Variations of hydrogen in the thermosphere: nature and causes

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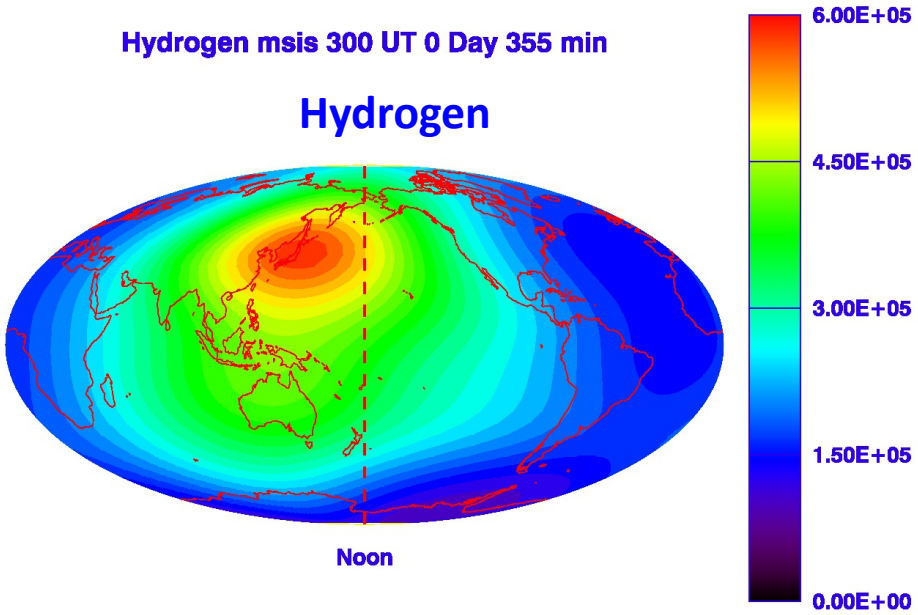
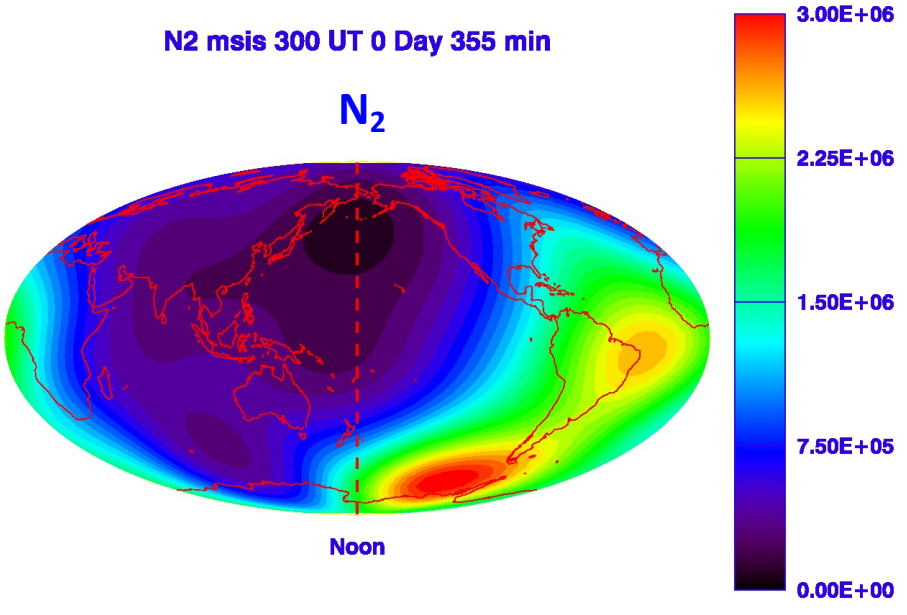
Why Study Hydrogen?

- Atmosphere's water budget
- Populating the plasmasphere and magnetosphere
- Extremely low mass tests physical understanding
- Getting the topside right, particularly as a response to forcing

Global Distribution of Hydrogen and N_2 at Solar Minimum



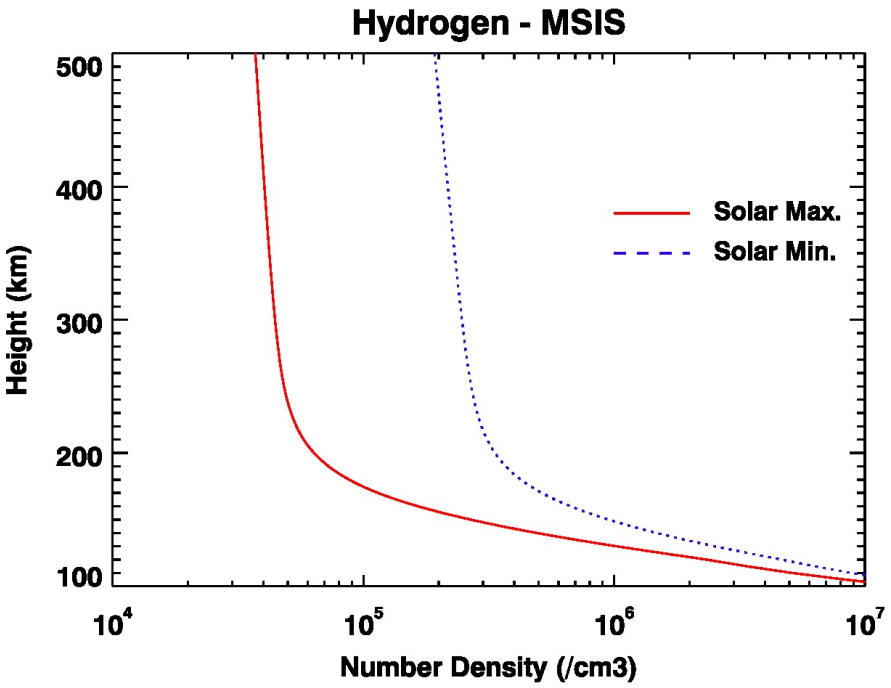


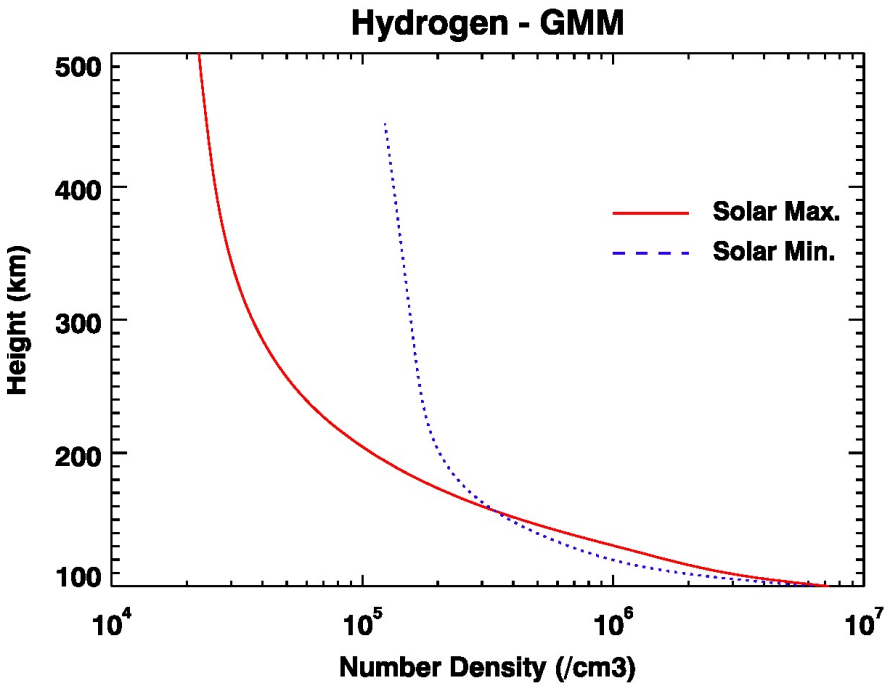
MSIS hydrogen derived from charge exchange reaction $H + O^+ \rightarrow H^+ + O$

Assumes diffusive equilibrium at 300 km, but not lower down

Note the large gradients of H, despite its large scale height

Vertical Profiles of Hydrogen- Solar Cycle Variations





Minor Species Continuity

Molecular diffusion

Production and Loss

$$\frac{\partial \tilde{\Psi}}{\partial t} = -e^{Z}\frac{\partial}{\partial Z}\left[\tilde{A}\left(\frac{\partial}{\partial Z} - \tilde{E}\right)\tilde{\Psi}\right] + \tilde{S} - \tilde{R} +$$

$$e^{Z}\frac{\partial}{\partial Z}\left[e^{-Z}K_{E}(Z)\left(\frac{\partial}{\partial Z} + \frac{1}{\overline{m}}\frac{\partial \overline{m}}{\partial Z}\right)\tilde{\Psi}\right] - \left(\vec{V}\bullet\nabla\tilde{\Psi} + w\frac{\partial \tilde{\Psi}}{\partial Z}\right)$$

Eddy diffusion

Advection

- Not time dependent
- Production and loss only through charge exchange in region of interest
- No advection
- Leaves only molecular and eddy diffusion

What is Diffusive Equilibrium, Dynamic Equilibrium and What is Molecular Diffusion

- Diffusive equilibrium is the decrease of the number density of a species with height with a rate that is exponentially dependent on the species scale height.

- Is the upper atmosphere ever in diffusive equilibrium?
  No because it is not a one species fluid.

- What is molecular diffusion?
  It represents collisions between species so that collisions between species result in the species being moved away from diffusive equilibrium. Species lighter than the mean molecular mass tend to have their scale height

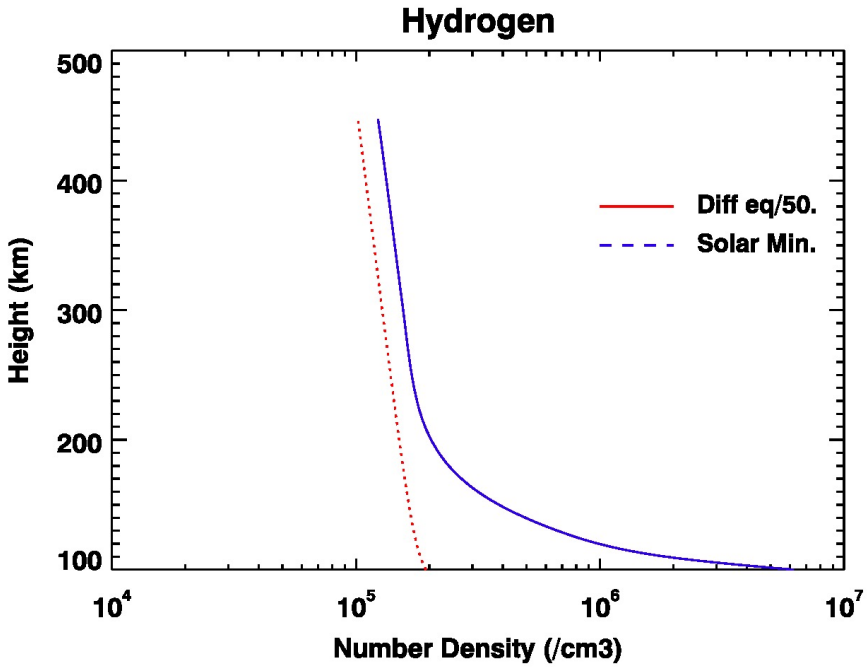
- Molecular diffusion therefore tends to mix the atmosphere. A very light species like hydrogen is partially mixed up to quite high latitudes and is far from diffusive equilibrium

- In the absence of winds Hydrogen is in a quasi equilibrium state (a dynamic equilibrium).

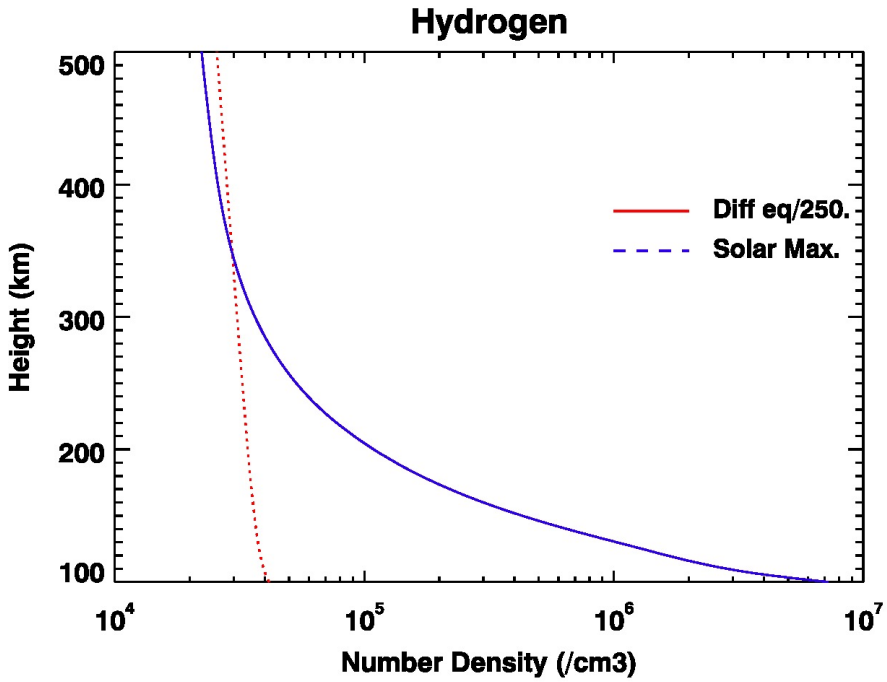
- Winds (particularly vertical ones) push hydrogen away from this dynamic equilibrium, molecular diffusion tends to act to restore the dynamic equilibrium.

- Because of the changes the winds cause to the major species, hydrogen is very strongly affected by dynamic changes.

How Far is Hydrogen from an Exponential Function with a Constant Scale Height?



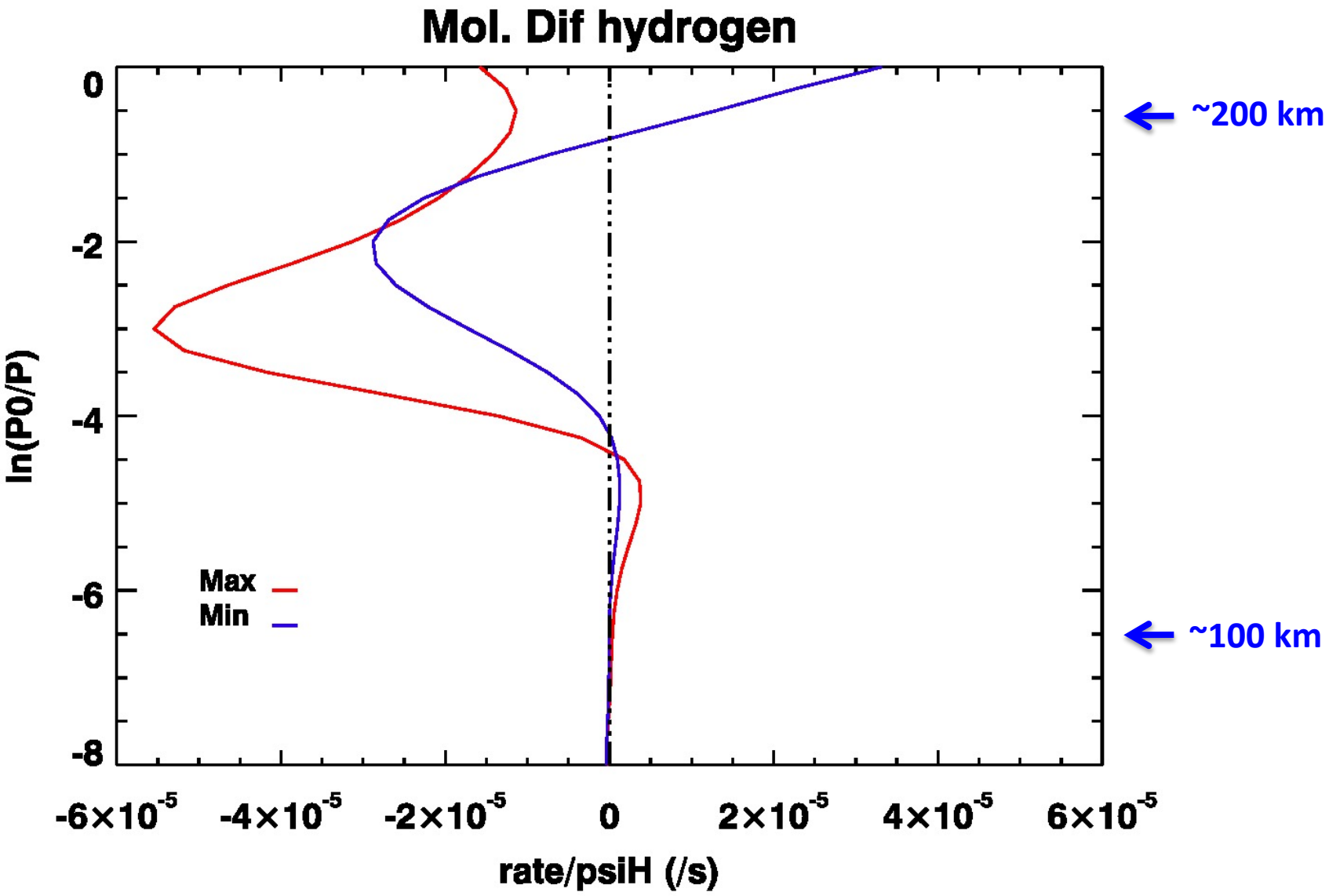
Solar Minimum



Solar Maximum

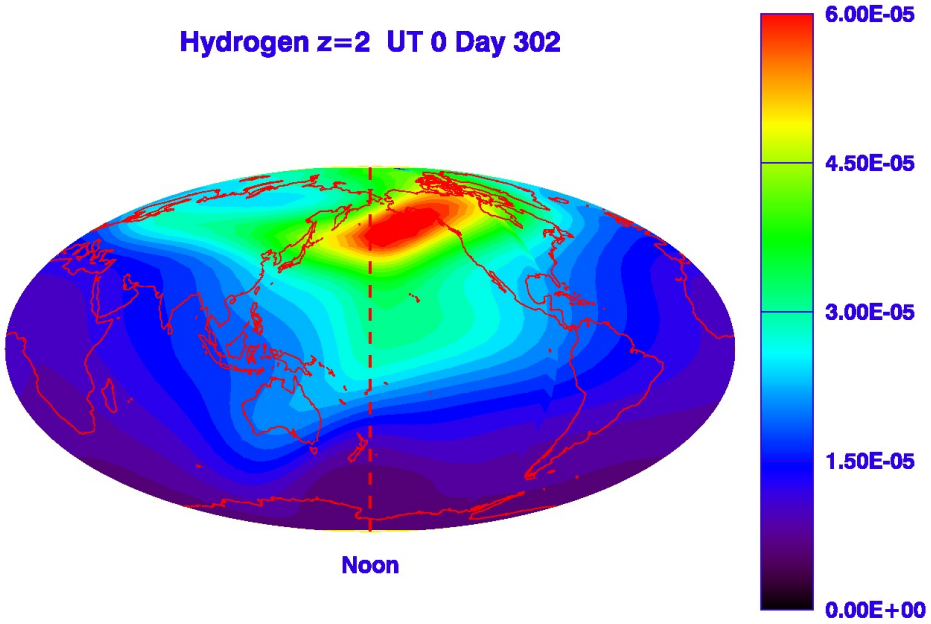
Molecular Diffusion

(Plotted in mass mixing ratio)

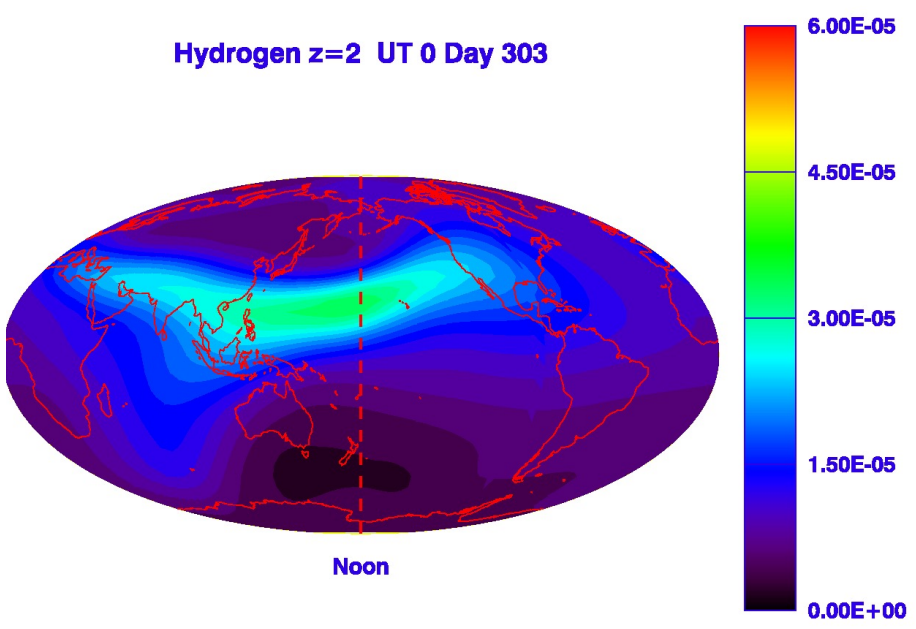


How Dynamic is Hydrogen?

(Plotted in mass mixing ratio)



Quiet



Storm

Conclusions

- There is much more hydrogen in the upper thermosphere at solar minimum than solar maximum
- Because of hydrogen's large scale height, it has a large partial pressure pushing it downward relative to the other species
- This pressure is greater at solar maximum, due to the larger vertical gradient of mean molecular mass with pressure
- These large partial pressures mean that the temperatures and winds (particularly vertical ones) that change major species composition also change H
- Hydrogen is very dynamic because other species are dynamic in the thermosphere

Molecular and Eddy Diffusion of Hydrogen

(Plotted in mass mixing ratio)