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STUDY ON CHANGE OF GRAVITY WITH TIME
PART III. ON THE TIDAL FACTOR OF GRAVITY

BY

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ABSTRACT

For the purpose of determining the accurate value of the tidal factor of gravity ($G \equiv 1-3k/2+h$; h, k: Love numbers), the one month's gravimetric observations were made at three stations of Kyoto, Chikubushima, and Shionomisaki where the effects of the ocean tide and geological structure, if existing, upon the tidal factor value were considered to be representatively different from each other. As deduced from the analysis of the present observations and after the calculation of disturbance effect, the most valid value of G was estimated as 1.18 ± 0.02. And by combining the present value of $G=1.18$ and $D=0.66$ ($D \equiv 1+k-h$) derived from the tiltmetric observation on earth tide, the Love number values were calculated as $h=0.66$, and $k=0.32$, which gave the earth tidal upheaval of the ground of more than 50 cm in the maximum. Moreover, in the present article the gravity variation connected with the variation of atmospheric pressure is discussed in some detail.

1. Introduction

(1) *Outline of the theory of earth tides*

Detailed theoretical investigations on the phenomena of earth tides have been fully made by Lord Kelvin, A. E. H. Love, H. Takeuchi, and many others, as briefly described in Part I of this series of research. Though it is not the purpose of the present article to describe the details of those theoretical treatments, it is considered to be convenient to describe an outline of the theory of earth tides to clarify the aim of the present investigation and the significance of the results obtained in our observation.

Let the tide-producing potential at any point within or near the earth due to a celestial body be denoted by W_2, then W_2 can be expressed with sufficient approximation by the formula

$$W_2 = \frac{1}{2}\gamma M D^{-3} r^2 (3\cos^2\theta - 1)\,, \tag{1}$$

where γ denotes the constant of gravitation, M the mass of the celestial body, D the distance between the centres of the earth and the celestial body, r the distance of the point from the earth's centre, θ the angle between the radius vectors drawn from the earth's centre to the point and to the centre of the celestial body. Then W_2/g expresses the theoretical equilibrium height of the ocean tide caused by the celestial body, g being the mean value of gravity at the earth's surface. This theoretical equilibrium height of the ocean tide can be calculated under the assumption that the earth is perfectly rigid and therefore it does not yield to the tidal force. Assuming that the distribution of mass in the earth's interior is spherically symmetrical, and that the rigidity and incompressibility are constant over the same surface as the density (if the rotation were taken into account, the spherical surfaces of equal density would have to be replaced by ellipsoidal surfaces), the radial displacement U of any point of the solid earth, which is produced by the force derived from the potential W_2, ought to be expressed by the product of W_2 and a certain function of r; thus we may write

$$U=H(r)\frac{W_2}{g}, \tag{2}$$

where the function $H(r)$ depends upon the distribution of density and elasticity in the earth. The potential due to the increment, or decrement, of density that accompanies the cubical dilatation, and to the superficial displacement of matter, ought to be also expressed by the product of W_2 and some function of r, so that we may write for the potential of the earth deformed by the tidal force an expression of the form

$$V=V_0+K(r)W_2, \tag{3}$$

where V_0 denotes the potential of the undisturbed earth. Now denote the mean radius of the earth by a and write

$$h=H(a), \qquad k=K(a),$$

then h and k are two numbers which define the height of the earth tide at the earth's surface and the additional potential that is produced by the earth's deformation, and are usually called "Love numbers". Using these Love numbers, for the surface of the earth we have

$$U=h\frac{W_2}{g}, \tag{4}$$

$$V=V_0+kW_2. \tag{5}$$

Combining (5) with W_2 in (1), we get the total potential due to the deformed earth and the original tide-producing potential, which is expressed by

$$V_0+kW_2+W_2.$$

From this we get for the equilibrium height of the ocean tide, referred to the undisturbed earth, a formula of

$$(1+k)\frac{W_2}{g}.$$

Accordingly, if the height of the ocean tide is observed at a point of the deformed earth's surface, which is expressed by $r=a+h\dfrac{W_2}{g}$, its height ought to become

$$(1+k-h)\frac{W_2}{g};$$

in other words, the equilibrium height of the ocean tide is modified in the ratio $(1+k-h)/1$ to that for a perfectly rigid earth, in consequence of the existence of the earth tide. The number $D\equiv 1+k-h$ is usually called "diminishing factor".

The diminishing factor D is also obtained by observation of the deflection of plumb-line. The amount of deflection of plumb-line, or change of the direction of gravity, caused by tidal force ought to be diminished in the same ratio D in consequence of the deformation of the earth. It will be understood by the following. As was already seen, the surface of the deformed earth is expressed by the equation

$$\varphi(r,\ \theta)\equiv r-a-h\frac{W_2}{g}=0; \tag{6}$$

on the other hand, the level surface defined by the total potential due to the deformed earth and the original tide-producing potential is expressed by the equation

$$\psi(r,\ \theta)\equiv V_0+kW_2+W_2+\text{const.}=0. \tag{7}$$

The angle between the normal lines of these two surfaces is that which is observed with the tiltmeters settled on the earth's surface as the tidal deflection of the plumb-line. The angle α_1 between the radius vector and normal line of the surface (6) at a point is calculated by the expression

$$\alpha_1=-\frac{1}{r}\frac{\dfrac{\partial\varphi}{\partial\theta}}{\dfrac{\partial\varphi}{\theta r}}=\frac{h}{ag}\frac{\partial W_2}{\partial\theta}; \tag{8}$$

similarly, the angle α_2 between the radius vector and normal line of the surface (7) at the same point is calculated by the expression

$$\alpha_2=-\frac{1}{r}\frac{\dfrac{\partial\psi}{\partial\theta}}{\dfrac{\partial\psi}{\theta r}}=\frac{1+k}{ag}\frac{\partial W_2}{\partial\theta}. \tag{9}$$

Subtracting α_1 from α_2, its remainder becomes

$$(1+k-h)\frac{1}{ag}\frac{\partial W_2}{\partial\theta},$$

which is the tidal deflection of plumb-line to be observed actually. If the earth were perfectly rigid, it would be $\frac{1}{ag}\frac{\partial W_2}{\partial\theta}$. Accordingly the ratio of the observed deflection of plumb-line to that which would occur if the earth were perfectly rigid is also $(1+k-h)/1$.

Now, the tidal variation of the intensity of gravity in case that the earth yields to the tidal force can be derived by the following processes. The potential at a point on the surface of the deformed earth is considered to consist of the following four parts:

(i) potential of the undisturbed earth V_0,
(ii) potential induced by the displacement of the point $U\frac{dV_0}{dr}$,
(iii) potential induced by the deformation of the earth $K(r)W_2$, and
(iv) original tide-producing potential W_2.

Formularizing this, it becomes

$$V=V_0+U\frac{dV_0}{dr}+K(r)W_2+W_2\,. \tag{10}$$

Differentiating (10) with respect to r, we get for the variational part of gravity Δg an expression of the form

$$\Delta g=U\frac{d^2V_0}{dr^2}+\frac{\partial}{\partial r}(K(r)W_2)+\frac{\partial W_2}{\partial r}\,. \tag{11}$$

From Laplace's equation

$$\nabla^2 V_0=\frac{d^2V_0}{dr^2}+\frac{2}{r}\frac{dV_0}{dr}=0\,,$$

we get

$$\frac{d^2V_0}{dr^2}=-\frac{2}{r}\frac{dV_0}{dr}\,. \tag{12}$$

Next, since $K(r)W_2$ is proved to be approximately proportional to $\frac{1}{r^3}$, we get

$$\frac{\partial}{\partial r}(K(r)W_2)=-\frac{3}{r}(K(r)W_2)\,. \tag{13}$$

Lastly, by differentiating the expression (1) we get

$$\frac{\partial W_2}{\partial r}=\frac{2}{r}W_2\,. \tag{14}$$

Inserting (12), (13), and (14) into (11), and taking into account that $H(r)=h$, $K(r)=k$ for $r=a$, and $\left(\frac{dV_0}{dr}\right)_{r=a}=-g$, we get

$$\Delta g=(2h-3k+2)\frac{W_2}{r}\,. \tag{15}$$

Inserting (14) into (15), we obtain the final result for the earth's surface

$$\Delta g=\left(1-\frac{3}{2}k+h\right)\left(\frac{\partial W_2}{\partial r}\right)_{r=a}.$$

If the earth were perfectly rigid, h and k would be zero and Δg become $\left(\frac{\partial W_2}{\partial r}\right)_{r=a}$. Accordingly the tidal variation of gravity intensity on the surface of deformed earth ought to be reduced in the ratio $\left(1-\frac{3}{2}k+h\right)/1$. The number $G\equiv 1-\frac{3}{2}k+h$ is usually called "tidal factor of gravity" or, in short, "gravimetric factor".

If the diminishing factor D is known from observations of the ocean tide or tiltmetric observations and the gravimetric factor G is known from gravimetric observations, we can easily determine, without any assumption on the distribution of density and elasticity of the earth's interior, the values of Love numbers h and k individually by algebraic calculation. But, as the next step, it is theoretically very difficult to calculate the distribution of density and elasticity of the earth's interior from the obtained values of Love numbers. In case of a simplified earth model under the assumption that the matter within the earth is absolutely incompressible and the density is uniform, we should have

$$k=\frac{3}{5}h; \tag{16}$$

if, further, the rigidity is assumed to be also uniform, we have the following relation

$$h=\frac{5}{2}\left(1+\frac{19}{2}\frac{\mu}{\rho g a}\right)^{-1}, \tag{17}$$

where ρ and μ denote the mean density and mean rigidity of the earth respectively. For a complex model of almost real earth, it needs an elaborate numerical calculation to determine the distribution of density and elasticity with the aid of knowledges obtained from the geodetic and seismological observations, and moreover the result thus obtained contains many undesirable uncertainties.

(2) *Purpose of the present investigation*

In spite of such difficulties as mentioned above, the diminishing factor D and gravimetric factor G undoubtedly supply us very important information on the elasticity of the matter within the earth. On account of this importance, a large number of investigators have made efforts to determine the most reliable values of D and G since the time of Lord Kelvin. In spite of their extraordinary efforts, various difficulties annexed to the observations have, especially in case of the gravimetric factor, disturbed the accurate determination of the values of D and G. The difficulties in the determination of the diminishing factor exist mainly in the fact that the actual height of the ocean tide is far apart from that which is expected from the equilibrium theory of the ocean tide, and in the fact that in case of tiltmetric observations the existence of the ocean tide produces baneful effects upon the study of the pure earth tide. From this point of view, the tiltmetric observations by A. A. Michelson (**1**) and E. Nishimura (**2**) which were made at the observation stations far apart from the ocean are considered to be ones to give the most reliable value of D. On the other hand, the determination of the gravimetric factor had been left behind that of the diminishing factor, chiefly because of instrumental difficulties with the gravimeter available for the purpose. The appearance of portable gravimeters which were rapidly developed since the end of the Second World War made it covenient not only for exploration but for the study of the earth tide; however, all the values of G obtained in the past days with portable gravimeters and station gravimeters are, as were shown in Table 1 of Part I of this series (**3**), greatly diverse from each other. The causes of diversity of those G-values are considered to exist, as mentioned in Part I, partly in the secondary effects of the ocean tide and the effects of local geological structure; however, it should be emphasized that the difference of the length of observation period also produces considerable effects on the G-value. As it will be illustrated by numerical results in the following section, there is great difference between the G-values obtained by observations for each period of a month, a fortnight, and a week, even in regard to M_2-component; and it is generally concluded that it needs the observation of at least a month or more in order to get a reliable G-value of the M_2-component.

Considering the above-mentioned circumstances on observation period and the effects of the ocean tide and local geological structure, it is concluded that, in order to examine these effects and obtain an accurate value of G, it must be observed for period of one month at least at many observation stations under various conditions. Under these circumstances the observations of the tidal variation of gravity were made at three stations under different conditions in the Kinki District for period of one month respectively. In the present article, the values of G obtained from each observation and the most reliable value of G obtained after examination of the above-mentioned effects will be reported, and further the values of Love numbers h and k will be computed.

2. Observations

(1) *Observation stations*

In order to accomplish the above-mentioned purposes, observation stations where the effects of the ocean tide and geological structure are possibly large ought to be selected. In regard to the meaning of "geological structure", it must be noticed that the "geological structure" which should affect the value of G, means such one of large scale as the thickness of the earth's crust or the tectonic differences between the continent and the ocean. From this point of view, it is considered to be most effective for the present purpose to observe at any number of stations on the continent as well as on solitary islands in the far-off ocean. But in the present state of our country, the accomplishment of this sort of observation is extremely troublesome and practically

Table 1.

	Station	Latitude (N)	Longitude (E)	Height (m)	g (gal)	BOUGUER anomaly (mgal)
I	Kyoto	35°02′	135°47′	58	979.722	− 12
II	Chikubushima	35°25′	136°09′	98	979.714	− 45
III	Shionomisaki	33°27′	135°46′	74	979.740	+139
I	Observation period	June 11th 12h 00m～July 13th 05h 00m, 1954				
II		Sep. 28th 15h 00m～Oct. 30th 12h 30m, 1955				
III		Nov. 16th 09h 00m～Dec. 17th 12h 00m, 1955				
I	Kyoto University, Geophysical Institute, No. 22 Laboratory, on the concrete block for experiment.					
II	Hōgonji Temple, The Office of Temple, on the earth floor of the side entrance.					
III	Shionomisaki Weather-station, Seismograph Room, on the surface of the concrete block.					

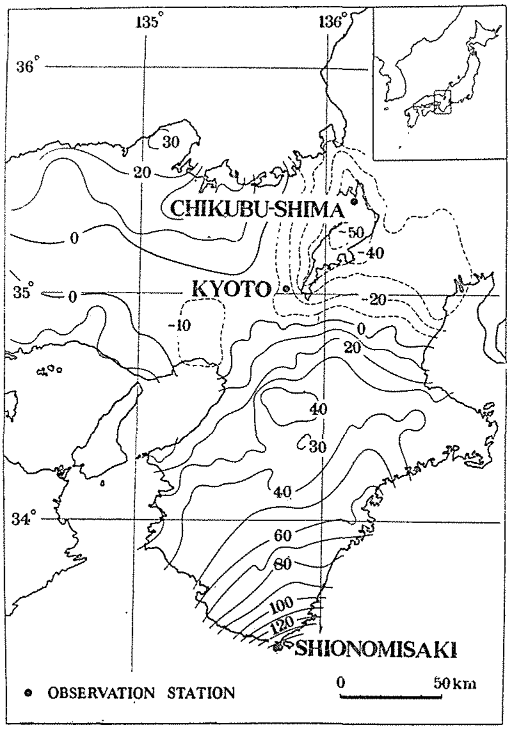

Fig. 1. Positions of the observation stations, and distribution of BOUGUER anomaly in mgal.

impossible; therefore, as a second best plan, some stations where the thickness of the crust is considered to be different from each other in our country were selected for the present gravimetric observation. Concerning the problem of the thickness of the crust in our country, the "map of BOUGUER anomalies" compiled by C. Tsuboi (4) gives the most precise information. Considering the distance from the Pacific Ocean shore in regard to the effects of the ocean tide, BOUGUER anomalies in regard to the effects of geological structure, and some other circumstances, three stations of Kyoto, Chikubushima in Lake Biwa, and Shionomisaki of the Kii Peninsula were finally selected as the most suitable ones for the present purpose. The locations of these stations, the observation periods and others are as shown in Table 1. Fig. 1 shows the relative positions of these stations for the aspect of BOUGUER anomalies. The variations of temperature and atmospheric pressure in each observation room are shown in Fig. 2. Hereafter, these three stations and the observations made at these stations will be called the station I, II, III, and the observation I, II, III respectively in this sequence.

(2) *Instrument*

All of the present observations were made by the use of the same instrument, a Worden Gravimeter No. 127. Its sensitivity given by the factory is 0.18473 mgal/div., and for practical purposes it can be read to one tenth of the scale division by the vernier. According to the experiments on the reliability of the scale constant made by the comparison with North American Gravimeter AG-1, 108, the accuracies of the scale constants of the both gravimeters accord well with each other within the limits of experimental errors. Although the problem concerning the absolute value of the gravimeter scale constant is generally very troublesome owing to the difficulties in the method of check, it may safely be said from various considerations that the scale constant given by the factory is trustworthy at least to the third significant figure. Consequently, in case of discussing the tidal factor of gravity to its third significant figure, the value of scale constant given by the factory will correctly be adopted in the present observation. On the other hand, from our other experiments and the experiments made independently by the members of the Geological Institute of Kyoto University, the above-described scale constant has remained constant within the limits of experimental errors since the time of its importation (1953); in other words, there is no noticeable time variation in the scale constant of that gravimeter. The plastic flow of the spring, or simply expressed as drift, of the gravimeter was fairly large, and moreover, the drift speed was never uniform. The subject of non-uniformity of the drift speed will be discussed in some detail in the next section, together with the influences of the meteorological factors upon the gravimetric observation. The average values of drift speed were estimated, in the present case, to be 0.600 mgal/day, 0.935 mgal/day, and 0.863 mgal/day for the periods of the observations I, II, and III respectively.

3. Results of the observations

The gravity variations at each station were read at intervals of half an hour, those values being collectively shown in the table at the end of the present article. Although the readings were made at intervals of half an hour, the hourly values alone were used for harmonic analysis under considerations of all the values. At the first step to enter harmonic analysis, it needs the reduction of drift. Since the drift speed was, as already mentioned, not uniform even in each observation period, the reduction was done by subtracting the running means of the observed values of 25 hours from the corresponding observed values in the middle of the 25 hours period. The curve joining the points which correspond to the values of running means represents the aspect of the drift, and the drift curve thus obtained was not a linear and monotonously increasing line in the present case. Since the proper plastic flow of the spring is perhaps linear with time for the period of only one month, the deviation of the actual drift curve from a straight line is considered to be affected by some external causes other than the proper plastic flow of the spring, for example such as meteorological factors. And so, before beginning the harmonic analysis, the correlation between the drift and meteorological factors should be examined.

(1) *Correlation between the drift and meteorological factors*

The uppermost curves at each station in Fig. 2 represent the deviations of actual drift curves from the straight lines corresponding to the mean drift speeds described in the preceding section; and the middle and lowermost curves represent the variations of the atmospheric pressure and temperature respectively. Since the variations of atmospheric pressure and temperature at station I were observed by reading the scales of a siphon mercurial barometer and a thermometer, and those at stations II and III were read from the records of a self-recording barograph and thermograph, some differences are to be noticed between the modes of the variations of those at stations I and II, III; but the differences are small and negligible for the purpose of discussing the general aspects of variations. Comparing the three curves of drift, pressure, and temperature with each other, it will be recognized that there exists generally a fairly good correspondence between the curves of drift deviation and atmospheric pressure for every station, though it is not always so in the details of variation. Furthermore, the both variations show the same sense. This fact contains an important significance in itself, for it represents that the increase or decrease of atmospheric pressure

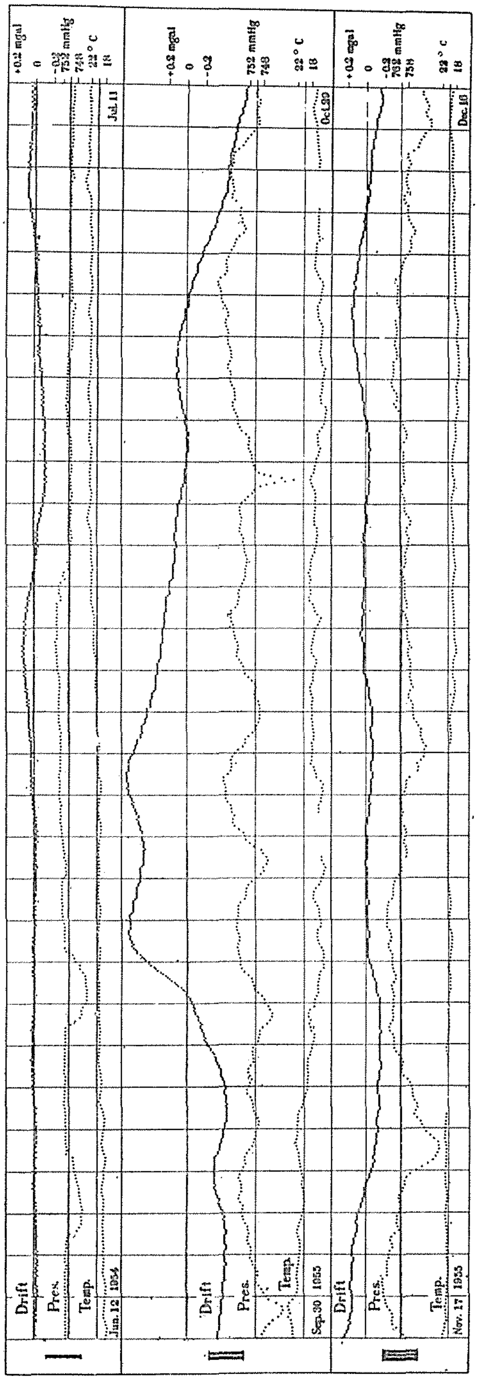

Fig. 2. Drift residuals in the observations at the three stations, and changes of atmospheric pressure and temperature.

apparently cause the increase or decrease of gravity. The phenomenon is entirely similar to that which was observed in the case of gravimetric investigation with the double bifilar gravimeter designed by the present writer (**3**). As described in that occasion, if it is assumed that the increase or decrease of atmospheric pressure corresponds to the increase or decrease of density of air, by whatever manner of the effect caused by the variation of buoyancy for the bob of gravimeter or the upward attraction of air mass, the increase or decrease of atmospheric pressure should produce the decrease or increase of gravity; but in practical case the effect is entirely reversed. From the fact that such curious phenomena as abovementioned were observed with two kinds of gravimeters having structures entirely different from each other, it is possibly concluded that the residual drift or, if a simple expression be permitted, the nonperiodic variation of gravity thus observed is caused by some unkown mechanism other than the effects of buoyancy and attraction of air mass. Upheaval or subsidence of the earth's surface caused by the variation of atmospheric pressure, which accompanies the vertical displacement of observation station as a necessary consequence, is considered to be a possible mechanism explaining the phenomena. If the phenomena really originate from such a mechanism, it will afford an important clue for study of the elastic properties of the earth's crust; on the other hand, however, if it is assumed that the phenomena originate merely from such a mechanism, the fact shown in Fig. 2 requires the earth's surface to ascend or descend to the extent of 1~3 meters for the atmospheric pressure variation of 1 cm Hg; and such an enormous change is, at present, beyond our common knowledge. The relation of the variation of atmospheric pressure to the movement of the earth's surface is a very attractive problem, but its complete solution should await the further development of the gravimetric observation, and consequently the consideration of the nature of residual drift discussed above will be postponed to future investigation.

Now, although it is the matter little connected with the theme of the present article, some descriptions need to be made concerning the gravity variation at the time of solar eclipse. Observation of the gravity variation at the time of solar eclipse contains an important and attractive significance, because it is related to the problem whether the gravitational attraction of the sun is screened or not, however slightly, by the moon. From the data of his observation on gravity variation during the solar eclipse on June 30, 1954, R. Tomaschek (5) has reported the negative result in regard to the screen effect of solar gravitational attraction by the moon. In course of the present observation III, at Shionomisaki, the partial solar eclipse was observed on December 14, 1955. The eclipse, being on the wane of nearly a quarter, continued from about 16h 32m till sunset; the gravity variations during the eclipse were especially read at short intervals of 15 minutes. As shown in Fig. 3, some slight influence of the solar eclipse upon the variation of gravity may be traced by partial eyes of

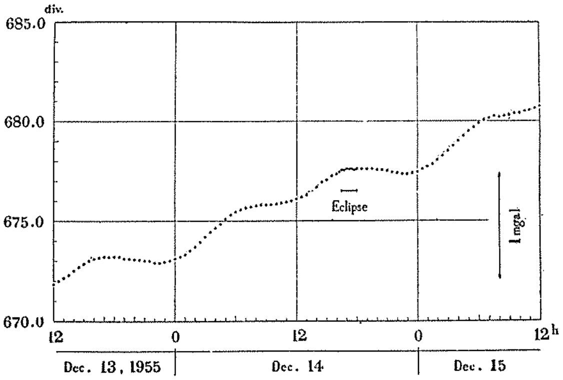

Fig. 3. Change of gravity at Shionomisaki before and after the time of the solar eclipse.

looking, but this attractive problem on the screen effect of gravitation and other particulars will be fully discussed after the accomplishment of observation with an evacuated gravimeter of extremely high sensitivity of 10^{-10} mgal/mm which is now in course of construction.

(2) *Tidal factor of gravity*

After the application of reduction for drift, the gravity values observed were harmonically analyzed to obtain the values of component tides. The observation periods used for analysis are as follows:

at the station I, June 11th 15h~July 11th 15h, 1954;
at the atation II, Sep. 29th 15h~Oct. 29th 15h, 1955;
at the station III, Nov. 16th 15h~Dec. 16th 15h, 1955,

in Greenwich Mean Time respectively. Harmonic analysis was made for the component tides of lunar semi-diurnal M_2, solar semi-diurnal S_2, lunar diurnal O_1, and lunisolar diurnal K_1. It is to be remarked that values for S_2, O_1, and K_1 are considered to be certainly less accurate compared with that for M_2 because of the short analysis period of one month among other reasons. Expressing the results of harmonic analyses for each component tide by the form of $R_{\mathrm{obs}} \cos(nt-\zeta_{\mathrm{obs}}) \pm \delta$, R_{obs}, ζ_{obs}, and δ are as shown in Table 2, where ζ_{obs} denotes the time interval from the instant when the imaginary celestial body corresponding to that component tide had transitted the meridian of that observation station till the instant when the observed gravity actually reached the maximum value, and δ signifies the mean error which mainly originated in the accuracies of the gravimeter and reading techniques. The values in Table 2 show the actual variations of gravity in those observation periods; but it is convenient for succeeding discussions to reduce these values of lunar components to ones in the case that the inclination of the moon's orbit to the equator is equal to its average value of 23°27′. Expressing such reduced results by the form of $H_{\mathrm{obs}} \cos(nt-\zeta_{\mathrm{obs}}) \pm \varepsilon$, H_{obs}, ζ_{obs}, and ε are as shown in Table 3. As natural results of the reduction, those values of H_{obs} do no longer include in themselves the factors originating from the difference of the epochs of observations; therefore, the difference between those values of H_{obs} in the same component tide is

Table 2.

	M_2			S_2			O_1			K_1		
	R_{obs} (μgal)	δ (μgal)	ζ_{obs}	R_{obs} (μgal)	δ (μgal)	ζ_{obs}	R_{obs} (μgal)	δ (μgal)	ζ_{obs}	R_{obs} (μgal)	δ (μgal)	ζ_{obs}
I	58.9	0.6	181°.96	27.2	0.5	176°.67	36.1	1.1	178°.07	55.6	2.7	202°.73
II	60.6	0.5	181°.20	28.5	0.4	182°.22	32.5	1.3	174°.30	53.6	5.3	180°.95
III	64.6	0.7	182°.42	30.0	0.4	185°.37	27.7	1.2	179°.61	54.4	3.8	199°.62

entirely attributed to the local effects comprising the difference of the latitudes of the observation stations.

Table 3.

	M_2			S_2			O_1			K_1		
	H_{obs} (μgal)	ε (μgal)	ζ_{obs}	H_{obs} (μgal)	ε (μgal)	ζ_{obs}	H_{obs} (μgal)	ε (μgal)	ζ_{obs}	H_{obs} (μgal)	ε (μgal)	ζ_{obs}
I	59.4	0.6	181°.96	27.2	0.5	176°.67	33.7	1.1	178°.07	53.3	2.7	202°.73
II	60.2	0.5	181°.20	28.5	0.4	182°.22	32.8	1.3	174°.30	54.1	5.3	180°.95
III	64.0	0.7	182°.42	30.0	0.4	185°.37	28.2	1.2	179°.61	54.1	3.8	199°.62

On the other hand, the theoretical values of tidal variation of gravity—the values of tidal variation of gravity which would occur if the earth were perfectly rigid or it does not entirely yield to tidal force—can be theoretically computed from the results of astronomical and geodetic observations. As the most appropriate numerical values of the constants necessary for the computation the values quoted in the paper by J. T. Pettit (**6**) were adopted. The theoretical values of H_{theor} and ζ_{theor} corresponding to H_{obs} and ζ_{obs} are as shown in Table 4. Difference beteen the values of H_{theor} of the same component tide in Table 4 is entirely attributed to the difference of the latitudes of the observation stations. The tidal factor of gravity G is obtained by taking the ratio of H_{obs} to H_{theor}; and phase lag κ is also calculated by taking the difference of ζ_{obs} and ζ_{theor}. The obtained values of G and κ are as shown in Table 5, where the plus sign of κ means that the observed phase is behind the theoretical one.

Table 4.

	M_2		S_2		O_1		K_1	
	H_{theor} (μgal)	ζ_{theor}	H_{theor} (μgal)	ζ_{theor}	H_{theor} (μgal)	ζ_{theor}	H_{theor} (μgal)	ζ_{theor}
I	50.3	180°.00	23.4	180°.00	29.3	180°.00	41.2	180°.00
II	49.8	180°.00	23.2	180°.00	29.4	180°.00	41.4	180°.00
III	52.2	180°.00	24.3	180°.00	28.6	180°.00	40.3	180°.00

The values shown in Table 5 are entirely independent of the epochs of obser-

Table 5.

	M_2		S_2		O_1		K_1	
	$G=1-3k/2+h$	κ	$G=1-3k/2+h$	κ	$G=1-3k/2+h$	κ	$G=1-3k/2+h$	κ
I	1.18 ± 0.02	+1°.96	1.16 ± 0.03	−3°.33	1.15 ± 0.04	−1°.93	1.29 ± 0.07	+22°.73
II	1.21 ± 0.02	+1°.20	1.23 ± 0.02	+2°.22	1.12 ± 0.05	−5°.70	1.31 ± 0.13	+ 0°.95
III	1.23 ± 0.02	+2°.42	1.23 ± 0.02	+5°.37	0.99 ± 0.05	−0°.39	1.34 ± 0.10	+19°.62

vations and the latitudes of observation stations; consequently the difference of those values, if it has any significance, is interpreted as showing local character of tidal factor. But, in this point, the reliability of numerical values for each component tide should carefully be examined. From the fact that those values of S_2-, O_1-, and K_1-components in each station are largely diverse from each other, but those of the M_2-component show comparatively good accordance for the three stations, it is clear that the diversity with respect to the S_2-, O_1-, and K_1-components is explained by the incompleteness of extraction of the component tides in the process of analysis, which will be improved by elongation of the observation period. Hence the following is generally concluded. "Concerning all the component tides except M_2, the reliable values of tidal factor of gravity can never be obtained from the observations for a period shorter than one month." For this reason the succeeding discussions will be restricted to the lunar semi-diurnal component alone.

Concerning the appropriate period of observation for M_2-component fit to the treatment of a certain problem, the following consideration may serve the purpose. Gravity values observed during one month at station I were tentatively divided into two periods of a fortnight and four periods of a week, and harmonic analysis was applied to the values for each period. The results are as shown in Table 6. From these results the following is generally concluded. "Concerning the M_2-component, a reliable value for the tidal factor of gravity cannot be expected from the observations for a period shorter than a fortnight." Needless to say, the word "reliable" in the above expression is a vague term, but in the present case it is conveniently used to designate a result with an accuracy in numerical values deserving of discussion on the local effect of the station upon the tidal factor of gravity or, simply expressed, the values with a mean error of within 0.02 of the tidal factor of gravity. From the above-mentioned results it is understood that one month is the necessary minimum period for obtaining a reliable tidal factor of the M_2-component; and the discussion

Table 6.

	Period of analysis	$G(M_2)$
Monthly	June 12th 00h~July 12th 00h, 1954	1.18
Fortnightly	June 12th 00h~June 26th 12h, "	1.17
	June 26th 12h~July 11th 00h, "	1.26
Weekly	June 12th 00h~June 19th 06h, "	1.25
	June 19th 06h~June 26th 12h, "	1.11
	June 26th 12h~July 3rd 18h, "	1.60
	July 3rd 18h~July 11th 00h, "	0.93

on the problem whether one month is a sufficient period or not for the detailed study on local character of the tidal factor of gravity will be made in a later paragraph.

The three stations I, II and III were primarily selected for the convenience of detecting the local character, if existing, of the tidal factor of gravity, the three stations being representative in the point of effects concerned with crustal structure and ocean tide as seen in Fig. 1. Consequently the values for the M_2-component obtained at the three stations are considered to be highly reliable and deserve the discussion on the problem of the local effect of crustal structure and ocean tide upon the value of the tidal factor of gravity.

4. Local effect on tidal factor of gravity

As the effects which are supposed to affect the value of G, two effects caused by the oceanic tidal change and the local geological or crustal structure are most conspicuous; but the influence of height difference of the observation stations will be worthy of consideration. In the following the orders of magnitude of influence upon G by these causes will be estimated.

(1) *Effect caused by the height difference of observation station*

As already described in section 1, the tide-producing potential W_2 is a function of r, in other words, a function of height of observation station; consequently the vertical component of tidal force depends also on height. Differentiating W_2 with respect to r, we get

$$\frac{\partial W_2}{\partial r} = \gamma M D^{-3} r (3\cos^2\theta - 1) \,,$$

which represents that the vertical component of tidal force is proportional to r. In the present case the maximum height difference between three observation stations is only 40 m; and the effect due to this height difference calculated by the above equation is estimated to be 1/160000 of the original force. With regard to Love numbers, they are also functions of r, but the effect of height difference upon them is negligibly small in the similar order of the above case. Hence, the effect on the value of G by the height difference between the observation stations may safely be disregarded in the present case.

(2) *Effect caused by the ocean tide*

The supposed effects upon the value of G caused by the ocean tide are generally divided into three principal parts. The first is the effect of the vertical component of attraction by the tidal change of sea water, the second the effect of the vertical displacement of the observation point caused by the tidal load of sea water, and the third the effect caused by the distortion of potential field as the result of deformation of the ground and sea bottom. Besides these, the effect originating from the horizontal displacement of the ground caused by the tidal load of sea water may also to be taken into account, but this effect was ascertained to be negligibly small compared with the above described three effects in the present case. On the effects caused by the tidal change of sea water the station to be discussed is the station III, Shionomisaki, whose observation point is 74 m high above the sea level and 400 m distant from the sea shore of Pacific Ocean. Concerning other two stations, I and II, the effects concerned with the ocean tide are ascertained to be negligibly small as the distances from the nearest sea shore of Pacific Ocean are 110 km and 140 km respectively.

The vertical component of attraction of M_2-period caused by the neighbouring sea water for the observation point at the station III is calculated as nearly 0.9μ gal $\cos(2nt-165°)$. Concerning the effect originated from the vertical displacement of ground at the observation point caused by the tidal load of sea water, the formula of H. Nagaoka (7) on the elastic deformation of the ground by surface load is applicable. According to his formula the effect caused by the vertical displacement of ground is computed to be more than 2.3μ gal $\cos(2nt-165°)$, and this value seems to be too large from the practical point of view. This improbable large value seems to originate from the fact that the real elastic properties of the earth's crust is far remote from the one which is assumed for the formation of Nagaoka's formula. Consequently some theory except Nagaoka's formula must be adopted for our case. This problem will be discussed together with the problem concerning the distortion of potential field caused by the deformation of the ground and sea bottom in the following.

The effect caused by the distortion of potential field as the result of the deformation of the ground and sea bottom is considered to be important part in calculation of oceanic tidal effect, but its strict estimation is very difficult and is beyond our ability at present. But fortunately, the theory of H. Takeuchi (8) on the deformation of the earth by surface loads, which is originally available for the case that the surface loads can be expressed by a spherical harmonic, can be approximately applied in present case. According to his theory, the total effects upon gravity change caused by the tidal change of sea water within a distance of several hundreds kilometres from the observation point are calculated to be nearly 1.1 times the attraction term. In present case the attraction term is calculated to be 0.9μ gal $\cos(2nt-165°)$. Accordingly the total effects of the ocean tide are computed to be nearly 1.0μ gal $\cos(2nt-165°)$.

The value obtained by subtracting the above computed effects from the value of M_2-component at the station III in Table 3 is considered to be completely free from the influences of ocean tide. In this way,

$$\begin{aligned} &64.0\mu\,\text{gal}\ \cos(2nt-182^\circ.42)-1.0\mu\,\text{gal}\ \cos(2nt-165^\circ) \\ &=63.0\mu\,\text{gal}\ \cos(2nt-182^\circ.73)\,. \end{aligned}$$

Since the corresponding theoretical value is

$$52.2\mu\,\text{gal}\ \cos(2nt-180^\circ.00)\,,$$

the values of G and κ are calculated as follows:

$$G=1.21 \qquad \kappa=2^\circ.73\,.$$

Consequently, the values of G and κ for the three stations which are considered to be entirely free from the effects of ocean tide are as shown in Table 7.

Table 7.

	Station	G (M_2)	κ (M_2)	g (gal)	BOUGUER anomaly
I	Kyoto	1.18±0.02	+2°.0	979.722	−12 mgal
II	Chikubushima	1.21±0.02	+1°.2	979.714	−45 ″
III	Shionomisaki	1.21±0.02	+2°.7	979.740	+139 ″

(3) *Effect caused by the local crustal structure*

The values of G listed in Table 7 are considered to be ones corrected for all influences but the local geological or crustal structure. Concerning the local effect caused by the geological, or generally, crustal structure upon the value of G, its exact theoretical treatment is supposed to be very difficult and laborious; but the problem is very important and attractive for the studies of not only the earth tide but also the nature of the earth's crust, and it shall be rigorously treated in the near future. For the advancement of study on this problem, first of all, it is a most necessary and pressing matter to raise the accuracy of measurement by using more highly sensitive gravimeters and by observing for periods much longer than one month, and, on the other hand, to increase the number of observation stations under different conditions to better examine the various effects. Under these considerations, the highly precise determination of the G-value at two stations by observations during one year with two evacuated gravity variometers of especially high sensitivity in nearly 0.0001 mgal/mm/5 m, and the concurrent observations at twenty stations in our country with twenty gravity variometers of sensitivity in nearly 0.01 mgal/mm/2 m are scheduled to be put into effect in this year. All gravity variometers, now in construction, are of the type of double bifilar suspension which are described in detail in part I of the present series of investigations (**3**). The detailed report on the resuls of these observations will be made on another occasion.

In the present case the G-value at station I, Kyoto, of 1.18 will provisionally be adopted as the representative value, because the crustal thickness at Kyoto is estimated to be nearly 30 km from the seismometric investigation, the value of which being considered to be nearly a mean thickness in the world over.

5. Love numbers and tidal upheaval of the ground

The values of G obtained from the present investigation and D obtained from the tiltmetric observation by E. Nishimura (2) are as follows:

$$G \equiv 1 - \frac{3}{2}k + h = 1.18\,,$$

$$D \equiv 1 + k - h = 0.66\,.$$

By combining the both values, Love numbers h and k are calculated as follows:

$$h = 0.66\,, \qquad k = 0.32\,.$$

Applying the value of h above calculated to the expression of the radial displacement $U = h\frac{W_2}{g}$ at the observation station of Kyoto, the tidal upheaval of the ground is estimated as follows:

Range of M_2-component in tidal upheavel of the ground at Kyoto = 21.3 cm,

Range of lunisolar total components in tidal upheaval of the ground at Kyoto = 50.5 cm.

And the greatest tidal upheaval of the ground that could occur on the earth is calculated as follows:

Range of greatest tidal upheaval of the ground on the earth = 51.5 cm.

6. Summary

The purpose of the present investigation was to explain the diversity in values of the tidal factor of gravity obtained by many observers over the world. The gravimetric observations for earth tide were made under consideration of the problems of instrumental errors, reliability of instrumental scale value, length of observation period, etc. on the one hand, and the problem of effects caused by the ocean tide and local geological or crustal structure on the other. From the present one month's observations made at three stations of different crustal structure and oceanic tidal effect, it is generally concluded that the values of G obtained at the three stations are highly trustworthy, at least for the M_2-component. And it was roughly estimated that the small difference of the third figures in G-values is mainly attributed to the effects caused by the ocean tide and local crustal structure. And, at the present stage, the most reliable value of G was calculated to be 1.18±0.02, and the greatest tidal upheaval of the ground on the earth was estimated as nearly 52 cm.

For the further advancement of study on the present problem, the following researches are earnestly recommended, and some of them are scheduled to be made at our institute at an early opportunity: gravimetric observations of the earth tide with more highly sensitive gravity variometer of continuous self-recording as compared with the usual gravimeter of sensitivity in the order of 0.1 mgal/div. and intermittent reading; concurrent observations with the gravity variometers of same type and same sensitivity at many stations where the conditions for the effects by the ocean tide, crustal structure and others are largely different, for example, at widely different latitudes, at the middle of the continent, at the continental margin, and at the solitary island in the ocean. From these precise and complete measurements of tidal variation of gravity, the mode and behaviour of the earth and earth's crust against the tidal forces will be revealed. And it will afford us an important and powerful tool to better understand the nature of the earth and the earth's crust.

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Observation I

1954-VI-10		11	12	13	14	15	16	17	18	19
h m										
0.00		616.5	619.6	622.6	625.7_5	629.0	632.3	635.6	638.9	642.3
30		16.6	19.7	22.8	25.8	29.1	32.4	35.6	39.0	42.3
1.00		16.6	19.8	22.9	25.9	29.3	32.5	35.7	39.0	42.3_5
30		16.6	19.9	23.0	26.1	29.4	32.6	35.8	39.1	42.3_5
2.00		16.8	19.9	23.1	26.3	29.5	32.8	35.9	39.2	42.4
30		16.8	19.9_5	23.2	26.4	29.6	32.9	36.0	39.3	42.4
3.00		16.8	20.0	23.2	26.4_5	29.7	33.0	36.2	39.5	42.6
30		16.8	20.0	23.2	26.5	29.8	33.1	36.4	39.6	42.8
4.00		16.8	20.0	23.1	26.6	29.9	33.1	36.5	39.7	43.0
30		16.8	20.0	23.1	26.6	30.0	33.1	36.5	39.8	43.1
5.00		16.8	20.0	23.1	26.6	30.0	33.2	36.4	39.9	43.2
30		16.8	20.0	23.2	26.6	30.0	33.3	36.4	40.0	43.2_5
6.00		16.7	20.0	23.2	26.5	30.0	33.3	36.7	40.2	43.3
30		16.7	19.8	23.2	26.5	29.9	33.3	36.6	40.3	43.4
7.00		16.7	19.7	23.0	26.3_5	29.9	33.2	36.5	40.1	43.4
30		16.7	19.7	23.0	26.3	29.9	33.1_5	36.5	40.1	43.4
8.00		16.7	19.7	23.0	26.3	29.8	33.1	36.5	40.0	43.4
30		16.7	19.7	23.0	26.2	29.8	33.0	36.4	40.0	43.4
9.00		16.7	19.7	23.0	26.1	29.8	32.9	36.3	39.8	43.4
30		16.8	19.8	22.9	26.1	29.5	32.8	36.3	39.8	43.3
10.00		16.9	19.8	22.9	26.1	29.4	32.7	36.1_5	39.7	43.2
30		17.0	19.9	23.0	26.2	29.4_5	32.7	36.1	39.6	43.1
11.00		17.2	20.0	23.1	26.3	29.5	32.7	36.0_5	39.5	43.0
30		17.3_5	20.2	23.1_5	26.4	29.5	32.8	36.1	39.6	42.9
12.00	615.1	17.5	20.4	23.2	26.5	29.7	32.9	36.1	39.6	42.8
30	15.0	17.6	20.5	23.3	26.6	29.8	33.0	36.2	39.6	42.8
13.00	15.0	17.7	20.6	23.6	26.8	29.9	33.1	36.3	39.6	42.8_5
30	15.0	17.8	20.9	23.8	27.0	30.1	33.3	36.5	39.7	42.8
14.00	15.1	17.9	20.9	23.9	27.2	30.2	33.5	36.6_5	39.8	43.0
30	15.2	18.0	21.0	24.1	27.5	30.5	33.7	36.8	40.0	43.1
15.00	15.3	18.1	21.3	24.3	27.7	30.9	33.9	36.9_5	40.2	43.3
30	15.3	18.3	21.4	24.4	27.8	31.1	34.1	37.1	40.4	43.5
16.00	15.4	18.3	21.5	24.5	27.9	31.3_5	34.3	37.4	40.5	43.7
30	15.5	18.4	21.6	24.8	28.0_5	31.4	34.5	37.6	40.7	43.9
17.00	15.5	18.4_5	21.7	24.9	28.2	31.6	34.5_5	37.8	41.0	44.1
30	15.5	18.5	21.7	25.1	28.4	31.7	34.7	38.0	41.2_5	44.3
18.00	15.5	18.5_5	21.8	25.1	28.4	31.9	34.9	38.2	41.4	44.5
30	15.5	18.6	21.8	25.1	28.4	32.0	35.0	38.3	41.5_5	44.6
19.00	15.6	18.6	21.9	25.3	28.5	32.0	35.1	38.5	41.7	44.8
30	15.6	18.6_5	21.9	25.3	28.6	32.1	35.2	38.6	41.8	45.0
20.00	15.7	18.7	22.0	25.3	28.6	32.1	35.3	38.6	41.9_5	45.1
30	15.7	18.7_5	22.0	25.3	28.6	32.1	35.4	38.6	42.0	45.2
21.00	15.8	18.8	22.0	25.3	28.7	32.1_5	35.4	38.6	42.0_5	45.3
30	15.8	19.0	22.0	25.3	28.7	32.2	35.4	38.7	42.1	45.3
22.00	16.0	19.1	22.1	25.4	28.8	32.2	35.3	38.7	42.2	45.3_5
30	16.1	19.3	22.1	25.4	28.8_5	32.2	35.4	38.7	42.2	45.4
23.00	16.2	19.4	22.4_5	25.6	28.9	32.2	35.5	38.8	42.2	45.3
30	16.5	19.4	22.5	25.7	29.0	32.3	35.6	38.8	42.2_5	45.3

The numerals express the dial scale of the gravimeter used, and one scale division corresponds to 0.18473 mgal in gravity change.

Observation I (continued)

20	21	22	23	24	25	26	27	28	29	30	VII-1
645.3	648.8	651.4	654.5	657.8	663.1	666.3	669.6	673.2	676.3	679.1_5	682.0
45.4	48.8	51.4	54.6	57.9	63.2	66.4	69.7	73.3	76.4	79.1_5	82.0
45.4	48.9	51.3	54.6	57.9	63.3	66.6	69.9	73.4	76.5	79.3	82.1
45.5	48.9	51.3	54.6	57.8	63.3	66.7	69.9	73.5	76.7	79.4	82.2
45.5	48.9_5	51.3	54.5	57.8	63.3	66.7	70.0	73.7	76.8	79.5	82.3_5
45.6	49.0	51.3	54.5	57.8	63.3	66.7	70.2	73.8	76.9	79.6	82.5
45.7	49.0	51.4	54.4_5	57.7	63.3	66.7	70.3	73.8_5	77.0	79.7	82.6
45.8	49.0_5	51.4	54.5	57.7	63.3	66.6_5	70.3	73.9	77.1	79.9	82.6_5
45.8	49.2	51.4	54.5	57.8	63.3	66.6	70.3	73.9	77.1	80.0	82.8
45.9	49.3	51.5	54.5_5	57.8	63.2	66.6_5	70.2	73.9	77.2	80.0	82.9
45.9	49.4	51.6	54.6	57.8	63.2	66.7	70.0	73.8	77.2	80.0_5	83.0
46.0	49.5	51.6	54.7	57.8	63.1	66.6_5	70.0	73.7	77.2	80.0_5	83.1
46.4	49.6	51.7	54.7	57.8	63.1	66.6	69.9	73.6	77.1	80.0	83.1
46.4	49.8	51.8	54.8	57.8	63.1	66.5	69.9	73.5_5	77.0	80.0	83.2
46.4	49.8	52.0	54.9	57.9	63.1	66.4_5	69.9	73.5	76.8	79.8_5	83.2
46.4	49.8	52.1	55.0_5	58.0	63.1	66.4_5	69.8	73.4	76.7	79.7	83.2
46.6	49.9	52.2	55.2	58.0	63.1	66.4	69.8	73.3	76.5_5	79.6	83.2_5
46.6	50.0	52.3	55.3	58.1	63.2	66.4_5	69.6	73.2	76.5	79.5	82.7
46.5	—	52.4	55.4	58.3	63.4	66.5	69.6	73.2	76.4	79.4_5	82.7
46.5	—	52.3	55.5	58.5	63.5	66.6	69.7	73.1_5	76.4	79.3	82.6
46.5	—	52.3	55.6_5	58.7	63.6_5	66.7	69.8_5	73.2	76.4	79.2	82.5
46.4	—	52.3	55.7	58.7	63.8	66.9	70.0	73.3	76.4	79.2	82.4
46.3_5	*49.0	52.4	55.8	58.7	63.9	67.0	70.1_5	73.5	76.4_5	79.3	82.4
46.3_5	49.1	52.4	55.8	58.9	64.1	67.1	70.3_5	73.7	76.6	79.3	82.4_5
46.3	49.0	52.4	55.9	59.1	64.3	67.3	70.5	73.8	76.7	79.4	82.4
46.3	49.0	52.4	55.9	59.2	64.4	67.5	70.7	74.0	76.8_5	79.5	82.4_5
46.2	49.1	52.4	55.9	59.3	64.5	67.8	70.9	74.2	77.0	79.6	82.6
46.2	49.1	52.4	55.8	59.3_5	64.6_5	67.9	71.1_5	74.4	77.2	79.7	82.6_5
46.2	49.1_5	52.4	55.8	59.4	64.7	68.1	71.3_5	74.6	77.4	79.9	82.8
46.3_5	49.2	52.4	55.8	*61.1_5	64.8_5	68.3	71.6	74.8	77.6	80.2	83.0
46.5	49.3	52.5	55.8	61.2	64.9	68.4	71.7_5	75.0	77.9	80.4	83.2
46.7	49.4	52.5	55.9	61.2_5	65.0	68.4	71.9	75.2	78.1	80.6	83.4_5
46.8	49.5	52.6	56.0	61.4	65.1	68.5	72.0	75.4	78.3_5	80.9	83.6_5
46.9	49.5	52.7	56.1	61.4	65.1	68.6	72.1	75.6	78.4	81.1	83.8_5
47.1	49.6	52.8	56.2	61.5	65.0	68.6	72.1_5	75.7	78.5	81.2	84.1
47.3	49.8	52.9	56.1	61.6	65.1	68.7	72.3	75.7	78.6	81.4	84.3
47.6	50.0	53.0_5	56.4	61.7_5	65.1_5	68.8	72.4	75.8	78.7	81.5	84.4
47.8	50.0_5	53.2	56.5	61.9	65.2	68.8	72.4	75.9	78.8	81.5_5	84.6
48.0	50.3	53.4	56.6	62.0	65.3	68.9	72.4	76.0	78.9	81.7	84.7
48.2	50.4	53.5	56.6	62.1	65.4	68.9	72.4	76.0	79.0	81.8	84.8
48.3	50.6	53.7	56.9	62.2	65.4_5	68.9	72.5	75.9	79.0_5	81.8	84.8_5
48.4	50.7	53.9	57.0	62.3	65.5	69.0	72.5	75.8	79.0	81.8	84.9
48.5	50.8	54.1	57.1	62.5	65.5_5	69.1	72.5	75.8	79.0	81.9	85.0
48.6	50.9	54.2	57.4	62.6	65.7	69.1	72.6	75.8	78.9	81.9	84.9
48.6	51.0	54.3_5	57.4_5	62.7	55.8	69.1	72.7	75.8	78.8_5	81.9	84.9
48.7	51.2	54.4	57.6	62.9	66.0	69.2	72.7_5	75.9	78.9	81.9	84.8
48.7	51.3	54.4	57.7	63.0	66.1	69.4	72.8	76.0	78.9	81.9	84.9
48.7	51.3	54.5	57.8	63.1	66.3	69.5	73.0	76.2	79.0	81.8_5	84.9

* Where the series of reading was shifted to another series because of hitch in the illuminating lamp attached to the gravimeter.

Observation I (continued)

2	3	4	5	6	7	8	9	10	11	12	13
684.9	687.9	690.4	693.7	697.3	700.8	704.1	706.9	710.2_5	713.4	716.4	719.6
84.7_5	87.9	90.4	93.7	97.3	00.8	04.1	07.0	10.3	13.4	16.5	19.9
84.8_5	88.0	90.4	93.7	97.3	00.8	04.1_5	07.0	10.3	13.4	16.7	19.9
84.8_5	*87.3	90.4	93.8	97.3_5	00.7	04.1	07.0	10.3	13.5	16.6	19.9
84.9	87.3	90.5	93.8	97.3_5	00.7	04.1_5	07.1	10.4	13.5	16.8	20.0
85.0	87.4	90.6	93.9	97.1	00.8	04.1	07.1	10.4	13.5	16.9	19.9_5
85.0	87.6	90.7	93.9	97.3	00.8	04.1	07.1	10.4	13.5_5	16.8	20.0
85.5	87.7	90.8	93.9	97.3	00.8	04.1_5	07.1	10.3	13.7	16.8	20.0
85.6	87.7	90.9	94.0	97.3_5	00.8	04.1_5	07.1	10.3	13.5	16.9	20.4
85.6_5	87.9	91.1	94.2	97.5	00.9	04.1	07.0_5	10.3	13.5	17.0	20.6
85.8_5	88.1	91.2	94.3_5	97.5	01.0	04.1_5	07.0	10.3	13.5	17.0	20.4
85.9	88.3	91.3	94.4_5	97.5	01.0	04.1_5	07.0	10.3	13.5	16.9	20.4
85.8_5	83.4_5	91.4	94.8	97.7	01.1	04.2	07.0	10.3	13.5	16.8	20.5
86.0	88.5	91.5	94.9	97.8	01.2	04.3	07.2	10.3	13.4	16.8	20.5
86.0_5	88.5	91.6	95.0	97.9	01.3	04.4	07.2	10.3_5	13.4	16.6	20.4_5
85.9	88.5	91.7	95.2	98.1	01.4	04.5	07.2_5	10.4	13.4	16.6	20.3_5
85.9	88.5	—	95.3	98.2	01.5	04.6	07.4	10.4_5	13.5	16.6	20.3_5
86.0	88.4	91.7	95.3	98.3	01.6	04.7	07.5	10.5	13.4	16.7	20.2_5
85.7_5	88.4	91.7	95.4	98.3_5	01.6_5	*04.0	07.6_5	10.6	13.5	16.7	20.2_5
85.7	88.3_5	91.5	95.4	98.5	01.7_5	04.2	07.7	10.6	13.6	16.7	20.2_5
85.7	88.3	92.0	95.4	98.6	01.8	04.3_5	07.8	10.6	13.8	16.7_5	20.2_5
85.5	88.2	91.8	95.3	98.6_5	01.9	04.5	07.9	10.7	13.9	16.8	20.3
85.4_5	88.1	91.9	95.3	98.7	01.9	04.6	08.0	10.9	14.0	16.9	20.5
85.4_5	88.0_5	91.9	95.3	98.7	01.8_5	04.7	08.1	11.0	14.1	17.1	20.5
—	88.0	91.9	95.3	98.7	01.9	04.8	08.2_5	11.2	14.2	17.2	20.6
85.3	88.0	91.8	95.3	98.7	02.1	04.9	08.4	11.3	14.4	17.3	20.7
85.4	88.0	91.9	95.3	98.6_5	02.1	05.0	08.5	11.5	14.6	17.4	20.8
85.5_5	88.0	91.8	95.3	98.6	02.1	05.0	08.6	11.6	14.8	17.7	21.0
85.7	88.0_5	91.8	95.4	98.6_5	02.2	05.0	08.7	11.7	14.9	17.8	21.3
85.8	88.1_5	91.6	95.4	98.7	02.3	05.1	08.8	11.9	15.1	17.9	21.6
85.9_5	88.2	92.0	95.4	98.8	02.3	05.1_5	08.8	12.0	15.2	18.0	21.9
86.2	88.4	92.0	95.5	98.8	02.3	05.3	08.9	12.0_5	15.3	18.1	22.1
86.5	88.6	92.0	95.6	98.9	02.4	05.3	09.0	12.1	15.5	18.3	22.3
86.7	88.7	92.3	95.7	98.9	02.4	05.4	09.1	12.2	15.5	18.4	22.4
86.8	89.0	92.3	95.8	99.1	02.7	05.5	09.2	12.2	15.6	18.6	22.6
87.0	89.2	92.6	95.9	99.2	02.7_5	05.5	09.1_5	12.3	15.3	18.8	
87.2	89.5	92.8	96.1	99.3	02.8	05.6	09.1_5	12.4	15.1_5	19.0	
87.4	89.7	92.9	96.3	99.5	03.0	05.6_5	09.4	12.4	15.6	19.1	
87.6	90.0	93.2	96.5	99.8	03.1	05.5_5	09.5	12.4	15.8	19.2	
87.7_5	90.1	93.4	96.7	700.0	03.2	05.9	09.5_5	12.5	15.9	19.2	
87.8	90.2	93.5	96.8	00.1_5	03.3	06.1	09.5_5	12.6	15.7_5	19.2	
87.9	90.3	93.5	96.9	00.3	03.4	06.3	09.6	12.7	15.6_5	19.2_5	
87.9	90.3	93.6	97.0	00.4	03.6	06.4	09.7	12.7_5	15.7	19.3	
87.9	90.4	93.7	97.1	00.5_5	03.7	06.6	09.8	12.8	15.8_5	19.3_5	
88.0	90.4	93.7	97.2	00.7	03.8	06.7	10.0	12.9	15.9	19.4	
88.0	90.4	93.7	97.3	00.7	03.8	06.8	10.0	13.0	16.1	19.5	
88.0	90.4	93.7	97.3	00.7	03.9	06.8	10.0	13.2	16.4	19.5	
87.9	90.4	93.7	97.4	00.8	04.0	06.9	10.1	13.4	16.4	19.5	

Observation II

	1955-IX-28	29	30	X-1	2	3	4	5	6	7	8
h m											
0.00		064.3	068.4	073.1	077.9	082.3	088.5	092.7	097.9	104.0_5	110.1_5
30		64.4	68.6	73.2	78.0	82.6	88.4	92.7	98.0	04.1	10.2
1.00		64.6	68.8	73.5	78.2	82.9	88.4	92.7	98.0	04.1	10.3
30		64.7	69.0	73.8	78.3	83.1	88.5	92.8	98.0	04.2	10.3
2.00		64.8	69.3	74.0	78.5	83.3	88.6	92.8	98.0	04.3	10.4
30		64.8	69.5	74.2	78.8	83.5	88.8	92.9	98.1	04.4	10.4
3.00		65.0	69.7	74.5	79.1	83.8	89.0	93.1	98.2	04.5	10.5
30		65.2	69.9	74.7	79.3	84.0	89.3	93.3	98.3	04.6_5	10.6
4.00		65.3	70.0	74.9	79.5	84.3	89.6	93.6	98.4	04.7_5	10.7
30		65.4	70.1	75.0	79.8	84.6	89.9	93.8	98.5	04.9	10.8
5.00		65.5	70.2	75.1	80.1	85.0	90.1	94.0	99.1	05.1_5	11.0
30		65.5	70.3	75.2	80.4	85.2	90.3	94.3	99.6	05.3_5	11.3_5
6.00		65.5	70.3	75.4	80.5	85.2	90.5	94.5	99.7	05.6	11.6
30		65.5	70.3	75.4	80.5	85.7	90.7	94.9	99.9	06.0	11.8
7.00		65.6	70.3	75.4	80.5	85.7	90.8	95.1	100.1	06.3	11.9_5
30		65.6	70.3	75.4	80.5	85.7	90.9	95.3	00.3_5	06.5	12.2
8.00		65.6	70.3	75.4	80.5	85.8	91.0	95.5	00.5	06.7	12.4_5
30		65.6	70.3	75.4	80.5	85.9	91.0	95.7	00.8	07.0	12.7
9.00		65.6	70.3	75.4	80.5	85.9	91.0	95.8	00.9	07.3	13.0_5
30		65.6	70.3	75.4	80.5	85.9	91.0	95.8	00.9_5	07.5	13.3
10.00		65.6	70.4	75.4	80.5	85.9	91.0	95.8_5	01.0_5	07.6	13.5
30		65.7	70.4	75.4	80.5	86.0	91.0	95.8_5	01.3	07.7	13.6_5
11.00		65.8	70.4	75.4	80.5	86.0	91.1	95.8	01.4	07.8_5	13.8
30		65.9	70.5	75.4	80.6	86.0	91.1	95.9	01.5	07.9_5	14.1
12.00		66.1	70.9	75.6	80.6	86.1	91.1	96.0	01.6	07.9_5	14.2_5
30		66.3	71.2	75.7_5	80.7	86.1	91.3	96.1	01.7	08.1_5	14.3
13.00		66.5	71.5	75.9	80.9	86.3	91.4	96.1	01.8	08.2	14.4
30		66.7	71.5	76.2	*80.8	86.5	91.6	96.0	01.8	08.3	14.5
14.00		66.9	71.5	76.4	81.0	86.7	91.7	96.1	02.0	08.4	14.6_5
30		67.1	71.7	76.5_5	81.2	86.9	91.8	96.3	*02.1	08.5	14.7_5
15.00	063.0	67.3	72.0	76.7	81.4	87.1	92.0	96.5	02.3	08.6_5	15.0
30	63.3	67.5	72.2	76.9	81.6	87.3	92.0_5	96.7	02.3	08.6_5	15.1_5
16.00	63.4	67.7	72.4	77.1	81.8	87.6	92.3	96.9	02.5	08.6	15.4
30	63.3	67.8	72.6	77.3	82.0	87.8	92.6	96.9_5	02.6	08.6_5	15.7
17.00	63.4	67.9	72.6	77.4	82.3	88.0	92.6_5	97.1	02.8_5	08.8_5	15.8
30	63.5	67.9	72.8	77.5	82.5	88.2	92.8	97.2	03.0_5	09.0	15.9
18.00	63.5	68.0	72.9	77.6	82.6	88.3	93.0	97.3_5	03.4	09.0	16.4
30	63.4	68.0	72.9	77.7	82.6	88.5	92.9_5	97.7	03.5_5	09.0_5	16.5
19.00	63.2	68.0	72.8	77.7	82.6	88.6	92.9_5	97.8	03.5_5	09.1	16.7
30	63.2	68.0	72.8	77.7	82.6	88.6	92.9_5	97.9	03.6	09.3	16.9
20.00	63.4	68.0	72.8	77.7	82.6	88.6	92.9	98.0	03.6_5	09.5	17.1
30	63.4	68.0	72.8	77.7	82.6	88.6	92.9	98.0_5	03.6_5	09.6	17.3
21.00	63.5	68.0	72.8	77.6	82.6	88.6	92.9	98.0_5	03.7	09.7	17.4
30	63.6	68.0	72.8	77.5	82.6	88.5	92.9	98.0_5	03.7_5	09.8	17.5_5
22.00	63.7	68.0	72.8	77.5	82.5	88.5	92.9	98.0_5	03.8	09.8_5	17.8
30	63.8	68.0	72.8	77.5	82.5	88.5	92.9	98.0	03.9	09.9	18.0
23.00	64.0	68.2	72.9	77.7	82.4	88.5	92.8	97.9	04.0	10.0	18.2
30	64.2	68.5	72.9	77.7	82.4	88.5	92.7	97.9	04.0	10.1	18.3

Observation II (continued)

9	10	11	12	13	14	15	16	17	18	19
118.5	124.3	128.6_5	133.2_5	139.1	143.8	147.8_5	152.2	156.8_5	161.8	166.7_5
18.6	24.3_5	28.8	33.6_5	39.2	44.0	48.1	52.3_5	56.9_5	61.9_5	66.8
18.7	24.4_5	28.9	33.9_5	39.4	44.2	48.3	52.6	57.1	62.1_5	66.9
18.9	24.5_5	29.0_5	34.1	39.7	44.4	48.5	52.9	57.2_5	62.3	67.0
19.0	24.6	29.2_5	34.3	40.0	44.6	48.7_5	53.1	57.5	62.3_5	67.2
19.1	24.7	29.3_5	34.5	40.2_5	44.9	49.0	53.2	57.8	62.6	67.3_5
19.2	24.7	29.3_5	34.6	40.4	45.1	49.3	53.5	58.0	62.9	67.6
19.3	24.7_5	29.4	34.7	40.6_5	45.3_5	49.5	53.8	58.3_5	63.0	67.8
19.4	24.8	29.4	34.8	40.9	45.4	49.6	54.0	58.5	63.2	68.1
19.4_5	24.8	29.4_5	34.8	41.0	45.5_5	49.7	54.4	58.8	63.5	68.3
19.5	24.8_5	29.6	34.9	41.0_5	45.6	49.8	54.5	59.0	63.6	68.5
19.7	24.9	29.6	34.9_5	41.1	45.7	49.9_5	54.5	59.2	63.8	68.7_5
19.8_5	25.0	29.6	35.0	41.2	45.8	49.9_5	54.6	59.4_5	64.0	68.9
19.9	25.0	29.6	35.0_5	41.4	45.8_5	49.9_5	54.8	59.6	64.3_5	69.0_5
20.0_5	25.1	29.6	35.1	41.4_5	45.8_5	50.1	55.0	59.6	64.5	69.2_5
20.2	25.2_5	29.7	35.2	41.4	45.5_5	50.1	54.9_5	59.8	64.6	69.4
20.4	25.3	29.8	35.3	41.4	45.7	50.0_5	55.0	59.8	64.6	69.5
20.6	25.4	29.9	35.4_5	41.4_5	45.7	50.0_5	54.9	59.9	64.7	69.7
20.8_5	25.5	29.9_5	35.5_5	41.5	45.6	50.0_5	54.9	59.9	64.7	69.6
21.0_5	25.7	30.1	35.6	41.5	45.5	49.9_5	54.9	59.9	64.7_5	69.6
21.2	25.8	30.2_5	35.7	41.5	45.5_5	50.0	54.9	59.9	64.9	69.7
21.4	25.9_5	30.4	35.8	41.6_5	45.6	50.0	54.8	59.8	64.9	69.8
21.5_5	26.0_5	30.5_5	36.0	41.8	45.7	50.2	54.9	59.9_5	64.8	69.8
21.7	26.2	30.8	36.3	41.9	45.9_5	50.1	55.0	59.9_5	64.9	69.9
22.3	26.4	31.0	36.5	42.1	46.1	50.4	54.9	60.0	65.0	69.9
22.4	26.6_5	31.2	36.6	42.2_5	46.2_5	50.5	55.1	60.0	65.0_5	70.0
22.5	26.9	31.4	36.9	42.4_5	46.3	50.8	55.3	60.2	65.2	70.1_5
22.6	27.0	31.5_5	37.1	42.7	46.8	50.8_5	55.5	60.4	65.3	70.3
22.6	27.2	31.7_5	37.2_5	42.9	47.0	51.1	55.7_5	*60.9	65.3	70.4
22.7	27.3	31.9	37.5_5	43.0_5	47.1	51.4	55.8	61.1_5	65.5	70.5
22.8	27.4	32.1	37.6_5	43.2_5	47.3	51.5	56.0	61.4	65.5	70.6
22.8	27.5	32.1_5	37.8	43.4	47.2_5	51.6_5	56.2	61.6	65.8	70.8
22.8_5	27.5_5	32.2_5	37.9	43.5_5	47.5	51.8_5	56.5	61.8	66.0	71.0
23.0_5	27.6	32.3	37.9_5	43.6	47.8	51.8_5	56.7	61.9	66.3	71.1
23.1	27.6	32.3	38.0	43.6	47.7	52.0	56.6	61.9	66.4	71.3
23.2	27.7	32.3_5	38.1	43.6	47.7	52.1	56.6	61.9_5	66.4	71.4_5
23.2	27.7	32.3	38.1	43.5_5	47.7	52.2	56.7	62.0	66.5	71.5
23.2_5	27.8	32.3	38.1_5	43.6_5	47.7	52.3	56.9	62.2	66.6	71.6_5
23.3	27.9	32.3	38.1	43.6	47.7	52.3	56.9_5	62.2	66.8	71.8
23.4	27.9	32.4	38.1	43.6_5	47.7	52.2	56.9	62.2	66.8	71.8
23.6	28.0	32.4_5	38.1_5	43.4_5	47.7	52.1	56.8_5	61.9_5	66.8_5	71.8
23.6	28.1	32.4_5	38.1_5	43.4_5	47.7	52.0	56.9	62.1_5	66.8_5	71.8_5
23.7	28.1_5	32.5	38.1_5	43.4_5	47.6	51.9	56.9	62.0	66.8_5	71.9
23.9	28.2	32.6	38.2	43.4_5	47.5_5	51.9_5	56.9	62.0	66.8_5	71.9
24.0	28.2_5	32.7	38.3	43.4_5	47.5	51.9_5	56.8	61.8	66.8_5	71.7
24.1	28.3_5	32.8	38.3_5	43.5	47.4_5	51.9_5	56.8	61.7	66.8	71.7
24.2	28.5	32.9	38.6	43.6	47.4_5	52.1	56.8	62.0	66.7	71.7
24.2	28.5_5	33.0_5	28.9_5	43.7	47.6	52.1	56.8_5	61.9	66.7	71.7_5

Observation II (continued)

20	21	22	23	24	25	26	27	28	29	30
171.7	176.4	181.6_5	187.5	192.6	197.1	201.3	205.3	209.6	214.0	218.3
71.7	76.4_5	81.9	87.5	92.6	97.2	01.5	05.6	09.8	14.2	18.5
71.7	76.5	81.9	87.5	92.6	97.2	01.5	05.7	10.0	14.1	18.7
71.8	76.5_5	81.8	87.6	92.6_5	97.2	01.7	05.7_5	10.2_5	14.6	18.8
72.0	76.6	81.9_5	87.6	92.7	97.3	01.7	05.9	10.5	14.8	19.0
72.2	76.7	82.0_5	87.6	92.8	97.3	01.8_5	06.0	10.7	15.0	19.2
72.4	76.8	82.2	87.7	92.8_5	97.4	01.9_5	06.1_5	10.8_5	15.2	19.5
72.6	76.9	82.2	87.7	92.9	97.5	02.0	06.2_5	11.0	15.4	19.6
72.6	77.1	82.5	88.0	92.9_5	97.5	02.0	06.3	11.1	15.5	19.8
72.9	77.3_5	82.6	88.0	93.0	97.5_5	02.0_5	06.3	11.2	15.6	20.0
73.0	77.5_5	82.7	88.1	93.1	97.6	02.1	06.4	11.2	15.7	20.3
73.2	77.8	82.9_5	88.4	93.2	97.7	02.1	06.4	11.2_5	15.8	20.4
73.5_5	78.0	83.2	88.6	93.2	97.7	02.1	06.4	11.3	15.8	20.6
73.6	78.1	83.4	88.7	93.3	98.0	02.1	06.4	11.2_5	15.8	20.8
73.8	78.2_5	83.6	88.9	93.4	98.0_5	02.2	06.5	11.3	16.0	20.8
73.9	78.5	83.7_5	89.0	93.5	98.1	02.3	06.5	11.3	16.0	20.8
74.0	78.7	83.9	89.3	93.7	98.3	02.3	06.6	11.3	16.0	20.8
74.2	78.8	84.1	89.5	93.8	98.5	02.4	06.7	11.3	16.2	20.8
74.3_5	79.0	84.3	89.6	93.9	98.5	02.5	06.7	11.4	16.1	20.9_5
74.4	79.1	84.4	89.8	94.1	98.6	02.6	06.8	11.4	16.2	21.0
74.5	79.2	84.6	89.9	94.3	98.8	02.8	06.9_5	11.4_5	16.2	20.9_5
74.5_5	79.2_5	84.7	90.0	94.5	99.0	02.8_5	07.1	11.6	16.3	21.0
74.6	79.4	84.8	90.1	94.6	99.1	03.1	07.2	11.8	16.4	21.0_5
74.6	79.4_5	85.0	90.2	94.7	99.3	03.3	07.3	11.9	16.5	21.1_5
74.6	79.5	85.1	90.4	94.8	99.5	03.4	07.4	12.1	16.6	21.3_5
74.7	79.6	85.3	90.5	95.0	99.6	03.5	07.5	12.4	16.8	21.6
74.7_5	79.7	85.4	90.7	95.3	99.8	03.6	07.8	12.6	17.0	
74.8_5	79.7_5	85.6	90.7	95.4	99.9	03.8	07.9	12.7	17.1_5	
75.0	79.9	85.6	90.7_5	95.5	99.9	04.0	08.0	12.7	17.3	
75.1	80.0	85.6	90.8	95.5	200.1	04.1	08.2	13.2	17.4	
75.2	80.1_5	85.8	90.9	95.6	00.1	04.1	08.3_5	13.3	17.6	
75.2_5	80.1_5	85.9	91.0	95.6	00.2	04.2	08.4	13.4	17.8_5	
75.3	80.2	86.0	91.2	95.8	00.2	04.2	08.6	13.5	17.9	
75.5	80.3	86.1	91.3	95.8	00.2_5	04.3	08.7	13.5	18.0	
75.7	80.4	86.2	91.3	95.9	00.2_5	04.4	08.8	13.5	18.1	
75.9	80.7	86.3	91.3_5	96.0	00.2_5	04.4_5	08.8	13.6	17.9	
76.0	80.9	86.4	91.5	96.0	00.3	04.4	08.8	13.6	17.9	
76.1	81.1	86.4	91.7	96.0	00.3_5	04.5	08.9	13.5	17.9	
76.2_5	81.1	86.5	91.7	96.0	00.4	04.5	08.7	13.5_5	17.9	
76.4	81.2	86.6	91.9	96.2	00.4_5	04.4	08.8	13.5	17.8	
76.4_5	81.3	86.8	91.9	96.2	00.4_5	04.5	08.9	13.5	17.7_5	
76.5	81.3	86.9	92.0	96.3	00.5	04.5	08.9	13.5	17.7	
76.4_5	81.5	87.1	92.0	96.3	00.6	04.6	08.9	13.4	17.7	
76.4	81.6	87.2	92.2	96.5	00.7	04.6	09.0	13.4	17.7_5	
76.3_5	81.6	87.3	92.3	96.6	00.8	04.8	09.1_5	13.5	17.8_5	
76.3_5	81.6	87.3	92.3	96.7	00.9_5	04.8_5	09.3	13.6	17.8_5	
76.4	81.6_5	87.4	92.4_5	96.9	01.1	04.9	09.4	13.7	17.9_5	
76.4	81.6_5	87.4	92.5	96.9	01.2	05.2	09.5	13.8	18.1	

Observation III

1955-XI-16		17	18	19	20	21	22	23	24	25
h m										
0.00		548.8	553.2	557.9	562.3	567.2_5	571.8	576.3	581.0	585.5
30		49.0	53.1	57.9	62.3	67.2	71.8	76.4	81.2	85.8
1.00		49.0	53.3	57.9	62.4	67.2_5	71.8_5	76.5	81.3	85.9_5
30		49.0	53.3	58.0	62.5	67.2_5	71.8_5	76.5_5	81.4	86.1_5
2.00		49.2	53.4_5	58.1_5	62.6	67.3	71.8_5	76.6	81.5	86.3
30		49.2	53.6	58.3	62.7	67.4	71.8_5	76.7_5	81.5_5	86.4
3.00		49.3	53.9	58.4	62.8	67.5	71.9	76.7_5	81.6	86.5
30		49.6	54.1	58.5	62.9	67.6	71.9	76.8	81.6_5	86.5_5
4.00		49.8	54.3	58.7	63.0	67.7	71.9_5	76.8	81.7	86.6
30		50.2	54.4	58.8	63.1_5	67.8	72.0_5	76.9	81.7_5	86.7
5.00		50.3	54.7	59.1	63.4	67.9_5	72.2	76.9_5	81.8	86.7_5
30		50.5	54.9_5	59.3	63.6	68.1	72.3_5	77.1	81.8_5	86.7_5
6.00		50.6_5	55.2	59.5_5	63.8	68.2_5	72.5	77.2	81.9	86.8
30		50.8_5	55.3	59.8	64.0	68.4	72.7	77.3	82.0	86.9
7.00		51.0	55.5	60.0	64.2	68.5	72.9	77.4_5	82.1	86.9
30		51.0_5	55.7	60.2	64.3	68.7_5	73.0	77.6	82.2	86.9
8.00		51.2	55.8	60.4	64.4	68.9_5	73.2_5	77.7_5	82.3_5	87.0
30		51.3_5	55.9_5	60.6	64.5	69.1	73.4	77.9_5	82.5	87.2
9.00	547.9	51.4	56.0	60.7_5	64.7	69.3_5	73.6	78.1	82.6_5	87.4
30	48.0_5	51.3_5	56.0	60.8_5	64.8	69.5	73.8	78.3	82.8	—
10.00	48.2	51.3	55.9_5	60.9	64.9	69.6	73.9	78.4	82.9_5	*86.6
30	48.2_5	51.5	56.2	60.9_5	65.1	69.7_5	74.0	78.5	83.1_5	86.8
11.00	48.3	51.5	56.3	61.0	65.1	69.8_5	74.2	78.7	83.3	86.9
30	48.3	51.6_5	56.2	61.0	65.1_5	69.8_5	74.2_5	78.9	83.5	87.0
12.00	48.2	51.7	56.2	61.0_5	65.2	69.8	74.3	79.1	83.7	87.1
30	48.2_5	51.8	56.4	61.0_5	65.2_5	69.7_5	74.4	79.2	83.8	87.4
13.00	48.5	51.9	56.5_5	61.0_5	65.3_5	69.9	74.5	79.3	83.9	87.6
30	48.5	51.9	56.6	61.2	65.4	69.9	74.6	79.3	84.0	87.7
14.00	48.6	51.9_5	56.7	61.1	65.4	70.0	74.7	79.3_5	84.1	87.8_5
30	48.7	52.2	56.8_5	61.1_5	*66.0	70.0	74.8	79.4	84.1_5	87.9_5
15.00	48.9	52.3	57.0	61.4	66.1_5	70.1	74.9	79.4_5	84.2	88.0
30	48.9_5	52.5	57.2	61.4	66.2	70.2	74.9_5	79.5	84.2	88.1
16.00	48.9_5	52.7	57.3	61.5	66.2	70.4	75.0	79.5	84.2	88.1_5
30	49.1	52.8	57.5	61.6_5	66.2_5	70.4	75.0_5	79.5	84.3	88.2
17.00	49.1	52.9	57.6_5	61.7	66.3	70.6	75.1	79.5_5	84.3	88.2
30	49.2	53.0	57.8	62.0_5	66.4_5	70.7	75.2	79.6	84.3_5	88.2
18.00	49.3	53.1	57.9	62.1_5	66.5_5	70.8	75.2_5	79.7	84.4	88.2
30	49.3	53.3	58.0	62.3	66.7	71.0	75.3	79.8	84.4	88.2_5
19.00	49.3	53.4	58.0	62.3	66.8	71.1	75.3_5	79.9	84.4_5	88.3
30	49.3	53.5	58.0	62.2	66.9	71.2	75.4	79.9	84.4_5	88.3_5
20.00	49.2	53.5	58.1	62.2_5	67.1	71.3	75.5	79.9	84.5	88.4_5
30	49.2	53.5	58.1	62.3	67.1	71.4	75.6	80.0	84.5	88.5
21.00	49.0	53.4	58.1	62.3	67.2	71.5	75.7	80.1	84.6	88.6
30	49.0	53.4	58.1	62.4	67.2	71.6	75.8_5	80.2	84.7	88.7
22.00	48.9	53.3	58.0_5	62.3_5	67.2_5	71.7	76.0	80.5	84.8	88.8
30	48.9	53.3	58.0_5	62.4_5	67.1_5	71.7_5	76.1	80.6	84.9	88.9_5
23.00	48.9	53.2	58.0	62.4_5	67.2	71.8	76.1_5	80.7	85.1	89.1
30	48.9	53.2	57.9	62.4_5	67.2	71.8	76.2	80.9	85.4	89.4

Observation III (continued)

26	27	28	29	30	XII-1	2	3	4	5	6
589.6	593.9_5	598.3_5	602.7	607.1	611.6_5	616.6	622.0	627.2	631.8	636.7_5
89.9	94.2	98.5_5	02.9	07.2	11.7	16.6	22.0	27.1_5	31.8	36.7_5
90.1	94.4	98.8_5	03.2	07.4_5	11.8	16.6_5	22.0	27.1	31.8	36.7_5
90.2	94.5	99.1	03.4	07.6	12.0	16.6_5	22.0	27.0_5	31.8_5	36.9
90.3_5	94.7	99.4	03.7	07.9	12.2	16.7	22.0	27.0_5	31.9	36.9
90.5	94.9	99.6	04.1	08.1	12.5	16.8	22.1	27.1	31.9	36.8_5
90.6	95.2	99.8_5	04.4	08.4	12.7	17.0	22.4	27.2	32.0	36.8_5
90.6_5	95.4	600.1	04.6	08.7	12.9	17.2	22.5	27.4	32.0_5	36.9
90.7	95.5	00.3	04.8	09.1	13.2	17.5	22.7	27.5	32.1_5	37.0
90.7_5	95.7	00.5	05.1	09.3_5	13.5	17.8	22.9	27.7	32.3	37.0_5
90.8	95.8	00.6_5	05.3_5	09.6	13.9	18.1	23.1	27.8	32.4	37.1
90.8	95.8_5	00.7_5	05.5	09.8	14.3	18.4	23.4	28.1	32.6	37.2
90.9	95.9	00.8	05.6	10.0	14.5	18.7	23.6	28.4	32.7	37.4
90.9_5	95.9_5	00.8_5	05.7	10.1_5	14.7	19.0	23.8	28.6_5	33.0	37.5
91.0	96.0	00.9	05.7_5	10.2	14.8	19.2	24.1	28.9	33.2_5	37.7
91.1	96.0	00.9	05.8	10.3	14.9	19.4	24.4	29.1	33.3	37.9
91.2	96.0_5	00.9	05.8_5	10.3	15.0	19.7	24.6	29.3	33.4	38.1
91.3	96.1	00.9	05.9	10.4	15.1	19.9	24.8	29.5	33.6	38.4
91.4	96.1_5	00.9	05.9	10.4	15.1_5	20.0	25.0	29.6_5	33.8	38.6
91.5	96.2	00.9	05.9	10.4	15.2	20.2	25.0_5	29.7	34.1	38.8
91.6	96.2_5	01.0	05.9	10.4	15.2_5	20.2_5	25.1	29.9	34.2	38.9
91.7	96.3_5	01.1	05.9_5	10.4	15.2_5	20.2_5	25.1	29.9	34.4	39.2
91.8	96.5	01.2	06.0	10.5	15.3	20.3	25.2	30.0	34.5	39.2
92.0	96.7	01.3	06.0_5	10.5	15.3	20.3	25.2	30.0	34.6	39.2
92.2	96.9	01.4	06.1_5	10.6	15.4	20.3	25.3	30.0	34.7	39.3_5
92.4	97.1	01.5	06.2	10.7	15.4	20.3	25.4	30.0	34.8	39.4
92.6	97.3	01.7	06.2	10.8	15.5	20.3	25.5	30.1	34.8	39.5
92.8	97.5_5	01.9	06.4	10.9_5	15.7	20.4	25.4	30.1	34.9	39.6
93.0	97.6_5	02.1_5	06.6	11.1	15.7_5	20.5	25.4	30.2	34.9	39.6
93.1_5	97.8	02.3_5	06.8	11.2	15.9	20.6_5	25.6	30.3	35.0	39.6
93.3	97.9	02.5	07.0	11.3	16.1	20.8	25.7	30.3	35.0	39.5_5
93.4	98.1	02.6_5	07.2	11.5_5	16.3	21.0	25.8	30.4	35.0	39.5_5
93.5	98.1	02.7	07.2	11.7	16.5	21.2_5	26.0	30.5	35.1	39.5_5
93.5	98.1	02.7	07.4	11.9	16.6	21.4	26.2	30.6	35.1_5	39.6
93.4	98.1	03.0	07.5	12.1	16.6	21.6	26.3	30.7	35.3	39.6
93.3_5	*97.9	03.1_5	07.7	12.2	16.8	21.8	26.3	30.8	35.4_5	39.6
93.3_5	98.0	03.2	07.8	12.2_5	16.9_5	21.9	26.5	30.9	35.4_5	39.6_5
93.3	97.9_5	03.0	07.6	12.3	17.1	22.0	26.7	31.0	35.4_5	39.7
93.2	97.9	02.9	07.6	12.3	17.1	22.0	26.8	31.1	35.6	39.9
93.1	97.8_5	02.8_5	07.4_5	12.3	17.0_5	22.1	26.9	31.2_5	35.7	40.2
93.0_5	97.8	02.8	07.3	12.2	17.0	22.2	27.0	31.4	35.9	40.3
93.0	97.7	02.6	07.2_5	12.1	17.0	22.3	27.1	31.6	36.1	40.3
93.0	97.7	02.6	07.2	11.9_5	16.9	22.3	27.1	31.6_5	36.2	40.4
93.1_5	97.7	02.5	07.1	11.9	16.8	22.3	27.2	31.7	36.4	40.5
93.3	97.7	02.5	07.1	11.8	16.8	22.1	27.2	31.7	36.5	40.7_5
93.4	97.8	02.6	07.1	11.7	16.7	22.1	27.2	31.7	36.5	40.9
93.5_5	97.9	02.6	06.9	11.6	16.7	22.0	27.2	31.7	36.6	40.9
93.7	98.1_5	02.6	06.9_5	11.6	16.6	22.0	27.2	31.8	36.7	40.9_5

Observation III (continued)

7	8	9	10	11	12	13	14	15	16	17
641.0_5	645.7	650.3	655.2	659.9	664.5_5	668.7_5	673.1	677.4_5	681.8_5	686.2
41.2_5	—	50.5	55.4	60.2	64.8	68.9	73.2	77.6	81.8_5	86.2_5
41.3_5	—	50.7	55.6	60.5	64.9_5	69.1	73.3	77.7	81.9_5	86.3_5
41.3_5	46.1	50.9	55.8	60.7	65.2	69.4_5	73.5	77.8_5	82.1	86.5_5
41.4_5	46.2	51.0	56.0	60.9	65.4_5	69.7	73.7	78.0_5	82.3	86.7_5
41.5	46.3	51.2	56.3	61.1	65.6	69.8_5	73.9_5	78.2_5	82.5	86.8_5
41.5	46.3_5	51.4	56.4	61.3	65.8	70.1	74.2	78.5	82.8	87.1
41.5	46.3_5	51.5	56.5_5	61.5	66.0	70.3	74.4_5	78.7_5	83.0	87.3_5
41.5_5	46.4	51.6	56.6_5	61.7	66.1_5	70.5_5	74.6_5	79.0	83.2_5	87.5
41.7	46.5	51.7	56.8	61.8_5	66.3_5	70.8	74.8_5	79.2_5	83.4_5	87.7_5
41.8	46.5	51.8	56.9	61.9_5	66.5_5	70.9_5	75.1	79.5	83.6_5	88.1
41.9	46.6	51.7	57.0	62.0_5	66.7	71.0_5	75.3	79.7	83.8	88.3_5
42.0	46.7	51.8_5	57.1	62.1	66.8	71.3	75.4_5	79.9	84.0	88.5
42.2	46.8	51.9	57.1_5	62.2	66.9	71.4	75.5_5	80.0_5	84.1_5	88.7_5
42.3	46.8	52.0	57.1_5	62.2	67.0	71.4_5	75.6_5	80.1_5	84.3	88.9
42.4	46.9	52.1	57.2_5	62.2	67.0	71.4_5	75.7	80.2_5	84.4_5	89.1
42.5_5	47.0	52.2	57.3	62.3	67.0_5	71.4_5	75.7_5	80.2	84.5_5	89.3
42.7	47.1	52.3	57.3_5	62.4	67.0_5	71.4_5	75.8	80.2_5	84.6	89.4
42.9	47.4	52.4	57.5	62.4_5	67.0_5	71.4_5	75.8	80.3	84.6_5	89.4_5
43.1	47.6	52.5	57.6	62.5_5	67.1	71.4_5	75.8	80.4	84.6_5	89.5
43.3	47.8	52.7	57.7	62.7_5	67.2	71.5	75.8_5	80.4	84.6_5	89.5
43.4_5	47.8_5	52.9_5	57.9_5	62.8_5	67.3	71.6	75.9	80.5	84.6_5	89.5_5
43.6	48.0	53.1	58.0	63.0	67.4	71.6_5	75.9_5	80.5_5	84.7	89.6
43.7_5	48.2_5	53.3	58.3	63.1	67.5	71.7_5	76.0	80.6_5	84.7_5	89.6_5
43.8_5	48.5	53.4	58.4	63.2	67.7	71.8_5	76.1	80.7_5	84.8_5	89.7
43.9	48.4	53.6_5	58.5_5	63.3	67.7	72.0	76.2	80.8_5	84.9	
43.9	48.7	53.7	58.7	63.5	67.8_5	72.1_5	76.3	80.9_5	84.9	
44.1	48.8	53.8	58.8	63.7	68.0	72.3	76.5_5	81.0_5	85.0	
44.2_5	48.8	53.9_5	58.9_5	63.9	68.2	72.5	76.7	81.1_5	85.1	
44.1_5	48.8_5	54.0	59.1	63.9_5	68.3_5	72.7	76.9_5	81.3_5	85.2	
44.1	48.9_5	54.1	59.2	64.1	68.5	72.8_5	77.0_5	81.5	85.4	
44.2	49.0	54.1_5	59.3	64.2	68.6_5	73.0	77.2_5	81.6	85.6	
44.2	49.1	54.2	59.3_5	64.2	68.7_5	73.1	77.3_5	81.8_5	85.8	
44.2	49.1	54.2_5	59.4	64.2	68.8_5	73.1_5	77.5_5	81.9_5	86.0	
44.1	49.1	54.2_5	59.4	64.2	68.9	73.2	77.6	82.0	86.1	
44.2	49.1	54.2_5	59.3_5	64.2	68.9	73.2	77.6	82.1_5	86.2_5	
44.3	49.1	54.2_5	59.3_5	64.3	68.9	73.2	77.6	82.2	86.3_5	
44.3_5	49.0	54.2_5	59.3_5	64.3	68.8	73.2	77.6	82.3	86 4	
44.4	49.0	54.2_5	59.3	64.3	68.7	73.1	77.6	82.3	86.4_5	
44.4	49.0_5	54.2_5	59.3	64.2	68.6_5	73.1	77.6	82.2_5	86.5	
44.5	49.1	54.3	59.3_5	64.2	68.6	73.0_5	77.5_5	82.2	86.5	
44.6	49.3	54.2	59.4	64.2	68.5_5	73.0_5	77.5_5	82.2	86.5	
44.7	49.3	54.3	59.4	64.2	68.5	73.0	77.5	82.1	86.4_5	
44.8_5	49.5	54.3	59.3	64.2_5	68.5	73.0	77.4_5	82.0	86.4	
45.0	49.6	54.4	59.4	64.2_5	68.5	72.9	77.4	81.9_5	86.3_5	
45.2	49.7	54.6	59.5	64.3	68.5	72.9	77.3_5	81.9	86.3	
45.4	49.8	54.8	59.6	64.3_5	68.5_5	72.9_5	77.3_5	81.8_5	86.2_5	
45.6	50.1	55.0	59.7	64.4	68.6_5	73.0	77.4	81.8_5	86.2	

14th 16.15,677.4_5 ; 16.45,677.5_5 ; 17.15,677.6 ; 17.45, 677.5_5