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The importance of the three-dimensional geometry of solar eclipses for analysis of the impact on the ionosphere

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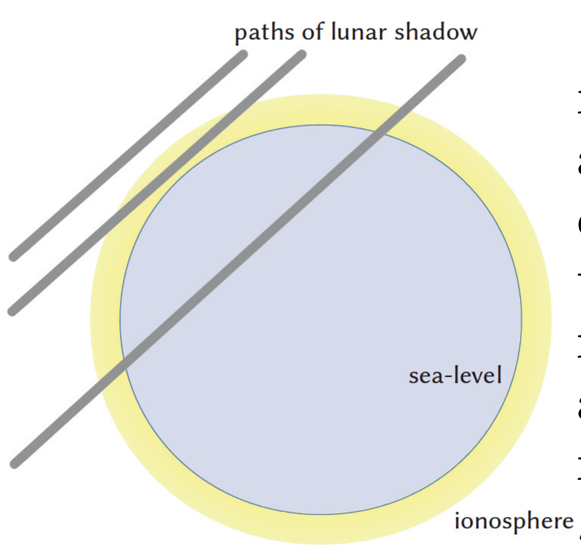
Abstract

Solar eclipses are well known to cause major disturbances in the ionosphere. Even an eclipse that does not reach totality anywhere can have a significant impact on the total electron density, the peak height and density, and other ionospheric characteristics all along its path. Additionally, travelling ionospheric disturbances can be generated in the path of the eclipse and travel well outside the region of obscuration. An extensive catalogue exist of all solar eclipses from 2000 BC to 3000 AD, with detailed information on the timing of the eclipse and the obscurations observable from different locations on the earth. However, investigations of the effects of the total eclipses visible in Europe in 2015 and in North-America in 2017 on the ionosphere have indicated that not only the latitude and longitude should be considered when calculating the obscuration levels and timing during a solar eclipse, but the altitude as well. Various effects have been observed that can only be explained by taking into account the three-dimensional nature of the shadow of the moon during an eclipse. We present theoretical calculations considering the full, three-dimensional geometry of solar eclipses, and show some examples of the importance of the height dependency of the eclipses' effects on the ionosphere.

Solar eclipses in the ionosphere

Predictions of solar eclipses have been available already for some time. However, those predictions are usually provided for visual observations from sea-level. To accurately predict the reaction of the ionosphere to an eclipse, different predictions are needed. We calculate eclipses taking two effects into consideration:



1) The altitude of the observer needs to be taken into account. If the top of the ionosphere is taken at 1500 km, that corresponds to an extension of the earth's radius by 23.5%. This means that eclipses at this altitude can look very different in terms of maximal obscuration, first and last contacts etc. In addition, there are a number of (partial) eclipses not seen at sea-level

2) A significant part of the ionising radiation comes from the solar corona instead of the disk seen in visual light. To model this in the context of eclipse predictions, we use an effective solar radius extended by 12.6%.

For the fifty year period between 1986 and 2035, the standard canon contains 109 solar eclipses. Taking into account a 1500 km thick ionosphere gives an additional 29 eclipses. In addition, there are 10 more cases where only a part of the corona gets obscured by the lunar disk.

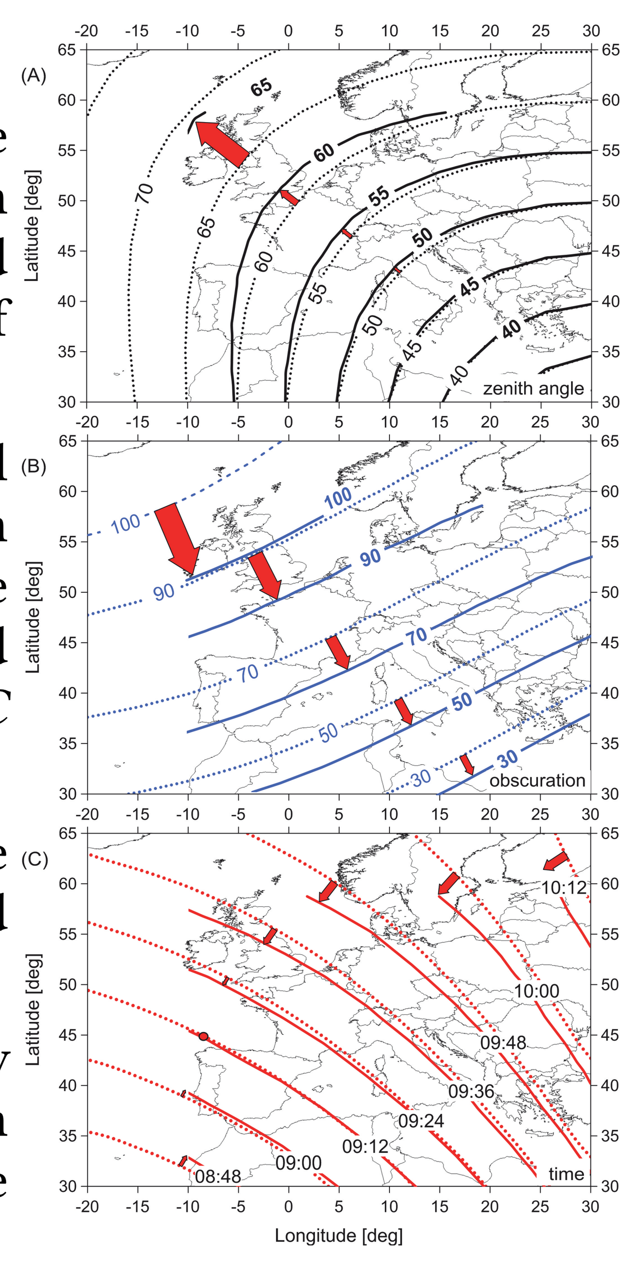
The European eclipse of 2015

During the observations of the ionosphere over Belgium and Europe, as described in *Stankov et. al* (2017), early as well as delayed responses of the ionosphere to the eclipse of 20 March 2015 were observed.

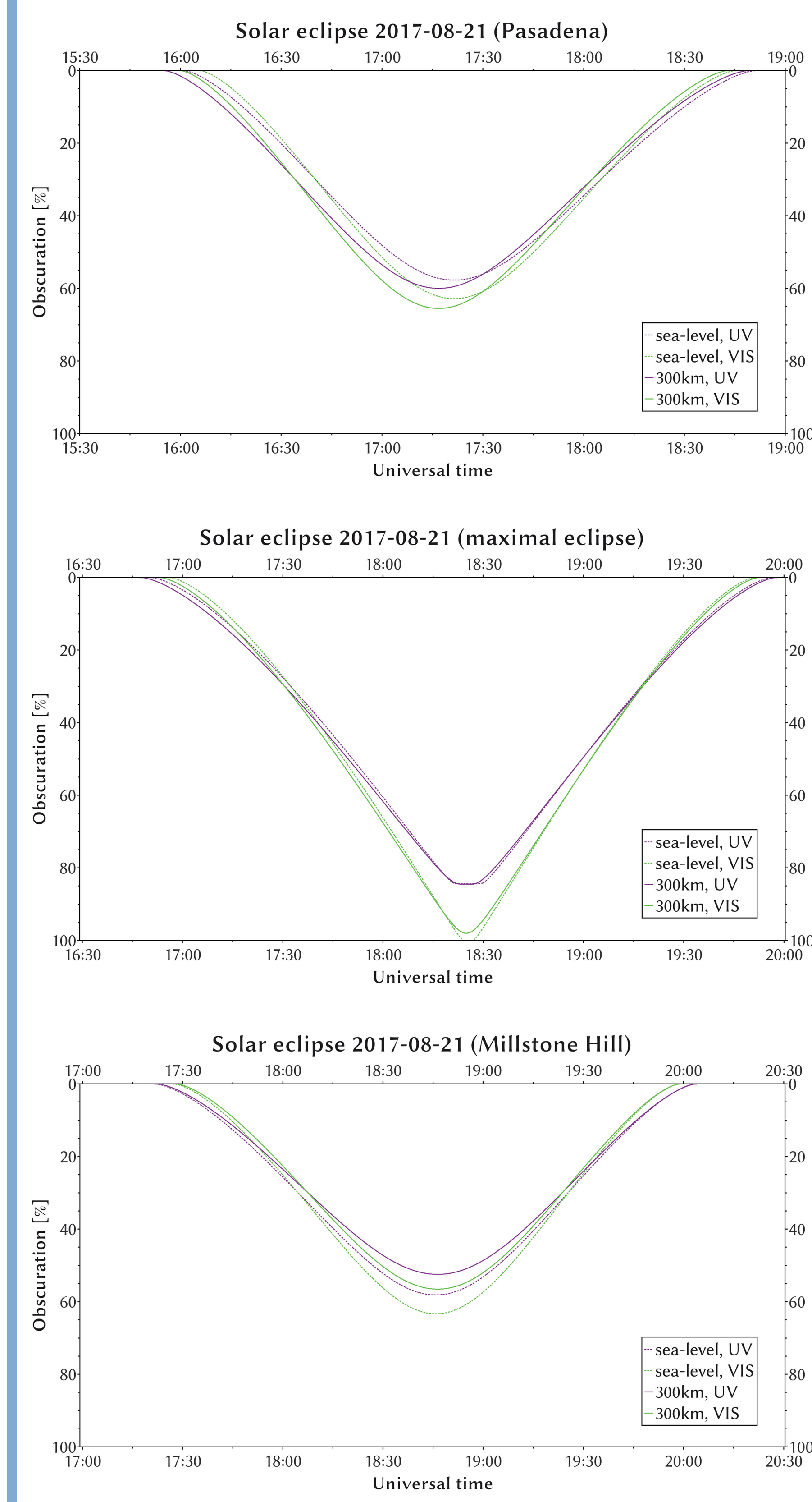
Determining the solar zenith angle, maximal obscuration and time of maximal obscuration at 300 km altitude—about the height of the ionospheric electron density peak—provided an explanation of, for instance, the *TEC* behaviour.

The figure to the right indicates how these parameters vary between sea-level (dotted lines) and 300 km altitude (solid lines).

Especially the maximum obscuration is very different depending on altitude; areas with 90% obscuration at sea-level see a total eclipse at the height of the peak.



The American eclipse of 2017



For the solar eclipse of 21 August 2017, the figure to the left shows the time evolution at three different locations: Pasadena, the point of maximal eclipse at sea-level (36.967°N, 272.328°E), and Millstone Hill.

For each location, four curves are shown. The obscuration is calculated both at sea-level and at 300 km altitude, around the height of the ionospheric peak. For either altitude, we use both the visible light solar disk, and a solar disk extended by 12.6% to account for the ionising emissions from the corona.

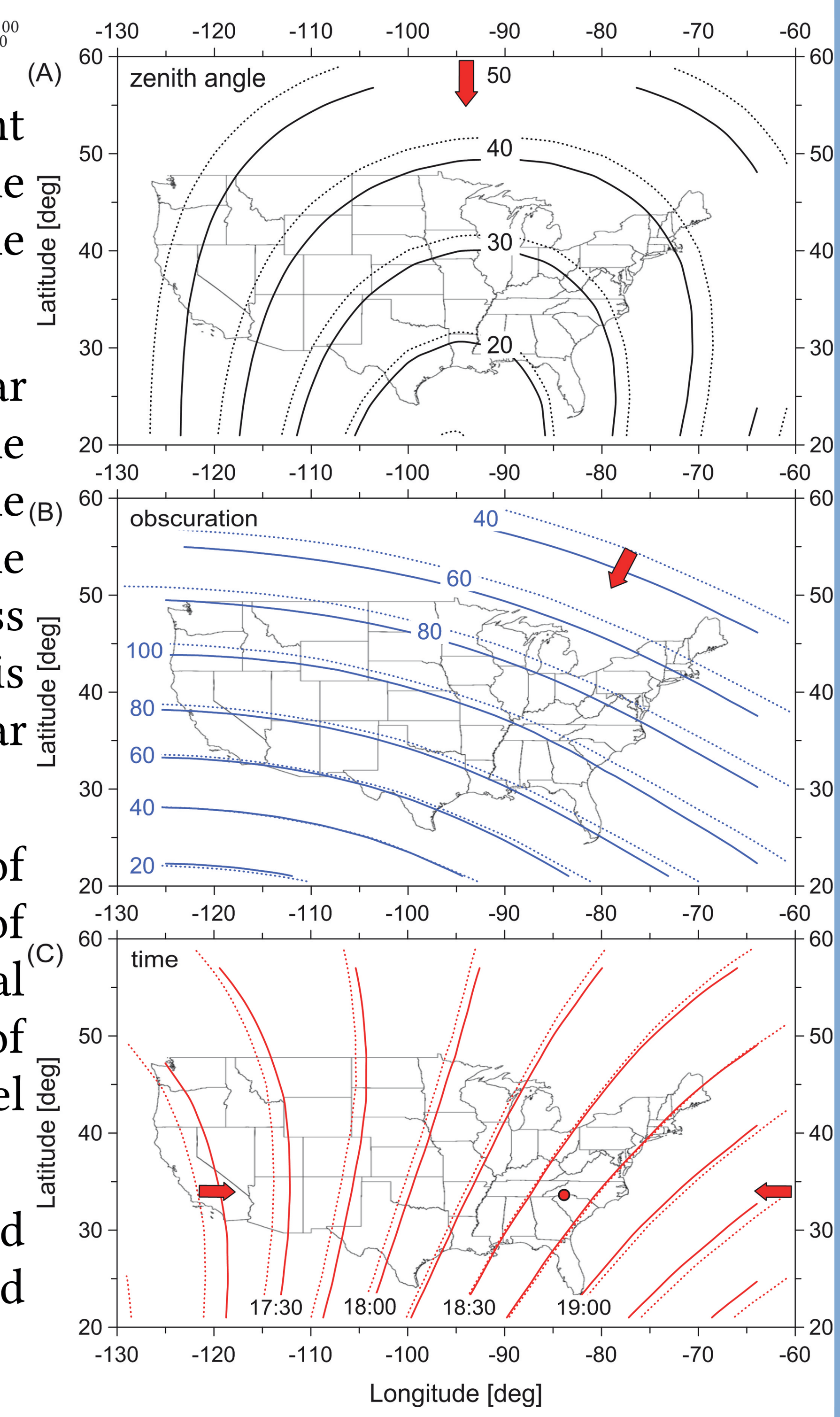
Various effects of the three-dimensional geometry can be seen:

- Shifts in the time of maximum obscuration with altitude (depending on location and local time),
- Changes in maximal obscuration with altitude (location of maximal eclipse at sea-level does not see a total eclipse at 300 km altitude!),
- The obscuration curves for different altitudes can cross each other as time goes on (especially clear in the Pasadena plot).

The obscuration of the extended solar disk is usually lower around the time of maximum, but higher at the beginning and end of the eclipse. The maximal obscuration is always less than 100%, because the lunar disk is too small to obscure the entire solar corona.

The figure to the right shows maps of the solar zenith angle at the time of maximal obscuration, the maximal obscuration in percentage, and time of maximal eclipse, both for sea-level and 300 km altitude over the USA.

The values at sea-level are displayed by dotted lines, at 300 km by solid lines.



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