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Reconstruction of the solar spectrum for planetary atmosphere studies

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Abstract

In recent years, space environments of planets have become a very important subject of studies. The major dayside input is solar electromagnetic radiation in the UV band. At Earth, most studies rely on proxies, such as the f10.7 index, because direct UV observations are scarce. Equivalent proxies have been built for planets. An important question is: can the UV spectral variability be reconstructed from proxies or from observations with incomplete spectral coverage? In a series of papers, we have shown that this spectral variability can indeed be remarkably well reconstructed from the observation of a few spectral lines. We have studied three different methods explained here. We also show an applications on Ganymede's ionosphere. Finally, we provide recommendations for future planetary missions in terms of solar flux observation and instrumentation.

1. Three different approaches

1.1 Physics based

In this first approach, we determine a mean differential emission measure, mean intensity for several optically thick lines, and a mean intensity for H I and C I continua for quiet areas of the solar atmosphere in order to retrieve the solar spectrum in the EUV range. We use it on a large amount of data from the SOHO/SUMER spectrometer, spread over the ascending phase of the solar cycle 21 to obtain a reference spectrum of the quiet sun [1]. Using the solar extreme ultraviolet (EUV) irradiance data from the Solar EUV Experiment aboard TIMED, we show that one may retrieve the whole solar EUV irradiance from 6 lines only [2].

1.2 Characteristic fluxes

Starting from 1.1, we examine how to reconstruct the solar flux from a linear combination of a given number of characteristic fluxes, each of one corresponding to specific contributions. We consider that these contributions are not imposed a priori but effectively and robustly inferred from spectral irradiance measurements. This is a source separation problem with a positivity constraint, for which we use a Bayesian solution. Using several years of daily EUV spectra recorded by the TIMED/SEE satellite, we show that the spectral irradiance can be decomposed into three elementary spectra [3].

1.2 Statistical approach

We finally use a Principal Component analysis to extract and classify the information contained in the temporal variability of EUV spectra. A basic set of lines is extracted, from which the features of the spectral variability can be reconstructed. This approach confirms the physics based one, i.e. the best results are achieved with a selection of 5 to 8 of these lines. In figure 1, we show that the relative error on the reconstruction minimizes with only 6 lines [4].

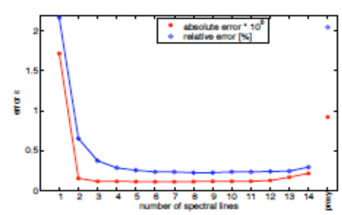

Figure 1: The minimum error (absolute and relative) achieved with the best combination of 1 up to 14 lines. Also shown (on the far right), are the errors obtained by fitting the spectrum using the two best proxies (Mg II index and F10.7 index).

This method is then extended to bands for space observations. Using a multivariate statistical approach, we compare six years of daily-averaged UV spectra and a selection of passbands from existing radiometers and solar indices. This leads to a strategy for defining these passbands that are most appropriate for reconstructing the spectrum. We show that with four passbands, we reconstruct the UV spectrum with a much better relative error than with a combination of indices [5].

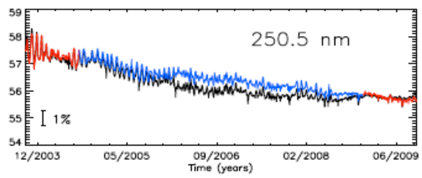

Figure 2: Measured (black) / fitted irradiances at 250.5 nm. The measurement precision is indicated. Red: estimated from the maximum and the minimum of the solar cycle, while the relative error is estimate within the blue interval, which corresponds approximatively to 1600 days.

2. Case-study : Ganymede

As a case study, we use a Beer-Lambert approach to compute the primary production of excited and ionized states due to photoabsorption of the solar flux, neglecting the secondary production due to photoelectrons impacts as well as precipitated electrons. Computations are performed at the equator and close to the pole, in the same conditions than during the Galileo flyby. From the excitations, we compute the radiative relaxation leading to the atmospheric emissions. We show that the input EUV solar flux may be directly measured or reconstructed from only two passbands with no degradation of the modeled response of the Ganymede's atmosphere.

6. Summary and Conclusions

The solar spectral irradiance (especially in the UV band) is a key input for specifying planetary environments [7] and is therefore required for planning planetary missions. This work points out that it is unnecessary monitor the full spectrum. The UV part (27-280 nm) can be reconstructed using only four passbands with a relative error <20%, i.e. about 2 times better thant when reconstructed from solar indices (F10.7, Mg II…). This paves the way for a simple instrumental concept to be used for monitoring the solar UV spectrum in any future planetary space mission.

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