Dynamic Three-Dimensional Tomography of the Solar Corona

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Abstract Empirical, three-dimensional electron-density maps of the solar corona can be tomographically reconstructed using polarized-brightness images measured from ground- and space-based observatories. Current methods for computing these reconstructions require the assumption that the structure of the corona is unchanging with time. We present the first global reconstructions that do away with this static assumption and, as a result, allow for a more accurate empirical determination of the dynamic solar corona. We compare the new dynamic reconstructions of the coronal density during February 2008 to a sequence of static reconstructions. We find that the new dynamic reconstructions are less prone to certain computational artifacts that may plague the static reconstructions. In addition, these benefits come without a significant increase in computational cost.

Keywords Corona · Tomography · Statistical image processing

1. Introduction

The dynamic physical processes that heat the corona and drive the solar wind are not completely understood (Aschwanden, 2004). Empirical estimates of plasma parameters, such
as temperature and electron density, can provide insight into these processes (Cohen et al., 2007; Vásquez et al., 2008). Solar tomography (Davila, 1994; Frazin and Kamalabadi, 2005) has been used to reconstruct the global three-dimensional (3D) structure of the corona based on observations. In this paper, the electron density is reconstructed in a dynamic estimation framework that moves away from the static assumption made in prior work (Butala et al., 2008). These improved estimates will provide a more complete view of the dynamic electron-density distribution, which will, in turn, contribute to a better physical picture of the corona.

For electron-density reconstruction, the inputs to solar tomography are images of polarized brightness (pB), which are routinely measured by coronagraphs. Each pixel of each pB image is proportional to the electron density integrated along the pixel’s line-of-sight through the optically thin corona. A tomographic reconstruction of the electron density combines pB images from multiple points of view, ideally spanning 180° about the Sun, to resolve the depth ambiguity resulting from the line-of-sight integration. Distinct points of view are provided by solar rotation (the Sun has a synodic rotation period of 27.3 days) and spatially separated sensors, such as those provided by the Solar and Terrestrial Relations Observatory (STEREO: Kaiser et al., 2007).

The coronal electron density was first empirically determined by van de Hulst (1950) under the assumption of azimuthal symmetry and a power-law parametrization. With subsequent advancements in computational resources, such simplifying assumptions are no longer necessary and 3D estimates of the coronal electron density are now routinely computed; see e.g. Butala, Frazin, and Kamalabadi (2005) or Kramar et al. (2009) for examples of such 3D reconstructions and Frazin and Kamalabadi (2005) for a recent review of solar tomography including references to contemporary work. However, existing methods for recovering the global 3D coronal electron density assume that the structure of the corona is static over the measurement interval and significant changes in the corona can result in reconstruction artifacts (Butala, Frazin, and Kamalabadi, 2005; Frazin and Kamalabadi, 2005). Prior to STEREO, a full 180° view of the corona required nearly 14 days of observation. Three simultaneous viewpoints (from the Earth and the two STEREO satellites, each separated by 60° from the Earth) can reduce the measurement interval to less than five days, although the corona can change significantly at even shorter time scales.

In this paper, we show the first time-dependent 3D estimates, i.e. 4D estimates, of the electron density based on our recently developed dynamic tomography framework (Butala et al., 2008, 2009). Time-dependent tomography of solar-wind parameters was explored by Dunn et al. (2005). Four-dimensional reconstruction of solar plumes has been considered in Barbey et al. (2008), but this work differs in that we reconstruct the global 4D electron density structure of the global corona. The electron-density reconstructions are based on individual STEREO coronagraph measurements, and, to our knowledge, Kramar et al. (2009) present the only other solar tomography work that uses such data. The dynamic estimates are compared to a sequence of static electron-density reconstructions based on a sliding measurement time window. The results demonstrate that the dynamic electron-density estimates have a smaller residual and fewer reconstruction artifacts when compared to the static estimates. Additionally, we find that the dynamic reconstruction algorithm is less computationally demanding than creating a sequence of windowed static electron-density estimates.

The remainder of the paper is organized as follows: first, the time period of interest, instrumental details, and data prepossessing procedures are given in Section 2. Then the static and dynamic tomographic reconstruction methods are described in Section 3. Next, Section 4 presents the static and dynamic electron-density reconstructions to demonstrate...