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LUNAR ECLIPSES OPTICAL PROFILES: AEROSOL, WATER VAPOR AND OZONE RELATIONS

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Abstract. The paper contains the description of basic problems of lunar eclipse brightness analysis, the atmosphere investigations made by the lunar eclipses measurements. The basic part of the paper is the photometric review of 5 lunar eclipses in 2004-2008 in the near-IR spectral range. The data allowed to build the latitude distribution of aerosol and water vapor at different altitudes in the troposphere. The correlation of aerosol and total ozone amounts is seen in the southern hemisphere.

1. Introduction

The history of lunar eclipses observations covers more than 3000 years since the first event description was made by ancient Chinese observers in 1137 BC. Along with the solar ones, the lunar eclipses prediction was the basic aim of ancient astronomy, that caused the development of lunar motion theory and the celestial mechanics in general. The large array of observations and timings made by Babylonian and Greek astronomers covered a number of centuries and was used by Hipparchus and then Ptolemaios to increase the accuracy of lunar orbit description. Now the accuracy of this theory allows to predict the exact moments of the eclipses over the thousands of years to the future and the past and it develops the historical science with the use of ancient eclipses descriptions.

But there is the other part of the lunar eclipses science which may be called as phenomenological or optical one. It appeared to be more difficult. It took a number of centuries to answer on the questions why does the Moon remain visible even during the total eclipse, why does it have such dangerous red color and why the brightness of the Moon is unpredictable and variable from eclipse to eclipse. All the answers are related with the atmosphere of the Earth, the strong spectral dependency of the atmospheric light extinction and the wide temporal and spatial variations of aerosol content in the lower atmosphere.

There were the darkest eclipses, when the Moon was hardly visible in the sky. In XIX century the correlation of such eclipses with strongest volcanic eruptions was noticed. It was confirmed in XX century, when the darkest eclipses followed the eruptions of Agung (1963), El Chichon (1982) and Pinatubo (1991) volcanoes. In 1920 the French astronomer Andre Danjon noticed the changes of lunar eclipses brightness with the solar activity: the eclipses turned darker after the solar minimum epoch.

During the eclipse the Moon is illuminated by the solar emission refracted and absorbed in the Earth's atmosphere. The geometry of the eclipse is like the space experiment for the atmospheric research, the role of the spacecraft is played by the Moon. This geometry allows to measure the light absorption at different altitudes above the different points of the Earth's limb. Until the start of cosmic era, the lunar eclipses analysis was the only way to hold the remote sensing of distant regions the atmosphere using such geometry. Wide review of theoretical and observational papers on the lunar eclipses analysis in the middle of XX century was made by *F.Link* [1962].

2. The eclipses in 2004-2008: Observations and results on aerosol

The lunar surface photometric measurements were conducted during the total lunar eclipses of May, 4 and October, 28, 2004, March, 4, 2007 and February, 21, 2008 in Southern Laboratory of Sternberg Astronomical Institute, Moscow State University (Crimea, Ukraine) and during the deep partial eclipse of August, 16, 2008 in Moscow. The observational devices consisted of the CCD-cameras SBIG ST-6 and Sony DSI Pro with the lenses "Rubinar-500" and "Jupiter-36B", respectively. The observations covered the periods outside the eclipse, penumbral, partial and total umbral eclipse stage. The exposure time changed from 0.005 to 20 seconds depending on camera, spectral band and eclipse stage. The photometric control of atmosphere transparency was held by the photometry of standard star close to the Moon. The procedures of surface photometry and sky background reduction (including the lunar halo) are described in [*Ugolnikov, Maslov,* 2006].

The measurements of both eclipses in 2004 were conducted in double spectral band with peak wavelengths equal to 675 and 855 nm. This band is almost free from gaseous absorption, slightly overlapping the O_3 and H_2O absorption bands that were taken into account during the data processing. Optical map of 2007 and 2008 eclipses was built in narrow band with the wavelength 867 nm. This band is totally free from gaseous absorption. The light extinction in these bands is defined by the molecular and aerosol scattering.

The period of 2004-2008 is especially interesting since it contains the epoch of solar activity minimum around 2007 and Rabaul volcano eruption in October 2006. So, the eclipses of 2007 and 2008 were expected to be quite dark.

Figure 1 shows the maps of the lunar surface relative darkening inside the umbra for four lunar eclipses in the spectral ranges described above. We see that 2007-2008 eclipses are not darker than the 2004 one (the brightness values are even higher, but it is related with the instrumental wavelength difference). The umbra of the eclipses of May, 4, 2004 and March, 4, 2007 is characterized by the darkening in equatorial zone. It is the typical picture [*Link*, 1962] related with the high aerosol concentration in the equatorial atmosphere. The map of March, 4, 2007 even contains the equatorial brightness minimum far from the umbra center. But the polar spot is also seen for the eclipse of May, 4, 2004, and both 2008 eclipses are characterized by general polar darkening of the umbra.

The brightness of lunar surface is less than the one predicted by gaseous model of the atmosphere, the difference can be explained by the aerosol extinction and used to retrieve the aerosol distribution along the limb at different altitudes. The method is described in [*Ugolnikov, Maslov*, 2006, 2008]. The results of the procedure are the values of aerosol optical depth by the tangent trajectories with different perigee altitudes. Figure 2 shows such distributions for the perigee altitude 10.5 km for all five eclipses.

As it was expected, the dark spots in the umbra correspond to the region of high aerosol amount above the limb. The comparison of the obtained distribution with the meteorological maps for the eclipse dates shows the correlation of the aerosol amount in the upper troposphere with the clouds distribution below. During the eclipses of May, 4, 2004 and March, 4, 2007 equatorial part of the limb corresponded to the continental regions with the high tropospheric aerosol concentration. The equatorial limb part in March, 4, 2007 is not far from the Rabaul volcano, that can also increase the aerosol level.

The picture of both 2008 eclipses differs. Equatorial limb falls to the oceans, where troposhpere is more transparent. Cloud clusters above Antarctic and Iceland absorb the solar emission and cause the polar darkening during the eclipses of February, 21 and August, 16, respectively. Antarctic clouds also causes the polar spot in the umbra in May, 4, 2004.

The aerosol distribution in the upper troposphere and lower stratosphere during the eclipses of May, 4, 2004 and February, 21, 2008, also shows the anti-correlation with the total ozone amount distributions for the same dates. The maximal aerosol concentration corresponds to the minimal ozone amount. During these two eclipses the Moon crossed the southern part of the umbra and the picture was defined by the southern regions of the limb. This fact is possibly related with the polar stratospheric aerosol in the southern hemisphere and corresponding chemical processes of ozone destruction. During the eclipses of March, 4, 2007 and August, 16, 2008, when the Moon crossed the northern umbra regions, such correlation is not observed.

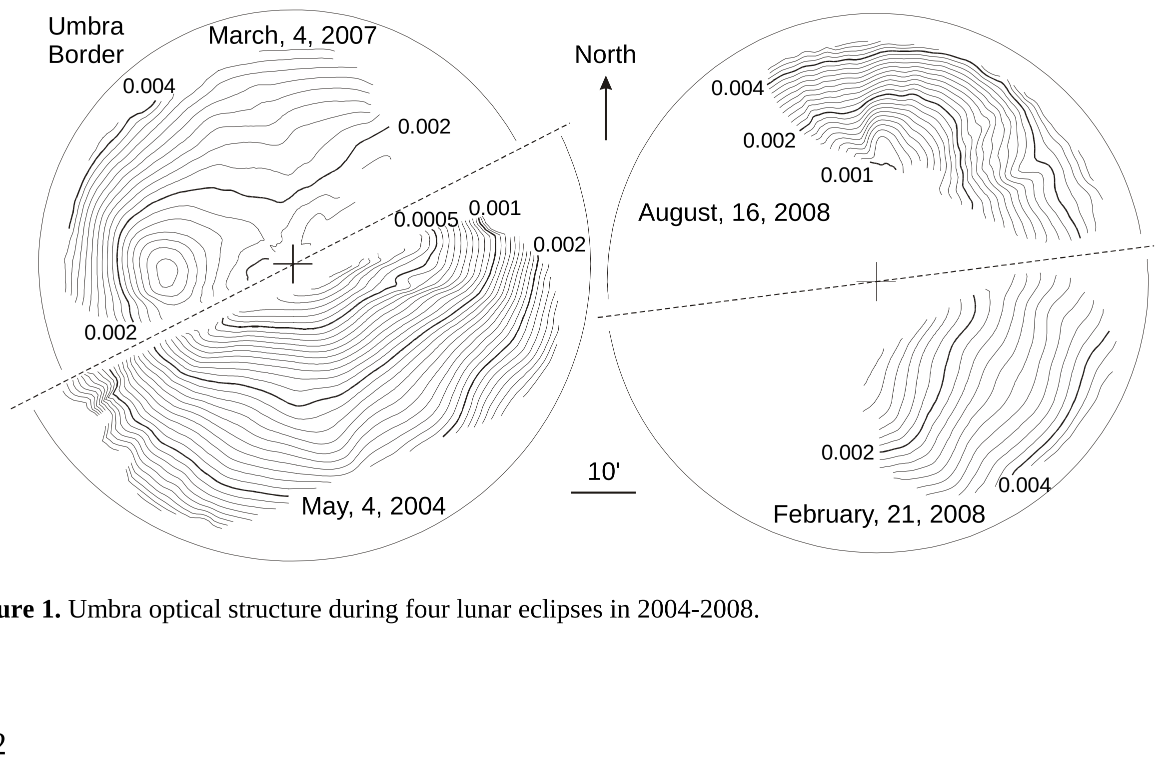

Figure 1. Umbra optical structure during four lunar eclipses in 2004-2008.

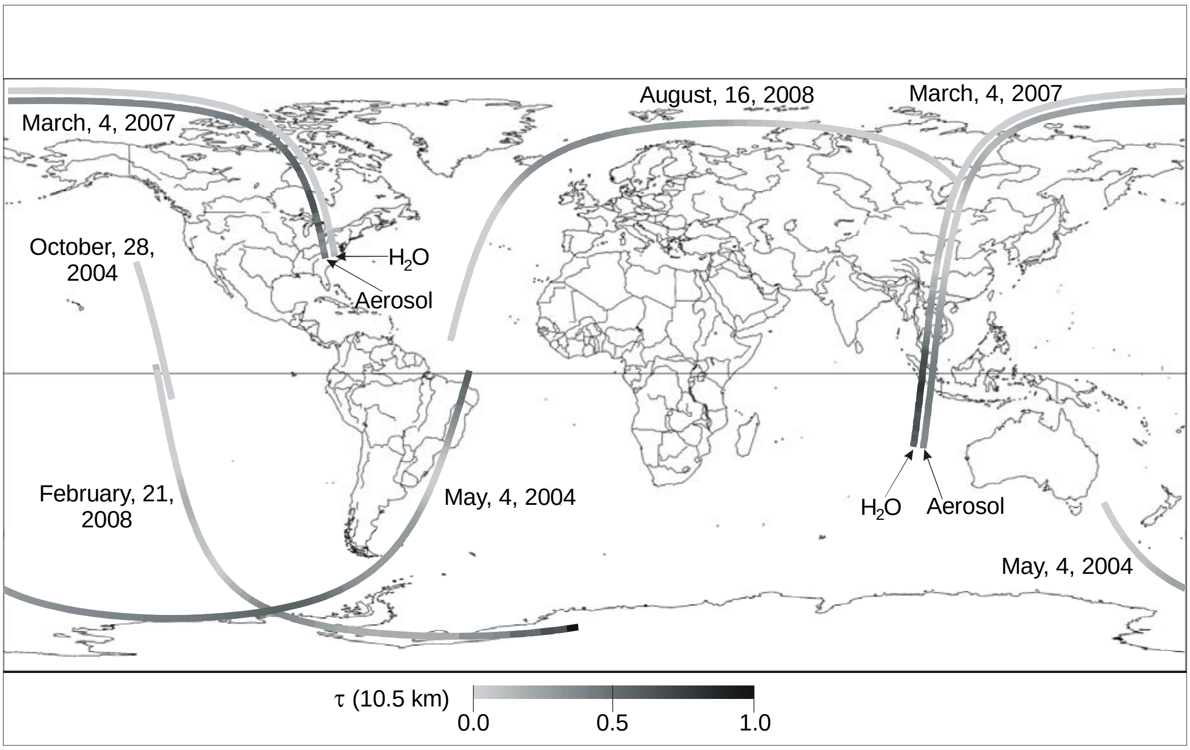

Figure 2. Aerosol distribution in the upper troposphere based on the lunar eclipse data.

3. Water Vapor Investigations

Lunar eclipses can be also used for the investigations of atmospheric gases having the absorption bands in the visible or IR spectral range. During the total eclipse of March, 4, 2007 the photometry was hold also in the band with the effective wavelength equal to 938 nm. It corresponds to the range of water vapor absorption, effective cross-section for this band is equal to $5.6 \cdot 10^{-23}$ cm. Using the aerosol data obtained for the same eclipse at the wavelength 867 nm, we can find the values of water vapor optical depth by the tangent trajectories above the limb analogous to the ones for aerosol.

Umbra optical structure for the wavelength 938 nm at March, 4, 2007 is close to the one for 867 nm, but the equatorial dark spot is more deep [*Ugolnikov*, *Maslov*, 2008]. It points to the high water vapor amount above the equatorial part of the limb (Indonesia), that is quite natural. It can be also seen in the Figure 2, where the distribution of water vapor tangent optical depth for 10.5 km is also shown.

This latitude distribution of water vapor for upper troposphere is in good agreement with the spaceborn data for total water vapor amount. Figure 3 shows the values of tangent H_2O optical depth at 10.5 km and total H_2O column density at the same date and regions by the SCIAMACHY data (see the description in [*Noel et al.*, 2005]). Good correlation of both values allows determining the scale of vertical water vapor distribution that is also shown in the Figure 3. The typical scale is about 1.3 km, which is 6 times less than the one for total gaseous density. The meridional variations are not so large, we just can see the decrease in the mountain regions of South-Eastern Asia.

4. Conclusion

Lunar eclipses have the rich history of observations and show the relation with different problems of atmospheric optics. There is a number of questions arisen in XX century but there's no exact answers until the present time. Danjon's correlation with solar activity is not seen for 2004-2008 eclipses. The relation of aerosol and ozone is detected for two eclipses in southern hemisphere but needs the statistical confirmation. Lunar eclipses photometry after the volcanic eruptions will help to retrieve the properties of stratospheric aerosol transformation.

Next total lunar eclipses will occur in December, 21, 2010, in June, 15 and December, 10, 2011.

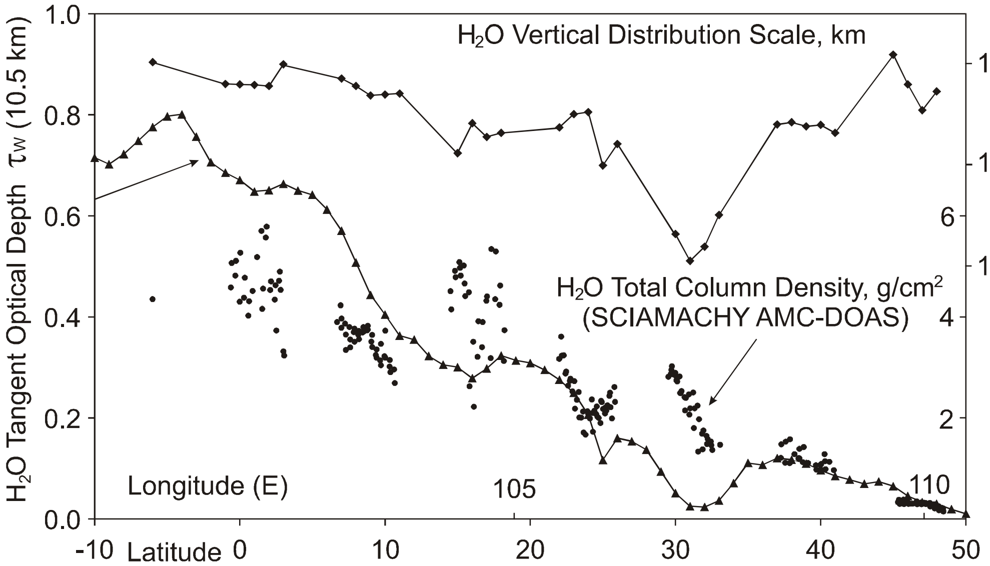

Figure 3. Water vapor characteristics by the observations of the eclipse of March, 4, 2007.

References

1. *Link F.* Lunar Eclipses. Moscow, Nauka, 1962 (in Russian).
2. *Noel S., Buchwitz M., Bovensmann H.P., Burrows J.* Validation of SCIAMACHY AMC-DOAS water vapour columns // Atmosphere Chemistry and Physics, 2005, V.5, P.1835.
3. *Ugolnikov O.S., Maslov I.A.* Atmospheric Aerosol Limb Scanning Based on the Lunar Eclipses Photometry // Journal of Quantitative Spectroscopy and Radiative Transfer, 2006, V.102, P.499.
4. *Ugolnikov O.S., Maslov I.A.* Altitude and Latitude Distribution of Atmospheric Aerosol and Water Vapor from the Narrow-Band Lunar Eclipse Photometry // Journal of Quantitative Spectroscopy and Radiative Transfer, 2008, V.109, P.378.