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Towards a Future ICRF Realization

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Abstract

The data and analysis for the ICRF were completed in 1995 to define a frame to which the Hipparcos optical catalog could be fixed. Additional observations on most of the 608 sources in the overall ICRF catalog have been acquired using a small portion of geodetic observing time as well as astrometric sessions concentrating on the Southern Hemisphere. Positions of new sources have been determined, including ∼1200 from a VLBA phase calibrator survey. A future ICRF realization will require improved geophysical modeling, sophisticated treatment of position variations and/or source structure, optimized data selection and weighting, and re-identification of defining sources. The motivation for the next realization could be significant improvement in accuracy and density or preparation for optical extragalactic catalogs with microarcsecond precision.

1. Introduction

The ICRF (International Celestial Reference Frame), which became effective as the realization of the ICRS (International Celestial Reference System) on 1 January 1998, is a fundamental change from previous realizations. The most important characteristics are summarized in Table 1.

Table 1. Characteristics of the ICRF

Set of positions of 212 defining radio sources
Independent of equator, equinox, ecliptic
Independent of epoch
Position error floor 0.25 milliarcsec
Orientation stability ∼20 microarcsec

Each characteristic is radically different from the earlier reference frames defined by the series of FK5 stellar catalogs. While the changes go in the direction of conceptual simplicity along with significantly better accuracy and stability, in two areas the ICRF is less accessible than FK5. The number of defining sources is an order of magnitude smaller, and the wavelength and mode of observation are quite different from usual astrometry.

The analysis of the VLBI data that resulted in the ICRF is summarized in Table 2. It should be emphasized that this analysis was developed to optimize the accuracy of the defining source positions and the positions of "candidate" sources that had no evidence of instability. Because the majority of sources had few observations, sufficient data to determine position instability was not the norm. The ICRF was isolated from problems in the terrestrial reference frame by estimating

Table 2. Characteristics of the ICRF analysis

Used all relevant data 1979-1995.6
Treated "unstable" sources as arc parameters
Treated stations as arc parameters
State of the art analysis for 1995

station positions independently for each session as arc parameters. The geophysical modeling, notably for the troposphere, was at the state of the art for 1995. ICRF-Ext.1 was completed in 1999 to make use of additional data to improve the errors of the candidate sources and to add 59 new sources. The VLBA Calibrator Survey (VCS) added ~1200 more sources north of -30 degrees to the overall astrometric list. A second extension is planned for 2002. A basic requirement for ICRF extensions is that they do not differ systematically from the ICRF. Consequently only small changes have been made in modeling and the analysis procedures.

2. Considerations for a New ICRF

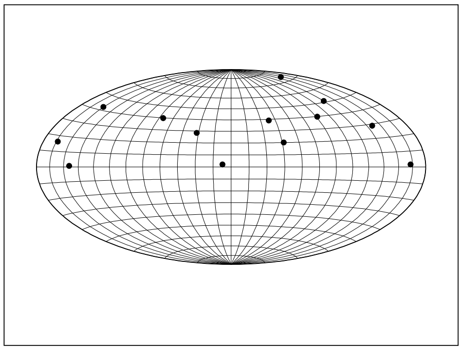
Since VLBI data and analysis both continue to progress, a new ICRF realization from VLBI is almost inevitable. A number of considerations are discussed below.

2.1. Rationale or Goal

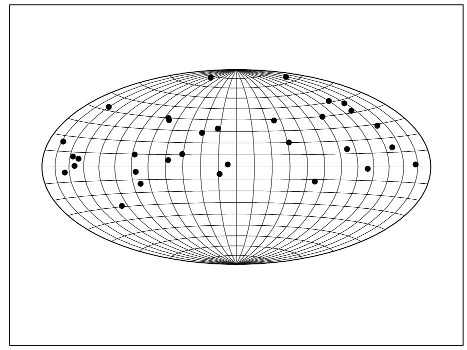
The rationale of the next ICRF may be derived from internal improvements or from external needs. Criteria for internal justification might be the ability to reach a significantly higher level of accuracy or to greatly expand the number or distribution of defining sources. The external need might be to provide a refined catalog for connection or comparison to a precise frame observed at another wavelength. The impetus for completion of the ICRF was, in fact, the requirement of the Hipparcos optical catalog for precise alignment with the ICRS. At present there is no catalog at another wavelength as good as the ICRF, but future satellites like GAIA and SIM have the potential to measure extragalactic objects in the optical with much better precision than the radio ICRF.

2.2. Data

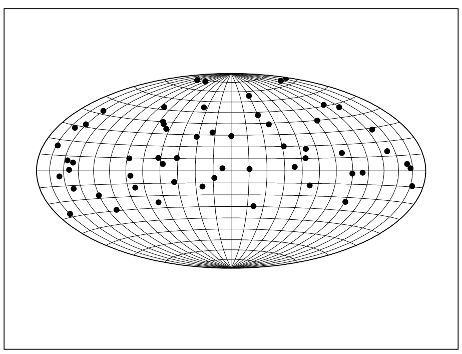
The data set of the ICRF was 95% from geodetic programs. The criteria for selecting sources for geodetic observing are rather different from what would be most desirable for an optimal astrometric data set. The geodetic sources are selected balancing source strength and source structure, with greater emphasis on the former. Especially in the early years of dual-frequency VLBI, lack of instrumental sensitivity required the use of the relatively few very strong compact objects whose structure resulted in positional instability. An astrometric observing program would distribute the observations over a large number of sources uniformly in time and on the sky. The geodetic source list is by comparison much smaller although it has grown and changed over time as shown in Figures 1A through 1E. Since the geodetic data will most likely be the dominant part of a new ICRF, these sources are the real skeleton of the frame. However, as there are significantly



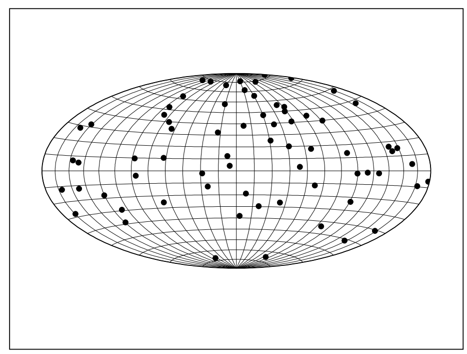
A. 13 sources, 1979–1983.



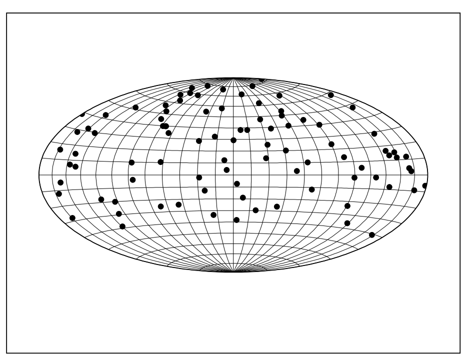
B. 32 sources, 1984–1988.



C. 57 sources, 1989–April 1993.



D. 70 sources, May 1993–1996.



E. 92 sources, 1997–2001.

Figure 1. Progression of most commonly observed sources, 1979–2001.

more data available now than in 1995, it might be advisable to discard the early data dominated by unstable sources. It would also be worthwhile to have a more extensive observing program for the astrometric sources. Because of limited resources, there have been few astrometric sessions in recent years but the astrometric sources are observed a few at a time in some of the geodetic programs. The current observing program for the celestial reference frame focuses on the Southern Hemisphere with different networks for astrometry and mapping.

2.3. Defining and Unstable Sources

The current ICRF has 212 defining sources with preponderance in the Northern Hemisphere. This is a consequence of the small number of VLBI stations in the south. An important consideration for the new ICRF is the expansion in numbers and spatial distribution of the defining sources. A second consideration is the proper identification of the unstable sources. Unless it can be shown conclusively that the positional stability of a source can be inferred from source structure information at one or only a few epochs, both aspects require sufficient data on a large set of sources to provide position time series for statistical analysis. At present generally only geodetic sources have sufficient data, and some of these have detectable instability or apparent motion over the time span of their observations. Providing such data would probably require a significantly greater commitment of VLBI resources to the ICRF than allotted recently.

2.4. Analysis Changes

There are several areas where analysis improvements may contribute to a new ICRF. In the ICRF analysis geophysical and geometric effects impinge on the celestial position results in two main ways: motions of the VLBI antenna reference points within one day (loading phenomena of various origins, thermal changes, antenna flexure, etc.) and propagation media delays. Models of such effects are better than in 1995 although modeling of antenna structure changes is still rudimentary. The troposphere delay probably can never be adequately modeled a priori, so accuracy of the mapping function and gradient estimation may be a limiting factor for the ICRF.

Astrophysical modeling using source maps is attractive in principle but may have limited application in the actual ICRF. It is not possible to have maps for all sources for all times, and it seems unlikely that it will be possible to have sufficient maps for both the north and south for the same times. In addition, assigning the correct reference point for a given source from map to map is as yet a rather time-consuming task. In concept, however, a new ICRF could be generated from a limited number of observing sessions that provide both astrometric and astrophysical information, perhaps observations from the extended VLBA along with the best southern hemisphere mapping and astrometric networks.

The modeling of unstable sources in the ICRF analysis could be refined. For the original ICRF all sources identified as unstable were treated as arc parameters. This method diluted the effect of a source's position instability on the relative positions of the other sources observed in the same session. If the position of a source fluctuates randomly significantly above the level expected from the observation errors, this procedure is probably the only possibility that still allows the use of the source's observations for other parameters like the clock and troposphere. However, a source position could change linearly or smoothly or could have periods of stability. The use of proper motion parameters, piecewise linear approximations, or arc parameters when the position is unstable could permit such sources to contribute to the strength of the daily and concatenated reference frames.

The weighting of the data is an area that was insufficiently explored in the ICRF analysis because of software limitations. Other weighting algorithms should be examined carefully for the next ICRF. Besides reweighting by added station noise, reweighting by elevation and source might improve the analysis.

The error analysis of a new ICRF is critical to understand the real accuracy. This analysis requires detailed comparisons between results from different software, data sets, models, and plausible analysis strategies. Creating a catalog from the combination of results from different solutions should be explored but the data and analysis similarities may preclude a significant improvement.

Finally, the unique capability of VLBI is to tie the ICRF and ITRF directly, but the current ICRF analysis optimizes the first in a way that prevents the realization of the second. Analysis strategies must be developed that allow both frames to be derived from the same solution while reducing systematic errors from nonlinear motions or unstable positions.