A NEW METHOD FOR CALCULATING SOLAR IRRADIANCE AT MARS.

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Introduction

Solar irradiance is an important source of energy for planetary atmospheres. This quantity is, however, mainly measured from the vantage point of Earth. Recently, we have been provided with measurements of extreme ultraviolet solar radiation at Mars, determined by the Extreme UltraViolet Monitor (EUVM, Eparvier et al. 2015), onboard the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission, which is in orbit of Mars since September, 2014.

Several studies used measurements of irradiance from Earth to estimate the irradiance at Mars (e.g. Peter et al. 2014; Ramstad et al. 2015). This estimation can be done by applying an extrapolation method, described by Thiemann et al. [2017]. The method assumes that the irradiance source regions on the surface of the Sun simply rotate with a Carrington sidereal period of 25.38 days, i.e., that changes of the solar irradiance are only caused by the rotation of the Sun, ignoring the evolution of active regions on the solar surface. Measurements of irradiance at Earth made before and after the visible solar disk rotates past Mars at a specific day are linearly interpolated. This gives us, in principle, the irradiance at Mars on that day.

In this work, we test the accuracy of the interpolation method and develop a new method for calculating the irradiance at Mars, as well as at any other body in the Solar System.

Data and Methods

To obtain the solar irradiance, we need to first calculate the distribution of magnetic features (faculae and spots) on the surface of the Sun. We utilize the Surface Flux Transport Model (SFTM, Cameron et al. 2010), which is an advective-diffusive model that describes the transport of radial magnetic field on the surface of the Sun. It is, on average, a reliable statistical representation of the distribution of faculae and spots on the Sun. We use full-surface magnetic field maps obtained using the SFTM model. We follow an approach of Nèmec et al. [2020] and Sowmya et al. [2021] and use these full-surface maps for calculating solar irradiance as a sum of contributions from the quiet Sun (i.e. regions without magnetic activity), faculae, and spots.

For this study, we calculate the irradiance at 200.5 nm as it would be observed at four different longitudes within the ecliptic: 0°, 90°, 180°, and 270°. For the purpose of this work, we assume that the Earth is always located at 0° longitude and the location of Mars varies between 90°, 180°, and 270° (i.e., the Mars-Sun-Earth angle). Figure 1 shows an example of faculae and spots on the visible solar disks at the four longitudes.

Our method directly calculates the irradiance at a given position within the ecliptic. We apply the extrapolation method (Thiemann et al. 2017), i.e., we extrapolate the measurements obtained at 0° to the other three longitudes, in order to compare the two methods and assess how well the results correlate.

As for the time series, we choose two periods of one year each, corresponding to a period of high solar activity (from September 15th, 1989) and a period of low solar activity (from August 7th, 1995).

Results

Figures 2 and 3 show the irradiance at 200.5 nm calculated with our method at 90° longitude (red) and extrapolated to 90° (blue), for periods of low and high solar activity, respectively. The irradiance values are normalized to 1 AU, for the purpose of comparison.

We perform a Pearson correlation of the calculated and extrapolated curves. The correlation coefficient is denoted as "r" in the Figures, and it is 0.97 for a period of low solar activity and 0.92 for a period of high solar activity.

The correlation between our method and the extrapolation method is the largest for time ranges of lower solar activity, i.e., when there are less faculae and spots on the Sun. However, the correlation is still large for periods of high solar activity. This pattern extends to the results of Mars-Sun-Earth angles of 180° and 270° as well.

The correlation coefficients at 180° are the smallest among all Mars-Sun-Earth angles analyzed (r = 0.89 for the period of high solar activity). This is expected, since the extrapolation method only averages irradiance at Earth before and after the visible solar disk rotates past the point of interest, and this point is the furthest to

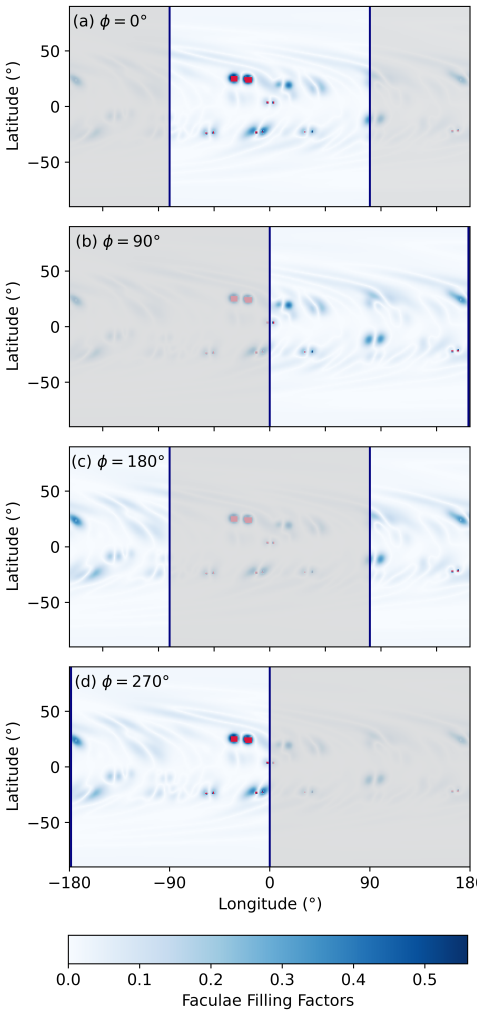

Figure 1: Synthetic maps of the distribution of faculae (blue shades) and spots (red) on the surface of the Sun on December 22nd, 1989. The visible disk (bright area) is centered at the longitude indicated in the top left corner of each panel.

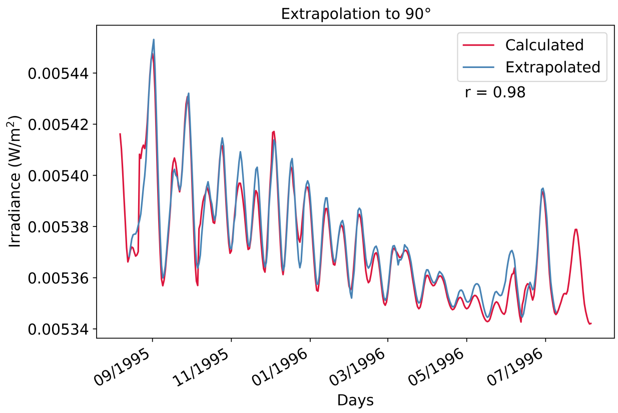

Figure 2: Time series of the S-index, calculated at a Mars-Sun-Earth angle of 90°(red) and extrapolated from Earth position (blue), for a year of low solar activity.

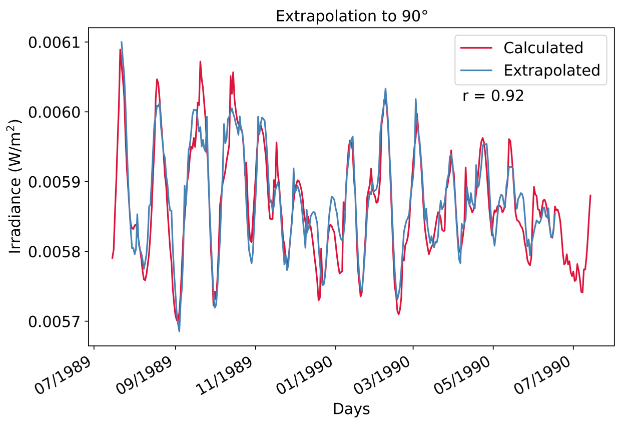

Figure 3: The same as in Figure 2, but for a year of high solar activity.

Earth at an angle of 180°. The accuracy of our method is higher, because it calculates irradiance at the point of interest.

Conclusions

We propose a simple method for estimating irradiance at Mars, based on a statistically correct solar model (SFTM). We calculate the irradiance at 200.5 nm at three Mars-Sun-Earth angles, and compare our results with the extrapolation method, described by Thiemann et al. [2017].

The results of our method correlate well with the extrapolation method. However, our method has greater accuracy, once it is based on the distribution of magnetic features on the whole surface of the Sun, while the extrapolation method only takes into account the the solar disk which is visible from Earth.

As a future work, we will estimate the irradiance at Mars in real-time, making use of methods of far-side imaging of the Sun. Then, our method will not only be statistically correct, but also realistic.

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