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# Change of atmospheric density at high altitudes due to tidal forces

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## SUMMARY

The combined European database of meteor orbits EDMOND for 2012-2016 was analyzed. It was found that meteors at high altitudes (120 - 145 km) are mainly registered in the phase of ebbs in the atmosphere. This shows that tidal forces from the Moon and the Sun can change the density of the upper atmosphere in a significant range of altitudes.

## Introduction

Lunar-solar gravitational tides should be manifested not only in the ocean or the earth's crust, but in the atmosphere as well. In particular, in the upper layers, at altitudes of more than 100 km, the movement of gas molecules under the action of tidal force will be directed along the resultant tidal forces from the Moon and the Sun. In this zone the air is so thin that the interaction between neighboring gas molecules may be neglected. However, it is difficult to directly register the movement of the atmosphere under the action of tidal forces in this area. After all, such a movement practically does not change either the atmospheric pressure near the earth's surface or the optical thickness of the atmosphere.

However, the movement of air molecules in the upper layers under the action of tidal forces can cause a change in the density of the atmosphere at a certain height at different phases of tides. Such changes in atmospheric density, in principle, can be detected by results of meteor observations.

## Calculations of tidal forces

The direction and value of the tidal force from the cosmic bodies is determined by the resultant of two tidal forces: from the Moon ($\boldsymbol{F}_{tM}$) and the the Sun ($\boldsymbol{F}_{tS}$), but not their separate action. The resultant force is defined as the vector sum of these forces: $\boldsymbol{F}_{tR} = \boldsymbol{F}_{tM} + \boldsymbol{F}_{tS}$.

To determine the components of tidal forces of the Moon, analytical formulae for calculation of geocentric coordinates and the distances to the Moon were used. The deviation of the calculated Moon’s coordinates from the data obtained using the modern program DE406/LE406 is about 0.3%. A brief description of the calculation method for tidal forces is presented in (Kazantsev and Kazantseva, 2016; 2017).

## Dependence of tidal forces on coordinates and altitude

The range of the $\boldsymbol{F}_{tR}$ value of is significantly different at different latitudes. At low latitudes ($-25^o < \varphi < 25^o$), the maximum of the $\boldsymbol{F}_{tR}$ value in one place on the Earth's surface can exceed the minimum by 40 times, near the poles ($85^o < \varphi$ and $\varphi < -85^o$) the maximum value don’t exceed the minimum more than twice (Kazantsev and Kazantseva, 2017).

At the tidal phase, the vector of resultant force $\boldsymbol{F}_{tR}$ is directed up the horizon, although at different angles. At the ebb phase the vector is directed below the horizon, also at different angles. The absolute value of $F_{tR}$ in the tidal phase on average exceeds this value in the ebb phase.

In the atmosphere, the value the tidal force increases slightly at altitude $h$ increase. The $F_{tR}(h)$ dependence is linear. At altitudes of 200 km, the $F_{tR}$ value is about by 3% higher than the corresponding value on the Earth's surface.

At the ebbs, the upper layers of air should descend slightly faster than the lower layers. Therefore, some increase in the density of the atmosphere may occur at certain altitudes. In this study, we make an attempt to detect changes in air density at altitudes above 100 km at different phases of tides according to meteor observations.

## Selection of meteor observations

Every meteor has a certain beginning height h1. This is the height above sea-level where the meteor phenomenon can be already registered by equipment. Besides the characteristics of the equipment itself, the value of h1 depends on the velocity of the meteor body and its physical characteristics, as well as the density of the atmosphere at the altitude. The higher the density, the brighter a meteor will be at other equal values. Most meteors are observed at altitudes of 70 - 120 km. A number of meteors are observed at altitudes up to 130 km. But there are also so-called anomalous altitudes h1 > 130 km.

Today, the combined European database of meteor orbits EDMOND can be found in easy access. It contains data from multi-station optical observations of meteors over almost the entire Europe. Currently, the database contains almost 600,000 orbits of individual meteors obtained from observations in 2000 - 2016. When using the database of observations, the determination accuracy of the elements of each orbit has a crucial role. This base contains beginning height from 20 to 200 km. This range of the h1 values is erroneous. In order to use more accurate data, for further analysis we used databases for the last 5 years (2012 - 2016). The total number of meteor orbits during this period is over 244,000.

**Anomalous beginning heights of meteors and their possible explanation**

We analyzed meteors with beginning heights from 120 to 145 km. The higher altitudes are more likely caused by observation errors. The total number of meteors in the EDMOND database with such altitudes for 5 years is 1353. Of these, 1002, i.e. 74% were registered at the ebb phase. However, it should be noted that for the analyzable European zone, the duration of the ebb phase is 70%. Therefore, the total sample does not indicate an obvious advantage in the number of meteors with high altitudes in the ebb phase.

But the total sample contains many inaccurately calculated orbits. The accuracy of the orbit elements depends on a number of parameters. First of all, it is the length of the observed meteor trail *dg* and the accuracy of the meteor velocity determination *dv*. Figure 1 shows the dependence of the beginning heights of the meteors on the length of the trail. It is clearly seen that abnormally small and abnormally large heights occur mainly at *dg* < 10º. This indicates on significant errors in determining the beginning heights at small *dg* values.

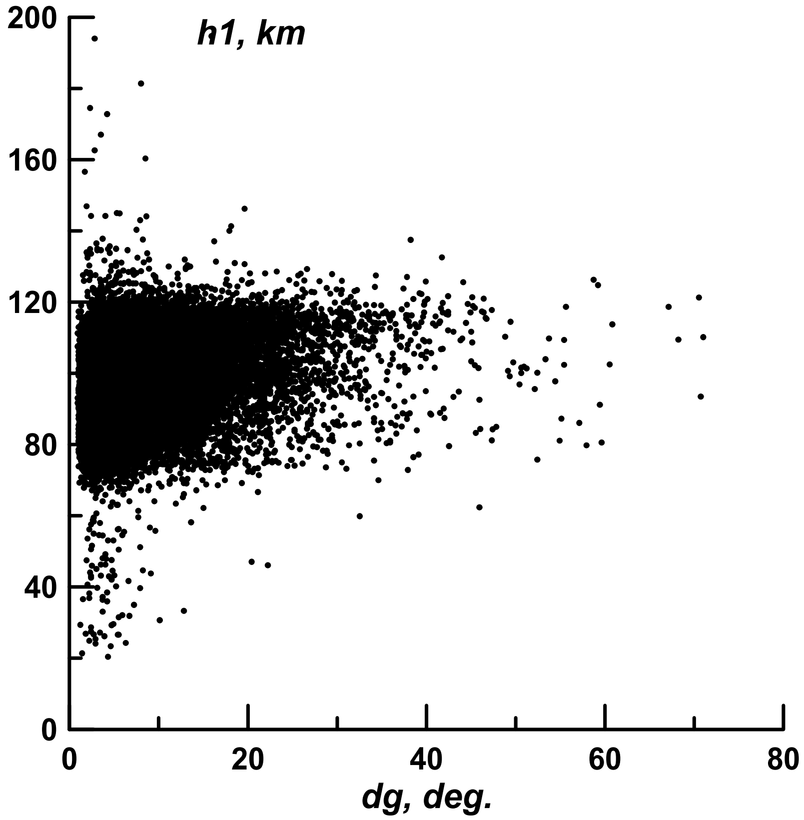


***Figure 1*** *The dependence of the beginning heights of the meteors on the length of the trail*

The numbers of meteors with beginning heights of 120-145 km in the ebb phase for different ranges of *dg* and *dv* values were determined. The data are given in Table 1. Here *Ns* is the total number of meteors with such altitudes, *Nv* is the number of meteors in the ebb phase, *Nv*% is the percentage of *Nv*.

The table clearly shows that at increasing orbit accuracy, the percentage of meteors with high altitudes in the ebb phase increases. This indicates the influence of tidal forces from the Moon and the Sun on the number of meteors with high altitudes. Obviously, in the ebb phase, the highest layers of the atmosphere descend, increasing the air density at altitudes of 120 - 145 km. Probably at significantly higher altitudes, the air density decreases during these periods. Such phenomena can affect the motion of spacecraft in low orbits. It is difficult to say what the density distribution is at lower altitudes.

***Table 1***. *The number of meteors with high altitudes at different orbit accuracy*

| *dg* (deg) | *dv* (%) | *Ns* | *Nv* | *Nv*% |
|---|---|---|---|---|
| all | all | 1353 | 1002 | 74 |
| > 10 | < 5 | 807 | 639 | 79 |
| > 15 | < 3 | 490 | 395 | 81 |
| > 20 | < 3 | 302 | 255 | 84 |

This result is only evaluative. It is clear that the distribution of atmospheric density is influenced not only by tidal forces, but also by other factors. It is possible that such processes occur differently in different zones of the globe and in different periods. But this is already the subject for further research.

**Conclusions**

Tidal forces from the Moon and the Sun can change the density of the upper atmosphere in a significant range of altitudes. In particular, in the ebb phase at altitudes of 120 - 145 km the density increases to values sufficient for appearance of more number of meteors. This is confirmed by the analysis of meteor catalogs.

**References**

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