A numerical study of overcooling in the upper thermosphere during the recovery phases of the October 2003 storms

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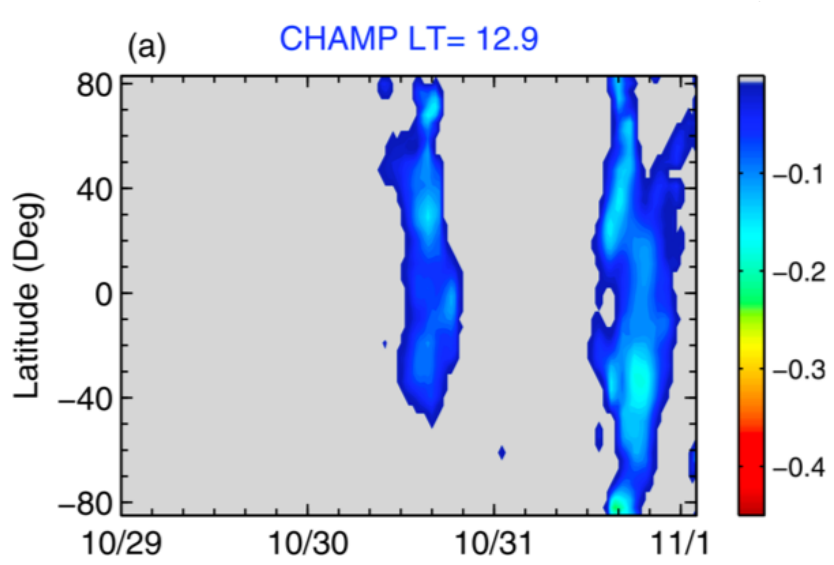
Introduction

The infrared radiation of carbon dioxide (CO2) and nitric oxide (NO) and heat conduction are the major cooling mechanisms in the thermosphere. The great energy injection from magnetosphere by Joule heating and energetic particle precipitation heats the thermosphere severely during storm time. Meanwhile, the NO densities increase quickly due to the sensibility of NO production to the temperature and the particle precipitation. Infrared radiation of NO increases significantly in high geomagnetic activity, while the additional infrared emission from CO2 changes slightly. The enhanced NO cooling is the major way in offsetting the energy injection from upper atmosphere and results in the recovery of the thermosphere. The NO density recovery is generally longer than neutral density recovery. This time delay of NO cooling recovery results in neutral density rapid recovery and overcooling (lower density than in pre-storm period) in severe storms.



Condition of IMF and Dst

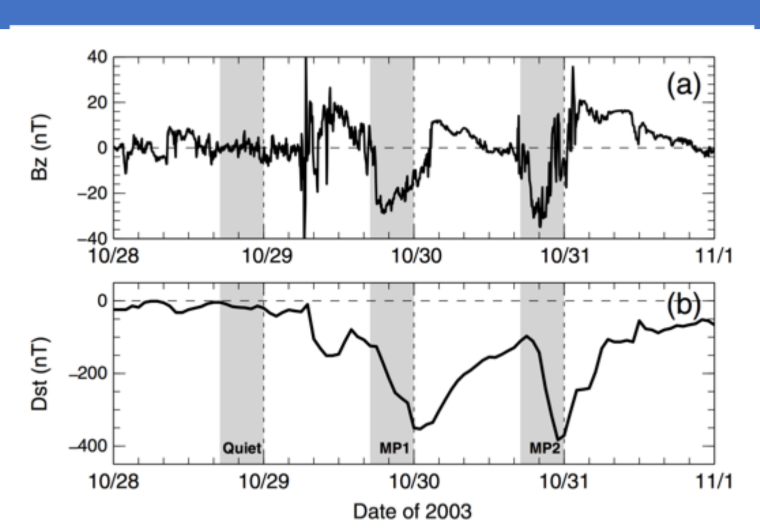


Figure 1. Variations of (a) the north-south component of the interplanetary magnetic field (IMF Bz) observed by the ACE satellite, and (b) Dst from 28 Oct. 2003 to 1 Nov. 2003.

NO production and emission

The generation of NO in the upper atmosphere is mainly from reactions between atomic nitrogen and oxygen molecule:

$$N(^4S) + O_2 \rightarrow NO + O \quad \text{(R1)}$$

$$N(^2D) + O_2 \rightarrow NO + O \quad \text{(R2)}$$

The primary process for vibrational excited NO is through particle collision between NO and O, which results in the first vibrational level of NO:

$$NO + O \rightarrow NO(v=1) + O \quad \text{(R3)}$$

The formula for calculating the 5.3 μm emission from NO(v=1) vibrational level transition, *Lno*, in the TIEGCM is given as follows:

$$Lno = \frac{k_o N_o + k_{o2} N_{o2}}{k_o N_o + k_{o2} N_{o2} + A_{10}} \times h\nu A_{10} N_{no} e^{-\frac{h\nu}{kT_n}}$$

To explore the mechanism of thermosphere overcooling, we carried out three simulations with different coefficients of R2 in the TIEGCM.

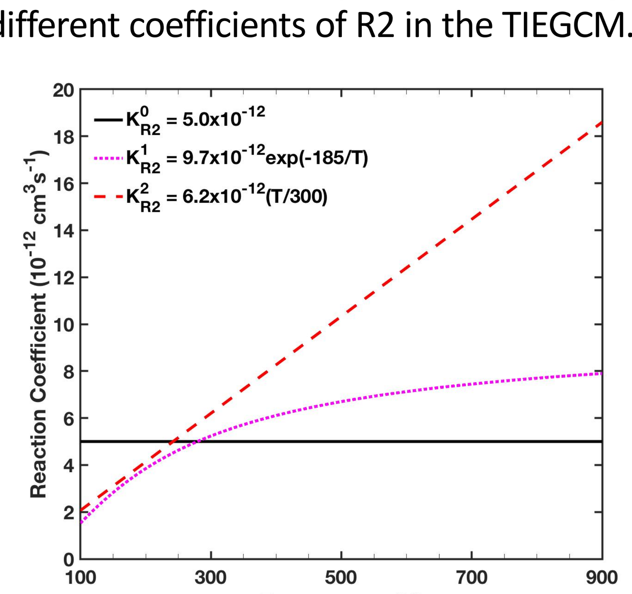


Figure 2. Comparison of different reaction coefficients of N(^{2}D) + O$_2$, namely the fixed value (k^0_{R2}), those from *Herron* [1999] (k^1_{R2}) and *Duff et al.* [2003] (k^2_{R2}).

Comparison of NO cooling

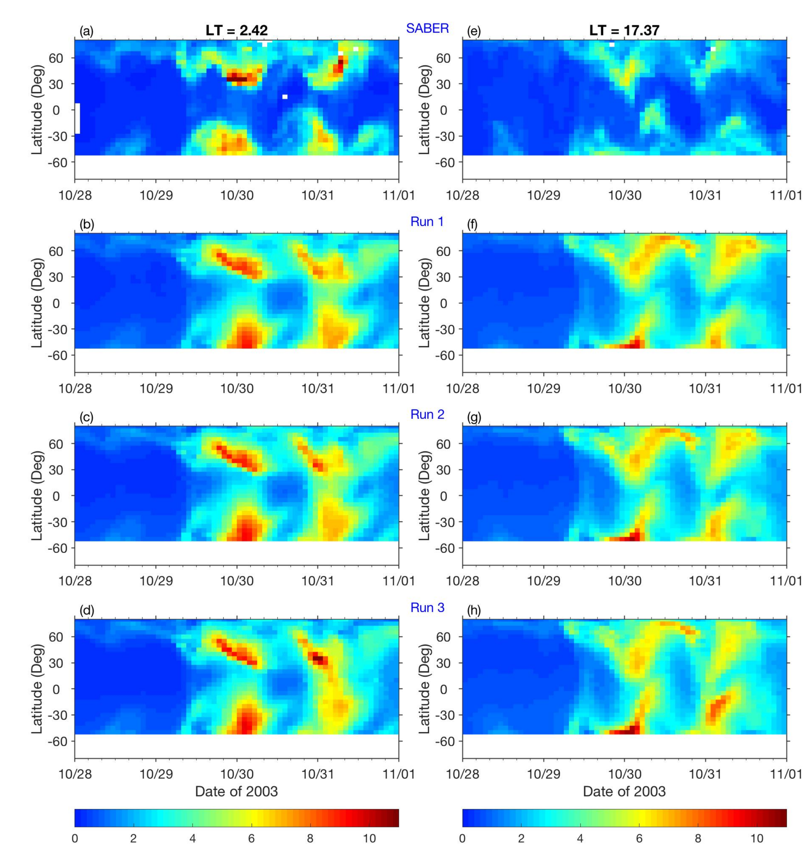


Figure 3. The column NO cooling (in units of *erg/cm²/s*) integrated from 100 km to 250 km from TIMED/SABER and Runs 1-3.

- **The evolutions of simulated NO cooling are similar with those from observations**
- **The simulated NO cooling with Duff coefficient agrees better with observations at 2.42 LT**

Simulated mass density overcooling

Serial Number	Parameter set in the TIEGCM
Run1	Default simulation with the fixed value (k^0_{R2})
Run2	With temperature-dependent reaction rate of N(^{2}D) + O$_2$ from *Herron* [1999] (k^1_{R2})
Run3	With temperature-dependent reaction rate of N(^{2}D) + O$_2$ from *Duff et al.* [2003] (k^2_{R2})

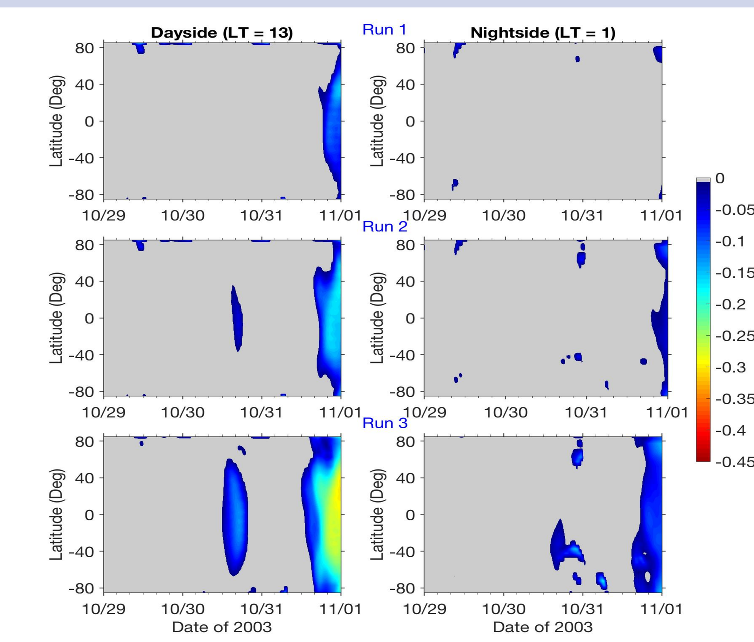


Figure 4. Relative depletion of neutral densities with respect to the reference value at the same universal time on 27 October at 390 km.

- **The mass density overcooling regions with Duff coefficient are consistent with those from observations**

The evolution and altitudinal distribution of NO cooling

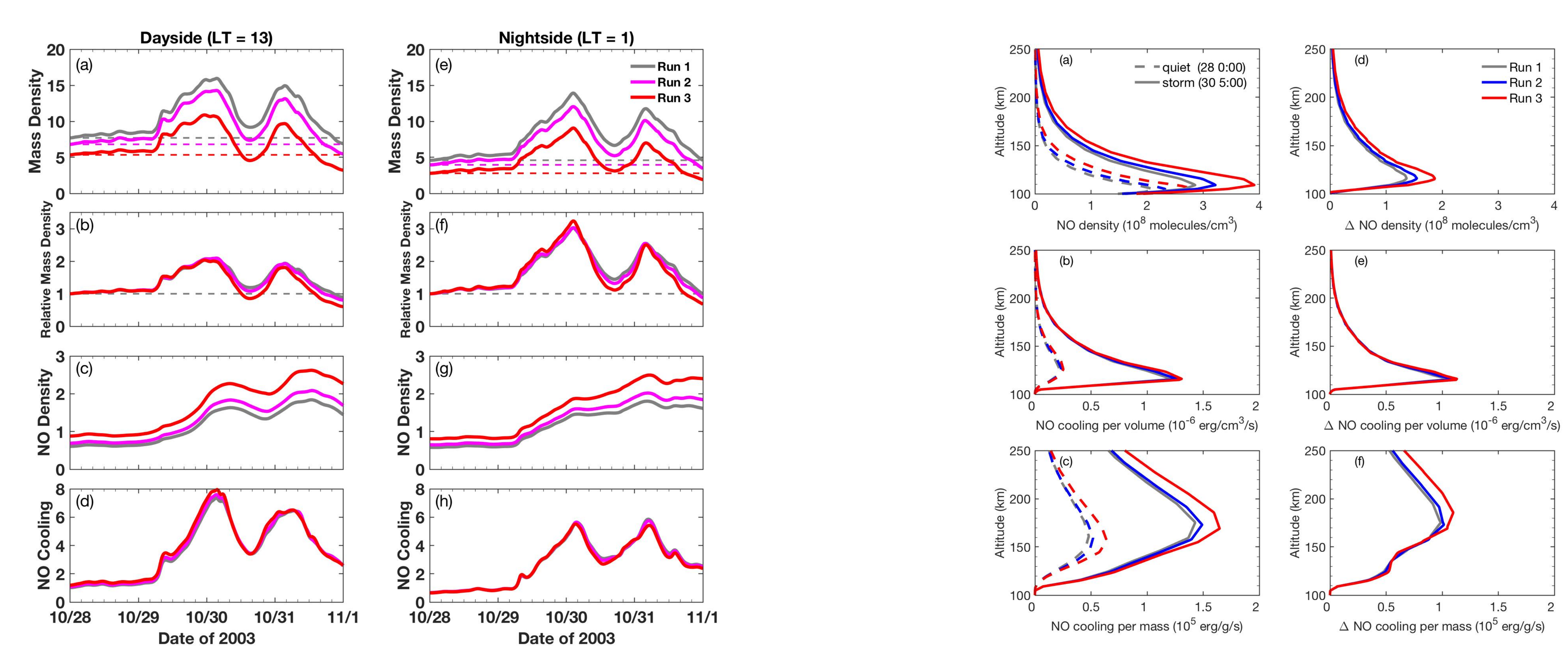
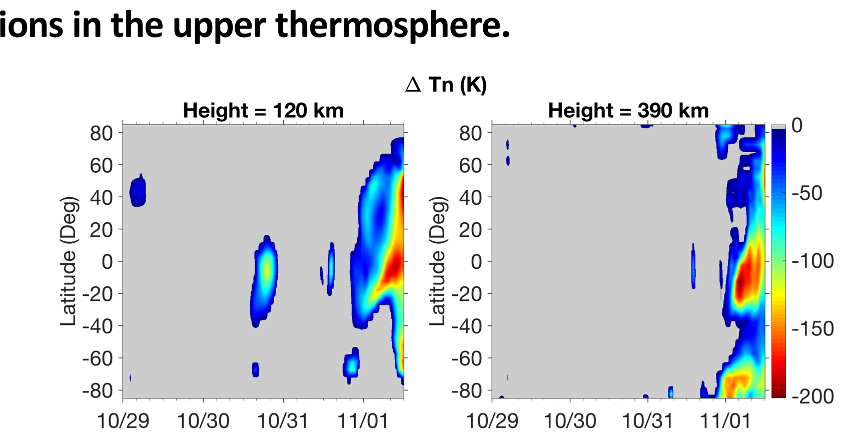


Figure 5. Evolutions of averaged neutral density (10^{-15} *g/cm³*), relative mass density changes with respect to the reference value at 0:00 UT on 28 October, column NO density (10^{-15} *cm⁻²*) and column NO cooling (*erg/cm²/s*). Δ presents the difference between 0:00 UT on 28 October (quiet time) and 5:00 UT on 30 October (storm).

- **The simulations with temperature-dependent reaction rate have shorter recovery time and show mass density overcoolings.**
- **The thermosphere recovery depends on the altitudinal NO emission per mass rather than the NO cooling flux alone.**

Temperature recovery

- **The temperature overcooling at NO production source region (around 120 km) makes important contributions to the mass density overcooling during the recovery phase of this event.**
- **The density overcooling is not only controlled by neutral temperature, but also modulated by neutral winds, which subsequently alter neutral compositions in the upper thermosphere.**



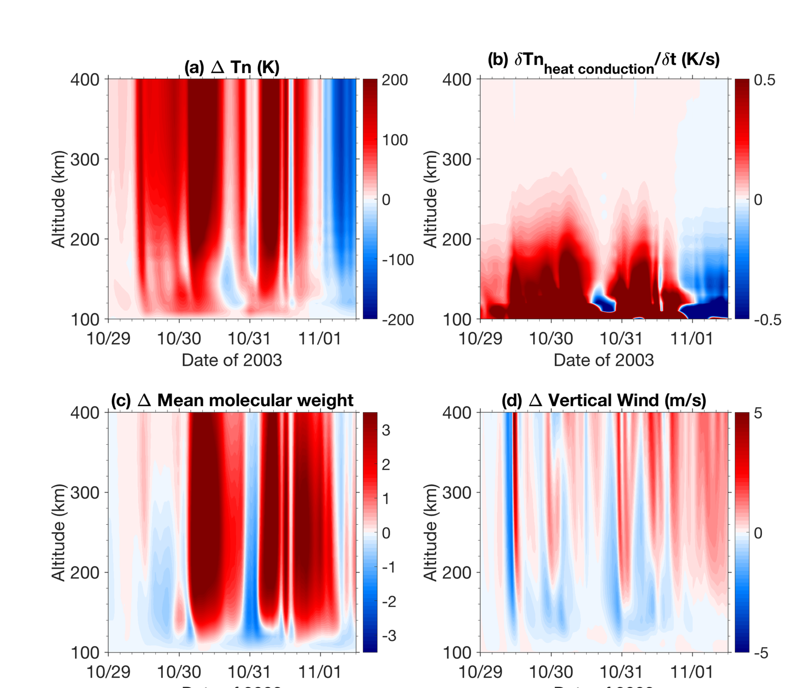


Figure 6. Changes of (a) neutral temperature, (b) temperature change rate due to vertical heat conduction, (c) mean molecular weight, and (d) vertical winds at the equator on the dayside (LT = 13) with respect to the reference value at the same universal time on 27 October from Run 3. The latitudinal distributions are at 120km (around the NO source) and 390 km (CHAMP altitude) respectively.

Summary

- The simulated overcooling in thermospheric density from the TIEGCM with the reaction rate of N(2D) + O2 from Duff et al. [2003] agrees better with the observations.
- The NO densities are remarkably different in different simulations, whereas the total NO cooling, which tends to be balanced with Joule heating and particle precipitation. The thermosphere recovery depends on the altitudinal NO emission per mass rather than the NO cooling flux alone.
- During the recovery phases, the temperature overcooling at NO production source region makes important contributions to the mass density overcooling during the recovery phase of this event. In addition, the density overcooling is not only controlled by neutral temperature, but also modulated by neutral winds.