Correction to "Energy transport in the thermosphere during the solar storms of April 2002"

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Abstract. We present corrected computations of the infrared power and energy radiated by nitric oxide (NO) and carbon dioxide (CO_2) during the solar storm event of April 2002. The computations in our previous paper underestimated the radiated power due to improper weighting of the radiated power and energy with respect to area as a function of latitude. We now find that the radiation by NO during the April 2002 storm period accounts for 50% of the estimated energy input to the atmosphere from the solar storm. The prior estimate was 28.5%. Emission computed for CO_2 is also correspondingly increased, but the relative roles of CO_2 and NO remain unchanged. NO emission enhancement is still, far and away, the dominant infrared response to the solar storms of April 2002.

1. Summary

[1] In a recent paper, *Mlynczak et al*. [2005, hereafter M1] computed the power (W) radiated by NO and by CO_2 in the thermosphere during conditions which were strongly disturbed by the occurrence of geomagnetic storms initiated by a series of coronal mass ejections from the Sun. Large enhancements in the emission from NO were observed by the SABER instrument on the TIMED satellite. It was shown that these enhancements resulted in a significant increase in the rate of infrared energy loss and cooling in the thermosphere, leading to the concept that the NO enhancement acts as a "natural thermostat," allowing energy to be efficiently shed from the atmosphere subsequent to a major disturbance [*Mlynczak et al*., 2003].

[2] To obtain the radiated power from the SABER measurements, M1 followed a six-step procedure: (1) invert the SABER-measured radiances (W cm^{-2} sr^{-1}) using an Abel (weak-line) inversion to get volumetric emission rates of energy (W m^{-3}); (2) apply a correction to account for the limited bandpass of the SABER instrument at 5.3 μm; (3) Vertically integrate the

volumetric emission rates of energy with respect to altitude to get radiative fluxes of power (W m^{-2}); (4) zonally integrate the fluxes with respect to area to get the radiated power (W) in five degree latitude bins; (5) integrate with respect to time to get the total energy (erg or J) radiated by NO; and (6) integrate meridionally to obtain the total global radiated energy. This process is followed for both the NO and CO_2 emissions and is detailed in Section 3 of M1.

[3] In computing step (6), M1 incorrectly applied a cosine latitude weighting function to the computed energy (see Eq. (13) of M1). The purpose of this weighting was to properly account for the different atmospheric area projected onto each latitude bin, as is common when dealing with radiative fluxes. However, step (4) implicitly accounts for the area of each latitude bin, thereby eliminating any need to further account for atmospheric area when computing the global radiated power or energy. The total power and energy are correctly obtained by adding the results from step 5 for each five degree latitude bin. The effect of additional cosine latitude weighting is to reduce the computed radiated energy because high latitude regions, where much of the enhanced emission occurs, are then underweighted relative to lower latitudes. Correcting this error increases the computed amounts of radiated energy and thus changes the results presented in Tables 2 and 3 of M1. All other figures in the paper are correct as published. We present here in Tables 1 and 2 below the correct power and energy radiated by NO and CO_2, respectively, for days 104 through 113 of 2002. These tables replace the results of Tables 2 and 3 in M1.

[4] Central to the analysis of the efficacy of the “thermostat” effect is the estimate of the energy radiated by NO and CO_2 during the storm time relative to other mechanisms such as heat conduction, and relative to the estimated storm input. The storm-enhanced radiative emission from the atmosphere is determined by computing the average radiated energy for three days prior

to and three days subsequent to the storm. This average is then subtracted from the total radiated energy for each of the 4 storm days (107 – 110), and the residual energy for each storm day is added together to obtain the total storm radiated energy. M1 estimated the total energy radiated by NO and CO_2 to be 7.7 x 10^{23} erg and 1.8 x 10^{22} erg, respectively. The estimated storm input energy is 2.7 x 10^{24} erg.

[5] Using this approach and the data in Tables 1 and 2 below, we compute the energy radiated by NO and CO_2 to be 1.36 x 10^{24} erg and 3.36 x 10^{22} erg, respectively, for a total of 1.4 x 10^{24} erg. NO emission is now found to account for 50% of the estimated storm input energy. The fraction based on the previous calculations in M1 was 28.5%. The revised calculations demonstrate that NO emission accounts for one-half of the estimated storm input energy. Enhanced CO_2 emission is about 2.5% of the enhanced NO emission during the storm time (days 107 to 110), which is essentially the same relative proportion as in M1. Together enhanced NO and CO_2 emission account for 52% of the estimated storm input energy. We emphasize, as in M1, that it is not necessary for the entire input energy to be accounted for in the thermosphere as the observed ozone destruction in the mesosphere and stratosphere implies substantial deposition of energy in those regions.

Conclusion

[6] We have presented a recalculation of the enhancement in infrared radiation by NO and CO_2 during the geomagnetic storm period of April 2002. In our prior study we effectively area-weighted the computed power and energy as a function of latitude twice, resulting in an underestimation of the emitted power and energy by NO and CO_2. The new results show a substantially larger amount of energy radiated by NO and CO_2. Infrared emission by NO is now shown to account for 50% of the estimated storm energy input as opposed to 28.5% previously.

NO emission still represents the dominant and nearly total infrared energy enhancement in the thermosphere during storm conditions.

References

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Table 1. NO Power (P, W) in four separate latitude bands, global power (Total P, W), and total energy (Total E, erg) radiated by NO for days 104 through 113 of 2002.

Day	P (0 – 52 N)	P (52 – 90 N)[a]	P(0 – 52 S)	P (52 – 90 S)	Total P(W)	Total E (erg)
104	0.9891E+11	0.4422E+11	0.8325E+11	0.3722E+11	0.2636E+12	0.2277E+24
105	0.7909E+11	0.2446E+11	0.7181E+11	0.2220E+11	0.1976E+12	0.1707E+24
106	0.8597E+11	0.3509E+11	0.7325E+11	0.2990E+11	0.2242E+12	0.1937E+24
107	0.1507E+12	0.7106E+11	0.1416E+12	0.6679E+11	0.4301E+12	0.3716E+24
108	0.2416E+12	0.1611E+12	0.1721E+12	0.1148E+12	0.6896E+12	0.5958E+24
109	0.2440E+12	0.1432E+12	0.1791E+12	0.1051E+12	0.6714E+12	0.5801E+24
110	0.2487E+12	0.1776E+12	0.1704E+12	0.1217E+12	0.7183E+12	0.6206E+24
111	0.1003E+12	0.7073E+11	0.6581E+11	0.4642E+11	0.2832E+12	0.2447E+24
112	0.6975E+11	0.4469E+11	0.4842E+11	0.3102E+11	0.1939E+12	0.1675E+24
113	0.8134E+11	0.4666E+11	0.6583E+11	0.3777E+11	0.2316E+12	0.2001E+24

Table 2. CO_2 Power (P, W) in four separate latitude bands, global power (Total P, W), and total energy (Total E, erg) radiated by CO_2 for days 104 through 113 of 2002.

Day	P (0 – 52 N)	P (52 – 90 N)[a]	P(0 – 52 S)	P (52 – 90 S)	Total P(W)	Total E (erg)
104	0.2271E+11	0.5960E+10	0.2092E+11	0.5491E+10	0.5509E+11	0.4760E+23
105	0.2192E+11	0.5405E+10	0.2041E+11	0.5033E+10	0.5278E+11	0.4560E+23
106	0.2150E+11	0.5466E+10	0.2072E+11	0.5268E+10	0.5297E+11	0.4576E+23
107	0.2345E+11	0.6451E+10	0.2158E+11	0.5937E+10	0.5743E+11	0.4962E+23
108	0.2605E+11	0.7732E+10	0.2404E+11	0.7137E+10	0.6496E+11	0.5613E+23
109	0.2572E+11	0.7956E+10	0.2377E+11	0.7351E+10	0.6480E+11	0.5599E+23
110	0.2706E+11	0.8130E+10	0.2430E+11	0.7300E+10	0.6680E+11	0.5772E+23
111	0.2355E+11	0.6725E+10	0.1988E+11	0.5676E+10	0.5584E+11	0.4825E+23
112	0.2232E+11	0.6172E+10	0.1912E+11	0.5287E+10	0.5291E+11	0.4571E+23
113	0.2238E+11	0.6009E+10	0.1938E+11	0.5203E+10	0.5297E+11	0.4577E+23