ROCZNIK ASTRONOMICZNY (ASTRONOMICAL ALMANAC) OF THE INSTITUTE OF GEODESY AND CARTOGRAPHY AGAINST THE IAU 2000 RESOLUTIONS

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ABSTRACT. Since 1945 the Institute of Geodesy and Cartography publishes an Astronomical Almanac "Rocznik Astronomiczny". The paper describes the changes made in the RA almanac (edition 2004), according to the new concepts adopted in the resolutions of the XXIV IAU General Assembly in Montreal 2000 (IAU, 2001) and recommended to be applied in astronomical almanacs starting from 1 January 2003.

As the main users of RA almanac are now students of geodesy, for educational aspects a general decision was made to switch to the new CEO concept as well as to present the ICRS – ITRS transformation according to the new paradigm based on a direct use of the CEO and the ERA. For continuity reasons, however, some tables and data were left presented in old version too.

Some problems, caused by the changes, concerning mainly the new concept terminology and the structure of data are also pointed out.

1. INTRODUCTION

There are some points that must be considered when implementing any changes to the almanacs: a) generally almanacs are to provide practical astronomical data; b) almanacs must satisfy the needs of a wide variety of user applications (i.e. navigation, ephemeris computation, planning observing sessions, pointing a telescope, research and education); c) almanacs are expected to be formally unchanged from year to year. There are also particular criteria of when or if to make the changes. The changes should then result in more accurate information, have a reliable scientific motivation and finally they must result in data relevant to the users.

The implementation of the IAU 2000 resolutions requires an adoption of: a) the concept of the Celestial Intermediate Pole (CIP) and the Intermediate Reference System (IRS) as the basis for positions of planets as well as the apparent places of stars; b) the IAU2000 precession–nutation model to replace the IAU1976 and IAU1980 ones for the motion of the Celestial Intermediate Pole (CIP) with respect to the Geocentric Celestial Reference System (GCRS); c) the conventional relationship for defining UT1 as proportional to the Earth Rotation Angle (ERA) between the Celestial and the Terrestrial Ephemeris Origins (CEO and TEO). There are also two equivalent ways for transformation between International Terrestrial and Celestial Systems (ITRS and ICRS): a) based on the new paradigm, with direct use of the CEO and the ERA and b) based

Figure 1: Example cover pages of Astronomical Almanac of IGiK

on classical paradigm, with direct use of the equinox and Greenwich Apparent Sidereal Time (GAST), and indirect use of the CEO and the ERA.

The changes in the RA almanac have been introduced starting from the edition of 2004 (Kryński J., Sękowski M., 2003). Considering the fact that the main group of users of the RA almanac are undergraduate and graduate students of geodesy, a general and fundamental decision was made to switch entirely to the new CEO concept, as well as to present the ICRS – ITRS transformation according to the new paradigm based on a direct use of the CEO and the ERA. These changes have been supplemented by switching from the FK5 system to ICRS (HCRF — Hipparcos Celestial Reference Frame) in the stars' positions and from LE200/DE200 to LE405/DE405 in Solar System ephemeris data. For continuity reasons, however, some parts of the RA almanac were left presented in the old version too.

2. THE CONTENT OF THE RA ASTRONOMICAL ALMANAC

The content of the RA astronomical almanac consists of several tables that generally can be classified into two sets of data. These are the primary data, used by a large majority of users: students, professional users but also the amateurs of astronomy; and the secondary data, mainly dedicated for specific or particular astro-geodetical applications, but also covering less important or not so often used astronomical data. The primary data are grouped into tables of sidereal time, Sun and Moon apparent equatorial co-ordinates, mean positions of stars, Besselian numbers and the apparent positions of selected stars. The secondary data are the tables of the Earth orientation parameters (x, y pole co-ordinates, UT1 − UTC), the tables of azimuth and zenith distance of Polaris, the tables for calculation of astronomical latitude from the altitude of Polaris, as well as the tables of equatorial co-ordinates of planets and tables for calculation the rises and sets of Sun, Moon and the planets. The RA almanac contains also an astronomical calendar, list of stellar constellations, set of simple sky maps, dates of introducing a daylight-saving time in Poland, a map of magnetic declination of Poland and other data. Finally the almanac is supplemented with a detailed description of the history and present of the celestial, terrestrial and time systems used with the extensive explanations, as well as practical examples

of corresponding transformations and algorithms.

Before the changes coming from the IAU 2000 Resolutions were introduced, the RA almanac Sidereal Time tables consisted of four columns. They were the GMST (Greenwich Mean Sidereal Time) data, the long- and short-period components of nutation and the GAST (Greenwich Apparent Sidereal Time) data. The data were presented for 0^h UT1 with 1 day interval. They were calculated according to the formulae adopted by IAU GA (Montreal, 1979; Patras, 1982) (IAU, 1980; 1983), IAU80 nutation theory (McCarthy, 1996) and the equation of the equinoxes in the form: $\mathrm{GAST} = \mathrm{GMST} + (\Delta\psi + \delta\psi)\cos\varepsilon_0$.

The Sun and Moon tables contain the respective apparent positions, placed in a table with 1 day interval, as well as some additional parameters including e.g. the Sun and Moon parallaxes and rises and sets in Warsaw. Before changes were made, the data were based on the DE200/LE200 planetary ephemeris, IAU76/IAU80 precession–nutation theory and were calculated for 0^h in TDT time scale. In computations the classical formula for the annual aberration was used. The equation of time values, which are also included in the tables with 1 day interval, were calculated on the basis of the formula: $E + 12^h = \mathrm{GAST} - \alpha_\odot|_{\mathrm{TDT}=0^h}$.

The tables of mean positions of stars, containing 949 stars homogeneously distributed on the northern and partially southern hemisphere, based on the data of the FK5 fundamental catalogue, were expressed in the FK5 System. The positions were computed every year for the epoch of the middle of the year using the IAU76 precession formulae (Lieske et al., 1977). Along with the mean positions the tables contained also stars' FK5 numbers, visual magnitudes, spectral types, parallaxes and the annual rate of mean position change.

The mean positions tables are followed by the tables of Besselian numbers to provide a possibility of computation an apparent position for each star starting from its mean position. The Besselian numbers which are derived from the precession constant and long- and short-period nutation series were computed according to the IAU76 system of constants and IAU80 nutation theory. The tables consist of columns presenting the Besselian number (A, A', B, B', C, D, E) as well as part of year parameter (τ) at 0^h sidereal time, in 1 sidereal day interval.

The RA almanac contains also the data of apparent places of 61 selected stars, including 56 stars of declination in the range of $-30^\circ \div 80^\circ$ and 5 northern circumpolar stars. The apparent places of stars are placed in a table with 10 days interval (1 day in the case of circumpolar stars). The data are supplemented with the double upper transit date (for circumpolar stars a lower transit date is given too). Consequently, as in the case of mean position tables from before the RA 2004 edition, the tables of apparent places were based on the data of the FK5 catalogue and were expressed in the FK5 System. The algorithm is based on a simple formula for shifts due to proper motions, transformation from the barycentric to geocentric systems with use of star parallaxes and the formulae for light deflection and annual aberration. The combined matrix of IAU76 precession and IAU80 nutation matrices was used.

3. CHANGES MADE IN THE ASTRONOMICAL ALMANAC IN 2004

Changes into the RA almanac due to the IAU Recommendations were introduced starting from the edition for the year 2004. The general decision has also been made to fully adopt the new concepts including the changes in the right ascension origin. For continuity reasons, however, most of the old tables are still kept. There are thus in the RA some new tables added and some tables that have been doubled with their new versions. There are also some tables left unchanged, some changed by adding the new data or by an application of new definition, theory or formulae.

The Sidereal Time tables were extended by adding a new column of the ERA and changed by adoption the new formula for the GMST (Capitaine et al., 2003) relating it to the ERA. The tables contain now four columns representing GMST, GAST and θ (ERA) for 0^h UT1.

CZAS GWIAZDOWY GREENWICH I KĄT OBROTU ZIEMI 2005

DATA		0^h UT1				DATA		0^h UT1			
		GMST	Eq	GST	ERA			GMST	Eq	GST	ERA
			$0^s.0001$						$0^s.0001$		
Styczeń	0	$6^h39^m02^s.3728$	−4526	$01^s.9202$	$6^h38^m47^s.0041$	Luty	15	$9^h40^m23^s.9197$	−3788	$23^s.5410$	$9^h40^m08^s.1637$
	1	6 42 58.9282	−4532	58.4750	6 42 43.5510		16	9 44 20.4751	−3783	20.0968	9 44 04.7107
	2	6 46 55.4835	−4557	55.0278	6 46 40.0980		17	9 48 17.0305	−3756	16.6548	9 48 01.2576
	3	6 50 52.0389	−4593	51.5796	6 50 36.6449		18	9 52 13.5858	−3715	13.2144	9 51 57.8046
	4	6 54 48.5943	−4627	48.1316	6 54 33.1919		19	9 56 10.1412	−3667	09.7745	9 55 54.3515
	5	6 58 45.1496	−4645	44.6851	6 58 29.7388		20	10 00 06.6966	−3623	06.3342	9 59 50.8985
	6	7 02 41.7050	−4633	41.2417	7 02 26.2858		21	10 04 03.2519	−3592	02.8927	10 03 47.4454
	7	7 06 38.2604	−4580	37.8024	7 06 22.8327		22	10 07 59.8073	−3581	59.4492	10 07 43.9924
	8	7 10 34.8158	−4484	34.3674	7 10 19.3797		23	10 11 56.3627	−3595	56.0032	10 11 40.5393
	9	7 14 31.3711	−4354	30.9357	7 14 15.9266		24	10 15 52.9180	−3635	52.5545	10 15 37.0863

Figure 2: Astronomical Almanac 2005: example of the table of Sidereal Time & ERA

The data interval of 1 day has not been changed. Former two columns of long- and short-period components of nutation have been reduced to one column of total equation of the equinoxes. The main reason of that is a recent computation algorithm. The equation of the equinoxes values are computed on the basis of new IAU2000 precession–nutation theory and the IAU2000 algorithms in their presently published form do not provide the separation between long- and short-period components.

The main subject of the Sun and Moon tables is, as in the previous RA editions, the respective apparent positions, tabulated with 1 day interval for 0^h in TT time scale. However, position computation is based now on DE405/LE405 planetary ephemeris. The IAU2000 precession–nutation model is fully applied as well as more sophisticated, relativistic formulae for annual and planetary aberrations are used. Besides, the main change is an extension of the existing data by adding new column of $\alpha_{app}^{\mathrm{CEO}}$. The equation of time values are calculated now on the basis of the formula: $E + 12^h = \mathrm{ERA} - \alpha_{\odot}^{\mathrm{CEO}}|_{\mathrm{TT}=0^h}$. Additional data including e.g. Sun and Moon rises and sets in Warsaw are presented with no changes.

The major change concerning the data of mean positions of stars is a supplement of existing tables (left unchanged, in FK5 System) by the new ones providing the ICRF (HCRF) positions of the stars for the epoch of the year (concerning only the proper motion of stars). The adoption of the ICRS which is motionless in outer space makes the mean positions data more or less redundant. Movements due to precession and nutation are now concerned jointly within the transformation from ICRS (GCRS) to IRS procedure. The old tables as well as the new ones are kept then just for continuity and educational reasons. The new tables contain the same 949 stars. The data are the Hipparcos catalogue positions, supplemented with FK6 (FK5) radial velocities. Computations from the epoch of the Hipparcos catalogue (J1991.25) are based on the Standard Model of Stellar Motion (ESA, 1997).

Tables of Besselian numbers for the reasons mentioned above have not been changed too and they are left referred to IAU76 system of constants and IAU80 nutation theory.

The RA almanac data of stars' apparent places have also been modified by adding supplementary tables realizing the new concepts. The added tables contain $\alpha_{app}^{\mathrm{CEO}}$, δ_{app} co-ordinates of the same set of stars as the old tables do. The data are presented for 0^h UT1 with 7 days interval (1 day in the case of circumpolar stars). Computations are based on the Hipparcos positional data complemented with the FK6 (FK5) radial velocities of stars. The main improvements in the algorithm for apparent places computations are due to the adoption of the Standard

Model of Stellar Motion instead of former simple formulae and the replacement of IAU76/IAU80 precession–nutation matrix with the new IAU2000 matrix.

Along the changes due to the IAU Resolutions, but also aiming to provide a complete data set for transformation between terrestrial and celestial systems for those who use the Almanac in their educational activity there are also some new tables added. These are, first of all, the table containing the components of the precession–nutation matrix (Q). The table of barycentric and heliocentric position and velocity of the Earth was also added. The data in the tables are computed on the basis of IAU2000 model and DE405/LE405 ephemeris and are tabulated with 1 day interval for 0^h TT and TDB respectively.

Finally, the new editions of RA almanac are supplemented with the extensive description of the systems and explanations of all changes coming from the recent IAU Resolutions. The text of IAU 2000 Resolutions in Polish translation have also been published in the RA almanac issue of 2004.

4. PROBLEMS TO BE SOLVED

There are still some problems remaining to be solved. The first group of them are the problems concerning a proper or standard terminology and symbolic designations, e.g. naming of α^{CEO}. In the RA almanac the term "right ascension" is applied to both α^{CEO} and α^{γ} quantities. Also the designation α^{CEO} is used instead of sometimes suggested A. There are also some abbreviation problems concerning newly introduced systems and frames. In the RA almanac the abbreviation IRS is adopted and consequently used for the Intermediate Reference System. Two other designations $\mathrm{IRS}_{CELESTIAL}$ and $\mathrm{IRS}_{TERRESTRIAL}$ are also used to distinguish between IRS before and after applying the transformation due to Earth rotation ($R_3(\theta)$).

The second group of problems concerns the interpolation of the tabularized data. Publication of the apparent places of stars with 10- or 7-days interval is not sufficient for reliable interpolation when the short-period nutation terms are not filtered out. The same concerns the interpolation of the components of precession–nutation matrix (Q). There is a need then to redesign the IAU2000 algorithms to allow separate application of long- and short-period nutation terms.

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