

# Chronology of Developments of Geodynamic Investigations in XIX and XX Centuries

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**Abstract.** There were big developments of geodynamic investigations in the XX century. In the paper the scope of the chronology of developments of geodynamic investigations from the end of XIX century until the beginning of XXI century is presented. It is presented in the following six areas:

1. Theory
2. Establishment of definitions and models
3. Analysis of observations
4. Celestial reference frames
5. Terrestrial reference frames
6. Organizations of investigations.

During all XX century the new more accurate theories of nutation and precession were developed and they are mentioned. Chronology of adoption of more accurate new systems of the fundamental astronomical constants, of introducing new more accurate star catalogs (GC, FK<sub>3</sub> - FK<sub>5</sub>, Hipparcos) and new time scales (Ephemeris Time - ET and Atomic Time - AT) are given. Introducing new observational techniques using satellite and VLBI methods in the seventies of the XX century caused quick development of the geodynamics investigations, especially of global gravity field (Standard Earth) of Earth's Orientation Parameters (EOP), and of celestial and terrestrial reference systems (ICRS, ITRS) which are presented in the chronology. The higher accuracy of observations and determined data allowed for deep studies of excitations of the Chandler Wobble, of geophysical excitations of polar motion and of UT and of free core nutation. In the paper the chronology of improvements of organization of

observations and determinations of the Earth's Orientation Parameters and of Celestial and Terrestrial Reference System (International Latitude Service - ILS, Bureau International de l'heure - BIH, International Polar Motion Services - IPMS, International Earth Rotation and Reference System Service - IERS) are given too. In 1997 the IERS Geophysical Global Fluid Centers with eight Fluid Bureaus was organized in order to collect and distribute geophysical models of these fluids. In 2003 organization of the Global Geodetic Observing System - GGOS was organized by the International Association of Geodesy - IAG.

## 1 The earlier most important discoveries and theories

- In the second century B.C. Hipparchus discovered the Earth precession with the constant of the annual precession of the equinoxes,  $p = 46''$
- In 1748 Bradley discovered of the astronomical nutation from observation analyses.
- In 1687 Newton in his book "Philosophiae naturalis principia mathematica" defined as the first the bases of dynamics, law of gravitation and the theory of the Earth Rotation.
- In 1758 Euler foresaw the free nutation of the solid Earth with the period of 305 days.
- In 1828 Gauss introduced and defined the idea of geoid.

TABLE 1		1850 - 1910		
<b>THEORY</b>	<p><b>Über die Grösse und Figur der ERDE</b> Baeyer 1861</p>	<p>Bessel, Clarke, Krasowsky, Hayford 1841 1866 1909/1940 1909/1924 (IUGG)</p>	<p>Elipsoids</p>	<p>Investigations of the free nutation of the Earth with liquid core D'Alambert, Lagrange, Laplace, Poinsoit XVIII-XIX</p>
<b>DEFINITIONS ASTRONOMICAL CONSTANTS AND GEOPHYSICAL MODELS</b>	<p>Adoption of the First System of the Fundamental Astronomical Constants (10 Constants) 1896</p>			
<b>ANALYZES OF OBSERVATIONS</b>	<p>First determinations of annual (360d) and Chandler (427d) oscillations of polar motion 1891/1892</p> <p>Determinations of latitude variations with opposite phases in Berlin and Honolulu 1891/1892</p>	<p>Explanation of the lengthening of CW period by elastic yielding of the Earth (Newcomb) 1895</p>	<p>Determination of astronomical nutation constant, 9,210, Newcomb 1895</p>	
<b>ORGANIZATIONS</b>	<p>Organization of the International Latitude Service - ILS (6 stations on the parallel of 39° 0.8") 1899</p>			
<b>CELESTIAL REFERENCE FRAMES</b>				
<b>TERRESTRIAL REFERENCE FRAMES</b>				
		1850		1910

TABLE 2		1910 - 1960			
<b>THEORY</b>	<p>Woolard's theory of nutation with 69 terms and (0.05" accuracy) 1950</p>	<p>Development of theory of nutation of the elastic Earth with the liquid core Sir H. Jeffreys, Sir H. Jeffreys and R.O. Vicente, S.M. Molodensky 1948 1957 1961</p>			
<b>DEFINITIONS, ASTRONOMICAL CONSTANTS AND GEOPHYSICAL MODELS</b>	<p>General star catalogue GC 33342 stars with accuracy of 1", Boss 1937</p>	<p>Fundamental star catalogues FK3, FK4, FK5 containing respectively: 873, 1535 stars with accuracy 0.02" 1937-1988</p> <p>Definition of the Ephemeris Time - ET 1s=1/31556925.9747 of the tropical year 1900 1954</p>			
<b>NEW INSTRUMENTS</b>	<p>Photographic Zenith Tube - PZT 1913</p>	<p>Quartz Clock (1x10<sup>-4</sup>) 1940</p>	<p>Atomic Clock (1x10<sup>-6</sup>) 1955</p>	<p>Danjon Astrolabe 1958</p>	
<b>ANALYZES OF OBSERVATIONS</b>	<p>Discover of seasonal oscillation of UT Stoyko 1937</p>	<p>Detection of retardation of the rate of Earth's Rotation De Sitter, Spencer Jones, Clemens 1927 1939 1948</p>	<p>Determinations of secular polar motion (0.02"-0.03" per year) Markowitz 1960-1967</p>		
<b>CELESTIAL REFERENCE FRAMES</b>					
<b>TERRESTRIAL REFERENCE FRAMES</b>					
		1910		1960	

TABLE 3		1960 - 1980		
<b>THEORY</b>		New theory of precession (J.H. Lieske) 1977		New theory of nutation (J. Wahr) 1980
<b>DEFINITIONS, ASTRONOMICAL CONSTANTS AND GEOPHYSICAL MODELS</b>		Adoption of the second system of the fundamental astronomical constants (36) 1964	Adoption of the third system of the fundamental astronomical constants (28) 1976	Definition of the Atomic Time-TAI (9192631770 oscillations of cesium 133 atom) 1971
		Adoption of the Geodetic Reference System 1967	Definition of the Conventional International Origin of the Terrestrial Coordinate System-CIO 1967	The Earth's Model 1066A, PREM Gilbert-Dziewoński, 1967 Dziewoński and Anderson, 1981
<b>NEW INSTRUMENTS</b>		Application of the observation of geodetic Artificial Earth's Satellites, Lageos-1 (1976), Lageos-2 (1992), Seasat (1978), Starlette (1975), Ajisai (1986), Stella (1993), TOPEX -POSEIDON (1992) for determination of Earth's Rotation. Introducing of the new observational techniques to determination of Earth's Rotation, Doppler (1973), SLR (1978), VLBI (1978), GPS (1983)		
<b>ANALYZES OF OBSERVATIONS</b>		Determinations of the global gravity field models (from 8 – 1420 harmonics) „Standard Earth” from observations of Artificial Earth's Satellites (1966-2011)		
<b>ORGANIZATIONS</b>		Bureau International de l'heure – BIH, Rapid Service 1955-1967	International Polar Merion Services IPMS 1962-1988	BIH Service of Earth's Rotation 1968
<b>CELESTIAL REFERENCE FRAMES</b>		Determinations of the BIH Terrestrial Reference System in 1968, and 1984 and improving it to 1988		
<b>TERRESTRIAL REFERENCE FRAMES</b>				
		1960		1980

TABLE 4		1980 - 1999		
<b>THEORY</b>		MERIT Standards	IERS Standards	Adoption of the International Celestial Reference System – ICRS (0.1 mas-pole, 10 mas equator) and Frames – ICRF (608 radiosoources with 212 defining ones) IAU 1997/1998
<b>DEFINITIONS, ASTRONOMICAL CONSTANTS AND GEOPHYSICAL MODELS</b>		Numerical constants and models 1983-1984	Numerical constants and models 1989-1996	Model of the tectonic plate motion – Nuvel 1, 1992
		Star Catalogue Hipparcos with accuracy of 1 mas (118218 stars), 1996	Astrometric Satellite Hipparcos, 1990-1993	
<b>NEW INSTRUMENTS</b>		Studies of excitations of the Chandler Wobble, determinations and analyses of parameters of the Chandler Wobble: (period 434 days), coefficient Q		
<b>ANALYZES OF OBSERVATIONS</b>		Detection of the high correlation of seasonal oscillation of Atmospheric Angular Momentum (AAM) and LOD (Hide), 1980 Introduction of the definition of the Effective Angular Momentum Function (Barnes), 1983 Intensive investigations of the geophysical excitations of LOD and polar motion by AAM (Atmospheric Angular Momentum), OAM (Oceanic Angular Momentum), HAM (Hydrological Angular Momentum) 1980-2010 Detection and investigation of short and rapid periodical variation of the Earth rotation with sub-seasonal periods 30, 40, 60, 90, 120 days and 6, 8, 12 hours. 1980-2010		
		Determinations and analyses of the Free Core Nutation (0.2mas) 1980-	Determinations and analyses of seasonal variations of the geocenter (~ 5mas) 1980-	
<b>ORGANIZATIONS</b>		Observational Campaign MERIT Monitoring of Earth Rotation and Intercomparison of Techniques 1983-1984	Organizations of the new International Earth Rotation Services – IERS, 1988	Organization of the IERS Geophysical Global Fluid Centers – GGFC with the Bureaus: Mantle, Core Gravity Geocenter 1997
		New Services of the Earth Rotation IGS IIRS DORIS IVS 1993 1998 1999 2000	IAU Colloquium 178, Polar Motion: Historical and Scientific Problems, Cagliari, 1999	S. Dick, D. McCarthy, 2000
<b>CELESTIAL REFERENCE FRAMES</b>		The first International Terrestrial Reference System – ITRS and Frames – ITRF, 1988		
<b>TERRESTRIAL REFERENCE FRAMES</b>				
		1980		1999

TABLE 5		2000 - 2010	
<b>THEORY</b>	Adoption of the new theory of precession and nutation IAU 2000A (0.2 mas), IAU 2000B (1 mas) (Mathews, Herring, Buffet) by the IAU XXIV IAU General Assembly Resolutions 2003	PO 3 precession theory (Captain et al. 2003) Adopted by XXVII IAU GA Resolution 2006	
<b>DEFINITIONS, ASTRONOMICAL CONSTANTS AND GEOPHYSICAL MODELS</b>	IERS Conventions numerical constants and geophysical models 2003, 2010	Adoption of the second realization of the Celestial Reference Frames (ICRF 2) and International Celestial Reference System (ICRS) XXVII IAU GA Resolution, 2009	Adoption of the IAU 2009 System of the Astronomical Constants XXVII IAU GA Resolution, 2009
<b>NEW INSTRUMENTS</b>	Gravity satellite GRACE - Gravity Recovery and Climate Experiment, 2002	Gravity satellite GOCE -Gravity Field Steady – State Ocean Circulation Explorer, 2009	
<b>ANALYZES OF OBSERVATIONS</b>	Explanation of the CW excitation by combination of the atmospheric and oceanic angular momentum (Gross, Brzezinski, Nastula) 2000-2005		
<b>ORGANIZATIONS</b>	IAU Colloquium 178 Polar Motion: Historical and Scientific Problems, Cagliari, 1999 S. Dick, D. McCarthy 2000	Organization of the GGOS - Global Geodetic Observing System of the IAG – International Association of Geodesy 2003	
<b>CELESTIAL REFERENCE FRAMES</b>			
<b>TERRESTRIAL REFERENCE FRAMES</b>	New ITRS/ITRF 2008 (934 stations at 580 sites) 2010		
	2000		2010

## 2 Acknowledgments

The research reported here was supported by the Polish National Science Centre and Information Technology, through project N526157040. We thank Mr. M. Sawicki for preparation of the form of Tables.

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