Parametric estimation of neutral hydrogen density using proton continuity balance with TIMED/GUVI and SAMI3

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INTRODUCTION

The objectives of this work are:

To present a novel technique for estimation of [H] in the topside ionosphere using charge-exchange driven transport of H^+ and O^+ between plasmasphere-ionosphere

To investigate the climatology of the estimated H densities in comparison to NRLMSIS00 specification.

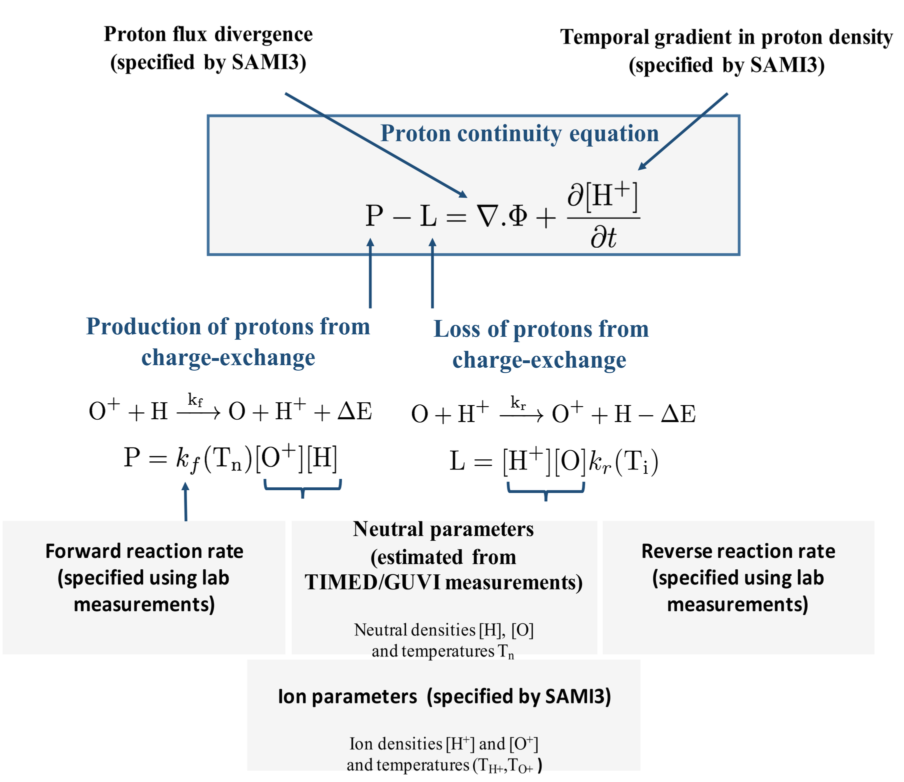
What is the major advantage of this work?

Presents a new technique for [H] estimation with implications for neutral density models.

Motivates several important questions in MIT coupling which can be addressed using upcoming space missions.

METHODOLOGY

H^+ CONTINUITY



[H] ESTIMATION

$$[\mathrm{H}]_{\mathrm{CB}} = \underbrace{\frac{k_r(\mathrm{T_i})}{k_f(\mathrm{T_n})}\frac{[\mathrm{H}^+]}{[\mathrm{O}^+]}[\mathrm{O}]_{\mathrm{GUVI}}}_{[\mathrm{H}]_{\mathrm{EQ}}} + \underbrace{\frac{\nabla\cdot\Phi+\frac{\partial[\mathrm{H}^+]}{\partial t}}{k_f(\mathrm{T_n})[\mathrm{O}^+]}}_{[\mathrm{H}]_{\mathrm{NEQ}}}$$

$$\nabla\cdot\Phi = \underbrace{\frac{\partial(v_{\mathrm{H}_z^+}[\mathrm{H}^+])}{\partial z}}_{\text{zenith}} + \underbrace{\frac{\partial(v_{\mathrm{H}_u^+}[\mathrm{H}^+])}{\partial u}}_{\text{zonal}} + \underbrace{\frac{\partial(v_{\mathrm{H}_v^+}[\mathrm{H}^+])}{\partial v}}_{\text{meridional}}$$

ANALYSIS INTERVAL

26 March, 2003 (Average Ap = 8 nT, F10.7 = 130 sfu)

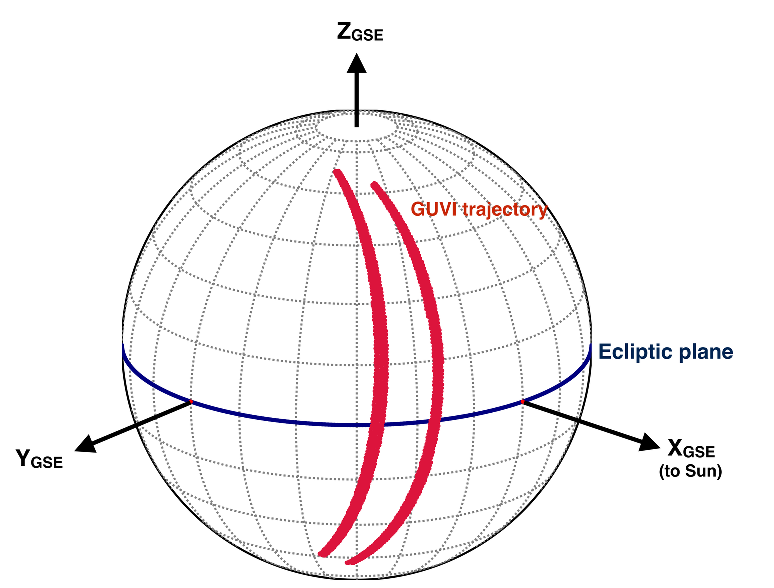
Quite-time dayside interval in solar maximum.

PARAMETER SPECIFICATION

TIMED/GUVI

Thermospheric density and temperature:

Neutral oxygen density [O] and neutral temperatures T_n estimated for GUVI limb scans using radiative transfer inversion of 135.6 nm emission [Meier et al, 2015] .



In one day GUVI has 15 orbits with ~135-150 limb scans over the dayside. TIMED/GUVI trajectory for all 15 orbits is shown (in **red**) in Figure 1 above.

Each limb scan provides [O] for 21 altitude steps uniformly spaced from 110 - 670 km.

We use height-resolved $[O]_{GUVI}$ profiles from 2012 scans spanning 15 orbits on 26 March, 2003.

SAMI3

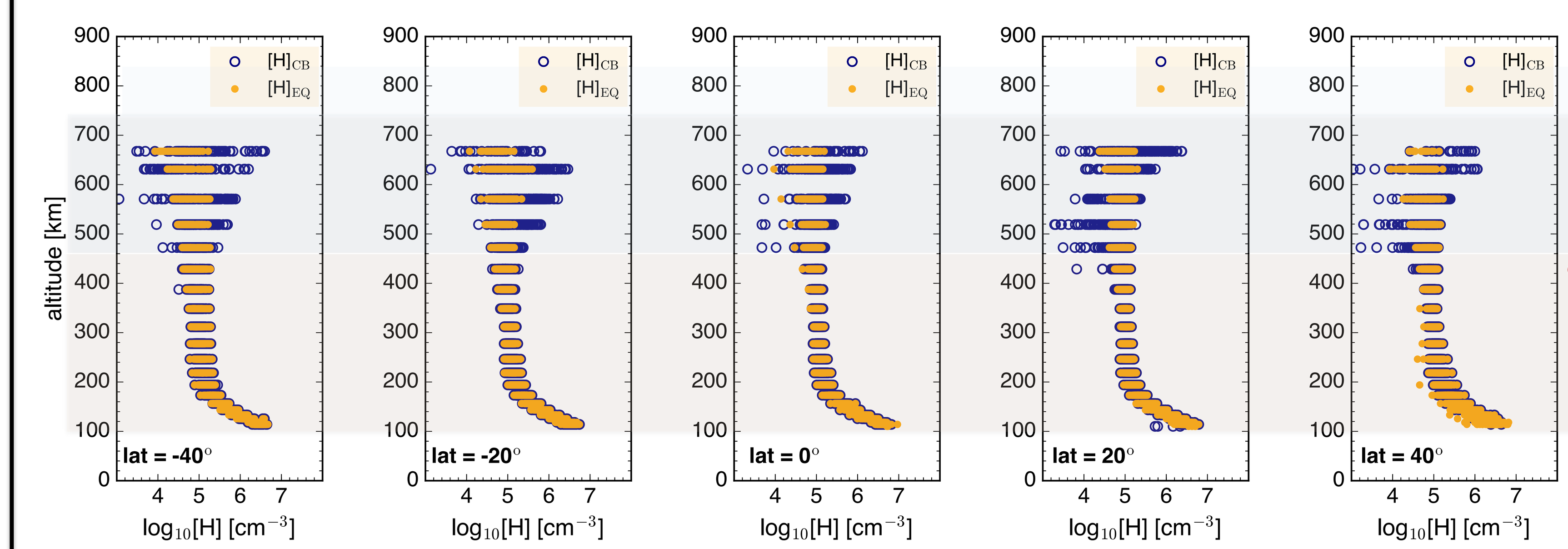
Ionospheric state parameters:

SAMI3 is a 3-dimensional global ionospheric model that provides the densities, temperature and velocities for seven ion species (H^+, He^+, N^+, O^+, NO^+, N_2^+ and O_2^+) in the altitude range 85 km to 20,000 km [Huba et al., 2000, 2008].

We use co-located estimates of H+ density $[H^+]$, temperature (T_{H+}) and 3-dimensional velocity ($\mathbf{v_{H+}}$) from SAMI3.

NEUTRAL HYDROGEN DENSITY ESTIMATION

REGIONS OF VALIDITY



PROTON TRANSPORT

$$\nabla\cdot\Phi + \frac{\partial[\mathrm{H}^+]}{\partial t} \neq 0$$

$$[\mathrm{H}]_{\mathrm{CB}} = [\mathrm{H}]_{\mathrm{EQ}} + [\mathrm{H}]_{\mathrm{NEQ}}$$

CHARGE-EXCHANGE EQUILIBRIUM

$$\nabla\cdot\Phi + \frac{\partial[\mathrm{H}^+]}{\partial t} \approx 0$$

$$[\mathrm{H}]_{\mathrm{CB}} = [\mathrm{H}]_{\mathrm{EQ}}$$

SOUTH HEMISPHERE ← EQUATOR → NORTH HEMISPHERE

OBSERVATIONS

VARIATION OF [H] WITH LATITUDE

Charge-exchange equilibrium is valid from ~110 – 450 km, whereas proton transport becomes increasingly significant at altitudes >450km.

Ionosphere acts as a proton source for the plasmasphere during the day at altitudes >450 km.

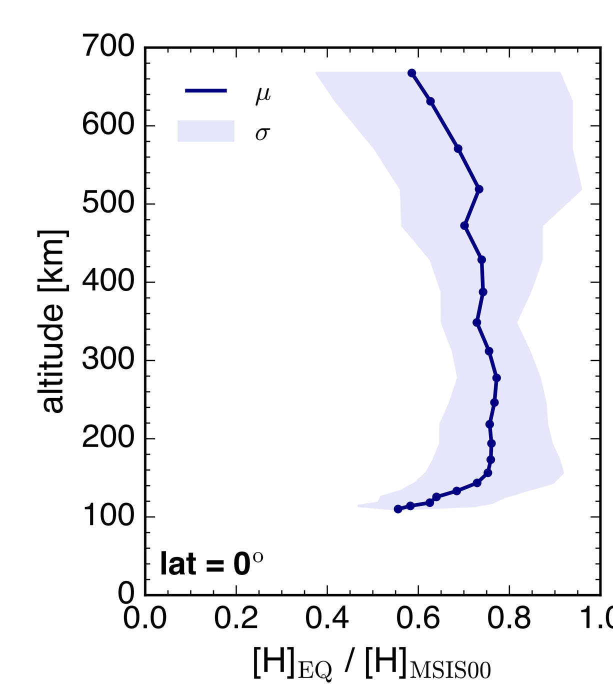
VARIATION OF [H] WITH LATITUDE

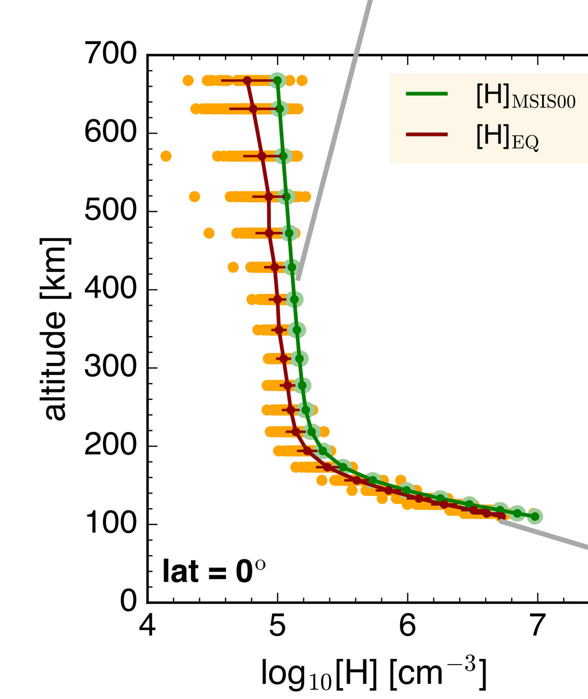
The derived $[H]_{EQ}$ estimate below ~450 km can be reliably used to:

1) Evaluate potential bias in neutral atmosphere models such as MSIS00 which derive [H] assuming charge-exchange equilibrium,
2) To constraint the inverse-theoretic [H] estimates from radiative transfer models,
3) Evaluate thermal Jeans' escape flux at the terrestrial exobase (~400-500 km)

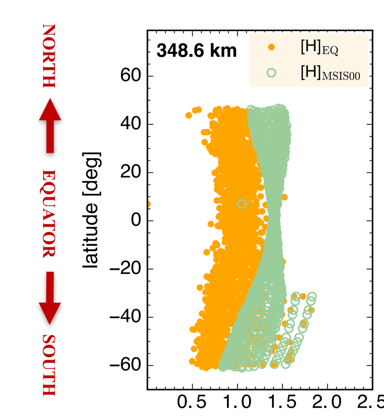
VARIABILITY OF ESTIMATED [H] AND COMPARISON WITH NRLMSIS00

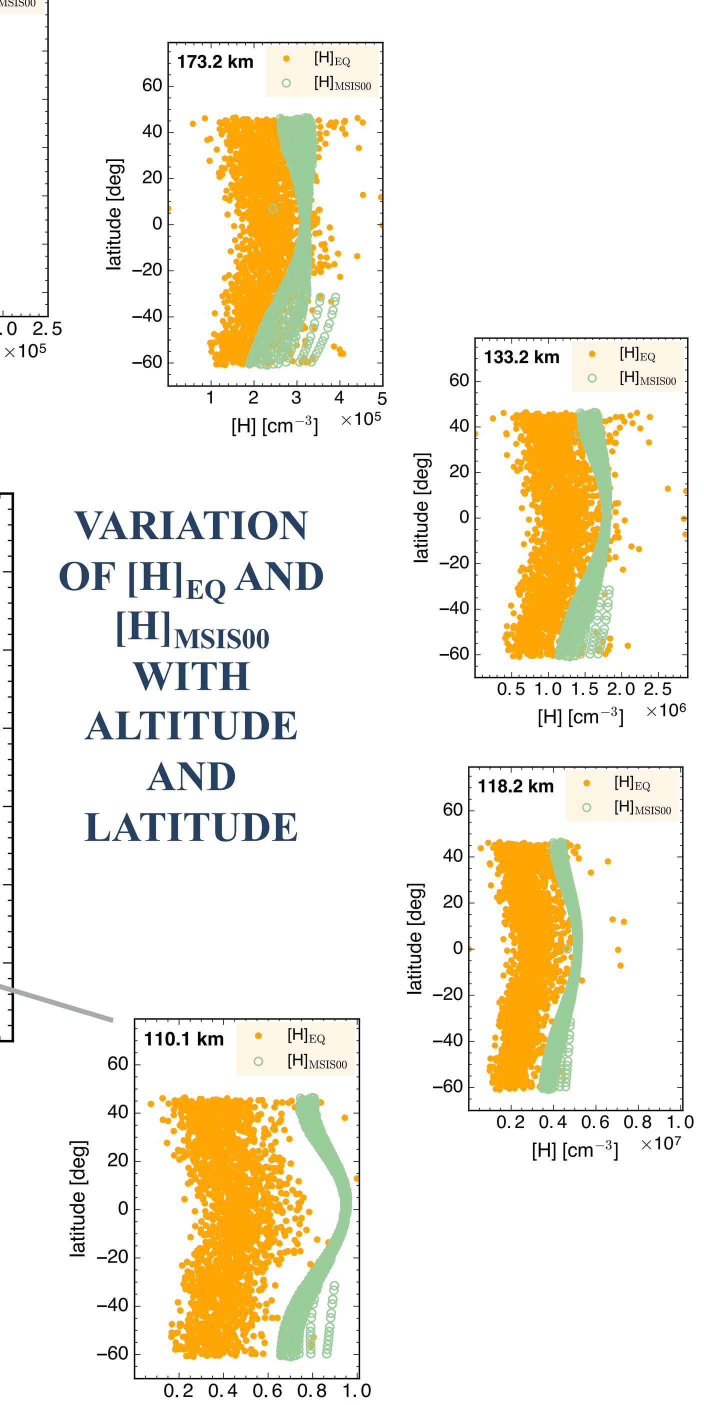
POTENTIAL SCALING FACTOR FOR $[H]_{MSIS00}$





VARIATION OF $[H]_{EQ}$ AND $[H]_{MSIS00}$ WITH ALTITUDE AND LATITUDE





INCREASING ALTITUDE

OBSERVATIONS

VARIATION OF [H] WITH LATITUDE

$[H]_{EQ}$ and $[H]_{MSIS00}$ have the same average climatology and relative magnitude independent of latitude.

VARIATION OF [H] WITH ALTITUDE

The difference between $[H]_{EQ}$ and $[H]_{MSIS00}$ is largest from 100-150 km and stays about constant between 150-450 km.

COMPARISON WITH MSIS00

At all latitudes from -40° to 40°, MSIS potentially overestimates [H] during the day by ~20-25% for altitudes ~150-450 km and up to ~40% for MLT altitudes spanning 110-150 km.

SOURCES OF UNCERTAINTY

1) $[O]_{GUVI}$ is underestimated
2) SAMI3 underestimates H^+ and/or overestimates O^+.

SUMMARY AND CONCLUSIONS

Proposed technique for [H] estimation is very promising and motivates several important questions which can be addressed using upcoming space missions and ionospheric models.
Proposed technique has strong potential to address long-standing discrepancies between models and observations in quantification of plasmasphere-ionosphere transport through model-independent calculations.

1. In-situ mass spectrometer measurements of ion densities and velocities from constellation satellite missions like NASA Dellinger and Exocube would be highly useful for model-independent implementation of [H] estimation.
2. Derivation of neutral hydrogen density [H] from inversion of Lyman-alpha radiances from upcoming mission like NASA ICON and GOLD would allow for MSIS-independent implementation of [H] estimation.
3. Derivation of [H] and/or [O] using self-consistent solution of both, O+ and H+ continuity balance would allow for validation of new inversion algorithms for ICON/GOLD, MSIS models as well as impact all IT studies.

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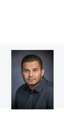

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