Spatial and Temporal Variation of Water in Titan's Atmosphere

B. P. Murphy[1], B. L. Steffens[1], S. Bauduin[2], G. L. Bjoraker[3], C. A. Nixon[3], and P. G. J. Irwin[4]

[1]Florida Institute of Technology, 150 W University Blvd. Melbourne, FL 32901. [2]Université libre de Bruxelles (ULB), Spectroscopy, Quantum Chemistry and Atmospheric Remote Sensing (SQUARES), Brussels, Belgium. [3]NASA Goddard Space Flight Center, Planetary Systems Laboratory, Code 693, Greenbelt, MD 20771. [4]Atmospheric, Oceanic, and Planetary Physics, Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, UK.

Introduction

Previous atmospheric modeling and retrieval efforts have targeted Titan's water at specific spatial and temporal intervals within Cassini's operational lifetime.[1] These efforts have successfully retrieved isolated stratospheric mixing ratios of 0.023 ppb at 12.1 mbar and 0.14 ppb at 10.7 mbar.[2-3] Additionally, new efforts to rectify these contrasting mixing ratios have been completed, however, results show that methodology, observations, and conclusions are accurate for both retrievals.[4] These results hint that there are additional mechanisms that govern Titan's stratospheric water abundances. Similarly, no conclusive evidence has yet been gathered to identify systematic latitudinal variation of water vapor abundances—which is a behavior observed with other trace gas species.

Scientific Motivations

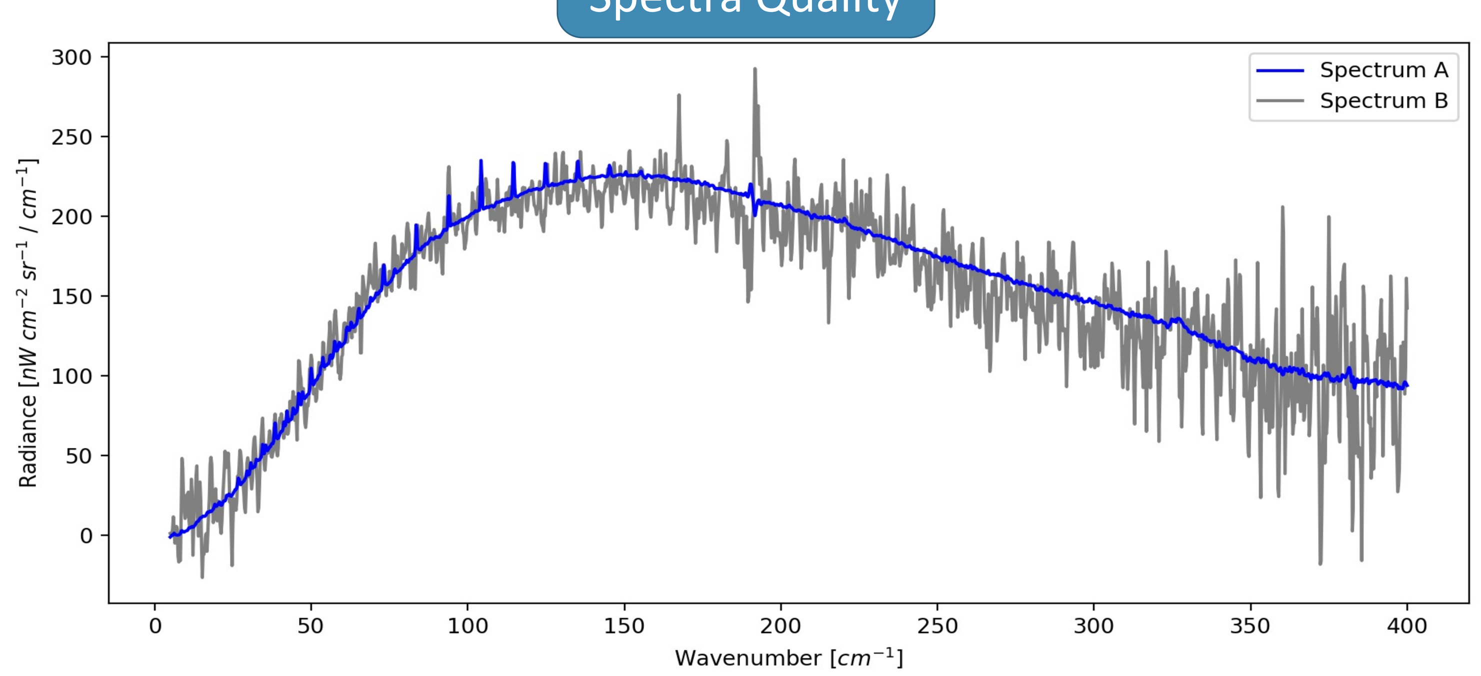
Water is one of three main oxygen-bearing compounds in Titan's atmosphere, and its presence plays an important role in Titan's complex photochemistry.[5] It is theorized that the bulk of Titan's water budget is deposited in the upper atmosphere through either micrometeorite ablation or infalling oxygen compounds from Saturn's rings, Enceladus's plumes, or interplanetary dust.[6] Through further investigation of Titan's spatial and temporal variation of water vapor, we aim to provide insight into important questions regarding water's behavior, and dominant sources and sinks on the moon.

Observations

We have focused our search for latitudinal variation of water vapor in the 120-260 cm^{-1} range, using Cassini's Composite Infrared Spectrometer (CIRS) instrument.[7] CIRS Focal Plane 1 (FP1, 10-600 cm^{-1}) has high spectral resolution (0.5 cm^{-1}), which is required for the detection of weak water lines. We chose nadir spectra to support our modeling effort due to the high availability and quality of the data over Cassini's operational lifetime.

Due to Titan's extreme low temperature, miniscule abundance of water vapor, and complex atmospheric conditions, a single nadir spectrum does not have sufficient signal to noise ratio to detect weak water lines. Therefore, we averaged thousands of nadir spectra together in order to boost the final signal to noise ratio, and enhance our water lines. Figure 1 depicts the signal quality of two separate spectra, where Spectrum A (blue) has 2542 averaged spectra and Spectrum B (grey) has 1 spectrum.

Figure 1
Spectra Quality



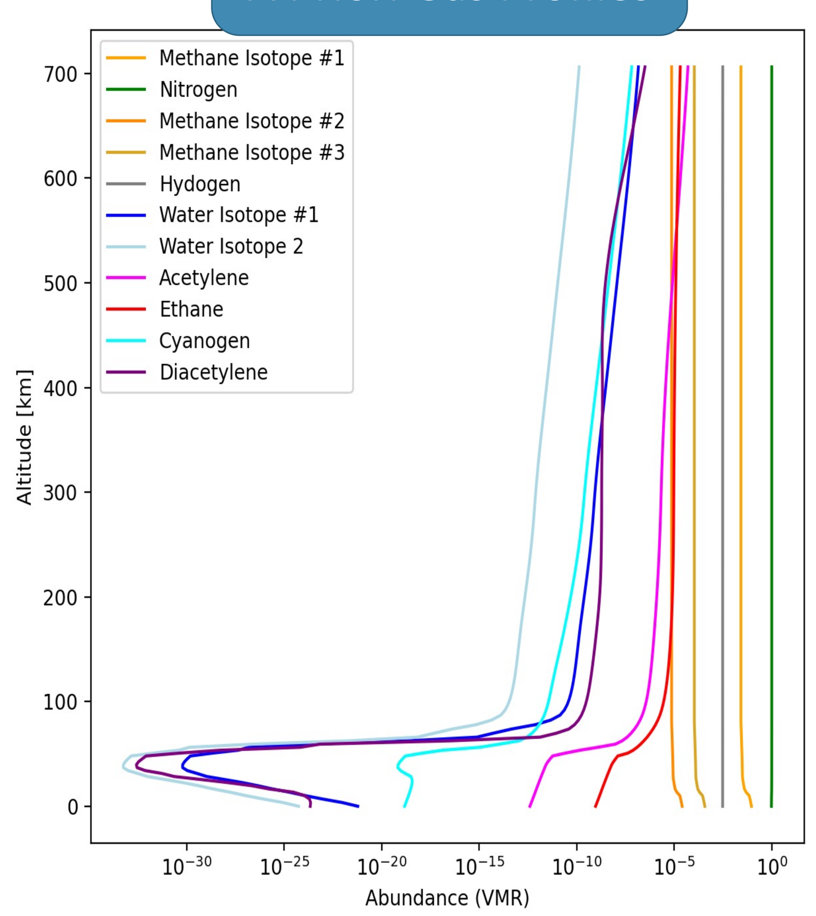
Methods

Cassini observed Titan from 2005–2017, and we chose to use the entire 12.5-year data set in order to investigate water's latitudinal variation over time. We split the 12.5-year data set into five Titan months, which are 2.5 Earth years each, to allow for high temporal resolution of the averaged nadir spectra around seasonal changes. Each Titan month was split again and into six latitude bins corresponding to 30 degrees latitude each, for a total of 30 bins over the entire 12.5-year temporal range.

We modeled the 30 individual bins using the **N**on-linear Optimal **E**stimator for **M**ultivariat**E** Spectral Analy**SIS** (**NEMESIS**) planetary atmosphere radiative transfer and retrieval tool.[8] The models were built from various *a priori* gas profiles, bin-dependent temperature profiles, and bulk atmospheric composition estimates (Figure 2). We fixed the *a priori* methane profiles since methane does not vary significantly over latitude, and vertical methane abundances are well known from the Huygens probe.[9]

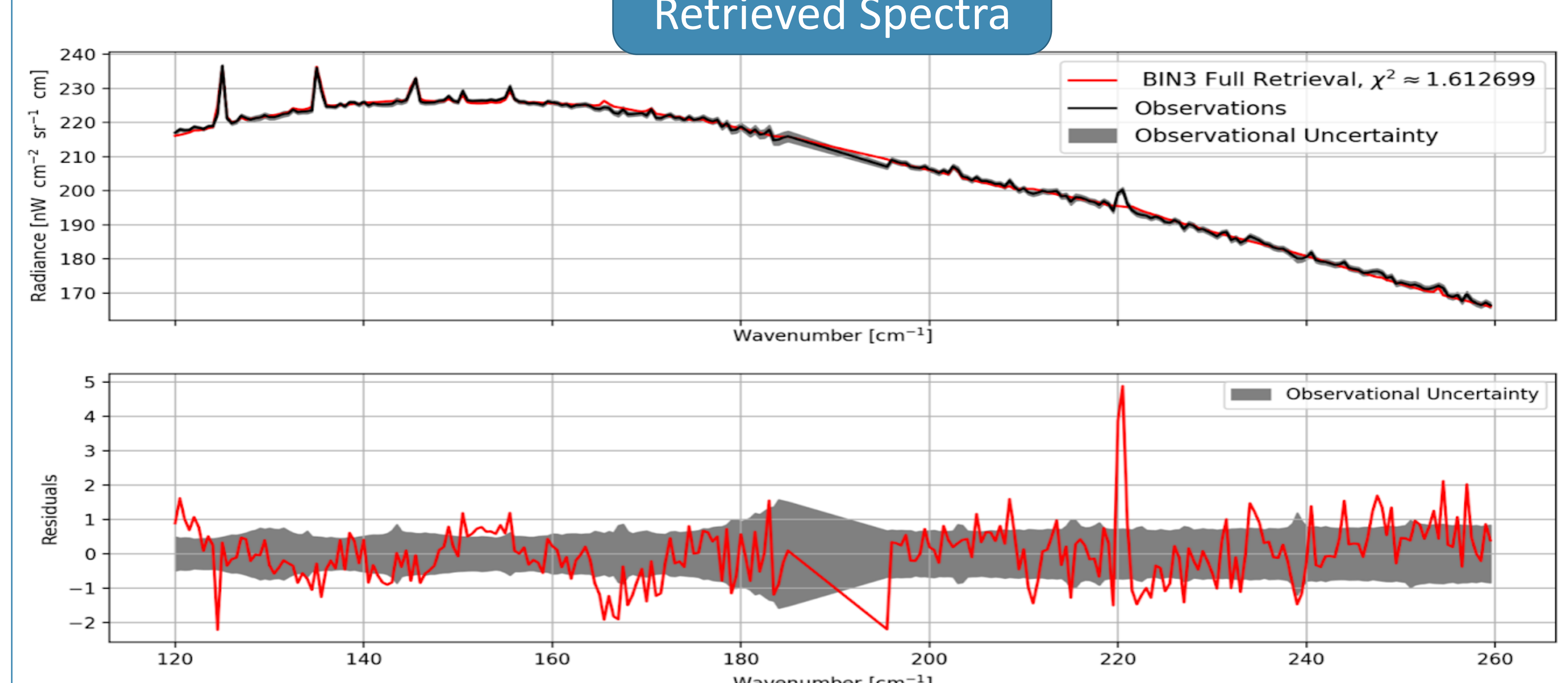
We began by retrieving temperature profiles through modeling a series of methane lines between 125 and 155 cm^{-1}. Aerosols, trace gas, and water vapor scaling factors were also retrieved from the set of modeled *a priori* estimates. The models targeted the entire 120-260 cm^{-1} range, which allowed for the robust detection and modeling of rotational water lines. In these models, contribution functions, which denote our retrieval's water sensitivity, peaked in the lower stratosphere (90-180km).

Figure 2
A Priori Gas Profiles



The primary output of the models is a spectral fit between the modeled spectrum and the observed spectrum, as seen in Figure 3: the modeled retrieved spectral fit for Bin 3, 30 to 0 degrees S, 2005 to 2007.

Figure 3
Retrieved Spectra

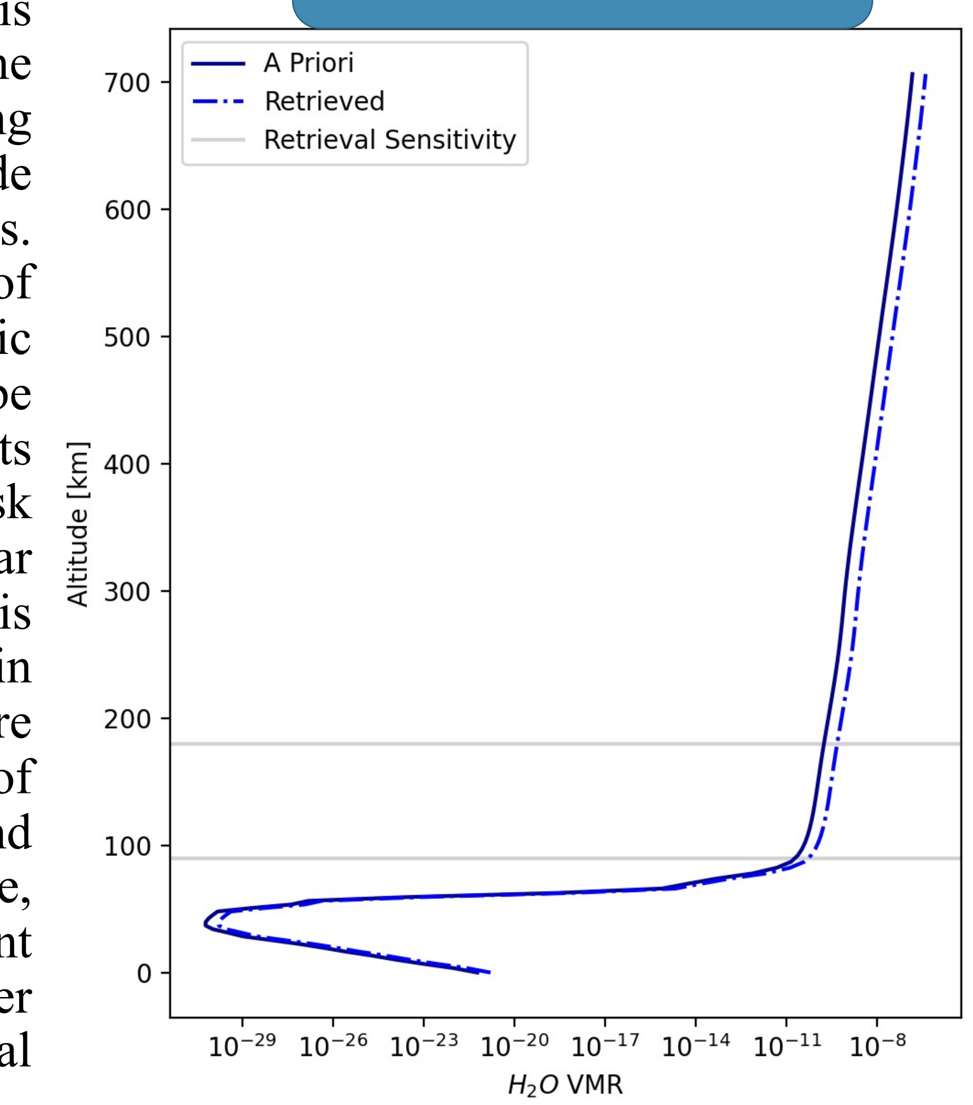


Conclusions

Here, we are able to provide new stratospheric water vapor mixing ratios for the first modeled equatorial bin, Bin 3, from 2005 to 2007. At an altitude of 107 km and latitude range of 30 to 0 degrees South, we retrieved water vapor mixing ratios of 0.11 ppb. These initial results are in agreement with previous retrievals, such as Cottini et al. (2012), who found an abundance of 0.14 ppb at 97 km.[3] Figure 4 depicts the retrieved vertical water vapor profile for the Bin 3 (dashed) and the *a priori* estimate (solid).

Next steps for this research consists of the continuation of modeling efforts across midlatitude and polar latitude bins. Upon completion of modeling, stratospheric mixing ratios will be derived at various heights over Titan's entire disk and the entire 12.5-year data set. This analysis will aid researchers in constraining future photochemical models of Titan's atmosphere, and help determine where, when, and to what extent external sources of water contribute to Titan's total water budget.

Figure 4
Retrieved Water Profile



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Acknowledgments

We would like to thank the University Space Research Association for funding this work. Additionally, we thank the NASA Goddard Space Flight Center for hosting this research over their 2021 Summer Intern session. Dr. Conor Nixon, Dr. Gordon Bjoraker, Dr. Sophie Bauduin, and Brendan Steffens deserve notable commendation for their continued support and mentorship of Summer 2021 NASA Goddard Space Flight Center intern Brian Murphy throughout this research. Brian Murphy wishes the best to his colleagues and mentors who collaborated on this research, and looks forward to future collaborations with them, NASA Goddard Space Flight Center, and University Space Research Association.