

# Modeling Electron Density, Temperature Distribution in the Solar Corona based on Solar Surface Magnetic Field Observations

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2015 Sun-Climate Symposium Multi-Decadal Variability in Sun and Earth During the Space Era, Savannah, Georgia.



Ministério da  
Ciência, Tecnologia  
e Inovação



## Introduction

Magnetic fields constitute a natural link between the Sun, the Earth and the Heliosphere in general. The structure of the solar corona is mostly determined by the configuration and evolution of the magnetic field. While open magnetic field lines carry plasma into the heliosphere, closed field lines confine plasma. Additionally, key physical processes that impact the evolution of Earth's atmosphere on timescales from days to millennia, such as the soft X-ray and EUV emission, are also determined by the solar magnetic field. However, observations of the solar spectral irradiance are restricted to the last few solar cycles and they are subject to large uncertainties.

Here we present a physics-based model to reconstruct in near-real time the evolution of the solar EUV emission based on the configuration of the magnetic field imprinted on the solar surface and assuming that the emission lines are optically thin. The structure of the coronal magnetic field is estimated employing a potential field source surface extrapolation based on synoptic charts and solar surface magnetic field from surface flux model. A hydrostatic model describes the coronal plasma temperature and density. The emission is estimated to employ the CHIANTI atomic database. The performance of the model is compared to the emission observed by SDO/EVE (Extreme Ultraviolet Variability Experiment) and solar images from SDO/AIA (Solar Imaging Assembly) at 171 Å. This model was originally presented by Marqué, C. and Kretzschmar, M. (2007), the goal was modeling of electron density and temperature distribution in the corona using EUV and Radio observations.

## Model

In order to modeling electron density and temperature distribution in the solar corona we were using solar surface magnetic field from synoptic charts and surface flux model Schrijver, C. (2001). The surface flux model was updated each six hours. It was considered a diffusion model and the evolution of active regions, in general the transport process at the solar photosphere.

Potential field source surface (PFSS/SSW [9]) was used to extrapolate the line-of-sight surface magnetic field from the photosphere  $r = 1$  Rs up to the corona  $r_s = 2.5$  Rs.

It was determined the length  $L$  for each line, assuming hydrostatic profile, electron density ( $N$ ) and temperature ( $T$ ) fixed for each field line, and defined as:

$$\text{Closed field lines } T = T_0 \times B^\alpha \times L^\beta \quad N = N_0 \times B^\gamma \times L^\delta \quad \text{Open field lines } T = T_0 \quad N = N_0$$

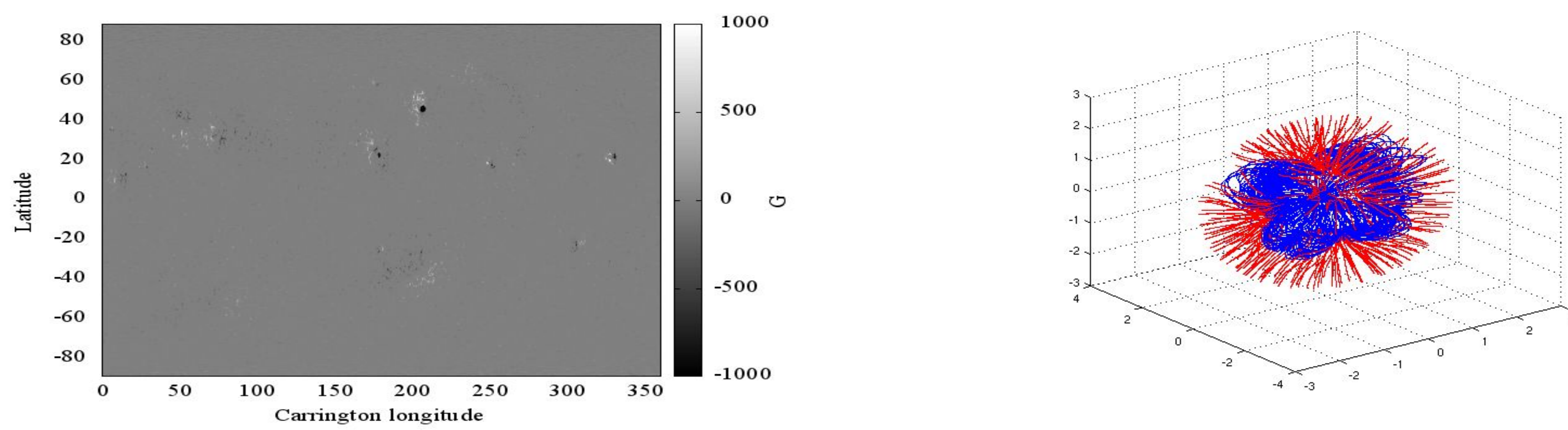


Figure 1. Left panel: SOHO/MDI Synoptic chart for Carrington rotation 2104 from Nov. 26 (2010) to Dec. 24 (2010). Right panel: Open (red lines) and closed (blue lines) field lines from the surface magnetic field.

where  $B$  is the constant magnetic field for each line,  $T_0$  and  $N_0$  are constant values of temperature and electron density.  $\alpha$ ,  $\beta$ ,  $\gamma$  and  $\delta$  correspond to model parameters and they are adjusted using genetic algorithm Pikaia [2].

Assuming that the emission lines are optically thin, it's possible to measure only the integrated emission along a given line of sight. Then, the intensity can be measured by:

$$I = \iint R(\lambda)G(\lambda, T)ne^2 d\lambda ds$$

where  $R(\lambda)$  is the instrumental spectral response,  $G(\lambda, T)$  is the contribution function from The CHIANTI atomic database [8]. The contribution function was used to construct the solar spectra for specific wavelength, abundance, ionization equilibrium and pressure or density.

Integration line of sight was made from 1 Rs to 216 Rs (1UA) in order to reconstruct the spectral solar irradiance (SSI) and solar images using the solar surface magnetic field.

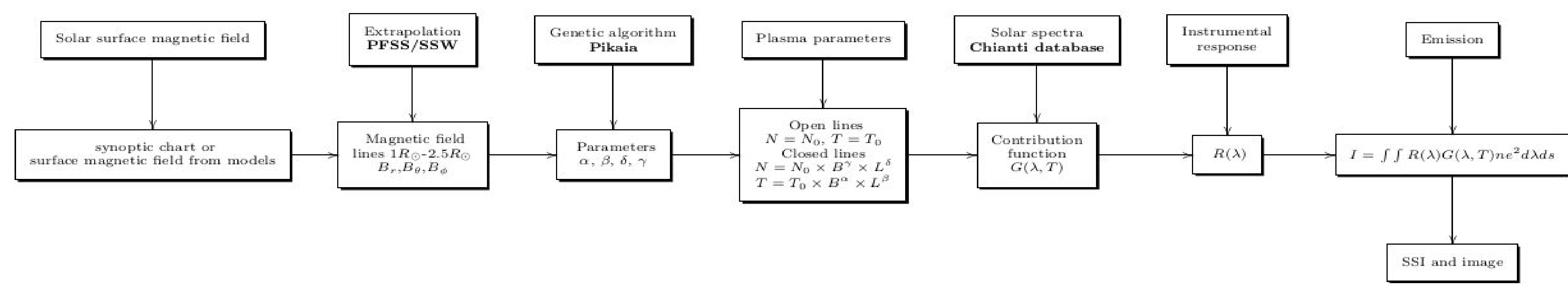


Figure 2. Model schematic description: this model uses as an input data synoptic chart or solar surface magnetic field of the transport flux model, potential field source surface (PFSS/SSW) to extrapolate magnetic field lines, Pikaia algorithm to choose parameters and the CHIANTI atomic database to construct the contribution function (solar reference spectra) and the instrumental response. The goal is to reconstruct solar spectral irradiance (SSI) and solar images.

## Solar Spectral Irradiance (SSI)

Solar spectral irradiance (SSI) describes the spectral integrated radiant energy from the Sun at 1 UA. It is an important forcing for the Earth's climate. Following, we are present the comparison between SSI from EVE/SDO data at 171 Å and SSI from our model using solar surface magnetic field from SOHO/MDI synoptic chart and surface magnetic field from the magnetic flux transport model [6], from Nov. 26 (2010) to Dec. 24 (2010).

Coronal abundances from Meyer (1985) and ionization equilibrium from Mazzotta et al.(1998) were used to compute solar reference spectra. It was considered the central wavelength FeIX line at 171.2634 Å. In this approach it was not considered the instrumental response  $R(\lambda)$ . Two different line densities were considered, 732 and 2932 lines from PFSS/SSW.

The model parameters used were  $\alpha = 0.27$ ,  $\beta = 0.64$ ,  $\gamma = 0.64$  and  $\delta = -0.44$ ,  $T_0 = 1 \times 10^6$  K and  $N_0 = 3 \times 10^8$  cm<sup>-3</sup>. In this approach it was not considered solar limb neither employed the Pikaia algorithm for adjusting the parameters. The physical units were normalized using  $y = (x - \bar{x})/\sigma$ , where  $\bar{x}$  is the mean value and  $\sigma$  is the standard deviation.

### SOHO/MDI synoptic chart

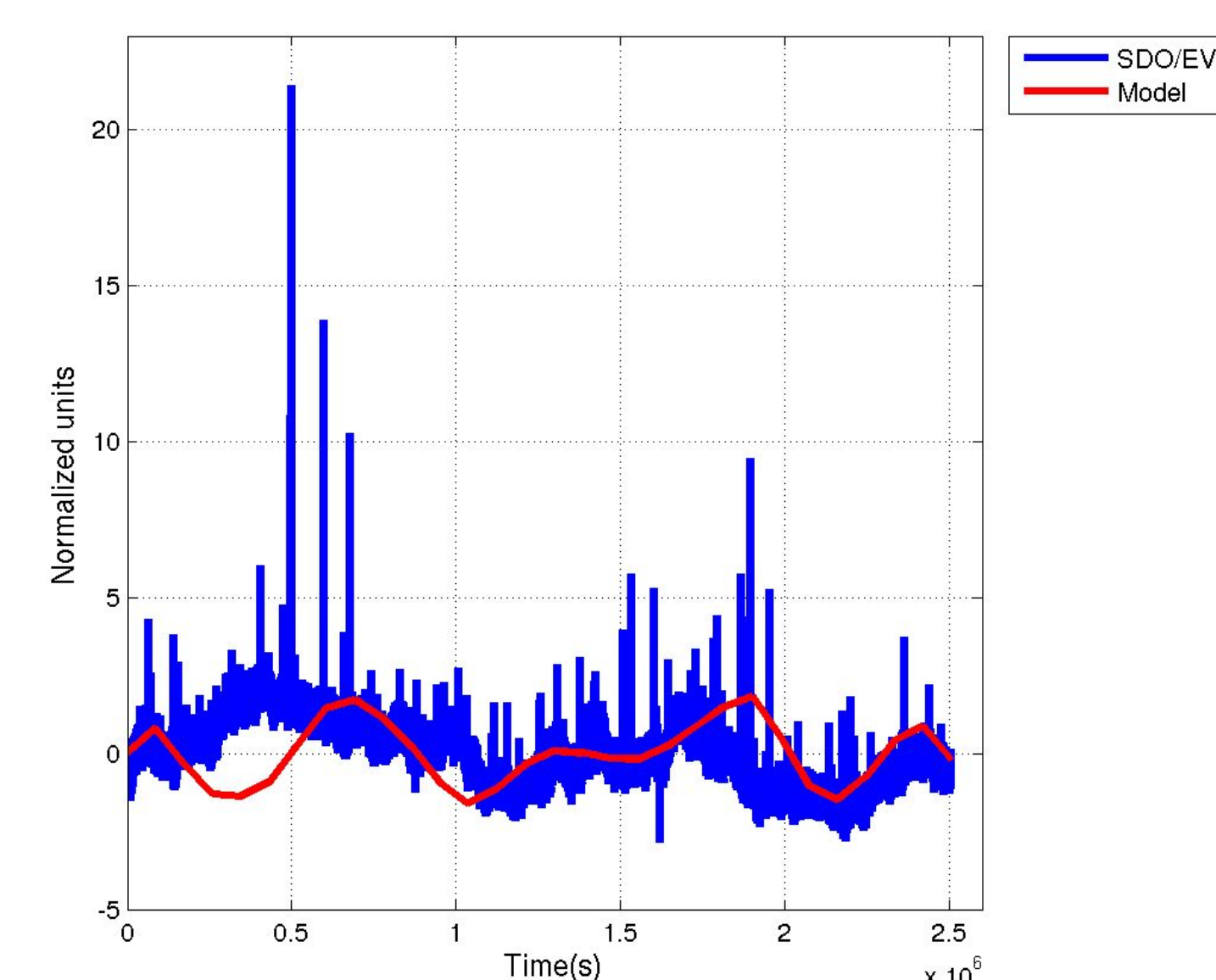


Figure 3. Solar spectral irradiance (SSI) from SDO/EVE at 171 Å, and SSI from our model using SOHO/MDI synoptic chart from Nov. 26 (2010) to Dec. 24 (2010), 732 lines were extrapolated, test  $\chi^2 = 21.9218$ .

### Magnetic flux transport model

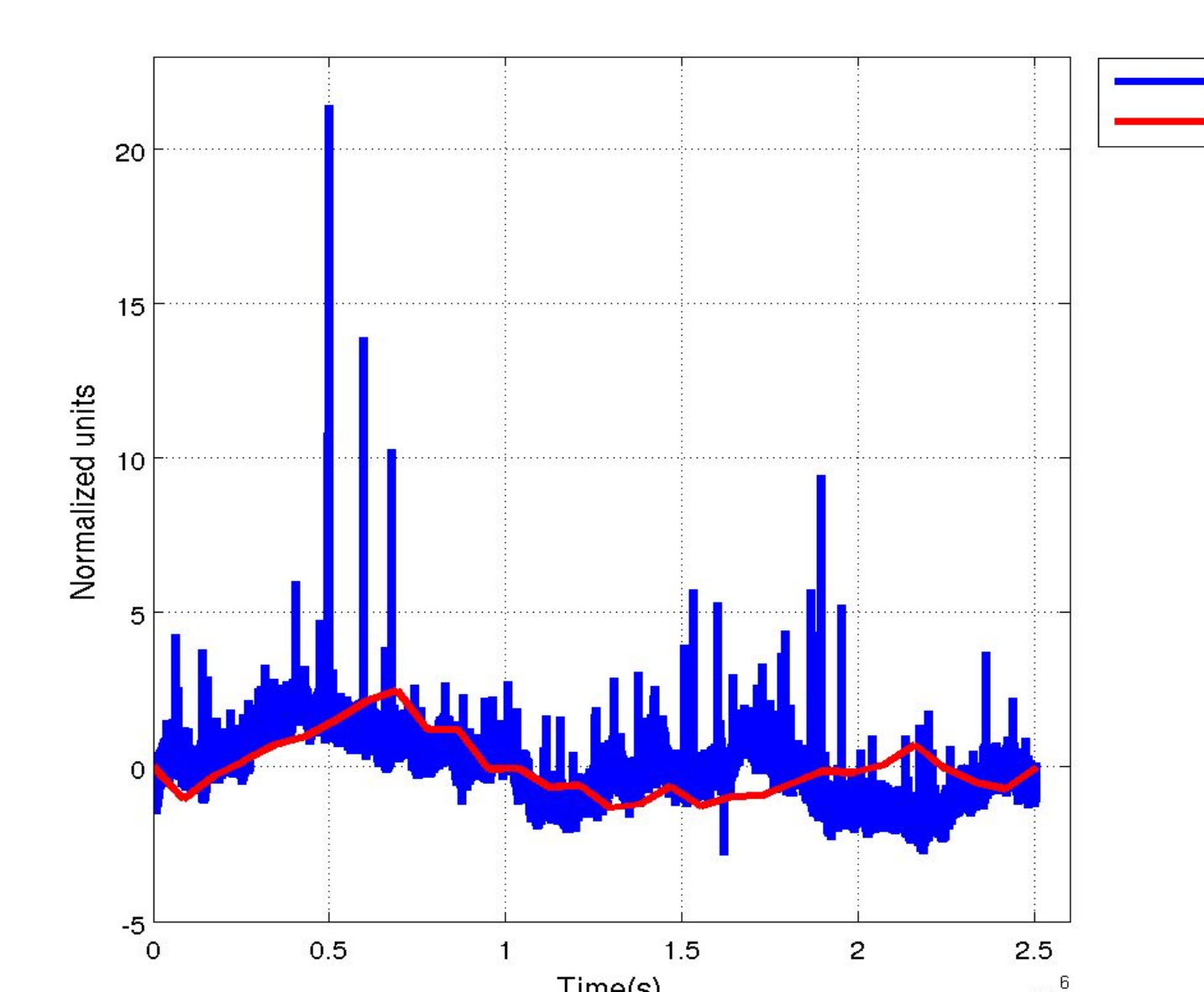


Figure 5. Solar spectral irradiance (SSI) from SDO/EVE at 171 Å, and SSI from our model using magnetic flux transport model [6] from Nov. 26 (2010) to Dec. 24 (2010), 732 lines were extrapolated, test  $\chi^2 = 12.8626$ .

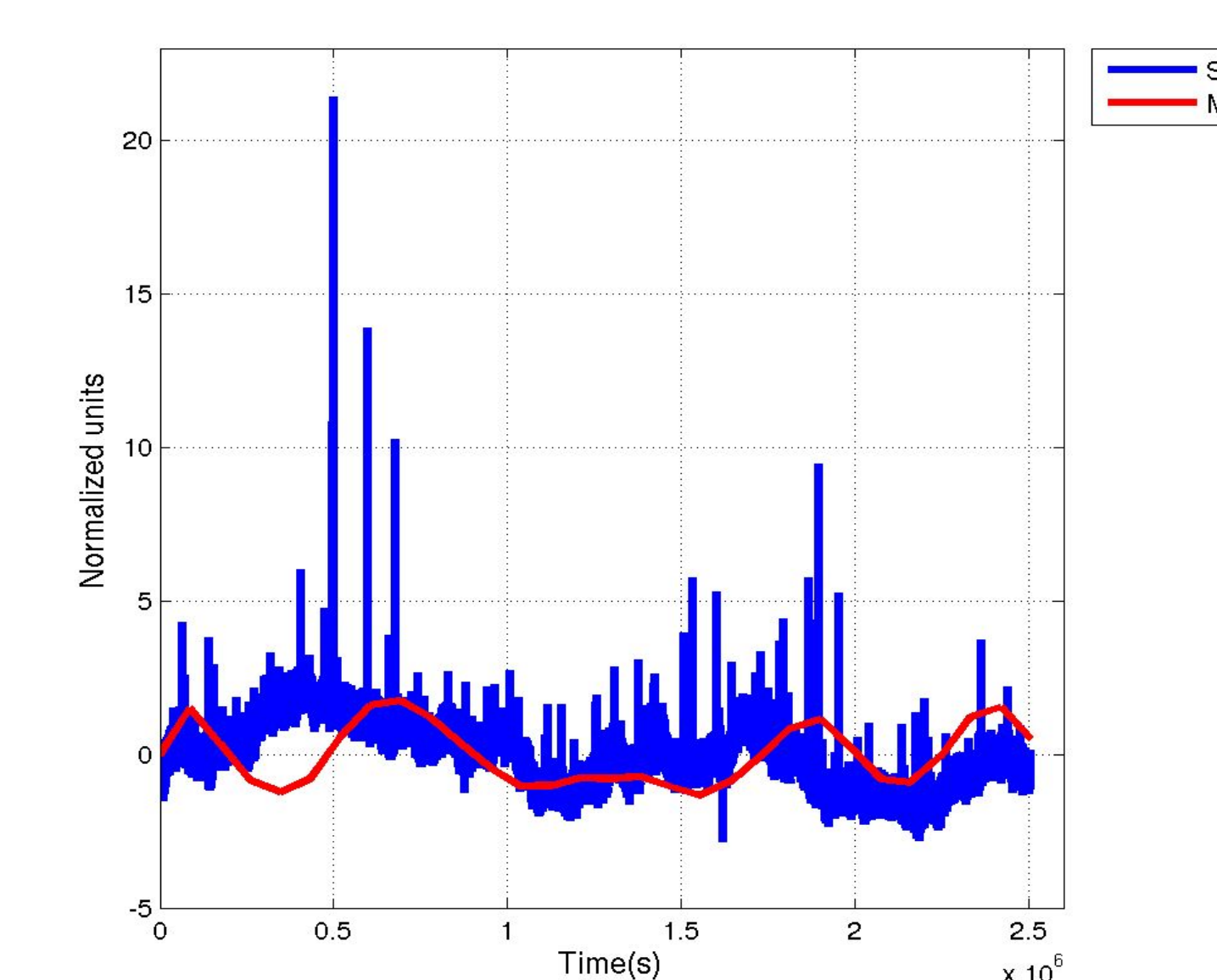


Figure 4. Solar spectral irradiance (SSI) from SDO/EVE at 171 Å, and SSI from our model using SOHO/MDI synoptic chart from Nov. 26 (2010) to Dec. 24 (2010), 2932 lines were extrapolated, test  $\chi^2 = 22.2726$ .

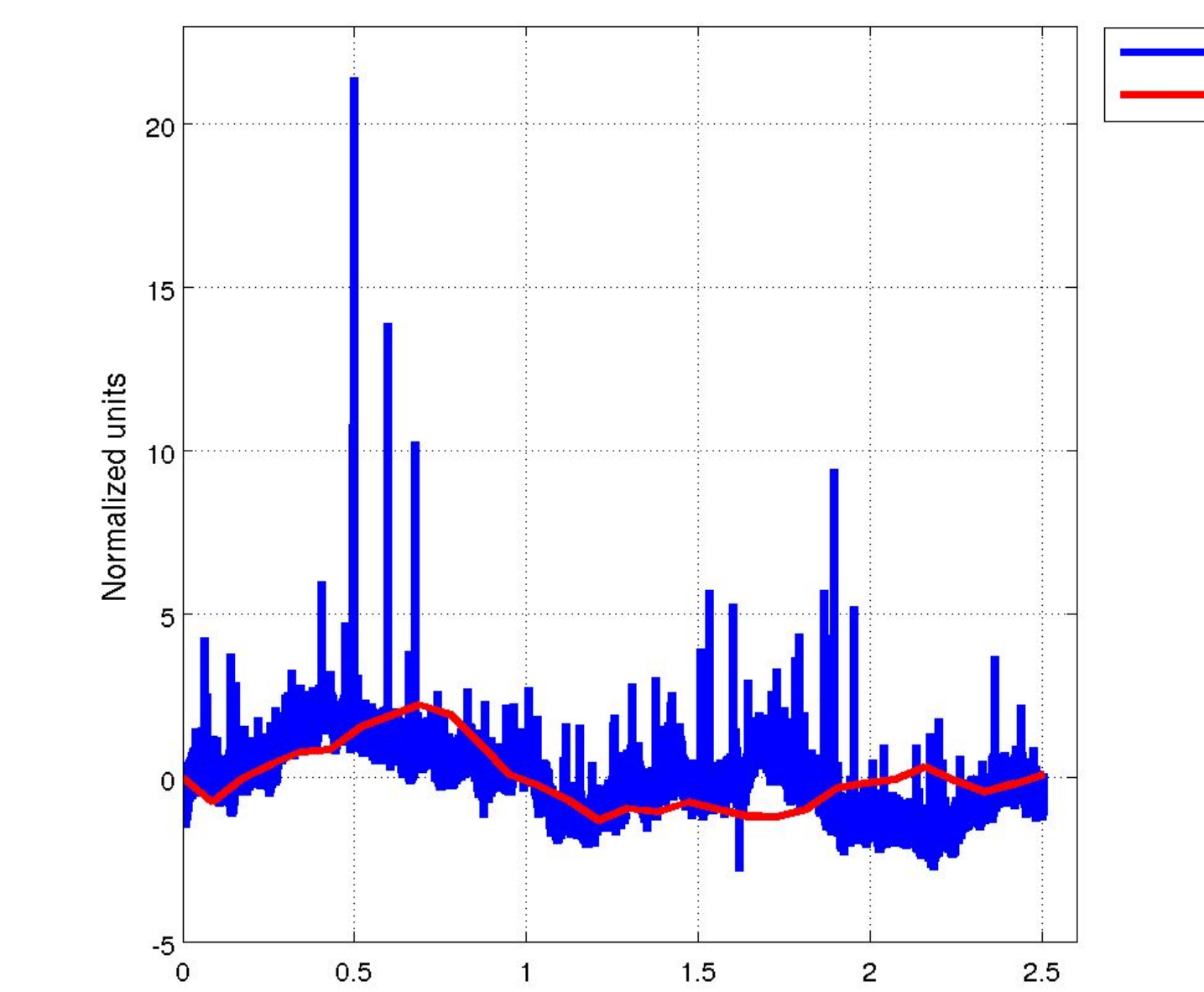


Figure 6. Solar spectral irradiance (SSI) from SDO/EVE at 171 Å, and SSI from our model using magnetic flux transport model [6] from Nov. 26 (2010) to Dec. 24 (2010), 2932 lines were extrapolated, test  $\chi^2 = 12.1343$ .

## Some models of coronal abundances and ionization equilibrium

The SSI were obtained to use ionization equilibrium model Mazzotta et al. (1998) and three different models of coronal abundances, Schmelz et al. (2012), Grevesse and Sauval (1998) and Meyer (1985) to construct the solar reference spectra at the central wavelength FeIX line at 171.2634 Å. The model parameters used were  $\alpha = 0.27$ ,  $\beta = 0.64$ ,  $\gamma = 0.64$  and  $\delta = -0.44$ ,  $T_0 = 1 \times 10^6$  K and  $N_0 = 3 \times 10^8$  cm<sup>-3</sup>, 732 lines were extrapolated from the MDI synoptic chart.

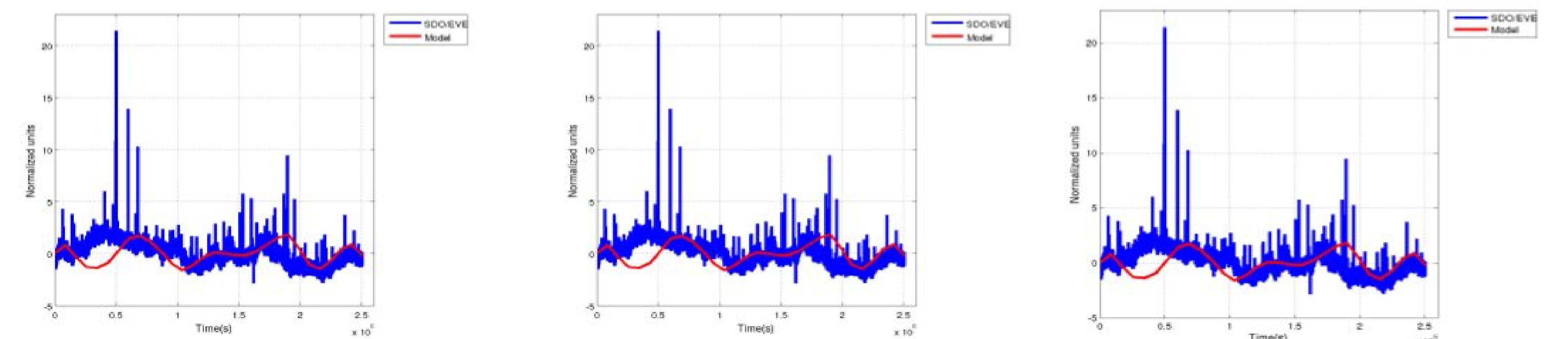


Figure 7. Solar spectral irradiance (SSI) reconstruction with different solar reference spectra. Left panel: Ionization equilibrium model Mazzotta et al. (1998) and coronal abundances Schmelz et al. (2012), test  $\chi^2 = 21.9218$ . Middle panel: Ionization equilibrium model Mazzotta et al. (1998) and coronal abundances Grevesse and Sauval (1998), test  $\chi^2 = 21.9218$ . Right panel: Ionization equilibrium model Mazzotta et al. (1998) and coronal abundances Meyer (1985), test  $\chi^2 = 21.9218$ .

## Image reconstruction

The image reconstruction was obtained from our model using parameters  $\alpha = 0.27$ ,  $\beta = 0.64$ ,  $\gamma = 0.64$  and  $\delta = -0.44$ ,  $T_0 = 1 \times 10^6$  K and  $N_0 = 3 \times 10^8$  cm<sup>-3</sup> in order to reconstruct plasma parameters (density and temperature). Coronal abundances from Meyer (1985) and ionization equilibrium from Mazzotta et al.(1998) were used to compute solar reference spectra. It was considered the central wavelength FeIX line at 171.2634 Å. It was used surface magnetic field from SOHO/MDI and surface flux model, 732 and 2932 lines were extrapolated for Nov. 26 (2010) to Dec. 24 (2010). These images were compared with AIA/SDO images at 171 Å, also temperature and density profiles from our model.

### SOHO/MDI synoptic chart

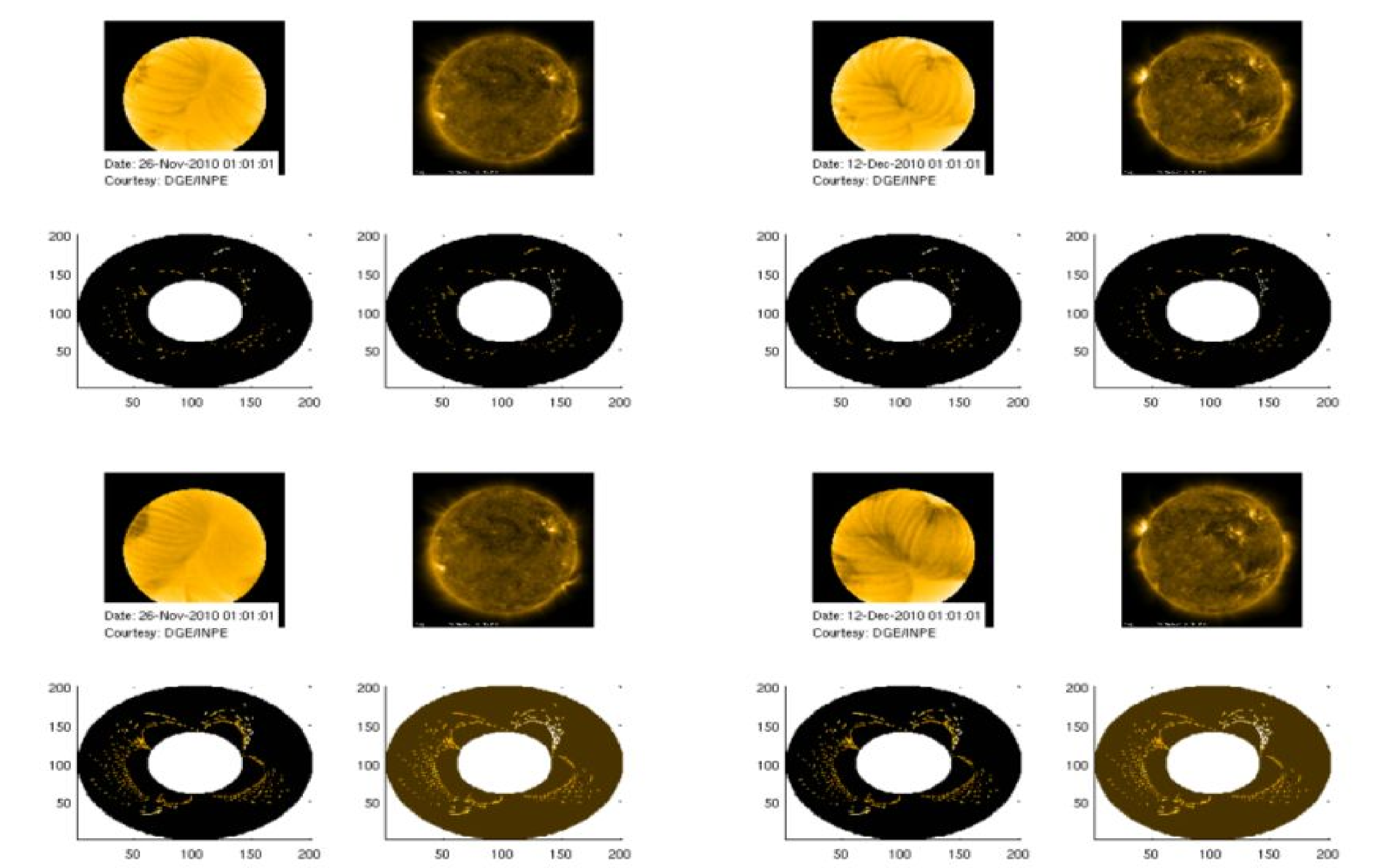


Figure 8. Image reconstruction from our model using SOHO/MDI synoptic chart for Nov. 26 (2010) to Dec. 24 (2010) compared with SDO/AIA 171 Å images, temperature and density profiles. Upper panel: 732 lines were extrapolated. Lower panel: 2932 lines were extrapolated.

### Magnetic flux transport model

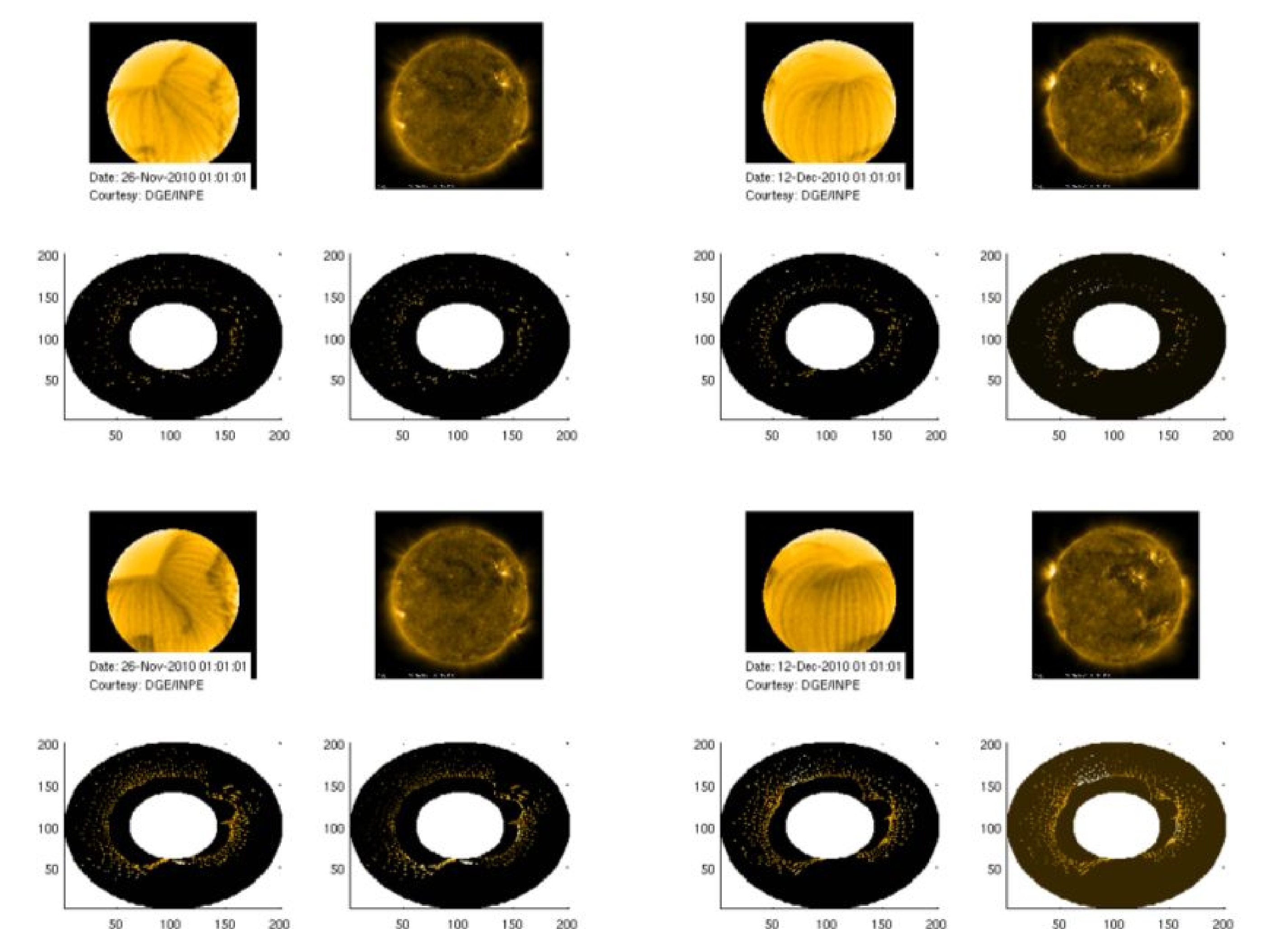


Figure 9. Image reconstruction from our model using surface magnetic field from surface flux model for Nov. 26 (2010) to Dec. 24 (2010) compared with SDO/AIA 171 Å images, temperature and density profiles. Upper panel: 732 lines were extrapolated. Lower panel: 2932 lines were extrapolated.

## Discussion

- It's possible to reproduce the spectral solar irradiance (SSI) and solar images for a given wavelength using this model.
- The solar spectral irradiance from the model shows some differences using SOHO/MDI synoptic charts and in the first days of this period it was not found a correlation. However, using the surface magnetic field from the magnetic flux transport model it was found a good agreement between SSI modeling and observations.
- There exist the important relationship between magnetic field line density and image reconstruction. The best results were obtained using the magnetic flux transport and high line density.
- Solar spectral irradiance (SSI) reconstructions using different solar reference spectrum show the same behavior.

## Next steps

- The parameters of the model will be adjusted using the genetic algorithm pikaia for searching the optimal solution.
- It will be used non constant magnetic field along the magnetic field line and the instrumental response  $R(\lambda)$ .
- It will be used all contributions from wavelength (ie. Fe IX 171.2634 Å, 171.7800 Å, 171.8296 Å, 171.9256 Å)

## References

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## Acknowledgement

This work is partially supported by CNPq/Brazil under the grant agreement no. 140779/2015-9 and no. 304209/2014-7.