Enhancing Planetary Wind Measurements with Radio Science Flight Instruments

Kamal Oudrhiri, Sami Asmar, David Atkinson*

Jet Propulsion Laboratory, California Institute of Technology

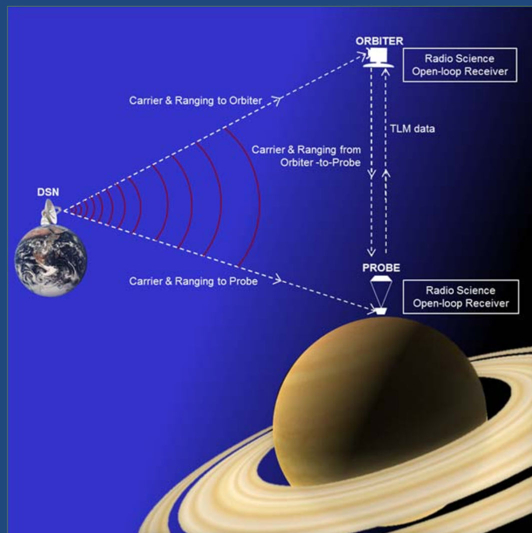
*University of Idaho

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Abstract

Advances in Radio Science flight instrument technologies and post-processing capabilities allow for the possibility of utilizing a One-Way carrier and sequential ranging signals transmitted from Deep Space Network antennas and recorded onboard a probe-mounted Radio Science open-loop receiver with onboard post-processing algorithms to 1. record raw radio science data samples 2. produce precision measurements of probe range and position, thereby significantly improving occultation investigations and atmospheric wind retrievals using standard probe-orbiter Doppler Wind retrieval techniques.

In this poster we will review opportunities for and benefits of using a Radio Science Instrument "Open-Loop Receiver" on-board the orbiter and the probe to improve the accuracy of planetary atmospheric wind profiles measured during entry probe descent.



Deep Space Network Instrument

The Deep Space Network (DSN) will provide an uplink carrier with a frequency phase modulated with a Pseudo-Noise (PN) ranging signal. The DSN will use the 70-meter diameter antennas to produce enough signal margin at the probe's open-loop recorder. The signal margin will be largely determined by the type of probe antenna used to maintain the Earth-pointing link during the wind experiment. The one uplink signal from DSN will be detected and recorded by the open-loop receiver both on-board the Orbiter and the Probe.

Planetary Winds in the Outer Solar System

The atmospheres of the giant planets represent time capsules dating to the epoch of solar system formation. Atmospheric dynamics - winds, waves, convection, and turbulence – are responsible for horizontal and vertical mixing of atmospheric constituents. The altitude profile of the winds places important constraints on the location of solar energy deposition which can affect cloud structure and the static stability of the atmosphere, and can also provide an indication of the relative importance to the atmospheric energy structure of solar energy relative to internal energy sources.

Doppler Wind Measurement Techniques

The dynamics of the atmosphere can be inferred by utilizing Doppler techniques to track the motions of a probe descending under parachute. Accurate modelling of the entry and descent profile of the probe, including location, altitude, and descent speed, and the assumption of predominantly zonal (east-west) winds are used to extract the relatively small signature of probe motions (reflected as Doppler residuals in the probe radio link frequency profile) resulting from atmospheric dynamics. From the Doppler residuals, the vertical profile of zonal winds can be retrieved utilizing an iterative inversion algorithm that accounts for the integrated effect of the winds on the probe descent longitude. Further analysis of the probe radio link frequency residuals may also provide evidence of atmospheric waves and turbulence, as well as probe microdynamics including spin and pendulum motion. The heritage of outer solar system Doppler wind retrievals comprises measurements of the zonal winds on Jupiter by the Galileo probe in 1995 and the Titan zonal winds by Huygens a decade later. The Jovian zonal wind profile along the path of the Galileo probe descent, retrieved under the assumption of negligible meridional winds and requiring accurate measurement of the probe descent speed, allowed the development of a Doppler residuals inversion algorithm to retrieve the zonal winds while accounting for both the initial uncertainty in probe descent longitude and the changing probe longitude due to the integrated effect of the winds. In 2005 the profile of zonal winds on Titan was measured by the Huygens probe using a significantly simpler retrieval algorithm that did not include probe longitude drift effects in the first iteration, since the small size and slow rotation of Titan make the effect of initial uncertainties and the integrated winds on the probe descent longitude negligibly small.

Radio Science Open-Loop Receiver

Radio Science Open-Loop Receiver will consist of two modules: a radio frequency (RF) front end and a baseband processor (Figure 2). The fixed gain RF front end accepts a radio signal, amplifies it (with fixed gain), and down-converts it (with fixed local oscillator) to an intermediate frequency. The baseband processor digitizes the signal, applies an open-loop tuning function to reduce frequency dynamics, and filters/decimates the data to the final digital bandwidth. The data is stored in local memory as I & Q samples.

Currently in initial development. Builds on the JPL flight-proven Electra communications payload. Modification for science applications include fixed gain, higher dynamic range, and excellent frequency stability.

Benefits of Precision Range Measurements

Precision measurements of probe range and position enable significant improvement of Doppler retrievals of atmospheric winds. The probe velocity relative to Earth is computed as the derivative of the ranging positional information and is therefore unaffected by any constant biases in the ranging data. In addition, velocities derived from ranging data will not have an error term that grows with the descent time. By providing an accurate Earth-to-probe baseline range and velocity, knowledge of the planet-centered probe descent location can be significantly improved.

Probe measurement of the DSN uplink signal can also provide a second projection of the horizontal winds that, when coupled with the probe-orbiter wind projection, will provide the complete horizontal wind vector. To make the measurements fully complementary, the angle between the Earth-to-probe and probe-to-orbiter baselines should be large, and to increase the sensitivity to winds in the probe local horizontal plane, the probe-orbiter and probe-Earth angles should be at a non-zero angle to the probe nadir vector.

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Processing Techniques for Ranging

The RF spectrum of the DSN uplink carrier and ranging signals are immediately recorded via the Radio Science Open-Loop Receiver on-board the probe. The received data (Carrier & TLM) is stored as I & Q samples. An on-board Software Receiver is further used to decode telemetry and extract "Probe Solution" of the pseudo-range & phase time tagged with UTC reference. These two parameters along with information on the received carrier are then transferred into the Probe Command & Data Handling System to be telemetered to the Orbiter. Similarly, the DSN uplink carrier and ranging signals are simultaneously recorded and processed on-board the orbiter to compute an "Orbiter Solution" of the pseudo-range & phase time tagged with UTC.

The carrier with ranging signals from orbiter to probe is also recorded with the open-loop on-board the probe and processed to compute the "Orbiter-Probe Solution" of the pseudo-range & phase time tagged with probe-time reference. This solution is further transferred as telemetry to the orbiter. The three "Solutions" are then used to determine and improve the probe range and position.