IERS TECHNICAL NOTE 13

IERS Standards (1992)

Dennis.D. McCarthy (ed.)

July 1992

Observatoire de Paris

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Dennis.D. McCarthy

US Naval Observatory

July 1992

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TO THE MEMORY OF

JAMES A. HUGHES

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IERS Technical Notes

This series of publications gives technical information related to the IERS activities, e.g. reference frames, excitation of the Earth rotation, computational or analysis aspects, models, etc. It also contains the description and results of the analyses performed by the IERS Analysis Centres for the Annual Report global analyses.

Back issues

No 1 : C. Boucher and Z.Altamimi. The initial IERS Terrestrial Reference Frame.

No 2 : Earth orientation and reference frame determinations, atmospheric excitation functions, up to 1988 (Annex to the IERS Annual Report for 1988). *[No longer available, superseded by N.T. No 5].*

No 3 : D.D. McCarthy (ed). IERS Standards (1989)

No 4 : C. Boucher and Z. Altamimi. Evaluation of the realizations of the Terrestrial Reference System done by the BIH and IERS (1984-1988).

No 5: Earth orientation and reference frame determinations, atmospheric excitation functions, up to 1989 (Annex to the IERS Annual Report for 1989).*[Superseded by N.T. No 8].*

No 6 : C. Boucher and Z. Altamimi. ITRF89 and other realizations of the IERS Terrestrial Reference System for 1989.

No 7 : E.F. Arias, M. Feissel and J.-F. Lestrade. The IERS extragalactic Celestial Reference Frame and its tie with HIPPARCOS.

No 8: Earth orientation and reference frame determinations, atmospheric excitation functions, up to 1990 (Annex to the IERS Annual Report for 1990).

No 9 : C. Boucher and Z. Altamimi. ITRF90 and other realizations of the IERS Terrestrial Reference System for 1990.

No 10: C. Boucher and Z. Altamimi. The IERS GPS Terrestrial Reference Frame.

No 11: P. Charlot (ed.). Earth orientation, reference frames and atmospheric excitation functions submitted for the 1991 IERS Annual Report.

No 12: C. Boucher and Z. Altamimi. ITRF90 and other realizations of the IERS Terrestrial Reference System for 1991.

No 13: D.D. McCarthy (ed.). IERS Standards (1992).

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IERS STANDARDS

1992

The Directing Board of the International Earth Rotation Service (IERS) is distributing the attached questionnaire with the 1992 edition of the IERS Standards in order to establish directions for future editions of the Standards. Your assistance in providing answers to the questions below will be valuable in the determination of the contents and distribution of new standards. The second side of the page provides an opportunity to make additional suggestions about the contents of the IERS Standards. Please print clearly in ink or type in the space provided and return the page to us. We thank you for your assistance.

Martine Feissel
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Central Bureau of IERS

Dennis D. McCarthy
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QUESTIONNAIRE

ON THE CONTENTS AND DISTRIBUTION OF IERS STANDARDS

Name ______________________________

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1. Please describe your application of the IERS Standards.

- ☐ a. I use the information to prepare software.
- ☐ b. I use the information to analyze data using already prepared software.
- ☐ c. I use the information to keep abreast of current developments.
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2. Please describe your usage of the individual chapters of the IERS Standards by indicating on a scale of 1 (not useful at all) to 5 (extremely useful) for each chapter.

____ NUMERICAL STANDARDS
____ CELESTIAL REFERENCE SYSTEM
____ CONVENTIONAL TERRESTRIAL REFERENCE FRAME
____ LUNAR AND PLANETARY EPHEMERIDES
____ TRANSFORMATION BETWEEN THE CELESTIAL AND TERRESTRIAL SYSTEMS
____ GEOPOTENTIAL
____ SOLID EARTH TIDES
____ OCEAN TIDE MODEL
____ LOCAL SITE DISPLACEMENT
____ TIDAL VARIATIONS IN THE EARTH'S ROTATION
____ TROPOSPHERIC MODEL
____ RADIATION PRESSURE REFLECTANCE MODEL
____ GENERAL RELATIVISTIC MODELS FOR TIME, COORDINATES AND EQUATIONS OF MOTION
____ GENERAL RELATIVISTIC MODELS FOR PROPAGATION

3. About how often do you feel that it is necessary to issue a new version of the IERS Standards? (*e. g.* every three years, as often as necessary). Please note that the preceding version of the IERS Standards was distributed in 1989.

4. What additional information would be helpful in future editions?

5. Would other means of dissemination of IERS be desired? Please be specific.

6. Please list any other suggestions or comments regarding the IERS Standards below and return to

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Thank you for your cooperation.

INTRODUCTION

This document is intended to define the standard reference system to be used by the International Earth Rotation Service (IERS). It is based on the Project MERIT Standards (Melbourne, *et al.*, 1983) and the IERS Standards (McCarthy, 1989) with revisions being made to reflect improvements in models or constants since the previous IERS Standards were published. If contributors to IERS do not fully comply with these guidelines, they will carefully identify the exceptions. In these cases, the institution is obliged to provide an assessment of the effects of the departures from the standards so that its results can be referred to the IERS Reference System. In the case of models, contributors may use models equivalent to those specified herein. Different observing methods have varying sensitivity to the adopted standards and reference systems. No attempt has been made in this document to assess the sensitivity of each technique to the adopted reference systems and standards.

The recommended system of astronomical constants corresponds closely to those of the previous IERS Standards with the exception of the changes listed below. The units of length, mass, and time are in the International System of Units (SI) as expressed by the meter (m), kilogram (kg) and second (s). The astronomical unit of time is the day containing 86400 SI seconds. The Julian century contains 36525 days of atomic time. The Gaussian constant, $k = 0.01720209895$, is the defining constant relating the heliocentric gravitational constant ($GM_\odot$) to the astronomical unit of length (A) and to the unit of time through the relationship

$$GM_\odot = A^3 k'^2$$

where $GM_\odot$ is expressed in $m^3\ s^{-2}$, A is the astronomical unit in meters (derived from the measured value of the astronomical unit in light-seconds and the defined value of the velocity of light in $m\ s^{-1}$), and k' is $k/86400$.

In general, each observational technique uses different realizations of both the terrestrial and celestial frames. In addition, the techniques use different transformations between these frames. The J2000.0 epoch is recommended for use in reference system algorithms. The transformation from the 1950.0 frame to J2000.0 should use the IAU 1976 value of the precession constant. The value of the correction to the FK4 equinox is (Fricke, 1982)

$$E(T) = 0^s.035 + 0^s.085T,$$

where T is measured in Julian centuries from 1950.0. This expression for E(T) is adopted and is applied at the epoch J2000.0.

Differences Between This Document and IERS Technical Note 3

Most chapters of IERS Technical Note 3 have been revised, and known typographical errors contained in that work have been corrected in this addition. There are some major differences between the current version of the IERS Standards and the past version of the IERS Standards. The following is a brief list of the major modifications by chapter.

CHAPTER 1 Numerical Standards

Numerical values have been changed for the solar parallax, the ratio of the solar mass to the mass of the Earth, the ratio of the solar mass to that of the Earth-Moon system, the solar mass and GM of the Moon. Reference to scaling of masses necessitated by the use of the TDB time scale has been removed.

CHAPTER 3 IERS Terrestrial Reference Frame

The permanent solid Earth tide correction is no longer included in the site position. The permanent tide, an intrinsic constituent of site position, is now to be included as a site displacement. The chapter incorporates the material of Chapters 3 and 9 of IERS Technical Note 3. The NUVEL NNR-1 Model (DeMets, *et al.*, 1990) for plate motion has replaced the AM0-2 Model of IERS Technical Note 3.

CHAPTER 5 Transformation Between Celestial and Terrestrial Reference Systems

Chapters 4 and 5 of IERS Technical Note 3 have been combined, and the option of using the "non-rotating origin" (Guinot, 1979) procedure to transform between the reference systems has been added. Small terms not given in IERS Technical Note 3 for nutation have been added, and the effects of geodesic nutation are discussed briefly.

CHAPTER 6 Geopotential

GEM-T3 has replaced GEM-T1 as the adopted gravity field.

CHAPTER 9 Local Site Displacements

Horizontal components of site displacement due to ocean loading have been included.

CHAPTER 10 Tidal Variations in UT1

The effect of ocean tides has been added to the effects listed in IERS Technical Note 3.

CHAPTER 13 General Relativistic Models for Time, Coordinates, and Equations of Motion

The consequences of the resolutions adopted by the 1991 IAU General Assembly have been included.

CHAPTER 14 General Relativistic Models for Propagation

A consensus model for VLBI propagation delays replaces the previous models.

APPENDIX IAU, IAG and IUGG Resolutions

Resolutions adopted at the International Astronomical Union (IAU), the International Association of Geodesy (IAG) and the International Union of Geodesy and Geophysics (IUGG) General Assemblies in 1991 dealing with reference systems have been reproduced and included.

References

DeMets, C., Gordon, R. G., Argus, D. F., and Stein, S., 1990, "Current Plate Motions," *Geophys. J. Int.*, **101**, pp. 425-478.

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Guinot, B., 1979, "Basic problems in the kinematics of the rotation of the Earth," in *Time and the Earth's Rotation*, D. D. McCarthy and J. D. Pilkington (eds), D. Reidel Publishing Company.

Melbourne, W., Anderle, R., Feissel, M., King, R., McCarthy, D., Smith, D., Tapley, B., Vicente, R., 1983, *Project MERIT Standards*, U.S. Naval Observatory Circular No. 167.

McCarthy, D. D., 1989, *IERS Standards*, IERS Technical Note 3, Observatoire de Paris, Paris.

CHAPTER 1 NUMERICAL STANDARDS

The tables are organized into three columns: the item, the standard value, and comments. The comments note departures from the IAU values and direct the reader to the appropriate chapter for an expanded discussion or listing of values. In some cases, the succeeding chapters contain tutorial material that might prove helpful. Algorithms are, in some cases, provided to clarify a formulation.

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Astronomical Almanac for 1984, U. S. Government Printing Office, Washington D. C.

Bursa, M., 1991, *Parameters of Common Relevance of Astronomy, Geodesy, and Geodynamics*, Report of IAG Special Study Group 5-100.

Cohen, E. R., and Taylor, B. N., 1986, *The 1986 Adjustment of the Fundamental Physical Constants*, CODATA Bulletin No. 63, Pergamon Press.

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Jacchia, L. G., 1971, "Revised Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles," *Smithson. Astrophys. Observ. Spec. Rep.*, 332, Cambridge, Mass.

Lieske, J. H., Lederle, T., Fricke, W., and Morando, B., 1977, "Expression for the Precession Quantities Based upon the IAU (1976) System of Astronomical Constants," *Astron. Astrophys.*, 58, pp. 1-16.

Marini, J. W. and Murray, C. W., 1973, *Correction of Laser Range Tracking Data for Atmospheric Refraction at Elevations Above 10 Degrees*, NASA GSFC X-591-73-351.

Melbourne, W., Anderle, R., Feissel, M., King, R., McCarthy, D., Smith, D., Tapley, B., Vicente, R., 1983, *Project MERIT Standards*, U. S. Naval Observatory Circular No. 167.

McCarthy, D. D., 1989, *IERS Standards*, IERS Technical Note 3, Observatoire de Paris, Paris.

NUMERICAL STANDARDS

ITEM	RECOMMENDED VALUE	COMMENTS
ASTRONOMICAL CONSTANTS		
Defining Constants		
- Gaussian Gravitational Constant	$k = 0.01720209895$	
- Velocity of Light	$c = 2.99792458 \times 10^8 ms^{-1}$	
Primary Constants		
- Astronomical Unit in Light-Seconds	$\tau_A = 499.00478353$ s	IAU (1976) Value = 499.004782 s.
- Equatorial Radius of the Earth	$a_e = 6378136.3m$	IAU Value = 6378140m. GEM T3 Value = 6378137m.
- Dynamical Form Factor for Earth	$J_2 = 0.0010826362$	GEM T3 Value = 0.0010826361
- Geocentric Constant of Gravitation	$GM_\oplus = 3.986004418 \times 10^{14} m^3 s^{-2}$ (TT Units) $= 3.986004415 \times 10^{14} m^3 s^{-2}$ (TCG Units)	IAU (1976) Value = $3.986005 \times 10^{14} m^3 s^{-2}$. GEMT3 Value = $3.98600436 \times 10^{14} m^3 s^{-2}$.
- Constant of Gravitation	$G = 6.67259 \times 10^{-11} m^3 kg^{-1} s^{-2}$	
- Earth-Moon Mass Ratio	$\mu = 0.012300034$	IAU (1976) Value = 0.01230002.
- General Precession in Longitude Per Century for J2000.0	$p = 5029''.0966$	
- Obliquity of the Ecliptic for J2000.0	$\epsilon_0 = 23° 26' 21''.4119$	IAU (1976) Value = $23°26'21''.448$. (see Chapter 5).
- Mean Angular Velocity of the Earth	$\omega = 7.292115 \times 10^{-5}$ rad s^{-1}	
Derived Constants		
- Astronomical Unit	$c\tau_A = 1.4959787061 \times 10^{11} m$	IAU (1976) Value = $1.49597870 \times 10^{11}$ m.
- Solar Parallax	$\pi_\odot = \sin^{-1}(a_e/A) = 8''.794142$	IAU (1976) Value = $8''.794148$.
- Earth Flattening	$f^{-1} = 298.257$	
- Heliocentric Constant for Gravitation	$GM_\odot = 1.32712440 \times 10^{20} m^3 s^{-2}$	IAU (1976) Value = $1.32712438 \times 10^{20} m^3 s^{-2}$.
- Ratio of the solar Mass to the Mass of the Earth	$M_\odot/M_\oplus = 332,946.045$	IAU (1976) Value = 332,946.0.
- Ratio of the Solar Mass to the Mass of the Earth-Moon System	$M_\odot/M_\oplus(1 + \mu) = 328,900.56$	IAU (1976) Value = 328,900.5.
- Solar Mass	$M_\odot = 1.9889 \times 10^{30} kg$	
System of Masses (See Chapter 4 for references and discussion) (Expressed in Reciprocal Solar Masses)		
- Mercury	6,023,600	IAU (1976) Value = 6,023,600
- Venus	408,523.71	IAU (1976) Value = 408,523.5

<u>NUMERICAL STANDARDS</u>
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
- Earth-Moon System	328,900.56	IAU (1976) Value = 328,900.5. (adjustable in LLR)
- Mars	3,098,708	IAU (1976) Value = 3,098,710
- Jupiter	1,047.3486	IAU (1976) Value = 1,047.355.
- Saturn	3,497. 90	IAU (1976) Value = 3,498.5.
- Uranus	22,902.94	IAU (1976) Value = 22,869.
- Neptune	19,412.24	IAU (1976) Value = 19,314
- Pluto-Charon	135,000,000	IAU (1976) Value = 3,000,000.
- Ceres	2.0×10^9	IAU (1976) Value = 1.7×10^9.
- Pallas	8×10^9	IAU (1976) Value = 9.1×10^9.
- Vesta	7×10^9	IAU (1976) Value = 8.3×10^9.
<u>Lunar Gravitational Parameters for LLR</u>		The values of these parameters are consistent with the DE200/LE200 ephemerides but they are adjustable in LLR.
$\gamma = (B-A)/C$	2.280043×10^{-4}	IAU (1976) Value = 2.278×10^{-4}.
$\beta = (C-A)/B$	6.316769×10^{-4}	IAU (1976) Value = 6.313×10^{-4}.
C/MR^{2*}	0.39053	IAU (1976) Value = 0.392.
Γ^*	5553″.5	IAU (1976) Value = 5552″.7 = 1° 32′ 32″.7.
GM^*	4902.7989 km^3/sec^2	
Love Number (k_2)	0.0222	
Rotational Dissipation (k_2T)	4.643×10^5 days	
C_{20}	-2.02151×10^{-4}	IAU (1976) Value = -2.027×10^{-4}.
C_{22}^*	2.2302×10^5	IAU (1976) Value = $+2.23 \times 10^{-5}$.
C_{30}	-8.626×10^6	IAU (1976) Value = -6×10^6.
C_{31}	3.071×10^5	IAU (1976) Value = $+2.9 \times 10^{-5}$.
S_{31}	5.6107×10^6	IAU (1976) Value = $+4 \times 10^6$.
C_{32}	4.8348×10^6	IAU (1976) Value = $+4.8 \times 10^6$.
S_{32}	1.684×10^6	IAU (1976) Value = $+1.7 \times 10^6$.
C_{33}	1.436×10^6	IAU (1976) Value = $+1.8 \times 10^6$.

<u>Lunar Gravitational Parameters for LLR (continued)</u>

S_{33}	-3.3435×10^7	IAU (1976) Value = -1×10^6.
C_{40}	1.5×10^7	

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
C_{41}	-7.18×10^{-6}	
S_{41}	2.95×10^{-6}	
C_{42}	-1.440×10^{-6}	
S_{42}	-2.884×10^{-6}	
C_{43}	-8.5×10^{-8}	
S_{43}	-7.89×10^{-7}	
C_{44}	-1.549×10^{-7}	
S_{44}	5.64×10^{-8}	

*Derived Constants

DYNAMICAL MODELS

Geopotential

- Laser Satellites		
Lageos	GEM-T3, truncated at degree and order 20	See Chapter 6.
GPS, Etalon	GEM-T3, truncated at degree and order 8	See Chapter 6.
- LLR	IAU (1976) zonals through degree 4 for DE200/LE200.	

Solid Earth Tides

- Lageos, GPS, Etalon		See Chapter 7.

Ocean Tides

- Lageos, GPS, Etalon	Schwiderski Ocean Tide Model	See Chapter 8.

Non-gravitational Force Parameters (Area and Mass)

- Lageos	$A = 0.283 m^2$, $m = 407$ kg	
- Etalon-1, -2	$A = 1\ 315 m^2$, $m = 1346$kg	
- GPS (Satellite Dependent)		See Fliegel, *et al.* (1992)

Radiation Pressure

See Chapter 12.

- Reflectance Model		See Chapter 12.
- Earth Radiation Pressure	Ignored	For GPS see Fliegel (1992).
- Penumbra Model	6 402 km	Radius of Earth for shadow model.
	1 738 km	Radius of Moon for shadow model.
	696 000 km	Radius of Sun for shadow model

Along-Track Force

- Lageos, Etalon-1, -2	$C_T \times 10^{-12} ms^{-2} \bar{v}/v$ per unit mass	C_T is an adjusted parameter.

Other Non-gravitational Force

- GPS	y-bias, C_Y	C^Y is an adjusted parameter for each satellite

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
Relativistic Corrections		
- Propagation		
- LLR	Retardation due to Sun and Earth	See Chapter 14.
- VLBI	Retardation and bending due to Sun, Earth, and Moon	See Chapter 14.
- SLR	Retardation due to Earth	See Chapter 14.
- GPS	Retardation due to Earth	See Chapter 14
- Time Epoch and Interval		
- LLR, VLBI	Annual, diurnal, and other periodic terms	See Chapter 13.
- SLR, GPS	none	See Chapter 13.
- Dynamics		
- LLR	Barycentric (n-body) formulation ($\beta=\gamma=1$)	See Chapter 13.
- SLR	Geocentric (1-body) formulation ($\beta=\gamma=1$)	See Chapter 13.
- GPS	Geocentric (1-body) formulation ($\beta=\gamma=1$)	See Chapter 13.
Secular Acceleration of the Moon,	$\dot{n}$ = -24.9 arcsec cy^{-2}	$\dot{n}$ is an adjusted parameter in LLR. IAG (1991) Value.
MEASUREMENT MODEL		
Troposphere		
- SLR and LLR	Surface meteorology measurement plus Marini and Murray Model (1973).	See Chapter 11.
- VLBI		See Chapter 11. Water vapor radiometry if available-otherwise use model plus possible adjustment of vertical delay.
- GPS		See Chapter 11.

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
Satellite Center of Mass Correction		
- Lageos	0.251 m	This may vary depending on detection type for site.
- Etalon-1, -2	0.558 m	
- GPS Block I	dx = 0.210 m dy = 0.0 m dz = 0.854 m	dx, dy, dz are given in the satellite body-fixed coordinate frame (Fliegel, 1991).
-GPS Block II	dx = 0.2794 m dy = 0.0 m dz = 1.0229 m	dx, dy, dz are given in the satellite body-fixed coordinate frame (Fliegel, 1991). Unit vectors for the body fixed coordinates are given by $\hat{k}$, defined as a unit vector pointing from the satellite center of mass to the center of the Earth; $\hat{j}$, defined by $\hat{j} = \hat{k} \times \hat{S}$, where $\hat{S}$ is a unit vector pointing from the center of mass of the satellite to the Sun, assuming the cross product is not zero; and $\hat{i}$, determined by $\hat{i} = \hat{j} \times \hat{k}$. Within 3 degrees of Earth-Sun-satellite line, only the correction to the x-coordinate is made
Solid Earth Tides Displacement	Wahr Solid Tide Model	See Chapter 7.
Ocean Loading Site Displacement	Schwiderski tides	See Chapter 10.
REFERENCE SYSTEMS	1984 Conventions except as noted.	
Conventional Inertial System	Mean equinox and equator of J2000.0	See Chapter 2.
Time Synchronization	UTC as given by BIPM	If using UTC(USNO), then use UTC(USNO)-UTC(BIPM) as published by BIPM to correct to UTC(BIPM).
Precession	IAU 1976	See Lieske, *et al.* (1977) for application.
Nutation	IAU 1980	Based on Wahr Theory. Reference pole is the Celestial Ephemeris Pole (CEP). See Chapter 4.
Terrestrial Reference Frame		See Chapter 3.
Tidal Variations in UT1		See Chapter 10.
VLBI Radio Source Positions and Designations		See Chapter 2.
Tectonic Motion	NUVEL No Net Rotation	See Chapter 3.

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
Ephemeris System	Astronomical Almanac, 1984 (DE200/LE200).	Uses the Equinox and Equator of J2000.0. Origin in right ascension is set equal to the dynamical equinox of J2000.0. See Chapter 5.
Lunar Reference Frame		
- Retro-Reflector Coordinates (meters)		These coordinates are consistent with the DE200/LE200 ephemeris system but they are adjustable in LLR.

Apollo 11

	X1	X2	X3
PA	1592012.174	690605.998	21006.310
ME	1591752.786	691221.955	20394.850
	R	LONG	LAT
PA	1735477.073	23.45093088	.69352820
ME	1735477.073	23.47299617	.67333975

Apollo 14

	X1	X2	X3
PA	1652662.237	-521095.647	-109727.640
ME	1652821.419	-520455.963	-110364.156
	R	LONG	LAT
PA	1736339.050	-17.50041767	-3.62321101
ME	1736339.050	-17.47866283	-3.64425710

Apollo 15

	X1	X2	X3
PA	1554686.268	98004.046	765010.082
ME	1554942.413	98604.650	764412.078
	R	LONG	LAT
PA	1735481.089	3.60702873	26.15530389
ME	1735481.089	3.62847880	26.13331104

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
Lunakhod 2		

	X1	X2	X3
PA	1339413.779	801793.356	756361.607
ME	1339394.295	802310.618	755847.426
	R	LONG	LAT
PA	1734642.539	30.90537743	25.85105146
ME	1734642.539	30.92203167	25.83218088

PA = Principal Axis Coordinates
ME = Mean Earth Coordinates

Rotation Angles between mean Earth and principal axis coordinates are tau = 79.815, P1 = -79.350, P2 = 0.295 arcseconds.

CHAPTER 2 CELESTIAL REFERENCE SYSTEM

The IERS Celestial Reference Frame (ICRF) is based on the coordinates of extragalactic objects determined by VLBI and is a realization of a system of directions which are consistent with those of the FK5 (Fricke, *et al.*, 1988). The origin of right ascension of the frame was implicitly defined in the initial realization (Arias, *et al.*, 1988) by the adoption of the right ascensions of 23 radio sources in catalogs obtained by the Goddard Space Flight Center, the Jet Propulsion Laboratory, and the National Geodetic Survey. These catalogs had been compiled by fixing the right ascension of 3C273B to the usual (Hazard, *et al.*, 1971) conventional FK5 value (12^h 29^m $6^s\!.6997$s at J2000.0). A recent re-analysis of the same observations (Soma, *et al.*, 1990) gives a value which does not differ significantly from the conventional one ($0''\!.078 \pm 0''\!.105$). Using the right ascensions of 28 extragalactic objects in the FK5 System given by Ma, *et al.* (1990), one finds a shift of the ICRF origin relative to the FK5 of $0''\!.009 \pm 0''\!.017$. On the other hand, the accuracy of the FK5 origin of right ascensions can be estimated to be $\pm 0''\!.055$ based on the evaluations given by Fricke (1982) and Schwann (1988). Thus the IERS origin of right ascensions is consistent with that of the FK5 within the uncertainty of the latter. Comparing VLBI and LLR Earth orientation and terrestrial frames shows that the IERS origin of right ascensions is consistent with the dynamical equinox of the JPL ephemeris DE200 within $\pm 0''\!.01$ (Finger and Folkner, 1992; Charlot, *et al.* 1991)

The ICRF polar axis points in the direction of the mean pole at J2000.0 as defined by the IAU conventional models for precession and nutation (see Chapters 1 and 4). As a result of the inaccuracy of the conventional models, it is shifted from the expected exact position of the mean pole at J2000.0 by about $0''\!.016$ in the direction to 0^h and $0''\!.001$ in the direction to 6^h based on Steppe, *et al.*, 1991, and the *IERS Annual Report for 1990*.

The IERS celestial reference system is barycentric through the appropriate modelling of observations by the IERS Analysis Centers (see Chapters 4 and 14). The condition that the sources have no proper motion is also applied by the Analysis Center. Checks are regularly performed to insure the validity of this constraint (Ma and Shaffer, 1991) to avoid spurious motions of some fiducial objects. The ICRF should eventually be linked astrometrically to the HIPPARCOS reference frame to unify the radio and optical coordinate systems at the level of $\pm 0''\!.001$ in direction and $\pm 0''\!.001$/year in rotation (Arias, 1990).

Several extragalactic frames are produced each year by independent VLBI groups. Selected realizations are compared and combined to form the ICRF consistent with the Earth Orientation Parameters and the IERS Terrestrial Reference Frame, ITRF (see

Chapter 3). The algorithm used for the combination is designed primarily to maintain the three directions of axes fixed for successive realizations. The initial definition of the system and the maintenance process is described by Arias and Feissel (1990).

New realizations of the IERS celestial reference system are produced whenever justified by progress in the observations or in modelling. The source coordinates are published in the IERS Annual Report. Successive realizations produced up to now have maintained the initial definition of the axes within ±0"0001.

The realization of the celestial reference system published in the Annual Report of IERS for 1990 contains 396 sources in three categories, primary, secondary and complementary. A subset of sources dubbed primary are selected to fix the global orientation of the frame. They are chosen on the basis of consistency of their estimated coordinates in the various individual frames, after removing the relative rotations. Their rms position uncertainty in the IERS frame, derived from this consistency, is ±0"0003. The other sources common to the two frames but with larger position discrepancies, are considered secondary; there are 122 of them in the realization described here. Altogether in the primary and secondary categories 109 sources have position uncertainties smaller than ±0"0005, fifty between ±0"001 and ±0"003, and twenty over ±0"003. Finally, the ICRF includes 217 complementary sources, which were available from only one individual catalogue.

The observational history and the physical properties of the sources are described in *IERS Technical Note No. 7* (1991). The red-shifts span the interval 0.1-2.5 quite evenly. The total flux is, in general, over 1 Jansky. The spectral indices are between -0.8 and +1.4. The distribution in optical magnitudes peaks around the 18th visual magnitude. Some of the IERS sources have been mapped at S and X bands (e.g. Charlot, 1990). The primary sources mapped show no significant structure at the angular scale of 0"001.

The consistency of the IERS series of the Earth Orientation Parameters with the given realizations of the ICRF and of the ITRF is at the level of ±0"001. Evaluations of the discrepancies are given each year in the *IERS Annual Report*.

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CHAPTER 3 CONVENTIONAL TERRESTRIAL REFERENCE FRAME

Definition

The Terrestrial Reference System adopted for either the analysis of individual data sets by techniques (VLBI, SLR, LLR, GPS...) or the combination of individual solutions into a unified set of data (station coordinates, Earth orientation parameters, etc...) follows these criteria (Boucher, 1991):

a) It is geocentric, the center of mass being defined for the whole Earth, including oceans and atmosphere.

b) Its scale is that of a local Earth frame, in the meaning of a relativistic theory of gravitation.

c) Its orientation is given by the BIH orientation at 1984.0.

d) Its time evolution in orientation will create no residual global rotation with regards to the crust.

Realization

When one wants to realize such a conventional terrestrial reference system through a reference frame i.e. a network of station coordinates, it will be specified by Cartesian equatorial coordinates X, Y, and Z, by preference. If geographical coordinates are needed, the GRS80 ellipsoid is recommended (see table 3.2).

Each analysis center compares its reference frame to a realization of the Conventional Terrestrial Reference System (CTRS), as described above. Within IERS, each Terrestrial Reference System (TRF) is either directly, or after transformation, expressed as a realization of the CTRS adopted by IERS as its ITRS. The position of a point located on the surface of the solid Earth should be expressed by

$$\vec{X}(t) = \vec{X}_0 + \vec{V}_0(t-t_0) + \sum_i \Delta\vec{X}_i(t) ,$$

where $\Delta\vec{X}_i$ are corrections to various time changing effects, and $\vec{X}_0$ and $\vec{V}_0$ are position and velocity at the epoch t_0. The corrections to be considered are solid Earth tide displacement (full correction including permanent effect, so that the extra correction which was originally recommended in order to have zero mean correction is no longer valid), ocean loading, and atmospheric loading.

Further corrections could be added if they are at mm level and can be computed by a suitable model. The velocity $\vec{V}_0$ should be expressed as

$$\vec{V}_0 = \vec{V}_{plate} + \vec{V}_r$$

where $\vec{V}_{plate}$ is the horizontal velocity computed from the NNR-NUVEL-1 model (DeMets, *et al.*, 1990; Argus and Gordon, 1991) and $\vec{V}_r$ a residual velocity.

In data analysis, $\vec{X}_0$ and $\vec{V}_r$ should be considered as solve-for parameters. In particular, if a non linear change occurs (earthquake, volcanic event ...), a new $\vec{X}_0$ parameter should be adopted. When adjusting parameters, particularly velocities, the IERS orientation should be kept at all epochs, ensuring the alignment at a reference epoch and the time evolution through a no net rotation condition. The way followed by various analysis centers depends on their own view of modelling, and on the techniques themselves. For the origin, only data which can be modelled by dynamical techniques (currently SLR, LLR or GPS for IERS) can determine the center of mass. The VLBI system can be referred to a geocentric system by adopting for a station its geocentric position at a reference epoch as provided from external information.

The scale is obtained by appropriate relativistic modelling. This is particularly true for VLBI and LLR which are usually modelled in a barycentric frame. A more detailed treatment can be found in chapter 14. The orientation is defined by adopting IERS (or BIH) Earth orientation parameters at a reference epoch. In the case of SLR, an additional constraint in longitude is necessary.

The unit of length is the meter (SI). The IERS Reference Pole (IRP) and Reference Meridian (IRM) are consistent with the corresponding directions in the BIH Terrestrial System (BTS) within ± 0".005. The BIH reference pole was adjusted to the Conventional International Origin (CIO) in 1967; it was then kept stable independently until 1987. The uncertainty of the tie of the IRP with the CIO is ± 0".03. The time evolution of the orientation will be insured by using a no-net-rotation condition with regards to horizontal tectonic motions over the whole Earth.

Transformation Parameters of World Coordinate Systems and Datums

The seven-parameter (similarity transformation between any two Cartesian systems, *e. g.*, from (u,v,w) to (x,y,z), or in short (u,v,w) → (x,y,z) can be written (Soler and Hothem, 1989) as

$$\begin{Bmatrix} x \\ y \\ z \end{Bmatrix} = \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} + (1 + \delta s) \begin{bmatrix} 1 & \delta\omega & -\delta\psi \\ -\delta\omega & 1 & \delta\epsilon \\ \delta\psi & -\delta\epsilon & 1 \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}, \tag{1}$$

where $\Delta x, \Delta y, \Delta z$ = coordinates of the origin of the frame (u,v,w) in the frame (x,y,z); $\delta\epsilon$, $\delta\psi$, $\delta\omega$ = differential rotations (expressed in radians) respectively, around the axes (u,v,w) to establish parallelism with the (x,y,z) frame (Positive rotations are counterclockwise rotations as viewed looking toward the origin of the right handed coordinate system.); and δs = differential scale change (expressed in ppm $\times 10^{-6}$) (see Table 3.1).

Table 3.1. Transformation parameters from ITRF90 to major global or local datums.

Coordinate System (datum)	Δx T1 (m)	Δy T2 (m)	Δz T3 (m)	δs D (ppm)	$\delta\varepsilon$ -R1 (")	$\delta\phi$ -R2 (")	$\delta\omega$ -R3 (")
WGS84	0.060	-0.517	-0.223	-0.011	-0.0183	0.0003	0.0070
WGS72	0.060	-0.517	-4.723	-0.231	-0.0183	0.0003	0.5470
NWL9D	0.060	-0.517	-4.723	0.599	-0.0183	0.0003	0.8070
BTS84	-0.058	0.028	-0.036	0.030	-0.0035	-0.0020	-0.0017
BTS85	-0.004	0.049	0.006	0.025	-0.0026	0.0005	0.0014
BTS86	0.027	-0.011	-0.044	0.008	-0.0008	0.0023	0.0072
BTS87	-0.011	-0.008	-0.057	0.006	-0.0004	-0.0002	-0.0003
ITRF0	-0.007	-0.009	-0.055	0.005	-0.0004	-0.0002	-0.0001
ITRF88	0.000	-0.012	-0.062	0.006	-0.0001	0.0000	0.0000
ITRF89	0.005	0.024	-0.038	0.003	0.0000	0.0000	0.0000

Once the Cartesian coordinates (x,y,z) are known, they can be transformed to "datum" or curvilinear geodetic coordinates (λ,ϕ,h) referred to an ellipsoid of semi-major axis a and flattening f (see Table 3.2), using the following noniterative method (Bowring, 1985):

$$\tan \lambda = \frac{y}{x}, \tag{2}$$

$$\tan \phi = \frac{z(1 - f) + e^2 a \sin^3 \mu}{(1 - f)\,(p - e^2 a \cos^3 \mu)}, \tag{3}$$

$$h = p \cos \phi + z \sin \phi - a(1 - e^2 \sin^2 \phi)^{1/2}, \tag{4}$$

$$e^2 = 2f - f^2, \tag{5}$$

$$p = (x^2 + y^2)^{1/2}, \tag{6}$$

$$r = (p^2 + z^2)^{1/2}, \tag{7}$$

$$\tan \mu = \frac{z}{p}\left[(1 - f) + \frac{e^2 a}{r}\right]. \tag{8}$$

The preceding equations can be used in conjunction with Tables 3.1 and 3.2 superseding the ones previously presented in Soler and Hothem (1988).

Table 3.2. Parameters of Some Adopted Reference Ellipsoids.

Coordinate system (datum)	Reference ellipsoid used	a (m)	1/f
AGD	AN (or SA-69)	6,378,160	298.25
ED-79	International	6,378,388	297
GEM-8	GEM-8	6,378,145	298.255
GEM-9 (or GEM-10)	GEM-9 or (GEM-10)	6,378,140	298.255
GEM-10B	GEM-10B	6,378,138	298.257
GEM-T1	GEM-T1	6,378,137	298.257
GEM-T3	GEM-T3	6,378,137	298.257
NAD-27	Clarke 1866	6,378,206.4	294.9786982
NAD-83	GRS-80	6,378,137	298.257222101
NWL-9D = NSWC-9Z2	WGS-66	6,378,145	298.25
SA-69	SA-69 (or AN)	6,378,160	298.25
WGS-72	WGS-72	6,378,135	298.26
WGS-84	WGS-84	6,378,137	298.257223563

Note: AGD = Australian geodetic datum; AN = Australian national; ED = European datum; GEM = Goddard Earth model; GRS = geodetic reference system; NAD = North American datum; NSWC = Naval surface warfare center; NWL = Naval Weapons Laboratory; SA = South American; WGS = World geodetic system.

In the case of IERS, these algorithms are used with Table 3.1, where (x,y,z) are coordinates in the specified coordinate system (datum), and (u,v,w,) are identified with ITRF, or a more specific realization (ITRF90 for table 3.1). In the current practice of the IERS/CB and its publications, (u,v,w) are denoted (X,Y,Z) and the coordinates in an individual system by (XS, YS, ZS), while the 7 parameters are identified as (T_1, T_2, T_3) refer to (Δx, Δy, Δz), D to δs and (R_1,R_2,R_3) to ($-\delta\varepsilon$,$-\delta\Psi$,$-\delta\omega$).

Transformations to Current Datums

Table 3.1 gives values recommended to convert ITRF90 coordinates into other datums. Table 3.2 Lists the required two parameters for several adopted reference ellipsoids defining important geodetic datums. Some ellipsoids were introduced by NASA's GSFC to reference their Goddard Earth Models (GEM, series 8,9, and 10). They were primarily used to obtain geoid heights (undulations) and depict global geoid maps.

These transformation formulae should be used with care. There are several ways to determine such parameters, either by direct comparison between two realizations of the datums, or by combining formula through an intermediate datum. This is well illustrated by WGS84 as mentioned below.

The numbers given in Table 3.1 have been determined using the following data:

a) The transformation between BTS87 and WGS84 derived from Boucher, Altamimi, and Willis (1988).

b) Transformation parameters between the Doppler realized frames (i.e., NWL-9D = NSWC-9Z2, WGS-72, WGS-84) have been adopted by the Defense Mapping Agency. Recall that Cartesian coordinates, derived from using the Global Positioning System (GPS), are also referred to the WGS-84 coordinate system. Nevertheless, the Doppler WGS-84 (GPS) frames are not necessarily coincident (Malys, 1988). Similarly, although by definition, the NAD-83 and WGS-84 realized Cartesian frames should coincide, small differences (<0.5 ppm) in shifts, rotations, and scale between the two frames may be discovered. These differences merely reflect small, random regional distortions still present in the NAD-83 horizontal datum, which was primarily established by simultaneously adjusting all archived classical-geodetic observations(Bossler, 1987; Schwarz, 1989).

c) Transformations to old BIH or IERS systems are derived from IERS TN4, 6, and 9.

Transformations to major local datums can be obtained through WGS84.

Plate Motion Model

One of the factors which can affect Earth rotation results is the motion of the tectonic plates which makes up the Earth's surface. As the plates move, fixed coordinates for the observing stations will become inconsistent with each other. The rates of relative motions for some regular observing sites are believed to be 5 cm per year or larger. The observations of plate motions so far by Satellite Laser Ranging and Very Long Baseline Interferometry appear to be roughly consistent with the average rates over the last few million years derived from the geological record and other geophysical information. Thus, in order to reduce inconsistencies in the station coordinates and to make the results from different techniques more directly comparable, a model for plate motions given by DeMets, *et al.* (1990) is recommended.

The Cartesian rotation vector for each of the major plates is given in Table 3.3 A subroutine called ABSMO_NUVEL, provided by J. B. Minster, is also included below. It computes the new site position at time t from the old site position at time t0 using the recommended plate motion model.

Table 3.3. Cartesian rotation vector for each plate using the NUVEL NNR-1 kinematic plate model (no net rotation)

Plate Name	Ω_X deg/My.	Ω_Y deg/My.	Ω_Z deg/My.
Pacific	-0.0907	0.2902	-0.5976
Cocos	-0.6249	-1.2944	0.6544
Nazca	-0.0921	-0.5138	0.5756
Caribbean	-0.0109	-0.2027	0.0945
South America	-0.0624	-0.0906	-0.0523
Antarctica	-0.0494	-0.1018	0.2218
India	0.3995	0.0026	0.4066
Australia	0.4695	0.3072	0.3762
Africa	0.0532	-0.1856	0.2348
Arabia	0.4003	-0.0311	0.4049
Eurasia	-0.0590	-0.1434	0.1887
North America	0.0152	-0.2155	-0.0094
Juan de Fuca	0.2995	0.4805	-0.2936
Philippine	0.5913	-0.4412	-0.5976

The NUVEL model should be used as a default, for stations which appear to follow reasonably its values. For some stations, particularly in the vicinity of plate boundaries, users may benefit by estimating velocities or using specific values not derived from NUVEL. This is also a way to take into account now some non-negligible vertical motions. Published station coordinates should include the epoch associated with the coordinates.

The original subroutine is a coding of the AM0-2 model from J. B. Minster. This was made by modifying the earlier subroutine. The changes were made by Don Argus and verified by Alice Gripp.

```
      SUBROUTINE ABSMO_NUVEL(PSIT,T0,X0,Y0,Z0,T,X,Y,Z)
C
C   ABSMO_NUVEL take a site specified by its initial coordinates
C   X0,Y0,Z0 at time T0, and computes its updated positions X,Y,Z
C   at time T, based on the geological "absolute", (no net
C   rotation) plate motion model AM0-2 (Minster and Jordan,
C   1978).
C
C   Original author: J.B. Minster, Science Horizons.
C   DFA: Revised by Don Argus, Northwestern University
C   DFA: uses absolute model NNR-NUVEL1
C
C   Transcribed from USNO Circular 167 "Project Merit Standards"
C   by Tony Mallama with slight modification to the documentation
C   and code.
C
C   Times are given in years, e.g. 1988.0 for Jan 1, 1988.
C
C   PSIT is the four character abbreviation for the plate name,
C   if PSIT is not recognized then the new positions are returned
C   as zero.
C
      IMPLICIT NONE
      CHARACTER*4         PSIT,PNM(14)
      REAL*8              OMX(14),OMY(14),OMZ(14)
      REAL*8              X0,Y0,Z0
      REAL*8              X,Y,Z,T,T0
      REAL*8              ORX,ORY,ORZ
      INTEGER*2           IPSIT,I
C
C   DFA: NNR-NUVEL1
C
      DATA     (PNM(I),      OMX(I),       OMY(I),       OMZ(I),
     &          I =  1,14)
     &         /'PCFC',    -0.0907,       0.2902,      -0.5976,
     &          'AFRC',     0.0532,      -0.1856,       0.2348,
     &          'ANTA',    -0.0494,      -0.1018,       0.2218,
     &          'ARAB',     0.4003,      -0.0311,       0.4049,
     &          'AUST',     0.4695,       0.3072,       0.3762,
     &          'CARB',    -0.0109,      -0.2027,       0.0945,
     &          'COCO',    -0.6249,      -1.2944,       0.6544,
     &          'EURA',    -0.0590,      -0.1434,       0.1887,
     &          'INDI',     0.3995,       0.0026,       0.4066,
     &          'NAZC',    -0.0921,      -0.5138,       0.5756,
     &          'NOAM',     0.0152,      -0.2155,      -0.0094,
     &          'SOAM',    -0.0624,      -0.0906,      -0.0523,
     &          'JUFU',     0.2995,       0.4805,      -0.2936,
     &          'PHIL',     0.5913,      -0.4412,      -0.5976/
C
C
C   Initialize things properly
C
```

```
      IPSIT = -1
      X = 0.0D0
      Y = 0.0D0
      Z = 0.0D0
C
C   Look up the plate in the list.
C
      DO 20 I = 1,14
   20 IF (PSIT .EQ. PNM(I)) IPSIT = I
C
C   If plate name is not recognized return the new plate position
C   as zero.
C
      IF (IPSIT .EQ. -1) RETURN
C
C   Convert from degree/My to radians/yr.
C
      ORX = OMX(IPSIT) * 1.7453292D-08
      ORY = OMY(IPSIT) * 1.7453292D-08
      ORZ = OMZ(IPSIT) * 1.7453292D-08
C
C   Compute the new coordinates
C
      X = X0 + (ORY*Z0 - ORZ*Y0) * (T-T0)
      Y = Y0 + (ORZ*X0 - ORX*Z0) * (T-T0)
      Z = Z0 + (ORX*Y0 - ORY*X0) * (T-T0)
C
C   Finish up
C
      RETURN
      END
```

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CHAPTER 4 LUNAR AND PLANETARY EPHEMERIDES

The planetary and lunar ephemerides recommended for the IERS standards are the JPL Development Ephemeris DE200 and the Lunar Ephemeris LE200. These have formed the basis for the *Astronomical Almanac* since 1984. DE200/LE200 should be used in the analysis of SLR and VLBI. However, in LLR analysis, parameters of the Earth-Moon system should be fit or a more recent lunar ephemeris should be used.

The ephemerides, DE200/LE200, were created from the 1950-based ephemerides, DE118/LE62. Their orientation with respect to the dynamical equinox of J2000.0 was described by Standish (1982). The data used in the fitting of DE118 was described by Standish (1990).

Associated with the ephemerides is the set of astronomical constants used in the creation of the ephemerides which are listed in Table 4.1. Many of these values do not agree exactly with those of the IAU 1976 or the current best estimates. Table 4.2 shows a comparison of the planetary masses among the IAU 1976, the DE200/LE200 and the current best estimates referred to as "1992". Also shown in the table are the references for the current best estimates. Differences, listed in Table 4.3, are necessary in order to provide a best fit of the ephemerides to the observational data. Constants are provided directly with the ephemerides and should be considered to be an integral part of them.

Table 4.1. JPL Planetary and Lunar Ephemerides DE200/LE200.

Scale (km/au)	149597870.66
Speed of light (km/sec)	299792.458
Obliquity of the ecliptic	23° 26′ 21.″4119
Earth-Moon mass ratio	81.300587
GM(Sun)/GM(Mercury)	6023600
GM(Sun)/GM(Venus)	408523.5
GM(Sun)/GM(Mars)	3098710
GM(Sun)/GM(Jupiter)	1047.350
GM(Sun)/GM(Saturn)	3498.0
GM(Sun)/GM(Uranus)	22960
GM(Sun)/GM(Neptune)	19314
GM(Sun)/GM(Pluto)	130000000
GM(Sun)/GM(Earth+Moon)	328900.55

Table 4.2. Comparison of planetary mass estimates expressed in reciprocal solar masses.

Planet	IAU (1976)	DE200	"1992"	Reference for "1992" estimate
Mercury	6023600.	6023600.	6023600.	Anderson, *et al.*, 1987b
Venus	408523.5	408523.5	408523.71	Sjogren, *et al.*, 1990
Earth & Moon	328900.5	[illegible] 3900.55	328900.56	Williams, 1991
Mars	3098710.	[illegible] 8710.	3098708.	Null, 1969
Jupiter	1047.355	1047.350	1047.3486	Campbell, *et al.*, 1985
Saturn	3498.5	3498.0	3497.90	Campbell and Anderson, 1989
Uranus	22869.	22960.	22902.94	Anderson, *et al.*, 1987a
Neptune	19314.	19314.	19412.24	Tyler, *et al.*, 1989
Pluto	3000000.	130000000.	135000000.	Tholen and Buie, 1988

Table 4.3. IAU Values Which Differ From Those of DE200/LE200.

Scale (sec/au) (149597870.15...km/au)	449.004782
Moon-Earth mass ratio (E/M = 81.30068...)	0.0123002
Obliquity of the ecliptic	23° 26′ 21″.448

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CHAPTER 5 TRANSFORMATION BETWEEN THE CELESTIAL AND TERRESTRIAL SYSTEMS

The coordinate transformation to be used from the TRS to the CRS at the date t of the observation can be written as:

$$[CRS] = PN(t) \cdot R(t) \cdot W(t) \ [TRS],$$

where PN(t), R(t) and W(t) are the transformation matrices arising from the motion of the Celestial Ephemeris Pole (CEP) in the CRS, from the rotation of the Earth around the axis of the CEP, and from polar motion respectively.

Two equivalent options can be used giving rise to the forms (1) and (2) of the coordinate transformation. These two options have been shown to be consistent within ±0.05 milliseconds of arc (mas) both theoretically (Capitaine, 1990) and numerically using existing astrometric data (Capitaine and Chollet, 1991) or simulated data over two centuries (Capitaine and Gontier, 1991).

Option (1), corresponding to the classical procedure, makes use of the equinox for realizing the intermediate reference frame of date t. It uses apparent Greenwich Sidereal Time in the transformation matrix R(t) and the classical precession and nutation parameters in the transformation matrix PN(t),

Option (2) makes use of the nonrotating origin (Guinot, 1979) to realize the intermediate reference frame of date t: it uses the stellar angle (from the NRO in the TRS to the NRO in the CRS) in the transformation matrix R(t) and the two coordinates of the Celestial Ephemeris Pole in the CRS (Capitaine, 1990) in the transformation matrix PN(t). This leads to very simple expressions of the partial derivatives of observables with respect to polar coordinates, UT1, and celestial pole offsets.

The following sections give the details of these two options as well as the standard expressions necessary to obtain the numerical values of the relevant parameters at the date of the observation. Subroutines for options 1 and 2 of the coordinate transformation from the TRS to the CRS are available from the Central Bureau on request together with the development of the parameters.

The expressions of the precession and nutation quantities have been developed originally as functions of barycentric dynamical time (TDB) defined by IAU recommendations of 1976 and 1979. In 1991 the IAU adopted definitions of other time scales. See Chapter 13 for the relationships among these time scales. At the level of accuracy needed in the coordinate transformations which are considered here, the parameter t defined by

$$t = (\text{TAI} - 2000 \text{ January 1d 12h TAI}) \text{ in days} / 36\,525$$

can be used in place of

$$[\text{TDB} - \text{J2000.0 (TDB)}] \text{ in days} / 36\,525.$$

In all of the following formulas, t is defined as indicated above. In the following, R_1, R_2 and R_3 denote direct rotations about the axes 1, 2 and 3 of the coordinate frame.

Coordinate Transformation Referred to the Equinox

Option (1) uses the form of the coordinate transformation

$$[\text{CRS}] = PN'(t) \cdot R'(t) \cdot W'(t) \ [\text{TRS}], \qquad (1)$$

in which the three fundamental components are (Mueller, 1969)

$$W'(t) = R_1(y_p) \cdot R_2(x_p),$$

x_p and y_p being the "polar coordinates" of the CEP in the TRS;

$$R'(t) = R_3(-\text{GST}),$$

GST being Greenwich True Sidereal Time at date t, including both the effect of Earth rotation and the accumulated precession and nutation in right ascension; and

$$PN'(t) = [P]\ [N],$$

$$\text{with } [P] = R_3(\zeta_A) \cdot R_2(-\theta_A) \cdot R_3(z_A)$$

for the transformation matrix corresponding to the precession between the reference epoch and the date t,

$$[N] = R_1(-\epsilon_A) \cdot R_3(\Delta\psi) \cdot R_1(\epsilon_A + \Delta\epsilon)$$

for the transformation matrix corresponding to the nutation at date t.

Standard values of the parameters to be used in form (1) of the transformation are explained below.

The standard polar coordinates to be used for the parameters x_p and y_p (if not estimated from the observations) are those published by the IERS.

Apparent Greenwich Sidereal Time GST at the date t of the observation, must be derived from the following expressions:

(i) the relationship between Greenwich Mean Sidereal Time (GMST) and Universal Time as given by Aoki, *et al.* (1982):

$$GMST_{0h\,UT1} = 6^h\ 41^m\ 50\overset{s}{.}548\ 41 + 8\ 640\ 184\overset{s}{.}812\ 866\ T'_u$$

$$+ 0\overset{s}{.}093\ 104\ T'^2_u - 6\overset{s}{.}2 \times 10^{-6}\ T'^3_u,$$

with $T'_u = d'_u/365\ 25$, d_u being the number of days elapsed since 2000 January 1, 12h UT1, taking on values ±0.5, ±1.5, ...,

(ii) the interval of GMST from 0h UT1 to the hour of the observation in UT1,

$$GMST = GMST_{0h\,UT1} + r[(UT1-UTC)+UTC],$$

where r is the ratio of universal to sidereal time as given by Aoki, *et al.* (1982),

$$r = 1.002\ 737\ 909\ 350\ 795 + 5.900\ 6 \times 10^{-11}\ T'_u - 5.9 \times 10^{-15}\ T'^2_u$$

and the UT1-UTC value to be used (if not estimated from the observations) is the IERS value. The use of (i) and (ii) is equivalent to using the relationship (Sovers and Fanselow, 1987) between GMST and UT1,

$$GMST = (\text{UT1 Julian day fraction}) \times 24h + 18^h41^m50\overset{s}{.}548\ 41$$
$$+ 8\ 640\ 184\overset{s}{.}812\ 866T_u + 0\overset{s}{.}093\ 104T_u^2 - 6\overset{s}{.}2 \times 10^{-6}\ T_u^3,$$

where T_u = [Julian UT1 date - 2 451 545.0]/36 525).

(iii) accumulated precession and nutation in right ascension (Aoki and Kinoshita, 1983),

$$GST = GMST + \Delta\psi\cos\epsilon_A + 0\overset{''}{.}002\ 64\ \sin\Omega + 0\overset{''}{.}000\ 063\ \sin 2\Omega,$$

where Ω is the mean longitude of the ascending node of the lunar orbit. The last two terms have not been included in the IERS Standards previously. They should not be included in (iii) until 26 February 1997 when their use will begin. This date is chosen to eliminate any discontinuity in UT1. The effect of these terms on the estimation of UT1 has been described by Gontier and Capitaine (1991).

The numerical expression for the precession quantities ζ_A, θ_A, z_A and ϵ_A have been given by Lieske, *et al.* (1977) as functions of two time parameters t and T (the last parameter representing Julian centuries from J2000.0 to an arbitrary epoch). The simplified expressions when the arbitrary epoch is chosen to be J2000.0 (*i.e.* T = 0) are

$$\zeta_A = 2\,306''.218\,1\ t + 0''.301\,88\ t^2 + 0''.017\,998\ t^3,$$

$$\theta_A = 2\,004''.310\,9\ t - 0''.426\,65\ t^2 - 0''.041\,833\ t^3,$$

$$z_A = 2\,306''.2181\ t + 1''.094\,68\ t^2 + 0''.018\,203\ t^3,$$

$$\epsilon_A = 8\,4381''.448 - 46''.815\,0\ t - 0''.000\,59\ t^2 + 0''.001\,813\ t^3.$$

The nutation quantities $\Delta\psi$ and $\Delta\epsilon$ to be used are the standard nutation angles in longitude and obliquity as derived from the IAU 1980 Theory of Nutation (Seidelmann, 1982; Wahr, 1981) using the fundamental arguments as given below. The constants defining this theory are given in Table 5.1.

For observations requiring values of the nutation angles with an accuracy of ±1 mas, it is necessary to add (if those quantities are not estimated from the observations) the IERS published values (observed or predicted) for the "celestial pole offsets" *i.e.* corrections dpsi and deps).

The IAU 1980 Theory of Nutation

The IAU 1980 Theory of Nutation (Seidelmann, 1982; Wahr, 1981) is based on a modification of a rigid Earth theory published by Kinoshita (1977) and on the geophysical model 1066A of Gilbert and Dziewonski (1975). It therefore includes the effects of a solid inner core and a liquid outer core and a "distribution of elastic parameters inferred from a large set of seismological data."

VLBI and LLR observations have shown that there are deficiencies in the IAU 1976 Precession and in the IAU 1980 Theory of Nutation. However, these models are kept as part of the IERS Standards and the observed differences ($\delta\Delta\psi$ and $\delta\Delta\epsilon$, equivalent to dpsi and deps in the IERS Bulletins) with respect to the conventional celestial pole position defined by the models are monitored and reported by the IERS as "celestial pole offsets". Using these offsets the corrected nutation is given by

$$\Delta\psi = \Delta\psi(\text{IAU 1980}) + \delta\Delta\psi, \text{ and}$$
$$\Delta\epsilon = \Delta\epsilon(\text{IAU 1980}) + \delta\Delta\epsilon.$$

This is practically equivalent to replacing N with the rotation described by Lieske (1991),

$$\tilde{N} = \mathcal{R} N_{IAU}.$$

where N_{IAU} represents the IAU 1980 Theory of Nutation,

$$\mathfrak{R} = \begin{bmatrix} 1 & -\delta\Delta\psi\cos\epsilon_t & -\delta\Delta\psi\sin\epsilon_t \\ \delta\Delta\psi\cos\epsilon_t & 1 & \delta\Delta\epsilon \\ \delta\Delta\psi\sin\epsilon_t & \delta\Delta\epsilon & 1 \end{bmatrix}$$

and $\epsilon_t = \epsilon_A + \Delta\epsilon$. Mathematical models of the corrections to the IAU 1980 Theory of Nutation derived from observations are available (McCarthy and Luzum, 1991).

Fundamental Arguments of the IAU 1980 Theory of Nutation

The fundamental arguments of the nutation series are given by the following functions of t:

$$\begin{aligned} l &= \text{Mean Anomaly of the Moon} \\ &= 134^\circ\ 57'\ 46''.733 + (1325^r + 198^\circ\ 52'\ 02''.633)\ t \\ &\quad + 31''.310\ t^2 + 0''.064\ t^3, \\ l' &= \text{Mean Anomaly of the Sun} \\ &= 357^\circ\ 31'\ 39''.804 + (99^r + 359^\circ\ 03'\ 01''.224)\ t \\ &\quad - 0''.577\ t^2 - 0''.012\ t^3, \end{aligned}$$

$$\begin{aligned} F &= L - \Omega \\ &= 93^\circ\ 16'\ 18''.877 + (1342^r + 82^\circ\ 01'\ 03''.137)\ t \\ &\quad - 13''.257\ t^2 + 0''.011\ t^3, \end{aligned}$$

$$\begin{aligned} D &= \text{Mean Elongation of the Moon from the Sun} \\ &= 297^\circ\ 51'\ 01''.307 + (1236^r + 307^\circ\ 06'\ 41''.328)\ t \\ &\quad - 6''.891\ t^2 + 0''.019\ t^3, \end{aligned}$$

$$\begin{aligned} \Omega &= \text{Mean Longitude of the Ascending Node of the Moon} \\ &= 125^\circ\ 02'\ 40''.280 - (5^r + 134^\circ\ 08'\ 10''.539)\ t \\ &\quad + 7''.455\ t^2 + 0''.008\ t^3, \end{aligned}$$

L = Mean Longitude of the Moon,

where t is measured in Julian Centuries of 36525 days of 86400 seconds of Dynamical Time since J2000.0 and where $1^r = 360^\circ = 1\ 296\ 000''.0$.

Table 5.1. Series for nutation in longitude $\Delta\psi$ and obliquity $\Delta\epsilon$, referred to the mean equator and equinox of date, with T measured in Julian centuries from epoch J2000.0.

$$\Delta\psi = \Sigma_{i=1,106} (A_i + A'_i t) \sin(\text{ARGUMENT}),$$

$$\Delta\epsilon = \Sigma_{i=1,106} (B_i + B'_i t) \cos(\text{ARGUMENT}).$$

ARGUMENT					PERIOD	LONGITUDE (0".0001)		OBLIQUITY (0".0001)	
l	l'	F	D	Ω	(days)	A_i	A'_i	B_i	B'_i
0	0	0	0	1	6798.4	-171996	-174.2t	92025	8.9t
0	0	2	-2	2	182.6	-13187	-1.6t	5736	-3.1t
0	0	2	0	2	13.7	-2274	-0.2t	977	-0.5t
0	0	0	0	2	3399.2	2062	0.2t	-895	0.5t
0	1	0	0	0	365.3	1426	-3.4t	54	-0.1t
1	0	0	0	0	27.6	712	0.1t	-7	0.0t
0	1	2	-2	2	121.7	-517	1.2t	224	-0.6t
0	0	2	0	1	13.6	-386	-0.4t	200	0.0t
1	0	2	0	2	9.1	-301	0.0t	129	-0.1t
0	-1	2	-2	2	365.2	217	-0.5t	-95	0.3t
1	0	0	-2	0	31.8	-158	0.0t	-1	0.0t
0	0	2	-2	1	177.8	129	0.1t	-70	0.0t
-1	0	2	0	2	27.1	123	0.0t	-53	0.0t
1	0	0	0	1	27.7	63	0.1t	-33	0.0t
0	0	0	2	0	14.8	63	0.0t	-2	0.0t
-1	0	2	2	2	9.6	-59	0.0t	26	0.0t
-1	0	0	0	1	27.4	-58	-0.1t	32	0.0t
1	0	2	0	1	9.1	-51	0.0t	27	0.0t
2	0	0	-2	0	205.9	48	0.0t	1	0.0t
-2	0	2	0	1	1305.5	46	0.0t	-24	0.0t
0	0	2	2	2	7.1	-38	0.0t	16	0.0t
2	0	2	0	2	6.9	-31	0.0t	13	0.0t
2	0	0	0	0	13.8	29	0.0t	-1	0.0t
1	0	2	-2	2	23.9	29	0.0t	-12	0.0t
0	0	2	0	0	13.6	26	0.0t	-1	0.0t
0	0	2	-2	0	173.3	-22	0.0t	0	0.0t
-1	0	2	0	1	27.0	21	0.0t	-10	0.0t
0	2	0	0	0	182.6	17	-0.1t	0	0.0t
0	2	2	-2	2	91.3	-16	0.1t	7	0.0t
-1	0	0	2	1	32.0	16	0.0t	-8	0.0t
0	1	0	0	1	386.0	-15	0.0t	9	0.0t
1	0	0	-2	1	31.7	-13	0.0t	7	0.0t
0	-1	0	0	1	346.6	-12	0.0t	6	0.0t
2	0	-2	0	0	1095.2	11	0.0t	0	0.0t
-1	0	2	2	1	9.5	-10	0.0t	5	0.0t
1	0	2	2	2	5.6	-8	0.0t	3	0.0t
0	-1	2	0	2	14.2	-7	0.0t	3	0.0t
0	0	2	2	1	7.1	-7	0.0t	3	0.0t
1	1	0	-2	0	34.8	-7	0.0t	0	0.0t
0	1	2	0	2	13.2	7	0.0t	-3	0.0t
-2	0	0	2	1	199.8	-6	0.0t	3	0.0t
0	0	0	2	1	14.8	-6	0.0t	3	0.0t
2	0	2	-2	2	12.8	6	0.0t	-3	0.0t
1	0	0	2	0	9.6	6	0.0t	0	0.0t
1	0	2	-2	1	23.9	6	0.0t	-3	0.0t
0	0	0	-2	1	14.7	-5	0.0t	3	0.0t
0	-1	2	-2	1	346.6	-5	0.0t	3	0.0t
2	0	2	0	1	6.9	-5	0.0t	3	0.0t

Table 5.1 (continued)

ARGUMENT					PERIOD	LONGITUDE (0".0001)		OBLIQUITY (0".0001)	
l	l'	F	D	Ω	(days)	A_i	A'_i	B_i	B'_i
1	-1	0	0	0	29.8	5	0.0t	0	0.0t
1	0	0	-1	0	411.8	-4	0.0t	0	0.0t
0	0	0	1	0	29.5	-4	0.0t	0	0.0t
0	1	0	-2	0	15.4	-4	0.0t	0	0.0t
1	0	-2	0	0	26.9	4	0.0t	0	0.0t
2	0	0	-2	1	212.3	4	0.0t	-2	0.0t
0	1	2	-2	1	119.6	4	0.0t	-2	0.0t
1	1	0	0	0	25.6	-3	0.0t	0	0.0t
1	-1	0	-1	0	3232.9	-3	0.0t	0	0.0t
-1	-1	2	2	2	9.8	-3	0.0t	1	0.0t
0	-1	2	2	2	7.2	-3	0.0t	1	0.0t
1	-1	2	0	2	9.4	-3	0.0t	1	0.0t
3	0	2	0	2	5.5	-3	0.0t	1	0.0t
-2	0	2	0	2	1615.7	-3	0.0t	1	0.0t
1	0	2	0	0	9.1	3	0.0t	0	0.0t
-1	0	2	4	2	5.8	-2	0.0t	1	0.0t
1	0	0	0	2	27.8	-2	0.0t	1	0.0t
-1	0	2	-2	1	32.6	-2	0.0t	1	0.0t
0	-2	2	-2	1	6786.3	-2	0.0t	1	0.0t
-2	0	0	0	1	13.7	-2	0.0t	1	0.0t
2	0	0	0	1	13.8	2	0.0t	-1	0.0t
3	0	0	0	0	9.2	2	0.0t	0	0.0t
1	1	2	0	2	8.9	2	0.0t	-1	0.0t
0	0	2	1	2	9.3	2	0.0t	-1	0.0t
1	0	0	2	1	9.6	-1	0.0t	0	0.0t
1	0	2	2	1	5.6	-1	0.0t	1	0.0t
1	1	0	-2	1	34.7	-1	0.0t	0	0.0t
0	1	0	2	0	14.2	-1	0.0t	0	0.0t
0	1	2	-2	0	117.5	-1	0.0t	0	0.0t
0	1	-2	2	0	329.8	-1	0.0t	0	0.0t
1	0	-2	2	0	23.8	-1	0.0t	0	0.0t
1	0	-2	-2	0	9.5	-1	0.0t	0	0.0t
1	0	2	-2	0	32.8	-1	0.0t	0	0.0t
1	0	0	-4	0	10.1	-1	0.0t	0	0.0t
2	0	0	-4	0	15.9	-1	0.0t	0	0.0t
0	0	2	4	2	4.8	-1	0.0t	0	0.0t
0	0	2	-1	2	25.4	-1	0.0t	0	0.0t
-2	0	2	4	2	7.3	-1	0.0t	1	0.0t
2	0	2	2	2	4.7	-1	0.0t	0	0.0t
0	-1	2	0	1	14.2	-1	0.0t	0	0.0t
0	0	-2	0	1	13.6	-1	0.0t	0	0.0t
0	0	4	-2	2	12.7	1	0.0t	0	0.0t
0	1	0	0	2	409.2	1	0.0t	0	0.0t
1	1	2	-2	2	22.5	1	0.0t	-1	0.0t
3	0	2	-2	2	8.7	1	0.0t	0	0.0t
-2	0	2	2	2	14.6	1	0.0t	-1	0.0t
-1	0	0	0	2	27.3	1	0.0t	-1	0.0t
0	0	-2	2	1	169.0	1	0.0t	0	0.0t
0	1	2	0	1	13.1	1	0.0t	0	0.0t
-1	0	4	0	2	9.1	1	0.0t	0	0.0t
2	1	0	-2	0	131.7	1	0.0t	0	0.0t
2	0	0	2	0	7.1	1	0.0t	0	0.0t
2	0	2	-2	1	12.8	1	0.0t	-1	0.0t
2	0	-2	0	1	943.2	1	0.0t	0	0.0t
1	-1	0	-2	0	29.3	1	0.0t	0	0.0t
-1	0	0	1	1	388.3	1	0.0t	0	0.0t
-1	-1	0	2	1	35.0	1	0.0t	0	0.0t

Table 5.1 (continued)

ARGUMENT					PERIOD	LONGITUDE (0".0001)		OBLIQUITY (0".0001)	
l	l'	F	D	Ω	(days)	A_i	A_i'	B_i	B_i'
0	1	0	1	0	27.3	1	0.0t	0	0.0t

$\epsilon_0 = 23° \ 26' \ 21''.448$

$\sin \epsilon_0 = 0.39777716$

Coordinate Transformation Referred to the Nonrotating Origin

Option (2) uses form (2) of the coordinate transformation from the TRS to the CRS

$$[CRS] = PN''(t) \cdot R''(t) \cdot W''(t) \ [TRS], \tag{2}$$

where the three fundamental components of (2) are given below (Capitaine, 1990)

$$W''(t) = R_3(-s') \cdot R_1(y_p) \cdot R_2(x_p),$$

x_p and y_p being the "polar coordinates" of the CEP in the TRS and s' the accumulated displacement of the terrestrial NRO on the true equator due to polar motion. The use of the quantity s' (which is neglected in the classical form (1)) provides an exact realization of the "instantaneous prime meridian".

$$R''(t) = R_3(-\theta),$$

θ being the stellar angle at date t due to the Earth's angle of rotation,

$$PN''(t) = R_3(-E) \cdot R_2(-d) \cdot R_3(E) \cdot R_3(S),$$

E and d being such that the coordinates of the CEP in the CRS are $X = \sin d \cos E$, $Y = \sin d \sin E$, $Z = \cos d$ and S being the accumulated rotation (between the epoch and the date t) of the celestial NRO on the true equator due to the celestial motion of the CEP. PN"(t) can be given in an equivalent form involving directly X and Y (to which all the observations of a celestial object from the Earth are actually sensitive) as:

$$PN''(t) = Q_1 = \begin{bmatrix} 1-aX^2 & -aXY & X \\ -aXY & 1-aY^2 & Y \\ -X & -Y & 1-a(X^2+Y^2) \end{bmatrix} \cdot R_3(s),$$

with $a = 1/(1+\cos d)$, which can also be written, with sufficient accuracy as $a = 1/2 + 1/8 \ (X^2+Y^2)$.

The standard values of the parameters to be used in the form (2) of the transformation are detailed below.

The standard pole coordinates to be used for the parameters x_p and y_p (if not estimated from the observations) are those published by the IERS. The quantity s′ (of the order of 0.1 mas/c) is:

$$s' = 0.0015(a_c^2/1.2 + a_a^2)\ t,$$

a_c and a_a being the average amplitudes (in arc seconds) of the Chandlerian and annual wobbles, respectively in the period considered (Capitaine, *et al.*, 1986).

The stellar angle is obtained by the use of the conventional relationship between the stellar angle θ, the hour angle of the nonrotating origin of Guinot (1979) and UT1 as given by Capitaine, *et al.*, (1986),

$$\theta(T_u) = 2\pi\ (0.779\ 057\ 273\ 264 + 1.002\ 737\ 811\ 911\ 354\ 48\ T_u \times 365\ 25),$$

where T_u = (Julian UT1 date - 2 451 545.0)/36 525, and

UT1 = UTC + (UT1-UTC), or equivalently

$$\theta(T_u) = 2\pi\ (\text{UT1 Julian day number elapsed since } 2451545.0 + 0.779\ 057\ 273\ 264 + 0.002\ 737\ 811\ 911\ 354\ 48\ T_u \times 36\ 525),$$

the quantity UT1-UTC to be used (if not estimated from the observations) being the IERS value.

The celestial coordinates X and Y of the CEP to be used are the standard values as derived from the series are in Table 5.2 (with the same fundamental arguments and similar coefficients as in Table 5.1). These developments of the celestial polar coordinates have been derived (Capitaine, 1990) from the previous standard expressions for precession and nutation with a consistency of 5×10^{-5}" after a century; such consistency has been numerically checked over two centuries (Gontier, 1990). For observations requiring values of the nutation angles with a milliarcsecond accuracy, it is necessary to add (if those quantities are not estimated from the observations) the IERS published values (observed or predicted) for the "celestial pole offsets" (*i.e.* corrections $dX = d\psi \sin\epsilon_0$ and $dY = d\epsilon$).

The standard value of s to be used can be derived with an accuracy of 5×10^{-5}" after a century (Capitaine, 1990) from the following numerical development and the numerical values of X and Y (Table 5.2),

$$s = -XY/2 + 0''\!.003\,85\ t - 0''\!.072\,59\ t^3 - 0''\!.002\,65 \sin \Omega$$
$$- 0.000\,06 \sin 2\Omega + 0''\!.000\,74\ t^2 \sin \Omega + 0''\!.000\,06\ t^2 \sin 2(F-D+\Omega)$$

Table 5.2 Series for the celestial coordinates X and Y of the CEP referred to the mean equator and equinox of epoch J2000.0, with t measured in Julian centuries from epoch J2000.0. The terms between the two lines are identical in Tables 5.1 and 5.2

$$X = 2004''\!.310\,9\ t - 0''\!.426\,65\ t^2 - 0''\!.198\,656\ t^3 + 0''\!.000\,014\,0\ t^4$$
$$+ 0''\!.000\,06\ t^2 \cos \Omega$$
$$+ \sin\epsilon_0 \{\Sigma_{i=1,106} [(A_i + A'_i t) \sin (\text{ARGUMENT}) + A''_i t \cos (\text{ARGUMENT})]\}$$
$$+ 0''\!.002\,04\ t^2 \sin \Omega + 0''\!.000\,16\ t^2 \sin 2(F - D + \Omega),$$

$$Y = - 0''\!.000\,13 - 22''\!.409\,92\ t^2 + 0''\!.001\,836\ t^3 + 0''\!.001\,113\,0\ t^4$$
$$+ \Sigma_{i=1,106} [(B_i + B'_i t) \cos (\text{ARGUMENT}) + B''_i t \sin (\text{ARGUMENT})]$$
$$- 0''\!.002\,31\ t^2 \cos \Omega - 0''\!.000\,14\ t^2 \cos 2(F - D + \Omega)$$

ARGUMENT					PERIOD	LONGITUDE (0.0001")			OBLIQUITY (0.0001")		
l	l'	F	D	Ω	(days)	A_i	$A'_i t$	$A''_i t$	B_i	$B'_i t$	$B''_i t$
0	0	0	0	1	6798.4	-171996	-84.2t	5173.2t	92025	8.9t	1529.9t
0	0	2	-2	2	182.6	-13187	5.3t	322.2t	5736	-3.1t	117.3t
0	0	2	0	2	13.7	-2274	1.0t	54.8t	977	-0.5t	20.2t
0	0	0	0	2	3399.2	2053.2	-1.0t	-50.5t	-893.7	0.5t	-18.3t
0	1	0	0	0	365.3	1426	-4.3t	3.0t	54	-0.1t	-12.7t
1	0	0	0	0	27.6	712	0.1t	0.0t	-7	0.0t	-6.3t
0	1	2	-2	2	121.7	-517	1.5t	12.6t	224	-0.6t	4.6t
0	0	2	0	1	13.6	-386	-0.4t	11.3t	200	0.0t	3.4t
1	0	2	0	2	9.1	-301	0.0t	7.3t	129	-0.1t	2.7t
0	-1	2	-2	2	365.2	217	-0.5t	-5.3t	-95	0.3t	-1.9t
1	0	0	-2	0	31.8	-158	0.0t	0.0t	-1	0.0t	1.4t
0	0	2	-2	1	177.8	129	0.1t	-4.0t	-70	0.0t	-1.2t
-1	0	2	0	2	27.1	123	0.0t	-3.0t	-53	0.0t	-1.1t
1	0	0	0	1	27.7	63	0.1t	-1.8t	-33	0.0t	-0.6t
0	0	0	2	0	14.8	63	0.0t	0.0t	-2	0.0t	-0.6t
-1	0	2	2	2	9.6	-59	0.0t	1.5t	26	0.0t	0.5t
-1	0	0	0	1	27.4	-58	-0.1t	1.8t	32	0.0t	0.5t
1	0	2	0	1	9.1	-51	0.0t	1.5t	27	0.0t	0.5t
2	0	0	-2	0	205.9	48	0.0t	0.0t	1	0.0t	0.0t
-2	0	2	0	1	1305.5	46	0.0t	-1.3t	-24	0.0t	0.0t
- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
0	0	2	2	2	7.1	-38	0.0t		16	0.0t	
2	0	2	0	2	6.9	-31	0.0t		13	0.0t	
2	0	0	0	0	13.8	29	0.0t		-1	0.0t	
1	0	2	-2	2	23.9	29	0.0t		-12	0.0t	
0	0	2	0	0	13.6	26	0.0t		-1	0.0t	
0	0	2	-2	0	173.3	-22	0.0t		0	0.0t	
-1	0	2	0	1	27.0	21	0.0t		-10	0.0t	
0	2	0	0	0	182.6	17	-0.1t		0	0.0t	
0	2	2	-2	2	91.3	-16	0.1t		7	0.0t	
1	0	0	2	1	32.0	16	0.0t		-8	0.0t	
0	1	0	0	1	386.0	-15	0.0t		9	0.0t	
1	0	0	-2	1	31.7	-13	0.0t		7	0.0t	
0	-1	0	0	1	346.6	-12	0.0t		6	0.0t	
2	0	-2	0	0	1095.2	11	0.0t		0	0.0t	
-1	0	2	2	1	9.5	-10	0.0t		5	0.0t	

1	0	2	2	2	5.6	-8	0.0t	3	0.0t
0	-1	2	0	2	14.2	-7	0.0t	3	0.0t
0	0	2	2	1	7.1	-7	0.0t	3	0.0t
1	1	0	-2	0	34.8	-7	0.0t	0	0.0t
0	1	2	0	2	13.2	7	0.0t	-3	0.0t
-2	0	0	2	1	199.8	-6	0.0t	3	0.0t
0	0	0	2	1	14.8	-6	0.0t	3	0.0t
2	0	2	-2	2	12.8	6	0.0t	-3	0.0t
1	0	0	2	0	9.6	6	0.0t	0	0.0t
1	0	2	-2	1	23.9	6	0.0t	-3	0.0t
0	0	0	-2	1	14.7	-5	0.0t	3	0.0t
0	-1	2	-2	1	346.6	-5	0.0t	3	0.0t
2	0	2	0	1	6.9	-5	0.0t	3	0.0t
1	-1	0	0	0	29.8	5	0.0t	0	0.0t
1	0	0	-1	0	411.8	-4	0.0t	0	0.0t
0	0	0	1	0	29.5	-4	0.0t	0	0.0t
0	1	0	-2	0	15.4	-4	0.0t	0	0.0t
1	0	-2	0	0	26.9	4	0.0t	0	0.0t
2	0	0	-2	1	212.3	4	0.0t	-2	0.0t
0	1	2	-2	1	119.6	4	0.0t	-2	0.0t
1	1	0	0	0	25.6	-3	0.0t	0	0.0t
1	-1	0	-1	0	3232.9	-3	0.0t	0	0.0t
-1	-1	2	2	2	9.8	-3	0.0t	1	0.0t
0	-1	2	2	2	7.2	-3	0.0t	1	0.0t
1	-1	2	0	2	9.4	-3	0.0t	1	0.0t
3	0	2	0	2	5.5	-3	0.0t	1	0.0t
-2	0	2	0	2	1615.7	-3	0.0t	1	0.0t
1	0	2	0	0	9.1	3	0.0t	0	0.0t
-1	0	2	4	2	5.8	-2	0.0t	1	0.0t
1	0	0	0	2	27.8	-2	0.0t	1	0.0t
-1	0	2	-2	1	32.6	-2	0.0t	1	0.0t
0	-2	2	-2	1	6786.3	-2	0.0t	1	0.0t
-2	0	0	0	1	13.7	-2	0.0t	1	0.0t
2	0	0	0	1	13.8	2	0.0t	-1	0.0t
3	0	0	0	0	9.2	2	0.0t	0	0.0t
1	1	2	0	2	8.9	2	0.0t	-1	0.0t
0	0	2	1	2	9.3	2	0.0t	-1	0.0t
1	0	0	2	1	9.6	-1	0.0t	0	0.0t
1	0	2	2	1	5.6	-1	0.0t	1	0.0t
1	1	0	-2	1	34.7	-1	0.0t	0	0.0t
0	1	0	2	0	14.2	-1	0.0t	0	0.0t
0	1	2	-2	0	117.5	-1	0.0t	0	0.0t
0	1	-2	2	0	329.8	-1	0.0t	0	0.0t
1	0	-2	2	0	32.8	-1	0.0t	0	0.0t
1	0	-2	-2	0	9.5	-1	0.0t	0	0.0t
1	0	2	-2	0	32.8	-1	0.0t	0	0.0t
1	0	0	-4	0	10.1	-1	0.0t	0	0.0t
2	0	0	-4	0	15.9	-1	0.0t	0	0.0t
0	0	2	4	2	4.8	-1	0.0t	0	0.0t
0	0	2	-1	2	25.4	-1	0.0t	0	0.0t
-2	0	2	4	2	7.3	-1	0.0t	1	0.0t
2	0	2	2	2	4.7	-1	0.0t	0	0.0t
0	-1	2	0	1	14.2	-1	0.0t	0	0.0t
0	0	-2	0	1	13.6	-1	0.0t	0	0.0t
0	0	4	-2	2	12.7	1	0.0t	0	0.0t
0	1	0	0	2	409.2	1	0.0t	0	0.0t
1	1	2	-2	2	22.5	1	0.0t	-1	0.0t
3	0	2	-2	2	8.7	1	0.0t	0	0.0t
-2	0	2	2	2	14.6	1	0.0t	-1	0.0t
-1	0	0	0	2	27.3	1	0.0t	-1	0.0t
0	0	-2	2	1	169.0	1	0.0t	0	0.0t
0	1	2	0	1	13.1	1	0.0t	0	0.0t

Table 5.2 (continued)

ARGUMENT					PERIOD	LONGITUDE (0.0001")			OBLIQUITY (0.0001")		
l	l′	F	D	Ω	(days)	A_i	$A'_i t$	$A''_i t$	B_i	$B'_i t$	$B''_i t$
-1	0	4	0	2	9.1	1	0.0t		0	0.0t	
2	1	0	-2	0	131.7	1	0.0t		0	0.0t	
2	0	0	2	0	7.1	1	0.0t		0	0.0t	
2	0	2	-2	1	12.8	1	0.0t		-1	0.0t	
2	0	-2	0	1	943.2	1	0.0t		0	0.0t	
1	-1	0	-2	0	29.3	1	0.0t		0	0.0t	
-1	0	0	1	1	388.3	1	0.0t		0	0.0t	
-1	-1	0	2	1	35.0	1	0.0t		0	0.0t	
0	1	0	1	0	27.3	1	0.0t		0	0.0t	
0	0	2	-2	3	177.8	-1.2	0.0t		0	0.0t	

Geodesic Nutation

Fukushima (1990) has pointed out that, if extreme precision is required, the effect of geodesic nutation must be taken into account. For Option (1) this would require a correction in longitude of

$$\Delta\psi_g = -0''.000\,153 \sin l' - 0''.000\,002 \sin 2l',$$

where l′ is the mean anomaly of the Sun. For Option (2) it would require a correction to X of

$$\Delta X_g = (-0''.000\,060\,9 \sin l' - 0''.000\,000\,8 \sin 2l') \sin \epsilon_0.$$

In both cases the correction would be added to the uncorrected determination of ψ or X.

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CHAPTER 6 GEOPOTENTIAL

The recommended geopotential field is the GEM-T3 model given in the following table.

The $GM_\oplus$ and a_e values reported with GEM-T3 (398600.436 km^3/s^2 and 6378137 m) should be used as scale parameters with the geopotential coefficients. The recommended $GM_\oplus$ = 398600.4418 should be used with the two-body term. Although the GEM-T3 is given with terms through degree and order 50, only terms through degree and order twenty are required for Lageos.

Values for the C_{21} and S_{21} coefficients are not included in the GEM-T3 model (they were constrained to be zero in the solution), and so they should be handled separately.

The C_{21} and S_{21} coefficients describe the position of the Earth's figure axis. When averaged over many years, the figure axis should closely coincide with the observed position of the rotation pole averaged over the same time period. Any differences between the mean figure and mean rotation pole averaged would be due to long-period fluid motions in the atmosphere, oceans, or Earth's fluid core (Wahr, 1987, 1990). At present, there is no independent evidence that such motions are important. So, it is recommended that the mean values used for C_{21} and S_{21} give a mean figure axis that corresponds to the mean pole position of the Chapter 3 Terrestrial Reference Frame.

The BIH Circular D pole positions from 1982 through 1988 are consistent with the IERS Reference Pole to within ± 0".005 corresponding to an uncertainty of ± 0.01 × 10^{-9} in $\bar{C}_{21}$(IERS) and $\bar{S}_{21}$ (IERS).

This choice for C_{21} and S_{21} is realized as follows. First, to use the geopotential coefficients to solve for a satellite orbit, it is necessary to rotate from the Earth-fixed frame, where the coefficients are pertinent, to an inertial frame, where the satellite motion is computed. This transformation between frames should include polar motion. We assume the polar motion parameters used are relative to the IERS Reference Pole. Then, if $C_{21} = S_{21} = 0$ were used, the assumed mean figure axis would coincide with the IERS Reference Pole.

If $\bar{x}$ and $\bar{y}$ are the angular displacements of the Terrestrial Reference Frame described in Chapter 3 relative to the IERS Reference Pole then the values

$$\bar{C}_{21} = \sqrt{3}\ \bar{x}\bar{C}_{20},$$

$$\bar{S}_{21} = -\sqrt{3}\ \bar{y}\bar{C}_{20},$$

where $\bar{x} = 2.0362 \times 10^{-7}$ (equivalent to 0".042 in radians) and $\bar{y} = 1.421 \times 10^{-6}$ (equivalent to 0".293 in radians) (Lambeck, 1970) should be added to the geopotential model, so that the mean figure axis coincides with the pole described in Chapter 3. This gives normalized coefficients of

$$\bar{C}_{21}(\text{IERS}) = -0.17 \times 10^{-9},$$

$$\bar{S}_{21}(\text{IERS}) = 1.19 \times 10^{-9}.$$

For consistency with the IERS Terrestrial Reference Frame, the $\bar{C}_{21}$(IERS) and $\bar{S}_{21}$(IERS) are recommended for use in place of $\bar{C}_{21}$(GEM-T3) and $\bar{S}_{21}$(GEM-T3).

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GEM-T3 NORMALIZED COEFFICIENTS

$(\times 10^{6})$

ZONALS

INDEX n m	VALUE	INDEX n m	VALUE	INDEX n m	VALUE	INDEX n m	VALUE	INDEX n m	VALUE
*2 0	-484.1650994	3 0	0.9572011	4 0	0.5395212	5 0	0.0683433	6 0	-0.1495135
7 0	0.0913009	8 0	0.0488832	9 0	0.0268624	10 0	0.0540650	11 0	-0.0494638
12 0	0.0356285	13 0	0.0401122	14 0	-0.0215549	15 0	0.0032275	16 0	-0.0061891
17 0	0.0174266	18 0	0.0085246	19 0	-0.0021551	20 0	0.0199238	21 0	0.0060954
22 0	-0.0095105	23 0	-0.0216426	24 0	-0.0002292	25 0	0.0051981	26 0	0.0057590
27 0	0.0037752	28 0	-0.0099775	29 0	-0.0025026	30 0	0.0067263	31 0	0.0059286
32 0	-0.0040391	33 0	-0.0011500	34 0	-0.0045042	35 0	0.0068919	36 0	-0.0037241
37 0	-0.0066619	38 0	0.0006767	39 0	0.0004215	40 0	-0.0017227	41 0	-0.0023976
42 0	0.0018083	43 0	0.0045338	44 0	0.0024867	45 0	-0.0028338	46 0	-0.0015925
47 0	0.0000205	48 0	0.0031619	49 0	-0.0011610	50 0	-0.0032544		

SECTORIALS AND TESSERALS

Index n	m	Value C	S	Index n	m	Value C	S	Index n	m	Value C	S
2	2	2.4390658	-1.4000946								
3	1	2.0277142	0.2492171	3	2	0.9044707	-0.6194477	3	3	0.7203425	1.4138845
4	1	-0.5361511	-0.4734360	4	2	0.3502181	0.6630152	4	3	0.9909337	-0.2009274
4	4	-0.1887706	0.3094237								
5	1	-0.0582802	-0.0960839	5	2	0.6527110	-0.3238637	5	3	-0.4523301	-0.2152958
5	4	-0.2955841	0.0496903	5	5	0.1737635	-0.6689070				
6	1	-0.0768942	0.0269984	6	2	0.0487345	-0.3740131	6	3	0.0572032	0.0093728
6	4	-0.0868265	-0.4713064	6	5	-0.2673304	-0.5367802	6	6	0.0096846	-0.2371348
7	1	0.2748687	0.0974659	7	2	0.3277950	0.0932467	7	3	0.2512201	-0.2152927
7	4	-0.2755610	-0.1237672	7	5	0.0013262	0.0186200	7	6	-0.3588314	0.1517387
7	7	0.0009703	0.0240836								
8	1	0.0236282	0.0588472	8	2	0.0775985	0.0660087	8	3	-0.0177852	-0.0863470
8	4	-0.2463398	0.0701796	8	5	-0.0250411	0.0894628	8	6	-0.0649237	0.3091226
8	7	0.0674622	0.0750948	8	8	-0.1241984	0.1201722				
9	1	0.1460968	0.0199707	9	2	0.0224514	-0.0335532	9	3	-0.1612938	-0.0759683
9	4	-0.0101377	0.0189722	9	5	-0.0171468	-0.0537733	9	6	0.0639143	0.2226482
9	7	-0.1190107	-0.0969910	9	8	0.1871323	-0.0023539	9	9	-0.0481324	0.0987392
10	1	0.0814935	-0.1302777	10	2	-0.0912766	-0.0511029	10	3	-0.0086059	-0.1550282
10	4	-0.0853424	-0.0787340	10	5	-0.0510215	-0.0511065	10	6	-0.0370547	-0.0783798
10	7	0.0075611	-0.0033501	10	8	0.0400547	-0.0916800	10	9	0.1243124	-0.0380328
10	10	0.0997532	-0.0224543								
11	1	0.0151438	-0.0266145	11	2	0.0167542	-0.0984958	11	3	-0.0284259	-0.1462895
11	4	-0.0406835	-0.0644826	11	5	0.0376146	0.0503126	11	6	-0.0003918	0.0349216
11	7	0.0038817	-0.0895537	11	8	-0.0069703	0.0253251	11	9	-0.0322248	0.0432902
11	10	-0.0520650	-0.0173310	11	11	0.0453181	-0.0690741				
12	1	-0.0545002	-0.0420954	12	2	0.0123808	0.0319206	12	3	0.0421598	0.0246728
12	4	-0.0695574	0.0028552	12	5	0.0319159	0.0096522	12	6	0.0041892	0.0401345
12	7	-0.0183894	0.0358166	12	8	-0.0255168	0.0161921	12	9	0.0409053	0.0243333
12	10	-0.0064899	0.0317633	12	11	0.0105182	-0.0068164	12	12	-0.0033602	-0.0108797

* $\bar{C}_{20}$ does not include the zero frequency term; see Chapter 7 (Eq. 5) for the adjusted value.

** $\bar{C}_{21}$ and $\bar{S}_{21}$ should be the IERS values; see this chapter for recommended values.

Index n	m	Value C	S	Index n	m	Value C	S	Index n	m	Value C	S
13	1	-0.0559665	0.0395293	13	2	0.0543242	-0.0634283	13	3	-0.0211569	0.0963808
13	4	-0.0038557	-0.0133028	13	5	0.0607207	0.0646537	13	6	-0.0341536	-0.0042568
13	7	0.0035556	-0.0058836	13	8	-0.0116966	-0.0088473	13	9	0.0241467	0.0460357
13	10	0.0414659	-0.0361843	13	11	-0.0445391	-0.0043063	13	12	-0.0312803	0.0877964
13	13	-0.0614129	0.0678124								
14	1	-0.0206693	0.0304582	14	2	-0.0371952	-0.0033551	14	3	0.0329887	0.0210216
14	4	-0.0007851	-0.0192933	14	5	0.0259548	-0.0162511	14	6	-0.0188109	0.0054356
14	7	0.0376788	-0.0063813	14	8	-0.0348919	-0.0149848	14	9	0.0322984	0.0276200
14	10	0.0385106	-0.0010119	14	11	0.0147653	-0.0394554	14	12	0.0083128	-0.0313314
14	13	0.0319584	0.0452989	14	14	-0.0517851	-0.0050039				
15	1	0.0130794	0.0070987	15	2	-0.0235054	-0.0333181	15	3	0.0542768	0.0150957
15	4	-0.0434805	0.0070734	15	5	0.0113901	0.0088505	15	6	0.0342069	-0.0358331
15	7	0.0568236	0.0061453	15	8	-0.0327261	0.0235054	15	9	0.0117403	0.0374328
15	10	0.0114793	0.0155961	15	11	-0.0008754	0.0191309	15	12	-0.0324556	0.0147756
15	13	-0.0287572	-0.0042554	15	14	0.0054459	-0.0243198	15	15	-0.0195731	-0.0051538
16	1	0.0237694	0.0340855	16	2	-0.0212918	0.0268320	16	3	-0.0341109	-0.0271230
16	4	0.0391220	0.0454734	16	5	-0.0141227	0.0000332	16	6	0.0169119	-0.0328518
16	7	-0.0069833	-0.0070595	16	8	-0.0206218	0.0056652	16	9	-0.0240037	-0.0383121
16	10	-0.0109552	0.0128282	16	11	0.0184275	-0.0029384	16	12	0.0198974	0.0061632
16	13	0.0137124	0.0012041	16	14	-0.0196596	-0.0386771	16	15	-0.0134780	-0.0333624
16	16	-0.0361270	0.0037964								
17	1	-0.0273808	-0.0318449	17	2	-0.0191519	0.0077318	17	3	0.0127131	0.0085514
17	4	0.0068147	0.0210642	17	5	-0.0125322	0.0050564	17	6	-0.0109756	-0.0274779
17	7	0.0247642	-0.0035158	17	8	0.0378171	0.0039291	17	9	0.0022023	-0.0283061
17	10	-0.0025898	0.0186970	17	11	-0.0157889	0.0118557	17	12	0.0291379	0.0193775
17	13	0.0164865	0.0207531	17	14	-0.0140956	0.0116438	17	15	0.0053064	0.0053556
17	16	-0.0294099	0.0032961	17	17	-0.0329779	-0.0190370				
18	1	0.0012802	-0.0362621	18	2	0.0131239	0.0129394	18	3	-0.0033638	-0.0014744
18	4	0.0521647	0.0020212	18	5	0.0019873	0.0291036	18	6	0.0156997	-0.0115996
18	7	0.0058839	0.0033474	18	8	0.0301291	0.0024813	18	9	-0.0178758	0.0344506
18	10	0.0047002	-0.0051744	18	11	-0.0078403	0.0021961	18	12	-0.0287346	-0.0169012
18	13	-0.0061816	-0.0346579	18	14	-0.0088533	-0.0128693	18	15	-0.0393857	-0.0208743
18	16	0.0113318	0.0071843	18	17	0.0036682	0.0050833	18	18	0.0027594	-0.0105434
19	1	-0.0096289	-0.0029679	19	2	0.0275281	-0.0023289	19	3	-0.0033835	-0.0009951
19	4	0.0121511	-0.0042207	19	5	0.0154597	0.0273694	19	6	-0.0038121	0.0201077
19	7	0.0050712	-0.0063049	19	8	0.0294184	-0.0093126	19	9	0.0022164	0.0025673
19	10	-0.0337049	-0.0069966	19	11	0.0157465	0.0102937	19	12	-0.0021222	0.0081173
19	13	-0.0070964	-0.0280235	19	14	-0.0048124	-0.0129043	19	15	-0.0175393	-0.0137024
19	16	-0.0210506	-0.0075292	19	17	0.0306525	-0.0137472	19	18	0.0330342	-0.0087291
19	19	-0.0023480	0.0042819								
20	1	0.0052111	0.0058030	20	2	0.0174860	0.0137476	20	3	-0.0081594	0.0303065
20	4	0.0014180	-0.0229616	20	5	-0.0134176	-0.0035994	20	6	0.0113814	0.0008935
20	7	-0.0194055	-0.0015386	20	8	0.0049122	0.0034216	20	9	0.0190121	-0.0048859
20	10	-0.0301615	-0.0054108	20	11	0.0131223	-0.0184290	20	12	-0.0059513	0.0173580
20	13	0.0277741	0.0067269	20	14	0.0108561	-0.0139252	20	15	-0.0246481	-0.0014079
20	16	-0.0106927	-0.0002663	20	17	0.0044349	-0.0125965	20	18	0.0152411	-0.0005928
20	19	-0.0047068	0.0106734	20	20	0.0040221	-0.0112091				
21	1	-0.0171788	0.0205518	21	2	-0.0061390	0.0047932	21	3	0.0263792	0.0187134
21	4	-0.0094317	0.0139320	21	5	0.0043733	-0.0009704	21	6	-0.0116607	0.0018168
21	7	-0.0118226	0.0035729	21	8	-0.0152436	0.0040667	21	9	0.0150203	0.0068850
21	10	-0.0096824	-0.0005874	21	11	0.0084047	-0.0351392	21	12	-0.0019522	0.0140674
21	13	-0.0185066	0.0136367	21	14	0.0203698	0.0079163	21	15	0.0178471	0.0109014
21	16	0.0084445	-0.0073172	21	17	-0.0056776	-0.0059467	21	18	0.0243699	-0.0094126
21	19	-0.0277508	0.0153133	21	20	-0.0263062	0.0158605	21	21	0.0075180	-0.0022236
22	1	0.0096642	-0.0009644	22	2	-0.0196408	-0.0020826	22	3	0.0092976	0.0082274
22	4	-0.0038186	0.0143386	22	5	-0.0082423	0.0035020	22	6	0.0138314	-0.0052023
22	7	0.0146058	0.0018228	22	8	-0.0234988	0.0021983	22	9	0.0102897	0.0083148
22	10	0.0051671	0.0241261	22	11	-0.0034556	-0.0164381	22	12	0.0038281	-0.0087932
22	13	-0.0169513	0.0197295	22	14	0.0101780	0.0077608	22	15	0.0263472	0.0042003
22	16	0.0012215	-0.0071400	22	17	0.0089480	-0.0134798	22	18	0.0087670	-0.0149852
22	19	0.0125137	-0.0037544	22	20	-0.0166678	0.0189291	22	21	-0.0246156	0.0223187
22	22	-0.0089299	0.0024228								

Index n	Index m	Value C	Value S	Index n	Index m	Value C	Value S	Index n	Index m	Value C	Value S
23	1	0.0063465	0.0130062	23	2	-0.0130827	-0.0040371	23	3	-0.0121940	-0.0173193
23	4	-0.0191162	0.0064667	23	5	0.0080082	-0.0023536	23	6	-0.0128872	0.0167174
23	7	-0.0061313	0.0028610	23	8	0.0055469	-0.0015897	23	9	-0.0005856	-0.0184242
23	10	0.0145345	-0.0031764	23	11	0.0080666	0.0153789	23	12	0.0170577	-0.0133824
23	13	-0.0111264	-0.0044652	23	14	0.0068014	-0.0020947	23	15	0.0184178	-0.0031340
23	16	0.0068979	0.0111168	23	17	-0.0040494	-0.0116880	23	18	0.0074796	-0.0120752
23	19	-0.0071169	0.0090105	23	20	0.0098040	-0.0068659	23	21	0.0157680	0.0132542
23	22	-0.0170923	0.0036873	23	23	0.0045640	-0.0108964				
24	1	-0.0050423	-0.0033127	24	2	-0.0021465	0.0134247	24	3	-0.0033462	-0.0082340
24	4	0.0071525	0.0037349	24	5	-0.0060088	-0.0126654	24	6	0.0042666	0.0009019
24	7	-0.0024921	0.0028966	24	8	0.0156587	-0.0048357	24	9	-0.0074084	-0.0162834
24	10	0.0113588	0.0172884	24	11	0.0118893	0.0185777	24	12	0.0116255	-0.0055536
24	13	-0.0025191	0.0027378	24	14	-0.0201557	-0.0006099	24	15	0.0066161	-0.0161023
24	16	0.0094515	0.0037852	24	17	-0.0119890	-0.0046886	24	18	-0.0007572	-0.0095976
24	19	-0.0049208	-0.0086425	24	20	-0.0049044	0.0076167	24	21	0.0081466	0.0126573
24	22	0.0033959	-0.0019883	24	23	-0.0071693	-0.0091901	24	24	0.0111403	-0.0032617
25	1	0.0065866	-0.0105297	25	2	0.0164017	0.0104728	25	3	-0.0068317	-0.0146739
25	4	0.0051081	0.0041833	25	5	-0.0037811	-0.0036623	25	6	0.0146476	0.0039237
25	7	0.0069129	-0.0074194	25	8	0.0051782	0.0016270	25	9	-0.0297856	0.0136280
25	10	0.0075753	-0.0047882	25	11	0.0044306	0.0079569	25	12	-0.0082098	0.0122275
25	13	0.0080624	-0.0116876	25	14	-0.0206731	0.0078295	25	15	-0.0036319	-0.0072531
25	16	0.0015538	-0.0128630	25	17	-0.0131607	-0.0014118	25	18	0.0006051	-0.0129151
25	19	0.0065226	0.0084412	25	20	-0.0062665	-0.0021786	25	21	0.0120874	0.0078646
25	22	-0.0127725	0.0041807	25	23	0.0084211	-0.0108240	25	24	0.0048718	-0.0077411
25	25	0.0089668	0.0052191								
26	1	-0.0026664	-0.0082430	26	2	-0.0015746	0.0092185	26	3	0.0090689	-0.0031308
26	4	0.0147221	-0.0165285	26	5	0.0038380	0.0106647	26	6	0.0114084	-0.0064852
26	7	-0.0002373	0.0011771	26	8	0.0035161	0.0014723	26	9	-0.0072798	0.0016990
26	10	-0.0130950	-0.0042049	26	11	-0.0017838	0.0018849	26	12	-0.0167307	0.0017457
26	13	0.0001750	0.0021769	26	14	0.0073958	0.0065215	26	15	-0.0136750	0.0076166
26	16	0.0025097	-0.0075036	26	17	-0.0108818	0.0080828	26	18	-0.0131056	0.0059036
26	19	-0.0011322	0.0029262	26	20	0.0066384	-0.0129144	26	21	-0.0065967	0.0016121
26	22	0.0121192	0.0084746	26	23	-0.0002176	0.0118854	26	24	0.0067431	0.0131699
26	25	0.0036502	0.0014493	26	26	-0.0008396	0.0053570				
27	1	0.0039251	-0.0001427	27	2	0.0036962	0.0031720	27	3	0.0056586	0.0021285
27	4	0.0005868	0.0092714	27	5	0.0157567	0.0079196	27	6	0.0000031	0.0062788
27	7	-0.0128755	-0.0023621	27	8	-0.0052481	-0.0098613	27	9	0.0001650	0.0076483
27	10	-0.0128522	0.0007021	27	11	0.0027283	-0.0076154	27	12	-0.0086416	0.0004264
27	13	-0.0045566	-0.0025631	27	14	0.0161760	0.0106701	27	15	-0.0023151	0.0010878
27	16	0.0043339	0.0016663	27	17	0.0045031	0.0009341	27	18	-0.0026533	0.0109539
27	19	-0.0008081	-0.0041454	27	20	0.0006343	0.0023214	27	21	0.0059841	-0.0055616
27	22	-0.0054096	0.0034241	27	23	-0.0050968	-0.0080894	27	24	0.0000222	-0.0006148
27	25	0.0107286	0.0039942	27	26	-0.0058367	-0.0029276	27	27	0.0068460	0.0021541
28	1	-0.0073065	0.0062148	28	2	-0.0119628	-0.0116064	28	3	0.0024984	0.0090420
28	4	0.0042378	0.0033269	28	5	0.0055800	0.0003283	28	6	-0.0023067	0.0049177
28	7	-0.0008591	0.0052729	28	8	-0.0020045	-0.0053160	28	9	0.0082431	-0.0064753
28	10	-0.0075322	0.0079033	28	11	-0.0041603	0.0023566	28	12	0.0014296	0.0109002
28	13	0.0016576	0.0055353	28	14	-0.0062353	-0.0109321	28	15	-0.0108597	-0.0009772
28	16	-0.0031454	-0.0119188	28	17	0.0135711	-0.0034580	28	18	0.0038205	-0.0029946
28	19	0.0041720	0.0224177	28	20	-0.0018593	0.0046445	28	21	0.0077244	0.0053421
28	22	-0.0010523	-0.0058838	28	23	0.0045909	0.0029153	28	24	0.0096282	-0.0137817
28	25	0.0056097	-0.0172084	28	26	0.0086338	0.0029512	28	27	-0.0073755	0.0011044
28	28	0.0072606	0.0054995								
29	1	0.0019969	-0.0031928	29	2	-0.0025286	-0.0006536	29	3	0.0015286	-0.0082880
29	4	-0.0219913	-0.0001364	29	5	-0.0031615	0.0018419	29	6	0.0099066	0.0068548
29	7	-0.0044996	-0.0046636	29	8	-0.0121845	0.0074113	29	9	-0.0050682	-0.0038189
29	10	0.0084163	0.0018969	29	11	-0.0057378	0.0070722	29	12	-0.0026580	-0.0017172
29	13	-0.0007273	-0.0017458	29	14	-0.0061507	-0.0043946	29	15	-0.0077083	-0.0062682
29	16	-0.0001679	-0.0131772	29	17	0.0004103	-0.0028975	29	18	-0.0048796	-0.0036690
29	19	-0.0062727	0.0057826	29	20	-0.0060496	0.0030399	29	21	-0.0077158	-0.0040463
29	22	0.0124541	0.0007009	29	23	-0.0022660	0.0016815	29	24	0.0001001	-0.0009304
29	25	0.0056260	0.0063145	29	26	0.0090138	-0.0086781	29	27	-0.0067189	-0.0012353
29	28	0.0079715	-0.0053912	29	29	0.0104845	-0.0080465				

Index		Value		Index		Value		Index		Value	
n	m	C	S	n	m	C	S	n	m	C	S
30	1	-0.0017521	0.0017543	30	2	-0.0092718	-0.0030842	30	3	0.0038608	-0.0094093
30	4	-0.0008453	-0.0030521	30	5	-0.0019984	-0.0033849	30	6	0.0000790	0.0014467
30	7	0.0070755	0.0014215	30	8	0.0016690	0.0025351	30	9	-0.0054353	-0.0075011
30	10	0.0016218	-0.0055395	30	11	-0.0110613	0.0099434	30	12	0.0123714	-0.0085305
30	13	0.0134213	0.0034719	30	14	0.0043796	0.0060830	30	15	-0.0016879	-0.0019559
30	16	-0.0088026	0.0033801	30	17	-0.0065044	-0.0043441	30	18	-0.0100442	-0.0078314
30	19	-0.0116142	0.0005241	30	20	-0.0039430	0.0107706	30	21	-0.0088595	-0.0065115
30	22	-0.0026737	-0.0055581	30	23	0.0033951	-0.0084043	30	24	-0.0026160	-0.0032619
30	25	0.0034385	-0.0150723	30	26	0.0003689	0.0100453	30	27	-0.0056395	0.0126688
30	28	-0.0037860	-0.0050892	30	29	0.0021892	0.0033030	30	30	-0.0000546	0.0041453
31	1	0.0046821	-0.0119952	31	2	0.0013617	0.0057275	31	3	-0.0063297	-0.0086681
31	4	0.0078644	-0.0008477	31	5	-0.0046503	-0.0020512	31	6	-0.0019375	0.0033188
31	7	0.0003401	-0.0024004	31	8	-0.0001190	0.0001917	31	9	-0.0014884	0.0017420
31	10	0.0001981	-0.0080774	31	11	0.0008508	0.0157155	31	12	0.0027783	0.0031965
31	13	0.0093805	0.0036678	31	14	-0.0060838	0.0031072	31	15	0.0017530	-0.0033483
31	16	-0.0046678	0.0052229	31	17	-0.0039763	0.0074653	31	18	-0.0011249	0.0019858
31	19	0.0025044	0.0022134	31	20	-0.0022369	0.0056220	31	21	-0.0061490	0.0052115
31	22	-0.0074700	-0.0090753	31	23	0.0086392	0.0061025	31	24	-0.0030547	-0.0029426
31	25	-0.0162449	-0.0017283	31	26	-0.0113406	-0.0009352	31	27	0.0006200	0.0101357
31	28	0.0089151	0.0028652	31	29	-0.0021781	-0.0041551	31	30	-0.0009474	-0.0056003
31	31	-0.0091732	-0.0018424								
32	1	-0.0019391	0.0003407	32	2	0.0083160	-0.0049377	32	3	-0.0015101	0.0013112
32	4	0.0020707	-0.0065448	32	5	0.0050124	0.0005448	32	6	-0.0059529	-0.0085579
32	7	0.0025425	0.0024856	32	8	0.0100396	0.0030255	32	9	0.0058074	0.0010645
32	10	0.0014409	-0.0056584	32	11	-0.0054062	0.0048110	32	12	-0.0125972	0.0139195
32	13	0.0041740	0.0023826	32	14	-0.0005282	0.0033685	32	15	0.0050419	-0.0077404
32	16	0.0025011	0.0031105	32	17	-0.0051155	0.0098834	32	18	0.0082254	0.0001041
32	19	-0.0001352	-0.0014221	32	20	0.0028538	0.0004540	32	21	-0.0015404	0.0090298
32	22	-0.0091125	-0.0020045	32	23	0.0067808	0.0000637	32	24	-0.0046501	0.0006893
32	25	-0.0180762	-0.0055121	32	26	0.0042350	-0.0037772	32	27	-0.0036280	-0.0070195
32	28	0.0029940	-0.0025111	32	29	0.0031745	0.0034310	32	30	-0.0042626	-0.0014378
32	31	-0.0032430	0.0005946	32	32	0.0050965	0.0024247				
33	1	-0.0031761	0.0007467	33	2	-0.0068686	0.0015229	33	3	-0.0054440	0.0026048
33	4	-0.0032131	0.0031032	33	5	-0.0048493	0.0011091	33	6	0.0011795	-0.0048727
33	7	-0.0048291	-0.0001447	33	8	0.0011497	0.0110768	33	9	0.0030106	0.0036264
33	10	-0.0027285	0.0005344	33	11	0.0020113	-0.0077170	33	12	-0.0006898	0.0101392
33	13	0.0034057	0.0052654	33	14	0.0037931	0.0034850	33	15	-0.0050422	-0.0017867
33	16	0.0043555	0.0037108	33	17	-0.0043786	0.0094764	33	18	-0.0096200	-0.0049603
33	19	0.0084762	0.0024841	33	20	-0.0008262	-0.0080769	33	21	0.0017740	0.0030135
33	22	-0.0060013	-0.0132287	33	23	-0.0007092	-0.0071528	33	24	0.0090193	-0.0062329
33	25	0.0029450	-0.0104979	33	26	0.0105189	0.0027860	33	27	-0.0008576	0.0016316
33	28	0.0009262	0.0003210	33	29	-0.0159411	0.0040291	33	30	-0.0003193	-0.0173273
33	31	0.0036344	0.0022099	33	32	0.0065942	-0.0041506	33	33	0.0024732	0.0089333
34	1	-0.0001409	0.0024123	34	2	0.0096775	0.0063670	34	3	0.0101568	0.0074331
34	4	-0.0044927	-0.0037018	34	5	-0.0040991	0.0059137	34	6	-0.0003786	0.0035989
34	7	0.0044473	-0.0033291	34	8	-0.0135093	0.0037096	34	9	0.0000574	0.0040019
34	10	-0.0067002	0.0008173	34	11	-0.0042243	0.0024097	34	12	0.0103061	-0.0024785
34	13	-0.0052038	0.0031756	34	14	-0.0012806	0.0071895	34	15	-0.0009321	0.0071018
34	16	0.0005727	-0.0022595	34	17	-0.0055791	0.0004070	34	18	-0.0109181	-0.0058118
34	19	-0.0003830	0.0042619	34	20	0.0043770	-0.0057622	34	21	-0.0005696	-0.0057345
34	22	-0.0020442	0.0056377	34	23	-0.0014310	-0.0080674	34	24	0.0048197	0.0045287
34	25	0.0058310	-0.0095515	34	26	0.0024295	-0.0136956	34	27	0.0125297	-0.0041028
34	28	0.0010961	-0.0184406	34	29	0.0051354	-0.0047807	34	30	-0.0169733	-0.0019148
34	31	-0.0028722	0.0011197	34	32	0.0062400	0.0036500	34	33	0.0106401	0.0017421
34	34	-0.0057815	0.0009623								
35	1	-0.0110388	-0.0057405	35	2	-0.0132095	0.0024944	35	3	0.0021370	0.0035835
35	4	0.0001172	0.0018779	35	5	-0.0062657	-0.0089832	35	6	0.0015395	0.0060509
35	7	-0.0011804	0.0029285	35	8	0.0023739	0.0101232	35	9	-0.0041608	-0.0017540
35	10	-0.0063195	0.0068520	35	11	0.0032848	-0.0018095	35	12	0.0067832	-0.0054193
35	13	-0.0017808	0.0025409	35	14	-0.0068707	-0.0067366	35	15	-0.0143511	0.0087397
35	16	-0.0041017	-0.0012433	35	17	0.0007911	-0.0072514	35	18	-0.0044956	-0.0091086
35	19	0.0004439	-0.0043685	35	20	-0.0011466	0.0028395	35	21	0.0104901	-0.0001515
35	22	0.0022850	0.0041636	35	23	-0.0067572	-0.0019524	35	24	0.0021631	0.0048391
35	25	0.0053014	0.0017015	35	26	-0.0046326	0.0017638	35	27	0.0116954	-0.0131225
35	28	0.0068818	-0.0150441	35	29	0.0080871	0.0018070	35	30	-0.0026502	0.0036857
35	31	0.0064792	0.0066707	35	32	-0.0053443	-0.0060513	35	33	0.0060071	-0.0016236

Index n	Index m	Value C	Value S	Index n	Index m	Value C	Value S	Index n	Index m	Value C	Value S
35	34	-0.0020539	0.0025193	35	35	-0.0055092	-0.0049306				
36	1	0.0023560	0.0050525	36	2	-0.0048740	-0.0020946	36	3	-0.0006015	-0.0099549
36	4	0.0008456	-0.0030955	36	5	-0.0035798	0.0001649	36	6	0.0073452	-0.0046862
36	7	0.0007953	0.0041388	36	8	0.0003665	-0.0034356	36	9	0.0023524	-0.0012762
36	10	0.0013133	0.0053536	36	11	-0.0004069	0.0019427	36	12	-0.0007252	-0.0034005
36	13	-0.0065508	0.0056450	36	14	-0.0080168	-0.0041710	36	15	0.0007518	0.0021176
36	16	0.0003254	0.0020824	36	17	0.0054933	-0.0044269	36	18	0.0003531	0.0040581
36	19	-0.0042858	-0.0035370	36	20	-0.0057191	0.0016195	36	21	0.0062678	-0.0047130
36	22	0.0009862	-0.0006426	36	23	-0.0009853	0.0000774	36	24	0.0017057	-0.0045421
36	25	0.0034153	0.0137161	36	26	0.0030975	0.0073591	36	27	-0.0071208	0.0073981
36	28	0.0019694	-0.0034621	36	29	0.0027623	-0.0001453	36	30	-0.0089974	0.0043111
36	31	-0.0058913	-0.0007781	36	32	0.0074786	0.0047942	36	33	0.0013699	-0.0066836
36	34	-0.0057021	0.0048662	36	35	-0.0014267	-0.0090704	36	36	0.0013751	-0.0038035
37	1	-0.0049156	0.0000010	37	2	-0.0040717	-0.0121681	37	3	-0.0012606	0.0023331
37	4	0.0030456	0.0004847	37	5	-0.0067343	-0.0012726	37	6	-0.0025474	0.0067216
37	7	0.0032984	0.0016145	37	8	-0.0003339	-0.0016667	37	9	0.0014276	-0.0018175
37	10	-0.0002799	0.0016925	37	11	0.0023445	0.0001202	37	12	-0.0023757	-0.0007566
37	13	-0.0001109	-0.0071643	37	14	-0.0027542	-0.0027844	37	15	0.0081779	-0.0015877
37	16	0.0025799	0.0121828	37	17	0.0034629	-0.0018732	37	18	-0.0006381	0.0028466
37	19	-0.0056396	0.0002456	37	20	-0.0066777	-0.0041323	37	21	0.0015215	-0.0018213
37	22	0.0065414	0.0008810	37	23	-0.0011832	0.0008553	37	24	-0.0053148	-0.0060258
37	25	0.0047611	-0.0027142	37	26	0.0034336	0.0087185	37	27	-0.0029964	0.0033606
37	28	0.0128425	0.0045323	37	29	0.0070112	0.0043474	37	30	-0.0064958	0.0123353
37	31	0.0025817	-0.0060123	37	32	-0.0030583	0.0053792	37	33	0.0001545	-0.0156965
37	34	0.0019726	-0.0008856	37	35	-0.0081669	-0.0085347	37	36	-0.0033317	-0.0040689
37	37	0.0035724	-0.0024595								
38	1	0.0051868	0.0005152	38	2	0.0053427	0.0012862	38	3	-0.0012612	-0.0011765
38	4	0.0006688	-0.0003666	38	5	-0.0046791	0.0051471	38	6	-0.0079824	0.0034923
38	7	-0.0020373	-0.0012743	38	8	0.0010329	0.0019980	38	9	0.0035695	0.0004752
38	10	-0.0031151	-0.0034466	38	11	-0.0011352	0.0056709	38	12	-0.0012791	-0.0028368
38	13	-0.0009556	-0.0083390	38	14	-0.0025002	0.0012922	38	15	0.0021553	-0.0027905
38	16	-0.0050750	0.0054249	38	17	0.0014166	0.0016680	38	18	0.0065761	-0.0012532
38	19	0.0010060	-0.0013716	38	20	0.0010583	-0.0021540	38	21	0.0016723	-0.0001027
38	22	0.0004339	0.0071497	38	23	-0.0002480	0.0043683	38	24	-0.0084124	0.0001756
38	25	-0.0014453	-0.0007891	38	26	-0.0039493	0.0045460	38	27	-0.0016060	0.0069831
38	28	-0.0043893	-0.0038518	38	29	0.0059171	0.0020835	38	30	0.0011511	0.0026892
38	31	0.0023266	-0.0043175	38	32	0.0025487	0.0030305	38	33	-0.0000432	0.0075551
38	34	-0.0044932	0.0019497	38	35	0.0041587	0.0040092	38	36	-0.0004538	-0.0020779
38	37	-0.0018945	0.0010750	38	38	0.0030752	-0.0011208				
39	1	-0.0029291	0.0049006	39	2	0.0039756	0.0045104	39	3	-0.0014023	0.0044364
39	4	-0.0025898	-0.0028432	39	5	0.0007810	0.0031819	39	6	0.0006507	0.0041436
39	7	0.0004544	-0.0029071	39	8	0.0009166	0.0091713	39	9	0.0051866	0.0038905
39	10	0.0001178	0.0000877	39	11	0.0099610	-0.0001755	39	12	-0.0029172	0.0067749
39	13	-0.0008276	-0.0035592	39	14	-0.0044839	0.0007530	39	15	-0.0024110	0.0017039
39	16	-0.0014517	-0.0027009	39	17	-0.0014440	-0.0020140	39	18	0.0010577	-0.0019332
39	19	0.0037789	0.0047925	39	20	-0.0003241	-0.0097518	39	21	-0.0027525	-0.0020255
39	22	-0.0033813	-0.0004058	39	23	-0.0026940	0.0043824	39	24	-0.0068925	0.0057119
39	25	-0.0020101	-0.0027154	39	26	-0.0023117	0.0071160	39	27	-0.0077364	-0.0021167
39	28	-0.0024204	-0.0101477	39	29	-0.0020169	-0.0033467	39	30	0.0055821	-0.0098472
39	31	0.0018862	-0.0073454	39	32	0.0001311	0.0052857	39	33	-0.0083180	0.0003784
39	34	-0.0009031	0.0001508	39	35	-0.0103099	0.0028057	39	36	0.0028572	-0.0017494
39	37	-0.0016599	-0.0048817	39	38	-0.0016177	0.0037600	39	39	-0.0000654	0.0001047
40	1	0.0032840	-0.0001586	40	2	-0.0021234	0.0011420	40	3	-0.0031044	-0.0025156
40	4	0.0017363	-0.0043984	40	5	0.0088006	0.0003928	40	6	-0.0001346	0.0009513
40	7	-0.0026367	0.0053655	40	8	0.0040907	0.0007677	40	9	-0.0010176	0.0008677
40	10	-0.0042810	0.0032747	40	11	0.0020340	-0.0001802	40	12	0.0044421	0.0000164
40	13	-0.0037796	-0.0018936	40	14	0.0006834	0.0015879	40	15	-0.0038797	0.0005316
40	16	-0.0031858	-0.0037195	40	17	0.0005927	-0.0008076	40	18	-0.0005346	-0.0013222
40	19	-0.0012587	-0.0000521	40	20	-0.0043835	0.0046265	40	21	-0.0014222	-0.0011424
40	22	-0.0063277	-0.0117123	40	23	-0.0012227	-0.0094841	40	24	0.0030406	0.0039924
40	25	0.0007345	-0.0028817	40	26	0.0060268	-0.0019383	40	27	-0.0005875	0.0011196
40	28	0.0029705	0.0049953	40	29	0.0017296	0.0011912	40	30	0.0008827	0.0011420
40	31	-0.0055260	0.0005049	40	32	-0.0033430	-0.0027049	40	33	-0.0031163	-0.0032749
40	34	0.0030161	-0.0004945	40	35	0.0052964	-0.0050303	40	36	0.0004912	0.0040246
40	37	-0.0023041	0.0009372	40	38	0.0000925	0.0051273	40	39	0.0057131	0.0021486
40	40	-0.0013794	-0.0021706								

Index		Value		Index		Value		Index		Value	
n	m	C	S	n	m	C	S	n	m	C	S
41	1	-0.0032974	-0.0024119	41	2	0.0028399	0.0014783	41	3	0.0034184	0.0032957
41	4	-0.0015694	0.0019214	41	5	0.0012139	-0.0016050	41	6	-0.0001380	0.0005462
41	7	0.0009845	0.0007174	41	8	-0.0020735	-0.0031634	41	9	-0.0044253	0.0036733
41	10	0.0048671	-0.0006390	41	11	0.0020043	-0.0041575	41	12	0.0007892	0.0005245
41	13	-0.0014747	0.0009168	41	14	0.0012302	-0.0012876	41	15	-0.0005881	0.0013570
41	16	-0.0020793	-0.0004557	41	17	-0.0011739	0.0011708	41	18	0.0005731	0.0047586
41	19	0.0004196	-0.0008594	41	20	-0.0008079	-0.0009923	41	21	0.0001517	-0.0000071
41	22	-0.0056367	-0.0008416	41	23	0.0006823	-0.0092436	41	24	0.0039405	-0.0012279
41	25	-0.0009173	0.0025235	41	26	0.0042286	-0.0057720	41	27	0.0015488	-0.0000018
41	28	-0.0013986	-0.0042759	41	29	-0.0030313	0.0037440	41	30	0.0026878	-0.0015818
41	31	0.0086719	0.0021279	41	32	-0.0052892	0.0042570	41	33	-0.0040296	0.0074972
41	34	-0.0022838	0.0005172	41	35	-0.0098255	0.0043609	41	36	0.0017542	-0.0012226
41	37	-0.0009056	-0.0100823	41	38	-0.0065801	-0.0000297	41	39	-0.0035437	-0.0002503
41	40	0.0020794	-0.0019584	41	41	0.0022039	0.0040887				
42	1	-0.0010549	0.0024804	42	2	-0.0020493	-0.0017886	42	3	-0.0000935	0.0054527
42	4	0.0019032	0.0017889	42	5	-0.0056812	-0.0044196	42	6	-0.0006180	-0.0007461
42	7	0.0035194	-0.0021540	42	8	0.0008779	0.0015092	42	9	-0.0003542	0.0011971
42	10	0.0030211	0.0044013	42	11	0.0008017	0.0014187	42	12	0.0043636	-0.0077228
42	13	0.0006714	0.0010780	42	14	-0.0036389	0.0031713	42	15	-0.0008635	0.0052410
42	16	0.0030972	-0.0029467	42	17	-0.0027801	-0.0024590	42	18	-0.0085518	0.0038762
42	19	-0.0012846	-0.0015350	42	20	0.0058399	0.0020848	42	21	0.0012403	-0.0011678
42	22	-0.0009454	-0.0015454	42	23	-0.0031263	-0.0008805	42	24	0.0009781	0.0017079
42	25	-0.0049920	0.0015279	42	26	-0.0014004	-0.0054051	42	27	0.0046599	-0.0009781
42	28	-0.0028763	0.0024781	42	29	-0.0048047	-0.0004893	42	30	0.0035784	0.0007136
42	31	0.0055411	0.0046499	42	32	0.0039092	0.0044224	42	33	0.0016808	0.0037711
42	34	0.0031443	0.0069991	42	35	-0.0029544	-0.0002303	42	36	0.0045869	-0.0055909
42	37	-0.0026086	0.0037980	42	38	0.0018011	-0.0067936	42	39	0.0024849	0.0089295
42	40	0.0019980	-0.0027079	42	41	-0.0001768	0.0009606	42	42	-0.0063007	0.0022353
43	1	-0.0008316	0.0020286	43	2	-0.0056119	-0.0006628	43	3	0.0031178	0.0007431
43	4	0.0019077	-0.0006349	43	5	-0.0070054	0.0026595	43	6	0.0050181	0.0041881
43	7	-0.0016264	-0.0010956	43	8	-0.0008173	0.0041930	43	9	-0.0025299	-0.0053650
43	10	0.0000195	-0.0005122	43	11	-0.0027799	0.0039610	43	12	-0.0013027	0.0001380
43	13	0.0024777	-0.0028463	43	14	-0.0022186	0.0014669	43	15	0.0025039	0.0060175
43	16	0.0012199	0.0007061	43	17	0.0003756	-0.0009282	43	18	-0.0002852	-0.0039074
43	19	-0.0060716	-0.0032356	43	20	-0.0003431	0.0016274	43	21	0.0009576	0.0061367
43	22	0.0019677	-0.0000828	43	23	0.0001647	-0.0064914	43	24	0.0020583	0.0023257
43	25	-0.0014060	0.0002575	43	26	-0.0021524	0.0016623	43	27	0.0040223	0.0010344
43	28	-0.0016798	0.0071065	43	29	-0.0010411	0.0008117	43	30	-0.0079572	-0.0061139
43	31	-0.0033059	-0.0019594	43	32	-0.0026257	0.0050419	43	33	0.0033950	-0.0020095
43	34	0.0028516	-0.0021425	43	35	-0.0016056	0.0051703	43	36	-0.0012074	-0.0011083
43	37	0.0029798	0.0030621	43	38	-0.0031235	0.0005426	43	39	0.0027912	0.0005902
43	40	0.0073136	-0.0003218	43	41	-0.0024349	0.0013503	43	42	-0.0045843	0.0035128
43	43	-0.0011373	-0.0064975								
44	1	0.0029297	0.0011940	44	2	0.0010687	0.0032316	44	3	-0.0002384	-0.0036957
44	4	0.0018471	-0.0012678	44	5	0.0034121	0.0017682	44	6	-0.0038622	0.0025786
44	7	0.0013370	0.0075225	44	8	-0.0018939	0.0016363	44	9	0.0002772	-0.0035145
44	10	-0.0024947	-0.0021794	44	11	0.0012324	-0.0000826	44	12	-0.0003520	-0.0006908
44	13	0.0016425	-0.0016159	44	14	-0.0009325	-0.0043967	44	15	0.0001944	-0.0044618
44	16	0.0039739	0.0025995	44	17	0.0018932	0.0029772	44	18	0.0026380	-0.0025727
44	19	-0.0009661	-0.0023623	44	20	-0.0033284	-0.0017765	44	21	-0.0077975	-0.0000412
44	22	0.0038111	0.0014278	44	23	-0.0000186	0.0044105	44	24	0.0006760	-0.0032237
44	25	-0.0006909	-0.0005947	44	26	-0.0026699	-0.0003930	44	27	0.0038838	-0.0032201
44	28	-0.0016089	0.0027245	44	29	-0.0051754	0.0032688	44	30	0.0042510	0.0020496
44	31	-0.0009448	0.0033906	44	32	-0.0031967	0.0009834	44	33	-0.0029287	-0.0003965
44	34	-0.0028548	0.0028183	44	35	-0.0040191	-0.0027811	44	36	0.0003855	-0.0061805
44	37	0.0078193	0.0055376	44	38	0.0030486	-0.0050440	44	39	0.0053568	0.0019902
44	40	-0.0022656	0.0049728	44	41	0.0004467	0.0001770	44	42	-0.0026354	-0.0019834
44	43	0.0035684	-0.0032760	44	44	0.0037782	-0.0006886				
45	1	0.0026951	-0.0027440	45	2	0.0000148	-0.0017983	45	3	-0.0007616	-0.0023328
45	4	0.0002985	-0.0012819	45	5	0.0035373	-0.0005212	45	6	-0.0014242	0.0009479
45	7	-0.0008588	0.0015494	45	8	-0.0031837	0.0012239	45	9	0.0015806	-0.0015151
45	10	0.0002887	0.0015372	45	11	0.0001222	-0.0004875	45	12	-0.0021671	-0.0010538
45	13	-0.0034052	-0.0008497	45	14	0.0007696	-0.0037004	45	15	-0.0026414	0.0016431
45	16	0.0032011	-0.0003423	45	17	0.0020754	-0.0006589	45	18	0.0004705	-0.0043553
45	19	-0.0043586	-0.0023125	45	20	0.0021153	0.0009336	45	21	-0.0034361	-0.0013003
45	22	0.0024224	0.0019235	45	23	0.0002953	0.0000911	45	24	-0.0057726	0.0034637
45	25	0.0041370	-0.0030598	45	26	-0.0007239	0.0031661	45	27	-0.0042952	-0.0002781

Index		Value		Index		Value		Index		Value	
n	m	C	S	n	m	C	S	n	m	C	S
45	28	0.0062681	-0.0008717	45	29	-0.0059262	-0.0033256	45	30	-0.0000580	-0.0003571
45	31	-0.0017040	-0.0018854	45	32	-0.0020496	-0.0030384	45	33	-0.0030386	-0.0017780
45	34	-0.0003018	0.0033467	45	35	-0.0036964	0.0054399	45	36	-0.0056363	0.0065188
45	37	-0.0066606	0.0032181	45	38	-0.0032027	0.0037589	45	39	-0.0038397	-0.0046705
45	40	0.0007054	-0.0033151	45	41	0.0016370	-0.0013952	45	42	-0.0027772	-0.0081510
45	43	0.0006000	0.0030227	45	44	0.0084758	0.0004522	45	45	-0.0005275	0.0001983
46	1	0.0003902	0.0019348	46	2	0.0039107	0.0003363	46	3	-0.0015697	0.0003988
46	4	0.0016600	-0.0049421	46	5	-0.0027228	-0.0029434	46	6	-0.0031675	-0.0015616
46	7	0.0020442	-0.0053048	46	8	-0.0002472	0.0023184	46	9	0.0048027	0.0043677
46	10	-0.0005557	0.0010901	46	11	-0.0025667	-0.0015273	46	12	-0.0002748	0.0009639
46	13	-0.0015386	-0.0006741	46	14	0.0003575	0.0006596	46	15	-0.0028107	-0.0010545
46	16	0.0006898	0.0023582	46	17	-0.0034898	-0.0005418	46	18	0.0022656	-0.0029780
46	19	-0.0002686	-0.0023467	46	20	-0.0021061	-0.0041320	46	21	-0.0052484	0.0014604
46	22	0.0063494	0.0008493	46	23	0.0012049	0.0010192	46	24	-0.0001629	-0.0017623
46	25	0.0028610	-0.0050933	46	26	0.0029405	0.0080656	46	27	-0.0011910	0.0001431
46	28	-0.0001483	-0.0055951	46	29	-0.0016279	-0.0022368	46	30	-0.0028077	-0.0057572
46	31	-0.0020010	0.0002963	46	32	-0.0021572	-0.0005208	46	33	0.0109984	0.0002125
46	34	-0.0017368	0.0025661	46	35	-0.0043511	0.0001382	46	36	0.0002680	-0.0011718
46	37	-0.0028315	0.0028776	46	38	-0.0053348	-0.0027991	46	39	0.0055427	-0.0007327
46	40	0.0006478	0.0002631	46	41	-0.0011737	-0.0022143	46	42	-0.0009337	0.0050951
46	43	-0.0022300	0.0103393	46	44	0.0001587	-0.0016435	46	45	-0.0027172	0.0031762
46	46	0.0005050	-0.0020583								
47	1	-0.0053435	-0.0007635	47	2	0.0016198	0.0000823	47	3	0.0009059	0.0023499
47	4	-0.0017473	0.0002132	47	5	-0.0012637	-0.0022936	47	6	0.0013596	-0.0012630
47	7	0.0001166	-0.0040506	47	8	0.0008843	-0.0008776	47	9	-0.0011285	0.0017593
47	10	0.0019215	0.0015586	47	11	0.0008545	-0.0027904	47	12	0.0058705	0.0016457
47	13	-0.0027401	-0.0010902	47	14	0.0002416	0.0010597	47	15	-0.0014275	-0.0001426
47	16	-0.0017942	-0.0005419	47	17	-0.0017814	0.0024817	47	18	-0.0006259	0.0068878
47	19	0.0025376	0.0012821	47	20	-0.0065500	0.0006051	47	21	-0.0039365	-0.0010039
47	22	-0.0040330	0.0007903	47	23	0.0026870	0.0008748	47	24	-0.0007888	-0.0013627
47	25	-0.0016422	-0.0064498	47	26	0.0050061	-0.0007265	47	27	-0.0037071	-0.0028474
47	28	0.0019022	-0.0060338	47	29	0.0053198	0.0005651	47	30	-0.0014446	0.0029410
47	31	0.0007062	0.0024173	47	32	-0.0026391	0.0011748	47	33	-0.0042830	0.0021022
47	34	-0.0008726	0.0006783	47	35	-0.0039723	0.0003526	47	36	0.0058505	-0.0021634
47	37	0.0074399	0.0019451	47	38	0.0007072	-0.0011637	47	39	-0.0005401	0.0065295
47	40	-0.0080805	0.0041903	47	41	-0.0018862	0.0077747	47	42	-0.0022845	-0.0014633
47	43	-0.0014626	0.0011128	47	44	-0.0020330	0.0057069	47	45	0.0054800	0.0027301
47	46	-0.0019032	-0.0015629	47	47	0.0024330	-0.0034586				
48	1	0.0005538	0.0012148	48	2	0.0035724	0.0015917	48	3	-0.0006864	-0.0003342
48	4	-0.0007062	-0.0007040	48	5	0.0044193	0.0004521	48	6	0.0030947	0.0036867
48	7	-0.0014992	0.0018387	48	8	0.0004006	0.0012714	48	9	0.0006931	0.0021397
48	10	-0.0015349	0.0015451	48	11	0.0026793	0.0005879	48	12	0.0001334	-0.0019480
48	13	0.0018516	0.0001842	48	14	-0.0004517	0.0002950	48	15	0.0031099	0.0004613
48	16	0.0009952	0.0013374	48	17	0.0008646	0.0005053	48	18	-0.0007917	0.0022628
48	19	-0.0009128	0.0023804	48	20	-0.0013079	0.0041606	48	21	0.0021234	-0.0008577
48	22	-0.0037062	0.0036039	48	23	-0.0030785	-0.0005105	48	24	-0.0044177	-0.0010251
48	25	-0.0004567	0.0001535	48	26	-0.0011981	-0.0039966	48	27	-0.0053468	0.0042815
48	28	0.0013954	-0.0050730	48	29	0.0022356	-0.0043115	48	30	-0.0016900	-0.0007810
48	31	0.0001248	-0.0017717	48	32	0.0010593	-0.0007825	48	33	0.0004008	0.0009590
48	34	-0.0009807	0.0040984	48	35	-0.0027110	-0.0007886	48	36	-0.0017322	0.0013982
48	37	-0.0031590	0.0001357	48	38	-0.0079164	-0.0003110	48	39	0.0021019	-0.0070046
48	40	0.0019652	0.0016491	48	41	-0.0026586	-0.0096586	48	42	0.0012291	0.0026088
48	43	0.0034306	0.0042050	48	44	-0.0000205	-0.0015323	48	45	0.0049022	0.0011523
48	46	-0.0020915	0.0067677	48	47	0.0030068	0.0051068	48	48	0.0041556	-0.0019210
49	1	0.0043368	0.0000709	49	2	0.0010682	0.0042526	49	3	-0.0001052	-0.0001249
49	4	0.0009678	0.0066156	49	5	0.0007732	-0.0003730	49	6	-0.0006717	0.0001671
49	7	0.0015788	0.0023319	49	8	-0.0021954	0.0026171	49	9	-0.0017627	0.0032456
49	10	-0.0034344	-0.0006411	49	11	0.0044174	-0.0000399	49	12	-0.0033296	-0.0015868
49	13	0.0013113	0.0018309	49	14	0.0003211	-0.0007456	49	15	-0.0005472	-0.0009267
49	16	0.0002820	-0.0036641	49	17	-0.0018398	-0.0003205	49	18	-0.0003905	-0.0005100
49	19	-0.0017828	-0.0007865	49	20	0.0038187	0.0000889	49	21	-0.0010906	-0.0030666
49	22	-0.0009327	0.0038366	49	23	0.0017917	0.0007186	49	24	0.0025186	0.0003714
49	25	-0.0018632	0.0023003	49	26	-0.0061364	0.0010063	49	27	-0.0023229	0.0031887
49	28	-0.0027142	-0.0090119	49	29	-0.0002811	0.0011873	49	30	0.0016574	0.0016788
49	31	0.0005052	-0.0058855	49	32	0.0011389	-0.0050365	49	33	0.0010842	-0.0009892
49	34	0.0036489	0.0000702	49	35	0.0022276	0.0022634	49	36	-0.0019451	0.0022716
49	37	-0.0019750	0.0020364	49	38	0.0011548	-0.0001104	49	39	0.0017274	0.0000864

Index n	m	Value C	Value S	Index n	m	Value C	Value S	Index n	m	Value C	Value S
49	40	-0.0019194	0.0010767	49	41	0.0017339	-0.0057150	49	42	-0.0034542	0.0018620
49	43	0.0032430	-0.0077262	49	44	0.0057092	0.0051676	49	45	0.0037451	-0.0008910
49	46	0.0019567	0.0005388	49	47	0.0023910	-0.0013929	49	48	0.0000523	0.0009792
49	49	0.0022866	0.0011051								
50	1	0.0017666	-0.0022281	50	2	-0.0058765	-0.0036022	50	3	0.0004426	-0.0008402
50	4	-0.0047777	0.0001146	50	5	-0.0019977	0.0002767	50	6	0.0000882	0.0003448
50	7	0.0025973	0.0024513	50	8	-0.0032385	-0.0013418	50	9	-0.0010077	0.0018888
50	10	-0.0033841	-0.0007892	50	11	-0.0010069	0.0016175	50	12	-0.0029256	0.0039480
50	13	0.0009021	-0.0004416	50	14	-0.0026214	0.0027302	50	15	-0.0014314	-0.0022591
50	16	-0.0007214	-0.0052738	50	17	-0.0000520	-0.0018828	50	18	0.0011816	-0.0023998
50	19	0.0011347	0.0018687	50	20	0.0015556	-0.0011293	50	21	0.0000305	-0.0001589
50	22	-0.0004390	0.0004109	50	23	-0.0028784	-0.0042220	50	24	0.0058694	-0.0003756
50	25	0.0048968	0.0001811	50	26	-0.0054587	-0.0016869	50	27	0.0043118	-0.0016602
50	28	-0.0006827	0.0052310	50	29	0.0047011	0.0029798	50	30	0.0034870	0.0054217
50	31	-0.0028706	0.0041099	50	32	-0.0010662	0.0014943	50	33	-0.0025429	-0.0017283
50	34	-0.0014786	-0.0012403	50	35	0.0003762	0.0005054	50	36	-0.0002935	0.0006947
50	37	-0.0010860	-0.0002919	50	38	-0.0026838	-0.0055295	50	39	-0.0045147	0.0060185
50	40	0.0044884	0.0040792	50	41	-0.0007966	-0.0009059	50	42	0.0044166	-0.0017972
50	43	-0.0022517	-0.0008207	50	44	-0.0015030	-0.0013688	50	45	-0.0022066	0.0033629
50	46	-0.0019619	0.0021132	50	47	-0.0056726	-0.0081046	50	48	-0.0010699	-0.0019044
50	49	0.0025218	-0.0049950	50	50	0.0023135	0.0019352				

CHAPTER 7 SOLID EARTH TIDES

The solid Earth tide model is based on an abbreviated form of the Wahr model (Wahr, 1981) using the Earth model 1066A of Gilbert and Dziewonski (1975).

The Love numbers for the induced free space potential, k, and for the vertical and horizontal displacements, h and ℓ, have been taken from Wahr's thesis, Tables 13 and 16. The long period, diurnal, and semi-diurnal terms are included. Third degree terms are neglected.

Calculation of the Potential Coefficients

The solid tide induced free space potential is most easily modelled as variations in the standard geopotential coefficients C_{nm} and S_{nm} (Eanes, *et al.*, 1983). The Wahr model (or any other having frequency dependent Love numbers) is most efficiently computed in two steps. The first step uses a frequency independent Love number k_2 and an evaluation of the tidal potential in the time domain from a lunar and solar ephemeris. The second step corrects those arguments of a harmonic expansion of the tide generating potential for which the error from using the k_2 of Step 1 is above some cutoff.

The changes in normalized second degree geopotential coefficients for Step 1 are:

$$\Delta\bar{C}_{20} = \frac{1}{\sqrt{5}} k_2 \frac{R_e^3}{GM_\oplus} \sum_{j=2}^{3} \frac{GM_j}{r_j^3} P_{20}(\sin\phi_j), \tag{1a}$$

$$\Delta\bar{C}_{21} - i\Delta\bar{S}_{21} = \frac{1}{3}\sqrt{\frac{3}{5}} k_2 \frac{R_e^3}{GM_\oplus} \sum_{j=2}^{3} \frac{GM_j}{r_j^3} P_{21}(\sin\phi_j)\, e^{-i\lambda_j}, \tag{1b}$$

$$\Delta\bar{C}_{22} - i\Delta\bar{S}_{22} = \frac{1}{12}\sqrt{\frac{12}{5}} k_2 \frac{R_e^3}{GM_\oplus} \sum_{j=2}^{3} \frac{GM_j}{r_j^3} P_{22}(\sin\phi_j)\, e^{-i2\lambda_j}, \tag{1c}$$

where

k_2 = nominal second degree Love number,

R_e = equatorial radius of the Earth,

$GM_\oplus$ = gravitational parameter for the Earth,

GM_j = gravitational parameter for the Moon (j=2) and Sun (j=3),

r_j = distance from geocenter to Moon or Sun,

ϕ_j = body fixed geocentric latitude of Moon or Sun,

λ_j = body fixed east longitude (from Greenwich) of Sun or Moon.

The changes in normalized coefficients from Step 2 are:

$$\Delta \bar{C}_{nm} - i\Delta \bar{S}_{nm} = A_m \sum_{s(n,m)} \delta k_s H_s \left(\begin{matrix} 1 \\ -i \end{matrix} \right)_{n+m \text{ odd}}^{n+m \text{ even}} e^{i\theta_s}, \qquad (2)$$

where

$$A_m = \frac{(-1)^m}{R_e\sqrt{4\pi\ (2-\delta_{om})}}, \quad \delta_{om} = \begin{cases} 1 & m=0 \\ 0 & m\neq 0 \end{cases},$$

δk_s = difference between Wahr model for k at frequency s and the nominal value k_2 in the sense $k_s - k_2$,

H_s = amplitude (m) of term at frequency s from the Cartwright and Tayler (1971) and Cartwright and Edden (1973) harmonic expansion of the tide generating potential,

$$\theta_s = \bar{n}\cdot\bar{\beta} = \sum_{i=1}^{6} n_i \beta_i,$$

where

$\bar{n}$ = six vector of multipliers of the Doodson variables,

$\bar{\beta}$ = the Doodson variables, and

δS_{20} = 0.

The Doodson variables are related to the fundamental arguments of the nutation series (see Chapter 5) by:

$s = F + \Omega = \beta_2$ (Moon's mean longitude), (3)

$h = s - D = \beta_3$ (Sun's mean longitude),

$p = s - \ell = \beta_4$ (Longitude of Moon's mean perigee),

$N' = -\Omega = \beta_5$ (Negative longitude of Moon's mean node),

$p_1 = s - D - \ell' = \beta_6$ (Longitude of Sun's mean perigee), and

$\tau = \theta_g + \pi - s = \beta_1$ (Time angle in lunar days reckoned from lower transit), where

θ_g = mean sidereal time of the conventional zero meridian.

The normalized geopotential coefficients ($\bar{C}_{nm}$, $\bar{S}_{nm}$) are related to the unnormalized coefficients (C_{nm}, S_{nm}) by

$$C_{nm} = N_{nm} \bar{C}_{nm},$$

$$S_{nm} = N_{nm} \bar{S}_{nm},$$

$$N_{nm} = \sqrt{\frac{(n-m)!\,(2n+1)\,(2-\delta_{om})}{(n+m)!}}$$

Using a nominal k_2 of 0.30 and an amplitude cutoff of 9×10^{-12} change in normalized geopotential coefficients, the summation S(n,m) requires six terms for the diurnal species (n=2, m=1) modifying $\bar{C}_{21}$ and $\bar{S}_{21}$ and two semi-diurnal terms (n=2, m=2) modifying $\bar{C}_{22}$ and $\bar{S}_{22}$. With the exception of the zero frequency tide, no long period terms are necessary. Table 7.1 gives required quantities for correcting the (2,1) and (2,2) coefficients. The correction to $\bar{C}_{20}$ is discussed in more detail below.

The Step 2 correction due to the K_1 constituent is given below as an example.

$$\begin{aligned}(\Delta\bar{C}_{21} \times 10^{12})_{K_1} &= 507.4 \sin(\tau+s), \\ &= 507.4 \sin(\theta_g+\pi), \\ &= -507.4 \sin \theta_g.\end{aligned}$$

$$(\Delta\bar{S}_{21} \times 10^{12})_{K_1} = -507.4 \cos \theta_g.$$

The total variation in geopotential coefficients due to the solid tide is obtained by adding the results of Step 2 (Eq. 2) to those of Step 1 (Eq. 1).

Table 7.1

Step 2 Solid Tide Corrections When k_2 = .30 in Step 1

Using a Cutoff Amplitude of 9 × 10^{-12} for $A_m \delta k_s H_s$

Long Period Tides (n=2, m=0)

None except zero frequency tide.

Diurnal Tides (n=2, m=1)

Doodson Number	τ	s	h	p	N′	p_1	$A_m \delta k_s H_s \times 10^{12}$
	$\bar{n}$, argument multipliers						
145.555 (O_1)	1	-1	0	0	0	0	-16.4
163.555 (P_1)	1	1	-2	0	0	0	-49.6
165.545	1	1	0	0	-1	0	-9.4
165.555 (K_1)	1	1	0	0	0	0	507.4
165.565	1	1	0	0	1	0	73.5
166.554 (ψ_1)	1	1	1	0	0	-1	-15.2

Semi-Diurnal Tides (n=2, m=2)

Doodson Number	τ	s	h	p	N′	p_1	$A_m \delta k_s H_s \times 10^{12}$
	$\bar{n}$, argument multipliers						
255.555 (M_2)	2	0	0	0	0	0	39.5
273.555 (S_2)	2	2	-2	0	0	0	18.4

Treatment of the Permanent Tide

The mean value of $\Delta\bar{C}_{20}$ from Eq. 1a is not zero, and this permanent tide deserves special attention. The mean value of the correction could be included in the adopted value of $\bar{C}_{20}$ and hence not included in the $\Delta\bar{C}_{20}$. The practical situation is not so clear because satellite derived values of $\bar{C}_{20}$ as in the GEM geopotentials have been obtained using a mixture of methods, some applying the corrections and others not applying it. There is no way to ensure consistency in this regard short of re-estimating C_{20} with a consistent technique. If this is done the inclusion of the zero frequency term in Eq. 1a should be avoided because k_2 is not the appropriate Love number to use for such a term. The zero frequency change in $\bar{C}_{20}$ can be removed by computing $\Delta\bar{C}_{20}$ as

$$\Delta \bar{C}^{*}_{20} = \Delta \bar{C}_{20}(Eq.1a) - \langle \Delta \bar{C}_{20} \rangle, \tag{4}$$

where

$$\langle \Delta \bar{C}_{20} \rangle = A_0 H_0 k_2$$

$$= (4.4228 \times 10^{-8})(-0.31455)k_2$$

$$= -1.39119 \times 10^{-8} k_2.$$

Using $k_2 = 0.30$ then

$$\langle \Delta \bar{C}_{20} \rangle = -4.1736 \times 10^{-9}$$

or

$$\langle \Delta J_2 \rangle = -\langle \Delta \bar{C}_{20} \rangle \sqrt{5} = 9.3324 \times 10^{-9}.$$

The decision to remove or not to remove the mean from the corrections depends on whether the adopted $\bar{C}_{20}$ does or does not already contain it and on whether k_2 is a potential 'solve for' parameter. If k_2 is to be estimated then it must not multiply the zero frequency term in the correction. In the most recent data reductions leading to GEM-T3, the total tide correction was applied. If we assume the more recent data has most of the weight in the determination of $\bar{C}_{20}$ then we conclude that the permanent deformation is not included in the GEM-T3 value of $\bar{C}_{20}$. Hence, if k_2 is to be estimated, first $\langle \Delta \bar{C}_{20} \rangle$ must be added to $\bar{C}_{20}$ and then $\Delta \bar{C}_{20}^{*}$ should be used in place of $\Delta \bar{C}_{20}$ of Eq. 1a. The k_2 used for restoring the permanent tide should match what was used in deriving the adopted value of $\bar{C}_{20}$.

The GEM-T3 value of $\bar{C}_{20}$ is $-484.16499 \times 10^{-6}$ and does not include the permanent deformation. The tidal corrections employed in the computations leading to GEM-T3 were equivalent to Eq. 1a with $k_2 = 0.30$. Let $\bar{C}_{20}^{*}$ denote the coefficient which includes the zero frequency term; then the GEM-T3 values of $\bar{C}_{20}$ with the permanent tide restored are:

$$\bar{C}_{20}^{*}(\text{GEM-T3}) = -484.16499 \times 10^{-6} - (1.39119 \times 10^{-8}) \times 0.30,$$

$$\bar{C}_{20}^{*}(\text{GEM-T3}) = -484.169164 \times 10^{-6}. \tag{5}$$

These values for $\bar{C}_{20}^{*}$ are recommended for use with the respective gravity field and should be added to the periodic tidal correction given as $\Delta \bar{C}_{20}^{*}$ in Eq. 4 to get the total time dependent value of $\bar{C}_{20}$.

Solid Tide Effect on Station Coordinates

The variations of station coordinates caused by solid Earth tides predicted using Wahr's theory are also most efficiently implemented using a two-step procedure. Only the second degree tides are necessary to retain 0.01 m precision. Also terms proportional to y, h+, h-, z, l+, w+, and w- are ignored. The first step uses frequency independent Love and Shida numbers and a computation of the tidal potential in the time domain. A convenient formulation of the displacement is given in the documentation for the GEODYN program. The vector displacement of the station due to tidal deformation for Step 1 can be computed from

$$\Delta \vec{r} = \sum_{j=2}^{3} \frac{[GM_j r^4]}{[GM_\oplus R_j^3]} \{[3 l_2 (\hat{R}_j \cdot \hat{r})] \hat{R}_j + [3(\frac{h_2}{2} - l_2)(\hat{R}_j \cdot \hat{r})^2 - \frac{h_2}{2}] \hat{r}\}, \quad (6)$$

GM_j = gravitational parameter for the Moon (j=2) or the Sun (j=3),

$GM_\oplus$ = gravitational parameter for the Earth,

$\hat{R}_j, R_j$ = unit vector from the geocenter to Moon or Sun and the magnitude of that vector,

$\hat{r}, r$ = unit vector from the geocenter to the station and the magnitude of that vector,

h_2 = nominal second degree Love number,

ℓ_2 = nominal Shida number.

If nominal values for h_2 and ℓ_2 of 0.6090 and 0.0852 respectively are used with a cutoff of 0.005m of radial displacement, only one term needs to be corrected in Step 2. This is the K_1 frequency where h from Wahr's theory is 0.5203. Only the radial displacement needs to be corrected and to sufficient accuracy this can be implemented as a periodic change in station height given by

$$\delta h_{STA} = \delta h_{K_1} H_{K_1} (-\sqrt{\frac{5}{24\pi}}) 3 \sin\phi \cos\phi \sin(\theta_{K_1} + \lambda), \quad (7)$$

where

δh_{K_1} = h_{K_1} (Wahr) - h_2 (Nominal) = -0.0887,

H_{K_1} = amplitude of K_1 term (165.555) in the harmonic expansion of the tide generating potential = 0.36878 m,

ϕ = geocentric latitude of station,

λ = east longitude of station,

θ_{K_1} = K_1 tide argument = $\tau + s = \theta_g + \pi$,

or simplifying

$$\delta h_{STA} = -0.0253 \sin\phi \cos\phi \sin(\theta_g + \lambda).$$

The effect is maximum at ϕ = 45° where the amplitude is 0.013 m.

Equation (6) contains a site displacement that is independent of time. If nominal Love and Shida numbers of 0.6090 and 0.0852 respectively are used with Eq. 6, the permanent deformation introduced is in the radial direction.

$$\Delta\vec{r}\cdot\hat{r} = \sqrt{\frac{5}{4\pi}}(0.6090)(-0.31455)(\frac{3}{2}\sin^2\phi-\frac{1}{2}) \quad (8a)$$

$$= -0.12083(\frac{3}{2}\sin^2\phi-\frac{1}{2})\, meters,$$

and in the north direction

$$\Delta\vec{r}\cdot\hat{e}_p = \sqrt{\frac{5}{4\pi}}(0.0852)(-0.31455)3\cos\phi\sin\phi \quad (8b)$$

$$= -0.05071 \cos\phi \sin\phi \text{ meters.}$$

Since values for the Love numbers h_2 and ℓ_2 substituted in (6) are representative only for short-period deformation, this permanent part has no physical significance and must be subtracted from (6). As a result, the tide model relates to the true long-time average positions of sites.

Rotational Deformation Due to Polar Motion

The variation of station coordinates caused by the polar tide is recommended to be taken into account. Let us choose $\hat{x}$, $\hat{y}$, and $\hat{z}$ as a terrestrial system of reference. The $\hat{z}$ axis is oriented along the Earth's mean rotation axis, the $\hat{x}$ axis is in the direction of the adopted origin of longitude and $\hat{y}$ axis is oriented along the 90° E meridian.

The centrifugal potential caused by the Earth's rotation is

$$V = \frac{1}{2} \, [r^2 |\vec{\Omega}|^2 - (\vec{r} \cdot \vec{\Omega})^2], \tag{9}$$

where $\vec{\Omega} = \Omega(m_1\hat{x} + m_2\hat{y} + (1 + m_3)\hat{z})$. Ω is the mean angular velocity of rotation of the Earth, m_i are small dimensionless parameters, m_1, m_2 describing polar motion and m_3 describing variation in the rotation rate, r is the radial distance to the station.

Neglecting the variations in m_3 which induce displacements that are below the mm level, the m_1 and m_2 terms give a first order perturbation in the potential V (Wahr, 1985)

$$\Delta V(r, \theta, \lambda) = -\frac{\Omega^2 r^2}{2} \sin 2\theta \; (m_1 \cos \lambda + m_2 \sin \lambda), \tag{10}$$

where θ is the co-latitude, and λ is the eastward longitude.

Let us define the radial displacement S_r, the horizontal displacements S_θ and S_λ, positive upwards, south and east respectively, in a horizon system at the station due to ΔV using the formulation of tidal Love numbers (W. Munk and G. MacDonald, 1960).

$$S_r = h \, \frac{\Delta V}{g},$$

$$S_\theta = \frac{\ell}{g} \, \partial_\theta \Delta V, \tag{11}$$

$$S_\lambda = \frac{\ell}{g} \, \frac{1}{\sin \theta} \, \partial_\lambda \Delta V,$$

where g is the gravitational acceleration at the Earth's surface, h, ℓ are the second-order body tide displacement Love Numbers.

In general, these computed displacements have a non-zero average over any given time span because m_1 and m_2, used to find ΔV, have a non-zero average. Consequently, the use of these results will lead to a change in the estimated mean station coordinates. When mean coordinates produced by different users are compared at the centimeter level, it is important to ensure that this effect has been handled consistently. It is recommended that m_1 and m_2 used in eq. 10 be replaced by parameters defined to be zero for the Terrestrial Reference Frame discussed in Chapter 3.

Thus, define

$$x_p = m_1 - \bar{x}, \qquad y_p = -m_2 - \bar{y}, \tag{12}$$

where $\overline{x}$ and $\overline{y}$ are the values of m_1 and $-m_2$ for the Chapter 3 Terrestrial Reference Frame. Then, using $h = 0.6$, $\ell = 0.085$, and $r = a = 6.4 \times 10^6$m,

$$S_r = -32 \sin 2\theta \ (x_p \cos \lambda - y_p \sin \lambda) \text{ mm},$$

$$S_\theta = -9 \cos 2\theta \ (x_p \cos \lambda - y_p \sin \lambda) \text{ mm}, \tag{13}$$

$$S_\lambda = 9 \cos \theta \ (x_p \sin \lambda + y_p \cos \lambda) \text{ mm}.$$

for x_p and y_p in seconds of arc.

Taking into account that x_p and y_p vary, at most, 0.8 arcsec, the maximum radial displacement is approximately 25 mm, and the maximum horizontal displacement is about 7 mm.

If X, Y, and Z are Cartesian coordinates of a station in a right-hand equatorial coordinate system, we have the displacements of coordinates

$$[dX, dY, dZ]^T = R^T [S_\theta, S_\lambda, S_r]^T, \tag{14}$$

where

$$R = \begin{bmatrix} \cos\theta \cos\lambda & \cos\theta \sin\lambda & -\sin\theta \\ -\sin\lambda & \cos\lambda & 0 \\ \sin\theta \cos\lambda & \sin\theta \sin\lambda & \cos\theta \end{bmatrix}$$

The formula (13) can be used for determination of the corrections to station coordinates due to polar tide.

The deformation caused by the polar tide also leads to time-dependent perturbations in the C_{21} and S_{21} geopotential coefficients. The change in the external potential caused by this deformation is $k_2\Delta V$, where ΔV is given by eq. 10. Using $k_2 = 0.30$ gives

$$\overline{C}_{21} = -1.3 \times 10^{-9} \ (x_p),$$

$$\overline{S}_{21} = -1.3 \times 10^{-9} \ (-y_p),$$

where x_p and y_p are in seconds of arc and are used instead of m_1 and $-m_2$ so that no mean is introduced into $\overline{C}_{21}$ and $\overline{S}_{21}$ when making this correction.

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CHAPTER 8 OCEAN TIDE MODEL

The dynamical effect of ocean tides is most easily implemented as periodic variations in the normalized geopotential coefficients. The variations can be written as (Eanes, *et al.*, 1983):

$$\Delta\bar{C}_{nm} - i\Delta\bar{S}_{nm} = F_{nm} \sum_{s(n,m)} \sum_{+}^{-} (C^{\pm}_{snm} \mp i S^{\pm}_{snm}) e^{\pm i\theta_s}, \qquad (1)$$

where

$$F_{nm} = \frac{4\pi G\rho_w}{g}\sqrt{\frac{(n+m)!}{(n-m)!(2n+1)(2-\delta_{om})}}\frac{1+k'_n}{2n+1},$$

g = 9.798261 ms^{-2},

G = The universal gravitational constant = 6.673 × $10^{-11} m^3 kg^{-1} s^{-2}$,

ρ_w = density of seawater = 1025 kg m^{-3},

k'_n = load deformation coefficients (k'_2 = −0.3075, k'_3 = −0.195, k'_4 = −0.132, k'_5 = −0.1032, k'_6 = −0.0892),

$C^{\pm}_{snm}$, $S^{\pm}_{snm}$ = ocean tide coefficients in m for the tide constituent s (see Table 8.2),

θ_s = argument of the tide constituent s as defined in the solid tide model (Chapter 7).

The summation, $\sum_{+}^{-}$, implies addition of the expression using the top signs (the prograde waves C^{+}_{snm} and S^{+}_{snm}) to that using the bottom signs (the retrograde waves C^{-}_{snm} and S^{-}_{snm}). The ocean tide coefficients $C^{\pm}_{snm}$ and $S^{\pm}_{snm}$ as used here are related to the Schwiderski (1983) ocean tide amplitude and phase by

$$C^{\pm}_{snm} - iS^{\pm}_{snm} = -i\hat{C}^{\pm}_{snm}\, e^{i(\epsilon^{\pm}_{snm} + \chi_s)}, \qquad (2)$$

where

$\hat{C}^{\pm}_{snm}$ = ocean tide amplitude for constituent s using the Schwiderski notation,

$\epsilon^{\pm}_{snm}$ = ocean tide phase for constituent s,

and χ_s is obtained from Table 8.1, with H_s being the Cartwright and Tayler amplitude at frequency s.

Table 8.1. Values of χ_s for long-period, diurnal and semidiurnal tides.

Tidal Band	$H_s \geq 0$	$H_s < 0$
Long Period	π	0
Diurnal	$\pi/2$	$-\pi/2$
Semi-diurnal	0	π

For clarity, equation 1 is rewritten in two forms below:

$$\Delta\bar{C}_{nm} = F_{nm} \sum_{s(n,m)} [(C^{+}_{snm} + C^{-}_{snm}) \cos\theta_s + (S^{+}_{snm} + S^{-}_{snm}) \sin\theta_s] \quad (3a)$$

or

$$\Delta\bar{C}_{nm} = F_{nm} \sum_{s(n,m)} [\hat{C}^{+}_{snm} \sin(\theta_s + \epsilon^{+}_{snm} + \chi_s) + \hat{C}^{-}_{snm} \sin(\theta_s + \epsilon^{-}_{snm} + \chi_s)], \quad (3b)$$

$$\Delta\bar{S}_{nm} = F_{nm} \sum_{s(n,m)} [(S^{+}_{snm} - S^{-}_{snm}) \cos\theta_s - (C^{+}_{snm} - C^{-}_{snm}) \sin\theta_s] \quad (3c)$$

or

$$\Delta\bar{S}_{nm} = F_{nm} \sum_{s(n,m)} [\hat{C}^{+}_{snm} \cos(\theta_s + \epsilon^{+}_{snm} + \chi_s) - \hat{C}^{-}_{snm} \cos(\theta_s + \epsilon^{-}_{snm} + \chi_s)]. \quad (3d)$$

The summation over s(n,m) should include all constituents for which Schwiderski has computed a model. Except for cases of near resonance, the retrograde terms do not produce long period (> 1 day) orbit perturbations for the diurnal and semi-diurnal tides. The rms of the along-track perturbations on Lageos due to the combination of all of the retrograde waves is less than 5 cm.

For computing inclination and node perturbations, only the even degree terms are required, but for the eccentricity and periapsis the odd degree terms are not negligible. Long period perturbations are only produced when the degree (n) is greater than 1 and the order (m) is 0 for long period tides, 1 for diurnal tides, and 2 for semi-diurnal tides. Finally, the ocean tide amplitudes and their effect on satellite orbits decrease with increasing degree, so truncation above degree 6 is justified for Lageos.

Thus, for the diurnal tides (Q_1, O_1, P_1, K_1) only the n = 2, 3, 4, 5, 6 and m = 1 terms need be computed. For the semi-diurnal tides (N_2, M_2, S_2, K_2) only n = 2, 3, 4, 5, 6 and m = 2 terms need be computed. For the long period tides (S_{sa}, M_m, M_f) only n = 2, 3, 4, 5, 6 and m = 0 terms need be computed. Table 8.2 gives the values required for each of the constituents for which Schwiderski has computed a model. Note that the units in Table 8.2 are cm and hence must be scaled to m for use with the constants given for use with equation (1).

The n = 2, m = 2 term for the S_2 argument can be modified to account for the atmospheric tide using the results of Chapman and Lindzen (1970). The modified values to be used instead of those in Table 8.2 are:

$$C^{+}_{22} = -0.537 \text{ (cm)}, \quad S^{+}_{22} = 0.321 \text{ (cm)}.$$

For the most precise applications, more than the 11 terms listed in Table 8.2 need to be modelled. This can be accomplished by assuming that the ocean tide admittance varies smoothly with frequency and by using the Schwiderski values as a guide to the interpolation to other frequencies.

Table 8.2. Ocean tide coefficients from the Schwiderski model.

ARGUMENT NUMBER		n	m	$\hat{C}^{+}_{snm}$ (cm)	ε^{+}_{snm} (deg)	C^{+}_{snm} (cm)	S^{+}_{snm} (cm)
057.555	S_{sa}	2	0	.6215	221.672	-.8264	-.9284
057.555	S_{sa}	3	0	.0311	1.735	.0019	.0621
057.555	S_{sa}	4	0	.1624	92.674	.3244	-.0152
057.555	S_{sa}	5	0	.2628	251.737	-.4991	-.1647
057.555	S_{sa}	6	0	.4363	145.744	.4912	-.7213
065.455	M_m	2	0	.5313	258.900	-1.0428	-.2046
065.455	M_m	3	0	.0317	94.298	.0632	-.0047
065.455	M_m	4	0	.0998	69.054	.1863	.0713
065.455	M_m	5	0	.2279	292.291	-.4218	.1729
065.455	M_m	6	0	.0660	39.882	.0847	.1014
075.555	M_f	2	0	.8525	251.956	-1.6211	-.5281
075.555	M_f	3	0	.0951	148.236	.1001	-.1617
075.555	M_f	4	0	.2984	102.723	.5822	-.1315
075.555	M_f	5	0	.2960	223.167	-.4050	-.4318
075.555	M_f	6	0	.0880	107.916	.1675	-.0542
135.655	Q_1	2	1	.5373	313.735	-.3715	-.3882
135.655	Q_1	3	1	.3136	107.346	.0935	.2994
135.655	Q_1	4	1	.2930	288.992	-.0953	-.2770
135.655	Q_1	5	1	.2209	112.383	.0841	.2042
135.655	Q_1	6	1	.0396	287.824	-.0121	-.0377
145.555	O_1	2	1	2.4186	313.716	-1.6715	-1.7481
145.555	O_1	3	1	1.3161	83.599	-.1467	1.3079
145.555	O_1	4	1	1.4301	276.282	-.1565	-1.4215
145.555	O_1	5	1	.9505	109.128	.3115	.8980
145.555	O_1	6	1	.1870	282.623	-.0409	-.1825

Table 8.2 (continued)

ARGUMENT NUMBER	n	m	$\hat{C}^{+}_{snm}$ (cm)	ε^{+}_{snm} (deg)	C^{+}_{snm} (cm)	S^{+}_{snm} (cm)
163.555 P_1	2	1	.9020	313.912	-.6256	-.6498
163.555 P_1	3	1	.2976	39.958	-.2281	.1911
163.555 P_1	4	1	.6346	258.311	.1286	-.6215
163.555 P_1	5	1	.4130	104.438	.1030	.4000
163.555 P_1	6	1	.0583	276.591	-.0067	-.0579
165.555 K_1	2	1	2.8158	315.113	1.9950	1.9872
165.555 K_1	3	1	.8925	33.752	.7421	-.4959
165.555 K_1	4	1	1.9121	254.229	-.5197	1.8401
165.555 K_1	5	1	1.2111	104.672	-.3068	-1.1716
165.555 K_1	6	1	.1645	281.867	.0338	.1610
245.655 N_2	2	2	.6516	321.788	-.4030	.5120
245.655 N_2	3	2	.1084	171.923	.0152	-.1074
245.655 N_2	4	2	.2137	141.779	.1322	-.1679
245.655 N_2	5	2	.0836	5.034	.0073	.0832
245.655 N_2	6	2	.0674	346.544	-.0157	.0656
255.555 M_2	2	2	2.9551	310.553	-2.2453	1.9213
255.555 M_2	3	2	.3610	168.623	.0712	-.3539
255.555 M_2	4	2	1.0066	124.755	.8270	-.5738
255.555 M_2	5	2	.2751	356.561	-.0165	.2746
255.555 M_2	6	2	.4130	329.056	-.2124	.3542
273.555 S_2	2	2	.9291	314.011	-.6682	.6456
273.555 S_2	3	2	.2633	201.968	-.0985	-.2442
273.555 S_2	4	2	.3716	103.027	.3621	-.0838
273.555 S_2	5	2	.1365	3.772	.0090	.1362
273.555 S_2	6	2	.1726	280.381	-.1698	.0311
275.555 K_2	2	2	.2593	315.069	-.1832	.1836
275.555 K_2	3	2	.0943	195.007	-.0244	-.0911
275.555 K_2	4	2	.1059	103.521	.1029	-.0247
275.555 K_2	5	2	.0382	.411	.0003	.0382
275.555 K_2	6	2	.0467	281.357	-.0458	.0092

NOTES:

1. The Doodson variable multipliers ($\bar{n}$) are coded into the argument number (A) after Doodson (*Proc. R. Soc. A.*, **100**, pp. 305-329, 1921) as:

   $A = n_1(n_2+5)(n_3+5) \ . \ (n_4+5)(n_5+5)(n_6+5)$.

2. For the long period tides (m = 0), the value of $\hat{C}^{+}_{snm}$ used to compute C^{+}_{snm} and S^{+}_{snm} was twice that shown to account for the combined effect of the retrograde and prograde waves.

3. The spherical harmonic decomposition of Schwiderski's models was computed by C. Goad of the Ohio State University.

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Schwiderski, E., 1983, "Atlas of Ocean Tidal Charts and Maps, Part I: The Semidiurnal Principal Lunar Tide M_2," *Marine Geodesy*, **6**, pp. 219-256. (See also Chapter 8).

CHAPTER 9 LOCAL SITE DISPLACEMENT

Ocean Loading

The three components (radial, East-West, North-South) of the site displacements are given by the loading mass convolution with the Green's function of the loading problems as the integration kernel (Farrell, 1972). For practical computations, the integral is replaced by a sum over a discrete ocean tide model grid (Scherneck, 1983). The resulting displacements computed according to Scherneck (1991) are given in Table 9.1.

Schwiderski's (1983) revised global ocean tide models were adopted (*cf.* Schwiderski and Szeto, 1981), which comprise the semidiurnal waves M_2, S_2, N_2, K_2, the diurnal waves K_1, O_1, P_1, Q_1, and the long-period waves M_f, M_m, and S_{sa}. They are given on a 1° by 1° grid.

In the case of European stations (Wettzell, Onsala, Madrid), regional tide models for the North-East Atlantic by Flather (1981) were included in the case of the tides M_2, S_2, K_1, and O_1. They are given on a ½° by ⅓° grid.

Loading Green's functions for an oceanic Earth structure were adopted from Farrell (1972) in the case of those stations where ocean loading within a zone of 300 km radius around the site is predominantly on ocean lithosphere. These Green's functions are valid for an elastic Earth model. In the case of inland stations or sites on a wide continental shelf, Green's functions for a visco-elastic structure according to PREM-C (Zschau, 1983) were used.

The discrete point mass convolution formulation is too crude if the distance between the loading mass and the site is less than ten times the mesh width. In this case, the grid cell was subdivided into 25 or 26 elements. The tide height was linearly interpolated on this regionally refined grid. Since Schwiderski's models specify observed tide elevation (as opposed to tide masses), refined coastlines in the region around the site were used to derive the actual tide mass in the water covered area. The coastlines were obtained using the ETOPO05 data set of the National Geophysical Data Center, Boulder CO.

Since the ocean tides imply cyclic redistribution of ocean water, the constraint of mass conservation applies. However, summing up all tide masses over the global grid leaves a small but significant mass imbalance. The loading effect of this imbalance was compensated assuming a uniform oceanic co-oscillating mass layer.

The average accuracy of the individual parameters presented is estimated to be better than ± five mm. The site displacements computed on the basis of Table 9.1 are estimated to be accurate on the ± three mm level.

A FORTRAN Subroutine "ARG" is included below to return the proper angular argument to be used with the Schwiderski phases.

```
C      SUBROUTINE ARG(IYEAR,DAY,ANGLE)
C
C   COMPUTES THE ANGULAR ARGUMENT WHICH DEPENDS ON TIME FOR 11
C   TIDAL ARGUMENT CALCULATIONS
C
C
C      ORDER OF THE 11 ANGULAR QUANTITIES IN VECTOR ANGLE
C
C   01-M2
C   02-S2
C   03-N2
C   04-K2
C   05-K1
C   06-O1
C   07-P1
C   08-Q1
C   09-Mf
C   10-Mm
C   11-Ssa
C
C   TAKEN FROM 'TABLE 1 CONSTANTS OF MAJOR TIDAL MODES'
C        WHICH DR. SCHWIDERSKI SENDS ALONG WITH HIS TAPE OF TIDAL
C        AMPLITUDES AND PHASES
C
C
C   INPUT--
C
C      IYEAR - EX. 79 FOR 1979
C      DAY - DAY OF YEAR GREENWICH TIME
C                        EXAMPLE 32.5 FOR FEB 1   12 NOON
C                                1.25 FOR JAN 1    6 AM
C
C   OUTPUT--
C
C      ANGLE - ANGULAR ARGUMENT FOR SCHWIDERSKI COMPUTATION
C
C************************************************************
C
C
C              C A U T I O N
C
C   OCEAN LOADING PHASES COMPUTED FROM SCHWIDERSKI'S MODELS
C   REFER TO THE PHASE OF THE ASSOCIATED SOLID EARTH TIDE
C   GENERATING POTENTIAL AT THE ZERO MERIDIAN ACCORDING TO
C
C       OL_DR = OL_AMP × COS (SE_PHASE" - OL_PHASE)
C
C   WHERE OL = OCEAN LOADING TIDE,
```

```
C        SE = SOLID EARTH TIDE GENERATING POTENTIAL.
C
C  IF THE HARMONIC TIDE DEVELOPMENT OF CARTWRIGHT, ET AL.
C  ( = CTE) (1971, 1973) IS USED, MAKE SURE THAT SE_PHASE"
C  TAKES INTO ACCOUNT
C
C  (1) THE SIGN OF SE_AMP IN THE TABLES OF CARTWRIGHT ET AL.
C
C  (2) THAT CTE'S SE_PHASE REFERS TO A SINE RATHER THAN A
C      COSINE FUNCTION IF (N+M) = (DEGREE + ORDER) OF THE
C      TIDE SPHERICAL HARMONIC IS ODD.
C
C  I.E. SE_PHASE" = TAU(T) X N1 + S(T) X N2 + H(T) X N3
C                 + P(T) X N4 + N'(T) X N5 + PS(T) X N6
C                 + PI   IF CTE'S AMPLITUDE COEFFICIENT < 0
C                 - PI/2 IF (DEGREE + N1) IS ODD
C
C  WHERE TAU ... PS = ASTRONOMICAL ARGUMENTS,
C         N1 ... N6 = CTE'S ARGUMENT NUMBERS.
C
C  MOST TIDE GENERATING SOFTWARE COMPUTE SE_PHASE" (FOR
C  USE WITH COSINES).
C
C  THIS SUBROUTINE IS VALID ONLY AFTER 1973.
C
C*******************************************************************
      SUBROUTINE ARG(IYEAR,DAY,ANGLE)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      REAL ANGFAC(4,11)
      DIMENSION ANGLE(11),SPEED(11)
C
C  SPEED OF ALL TERMS IN RADIANS PER SEC
C
      EQUIVALENCE (SPEED(1),SIGM2),(SPEED(2),SIGS2),(SPEED(3),SIGN2)
      EQUIVALENCE (SPEED(4),SIGK2),(SPEED(5),SIGK1),(SPEED(6),SIGO1)
      EQUIVALENCE (SPEED(7),SIGP1),(SPEED(8),SIGQ1),(SPEED(9),SIGMF)
      EQUIVALENCE (SPEED(10),SIGMM),(SPEED(11),SIGSSA)
      DATA SIGM2/1.40519D-4/
      DATA SIGS2/1.45444D-4/
      DATA SIGN2/1.37880D-4/
      DATA SIGK2/1.45842D-4/
      DATA SIGK1/.72921D-4/
      DATA SIGO1/.67598D-4/
      DATA SIGP1/.72523D-4/
      DATA SIGQ1/.64959D-4/
      DATA SIGMF/.053234D-4/
      DATA SIGMM/.026392D-4/
      DATA SIGSSA/.003982D-4/
      DATA ANGFAC/2.E0,-2.E0,0.E0,0.E0,4*0.E0,
     .            2.E0,-3.E0,1.E0,0.E0,2.E0,3*0.E0,
     .            1.E0,2*0.E0,.25E0,1.E0,-2.E0,0.E0,-.25E0,
     .            -1.E0,2*0.E0,-.25E0,1.E0,-3.E0,1.E0,-.25E0,
     .            0.E0,2.E0,2*0.E0,0.E0,1.E0,-1.E0,0.E0,
     .            2.E0,3*0.E0/
      DATA TWOPI/6.28318530718D0/
      DATA DTR/.174532925199D-1/
C
C  DAY OF YEAR
C
      ID=DAY
C
C  FRACTIONAL PART OF DAY IN SECONDS
```

```
C
      FDAY=(DAY-ID)*86400.D0
      ICAPD=ID+365*(IYEAR-75)+((IYEAR-73)/4)
      CAPT=(27392.500528D0+1.000000035D0*ICAPD)/36525.D0
C
C MEAN LONGITUDE OF SUN AT BEGINNING OF DAY
C
      H0=(279.69668D0+(36000.768930485D0+3.03D-4*CAPT)*CAPT)*DTR
C
C MEAN LONGITUDE OF MOON AT BEGINNING OF DAY
C
      S0=(((1.9D-6*CAPT-.001133D0)*CAPT+481267.88314137D0)*CAPT
     .  +270.434358D0)*DTR
C
C MEAN LONGITUDE OF LUNAR PERIGEE AT BEGINNING OF DAY
C
      P0=(((-1.2D-5*CAPT-.010325D0)*CAPT+4069.0340329577D0)*CAPT
     .  +334.329653D0)*DTR
      DO 500 K=1,11
      ANGLE(K)=SPEED(K)*FDAY+ANGFAC(1,K)*H0+ANGFAC(2,K)*S0
     .  +ANGFAC(3,K)*P0+ANGFAC(4,K)*TWOPI
      ANGLE(K)=DMOD(ANGLE(K),TWOPI)
      IF(ANGLE(K).LT.0.D0)ANGLE(K)=ANGLE(K)+TWOPI
  500 CONTINUE
      RETURN
      END
```

Table 9.1 Ocean Loading Parameters:

The table specifies (1) the Darwin tide symbols as the header of column j, (2) for each site, site name and geographic coordinates and (3) for each displacement component, amplitudes A_{cj} (m) and phases Φ_{cj} (deg). Let Δc denote the displacement component of a particular site at time t. Let the tidal frequency be given by ω_j and the astronomical argument at t= 0 by χ_j (given by subroutine ARG above). Then,

$$\Delta c = \sum_j f_j A_{cj} \cos(\omega_j t + \chi_j + u_j - \Phi_{cj}),$$

where f_j and u_j depend on the longitude of the lunar node according to Table 26 of Doodson (1928). Tangential displacements are to be taken positive in west and south directions..

ADEA4240

ADEA424042 lon/lat: 140°0014 -66°6617

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00508	.00279	.00108	.00073	.01141	.01035	.00276	.00237	.00127	.00079	.00112
Tangential (EW)	.00173	.00108	.00052	.00032	.00124	.00104	.00035	.00022	.00007	.00012	.00020
Tangential (NS)	.00227	.00097	.00052	.00024	.00232	.00200	.00063	.00041	.00017	.00015	.00027
Phases (deg)											
Radial	-102.9	-79.6	-121.6	-75.4	43.6	29.4	40.7	18.3	17.2	-9.3	-12.1
Tangential (EW)	152.1	-160.4	148.9	-149.2	-11.0	-34.5	-16.3	-45.5	10.1	46.3	75.2
Tangential (NS)	-126.6	-75.4	-143.5	-68.4	63.6	43.1	62.0	34.3	16.4	-4.8	0.4

ALASKANO

ALASKANO lon/lat: -147°4975 64°9775

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00779	.00324	.00112	.00082	.00501	.00348	.00161	.00064	.00072	.00044	.00012
Tangential (EW)	.00063	.00025	.00017	.00009	.00095	.00071	.00030	.00017	.00004	.00000	.00017
Tangential (NS)	.00332	.00133	.00058	.00036	.00202	.00127	.00064	.00023	.00013	.00012	.00021
Phases (deg)											
Radial	101.4	139.7	87.1	135.6	96.5	88.2	95.9	81.7	17.8	20.6	-117.6
Tangential (EW)	103.0	-81.6	56.1	-63.5	-1.6	-36.2	-3.6	-41.0	-179.4	131.4	147.3
Tangential (NS)	-90.1	-49.3	-104.5	-50.5	-101.1	-112.1	-101.3	-116.6	147.0	-136.7	-132.0

ALGO 90

ALGO 9001 lon/lat: -78°0714 45°9545

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00562	.00173	.00098	.00051	.00273	.00170	.00091	.00034	.00032	.00009	.00063
Tangential (EW)	.00303	.00070	.00064	.00021	.00035	.00030	.00012	.00007	.00005	.00007	.00025
Tangential (NS)	.00045	.00036	.00013	.00011	.00005	.00017	.00002	.00005	.00005	.00004	.00007
Phases (deg)											
Radial	150.2	-175.3	125.6	-175.9	-0.9	-2.5	1.9	2.1	13.4	-40.3	-66.7
Tangential (EW)	-162.8	-141.2	174.7	-144.8	119.2	-176.4	-124.5	163.6	-8.5	-141.2	-93.2
Tangential (NS)	11.1	52.9	28.9	47.7	114.7	-98.1	74.5	-150.1	-1[illegible]9.7	-163.8	42.5

ALGO PARK

ALGOPARK lon/lat: -78°0727 45°9555

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00570	.00179	.00098	.00052	.00281	.00176	.00093	.00037	.00025	.00007	.00027
Tangential (EW)	.00278	.00066	.00060	.00019	.00032	.00019	.00010	.00004	.00005	.00004	.00014
Tangential (NS)	.00052	.00030	.00013	.00008	.00012	.00011	.00003	.00004	.00009	.00007	.00005
Phases (deg)											
Radial	150.4	-175.1	127.4	-176.0	-0.5	-3.1	1.1	1.8	13.1	-1.5	-174.1
Tangential (EW)	-163.0	-137.4	173.4	-142.2	-101.8	-161.3	-105.1	165.1	-6.8	-149.6	-93.7
Tangential (NS)	1.0	49.7	14.0	46.0	123.5	-132.0	118.4	-170.2	-147.6	-158.3	-32.3

AMSA8 40

AMSA8 4008 lon/lat: 77°5714 -37°7972

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.02082	.01334	.00472	.00359	.00562	.00452	.00189	.00080	.00016	.00057	.00204
Tangential (EW)	.00059	.00040	.00007	.00013	.00151	.00106	.00047	.00016	.00002	.00005	.00018
Tangential (NS)	.00278	.00129	.00066	.00031	.00080	.00084	.00028	.00019	.00007	.00009	.00007
Phases (deg)											
Radial	56.4	92.7	37.3	93.0	7.4	25.2	6.5	19.2	33.1	-95.7	-46.6
Tangential (EW)	10.3	100.0	33.0	102.6	39.0	19.3	37.7	-0.7	-145.2	-28.5	45.9
Tangential (NS)	96.5	108.0	92.3	107.3	-96.8	-104.2	-91.6	-126.5	-142.5	174.0	-121.9

AM-SOM70

AM-SOM7096 lon/lat: -170°7249 -14°3348

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.02596	.00565	.00687	.00148	.00361	.00244	.00137	.00059	.00099	.00056	.00113
Tangential (EW)	.00253	.00132	.00067	.00036	.00162	.00097	.00048	.00020	.00003	.00007	.00002
Tangential (NS)	.00423	.00177	.00053	.00045	.00087	.00029	.00022	.00004	.00005	.00004	.00012
Phases (deg)											
Radial	-6.4	-13.4	-19.5	-19.0	-133.6	-138.4	-135.7	-153.3	-162.7	-156.2	-121.8
Tangential (EW)	176.6	168.4	159.3	169.1	37.2	15.8	34.7	-9.6	-90.2	-128.6	129.3
Tangential (NS)	-91.7	-39.9	-122.0	-42.8	35.9	42.5	26.9	80.9	-143.2	-164.3	117.4

AREA4640

AREA464046	lon/lat:	-71°4931	-16°4651								
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00404	.00090	.00149	.00037	.00516	.00261	.00404	.00048	.00044	.00015	.00025
Tangential (EW)	.00213	.00044	.00042	.00018	.00153	.00079	.00069	.00013	.00005	.00003	.00019
Tangential (NS)	.00311	.00086	.00064	.00025	.00101	.00052	.00104	.00009	.00004	.00004	.00027
Phases (deg)											
Radial	132.8	101.7	98.8	111.4	-140.8	-163.0	-147.8	178.9	-177.6	-174.9	-29.7
Tangential (EW)	15.7	17.4	-22.6	-8.4	43.5	-1.3	38.7	-25.9	19.1	-140.8	-131.0
Tangential (NS)	45.6	97.3	13.2	96.1	84.7	67.0	42.8	39.2	-103.8	130.3	148.0

AREQUI79

AREQUI7907	lon/lat:	-71°4931	-16°4651								
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00404	.00090	.00149	.00037	.00516	.00261	.00404	.00048	.00044	.00015	.00025
Tangential (EW)	.00213	.00044	.00042	.00018	.00153	.00079	.00068	.00013	.00005	.00003	.00019
Tangential (NS)	.00311	.00086	.00064	.00025	.00101	.00052	.00104	.00009	.00004	.00004	.00027
Phases (deg)											
Radial	132.8	101.7	98.8	111.4	-140.8	-163.0	-147.8	178.9	-177.6	-174.9	-29.7
Tangential (EW)	15.7	17.4	-22.6	-8.4	43.5	-1.3	38.7	-25.9	19.1	-140.8	-131.0
Tangential (NS)	45.6	97.3	13.2	96.1	84.7	67.0	42.8	39.2	-103.8	130.3	148.0

ARLA3540

ARLA354035	lon/lat:	7°3773	18°7355								
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00504	.00159	.00099	.00043	.00054	.00030	.00019	.00013	.00025	.00015	.00010
Tangential (EW)	.00067	.00023	.00019	.00006	.00056	.00045	.00013	.00010	.00005	.00009	.00001
Tangential (NS)	.00059	.00009	.00020	.00005	.00043	.00046	.00011	.00015	.00006	.00003	.00013
Phases (deg)											
Radial	-68.3	-52.5	-78.9	-54.9	-160.1	34.9	-162.7	1.5	-151.3	-148.9	178.4
Tangential (EW)	34.9	-8.6	7.0	18.4	-120.1	-138.8	-116.7	-174.2	28.5	34.8	-78.6
Tangential (NS)	-114.0	-104.5	-162.5	-151.3	78.2	132.5	88.3	129.7	-82.0	121.0	103.5

ASKITE75

ASKITE7510	lon/lat:	25°5662	40°9268								
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00363	.00101	.00075	.00024	.00080	.00051	.00026	.00006	.00019	.00021	.00033
Tangential (EW)	.00198	.00042	.00051	.00011	.00033	.00015	.00013	.00004	.00005	.00002	.00005
Tangential (NS)	.00108	.00020	.00017	.00005	.00055	.00025	.00014	.00005	.00010	.00006	.00011
Phases (deg)											
Radial	-65.7	-39.4	-88.5	-40.5	-83.6	-113.2	-88.4	-120.5	11.5	2.5	42.3
Tangential (EW)	31.0	52.2	10.8	58.5	129.8	64.2	111.6	82.3	174.4	34.3	-126.7
Tangential (NS)	-81.3	-37.7	-116.4	-49.8	50.1	56.5	48.5	83.6	-143.0	171.6	124.8

AUSTIN TX

AUSTIN TX	lon/lat:	-97°6957	30°3393								
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00222	.00129	.00027	.00032	.00286	.00187	.00092	.00039	.00020	.00013	.00042
Tangential (EW)	.00148	.00034	.00033	.00011	.00166	.00118	.00052	.00023	.00006	.00003	.00028
Tangential (NS)	.00049	.00016	.00020	.00005	.00044	.00018	.00015	.00003	.00006	.00003	.00003
Phases (deg)											
Radial	129.7	-152.5	11.0	-139.4	25.1	11.4	22.5	9.0	164.7	-175.0	-168.6
Tangential (EW)	157.6	169.1	129.7	157.2	-146.9	-164.4	-148.7	-175.5	116.2	175.5	-129.8
Tangential (NS)	165.6	74.5	146.7	79.9	90.2	66.1	89.8	113.7	-121.1	-174.8	57.0

BARGI075

BARGI07530 lon/lat: 35°0885 31°7213

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00306	.00092	.00065	.00024	.00095	.00058	.00034	.00011	.00001	.00015	.00032
Tangential (EW)	.00205	.00048	.00050	.00011	.00055	.00022	.00018	.00007	.00004	.00001	.00009
Tangential (NS)	.00092	.00005	.00017	.00001	.00099	.00059	.00028	.00011	.00010	.00007	.00015
Phases (deg)											
Radial	-66.6	-46.1	-89.8	-48.9	-173.3	-158.4	-169.2	-163.2	170.4	5.9	54.8
Tangential (EW)	9.2	25.1	-6.3	28.3	154.6	144.4	146.0	137.6	-161.9	-30.7	-89.8
Tangential (NS)	-89.0	-17.3	-128.0	-59.1	46.6	47.4	45.9	46.8	-140.3	169.2	128.2

BARST072

BARST07265 lon/lat: -116°8913 35°3300

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00181	.00140	.00104	.00052	.00955	.00606	.00318	.00112	.00011	.00009	.00044
Tangential (EW)	.00241	.00081	.00042	.00020	.00320	.00206	.00106	.00036	.00008	.00004	.00031
Tangential (NS)	.00340	.00135	.00074	.00042	.00170	.00100	.00056	.00021	.00001	.00003	.00013
Phases (deg)											
Radial	-6.8	-110.7	-51.2	-88.9	44.0	29.6	41.5	21.5	-89.0	-155.5	15.3
Tangential (EW)	-137.2	-86.6	-164.4	-91.1	-133.5	-148.1	-135.7	-153.5	134.4	142.3	-147.8
Tangential (NS)	96.0	110.4	80.1	105.2	178.9	172.5	177.6	162.8	-57.8	100.7	-172.7

BASOV175

BASOV17550 lon/lat: 13°8756 45°6417

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00496	.00144	.00100	.00033	.00151	.00060	.00047	.00003	.00035	.00021	.00033
Tangential (EW)	.00229	.00056	.00056	.00016	.00032	.00025	.00014	.00004	.00007	.00005	.00005
Tangential (NS)	.00103	.00030	.00013	.00007	.00029	.00005	.00006	.00005	.00007	.00003	.00009
Phases (deg)											
Radial	-69.5	-40.6	-89.2	-42.4	-62.7	-100.7	-65.0	-103.3	5.3	-10.0	8.4
Tangential (EW)	56.0	85.2	30.4	84.3	102.0	29.5	85.4	31.1	156.5	51.7	171.9
Tangential (NS)	-50.7	-6.9	-64.9	-7.7	50.0	122.0	45.8	143.4	-136.3	148.2	112.3

BEARLA70

BEARLA7082 lon/lat: -111°4206 41°9324

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00301	.00131	.00041	.00027	.00599	.00385	.00193	.00073	.00015	.00004	.00034
Tangential (EW)	.00276	.00098	.00051	.00026	.00239	.00162	.00076	.00029	.00007	.00004	.00028
Tangential (NS)	.00175	.00074	.00042	.00023	.00107	.00058	.00032	.00014	.00003	.00003	.00008
Phases (deg)											
Radial	96.9	179.2	15.8	-163.2	47.2	33.6	45.8	26.5	0.4	3.5	-8.1
Tangential (EW)	-127.1	-82.8	-150.8	-86.1	-128.8	-144.7	-130.8	-150.9	138.4	171.2	-144.1
Tangential (NS)	109.4	108.9	92.5	103.4	175.7	171.3	170.5	161.6	-141.8	168.7	-159.0

BERMUDA

BERMUDA lon/lat: -64°6695 32°3612

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01992	.00458	.00425	.00139	.00467	.00349	.00152	.00083	.00035	.00055	.00117
Tangential (EW)	.00155	.00043	.00031	.00015	.00022	.00026	.00007	.00006	.00005	.00018	.00026
Tangential (NS)	.00244	.00057	.00057	.00014	.00061	.00067	.00021	.00015	.00007	.00006	.00007
Phases (deg)											
Radial	165.9	-162.5	144.9	-167.5	-2.4	5.6	-0.4	8.3	-68.5	-120.2	-128.1
Tangential (EW)	169.6	-171.1	137.8	-167.4	114.9	98.2	116.1	87.9	-59.9	-130.1	-75.9
Tangential (NS)	-144.3	-101.4	-170.4	-98.9	-91.4	-112.8	-91.8	-137.7	-39.9	92.5	45.7

BLKBUTTE

BLACK BUTTE lon/lat: -115°7198 33°6638

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00276	.00201	.00133	.00073	.00979	.00623	.00306	.00118	.00013	.00009	.00044
Tangential (EW)	.00210	.00057	.00037	.00013	.00339	.00218	.00106	.00038	.00008	.00003	.00032
Tangential (NS)	.00361	.00143	.00079	.00044	.00170	.00100	.00054	.00023	.00001	.00002	.00014
<u>Phases (deg)</u>											
Radial	-44.9	-96.6	-64.1	-82.4	41.3	.26.4	40.1	17.9	-109.2	-176.4	43.6
Tangential (EW)	-152.9	-99.5	176.4	-108.1	-136.9	-151.7	-137.6	-157.6	128.1	131.7	-146.2
Tangential (NS)	95.1	109.8	79.1	106.0	177.5	171.0	176.1	163.7	-94.8	166.6	-123.2

BLOOMIND

BLOOMIND lon/lat: -86°4984 39°1793

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00459	.00155	.00063	.00041	.00268	.00184	.00089	.00039	.00007	.00001	.00034
Tangential (EW)	.00267	.00057	.00059	.00017	.00055	.00036	.00017	.00007	.00002	.00003	.00015
Tangential (NS)	.00031	.00015	.00012	.00004	.00018	.00001	.00006	.00003	.00008	.00006	.00004
<u>Phases (deg)</u>											
Radial	140.3	-175.2	110.0	-175.0	11.1	5.9	11.6	7.5	44.5	-163.9	-176.0
Tangential (EW)	-169.6	-144.1	167.0	-150.9	-133.8	-167.7	-136.8	174.3	21.7	-161.0	-113.7
Tangential (NS)	-164.3	57.5	146.3	57.8	101.5	-112.9	96.9	178.4	-138.4	-164.3	-14.2

BOLOGN75

BOLOGN7546 lon/lat: 11°6465 44°5188

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00541	.00159	.00108	.00037	.00155	.00056	.00048	.00001	.00034	.00019	.00031
Tangential (EW)	.00243	.00061	.00058	.00018	.00029	.00023	.00014	.00003	.00007	.00006	.00005
Tangential (NS)	.00117	.00036	.00016	.00008	.00026	.00007	.00005	.00006	.00006	.00003	.00009
<u>Phases (deg)</u>											
Radial	-71.2	-42.9	-90.5	-45.6	-63.1	-100.2	-65.4	-72.1	2.0	-16.9	0.6
Tangential (EW)	58.5	86.9	32.9	85.2	101.7	23.3	83.5	26.3	151.4	50.9	161.6
Tangential (NS)	-49.6	-7.8	-63.6	-8.6	49.4	151.6	45.1	146.3	-130.9	148.6	115.3

BOROWC78

BOROWC7811 lon/lat: 17°0746 52°2757

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00400	.00113	.00079	.00025	.00170	.00082	.00053	.00007	.00050	.00032	00044
Tangential (EW)	.00189	.00042	.00047	.00012	.00044	.00042	.00018	.00008	.00010	.00002	.00007
Tangential (NS)	.00048	.00013	.00004	.00003	.00028	.00006	.00006	.00003	.00004	.00002	.00013
<u>Phases (deg)</u>											
Radial	-64.7	-31.5	-84.9	-28.5	-57.8	-101.8	-60.1	-129.9	13.1	1.8	15.7
Tangential (EW)	54.6	90.4	27.5	89.1	93.7	36.8	82.7	26.9	168.4	66.2	177.0
Tangential (NS)	-36.8	24.7	7.6	36.7	47.4	-33.3	37.8	162.0	-158.3	101.1	94.4

BREST

BREST lon/lat: -4°5038 48°4079

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.03844	.01290	.00749	.00336	.00401	.00141	.00123	.00046	.00095	.00049	.00065
Tangential (EW)	.00293	.00101	.00168	.00077	.00012	.00004	.00020	.00011	.00017	.00020	.00015
Tangential (NS)	.00639	.00278	.00119	.00070	.00050	.00033	.00016	.00008	.00001	.00007	.00010
<u>Phases (deg)</u>											
Radial	-58.6	-20.6	-83.3	-27.4	-70.5	-170.7	-72.5	92.8	-22.7	-100.0	-78.6
Tangential (EW)	44.3	83.1	71.0	122.8	-30.0	-79.6	82.2	-72.2	135.3	47.3	107.7
Tangential (NS)	29.0	67.2	14.2	61.2	0.7	-95.6	-0.3	-167.5	1.9	42.1	78.5

CABO S78

CABO S7882 lon/lat: -109°8644 22°9166

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01231	.00787	.00329	.00244	.01126	.00758	.00360	.00152	.00060	.00045	.00094
Tangential (EW)	.00183	.00046	.00039	.00016	.00279	.00170	.00089	.00029	.00006	.00002	.00026
Tangential (NS)	.00281	.00113	.00053	.00032	.00114	.00073	.00026	.00018	.00005	.00004	.00023
Phases (deg)											
Radial	-84.8	-76.9	-83.5	-78.1	22.7	7.5	16.2	-2.9	-154.2	-155.9	17.1
Tangential (EW)	103.3	150.3	68.4	130.4	-143.0	-160.6	-145.2	-170.6	102.1	127.2	-147.5
Tangential (NS)	71.4	91.5	68.4	88.2	157.2	169.0	138.2	161.4	3.7	63.8	167.8

CAGLIA75

CAGLIA7545 lon/lat: 8°9730 39°1342

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00570	.00171	.00114	.00041	.00134	.00037	.00041	.00004	.00023	.00013	.00023
Tangential (EW)	.00246	.00065	.00059	.00020	.00016	.00011	.00009	.00000	.00005	.00007	.00003
Tangential (NS)	.00156	.00048	.00025	.00011	.00023	.00018	.00004	.00009	.00008	.00004	.00008
Phases (deg)											
Radial	-75.1	-50.4	-93.8	-54.9	-68.0	-94.3	-70.5	10.4	-9.5	-40.4	-8.6
Tangential (EW)	54.0	76.2	29.5	75.5	118.9	-7.4	83.7	57.9	134.5	45.6	156.3
Tangential (NS)	-64.0	-26.0	-88.2	-31.0	53.4	150.3	56.8	141.8	-120.7	164.3	131.3

CANB 90

CANB 9002 lon/lat: 148°9818 -35°3999

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00952	.00128	.00207	.00033	.00273	.00275	.00118	.00080	.00011	.00009	.00069
Tangential (EW)	.00507	.00179	.00091	.00049	.00123	.00072	.00040	.00014	.00003	.00015	.00009
Tangential (NS)	.00113	.00036	.00018	.00012	.00142	.00126	.00048	.00028	.00005	.00007	.00025
Phases (deg)											
Radial	126.0	172.4	95.8	162.7	119.5	67.8	110.9	55.9	-24.4	-101.6	-82.8
Tangential (EW)	93.1	126.4	82.5	128.8	-169.3	168.5	-169.8	147.6	-105.4	73.2	135.6
Tangential (NS)	9.1	72.1	-36.6	78.5	-117.6	-143.7	-117.8	-160.5	-139.9	83.6	118.4

CARNUSTY

CARNOUSTIE lon/lat: -2°7830 56°4785

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.02365	.00873	.00351	.00164	.00536	.00324	.00120	.00061	.00123	.00095	.00066
Tangential (EW)	.00768	.00296	.00142	.00066	.00105	.00069	.00034	.00015	.00008	.00020	.00009
Tangential (NS)	.00205	.00076	.00075	.00030	.00078	.00036	.00015	.00010	.00005	.00013	.00022
Phases (deg)											
Radial	-104.8	-72.4	-110.6	-45.4	-20.8	-128.9	-25.6	-177.5	4.7	22.2	-17.4
Tangential (EW)	-83.2	-51.3	-177.5	-115.3	3.1	-148.6	80.2	-126.4	102.2	41.3	17.4
Tangential (NS)	152.0	-171.6	83.8	124.9	6.9	-122.2	7.[illegible]	173.8	110.7	66.5	78.6

CARROLGA

CARROLLTON GA lon/lat: -85°1096 33°5726

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00507	.00164	.00072	.00043	.00228	.00156	.00076	.00034	.00011	.00007	.00047
Tangential (EW)	.00297	.00061	.00066	.00018	.00028	.00020	.00008	.00004	.00002	.00002	.00015
Tangential (NS)	.00075	.00009	.00022	.00002	.00025	.00014	.00008	.00001	.00008	.00005	.00008
Phases (deg)											
Radial	142.7	-173.1	111.8	-175.1	5.2	2.7	6.2	7.5	138.3	170.2	-169.9
Tangential (EW)	-176.1	-155.3	161.9	-161.8	-149.5	152.4	-156.4	125.4	20.9	-164.1	-115.6
Tangential (NS)	-149.3	-12.5	174.2	-25.3	49.9	-13.4	46.5	-97.4	-120.7	-164.0	40.1

CEBRER26

CEBREROS 26 lon/lat: -4°3678 40°4531

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01375	.00459	.00291	.00121	.00232	.00031	.00070	.00021	.00035	.00022	.00021
Tangential (EW)	.00307	.00114	.00088	.00039	.00024	.00012	.00010	.00006	.00008	.00007	.00005
Tangential (NS)	.00310	.00114	.00060	.00030	.00032	.00026	.00009	.00009	.00009	.00005	.00008
<u>Phases (deg)</u>											
Radial	-87.5	-61.8	-106.9	-65.4	-71.0	-148.9	-73.1	58.4	-30.8	-110.4	-25.7
Tangential (EW)	-51.1	-20.5	41.7	85.8	-87.5	-171.8	64.9	-102.4	128.4	49.4	-36.0
Tangential (NS)	-56.3	-17.9	-77.1	-19.0	-29.2	-156.1	-39.4	155.3	-98.1	-176.7	175.3

CER TO74

CER TO7401 lon/lat: -70°8000 -30°1714

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00597	.00208	.00165	.00048	.00660	.00449	.00218	.00095	.00012	.00016	.00065
Tangential (EW)	.00364	.00093	.00079	.00021	.00188	.00109	.00063	.00022	.00002	.00007	.00033
Tangential (NS)	.00035	.00053	.00021	.00016	.00126	.00103	.00042	.00022	.00006	.00004	.00025
<u>Phases (deg)</u>											
Radial	-138.2	-74.8	176.9	-76.8	-134.0	-156.2	-134.5	-173.2	98.5	10.8	22.4
Tangential (EW)	52.5	83.4	24.8	61.8	41.8	-9.1	41.3	-36.2	-128.3	169.8	-139.8
Tangential (NS)	88.8	119.6	65.2	124.3	121.2	91.5	124.3	67.7	-154.9	161.3	130.6

CHAA3940

CHAA394039 lon/lat: -176°5720 -43°9559

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01911	.00253	.00406	.00066	.00100	.00071	.00026	.00028	.00061	.00042	.00040
Tangential (EW)	.00225	.00068	.00044	.00018	.00077	.00056	.00027	.00015	.00004	.00006	.00010
Tangential (NS)	.00452	.00109	.00089	.00033	.00101	.00095	.00036	.00025	.00009	.00003	.00013
<u>Phases (deg)</u>											
Radial	0.9	132.8	-27.0	143.7	-174.1	-8.0	165.7	-0.9	21.1	36.3	-39.4
Tangential (EW)	44.4	97.8	28.8	105.4	-38.5	-67.9	-48.9	-79.3	-5.6	-97.3	63.2
Tangential (NS)	50.8	88.5	20.3	93.5	-169.0	178.3	-172.1	164.5	-148.8	176.0	126.0

CHICHI78

CHICHI7844 lon/lat: 142°2168 27°0907

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01284	.00528	.00273	.00162	.01332	.00993	.00415	.00205	.00036	.00025	.00053
Tangential (EW)	.00327	.00160	.00046	.00038	.00119	.00101	.00040	.00022	.00001	.00006	.00022
Tangential (NS)	.00175	.00058	.00021	.00016	.00155	.00111	.00046	.00019	.00004	.00002	.00015
<u>Phases (deg)</u>											
Radial	86.0	100.2	85.4	104.9	-126.7	-146.1	-126.6	-155.1	-125.9	47.8	114.0
Tangential (EW)	-23.6	2.3	-28.3	7.1	177.6	153.5	-177.4	150.6	-19.0	-8.6	52.5
Tangential (NS)	-6.6	52.5	-22.5	40.8	118.0	101.4	120.1	85.6	-57.2	-175.8	110.2

CHLBOLTN

CHILBOLTN lon/lat: -1°4384 51°1450

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01122	.00347	.00193	.00065	.00328	.00120	.00099	.00014	.00080	.00034	.00039
Tangential (EW)	.00530	.00187	.00130	.00061	.00034	.00018	.00070	.00011	.00015	.00009	.00002
Tangential (NS)	.00097	.00029	.00023	.00019	.00051	.00033	.00015	.00007	.00006	.00008	.00017
<u>Phases (deg)</u>											
Radial	-39.7	2.0	-53.4	7.7	-57.7	-122.9	-61.6	136.3	-3.7	-23.3	-69.8
Tangential (EW)	-27.0	9.0	97.1	169.0	-76.0	166.9	104.8	-64.6	146.1	44.0	178.5
Tangential (NS)	99.1	107.3	-29.1	18.9	41.9	-67.6	49.4	-120.1	-176.7	89.9	88.2

CUBA 19

CUBA 1953 lon/lat: -75°7622 20°0111

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00637	.00207	.00109	.00064	.00271	.00225	.00088	.00052	.00066	.00045	.00182
Tangential (EW)	.00205	.00028	.00051	.00009	.00056	.00050	.00019	.00010	.00002	.00009	.00018
Tangential (NS)	.00348	.00074	.00088	.00021	.00025	.00044	.00009	.00012	.00005	.00005	.00012
<u>Phases (deg)</u>											
Radial	137.0	167.1	102.1	162.8	20.6	24.8	28.0	29.2	171.8	-157.6	-109.7
Tangential (EW)	173.0	172.4	152.4	179.0	77.6	62.9	83.0	56.3	-42.6	-129.0	-95.2
Tangential (NS)	-152.1	-93.1	-175.7	-90.7	-82.4	-110.4	-70.6	-138.1	-59.8	111.1	156.6

DAKA1840

DAKA184018 lon/lat: -17°4334 14°7313

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01686	.00467	.00402	.00123	.00197	.00193	.00093	.00064	.00101	.00114	.00121
Tangential (EW)	.00472	.00143	.00107	.00039	.00069	.00063	.00022	.00012	.00014	.00017	.00010
Tangential (NS)	.00663	.00221	.00155	.00062	.00035	.00081	.00014	.00024	.00014	.00007	.00018
<u>Phases (deg)</u>											
Radial	62.4	105.6	44.7	108.6	177.8	52.7	179.2	15.5	-161.8	-149.2	-113.9
Tangential (EW)	-105.3	-60.8	-117.2	-50.6	-70.3	-105.0	-46.4	-135.3	20.0	33.9	46.8
Tangential (NS)	-143.5	-117.9	-159.4	-123.5	-106.9	178.9	-96.3	153.9	-23.2	48.2	86.1

DEADMANL

DEADMAN LAKE lon/lat: -116°2789 34°2550

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00257	.00183	.00129	.00067	.00996	.00632	.00311	.00120	.00012	.00008	.00045
Tangential (EW)	.00224	.00067	.00039	.00016	.00338	.00217	.00105	.00038	.00008	.00004	.00032
Tangential (NS)	.00367	.00146	.00081	.00045	.00178	.00105	.00057	.00024	.00001	.00002	.00014
<u>Phases (deg)</u>											
Radial	-34.5	-99.1	-60.6	-82.7	42.1	27.3	41.1	18.9	-98.2	-179.1	45.1
Tangential (EW)	-146.7	-93.8	-176.3	-100.3	-135.7	-150.4	-136.3	-156.1	130.6	134.7	-146.7
Tangential (NS)	96.7	110.5	80.3	106.8	179.0	171.9	177.8	164.1	-107.7	165.4	-121.5

DIOA4740

DIOA474047 lon/lat: 23°9329 38°0772

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00379	.00107	.00078	.00026	.00072	.00043	.00024	.00005	.00015	.00017	.00030
Tangential (EW)	.00201	.00044	.00051	.00011	.00032	.00010	.00012	.00004	.00004	.00003	.00005
Tangential (NS)	.00114	.00022	.00018	.00005	.00057	.00028	.00014	.00006	.00010	.00006	.00011
<u>Phases (deg)</u>											
Radial	-67.8	-43.7	-89.7	-46.0	-90.6	-115.8	-95.6	-118.3	6.5	0.5	44.1
Tangential (EW)	31.3	49.0	11.2	55.7	143.7	90.8	122.5	109.7	171.2	34.0	-122.7
Tangential (NS)	-78.6	-34.5	-112.4	-47.3	53.3	65.7	53.3	89.6	-140.0	172.1	128.8

DIYARB75

DIYARB7575 lon/lat: 40°1949 37°9190

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00271	.00078	.00056	.00020	.00075	.00062	.00028	.00012	.00008	.00020	.00036
Tangential (EW)	.00191	.00042	.00047	.00009	.00044	.00019	.00015	.00005	.00005	.00001	.00007
Tangential (NS)	.00103	.00011	.00022	.00004	.00093	.00056	.00026	.00010	.00010	.00007	.00016
<u>Phases (deg)</u>											
Radial	-56.1	-27.9	-82.8	-28.2	-159.1	-143.7	-156.9	-149.2	32.4	7.5	52.1
Tangential (EW)	4.9	28.4	-10.6	30.7	128.4	83.2	119.5	94.9	-161.0	-60.1	-90.2
Tangential (NS)	-111.8	-117.2	-148.9	-116.8	38.2	36.1	35.3	32.3	-146.3	169.2	124.6

DJCB1041

DJCB104103 lon/lat: 42°.4453 11°.5344

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00521	.00260	.00109	.00074	.00566	.00277	.00165	.00063	.00047	.00009	.00031
Tangential (EW)	.00304	.00096	.00074	.00023	.00221	.00121	.00060	.00030	.00012	.00005	.00027
Tangential (NS)	.00195	.00080	.00037	.00021	.00146	.00090	.00045	.00017	.00006	.00002	.00019
Phases (deg)											
Radial	-91.9	-71.9	-95.3	-73.1	167.3	172.1	169.9	170.2	-169.1	-125.7	-29.2
Tangential (EW)	-11.5	4.1	-24.5	1.1	170.4	174.1	169.9	166.6	-164.5	-105.2	-63.7
Tangential (NS)	-1.7	54.5	-20.3	53.1	68.1	62.1	78.0	53.1	-101.0	126.3	114.3

DJIA2540

DJIA254025 lon/lat: 42°.8466 11°.5258

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00586	.00290	.00126	.00083	.00662	.00324	.00180	.00074	.00051	.00011	.00039
Tangential (EW)	.00336	.00109	.00083	.00027	.00251	.00134	.00063	.00033	.00014	.00006	.00029
Tangential (NS)	.00203	.00081	.00039	.00021	.00145	.00090	.00045	.00017	.00006	.00002	.00019
Phases (deg)											
Radial	-84.1	-65.5	-85.6	-66.7	167.6	172.5	169.7	170.8	-169.9	-122.7	-35.2
Tangential (EW)	-14.2	1.4	-26.7	-1.8	170.0	174.0	169.5	167.2	-165.8	-105.3	-62.8
Tangential (NS)	-3.3	51.9	-21.5	50.3	70.4	63.8	82.6	54.6	-102.8	125.7	113.9

DJMB1041

DJMB104102 lon/lat: 42°.5559 11°.6168

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00535	.00266	.00113	.00076	.00589	.00289	.00171	.00066	.00048	.00010	.00033
Tangential (EW)	.00313	.00100	.00077	.00024	.00229	.00124	.00062	.00031	.00013	.00005	.00027
Tangential (NS)	.00193	.00079	.00036	.00021	.00146	.00091	.00045	.00017	.00006	.00002	.00019
Phases (deg)											
Radial	-89.5	-69.9	-92.3	-71.1	167.4	172.2	169.8	170.4	-169.3	-124.4	-30.7
Tangential (EW)	-12.3	3.4	-25.2	0.2	170.2	174.0	169.7	166.7	-164.8	-105.0	-63.4
Tangential (NS)	-1.6	55.1	-20.1	53.7	67.1	61.3	78.9	52.3	-100.4	125.7	114.4

EASA4140

EASA414041 lon/lat: -109°.3837 -27°.1468

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.02032	.00130	.00520	.00103	.00675	.00359	.00212	.00074	.00046	.00010	.00103
Tangential (EW)	.00105	.00096	.00042	.00023	.00090	.00062	.00030	.00012	.00003	.00001	.00006
Tangential (NS)	.00234	.00056	.00044	.00016	.00099	.00074	.00033	.00016	.00013	.00007	.00021
Phases (deg)											
Radial	-161.0	76.6	173.0	65.4	-149.7	-161.9	-145.9	-164.5	157.8	-124.8	19.3
Tangential (EW)	-28.8	-66.9	-23.6	-66.0	-161.8	157.4	-162.3	128.7	35.4	-32.1	-127.6
Tangential (NS)	-145.3	144.7	171.6	143.0	91.1	73.9	101.4	54.0	-136.3	157.7	152.0

EASTER70

EASTER7061 lon/lat: -109°.3836 -27°.1468

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.02032	.00130	.00520	.00103	.00675	.00359	.00212	.00074	.00046	.00010	.00103
Tangential (EW)	.00105	.00096	.00042	.00023	.00090	.00062	.00030	.00012	.00003	.00001	.00006
Tangential (NS)	.00234	.00056	.00044	.00016	.00099	.00074	.00033	.00016	.00013	.00007	.00021
Phases (deg)											
Radial	-161.0	76.6	173.0	65.4	-149.7	-161.9	-145.9	-164.5	157.8	-124.8	19.3
Tangential (EW)	-28.8	-66.9	-23.6	-66.0	-161.8	157.4	-162.3	128.7	35.4	-32.1	-127.6
Tangential (NS)	-145.3	144.7	171.6	142.9	91.1	73.9	101.4	54.0	-136.3	157.7	152.0

ENSENA78

ENSENA7883 lon/lat: -116°.1607 31°.2555

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00698	.00385	.00223	.00134	.01201	.00763	.00432	.00143	.00023	.00021	.00059
Tangential (EW)	.00209	.00036	.00041	.00010	.00379	.00240	.00125	.00041	.00008	.00003	.00034
Tangential (NS)	.00411	.00170	.00085	.00052	.00178	.00106	.00049	.00024	.00003	.00004	.00017
Phases (deg)											
Radial	-55.8	-75.2	-68.7	-72.2	37.3	22.3	33.5	14.1	-128.3	-155.2	24.7
Tangential (EW)	-178.9	-145.4	148.0	-173.8	-140.2	-155.1	-142.3	-161.1	120.3	111.5	-144.6
Tangential (NS)	91.3	110.3	76.8	105.0	177.5	171.4	168.4	163.4	-3.7	76.9	-176.5

EFLSBERG

EFFELSBERG lon/lat: 6°.8836 50°.5236

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00606	.00182	.00127	.00042	.00214	.00088	.00065	.00003	.00048	.00024	.00013
Tangential (EW)	.00227	.00065	.00047	.00017	.00034	.00025	.00012	.00003	.00011	.00003	.00004
Tangential (NS)	.00071	.00031	.00022	.00011	.00030	.00015	.00008	.00003	.00004	.00005	.00011
Phases (deg)											
Radial	-69.0	-36.2	-81.9	-33.8	-57.7	-98.3	-59.0	-89.6	2.0	-1.3	-54.1
Tangential (EW)	80.9	116.3	57.7	110.0	100.0	26.9	88.9	-7.1	162.6	116.0	-129.4
Tangential (NS)	27.7	61.5	20.7	66.5	29.1	-69.7	27.8	-152.0	-145.5	83.6	109.4

ELY

ELY lon/lat: -114°.8429 39°.2920

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00241	.00123	.00054	.00026	.00757	.00481	.00236	.00091	.00012	.00003	.00034
Tangential (EW)	.00280	.00105	.00050	.00028	.00277	.00183	.00086	.00032	.00008	.00004	.00030
Tangential (NS)	.00248	.00099	.00058	.00031	.00137	.00077	.00042	.00018	.00003	.00003	.00011
Phases (deg)											
Radial	79.8	-167.6	-18.1	-136.2	47.5	33.4	46.6	25.4	-19.6	49.6	26.1
Tangential (EW)	-125.4	-80.3	-148.9	-83.3	-129.4	-144.5	-130.3	-150.0	139.2	163.1	-147.3
Tangential (NS)	102.0	109.1	84.4	105.3	176.8	169.9	175.2	161.9	-144.6	-175.8	-117.0

FAIR 90

FAIR 9003 lon/lat: -147°.4992 64°.9770

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00766	.00314	.00114	.00081	.00484	.00340	.00171	.00061	.00091	.00052	.00083
Tangential (EW)	.00064	.00040	.00015	.00014	.00081	.00068	.00026	.00017	.00005	.00003	.00015
Tangential (NS)	.00376	.00146	.00067	.00041	.00201	.00124	.00069	.00022	.00013	.00011	.00023
Phases (deg)											
Radial	102.3	139.8	86.9	136.9	96.8	88.2	95.6	84.2	18.1	16.2	44.0
Tangential (EW)	129.3	-85.2	84.9	-72.6	-13.1	-57.0	-17.1	-61.7	-176.9	-151.0	165.0
Tangential (NS)	-95.1	-54.9	-108.8	-54.8	-105.4	-116.5	-105.9	-120.9	130.1	-134.4	-141.9

FLAGSTAF

FLAGSTAFF lon/lat: -111°.6347 35°.2136

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00016	.00142	.00062	.00044	.00695	.00449	.00217	.00086	.00006	.00006	.00027
Tangential (EW)	.00186	.00061	.00032	.00015	.00273	.00179	.00085	.00032	.00007	.00003	.00030
Tangential (NS)	.00249	.00099	.00056	.00030	.00118	.00066	.00037	.00017	.00002	.00003	.00010
Phases (deg)											
Radial	116.4	-129.9	-59.1	-106.8	41.9	27.2	40.6	19.0	-114.1	-176.1	8.4
Tangential (EW)	-144.4	-93.1	-170.9	-98.1	-136.5	-152.1	-137.5	-159.0	127.1	151.4	-145.0
Tangential (NS)	95.3	106.2	81.5	102.5	170.1	168.1	168.2	162.0	-121.3	-177.8	-123.8

FLOA5340

FLOA534053 lon/lat: -31°1279 39°4539

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01960	.00744	.00393	.00210	.00357	.00018	.00111	.00037	.00099	.00092	.00186
Tangential (EW)	.00349	.00105	.00085	.00031	.00018	.00020	.00002	.00008	.00003	.00005	.00014
Tangential (NS)	.00313	.00114	.00057	.00032	.00064	.00071	.00021	.00017	.00010	.00005	.00006
Phases (deg)											
Radial	-127.3	-102.2	-148.6	-109.4	-61.2	-0.6	-67.9	59.3	-17.7	-123.1	-94.3
Tangential (EW)	-67.2	-34.2	-81.0	-25.7	-122.8	122.5	-140.7	84.6	-130.9	-143.1	-73.2
Tangential (NS)	-51.7	-7.4	-78.7	-6.5	-65.8	-126.1	-68.0	-162.5	-32.7	42.2	86.5

FT ORD

FORT ORD lon/lat: -121°7722 36°6698

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00844	.00047	.00225	.00049	.01545	.00961	.00475	.00180	.00028	.00007	.00086
Tangential (EW)	.00437	.00142	.00080	.00038	.00415	.00266	.00126	.00047	.00012	.00003	.00034
Tangential (NS)	.00413	.00161	.00093	.00050	.00230	.00135	.00071	.00028	.00001	.00002	.00017
Phases (deg)											
Radial	21.4	-54.2	-24.4	-34.8	46.4	32.0	46.8	23.5	-42.9	110.5	66.1
Tangential (EW)	-128.9	-84.5	-155.9	-91.7	-129.1	-142.8	-128.4	-147.6	143.8	156.7	-146.7
Tangential (NS)	101.3	113.1	82.2	109.7	-175.2	173.9	-174.9	164.4	-132.9	115.8	-118.8

GLDS1970

GLDS197085 lon/lat: -116°8864 35°4233

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00176	.00138	.00102	.00051	.00949	.00603	.00316	.00111	.00011	.00009	.00044
Tangential (EW)	.00243	.00082	.00042	.00021	.00318	.00205	.00105	.00036	.00008	.00004	.00030
Tangential (NS)	.00338	.00134	.00073	.00041	.00169	.00099	.00056	.00021	.00001	.00003	.00013
Phases (deg)											
Radial	-3.9	-112.3	-50.5	-89.7	44.1	29.7	41.7	21.6	-87.5	-155.5	15.0
Tangential (EW)	-136.6	-86.2	-163.5	-90.6	-133.4	-147.9	-135.5	-153.3	134.6	143.0	-147.8
Tangential (NS)	96.0	110.3	80.0	105.1	178.8	172.4	177.5	162.7	-60.4	101.4	-172.7

GLDST071

GLDST07115 lon/lat: -116°7919 35°2471

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00179	.00143	.00105	.00053	.00951	.00605	.00317	.00112	.00011	.00009	.00044
Tangential (EW)	.00238	.00080	.00041	.00020	.00320	.00206	.00106	.00036	.00008	.00004	.00031
Tangential (NS)	.00340	.00135	.00074	.00042	.00169	.00099	.00056	.00021	.00001	.00003	.00013
Phases (deg)											
Radial	-9.4	-110.0	-52.0	-88.8	43.9	29.4	41.4	21.3	-91.0	-155.5	14.9
Tangential (EW)	-137.9	-87.1	-165.3	-91.7	-133.7	-148.3	-135.9	-153.8	134.1	141.8	-147.7
Tangential (NS)	95.9	110.3	80.0	105.1	178.8	172.4	177.3	162.8	-57.1	100.6	-173.0

GND-TU70

GND-TU7068 lon/lat: -71°1319 21°4596

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01020	.00209	.00195	.00066	.00381	.00333	.00114	.00075	.00059	.00048	.00181
Tangential (EW)	.00133	.00028	.00035	.00008	.00049	.00040	.00017	.00007	.00005	.00013	.00016
Tangential (NS)	.00406	.00086	.00099	.00024	.00031	.00041	.00012	.00009	.00006	.00004	.00014
Phases (deg)											
Radial	154.7	175.1	131.8	169.2	19.5	23.9	21.4	25.2	175.5	-154.9	-109.5
Tangential (EW)	149.7	133.0	123.3	152.5	88.5	69.4	87.7	59.6	-73.2	-126.6	-75.6
Tangential (NS)	-155.2	-108.3	-177.6	-109.7	-59.4	-103.2	-47.8	-133.2	-78.8	150.6	161.1

GOLA1040

GOLA104010 lon/lat: -116°8917 35°3303

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00181	.00140	.00104	.00052	.00955	.00606	.00318	.00112	.00011	.00009	.00045
Tangential (EW)	.00241	.00081	.00042	.00020	.00320	.00206	.00106	.00036	.00008	.00004	.00031
Tangential (NS)	.00340	.00135	.00074	.00042	.00170	.00100	.00056	.00021	.00001	.00003	.00013
Phases (deg)											
Radial	-6.8	-110.7	-51.2	-88.9	44.0	29.6	41.5	21.5	-89.0	-155.5	15.3
Tangential (EW)	-137.2	-86.6	-164.4	-91.1	-133.5	-148.1	-135.7	-153.5	134.4	142.3	-147.8
Tangential (NS)	96.0	110.4	80.1	105.2	178.9	172.5	177.6	162.8	-57.8	100.7	-172.7

GORF7102

GORF7102 lon/lat: -76°8280 39°0207

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00923	.00246	.00172	.00070	.00333	.00226	.00108	.00049	.00017	.00008	.00035
Tangential (EW)	.00414	.00091	.00093	.00027	.00024	.00014	.00007	.00004	.00006	.00003	.00019
Tangential (NS)	.00096	.00031	.00014	.00008	.00017	.00025	.00005	.00008	.00009	.00007	.00006
Phases (deg)											
Radial	158.6	-169.7	141.0	-173.5	-2.5	-1.1	-1.0	3.1	21.6	75.9	-179.2
Tangential (EW)	-175.2	-149.1	164.7	-154.1	-29.7	41.9	-34.9	51.4	-2.5	-174.1	-85.8
Tangential (NS)	-37.6	11.9	-43.3	7.6	-171.8	-135.5	-167.8	-158.1	-137.6	-158.9	2.8

GORMAN

GORMAN lon/lat: -118°9047 34°9036

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00444	.00176	.00171	.00071	.01231	.00774	.00384	.00145	.00016	.00007	.00063
Tangential (EW)	.00286	.00095	.00050	.00024	.00358	.00229	.00110	.00039	.00009	.00004	.00032
Tangential (NS)	.00426	.00169	.00095	.00052	.00224	.00134	.00071	.00028	.00000	.00002	.00017
Phases (deg)											
Radial	-13.7	-86.9	-50.7	-70.6	43.2	28.5	42.7	20.1	-73.2	172.8	56.9
Tangential (EW)	-135.2	-85.7	-162.6	-91.0	-132.6	-146.8	-132.5	-152.0	136.6	136.4	-148.3
Tangential (NS)	100.7	113.4	83.1	109.7	-175.8	174.9	-176.4	165.9	-125.5	145.7	-117.7

GRASSE78

GRASSE7835 lon/lat: 6°9211 43°7535

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00672	.00205	.00134	.00049	.00174	.00049	.00053	.00003	.00036	.00017	.00033
Tangential (EW)	.00287	.00079	.00066	.00023	.00029	.00024	.00014	.00003	.00008	.00008	.00005
Tangential (NS)	.00143	.00049	.00021	.00011	.00019	.00013	.00003	.00008	.00006	.00003	.00007
Phases (deg)											
Radial	-74.3	-46.1	-92.8	-49.7	-63.3	-102.1	-65.6	42.8	-4.1	-36.9	-20.4
Tangential (EW)	65.6	94.2	39.9	90.6	94.5	9.1	76.8	0.8	142.6	50.5	133.6
Tangential (NS)	-44.6	-5.4	-56.3	-4.8	40.6	-176.9	25.6	154.1	-117.9	141.1	116.4

GRAZ 78

GRAZ 7839 lon/lat: 15°4934 47°0659

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00465	.00133	.00093	.00031	.00152	.00065	.00047	.00004	.00038	.00024	.00035
Tangential (EW)	.00218	.00051	.00053	.00015	.00035	.00029	.00015	.00005	.00008	.00004	.00005
Tangential (NS)	.00090	.00025	.0001[illegible]	.00006	.00030	.00003	.00006	.00004	.00006	.00003	.00010
Phases (deg)											
Radial	-68.0	-38.2	-88.1	-39.0	-61.9	-101.2	-64.2	-114.1	7.9	-5.6	12.9
Tangential (EW)	54.5	85.0	28.9	84.5	100.5	33.1	85.6	31.6	160.6	53.4	177.0
Tangential (NS)	-50.6	-4.2	-63.6	-4.2	49.5	81.0	44.4	143.1	-140.7	144.2	108.4

GOLD 90

GOLD 9004 lon/lat: -116°.8892 35°.4240

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00176	.00138	.00102	.00051	.00949	.00603	.00316	.00111	.00011	.00009	.00044
Tangential (EW)	.00243	.00082	.00042	.00021	.00318	.00205	.00105	.00036	.00008	.00004	.00030
Tangential (NS)	.00338	.00134	.00073	.00041	.00169	.00099	.00056	.00021	.00001	.00003	.00013
Phases (deg)											
Radial	-3.8	-112.3	-50.5	-89.7	44.1	29.7	41.7	21.6	-87.5	-155.5	15.0
Tangential (EW)	-136.5	-86.2	-163.5	-90.6	-133.4	-147.9	-135.5	-153.3	134.6	143.0	-147.8
Tangential (NS)	96.0	110.3	80.0	105.1	178.8	172.4	177.5	162.7	-60.4	101.4	-172.7

GRENWI78

GRENWI7840 lon/lat: 0°.3361 50°.8661

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00430	.00142	.00066	.00054	.00300	.00092	.00090	.00013	.00088	.00050	.00083
Tangential (EW)	.00466	.00118	.00088	.00031	.00064	.00056	.00027	.00012	.00013	.00010	.00012
Tangential (NS)	.00417	.00133	.00070	.00041	.00038	.00029	.00005	.00005	.00002	.00011	.00017
Phases (deg)											
Radial	-150.7	-102.5	67.9	-143.6	-62.1	-112.7	-67.1	-153.9	1.6	-33.3	-47.1
Tangential (EW)	126.9	165.6	85.2	168.5	102.2	9.7	86.8	-27.5	149.7	54.9	118.8
Tangential (NS)	-11.3	30.1	-51.0	27.0	76.1	-62.2	38.5	-145.1	-157.4	71.9	73.9

HALEAKAL

HALEAKAL lon/lat: -156°.2560 20°.7076

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01203	.00462	.00278	.00147	.01237	.00702	.00368	.00112	.00059	.00032	.00072
Tangential (EW)	.00263	.00128	.00066	.00033	.00198	.00127	.00058	.00028	.00002	.00005	.00013
Tangential (NS)	.00395	.00139	.00063	.00038	.00176	.00112	.00056	.00023	.00011	.00001	.00021
Phases (deg)											
Radial	-116.0	-131.9	-136.9	-132.2	57.7	49.0	57.5	46.0	-141.0	-174.5	113.6
Tangential (EW)	175.1	-165.1	170.6	-144.0	40.4	17.3	40.7	-1.9	-100.0	-174.9	113.7
Tangential (NS)	93.8	131.7	79.1	122.4	116.5	95.7	118.7	87.5	-28.2	-2.7	74.1

HART 90

HART 9005 lon/lat: 27°.7078 -25°.8861

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01585	.00716	.00316	.00202	.00091	.00143	.00027	.00036	.00024	.00023	.00030
Tangential (EW)	.00129	.00059	.00039	.00011	.00111	.00093	.00033	.00023	.00004	.00004	.00013
Tangential (NS)	.00172	.00054	.00042	.00015	.00081	.00017	.00024	.00002	.00003	.00001	.00018
Phases (deg)											
Radial	-128.8	-102.6	-137.3	-103.1	131.0	115.9	139.9	109.8	-172.3	138.0	-173.9
Tangential (EW)	17.3	-20.3	9.2	-31.7	-134.7	-159.7	-132.2	175.7	75.2	31.2	-12.3
Tangential (NS)	73.6	91.4	65.5	79.5	129.3	127.9	129.4	176.9	-49.7	-92.5	112.0

HARTRAO

HARTRAO lon/lat: 27°.6855 -25°.8888

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01634	.00740	.00332	.00207	.00090	.00142	.00029	.00035	.00015	.00021	.00024
Tangential (EW)	.00071	.00045	.00028	.00010	.00069	.00063	.00022	.00016	.00003	.00003	.00007
Tangential (NS)	.00132	.00046	.00038	.00013	.00059	.00005	.00018	.00004	.00004	.00003	.00004
Phases (deg)											
Radial	-128.0	-102.5	-136.2	-102.4	130.1	116.8	133.5	104.8	-178.6	120.0	102.3
Tangential (EW)	30.4	-38.4	17.0	-58.4	-130.5	-158.9	-128.5	172.9	87.1	49.8	-10.4
Tangential (NS)	70.1	81.1	64.7	73.3	137.2	179.0	143.8	-130.0	-14.4	-80.7	63.5

HATCREEK

HAT CREEK lon/lat: -121°.4705 40°.8163

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00751	.00166	.00143	.00022	.01142	.00713	.00351	.00133	.00026	.00013	.00029
Tangential (EW)	.00404	.00139	.00074	.00037	.00333	.00215	.00099	.00037	.00010	.00004	.00027
Tangential (NS)	.00286	.00112	.00065	.00035	.00163	.00096	.00048	.00020	.00007	.00004	.00014
Phases (deg)											
Radial	60.8	139.2	8.6	121.7	52.8	39.1	52.2	30.8	-21.3	44.8	100.8
Tangential (EW)	-116.2	-73.5	-142.0	-77.4	-119.6	-132.4	-119.7	-135.8	149.7	147.7	-170.2
Tangential (NS)	101.1	111.5	81.7	109.3	-178.0	168.8	-179.6	158.8	-165.5	178.1	-118.7

HBKA1940

HBKA194019 lon/lat: 27°.7075 -25°.8861

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01585	.00716	.00316	.00202	.00091	.00143	.00027	.00036	.00024	.00023	.00030
Tangential (EW)	.00129	.00059	.00039	.00011	.00111	.00093	.00033	.00023	.00004	.00004	.00013
Tangential (NS)	.00172	.00054	.00042	.00015	.00081	.00017	.00024	.00002	.00003	.00001	.00018
Phases (deg)											
Radial	-128.8	-102.6	-137.3	-103.1	131.0	115.9	139.9	109.8	-172.3	138.0	-173.9
Tangential (EW)	17.3	-20.3	9.2	-31.7	-134.7	-159.7	-132.2	175.7	75.2	31.2	-12.3
Tangential (NS)	73.6	91.4	65.5	79.5	129.3	127.9	129.4	176.9	-49.7	-92.5	112.0

HELA4340

HELA434043 lon/lat: -5°.6674 -15°.9415

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01977	.00678	.00362	.00209	.00250	.00156	.00072	.00042	.00131	.00105	.00195
Tangential (EW)	.00496	.00188	.00098	.00047	.00148	.00079	.00041	.00012	.00004	.00006	.00006
Tangential (NS)	.00341	.00121	.00079	.00034	.00115	.00061	.00036	.00009	.00004	.00007	.00016
Phases (deg)											
Radial	-93.2	-67.5	-103.8	-59.0	150.1	28.8	148.7	-28.2	-163.5	-177.7	-145.5
Tangential (EW)	-135.8	-113.4	-140.7	-118.8	-117.3	-147.7	-116.3	-172.8	9.9	32.9	-100.6
Tangential (NS)	22.7	52.1	7.9	52.2	125.4	97.4	126.8	67.1	-158.3	-128.3	81.7

HELWAN78

HELWAN7831 lon/lat: 31°.3427 29°.8579

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00333	.00102	.00070	.00027	.00087	.00049	.00031	.00009	.00003	.00013	.00030
Tangential (EW)	.00202	.00047	.00050	.00010	.00055	.00025	.00018	.00008	.00004	.00002	.00008
Tangential (NS)	.00091	.00010	.00016	.00002	.00094	.00054	.00026	.00010	.00010	.00007	.00014
Phases (deg)											
Radial	-71.3	-53.0	-93.0	-56.3	-170.8	-159.4	-166.8	-164.1	-152.0	5.3	57.7
Tangential (EW)	14.0	25.2	-2.0	30.2	164.3	161.0	154.7	146.7	-165.3	-2.6	-92.7
Tangential (NS)	-78.2	3.9	-117.1	-19.4	52.0	55.5	52.3	58.9	-137.8	169.6	128.7

HOBART26

HOBART 26 lon/lat: 147°.4406 -42°.8035

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01016	.00161	.00199	.00044	.00646	.00609	.00236	.00158	.00052	.00043	.00077
Tangential (EW)	.00473	.00189	.00073	.00050	.00109	.00069	.00036	.00010	.00003	.00020	.00022
Tangential (NS)	.00133	.00061	.00024	.00019	.00135	.00123	.00045	.00030	.00006	.00006	.00014
Phases (deg)											
Radial	154.1	-114.5	121.3	-114.4	86.9	58.0	85.2	47.5	9.6	-62.7	-49.1
Tangential (EW)	103.4	135.8	98.5	139.6	-154.3	-171.8	-163.3	-160.4	-63.6	72.0	127.3
Tangential (NS)	125.2	111.0	84.4	106.6	-139.1	-155.2	-143.5	-178.2	-152.7	101.0	115.8

HOHENFRG

HOHENFRG lon/lat: 10°.4764 53°.0506

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00443	.00138	.00098	.00031	.00210	.00091	.00064	.00004	.00050	.00028	.00010
Tangential (EW)	.00174	.00050	.00038	.00012	.00036	.00027	.00012	.00003	.00012	.00003	.00007
Tangential (NS)	.00030	.00011	.00015	.00007	.00032	.00010	.00008	.00002	.00004	.00006	.00014
<u>Phases (deg)</u>											
Radial	-72.4	-39.5	-80.5	-27.3	-55.4	-101.0	-56.9	-113.3	7.2	14.0	-67.7
Tangential (EW)	72.9	110.7	55.4	111.1	101.7	32.5	90.5	10.0	168.7	-151.6	-142.2
Tangential (NS)	76.3	84.3	51.7	83.0	24.3	-74.3	23.8	-173.0	-162.1	92.8	103.6

HONE 90

HONE 9006 lon/lat: 10°.2491 60°.1424

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00185	.00035	.00030	.00008	.00241	.00129	.00075	.00018	.00091	.00052	.00077
Tangential (EW)	.00100	.00012	.00028	.00004	.00060	.00070	.00024	.00014	.00019	.00004	.00017
Tangential (NS)	.00117	.00041	.00034	.00012	.00027	.00015	.00007	.00005	.00005	.00005	.00024
<u>Phases (deg)</u>											
Radial	-66.3	-13.1	-73.1	40.1	-47.0	-110.6	-50.4	-177.5	17.6	13.8	12.2
Tangential (EW)	42.3	58.7	9.4	55.2	101.2	39.3	88.9	10.1	-179.7	-143.6	-175.6
Tangential (NS)	102.2	136.9	85.9	129.8	45.2	-70.8	30.9	-156.9	115.2	24.1	85.2

HRAS 085

HRAS085 lon/lat: -103°.9472 30°.6356

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00105	.00153	.00045	.00044	.00473	.00320	.00149	.00064	.00015	.00011	.00025
Tangential (EW)	.00117	.00027	.00026	.00010	.00200	.00132	.00062	.00023	.00005	.00002	.00024
Tangential (NS)	.00114	.00050	.00028	.00015	.00058	.00032	.00019	.00009	.00005	.00004	.00006
<u>Phases (deg)</u>											
Radial	-177.9	-128.1	-63.7	-111.9	32.7	18.2	30.6	11.1	-171.6	-173.1	166.3
Tangential (EW)	149.9	159.8	119.8	141.1	-141.7	-158.4	-143.5	-168.1	114.2	127.9	-147.4
Tangential (NS)	96.8	96.3	93.3	95.6	140.3	147.9	136.8	151.3	-146.4	-175.9	-136.4

HUAA2740

HUAA274027 lon/lat: -151°.0412 -16°.7328

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00449	.00222	.00081	.00074	.00043	.00087	.00018	.00033	.00089	.00054	.00078
Tangential (EW)	.00623	.00087	.00157	.00021	.00071	.00056	.00021	.00014	.00001	.00005	.00009
Tangential (NS)	.00409	.00122	.00070	.00036	.00148	.00071	.00042	.00011	.00009	.00005	.00014
<u>Phases (deg)</u>											
Radial	-111.4	167.4	-126.7	174.8	148.3	-82.9	-157.5	-111.5	-158.1	-144.3	-97.9
Tangential (EW)	-161.5	-155.9	176.7	-153.0	54.9	38.7	58.7	7.8	-35.8	-153.6	110.0
Tangential (NS)	-106.2	-68.1	-130.3	-76.3	46.7	39.7	46.6	39.5	-153.6	166.4	135.5

HUAHIN71

HUAHIN7121 lon/lat: -151°.0411 -16°.7328

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00449	.00222	.00081	.00074	.00043	.00087	.00018	.00033	.00089	.00054	.00078
Tangential (EW)	.00623	.00087	.00157	.00021	.00071	.00056	.00021	.00014	.00001	.00005	.00009
Tangential (NS)	.00409	.00122	.00070	.00036	.00148	.00071	.00042	.00011	.00009	.00005	.00014
<u>Phases (deg)</u>											
Radial	-111.4	167.4	-126.7	174.8	148.3	-82.9	-157.5	-111.5	-158.1	-144.3	-97.9
Tangential (EW)	-161.5	-155.9	176.7	-153.0	54.9	38.7	58.7	7.8	-35.8	-153.6	110.0
Tangential (NS)	-106.2	-68.1	-130.3	-76.3	46.7	39.7	46.6	39.5	-153.6	166.4	135.5

ISHIGA73

ISHIGA7307 lon/lat: 124°1746 24°3548

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.02088	.00791	.00441	.00224	.01098	.00906	.00346	.00188	.00031	.00062	.00062
Tangential (EW)	.00452	.00191	.00088	.00057	.00242	.00171	.00078	.00033	.00004	.00012	.00029
Tangential (NS)	.00093	.00029	.00010	.00005	.00098	.00089	.00031	.00016	.00001	.00004	.00022
<u>Phases (deg)</u>											
Radial	132.1	151.9	121.7	150.2	-88.9	-107.9	-89.1	-116.6	172.9	106.0	147.4
Tangential (EW)	100.6	123.6	97.2	126.2	-126.9	-155.0	-127.1	-162.9	0.9	25.1	54.5
Tangential (NS)	-70.0	-59.8	-89.2	-74.8	145.8	120.7	150.0	100.8	81.8	162.3	124.1

JODRELLB

JODRELL BANK lon/lat: -2°3039 53°2327

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00932	.00301	.00287	.00115	.00342	.00154	.00092	.00012	.00083	.00035	.00036
Tangential (EW)	.00427	.00158	.00067	.00032	.00030	.00020	.00022	.00010	.00012	.00009	.00002
Tangential (NS)	.00207	.00049	.00036	.00017	.00061	.00035	.00015	.00009	.00003	.00013	.00016
<u>Phases (deg)</u>											
Radial	-51.5	-10.9	-67.9	-7.8	-46.1	-118.2	-52.2	159.9	-1.6	-7.5	-50.3
Tangential (EW)	-24.8	9.5	83.8	151.5	-30.7	-161.0	106.5	-60.4	144.7	46.9	-123.6
Tangential (NS)	124.6	157.5	45.5	78.7	24.0	-90.6	34.3	-147.0	142.6	56.0	83.4

JPLM 90

JPLM 9007 lon/lat: -118°1732 34°2036

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00480	.00222	.00180	.00086	.01213	.00768	.00447	.00141	.00015	.00013	.00056
Tangential (EW)	.00257	.00074	.00045	.00018	.00361	.00231	.00123	.00040	.00009	.00004	.00032
Tangential (NS)	.00424	.00172	.00092	.00053	.00221	.00134	.00061	.00027	.00001	.00004	.00016
<u>Phases (deg)</u>											
Radial	-27.1	-80.2	-54.8	-71.4	41.7	27.1	38.1	19.0	-95.3	-152.5	28.0
Tangential (EW)	-145.1	-93.7	-175.2	-100.6	-134.8	-149.1	-136.9	-154.6	133.3	130.1	-146.9
Tangential (NS)	100.0	113.8	83.9	108.8	-175.6	176.3	177.6	166.4	-0.3	84.3	-165.5

JPL MV* (This set can be used for JPL MV1 JPL MV2 JPL MV3)

JPL lon/lat: -118°1740 34°2040

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00515	.00230	.00192	.00089	.01247	.00787	.00390	.00147	.00016	.00008	.00064
Tangential (EW)	.00262	.00078	.00046	.00019	.00367	.00235	.00114	.00040	.00009	.00004	.00033
Tangential (NS)	.00441	.00177	.00098	.00054	.00230	.00139	.00074	.00030	.00000	.00002	.00018
<u>Phases (deg)</u>											
Radial	-27.6	-80.5	-56.5	-69.7	41.5	26.7	40.7	18.4	-85.0	-179.4	57.6
Tangential (EW)	-143.8	-92.2	-173.6	-98.9	-134.7	-149.0	-134.8	-154.5	133.3	130.3	-147.1
Tangential (NS)	101.3	113.9	84.2	110.3	-175.4	175.5	-176.2	167.0	-147.6	147.2	-116.8

KARITS75

KARITS,520 lon/lat: 20°6648 39°7330

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00409	.00116	.00084	.00028	.00091	.00045	.00029	.00004	.00019	.00018	.00029
Tangential (EW)	.00207	.00046	.00052	.00013	.00028	.00010	.00011	.00003	.00004	.00004	.00005
Tangential (NS)	.00117	.00027	.00018	.00006	.00047	.00020	.00011	.00006	.00009	.00005	.00010
<u>Phases (deg)</u>											
Radial	-68.6	-43.5	-89.9	-45.9	-77.5	-107.6	-81.5	-103.1	5.2	-3.1	35.9
Tangential (EW)	38.1	58.6	16.5	63.8	135.1	59.9	111.0	92.3	163.3	40.0	-137.4
Tangential (NS)	-73.8	-31.0	-105.0	-41.2	54.2	75.3	54.5	106.3	-138.6	170.7	127.6

KASHIMA

KASHIMA lon/lat: 140°6627 35°9529

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_1	M_m	S_{sa}
Amplitudes (m)											
Radial	.00948	.00486	.00137	.00136	.01180	.00926	.00364	.00188	.00020	.00054	.00108
Tangential (EW)	.00289	.00146	.00036	.00038	.00215	.00176	.00070	.00038	.00006	.00010	.00033
Tangential (NS)	.00167	.00068	.00030	.00022	.00188	.00141	.00057	.00026	.00004	.00013	.00010
Phases (deg)											
Radial	50.7	75.1	63.1	77.9	-138.7	-157.9	-138.9	-163.2	-11.2	42.5	103.5
Tangential (EW)	5.6	41.0	5.8	46.9	-166.5	172.3	-165.3	169.5	-7.1	10.3	48.6
Tangential (NS)	-70.4	-56.5	-74.4	-51.2	93.6	70.4	95.5	54.9	169.6	-158.8	-117.9

KATAVI75

KATAVI7512 lon/lat: 27°7808 35°9507

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_1	M_m	S_{sa}
Amplitudes (m)											
Radial	.00350	.00100	.00073	.00025	.00059	.00043	.00021	.00006	.00009	.00017	.00031
Tangential (EW)	.00199	.00043	.00050	.00011	.00039	.00012	.00013	.00005	.00004	.00002	.00006
Tangential (NS)	.00108	.00017	.00018	.00004	.00071	.00038	.00019	.00007	.00010	.00006	.00012
Phases (deg)											
Radial	-67.1	-44.4	-89.8	-46.8	-118.9	-129.7	-122.5	-136.6	8.3	3.7	50.7
Tangential (EW)	23.3	38.6	5.1	45.4	150.4	122.2	134.0	123.6	-178.1	22.5	-109.1
Tangential (NS)	-83.1	-35.9	-119.0	-52.6	51.5	57.7	51.1	71.3	-140.9	172.2	129.3

KAUAI

KAUAI lon/lat: -159°6651 22°1255

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_1	M_m	S_{sa}
Amplitudes (m)											
Radial	.00970	.00386	.00227	.00119	.01163	.00660	.00347	.00108	.00055	.00028	.00086
Tangential (EW)	.00268	.00128	.00060	.00030	.00215	.00137	.00065	.00030	.00002	.00004	.00012
Tangential (NS)	.00404	.00161	.00065	.00044	.00188	.00120	.00060	.00024	.00011	.00000	.00020
Phases (deg)											
Radial	-109.9	-129.4	-131.3	-138.3	61.5	55.6	61.4	56.2	-137.3	-177.7	114.4
Tangential (EW)	162.9	-173.5	160.7	-152.3	40.8	16.9	41.4	-1.9	-57.8	-173.4	115.5
Tangential (NS)	101.9	137.6	92.6	128.0	119.7	98.0	121.8	89.7	-30.0	-3.1	72.7

KERA9 40

KERA9 4009 lon/lat: 70°2627 -49°3508

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_1	M_m	S_{sa}
Amplitudes (m)											
Radial	.01442	.00777	.00348	.00242	.00580	.00578	.00186	.00120	.00077	.00050	.00179
Tangential (EW)	.00369	.00213	.00073	.00062	.00148	.00109	.00046	.00016	.00000	.00007	.00020
Tangential (NS)	.00190	.00100	.00053	.00019	.00118	.00104	.00039	.00022	.00004	.00006	.00006
Phases (deg)											
Radial	32.3	88.2	-0.3	88.2	49.6	64.4	48.9	59.6	21.3	-45.0	-37.5
Tangential (EW)	43.4	86.6	30.4	89.2	42.8	28.7	41.2	12.0	136.6	-36.5	21.5
Tangential (NS)	99.0	99.0	86.7	101.0	-96.9	-106.7	-94.4	-122.4	-176.6	-172.5	-125.7

KODIAK

KODIAK lon/lat: -152°4972 57°7389

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_1	M_m	S_{sa}
Amplitudes (m)											
Radial	.02725	.01033	.00500	.00267	.01530	.01012	.00500	.00183	.00122	.00101	.00155
Tangential (EW)	.00526	.00122	.00111	.00026	.00238	.00132	.00077	.00029	.00002	.00006	.00015
Tangential (NS)	.00490	.00209	.00089	.00058	.00349	.00216	.00108	.00039	.00018	.00018	.00037
Phases (deg)											
Radial	112.9	146.7	94.5	144.0	97.8	86.4	97.1	80.6	0.5	39.5	57.3
Tangential (EW)	98.8	149.0	71.7	145.2	53.6	21.1	50.6	5.1	-140.3	14.2	114.8
Tangential (NS)	-79.4	-41.9	-91.9	-42.7	-104.5	-116.6	-104.5	-123.2	155.4	-158.6	-126.9

KOKB 90

KOKB 9008 lon/lat: -159°.6649 22°.1254

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00894	.00348	.00195	.00113	.01064	.00623	.00316	.00096	.00057	.00039	.00011
Tangential (EW)	.00256	.00122	.00058	.00029	.00205	.00132	.00063	.00029	.00002	.00004	.00012
Tangential (NS)	.00392	.00155	.00062	.00042	.00179	.00112	.00058	.00023	.00011	.00002	.00025
Phases (deg)											
Radial	-111.3	-127.8	-132.7	-137.4	62.5	57.0	60.5	61.3	-141.5	-156.0	55.8
Tangential (EW)	162.3	-173.5	160.2	-151.8	40.6	16.4	41.9	-2.7	-52.0	-174.3	116.5
Tangential (NS)	100.0	136.1	91.1	125.6	122.3	100.0	116.6	89.0	-26.3	42.6	85.6

KOOTWI78

KOOTWI7833 lon/lat: 5°.8098 52°.1772

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00590	.00173	.00124	.00034	.00203	.00088	.00065	.00008	.00072	.00039	.00065
Tangential (EW)	.00226	.00059	.00049	.00016	.00044	.00039	.00020	.00008	.00015	.00006	.00012
Tangential (NS)	.00187	.00058	.00035	.00016	.00024	.00017	.00005	.00004	.00002	.00010	.00012
Phases (deg)											
Radial	-47.9	-20.7	-67.4	-19.3	-60.0	-84.0	-61.4	-76.0	4.0	-0.7	-22.7
Tangential (EW)	91.9	129.4	61.3	117.5	83.8	41.5	75.6	36.4	162.7	102.1	137.0
Tangential (NS)	28.7	64.8	17.6	70.1	61.4	-61.9	53.5	-149.4	-21.1	56.7	61.2

KOOTWJ88

KOOTWJ8833 lon/lat: 5°.8102 52°.1769

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00590	.00173	.00124	.00034	.00203	.00088	.00065	.00008	.00072	.00039	.00065
Tangential (EW)	.00226	.00059	.00049	.00016	.00044	.00039	.00020	.00008	.00015	.00006	.00012
Tangential (NS)	.00187	.00058	.00035	.00016	.00024	.00017	.00005	.00004	.00002	.00010	.00012
Phases (deg)											
Radial	-47.9	-20.7	-67.4	-19.3	-60.0	-84.0	-61.4	-76.0	4.0	-0.7	-22.7
Tangential (EW)	91.9	129.4	61.3	117.5	83.8	41.5	75.6	36.4	162.7	102.1	137.0
Tangential (NS)	28.7	64.8	17.6	70.1	61.4	-61.9	53.5	-149.4	-21.1	56.7	61.3

KOSG 90

KOSG 9009 lon/lat: 5°.8096 52°.1772

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00590	.00173	.00124	.00034	.00203	.00088	.00065	.00008	.00072	.00039	.00065
Tangential (EW)	.00226	.00059	.00049	.00016	.00044	.00039	.00020	.00008	.00015	.00006	.00012
Tangential (NS)	.00187	.00058	.00035	.00016	.00024	.00017	.00005	.00004	.00002	.00010	.00012
Phases (deg)											
Radial	-47.9	-20.7	-67.4	-19.2	-60.0	-84.0	-61.4	-76.0	4.0	-0.7	-22.7
Tangential (EW)	91.9	129.4	61.3	117.5	83.8	41.5	75.6	36.4	162.7	102.1	137.0
Tangential (NS)	28.7	64.8	17.6	70.1	61.4	-61.9	53.5	-149.4	-21.1	56.7	61.2

KRUA1640

KRUA164016 lon/lat: -52°.6450 5°.1137

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.02918	.00832	.00657	.00230	.00217	.00268	.00046	.00056	.00090	.00080	.00126
Tangential (EW)	.00542	.00177	.00125	.00046	.00086	.00074	.00026	.00015	.00013	.00020	.00029
Tangential (NS)	.00231	.00058	.00050	.00019	.00056	.00048	.00015	.00011	.00014	.00014	.00019
Phases (deg)											
Radial	53.0	69.5	38.6	74.6	72.9	41.7	78.2	31.2	-168.6	-152.0	-112.0
Tangential (EW)	54.3	68.3	40.5	67.0	66.8	26.8	66.8	6.0	-170.2	-147.7	-97.3
Tangential (NS)	78.4	106.9	69.9	123.1	115.6	114.4	144.5	110.8	-152.7	-161.6	-155.6

KWAJAL26

KWAJALEIN (m) lon/lat: 167°.4822 9°.3983

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.03042	.01642	.00503	.00409	.00965	.00673	.00315	.00134	.00101	.00046	.00126
Tangential (EW)	.00253	.00060	.00051	.00015	.00191	.00116	.00054	.00019	.00002	.00003	.00005
Tangential (NS)	.00180	.00098	.00059	.00035	.00124	.00081	.00037	.00014	.00008	.00003	.00016
Phases (deg)											
Radial	-46.5	-28.2	-45.9	-30.1	-125.7	-150.7	-127.1	-164.4	-160.7	175.3	-172.2
Tangential (EW)	-13.4	-2.9	-21.4	-9.3	52.3	38.6	50.8	27.6	-110.7	-113.2	69.6
Tangential (NS)	-177.3	161.3	164.2	154.7	87.6	81.3	88.1	74.8	-48.4	-113.0	77.5

LAJOLLA

LA JOLLA lon/lat: -117°.2505 32°.8656

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00746	.00350	.00246	.00126	.01337	.00846	.00422	.00160	.00019	.00012	.00071
Tangential (EW)	.00257	.00050	.00050	.00012	.00406	.00259	.00127	.00044	.00009	.00004	.00035
Tangential (NS)	.00435	.00175	.00095	.00054	.00208	.00125	.00067	.00028	.00001	.00001	.00017
Phases (deg)											
Radial	-41.7	-72.5	-62.7	-67.2	38.6	23.6	37.4	15.5	-101.6	-173.3	60.4
Tangential (EW)	-166.5	-124.1	160.8	-142.9	-138.5	-153.1	-139.0	-158.9	126.9	116.3	-144.0
Tangential (NS)	96.8	111.7	80.4	108.1	-178.7	173.0	-179.8	165.6	-16.5	150.3	-121.1

LEONRDOK

LEONARD OK lon/lat: -95°.7950 35°.9090

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00291	.00131	.00025	.00032	.00318	.00217	.00103	.00044	.00006	.00005	.00034
Tangential (EW)	.00186	.00038	.00040	.00011	.00124	.00083	.00039	.00016	.00003	.00003	.00020
Tangential (NS)	.00061	.00023	.00020	.00007	.00035	.00011	.00011	.00004	.00008	.00005	.00002
Phases (deg)											
Radial	130.6	-165.2	60.5	-157.1	26.0	14.8	24.8	11.7	141.5	-174.3	-175.8
Tangential (EW)	-173.2	-147.1	159.9	-160.3	-140.1	-160.4	-142.0	-171.5	110.3	-178.4	-126.7
Tangential (NS)	149.1	92.2	131.2	93.0	113.6	105.5	110.2	141.5	-138.6	-167.9	-53.5

LIBA1340

LIBA134013 lon/lat: 9°.6721 0°.3540

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01597	.00549	.00318	.00157	.00294	.00079	.00095	.00018	.00082	.00054	.00074
Tangential (EW)	.00295	.00071	.00060	.00026	.00098	.00086	.00029	.00020	.00020	.00019	.00016
Tangential (NS)	.00213	.00087	.00037	.00023	.00081	.00056	.00023	.00014	.00007	.00004	.00023
Phases (deg)											
Radial	-85.0	-61.8	-91.3	-60.1	166.2	79.5	165.5	-13.4	-164.4	-162.1	-149.6
Tangential (EW)	108.3	151.4	100.4	150.8	-88.3	-142.1	-83.3	177.3	13.3	30.3	49.2
Tangential (NS)	57.8	85.6	51.4	91.9	96.0	118.8	98.0	119.5	-19.1	29.0	81.3

LMPADU75

LMPADU7544 lon/lat: 12°.5674 35°.5166

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00491	.00145	.00099	.00035	.00097	.00029	.00030	.00004	.00014	.00010	.00019
Tangential (EW)	.00214	.00053	.00053	.00016	.00018	.00003	.00006	.00002	.00003	.00006	.00003
Tangential (NS)	.00144	.00040	.00024	.00009	.00034	.00022	.00007	.00009	.00009	.00005	.00009
Phases (deg)											
Radial	-73.3	-51.0	-92.2	-55.5	-76.1	-93.2	-79.6	-8.7	-15.8	-31.6	18.1
Tangential (EW)	45.0	61.7	22.0	64.9	163.9	-93.8	112.6	154.5	130.3	41.6	-158.9
Tangential (NS)	-72.8	-34.9	-102.6	-44.4	61.3	122.8	67.6	129.2	-125.5	168.7	133.5

MADR 90

MADR 9010 lon/lat: -4°2497 40°4279

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01328	.00447	.00271	.00115	.00222	.00026	.00066	.00019	.00038	.00030	.00059
Tangential (EW)	.00398	.00134	.00091	.00040	.00027	.00028	.00015	.00004	.00009	.00012	.00009
Tangential (NS)	.00339	.00127	.00062	.00032	.00020	.00037	.00007	.00013	.00009	.00003	.00004
Phases (deg)											
Radial	-88.4	-61.9	-106.9	-66.2	-71.4	-168.0	-74.7	65.2	-28.4	-106.9	-66.2
Tangential (EW)	62.2	84.9	38.2	81.0	68.4	-23.0	56.1	-69.2	120.9	48.1	93.1
Tangential (NS)	-56.9	-20.3	-74.7	-20.3	-57.0	-168.8	-75.0	158.9	-74.7	-178.2	163.6

MADRID64

MADRID64 lon/lat: -4°2480 40°4300

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01357	.00452	.00288	.00120	.00230	.00031	.00070	.00021	.00034	.00021	.00021
Tangential (EW)	.00311	.00114	.00083	.00039	.00023	.00012	.00013	.00007	.00007	.00012	.00016
Tangential (NS)	.00307	.00113	.00060	.00030	.00031	.00026	00009	.00009	.00009	.00005	.00008
Phases (deg)											
Radial	-87.4	-61.7	-106.8	-65.3	-70.9	-147.4	-72.9	58.0	-30.6	-110.0	-24.5
Tangential (EW)	-50.2	-20.0	38.6	82.9	-85.3	-165.1	59.6	-78.3	114.7	53.5	118.7
Tangential (NS)	-56.5	-18.1	-77.4	-19.2	-28.9	-156.3	-39.2	155.1	-98.6	-177.0	174.9

MALIBU

MALIBU lon/lat: -118°6458 34°0593

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00671	.00273	.00229	.00104	.01377	.00867	.00432	.00162	.00018	.00009	.00073
Tangential (EW)	.00270	.00081	.00047	.00020	.00373	.00238	.00115	.00041	.00009	.00004	.00033
Tangential (NS)	.00471	.00190	.00106	.00058	.00251	.00152	.00080	.00032	.00000	.00002	.00020
Phases (deg)											
Radial	-27.5	-72.7	-55.7	-64.8	40.8	26.0	40.1	17.1	-82.6	-177.7	61.7
Tangential (EW)	142.4	-91.0	-172.0	-97.7	-134.3	-148.6	-134.3	-154.0	133.9	129.0	-147.4
Tangential (NS)	103.0	115.1	85.7	111.5	-173.6	176.8	-174.4	168.0	106.8	139.0	-115.3

MAMMOTHL

MAMMOTH LAKES lon/lat: -118°9451 37°6416

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00324	.00097	.00099	.00026	.01022	.00642	.00316	.00120	.00016	.00004	.00050
Tangential (EW)	.00329	.00122	.00058	.00032	.00328	.00213	.00101	.00037	.00009	.00004	.00031
Tangential (NS)	.00334	.00130	.00075	.00040	.00182	.00105	.00056	.00023	.00002	.00002	.00014
Phases (deg)											
Radial	43.4	-154.0	-27.7	-100.2	47.8	33.5	47.3	25.2	-38.7	87.5	48.3
Tangential (EW)	-124.6	-79.5	-149.1	-83.4	-128.8	-142.9	-129.0	-147.6	142.0	157.6	-149.1
Tangential (NS)	99.6	111.0	81.3	107.3	-179.2	171.7	180.0	162.8	-142.8	164.0	-119.6

MARA2 40

MARA2 4022 lon/lat: 37°8570 -46°8776

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01604	.00797	.00404	.00224	.00163	.00384	.00063	.00103	.00064	.00036	.00091
Tangential (EW)	.00497	.00225	.00110	.00061	.00032	.00012	.00006	.00006	.00001	.00005	.00019
Tangential (NS)	.00226	.00112	.00039	.00031	.00084	.00061	.00027	.00010	.00003	.00007	.00013
Phases (deg)											
Radial	-113.4	-94.0	-113.9	-101.2	70.3	107.7	82.3	99.6	17.0	34.7	-51.1
Tangential (EW)	26.9	62.2	12.2	64.2	-149.6	165.7	-131.3	164.0	93.1	-29.1	-4.5
Tangential (NS)	-152.8	-103.8	-174.1	-94.2	-93.9	-91.1	-85.8	-91.9	161.7	158.4	175.6

MARPOINT

MARYLAND POINT	lon/lat: -77°.2306 38°.3730										
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00919	.00244	.00169	.00069	.00330	.00226	.00108	.00049	.00015	.00008	.00037
Tangential (EW)	.00414	.00090	.00093	.00026	.00022	.00015	.00006	.00004	.00006	.00003	.00019
Tangential (NS)	.00085	.00028	.00011	.00008	.00016	.00024	.00005	.00008	.00008	.00006	.00006
Phases (deg)											
Radial	158.0	-170.1	140.1	-173.8	-2.0	-0.6	-0.5	3.6	24.8	81.2	-179.1
Tangential (EW)	-176.0	-150.1	163.9	-155.0	-27.0	43.8	-31.9	51.8	-2.6	-170.9	-87.3
Tangential (NS)	-42.7	9.4	-52.6	5.0	-168.8	-132.9	-164.0	-156.8	-135.5	-161.0	6.0

MATE 90

MATE 9011	lon/lat: 16°.7046 40°.6478										
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00455	.00130	.00092	.00031	.00111	.00046	.00035	.00003	.00022	.00017	.00027
Tangential (EW)	.00218	.00051	.00054	.00015	.00025	.00012	.00011	.00002	.00005	.00005	.00004
Tangential (NS)	.00123	.00032	.00018	.00007	.00038	.00015	.00008	.00006	.00009	.00005	.00009
Phases (deg)											
Radial	-70.2	-44.6	-90.6	-47.4	-70.6	-102.0	-73.7	-79.6	2.2	-9.6	24.1
Tangential (EW)	45.4	68.1	22.2	70.9	126.6	37.4	100.3	75.3	154.8	44.1	-157.2
Tangential (NS)	-67.7	-26.2	-95.2	-33.8	55.0	95.9	55.9	123.4	-135.1	167.8	126.8

MATERA79

MATERA7939	lon/lat: 16°.7047 40°.6476										
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00455	.00130	.00092	.00031	.00111	.00046	.00035	.00003	.00022	.00017	.00027
Tangential (EW)	.00218	.00051	.00054	.00015	.00025	.00012	.00011	.00002	.00005	.00005	.00004
Tangential (NS)	.00123	.00032	.00018	.00007	.00038	.00015	.00008	.00006	.00009	.00005	.00009
Phases (deg)											
Radial	-70.2	-44.6	-90.6	-47.4	-70.6	-102.0	-73.7	-79.6	2.2	-9.6	24.1
Tangential (EW)	45.4	68.1	22.2	70.9	126.6	37.4	100.3	75.3	154.8	44.1	-157.2
Tangential (NS)	-67.7	-26.2	-95.2	-33.8	55.0	95.9	55.9	123.4	-135.1	167.8	126.8

MAZATL71

MAZATL7122	lon/lat: -106°.4591 23°.3419										
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00618	.00465	.00183	.00143	.00741	.00519	.00304	.00105	.00050	.00037	.00059
Tangential (EW)	.00275	.00112	.00061	.00036	.00315	.00204	.00104	.00038	.00008	.00002	.00040
Tangential (NS)	.00201	.00099	.00042	.00028	.00113	.00075	.00015	.00019	.00004	.00004	.00023
Phases (deg)											
Radial	-94.1	-89.9	-81.1	-87.2	21.2	7.0	9.3	-1.7	-160.1	-158.3	-4.9
Tangential (EW)	105.4	123.3	84.6	116.3	-153.7	-170.3	-158.6	178.7	87.0	89.2	-140.8
Tangential (NS)	77.6	89.1	85.4	86.5	155.8	170.1	106.3	164.5	5.9	69.5	175.1

MC-DON70

MC-DON7080	lon/lat: -104°.0152 30°.6792										
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00112	.00148	.00041	.00044	.00460	.00313	.00147	.00061	.00020	.00017	.00040
Tangential (EW)	.00131	.00030	.00025	.00009	.00228	.00153	.00073	.00028	.00006	.00003	.00032
Tangential (NS)	.00122	.00053	.00029	.00016	.00067	.00034	.00021	.00010	.00003	.00003	.00011
Phases (deg)											
Radial	179.1	-128.4	-61.4	-113.3	32.8	18.5	30.1	11.6	-170.0	-160.0	-59.2
Tangential (EW)	169.8	-159.0	139.6	-179.0	-146.0	-163.0	-148.3	-172.7	111.2	164.7	-137.9
Tangential (NS)	96.4	95.0	97.0	89.5	149.5	171.6	142.0	166.5	-78.9	122.8	150.2

MC-DON70

MC-DON7086 lon/lat: -104°.0159 30°.6760

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00112	.00148	.00041	.00044	.00460	.00313	.00147	.00061	.00020	.00017	.00040
Tangential (EW)	.00131	.00030	.00025	.00009	.00228	.00153	.00073	.00028	.00006	.00003	.00032
Tangential (NS)	.00121	.00053	.00029	.00016	.00067	.00034	.00021	.00010	.00003	.00003	.00011
<u>Phases (deg)</u>											
Radial	179.1	-128.4	-61.5	-113.3	32.8	18.5	30.1	11.6	-170.0	-160.0	-59.2
Tangential (EW)	169.8	-159.0	139.6	-179.0	-146.0	-163.0	-148.3	-172.7	111.2	164.7	-137.9
Tangential (NS)	96.4	95.0	97.0	89.5	149.5	171.6	142.0	166.5	-78.9	122.8	150.2

MEDICINA

MEDICINA lon/lat: 11°.6469 44°.5192

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00546	.00160	.00114	.00039	.00162	.00061	.00050	.00002	.00026	.00014	.00010
Tangential (EW)	.00208	.00059	.00049	.00017	.00026	.00015	.00009	.00001	.00006	.00002	.00006
Tangential (NS)	.00081	.00026	.00012	.00007	.00030	.00002	.00008	.00004	.00009	.00005	.00011
<u>Phases (deg)</u>											
Radial	-71.5	-43.6	-90.8	-45.1	-62.3	-100.1	-63.6	-45.9	-0.3	-10.2	8.2
Tangential (EW)	67.3	95.8	42.6	94.2	110.8	10.9	95.7	-61.1	156.5	57.6	-107.7
Tangential (NS)	-49.9	-3.8	-63.9	2.3	24.0	-120.3	22.4	144.8	-143.6	156.7	135.5

META6 40

META6 4006 lon/lat: 24°.3845 60°.2409

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00234	.00061	.00044	.00014	.00168	.00102	.00053	.00014	.00065	.00045	.00056
Tangential (EW)	.00154	.00031	.00040	.00008	.00054	.00060	.00021	.00012	.00012	.00001	.00009
Tangential (NS)	.00016	.00007	.00010	.00002	.00023	.00012	.00004	.00002	.00003	.00003	.00020
<u>Phases (deg)</u>											
Radial	-65.0	-25.9	-88.6	-7.9	-53.9	-104.8	-56.5	-137.4	22.1	7.7	32.7
Tangential (EW)	32.9	71.1	7.3	74.0	89.8	39.0	81.6	22.9	-179.8	167.7	-167.5
Tangential (NS)	-146.8	168.9	132.8	151.0	52.6	-43.7	35.7	-131.9	133.7	32.0	87.4

METSHOVI

METSAHOVI lon/lat: 24°.3841 60°.2420

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00231	.00058	.00048	.00015	.00179	.00106	.00054	.00014	.00048	.00035	.00024
Tangential (EW)	.00124	.00029	.00029	.00007	.00040	.00039	.00013	.00007	.00010	.00003	.00010
Tangential (NS)	.00023	.00008	.00010	.00002	.00026	.00012	.00006	.00002	.00005	.00002	.00020
<u>Phases (deg)</u>											
Radial	-71.1	-35.3	-89.6	-7.9	-52.0	-104.7	-54.1	-135.1	22.6	12.3	-154.5
Tangential (EW)	40.6	74.5	16.5	82.1	110.6	38.0	99.3	11.7	-176.0	-141.8	-127.8
Tangential (NS)	-165.1	-164.7	130.5	145.2	35.6	-51.4	35.8	-122.6	167.2	63.2	103.4

MILESMON

MILES CITY MT lon/lat: -105°.8608 46°.3965

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00373	.00147	.00044	.00031	.00461	.00297	.00147	.00058	.00018	.00009	.00024
Tangential (EW)	.00234	.00071	.00043	.00019	.00171	.00114	.00054	.00021	.00004	.00004	.00018
Tangential (NS)	.00102	.00044	.00027	.00014	.00068	.00038	.00021	.00009	.00009	.00007	.00009
<u>Phases (deg)</u>											
Radial	107.2	169.6	52.8	176.3	44.6	31.9	43.6	25.6	12.7	15.9	-168.7
Tangential (EW)	-132.6	-84.6	-160.9	-91.0	-121.1	-138.1	-122.2	-145.5	144.3	-176.7	-131.7
Tangential (NS)	127.5	109.7	105.0	107.4	172.1	163.3	168.6	155.0	-159.2	-162.6	-100.9

MLNGIC75

MLNGIC7580 lon/lat: 33°1912 37°3765

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00310	.00088	.00065	.00022	.00061	.00052	.00023	.00009	.00010	.00019	.00034
Tangential (EW)	.00196	.00043	.00049	.00010	.00042	.00016	.00015	.00005	.00004	.00001	.00007
Tangential (NS)	.00103	.00011	.00019	.00003	.00079	.00045	.00022	.00008	.00011	.00007	.00014
Phases (deg)											
Radial	-62.9	-38.0	-87.4	-39.2	-135.2	-135.4	-136.6	-143.4	18.9	6.4	51.6
Tangential (EW)	15.6	34.1	-1.3	39.3	139.7	99.3	127.2	108.6	-169.2	-4.1	-101.9
Tangential (NS)	-94.1	-57.9	-131.9	-73.9	45.4	45.8	43.6	50.6	-144.1	171.6	126.8

MOJAVE

MOJAVE lon/lat: -116°8876 35°3305 continental, Farrel

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00196	.00146	.00111	.00053	.00984	.00623	.00306	.00117	.00011	.00006	.00045
Tangential (EW)	.00186	.00051	.00032	.00011	.00306	.00193	.00094	.00033	.00008	.00003	.00029
Tangential (NS)	.00354	.00142	.00078	.00044	.00164	.00101	.00052	.00022	.00005	.00002	.00011
Phases (deg)											
Radial	-9.3	-111.4	-53.7	-87.5	44.0	29.4	43.1	21.0	-78.3	171.8	44.5
Tangential (EW)	-143.1	-81.9	-178.5	-90.2	-130.3	-144.2	-130.3	-149.2	135.2	161.5	-138.7
Tangential (NS)	96.1	110.8	78.9	107.7	178.5	166.8	176.8	158.0	10.6	32.4	-118.4

MOJAVE

MOJAVE lon/lat: 116°8876 35°3305 Earth structure: continental

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00202	.00146	.00112	.00054	.00986	.00623	.00307	.00117	.00011	.00006	.00045
Tangential (EW)	.00181	.00050	.00031	.00011	.00297	.00187	.00091	.00032	.00008	.00003	.00027
Tangential (NS)	.00341	.00138	.00075	.00043	.00159	.00097	.00050	.00021	.00005	.00002	.00011
Phases (deg)											
Radial	8.7	-110.7	-53.3	-86.9	44.0	29.3	43.1	20.9	-78.0	171.0	45.4
Tangential (EW)	-141.7	-81.5	-176.7	-90.1	-130.1	-144.0	-130.1	-149.3	135.8	157.3	-138.7
Tangential (NS)	97.1	111.5	80.0	108.4	179.5	168.0	177.8	159.2	12.3	36.3	-177.5

MOJAVE12

MOJAVE lon/lat: -116°8876 35°3305 Earth structure: oceanic

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00200	.00145	.00112	.00053	.00980	.00620	.00305	.00117	.00011	.00006	.00045
Tangential (EW)	.00247	.00084	.00043	.00021	.00326	.00211	.00101	.00037	.00008	.00004	.00031
Tangential (NS)	.00356	.00140	.00079	.00043	.00178	.00105	.00056	.00023	.00001	.00002	.00014
Phases (deg)											
Radial	-9.3	-110.8	-53.5	-87.0	43.9	29.2	43.0	20.8	-78.2	171.8	44.4
Tangential (EW)	-136.7	-86.1	-163.6	-90.6	-133.5	-148.0	-133.9	-153.5	134.4	142.2	-147.8
Tangential (NS)	97.7	110.7	80.8	107.0	179.6	171.9	178.5	163.7	-123.5	165.9	-120.5

MON PK

MNP MONUMENT PEA lon/lat: -116°4228 32°8917

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00467	.00265	.00179	.00096	.01123	.00711	.00352	.00135	.00013	.00009	.00041
Tangential (EW)	.00192	.00022	.00041	.00009	.00347	.00216	.00109	.00038	.00008	.00002	.00028
Tangential (NS)	.00385	.00157	.00083	.00049	.00165	.00102	.00053	.00023	.00004	.00003	.00016
Phases (deg)											
Radial	-46.4	-84.1	-65.2	-75.0	39.9	24.9	38.7	16.5	-104.2	-178.1	94.5
Tangential (EW)	-179.1	-156.8	141.4	170.0	-135.8	-150.4	-136.1	-156.6	136.2	153.4	-126.0
Tangential (NS)	94.6	111.2	78.2	108.0	178.6	167.4	176.7	159.7	-165.4	176.2	-121.3

MORA5540

MORA554055 lon/lat: 147°1858 -9°4357

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00648	.00327	.00210	.00082	.01122	.00564	.00407	.00086	.00080	.00042	.00107
Tangential (EW)	.00397	.00178	.00088	.00041	.00107	.00072	.00055	.00016	.00004	.00004	.00008
Tangential (NS)	.00274	.00174	.00071	.00042	.00072	.00048	.00025	.00013	.00001	.00003	.00012
<u>Phases (deg)</u>											
Radial	159.3	122.6	121.8	116.4	-126.1	-147.2	-132.0	-167.3	-158.3	-178.6	-128.6
Tangential (EW)	17.5	5.0	10.9	9.1	-151.1	-175.6	-147.0	179.9	-145.1	10.5	105.0
Tangential (NS)	-21.9	-37.9	-30.3	-42.6	-26.0	-80.7	-32.0	-103.6	-77.9	-165.3	117.6

MT1ATH75

MT1ATH7515 lon/lat: 23°9325 38°0774

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00379	.00107	.00078	.00026	.00072	.00043	.00024	.00005	.00015	.00017	.00030
Tangential (EW)	.00201	.00044	.00051	.00011	.00032	.00010	.00012	.00004	.00004	.00003	.00005
Tangential (NS)	.00114	.00022	.00018	.00005	.00057	.00028	.00014	.00006	.00010	.00006	.00011
<u>Phases (deg)</u>											
Radial	-67.8	-43.7	-89.7	-46.0	-90.6	-115.8	-95.6	-118.3	6.5	0.5	44.1
Tangential (EW)	31.3	49.0	11.2	55.7	143.7	90.8	122.5	109.7	171.2	34.0	-122.7
Tangential (NS)	-78.6	-34.5	-112.4	-47.3	53.3	65.7	53.3	89.6	-140.0	172.1	128.8

MT2MAT75

MT2MAT7541 lon/lat: 16°7043 40°6473

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00455	.00130	.00092	.00031	.00111	.00046	.00035	.00003	.00022	.00017	.00027
Tangential (EW)	.00218	.00051	.00054	.00015	.00025	.00012	.00011	.00002	.00005	.00005	.00004
Tangential (NS)	.00123	.00032	.00018	.00007	.00038	.00015	.00008	.00006	.00009	.00005	.00009
<u>Phases (deg)</u>											
Radial	-70.2	-44.6	-90.6	-47.4	-70.6	-102.0	-73.7	-79.6	2.2	-9.6	24.1
Tangential (EW)	45.4	68.1	22.2	70.9	126.6	37.4	100.3	75.3	154.8	44.1	-157.2
Tangential (NS)	-67.7	-26.2	-95.2	-33.8	55.0	95.9	55.9	123.4	-135.1	167.8	126.8

MTGNRO75

MTGNRO7590 lon/lat: 9°0178 45°9263

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00604	.00180	.00120	.00042	.00176	.00059	.00054	.00000	.00040	.00020	.00035
Tangential (EW)	.00263	.00069	.00061	.00020	.00033	.00028	.00015	.00004	.00008	.00007	.00006
Tangential (NS)	.00114	.00038	.00016	.00009	.00023	.00008	.00004	.00006	.00005	.00003	.00008
<u>Phases (deg)</u>											
Radial	-71.5	-42.1	-90.0	-44.8	-61.5	-101.5	-63.7	-59.6	1.1	-21.7	-10.6
Tangential (EW)	65.3	95.8	38.9	92.1	95.2	20.2	79.6	14.7	150.2	53.8	145.1
Tangential (NS)	-35.6	5.3	-39.2	8.3	44.8	-165.8	34.8	156.4	-126.5	124.4	107.7

MT-HOP79

MT-HOP7921 lon/lat: -110°8781 31°6832

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00162	.00189	.00086	.00063	.00693	.00453	.00222	.00087	.00017	.00015	.00036
Tangential (EW)	.00136	.00033	.00024	.00007	.00279	.00180	.00090	.00032	.00006	.00003	.00031
Tangential (NS)	.00249	.00099	.00052	.00030	.00108	.00062	.00034	.00015	.00002	.00003	.00013
<u>Phases (deg)</u>											
Radial	-97.7	-108.3	-74.3	-95.6	38.3	23.4	35.7	15.0	-150.4	-159.2	-17.6
Tangential (EW)	-172.4	-121.4	154.5	-140.5	-140.6	-156.5	-142.7	-164.2	118.0	139.2	-144.4
Tangential (NS)	87.7	103.7	76.8	98.3	165.2	168.6	159.8	161.1	-58.9	108.9	168.0

NALL 90

NALL 9012 lon/lat: 11°8651 78°9291

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00775	.00284	.00154	.00042	.00133	.00149	.00040	.00036	.00178	.00124	.00156
Tangential (EW)	.00283	.00083	.00062	.00016	.00067	.00079	.00024	.00016	.00017	.00004	.00019
Tangential (NS)	.00172	.00059	.00027	.00016	.00052	.00040	.00015	.00012	.00004	.00004	.00024
<u>Phases (deg)</u>											
Radial	-158.5	-116.3	175.4	-113.8	-25.3	-122.3	-25.2	-156.4	32.0	5.5	47.1
Tangential (EW)	-6.1	40.3	-30.6	43.8	90.7	47.2	83.5	34.8	-177.2	171.2	-149.8
Tangential (NS)	17.6	53.5	-13.6	70.9	136.0	42.2	137.7	-2.0	-32.8	-43.8	70.3

NATAL 79

NATAL 7929 lon/lat: -35°1646 -5°9275

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.03481	.01178	.00801	.00317	.00208	.00220	.00068	.00057	.00115	.00098	.00124
Tangential (EW)	.00334	.00150	.00085	.00045	.00007	.00057	.00003	.00017	.00018	.00020	.00033
Tangential (NS)	.00391	.00131	.00093	.00340	.00100	.00089	.00033	.00017	.00008	.00009	.00011
<u>Phases (deg)</u>											
Radial	33.9	48.9	22.4	48.8	104.8	15.0	104.1	-17.3	-167.9	-152.2	-127.1
Tangential (EW)	20.1	38.2	5.0	32.8	-134.6	-26.9	60.8	-41.3	-174.7	-150.6	-109.6
Tangential (NS)	70.3	110.5	46.8	119.8	137.6	118.3	147.0	95.8	-147.6	-144.1	118.1

NAT-MA78

NAT-MA7843 lon/lat: 148°9393 -35°6351

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00961	.00129	.00209	.00033	.00281	.00283	.00122	.00082	.00012	.00010	.00070
Tangential (EW)	.00508	.00180	.00091	.00049	.00123	.00072	.00039	.00014	.00003	.00015	.00010
Tangential (NS)	.00115	.00036	.00018	.00013	.00142	.00127	.00048	.00028	.00005	.00007	.00025
<u>Phases (deg)</u>											
Radial	126.9	173.2	96.3	164.0	117.8	67.4	109.8	55.8	-20.8	-99.4	-81.5
Tangential (EW)	93.4	126.8	82.9	129.2	-169.2	168.7	-169.3	147.7	-104.8	73.5	135.3
Tangential (NS)	11.8	74.9	-34.0	80.4	-118.0	-144.0	-117.5	-160.6	-139.9	83.8	118.6

NOME

NOME lon/lat: -165°3712 64°5618

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00464	.00277	.00067	.00073	.00473	.00421	.00149	.00075	.00134	.00064	.00127
Tangential (EW)	.00264	.00043	.00061	.00007	.00157	.00093	.00047	.00022	.00008	.00005	.00012
Tangential (NS)	.00211	.00124	.00023	.00037	.00132	.00116	.00042	.00022	.00024	.00017	.00030
<u>Phases (deg)</u>											
Radial	86.4	136.5	156.1	132.8	131.6	122.6	133.4	125.9	15.6	51.7	73.9
Tangential (EW)	112.8	163.0	78.9	166.5	29.0	-9.2	29.2	-20.0	-158.9	-58.9	133.2
Tangential (NS)	-110.0	-60.2	-81.8	-57.3	-69.1	-73.5	-67.7	-66.5	146.5	-100.1	-129.8

NOUA3640

NOUA364036 lon/lat: 166°4104 -22°2686

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01871	.00351	.00400	.00098	.00890	.00420	.00289	.00074	.00063	.00034	.00103
Tangential (EW)	.00572	.00089	.00133	.00020	.00075	.00039	.00018	.00009	.00001	.00005	.00004
Tangential (NS)	.00500	.00229	.00084	.00059	.00117	.00095	.00036	.00020	.00007	.00004	.00012
<u>Phases (deg)</u>											
Radial	48.7	61.4	23.1	63.3	-147.6	-170.7	-154.7	158.8	-164.2	-161.8	-131.8
Tangential (EW)	10.1	18.1	-9.1	11.9	11.8	-18.1	-7.4	-51.7	-164.2	-150.5	149.0
Tangential (NS)	-49.8	-17.8	-52.4	-17.8	-103.7	-139.2	-94.3	-161.5	-146.4	-151.1	110.0

NRAO 140

NRAO GREENBANK lon/lat: -79°8358 38°4366

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00720	.00205	.00124	.00057	.00293	.00200	.00096	.00043	.00010	.00003	.00036
Tangential (EW)	.00354	.00077	.00079	.00023	.00014	.00008	.00004	.00003	.00004	.00004	.00017
Tangential (NS)	.00050	.00022	.00004	.00006	.00009	.00017	.00002	.00006	.00008	.00006	.00005
Phases (deg)											
Radial	153.0	-172.4	132.4	-175.4	0.2	0.4	1.7	4.5	29.0	96.5	-178.3
Tangential (EW)	-174.2	-149.0	164.5	-154.1	-80.9	108.7	-90.8	90.5	-5.0	-154.7	-92.4
Tangential (NS)	-58.8	14.5	-94.9	9.5	164.5	-125.1	169.3	-156.9	-135.4	-163.0	5.2

OCOTILLO

OCOTILLO lon/lat: -115°7962 32°7901

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00404	.00251	.00162	.00090	.01048	.00666	.00328	.00127	.00015	.00011	.00049
Tangential (EW)	.00209	.00047	.00039	.00011	.00358	.00229	.00112	.00040	.00008	.00003	.00033
Tangential (NS)	.00381	.00152	.00083	.00047	.00174	.00103	.00056	.00024	.00001	.00002	.00015
Phases (deg)											
Radial	-50.9	-87.7	-66.9	-77.8	39.9	24.8	38.6	16.4	-116.3	-174.1	47.8
Tangential (EW)	-163.1	-113.0	164.6	-128.7	-138.3	-153.2	-139.0	-159.2	125.3	124.0	-145.3
Tangential (NS)	94.1	109.8	78.3	106.0	177.4	170.9	175.9	163.8	-64.0	162.7	-124.3

ONSALA60

ONSALA lon/lat: 11°9263 57°3947

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00384	.00091	.00084	.00019	.00224	.00120	.00071	.00003	.00084	.00063	.00017
Tangential (EW)	.00124	.00034	.00031	.00009	.00042	.00041	.00015	.00006	.00018	.00010	.00018
Tangential (NS)	.00058	.00027	.00021	.00008	.00032	.00017	.00009	.00004	.00007	.00001	.00018
Phases (deg)											
Radial	-56.0	-46.1	-90.7	-34.4	-44.5	-123.2	-49.6	178.4	14.9	37.3	3.4
Tangential (EW)	75.4	97.6	40.8	94.8	119.0	25.4	98.7	-14.1	-177.0	-126.7	-177.0
Tangential (NS)	84.2	131.3	77.7	103.9	17.2	-55.0	25.2	-165.0	173.3	121.8	106.4

ORRORA79

ORRORA7943 lon/lat: 148°9548 -35°6238

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00964	.00129	.00209	.00033	.00281	.00283	.00122	.00082	.00012	.00010	.00070
Tangential (EW)	.00509	.00180	.00091	.00049	.00123	.00072	.00039	.00014	.00003	.00015	.00010
Tangential (NS)	.00115	.00036	.00018	.00013	.00142	.00127	.00048	.00028	.00005	.00007	.00025
Phases (deg)											
Radial	126.8	173.0	96.3	163.7	118.0	67.5	110.0	55.9	-21.1	-99.5	-81.6
Tangential (EW)	93.4	126.8	82.9	129.1	-169.3	168.6	-169.3	147.6	-104.8	73.5	135.4
Tangential (NS)	11.6	74.7	-34.1	80.2	-118.0	-144.0	-117.6	-160.6	-139.9	83.8	118.6

OTAY

OTAY MOUNTAIN lon/lat: -116°8408 32°6007

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00663	.00333	.00225	.00119	.01257	.00796	.00396	.00151	.00018	.00013	.00065
Tangential (EW)	.00243	.00046	.00047	.00011	.00397	.00253	.00124	.00044	.00009	.00004	.00035
Tangential (NS)	.00425	.00171	.00092	.00053	.00199	.00119	.00064	.00027	.00001	.00001	.00017
Phases (deg)											
Radial	-45.3	-75.8	-64.6	-69.8	38.7	23.6	37.5	15.4	-108.0	-173.2	57.5
Tangential (EW)	-168.3	-126.1	159.1	-146.5	-138.8	-153.5	-139.4	-159.4	125.5	116.5	-144.2
Tangential (NS)	95.7	111.2	79.5	107.5	-179.9	172.3	178.9	165.1	-23.3	152.7	-122.3

OTTA4840

OTTA484048 lon/lat: -75°.7059 45°.3986

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00615	.00184	.00111	.00056	.00283	.00176	.00095	.00035	.00033	.00009	.00067
Tangential (EW)	.00311	.00072	.00066	.00021	.00025	.00022	.00009	.00006	.00006	.00007	.00026
Tangential (NS)	.00070	.00039	.00017	.00012	.00005	.00022	.00001	.00006	.00005	.00004	.00008
<u>Phases (deg)</u>											
Radial	155.2	-172.2	132.0	-173.9	-3.9	-4.2	-1.1	0.8	12.2	-43.6	-68.7
Tangential (EW)	-162.3	-142.1	175.3	-145.8	-108.4	172.5	-114.8	151.2	-10.3	-140.6	-89.4
Tangential (NS)	5.0	46.9	12.9	41.6	176.1	-107.4	129.9	-149.3	-120.5	-162.4	48.5

OVRO 130

OVRO130 lon/lat: -118°.2827 37°.2303

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00276	.00102	.00097	.00031	.01000	.00629	.00310	.00118	.00012	.00003	.00025
Tangential (EW)	.00238	.00079	.00041	.00020	.00295	.00188	.00089	.00032	.00007	.00004	.00025
Tangential (NS)	.00319	.00127	.00071	.00039	.00156	.00094	.00048	.00020	.00006	.00004	.00014
<u>Phases (deg)</u>											
Radial	38.5	-143.5	-33.2	-97.2	47.1	32.7	46.5	24.4	-45.0	99.2	105.6
Tangential (EW)	-125.7	-75.0	-153.8	-78.8	-126.1	-139.4	-125.9	-143.3	141.2	113.5	-169.2
Tangential (NS)	97.7	111.2	79.6	108.1	179.6	167.4	178.1	158.1	-162.1	177.3	-119.8

P VRDS

PVE PALOS VERDES lon/lat: -118°.4035 33°.7426

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00756	.00314	.00250	.00117	.01418	.00895	.00446	.00167	.00018	.00010	.00076
Tangential (EW)	.00264	.00073	.00047	.00018	.00381	.00243	.00118	.00041	.00009	.00004	.00034
Tangential (NS)	.00471	.00190	.00105	.00058	.00246	.00149	.00079	.00032	.00000	.00002	.00020
<u>Phases (deg)</u>											
Radial	-31.5	-70.1	-57.5	-63.9	39.9	25.1	39.1	16.8	-86.2	-175.6	62.9
Tangential (EW)	-147.3	-95.6	-178.2	-103.6	-135.2	-149.6	-135.3	-155.1	132.4	125.8	-146.7
Tangential (NS)	102.0	114.6	84.9	111.0	-174.3	176.3	-175.1	167.7	71.4	140.1	-116.1

PTRK-A70

PTRK-A7069 lon/lat: -80°.6057 28°.2269

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01161	.00285	.00223	.00074	.00259	.00194	.00068	.00041	.00042	.00021	.00183
Tangential (EW)	.00491	.00092	.00110	.00026	.00061	.00064	.00020	.00014	.00003	.00004	.00026
Tangential (NS)	.00335	.00051	.00085	.00013	.00038	.00037	.00011	.00006	.00005	.00007	.00011
<u>Phases (deg)</u>											
Radial	170.9	-159.8	148.9	-165.1	9.9	13.2	7.8	21.8	147.7	155.7	-110.3
Tangential (EW)	-177.2	-162.5	162.5	-166.0	49.7	47.8	53.5	41.9	10.0	-150.3	-108.5
Tangential (NS)	-159.1	-108.8	174.7	-104.2	1.5	-51.7	-11.5	-80.3	-66.7	90.5	125.9

PENTICTN

PENTICTON lon/lat: -119°.6199 49°.3226

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00815	.00268	.00128	.00058	.00785	.00493	.00247	.00093	.00044	.00027	.00053
Tangential (EW)	.00412	.00154	.00075	.00042	.00266	.00177	.00083	.00032	.00010	.00008	.00026
Tangential (NS)	.00121	.00029	.00030	.00011	.00155	.00092	.00047	.00019	.00002	.00002	.00012
<u>Phases (deg)</u>											
Radial	84.7	139.0	45.8	133.6	59.7	46.9	58.8	39.5	4.6	23.6	41.9
Tangential (EW)	-108.8	-68.1	-132.6	-71.5	-109.4	-123.5	-110.5	-127.3	155.3	-160.2	-138.8
Tangential (NS)	164.6	125.0	129.7	121.1	-158.3	-171.5	-160.4	176.7	88.1	-133.0	-103.3

PGC1 90

PGC1 9013 lon/lat: -123°4511 48°6473

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01388	.00410	.00252	.00096	.01106	.00696	.00385	.00128	.00051	.00034	.00069
Tangential (EW)	.00650	.00239	.00126	.00066	.00367	.00246	.00128	.00045	.00014	.00011	.00033
Tangential (NS)	.00187	.00021	.00041	.00008	.00220	.00128	.00065	.00025	.00007	.00006	.00016
Phases (deg)											
Radial	75.8	122.8	41.4	114.1	61.9	49.1	59.5	41.9	-1.2	25.6	35.9
Tangential (EW)	-109.9	-72.9	-133.8	-76.6	-112.3	-126.7	-115.9	-131.1	158.2	-163.8	-147.4
Tangential (NS)	-169.0	-176.9	156.2	154.8	-152.5	-162.9	-158.0	-175.3	166.6	-169.0	-132.5

PIETWN

PTW PIE TOWN lon/lat: -108°1192 34°2999

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00065	.00143	.00049	.00042	.00586	.00385	.00184	.00075	.00006	.00006	.00021
Tangential (EW)	.00119	.00021	.00023	.00005	.00218	.00139	.00068	.00025	.00005	.00002	.00022
Tangential (NS)	.00180	.00074	.00041	.00023	.00079	.00046	.00025	.00012	.00006	.00005	.00008
Phases (deg)											
Radial	161.5	-132.1	-60.9	-111.7	38.9	24.3	37.4	16.5	-149.0	-178.8	160.1
Tangential (EW)	-171.4	-119.1	149.4	-153.0	-135.3	-151.4	-136.3	-159.5	131.2	166.8	-133.2
Tangential (NS)	95.0	104.2	83.1	101.8	158.1	154.8	154.7	151.6	-152.6	-173.1	-125.3

PINY 90

PINY 9014 lon/lat: -116°4582 33°6110

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00332	.00212	.00144	.00079	.01033	.00657	.00353	.00122	.00014	.00014	.00048
Tangential (EW)	.00219	.00057	.00039	.00013	.00347	.00223	.00118	.00038	.00008	.00003	.00032
Tangential (NS)	.00370	.00149	.00079	.00046	.00177	.00105	.00056	.00023	.00001	.00003	.00015
Phases (deg)											
Radial	-41.5	-90.2	-61.4	-79.6	41.2	26.5	38.2	18.3	-113.2	-155.2	18.1
Tangential (EW)	-154.2	-101.7	174.2	-111.3	-136.8	-151.5	-139.4	-157.3	128.9	128.7	-146.0
Tangential (NS)	94.7	110.5	79.4	105.4	178.9	172.8	175.3	163.7	-24.6	91.0	-174.0

PINYON

PNF PINYON FLAT lon/lat: -116°4579 33°6092

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00370	.00222	.00156	.00082	.01069	.00678	.00335	.00128	.00014	.00010	.00050
Tangential (EW)	.00225	.00058	.00041	.00013	.00357	.00229	.00111	.00039	.00008	.00004	.00033
Tangential (NS)	.00389	.00155	.00086	.00048	.00187	.00111	.00060	.00025	.00001	.00002	.00015
Phases (deg)											
Radial	-41.1	-89.5	-62.8	-77.6	41.0	26.0	39.9	17.7	-104.0	-176.5	49.4
Tangential (EW)	-154.5	-102.1	174.2	-112.1	-136.9	-151.6	-137.5	-157.4	128.7	128.2	-145.9
Tangential (NS)	96.6	111.0	80.3	107.3	179.7	172.3	178.5	164.7	-86.9	161.4	-121.5

PLATVL

PTV PLATTEVILLE lon/lat: -104°7260 40°1828

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00248	.00128	.00025	.00029	.00473	.00311	.00150	.00061	.00006	.00001	.00024
Tangential (EW)	.00179	.00045	.00034	.00011	.00178	.00117	.00056	.00021	.00004	.00003	.00020
Tangential (NS)	.00123	.00054	.00031	.00017	.00064	.00035	.00020	.00009	.00008	.00006	.00007
Phases (deg)											
Radial	115.7	-168.2	16.5	-152.2	39.9	26.4	38.7	19.9	12.3	41.4	-180.0
Tangential (EW)	-147.8	-97.9	-178.7	-108.6	-130.0	-146.9	-131.1	-155.1	135.1	176.7	-131.9
Tangential (NS)	112.2	106.4	97.2	104.2	158.9	153.9	155.2	150.7	-153.3	-167.0	-108.2

POTSDA11

POTSDA1181 lon/lat: 13°0653 52°3790

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00446	.00128	.00088	.00028	.00187	.00084	.00058	.00006	.00055	.00032	.00047
Tangential (EW)	.00192	.00046	.00047	.00013	.00045	.00042	.00019	.00008	.00011	.00003	.00009
Tangential (NS)	.00053	.00019	.00010	.00005	.00026	.00007	.00005	.00004	.00003	.00004	.00013
Phases (deg)											
Radial	-64.4	-31.6	-83.1	-29.7	-56.9	-100.8	-59.2	-133.8	10.5	0.8	4.5
Tangential (EW)	63.3	99.9	34.9	95.1	91.7	35.7	80.6	25.8	165.6	72.2	163.6
Tangential (NS)	-3.9	44.9	27.1	56.7	47.1	-67.3	37.1	168.9	-157.7	80.8	88.7

PRBLSM

PRB PEARBLOSSOM lon/lat: -117°9215 34°5121

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00400	.00195	.00163	.00075	.01159	.00731	.00362	.00137	.00014	.00008	.00057
Tangential (EW)	.00258	.00080	.00045	.00020	.00355	.00228	.00110	.00039	.00009	.00004	.00032
Tangential (NS)	.00416	.00166	.00093	.00051	.00214	.00128	.00068	.00028	.00000	.00002	.00017
Phases (deg)											
Radial	24.1	-88.4	-55.7	-74.0	42.4	27.6	41.6	19.2	-83.6	178.0	54.1
Tangential (EW)	-141.5	-90.0	-170.4	-95.9	-134.3	-148.6	-134.5	-154.1	133.8	133.7	-147.4
Tangential (NS)	100.1	113.0	82.9	109.3	-176.8	174.5	-177.6	166.0	-123.2	152.8	-118.0

PRSDIO

PRS PRESIDIO lon/lat: -122°4550 37°8041

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00976	.00052	.00230	.00034	.01558	.00969	.00476	.00181	.00033	.00011	.00087
Tangential (EW)	.00483	.00163	.00089	.00045	.00416	.00267	.00125	.00047	.00013	.00005	.00034
Tangential (NS)	.00379	.00148	.00087	.00046	.00240	.00141	.00073	.00029	.00001	.00001	.00018
Phases (deg)											
Radial	34.9	94.3	-12.1	-0.9	48.3	34.2	48.7	25.7	-34.9	76.3	66.6
Tangential (EW)	-124.7	-82.2	-151.1	-88.8	-127.1	-140.5	-126.6	-145.2	146.1	173.1	-146.8
Tangential (NS)	106.3	115.7	86.6	112.9	-172.6	176.3	-172.0	166.7	-179.4	132.3	-116.1

PT REY

PTR POINT REYES lon/lat: -122°9365 38°1023

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01111	.00089	.00253	.00039	.01637	.01018	.00497	.00190	.00037	.00014	.00093
Tangential (EW)	.00499	.00171	.00092	.00047	.00417	.00269	.00125	.00047	.00013	.00005	.00034
Tangential (NS)	.00376	.00146	.00086	.00046	.00240	.00140	.00073	.00029	.00001	.00001	.00017
Phases (deg)											
Radial	37.1	90.4	-8.4	16.4	48.8	34.8	49.2	26.3	-33.1	69.0	68.0
Tangential (EW)	-123.1	-80.9	-149.5	-87.2	-126.2	-139.4	-125.8	-144.1	147.0	174.1	-147.1
Tangential (NS)	106.0	115.5	86.2	112.9	-172.8	175.9	-172.2	166.3	-179.4	128.8	-116.5

PURA4540

PURA454045 lon/lat: 118°8248 32°0660

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00365	.00116	.00119	.00041	.00414	.00354	.00140	.00077	.00010	.00015	.00034
Tangential (EW)	.00156	.00087	.00049	.00030	.00165	.00116	.00057	.00023	.00006	.00009	.00024
Tangential (NS)	.00216	.00069	.00032	.00017	.00134	.00108	.00043	.00021	.00004	.00008	.00013
Phases (deg)											
Radial	132.5	134.1	138.9	136.4	-98.5	-110.5	-93.8	-116.6	136.0	114.2	172.7
Tangential (EW)	122.6	123.8	135.9	130.6	-113.0	-136.8	-108.6	-144.2	33.3	28.0	64.3
Tangential (NS)	9.0	38.3	20.4	40.9	122.7	97.0	128.0	77.1	-146.6	-137.2	145.9

QUINCY

QUI QUINCY lon/lat: -120°9447 39°9750

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00634	.00133	.00128	.00011	.01117	.00698	.00344	.00130	.00022	.00010	.00028
Tangential (EW)	.00365	.00125	.00063	.00034	.00325	.00206	.00099	.00038	.00011	.00005	.00025
Tangential (NS)	.00295	.00116	.00067	.00036	.00165	.00098	.00049	.00020	.00007	.00004	.00014
Phases (deg)											
Radial	58.1	149.5	1.1	144.4	51.5	37.7	51.1	29.4	-24.5	49.4	101.4
Tangential (EW)	-119.7	-73.5	-147.2	-80.6	-121.2	-134.5	-121.2	-139.9	153.7	-165.2	-129.3
Tangential (NS)	100.9	111.9	81.7	109.6	-177.8	169.1	-179.1	159.2	-165.2	178.5	-118.7

REUA1240

REUA124012 lon/lat: 55°5718 -21°2075

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00909	.00444	.00203	.00102	.00138	.00082	.00054	.00044	.00070	.00060	.00158
Tangential (EW)	.00592	.00342	.00109	.00092	.00032	.00028	.00012	.00006	.00005	.00006	.00024
Tangential (NS)	.00202	.00105	.00047	.00029	.00154	.00072	.00049	.00017	.00006	.00004	.00017
Phases (deg)											
Radial	139.5	129.0	120.9	135.9	-139.7	-175.5	-113.5	162.4	-173.0	-149.7	-62.5
Tangential (EW)	43.1	82.2	33.6	83.1	-7.8	-24.8	-11.8	-107.2	-135.3	-92.6	-28.2
Tangential (NS)	160.0	-131.4	144.8	-134.7	146.5	162.0	148.5	161.6	-139.6	160.4	142.4

RICA2340

RICA234023 lon/lat: -80°3856 25°6239

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00780	.00224	.00126	.00059	.00162	.00115	.00039	.00026	.00052	.00030	.00196
Tangential (EW)	.00379	.00070	.00085	.00020	.00062	.00067	.00019	.00014	.00003	.00005	.00021
Tangential (NS)	.00241	.00044	.00065	.00013	.00023	.00043	.00009	.00009	.00006	.00004	.00016
Phases (deg)											
Radial	162.7	-164.3	137.6	-170.6	14.0	26.4	20.2	44.0	157.3	-176.3	-109.6
Tangential (EW)	179.3	-171.9	159.6	-172.6	55.4	48.8	56.8	43.1	-16.6	-131.2	-100.6
Tangential (NS)	-153.7	-85.8	178.1	-83.4	-48.1	-89.8	-41.8	-117.5	-59.8	107.3	103.3

RICHMOND

RICHMOND lon/lat: -80°3847 25°6128

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00871	.00250	.00144	.00062	.00192	.00135	.00063	.00034	.00047	.00023	.00133
Tangential (EW)	.00401	.00070	.00091	.00020	.00072	.00075	.00025	.00016	.00002	.00002	.00018
Tangential (NS)	.00234	.00040	.00061	.00012	.00030	.00031	.00011	.00006	.00005	.00003	.00010
Phases (deg)											
Radial	167.2	-162.4	147.0	-168.8	17.2	26.4	14.9	36.7	148.0	144.7	-144.6
Tangential (EW)	-179.0	-163.9	160.7	-166.7	43.2	40.6	44.9	36.4	1.2	-140.6	-99.1
Tangential (NS)	-155.1	-88.0	176.1	-90.0	-16.8	-65.2	-3.9	-98.7	-94.5	144.1	80.2

RIGA 18

RIGA 1884 lon/lat: 24°0591 56°9474

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00284	.00077	.00055	.00017	.00160	.00093	.00051	.00012	.00057	.00040	.00050
Tangential (EW)	.00162	.00033	.00042	.00009	.00050	.00053	.00020	.00011	.00010	.00001	.00008
Tangential (NS)	.00025	.00001	.00006	.00001	.00026	.00010	.00005	.00002	.00003	.00002	.00017
Phases (deg)											
Radial	-62.6	-25.6	-85.5	-14.9	-56.6	-103.7	-59.1	-131.7	19.9	6.6	30.4
Tangential (EW)	39.3	77.7	13.7	80.6	90.5	38.8	81.8	25.2	177.4	115.4	-168.0
Tangential (NS)	-90.6	109.8	146.2	117.7	47.3	-30.6	32.4	-155.2	173.4	64.7	90.9

RIOA1740

RIOA174017 lon/lat: -67°7519 -53°7846

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01849	.00426	.00433	.00182	.00863	.00933	.00291	.00211	.00117	.00110	.00123
Tangential (EW)	.00622	.00185	.00156	.00056	.00026	.00072	.00015	.00015	.00002	.00009	.00030
Tangential (NS)	.00825	.00247	.00210	.00082	.00138	.00094	.00055	.00021	.00003	.00005	.00017
<u>Phases (deg)</u>											
Radial	151.2	-130.5	139.5	-132.5	-96.3	-129.2	-100.7	-145.9	14.0	23.1	24.3
Tangential (EW)	150.5	169.4	126.0	177.5	41.0	-120.8	95.8	-149.8	-72.6	82.3	-117.1
Tangential (NS)	-152.8	-98.7	177.7	-102.1	71.5	61.6	78.4	56.8	-85.6	91.5	114.9

ROUMEL75

ROUMEL7517 lon/lat: 24°6942 35°4030

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00375	.00107	.00077	.00026	.00061	.00039	.00021	.00004	.00009	.00015	.00029
Tangential (EW)	.00199	.00044	.00051	.00011	.00036	.00010	.00012	.00005	.00003	.00003	.00006
Tangential (NS)	.00112	.00020	.00019	.00005	.00064	.00033	.00017	.00007	.00010	.00006	.00011
<u>Phases (deg)</u>											
Radial	-68.8	-46.7	-90.5	-49.6	-107.9	-124.2	-112.4	-126.5	2.0	0.9	49.1
Tangential (EW)	27.8	42.1	8.8	49.4	155.5	134.8	135.8	130.1	174.0	29.8	-114.1
Tangential (NS)	-78.9	-32.4	-113.5	-47.6	54.6	66.5	55.2	84.7	-138.8	172.1	130.4

SADDLEPK

SADDLEPK lon/lat: -118°6561 34°0784

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00662	.00270	.00227	.00103	.01371	.00864	.00430	.00161	.00018	.00009	.00073
Tangential (EW)	.00271	.00082	.00047	.00020	.00372	.00238	.00115	.00041	.00009	.00004	.00033
Tangential (NS)	.00470	.00189	.00105	.00058	.00250	.00152	.00080	.00032	.00000	.00002	.00020
<u>Phases (deg)</u>											
Radial	-27.3	-73.0	-55.6	-64.9	40.9	26.1	40.2	17.8	-82.4	-177.9	61.5
Tangential (EW)	-142.2	-90.8	-171.7	-97.5	-134.3	-148.5	-134.2	-154.0	133.9	129.2	-147.4
Tangential (NS)	102.9	115.0	85.6	111.5	-173.7	176.7	-174.4	167.9	107.6	139.2	-115.4

SANA3840

SANA384038 lon/lat: -70°5369 -33°3947

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00410	.00198	.00129	.00046	.00605	.00452	.00194	.00099	.00016	.00023	.00065
Tangential (EW)	.00311	.00086	.00070	.00017	.00167	.00097	.00053	.00020	.00003	.00007	.00033
Tangential (NS)	.00061	.00027	.00010	.00010	.00132	.00113	.00044	.00025	.00006	.00004	.00025
<u>Phases (deg)</u>											
Radial	-134.3	-64.5	-179.1	-60.0	-130.2	-150.6	-129.9	-166.1	52.1	16.4	26.6
Tangential (EW)	62.2	95.4	37.7	75.2	43.4	-10.5	43.8	-38.2	-153.2	169.2	-137.9
Tangential (NS)	-121.8	134.2	141.8	138.4	124.4	93.1	124.9	70.5	-155.6	170.3	123.5

SANPAULA

SANTA PAULA lon/lat: -118°9988 34°3867

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00595	.00232	.00210	.00091	.01345	.00845	.00420	.00158	.00017	.00008	.00071
Tangential (EW)	.00282	.00090	.00049	.00023	.00368	.00235	.00114	.00040	.00009	.00004	.00033
Tangential (NS)	.00457	.00183	.00102	.00056	.00244	.00147	.00078	.00031	.00000	.00002	.00019
<u>Phases (deg)</u>											
Radial	-21.7	-76.0	-53.2	-65.6	41.9	27.1	41.3	18.7	-78.0	179.0	60.6
Tangential (EW)	-138.1	-87.8	-166.4	-93.7	-133.3	-147.5	-133.2	-152.9	135.5	131.8	-148.0
Tangential (NS)	102.2	114.5	84.6	110.9	-174.2	176.2	-174.8	167.2	136.8	139.3	-116.3

SANT 90

SANT 9015 lon/lat: -70°6680 -33°1499

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00456	.00209	.00138	.00048	.00621	.00458	.00198	.00099	.00016	.00023	.00067
Tangential (EW)	.00323	.00089	.00073	.00018	.00171	.00099	.00054	.00020	.00003	.00007	.00034
Tangential (NS)	.00063	.00028	.00011	.00010	.00131	.00113	.00044	.00025	.00006	.00004	.00025
<u>Phases (deg)</u>											
Radial	-133.3	-66.6	-177.5	-63.3	-130.6	-151.5	-130.4	-167.3	54.2	15.1	26.1
Tangential (EW)	61.4	94.4	36.5	74.7	43.3	-10.1	43.6	-37.8	-151.5	168.8	-138.4
Tangential (NS)	-124.3	136.7	141.9	140.8	125.5	93.9	125.6	71.1	-155.9	170.0	123.2

SCRI 90

SCRI 9016 lon/lat: -117°2523 32°8666

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00688	.00333	.00229	.00121	.01289	.00819	.00443	.00152	.00019	.00018	.00060
Tangential (EW)	.00248	.00049	.00048	.00012	.00394	.00251	.00126	.00043	.00009	.00004	.00034
Tangential (NS)	.00439	.00180	.00094	.00055	.00218	.00132	.00060	.00028	.00002	.00004	.00017
<u>Phases (deg)</u>											
Radial	-42.1	-72.9	-61.6	-69.0	38.8	24.1	35.8	16.1	-110.9	-152.7	30.1
Tangential (EW)	-166.2	-122.9	160.8	-141.3	-138.4	-152.9	-139.8	-158.8	127.1	117.0	-144.1
Tangential (NS)	98.4	113.2	83.1	108.3	-176.8	175.6	175.9	166.9	6.8	79.3	-167.1

SANTIA74

SANTIA7400 lon/lat: -70°6686 -33°1485

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00456	.00209	.00138	.00048	.00621	.00458	.00198	.00099	.00016	.00023	.00067
Tangential (EW)	.00323	.00089	.00073	.00018	.00171	.00099	.00054	.00020	.00003	.00007	.00034
Tangential (NS)	.00063	.00028	.00011	.00010	.00131	.00113	.00044	.00025	.00006	.00004	.00025
<u>Phases (deg)</u>											
Radial	-133.3	-66.6	-177.5	-63.3	-130.6	-151.5	-130.4	-167.3	54.2	15.1	26.1
Tangential (EW)	61.4	94.3	36.5	74.6	43.3	-10.1	43.6	-37.8	-151.5	168.8	-138.4
Tangential (NS)	-124.4	136.7	141.9	140.8	125.5	93.9	125.6	71.1	-155.9	170.0	123.2

SEATTLE1

SEATTLE 1 lon/lat: -122°2491 47°6857

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01170	.00348	.00202	.00077	.01042	.00652	.00328	.00122	.00048	.00033	.00067
Tangential (EW)	.00564	.00200	.00105	.00054	.00347	.00227	.00109	.00041	.00013	.00010	.00030
Tangential (NS)	.00147	.00037	.00037	.00014	.00184	.00109	.00056	.00022	.00003	.00001	.00013
<u>Phases (deg)</u>											
Radial	75.9	127.3	38.9	117.9	60.4	47.2	59.1	39.4	-1.3	29.3	52.3
Tangential (EW)	-109.9	-70.8	-134.7	-75.0	-110.9	-124.4	-112.5	-128.8	156.8	-156.9	-137.7
Tangential (NS)	159.5	130.0	126.0	125.4	-157.7	-171.0	-160.0	177.4	98.4	-135.5	-104.8

SHANGH78

SHANGH7837 lon/lat: 121°1917 31°0964

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00558	.00116	.00162	.00039	.00606	.00483	.00207	.00103	.00015	.00022	.00049
Tangential (EW)	.00224	.00075	.00055	.00027	.00227	.00160	.00077	.00032	.00007	.00011	.00025
Tangential (NS)	.00338	.00123	.00043	.00031	.00159	.00125	.00050	.00024	.00003	.00010	.00012
<u>Phases (deg)</u>											
Radial	170.9	-163.2	164.8	-175.7	-98.6	-114.5	-93.9	-118.6	120.4	113.2	171.5
Tangential (EW)	151.5	154.9	155.0	155.8	-112.3	-139.5	-109.7	-144.5	42.5	37.8	71.2
Tangential (NS)	-5.8	26.7	-5.1	23.4	118.4	91.5	122.3	72.5	-142.0	-132.0	160.4

SIGA5040

SIGA504050 lon/lat: -45°5956 -60°7077

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.02175	.01053	.00410	.00281	.00938	.01237	.00347	.00284	.00150	.00107	.00106
Tangential (EW)	.00130	.00047	.00028	.00018	.00092	.00069	.00036	.00015	.00007	.00010	.00032
Tangential (NS)	.00193	.00089	.00040	.00029	.00130	.00091	.00041	.00015	.00004	.00005	.00010
Phases (deg)											
Radial	96.2	121.6	86.3	133.1	-128.6	-146.4	-134.5	-158.0	20.6	17.9	9.7
Tangential (EW)	-134.1	82.5	-178.2	82.7	119.5	107.0	117.7	87.6	179.1	-161.5	-124.4
Tangential (NS)	-169.1	-87.6	161.7	-72.0	31.8	11.1	34.3	5.8	-20.3	94.0	159.2

SIMOSA78

SIMOSA7838 lon/lat: 135°9370 33°5765

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01357	.00597	.00273	.00175	.01123	.00869	.00386	.00183	.00012	.00049	.00063
Tangential (EW)	.00205	.00115	.00028	.00030	.00168	.00136	.00053	.00029	.00004	.00011	.00030
Tangential (NS)	.00309	.00126	.00058	.00037	.00217	.00166	.00061	.00033	.00005	.00013	.00010
Phases (deg)											
Radial	88.0	106.1	93.8	109.2	-126.7	-146.1	-126.0	-154.0	-36.3	40.5	102.5
Tangential (EW)	13.0	45.5	25.2	52.3	-161.8	173.7	-162.4	169.0	-51.5	-6.8	44.6
Tangential (NS)	-61.6	-43.0	-66.8	-41.5	90.0	67.9	99.0	51.3	-177.0	-155.5	-174.8

SNDPOINT

SAND POINT lon/lat: -160°4755 55°3511

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01873	.00812	.00337	.00215	.01469	.01061	.00496	.00193	.00140	.00097	.00162
Tangential (EW)	.00584	.00137	.00123	.00028	.00301	.00180	.00088	.00037	.00004	.00009	.00013
Tangential (NS)	.00306	.00179	.00072	.00055	.00386	.00235	.00117	.00047	.00010	.00024	.00032
Phases (deg)											
Radial	126.8	150.8	122.3	150.5	112.2	103.1	114.4	100.8	-4.6	54.9	66.2
Tangential (EW)	109.5	157.5	80.1	152.7	41.9	13.7	40.3	-2.3	171.9	-31.7	112.3
Tangential (NS)	-67.3	-38.0	-70.9	-38.7	-100.6	-119.6	-105.7	-128.7	165.2	179.0	-144.4

SOCA4040

SOCA404040 lon/lat: -110°9539 18°7256

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01581	.00929	.00401	.00288	.01201	.00821	.00350	.00166	.00083	.00056	.00112
Tangential (EW)	.00243	.00039	.00058	.00017	.00265	.00154	.00081	.00025	.00005	.00002	.00020
Tangential (NS)	.00227	.00043	.00042	.00011	.00063	.00011	.00020	.00006	.00005	.00003	.00022
Phases (deg)											
Radial	-90.2	-81.6	-88.7	-80.6	21.9	7.1	17.6	-4.0	-155.8	-159.7	12.8
Tangential (EW)	80.2	144.5	42.6	115.5	-142.6	-160.2	-144.1	-170.7	94.9	131.3	-154.6
Tangential (NS)	30.5	5.6	7.8	5.5	92.2	150.2	74.7	156.8	-15.9	76.2	121.5

SOURDOGH

SOURDOUGH lon/lat: -145°4837 62°6629

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01141	.00450	.00182	.00115	.00701	.00466	.00226	.00085	.00093	.00062	.00098
Tangential (EW)	.00026	.00052	.00009	.00018	.00092	.00079	.00029	.00019	.00006	.00003	.00017
Tangential (NS)	.00533	.00198	.00097	.00054	.00288	.00175	.00092	.00032	.00016	.00016	.00031
Phases (deg)											
Radial	101.8	139.5	83.2	135.8	92.0	82.2	91.2	75.7	13.2	24.7	56.8
Tangential (EW)	125.8	-71.8	53.8	-63.3	-23.3	-61.2	-28.0	-64.4	176.6	-153.6	169.7
Tangential (NS)	-90.5	-51.0	-107.7	-52.4	-106.8	-119.1	-107.5	-126.7	145.0	-140.7	-126.0

SPIA2040

SPIA204020 lon/lat: 11°9317 78°9229

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00772	.00283	.00154	.00041	.00132	.00149	.00040	.00036	.00178	.00124	.00155
Tangential (EW)	.00284	.00083	.00062	.00016	.00067	.00079	.00024	.00016	.00017	.00004	.00019
Tangential (NS)	.00172	.00059	.00027	.00016	.00052	.00040	.00015	.00012	.00004	.00004	.00024
<u>Phases (deg)</u>											
Radial	-158.4	-116.3	175.5	-113.8	-25.3	-122.3	-25.2	-156.4	32.0	5.5	47.1
Tangential (EW)	-6.1	40.4	-30.5	43.9	90.8	47.2	83.6	34.8	-177.1	171.3	-149.8
Tangential (NS)	17.7	53.6	-13.5	71.0	136.1	42.2	137.8	-2.1	-32.8	-43.9	70.2

TIDBIN64

TIDBINBILLA lon/lat: 148°9813 -35°4013

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00951	.00128	.00204	.00031	.00276	.00278	.00103	.00083	.00014	.00005	.00048
Tangential (EW)	.00515	.00182	.00091	.00049	.00125	.00073	.00040	.00014	.00003	.00015	.00010
Tangential (NS)	.00116	.00037	.00019	.00012	.00147	.00129	.00050	.00029	.00006	.00005	.00017
<u>Phases (deg)</u>											
Radial	125.7	173.0	96.0	161.2	118.6	67.0	111.9	53.9	-18.9	-73.9	-96.9
Tangential (EW)	93.0	126.4	82.3	128.8	-168.6	169.1	-170.4	148.2	-105.3	73.1	134.8
Tangential (NS)	7.9	70.2	-31.5	79.8	-117.0	-143.6	-117.5	-160.6	-144.8	92.7	116.0

TLRS-H78

TLRS-H7888 lon/lat: -110°8782 31°6840

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00162	.00189	.00086	.00063	.00693	.00453	.00222	.00087	.00017	.00015	.00036
Tangential (EW)	.00136	.00033	.00024	.00007	.00279	.00180	.00090	.00032	.00006	.00003	.00031
Tangential (NS)	.00249	.00099	.00052	.00030	.00108	.00062	.00034	.00015	.00002	.00003	.00013
<u>Phases (deg)</u>											
Radial	-97.7	-108.3	-74.3	-95.6	38.3	23.4	35.7	15.0	-150.4	-159.2	-17.6
Tangential (EW)	-172.4	-121.4	154.5	-140.5	-140.6	-156.5	-142.7	-164.2	118.0	139.2	-144.4
Tangential (NS)	87.7	103.7	76.8	98.3	165.2	168.6	159.8	161.1	-58.9	108.9	168.0

TLSA2 40

TLSA2 4002 lon/lat: 1°4812 43°5569

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01083	.00353	.00217	.00087	.00210	.00039	.00063	.00010	.00042	.00020	.00046
Tangential (EW)	.00435	.00135	.00094	.00038	.00036	.00032	.00016	.00004	.00010	.00012	.00010
Tangential (NS)	.00228	.00084	.00038	.00020	.00013	.00023	.00003	.00010	.00006	.00002	.00005
<u>Phases (deg)</u>											
Radial	-78.8	-49.0	-96.6	-52.4	-66.0	-126.3	-68.3	72.6	-13.8	-76.9	-47.5
Tangential (EW)	76.4	107.2	52.3	102.4	82.7	-9.4	69.3	-42.7	133.1	49.0	105.4
Tangential (NS)	-46.8	-9.0	-60.1	-8.1	-1.8	-166.8	-52.0	158.0	-92.4	149.6	120.7

TLTA2940

TLTA294029 lon/lat: 1°4835 43°5595

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01083	.00353	.00217	.00087	.00210	.00039	.00063	.00010	.00042	.00020	.00046
Tangential (EW)	.00435	.00135	.00094	.00038	.00036	.00032	.00016	.00004	.00010	.00012	.00010
Tangential (NS)	.00228	.00084	.00038	.00020	.00013	.00023	.00003	.00010	.00006	.00002	.00005
<u>Phases (deg)</u>											
Radial	-78.8	-49.0	-96.6	-52.4	-66.0	-126.3	-68.3	72.6	-13.8	-76.9	-47.5
Tangential (EW)	76.4	107.2	52.3	102.5	82.8	-9.4	69.3	-42.7	133.1	49.0	105.4
Tangential (NS)	-46.8	-9.0	-60.1	-8.1	-1.8	-166.8	-52.0	158.0	-92.4	149.5	120.7

TRIAS 40

TRIAS 4005 lon/lat: -12°3125 -37°0641

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01621	.00511	.00409	.00144	.00024	.00108	.00019	.00047	.00026	.00043	.00103
Tangential (EW)	.00436	.00170	.00089	.00043	.00124	.00046	.00032	.00007	.00003	.00002	.00011
Tangential (NS)	.00150	.00069	.00028	.00026	.00103	.00103	.00033	.00024	.00012	.00013	.00022
<u>Phases (deg)</u>											
Radial	-144.9	-121.0	-164.4	-108.6	-168.4	-148.3	-179.3	-152.6	-178.6	139.7	-146.0
Tangential (EW)	-129.5	-112.1	-126.4	-120.2	-123.1	-172.5	-123.9	127.6	-162.8	66.8	-102.4
Tangential (NS)	-32.0	-16.3	-44.5	-11.1	77.7	29.5	70.5	6.7	-164.0	-176.5	160.4

TROA5440

TROA544054 lon/lat: 18°9393 69°6621

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00913	.00319	.00181	.00080	.00224	.00169	.00065	.00043	.00135	.00099	.00109
Tangential (EW)	.00402	.00122	.00086	.00032	.00068	.00089	.00026	.00020	.00023	.00009	.00025
Tangential (NS)	.00190	.00071	.00046	.00019	.00039	.00017	.00008	.00005	.00015	.00015	.00034
<u>Phases (deg)</u>											
Radial	-168.3	-134.6	157.6	-142.8	-22.2	-115.2	-36.8	-170.4	38.4	8.2	46.3
Tangential (EW)	-8.3	26.7	-36.1	22.0	107.7	42.6	93.9	14.6	-156.5	172.6	-160.2
Tangential (NS)	-163.0	-125.3	160.3	-128.7	76.0	-44.4	80.6	-127.5	80.1	8.9	85.9

TROM 90

TROM 9017 lon/lat: 18°9383 69°6619

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00913	.00319	.00181	.00080	.00224	.00169	.00065	.00043	.00135	.00099	.00109
Tangential (EW)	.00402	.00122	.00086	.00032	.00068	.00089	.00026	.00020	.00023	.00009	.00025
Tangential (NS)	.00190	.00071	.00046	.00019	.00039	.00017	.00008	.00005	.00015	.00015	.00034
<u>Phases (deg)</u>											
Radial	-168.3	-134.6	157.6	-142.8	-22.2	-115.2	-36.8	-170.4	38.4	8.2	46.3
Tangential (EW)	-8.3	26.7	-36.1	22.0	107.7	42.6	93.9	14.6	-156.5	172.6	-160.2
Tangential (NS)	-163.0	-125.3	160.3	-128.7	76.0	-44.4	80.6	-127.5	80.1	8.9	85.9

TROMSO

TROMSO lon/lat: 18°9394 69°630

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01210	.00433	.00215	.00095	.00273	.00183	.00073	.00044	.00124	.00098	.00056
Tangential (EW)	.00455	.00147	.00078	.00032	.00063	.00063	.00019	.00015	.00022	.00010	.00025
Tangential (NS)	.00255	.00092	.00057	.00024	.00042	.00013	.00011	.00005	.00016	.00015	.00036
<u>Phases (deg)</u>											
Radial	-169.9	-134.5	159.8	-140.9	-17.5	-115.2	-24.5	-170.8	43.0	12.6	110.3
Tangential (EW)	-8.3	28.8	-40.8	19.1	139.6	42.9	116.1	3.5	-151.7	178.7	-154.3
Tangential (NS)	-159.2	-119.3	164.4	-126.2	68.1	-68.4	72.6	-145.7	86.3	13.4	98.5

USUD 90

USUD 9018 lon/lat: 138°3620 36°1319

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00668	.00328	.00128	.00094	.00888	.00688	.00319	.00144	.00010	.00032	.00044
Tangential (EW)	.00218	.00118	.00026	.00031	.00181	.00147	.00058	.00032	.00005	.00010	.00031
Tangential (NS)	.00190	.00079	.00035	.00025	.00185	.00140	.00066	.00028	.00004	.00012	.00011
<u>Phases (deg)</u>											
Radial	72.4	87.9	87.0	93.6	-134.0	-153.3	-133.3	-159.1	-7.4	43.8	101.6
Tangential (EW)	12.0	46.0	19.7	53.0	-164.4	173.2	-163.1	169.6	-13.9	8.0	47.5
Tangential (NS)	-67.0	-52.9	-71.3	-47.4	91.3	67.9	87.0	50.6	178.5	-162.8	-178.8

VACAVILL

VACAVILL	lon/lat: -121°9588	38°3751									
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00744	.00077	.00172	.00011	.01334	.00831	.00408	.00155	.00028	.00010	.00072
Tangential (EW)	.00453	.00159	.00083	.00044	.00386	.00250	.00117	.00044	.00012	.00005	.00033
Tangential (NS)	.00357	.00138	.00082	.00043	.00217	.00126	.00066	.00026	.00001	.00002	.00016
Phases (deg)											
Radial	42.8	143.8	-10.0	-6.6	49.5	35.5	49.5	27.1	-31.7	64.4	61.2
Tangential (EW)	-122.6	-79.9	-148.2	-85.4	-126.3	-139.7	-126.1	-144.3	146.4	171.2	-147.9
Tangential (NS)	103.5	113.6	84.0	110.6	-175.1	174.1	-175.1	164.6	-165.6	146.0	-117.8

VLA

VLA	lon/lat: -107°6184	34°0791									
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00071	.00143	.00048	.00042	.00572	.00376	.00180	.00074	.00007	.00006	.00021
Tangential (EW)	.00118	.00020	.00023	.00005	.00215	.00138	.00067	.00025	.00005	.00002	[illegible]
Tangential (NS)	.00173	.00072	.00039	.00022	.00076	.00044	.00024	.00012	.00006	.00005	.00008
Phases (deg)											
Radial	163.3	-132.2	-61.2	-112.2	38.4	23.8	36.8	16.0	-153.2	-177.9	[illegible]
Tangential (EW)	-174.4	-126.0	146.8	-161.5	-135.8	-152.0	-136.9	-160.3	130.1	166.8	-133.0
Tangential (NS)	95.3	103.7	83.8	101.5	156.7	154.1	153.2	151.4	-152.1	-173.1	-125.7

VNDNBERG

VANDENBERG	lon/lat: -120°6164	34°5550									
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00884	.00257	.00271	.00104	.01638	.01022	.00511	.00190	.00023	.00008	.00094
Tangential (EW)	.00334	.00111	.00059	.00029	.00384	.00244	.00118	.00042	.00010	.00004	.00033
Tangential (NS)	.00462	.00183	.00102	.00056	.00239	.00143	.00076	.00030	.00001	.00002	.00019
Phases (deg)											
Radial	-10.8	-61.0	-45.4	-53.3	42.2	27.5	42.3	18.8	-66.2	177.4	66.7
Tangential (EW)	-132.0	-84.1	-159.1	-90.2	-131.5	-145.3	-130.7	-150.5	138.8	131.5	-148.7
Tangential (NS)	98.7	112.6	80.7	108.9	-175.5	174.6	-175.8	164.7	-11.2	126.9	-119.7

VERNAL

VERNAL	lon/lat: -109°5707	40°3258									
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00238	.00128	.00034	.00028	.00581	.00375	.00183	.00072	.00011	.00003	.00027
Tangential (EW)	.00250	.00085	.00046	.00022	.00239	.00161	.00074	.00029	.00006	.00004	.00029
Tangential (NS)	.00184	.00076	.00045	.00023	.00101	.00055	.00031	.00014	.00004	.00004	.00009
Phases (deg)											
Radial	102.7	-169.4	-2.7	-148.2	44.4	30.5	43.3	23.2	-1.2	24.7	-4.7
Tangential (EW)	-133.0	-87.5	-157.1	-91.2	-131.9	-148.2	-133.1	-155.0	133.4	169.0	-142.6
Tangential (NS)	108.3	107.7	91.6	103.9	172.2	169.1	170.1	162.2	-140.4	-167.8	-109.6

WALA3740

WALA374037	lon/lat: -176°1795	-13°2652									
	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.03110	.00906	.00797	.00240	.00536	.00337	.00194	.00075	.00101	.00056	.00121
Tangential (EW)	.00184	.00133	.00049	.00036	.00184	.00108	.00055	.00021	.00002	.00006	.00003
Tangential (NS)	.00442	.00199	.00057	.00050	.00069	.00014	.00016	.00003	.00005	.00003	.00011
Phases (deg)											
Radial	-8.4	-14.3	-19.8	-18.5	-135.3	-144.9	-137.9	-160.3	-164.0	-160.8	-126.0
Tangential (EW)	168.0	164.6	150.3	167.6	38.1	16.7	34.7	-7.4	-66.6	-127.2	96.1
Tangential (NS)	-87.3	-38.3	-110.7	-40.7	25.7	40.1	9.0	120.5	-136.7	-152.5	107.7

WERTHOVN

WERTHOVN lon/lat: 7°1297 50°6166

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00597	.00179	.00125	.00041	.00213	.00088	.00065	.00003	.00048	.00024	.00013
Tangential (EW)	.00225	.00064	.00047	.00017	.00034	.00025	.00012	.00003	.00011	.00003	.00005
Tangential (NS)	.00069	.00030	.00022	.00011	.00030	.00015	.00008	.00003	.00004	.00005	.00011
<u>Phases (deg)</u>											
Radial	-68.8	-36.0	-81.8	-33.2	-57.6	-98.3	-58.9	-91.1	2.2	-0.3	-54.4
Tangential (EW)	81.2	116.7	58.0	110.6	100.2	27.6	89.0	-5.5	162.9	119.2	-129.9
Tangential (NS)	28.2	61.7	21.2	66.5	28.7	-69.7	27.6	-153.2	-146.2	84.6	109.2

WSTRBORK

WESTERBORK lon/lat: 6°5917 52°9141

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00464	.00137	.00123	.00033	.00205	.00097	.00063	.00009	.00064	.00039	.00022
Tangential (EW)	.00192	.00052	.00044	.00013	.00029	.00025	.00011	.00003	.00015	.00006	.00006
Tangential (NS)	.00123	.00033	.00030	.00014	.00029	.00014	.00007	.00002	.00002	.00011	.00011
<u>Phases (deg)</u>											
Radial	-56.3	-26.3	-65.0	-9.5	-59.7	-87.0	-60.4	-55.8	2.4	18.8	-51.6
Tangential (EW)	98.8	139.8	85.3	147.4	88.6	47.7	80.1	57.6	167.1	179.0	-162.5
Tangential (NS)	70.4	101.9	39.0	88.6	29.4	-59.2	33.4	-114.1	-109.3	74.0	87.7

WESTFORD

WESTFORD lon/lat: -71°4881 42°6163

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.01024	.00278	.00221	.00078	.00400	.00269	.00129	.00057	.00037	.00021	.00027
Tangential (EW)	.00421	.00096	.00095	.00026	.00036	.00022	.00010	.00004	.00009	.00004	.00023
Tangential (NS)	.00225	.00062	.00048	.00017	.00030	.00037	.00009	.00011	.00010	.00008	.00005
<u>Phases (deg)</u>											
Radial	-175.0	-151.1	168.0	-157.8	-5.0	-3.9	-3.6	-1.8	13.7	66.6	-176.3
Tangential (EW)	-144.8	-123.1	-169.4	-129.7	-11.4	23.6	-16.5	31.8	0.7	165.0	-76.2
Tangential (NS)	-17.6	21.3	-26.6	16.0	-177.5	-147.7	-173.2	-165.0	-151.4	-144.7	-6.4

WETB 90

WETB 9019 lon/lat: 12°8783 49°1430

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00494	.00143	.00098	.00033	.00174	.00072	.00054	.00004	.00046	.00026	.00039
Tangential (EW)	.00220	.00054	.00053	.00016	.00039	.00034	.00017	.00006	.00009	.00004	.00007
Tangential (NS)	.00078	.00025	.00010	.00006	.00027	.00002	.00005	.00004	.00005	.00003	.00011
<u>Phases (deg)</u>											
Radial	-67.3	-36.2	-86.5	-36.6	-59.3	-100.9	-61.6	-125.4	7.7	-6.1	3.8
Tangential (EW)	61.6	94.7	34.5	91.7	94.9	31.8	81.9	25.3	160.5	59.6	163.1
Tangential (NS)	-29.4	16.8	-20.1	23.3	47.9	-92.0	39.7	157.9	-141.4	109.0	98.7

WETTZELL

WETTZELL lon/lat: 12°8774 49°1437

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
<u>Amplitudes (m)</u>											
Radial	.00494	.00143	.00104	.00034	.00182	.00077	.00056	.00004	.00035	.00020	.00005
Tangential (EW)	.00182	.00049	.00041	.00015	.00031	.00021	.00012	.00004	.00007	.00004	.00010
Tangential (NS)	.00046	.00017	.00008	.00006	.00031	.00007	.00008	.00002	.00007	.00004	.00012
<u>Phases (deg)</u>											
Radial	-69.0	-38.1	-86.9	-35.9	-58.3	-101.1	-59.7	-112.2	5.8	0.7	61.4
Tangential (EW)	65.0	100.3	42.2	96.3	105.3	20.5	87.9	-7.6	161.2	70.2	157.6
Tangential (NS)	-27.6	23.2	-7.7	37.5	24.9	-64.8	23.6	164.8	-151.5	134.3	121.4

WHTHORSE

WHITEHORSE lon/lat: -135°0770 60°7102

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.01223	.00454	.00198	.00114	.00749	.00483	.00239	.00089	.00083	.00056	.00088
Tangential (EW)	.00298	.00153	.00055	.00045	.00181	.00142	.00058	.00028	.00010	.00008	.00024
Tangential (NS)	.00470	.00154	.00083	.00040	.00266	.00159	.00083	.00029	.00013	.00014	.00028
Phases (deg)											
Radial	98.1	138.0	74.6	133.5	81.5	70.7	80.4	63.2	11.9	23.2	52.6
Tangential (EW)	-89.9	-58.6	-108.8	-59.3	-80.2	-98.9	-83.1	-101.2	167.4	-160.2	-166.4
Tangential (NS)	-99.7	-55.5	-119.9	-58.1	-117.8	-130.9	-118.9	-141.4	148.6	-143.3	-117.7

XRISOK75

XRISOK7525 lon/lat: 21°8776 36°7902

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00398	.00114	.00082	.00028	.00072	.00039	.00024	.00004	.00013	.00015	.00028
Tangential (EW)	.00202	.00045	.00051	.00012	.00031	.00007	.00011	.00004	.00003	.00004	.00005
Tangential (NS)	.00118	.00025	.00019	.00006	.00055	.00027	.00014	.00007	.00010	.00006	.00011
Phases (deg)											
Radial	-69.2	-46.1	-90.4	-49.1	-90.1	-114.1	-94.9	-107.9	1.5	-2.4	43.3
Tangential (EW)	33.4	49.8	13.0	56.4	151.1	112.3	126.8	122.8	165.3	35.7	-124.4
Tangential (NS)	-76.3	-32.7	-109.2	-45.4	55.8	74.4	56.8	98.0	-137.6	171.8	130.4

YAKATAGA

YAKATAGA lon/lat: -142°4864 60°0804

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.02460	.00890	.00438	.00232	.01319	.00838	.00425	.00154	.00105	.00088	.00133
Tangential (EW)	.00162	.00114	.00032	.00035	.00146	.00118	.00048	.00026	.00009	.00006	.00023
Tangential (NS)	.00867	.00305	.00162	.00082	.00447	.00272	.00143	.00050	.00021	.00024	.00043
Phases (deg)											
Radial	101.0	137.4	78.1	133.3	87.4	75.1	85.7	67.3	5.1	31.7	54.2
Tangential (EW)	-69.8	-52.3	-80.9	-50.4	-56.9	-79.8	-60.2	-81.3	168.2	-155.7	-179.0
Tangential (NS)	-87.6	-49.4	-108.7	-52.1	-106.4	-119.7	-107.9	-128.8	154.2	-144.1	-123.8

YAR1 90

YAR1 lon/lat: 115°3470 -29°0455

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00412	.00141	.00077	.00025	.00826	.00658	.00272	.00128	.00015	.00051	.00136
Tangential (EW)	.00178	.00080	.00047	.00020	.00138	.00089	.00045	.00019	.00004	.00013	.00039
Tangential (NS)	.00249	.00080	.00062	.00019	.00068	.00074	.00020	.00013	.00005	.00011	.00021
Phases (deg)											
Radial	169.0	-107.0	95.0	-108.5	12.9	6.5	13.6	-3.3	-139.7	-129.5	-60.8
Tangential (EW)	-143.7	-99.9	-155.8	-97.3	144.7	146.1	143.5	122.3	34.7	31.0	99.5
Tangential (NS)	-146.9	-104.5	-163.8	-102.5	-63.7	-106.3	-71.9	-139.9	-125.8	121.3	133.4

YARAGA70

YARAGA7090 lon/lat: 115°3467 -29°0454

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00412	.00141	.00077	.00025	.00826	.00659	.00272	.00128	.00015	.00051	.00136
Tangential (EW)	.00178	.00080	.00047	.00020	.00138	.00089	.00045	.00019	.00004	.00013	.00039
Tangential (NS)	.00249	.00080	.00062	.00019	.00068	.00074	.00020	.00013	.00005	.00011	.00021
Phases (deg)											
Radial	169.0	-107.0	95.0	-108.5	12.9	6.5	13.6	-3.3	-139.7	-129.5	-60.8
Tangential (EW)	-143.7	-99.9	-155.8	-97.3	144.7	146.1	143.5	122.3	34.7	31.0	99.5
Tangential (NS)	-146.9	-104.5	-163.8	-102.5	-63.7	-106.3	-71.9	-139.9	-125.8	121.3	133.4

YELA5140

YELA514051 lon/lat: -114°.4801 62°.4799

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00536	.00197	.00078	.00048	.00351	.00221	.00119	.00042	.00069	.00037	.00055
Tangential (EW)	.00297	.00118	.00055	.00034	.00149	.00118	.00050	.00023	.00005	.00006	.00022
Tangential (NS)	.00152	.00028	.00023	.00006	.00086	.00046	.00026	.00009	.00005	.00006	.00012
Phases (deg)											
Radial	104.8	147.0	76.8	145.1	61.2	52.7	60.4	46.3	18.8	6.7	22.2
Tangential (EW)	-117.6	-75.2	-140.3	-77.3	-102.1	-122.9	-105.0	-129.3	165.5	-173.5	-142.4
Tangential (NS)	-121.4	-55.7	-141.6	-49.8	-142.9	-159.7	-145.9	179.2	124.5	-133.6	-98.7

YELL 90

YELL 9021 lon/lat: -114°.4807 62°.4799

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00536	.00197	.00078	.00048	.00351	.00221	.00119	.00042	.00069	.00037	.00055
Tangential (EW)	.00297	.00118	.00055	.00034	.00149	.00118	.00050	.00023	.00005	.00006	.00022
Tangential (NS)	.00152	.00028	.00023	.00006	.00086	.00046	.00026	.00009	.00005	.00006	.00012
Phases (deg)											
Radial	104.8	147.0	76.8	145.1	61.2	52.7	60.4	46.3	18.8	6.7	22.2
Tangential (EW)	-117.6	-75.2	-140.3	-77.3	-102.1	-122.9	-105.0	-129.3	165.5	-173.5	-142.4
Tangential (NS)	-121.4	-55.7	-141.6	-49.8	-142.9	-159.7	-145.9	179.2	124.5	-133.6	-98.7

YELLOWKN

YELLOWKNIFE lon/lat: -114°.4723 62°.4794

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00545	.00202	.00077	.00048	.00363	.00226	.00117	.00044	.00051	.00029	.00026
Tangential (EW)	.00244	.00097	.00041	.00028	.00133	.00099	.00042	.00019	.00005	.00005	.00015
Tangential (NS)	.00134	.00028	.00021	.00006	.00087	.00051	.00027	.00010	.00006	.00007	.00012
Phases (deg)											
Radial	104.2	147.0	76.5	144.2	61.2	52.5	60.4	45.1	19.1	9.9	-143.3
Tangential (EW)	-114.4	-69.6	-138.5	-73.2	-93.1	-112.5	-95.0	-119.1	169.5	-172.4	-136.9
Tangential (NS)	-118.7	-54.1	-143.0	-53.5	-138.5	-152.9	-139.5	-169.1	162.9	-143.2	-101.0

YIGILC75

YIGILC7587 lon/lat: 31°.4388 40°.9358

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00317	.00088	.00066	.00021	.00065	.00054	.00023	.00008	.00017	.00022	.00036
Tangential (EW)	.00191	.00040	.00049	.00010	.00038	.00018	.00014	.00004	.00005	.00001	.00006
Tangential (NS)	.00104	.00014	.00018	.00004	.00066	.00035	.00017	.00006	.00010	.00006	.00013
Phases (deg)											
Radial	-62.1	-34.8	-86.8	-34.8	-101.3	-121.9	-106.7	-131.2	17.6	6.0	48.1
Tangential (EW)	21.2	42.5	2.9	48.9	127.5	69.5	113.6	81.7	-174.9	13.6	-113.0
Tangential (NS)	-93.1	-56.6	-131.3	-69.5	45.2	44.6	42.4	56.1	-145.9	172.0	123.5

YOZGAT75

YOZGAT7585 lon/lat: 34°.8130 39°.7993

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00297	.00083	.00062	.00021	.00060	.00055	.00022	.00010	.00014	.00022	.00036
Tangential (EW)	.00190	.00041	.00048	.00009	.00040	.00019	.00014	.00005	.00005	.00001	.00007
Tangential (NS)	.00103	.00011	.00020	.00003	.00076	.00043	.00020	.00007	.00010	.00006	.00014
Phases (deg)											
Radial	-60.1	-32.7	-85.7	-32.8	-123.9	-130.1	-127.1	-138.4	21.3	7.1	50.6
Tangential (EW)	14.7	36.0	-2.3	41.3	129.0	76.6	117.1	88.2	-168.9	-13.4	-103.6
Tangential (NS)	-100.0	-74.6	-138.3	-85.2	42.7	40.9	39.7	44.6	-146.3	171.5	124.1

YUMA

YUM YUMA lon/lat: -114°.2031 32°.9380

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00231	.00204	.00119	.00072	.00881	.00564	.00275	.00108	.00013	.00011	.00037
Tangential (EW)	.00180	.00047	.00032	.00010	.00321	.00207	.00100	.00036	.00007	.00003	.00032
Tangential (NS)	.00329	.00130	.00072	.00040	.00147	.00086	.00047	.00021	.00001	.00002	.00012
Phases (deg)											
Radial	-61.7	-100.5	-69.2	-86.7	40.4	25.4	39.0	16.8	-126.1	-173.8	34.5
Tangential (EW)	-159.0	-105.3	169.7	-116.4	-138.2	-153.4	-139.1	-159.8	124.3	132.4	-145.8
Tangential (NS)	92.4	107.8	77.4	104.0	173.5	169.2	171.8	162.5	-89.7	171.4	-126.8

ZIMRWA78

ZIMRWA7810 lon/lat: 7°.4652 46°.8760

	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_f	M_m	S_{sa}
Amplitudes (m)											
Radial	.00648	.00196	.00128	.00046	.00189	.00062	.00058	.00001	.00044	.00021	.00039
Tangential (EW)	.00276	.00075	.00062	.00022	.00037	.00031	.00017	.00005	.00009	.00007	.00007
Tangential (NS)	.00111	.00039	.00018	.00009	.00021	.00009	.00004	.00006	.00004	.00003	.00009
Phases (deg)											
Radial	-71.4	-41.2	-89.2	-43.9	-60.7	-102.9	-63.1	122.0	0.6	-24.2	-16.8
Tangential (EW)	69.6	101.4	42.9	96.6	92.6	19.1	78.1	9.5	150.2	56.1	137.0
Tangential (NS)	-22.9	16.9	-19.6	22.5	42.0	-143.3	27.7	163.4	-122.6	100.2	101.5

Atmospheric Loading

The procedure described below is taken from the publication of Sovers and Fanselow (1987). A time varying atmospheric pressure distribution can induce crustal deformation. Rabbel and Schuh (1986) estimate the effects of atmospheric loading on VLBI baseline determinations, and conclude that they may amount to many millimeters of seasonal variation. In contrast to ocean tidal effects, analysis of the situation in the atmospheric case does not benefit from the presence of a well-understood periodic driving force. Otherwise, estimation of atmospheric loading via Green's function techniques is analogous to methods used to calculate ocean loading effects. Rabbel and Schuh recommend a simplified form of the dependence of the vertical crustal displacement on pressure distribution. It involves only the instantaneous pressure at the site in question, and an average pressure over a circular region C with a 2000 km radius surrounding the site. The expression for the vertical displacement (mm) is

$$\Delta r = -0.35p - 0.55\bar{p}, \tag{1}$$

where p is the local pressure anomaly with respect to the standard pressure of 101.3 kPA (equivalent to 1013 mbar), and $\bar{p}$ the pressure anomaly within the 2000 km circular region mentioned above. Both quantities are in 10^{-1} kPA (equivalent to mbar). Note that the reference point for this displacement is the site location at standard pressure. Equation (1) permits one to estimate the seasonal displacement due to the large-scale atmospheric loading with an error less than ±1 mm (Rabbel and Schuh, 1986).

An additional mechanism for characterizing $\overline{p}$ may be applied. The two-dimensional surface pressure distribution surrounding a site is described by

$$p(x,y) = A_0 + A_1x + A_2y + A_3x^2 + A_4xy + A_5y^2, \qquad (2)$$

where x and y are the local East and North distances of the point in question from the VLBI site. The pressure anomaly $\overline{p}$ may be evaluated by the simple integration

$$\overline{p} = \iint_C dx\, dy\, p(x,y) \;/\; \iint_C dx\, dy \qquad (3)$$

giving

$$\overline{p} = A_0 + (A_3 + A_5)R^2/4, \qquad (4)$$

where $R^2=(x^2 + y^2)$.

It remains the task of the data analyst to perform a quadratic fit to the available weather data to determine the coefficients A_{0-5}. Van Dam and Wahr (1987) computed the displacements due to atmospheric loading by performing a convolution sum between barometric pressure data and the mass loading Green's Function. They found that the corrections based on Eq. (1) are inadequate for stations close to the coast. For these coastal stations, Eq.(1) can be improved by extending the regression equation.

Finally, the dynamical reaction of the ocean to air pressure changes are not taken into account. The assumption of an inverted barometer ocean is not appropriate for the short-period variations of the air pressure.

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CHAPTER 10 TIDAL VARIATIONS IN THE EARTH'S ROTATION

Periodic variations in UT1 due to tidal deformation of the polar moment of inertia have been derived (Yoder, *et al.*, 1981) including the tidal deformation of the Earth with a decoupled core. This model leads to effective Love numbers that differ from the bulk value of 0.301 because of the oceans and the fluid core giving rise to different theoretical values of the ratio k/C for the fortnightly and monthly terms. However, Yoder, *et al.*, recommend the value of 0.94 for k/C for both cases.

Oceanic tides also cause variations in UT1 represented by models given by Brosche, *et al.*, (1991, 1989) and Dickman (1991a, 1991b, 1990, 1989). The contribution of the oceanic tides is split into a part which is in phase with the solid Earth tides and an out-of-phase part. The oceanic tides also cause variations in the rotation of the Earth at diurnal and semi-diurnal frequencies.

Table 10.2, below, is composed of the tidal coefficients derived from Yoder, *et al.*, (1981) modified by the ocean effects derived from Dickman (1991b). To avoid possible confusion with corrections recommended previously in IERS Technical Note 3, it is recommended that the terms UT1S, ΔS, ωS, be used to denote the use of the tide series contained in Table 10.2. In this way then, the term UT1R refers to the use of Table 11.1 in IERS Technical Note 3 which is reproduced below as Table 10.1.

Table 10.1. Zonal Tide Terms With Periods Up to 35 Days. UT1R, ΔR, and ωR represent the regularized forms of UT1, the duration of the day Δ, and the angular velocity of the Earth, ω. The units are 10^{-4} s for UT, 10^{-5} s for Δ, and 10^{-14} rad/s for ω.

ARGUMENT*					PERIOD	UT1−UT1R	Δ−ΔR	ω−ωR
						Coefficient of	Coefficient of	
l	l′	F	D	Ω	Days	Sin (Argument)	Cos (Argument)	
1	0	2	2	2	5.64	−0.02	0.3	−0.2
2	0	2	0	1	6.85	−0.04	0.4	−0.3
2	0	2	0	2	6.86	−0.10	0.9	−0.8
0	0	2	2	1	7.09	−0.05	0.4	−0.4
0	0	2	2	2	7.10	−0.12	1.1	−0.9
1	0	2	0	0	9.11	−0.04	0.3	−0.2
1	0	2	0	1	9.12	−0.41	2.8	−2.4
1	0	2	0	2	9.13	−0.99	6.8	−5.8
3	0	0	0	0	9.18	−0.02	0.1	0.1
−1	0	2	2	1	9.54	−0.08	0.5	−0.5
−1	0	2	2	2	9.56	−0.20	1.3	−1.1
1	0	0	2	0	9.61	−0.08	0.5	−0.4
2	0	2	−2	2	12.81	0.02	−0.1	0.1
0	1	2	0	2	13.17	0.03	−0.1	0.1
0	0	2	0	0	13.61	−0.30	1.4	−1.2
0	0	2	0	1	13.63	−3.21	14.8	−12.5
0	0	2	0	2	13.66	−7.76	35.7	−30.1
2	0	0	0	−1	13.75	0.02	−0.1	0.1
2	0	0	0	0	13.78	−0.34	1.5	−1.3
2	0	0	0	1	13.81	0.02	−0.1	0.1
0	−1	2	0	2	14.19	−0.02	0.1	−0.1
0	0	0	2	−1	14.73	0.05	−0.2	0.2
0	0	0	2	0	14.77	−0.73	3.1	−2.6
0	0	0	2	1	14.80	−0.05	0.2	−0.2
0	−1	0	2	0	15.39	−0.05	0.2	−0.2
1	0	2	−2	1	23.86	0.05	−0.1	0.1
1	0	2	−2	2	23.94	0.10	−0.3	0.2
1	1	0	0	0	25.62	0.04	−0.1	0.1
−1	0	2	0	0	26.88	0.05	−0.1	0.1
−1	0	2	0	1	26.98	0.18	−0.4	0.3
−1	0	2	0	2	27.09	0.44	−1.0	0.9
1	0	0	0	−1	27.44	0.53	−1.2	1.0
1	0	0	0	0	27.56	−8.26	18.8	−15.9
1	0	0	0	1	27.67	0.54	−1.2	1.0
0	0	0	1	0	29.53	0.05	−0.1	0.1
1	−1	0	0	0	29.80	−0.06	0.1	−0.1
−1	0	0	2	−1	31.66	0.12	−0.2	0.2
−1	0	0	2	0	31.81	−1.82	3.6	−3.0
−1	0	0	2	1	31.96	0.13	−0.3	0.2
1	0	−2	2	−1	32.61	0.02	0.0	0.0
−1	−1	0	2	0	34.85	−0.09	0.2	−0.1

* l = 134°96 + 13°064993(MJD−51544.5) Mean Anomaly of the Moon
l′ = 357°53 + 0°985600(MJD−51544.5) Mean Anomaly of the Sun
F = 93°27 + 13°229350(MJD−51544.5) L−Ω: L: Mean Longitude of the Moon
D = 297°85 + 12°190749(MJD−51544.5) Mean Elongation of the Moon from the Sun
Ω = 125°04 − 0°052954(MJD−51544.5) Mean Longitude of the Ascending Node of the Moon

Table 10.2. Zonal Tide Terms. UT1S, ΔS, and ωS represent the regularized forms of UT1, the duration of the day Δ, and the angular velocity of the Earth, ω. The units are 10^{-4} s for UT, 10^{-5} s for Δ, and 10^{-14} rad/s for ω.

ARGUMENT*					PERIOD	UT1-UT1S		Δ-ΔS		ω-ωS	
								Coefficient of			
l	l'	F	D	Ω	Days	Sin	Cos	Cos	Sin	Cos	Sin
1	0	2	2	2	5.64	-0.02		0.3		-0.2	
2	0	2	0	1	6.85	-0.04		0.4		-0.3	
2	0	2	0	2	6.86	-0.10		0.9		-0.8	
0	0	2	2	1	7.09	-0.05		0.4		-0.4	
0	0	2	2	2	7.10	-0.12		1.1		-0.9	
1	0	2	0	0	9.11	-0.04		0.3		-0.2	
1	0	2	0	1	9.12	-0.40	0.01	2.7	0.1	-2.3	-0.1
1	0	2	0	2	9.13	-0.98	0.03	6.7	0.2	-5.7	-0.2
3	0	0	0	0	9.18	-0.02		0.1		-0.1	
-1	0	2	2	1	9.54	-0.08		0.5		-0.5	
-1	0	2	2	2	9.56	-0.20		1.3		-1.1	
1	0	0	2	0	9.61	-0.08		0.5		-0.4	
2	0	2	-2	2	12.81	0.02		-0.1		0.1	
0	1	2	0	2	13.17	0.03		-0.1		0.1	
0	0	2	0	0	13.61	-0.30		1.4		-1.2	
0	0	2	0	1	13.63	-3.20	0.09	14.7	0.4	-12.4	-0.4
0	0	2	0	2	13.66	-7.73	0.21	35.6	1.0	-30.0	-0.8
2	0	0	0	-1	13.75	0.02		-0.1		0.1	
2	0	0	0	0	13.78	-0.34		1.5		-1.3	
2	0	0	0	1	13.81	0.02		-0.1		0.1	
0	-1	2	0	2	14.19	-0.02		0.1		-0.1	
0	0	0	2	-1	14.73	0.05		-0.2		0.2	
0	0	0	2	0	14.77	-0.72	0.02	3.1	0.1	-2.6	-0.1
0	0	0	2	1	14.80	-0.05		0.2		-0.2	
0	-1	0	2	0	15.39	-0.05		0.2		-0.2	
1	0	2	-2	1	23.86	0.05		-0.1		0.1	
1	0	2	-2	2	23.94	0.10		-0.3		0.2	
1	1	0	0	0	25.62	0.04		-0.1		0.1	
-1	0	2	0	0	26.88	0.05		-0.1		0.1	
-1	0	2	0	1	26.98	0.18		-0.4		0.3	
-1	0	2	0	2	27.09	0.44		-1.0		0.9	
1	0	0	0	-1	27.44	0.53		-1.2		1.0	
1	0	0	0	0	27.56	-8.33	0.12	19.0	0.3	-16.0	-0.2
1	C	0	0	1	27.67	0.54		-1.2		1.0	
0	0	0	1	0	29.53	0.05		-0.1		0.1	
1	-1	0	0	0	29.80	-0.06		0.1		-0.1	
-1	0	0	2	-1	31.66	0.12		-0.2		0.2	
-1	0	0	2	0	31.81	-1.84	0.02	3.6	0.0	-3.0	0.0
-1	0	0	2	1	31.96	0.13		-0.3		0.2	
1	0	-2	2	-1	32.61	0.02		0.0		0.0	
-1	-1	0	2	0	34.85	-0.09		0.2		-0.1	
0	2	2	-2	2	91.31	-0.06		0.0		0.0	
0	1	2	-2	1	119.61	0.03		0.0		0.0	
0	1	2	-2	2	121.75	-1.88		1.0		-0.8	
0	0	2	-2	0	173.31	0.25		-0.1		0.1	
0	0	2	-2	1	177.84	1.17		-0.4		0.3	
0	0	2	-2	2	182.62	-48.84	0.11	16.8	0.0	-14.2	0.0
0	2	0	0	0	182.63	-0.19		0.1		-0.1	
2	0	0	-2	-1	199.84	0.05		0.0		0.0	
2	0	0	-2	0	205.89	-0.55		0.2		-0.1	
2	0	0	-2	1	212.32	0.04		0.0		0.0	
0	-1	2	-2	1	346.60	-0.05		0.0		0.0	
0	1	0	0	-1	346.64	0.09		0.0		0.0	

Table 10.1 (continued)

ARGUMENT*					PERIOD	UT1-UT1S		Δ-ΔS Coefficient of		ω-ωS	
l	l'	F	D	Ω	Days	Sin	Cos	Cos	Sin	Cos	Sin
0	-1	2	-2	2	365.22	0.83		-0.1		0.1	
0	1	0	0	0	365.26	-15.55	0.02	2.6	0.0	-2.2	0.0
0	1	0	0	1	386.00	-0.14		0.0		0.0	
1	0	0	-1	0	411.78	0.03		0.0		0.0	
2	0	-2	0	0	1095.17	-0.14		0.0		0.0	
-2	0	2	0	1	1305.47	0.42		0.0		0.0	
-1	1	0	1	0	3232.85	0.04		0.0		0.0	
0	0	0	0	2	3399.18	7.90		0.1		-0.1	
0	0	0	0	1	6790.36	-1637.68	0.10	-10.4	0.0	8.8	0.0

* l = 134°96 + 13°064993(MJD-51544.5) Mean Anomaly of the Moon
l' = 357°53 + 0°985600(MJD-51544.5) Mean Anomaly of the Sun
F = 93°27 + 13°229350(MJD-51544.5) L-Ω: L: Mean Longitude of the Moon
D = 297°85 + 12°190749(MJD-51544.5) Mean Elongation of the Moon from the Sun
Ω = 125°04 - 0°052954(MJD-51544.5) Mean Longitude of the Ascending Node of the Moon

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CHAPTER 11 TROPOSPHERIC MODEL

Satellite Laser Ranging

The formulation of Marini and Murray (1973) is commonly used in laser ranging. The formula has been tested by comparison with ray-tracing radiosonde profiles.

The correction to a one-way range is

$$\Delta R = \frac{f(\lambda)}{f(\phi,H)} \cdot \frac{A+B}{\sin E + \dfrac{B/(A+B)}{\sin E + 0.01}}, \qquad (1)$$

where

$$A = 0.002357P_0 + 0.000141e_0, \qquad (2)$$

$$B = (1.084 \times 10^{-8})P_0\, T_0\, K + (4.734 \times 10^{-8})\,\frac{P_0^2}{T_0}\,\frac{2}{(3-1/K)}, \qquad (3)$$

$$K = 1.163 - 0.00968 \cos 2\phi - 0.00104\, T_0 + 0.00001435P_0, \qquad (4)$$

where

ΔR = range correction (meters),
E = true elevation of satellite,
P_0 = atmospheric pressure at the laser site (in 10^{-1} kPa, equivalent to millibars),
T_0 = atmospheric temperature at the laser site (degrees Kelvin),
e_0 = water vapor pressure at the laser site (10^{-1} kPa, equivalent to millibars),
$f(\lambda)$ = laser frequency parameter (λ = wavelength in micrometers), and
$f(\phi,H)$ = laser site function.

Additional definitions of these parameters are available. The water vapor pressure, e_0, can be calculated from a relative humidity measurement, $R_h(\%)$ by

$$e_0 = \frac{R_h}{100} \times 6.11 \times 10^{\frac{7.5(T_0 - 273.15)}{237.3 + (T_0 - 273.15)}}.$$

The laser frequency parameter, $f(\lambda)$, is

$$f(\lambda) \equiv 0.9650 + \frac{0.0164}{\lambda^2} + \frac{0.000228}{\lambda^4}.$$

$f(\lambda) = 1\mu m$ for a ruby laser, [i. e. $f(0.6943) = 1\mu m$], while $f(\lambda_G) = 1.02579\mu m$ and $f(\lambda_{IR}) = 0.97966\mu m$ for green and infrared YAG lasers.

The laser site function is

$$f(\phi,H) = 1 - 0.0026 \cos 2\phi - 0.00031 H,$$

where ϕ is the latitude and H is the geodetic height (km).

Very Long Baseline Interferometry

The most serious problem in practical atmospheric modelling is that of unmeasured atmospheric parameters. The differences between mathematical models are often less than the errors which would be introduced by the character and distribution of the wet component and breakdowns in azimuthal symmetry. For this reason, it is customary in the data reduction to determine the zenith atmospheric delay as a parameter and use models only for the mapping function which is the ratio of delay at a given zenith angle to the zenith delay. Accordingly, the IERS Standard model applies only to the mapping function which is the ratio of delay at a given zenith angle to the zenith delay.

Some standard models are available: CFA2.2 (Davis, *et al.*, 1985), Chao (1974), Saastamoinen (1972), Black (1984), Marini (1972), Hopfield (1969), Yionoulis (1970), Goldfinger (1980), Matsakis, *et al.*, (1986), Baby, *et al.* (1988), and Lanyi (1984). The reader should be aware of typographical errors in the published versions of the last three works cited. The models differ in their allowance for Earth curvature, atmospheric boundary structure, scale heights, and bending. Of these, the model which attempts to address all these aspects, particularly bending, in the most complete manner, is that of Lanyi. Some of the other models can be duplicated by dropping terms from the Lanyi model. Its abundance of adjustable parameters could prove useful for experimental applications. It is recommended that the lapse rate and the wet scale height parameter be adjusted for site dependence and seasonal variation (see Askne and Nordius, 1987). As pointed out by Davis, *et al.* (1985), the mapping function is considerably less sensitive than the zenith delay to the wet component.

There is some discrepancy in the reported literature concerning the numerical values of the refractivity coefficients for the wet delay. Measurements of the refractivity at radio wavelengths at different temperatures have been fit to a linear slope (in 1/T) by Boudouris (1963) and Birnbaum and Chatterjee (1952). Thayer (1974), using the same data, extrapolated values from the optical to derive slightly different values (Table 10.1) that were still within the measurement errors of the previous authors. The are actually a weighted average of their data and those of three other works, going back to 1935. Two works of these are based entirely upon data above 100° C; the coefficients of Boudouris are intermediate between the remaining two measurements. Within the range of atmospheric temperature variations, all three sets of coefficients are consistent with the data (Table 11.1) and the choice has little effect on the mapping function.

Table 11.1. Values of refractivity coefficients K2 and K3 for radio frequencies.

	K2	error	K3	error
Birnbaum and Chatterjee	71.40	5.8	3.747×10^5	0.03
Boudouris	72.00	10.5	3.754×10^5	0.03
Thayer	64.79	0.08	3.776×10^5	0.004

Global Positioning System

For GPS analysis, the model of Lanyi (1984; see also Sovers and Border, 1987) is recommended for mapping the zenith delay to line of sight delay at different elevations. The nominal value of the zenith path delay should include both the wet and dry components. The dry component should be determined from surface pressure measurements. If these are unavailable, a nominal value close to 200 cm should be specified, depending on the altitude of the observing site. Errors in the nominal value of the dry component will be absorbed in the subsequent adjustment for the wet component. The zenith wet delay can be initially between 1-30 cm, depending on *a priori* information (seasonal averages, water vapor radiometer data) available. The estimation strategy described below is recommended:

Random walk stochastic estimation (Bierman 1977; also Lichten 1990) of the zenith wet residual delay should be included in the adjustment procedure. The random walk constraint should be tailored to the observing site. In the absence of such information, a random walk constraint of $2\text{x}10^{-7}$ km/s$^{1/2}$ can be used, which is appropriate for GPS carrier phase data noise of about ± 1 cm over 6 minutes.

Where random walk modeling is not available, alternate approaches are recommended (in order of preference):

1. Estimation of piecewise linear or quadratic zenith troposphere correction to the nominal value, with a new polynomial determined every day.

2. Estimation of a single constant zenith delay correction for each site.

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CHAPTER 12 RADIATION PRESSURE REFLECTANCE MODEL

For a near-Earth satellite the solar radiation pressure acceleration, $\ddot{\bar{r}}$ is given by:

$$\ddot{\bar{r}} = \kappa \left[\frac{A}{R}\right]^2 C_R \frac{a}{m} \frac{\bar{R}}{R},$$

where

κ = 4.560 $\times 10^{-6}$ newtons/m^2 (1367 watts/m^2),

A = astronomical unit in meters,

R = heliocentric radius vector to the satellite,

a = cross-sectional area (m^2) of the satellite perpendicular to $\vec{R}$,

m = satellite mass,

C_R = reflectivity coefficient, usually an adjusted parameter.

The radiation pressure due to backscatter from the Earth is ignored. The model for the Earth's and Moon's shadows should include the umbra and the penumbra (Haley, 1973).

Earth Radius	6 402 km
Moon Radius	1 738 km
Solar Radius	696 000 km

Global Positioning System

For GPS satellites, the solar radiation pressure models T10 (for Block I) and T20 (for Block II) of Fliegel, *et al*. (1992) are recommended. These models include thermal reradiation.

The T10 and T20 models provide variations in the X and Z components of the total nominal solar pressure force as a function of the angle B between the Sun and the +Z axis of the satellite.

The model formulae for T10 are:

$$X = -4.55 \sin B + 0.08 \sin (2B + 0.9) - 0.06 \cos (4B + 0.08) + 0.08,$$

$Z = -4.54 \cos B + 0.20 \sin (2B - 0.3) - 0.03 \sin 4B.$

The model formulae for T20 are:

$X = -8.96 \sin B + 0.16 \sin 3B + 0.10 \sin 5B - 0.07 \sin 7B,$

$Z = -8.43 \cos B.$

In both cases the units are 10^{-5} N.

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CHAPTER 13 GENERAL RELATIVISTIC MODELS FOR TIME, COORDINATES AND EQUATIONS OF MOTION

The relativistic treatment of the near-Earth satellite orbit determination problem includes correction to the equations of motion, the time transformations, and the measurement model. The two coordinate systems generally used when including relativity in near-Earth orbit determination solutions are the solar system barycentric frame of reference and the geocentric or Earth-centered frame of reference.

Ashby and Bertotti (1986) constructed a locally inertial E-frame in the neighborhood of the gravitating Earth and demonstrated that the gravitational effects of the Sun, Moon, and other planets are basically reduced to their tidal forces, with very small relativistic corrections. Thus the main relativistic effects on a near-Earth satellite are those described by the Schwarzschild field of the Earth itself. This result makes the geocentric frame more suitable for describing the motion of a near-Earth satellite (Ries, *et al.*, 1988).

The time coordinate in the inertial E-frame is Terrestrial Time (designated TT) (Guinot, 1991) which can be considered to be equivalent to the previously defined Terrestrial Dynamical Time (TDT). This time coordinate (TT) is realized in practice by International Atomic Time (TAI), whose rate is defined by the atomic second in the International System of Units (SI). Terrestrial Time adopted by the International Astronomical Union in 1991 differs from Geocentric Coordinate Time (TCG) by a scaling factor:

$$\text{TCG-TT} = 6.9693 \times 10^{-10} \times (\text{MJD}-43144.0) \times 86400 \text{ seconds},$$

where MJD refers to the modified Julian date. Figure 13.1 shows graphically the relationships between the time scales.

Equations of Motion for an Artificial Earth Satellite

The correction to the acceleration of an artificial Earth satellite $\Delta\vec{a}$ is

$$\Delta\vec{a} = -\frac{GM_\oplus}{c^2r^3}\left[[2(\beta+\gamma)\frac{GM_\oplus}{r} - \gamma v^2]\vec{r} + [2(1+\gamma)(\vec{r}\cdot\vec{v})\vec{v}]\right], \qquad (1)$$

where c = speed of light,
β,γ = PPN parameters equal to 1 in General Relativity,
$\vec{r},\vec{v},\vec{a}$ = geocentric satellite position, velocity, and acceleration, respectively,

$GM_{\oplus}$ = gravitational parameter of the Earth.

The effects of Lense-Thirring precession (frame-dragging), geodesic (de Sitter) precession, and the relativistic effects of the Earth's oblateness have been neglected.

Equations of Motion in the Barycentric Frame

The n-body equations of motion for the solar system frame of reference (the isotropic Parameterized Post-Newtonian system with Barycentric Coordinate Time (TCB) as the time coordinate) are required to describe the dynamics of the solar system and artificial probes moving about the solar system (for example, see Moyer, 1971). These are the equations applied to the Moon's motion for Lunar Laser Ranging (Newhall, Williams, and Dickey, 1987). In addition, relativistic corrections to the laser range measurement, the data timing, and the station coordinates are required (see Chapter 14).

Scale Effect and Choice of Time Coordinate

The previous IAU definition of the time coordinate in the barycentric frame required that only periodic differences exist between Barycentric Dynamical Time (TDB) and Terrestrial Dynamical Time (TDT) (Kaplan, 1981). As a consequence, the spatial coordinates in the barycentric frame had to be rescaled to keep the speed of light unchanged between the barycentric and the geocentric frames (Misner, 1982; Hellings, 1986). Thus, when barycentric (or TDB) units of length were compared to geocentric (or TDT) units of length, a scale difference, L, appeared. This is no longer required with the use of the TCG time scale.

The difference between TCB and TDB is given in seconds by Fukushima *et al.* (1986) as

$$TCB-TDB = 1.550505\times10^{-8}(\pm1\times10^{-14})\times(MJD-43144.0)\times86400.$$

The difference between Barycentric Coordinate Time (TCB) and Geocentric Coordinate Time (TCG) involves a four-dimensional transformation,

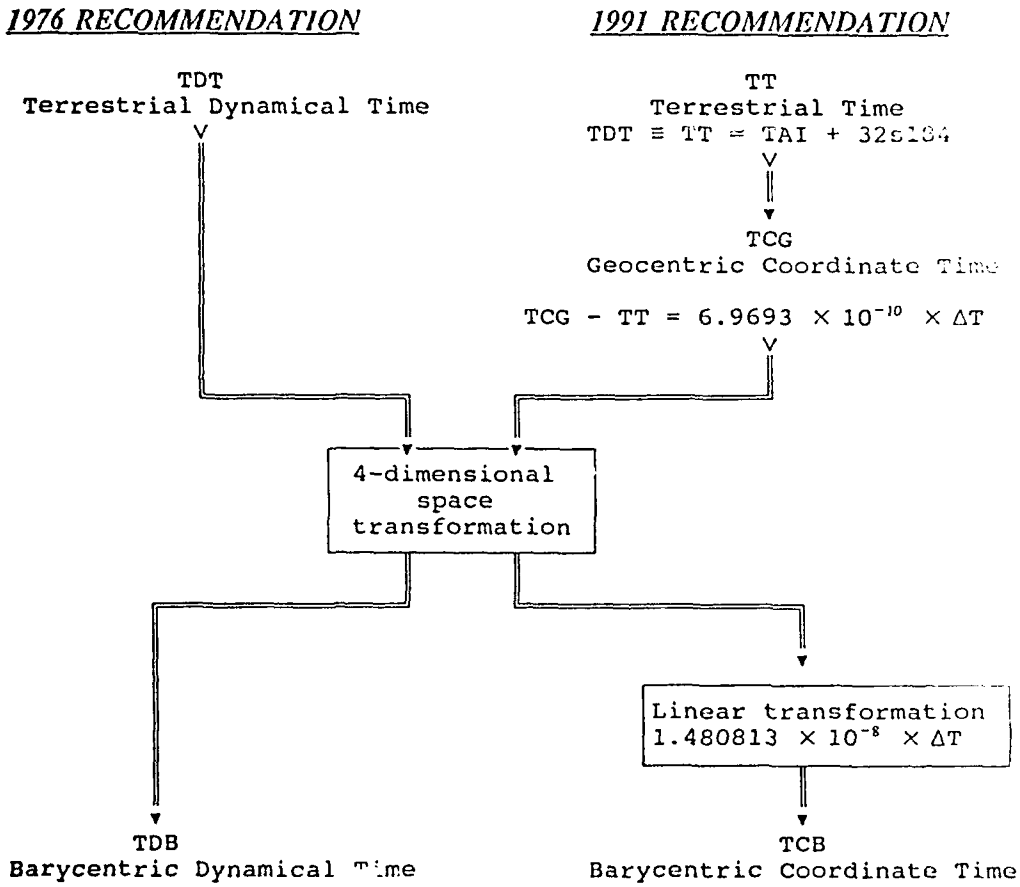
$$TCB-TCG = c^{-2}\left\{\int_{t_0}^{t}[\vec{v}\cdot\vec{v}/2 + U_{ext}(\vec{x}_e)]dt + \vec{v}_e\cdot(\vec{x}-\vec{x}_e)\right\},$$

where $\vec{x}_e$ and $\vec{v}_e$ denote the barycentric position and velocity of the Earth's center of mass and $\vec{x}$ is the barycentric position of the observer. U_{ext} is the Newtonian potential of all of the solar system bodies apart from the Earth evaluated at the geocenter. t_0 is chosen to be consistent with 1977 January 1, $0^h\ 0^m\ 0^s$ TAI and t is

TCB. An approximation is given in seconds by Fukushima *et al.* (1986) as

$$(TCB-TCG) = 1.480813 \times 10^{-8} (\pm 1 \times 10^{-14}) \times (MJD-43144.0) \times 86400 + c^{-2} \vec{v}_e \cdot (\vec{x} - \vec{x}_e) + P.$$

with MJD measured in TAI. For observers on the Earth's surface, diurnal periodic differences denoted by P with a maximum amplitude of 2.1 μs also remain. These can be evaluated from positions and motions of solar system bodies using expressions of Hirayama *et al.* (1987).



$$TCB = TDB + 1,550505 \times 10^{-8} \times \Delta T$$

$$\Delta T = (\text{date in days} - 1977 \text{ January } 1, 0^h) TAI \times 86400 \text{ sec}$$

Fig 13.1 Relations between time scales.

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CHAPTER 14 GENERAL RELATIVISTIC MODELS FOR PROPAGATION

VLBI Time Delay

There have been many papers dealing with relativistic effects which must be accounted for in VLBI processing; see (Robertson, 1975), (Finkelstein, *et al.*, 1983), (Hellings, 1986), (Pavlov, 1985), (Cannon, *et al.*, 1986), (Soffel, *et al.*, 1986), (Zeller, *et al.*, 1986), (Sovers and Fanselow , 1987), (Zhu and Groten, 1988), (Shahid-Saless, *et al.*, 1991), (Soffel, *et al.*, 1991). As pointed out by Boucher (1986), the relativistic correction models proposed in various articles are not quite compatible. To resolve differences between the procedures and to arrive at a standard model a workshop was held at the U. S. Naval Observatory on 12 October 1990. The proceedings of this workshop have been published (Eubanks, 1991) and the model given here is the consensus model resulting from that workshop. Much of this chapter dealing with VLBI time delay is taken directly from that work and the reader is urged to consult that publication for further details.

As pointed out by Eubanks, the use of clocks running at the geoid and delays calculated "at the geocenter" ignoring the scale change induced by the Earth's gravitational potential means that terrestrial distances calculated from the consensus model will not be the same as those calculated using meter sticks on the surface of the Earth. The accuracy limit chosen for the consensus VLBI relativistic delay model is 10^{-12} seconds (one picosecond) of differential VLBI delay for baselines less than two Earth radii in length. In the model all terms of order 10^{-13} seconds or larger were included to ensure that the final result was accurate at the picosecond level. Source coordinates derived from the consensus model will be solar system barycentric and should have no apparent motions due to solar system relativistic effects at the picosecond level.

The consensus model was derived from a combination of five different relativistic models for the geodetic delay. These are the Masterfit/Modest model, due to Fanselow and Thomas (see Treuhaft and Thomas, in (Eubanks, 1991), and (Sovers and Fanselow, 1987)), the I.I. Shapiro model (see Ryan, in (Eubanks, 1991)), the Hellings-Shahid-Saless model (Shahid-Saless *et al.*, 1991) and in (Eubanks, 1991), the Soffel, Muller, Wu and Xu model (Soffel, *et al.*, 1991) and in (Eubanks, 1991), and the Zhu-Groten model (Zhu and Groten, 1988) and in (Eubanks, 1991). Baseline results are expressed in geocentric coordinates as these are the coordinates effectively produced by current reductions of Satellite Laser Ranging data. This means that the gravitational potential of the Earth is not included in U, and that only the barycentric velocity of the geocenter, $\vec{V}_{\oplus}$, and not the geocentric station velocities, $\vec{w}_i$, appear in the Lorentz transformations (see Zhu and Groten, Soffel *et al.*, and Fukushima, all in Eubanks (1991), and Shahid-Saless *et al.* (1991) for further details on the implications of these choices). Since the time argument is based on TAI, which is a quasi-local time at the geoid, not at the geocenter, distance estimates from this model will not agree with "physical" distances as measured by a meter stick but will be longer by ~ $(1 + \gamma) \cdot 6.94$ parts in 10^{10}.

The model is designed for use in the reduction of VLBI observations of extra-galactic objects acquired from the surface of the Earth. The delay error caused by ignoring the annual parallax is > 1 psec for objects closer than several hundred thousand light years, which includes all of the Milky Way galaxy. The model is not intended for use with observations of sources in the solar system, nor is it intended for use with observations made from space-based VLBI, from either low or high Earth orbit, or from the surface of the Moon (although it would be suitable with obvious changes for observations made entirely from the Moon).

It is assumed that the inertial reference frame is defined kinematically and that very distant objects, showing no apparent motion, are used to estimate precession and the nutation series. This frame is not truly inertial in a dynamical sense, as included in the precession constant and nutation series are the effects of the geodesic precession (~ 19 milli arc seconds / year). Soffel *et al.* (in Eubanks (1991)) and Shahid-Saless *et al.* (1991) give details of a dynamically inertial VLBI delay equation. At the picosecond level, there is no practical difference for VLBI geodesy and astrometry except for the adjustment in the precession constant.

Although the delay to be calculated is the time of arrival at station 2 minus the time of arrival at station 1, it is the time of arrival at station 1 that serves as the time reference for the measurement. Unless explicitly stated otherwise, all vector and scalar quantities are assumed to be calculated at t_1, the time of arrival at station 1 including the effects of the troposphere.

The notation follows that of Hellings (1986) and Hellings and Shahid-Saless in Eubanks (1991) as closely as possible. It is assumed that the standard IAU models for precession, nutation, Earth rotation and polar motion have been followed and that all geocentric vector quantities have thus been rotated into a nearly non-rotating celestial frame. The errors in the standard IAU models are negligible for the purposes of the relativistic transformations. The notation itself is given in Table 14.1. The consensus model separates the total delay into a classical delay and a general relativistic delay, which are then modified by relativistic transformations between geocentric and solar system barycentric frames.

Table 14.1. Notation used in the model

t_i	the time of arrival of a radiointerferometric signal at the i^{th} VLBI receiver in terrestrial time (TAI)
T_i	the time of arrival of a radiointerferometric signal at the i^{th} VLBI receiver in barycentric time (TCB or TDB)
t_{g_i}	the "geometric" time of arrival of a radiointerferometric signal at the i^{th} VLBI receiver including the gravitational "bending" delay and the change in the geometric delay caused by the existence of the atmospheric propagation delay but neglecting the atmospheric propagation delay itself
t_{v_i}	the "vacuum" time of arrival of a radiointerferometric signal at the i^{th} VLBI receiver including the gravitational delay but neglecting the atmospheric propagation delay and the change in the geometric delay caused by the existence of the atmospheric propagation delay
t_{i_J}	the approximation to the time that the ray path to station i passed closest to gravitating body J
δt_{atm_i}	the atmospheric propagation delay for the i^{th} receiver = $t_i - t_{g_i}$
Δt_{grav}	the differential gravitational time delay, commonly known as the gravitational "bending delay"
$\vec{x}_i(t_i)$	the geocentric radius vector of the i^{th} receiver at the geocentric time t_i
$\vec{b}$	$\vec{x}_2(t_1) - \vec{x}_1(t_1)$ and is thus the geocentric baseline vector at the time of arrival t_1
$\vec{b}_0$	the *a priori* geocentric baseline vector at the time of arrival t_1
$\delta\vec{b}$	$\vec{b}(t_1) - \vec{b}_0(t_1)$
$\vec{w}_i$	the geocentric velocity of the i^{th} receiver
$\hat{K}$	the unit vector from the barycenter to the source in the absence of gravitational or aberrational bending
$\hat{k}_i$	the unit vector from the i^{th} station to the source after aberration
$\vec{X}_i$	the barycentric radius vector of the i^{th} receiver
$\vec{X}_\oplus$	the barycentric radius vector of the geocenter
$\vec{X}_J$	the barycentric radius vector of the J^{th} gravitating body
$\vec{R}_{i_J}$	the vector from the J^{th} gravitating body to the i^{th} receiver
$\vec{R}_{\oplus_J}$	the vector from the J^{th} gravitating body to the geocenter
$\hat{N}_{i_J}$	the unit vector from the J^{th} gravitating body to the i^{th} receiver
$\vec{V}_\oplus$	the barycentric velocity of the geocenter
U	the gravitational potential at the geocenter neglecting the effects of the Earth's mass = $\Sigma GM_J/(\vec{R}_{\oplus_J} c^2)$. At the picosecond level, only the solar potential need be included in U ($j \neq \oplus$)
M_i	the mass of the i^{th} gravitating body
$M_\oplus$	the mass of the Earth
γ	a PPN Parameter, = 1 in general relativity

c the speed of light in meters / second
G the Gravitational Constant in Newtons meters^2 kilograms^{-2}

Vector magnitudes are expressed by the absolute value sign [$|x| = (\Sigma x_i^2)^{1/2}$]. Vectors and scalars expressed in geocentric coordinates are denoted by lower case (*e.g.* $\vec{x}$ and t), while quantities in barycentric coordinates are in upper case (*e.g.* $\vec{X}$ and T). MKS units are used throughout. For quantities such as $V_\oplus$, $\vec{w}_i$, and U it is assumed that a table (or numerical formula) is available as a function of TAI and that they are evaluated at the atomic time of reception at station 1, t_1, unless explicitly stated otherwise. A lower case subscript (*e.g.* $\vec{x}_i$) denotes a particular VLBI receiver, while an upper case subscript (*e.g.* $\vec{x}_J$) denotes a particular gravitating body.

GRAVITATIONAL DELAY

The general relativistic delay, Δt_{grav}, is given for the J^{th} gravitating body by

$$\Delta t_{grav_J} = (1 + \gamma)\,\frac{GM_J}{c^3}\,\ln\frac{|\vec{R}_{1_J}| + \vec{K}\cdot\vec{R}_{1_J}}{|\vec{R}_{2_J}| + \vec{K}\cdot\vec{R}_{2_J}}. \qquad (21)$$

At the picosecond level it is possible to simplify the delay due to the Earth, $\Delta t_{grav\oplus}$, which becomes

$$\Delta t_{grav_\oplus} = (1 + \gamma)\,\frac{GM_\oplus}{c^3}\,\ln\frac{|\vec{x}_1| + \vec{K}\cdot\vec{x}_1}{|\vec{x}_2| + \vec{K}\cdot\vec{x}_2}. \qquad (22)$$

In the consensus model the Sun, the Earth and Jupiter must be included, as well as the other planets in the solar system along with the Earth's Moon, for which the maximum delay change is several picoseconds. The major satellites of Jupiter, Saturn and Neptune should also be included if the ray path passes close to them. This is very unlikely in normal geodetic observing but may occur during planetary occultations.

The effect on the bending delay of the motion of the gravitating body during the time of propagation along the ray path is small for the Sun but can be several hundred picoseconds for Jupiter (see Sovers and Fanselow (1987) page 9). Since this simple correction, suggested by Sovers and Fanselow (1987) and Hellings (1986) among others, is sufficient at the picosecond level, it was adapted for the consensus model. It is also necessary to account for the motion of station 2 during the propagation time between station 1 and station 2. In this model $\vec{R}_{i_J}$, the vector from the J^{th} gravitating body to the i^{th} receiver, is iterated once, giving

$$t_{1_J} = Minimum[t_1,\ t_1 - \hat{K}\cdot(\vec{X}_J(t_1) - \vec{X}_1(t_1))], \tag{23}$$

so that

$$\vec{R}_{1_J}(t_1) = \vec{X}_1(t_1) - \vec{X}_J(t_{1_J}), \tag{24}$$

and

$$\vec{R}_{2_J} = \vec{X}_2(t_1) - \frac{\vec{V}_\oplus}{c}(\hat{K}\cdot\vec{b}_0) - \vec{X}_J(t_{1_J}). \tag{25}$$

Only this one iteration is needed to obtain picosecond level accuracy for solar system objects. If more accuracy is required, it is probably better to use the rigorous approach of Shahid-Saless, *et al.* (1991). $\vec{X}_1(t_1)$ is not tabulated, but can be inferred from $\vec{X}_\oplus(t_1)$ using

$$\vec{X}_i(t_1) = \vec{X}_\oplus(t_1) + \vec{x}_i(t_1), \tag{26}$$

which is of sufficient accuracy for use in equations 3, 4, and 5, when substituted into equation 1 but not for use in computing the geometric delay. The total gravitational delay is the sum over all gravitating bodies including the Earth,

$$\Delta t_{grav} = \sum_J \Delta t_{grav_J}. \tag{27}$$

GEOMETRIC DELAY

In the barycentric frame the vacuum delay equation is, to a sufficient level of approximation:

$$T_2 - T_1 = -\frac{1}{c}\hat{K}\cdot(\vec{X}_2(T_2) - \vec{X}_1(T_1)) + \Delta t_{grav}. \tag{28}$$

This equation is converted into a geocentric delay equation using known quantities by performing the relativistic transformations relating the barycentric vectors $\vec{X}_i$ to the corresponding geocentric vectors $\vec{x}_i$, thus converting Equation 8 into an equation in terms of $\vec{x}_i$. The related transformation between barycentric and geocentric time can be used to derive another equation relating T_2-T_1 and t_2-t_1, and these two equations can then be solved for the geocentric delay in terms of the geocentric baseline vector $\vec{b}$. The papers by Soffel *et al.* in Eubanks (1991), Hellings and Shahid-Saless in Eubanks (1991), Zhu and Groten (1988) and Shahid-Saless *et al.* (1991) give details of the derivation of the vacuum delay equation.

To conserve accuracy and simplify the equations the delay was expressed as much as is possible in terms of a rational polynomial. In the rational polynomial form the total geocentric vacuum delay is given by

$$t_{v_2}-t_{v_1}=\frac{\Delta t_{grav}-\frac{\hat{K}\cdot\vec{b}_0}{c}\left[1-(1+\gamma)U-\frac{|\vec{V}_\oplus|^2}{2c^2}-\frac{\vec{V}_\oplus\cdot\vec{w}_2}{c^2}\right]-\frac{\vec{V}_\oplus\cdot\vec{b}_0}{c^2}\left(1+\hat{K}\cdot\vec{V}_\oplus/2c\right)}{1+\frac{\hat{K}\cdot(\vec{V}_\oplus+\vec{w}_2)}{c}}\,. \tag{29}$$

Given this expression for the vacuum delay, the total delay is found to be

$$t_2-t_1 = t_{v_2}-t_{v_1} + (\delta t_{atm_2}-\delta t_{atm_1}) + \delta t_{atm_1}\frac{\hat{K}\cdot(\vec{w}_2-\vec{w}_1)}{c}\,. \tag{30}$$

For convenience the total delay can be divided into separate geometric and propagation delays. The geometric delay is given by

$$t_{g_2}-t_{g_1} = t_{v_2}-t_{v_1} + \delta t_{atm_1}\frac{\hat{K}\cdot(\vec{w}_2-\vec{w}_1)}{c}\,, \tag{31}$$

and the total delay can be found at some later time by adding the propagation delay:

$$t_2-t_1 = t_{g_2}-t_{g_1} + (\delta t_{atm_2}-\delta t_{atm_1})\,. \tag{32}$$

The tropospheric propagation delay in equations 11 and 12 need not be from the same model. The estimate in equation 12 should be as accurate as possible, while the δt_{atm} model in equation 11 need only be accurate to about an air mass (~10 nanoseconds). If equation 10 is used instead, the model should be as accurate as is possible.

If the difference, $\delta\vec{b}$, between the *a priori* baseline vector $\vec{b}_0$ used in equation 9 and the true baseline vector is less than roughly three meters, then it suffices to add $-(\hat{K}\cdot\delta\vec{b})/c$ to t_2-t_1. If this is not the case, however, the delay must be modified by adding

$$\Delta(t_{g_2}-t_{g_1}) = -\frac{\dfrac{\hat{K}\cdot\delta\vec{b}_0}{c}}{1+\dfrac{\hat{K}\cdot(\vec{V}_{\oplus}+\vec{w}_2)}{c}} - \frac{\vec{V}_{\oplus}\cdot\delta\vec{B}}{c^2} \tag{33}$$

to the total time delay t_2-t_1 from equation 10 or 12.

OBSERVATIONS CLOSE TO THE SUN

For observations made very close to the Sun, higher order relativistic time delay effects become increasingly important. The largest correction is due to the change in delay caused by the bending of the ray path by the gravitating body described in Richter and Matzner (1983) and Hellings (1986). The change to Δt_{grav} is

$$\delta t_{grav_i} = \frac{(1+\gamma)^2 G^2 M_i^2}{c^5}\,\frac{\vec{b}\cdot(\hat{N}_{1_i}+\hat{K})}{(|\vec{R}|_{1_i}+\vec{R}_{1_i}\cdot\hat{K})^2}, \tag{34}$$

which should be added to the Δt_{grav} in equation (1).

SUMMARY

Assuming that time t_1 is the Atomic (TAI) time of reception of the VLBI signal at receiver 1, the following steps are recommended to correct the VLBI time delay for relativistic effects.

1. Use equation 6 to estimate the barycentric station vector for receiver 1.

2. Use equations 3, 4, and 5 to estimate the vectors from the Sun, the Moon, and each planet except the Earth to receiver 1.

3. Use equation 1 to estimate the differential gravitational delay for each of those bodies.

4. Use equation 2 to find the differential gravitational delay due to the Earth.

5. Sum to find the total differential gravitational delay.

6. Add Δt_{grav} to the rest of the *a priori* vacuum delay from equation 9.

7. Calculate the aberrated source vector for use in the calculation of the tropospheric propagation delay:

$$\vec{k}_i = \hat{K} + \frac{\vec{V}_{\oplus} + \vec{w}_i}{c} - \hat{K}\,\frac{\hat{K} \cdot (\vec{V}_{\oplus} + \vec{w}_i)}{c}. \qquad (35)$$

8. Add the geometric part of the tropospheric propagation delay to the vacuum delay, equation 11.

9. The total delay can be found by adding the best estimate of the tropospheric propagation delay

$$t_2 - t_1 = t_{g_2} - t_{g_1} + \left[\delta t_{atm_2}\left(t_1 - \frac{\hat{K} \cdot \vec{b}_0}{c},\ \vec{k}_2\right) - \delta t_{atm_1}(\vec{k}_1)\right]. \qquad (36)$$

10. If necessary, apply equation 13 to correct for "post-model" changes in the baseline by adding equation 13 to the total time delay from equation step 9.

Propagation Correction for Laser Ranging

The space-time curvature near a massive body requires a correction to the Euclidean computation of range, ρ. This correction in seconds, Δt, is given by (Holdridge, 1967)

$$\Delta t = \frac{(1+\gamma)\, GM}{c^3} \ln\left(\frac{R_1 + R_2 + \rho}{R_1 + R_2 - \rho}\right), \qquad (37)$$

where

c = speed of light,
γ = PPN parameter equal to 1 in General Relativity,
R_1 = distance from the body's center to the beginning of the light path,
R_2 = distance from the body's center to the end of the light path,
GM = gravitational parameter of the deflecting body.

For near-Earth satellites, working in the geocentric frame of reference, the only body to be considered is the Earth (Ries, Huang, and Watkins, 1989). For lunar laser ranging, which is formulated in the solar system barycentric reference frame, the Sun and the Earth must be considered (Newhall, Williams, and Dickey, 1987).

In the computation of the instantaneous space-fixed positions of a station and a lunar reflector in the analysis of LLR data, the body-centered coordinates of the two sites are affected by a scale reduction and a Lorentz contraction effect (Martin, Torrence, and Misner, 1985). The scale effect is about 15 cm in the height of a tracking station, while the maximum value of the Lorentz effect is about 3 cm. The equation for the transformation of $\vec{r}$, the geocentric position vector of a station expressed in the geocentric frame, is

$$\vec{r}_b = \vec{r}\left(1 - \frac{\gamma\Phi}{c^2}\right) + \frac{1}{2}\left(\frac{\vec{V}\cdot\vec{r}}{c^2}\right)\vec{V}, \qquad (38)$$

where

$\vec{r}_b$ = station position expressed in the barycentric frame,
Φ = gravitational potential at the geocenter (excluding the Earth's mass),
$\vec{V}$ = barycentric velocity of the Earth,

A similar equation applies to the selenocentric reflector coordinates; the maximum value of the Lorentz effect is about 1 cm (Newhall, Williams, and Dickey, 1987).

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APPENDIX IAU, IAG AND IUGG RESOLUTIONS

Recommendations of the International Astronomical Union (IAU), the International Association of Geodesy (IAG) and the International Union of Geodesy and Geophysics (IUGG) related to topics in this document and passed at the 1991 General Assemblies of these organizations are listed below.

IAU Resolution

Resolution A4: Recommendations from the Working Group on Reference Systems

Recommendations I to IX

The XXIst General Assembly of the International Union.

RECOMMENDATION I

considering

that it is appropriate to define several systems of space-time coordinates within the framework of the General Theory of Relativity,

recommends

that the four space-time coordinates ($x^0 = ct$, x^1, x^2, x^3) be selected in such a way that in each coordinate system centered at the barycenter of any ensemble of masses, the squared interval ds^2 be expressed with the minimum degree of approximation in the form:

$$ds^2 = -c^2 d\tau^2$$
$$= \left(1 - \frac{2U}{c^2}\right)(dx^0)^2 + \left(1 + \frac{2U}{c^2}\right)[(dx^1)^2 + (dx^2)^2 + (dx^3)^2],$$

where c is the velocity of light, τ is proper time, and U is the sum of the gravitational potentials of the above mentioned ensemble of masses and of a tidal potential generated by bodies external to the ensemble, the latter potential vanishing at the barycenter.

Notes for Recommendation I

1. *This recommendation explicitly introduces The General Theory of Relativity as the theoretical background for the definition of the celestial space-time reference frame.*

2. *This recommendation recognizes that space-time cannot be described by a single coordinate system because a good choice of coordinate system may significantly facilitate the treatment of the problem at hand, and elucidate the meaning of the relevant physical events. Far from the space origin, the potential of the ensemble of masses to which the coordinate system pertains becomes negligible, while the potential of external bodies manifests itself only by tidal terms which vanish at the space origin.*

3. *The ds^2 as proposed gives only those terms required at the present level of observational accuracy. Higher order terms may be added as deemed necessary by users. If the IAU should find it generally necessary, more terms will be added. Such terms may be added without changing the rest of the recommendation.*

4. *The algebraic sign of the potential in the formula giving ds^2 is to be taken as positive.*

5. *At the level of approximation given in this recommendation, the tidal potential consists of all terms at least quadratic in the local space coordinates in the expansion of the Newtonian potential generated by external bodies.*

RECOMMENDATION II

considering

a) the need to define a barycentric coordinate system with spatial origin at the center of mass of the solar system and a geocentric coordinate system with spatial origin at the center of mass of the Earth, and the desirability of defining analogous coordinate systems for other planets and for the Moon,

b) that the coordinate systems should be related to the best realization of reference systems in space and time, and,

c) that the same physical units should be used in all coordinate systems,

recommends that

1. the space coordinate grids with origins at the solar system barycenter and at the center of mass of the Earth show no global rotation with respect to a set of distant extragalactic objects,

2. the time coordinates be derived from a time scale realized by atomic clocks operating on the Earth,

3. the basic physical units of space-time in all coordinate systems be the second of the International System of Units (SI) for proper time, and the SI meter for proper length,

connected to the SI second by the value of the velocity of light c = 299792458 ms^{-1}.

Notes for Recommendation II

1. *This recommendation gives the actual physical structures and quantities that will be used to establish the reference frames and time scales based upon the ideal definition of the system given by Recommendation I.*

2. *The kinematic constraint for the rate of rotation of both the geocentric and barycentric reference systems cannot be perfectly realized. It is assumed that the average rotation of a large number of extragalactic objects can be considered to represent the rotation of the universe which is assumed to be zero.*

3. *If the barycentric reference system as defined by this recommendation is used for studies of dynamics within the solar systems, the kinematic effects of the galactic geodesic precession may have to be taken into account.*

4. *In addition, the kinematic constraint for the state of rotation of the geocentric reference system as defined by this recommendation implies that when the system is used for dynamics (e. g. motions of the Moon and Earth satellites), the time dependent geodesic precession of the geocentric frame relative to the barycentric frame must be taken into account by introducing corresponding inertial terms into the equations of motion.*

5. *Astronomical constants and quantities are expressed in SI units without conversion factors depending upon the coordinate systems in which they are measured.*

RECOMMENDATION III

considering

the desirability of the standardization of the units and origins of coordinate times used in astronomy,

recommends that

1. the units of measurement of the coordinate times of all coordinate systems centered at the barycenters of ensembles of masses be chosen so that they are consistent with the proper unit of time, the SI second,

2. the reading of these coordinate times be 1977 January 1, $0^h\ 0^m\ 32\overset{s}{.}184$ exactly, on 1977 January 1, $0^h\ 0^m\ 0^s$ TAI exactly (JD = 2443144.5, TAI), at the geocenter,

3. coordinate times in coordinate systems having their spatial origins respectively at the center of mass of the Earth and at the solar system barycenter, and established in conformity with the above sections (1) and (2), be designated as Geocen-

tric Coordinate Time (TCG) and Barycentric Coordinate Time (TCB).

Notes for Recommendation III

1. *In the domain common to any two coordinate systems, the tensor transformation law applied to the metric tensor is valid without re-scaling the unit of time. Therefore, the various coordinate times under consideration exhibit secular differences. Recommendation 5 (1976) of IAU Commissions 4, 8 and 31, completed by Recommendation 5 (1979) of IAU Commissions 4, 19 and 31, stated the Terrestrial Dynamical Time (TDT) and Barycentric Dynamical Time (TDB) should differ only by periodic variations. Therefore, TDB and TCB differ in rate. The relationship between these scales in seconds is given by:*

$$TCB - TDB = L_B \times (JD - 2443144.5) \times 86400.$$

The present estimate of the value of L_B is 1.550505×10^{-8} ($\pm 1 \times 10^{-14}$) (Fukushima et al., Celestial Mechanics, 38, 215, 1986).

2. *The relation TCB - TCG involves a full 4-dimensional transformation*

$$TCB - TCG = \frac{1}{c^2}\left[\int_{t_0}^{t}\left(\frac{v_e^2}{2} + U_{ext}(x_e)\right)dt + v_e(x - x_e)\right],$$

x_e and v_e denoting the barycentric position and velocity of the Earth's center of mass and x the barycentric position of the observer. The external potential U_{ext} is the Newtonian potential of all solar system bodies apart from the Earth. The external potential must be evaluated at the geocenter. In the integral, t = TCB and t_0 is chosen to agree with the epoch of Note 3. As an approximation to TCB - TCG in seconds one might use:

$$TCB - TCG = L_C \times (JD - 2443144.5) \times 86400 + c^{-2}v_e(x-x_e) + P.$$

The present estimate of the value of L_C is 1.480813×10^{-8} ($\pm 1 \times 10^{-14}$) (Fukushima et al., Celestial Mechanics, 38, 215, 1986). It may be written as $[3GM/2c^2a] + \epsilon$ where G is the gravitational constant, M is the mass of the Sun, a is the mean heliocentric distance of the Earth, and ϵ is a very small term (of order 2×10^{-12}) arising from the average potential of the planets at the Earth.

The quantity P represents the periodic terms which can be evaluated using the analytical formula by Hirayama et al., ("Analytical Expression of TDB-TDT_0", in Proceedings of the IAG Symposia, IUGG XIXth General Assembly, Vancouver, August 10-22 1987). For observers on the surface of the Earth, the terms depending upon their terrestrial coordinates are diurnal, with a maximum amplitude of 2.1 μs.

3. *The origins of coordinate times have been arbitrarily set so that these times all coincide with the Terrestrial Time (TT) of Recommendation IV at the geocenter on 1977 January 1, 0^h 0^m 0^s TAI. (See note 3 of Recommendation IV.)*

4. *When realizations of TCB and TCG are needed, it is suggested that these realizations be designated by expressions such as TCB(xxx), where xxx indicates the source of the realized time scale (e. g. TAI) and the theory used for the transformation into TCB or TCG.*

RECOMMENDATION IV

considering

a) that the time scales used for dating events observed from the surface of the Earth and for terrestrial metrology should have as the unit of measurement the SI second, as realized by terrestrial time standards,

b) the definition of the International Atomic Time, TAI, approved by the 14th Conférence Générale des Poids et Mesures (1971) and completed by a declaration of the 9th session of the Comité Consultatif pour la Définition de la Seconde (1980),

recommends that

1) the time reference for apparent geocentric ephemerides be Terrestrial Time, TT,

2) TT be a time scale differing from TCG of Recommendation III by a constant rate, the unit of measurement of TT being chosen so that it agrees with the SI second on the geoid,

3) at instant 1977 January 1, $0^h\ 0^m\ 0^s$ TAI exactly, TT have the reading 1977 January 1, $0^h\ 0^m\ 32\overset{s}{.}184$ exactly.

Notes for Recommendation IV

1. *The basis of the measurement of time on the Earth is International Atomic Time (TAI) which is made available by the dissemination of corrections to be added to the readings of national time scales and clocks. The time scale TAI was defined by the 59th session of the Comité International des Poids et Measures (1970) and approved by the 14th Conférence Générale des Poids et Mesures (1971) as a realized time scale. As the errors in the realization of TAI are not always negligible, it has been found necessary to define an ideal form of TAI, apart from the* $32\overset{s}{.}184$ *offset, now designated Terrestrial Time, TT.*

2. *The time scale TAI is established and disseminated according to the principle of coordinate synchronization, in the geocentric coordinate system, as explained in CCDS, 9th Session (1980) and in Reports of the CCIR, 1990, annex to Volume VII (1990).*

3. *In order to define TT it is necessary to define the coordinate system precisely, by the metric form, to which it belongs. To be consistent with the uncertainties of the frequency of the best standard, it is at present (1991) sufficient to use the relativistic metric given in Recommendation I.*

4. *For ensuring an approximate continuity with the previous time arguments of ephemerides, Ephemeris Time, ET, a time offset is introduced so that TT - TAI =* $32\overset{s}{.}184$ *exactly at 1977 January 1,* 0^h *TAI. This date corresponds to the implementation of a steering process of the TAI frequency, introduced so that the TAI unit of measurement remains in close agreement with the best realizations of the SI second on the geoid. TT can be considered as*

equivalent to TDT as defined by IAU Recommendation 5 (1976) of Commissions 4, 8 and 31, and Recommendation 5 (1979) of Commissions 4, 19 and 31.

5. *The divergence between TAI and TT is a consequence of the physical defects of atomic time standards. In the interval 1977-1990, in addition to the constant offset of 32.184 s, the deviation probably remained within the approximate limits of ± 10μs. It is expected to increase more slowly in the future as a consequence of improvements in time standards. In many cases, especially for the publication of ephemerides, this deviation is negligible. In such cases, it can be stated that the argument of the ephemerides is TAI + 32.184 s.*

6. *Terrestrial Time differs from TCG of Recommendation III by a scaling factor, in seconds:*

$$TCG - TT = L_G \times (JD - 2443144.5) \times 86400.$$

The present estimate of the value of L_G is 6.969291×10^{-10} ($\pm 3 \times 10^{-16}$). The numerical value is derived from the latest estimate of gravitational potential on the geoid, W = 62636860 (± 30) m^2/s^2 (Chovitz, Bulletin Géodesique, 62, 359, 1988). The two time scales are distinguished by different names to avoid scaling errors. The relationship between L_B and L_C of Recommendation III, notes 1 and 2, and L_G is, $L_B = L_C + L_G$.

7. *The unit of measurement of TT is the SI second on the geoid. The usual multiples, such as the TT day of 86400 SI seconds on the geoid and the TT Julian century of 36525 TT days, can be used provided that the reference to TT be clearly indicated whenever ambiguity may arise. Corresponding time intervals of TAI are in agreement with the TT intervals within the uncertainties of the primary atomic standards (e.g. within $\pm 2 \times 10^{-14}$ in relative value during 1990).*

8. *Markers of the TT scale can follow any date system based upon the second, e.g. the usual calendar date of the Julian Date, provided that the reference to TT be clearly indicated whenever ambiguity may arise.*

9. *It is suggested that realizations of TT be designated by TT(xxx) where xxx is an identifier. In most cases a convenient approximation is:*

$$TT(TAI) = TAI + 32.184\,s.$$

However, in some applications it may be advantageous to use other realizations. The BIPM, for example, has issued time scales such as TT(BIPM90).

RECOMMENDATION V

considering

that important work has already been performed using Barycentric Dynamical Time (TDB), defined by IAU Recommendation 5 (1976) of IAU Commissions 4, 8 and 31, and Recommendation 5 (1979) or IAU Commissions 4, 19 and 31.

recognizes

that where discontinuity with previous work is deemed to be undesirable, TDB may be used.

Note to Recommendation V

Some astronomical constants and quantities have different numerical values depending upon the use of TDB or TCB. When giving these values, the time scale used must be specified.

RECOMMENDATION VI

considering

the desirability of implementing a conventional celestial barycentric reference system based upon the observed positions of extragalactic objects, and,

noting

the existence of tentative reference frames constructed by various institutions and combined by the International Earth Rotation Service (IERS) into a frame used for Earth rotation series,

recommends

1. that intercomparisons of these frames be extensively made in order to assess their systematic differences and accuracy,

2. that an IAU Working Group consisting of members of Commissions 4, 8, 19, 24, 31 and 40, the IERS, and other pertinent experts, in consultation with all the institutions producing catalogues of extragalactic radio sources, establish a list of candidates for primary sources defining the new conventional reference frame, together with a list of secondary sources that may later be added to or replace some of the primary sources, and,

requests

1. that such a list be presented to the XXIInd General Assembly (1994) as a part of the definition of a new conventional reference system,

2. that the objects in this list be systematically observed by all VLBI and other appropriate astrometric programs.

Note for Recommendation VI

This recommendation essentially describes the first part of the work that must be done to prepare the realization of the reference system defined by Recommendations I and II. The choice of objects must be made in the first place by considering their observability by VLBI, but special care should be taken to include a large proportion of extragalactic radio sources with well identified optical counterparts.

RECOMMENDATION VII

considering

a) that the new conventional celestial barycentric reference frame should be as close as possible to the existing FK5 equator and equinox and dynamical equinox which are referred to J2000.0,

b) that it should be accessible to astrometry in visual as well as in radio wavelengths,

recommends

1. that the principal plane of the new conventional celestial reference system be as near as possible to the mean equator at J2000.0 and that the origin in this principal plane be as near as possible to the dynamical equinox of J2000.0,

2. that the positions of the extragalactic objects selected in accordance with Recommendation VI and representing the reference frame be computed initially for the equator and equinox J2000.0 using the best available values of the celestial pole offset with respect to the IAU expressions for precession and nutation,

3. that a great effort be made to compare reference frames of all types, in particular for FK5, solar system and extragalactic reference frame,

4. that observing programs be undertaken or continued in order to relate planetary positions to radio and optical objects, and to determine the relationship between catalogues of extragalactic source positions and the best catalogues of star positions, in particular the FK5 and Hipparcos catalogues.

Notes for Recommendation VII

1. *This recommendation specifies the choice of the coordinate axes that will be adopted in the final reference frame and describes the work to be done before such a frame can be constructed. Although the considerations call for visual and radio wavelengths for the primary catalogue, other observable wavelengths are not excluded. Positions of objects observed in other wavelengths should also be referred to the same system.*

2. *The objective set by this recommendation is that there should be no discontinuity in the positions of stars when the present FK5 frame is replaced by the extragalactic reference frame. This means that the position of the extragalactic objects should be in the FK5 system for J2000.0. It is acknowledged that the best values of precession and nutation must be used in order to avoid introducing spurious proper motions into the positions of extragalactic objects. The final transfer to the preferred equinox and principal plane will be done by applying a rotation at J2000.0.*

3. *The dynamical equinox in this recommendation is defined as the intersection of the mean equator and the ecliptic. The latter is defined as the uniformly rotating plane of the orbit of the Earth-Moon barycenter averaged over the entire period for which the ephemerides are valid. Since it is ephemeris dependent, the choice of the equinoctial point will be made using the most accurate and generally available ephemerides of the solar system at the time.*

4. *The definition given to the reference system by Recommendation I and II implies the stability in time of the system of coordinates realized by the celestial reference frame. The directions of the coordinate axes should not be changed even if at some later date the realizations of the dynamical equinox or the celestial ephemeris pole are improved. Similarly, modifications to the set of extragalactic objects realizing the reference system should be made in such a way that the directions of the axes are not changed. This means that once the coordinate axes have been specified, in the way described in the first part of the recommendation, the connection between the definition of the conventional reference system and the peculiarities of the Earth's kinematics will have been severed.*

5. *As long as the relationship between the optical and the extragalactic radio frame is not sufficiently accurately determined, the FK5 catalogue shall be considered as a provisional realization of the celestial reference system in optical wavelengths.*

RECOMMENDATION VIII

<u>recognizing</u>

a) the importance to astronomy of adopting conventional values of astronomical and physical constants,

b) the values of these constants should be unchanged unless they differ significantly from their latest estimates,

c) that estimates of these constants should be improved frequently to represent the current status of knowledge,

d) the necessity of providing standard procedures using these numerical values, and,

<u>noting</u>

a) that the MERIT Standards and IERS Standards have contributed significantly to the progress of astronomy and geodesy,

b) that numerical values in these standards have served as a system of constants in analyzing observations of high quality, and

<u>considering</u>

that procedures in these standards do not cover the whole of fundamental astronomy,

<u>recommends</u>

that a permanent working group be organized by Commissions 4, 5, 8, 19, 24 and 31, in consultation with the IAG and the IERS, in order to update and improve the system of astronomical units and constants, the list of estimates of fundamental astronomical quantities and standard procedures; this group shall:

1. prepare a draft report on the system of astronomical units and constants at least six months before the XXIInd General Assembly (1994),

2. prepare a draft list of best estimates of astronomical quantities at least six months before each following General Assembly,

3. prepare, at least six months before each following General Assembly, a draft report on standard procedures needed in fundamental astronomy, which,

   a) should have a maximum degree of compatibility with the IERS Standard,

   b) should include the implementations of procedures in the form of tested software and/or test cases,

   c) should be available not only in written form, but also in machine-readable form,

4. prepare a draft report on possible electronic access to these units, constants, quantities and procedures at least six months before the XXIInd General Assembly (1994).

RECOMMENDATION IX

<u>recognizing</u>

that a generally accepted non-rigid Earth theory of nutation, including all known effects at the one tenth milliarcsecond level, is not yet available,

<u>recommends</u>

1. that those satisfied with accuracy of the nutation angles (ϵ or $\psi \sin\epsilon_0$) numerically greater than ± 0.002" (one sigma rms) may continue to use the 1980 IAU Nutation Theory (P.K. Seidelmann, <u>Celestial Mechanics</u>, **27**, 79, 1982),

2. that those requiring values of the nutation angles more accurate than ± 0".002 (one sigma rms) should make use of the Bulletins of the IERS which publish observations and predictions of the celestial pole offsets accurate to about ± 0".0006 (one sigma rms) for a period of up to six months in advance,

3. that the IUGG be encouraged to develop and adopt an appropriate Earth model to be used as the basis for a new IAU Theory of Nutation.

IAG Resolution

RESOLUTION N°1

The International Association of Geodesy,

Considering the IUGG Resolution on Conventional Terrestrial Reference System (CTRS), and noting

1) that the International Earth Rotation Service (IERS) is currently implementing such a system under the name of the International Terrestrial Reference System (ITRS) from VLBI, SLR, LLR and now GPS data, and

2) that the ITRS is within one meter of WGS 84,

recommends

1) that groups making highly accurate geodetic, geodynamic or oceanographic analysis should either use the ITRS directly or carefully tie their own systems to it,

2) that IERS standards should contain all necessary documentation to assist this task,

3) that for mapping, navigation or digital databases where sub-meter accuracy is not required, WGS 84 may be used in the place of ITRS,

4) that for high accuracy in continental areas, a system moving with a rigid plate may be used to eliminate unnecessary velocities provided it coincides exactly with the ITRS at a specific epoch (e. g., the ETRS 89 system selected by the EUREF subcommission).

IUGG Resolution

RESOLUTION N°2

The International Union of Geodesy and Geophysics

considering the need to define a Conventional Terrestrial Reference System (CTRS) which would be unambiguous at the millimeter level at the Earth's surface and that this level of accuracy must take account of relativity and of Earth deformation, and

noting the resolutions on Reference Systems adopted by the XXIst General Assembly of the International Astronomical Union (IAU) at Buenos Aires, 1991,

endorses the Reference System as defined by the IAU at their XXI[st] General Assembly at Buenos Aires, 1991 and

recommends the following definitions of the CTRS :

1) CTRS to be defined from a geocentric non-rotating system by a spatial rotation leading to a quasi-Cartesian system,

2) the geocentric non-rotating system to be identical to the Geocentric Reference System (GRS) as defined in the IAU resolutions,

3) the coordinate-time of the CTRS as well as the GRS to be the Geocentric Coordinate Time (TCG),

4) the origin of the system to be the geocenter of the Earth's masses including oceans and atmosphere, and,

5) the system to have no global residual rotation with respect to horizontal motions at the Earth's surface.

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