The response of the ionosphere-thermosphere system to the August 21, 2017 solar eclipse

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ABSTRACT

On August 21, 2017, a total solar eclipse took place, casting a shadow that passed from the Pacific Ocean in a south-eastern path across the continental USA to the Atlantic Ocean. As a solar eclipse partially blocks the Sun's extreme ultraviolet (EUV) radiation, the temperature and electron density in the upper atmosphere are reduced dramatically due to decreased EUV heating and photo-ionization. This leads to further changes in thermosphere dynamics, which additionally interact with the ionospheric structure. Here we explore the response of the ionosphere and thermosphere to the August 21, 2017 solar eclipse with the Global Ionosphere Thermosphere Model (GITM) and compare the simulation results with various observational data sets and output from the Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM).

1) METHODOLOGY

GITM and TIME-GCM were both run with and without a mask to simulate the effects of the solar eclipse of August 21, 2017. GITM used the Weimer [2005] electric potential and Newell et al. [2013] auroral precipitation model, both driven by the solar wind and interplanetary magnetic field observed by the ACE satellite. TIME-GCM was driven by the Heelis [1982] electric potential model assuming a constant hemispheric power of 18 GW and cross-polar cap potential of 30 kV.

2) OVERVIEW OF THE SIMULATED THERMOSPHERIC RESPONSE

Both models show a strong decrease in neutral temperature as the eclipse progresses. Neutral winds converge towards the region of totality to fill the pressure hole this creates. GITM has a stronger neutral temperature response, while the wind response is stronger and persists longer in TIME-GCM.

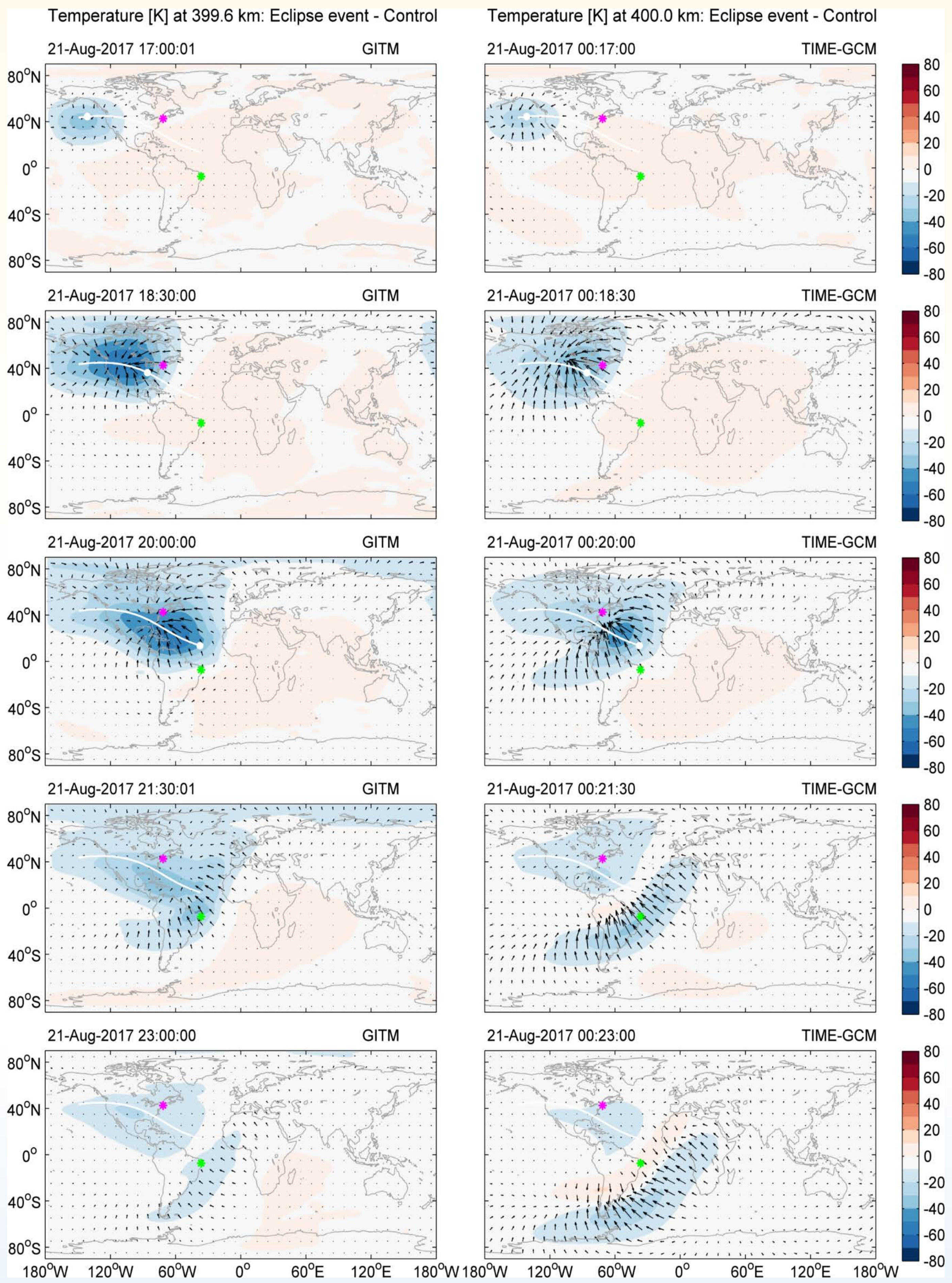

Figure 1. Snapshots of the response of the neutral temperature (coloured contours) and neutral wind (vectors) at 400 km to the solar eclipse event as simulated by GITM (left) and TIME-GCM (right). The white line indicates the trajectory of totality, with white dots marking the current location of totality where applicable. Magenta and green stars mark the locations of Millstone Hill and Cariri, respectively.

3) COMPARISON WITH FPI DATA FROM CARIRI (7.4°S, 36.5°W, 250 KM)

TIME-GCM reproduces the background temperature and eastward wind at Cariri quite well, while GITM reproduces the temperature during the eclipse event better. Both models struggle to capture the background and eclipse day northward winds, but are still able to capture some of the response, while the temperature and eastward wind responses are off for both models.

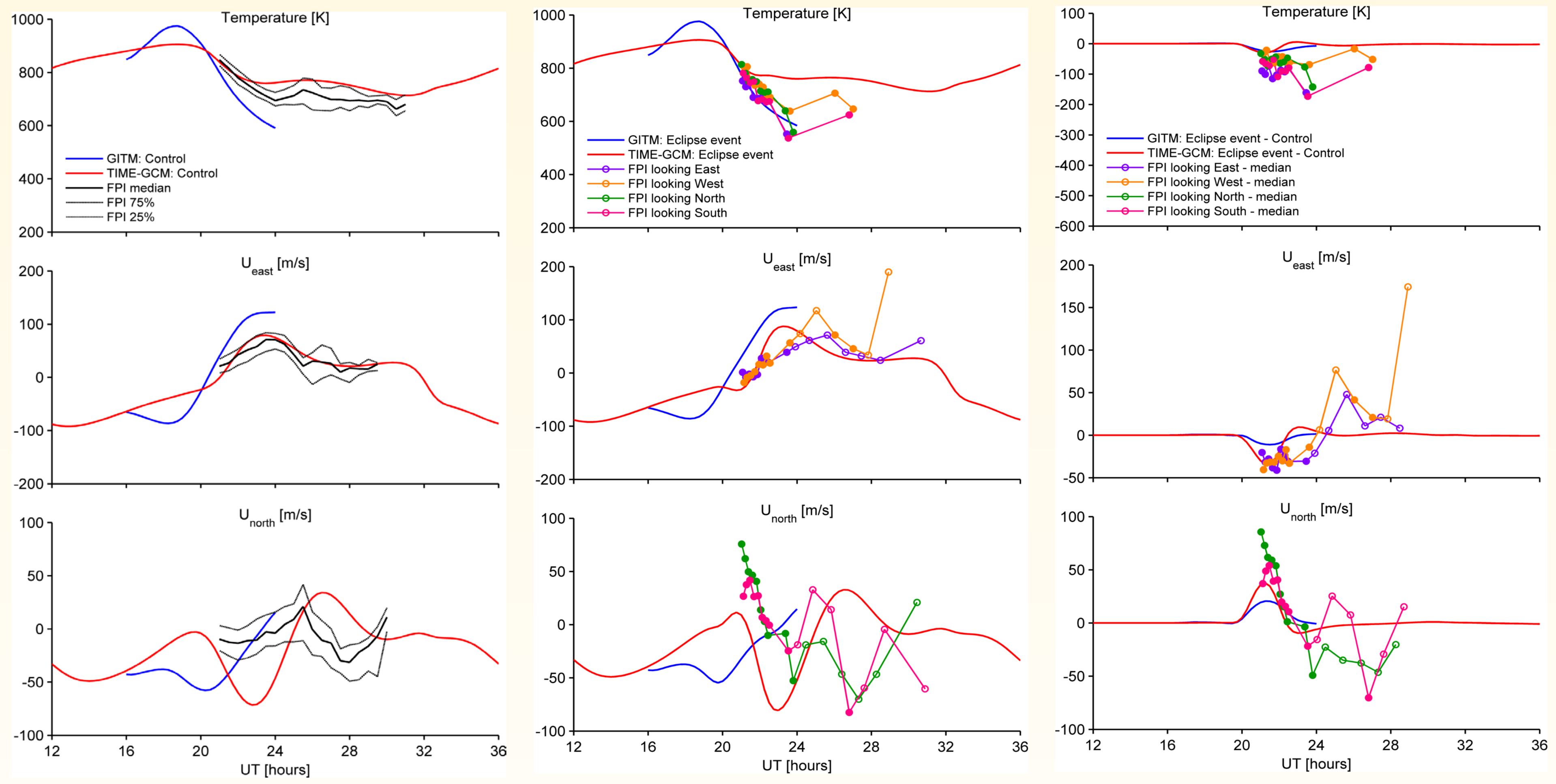

Figure 2. Temperature (top), eastward wind (middle) and northward wind (bottom) under background/control conditions (left), during and after the eclipse event (middle), and the response (event-control) at Cariri (7.4°S, 36.5°W) for GITM and TIME-GCM simulations and FPI measurements. Open circles represent lower quality data, taken during low brightness conditions.

4) EVOLUTION OF RESPONSES ALONG THE ECLIPSE TRAJECTORY

The maximum neutral temperature response in GITM quickly develops a lag of ~30 minutes behind totality, while the neutral density response only starts lagging about halfway through the event. There is almost no lag in either response for the TIME-GCM. The opposite is true for the ion and electron temperature responses. The TIME-GCM electron temperature response becomes positive half-way through the event and after the eclipse, which is not found with GITM.

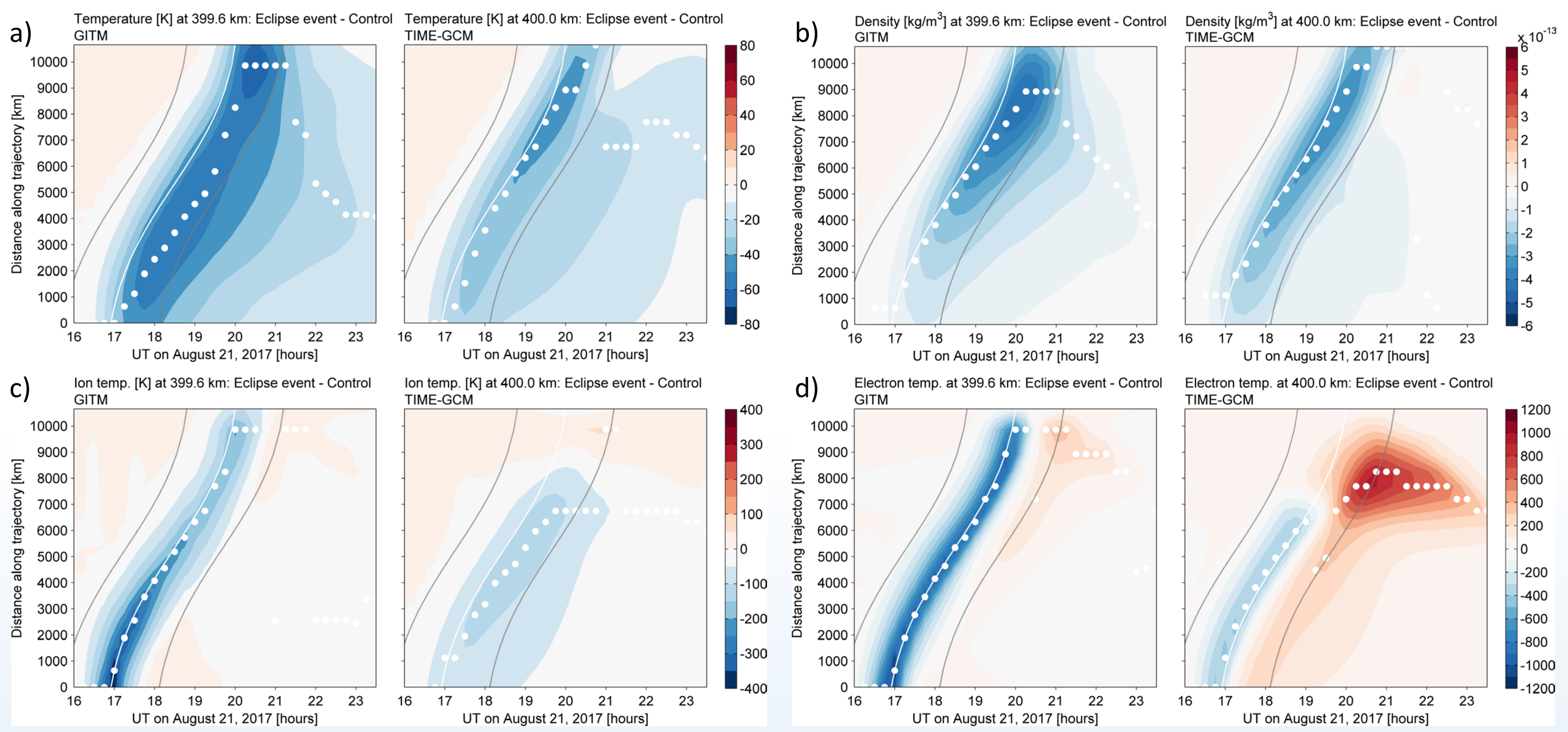

Figure 3. Response of the neutral temperature (a), mass density (b), ion temperature (c), and electron temperature (d) simulated by GITM (left panels) and TIME-GCM (right panels) plotted as a function of distance along the eclipse trajectory and time. The white line marks the path of totality, with grey lines indicating the approximate beginning and end of totality. The white dots mark the absolute maximum response at that time.

4) EVOLUTION OF RESPONSES ALONG THE ECLIPSE TRAJECTORY (CTD)

The maximum TEC response starts lagging behind totality earlier in GITM than in TIME-GCM, which is tentatively seen in GPS data as well.

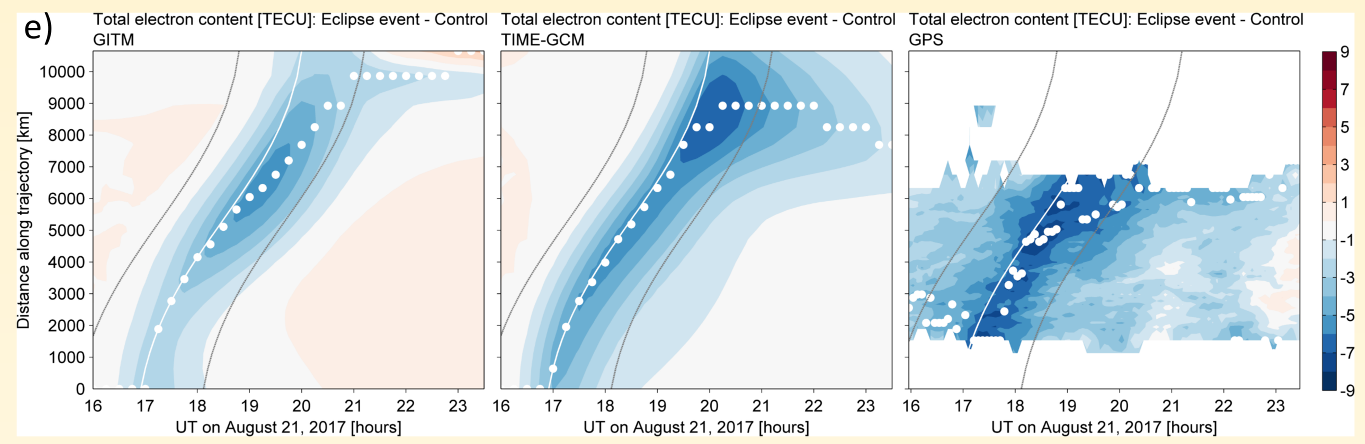

Figure 3e. Response of the total electron content (TEC) simulated by GITM (left) and TIME-GCM (middle) and observed in GPS data plotted as a function of distance along the eclipse trajectory and time. The GPS response was obtained by taking data from Aug 29 as representative of background conditions, following Coster et al. [2017].

5) COMPARISON WITH RADAR DATA AT MILLSTONE HILL (42.6°N, 71.5°W)

Both models overestimate the reduction in electron density and miss the post-eclipse enhancement. Both models also overestimate the electron temperature response and TIME-GCM shows a post-eclipse increase that is not observed. The ion temperature response in both models is fairly reasonable, but dies out too quickly. Both models show little response in vertical drift, in contrast to observations, but GITM appears to capture its structure slightly better than TIME-GCM.

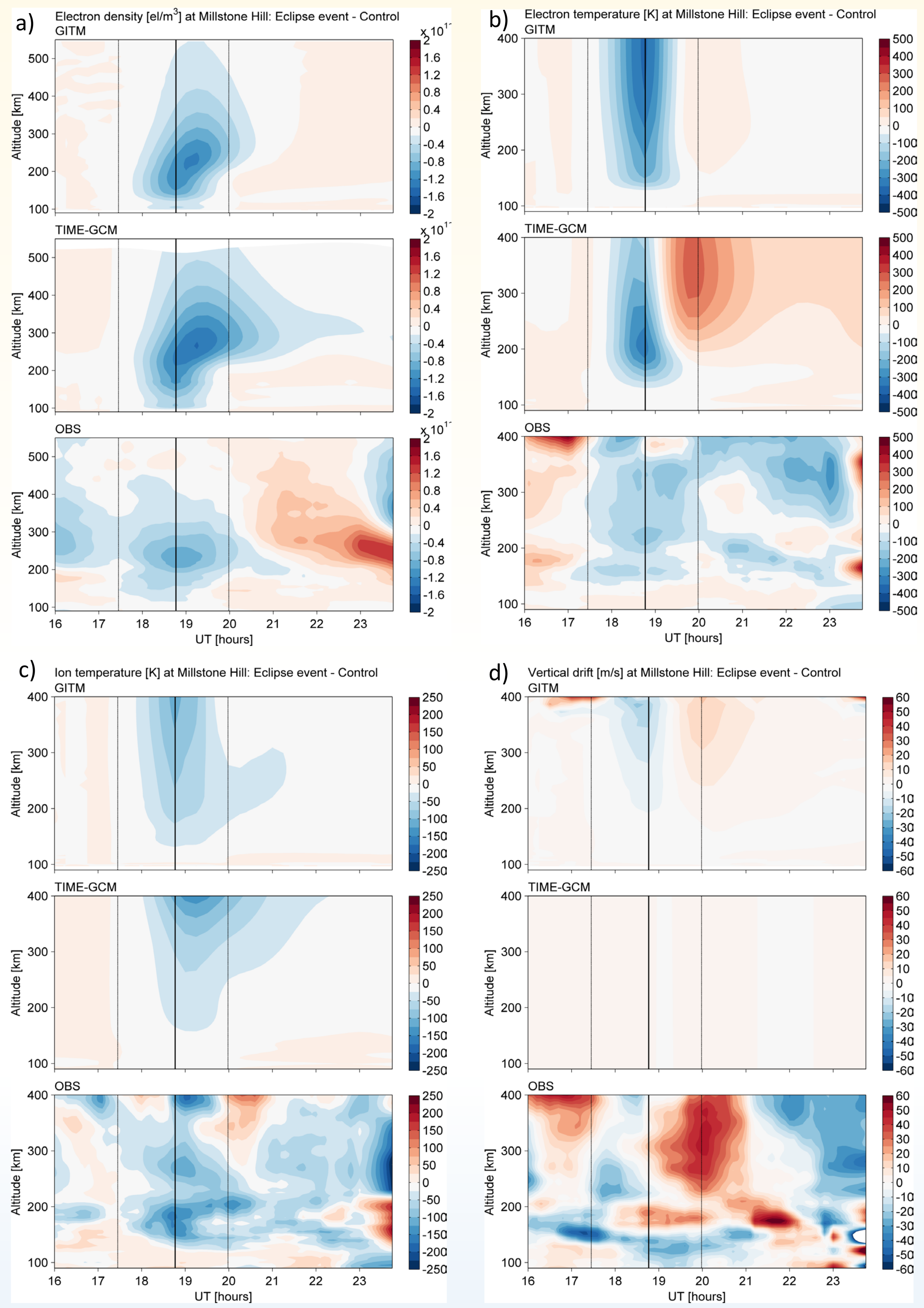

Figure 4. Response in electron density (a), electron temperature (b), ion temperature (c) and vertical drift (d) simulated by GITM (top panels), simulated by TIME-GCM (middle panels) and observed (bottom panels) at Millstone Hill (42.6°N, 71.5°W). The start and end of the partial eclipse are marked with thin black lines, while the thick black line marks the time of maximum obscuration.