JPL VLBI Analysis Center Report for 2009

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Abstract

This report describes the activities of the JPL VLBI Analysis Center for the year 2009. We continue to do celestial reference frame, terrestrial reference frame, earth orientation, and spacecraft navigation work using the VLBI technique. There are several areas of our work that are undergoing active development. An important development was moving measurements to higher data rates with our earth orientation work going to 448 Mbps and our reference frame work to 224 Mbps. Our international collaboration to build celestial frames at K- (24 GHz) and Q-bands (43 GHz) matured to roughly part-per-billion (ppb) accuracy. Our in-house work to build a reference at X/Ka-bands (8.4/32 GHz) is also close to ppb accuracy. We supported several missions with VLBI navigation measurements. We continue to study ways to improve spacecraft tracking using VLBI techniques.

1. General Information

The Jet Propulsion Laboratory (JPL) Analysis Center is located in Pasadena, California. Like the rest of JPL, the center is operated by the California Institute of Technology under contract to NASA. JPL has had a VLBI analysis group since about 1970. Our work is focused on supporting spacecraft navigation. This includes several components:

1. Celestial Reference Frame (CRF) and Terrestrial Reference Frame (TRF) are efforts that provide infrastructure to support spacecraft navigation and Earth orientation measurements.
2. Time and Earth Motion Precision Observations (TEMPO) measures Earth orientation parameters based on single baseline semi-monthly measurements. These VLBI measurements are then combined with daily GPS measurements, as well as other sources of Earth orientation information. The combined product is used to provide Earth orientation for spacecraft navigation use.
3. Delta differenced one-way range (ΔDOR) is a differential VLBI technique that measures the angle between a spacecraft and an angularly nearby extragalactic radio source. This technique thus complements the radial information from spacecraft doppler and range measurements by providing plane-of-sky information for the spacecraft trajectory.
4. ΔVLBI phase referencing using the VLBA to measure spacecraft positions.

2. Technical Capabilities

The JPL Analysis Center acquires its own data and supplements it with data from other centers. The data we acquire is taken using NASA's Deep Space Network (DSN).

1. Antennas: Most of our work uses 34-m antennas located near Goldstone (California, USA), Madrid (Spain), and Tidbinbilla (Australia). These include the following Deep Space Stations

(DSS): the "High Efficiency" subnet comprised of DSS 15, DSS 45, and DSS 65 (see Figure 1) which has been the most often used set of antennas for VLBI. More recently, we have been using the DSN's beam waveguide (BWG) antennas: DSS 13, DSS 24, DSS 25, DSS 26, DSS 34, DSS 54, and DSS 55. Less frequent use is made of the DSN's 70-m network (DSS 14, DSS 43, and DSS 63). Typical X-band system temperatures are 35K on the HEF antennas. The 70-m and BWGs are about 20K. Antenna efficiencies are typically well above 50% at X-band.

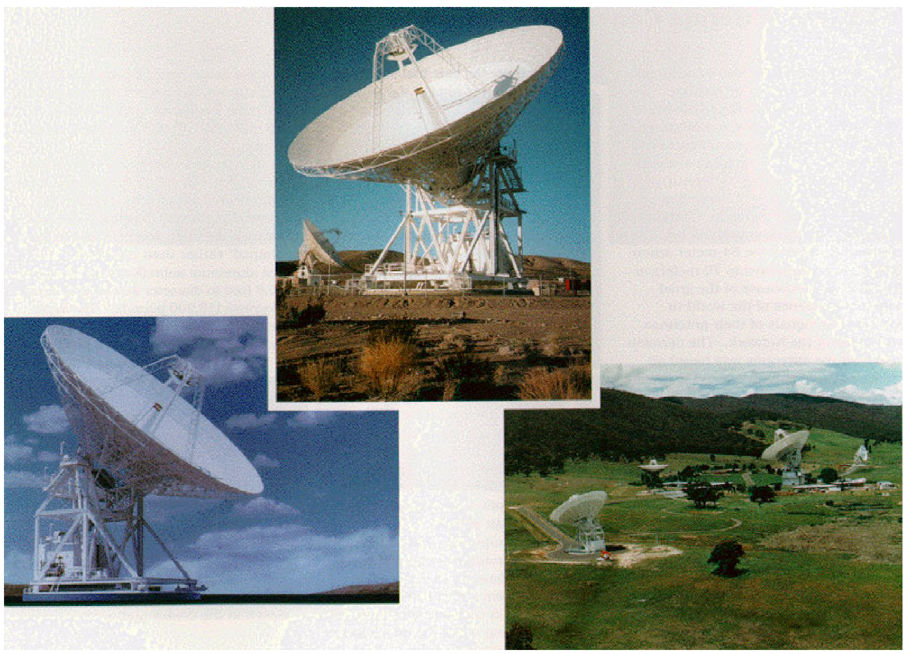

Figure 1. This figure shows the three high-efficiency antennas in the subnet: Goldstone is in the center; Robledo, Spain is on the lower left; and Tidbinbilla, Australia is on the lower right. These antennas were designed to have an optimum efficiency at X-band (8.4 GHz), which was to become the standard downlink frequency for solar-system exploration. An important secondary objective was to have a reasonable efficiency at Ka-band (32 GHz) thereby allowing for possible future use at the next highest band allocated for deep space communications. The subnet was completed in 1986 in time for the Voyager encounter with Uranus.

2. Data acquisition: We use the Mark 5A VLBI data acquisition systems. In addition, we have JPL-unique systems called the VLBI Science Recorder (VSR) and the Wideband VSRs (WVSR) which have digital baseband converters and record directly to hard disk. The data is later transferred via network to JPL for correlation with our software correlator.

3. Correlators: JPL VLBI Correlation systems are now exclusively based on the SOFTC software, which handles the ΔDOR, TEMPO, and CRF correlations of disk format recordings. The VSRs and the software correlator have also been used for connected element interferometry tests of antenna arraying concepts.

4. Solution types: We run several different types of solutions. For ΔDOR spacecraft tracking we make narrow field ($\approx 10^\circ$) differential solutions. The TEMPO solutions typically have a

highly constrained terrestrial (TRF) and celestial frame (CRF) as a foundation for estimating Earth orientation parameters. These reference frames are produced from global solutions which then provide the framework needed for use by TEMPO and ΔDOR.

3. Staff

Our staff are listed below with a brief indication of areas of concentration within the VLBI effort at JPL. Note that not all of the staff listed work on VLBI exclusively, as our group is involved in a number of projects in addition to our VLBI work.

- Durgadas Bagri: VLBI instrumental calibrations and TEMPO.
- Jim Border: ΔDOR spacecraft tracking.
- Mike Heflin: ΔDOR, CRF, and TRF. Maintains MODEST analysis code.
- Chris Jacobs: S/X, K, Q, X/Ka CRFs, and TRF.
- Peter Kroger: ΔDOR spacecraft tracking.
- Gabor Lanyi: VLBA phase referencing, ΔDOR, WVR, K-Q CRF, and TRF.
- Steve Lowe: Software correlator, fringe fitting software.
- Walid Majid: ΔDOR, VLBA phase referencing.
- Chuck Naudet: WVR, Mark 5A support, and K-Q CRF.
- Lyle Skjerve: Field support of VLBI experiments at Goldstone.
- Ojars Sovers: S/X, K, Q, and X/Ka CRFs and TRF. Maintains MODEST analysis code.
- Alan Steppe: TEMPO and TRF.
- L. D. Zhang: S/X, K & Q CRFs, and TEMPO.

4. Current Status and Activities

In order to support the DSN's move to Ka-band (32 GHz), JPL is leading a collaboration with the Goddard Space Flight Center, the U.S. Naval Observatory, the National Radio Astronomical Observatory, and the Bordeaux Observatory to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz). Results were presented by Fomalont & Jacobs (2009) and Jacobs et al. (2009). In-house work to build an X/Ka-band CRF was presented by Jacobs & Sovers (2009). Research on phase referencing for spacecraft navigation was done by Bagri & Majid (2009) and Majid, Fomalont, & Bagri (2009). We were also involved in the work which led to the acceptance of the ICRF2 by the IAU (Ma et al., 2009).

During 2009 we demonstrated that data taken at the maximum Mark 5A rate of 1024 Mbps could be processed by our software correlator. This data rate opens the door for a very high sensitivity VLBI system when combined with the large apertures and low system temperatures of the DSN's antennas.

In recent years our Delta-DOR spacecraft tracking team has provided direct measurements of spacecraft angular position to support navigation of the Phoenix landing on Mars, the Messenger flybys of Mercury, and the Dawn flyby of Mars, and it is now supporting Earth return navigation for the Hayabusa mission (Border, 2009).

5. Future Plans

In 2010, we expect to improve TEMPO by increasing data rates to 896 Mbps and reference frame VLBI to 448 Mbps—assuming that resources for recording media are approved. We plan to turn our proto-type Ka-band phase calibrator into a set of operational units for operational deployment in late 2010. Work on the Digital Back End (DBE) will continue. Our next generation fringe fitting program is also expected to come online in the next year. We anticipate refereed publications on our high frequency celestial reference frame work. We plan to contribute to a refereed publication describing the ICRF2. On the spacecraft front, we plan to continue supporting a number of operational missions while further improving techniques for using VLBI for spacecraft tracking.

6. Acknowledgements

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