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ATMOSPHERIC PRESSURE PERTURBATION DURING TOTAL SOLAR ECLIPSE

1. Change in the ground level atmospheric pressure is reported to occur during solar eclipse (Anderson *et al*., 1972). Many workers have attempted to explain the cause of atmospheric pressure perturbation since early 70's. Of these, proposal of gravity waves by Chimonas and Hines (1970) is most popular but not satisfactory. Till now lot of work has been done but complexity of the problem demands more research. However work of Touma and Wisdom (1994) is remarkable though it is not directly related with the present problem.

In this paper we use a different approach to explain the phenomena. Though we use simple classical mechanics to explain the process but it's penetration towards the complexity of the problem is immense.

Initially the change of height of atmospheric air column during eclipse is calculated by help of mechanics. Then the height is converted into a function of local parameters. Finally we show during eclipse pressure increases in totality region and some other conclusions have also been drawn.

2. The basis of this analysis is the assumption that at every instant of time the atmosphere, covering the rigid earth, is in dynamic equilibrium under the action of gravitational forces and disturbing force due to the moon and the sun. Therefore, the free surface of the atmosphere assumes the shape of a sphere, *i.e*., a level surface $V(x, y, z) = C_1$, V being the potential of all forces acting on the fluid and C_1 is an arbitrary constant.

Let us consider the total mass of the moon and the sun as a whole a point mass situated at the point of the centre of mass of the moon and the sun at the time of eclipse.

We first suppose that the disturbing point mass is absent, *i.e*., the moon and the sun is absent, denoted by $V_1(r, \phi, \psi)$ the potential of the gravitational force (which includes the centrifugal force of rotation of the earth), when r, ϕ, ψ are the spherical co-ordinates of the point, r being distance from the earth's centre, ϕ being the latitude, ψ being the western longitude. Let the equation of the top layer of the atmosphere in the absence of disturbing point mass be

$$r = r_0(\phi, \psi) \tag{1}$$

The top layer of the atmosphere being a level surface

$$V_1(r_0, \phi, \psi) = \text{constant} \tag{2}$$

Let $V_2(r, \phi, \psi)$ denote the potential of the force of the point mass (*i.e*., the moon and the sun) pulling the air mass. In the presence of the point mass (*i.e*., the moon and the sun), the equation of the top layer of our atmosphere takes the form

$$r = r_0(\phi, \psi) + h(\phi, \psi) \tag{3}$$

where h is the height of the top layer of the atmosphere above the equilibrium layer.

Since the potential of the forces on the atmosphere is $V_1(r_0 + h, \phi, \psi) + V_2(r_0 + h, \phi, \psi)$, we have, neglecting the variation in V_1 due to mass displacement of air caused by V_2

$$V_1(r_0 + h, \phi, \psi) + V_2(r_0 + h, \phi, \psi) = \text{constant} \tag{4}$$

Subtracting equation (2) from equation (4), we get

$$V_1(r_0 + h, \phi, \psi) + V_2(r_0 + h, \phi, \psi) - V_1(r_0, \phi, \psi) = \text{C} \tag{5}$$

where C is a constant.

Expanding equation (5) by Taylor's theorem gives

$$h\frac{\delta V_1}{\delta r} + V_2(R, \phi, \psi) = \text{C} \tag{6}$$

Since height $h << r$, higher order terms greater than first order can be neglected in equation (6) and $(r_0 + h)$ in V_2 is $\approx R$ which is earth's mean radius.

Also we have,

$$\left[-\frac{\partial V}{\partial r}\right]_{r=R} = -\text{g} \tag{7}$$

This gives the fundamental equation of our analysis.

$$\text{g}h + V_2(R, \phi, \psi) = \text{C} \tag{8}$$

From equation (8) we can compute the height of the atmosphere layer above the equilibrium layer.

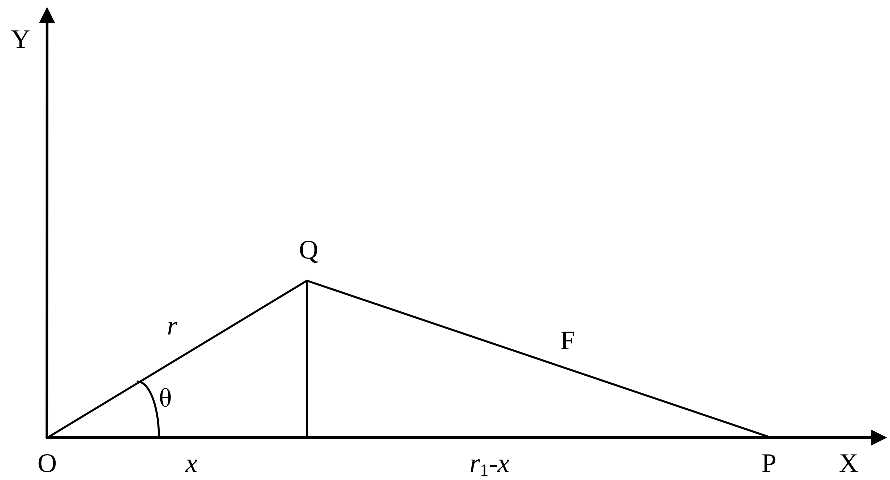

Fig. 1. r_1 = OP = distance of the point mass from the earth's centre O, θ = Zenith distance, r = OQ = distance of an arbitrary point Q within the atmosphere from the centre of the earth O, r_2 = PQ, E = mass of the earth, M = mass of the moon plus the sun

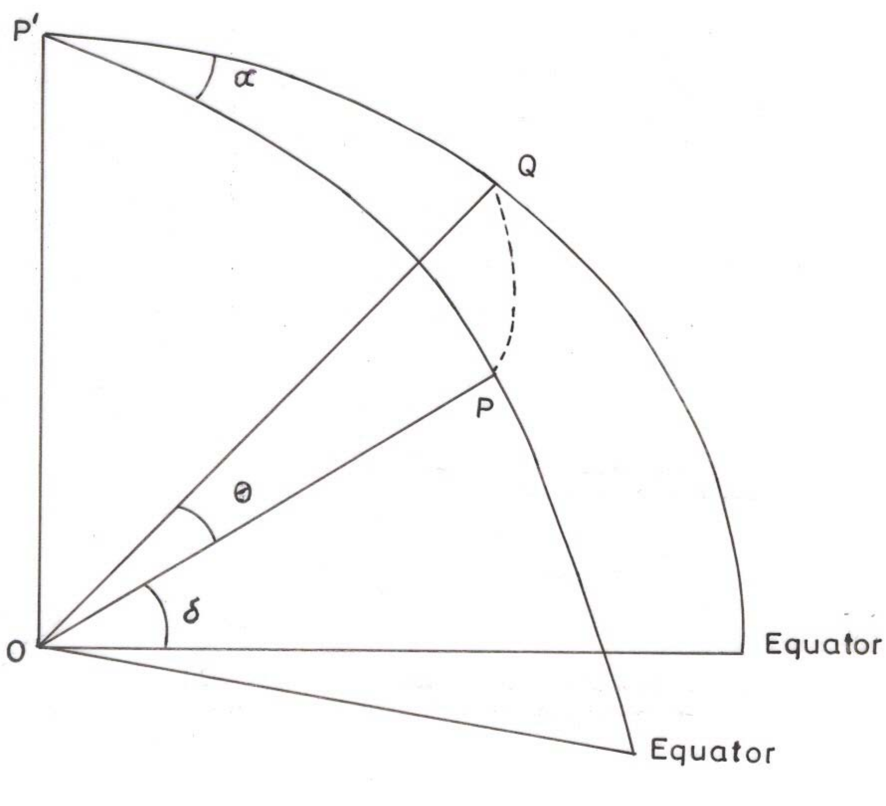

Fig. 2. φ = Latitude of the place, α = Hour angle between the meridians P'Q and P'P, measured in a westerly direction at the pole P' of the earth, δ = Declination of the centre of mass of the moon plus the sun

According to the law of gravitation, force $\vec{F}$ of attraction per unit mass at Q is given by

$$\vec{F} = \frac{M_{ms}R^2 g}{Er_2^2}\frac{r_1 - x}{r_2}\hat{i} - \frac{g}{r_2}\hat{j} \tag{9}$$

Now, we assume the earth to consist of homogeneous spherical layers, the acceleration $\vec{F}_0$ imparted by the point mass to the earth as a whole is given by

$$\vec{F}_0 = \frac{M_{ms}R^2 g}{Er_1^2}\hat{i} + 0\hat{j} \tag{10}$$

where in equation (9) and equation (10), $\hat{i}$ and $\hat{j}$ are unit vector along OX and OY respectively, again OP is parallel to OX, OY is perpendicular to OP .

Since only displacement of the fluid particles relative to the earth's sphere are considered, the force pulling the air mass is the difference $\vec{F} - \vec{F}_0$ since $r << r_1$, α is small and so $r_1 - x \approx r_2$,

then we can write

$$\vec{\nabla} V_2 = \vec{F} - \vec{F}_0 \tag{11}$$

Where,

$$\vec{\nabla} \equiv \frac{\partial}{\partial x}\hat{i} + \frac{\partial}{\partial y}\hat{j}$$

Adjusting the constant of integration we get,

$$V_2 = -\frac{M_{ms}R^2 r^2 g}{2Er_1^3}\left(3\cos^2\theta - 1\right) \tag{12}$$

Equation (8) and (12) gives

$$h = \mu\left(\cos^2\theta - \frac{1}{3}\right) + C' \tag{13}$$

where, $\mu = \frac{3M_{ms}R^4}{2Er_1^3}$

The constant C' is determined from the condition that the air covering the earth, remains unchanged in volume which gives C' = 0. So

$$h = \mu\left(\cos^2\theta - \frac{1}{3}\right) \tag{14}$$

To express h in terms of local parameters, ϕ, α and δ

Then from spherical triangle P'PQ of Fig. 2.

We can write h in terms of local parameters as follows

$$h = \mu/2\ \left[1/3\left(1 - 3\sin^2\delta\right)\left(1 - 3\sin^2\phi\right) + \sin 2\delta \sin 2\phi \cos\alpha + \cos^2\phi \cos^2\delta \cos^2 2\alpha\right] \tag{15}$$

The pressure perturbation during total solar eclipse is given by

$$\delta p = \rho h\left(g + \delta g\right) \tag{16}$$

where ρ and g are mean air density and mean acceleration due to gravity respectively. And δg□ is given Sazhina and Grushinsky , (1971) by

$$\delta g = g\sin^3 P\frac{M_{ms}}{E}\left(\cos 2\theta + \frac{1}{3}\right) \tag{17}$$

where P is the horizontal parallax.

3.1. Equations (14) and (16) show that there is always a pressure perturbation during total solar eclipse, if atmosphere is in normal condition (*i.e.*, cloud free, rain free etc. and temperature departure is not considered). From same equations, it is evident that pressure perturbation δp is maximum when centre of mass of the moon and the sun is at zenith. In general if the observation site is at the centre line of the totality path of the eclipse, atmospheric pressure increases. These are agreed well with statistical analysis and conclusion of Anderson *et al*., (1972). From equation (14) it is also evident that pressure perturbation δp has not been observed at those places where zenith distance is nearly 54°.7356.

3.2. Equation (14) shows that the mean free surface of the atmosphere has the shape of a spheroid of revolution, the axis of which is the line OP of Fig. 1.

3.3. The pressure variation of a place during total solar eclipse may readily be obtained by equation (15) and (16) if the local parameters are known [including ρ and P in equation (16) and (17) respectively].

4. Authors wish to place on record their sincere thanks to the Director General of Meteorology, India Meteorological Department and one of the author Nabajit Chakravarty expresses his thanks to Shri K. K. Chakraborty, Ex-Director, Positional Astronomy Centre, Kolkata for providing the opportunity to make this study possible.

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