O-O+ momentum imbalance in the topside ionosphere: implications for bias in MSIS oxygen density specification

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INTRODUCTION

The objectives of this work are:

To derive the notorious "Burnside" factor scaling of the O-O+ charge exchange cross section, Q(O-O+), from momentum balance analysis in order to improve calculations of plasma drift speeds, diffusion coefficients, and electron density distributions.

To investigate potential bias in the model specification of O density, [O], used in the analysis.

What is the unique advantage of this work?

Use of unprecedented 18-year baseline of combined incoherent scatter radar and neutral wind data acquired at Arecibo Observatory.

PARAMETER SPECIFICATION

Ionospheric state parameters:

Electron density [N_e] , ion densities [H^+] and, [O^+], ion temperature T_i, electron temperature T_e, plasma temperature $T_p = 0.5(T_i + T_e)$ and, anti-parallel plasma drift velocity v_{ap} measured by the Arecibo ISR from 1987-2004.

Thermospheric density and temperature:

Co-located neutral densities [H], [O], [O_2], [N_2] and temperatures T_n and, average ion-neutral temperature $T_r = 0.5(T_i + T_n)$.

Thermospheric winds:

$$Un_m = U_e sin(D) + U_n cos(D)$$

where, Un_m is the neutral wind along the magnetic meridian, D is magnetic declination, U_e and U_n are zonal and meridional winds from the neutral wind model of *Brum et al* [2012] which is based on the 630 nm redline emission measured by Arecibo Fabry-Perot interferometer (FPI).

Charge exchange cross section:

$Q'_{O^+-O} = 3\times10^{-11}.\sqrt{T_r}.(1 - 0.135.log(T_r/10^3))^2$ from *Pesnell et al* [1993]

METHODOLOGY

STEP 1:

For each of the 39,512 individual ISR measurements available, calculate the peak 630 nm emission altitude (h_{peak})using *Link and Cogger* [1988].

STEP 2:

Find the values of needed thermospheric and ionospheric parameters at h_{peak}.

STEP 3:

Use the O-O+ momentum balance equation to derive neutral wind Unm, Burnside factor F, and neutral O density for each measurement.

STEP 4:

Average the observations over 10 minutes of local time and calculate errors in terms of both propagated measurement uncertainty (via *Reddy et al* [1994]) and standard deviation of the binned data.

ASSESS SEASONAL DEPENDENCE:

Bin data by season, defined as +/- 45 days from March equinox (21 March), June solstice (21 June), September equinox (21 September) and, December solstice (21 December), respectively.

ASSESS SOLAR CYCLE DEPENDENCE:

Bin data by solar activity, defined in sfu as: 90< F10.7 <120, 120< F10.7 <150, 150< F10.7 <180 and,180< F10.7 <210.

ION-MOMENTUM BALANCE CALCULATIONS

NEUTRAL WINDS

Ion-momentum equation

$$Un_m = -(v_{ap} + v_d)sec(I)$$

⬆

O^+ - O diffusion velocity

$$v_d = D_a \frac{T_p}{T_r} sin(I) \left(\frac{1}{N_e}\frac{dN_e}{dz} + \frac{1}{T_p}\frac{dT_p}{dz} + \frac{0.36}{T_r}\frac{dT_r}{dz} + \frac{1}{H_p} \right)$$

⬆

Ambipolar diffusion coefficient

$$D_a = \frac{2K_B T_i}{m_{O^+}(v_{in})}$$

⬆

Ion-neutral collision frequency

$$v_{in} = v_{O^+-O} + v_{O^+-O_2} + v_{O^+-N_2} \equiv A[O]FQ'_{O^+-O} + C$$

BURNSIDE FACTOR

Ion-momentum equation with Un_{FPI} from neutral wind model of [*Brum et al*, 2012]

$$Un_{FPI} = -(v_{ap} + v_d)sec(I)$$

⬇

Burnside factor (F)

$$F = \frac{D}{[O](v_{ap} - Un_{FPI}cos(I))}$$

⬆

Term with ion and neutral measurables

$$D = \frac{2K_B T_i}{m_{O^+}Q'_{O^+-O}}(\frac{T_p}{T_r})sin(I) \left(\frac{1}{N_e}\frac{dN_e}{dz} + \frac{1}{T_p}\frac{dT_p}{dz} + \frac{0.36}{T_r}\frac{dT_r}{dz} + \frac{1}{H_p} \right)$$

OXYGEN DENSITY

Ion-momentum equation with Un_{FPI} from neutral wind model of [*Brum et al*, 2012]

$$Un_{FPI} = -(v_{ap} + v_d)sec(I)$$

⬇

Neutral oxygen density [O]

$$[O] = \frac{D}{F(v_{ap} - Un_{FPI}cos(I))}$$

⬆

Term with ion and neutral measurables

$$D = \frac{2K_B T_i}{m_{O^+}Q'_{O^+-O}}(\frac{T_p}{T_r})sin(I) \left(\frac{1}{N_e}\frac{dN_e}{dz} + \frac{1}{T_p}\frac{dT_p}{dz} + \frac{0.36}{T_r}\frac{dT_r}{dz} + \frac{1}{H_p} \right)$$

RESULTS

SEASONAL VARIATION

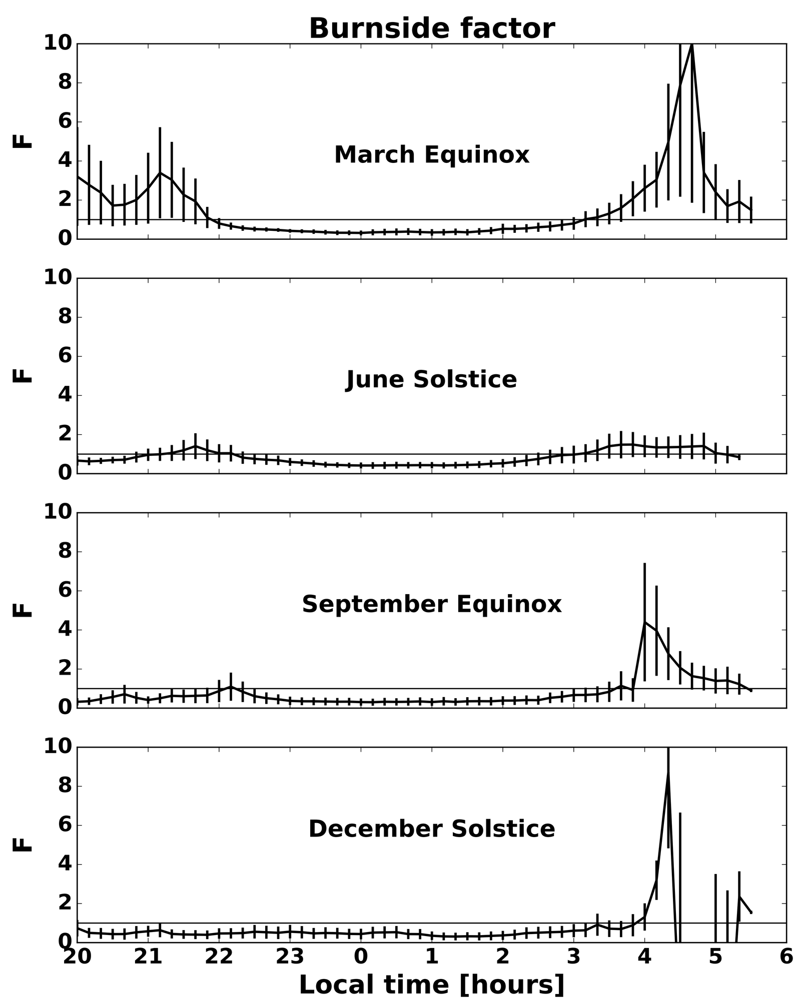

Figure 1. Local time/seasonal variation of the average Burnside factor (F) derived from the ISR-based momentum balance analysis using neutral wind (Unm) specified by the FPI wind model.

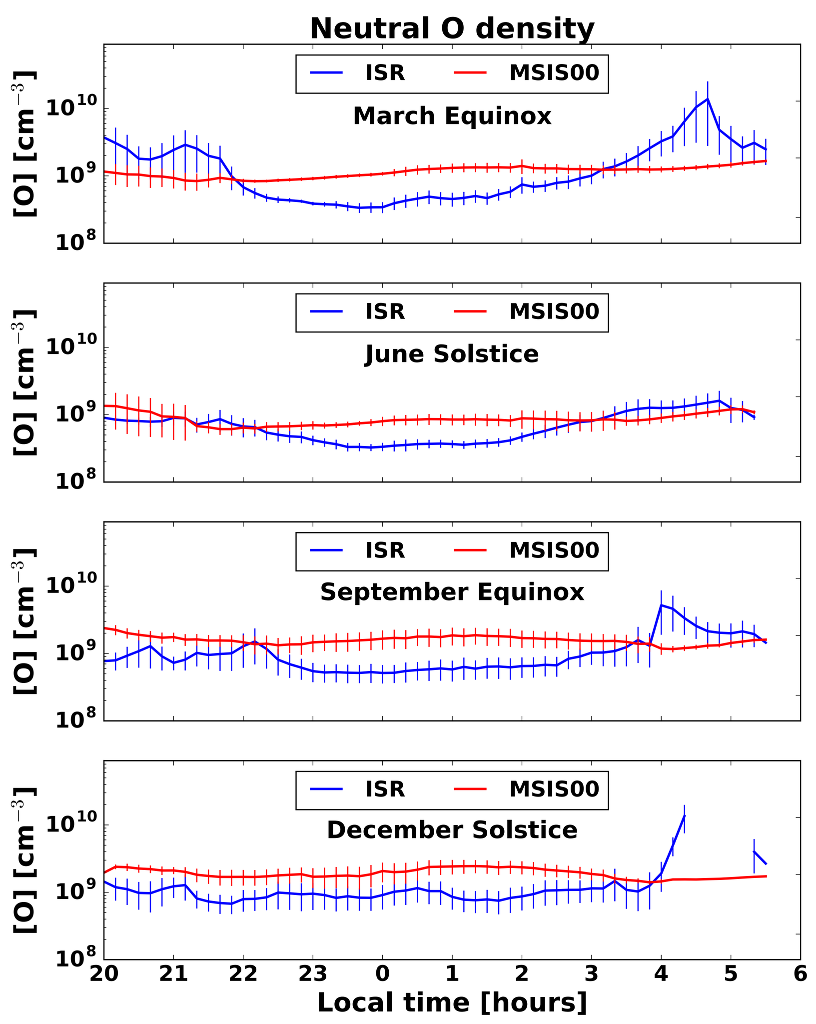

Figure 3. Local time/seasonal variation of the neutral oxygen density [O] specified by MSIS00 (red) and derived from the ISR-based momentum balance analysis (blue) using a Burnside factor F= 1

SOLAR CYCLE VARIATION

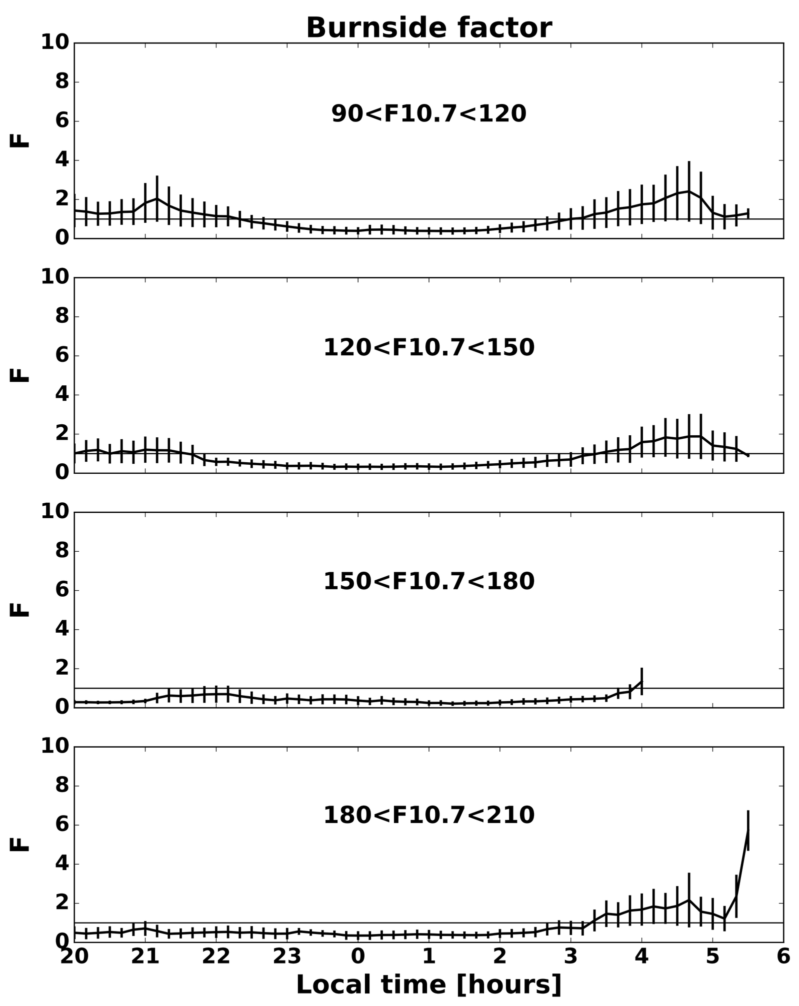

Figure 2. Local time/solar activity variation of the average Burnside factor (F) derived from the ISR-based momentum balance analysis using neutral wind (Unm) specified by the FPI wind model.

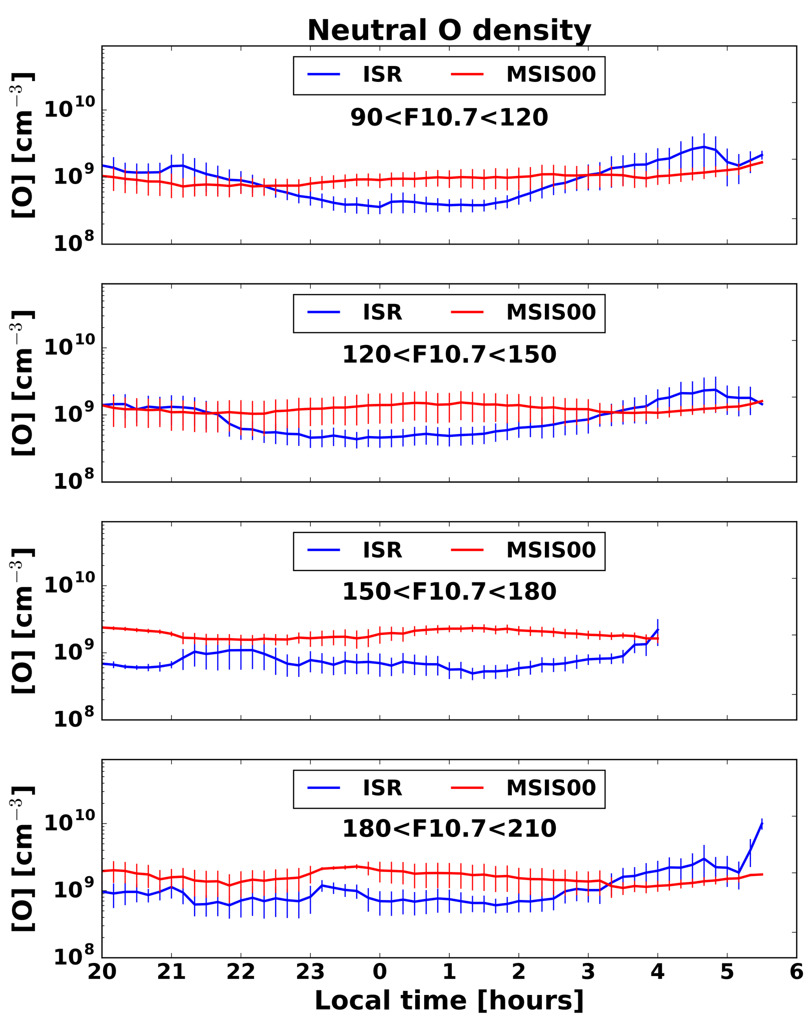

Figure 4. Local time/solar activity variation of the neutral oxygen density [O] specified by MSIS00 (red) and derived from the ISR-based momentum balance analysis (blue) using a Burnside factor F= 1.

FINDINGS

In Figures 1 and 2, a local time variation is observed in the Burnside factor where it is (<1) over the time from ~(22 LT – 4 LT) and (>1) just post the sunset and then again near the pre-dawn interval ~(4 LT – 6 LT).

The variations in the Burnside factor are consistent over all the seasons and solar activity levels.

We observe an average Burnside factor (F_{avg}) of 0.5603 +/- 0.0336 during (22 LT – 4 LT) and 0.7112 +/- 1.049 in the predawn (4 LT – 6 LT) interval and 0.9001 +/- 0.1228 over the entire (22 LT – 6 LT) interval.

In Figures 3 and 4, a systematic bias is observed between the [O] derived from momentum balance and MSIS00 as a function of local time. The resulting variation is consistent over all the seasons as well as solar activity.

MSIS00 is observed to overestimate [O] during the time interval from ~(22 LT - 4 LT) and underestimates [O] in the pre-dawn ~(4 LT- 6 LT) time interval.

UNCERTAINTIES

Altitude gradients in the plasma drift velocity which are currently neglected due to lack of height-resolved data.

Measurement uncertainties in the ISR data, which are not considered.

Assumption of negligible vertical wind gradients in the FPI wind model of *Brum et al* [2012].

Empirical calculation of peak emission altitude using Link and Cogger [1988]

Temperature dependence of the functional form of cross section (Q_{O^+-O}) by *Pesnell et al* [1993]

Uncertainty in the MSIS00 derived neutral temperature T_n

Tropospheric scattering effects in FPI measurements.

Possible effects of horizontal density gradients and wind field gradients.

CONCLUSIONS

The Burnside factor derived via momentum balance analysis of ISR and FPI data, which scales the product of Q(O+-O) and [O], is found to vary as a function of local time and solar activity. Similarly, such systematic discrepancies are observed between $[O]_{MSIS00}$ and [O] derived from momentum balance, assuming a Burnside factor of unity.

These results may arise from errors in the assumed functional form for Q(O+-O), from its miscalculation due to biased MSIS00 T_n specification, from systematic bias in ISR or neutral wind data, or from bias in the specified [O] provided by MSIS00. Potential bias in MSIS00 model output would impact numerous aeronomical investigations as well as the accuracy of numerical modeling of the space-atmosphere interaction region.

Future work will involve the refinement of our momentum balance analysis to include:

(1) coincident ISR and FPI data, rather than reliance on an empirical wind model
(2) more accurate plasma velocity data using the dual-beam mode at Arecibo
(3) coincident measurements of thermospheric O density

These refinements will allow for model-independent derivation of Q(O+-O) as well as an unambiguous assessment of potential MSIS00 bias.

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