THE DEEP TROPOSPHERE OF URANUS AS SEEN AT RADIO WAVELENGTHS: IMPLICATIONS FOR TARGETING AN ATMOSPHERIC PROBE. M. D. Hofstadter[1], B. J. Butler[2], A. B. Akins[1,] and M. A Gurwell[3]; [1]Jet Propulsion Laboratory, California Institute of Technology; [2]National Radio Astronomy Observatory; [3]Center for Astrophysics | Harvard & Smithsonian.

Introduction: The temperatures measured by an atmospheric probe, the abundance of condensable species, and the abundance of disequilibrium species are influenced by both local weather conditions and global circulation patterns. In this paper we report on a 40+ year record of ground-based radio observations of Uranus which show atmospheric circulation, chemistry, and weather patterns in the 1 to 100 bar pressure region of the atmosphere as a function of latitude, altitude, and season.. This information is of use when targeting an atmospheric probe.

The data set: The primary data used in this study are 25 images of Uranus made at the Very Large Array (VLA) and Submillimeter Array (SMA) radio observatories between 1981 and 2022 (Fig. 1). These observations were made at wavelengths between 0.1 and 21 cm. They are augmented by unresolved measurements at wavelengths from 350 µm to 1.3 mm from the James Clerk Maxwell Telescope (JCMT) and the Caltech Submillimeter Observatory (CSO).

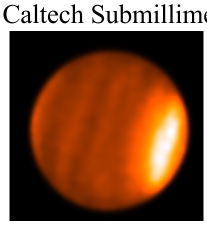

Figure 1: VLA image of Uranus at a wavelength of 1 cm, observed in 2012. The North Pole is on the right. See the text for a discussion.

Retrievals of atmospheric properties: The data set is primarily sensitive to the vertical opacity profile of the atmosphere between about 0.7 and 100 bars. Our retrieval free parameters are the abundances of H_2S, NH_3, and H_2O. We considered three atmospheric models to constrain their vertical profiles. *Chemical Equilibrium Model:* The abundance of condensable species deep in the troposphere is allowed to vary with latitude, but vertically they are assumed to condense out according to their saturation vapor pressures. The saturation vapor pressure is allowed to be modified by a relative humidity anywhere from 0 to 10. We find that no equilibrium model can adequately fit all observations of Uranus' polar regions. *Hadley-Type Model:* Low latitudes are in chemical equilibrium, and represent regions of upwelling. High latitudes represent areas of subsidence, with a very small mixing ratio of condensables at altitude, and a larger mixing ratio at depth representing the altitude at which subsidence no longer dominates the composition [1]. *Juno-Type Model:* Inspired by results from the Juno spacecraft at Jupiter [2], all opacity is represented by NH_3 with three free parameters: an upper atmospheric mixing ratio, a deep atmospheric mixing ratio, and the pressure at which the transition between mixing ratios occurs.

For all models that fit the data, we find:

- Regions poleward of ±50˚ are depleted in condensables relative to lower latitudes by a factor of ~50, down to a depth of ~20 to ~50 bars.
- Regions between the equator and ±30˚ are richer in condensables. Equilibrium models require more H_2S in these regions than NH_3, contrary to expectations based on solar abundances.
- Regions between 30˚ and 50˚ North and South are intermediate in their abundance of condensables.
- In the 1 to 5 bar region, relative humidities at low latitudes are ~1.4 and they are ~0 over the poles (consistent with expectations from the Hadley-Type model), and/or meridional temperature variations observed near 800 mbar [3] extend to these depths.
- The abundance of condensables over a large altitude range varies by ~30% near latitudes of 0˚, ±20˚ and ±75˚, creating the banding seen in images.

As reported in [1] we find that during mid-summer the pole to equator contrast decreases, suggesting a weakening in the circulation that maintains it. Many of the features reported above have been seen previously [e.g., 4], though our analysis is unique in spanning a large altitude and time range.

Implications for probe targeting: To increase the likelihood of encountering a vertically well-mixed region of the atmosphere, the probe should enter within 30˚ of the equator. Reaching a depth of 10 bars is sufficient to test if a vertically mixed region contains more H_2S than NH_3, and if those species are supersaturated. A probe depth of 40 bars is likely needed to measure the deep NH_3 abundance at low latitudes, and a depth of 50 bars at high latitudes.

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References: [1] Hofstadter, M.D. and Butler, B.J. (2003) *Icarus, 165,* 168–180. [2] Bolton, S.J. et al. (2017) *Science, 356*, 6340/821. [3] Hanel, R.B. et al. (1986) *Science, 233,* 70–74. [4] Molter, E.M, et al. (2021) *Plan. Sci Journ.* 2:3.