Extension and Maintenance of the ICRF

C. Ma
Goddard Space Flight Center

T.M. Eubanks
U.S. Naval Observatory

The ICRF (International Celestial Reference Frame) is the result of a long, carefully considered process, and the extension and maintenance of the ICRF are further steps to improve its usefulness. In the more distant future, based on the ever larger VLBI data set and continued research activities, a new realization of the ICRF will be made. For now the goals are more modest: determining positions of new sources consistent with the ICRF, improving the accuracy of some source positions, and monitoring the sources.

The fundamental concepts of the ICRF were developed and extensively discussed at the IAU Colloquium 127 on Reference Systems held in Virginia Beach in 1990. Under the leadership of J. Kovalevsky and J. Hughes, the General Theory of Relativity for space and time, the use of extragalactic radio objects, and the separation of the celestial reference frame from the equator and the ecliptic were summarized in nine recommendations adopted as a resolution by the XXIst IAU General Assembly in Buenos Aires in 1991. A working group under C. de Vegt was formed to select the list of radio sources to be used with emphasis on the need to connect the radio and optical frames. The XXIInd IAU General Assembly in Den Haag in 1994 adopted the list and established a new working group under L. Morrison to define the positions of the radio sources in the list. This work was done by a subgroup of VLBI and celestial reference system specialists. The resulting ICRF catalog was adopted by the XXXIIIrd IAU General Assembly in Kyoto in 1997 and came into effect 1 January 1998, replacing the FK5. A new Working Group for the International Celestial Reference System (ICRS) under F. Mignard was formed to carry on the ICRF work, to extend the frame to other objects and frequencies, and to consider the consequences of the ICRF.

The data used to determine the ICRF radio source positions included 1.6 million pairs of dual-frequency delays and rates from 1979 through the middle of 1995. The data were contributed from several geodetic and astrometric observing programs, the vast majority of the observations coming from the former but most of the sources coming from the latter. The design of the analysis was intended to provide (1995) state of the art source positions, in particular to free the results from contamination from anomalous source behavior, geodetic noise, and systematic tropospheric effects. Positions of sources with excessive scatter or apparent motion (as determined from test solutions) were treated as arc parameters as were station positions. An elevation limit of 6 degrees was adopted to balance the need for observing geometry against the difficulty in correctly modeling the troposphere at low elevations. Both delays and rates were used to maximize the information available and to decrease correlations. Tropospheric gradients were estimated to remove a significant systematic effect. Because of the large number and high quality of observations, the formal errors for the positions were exceedingly small, but a detailed error analysis suggested that a floor of ~0.25 mas was a better estimate of the accuracy of the catalog. The axes of the frame were aligned to the IERS realization of the ICRS with an error of ~0.020 mas. The ICRF work was published in Ma and Feissel (eds.), IERS Technical Note 23, June 1997 and in Ma et al., Astron. J. 116:516-546, 1998 July. The IERS Technical Note has a large amount of supplementary material including source structure maps, source structure correction plots, position time series, and source name aliases. Up to date maps and structure corrections are available from A. Fey, USNO and P. Charlot, Bordeaux Observatory, respectively.

The sources from the ICRF solution were divided after the fact into three categories: 212 defining sources that met a series of quality criteria; 294 candidate sources that failed one or more of the quality criteria, e.g., too few observations or observing interval too short; and 102 "other" sources (whose positions were arc parameters). While the distribution over the sky of the ICRF as a whole is quite uniform, the defining sources are sparser in the southern hemisphere because of a dearth of VLBI stations and limited observing. The "other" sources include a number with relatively bright optical counterparts that could be used to connect the radio and stellar frames.

Task Group T-1 of the IAU Working Group for the ICRS has the formal responsibility for maintaining and extending the ICRF. This includes both observing and analysis. However, the international VLBI community provides the observing and analysis resources for this work, so the IVS has an important role in carrying out this mandate. Since the ICRF was done in 1995, ~800 000 more observations including ~50 new sources have been acquired by geodetic and astrometric programs. These need to be integrated with the data and analysis used for the ICRF. The consensus of the Task Group is that the original ICRF solution need not be copied exactly to incorporate new data, but the new positions must be consistent with the ICRF at its stated level of accuracy, ~0.25 mas in overall source positions and ~0.020 mas in orientation. Positions will be determined for new sources, and updated positions and errors will be found for candidate sources with additional observations. The positions and uncertainties of the defining sources will not be changed since they are the actual realization of the ICRF. There will be some refinement in the analysis configuration, e.g., the use of the Niell mapping function, gradient parameters estimated more frequently than once per day, daily axis offset adjustments, etc. The data for new solutions made to update the ICRF will include the data used initially and whatever new data are relevant. The defining sources will be used in a no-net-rotation condition relative to the ICRF to assure that positions from new solutions are aligned with the ICRF.

Although an update to the ICRF will come from a single solution, it is hoped that several IVS analysis centers will provide source positions on a regular basis for use in the ICRF analysis. Comparison of results is an important part of checking for anomalies. The ICRS Section of the IERS Central Bureau has the responsibility for assuring that new information related to the ICRF is fully consistent with the ICRS. After the results from an update solution have been validated by the ICRS Section, the update will be available through the IERS and IVS web pages. It is anticipated that the time between ICRF updates will be about half a year, but preliminary positions of individual sources may be made available in less time for particular needs. In addition, it is planned to extend the position time series of all sources begun in IERS Technical Note 23 as part of monitoring source behavior.

While the updating process must adhere to the general pattern established for the ICRF in 1995, to advance VLBI astrometry requires new ideas and methods. These may include more sophisticated troposphere modeling, more systematic identification and treatment of anomalous source behavior, analysis of position time series, application of source structure corrections to delays and rates, and refining the distribution of added noise. Since the ICRF is now a unique contribution from VLBI, the IVS encourages such activities and will provide assistance in disseminating information about ICRF work.