GRAVITATIONAL TIDAL FORCES AND ATMOSPHERIC PROCESSES

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ABSTRACT

Recent studies have revealed a relationship between variations in gravitational tidal forces and rainfall. A possible mode of interaction of the tidal forces on atmospheric processes is suggested to explain how the tidal forces which are small may induce detectable effects on atmospheric circulation, considering both synoptic-scale and short-period processes in the atmosphere. The variability of gravitational tidal forces is compared with variations in precipitation as revealed by statistical studies. The interrelation between thermal and tidal forces is brought out to account for the anomalous distribution of maximum precipitation in the United States during the synodic month when classified according to seasons, geographical areas, and periods of high versus low solar activity. The model suggested in this paper is based on an intuitional approach to the problem. Its usefulness or validity can be ascertained only by further investigations of rainfall variations; in addition there is the need to devise sensitive tests to be applied to them.

1. INTRODUCTION

Statistical studies [1–7] of rainfall in recent years have revealed a lunar synodic period in its occurrence. Brier [4] explained the relation between atmospheric tides and rainfall in the United States. The gravitational tidal hypothesis suggested by him provides a plausible explanation of the nature of the luni-solar influences on precipitation variations. However, the difficulty remains as to how the tidal forces which are extremely small can induce detectable effects on atmospheric circulation. An attempt is made in this paper to suggest a possible mode of interaction between the tidal forces and atmospheric processes. In what follows "tidal force" will refer to the vertical component of the luni-solar tide-generating forces.

2. MODE OF INTERACTION

Brier [4] proposed a mathematical model to explain how a small periodic force can be important in deciding the timing of occurrence of an event. The discussions in the following paragraphs are essentially based on that model, but enlarged to include occasions when, in addition to change in the timing of the event, the probability of its occurrence is also altered.

Let F represent the total magnitude of the various meteorological forces influencing the event, F_w the maximum value of F during the period t_0 to t_1, and F_{tc} the resultant curve due to the effect of the tidal force F_t on F. The event E is considered likely when F_{tc} reaches some critical level F_c. If the critical level F_c is distributed beween F_{c1} and F_{c2} with some probability distribution $P(E)$, probability of event E is zero below the level F_{c1} and is 1 above the level F_{c2}, and

$$0<P(E)<1$$

when the critical force is between F_{c1} and F_{c2}.

In figure 1a the F_{tc} curve indicates the same probability of the event as the F curve and thus the influence of the tidal force is not to alter appreciably the probability of occurrence but to affect the timing of occurrence, which, in this case, becomes earlier. The timing of the event can be earlier or later depending upon whether the F_{tc} curve is to the left or right of the F curve. In figure 1b the F_{tc} curve is in phase with the F curve and this has resulted in an increase in probability of occurrence.

3. VARIABILITY OF TIDAL FORCES

The variability of the tidal force F_t is illustrated in figure 2. In figure 2a O designates the center of the earth; XY, the earth's axis; M_2OM_1, the plane of the ecliptic; GOH, the equator; M_1, the position of the moon; $ABCD$, the paraboloid of tidal force due to the moon; $PSRQ$, a latitude circle; PF_1, the tidal force vector at P; QF_2, the tidal force vector at Q; PF_1-QF_2, the diurnal inequality. Points A, B, C, D, P, Q, G, H, all lie in a plane perpendicular to the ecliptic. Any point on the latitude circle $PSRQ$ experiences the larger maximum F_1 and the smaller maximum F_2 once during the lunar day. Halfway between F_1 and F_2 the tidal force will be minimum as the moon will be 90° away from the local radius vector. The variation is as in figure 2b. Here, l_1 is a lunar day (approximately 25 hr.), l_2, approximately half a lunar day, l_4, approximately one-fourth a lunar day. The values of l_2 and l_4 vary about the mean value of ½ and ¼ lunar day

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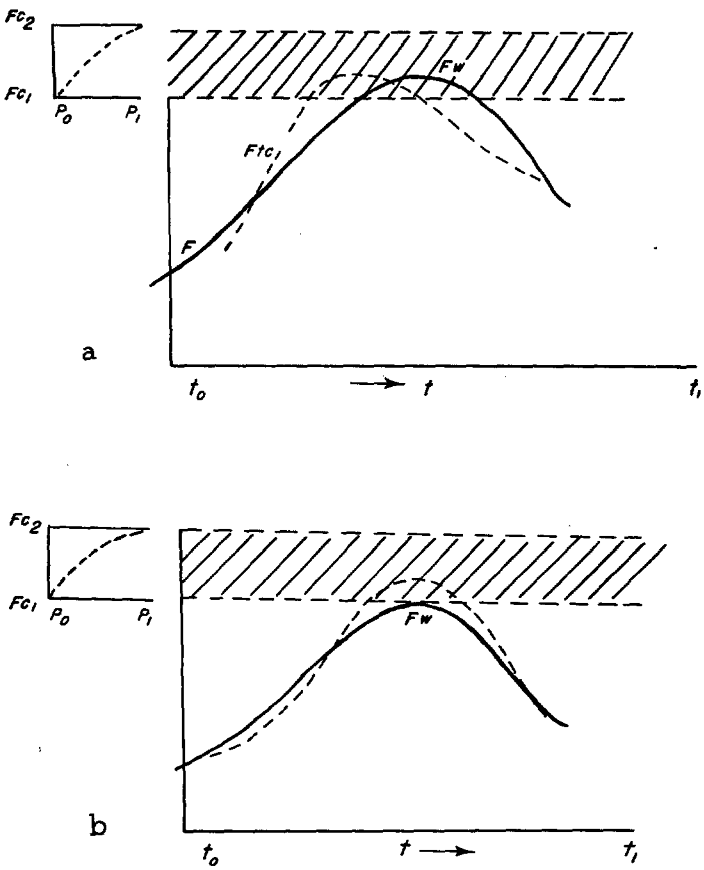

FIGURE 1.—Curves of F_{tc} and F_w in period t_0 to t_1, showing (a) an effect on timing of the event, and (b) an effect on probability of its occurrence.

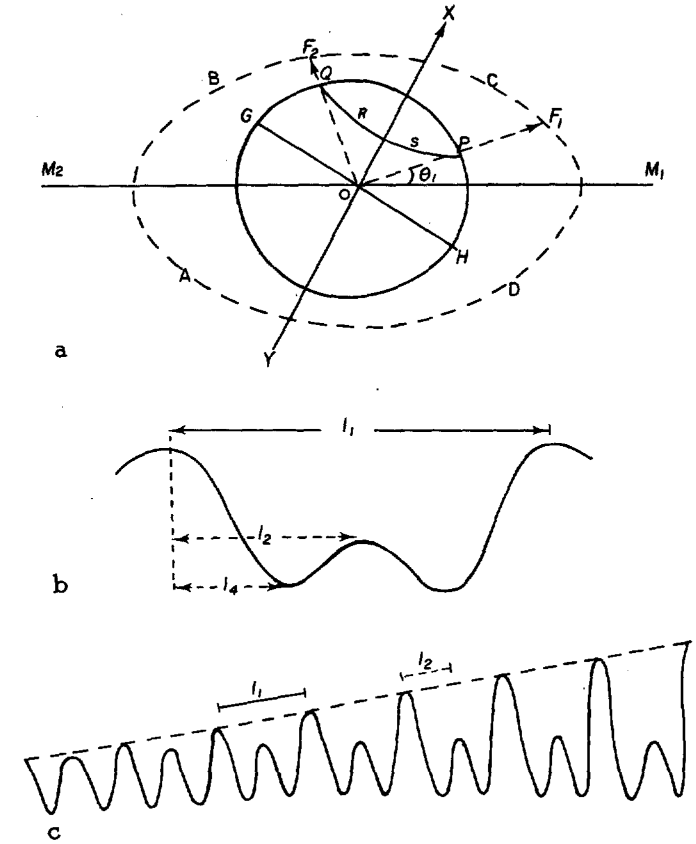

FIGURE 2.—Variability of the tidal force at 40°N. during a portion of the synodic month. See text for identification of symbols.

respectively. The above arguments apply to solar tidal force variations as well.

The variation in the luni-solar tidal forces at a station on latitude 40° N. during a portion of the synodic month is sketched, qualitatively, in figure 2. The semidiurnal oscillation gives rise to short-period fluctuations in tidal forces. The envelope passing through the maximum values represents the trend in longer-period tidal variations and the amplitude of the diurnal oscillation. The time of occurrence of the maximum luni-solar tidal force will be slightly ahead of or behind the passage of the moon because of a priming and lagging effect. But the luni-solar tidal force at the meridian of the moon (or at a point 180° opposite) will be a close approximation to the diurnal maximum, and the curve passing through the values for each day of the tidal force at the meridian of the moon (or 180° opposite whichever is greater) will be a close approximation to the envelope curve sketched in figure 2c. Such a curve for latitude 40° N. for two typical months is given in figure 3.

4. SYNOPTIC SCALE PROCESSES

In the atmospheric processes, the model may represent the cumulative or long-term effects of the tidal forces on the synoptic systems such as depressions, troughs, etc. The period t_0 to t_1 is a few days to a week and the tidal force is represented by the envelope of the luni-solar tidal oscillations. This curve (fig. 2c) has, generally speaking, a maximum near the syzygies and a minimum near the quadratures, so that the period from a minimum to the next maximum is about a week. The amplitude of the envelope curve is found to be large when new moon or full moon occurs near perigee, and in contrast, the amplitude is small when the moon is at the quadratures and near perigee.

Figure 3a gives the envelope curve of the luni-solar tidal force at 40° N. at the meridian of the moon (or 180° opposite, whichever is greater) at 1200 GMT each day of January 1965. In figure 3b is similar information for April 1965 when the perigee was near the first quarter. Brier

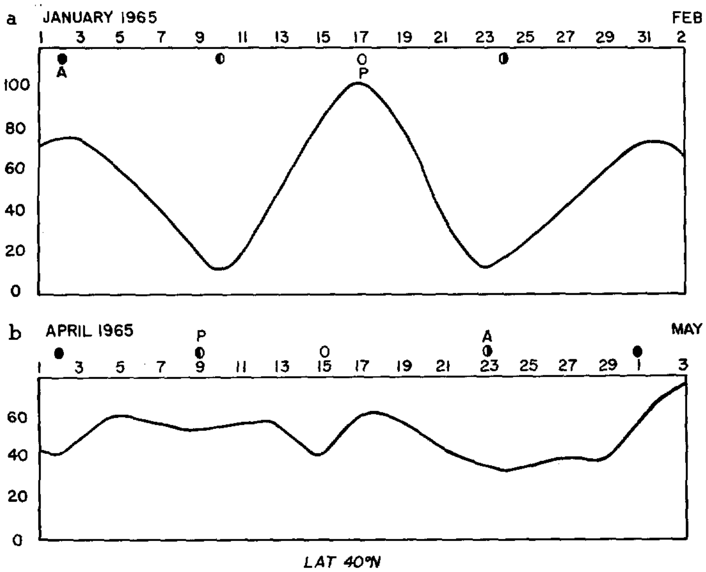

FIGURE 3.—Vertical component of the luni-solar tidal force at the meridian of the moon (or +180° whichever is greater) at 40° N. Unit: $1.6746 \times 10^{-9}g$. P=perigee, A=apogee.

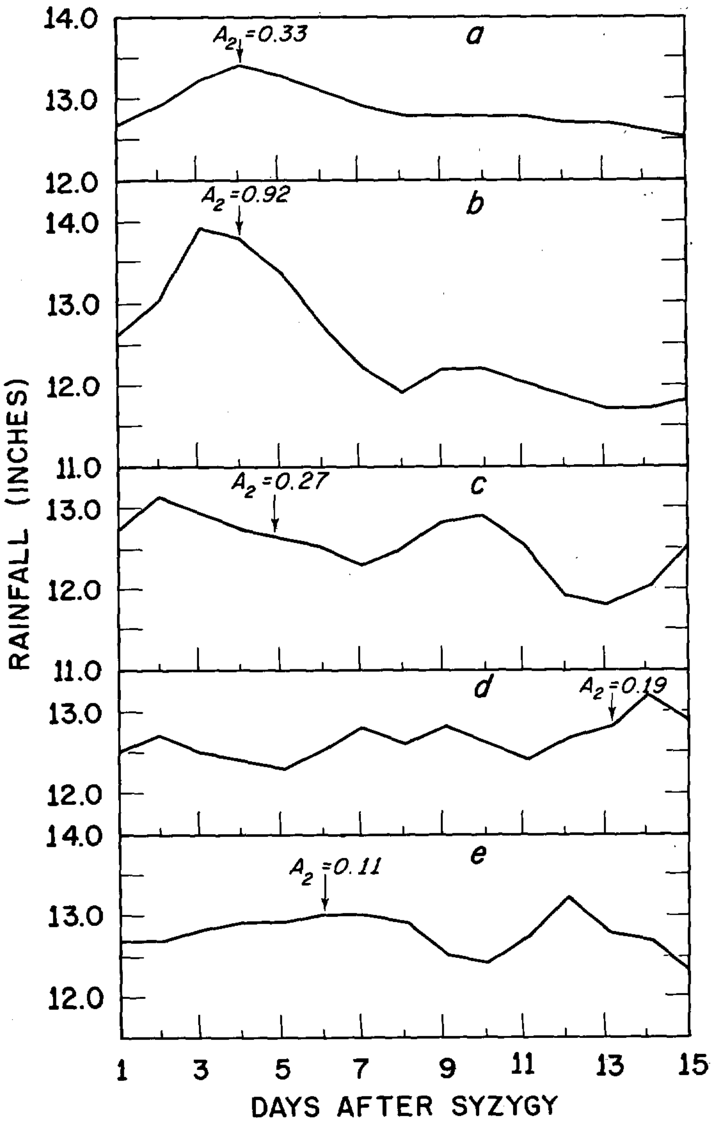

FIGURE 4.—Amplitude of lunar effect on rainfall in relation to days after syzygy. (From Brier [4].)

[4] found that the amplitude of the lunar effect on rainfall during the months of the former type (which has a larger amplitude of the envelope curve) is about four times the corresponding amplitude in lunar months of the latter type (see fig. 4).

5. SHORT-PERIOD VARIATIONS

The occurrence of rainfall is due to a combination of generally favorable conditions associated with synoptic systems and the purely local and diurnal variations. The mathematical model in figure 1 was discussed in relation to large-scale systems but may also be interpreted to explain short-period variations in precipitation processes. The F curve will now represent the meteorological forces favorable for the short-term precipitation processes and F_{tc} the resultant of F and the effects of the semidiurnal tidal force F_t on F. The period of the process represented by F is of the order of a few hours.

The semidiurnal oscillation of the luni-solar tidal force F_t has, in general, a maximum value F_{tm} about 6 hours after the preceding minimum so that the time between the minimum and the next maximum is a few hours. The period of F_t is therefore comparable to that of F. However, the semidiurnal tidal force and, consequently, the value of F_{tm} varies from day to day.

It is not known what are all the forces represented by F in the short-term precipitation processes. Temperature and humidity are two parameters which in combination determine the instability of the atmosphere. A warm moist air mass under otherwise similar conditions, is more unstable than dry air, and hence more likely to favor precipitation. This condition generally obtains during summer months and in coastal areas rather than in winter and inland. In these cases (summer and coastal areas) F_w has a larger value and $F_c - F_w$ is relatively small compared to F_{tm}. The tidal force required for the event is available on a larger number of days of the synodic month, that is, the frequency of occurrence of precipitation is more evenly distributed against the synodic scale. On the contrary, in winter and in inland areas, the tidal force required is larger and is available on relatively fewer days of the synodic month and the frequency of occurrence is higher in some classes of the synodic time scale than in others. It would follow from this, that, if the frequency of occurrence of rainfall expressed as a percentage of the mean is plotted as a function of the synodic decimal, the amplitude of the 14.765-day fitted harmonic will be larger in the case of winter and inland data than in the case of coastal areas and summer. These features are borne out in the maximum precipitation of the United States as found by Brier and Bradley [5].

In another stratification of rainfall according to high and low solar activity Brier and Bradley [5] found that the variance contributed by the 14.765-day period is larger in low sunspot periods than in high sunspot periods. Berson and Deacon [2] came to a similar conclusion in regard to Mangalore and Djakarta rainfall. It is not known what direct effects on precipitation are attributable to solar activity, but in an extension of the logic of the preceding paragraphs it would be expected that F_w has a higher value, that is, there is greater moisture content as a result of evaporation during high sunspot periods. Some evidence to support this assumption can be found in the inverse correlation between sunspot activity and temperature which is explained as being due to increased evaporation and cloudiness during high sunspot periods and consequent lowering of the diurnal maximum temperature as measured near the ground.

6. CONCLUSION

Rainfall statistics show a nonrandomness when stratified according to the position of the sun and moon relative to the earth. The tidal hypothesis provides one plausible explanation of the mechanism. The mathematical model discussed here is an attempt to interpret both the long-term cumulative effects and the short-term effects of the tidal forces. The extreme smallness of magnitude of the tidal forces would suggest that the long-term effects are more likely to be important than the short-term ones. However, evidence is available that the luni-solar effect is noticeable even in the diurnal variations. Brier [4] found a marked variation in excessive rate of precipitation classified according to lunar and solar hours. Though the tidal hypothesis is suggested by the geometry of the earth-sun-moon system, it should be conceded that there may be other forces related to these same parameters which may also be reflected in rainfall statistics. It would be useful to denote by a general term "luni-solar effect" the combined effect of the luni-solar forces which are related to the parameters—the angular distance of the sun and moon, the distance of these bodies from the earth, and their zenith distance at a given time and place. In the mathematical model F would then represent all the physical and meteorological forces favorable for the event and F_{tc} the combination of "luni-solar effect" on the forces represented by F.

The model discussed herein is not intended to provide a detailed explanation of the mode of interaction of the "luni-solar effect" on atmospheric processes. Its purpose is not to support the validity of the conclusions already arrived at but to suggest a framework for the collection and analysis of data in the future to study the "luni-solar effect" and devise sensitive tests which can be applied to it.

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