Thermodynamics of the Inner Solar Corona: A Tomographic Validation Study of the AWSoM Model

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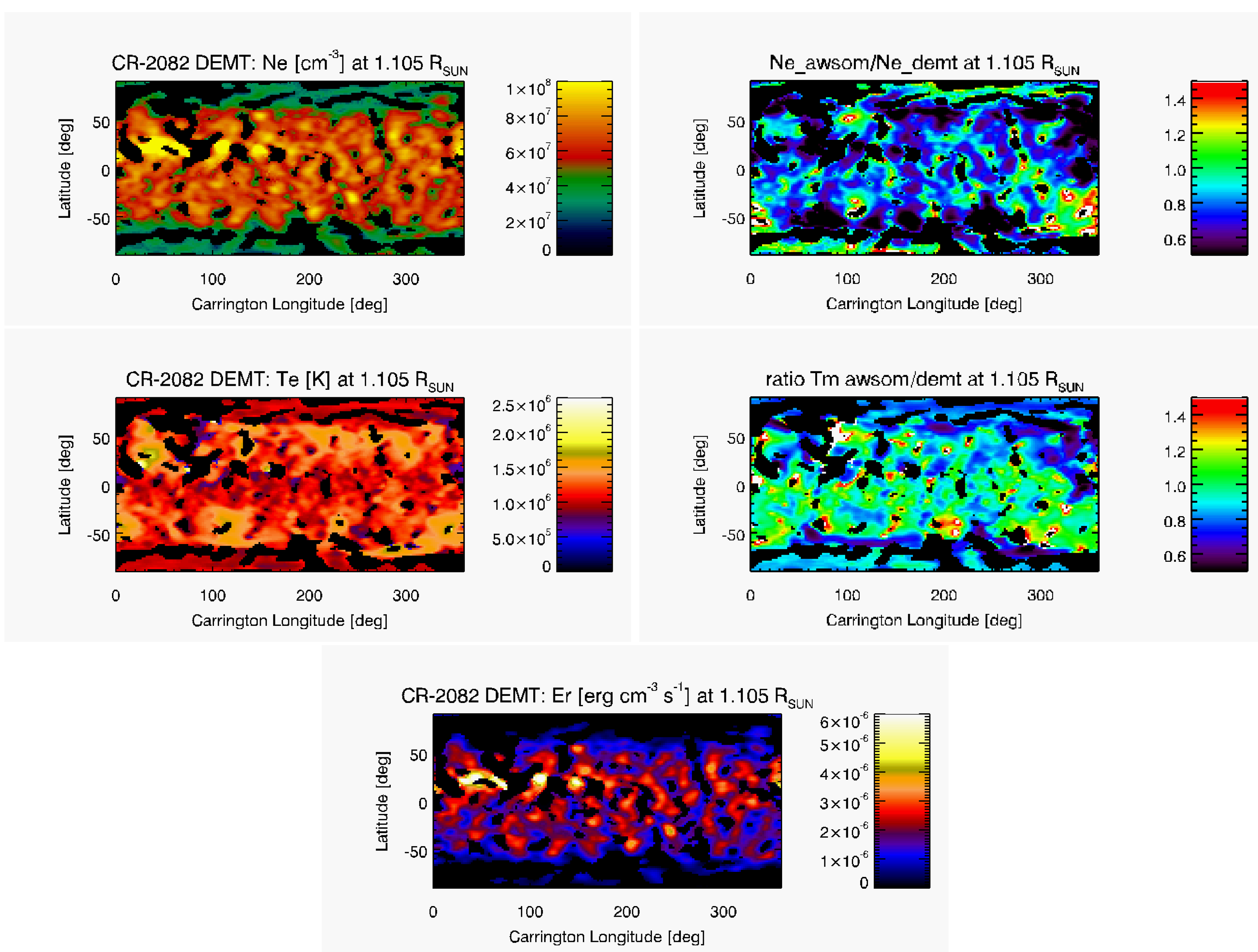
Abstract

To advance the understanding of the physics of the solar corona, magnetohydrodynamic (MHD) three-dimensional (3D) models need to be validated with observations. To that end, differential emission measure tomography (DEMT) provides global 3D maps of the electron density and temperature in the inner corona (1.0-1.25 Rsun). In combination with models of the coronal magnetic field, it allows estimating the energy input flux required at the coronal base to maintain thermodynamically stable coronal structures. Hence, the DEMT analysis can be useful to tune up the model's Alfven wave amplitudes and dissipation rates. Here, a DEMT validation study of the latest version of the Alfvén Wave Solar Model (AWSoM) of the Space Weather Modeling Framework (SWMF) is reported. The analysis is carried out for Carrington rotations selected from the previous solar minimum and the current declining phase of solar cycle 24. The capability of the model to reproduce the tomographic products is discussed, and the need for improvements in the model is evaluated.

DEMT Technique

DEMT technique calculates the Local Differential Emission Measure (LDEM) in each 3D volume element from series of EUV images taken during a solar rotation. By computing LDEM moments, 3D distributions of electronic density and temperature can be obtained. In this work DEMT was applied to EUV (Extreme Ultraviolet) images taken by the Extreme Ultraviolet Imager (EUVI) instrument on board the STEREO-B spacecraft during Carrington Rotation (CR)-2082 and by Atmospheric Imaging Assembly (AIA) instrument on board SDO during CR-2208.

CR2082



Carrington maps of the electronic density at $1.035\,\mathrm{R}_\odot$ (left panels) and $1.105\,\mathrm{R}_\odot$ (right panels) obtained with the DEMT technique (top) and AWSoM model (bottom). Black curves denote the magnetically open/closed boundary of the AWSoM model.

Global Comparison as a Function of Height

For each physical quantity X, we measure its relative difference between the AWSoM and DEMT results at each coronal computational cell i as: $Q_i \equiv 2\,\frac{|X_{\mathrm{AWSoM}}-X_{\mathrm{DEMT}}|}{(X_{\mathrm{AWSoM}}+X_{\mathrm{DEMT}})}$.

Median value of $\mathrm{Q_i}$ at every height for $\mathrm{N_e}$ and $\mathrm{T_e}$ within the Streamer and each polar Coronal Hole.

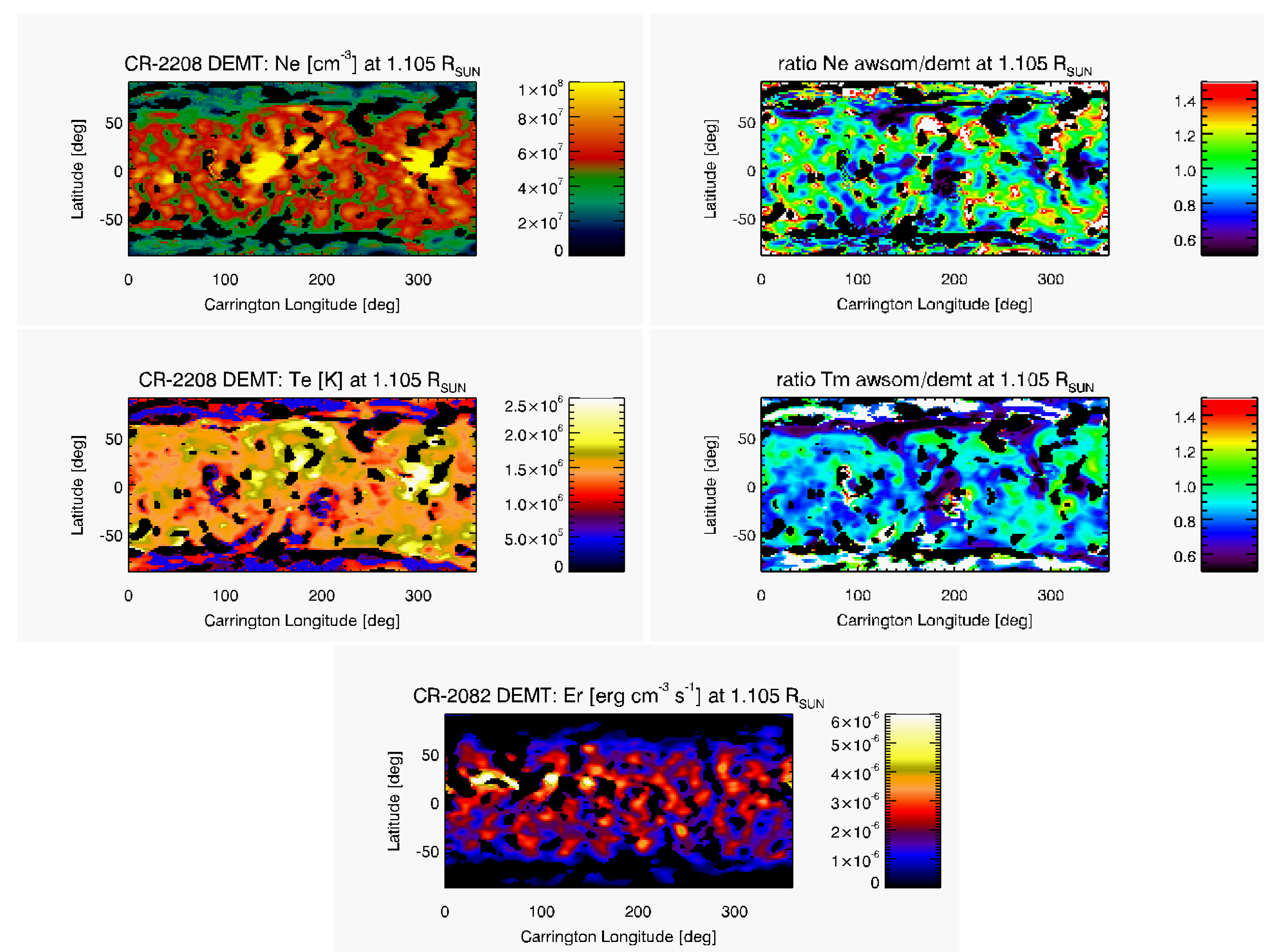
Statistical Comparison

Frequency histograms of $\mathrm{N_{ebasal}}$ and $\langle\mathrm{T_e}\rangle$ (above $1.05\,\mathrm{R}_\odot$) for the Streamer and the polar Coronal Holes.

Alfvén Wave Solar Model (AWSoM)

AWSoM is a global 3D MHD model of the solar chromosphere and corona driven by magnetogram data (van Der Holst et al., 2014). At the coronal base, Alfvén waves are reflected and generate a turbulent cascade. The dissipation of this cascade contributes to the coronal heating. Taking into account the turbulence generated by low frequency Alfvén waves, the model solves MHD equations and obtains 3D distributions of electronic density and temperature, together with many other physical quantities. In this work we perform a steady-state simulation of CR-2082 and CR-2208 using synoptic magnetograms from the Michelson Doppler Imager (MDI) instrument on board the SoHO spacecraft.

3D Reconstruction of $\mathrm{T_e}$



Average Fits to $\mathrm{N_e}$ and $\mathrm{T_e}$ along loops

The DEMT and AWSoM results are then traced along each magnetic field line obtained with AWSoM model allowing a detailed thermodynamic comparison along the magnetic field. Using a hydrostatic fit for density and a linear fit for the temperature, the coronal basal density $\mathrm{N_{ebasal}}$ (density at $1.025\,\mathrm{R}_\odot$) and the mean electronic temperature $\langle\mathrm{T_e}\rangle$ are determined for each field line.

DEMT fits in solid blue lines. The dashed blue lines indicate the uncertainty (Lloveras et al. 2017). In red lines AWSoM fits below $1.05\,\mathrm{R}_\odot$ and above $1.05\,\mathrm{R}_\odot$.

Conclusions

- Below $r \sim 1.05\mathrm{R_{SUN}}$, the electron temperatures of AWSoM are a factor ~ 2 smaller than those observed with DEMT, while the electron densities are a factor $\sim 2-5$ larger.
- Above $\sim 1.05\mathrm{R_{SUN}}$ (in both Streamers and CHs): T_e agreement within $\sim 15\%$, which is the uncertainty level of DEMT due to systematic sources. N_e agreement within a factor of 2 (with AWSoM under-estimating in Streamers, and over-estimating in CHs), well beyond uncertainty.
- The structure of the streamer is dominated by down loops which are not modeled by AWSoM.
- The lack of agreement in density, as well as the evident change of behavior of the AWSoM results below/above 1.05 R_{SUN}, are related to its treatment of the Chromosphere/Corona transition. The model is currently being udated to improve its performance. Future efforts will involve DEMT validation of its updated results.