Global-scale Observations of the Limb and Disk (GOLD): Overview of Daytime Exospheric Temperature Science Data Product

Victoir Veibell[1], J. Scott Evans[1], Jerry. D. Lumpe[1], John Correira[1], Jay Cummings[1], Richard Eastes[2], Alan Geoffrey Burns[3], Mihail Codrescu[4], Andrey Krywonos[5], Bill McClintock[2], Stanley C. Solomon[3], and the GOLD Science Team

[1]Computational Physics, Inc., [2]University of Colorado, LASP, [3]National Center for Atmospheric Research, [4]NOAA/Space Weather Prediction Center, [5]University of Central Florida, Florida Space Institute

Overview

On January 25, 2018 the Global-scale Observations of Limb and Disk (GOLD) mission launched an imaging spectrograph onboard the commercial SES-14 satellite. From geostationary orbit, GOLD images the Earth in the far-ultraviolet from 132 to 162 nm using two independent optical channels, allowing for simultaneous measurement sequences with different temporal cadences and spectral resolution. GOLD continuously scans the disk of the Earth while also performing routine limb scan and stellar occultation measurements. GOLD science algorithms are used to produce operational data products, including daytime exospheric neutral temperature on the limb. In this presentation we provide an overview of the theoretical basis for the GOLD Level 2 exospheric temperature science algorithm and demonstrate the effects of generalizing the standard Chapman profile approximation to allow for gravity and temperature gradients.

Science Objectives

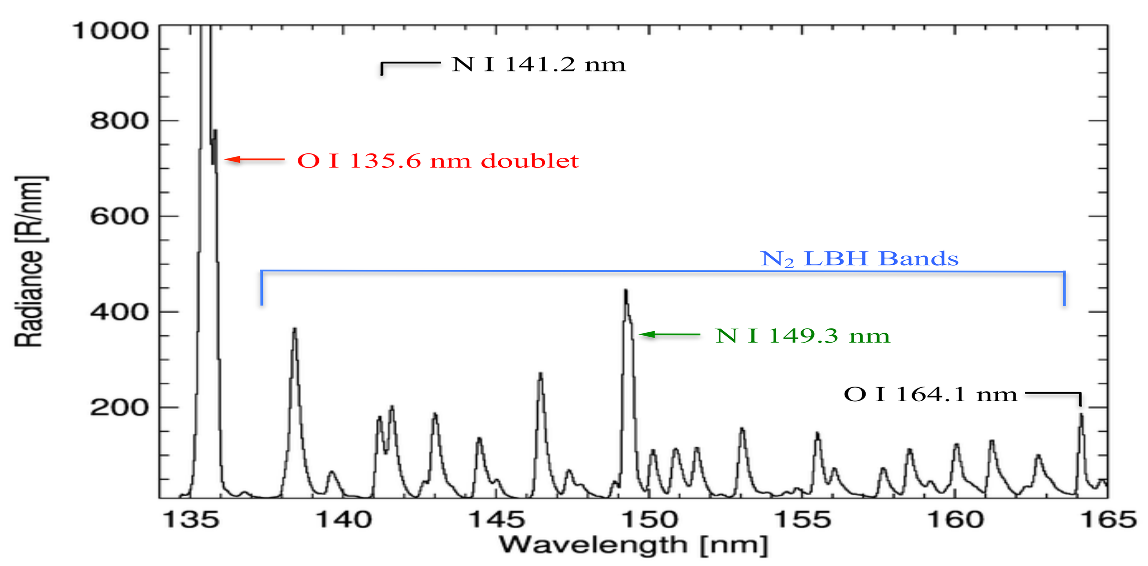
The GOLD limb intensity data will be used to address four primary GOLD Science Questions:

1. How do geomagnetic storms alter the temperature and structure of the exosphere?
2. What is the global-scale response of the thermosphere to solar extreme-ultraviolet variability?
3. How significant are the effects of atmospheric waves and tides propagating from below on the thermospheric temperature structure?
4. How does the nighttime equatorial ionosphere influence the formation and evolution of equatorial plasma density irregularities?

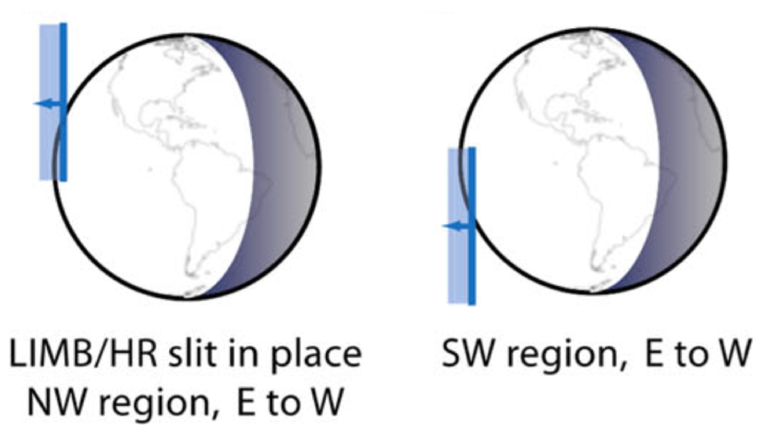
Implementation

Data Overview

- Frequency: Nominally every 30 minutes unless replaced by occultations
- Observation latitudes: 10° S to 10° N.
- Observation longitudes: 34° E and 129° W
- Observation vertical resolution: 50 km
- Retrieval altitude range: 100 – 300 km
- Retrieval temperature precision: 40 K
- Observations are performed using the GOLD High-Spectral Resolution (HR) slit configuration. The HR slit is 0.1-degree wide (E-W) by 10 degrees tall (N-S). Slit width covers ~ 40 km in tangent altitude at the equator.
- Measurements made between 03:00 and 21:00 hours satellite local time (GOLD is in solar safe mode and not operating from 21:00 to 03:00 each night).
- Slit is positioned at a tangent altitude of -50 km and scans up to 430 km in 12 km increments.
- Level 1C data binned to 16 km tangent altitude and 1.25 degree latittude sampling.
- Intensity used for neutral exospheric temperature retrieval is obtained by integrating over 137-155 nm bandpass, excluding atomic nitrogen emission at 149.3 nm. This corresponds to the Lyman-Birge-Hopfield (LBH) bands.



Mean of 11157 spectra from October 29, 2018 where solar zenith and emission angles are less than 30.



N_2 limb scan procedure. Image from [1]

Algorithm

Summary

A Chapman function is a semi-empirical approximation relating scale height and molecular emission characteristics to the intensity of emission observed at the limb. The scale height itself varies with temperature and altitude, allowing us to derive exospheric temperature profiles from band intensity observations. By adjusting the complexity of the scale height function used we are able to vary the degree of accuracy in the fit.

Chapman function

The Chapman function is the integrated emission along a column-of-sight:

$$I = 2\int_b^\infty \left(\Pi_F \sigma n_0 \mathrm{e}^{\left(\frac{z_0-z}{H}\frac{\sigma n_0 H}{cos(\chi)}\mathrm{e}^{\left(\frac{z_0-z}{H}\right)}\right)} \frac{r}{\sqrt{z^2-b^2}}\right) \mathrm{d}z$$

- Π_F - Accounts for solar flux and calibration factors
- z - Altitude
- b - Tangent altitude of the line of sight from the center of the planet
- z_0 - Reference altitude, which is set at 300 km in this analysis
- H - Scale height (see below)
- χ - Solar zenith angle
- σn_0 - Photo-absorption cross section of the UV photons
- n_0 - Density of N_2 at the reference altitude of z_0
- r = R + z, where R is the radius of Earth

Doing a numerical integration with three to five parameters based on scale height complexity:

$$I(k) = 2\sum_{j_0(k)}^{j_{max}} \left(a_0 a_2 \mathrm{e}^{\left(\frac{z_0-z_j}{a_1 H_j}\frac{a_0 a_1 H_j}{cos(\chi)}\mathrm{e}^{\left(\frac{z_0-z_j}{a_1 H_j}\right)}\right)} \frac{(R+z_j)\,\Delta z_j}{\sqrt{z_j^2 - z_{j_0(k)}^2}}\right)$$

- j - Fine altitude-grid index to integrate over
- k - Observation datapoints
- a_n - Fit parameters
- a_0 - Overall scaling factor
- a_1 - Multiplies the scale height altitude-dependent function at all altitudes
- a_2 - Emission cross section times molecular density
- $\Delta z_j = z_{j+1} - z_j$
- H_j - Scale height (fixed or containing fit parameters as described below)

Scale height

Since current published work [2,3] assume a scale height constant with temperature and gravity, we have developed a method capable of using four different scale height functions in our fits to allow for different levels of approximation:

$$H_j = \frac{kT_j}{mg_j}$$

- k – Boltzmann constant
- T_j – Average neutral temperature between z_0 and z_j
- m – Mass of Nitrogen
- g_j – Average acceleration due to gravity between z_0 and z_j

1. A single value scale height (not physical)
2. A single temperature, where scale height varies only with gravity
3. A typical fixed temperature-profile shape with a scaling factor
4. A function of altitude with three fit parameters meant to simply emulate an empirical profile

References

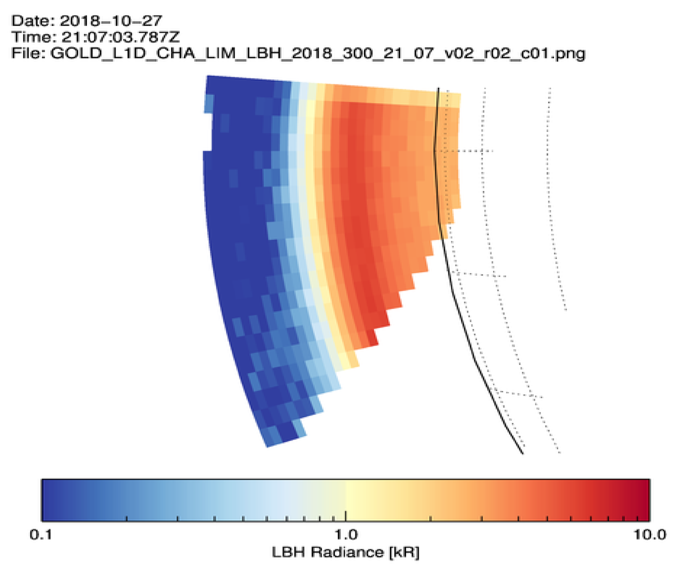
[1] Eastes, R. W. et al. (2017) The Global-Scale Observations of the Limb and Disk (GOLD) Mission. 212, 383–408, doi:10.1007/s11214-017-0392-2

[2] Bougher, S. W. et al.. (2017) The structure and variability of Mars dayside thermosphere from MAVEN NGIMS and IUVS measurements: Seasonal and solar activity trends in scale heights and temperatures. *JGR Space Physics* 122, 1296–1313. doi: 10.1002/2016JA023454

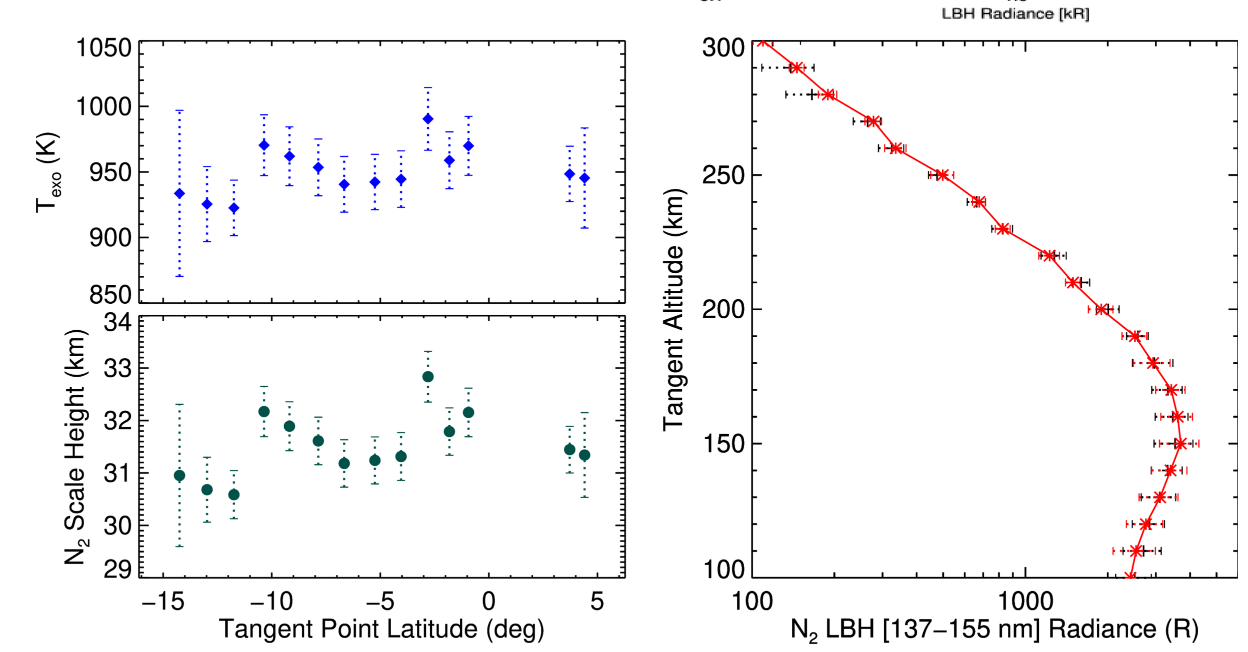
[3] Lo, D. Y. et al. (2015) Nonmigrating tides in the Martian atmosphere as observed by MAVEN IUVS. Geophys. Res. Lett. 42, 9057–9063, doi: 10.1002/2015GL066268

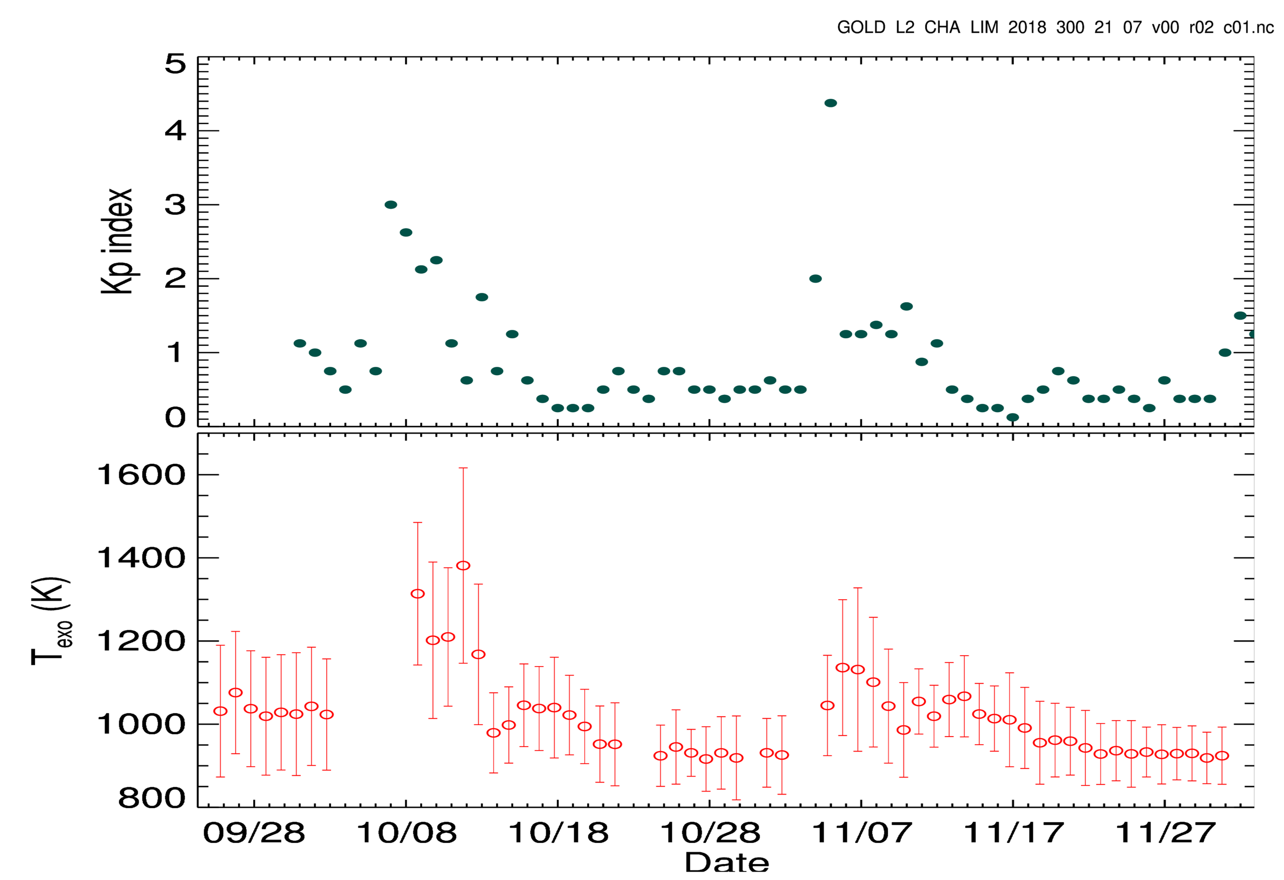
Results

Right: Sample L1D plot showing observed LBH radiance with latitude and altitude



Below: Observed LBH radiance versus the model fit profile, averaged for all latitudes. Also showing the strong dependence of exospheric temperature on scale height, and why an accurate scale height is important.





Two notable G1-class geomagnetic storms occurred around October 9 (day of year 282) and November 5 (day of year 309), as seen by an increased exospheric temperature and heightened Kp index. However, L1C data products do not subtract the background particles so the correlation between Texo and Kp may be due to enhanced particle background rather than storm-induced atmospheric heating.