Viscosity Effects on Low-Latitude Thermospheric Midnight Temperature Maximum (MTM)

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This study investigates the influence of viscosity on the MTM using the Global Ionosphere Thermosphere Model (GITM). By examining viscosity variations during the Equinox of 2013, we discuss their role in modulating MTM dynamics, which has significant implications for space weather.

INTRODUCTION

- The terrestrial thermosphere is important for understanding dynamics essential to satellite communication, navigation systems, and space weather forecasting, as it acts as the interface between Earth's lower atmosphere and space environment.
- Thermospheric dynamics are governed by complex interactions between solar radiation, geomagnetic activity, atmospheric composition, and transport processes like advection, convection, and gravity waves. Previous studies (Gardner L. C., et al., 2005; Killeen T. L., et al., 1982) have examined how these transport processes influence the dynamics of the thermosphere. However, the **forces that affect these processes are yet to be understood**. These forces include ion drag, pressure gradient, Coriolis force, and Viscosity.
- Neutral winds strongly control the transport of mass, momentum, and energy in the thermosphere. Viscosity controls the strength of the winds, so it indirectly controls the state of the thermosphere.
- One notable phenomenon within the thermosphere is the Midnight Temperature Maximum (MTM), which occurs predominantly in low-latitude regions (Spencer N. W., et al., 1979; Mesquita R. L., et al., 2018).

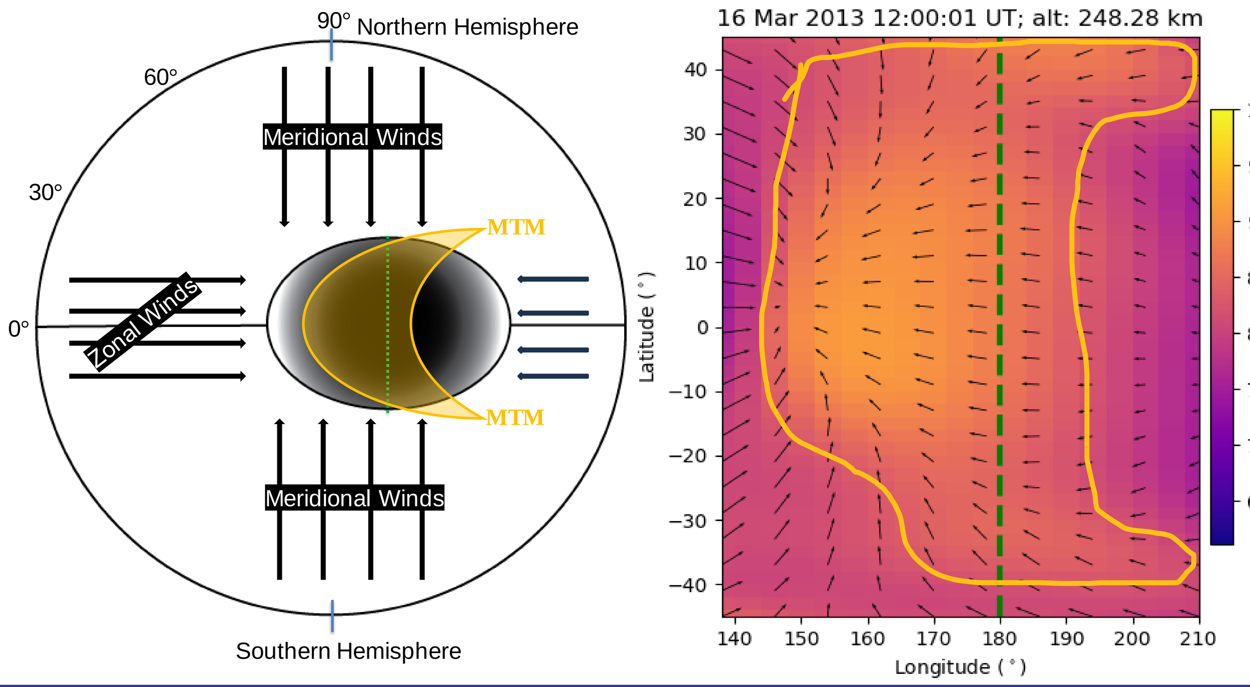


Fig. 1: Mechanism for MTM Formation

SCIENTIFIC OBJECTIVES

- ❖ Quantify how viscosity controls the MTM amplitude, location, and shape within the thermosphere.
- ❖ Introduce an innovative approach to analyzing the MTM, for altitude and latitude.

Research Questions

i. How does viscosity influence the occurrence, magnitude, and temporal variability of the MTM within the Earth's thermosphere, particularly in the low-latitude regions?
ii. What mechanisms govern the interaction between viscosity variations and MTM dynamics, and how do these mechanisms contribute to the observed behavior of the MTM?
iii. How does describing the influence of viscosity on MTM dynamics contribute to a deeper understanding of the fundamental processes governing the Earth's thermosphere?

METHODOLOGY

- We used the viscosity coefficient in GITM to compute the effects of viscosity using the principles of momentum exchange as described by the Navier-Stokes equations for horizontal dynamics.
- The eastward momentum equation, which includes the viscosity force term, F_ϕ is given by:

$$F_\phi = \rho_i v_{in}(v_\phi - u_\phi) + \frac{\partial}{\partial r}\eta\frac{\partial u_\phi}{\partial r}$$

- where η, the viscosity coefficient, for horizontal wind (neutral gas) is: $\eta_n = \frac{5p_n}{6v_{nn}}$

Table 1:
Range of Viscosity Coefficients (VC) Used in GITM

GITM	Multipliers on the Nominal VC
Run 1	0.1
Run 2	0.5
Run 3	1.0
Run 4	2.0
Run 5	10.0

- This equation is discretized and implemented in GITM to simulate momentum transfer at different scales, by altering the multipliers on the nominal η (as indicated in Table 1).
- Run 3 (VC=1.0) is the nominal η.
- The simulation was focused on March 16, 2013, which is part of the ascending phase of Solar Cycle 24. This day was characterized by moderate solar activity, providing an ideal context for studying the thermospheric dynamics under relatively stable geomagnetic conditions.

Approach to Analyzing MTM

To calculate the MTM, we adopt an approach that hinges on the temperature profile at 5° latitude.

We analyzed the temperature curve to identify the local maxima around midnight and the adjacent minima, thereby enabling us to quantify the MTM as the temperature differential at these key points:

1. Identify Key Points on the Temperature Curve: Local Maximum (D) and Adjacent Minima (A and C)
2. Determine the Linear Relationship Between Minima: Coordinates of Minima as points A and C
3. Calculate the Temperature at Midnight (B)
4. Quantify the MTM

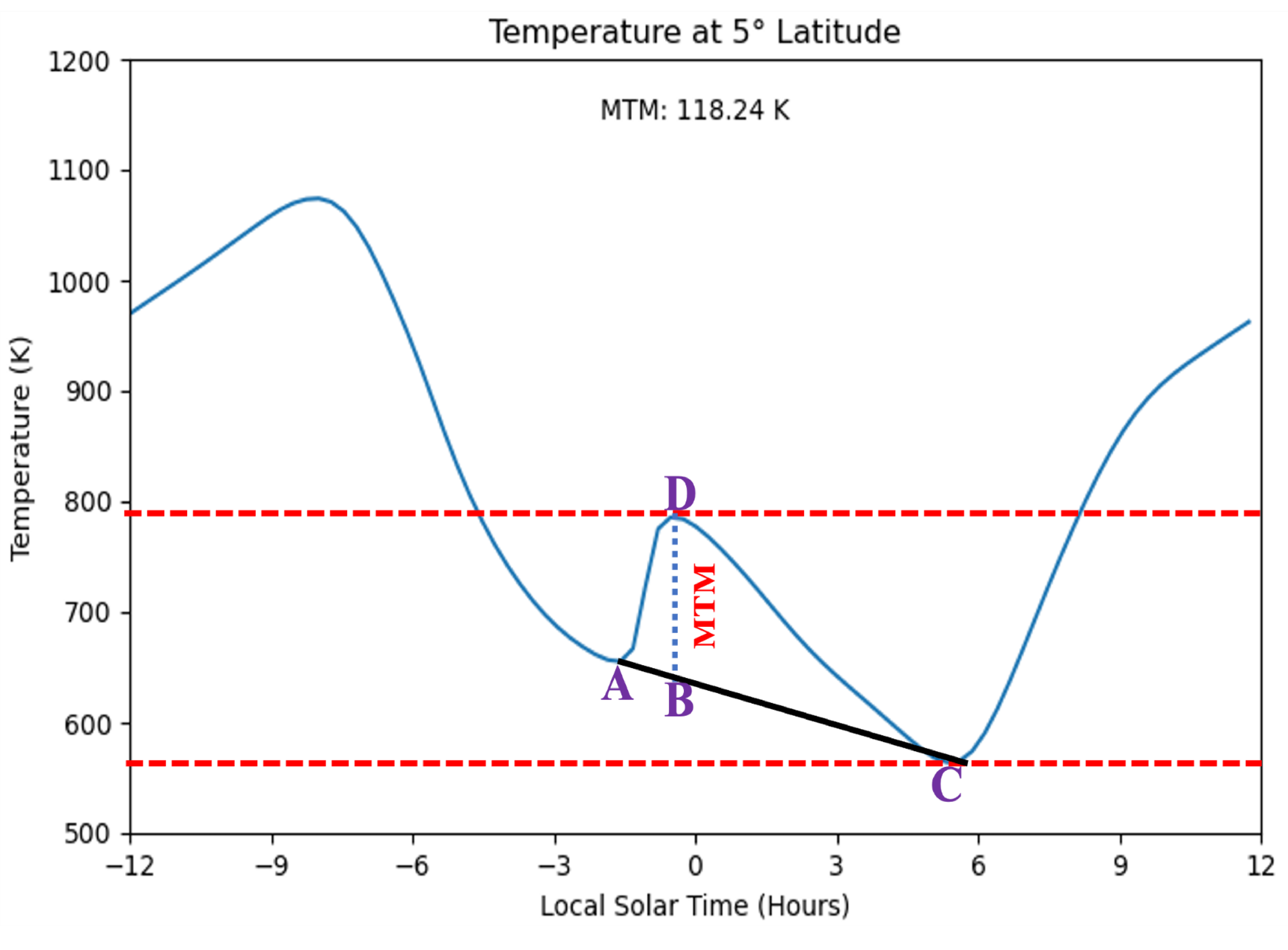


Fig. 2: Calculation of the Midnight Temperature Maximum (MTM)

RESULTS AND DISCUSSIONS

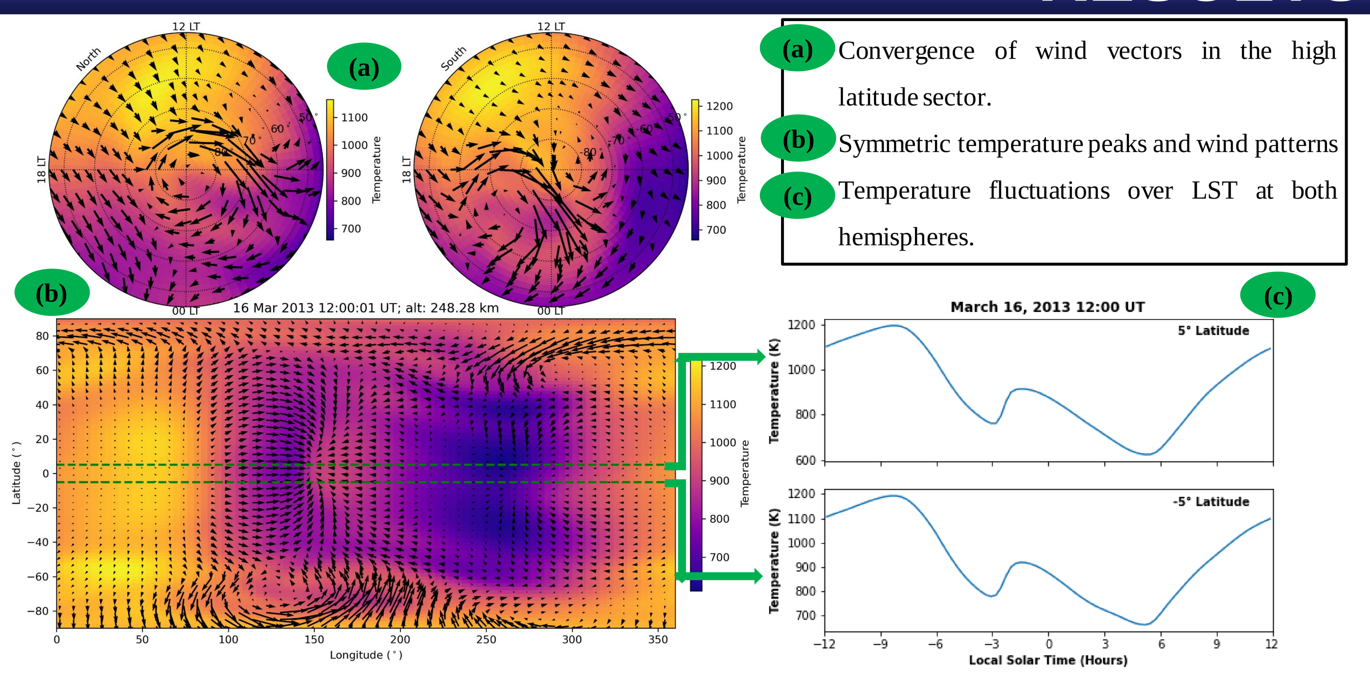


Fig. 3: Global hemispheric temperature distributions and wind patterns

(a) Convergence of wind vectors in the high latitude sector.
(b) Symmetric temperature peaks and wind patterns
(c) Temperature fluctuations over LST at both hemispheres.

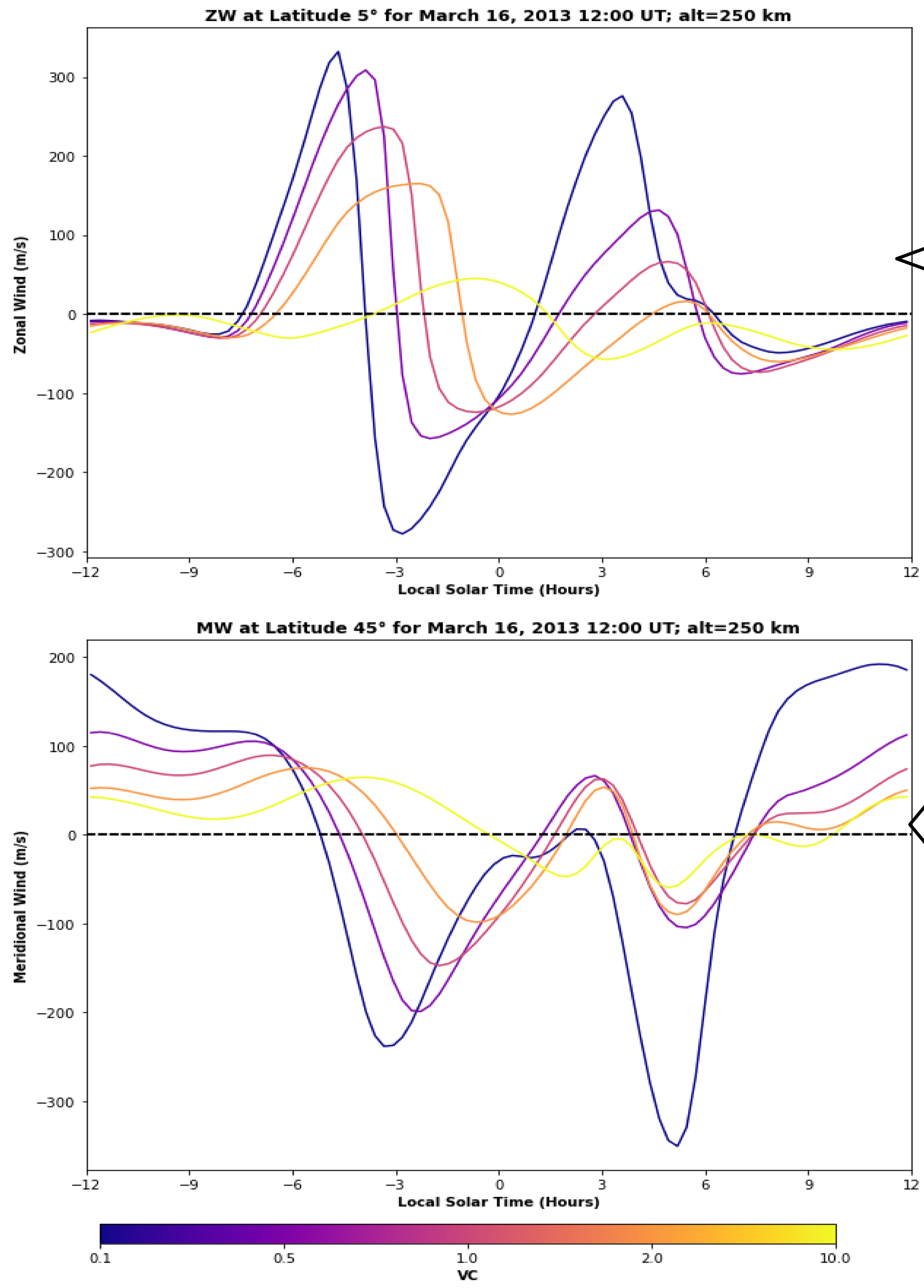


Fig. 5: Zonal and Meridional Neutral wind profiles

The low-latitude zonal neutral wind profiles show substantial variations in magnitude and direction with different viscosity coefficients.

At high latitudes, the meridional wind patterns show that the effects of viscosity are not uniform.

Variations in zonal and meridional winds due to different VCs modify the thermosphere's temperature behavior.

Comparing Figure 4 (panel c) and 5 (bottom panel), we see that convergent meridional wind patterns from high latitudes contribute to increased peak temperatures around midnight in the low-latitude thermosphere.

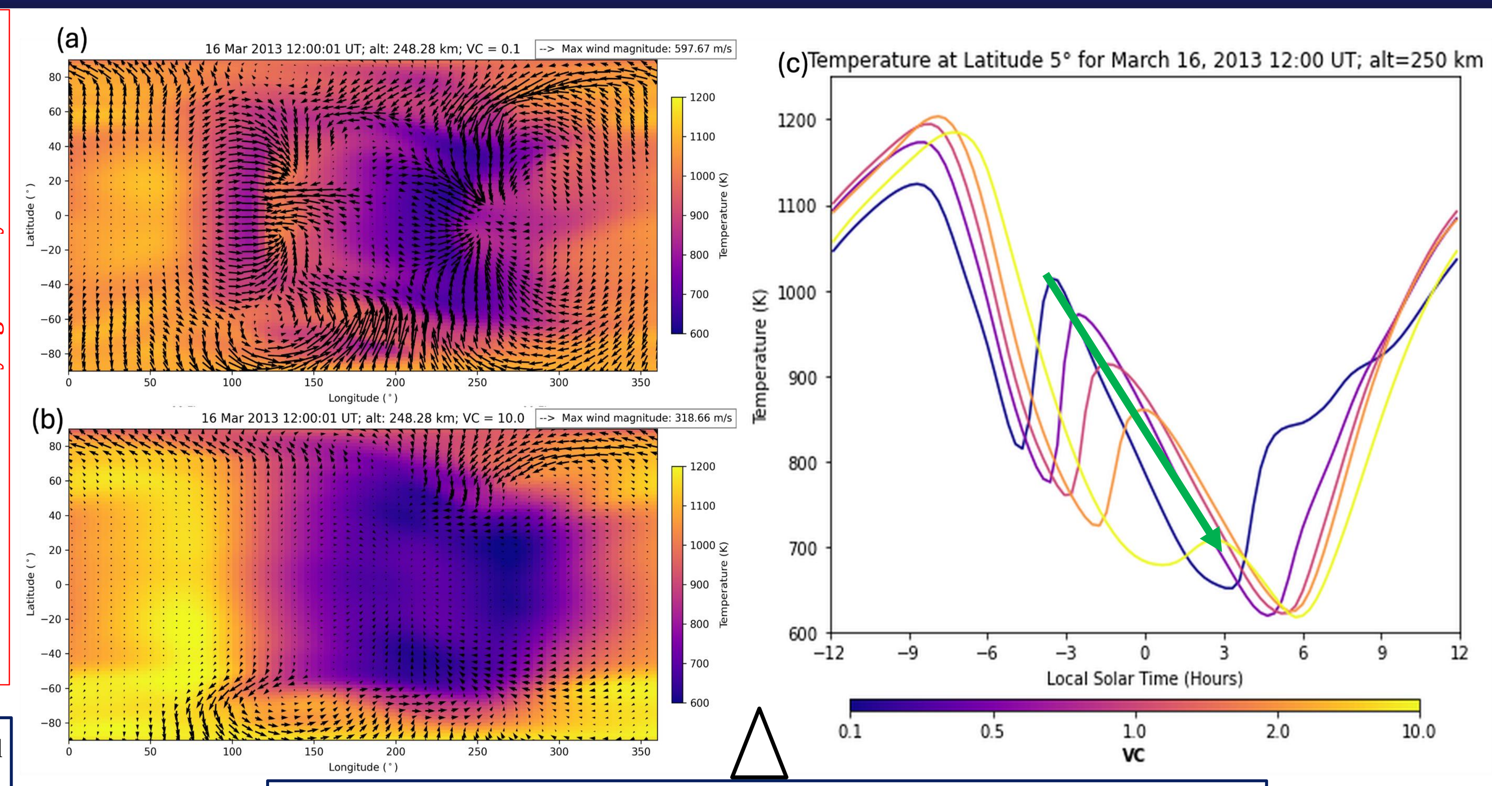
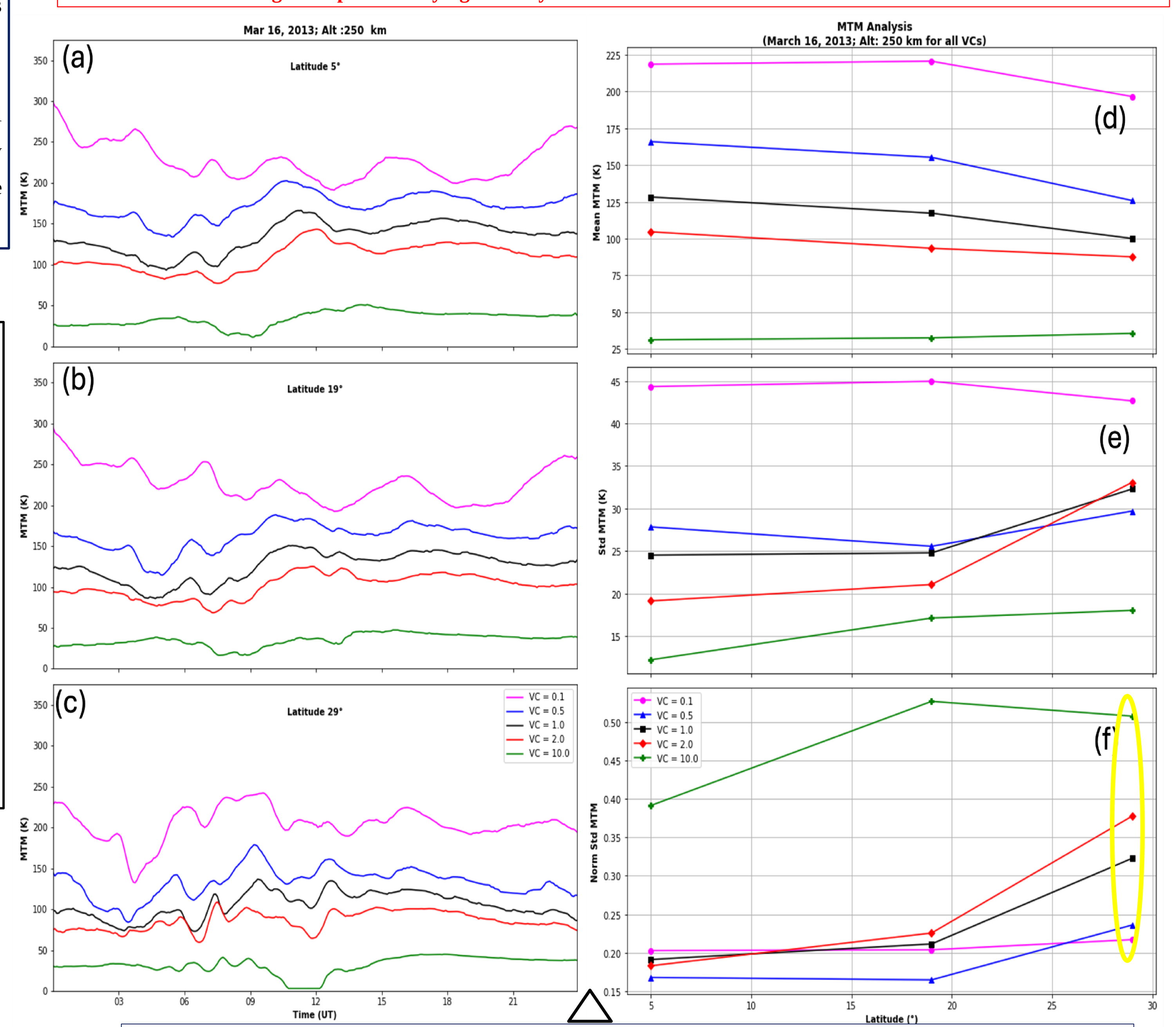


Fig. 4: Comparison of the global temperature and wind distributions with varying viscosity coefficients.

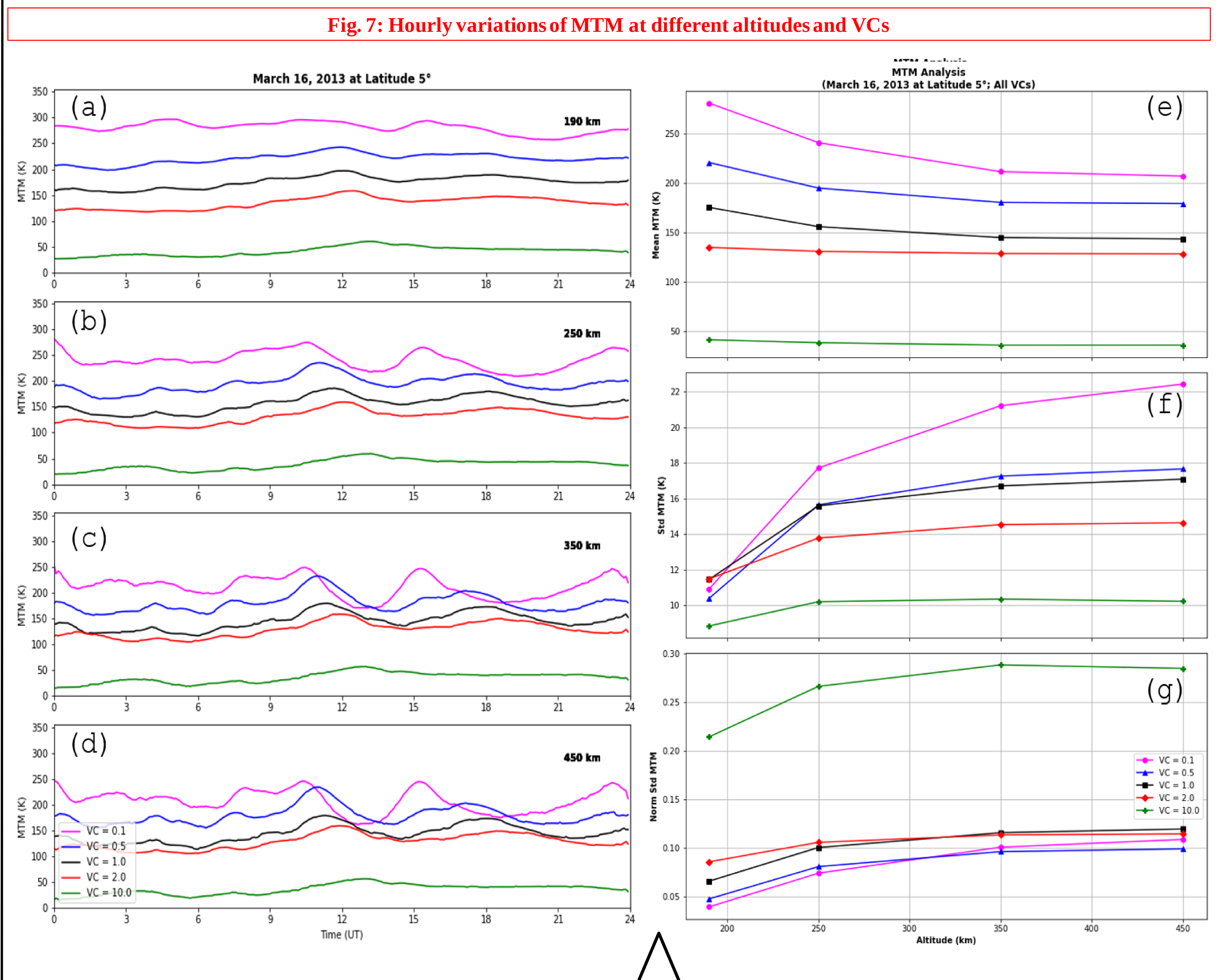
- Impact of low viscosity on the wind and temperature distribution.
- High viscosity shows a significant damping effect on the neutral wind patterns.
- Midnight temperature peak shifts with changing viscosity.
- There is an obvious correlation between viscosity and the MTM magnitude and timing.

Fig. 6: Impact of varying viscosity coefficients on MTM values at different latitudes



- Higher VC has decreased temperature variations and reduced peaks for MTM.
- As latitude goes up, the magnitude of MTM decreases.
- Latitudinal Variation of Mean MTM: There is a positive correlation between mean MTM and latitude.
- The standard deviation of MTM shows that there is variability of MTM with latitude and viscosity.
- The ratio between the mean and standard deviation of MTM becomes more variable at higher latitudes.

Fig. 7: Hourly variations of MTM at different altitudes and VCs



- At altitudes of 190 km and 250 km, the MTM profiles are less distinct but still show noticeable modulations with varying viscosity coefficients (VCs).
- Higher altitudes (350 km and 450 km) exhibit more pronounced variability in MTM, especially at VC=0.1.
- There is a consistent decrease in mean MTM with increasing altitude.
- The standard deviation of MTM increases with altitude.
- Normalized standard deviation slightly increases with altitude at lower viscosities but shows a significant increase at higher viscosity (VC=10.0).

CONCLUSIONS

- Viscosity significantly influences thermospheric dynamics, affecting neutral temperature, zonal, and meridional wind patterns, leading to differences in wind dynamics and temperature distributions (Fig 3, 4 and 5).
- The viscosity effects vary with latitude and altitude. Specifically, two mechanisms that may influence these variations include the Earth's magnetic field and tidal forces.
- At the baseline viscosity coefficient (VC=1.0), significant midnight sector dynamics are observed, with equatorial symmetry in temperature distributions.
- Lower VCs (e.g., 0.1) show increased structural complexity and dynamic temperature variations.
- Higher VCs result in more homogenized wind fields and temperature distributions.

FUTURE WORK

- Conduct comprehensive studies across different seasons to understand the seasonal dependencies of viscosity effects on the MTM and thermospheric dynamics.
- Utilize real-time satellite and ground-based observations to validate and refine GITM simulations.
- Compare the findings from GITM with other thermospheric models, such as the Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM).
- Perform targeted GITM experiments to test the hypothesis that the Earth's magnetic field and tidal forces govern viscosity-induced variations.

REFERENCES AND ACKNOWLEDGMENTS

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