

Geocoronal Hydrogen Density Estimates Using Solar Absorption in the Exosphere

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Introduction

The geocorona is a hydrogen (H) cloud around Earth that extends from about 500 km to >10,000 km in the exosphere and resonantly scatters solar irradiance at 121.6 nm (Lyman- α). The extent and density distribution of the geocorona varies with space weather and is important for observing short term variability of the terrestrial upper atmosphere. However, the dynamics of the H density in this region are currently not well-understood. Therefore, the purpose of this study is to use extreme ultraviolet (EUV) measurements of solar irradiance from GOES satellites to derive daily H density distributions of the terrestrial atmosphere using a new absorption technique.

Figure 1 shows the GOES orbit relative to the Sun and its corresponding Lyman- α measurements. When the GOES satellite is on the anti-solar side of the Earth, the Lyman- α irradiance exhibits a multi-hour decrease due to absorption by geocoronal hydrogen.

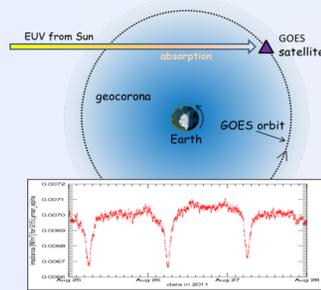


Figure 1

Methods

1. SATELLITE LOCATION

- An IDL program was created to read in satellite location data (in geocentric solar ecliptic coordinates) for a specified year.
- Two different data sets of spacecraft locations were compared.

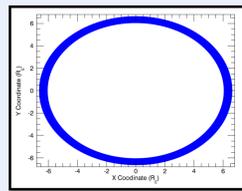


Figure 2

2. EUV ABSORPTION

- The 1-minute GOES EUV irradiance was read in from the NGDC website. (Fig 3)
- A baseline value was created for the daytime irradiance. (Fig 4)
- Night-time absorption dips were created by subtracting to the baseline in order to eliminate solar variability. (Fig 5)

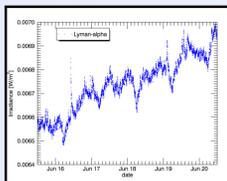


Figure 3

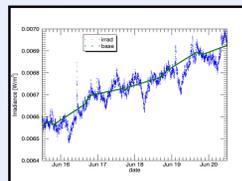


Figure 4

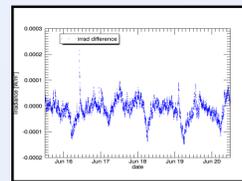


Figure 5

3. HYDROGEN DENSITY FIT

The absorption technique estimates a H density profile in the equatorial plane based on the dip in the Lyman- α irradiance [W/m²] measured by the GOES satellite as it traverses the anti-solar side of Earth. The total scattering loss along the line of sight through the atmosphere is:

$$F \downarrow \text{scattering} [\text{photons/cm}^2 \text{ s}] = g \int_0^L \int_{-\infty}^{\infty} n(L) I(\alpha) dL + F \uparrow P$$

(Bailey, 2012)
Following Bailey, a simple spherical power law for the H distribution, $n(r) = ar^b$, was assumed. The data was then fitted to determine constants a and b with the Levenberg-Marquardt non-linear least squares algorithm.

Part A – Integral Method:

Three integral fits were tested for $b = -1, -2, \text{ and } -3$. The integral solutions are:

- $\int \frac{1}{r} dx = \ln|x+r|$
- $\int \frac{1}{r^2} dx = -1/y$
- $\int \frac{1}{r^3} dx = x/y^2 r$

The regimes considered were:

- Any radius
- Radius $< 3 R_E$
- Radius $> 3 R_E$

Part B – Differential Method:

Total absorption is given by:

$$F = c \int \int n(r) dx$$

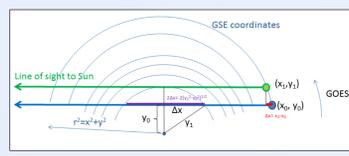


Figure 6

$$\Delta F = F[1] - F[0]$$

$$\Delta F = n(y \downarrow \text{GOES}) \cdot \Delta x \downarrow \text{center} - n(r \downarrow \text{GOES}) \cdot \Delta x \downarrow \text{edge}$$

Results

1. SATELLITE LOCATION COMPARISON

After comparing NASA's satellite locator data to Rob Redmon's location propagator data, the total xyz-coordinate discrepancy came to approximately 45 km with a noise of $\sim \pm 1$ km. Three large error spikes occurred on August 2-6, October 17-19, and December 13-15 (Fig 7).

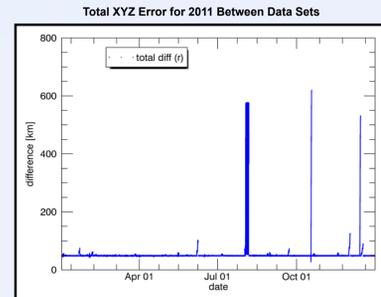


Figure 7

2. EUV ABSORPTION

Figure 7 shows the Lyman- α irradiance for the year 2011. The absorption dip, which was extracted by using the methods described in Figures 4, 5, and 6, can be seen clearly at local time = 0 (midnight). Seasonal variability is observed.

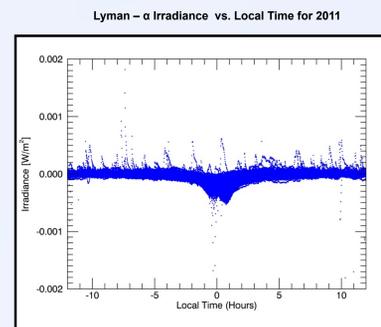


Figure 8

3A. HYDROGEN DENSITY FIT: INTEGRAL METHOD:

Figure 9 shows the integral fit for $n(r) \sim r^{-2}$ within a regime of $> 3 R_E$ for the entire year of 2011. Although this was the best fit among the three integer values that were tested, this method does not provide a good fit.

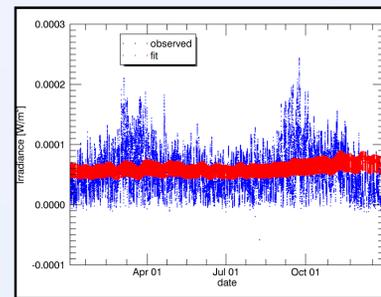


Figure 9

Figure 10 also shows the integral fit for $n(r) \sim r^{-2}$ within a regime of $> 3 R_E$ but for a time period of 8 days. The integral fit can be seen to cover only a portion of the EUV absorption dips.

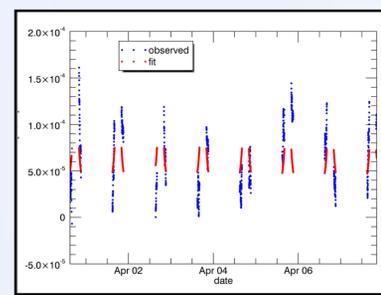


Figure 10

3B. HYDROGEN DENSITY FIT: DIFFERENTIAL METHOD:

Because the integral method did not provide a reasonable fit, a differential method was tested. Results showed that the exponents were fairly consistent for the years of 2011 and 2012, and the calculated density agreed with expected values of about -3 for $\geq 3 R_E$. (Fig 11)

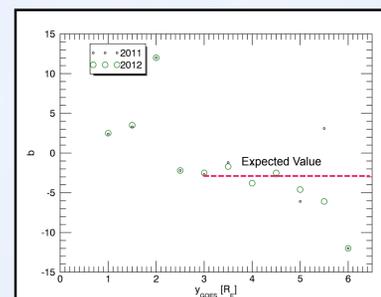


Figure 11

Conclusions

1. SATELLITE LOCATION COMPARISON

The two location data sets are very similar and have an overall discrepancy of ~ 45 km and a noise of $\sim \pm 1$ km. Three large error spikes occurred throughout the year, with the z-coordinates contributing the most to those error spikes. Overall, Rob Redmon's data is an accurate comparison to NASA's satellite location data and can be used to provide real time satellite position data for space weather purposes.

2. EUV ABSORPTION

The absorption dips from the GOES EUV irradiance data were able to be properly extracted from an interpolated baseline value. Absorption dips showed the most variability for an equinox period and the least variability for a solstice period,

3A. HYDROGEN DENSITY FIT: INTEGRAL METHOD:

Preliminary results for the integral method gives the best fit for $n(r) \sim r^{-2}$ for a regime of $> 3 R_E$, but still does not provide a good fit.

3B. HYDROGEN DENSITY FIT: DIFFERENTIAL METHOD:

Preliminary results for the differential method were somewhat consistent for the years of 2011 and 2012, and the calculated density is reasonably accurate for $\geq 3 R_E$.

To conclude, the results that were obtained from this study are encouraging, but there are still many refinements that can be made.

Future Work

Possible next steps include:

- Determine source of phase shift between satellite location data.
- Test b from second fit by numerical integration of $n(r) = ar^b$
- Try other improvements on integral fit, such as better smoothing.
- Estimate how close to the Earth can we get good estimates.
- Include measurements from other satellites.
- Try to fit data with a 2D model.

References

- Bailey, J., and M. Gruntman (2011), Experimental study of exospheric hydrogen atom distributions by Lyman-alpha detectors on the TWINS mission, *J. Geophys. Res.*, 116, A09302, doi:10.1029/2011JA016531.
- Bailey, J. J. (2012). *Three-dimensional exospheric hydrogen atom distributions obtained from observations of the geocorona in lyman alpha.* (Doctoral dissertation).