National Aeronautics and Space Administration

# Using Microwave Radiometers and Gravity Science to Probe Uranus' Deep Atmospheric Circulation and Interior Structure

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**Program: FY21 R&TD Strategic Initiative** **Strategic Focus Area: Ice Giant Science Leadership**

## I. Objectives

This is a three-year effort to help re-establish JPL as the scientific leader in studies of the deep troposphere and interior of Ice Giant planets by initiating new investigations and JPL first-author, peer-reviewed papers in collaboration with recognized leaders in those fields. It will also improve JPL's competitive position in the selection of future science teams, flight instruments, and missions by optimizing JPL instrument designs and exploring innovative mission architectures to address some of the highest-priority science questions at Uranus. Each phase of this work includes mentoring and a transfer of responsibilities to early-career personnel to enable JPL to maintain its leadership position into the future. The major efforts in the 3-year plan are:

**Year 1:** Analyze pre-2014 radio observations of Uranus to constrain the tropospheric circulation and its seasonal variations.

**Year 2:** Develop a dynamical model of the atmosphere that explains the features observed in Year 1, calculate normal-mode oscillations for candidate atmosphere/interior models, and determine the gravitational signature of all models.

**Year 3:** Explore innovative instrument and mission architectures to test the atmospheric and interior models developed in Year 2. Host an international workshop on Ice Giants.

This poster presents results at the end of Year 1.

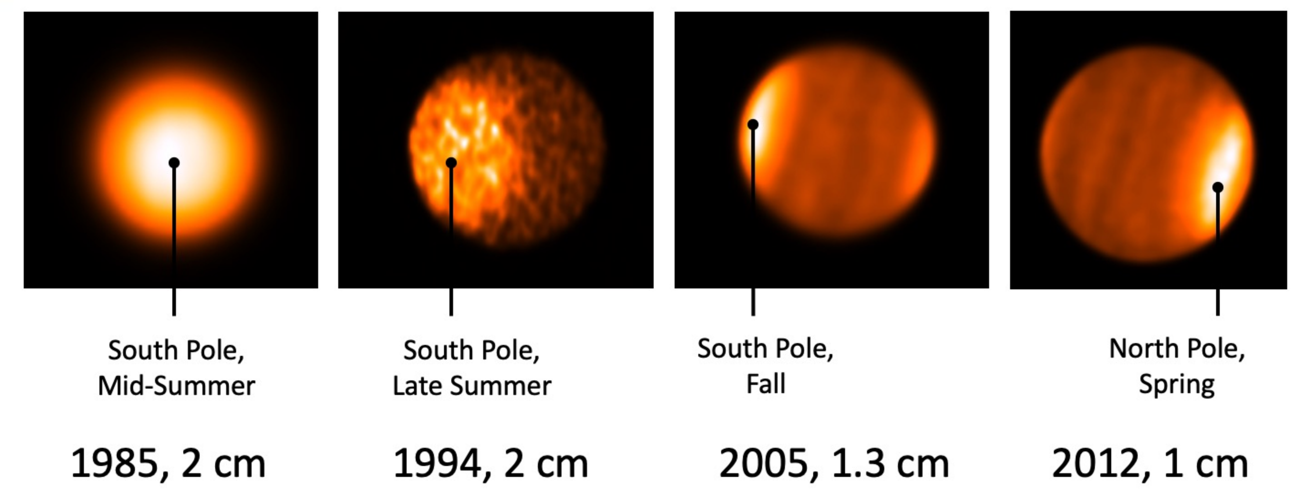


**Figure 1:** A sampling of radio images of Uranus, with season, observing year, and wavelength indicated. Note the changing viewing geometry from Earth, and that each season lasts 21 years. Relatively dark regions are rich in the absorbing vapor $H_2S$. $H_2S$ and the other atmospheric absorbers ($NH_3$ and $H_2O$) are condensable in the atmosphere, allowing them to be used as tracers of cloud formation and atmospheric motions.

## II. Background

Even basic questions about the Ice Giants, such as whether they are primarily made of ice or rock, are in dispute [1]. The importance of understanding them is highlighted by the currently active Decadal Survey [2] and a recent NASA-sponsored mission study [3], which identify atmospheric dynamics as one of the highest-priority science objectives. In Year 1 of our task we have determined the large-scale circulation patterns of the deep troposphere (pressures ~5 to 100 bars) and how they change seasonally.

We make use of a unique data set held by the PI, consisting of radio images of Uranus from 1981 to 2013, at a variety of wavelengths. Figure 1 shows a subset of this data, highlighting how the seasons and viewing geometry have changed over this time span. Bright regions in these images are areas depleted in $H_2S$, and the spatial distribution of species can be used to infer atmospheric motions. A montage of the entire data set is shown in Fig. 2. Longer wavelengths sense deeper into the atmosphere, with 1 cm wavelengths probing the atmosphere near the 5-bar pressure level, and 20 cm sensing down to 100 bars. At the longer wavelengths, $NH_3$ and $H_2O$ also contribute to atmospheric opacity.

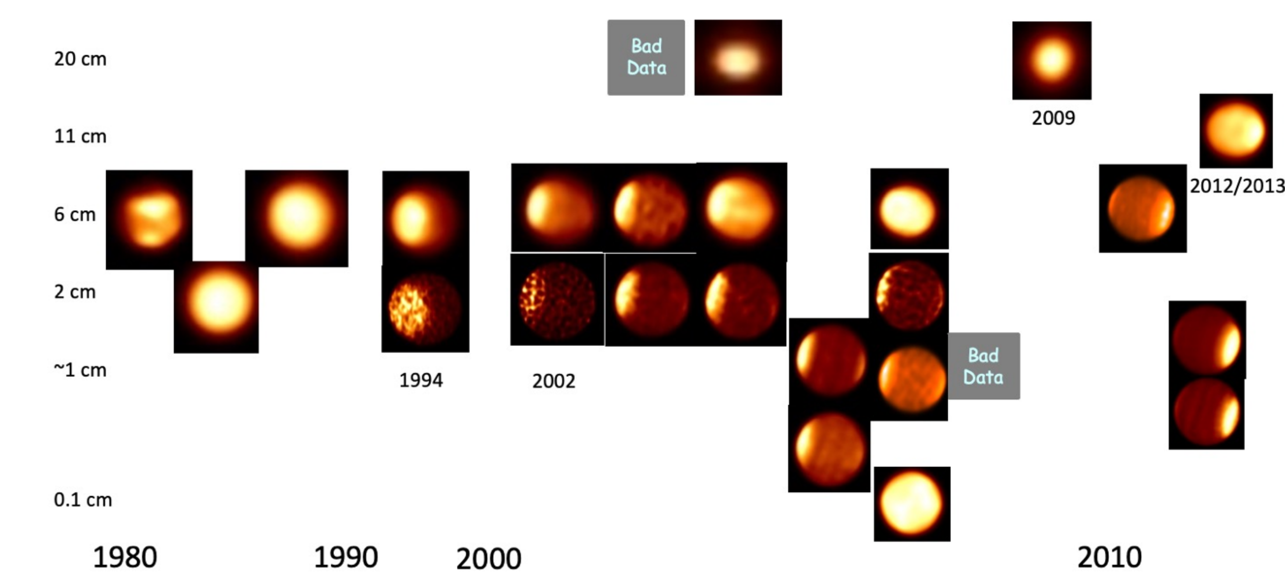


**Figure 2:** A montage of all 23 data sets used in this study. Columns indicate the year (data from 1981 to 2013), and rows indicate observing wavelength (0.14 to 20 cm). One data set in 2003 and one in 2007 were corrupted by equipment problems at the observatory.

## III. Approach and Results

The images shown in Figs. 1 and 2 have been used to map the spatial distributions of $H_2S$, $NH_3$, and $H_2O$ over time. Regions rich in the absorbing species are dark, indicating they are vertically well-mixed by upwelling air. Bright regions are absorber poor, indicative of dry air descending from high altitudes (all the absorbers having been removed from these air parcels via cloud formation).

The dominant feature in all images are the bright polar regions (indicative of dry, descending air parcels) and the relatively dim lower latitudes (indicative of vertically well-mixed regions.) This pattern has been known since 1989 [4], and was seen to strengthen sometime around 1990 [5]. We also see slightly brighter bands near ±20 degrees latitude and the Equator, which were also previously reported [6].

Our work is the first to quantify compositional variations associated with the mid-latitude bands, and to look for seasonal changes since 1994. It also improves upon the first-reported detection of seasonal change by using updated information on the composition of the Uranus atmosphere and new laboratory data on the properties of relevant species.

The most significant results of our analysis are:

- The polar regions are dominated by dry, descending air parcels throughout the uranian year. In the fall, winter, and spring, these dry regions contain ~50x less absorber than mid-latitudinal regions in the 5 to 50 bar pressure range.
- The circulation driving the polar depletion weakens in mid-summer, reducing the difference in absorber abundance between pole and equator to a factor of ~25.
- The mid-latitude bright bands are caused by a ~30% depletion in absorbers in the 5 to 10 bar region. We cannot reliably say whether these smaller-scale features change seasonally.
- We expect the large-scale circulation pattern to weaken between now and 2027, as the North Pole enters its summer season.

These results are summarized in Fig. 3.

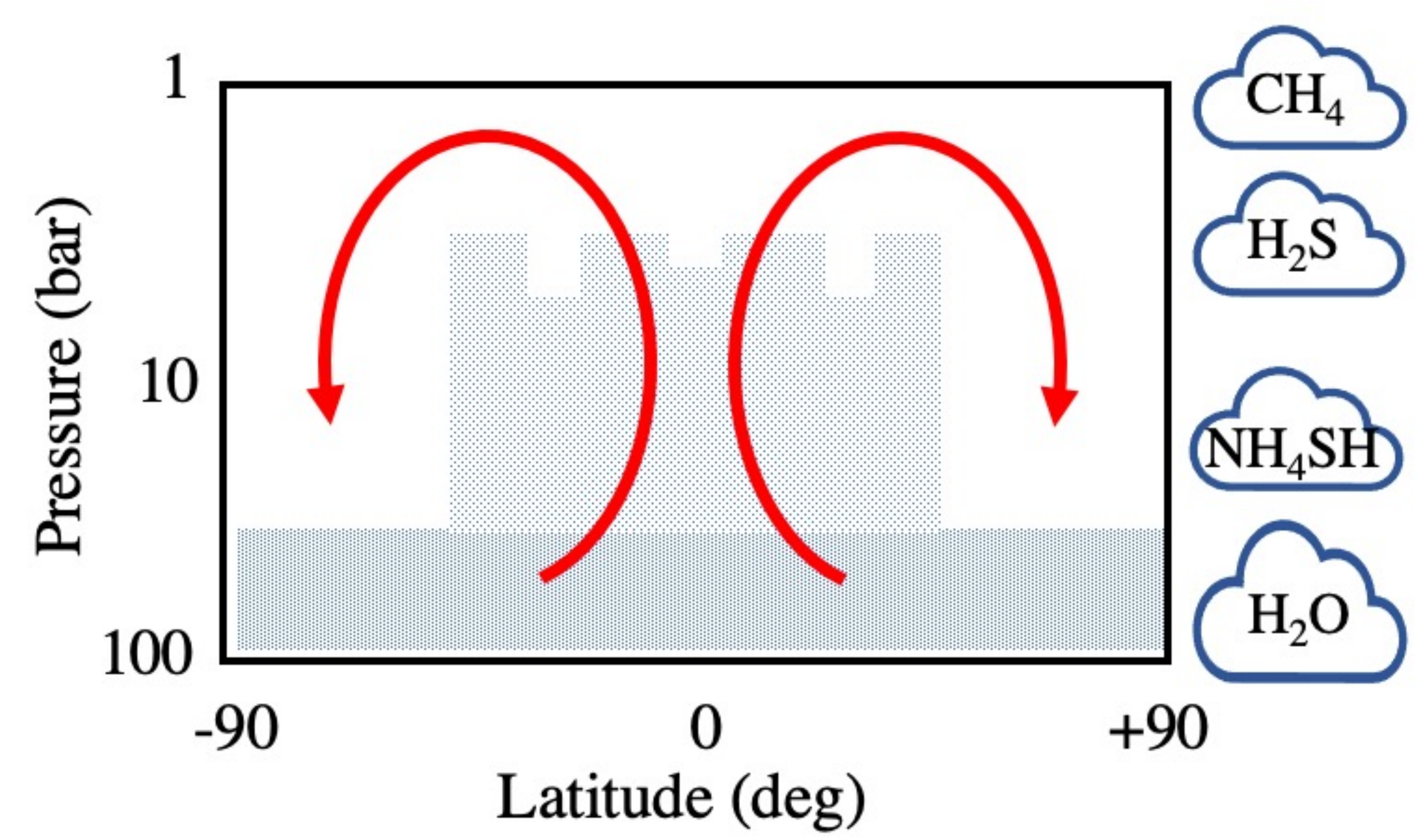


**Figure 3:** The distribution of species in the atmosphere, and the inferred global-scale circulation that creates it. The blue stippling indicates the abundance of absorbers. Note that at pressures greater than 50 bars, the atmosphere is relatively rich in the species $H_2O$, $H_2S$, and $NH_3$ at all latitudes. At lower pressures, absorbers are concentrated at low latitudes, and less abundant than at depth due to condensation (the presumed location of various clouds is indicated along the right). Near a pressure of 5 bars, smaller-scale circulation patterns create the fainter banding seen in Fig. 1. The red arrows indicate the global-scale circulation believed to create the variations between pole and equator. This circulation is always present, but weakens in summer.

## IV. Significance / Benefits to JPL and NASA

We have identified the major circulation patterns in the Uranus atmosphere and how they have changed over 3/4 of a uranian year. We have used our analysis to predict that observable changes will be seen again within the next ~5 years. We have also established a good working relationship with UC Berkeley personnel and given early-career JPL'ers leadership of key tasks. Our first-year efforts have also set the stage for Years 2 and 3 in which we will design experiments, instruments, and mission architectures to discriminate among competing models for Uranus' atmosphere and interior [7]. This will maximize the scientific return from future NASA missions to the Ice Giants, and positions JPL to be a leader in future instruments and missions to the outer solar system.

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**Publications**

A manuscript is in preparation.

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