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Long-lasting Mesospheric Inversion Layers in eCMAM30

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Abstract

Mesospheric inversion layers (MILs) are widely studied phenomena that reverse the usual temperature-altitude gradient due in part to planetary wave breaking and/or tides. This investigation uses the extended Canadian Middle Atmosphere Model (eCMAM30) for years 1997-2009 of dynamic and chemical data to explore the temperature and altitude distributions of long-lasting (>3 days) MILs. The temporal and spatial trends of MIL events are synoptically examined. Being the first time eCMAM30 is used to study the distribution of MILs events, this analysis presents an timely opportunity to compare results with other general circulation models. In agreement with WACCM [France et al. 2015] and lidar observations [Gan et al. 2012, Meriwether and Gerrard 2004], the eCMAM30 data-set shows similar trends in low and middle latitudes with the seasonal variability most distinct in the tropics during the equinoxes. The statistical properties of amplitude, thickness, duration and scale are also correlated with tides and wave breaking to elucidate the prevailing hypothesis of both middle and high altitude MILs as the they manifest in the eCMAM data set.

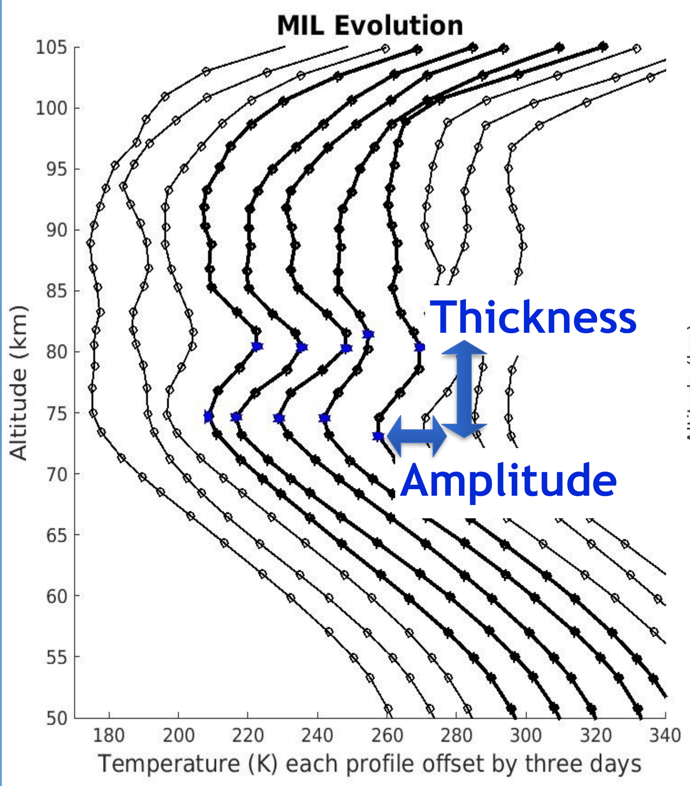

Figure 1. Altitude-Temperature profiles in the mesosphere, showing the development of MILs (in bold).

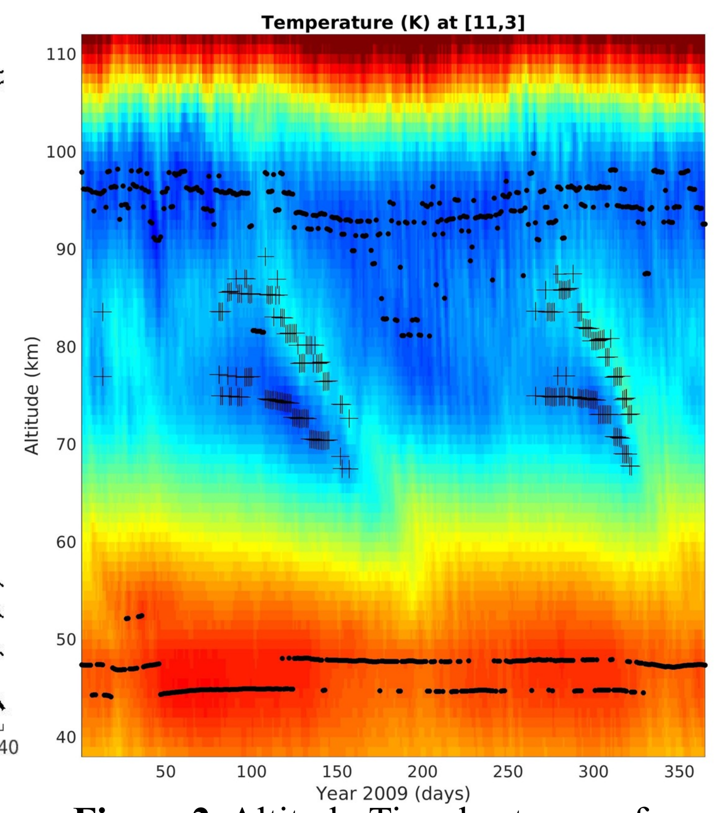

Figure 2. Altitude-Time heat-map of temperature, with mesopause/stratopause (dots) and MIL top/bottom (crosses)

Data and Methods of MILs

The present study aims to elucidate the statistical trends of long-lasting MIL events as they exist in the extended Canadian Middle Atmosphere Model. A long-lasting MIL event is a temperature inversion layer that satisfies the following conditions.

- The MIL altitude must be below the mesopause and above the stratopause. See the dots in Figure 2.
- The MIL must have a temperature-increasing lapse rate.
- The MIL amplitude (temperature inversion) must be greater than 10 K and a thickness (altitude scale of the temperature inversion) greater than 4 km [France, 2015]. See crosses in Figure 2 and blue dots in Figure 1.
- The MIL must persist over at least three of averaged temperature data.

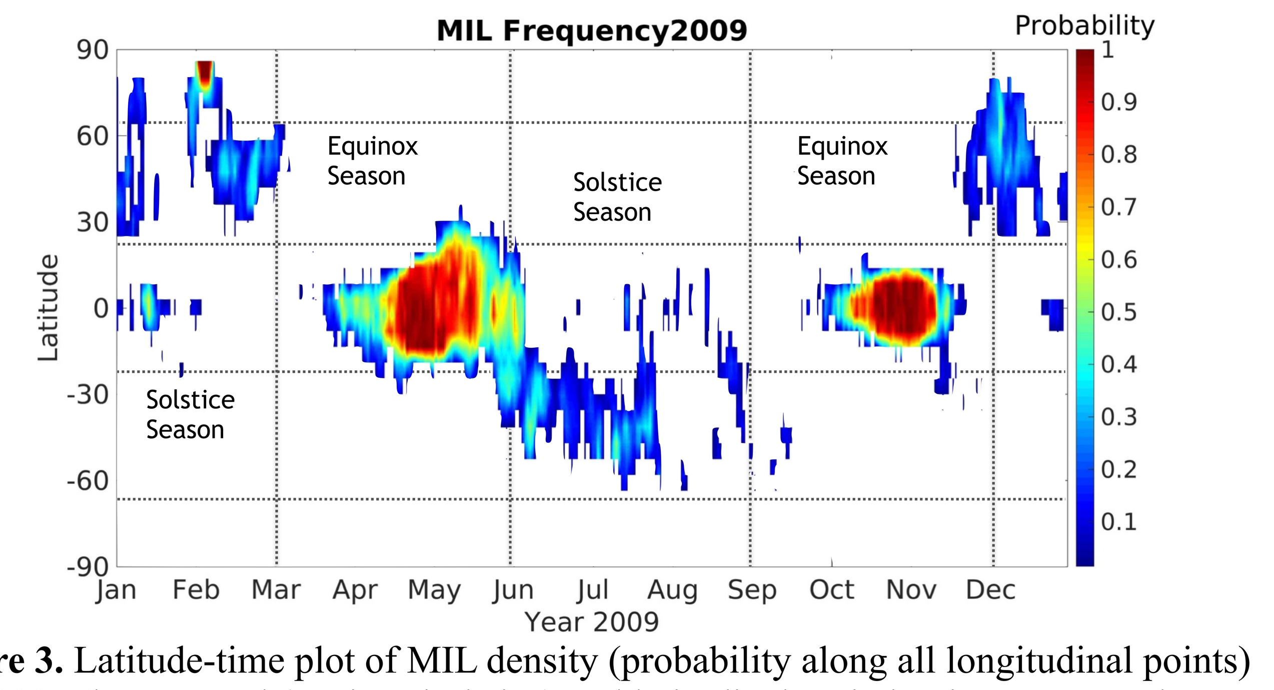

Figure 3. Latitude-time plot of MIL density (probability along all longitudinal points) for 2009. The seasonal (equinox/solstice) and latitudinal variation is pronounced.

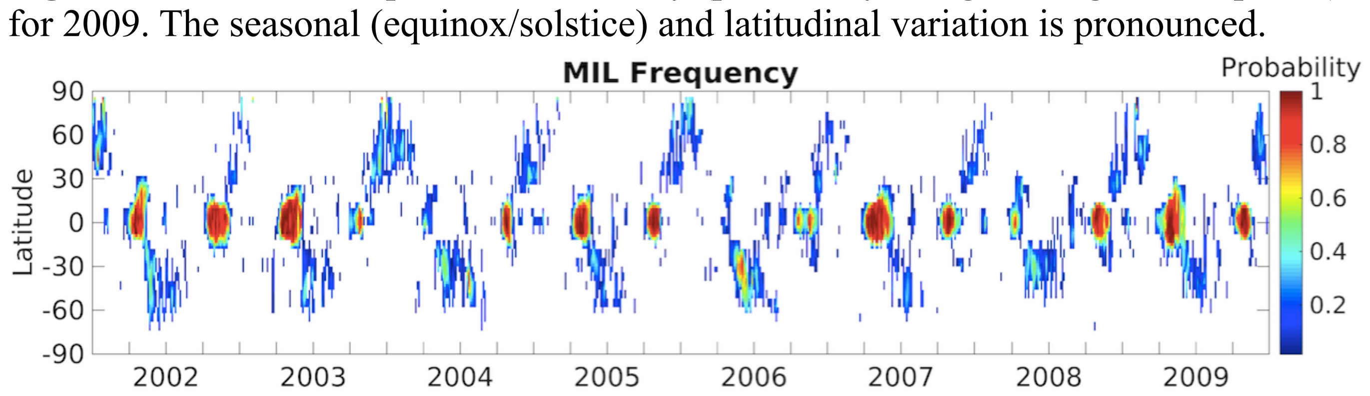

Figure 4. Same as Figure 3, only for years 2002-2009.

Time and Latitudinal Dependence

When MIL events are **longitudinally averaged** (Figures 3, 4 and 5), their distributions show strong seasonal and latitudinal dependences. In Figure 3 the tropical equinoxes (March/September) gradually increase and decrease in MIL density, peaking at 100% for the entire equatorial zone. At a given longitude MIL events can last up to 50 days. The solstices (June/December) show "wings" extending from the tropics into the middle latitudes of the winter hemisphere. Figure 4 shows this pattern consistently throughout the data-set, except when the spring equinox events are diminished every other year— most likely due to the quasi biannual oscillations [Garcia, 1997]. Figure 5(a) and (c) follow similar trends as the MIL density in Figure 3. Figure 5(b), 5(d) and 2 show the downward evolution of MIL events.

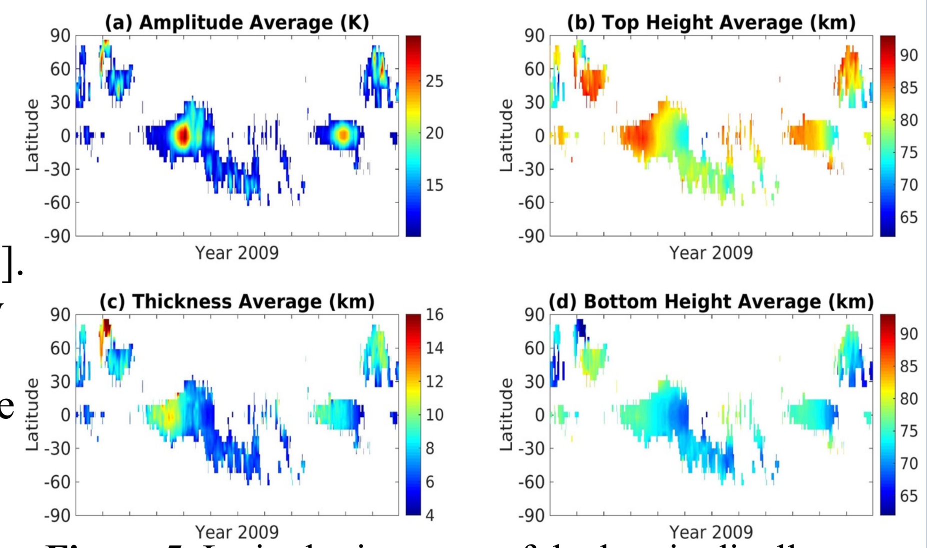

Figure 5. Latitude-time map of the longitudinally-averaged (a) amplitude, (c) thickness, (b) top and (d) bottom heights for year 2009

The **Time averaged** MIL densities for years 1979-2009 in Figure 6 show strong longitudinal and latitudinal trends. Long-lasting MILs events occur most frequently during the equinox seasons in the tropics, meaning that they are most likely tidally driven. The solstice events, however, primarily occur in the middle latitudes as shown in Figures 3, 4 and 6(c). Note the non-migrating tides in the tropics and middle latitudes. Also note that there are much fewer MIL in the Antarctic, even though the two hemispheres has an equal number of MIL events in total. Figure 10 shows that Arctic MIL events have greater amplitudes and thicknesses— a sign of planetary wave phenomena.

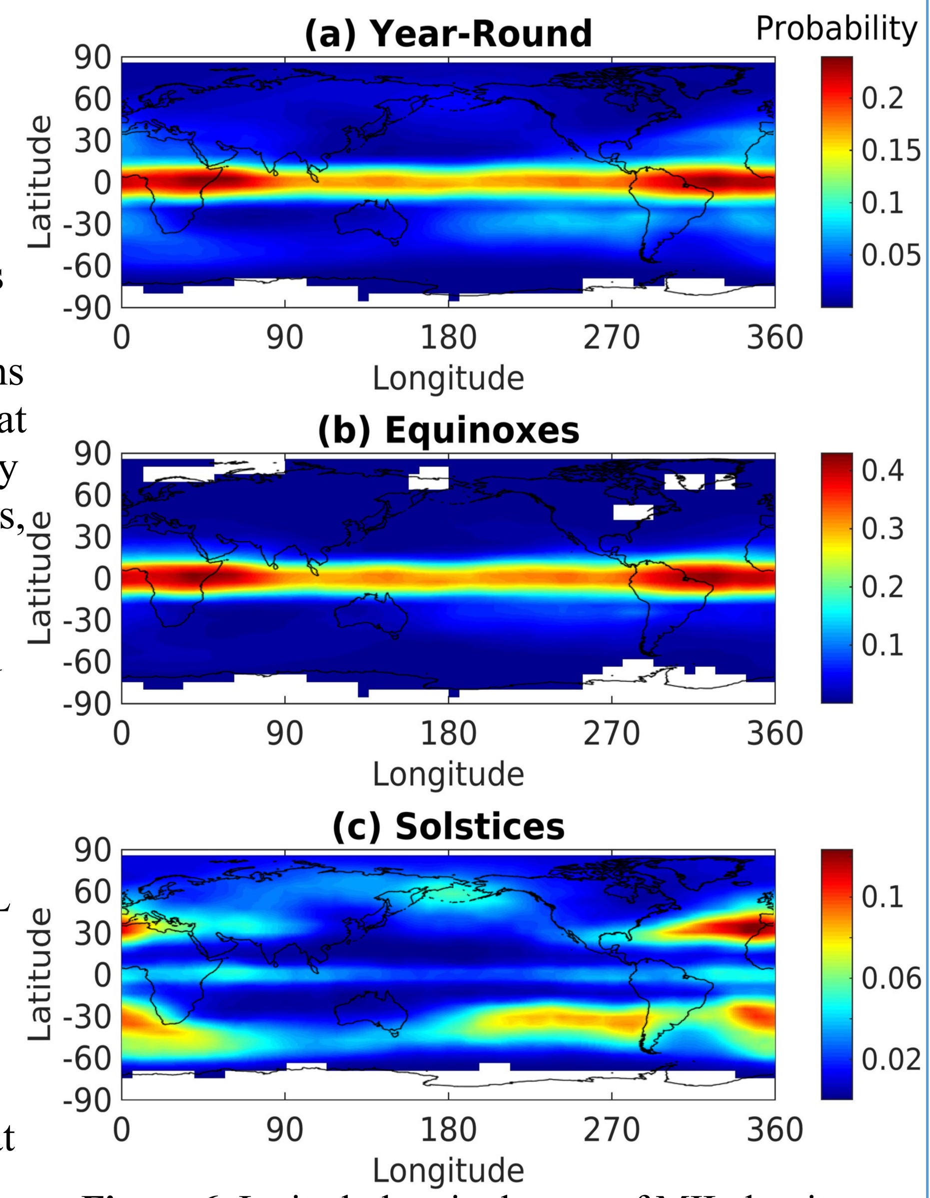

Figure 6. Latitude-longitude map of MIL density (time averaged) for 1997-2009 (a) year-round, (b) equinox and (c) solstice seasons.

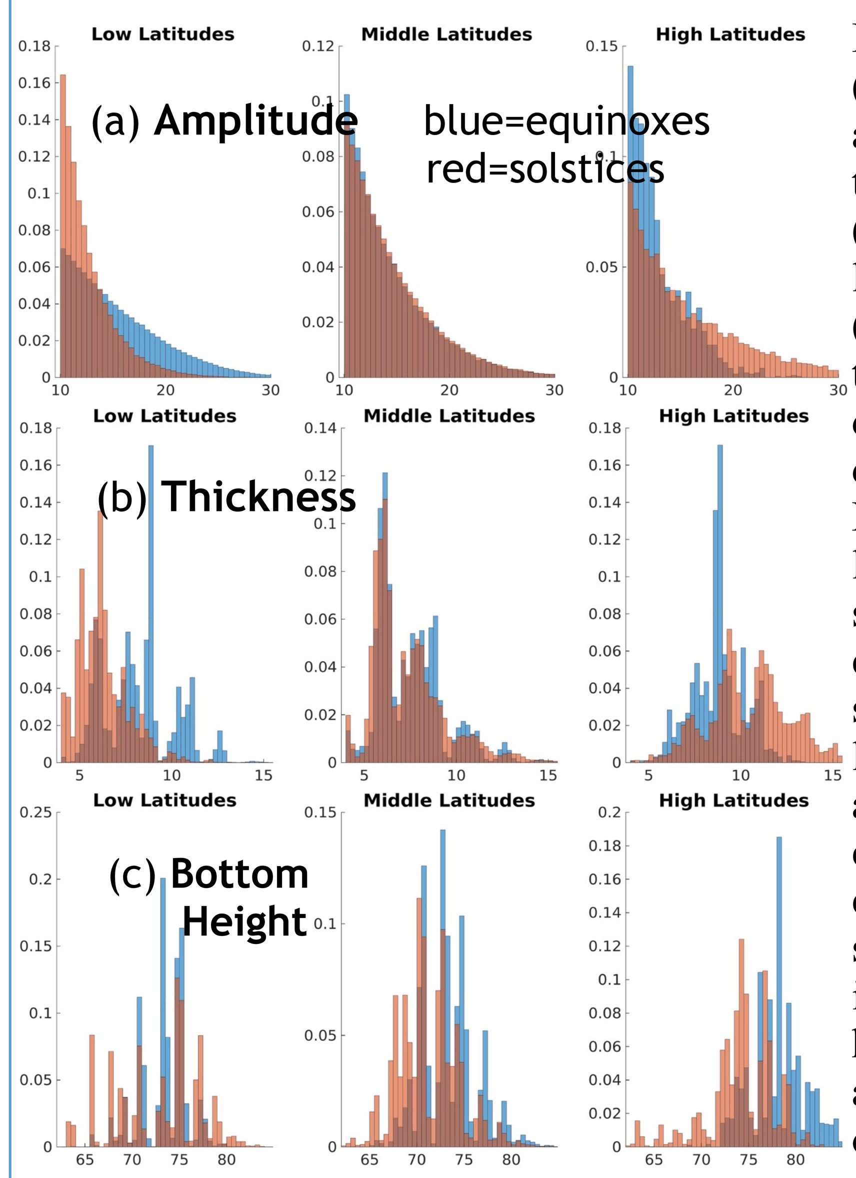

Figure 7. Histograms for MIL (a) amplitude, (b) thickness and (c) bottom height during the (blue) equinox seasons and the (red) solstice seasons for (left) low, (center) middle and (right) high latitudes illustrate the seasonal and zonal distributions for MIL events during the years 1979-2009. MIL events in tropics and high latitudes show the most seasonal variance, mirroring each other in all three metrics: solstice amplitudes in the low latitudes resemble the equinox amplitudes in high latitudes, etc. Middle latitude MIL events, however, show little seasonal variance, especially in amplitude and bottom height. MILs in high latitudes are both higher and thicker, occurring mostly in the Arctic, via Figure 10.

MIL Amplitude, Thickness and Height

The year-round **time averaged** values for MIL amplitudes, thicknesses and top/bottom heights are given in Figure 10. Here too, amplitude follows the trend of MIL event density in Figure 6(a). Contrasting the poles, Arctic events have greater amplitudes/thicknesses and lower heights compared to Antarctic events.

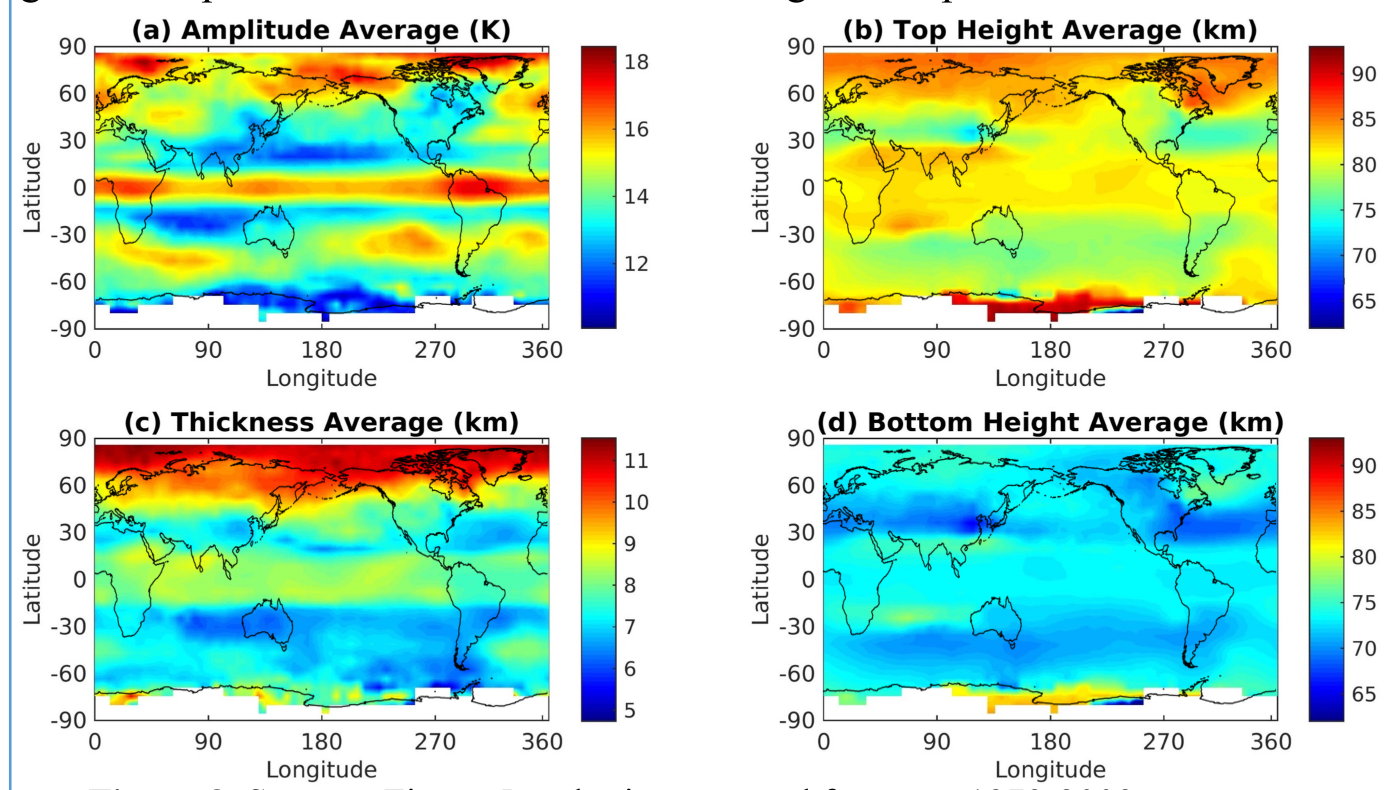

Figure 8. Same as Figure 5, only time-averred for years 1979-2009.

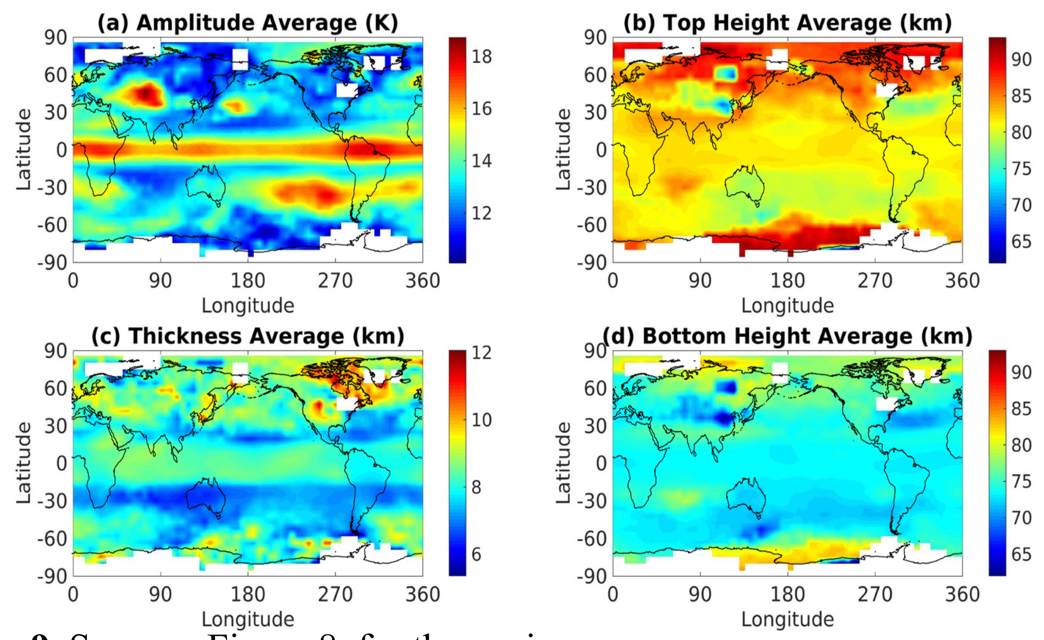

Figure 9. Same as Figure 8, for the equinox seasons.

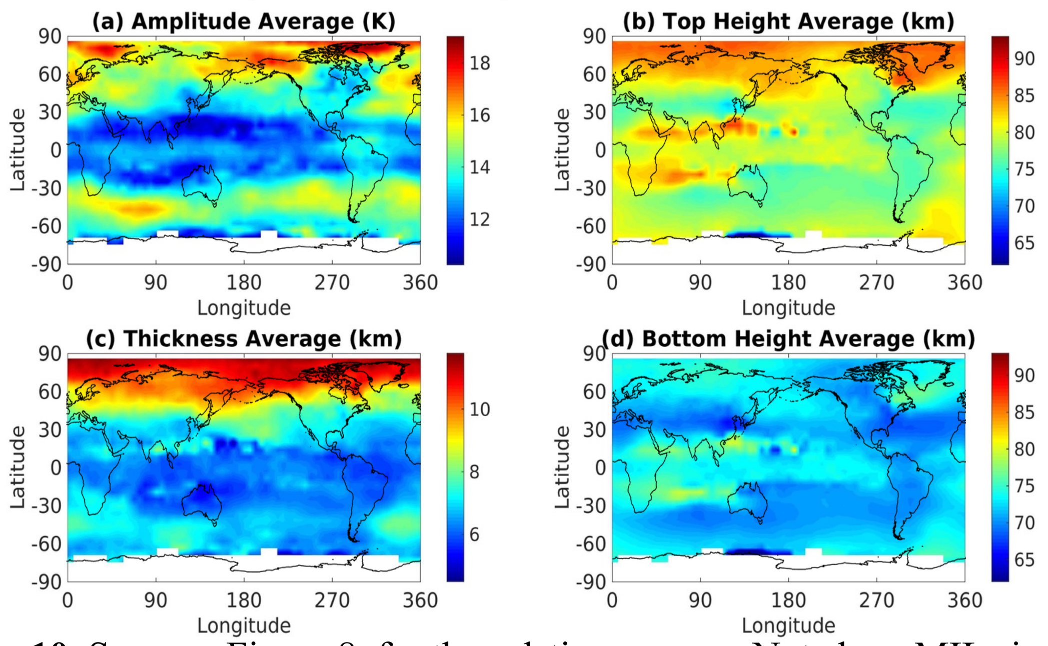

Figure 10. Same as Figure 8, for the solstice seasons. Note how MILs in the tropics have smaller amplitudes and thicknesses, while other latitudes have higher.

Conclusion and Future Work

This analysis of the eCMAM data reveals the strong spatial and seasonal dependent of long-lasting MILs and their amplitudes/thicknesses/heights. After thirty years of observational and dynamical modeling of MIL events, it is not clear which mechanism dominate their formation. Planetary wave breaking and tides are presently the most likely mechanisms, although further work is required to ascertain how these tides and waves generate long-lasting MIL events at different latitudes, seasons and time-scales. Future research will include correlations with tidal waves, diurnal tides, and planetary wave breaking in the mesosphere in addition to a detailed examination of the instabilities preceding and surrounding long-lasting MIL events.

References

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Acknowledgement

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