JPL VLBI Analysis Center Report for 2014

Christopher S. Jacobs

Abstract This report describes the activities of the JPL VLBI Analysis Center for the year 2014. Highlights for the year include tracking the Maven Mars mission, the commissioning of a new 34-m antenna in Australia, DSS 35, and continued operation for the combined NASA-ESA Ka-band network. In addition, our DVP backend was successfully interfaced to the JIVE and DiFX correlators. We continue to support VLBI-based navigation using our combined spacecraft, celestial reference frame, terrestrial reference frame, earth orientation, and planetary ephemeris VLBI systems.

1 General Information

The Jet Propulsion Laboratory (JPL) Analysis Center is in Pasadena, California. Like the rest of JPL, the center is operated by the California Institute of Technology under contract to NASA. JPL has done VLBI analysis since about 1970. We focus on spacecraft navigation, including:

1. The Celestial Reference Frame (CRF) and The Terrestrial Reference Frame (TRF) are efforts which provide infrastructure to support spacecraft navigation and Earth orientation measurements.
2. The 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 provides Earth orientation for spacecraft navigation.
3. Delta differenced one-way range (ΔDOR) is a differential VLBI technique which 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.

Jet Propulsion Laboratory, California Institute of Technology

JPL Analysis Center

IVS 2014 Annual Report

2 Technical Capabilities

The JPL Analysis Center acquires its own data and supplements it with data from other centers. The data we acquire are 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, which has been the most often used set of JPL 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 35, 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.

2. Data acquisition: We use ROACH-based Digital Back Ends with Mark 5C VLBI recorders. These units became fully operational in 2014. 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 are later transferred via network to JPL for processing with our software correlator.
3. Correlators: The JPL VLBI Correlator has been exclusively based on the SOFTC software which handles the ΔDOR, TEMPO, and CRF correlations as well as tests of antenna arraying.
4. Solution types: We run several different types of solutions. For ΔDOR spacecraft tracking we make narrow field ($\approx 10°$) 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 along with areas of concentration. 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 VLBI.

- Durgadas Bagri: TEMPO and Ka-band phase calibrators.
- Konstantin Belov: CRF global solutions.
- James Border: ΔDOR spacecraft tracking.
- Cristina García-Miró: Madrid data acquisition, NASA-ESA southern declination collaboration, and educational outreach.
- Shinji Horiuchi: Canberra data acquisition and NASA-ESA southern declination collaboration.
- Chris Jacobs: NASA-ESA southern declination collaboration, X/Ka CRF, TRF, and S/X CRF.
- Peter Kroger: ΔDOR spacecraft tracking.
- Gabor Lanyi: MODEST, fringe fitting and correlation support, ΔDOR, and TRF.
- Steve Lowe: Software correlator, fringe fitting software, and ΔDOR.
- Walid Majid: pulsars, ΔDOR, and VLBA phase referencing.
- Chuck Naudet: NASA-ESA southern declination collaboration and source stability studies.
- Andres Romero-Wolf: MODEST scripts.
- Lawrence Snedeker: Goldstone data acquisition and NASA-ESA southern declination collaboration.
- Ojars Sovers: S/X and X/Ka, and CRFs and TRF.
- Alan Steppe: TEMPO and TRF.

4 Current Status and Activities

The TEMPO task's EOP measurements continue. Our S/X CRF work is being downsized in favor of X/Ka-band (8.4/32 GHz) CRF which continues to make major strides forward. In particular, in 2014 with ESA's Malargüe, Argentina antenna adding much needed southern coverage and DSN operations at 2048 Mbps, our XKa median precision reached the level of the ICRF2 for 525 common sources.

VLBI spacecraft tracking continues to provide measurements of angular position in support of mission navigation and planetary ephemeris development. 2014 was a busy year for VLBI spacecraft tracking in the Deep Space Network. The ISRO Mars Orbiter Mission and the NASA MAVEN mission were supported by Delta-DOR for their cruise from Earth to Mars, achieving highly accurate orbit insertions in September. The ephemeris of Mars was maintained by Delta-DOR measurements of the MRO and 2001 Odyssey orbiters. Delta-DOR support for Rosetta was completed in June as the spacecraft started its approach to Comet 67P/Churyumov-Gerasimenko. A series of Delta-DOR measurements was completed with New Horizons in June—August to support a trajectory correction maneuver for targeting to Pluto. Regular measurements began in December for Pluto approach. Measurements continued in support of the Dawn low thrust cruise from Vesta to Ceres. Ceres is now in view, and the Delta-DOR support for Dawn is nearing completion. Finally, in December, Delta-DOR support began for the Hayabusa-2 (JAXA) mission. Also, a number of "mixed-baseline" Delta-DOR passes were completed between DSN antennas and antennas belonging to ESA, JAXA, and ISRO. These measurements are validating inter-agency operability for current and planned cross-support agreements. Preparations are now underway to support future measurements with Akatsuki (JAXA), Juno, InSight, OSIRIS-REx, and Solar Probe Plus.

5 Future Plans

In 2015, we hope to deploy operational Ka-band phase calibrators at our overseas sites. We expect the combined NASA-ESA deep space network to reach sub-nanoradian (200 μas) Ka-band CRF results over the south polar cap ($-90^\circ < \delta < -45^\circ$). Collaborative work at K-band is expected to complete full sky coverage as well as improve spatial density through an approved VLBA proposal. At S/X-band the VCS-II collaboration should complete its re-survey of over 2,000 sources. On the spacecraft front, we plan to continue supporting a number of operational missions while further improving techniques for using VLBI for spacecraft tracking.

Acknowledgements

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References

1. C. S. Jacobs and ICRF-3 working group, ‘ICRF3: Roadmap to the Next Generation ICRF,’ 223rd AAS, session 251.25, National Harbor, MD, 5–9 Jan 2014. http://extras.aas.org/meeting/aas223/251/251.25
2. C. S. Jacobs and ICRF-3 working group, ‘The ICRF-3: Status, Plans, and Progress on the next generation CRF.’ 8th IVS General Meeting, Shanghai, China, 2–7 March 2014.
3. C. S. Jacobs, J. E. Clark, C. García-Miró, C. E. Goodhart, S. Horiuchi, R. Madde, M. Mercolino, C. J. Naudet, L. G. Snedeker, I. Sotuela, L. A. White, The X/Ka-band (8.4/32 GHz) CRF: Results from combined NASA-ESA baselines including Malargüe, Argentina 8th IVS General Meeting Shanghai, China, 2–7 March 2014.
4. A. de Witt. A. Bertarini, C. Jacobs, J. McCallum, T. Jung, J. Quick, S. Horiuchi, J. Lovell, C. Phillips, B. W. Sohn, R. Ojha, ‘Completing K-band CRF in South Hemisphere,’ 8th IVS General Meeting, Shanghai, China, 2–7 March 2014
5. J. Boehm and ICRF-3 working group, The ICRF-3: Status, Plans, and Progress on the next generation CRF. EGU General Assembly, Vienna, Austria, 27 April 2014. http://publik.tuwien.ac.at/files/PubDat_229493.pdf
6. S. Horiuchi, J. E. Clark, C. García-Miró, C. S. Jacobs, R. Madde, M. Mercolino, L. G. Snedeker, I Sotuela, L. A. White, ‘All Sky CRF at X/Ka-band (8.4/32 GHZ),’ XXXI URSI General Assembly, Beijing, China, 16 Aug 2014.
7. Z. Malkin, C. S. Jacobs, and ICRF-3 working group, ‘ICRF-3: Status, Plans, Progress on Next Generation ICRF,’ Journées 2014, Pulkovo Observatory, St. Petersburg, Russia, 22 Sep 2014. http://www.gao.spb.ru/english/as/j2014/presentations/malkin.pdf
8. C. S. Jacobs and ICRF-3 working group, ‘ICRF-3: Roadmap to the next generation ICRF,’ poster, Astronomia Dinamica en Latino-America (ADeLA) 2014, ADeLA, Universidad de Santiago, Chile, 29 Sept-1 Oct 2014. adela2014.das.uchile.cl/talks/Posters/CJacobs_ADeLA2014@SCL.pdf
9. C. S. Jacobs, ‘Celestial Reference Frames,’ Astronomia Dinamica en Latino-America (ADeLA) 2014, workshop lectures, Universidad de Santiago, Chile, 2-3 Oct 2014. adela2014.das.uchile.cl/talks/Workshop_Classes/CJacobs_Santiago_ADeLA2014@SCL.pdf
10. C. S. Jacobs and P. Charlot, ‘Radio Sources,’ Astronomia Dinamica en Latino-America (ADeLA) 2014, workshop lecture, Universidad de Santiago, Chile, 2-3 Oct 2014. adela2014.das.uchile.cl/talks/Workshop_Classes/CJacobs_PCharlot_ADeLA2014@SCL.pdf.pdf
11. C. S. Jacobs, C. García-Miró, S. Horiuchi, J. E. Clark, J. de Vicente, M. Dugast, R. Madde, M. Mercolino, D. Pazos, C. J. Naudet, L. Snedeker, G. Bourda, P. Charlot, I. Sotuela, L. A. White, ‘The X/Ka CRF with tie to GAIA’s optical frame,’ CNEA/ITeDA Seminar, Mendoza, Argentina, 8 Oct 2014.
12. C. S. Jacobs and B. Garcia, ‘El físico de la NASA: Christopher Jacobs dio una charla en la CNEA,’ Interview/news piece by Pedro Fernandez of Noticias Acequia, Mendoza, Argentina, regarding CONAE/ESA/NASA Collaboration, https://www.youtube.com/watch?v=XWV9Mhu-TXQ
13. C. García-Miró, C. S. Jacobs, S. Horiuchi, J. E. Clark, R. Madde, M. Mercolino, D. Pazos, C. J. Naudet, L. Snedeker, G. Bourda, P. Charlot, I. Sotuela, L. A. White, ‘The X/Ka CRF: towards a GAIA frame tie,’ 12th EVN Symposium, Cagliari, Italy, 7–10 Oct 2014 http://evn2014.oa-cagliari.inaf.it/EVN2014/Talks/03/ Wed Morning/GarciaMiro_EVN2014.pptx
14. C. García-Miró, J. E. Clark, C. S. Jacobs, R. M. Campbell, M. Kettenis, S. P. Rogstad, S. Horiuchi, L. Snedeker, ‘The VLBI Digital Terminal at the NASA’s DSN: First Results from non-JPL Correlators,’ poster 14, 12th EVN Symposium, Cagliari, Italy, 7-10 Oct 2014
15. C. S. Jacobs and ICRF-3 working group, ‘The ICRF-3: Proposed Roadmap to the Next Generation ICRF,’ REFAG-2014, Luxembourg, 15 Oct 2014.

http://geophy.uni.lu/users/tonie.vandam/REFAG2014/SESS_III_CRF_EOP/Jacobs_a.pdf
16. C. S. Jacobs, J. E. Clark, C. García-Miró, S. Horiuchi, R. Madde, M. Mercolino, C. J. Naudet, D. Pazos, P. Pope, L. Snedeker, I. Sotuela, L. A. White, 'The X/Ka CRF: Results from combined NASA-ESA baselines including Malargüe, Argentina,' REFAG-2014, Luxembourg, 15 October 2014. http://geophy.uni.lu/users/tonie.vandam/REFAG2014/SESS_III_CRF_EOP/Jacobs_b.pdf
17. A. Iddink, C. S. Jacobs, T. Artz, A. Nothnagel, 'A Proposed Combination Process for ICRF-3,' REFAG-2014, Luxembourg, 15 Oct 2014. http://geophy.uni.lu/users/tonie.vandam/REFAG2014/SESS_III_CRF_EOP/Nothnagel.pdf
18. C. S. Jacobs and ICRF-3 Working Group, 'The ICRF-3: Proposed Roadmap to the next generation ICRF,' Seminar, Max Planck Institute for Radio Astronomy, Bonn, Germany, 20 Oct 2014.
19. C. S. Jacobs, C. García-Miró, S. Horiuchi, J. E. Clark, R. Madde, M. Mercolino, D. Pazos, C. J. Naudet, L. Snedeker, G. Bourda, P. Charlot, I. Sotuela, L. A. White, 'The X/Ka CRF: towards a GAIA frame tie,' Seminar, Centro Astronómico de Yebes, Yebes, Spain, 23 Oct 2014
20. C. S. Jacobs, C. García-Miró, S. Horiuchi, L. Snedeker, D. Bagri, J. E. Clark, G. E. Lanyi, C. J. Naudet, L. A.White, R. Madde, M. Mercolino, D. Pazos, G. Bourda, P. Charlot 'VLBI in the DSN: Cat M&E, Clock Sync/TEMPO, Delta-DOR,' MDSCC Seminar, Robledo de Chavela, Spain, 24 Oct 2014.
21. D. Shin, D. Bagri, J. Border, Advanced Calibration Technique for Accurate Three-Way Spacecraft Ranging Interplanetary Network Progress Report, vol. 42-199, p. 1-11 http://ipnpr.jpl.nasa.gov/progress_report/42-199/199C.pdf
22. C. S. Jacobs and ICRF-3 working group, 'ICRF-3: Multi-wavelength progress,' Extra-galactic Science with Gaia, Observatoire de Meudon, France, 10-12 Dec 2014 http://egsg2014.obspm.fr/cours/JACOBS.pdf
23. C. S. Jacobs, J. Souchay, R. Gaume, and ICRF-3 Working Group, ICRF-3 status report, IERS Directing Board, AGU splinter meeting, San Francisco, Dec 14 2014.