JPL VLBI Analysis Center Report for 2008

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Abstract

This report describes the activities of the JPL VLBI analysis center for the year 2008. 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 our earth orientation and reference frame work completely to Mark 5A recording and software correlation by the end of 2008. Our international collaboration to build celestial frames at K- (24 GHz) and Q-bands (43 GHz) matured to near a part-per-billion accuracy as documented in two submitted papers. Our in-house work to build a reference at X/Ka-bands (8.4/32 GHz) is also close to ppb accuracy. We supported the Phoenix Mars lander and other 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 focussed 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 uses 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.

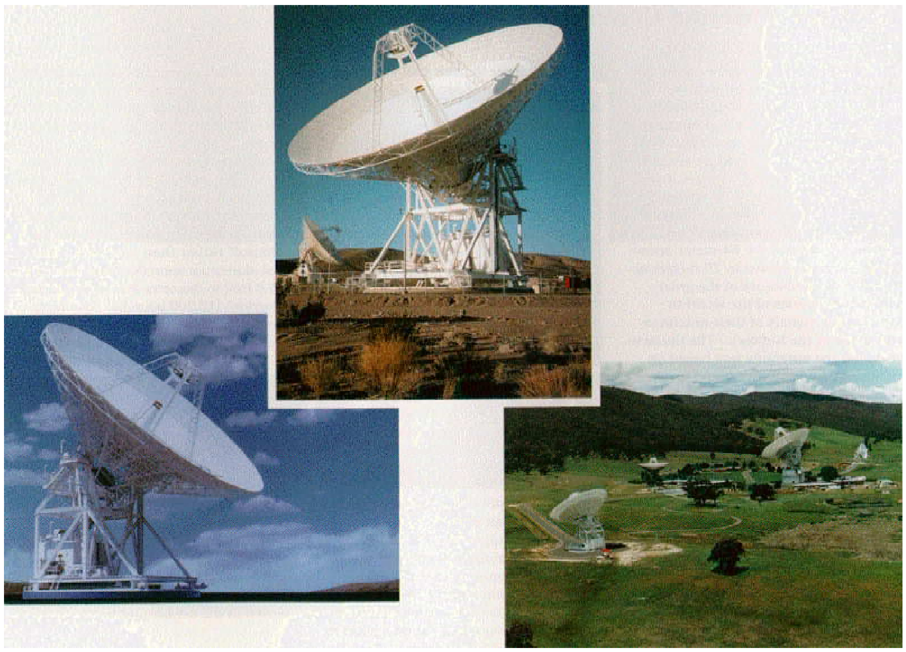

Figure 1. This figure shows the three high-efficiency antennas in the subnet: Goldstone is in the center; Robledo, Spain is on the lower left; and Tidbinbilla, Australia is on the lower right. These antennas were designed to have an optimum efficiency at X-band (8.4 GHz), which was to become the standard 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: The DSN's Mark IV tape recorders and the BlockII tape-based correlator were retired during 2008 and were replaced by Mark 5A VLBI data acquisition systems and software correlation. 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: antenna arraying and TEMPO.
- Jim Border: ΔDOR spacecraft tracking.
- Mike Heflin: ΔDOR, CRF, and TRF. Maintains MODEST analysis code.
- Chris Jacobs: TRF and S/X, K, Q, and X/Ka CRFs.
- Peter Kroger: ΔDOR spacecraft tracking.
- Gabor Lanyi: VLBA phase referencing, ΔDOR, WVR, K-Q CRF, and TRF.
- Steve Lowe: Software correlator and fringe fitting software.
- Walid Majid: ΔDOR and 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 and 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 Goddard Space Flight Center, the U.S. Naval Observatory, National Radio Astronomical Observatory, and the Bordeaux Observatory to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz). Results from the last seven years were summarized in papers submitted by Lanyi *et al* (2008) and Charlot *et al* (2008) for refereed publication. In-house work to build an X/Ka-band CRF has matured and was presented at international conferences (Jacobs & Sovers 2008; Jacobs 2008). We were also involved in the work to build the 2nd generation ICRF.

The advanced Water Vapor Radiometer (A-WVR) continues to be used in research applications. This device can calibrate water vapor induced delays to a fractional stability of roughly a few parts in 10^{15} over time scales of 2,000 to 10,000 seconds and has demonstrated threefold reduction in VLBI residuals on time scales of 100 to 1000 seconds.

During 2008 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.

The highlight of 2008 was our successful support of the Mars Phoenix lander mission with VLBI-based navigation measurements.

5. Future Plans

In 2009, we expect to improve TEMPO and reference frame VLBI by increasing our Mark 5A recording rate to 512 Mbps—assuming that resources for recording media are approved. We plan to turn our prototype Ka-band phase calibrator into a set of operational units for operational deployment in 2010. 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 continue our involvement with the ICRF-2 team. 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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References

[1] Lanyi, G. E., D. Boboltz, P. Charlot, A. Fey, E. Fomalont, B. Geldzahler, D. Gordon, C. S. Jacobs, C. Ma, C. J. Naudet, J. Romney, O. J. Sovers, and L. D. Zhang, 'The Celestial Reference Frame at Higher Radio Frequencies. I. Astrometry from VLBA Observations at 24 and 43 GHz,' submitted to AJ, 21 Nov 2008.

[2] Charlot, P., D. A. Boboltz, A. L. Fey, E. B. Fomalont, B. J. Geldzahler, D. Gordon, C. S. Jacobs, G. E. Lanyi, C. Ma, C. J. Naudet, J. D. Romney, O. J. Sovers, and L. D. Zhang, 'The Celestial Reference Frame at Higher Radio Frequencies. II. VLBA Imaging at 24 and 43 GHz,' submitted to AJ, 21 Nov 2008.

[3] Jacobs, C. S., and O. J. Sovers, 'Extending the ICRF to Higher Radio Frequencies: Global Astrometric Results at 32/8 GHz,' IVS 2008 General Meeting Proceedings, A. Finkelstein and D. Behrend, eds. Session 4-08, St. Petersburg, Russia, 04 March 2008, ftp://ivscc.gsfc.nasa.gov/pub/general-meeting/2008/pdf/jacobs.pdf

[4] Lanyi, G. E., D. Boboltz, P. Charlot, A. Fey, E. Fomalont, B. Geldzahler, D. Gordon, C.S. Jacobs, C. Ma, C. J. Naudet, J. Romney, O. J. Sovers, and L. D. Zhang, 'Astrometry from VLBA Observations at 24 and 43 GHz,' IVS 2008 General Meeting Proceedings, A. Finkelstein and D. Behrend, eds. Session 4-09P, St. Petersburg, Russia, 04 March 2008, ftp://ivscc.gsfc.nasa.gov/pub/general-meeting/2008/pdf/lanyi.pdf

[5] Jacobs, C. S., 'Extending the ICRF to Higher Radio Frequencies: 24, 32, & 43 GHz Global Astrometry,' Journees 2008 Proceedings, Session 5, Dresden, Germany, 24 Sep 2008, http://astro.geo.tu-dresden.de/journees2008/programme.htm