Time-dependent tomographic hydrogen density estimation and its role in the ring current decay after storm-time

Gonzalo Cucho-Padin, Lara Waldrop

University of Illinois at Urbana Champaign, Urbana, IL e-mail: gac3@illinois.edu

**Introduction**

- Ring current (RC) decay following a magnetic storm is driven by charge exchange collisions with cold exospheric neutral hydrogen (H) atoms, forming energetic neutral atoms (ENAs) which can escape the Earth system. Knowledge of the global, 3D distribution of exospheric H is required for accurate interpretation of ENA flux measurements and RC modeling.
- Hydrogen atoms (H) in Earth's upper exosphere resonate with solar Lyman-alpha (121.6 nm) radiation, creating the ultraviolet optical signature known as the H gecosonar.
- In the optically thin region, located beyond ~3R_E, the density number of H atoms is relatively low, but such scattering events can be assumed to occur exactly once.
- The relationship between optically thin emission radiance (I) and the exospheric H density (n_H) along the line of sight is given by:
  \[ I(\mathbf{r}, t) = \frac{q^2}{16\pi} \int_{0}^{\Delta t} n_H(\mathbf{r}, t') \lambda d\mathbf{n} + I_P(\mathbf{r}, t) \]
  
  Previous methods that estimate the 3D hydrogen density distributions have been based on parametric fitting of assumed functional forms involving spherical harmonics expansions.
- The linearity of previous equation allows for non-parametric formulation of H estimation as a tomographic inverse problem that can be solved through regularization techniques. This approach was evaluated with synthetic and real data in our previous work [3].
- Here, we use this approach to investigate the 3D, time-dependent structure of the outer exosphere during a geomagnetic storm that occurred on 15 June 2008, essentially in the ring current region [3-6] R_E.

**Methodology: Tomographic approach**

- Setting up the geometry
  1. Discretize region into J spherical voxels.
  2. Project unknown density function onto J orthonormal basis functions.
- Rewrite measurement of intensity and cast measurement ensemble as a matrix equation.
  \[ y = LX \]
  
- Inverse problem and regularization
  Since the observation matrix L is not full rank, a regularization technique must be used to solve the system. We have selected the technique known as Robust, regularized, positive estimation (RRPE), defined as follows:
  \[ x = \arg \min \Phi(x) \]
  \[ \Phi(x) = ||Lx - y||^2 + \lambda R P E(x) \]
  \[ \lambda R P E(x) = \lambda_1 ||x||_2 + \lambda_2 ||x||_1 + \lambda_3 ||x||_2 \]

**Previous results and main objective**

- Our previous work [3] demonstrated the feasibility of the technique for exospheric atomic hydrogen estimation based on optically thin emission data from TWINS.
- We propose to analyze a storm-time event through the generation of 4-hours averaged tomographic reconstructions and focus on the hydrogen structure in the RC region.

**Data**

- TWINS mission: Comprised of two (2) satellites which enable stereoscopic sensing of the magnetosphere. Each satellite has two (2) Lyman-alpha detectors (LADs) that acquired Ly-alpha (121.6 nm) scattered emission from neutral hydrogen. The data used in this study is from June 14, 15 and 16 of 2013 where a ~39 nT geomagnetic storm occurred.

**References**


**Acknowledgment**

This work was supported by NASA HgIP (NNX16AF77G).

---

**Time-dependent tomographic hydrogen density estimation**

**Legend**

- Direction to the Sun
- 4-hour averaged reconstruction
- Density (H atoms/cm^3)

**Conclusions**

- The 4-hour averaged tomographic reconstruction during June 15, 2008, show for the first time the exospheric hydrogen structure during the development of a geomagnetic storm.
- This study reveals a significant H density increment in the 3R_E region in response to the geomagnetic storm which could be related to transport processes in the lower atmospheric regions.
- Line-of-sight (LOS) coverage has a critical role in the tomographic reconstructions. Confidence in the estimated H densities is increased when a high number of LOS pass through a given voxel. Therefore, stereoscopic measurements (data acquired with both TWINS 1 and 2 during the same period of time) lead to the reduction of the uncertainty of the estimated H densities. However, these stereoscopic events are infrequent.
- Future work will focus on the analysis of several geomagnetic storms in order to identify a more stable relationship between geomagnetic indicators such as DST, AP, KP and the estimated H density.