TOWARDS A SPHERICAL CODE FOR THE EVALUATION OF SOLAR UV-BANDS THAT INFLUENCE THE CHEMICAL COMPOSITION IN THE STRATOSPHERE

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ABSTRACT

We present our analysis of data taken by SUSIM onboard UARS. We reconstruct the variability of the UV irradiance and compare it to available data. Up to now we model the solar irradiance according to the 3-component model by Unruh et al. (1999) based on LTE synthetic spectra modeled with Kurucz' ATLAS9 code. Our new approach will be that with COSI (CODE for Solar Irradiance) we model solar continuum and line formation in spherical symmetry and in non-local thermodynamic equilibrium (non-LTE). We present our first synthetic solar spectra (calculated in LTE) and validate them against spectra computed with Kurucz' ATLAS9 code.

Key words: Sun: UV irradiance; Sun: variability; radiative transfer.

1. INTRODUCTION

The total solar irradiance varies by 0.1% within a solar cycle, whereas the UV flux changes by a factor of 2. Furthermore, Rozanov et al. (2002) have shown that Lyα (121.6 nm) and two wavelength bands in the UV, ranging from 200 to 220 nm and from 260 to 280 nm, have strong influence on the temperature and chemical composition in the terrestrial stratosphere. In the view of that we model the variability of the UV irradiance. Our reconstructions will be used as an input for the analysis of the response of the stratospheric chemistry to the UV irradiance variability.

In the paper we proceed as follows. In the next section we present observational UV irradiance data taken by SUSIM onboard UARS. In the third section we briefly describe the 3-component model by Unruh et al. (1999). Then we present our spherical code COSI. In the fifth section we compare our first results with those of Kurucz' ATLAS9 code.

2. DATA

The solar irradiance measured by SUSIM (Solar Ultraviolet Spectral Irradiance Monitor) onboard UARS (Upper Atmosphere Research Satellite) comprises daily, 1 nm gridded irradiances (version 20, level 3BS) for the wavelengths from 115.5 to 410.5 nm for the time span from September 11, 1991 to August 8, 1998. In Fig. 1 the irradiance within 121.0 and 122.0 nm, including Lyα (121.6 nm), versus time is shown. The irradiance changes up to 100% within a solar cycle. We calculated a 28-day running mean of the irradiances for each wavelength and determined the spectral variability as (I_{max} - I_{min})/I_{min}, where I_{max} is the irradiance at solar maximum and I_{min} at solar minimum. In Fig. 2 the 28-day running mean is compared to SOLSTICE (SOLar STellar Irradiance Comparison Experiment) data compiled by Lean (1997). Between 140 and 250 nm both data sets show

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Figure 1. SUSIM data showing the solar irradiance variation of the 1-nm-wide bin at 121.5 nm containing Lyα is plotted versus time. The irradiance at that wavelength range doubles within a solar cycle.

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are in good agreement. Below 140 nm the SUSIM data shows a higher variability than the SOLSTICE data. Above 250 nm we also find a discrepancy between the data sets. Above 300 nm the irradiance variations are limited by the observational noise. For the ratio of the irradiance measured by SUSIM and SOLSTICE see Woods et al. (1996).

We also investigated the correlation of the relative irradiance variability $R = I/I_{\text{max}}$ at different wavelengths in the UV, where $I$ is the irradiance for each point in time, and $I_{\text{max}}$ is the irradiance at solar maximum. Fig. 3 shows the correlation of the relative variability of Lyα with the variabilities at 200.5, 220.5 and 260.5 nm respectively. We applied a linear fit to the data. The high correlation of the variabilities at these wavelengths indicates that the major part of the variabilities is caused by the same bright regions on the solar disc. The reason might well be that changing magnetic features on the solar disc are likely to be responsible for the variability of the solar UV irradiance, which in fact is the basic assumption for the 3-component model by Unruh et al. (1999), applied by us.

3. RECONSTRUCTION OF THE VARIABILITY OF UV IRRADIANCE

As a starting point for the reconstruction of the solar UV irradiance we will use the 3-component model by Unruh et al. (1999). They calculate synthetic solar intensity spectra with Kurucz' plane-parallel ATLAS9 for three model atmospheres, quiet Sun, faculae and sunspots, which leads to $I_q(\nu)$, $I_f(\nu)$ and $I_s(\nu)$ as a function of wavelength and $\mu$-values, where $\mu = \cos \Theta$ and $\Theta$ is the angle between the line from disk center and the line of sight. The time-dependent contribution by faculae and sunspots is represented by the filling factors $a_f(t)$ for faculae and $a_s(t)$ for sunspots. The time-dependent spectral irradiance $I(\nu,t)$ is calculated as

$$I(\nu,t) = I_q(\nu) + a_f(t) \cdot (I_f(\nu) - I_q(\nu)) + a_s(t) \cdot (I_s(\nu) - I_q(\nu)).$$

In Fig. 4 the reconstructed spectral variability of the UV irradiance within a solar cycle is plotted together with our analysis of SUSIM data. For the reconstruc-

![Image](https://via.placeholder.com/150)

Figure 4. Comparison of the modeled variability of the solar irradiance following the procedure by Unruh et al. (1999) to SUSIM observation (28-day mean). Notice the strong deviation of the model from the observation below 200 nm. The disagreement clearly indicates the breakdown of the LTE formation of lines and metal continua below 200 nm. For this figure we assumed $a_f = 0.04$ and $a_s = 0.0023$ for the filling factors of faculae and sunspots respectively.
tion we assume the filling factors at solar minimum $a_r=a_s=0$, and at solar maximum $a_r=0.04$ and $a_s=0.0023$. The model and data are in good agreement for wavelengths above 200 nm. Below 200 nm, however, the discrepancy is significant, mainly, as we assume, due to continuum and line formation in non-LTE, which is not represented in Kurucz’ ATLAS9 model. In particular, this is our motivation to achieve improvement by our non-LTE calculations of the solar spectra.

4. SPECTRAL SYNTHESIS - THE CODE COSI

The code COSI (CODer for Solar Irradiance) is a combination of a spherical atmosphere model to calculate the continuum opacities in non-LTE (Hamann & Schmutz, 1987; Schmutz, 1991; Schaerer & Schmutz, 1994), and the spectrum synthesis program SYNSPEC (Hubeny, 1988; Hubeny & Lites, 1995; Hubeny & Lanz, 2000). COSI accepts an atmosphere structure as input. We adopt the model atmosphere by Unruh et al. (1999) for the quiet Sun, sunspots and faculae. For the calculation of the radiation transfer in spherical symmetry a discrete mesh of impact parameters $p_i$ and formation height $z$ (see Fig. 5, Mihalas 1978) is applied. The impact parameters $p_i$ specify the distances, which provide a new set of populations. The whole iteration process is repeated until convergence.

The bound-free opacities as well as the free-free opacities, and electron scattering are included in the continuum radiation transfer calculation. To calculate a synthetic spectrum the program dynamically selects lines that contribute to the total opacity, based on the physical parameters of the actual model atmosphere. The program then solves the radiative transfer equation for each wavelength within a given wavelength range and for a given wavelength resolution. The opacities are evaluated on a narrowly spaced wavelength grid to ensure that neither line centers nor continuum windows are omitted (Hubeny & Lanz, 2000). The line profiles are calculated by using a depth-dependent temperature and pressure broadening plus a constant turbulence of $1\text{ km s}^{-1}$. As the atomic model of our code is still under development, we presently consider only hydrogen in non-LTE. Neutral hydrogen is represented by 12 levels. Presently, the metals are represented by one single generic atom. In the future, we will include the most important neutral elements, i.e. carbon, aluminum, magnesium, silicon and iron, in the non-LTE level population computation. So far the continuum opacity is given by $H^\infty$.

5. VALIDATION OF COSI AGAINST ATLAS9

To validate our new code we compare the spectra generated with our spherical symmetric code COSI to synthetic spectra generated with Kurucz’ ATLAS9 code. The latter is based on plane-parallel symmetry. It calculates intensity spectra in LTE for different $\mu$-values where $\mu=\cos\Theta=(1-p^2/r^2)^{1/2}$, and $\Theta$ is the angle between the line from the disc center and the line of sight. COSI, on the other hand, is based on spherical symmetry. In Fig. 6 the synthetic solar spectra for the quiet Sun calculated in LTE are plotted. We consider only the wavelength range from 300 to 500 nm, as towards shorter wavelengths metal continuum opacities become important, but are not yet considered in our first results. As the geometry of both codes is exactly the same for $\Theta=0^\circ$, we expect the spectra to be in perfect agreement. In general, the intensity levels agree well. However, neither continuum nor absorption lines match satisfactorily. We are investigating possible reasons for the disagreement, e.g. the disagreement might be due to the fact that we have not yet included all necessary opacity sources. Interestingly, for $\Theta=87^\circ$ the continua are in better agreement than for $\Theta=0^\circ$. Within the plotted spectral range ATLAS9 generally renders weaker absorption lines than COSI.

6. CONCLUSION

We presented our variability analysis of SUSIM data and compare it to SOLSTICE data compiled by Lean.
Figure 6. Comparison of the synthetic spectra for the quiet Sun generated with the plane parallel Kurucz' ATLAS9 code to the spectra generated with our spherical symmetric code COSI. The results of the ATLAS9 code and the COSI code are in good agreement for $\Theta=0^\circ$ (both spectra in the middle). However, we find some discrepancy between the models for $\Theta=90^\circ$ (upper two spectra). Note the emission lines for the spectrum with the impact parameters $p/R_\odot = 1.001$ (lower spectrum).

(1997). The difference between the two UARS instruments is a good indication of the observational uncertainties. For the reconstruction of the UV variability our starting point is the state-of-the-art model by Unruh et al. (1999). As non-LTE effects are important in the calculation of continua and lines in the UV, we intend to improve Unruh’s (1999) model, which is based on plane-parallel symmetry and LTE. With the code COSI we will be able to calculate synthetic solar spectra in spherical symmetry and non-LTE. This is highly important for the reconstruction of the UV irradiance below 200 nm, in particular for Ly$\alpha$, as at these wavelengths line formation departs from local thermodynamic equilibrium (LTE). In a first step we validate our code against Kurucz’ ATLAS9. We compare the results calculated with COSI in LTE to the results from Kurucz’ ATLAS9 code (also LTE). It turns out that the spectra do not match perfectly. Especially for $\Theta=0^\circ$ the codes should render the same results, as in that particular case the geometry of both models is identical. The fact that we have not yet included all opacity sources in the code COSI could explain the discrepancies. However, we do not understand the fact that the modeled continua are in better agreement for $\Theta=87^\circ$ than for $\Theta=0^\circ$. Obviously, further improvement of our code is needed.

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