TURBOPAUSE ALTITUDES AND MESOSPHERIC CLOUD FORMATION: EFFECTS OF WAVE PROPAGATION AND DISSIPATION IN THE MIDDLE-UPPER ATMOSPHERE. M. Slipski[1] and B. M. Jakosky[1], [1]LASP, University of Colorado Boulder (marek.slipski@colorodo.edu).

Introduction: Gravity waves have been observed throughout the atmosphere of Mars [1,2,3]. They transport energy and momentum through the atmosphere and can alter the circulation and thermal structure of the mesosphere and thermosphere [4,5]. Here, we investigate two effects of wave propagation and dissipation in the middle and upper atmosphere: the turbopause level and mesospheric cloud formation.

Wave breaking/saturation generates turbulence that drives mixing. The level at which the eddy diffusion coefficient equals the molecular diffusion coefficient is the turbopause. Below this level the atmosphere is well-mixed and above each species has its own scale height. We show that the turbopause varies spatially and seasonally across Mars using density measurements form the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft's Neutral Gas and Ion Mass Spectrometer (NGIMS) and temperature profiles form the Mars Climate Sounder (MCS) aboard the Mars Reconnaissance Orbiter.

CO_2 ice clouds have been observed repeatedly in the mesosphere of Mars [see 6]. Subcondensation temperatures have also been observed in the mesosphere, but models struggle to reproduce such low temperatures [7]. Perturbations caused by tides and gravity waves propagating into the middle atmosphere are thought to drive mesospheric temperatures low enough such that CO_2 clouds can form. Using temperature profiles from MCS, we assess the plausibility of this mechanism in regions and seasons where mesospheric clouds have typically been observed.

Variability of turbopause altitudes: The homopause level marks the change from the well-mixed lower atmosphere to the diffusive upper atmosphere. We extrapolate the N_2/Ar ratio downward from NGIMS densities to determine the homopause level. The average homopause altitude is 110 km, but altitudes as low as 60 km and as high as 140 km are found. The homopause does not track a constant density level. Assuming the eddy and molecular diffusion coefficients are equal at the homopause implies eddy coefficients vary from 12 to 1.2 x 10^4 m^2/s at the homopause. This range may reflect changes in the dominant breaking waves.

The homopause and turbopause are related concepts but they need not occur at the same level. While we cannot measure the turbopause directly, we can gain insight through the concept of the wave-turbopause [8,9]. The turbulence that drives mixing is generated by wave breaking/saturation. Above the turbopause, wave dissipation is weaker and waves can propagate more freely. Thus, the wave-turbopause marks the transition from strong wave breaking/saturation to freely propagating waves.

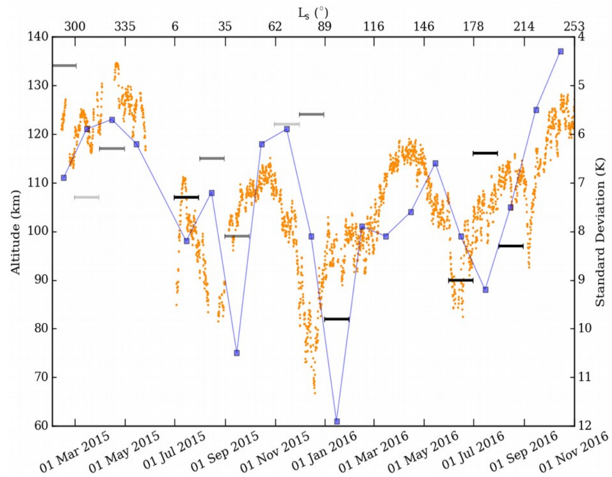

Figure 1: Homopause altitudes (orange) and wave-turbopause altitudes (black and gray bars) from Feb 2015 - Oct 2016. Blue squares are temperature standard deviations at 70 km (right axis, inverted).

Temperatures derived from a hydrostatic integration of Ar densities measured by NGIMS [10] show an isothermal temperature in the thermosphere above ~150 km. During deep dips, when MAVEN's periapse is lowered to ~120 km, a temperature increase is seen from 120 to 150 km. The static stability of this region, quantified by the square of the Brunt-Väisälä frequency, is higher than in the isothermal region. Waves can more readily propagate in highly stable regions. We use the standard deviation in temperature as a proxy for wave amplitudes which will, in the absence of dissipation, increase exponentially as density decreases exponentially. Temperature standard deviations between 120-150 km increase sharply, suggesting that waves propagate freely in this region.

Temperature profiles from MCS below 80 km are consistent with reduced static stability and the temperature standard deviations below 80 km do not increase exponentially with altitude. In some cases the temperature standard deviations decrease with altitude, suggesting wave saturation/breaking is strong. Extrapolating MCS and NGIMS temperature standard deviations, we find wave-turbopause altitudes that vary similarly to the homopause altitudes (Fig. 1).

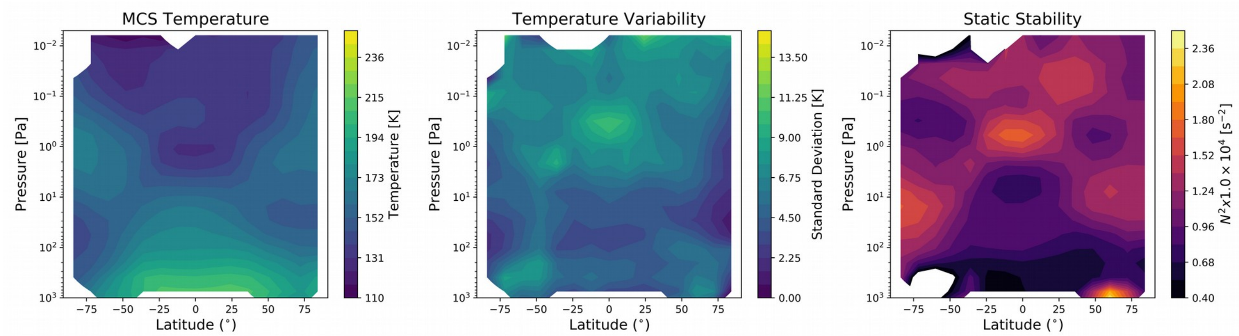

Figure 2: Cooler equatorial temperatures (left) above 40 km (~1 Pa) are associated with enhanced static stability (right) and high temperature standard deviations (middle) from Ls~20°–35° suggesting that gravity waves propagate more easily there than at mid-latitudes in the middle atmosphere.

Furthermore, the temperature standard deviations at 70 km are anti-correlated with the homopause altitudes (Fig. 1). Where wave amplitudes are relatively large at 70 km the transition from wave breaking/saturation occurs at a lower altitude bringing the homopause altitude down. This variation suggests that exospheric mixing ratios may vary strongly across the planet.

Gravity waves and mesospheric clouds: Temperatures compatible with CO_2 condensation have been observed in the atmosphere [11]. [12] presented further evidence of mesospheric CO_2 clouds and corroboration from orbiters has continued [6]. Although observed mesospheric clouds tend to be in regions of local temperature minima, the recorded temperatures are still frequently above the CO_2 condensation point [13,14]. Therefore, some additional cooling is required for clouds to form. Because gravity waves can have amplitudes of ~5–20 K at mesospheric altitudes, they can perturb the local atmosphere such that the temperature drops below the condensation temperature in regions of rarefaction [15,16].

We perform a similar analysis to that described in the previous section to assess gravity wave activity in regions and seasons with high frequencies of mesospheric cloud formation. For instance, martian mesospheric clouds have been observed predominantly near the equator after Ls~0° [6,13]. Low mesospheric temperatures are expected and observed at equatorial latitudes during this season (Fig. 2). In addition, the atmosphere is more stable above 40 km at the equator than at lower altitudes and higher latitudes (Fig. 2). Furthermore, temperature standard deviations increase rapidly above 40 km (Fig. 2), suggesting that wave propagation is fairly unhindered and amplitudes grow. This is evidence that gravity waves are important for the formation of equatorial mesospheric clouds during northern spring and summer. We present preliminary results further exploring the connection between temperature standard deviations in the middle atmosphere and previously observed mesospheric clouds.

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