Helium Structure in the Upper Thermosphere

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Abstract:

Helium is an important contributor to mass density behavior in the upper thermosphere. Its distribution is influenced by winds and diffusion as it transitions from a minor species in the lower thermosphere to a major species in the upper thermosphere. Because of its influence on mass density and the drag coefficient on spacecraft, helium behavior influences the drag force on spacecraft. This poster will exercise the NCAR-TIEGCM V2.0, which includes helium as a major species, and the NRLMSIS-00 model to evaluate simulations of helium structure in the upper thermosphere.

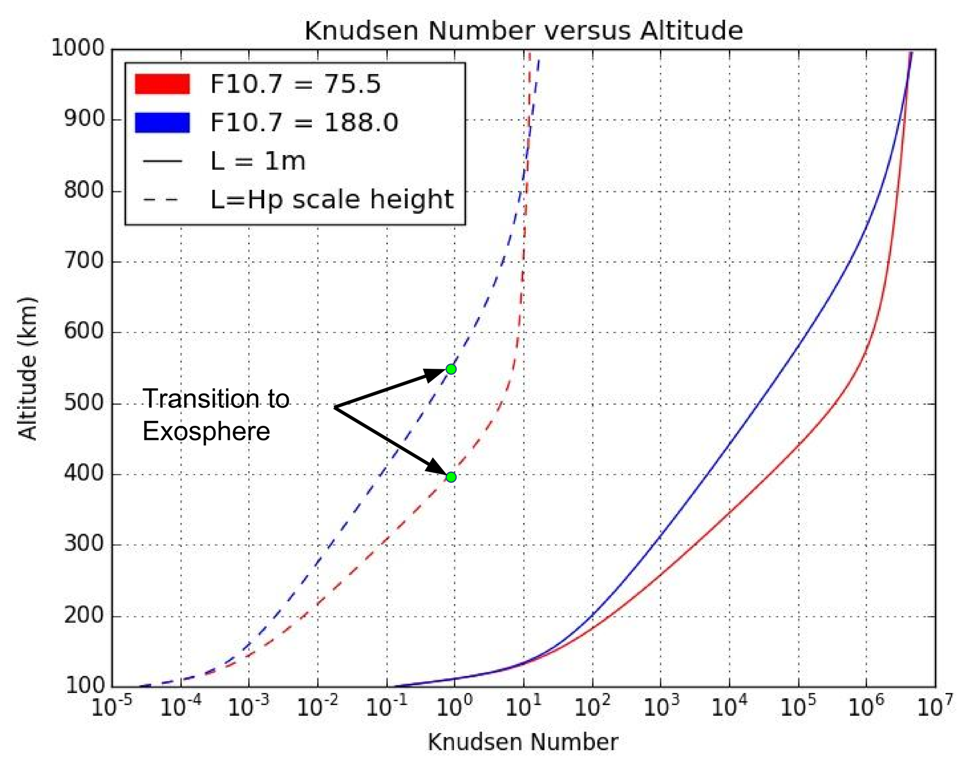
1. Motivation

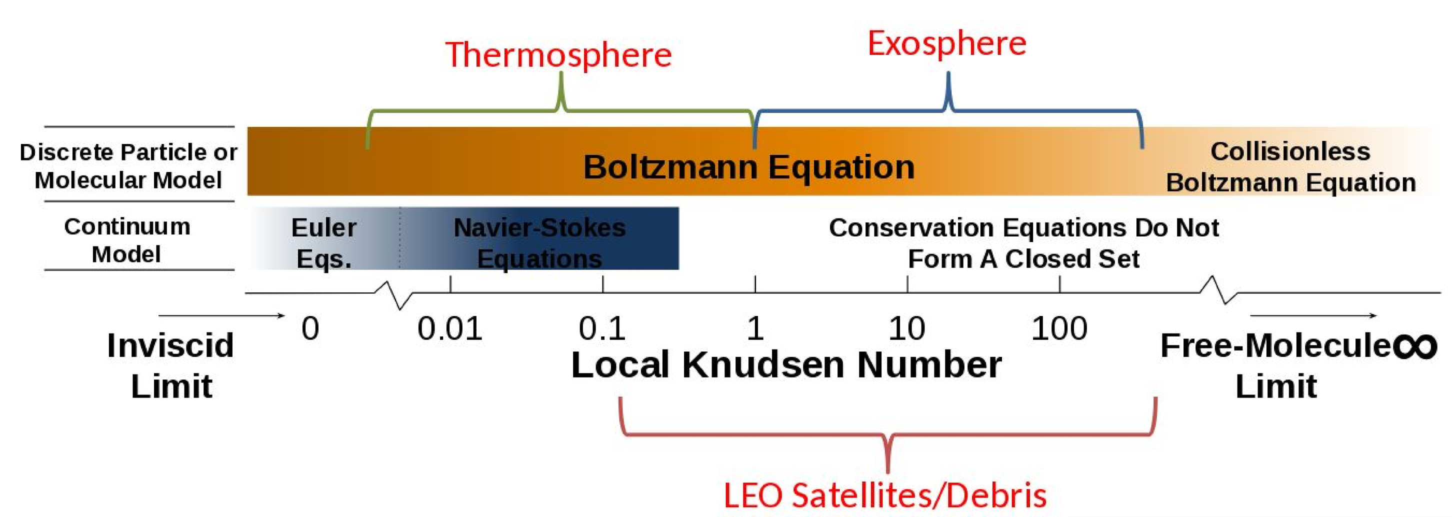
Satellite orbit prediction is crucial to avoiding space debris, maintaining mission sensitive parameters such as altitude, and executing orbital maneuvers. Consequently, the drag effects of the upper atmosphere on low-earth orbiting (LEO) satellites must be known to accurately model satellite position.

$$\vec{a} = \frac{-\rho V^2 C_d A}{2m} \cdot \frac{\vec{V}}{V}$$

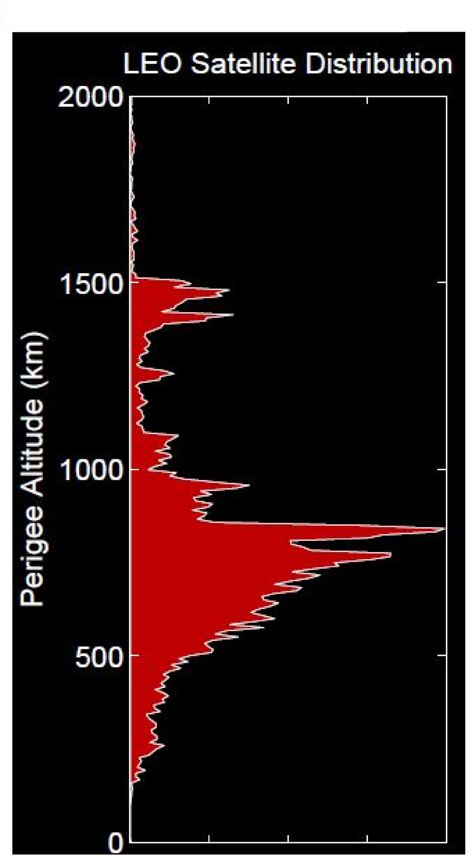
Physics-based modeling is used to find ρ and C_d with both dependent on gas composition and temperature.

- Knudsen Number shows what regimes and equations are relevant.
- Kn = λ/L, where λ is mean free path and L is characteristic length scale
- Solar maximum and minimum affect the Knudsen values.





The physics-based modeling differs between the gas dynamics (continuum mechanics in thermosphere) and the gas-satellite dynamics (free molecular flow).

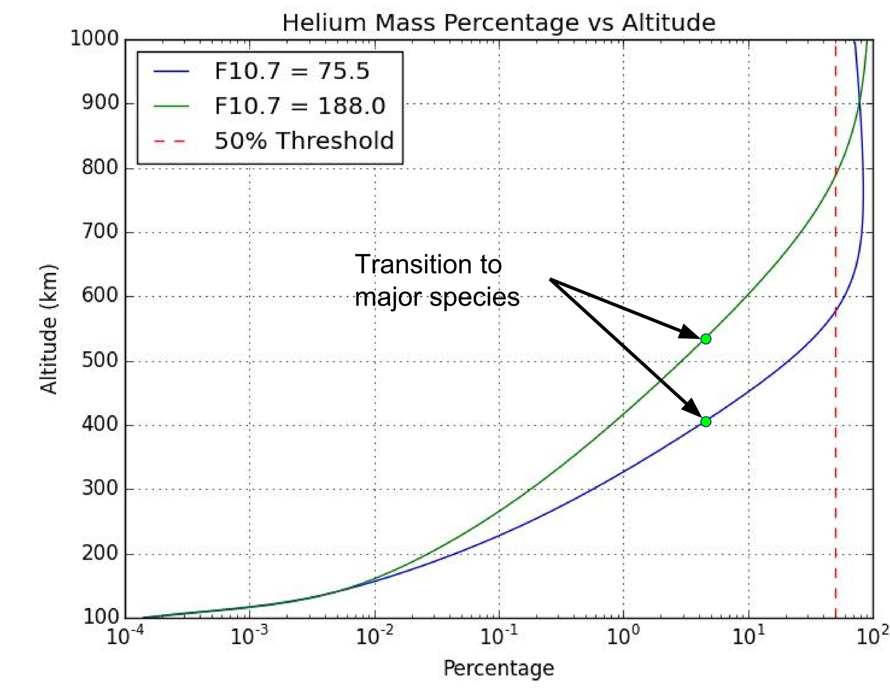


Statement: Helium becomes a critical contributor to satellite drag as the majority of LEO satellites reside where helium becomes a major species.

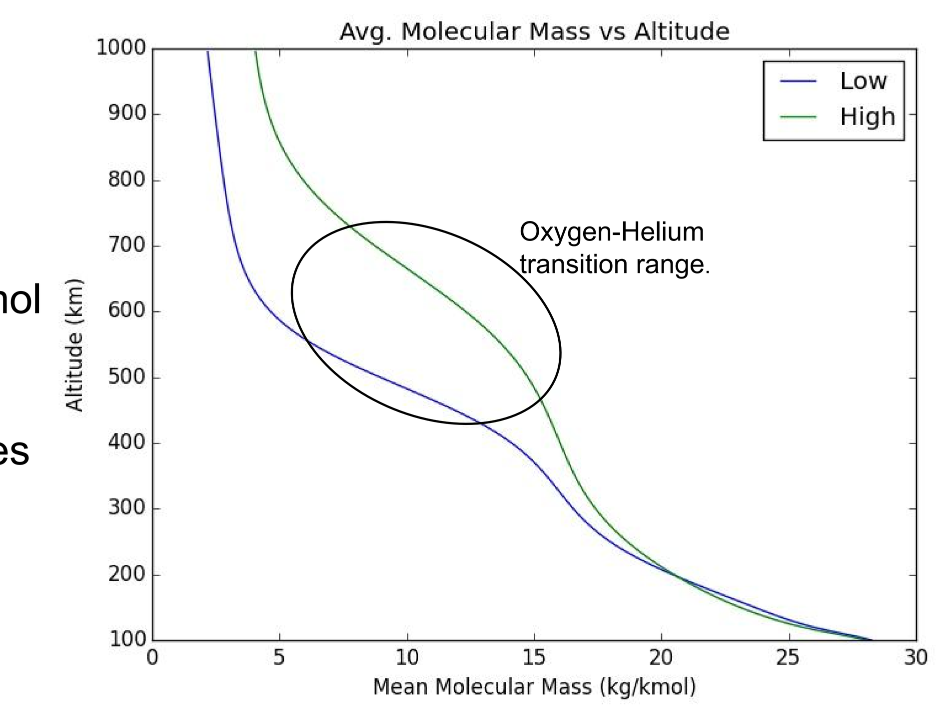
2. Helium / Oxygen Transition

At lower altitudes Helium is a minor species - meaning it does not contribute to mass continuity and can be decoupled from the conservation equations. However as the altitude increases it becomes more and more dominant. At altitudes above ~450km lighter species such as Helium and Hydrogen must be considered in the mass continuity equation. Helium is now included as a major species in NCAR-TIEGCM V2.0

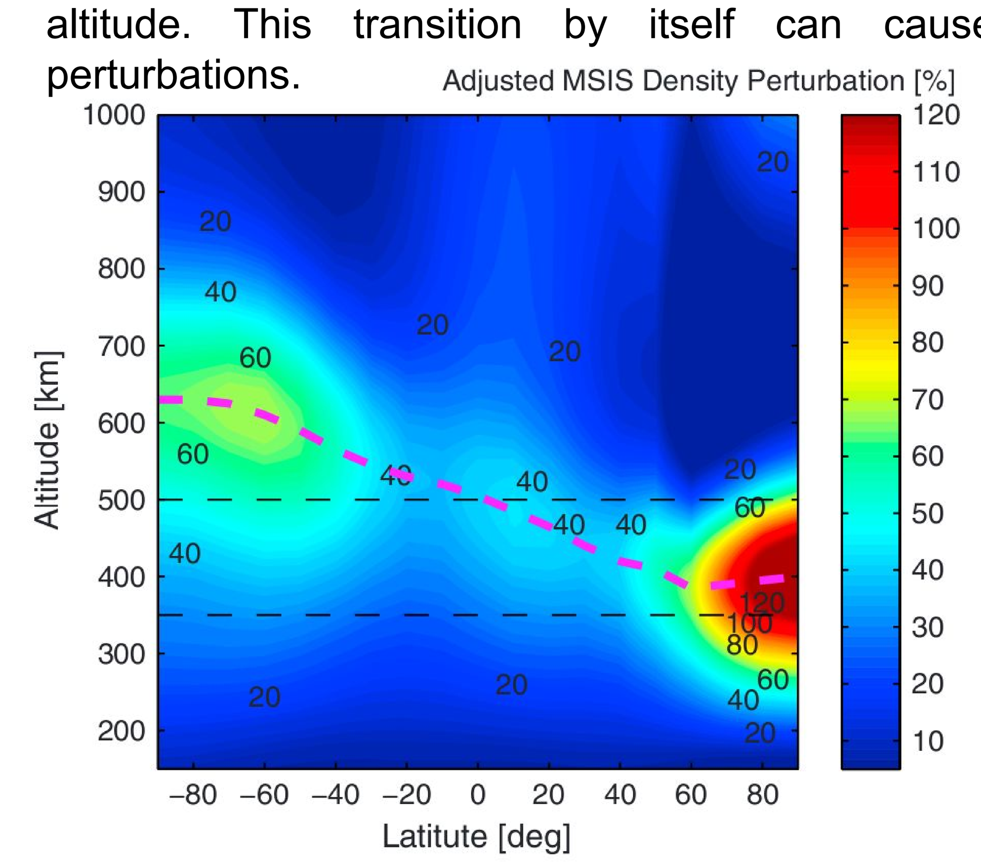
- Transition from minor to major gas alters Helium's role in the atmosphere.
- Threshold at 5% of the total mass density.



- Oxygen/Helium transition apparent from average molecular mass.
- Pause near 16kg/kmol is region of Oxygen dominance.
- Solar cycle influences transition altitude.



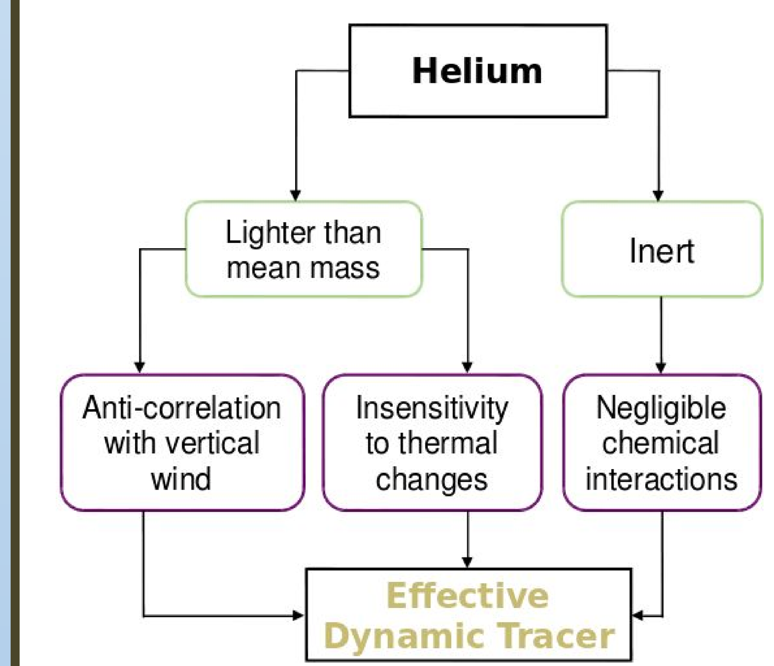
The Oxygen-Helium transition occurs at a highly populated satellite altitude. This transition by itself can cause significant density perturbations.



Altitudinal and latitudinal variations of the mass density perturbation in percent change (%) during the 5–6 December 2008 geomagnetic storm from the adjusted MSIS estimation. The black dash lines indicate the CHAMP and GRACE altitudes. (Liu et al. 2014, JGR)

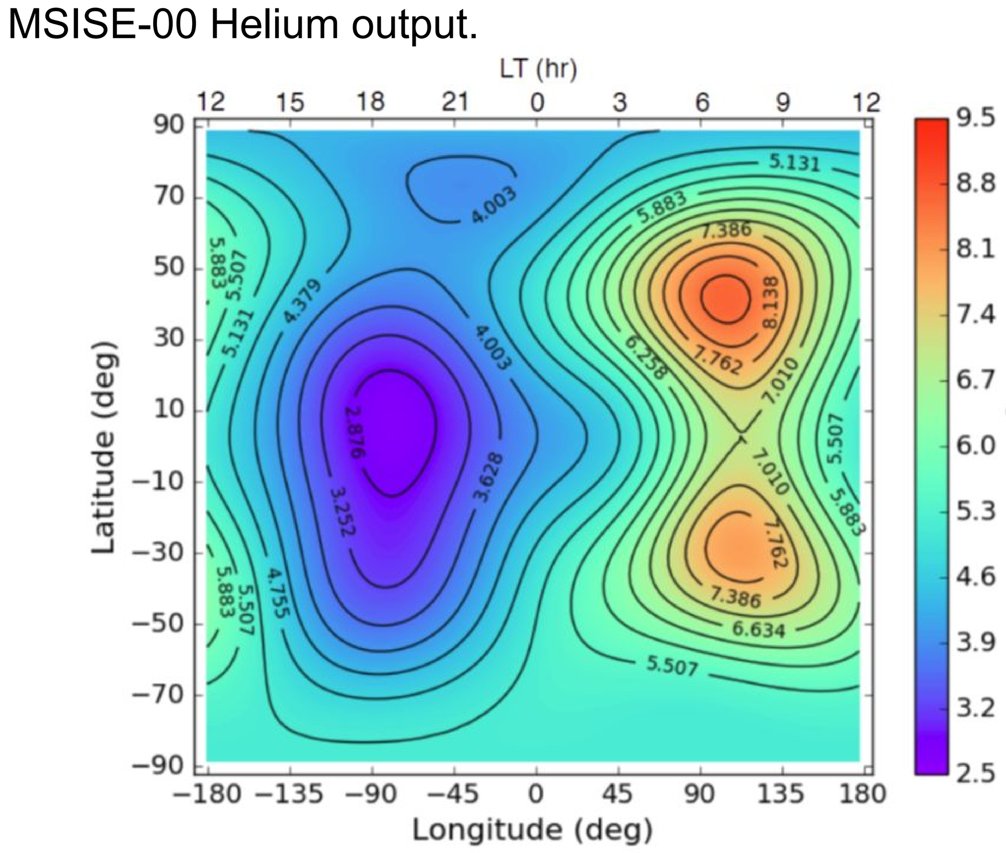
Statement: Oxygen-Helium transition altitude will fluctuate with local time, season, latitude, solar cycle, and geomagnetic activity. This produces distinct density perturbation patterns that require accurate physics-based modeling to capture its effects on satellite drag.

3. Helium as a Tracer of Vertical Motion

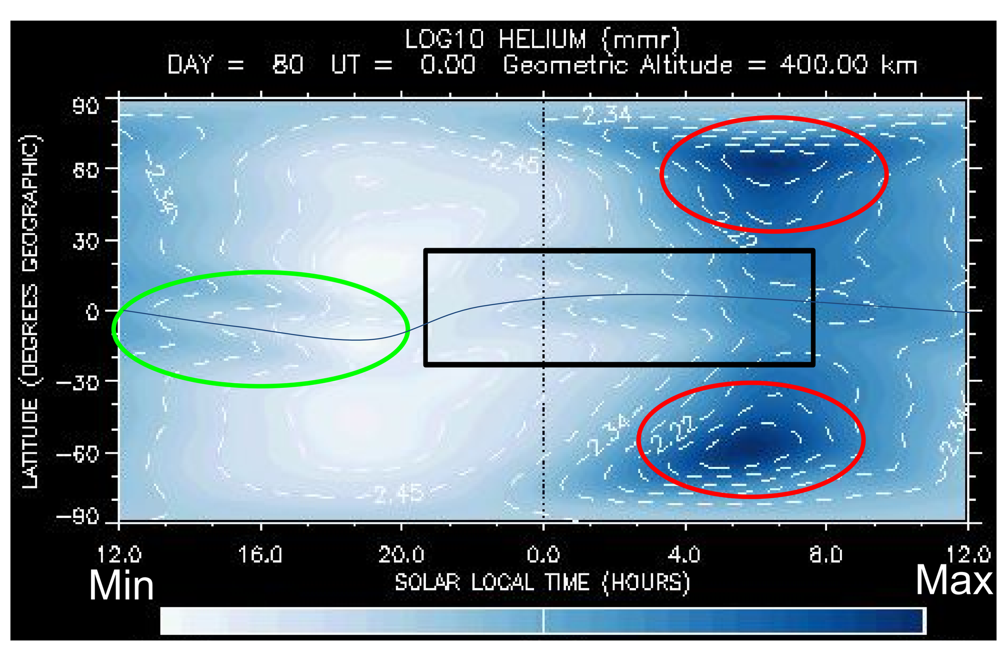


$$\frac{\partial n_i}{\partial t} = \text{Molecular Diffusion} + \text{Eddy Diffusion} + \text{Vertical Circulation}$$

- NRL MSISE-00 Helium output.



- NCAR-TIEGCM simulation Helium output.



Equatorial Thermosphere Anomaly Circulation
Nightside Convergence Circulation
Day-Night Circulation

Upward vertical wind on Dayside:
- Decrease helium
- Adiabatic cooling

Downward vertical wind on Nightside:
- Increase helium
- Adiabatic heating

Statement: Helium structure at a fixed altitude can indicate regions of vertical circulations. A helium maximum indicates downward winds while a helium minimum indicates upward winds.

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