA data.

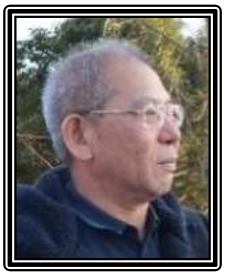
Taufiq is a member of the National Committee to develop Timau National Observatory on the island of Timor in the eastern part of Indonesia. He has written several textbooks on physics for undergraduate and graduate students and popular books of astronomy for children as well as editing the proceedings of several conferences. Apart from astrophysics and astronomy education, he has an interest in the history of Indonesian astronomy and—mainly in collaboration with ITB graduate students—has written a series of papers on archaeoastronomy and ethnoastronomy. He is on the Editorial Board of the *Journal of Astronomical History and Heritage*. In 2010, the International Astronomical Union named one of the main belt asteroids 12179 Taufiq (5030 T-3) in his honour.

Widjaja Martokusumo is Professor of Architecture and Urban Heritage Conservation (Architectural Design Research Group) in the School of Architecture, Planning, and Policy Development at the Institut Teknologi Bandung (ITB) in Indonesia. In 1999 he was awarded a Doktor-Ingenieur degree from the Faculty of Urban and Landscape Planning at the University of Kassel in Germany. During his career, he has held visiting academic positions in Australia, Germany and Lithuania.

Since 2006, Widjaja has actively contributed to several significant architectural and heritage conservation projects in collaboration with Bosscha Observatory, including renovation of 'Wisma Kerkhoven' (the Director's house, 2006–2007), the design and construction of a real-time solar telescope building (2007–2008), and the renovation of a timber house for Bosscha Observatory employees (2014–2015). Furthermore, he took part in the masterplan development of the Timau National Observatory in West Timor (2014 – 2015), and currently is involved in the VGOS radio telescope project (2024 – 2025).

Dr. Hesti Wulandari is a Lecturer in the Department of Astronomy at the Institut Teknologi Bandung (ITB) in Indonesia. She earned her Bachelor's degree in Astronomy and her Master's degree in Physics from ITB, while her doctorate in Physics was obtained from the Technical University of Munich in Germany. As a scientist, her primary research interests include galaxies and cosmology, with a particular focus on dark matter and dark energy. She is a former member of the CRESST dark matter collaboration.

Currently, Hesti serves as the Director of Bosscha Observatory and was previously Head of the Graduate and Undergraduate Programs in Astronomy at ITB. She was actively involved in the initial phase of establishing the Timau National Observatory on the island of Timor. Additionally, she represents Indonesia in the South East Asia Astronomical Network.



Jinling Li is a Professor at Shanghai Astronomical Observatory, Chinese Academy of Sciences in China. He obtained his Bachelor's degree in Physics, and Master's and PhD degrees in Astrometry and Celestial Mechanics in China.

As a scientist, his main interest recently has been to develop the 13-m radio telescopes for the VLBI Global Observation Systems stations that will be used to determine Earth Orientation Parameters (EOP), including the radio telescope at Bosscha Observatory which will be commissioning in 2025. The precise determination of EOP is crucial for economy development, remote sensing and deep space exploration.

Dr. Ibnu Nurul Huda received his Bachelor's and Master's degrees from the Institut Teknologi Bandung and his Doctorate from Paris Observatory.

He is currently a researcher at the Research Center for Computing, National Research and Innovation Agency (BRIN) in Indonesia. He has also joined Nanjing University (China) as a Post-doctoral researcher. His current main research interests include the dynamics of small bodies in the Solar System, Earth tides, Earth's rotation, and radio astronomy.

Dr Lucky Puspitarini is a faculty member at the Institut Teknologi Bandung (ITB). She obtained her Bachelor's degree in Astronomy from ITB in 2009. She then continued her studies in France, receiving a Master's degree from the Université Paris-Diderot in 2011 and a Doctorate from the Observatoire de Paris (Université PSL), in 2014.

Her main research topic is Interstellar Matter. She is currently an Astronomy Research Group member at ITB and a member of the ITB Center of Excellence for Space Science, Technology, and Innovation. She was the Head of the Astronomy Laboratory, Faculty Student Affairs team, and a member of the Internal Division for the Astronomical Instruments at Bosscha Observatory.

In addition to her academic and administrative roles, she is a jury member of the National Science Olympiad and a coordinator for the International Astronomical Olympiad Training under the Ministry of Education, Indonesia. She was also involved in the preparation of the Timau National Observatory, and currently is helping with the construction of the VGOS radio telescope at Bosscha Observatory.

Robert Voûte is Vice-President Consulting with the CGI company in the Netherlands, where he leads the Geo-ICT group. He has a Master's degree in Geodetic Engineering from Delft University of Technology and is a guest researcher at the University. He also supervises Master's students from four different universities in geo-related research.

His own research is mainly in 3D indoor geometics, i.e. mapping, localization and positioning to increase situation awareness. Ancient Egypt has been a special interest and after teaching Egyptian archaeology students surveying techniques he did his own field research in Egypt mapping an underground tomb in detail using 'low-cost' equipment. Apart from commercial work in the CGI company Robert has written many scientific publications. He is a member of the Board of the Association of Geo Business the Netherlands.