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NCAR

The Physical mechanism Driving the Effects of Geomagnetic Storms in the Mesosphere and Lower Thermosphere Temperature and Winds at Middle Latitudes

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Motivation

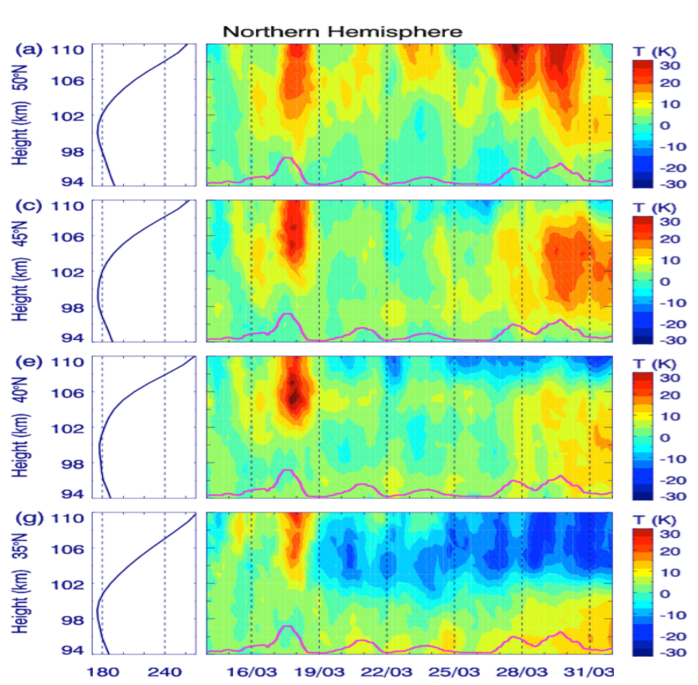
Recent ground- and space-based observations have shown that neutral temperature (Tn) in the mesosphere and lower thermosphere (MLT) region can have strong variations during storms. A number of physical processes have been proposed to explain these variations. However, most of the previous studies have been focused on the direct effects of energetic particle precipitation through chemical processes. Other possible physical mechanisms, including Joule heating, ion drag, and dynamics, have not been fully and self-consistently examined in the context of the global, coupled, mesosphere, thermosphere, and ionosphere system. Furthermore, the interplay between various processes in the MLT region during storms are not fully understood, leaving the causes of storm-time global thermal and wind response in the region unclear. Here, we use TIMEGCM to diagnostically investigate the mechanisms for the storm-time temperature and wind changes in the MLT region.

1. TIME-GCM

The TIMEGCM is a 3D global model that self-consistently simulates temperature, circulation, dynamics, photoionization, electrodynamics, chemistry, and composition of Earth's middle and upper atmosphere. The horizontal resolution of the model is 2.5°x 2.5° in geographic latitude and longitude. The vertical coordinate has 97 pressure levels with a resolution of 1/4 scale height. For the TIMEGCM runs in this paper, the high-latitude ion convection pattern is specified using the Heelis model driven by the 3-hour Kp index.

2. Lidar and Satellite observations

Recently, Yuan et al. [2015], using Na lidar data, found that, in the 04/2002 storm event, there were large changes in mid-latitude MLT temperature (Tn). Tn increased by ~ 44 K at 105 km during the storms at a mid-latitude station, Fort Collins, CO (41°N, 105°W, Fig. 1, Right,). Liu et al. [2018] studied the effects of the 2013 St. Patrick's Day storm (17th March, Fig. 1, left) on MLT Tn using TIMED/SABER data. The storm-time warming was larger than 15 K above 100 km and ~10 K below 100 km at middle latitudes.



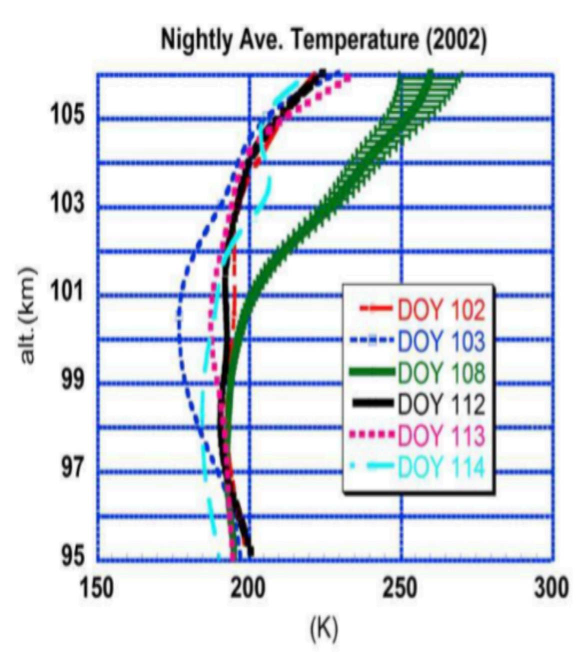
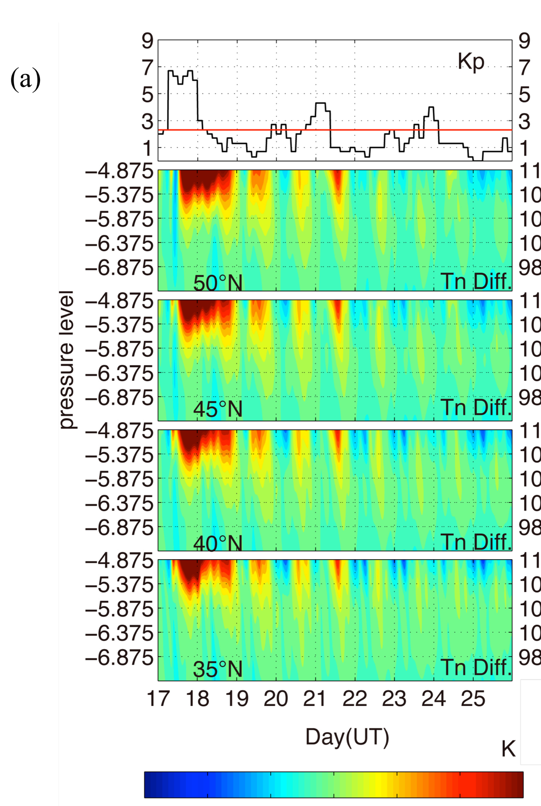


Fig. 1. (left) Zonal running mean SABER temperature differences between storm and quiet-time at different latitudes from 94-110 km around 17/03/2013. (right) The Na lidar nightly averaged temperature profiles during the April 2002 storm. The location was Fort Collins, CO (41°N, 105°W).

3. TIMEGCM simulations



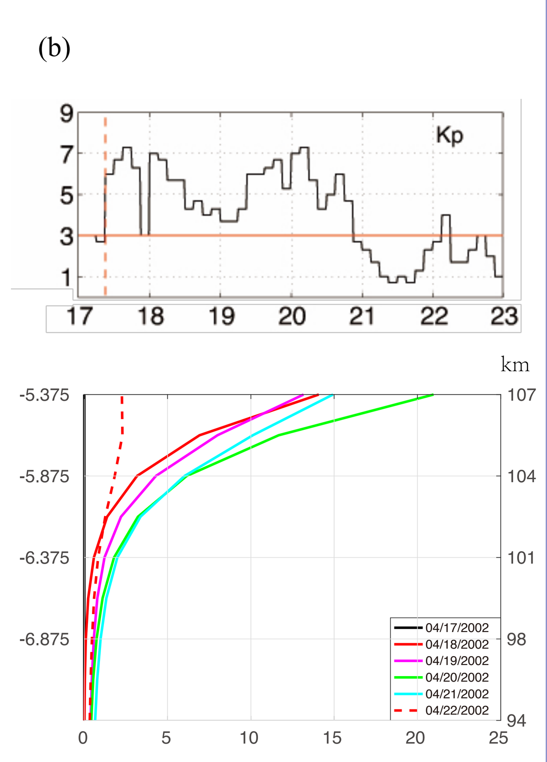


Fig. 2. TIMEGCM simulation of 03/2013 (left) and 04/2002 (right) storms. (top row) The black solid line shows the real Kp values during the storm and the red line is a constant Kp value of (a) 2.3 and (b) 3.0 for non-disturbed conditions. (Left, row 2 to 4) Tn differences at different latitudes. (Right, bottom) nightly averaged Tn differences. All at 105°W.

4. Thermospheric and Mesospheric Response at High Latitudes (60°N, 105°W)

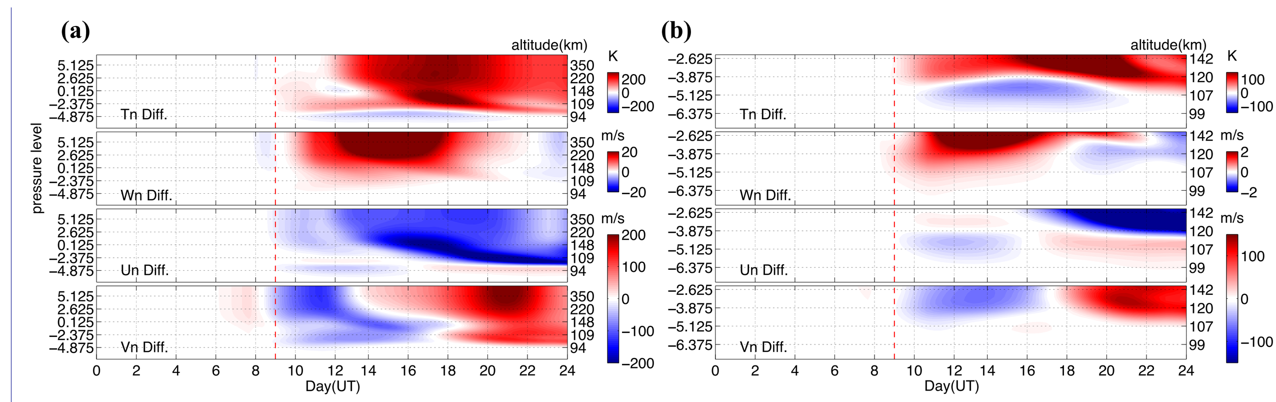


Fig. 3. TIMEGCM simulated temperature, vertical winds, zonal and meridional winds differences between storm and quite-time from (a) 90-400 km and (b) 94-150 km on 17/04/, 2002. The red dashed lines indicate the storm onset time. Tn, vertical and horizontal winds began to change at all height near 09 UT.

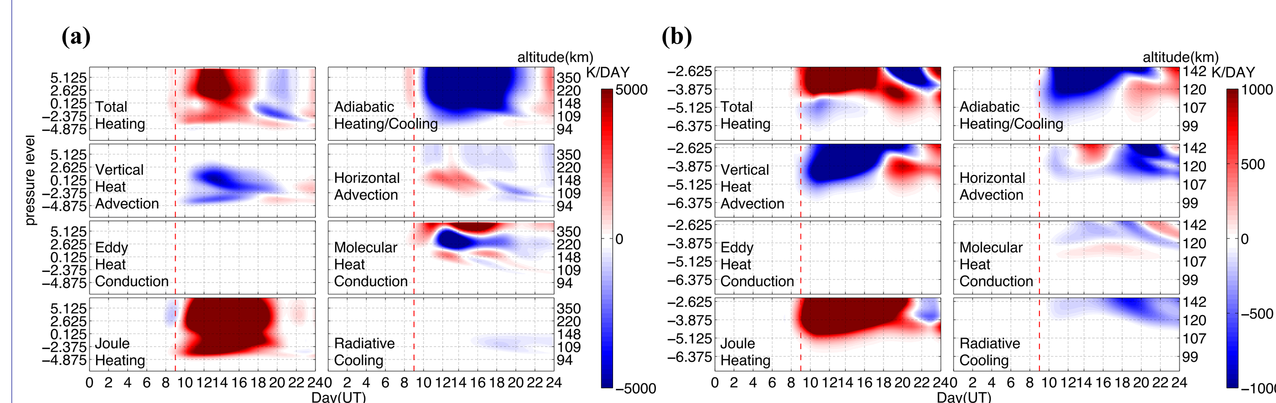


Fig. 4. Same as Fig. 3, but for the differences of heating terms. Joule heating, adiabatic heating/cooling, molecular heat conduction, and vertical heat advection are the dominate heating terms in the high latitudes.

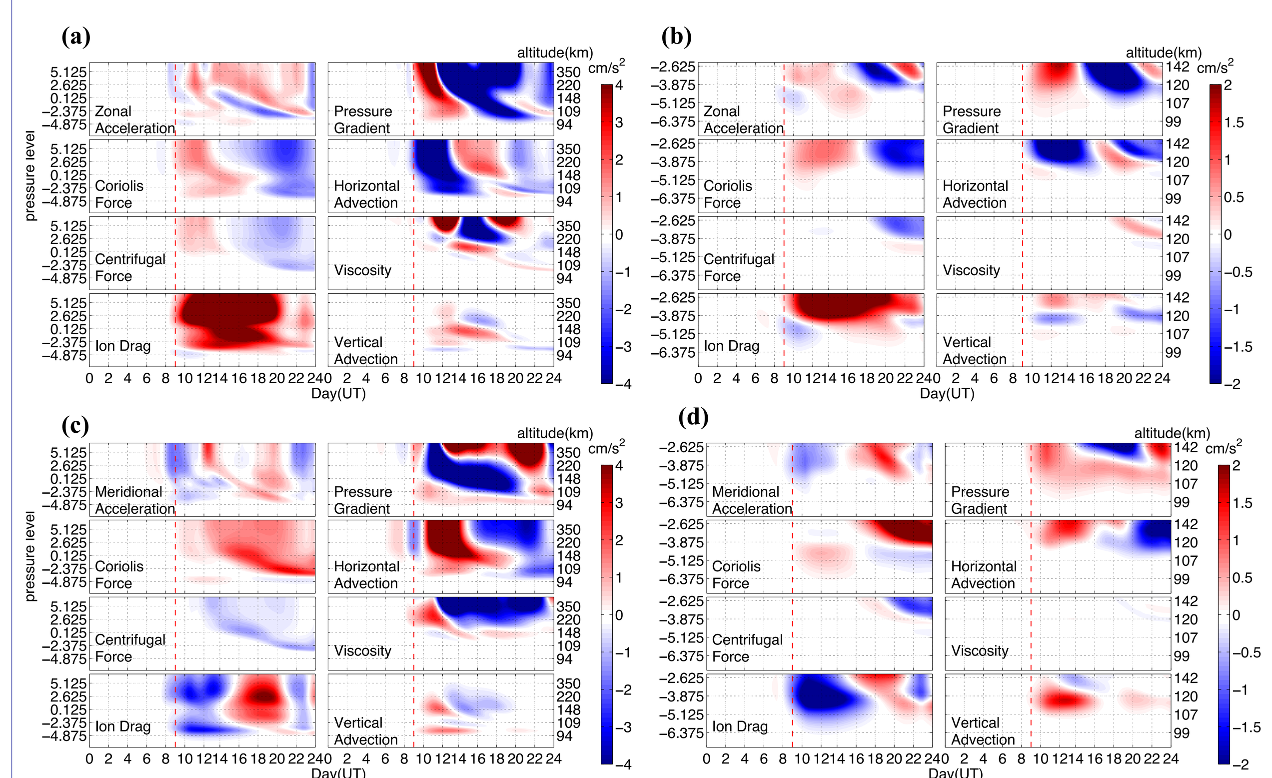
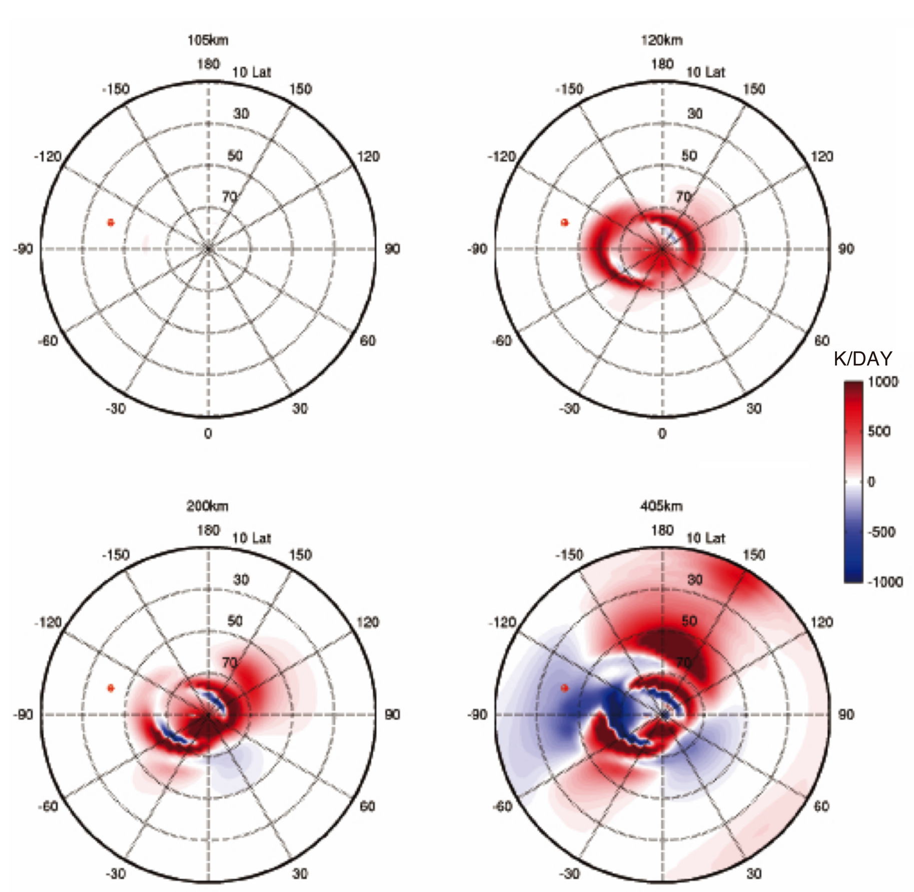


Fig. 5. Same as Fig. 3, but for the differences of (a, b) zonal and (c, d) meridional momentum forcing terms. Pressure gradient, Coriolis force, horizontal advec-tion, and ion drag are major forcing terms. Viscosity is important in the upper thermosphere. Ion drag is enhanced from the beginning of the storm.

5. Dynamic Processes

Fig. 6. Joule heating differences (storm-time minus non-disturbed) at 09 UT on 17/04, 2002 at different heights. The red crosses give the location of (40°N, 105°W). Joule heating cannot directly heat the MLT region in the middle and lower latitudes.



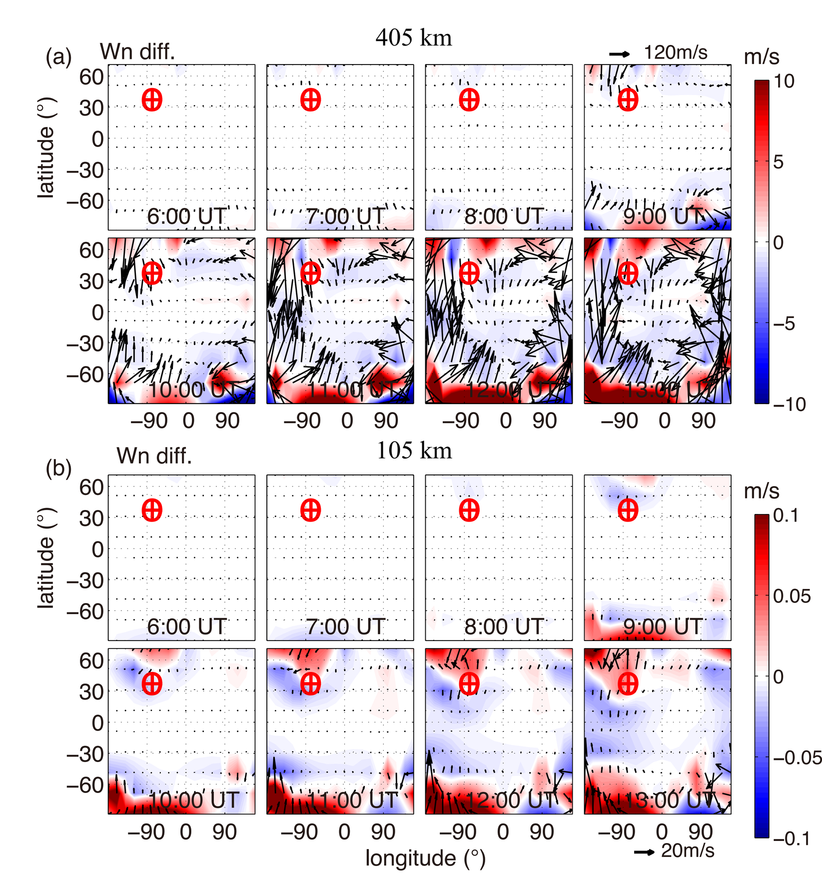


Fig. 7. Horizontal wind (vector) and vertical wind (contour) differences at (a) 405 km and (b) 105 km, from 06 to 13 UT. The red crosses give the location of (40°N, 105°W). Vertical winds are related to the gradient of horizontal winds. The changes in vertical winds in the MLT region appear to be caused by upper thermospheric vertical winds.

6. Thermospheric and Mesospheric Response at Middle Latitudes (40°N, 105°W)

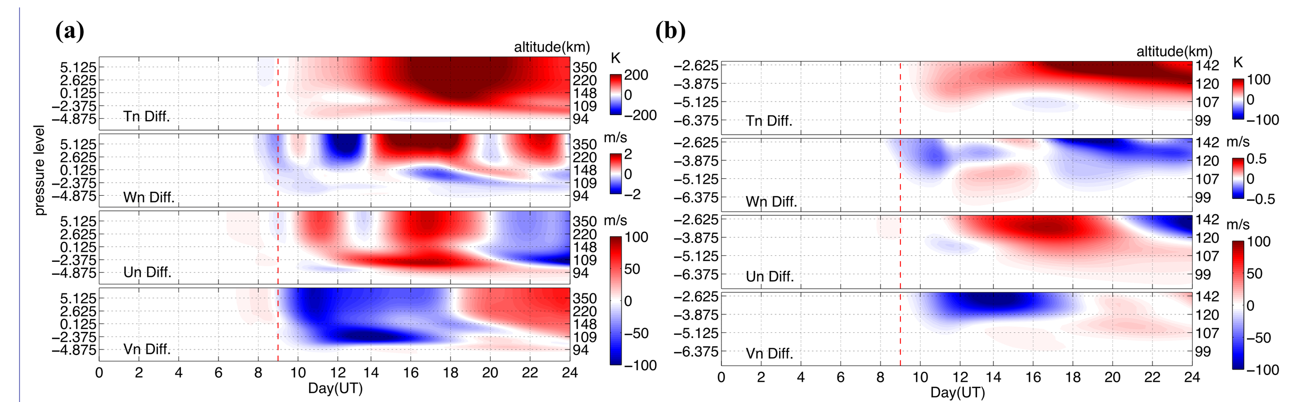


Fig. 8. Same as Fig. 3, but for 40°N. In the MLT region, vertical wind changes occur first, followed by Tn changes. Horizontal wind differences occur later. In the upper thermosphere, Tn, vertical winds and horizontal winds change at the same time.

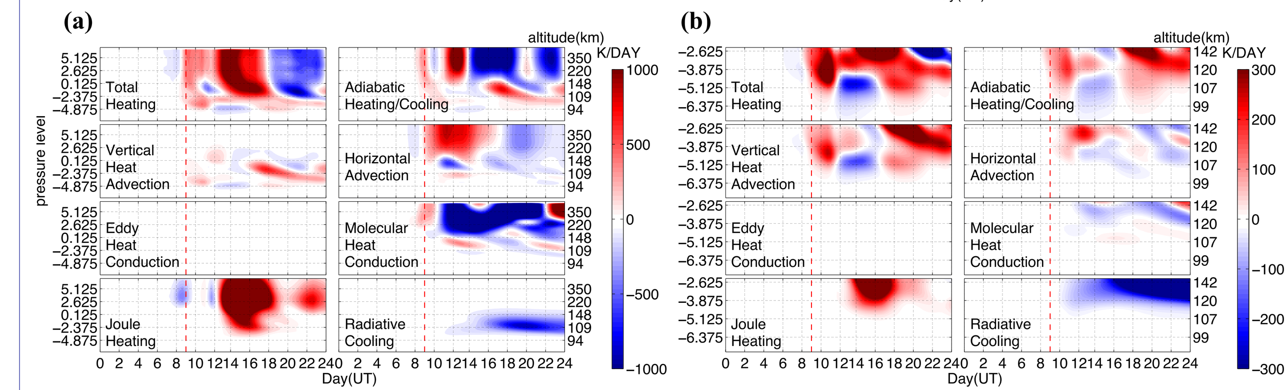


Fig. 9. Same as Fig. 6, but for the differences in heating terms at middle latitudes. Adiabatic heating/cooling, vertical heat advection are dominant heating/cooling terms in the MLT region at middle latitudes. These two major heating terms are related to vertical winds. Radiative cooling is important from 94 to 200 km. Molecular heat conduction and horizontal advection are important heating terms in the upper thermosphere.

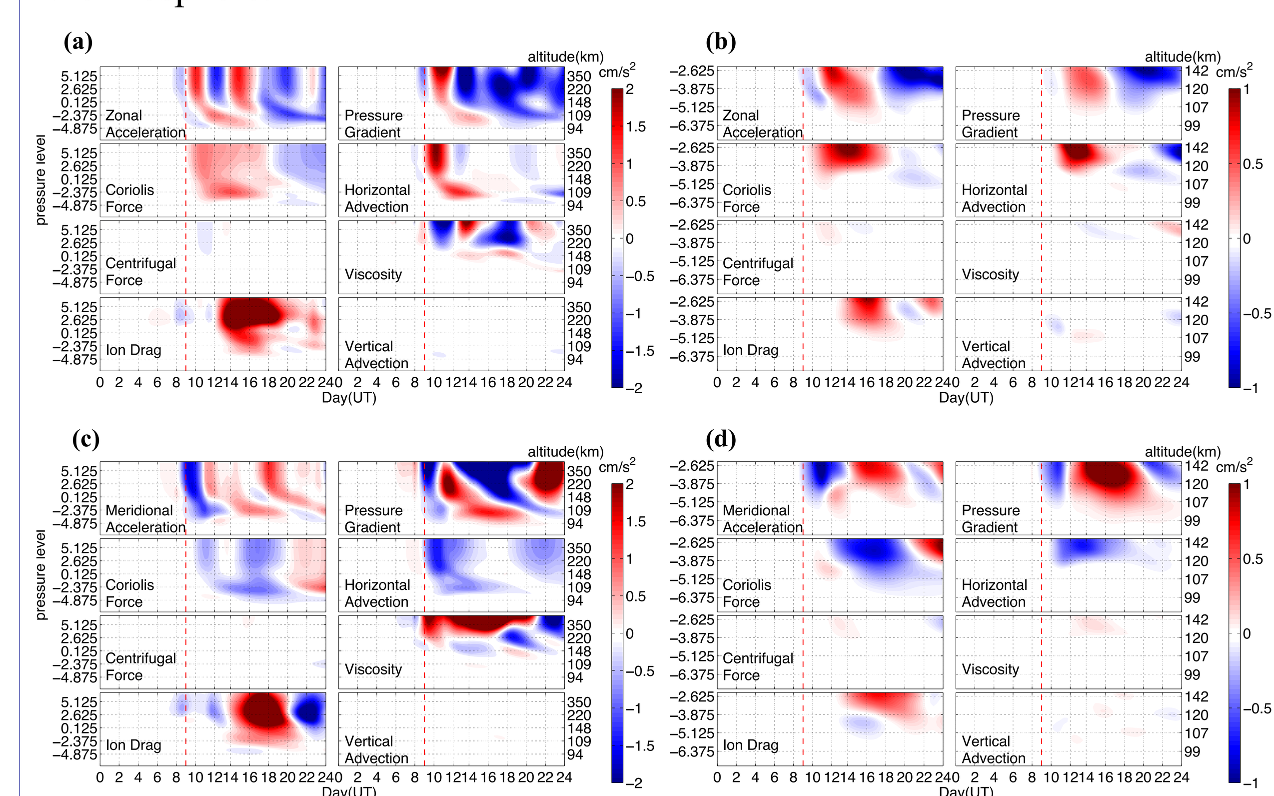


Fig. 10. Same as Fig. 6, but for the differences of (a, b) zonal and (c, d) meridional forcing terms. Pressure gradient, ion drag, and Coriolis force are the major forcing terms. The MLT horizontal wind changes at middle latitudes are closely related to local temperature changes during the storm. At the beginning of the storm, MLT wind changes are mostly caused by local temperature changes.

Conclusion

TIMEGCM simulations have been used to study the effects of geomagnetic storms on MLT temperature and winds at mid latitudes. By diagnostically analyzing TIMEGCM outputs in the MLT region from 94-150 km for the 17/04, 2002 storm event, we find:

(1) At high latitudes in the upper thermosphere storm-time temperature increases are mostly produced by Joule heating. In the MLT region, adiabatic heating/cooling and heat advection associated with vertical winds cause complicated vertical temperature structures with increased and/or decreased temperatures.

(2) Global wind circulation is changed due to pressure gradient that is related to high-latitude temperature variations and ion drag. The wind changes are greater and faster in the upper thermosphere. The changes in vertical winds in the MLT region are associated with those of the upper thermospheric vertical winds.

(3) At middle latitudes in the MLT region, vertical winds change first, followed by Tn changes, horizontal winds change later in the storm event.

(4) Adiabatic heating/cooling and vertical heat advection, both associated with changes in vertical winds, are the dominant heating processes at middle latitudes in the MLT region during storms. Horizontal heat advection and radiative cooling also contribute to temperature changes, but they occur later than the other major heating terms.

(5) Pressure gradient and Coriolis forces are the dominant momentum forcing terms at middle latitudes in the MLT region during storms. Ion drag and horizontal advection also contribute to wind changes.