SOME COMMON PROBLEMS IN GEODESY AND ASTROMETRY AFTER ESTABLISHMENT OF ICRF

V.V. POPADYOV[1], S.A. TOLCHELNIKOVA[2]
[1] Centre de géodésie et cartographie (CNIIGAiK)
Onezhkaya, 26, Moscow, Russia
e-mail: azyas@mail.ru
[2] Central Astronomical Observatory at Pulkovo of the Russian Academy of Sciences
Pulkovskoe shosse, 65, 196140 St. Peterburg, Russia
e-mail: stolchelnikova@gmail.ru

ABSTRACT. After the "revolution in astrometry" on the eve of XXI century radio frame ICRF and triad ICRS were established as the main reference for astronomy and sciences connected to it, e.g. geodesy and gravimetry. During previous years stars were used as reference points and unity of the sciences was achieved by means of using the plumb lines as terrestrial reference. The expansion of this terrestrial frame to vertical lines at many places has been one of the purposes of geodetic measurements. We consider very useful empirical unity of three branches of the one indivisible science should be preserved. Mutual dependence to each other is secured in modern geodesy and gravimetry, and up to now some parameters used or got in geodesy, are common with those used in gravimetry, astronomy and geodynamics. We discuss several problems in connecting geodetic and gravimetric observations with radio observations used for the compilation of the ICRF in order to attract the attention of experts in optical and radio astrometry.

1. INTRODUCTION

Proving the necessity of recognizing radiosystem as the International reference system, astronomers used the following arguments:

(i) the accuracy of the measurements in the radio range already achieved, is unattainable to optical observations;

(ii) the use of reference radioobjects are located at extragalactic distances, therefore the possibility to find the proper motions of reference radiosources will be unnoticed for a long time. (Walter and Sovers, 2000, p. 137). Some authors even suggest the epoch of observations of reference radiocatalogues might be not fixed in future (Feissell and Mignar, 1998, p. L35; Walter and Sovers, 2000, p. 137);

(iii) the possibility of observations in any weather and low value of radiorefraction in the Earth's atmosphere (in the opinion of the authors of the monograph (Gubanov et al., 1983, pp. 30–38) it does not exceed $0.01''$ and will decrease with the increase of the interferometer base), is also the privilege of the point like extragalactic sources.

The consequences of displacing the traditional optical frame for the radio one are not widely discussed. We believe that it is advisable to consider the influence of the transition to the geodesy and gravimetry, where the unsolved problems and questions have already appeared. At first we remained the method of the radio reference frame establishing and the new distribution of problems between the optical and radio astrometry.

2. ON THE METHOD OF ICRF ESTABLISHING AND THE NEW DISTRIBUTION OF PROBLEMS IN ASTROMETRY

The measurements of angular differences between radiosources are not sufficient for deriving their spherical coordinates, two points with already known spherical coordinates, are needed as the zero-points of a frame. As soon as the large circle passing through one of the points, is obtained the pole in 90 degree from it is found. The third point on the sphere will appear when the required center of the triad is found, it gives the origin of directions to the objects with the known distances as well as to the images of infinitely distant bodies.

On the necessity to distinguish the spherical coordinate system with an uncertain position of center from Cartesian system with fixed position of its origin center is written in Tolchelnikova (2009). Triad may be associated with the Sun or planet's centers, of the places of observation on the Earth's surface and in the future also the instruments' places on the Moon, Mars, etc. When the origin is changed the spherical coordinates of the stars will change, but the changes of the distances to the origin of celestial sphere is impossible to consider.

Although historically the solution of the coordinate problem began with the establishment the two spherical coordinate systems (frames), with one common zero-point, the spherical radiosystem ICRF was established simultaneously with the Cartesian triad ICRS with the origin at the barycenter of the Solar system. Since the information obtained from arc observations is not sufficient, to establish radioframe two the zero-points were accepted: equator of the catalog FK5 (mean observation epoch 1991.25) and dynamic equinox (standard epoch J2000.0). Three axes of ICRS were defined: x axis is directed to a point with coordinates $\alpha = 0^h$, $\delta = 0°$, y axis is directed to point $\alpha = 6^h$, $\delta = 0°$, and z axis is directed to the pole $\delta = 90°$. There is neither star nor quasar in these points.

Walter and Sovers (2000) write that "other designations should be taken in the ICRS to distinguish these coordinates from the standard catalog FK5. Such a change of notation, of course, was not held to preserve continuity in the customary practice" (Walter and Sovers, 2000, p. 142). Saving of the names cannot guarantee continuity, but we agree that the continuity with the fundamental catalog has been achieved for the epoch of the establishment of the radioframe.

The point of view on the "longevity" of quasar coordinate system became the common opinion, and therefore the solution of fundamental problems has been entrusted with the positional radioastronomy (radioastometry). Absolute concord in some questions is not achieved. For example, V.V. Vityazev writes about the system ICRS, which the directions of the coordinate axes fixed in space once and for ever and no changes will be allowed (Finkelstein et al., 2001, p. 95). Walter and Sovers (2000) believe that soon or later some small corrections might be need for "maintaining" of directions of the axes of established radiosystem. They call the coordinate system ICRS revolutionary because "for the first time in the history of a common celestial coordinate system is no longer connected with equinox and ecliptic plane" (Walter and Sovers, 2000, p. 165).

Based on the fact that the radiosystem is recognized as the main reference, which has international status, new distribution of problems is discussed in the papers of our fellow citizens as the perspectives for the development of astrometry designed by IAU. Their plenary papers presented to the conference "Astrometry, geodynamics and celestial mechanics on the threshold of the XXI century" were published in Finkelstein et al. (2001).

3. THE INFLUENCE OF DISPLACING THE OPTICAL REFERENCE COORDINATE SYSTEM FOR RADIOSYSTEM ON GEODESY AND GRAVIMETRY

As is known, in the XX century we distinguished three relatively independent sciences of the indivisible one: astrometry, geodesy and gravimetry. They solved their own and common fundamental problems, e.g. determination of terrestrial coordinate system and the Earth rotation.

Using the coordinates of International catalog of stars and now quasars does not solve the problem of establishing terrestrial system. In the traditional method the solution was provided that astrometry, geodesy and gravimetry had the common empirical foundation – their observations were based on vertical directions in the places of observations. Astronomers performed fundamental (absolute) observations and the observers of Earth rotation services, beginning with the ILS and BIH, were tied to plumb line, or to mercury horizon depending on the instrument they used. The coordinate system of fundamental star catalogs FK5 was expanded by relative method to larger number of stars, including those of the Catalog of geodetic stars.

The established optical frame CRF with the coordinates of over one hundred thousand stars was used as a celestial reference in astro-geodetic observations and plumb-lines in many points of the Earth as the terrestrial reference. The CRF with the moving equator and equinox was of practical importance e.g. for navigation up to XX century.

On the eve of the XX century the zero-points of terrestrial reference were accepted: the prime meridian of Greenwich observatory and the mean pole of the epoch, later replaced by Conventional International Origin (CIO). The new zero-points for longitude λ and latitude ϕ were needed for practice and to obtain the rotation of the Earth axis relative to CRF. The terrestrial reference based on the vertical directions has no center since the plumb-lines do not intersect in one point. Therefore to complete the foundation of the triad TRS is impossible without geodetic and gravimetric observations.

Studies of the figure of the Earth are performed in geodesy. Plumb-lines were used in order to measure their deviations from the normal directions to reference-ellipsoid for the purpose of obtaining the orientation of reference-ellipsoid and to establish geoid. Besides the two coordinates on the surface, one altitude coordinate is measured in many points to establish geoid.

For studies by means of dynamic methods we need the centers of masses of bodies. The methods of gravimetry permit to measure the gravitational deviations from vertical lines in the direction of the lines and from normals to reference ellipsoid to obtain the center of the Earth mass. It became the origin of TRS with terrestrial zero-points. Directions of the plumb-lines were common with those of the celestial frame CRF.

Thus the empirical unity of astrometry, geodesy and gravimetry was achieved by means of common celestial and terrestrial reference for observations of stars, the Sun, the Motion and planets. The results of geodesy and gravimetry, in turn, were used in astronomy, celestial mechanics, geodynamics, astrophysics and geology.

Radical changes during the "revolution in astrometry" (Walter and Sovers, 2000) were due to technical achievements, new techniques of observations and atomic clocks. Technology of GPS/GLONASS with the support of calculated ephemerides of satellites permits to obtain the coordinates and velocities of terrestrial points with precision, satisfying the civil users "within a certain period". The positions of points are connected to the Earth mass center, thereby the possibility of using dynamic methods is provided now.

When the GNSS (Global Navigation Satellite Systems) methods have appeared geodesy became less dependent on astrometry: the methods of geometrical positioning solved the Earth figure determination. The problem remains of verifying the appropriate physical characteristics of gravitation field, in particular the deflection of plumb-lines anomalies. A plumb-lines rotation ($\Delta\xi$, $\Delta\eta$) should be monitored by independent physical methods. Since astronomical latitude and longitude are not available any more no variations of plumb lines $\Delta\xi$ag, $\Delta\eta$ag are fixed to control gravity variations $\Delta\xi$gr, $\Delta\eta$gr and unless the updating of gravimetric field near the Earth surface is possible, technology of satellite gradiometry cannot submit a detailed field near the Earth surface. There are no clear solutions of astroorientation for areal and satellite surveys and determination of astronomical azimuths for ballistics starts.

Taking into account the impossibility to mount radio telescopes at the points of astro–geodetic net or points of GPS/GLONASS observations, we must ask: How should geodesy use ICRF?

The three mentioned sciences still need periodic reference to the celestial coordinate to ensure the possibility of obtaining secular and long periodic motions. Is it available in the case when celestial observations are not related to vertical lines? It seems that modern astronomers do not foresee mutual benefits of cooperation with geodesy and gravimetry. TRF with the new zero points on celestial sphere has neither origin, no directions to terrestrial points, nevertheless it is supposed to be used for establishment of the ITRF with the origin in center of the Sun or barycenter. Of cause, there is no possibility to observe from these points and from the Earth center, but evidently neither geodetic nor gravimetric methods could be ever used in measurements of the Sun or barycenter. Only the Solar disk is observable, to obtain the barycenter one needs the theory of orbital motions of planets.

The difficulties in linking of ITRS to ICRS using the modern numeral models reflected in IAU resolutions, are shown in Tolchelnikova (2009). The link is more complicated now due to increasing number of parameters in dynamic models, as a result the number of independent equations of conditions became less than the number of unknowns. In this case the system of equations is insoluble i.e. the solution of the system by means of precise methods of mathematics is impossible.

4. ON ESTIMATING ERRORS OF RADIOSYSTEM ICRF

Since ICRF is suggested as a reference for geodetic measurements we are interested in the precisions of radio coordinates. The process of compilation of radiocatalogues and the sources of their errors are described in several papers published by A.A. Lipovka and N.M. Lipovka, e.g., in Lipovka and Lipovka (2013a, 2013b). One of conclusions of the authors is that there are more radiostars in comparison with those, already known. It becomes evident that the "problem of empty fields" would have been eliminated if the experience of optical catalogues compilations were taken into account.

The author reduced the coordinates of radiosources to the system of star catalogue of Palomar Sky Survey and constellations of radiosources coincidences with the bright star images on the fields of $1^\circ \times 1^\circ$, was evident and analyzed by the authors. Previously it was supposed that there are no stars on the fields or 1–2 coincidences of stellar and radio images, which might be the accidental ones.

We have no place in this presentation for explanations of the results and several sources of errors. One of the new suggestions is eliminated since it became evident that it is not only our Sun but the other "yellow dwarfs" also emit radio waves. We should say that theoretical astrophysicists and physicists are reviled from explanations of the one more "paradox of Nature". The large errors in radiocatalogues shown by the authors might be regarded as the local errors of radiocatalogues due to the impossibility of achieving the same stability of mounting the radiotelescopes as optical instruments. In the last case the continual daily check on orientation of the optical axis of the telescope was provided.

To astrometry is important that some of the radiosources analyzed by the authors, previously considered as quasars, appear to be the bright stars. If it will be confirmed from analysis of more fields, we might ask: What preference remains for the quasars in comparison to the stars if the former are situated in our Galaxy?

5. CONCLUSIONS

Some experts in geodesy take care for preserving the empirical unity not only with gravimetry but also with astronomy as it becomes clear from the their papers in Brovar (2010). B.V. Brovar writes about coming years when geodesy should master the new scientific gift from astronomy and connect the created geodetic net to ICRS which is eager to break off the connection with equator and ecliptic (Brovar, 2010, p. 13).

The former empirical unity of the mentioned sciences was destroyed during the "revolution in astrometry" (Walter and Sovers, 2000), and we may ask whether something equivalent to it has been proposed.

It is well known separation of sciences is not fruitful for their development (Tolchelnikova, 2011). Remember the IAU Resolution about unification of several commissions which was realized. We suppose the Journées will give opportunity for discussion of many problems in scientific field of sciences about the measurements on the Earth and from our planet together with the historians of science interested in the topic.

6. REFERENCES

Brovar, B.V. (ed.), 2010, "Gravimetry and geodesy", Moscow: Nauchny Mir, 570 pp. (in Russian)

Feissell, M., Mignar, F., 1998, "The adoption of ICRS on 1 January 1998: meaning and consequences", A&A, 331, pp. L33–L136.

Finkelstein, A.M., et al. (eds.), 2001, "Astrometry, geodynamics and celestial mechanics on the threshold of XXI century", Transactions of IAA, v. 6. (in Russian)

Gubanov, V.S., Finkelshtein, A.M., Fridman P.A., 1983, "Introduction to radioastrometry", Moscow: Nauka, 280 pp. (in Russian)

Lipovka, A.A., Lipovka, N.M., 2013a, "Radio emission from the galactic cluster A1716 and a group of stars", Astrophysics, 56(2), pp. 221–228.

Lipovka, A.A., Lipovka, N.M., 2013b, "Problem of connecting the radio and optical systems. History and perspectives". Geodesy and cartography, No. 10, pp. 2–7. (in Russian)

Tolchelnikova, S.A., 2009, "On collaboration of astrometry and geodesy in studies of Earth rotations". Geodesy and Cartography, No. 8, pp. 24–29. (in Russian)

Tolchelnikova, S.A., 2011, "The role of classical heritage for fundamental studies". Geodesy and Cartography, No. 8, pp. 2–8. (in Russian)

Walter, H.G., Sovers, O.J., 2000, "Astrometry of Fundamental Catalogues: The Evolution from Optical to Radio Reference Frames", Heidelberg: Springer–Verlag, 232 pp.