Multidecadal Northern Hemisphere Midlatitude Geocoronal Hydrogen Emission Observations

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We also thank Fred Roesler, Ron Reynolds, Stan Solomon, Hanli Liu, Derek Gardner, Grant Petty, Alan Burns, Wenbin Wang, Jeff Percival, Kurt Jaehnig

This work was supported by NSF grants #AGS-2050072, #AGS-1343048 & #AGS-1352311

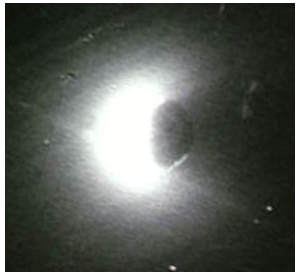
2022 Sun Climate Symposium

What is the predicted response of hydrogen to natural variability and to greenhouse gas increases? How do these predictions compare with observations?

To what extent might thermospheric hydrogen observations and model simulations contribute to a whole atmosphere understanding of hydrogen-containing species and serve as diagnostics of climate change processes?

To what extent might H and other hydrogen-containing species provide vertical footprints for climate change processes?

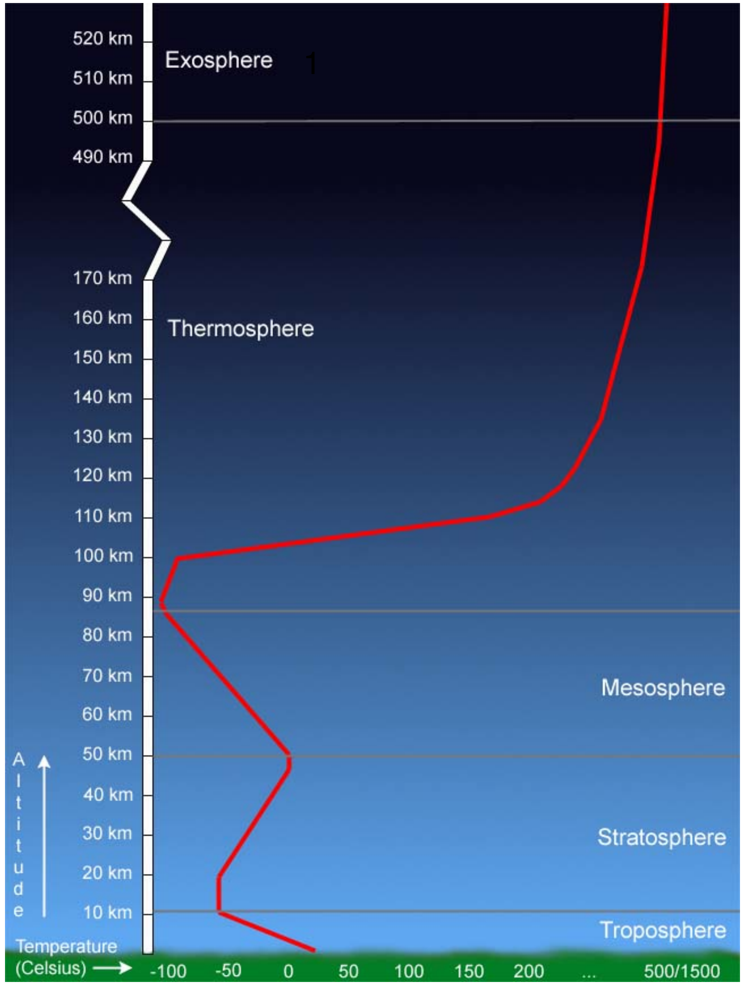
- Coupling of hydrogen-containing species
- Observations of midlatitude Northern Hemisphere H emission variation
- Calibration, reanalysis, and error analysis
- Model simulations of H sensitivity to solar variability and GHGs
- Future studies
- Conclusions



Source: Carruthers, Page, and Meier, Apollo 16 Lyman alpha imagery of the hydrogen geocorona, J. Geophy Res., 81, 1664, 1976. and . pluto.space.swri.edu/.../ apollo_geocorona2.gif

Coupling of hydrogen-containing species

1



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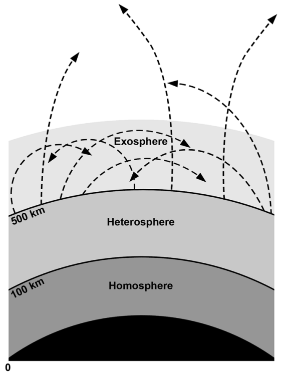
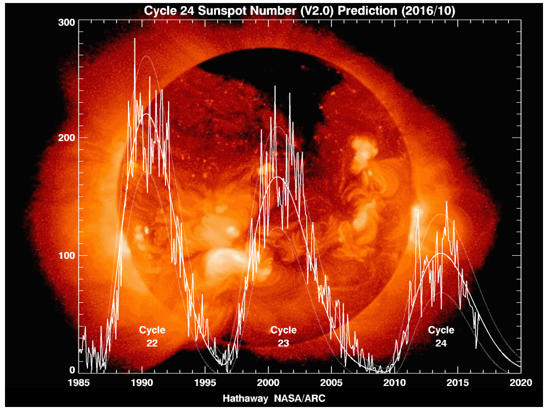
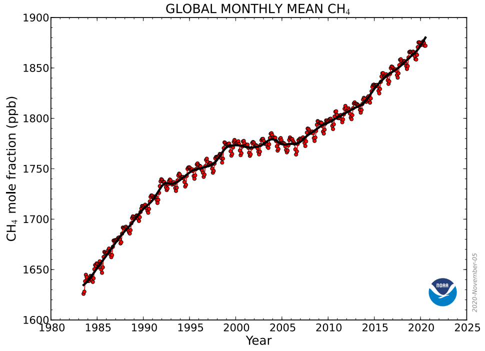


Atomic hydrogen becomes increasingly dominant with altitude



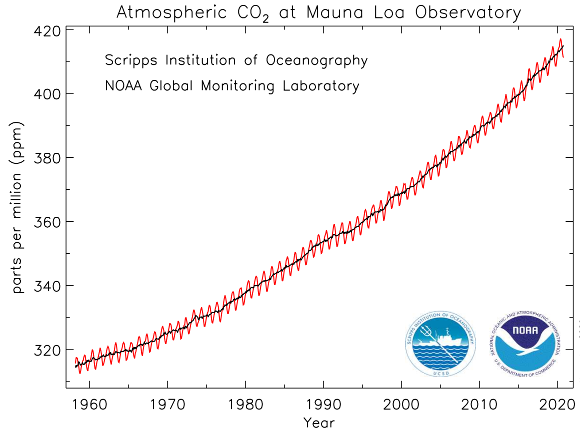
3

CH_4, H_2O, H_2 chemistry & photolysis reactions



Methane Concentrations

Sources of methane include: Agriculture, natural gas and petroleum systems, landfills, coal mining, wetlands, biomass burning



Carbon Dioxide Concentrations

[1]Courtesy of Windows to the Universe, http://www.windows.ucar.edu

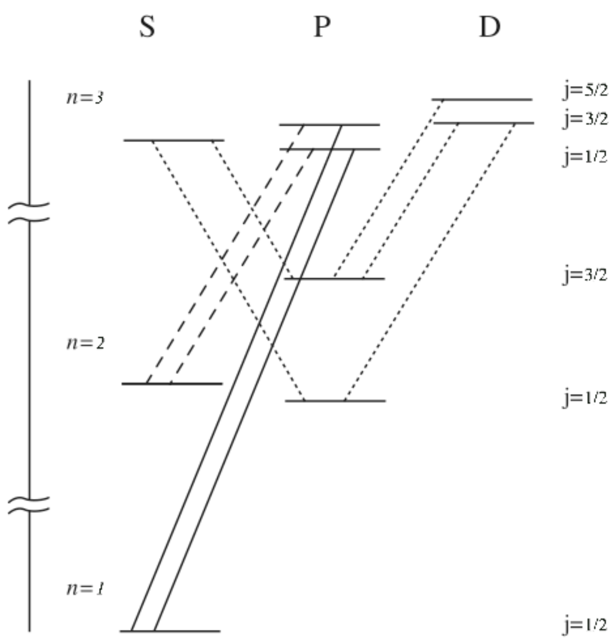
[2]from: http://earthobservatory.nasa.gov/Features/BiomassBurning/

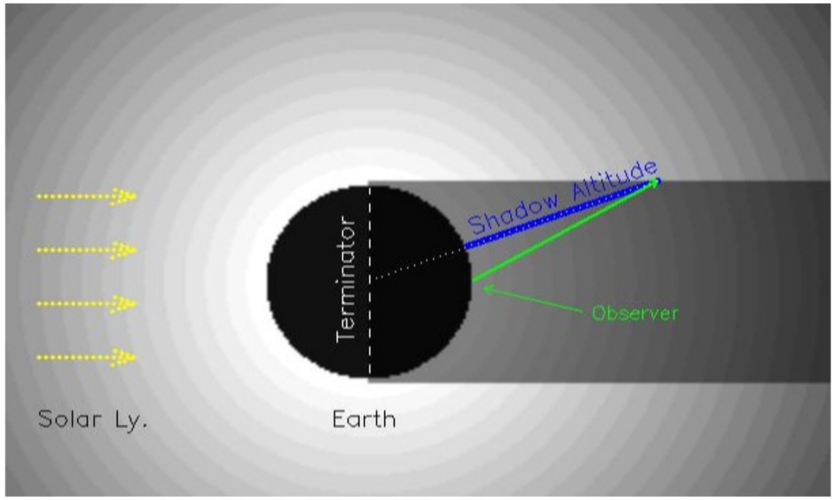
Online: http://www.britannica.com/ebc/art-95671

[3]© Pekka Parviainen From http://lasp.colorado.edu/noctilucent_clouds/

[4]Source: Carruthers, Page, and Meier, Apollo 16 Lyman alpha imagery of the hydrogen geocorona, J. Geophys. Res., 81, 1664, 1976. and .
pluto.space.swri.edu/.../ apollo_geocorona2.gif

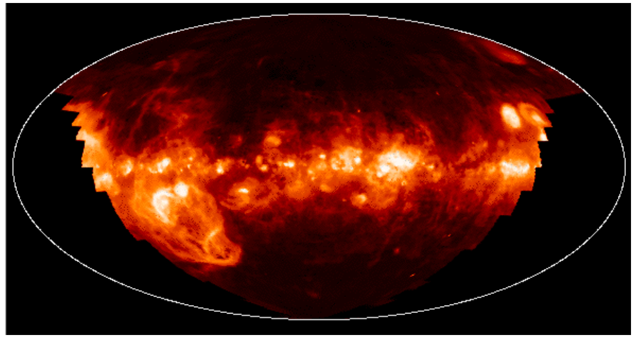
Ground-based Hydrogen Balmer α Observations



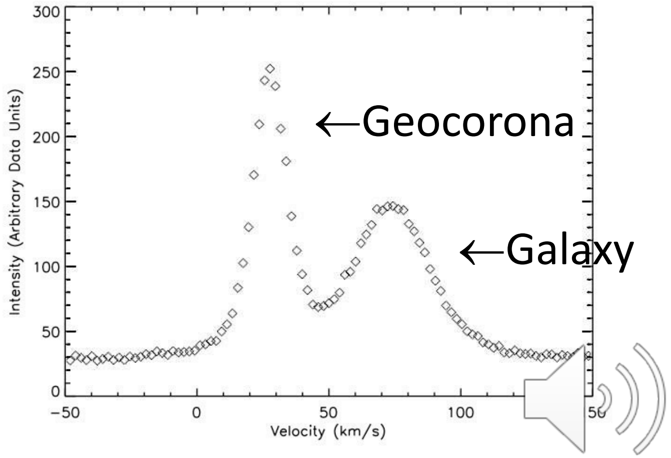


Reprinted From *Gardner et al.* [2017]

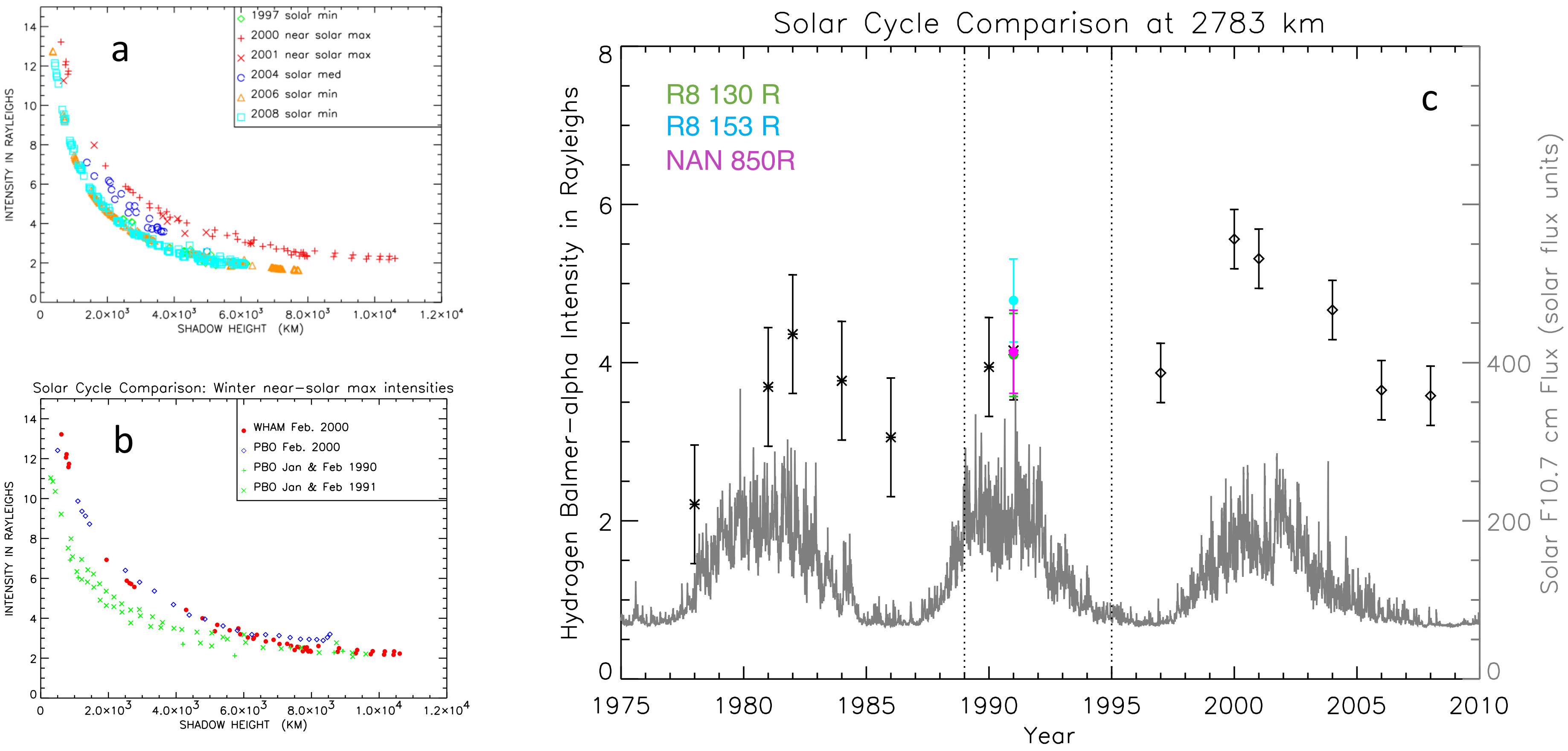
- Balmer α is a solar excited emission
- The Earth's shadow is used to determine the base of the emission column



WHAM Hα Galactic Survey
From www.astro.wisc.edu/wham



Northern Hemisphere Mid-latitude Balmer α Emission Observations



Daily Solar Radio F10.7 cm flux.

Data were downloaded from the LASP Interactive Solar Irradiance Data Center (http://lasp.colorado.edu/lisird/data/noaa_radio_flux/

[*Nossal et al.*, JGR, 2019]

- column emission intensity for a midrange shadow altitude of ~2800 km
- half-year bins spanning winter conditions represent many spectra and, in most cases, multiple nights.
- Error bars indicate uncertainty in the *relative* intensity

Reanalysis Strategy

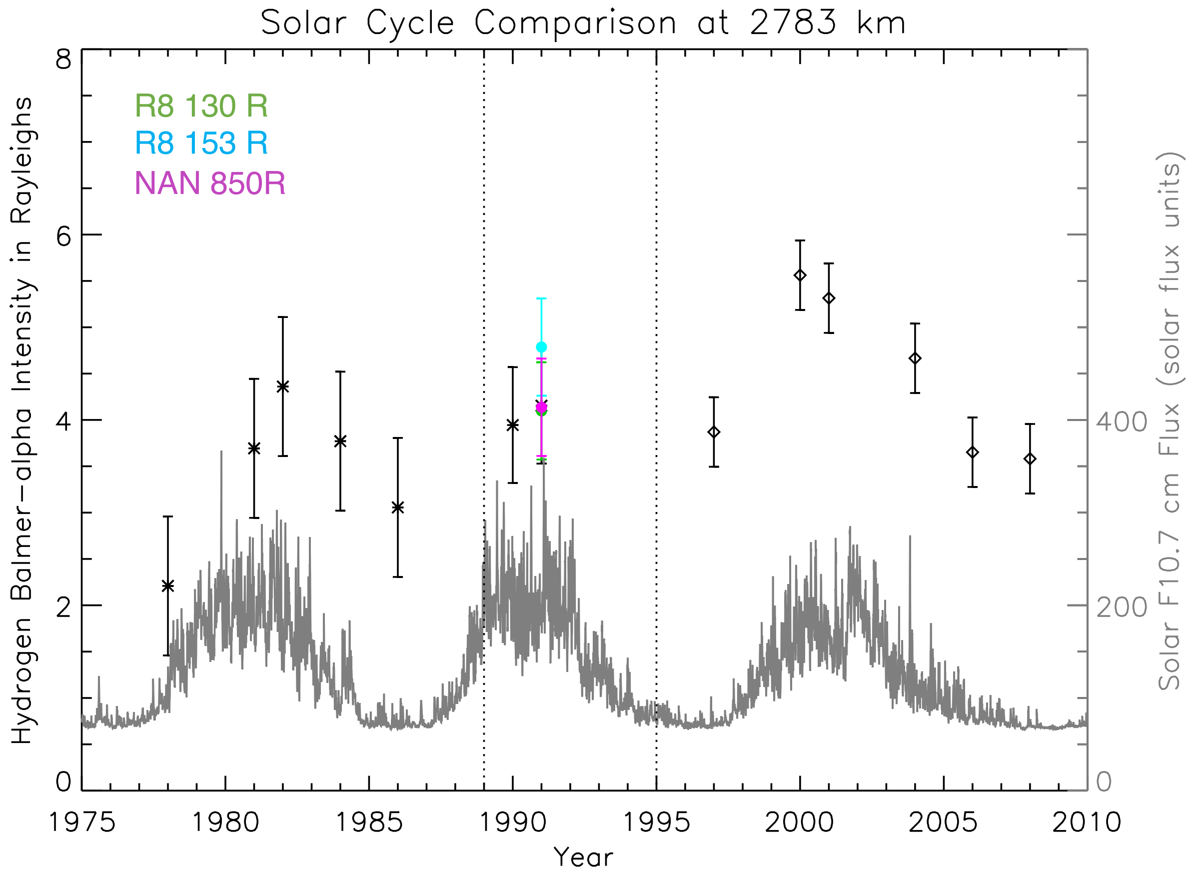
- Review of log notes for weather conditions & pointing info
- Refitting of original atmospheric and calibration spectra & recalibration of the observations from the early 1990s
- Sensitivity studies to assess differences in tropospheric scattering
- Review of observations in the context of knowledge of dusk-dawn asymmetries and cascade excitation.
- Corroboration of intensity calibration with multiple nebular sources, review of pointing, WHAM Galactic Map, and FOV checks

North American Nebula
Credit and Copyright: Dominique Dierick and Dirk De la Marche

From
http://antwrp.gsfc.nasa.gov/apod/ap960606.html

Nossal et al., 2019

Northern Hemisphere Mid-latitude Hα Emission Observations



[*Nossal et al.*, JGR, 2019]

Daily Solar Radio F10.7 cm flux.

Data were downloaded from the LASP Interactive Solar Irradiance Data Center (http://lasp.colorado.edu/lisird/data/noaa_radio_flux/

The WI Northern hemisphere data suggest an increase that has not been accounted for by uncertainties due to experimental factors, including calibration, tropospheric scattering, cascade fine structure excitation and Galactic emission, with the caveat that this is a limited data set.

Figure 3.1: The INSpIRe Observatory at Embry-Riddle Aeronautical University. Photo credit: Maggie Gallant, October 2016.

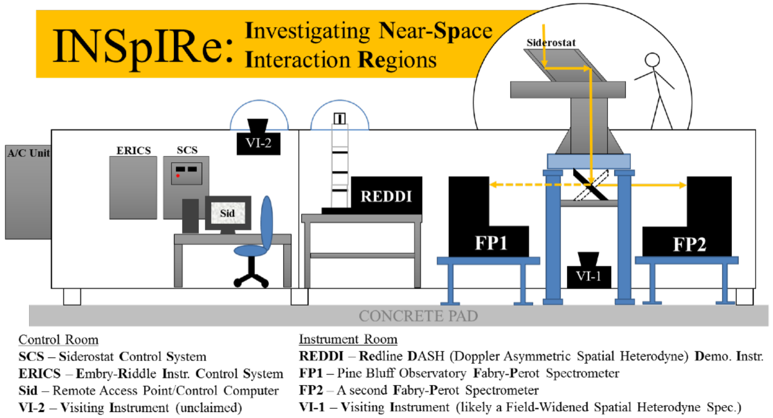


Figure 3.2: Five instrument ports are shown here, as well as the siderostat, electronics box locations, and control computer.

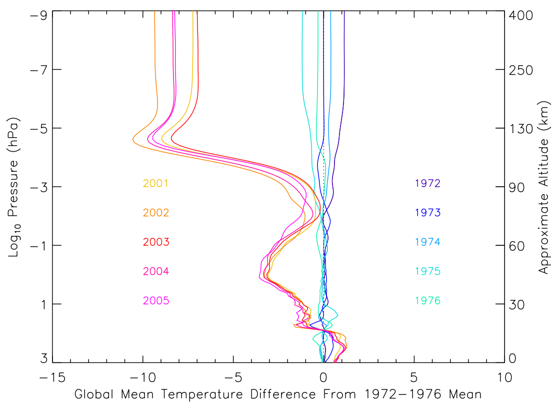
[*Mierkiewicz, 2019*]

WHAM at Cerro Tololo, Chile, *Haffner et al.*, 2003, 2010

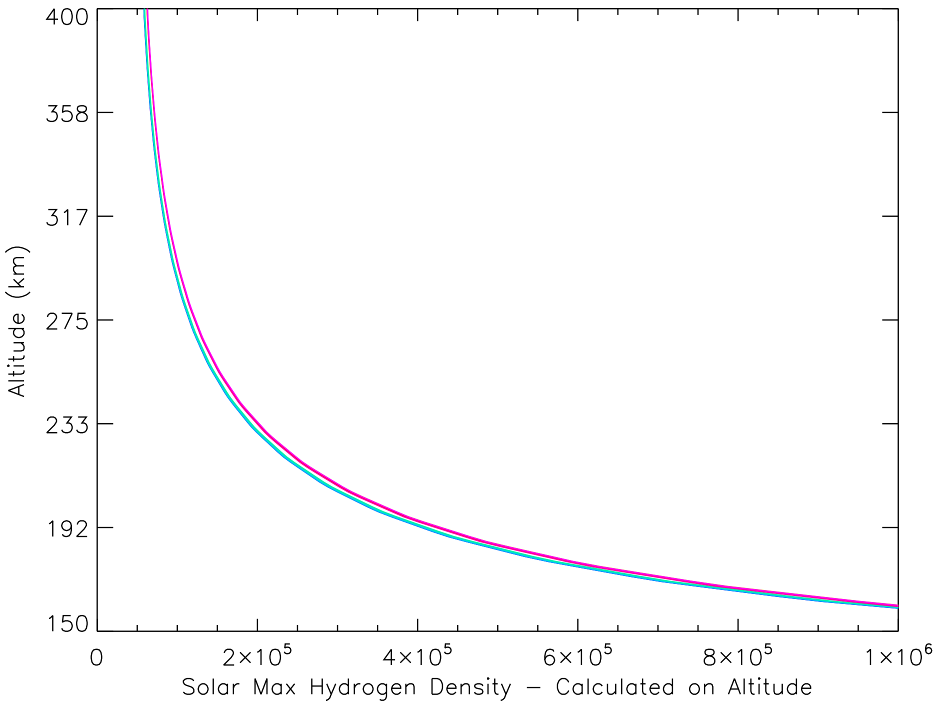
- Coincident Northern and Southern Balmer α observations with INSpIRe and WHAM
- INSpIRe will extend the Northern hemisphere mid-latitude data record
- WHAM Observations from Cerro Tololo, Chile will span about one solar cycle

WACCM-X Hydrogen Profile Calculated on Altitude

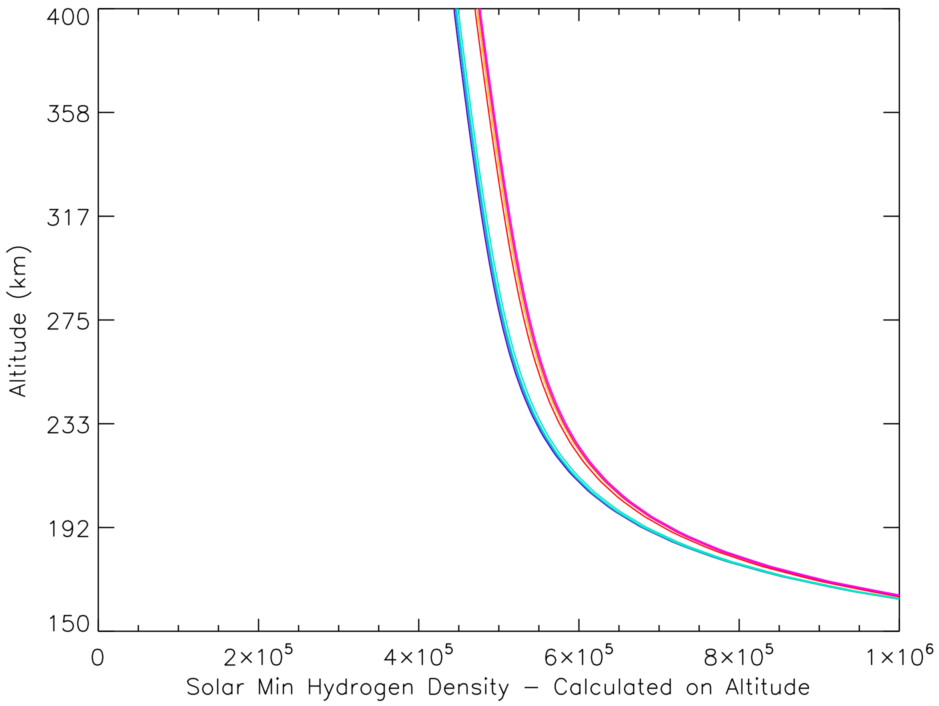
Temperature Difference



Solomon et al. [2018, 2019]



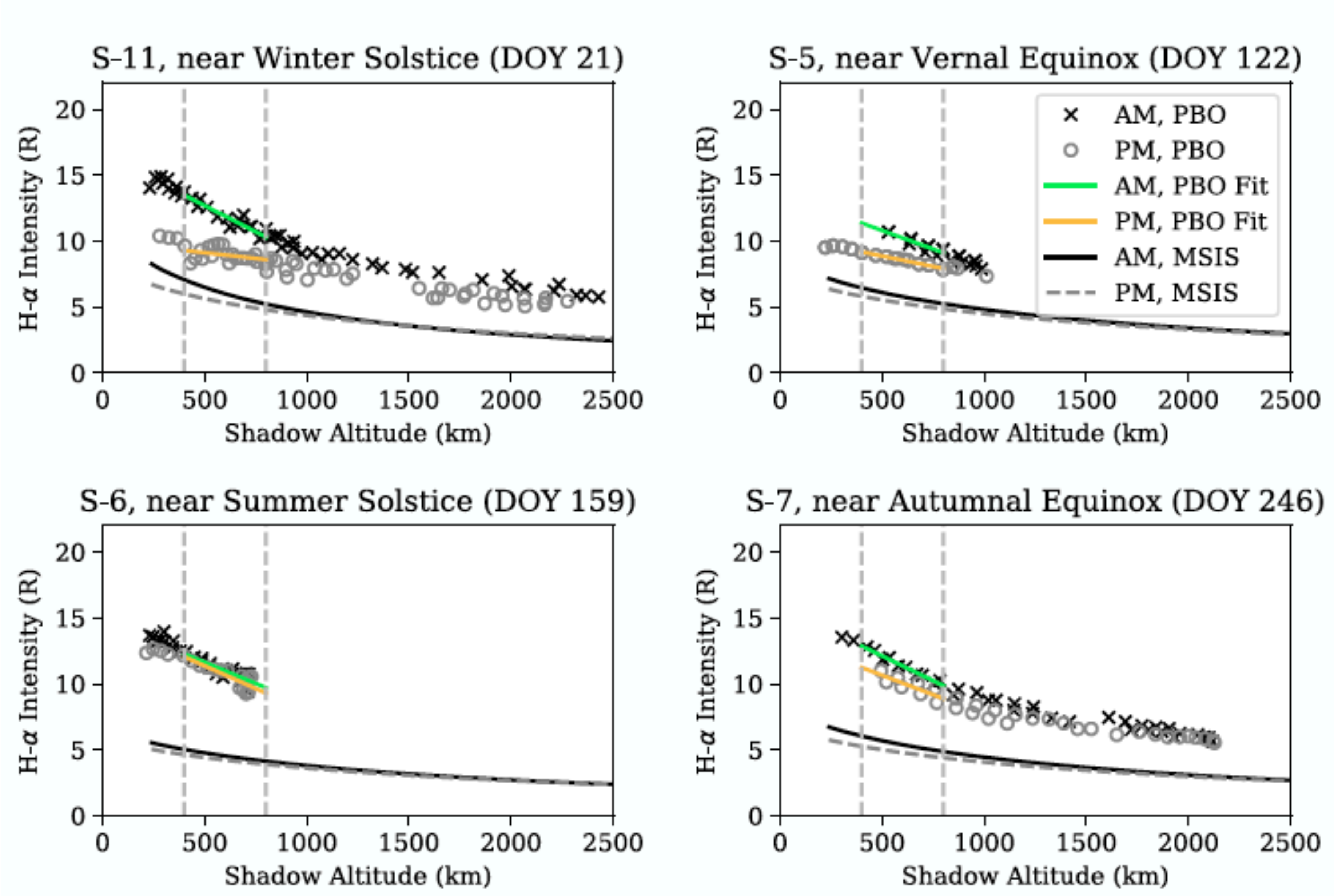
Solar Maximum



Solar Minimum

Using Output from WACCM-X model simulations for perpetual solar conditions run for *Solomon et al.* [2018, 201

Dusk-Dawn Asymmetry



Gallant et al., 2019

Ongoing and Future Work

How does the predicted response of thermospheric hydrogen to the solar cycle and to greenhouse gases compare to observations?

Which mechanisms are associated with solar cyclic and climatic influences on hydrogen-containing species?

To what extent might H and other hydrogen-containing species at different altitudes provide vertical footprints for climate change processes?

- Forward modeling to compare WI multidecadal Northern hemisphere hydrogen emission data set with NCAR Whole Atmosphere Community Climate Model eXtended (WACCM-X) simulations
- Use of the INSpIRe FPI to extend the Northern hemisphere midlatitude hydrogen emission data set and to investigate H variability over multiple timescales.
- Near simultaneous Balmer α observations from the Northern and Southern hemispheres using the INSpIRe FPI from Wisconsin and the WHAM FPI from Chile [*Mierkiewicz, Haffner*].
- Analysis of the WHAM Southern hemisphere Balmer α data set, including the H response to volcanic activity.
- Use of the WACCM-X to investigate sensitivity of thermospheric hydrogen to greenhouse gases and to changes in distributions of other hydrogen-containing constituents [CH_4, H_2O, CH_2O, OH].
- Comparison of H emission observations to observations of hydrogen-containing constituents at other altitudes and to polar mesospheric clouds.

Conclusions

- The observed hydrogen emission intensity indicates variability on time scales from dusk-dawn to solar cyclic to multidecadal.
- Comparison of 2000-2001 near-solar max H-emission observations with reanalysis of 1990-1991 solar max observations suggests a likely and somewhat surprising increase in hydrogen emission intensity, with the caveat that this is a limited data set & there are calibration uncertainties. We are looking forward to adding to this data set and connecting the data via nebular calibration.
- Over the timescale of the three decades, the solar cycle has a larger predicted impact on thermospheric H than do historical increases in greenhouse gases.
- The absolute increase in the upper thermospheric H density in responses to GHGs is about an order of magnitude greater at solar minimum conditions, consistent with carbon dioxide cooling of larger magnitude in the thermosphere during lower solar activity.
- The WACCM-X results are consistent with the NCAR Global Mean Model that predicted the thermospheric H response to GHGs depends on solar activity. Further, the Global Mean Model predicted that this increase in thermospheric H is due to both carbon dioxide cooling and methane increases to the source species.
- Future work includes analysis of existing and new H emission observations and of WACCM-X climate simulations, use of forward modeling to compare observations with model predictions, and comparison with observations and model predictions at other altitudes.

Please contact Susan Nossal (nossal@physics.wisc.edu; 608-332-3417) with questions or feedback.

Thank you!