Equatorial Thermosphere Anomaly and Related Helium Density Signatures

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Science Question:

How can helium be used as a tracer of upper thermosphere dynamics and elucidate the driving mechanism behind the equatorial thermosphere anomaly (ETA)?

Motivation

What is a "tracer" of vertical motion?

$$\frac{\partial n_{He}}{\partial t} = \{molecular\ diffusion\} + \{eddy\ mixing\} + \left\{\frac{n_{He}\, w}{H}\left(\frac{m_{He}}{M} - 1\right)\right\}$$

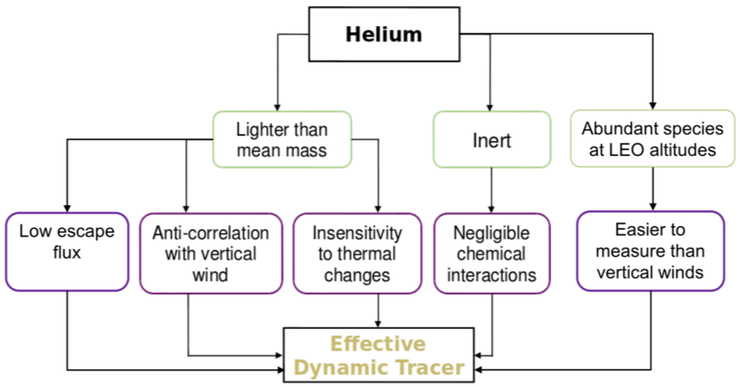
Vertical mixing

n_{He} = helium number density
w = vertical wind
H = $\frac{kT}{Mg}$, average neutral gas scale height
m_{He} = molecular mass of helium
M = mean molecular mass of neutral gas

- Vertical winds couple to the thermodynamic equation through adiabatic heating and cooling
- For a minor species like helium, $\left(\frac{m_{He}}{M} - 1\right) < 0$, therefore significant vertical winds will produce anti-correlated density features in helium with respect to a pure diffusive profile
- Changes in vertical winds with height affect helium composition at altitude of interest
- Driving forces of divergent motion:
  1) Pressure Gradients
  2) Coriolis
  3) Viscous Drag
  4) Ion Drag

} Affect bulk vertical motion differently, [Hsu et al., 2016]

Why use helium as opposed to another gas/method?



Helium's unique properties in the thermosphere make it a useful tool to evaluate seasonal, diurnal, and local time circulation processes.

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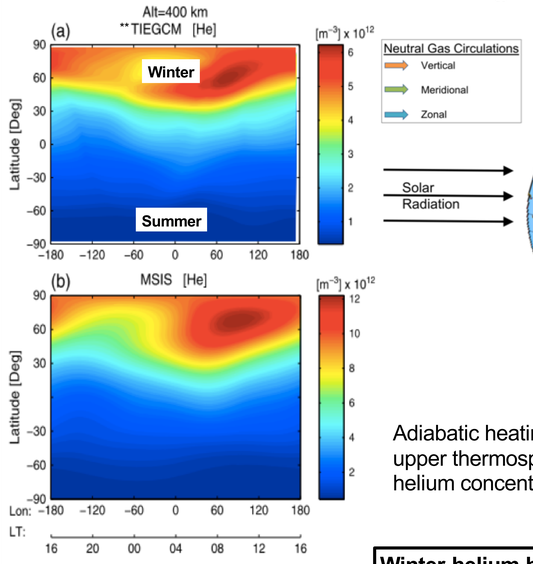
1. Seasonal Dynamics

The winter helium bulge:



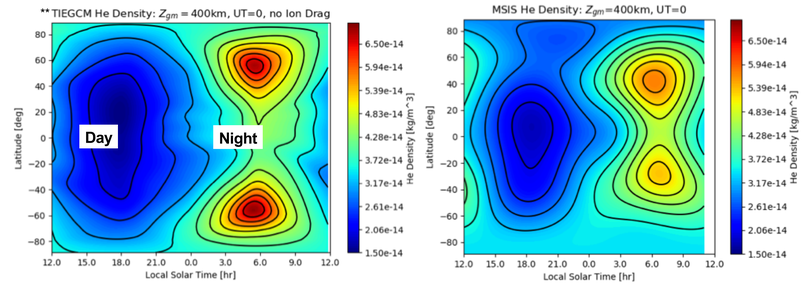
The latitudinal and longitudinal variations of (a) the helium number density from the TIEGCM (Run 1) on model day 10 and (b) helium number density from NRLMSISE-00 at 400 km and 0400 UT. LT = 4 + Lon/15. (Liu et al. 2014, JGR)

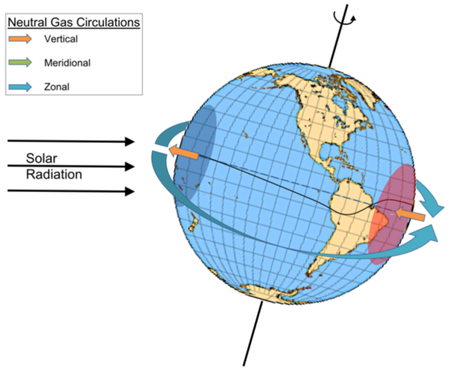
Adiabatic heating/cooling regions in the upper thermosphere, as interpreted from helium concentrations.

Winter helium bulge is a consequence of large scale, divergent, meridional circulations that produce bulk vertical motion.

2. Diurnal Dynamics

Day-to-night zonal circulation:





Diurnal solar heating causes bulk zonal circulation from day to night, which corresponds to upward vertical winds on dayside and downward on night. Helium is anti-correlated with these vertical winds.

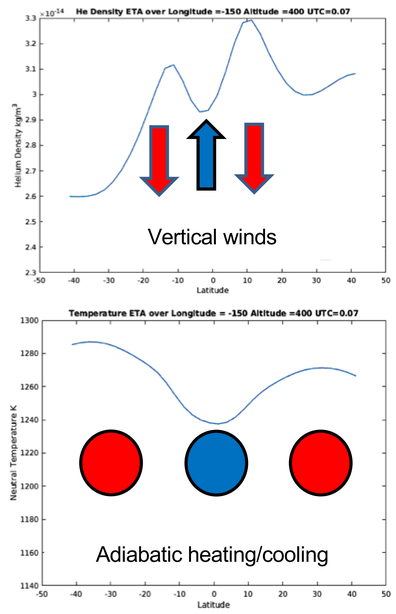
Same process as in section 1.

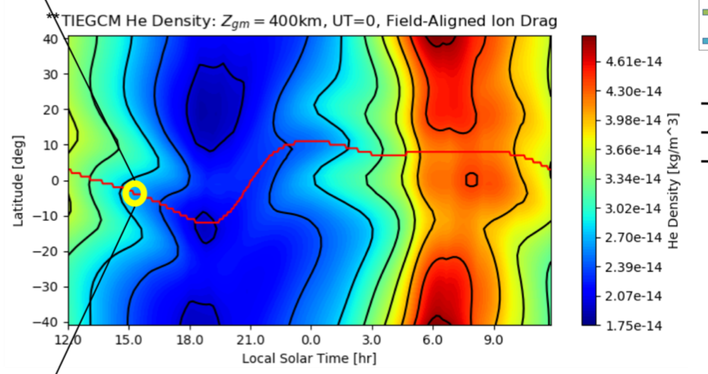
** All TIEGCM runs are for quiet geomagnetic conditions.

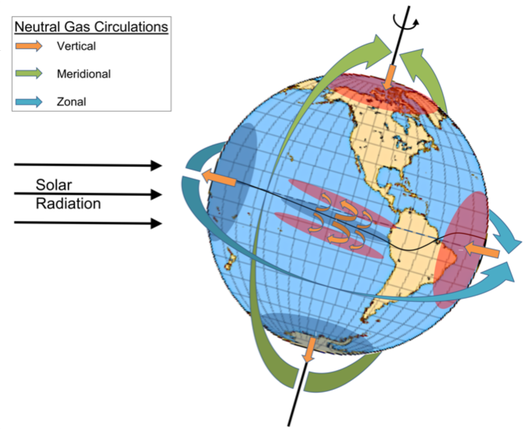
3. Local Time Dynamics

Same process as in section 1.

The Equatorial Thermosphere Anomaly:







The decrease in helium density and temperature implies upward vertical winds at the magnetic equator. Upward vertical winds, along with a temperature decrease, uncover the hydrodynamic/thermodynamic coupling of the ETA. Note: MSIS does not contain the ETA.

Conclusions

- **Helium can be used as a tracer of seasonal, diurnal, and local time divergent wind patterns and corresponding vertical motions.**
- **One consequence of divergent circulations is adiabatic heating and cooling.**
- **Helium structure around the ETA is indicative of circulations imposed by field-aligned ion drag.**