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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: (14) NSWC/TR-81-254	2. GOVT ACCESSION NO.: AD-A106 944
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): (6) THE NSWC GLOBAL OCEAN TIDE DATA TAPE (GOTD), ITS FEATURES AND APPLICATION, RANDOM-POINT TIDE PROGRAM.	5. TYPE OF REPORT & PERIOD COVERED: (9) Final rept.,
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) E. W. Schwiderski, L. T. Szeto	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Surface Weapons Center (K104), Dahlgren, Virginia 22448	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: (17) 61152N, ZR000-01-01 (16) ZR00001
11. CONTROLLING OFFICE NAME AND ADDRESS: Chief of Naval Material, Department of the Navy, Washington, DC 20360	12. REPORT DATE: (11) June 1981
	13. NUMBER OF PAGES: 43 (12) 42
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ocean Tides and Currents
Numerical Modeling
Tidal Charts

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In the following report, the authors highlight briefly the major qualitative and quantitative features of the NSWC ocean tide models, which now include the nine components (M_2, S_2, N_2, K_2), (K_1, O_1, P_1, Q_1), and Mf with models for Mm and Ssa nearing completion. Special characteristics of those models are pointed out, which require indispensable attention in various applications particularly in coastal areas with rapidly varying tides. Since the tide models interpolate

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hydrodynamically empirical tide data at over 2000 continental and island stations, certain simple corrections in the numerical procedures are presented. Plans for more extensive local and perhaps global refinements and improvements of the tide models are mentioned.

In the final part of this report, the authors describe the NSWC Global Ocean Tide Data (GOTD) tape including the data arrangement and the standard format. The report ends with a program that computes from the taped harmonic tidal constants instantaneous oceanic and geocentric tides at specified random points and instances in the Random-Point Tide (RPTIDE) program.

FOREWORD

In this report the authors elaborate the major features of the NSWC ocean tide models, which are significant in various applications. Simple improvements in coastal waters are suggested. The harmonic tidal constants are arranged on the NSWC Global Ocean Tide Data (GOTD) tape, which is described for possible users. The report concludes with the description of the NSWC Random-Point Tide (RPTIDE) program that computes tidal elevations at given random points and instances.

This project was supported by the Naval Surface Weapons Center's Independent Research Fund and by a grant from the National Geodetic Survey of the Department of Commerce/NOS/NOAA.* It is the author's most pleasant obligation to acknowledge the sustained and generous sponsorship of Mr. R. T. Ryland, Jr., Head of the Strategic Systems Department, his Associate, Dr. R. J. Anderle, and Mr. D. R. Brown, Jr., Head of the Space and Surface Systems Division. Many critical and stimulating suggestions were gratefully received from the author's colleagues, Drs. C. J. Cohen, C. Oesterwinter, and B. Zondek.

The date of completion was June 20, 1981.

Released by

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National Oceanographic and Atmospheric Administration (NOAA)

CONTENTS

ABSTRACT

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1. INTRODUCTION

Although the mathematical modeling of ocean tides enjoyed since Newton a tricentennial fascinating history (Schwiderski 1980a), due to the measured digital knowledge of the bathymetry of the real ocean basins, the solution of the problem was destined to await the advent of modern digital computers. Fortunately, along with the necessary computational tool, significantly improved numerical techniques and hydrodynamical notions of turbulent dissipation processes became available for the mathematically discrete and realistic definition of the ocean model (Schwiderski 1980a). Nevertheless, the strictly mathematical formulation of the problem failed to describe the true tides over some important ocean areas where low tides were predicted for observed high tides. The computed tidal charts conspicuously displayed none of the long-known strong distortions and retardations of ocean tides by shallow continental shelves (see, e.g., Figure 2) and narrow ocean ridges.

To overcome those fundamental shortcomings, the author (Schwiderski 1978a, b, 1979a - d, and 1980a) introduced a unique hydrodynamical interpolation technique, which incorporates into the model, empirical tide data collected from harmonically analyzed tide gauge measurements along shorelines and at some other ocean bottom irregularities. The combined mathematical-experimental method removed essentially all purely mathematical deficiencies and made the desired accurate charting of ocean tides possible (Schwiderski 1979e, 1980b, 1981a - h, j, and 1982a - d).

All earlier investigations started from the basic Laplace tidal equations (LTEs), which included only the astronomical equilibrium tide as its sole tide-forcing potential. Following suggestions of Proudman (1928) that there might exist significant interactions between the oceanic and terrestrial tides, Grace (1930) augmented the LTEs by including simple approximations of the terrestrial tide, the terrestrial response to the oceanic tidal load, and the corresponding three gravity perturbations of the equilibrium tide.

Remarkably, all numerical tidalists disregarded those investigations till Farrell (1972) derived a more accurate approximation of the same interaction terms, which were then considered by Hendershott (1972), Zahel (1977), Estes (1979), Parke and Hendershott (1979) and others. In order to avoid the involved computation of the loading effects, Accad and Pekeris (1978) assumed a uniform proportionality between the oceanic tide and its loading effects. Though this type of simplification was earlier suggested by Takahasi (1929) and Grace (1930), Accad and Pekeris justified this approach by displaying the striking resemblance of the corresponding global maps. The author (Schwiderski 1978a, 1979c, d, and 1980a) adopted the same approximation for all NSWC ocean tide models, and Goad (1980b) computed for the M_2 ocean tide the corresponding terrestrial dip, which also resembles closely its cause.

Since the first publication of the author's NSWC ocean tide model about three years ago, an unexpected wide range of applications to various problems in oceanography, geophysics, astronomy, and space technology has been conducted. Fortunately, most of those applications were very gratifying as they confirmed pointwise and/or globally the high accuracy and usefulness of the computed partial tides (see, e.g., Goad 1980a, b, Melchior et al. 1980, and Wahr and Sasao 1980). Since numerical global tide models are naturally limited in detailed accuracy in certain local ocean areas, some foreseeeable difficulties emerged particularly in applications to compute loading effects of ocean tides on the earth gravity field.

In order to avoid unnecessary complications in such applications, relevant qualifying and limiting features of the NSWC ocean tide models will be pointed out in Section 2. Simple immediate and future improvements of the models will be mentioned and discussed in Section 3. The arrangement of the gridded ocean tide data on the NSWC magnetic tape is described in Section 4. Finally Section 5 describes a program to compute from the taped harmonic ocean tide constants intantaneous ocean and geocentric tidal heights at a given set of random geographical points and specified instances. The corresponding user's guide and program listing are presented in Appendixes A and B.

2. MAJOR FEATURES OF THE NSWC OCEAN TIDE MODELS

In applications, the following special characteristics of the NSWC ocean tide models require scrupulous attention and evaluation. All these features are directly discernible from the author's various publications listed in the References.

(a) Modes of the NSWC Ocean Tide Models: The NSWC ocean tide model includes now (see Table 1) nine completed harmonic partial tides of the semidiurnal (M_2, S_2, N_2, K_2), diurnal (K_1, O_1, P_1, Q_1) and long-period (Mf) species with models of the additional long-period components (Mm, Ssa) nearing completion. All partial tides are represented by their harmonic constants, that is, amplitudes and phases which are recorded gridwise on magnetic tape (Schwiderski 1980d, and 1981j). Also, gridwise tabulated data charts and corange and cotidal maps of all eleven constituents are presented in NSWC technical reports (Schwiderski 1979e, 1981a - g, and 1982a - c).

(b) The Gridded Ocean Basins: For the recording of the harmonic tidal constants, the simply connected global ocean basins are divided by integral-degree longitudes and colatitudes into uniform 1° x 1° grid cells. Naturally, the model excludes all inland waters such as the Great Lakes and the Black and Dead Seas, as well as the following gridwise disconnected bordering waters: the Baltic, Kattegat, Irish, Mediterranean, Red, Ceram, Sulu, and Japan Seas; the Gulfs of California, Persia, Chihli, and Huraki; and the Hudson and Korean Bays. Similarly, many shallow (less than 5-m depth) and/or narrow waters such as the entire Barrier Reef area, the Gironde Estuary, and the Fjords of Norway could not be modeled.

(c) Computed and Empirical Tide Data: The recorded harmonic constants include all computed and hydrodynamically interpolated empirical tide data. The latter values are specially labeled in the printed charts (Schwiderski 1979e, 1981a - g and 1982a - c) for accuracy verification and for proper applications (see Section 3). All data are tabulated as representative for the centers of the corresponding grid cells; which is strictly realistic only for all open ocean areas where the tides vary negligibly over the mesh area. In fact, the computed data are rigorously defined as cell averages, which may deviate somewhat from the true point values where the tides suffer strong distortions and/or retardations over short distances.

The empirical data are by definition (Schwiderski 1978a, 1979d, and 1980a) aligned boundary values at continental or island shore stations or point values at some bottom irregularities. In addition to their obvious displacement (see Figure 1 below), many of those data must be viewed as crude averages of drastically varying high tides. This applies, for instance, to the Skagerak; the English Channel; the Bays of Fundy, Baffin, and Bristol; the Gulfs of St. Lawrence, Aden, Oman, Thailand, Tonkin, and Carpentaria; the Straits of Florida, Hudson, Formosa, Bass, and Cook; as well as most Seas of the Indonesian Archipelago, where mostly empirical input data are listed.

Table 1. Constants of Major Tidal Modes

Tidal Mode	K (m)	σ (10^{-4}/sec)	χ (deg)
	Semidiurnal Species		
M_2 = Principal Lunar	0.242 334	1.405 19	$2h_0 - 2s_0$
S_2 = Principal Solar	0.112 841	1.454 44	0
N_2 = Elliptical Lunar	0.046 398	1.378 80	$2h_0 - 3s_0 + p_0$
K_2 = Declination Luni-Solar	0.030 704	1.458 42	$2h_0$
	Dirnal Species		
K_1 = Declination Luni-Solar	0.141 565	0.729 21	$h_0 + 90$
O_1 = Principal Lunar	0.100 574	0.675 98	$h_0 - 2s_0 - 90$
P_1 = Principal Solar	0.046 843	0.725 23	$-h_0 - 90$
Q_1 = Elliptical Lunar	0.019 256	0.649 59	$h_0 - 3s_0 - 90$
	Long-Period Species		
Mf = Fortnightly Lunar	0.041 742	0.053 234	$2s_0$
Mm = Monthly Lunar	0.022 026	0.026 392	$s_0 - p_0$
Ssa = Semiannual Solar	0.019 446	0.003 8921	$2h_0$

K = amplitude of the partial tide
σ = frequency of the partial tide
χ = astronomical argument of the partial tide.
(h_0, s_0, p_0) = mean longitudes of sun, moon, and lunar perigee at Greenwich midnight
$h_0 = 279.696\,68 + 36\,000.\,768\,930\,485T + 3.03 \cdot 10^{-4} T^2$
$s_0 = 270.434\,358 + 481\,267.883\,141\,37T - 0.001\,133T^2 + 1.9 \cdot 10^{-6} T^3$
$p_0 = 334.329\,653 + 4\,069.034\,032\,957\,5T - 0.010\,325T^2 - 1.2 \cdot 10^{-5}\, T^3$

where

$T = [27\,392.500\,528 + 1.000\,000\,035\,6D]/36\,525$
$D = d + 365(y - 1975) + \mathrm{Int}\,[(y - 1973)/4]$
d = day number of year (d = 1 for January 1)
$y \geqslant 1975$ = year number

and

Int [x] = integral part of x

(d) **Accuracy in Open Oceans:** In the publications (Schwiderski (1978a, b, 1979a - c, 1980a, 1981a - h, and 1982a - d) a tide prediction accuracy of better than 5 cm anywhere in the open oceans has been claimed for the dominant M_2 tide. This accepted estimate is based on the worldwide agreement of the computed tide data with empirical data which carry the same accuracy. Indeed, due to the somewhat controversial harmonic analysis of tide gauge measurements, no higher accuracy can be claimed even by the most recent deep-sea tide data (see, e.g., Schwiderski 1981b). All lesser computed partial tides (see Table 1) carry relatively the same component accuracy as M_2. Thus, in superposition a total tide prediction accuracy of better than 10 cm can now be assumed over all open oceans.

(e) **Accuracy in Coastal Waters:** Due to the a priori resolution limits of the $1^\circ \times 1^\circ$ grid system mentioned under (b) and (c) above, the NSWC tide models may lose some of their open ocean accuracy (d) in coastal waters of rapidly varying tides. Of course, a similar loss of accuracy may be encountered in shore areas where the available empirical data are marginal in quantity and/or quality. This applies particularly to the Arctic and Antarctic coastlines, where large ice sheets may also cause some tidal distortions and retardations which have been assumed as negligible.

(f) **Interactions of Oceanic and Terrestrial Tides:** All NSWC partial tide models include effects of tide-generated terrestrial and oceanic mass perturbations in the simplified forms described in Section I. In agreement with other investigations, the inclusion of the earth tides produced significant first-order effects on the tidal amplitudes. As expected useful second-order corrections of amplitudes and phases were registered when oceanic load effects were introduced, which is also in agreement with other numerical experiments conducted for instance by Zahel (1977), Accad and Pekeris (1978), Estes (1979), and Parke and Hendershott (1979).

(g) **Hydrodynamical Properties:** The ocean tidal equations are the basic LTEs augmented by physically meaningful lateral eddy dissipation and linear bottom friction terms with novel eddy and friction coefficients depending linearly on the respective vertical and horizontal cell wall areas. Accordingly, eddy dissipation was found significant in deep oceans while bottom friction dominated in shallow waters. It may be emphasized that both terms were needed to achieve realistic decay and dispersion features and to bring the computed data in good agreement with empirical data. They were not necessary to enforce stability of the numerical procedure. In particular, the friction coefficients were meshwise modified by the unique hydrodynamical interpolation in order to achieve a realistically smooth acceptance of over 2000 empirical tide data pairs.

(h) **Mathematical Features:** The finite difference analogue of the ocean tidal equations uses the Hansen-Zahel (Zahel 1970) staggered difference scheme in space and improved differences in time. At boundaries, the free-slip condition is strictly imposed while the no-crossflow condition is acceptably violated by the hydrodynamical interpolation of empirical boundary data. To avoid the polar singularity of the tidal equations, a new series expansion is incorporated, which will be described in a forthcoming paper (Schwiderski 1981i).

3. APPLICATIONS OF THE NSWC OCEAN TIDE DATA

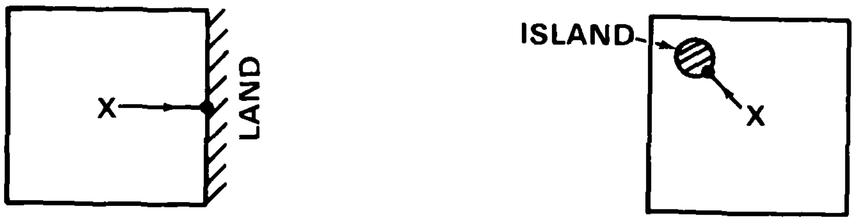
Various applications of the NSWC ocean tide models require indispensable consideration of the major features summarized in Section 2. This is particularly true in applications to compute interactions of oceanic and terrestrial tides, which manifest themselves as anomalies in the earth's gravity field. Though such perturbations amount to only a few microgals, they can now be determined by precision measurements such as those carried out by Kuo et al. (1970) and more recently on a global scale by Melchior et al. (1980). On the other hand, gravity anomalies caused by ocean tidal loading can be computed from accurate ocean tide (e.g., Schwiderski 1980b and 1981j) and solid earth (e.g., Farrell 1972) models (see, for instance, Goad 1980a, b and Melchior et al. 1980). Unfortunately, both the experimentally derived and computed gravity perturbations of ocean tidal loads are subject to the following difficulties.

(a) **Empirical Gravity Anomalies of Ocean Tidal Loads:** The measured gravity anomalies include dominant perturbations caused by the direct terrestrial tides, which are usually modeled by neglecting all lateral density and elasticity variations of the solid earth. Yet, those heterogeneities exist and may not be negligible especially in tectonically active areas. Furthermore, after subtraction of the modeled terrestrial tide effects, the remaining gravity anomalies must be subjected to the same harmonic analysis as the measured ocean tide, which is particularly controversial for short-time observations.

(b) **Computed Gravity Anomalies of Ocean Tidal Loads:** The computation of the yielding of the solid earth under the oceanic tide is also based on a highly simplified lateral homogeneous earth model as the terrestrial tide model (a) above. Moreover, as has been pointed out by various investigators (e.g., Pekeris 1978, Accad and Pekeris 1978, Goad 1980a, b, and Schwiderski 1980a), the purely numerical computation of gravity anomalies from ocean tidal loads poses considerable difficulties and may be the cause of significant errors. This is particularly true at coastal and oceanic stations where the convolution of the numerical ocean tide with a singular Green's function must be computed. Indeed, depending on the actual numerical procedure chosen, the singularity may amplify in various ways any or all of the deficiencies of the NSWC ocean tide models discussed in Section 2.

In spite of all the possible error sources, Goad (1980a, b) and Melchior et al. (1980) arrive at excellent agreements for the bulk of their compared empirical and computed gravity anomalies. These results lend convincing support to the accuracy claim of Melchior et al. concerning their worldwide gravity measurements. Vice versa, these investigations verify indirectly the oceanwide accuracy and usefulness of the NSWC tide models. In fact, a detailed analysis of the massive Melchior et al. data indicates that all of the remaining discrepancies between the empirical and computed data can probably be traced to one or more of the modeling and computing difficulties elaborated above.

(c) **Immediate Improvements:** In coastal and oceanic areas some of the deficiencies of the NSWC tide models (Section 2, b, c, e) can be immediately removed by preparing more detailed limited-area tide models on a locally refined grid system. Models of this sort have already been constructed by various researchers especially for excluded or insufficiently resolved bordering waters. Where no refined models are available, the refinement may be accomplished by linear or higher-order interpolation of the listed 1° x 1° data and by using additional empirical data, say, from the huge collections of the British Admiralty (1977) and the International Hydrographic Bureau (1978), which are in possession of the author. In such a refining process the hydrodynamically interpolated empirical tide data, which have been displaced to the centers of the grid cells (Section 2, c), should be first returned as closely as possible to the original tide gauge locations. Specifically, in boundary cells the empirial data should be moved from the cell centers to the centers of the boundary segments (Figure 1a). For small oceanic (unresolved) islands, the tabulated empirical data should be moved from the cell centers to the original stations (Figure 1b). This relatively simple local procedure is strongly recommended where the ocean tides suffer drastic distortions and retardations from the deep oceans to the shallow areas.



a. In Boundary Cells

b. Near Unresolved Islands

Figure 1. Replacing of Empirical Tide Data

The important effect of the replacement of empirical data may be illustrated by the incredibly sharp decay of the tidal ranges (= double amplitudes) across the continental shelf of the New York Bight. As can be seen in Figure 2, the tidal ranges measured by Gill and Porter (1980) drop from 4.6 ft at the coast over a shelf width of less than 200 km to an almost constant height of about 3 ft in the deep ocean. The global NSWC ocean tide model approximates this distortion very closely, but only when the empirical boundary datum $\overline{x}$ is returned to the original boundary position x. Obviously, simple linear interpolations between the adjusted model data x and x′ could significantly improve computations of corresponding gravity anomalies in that neighborhood.

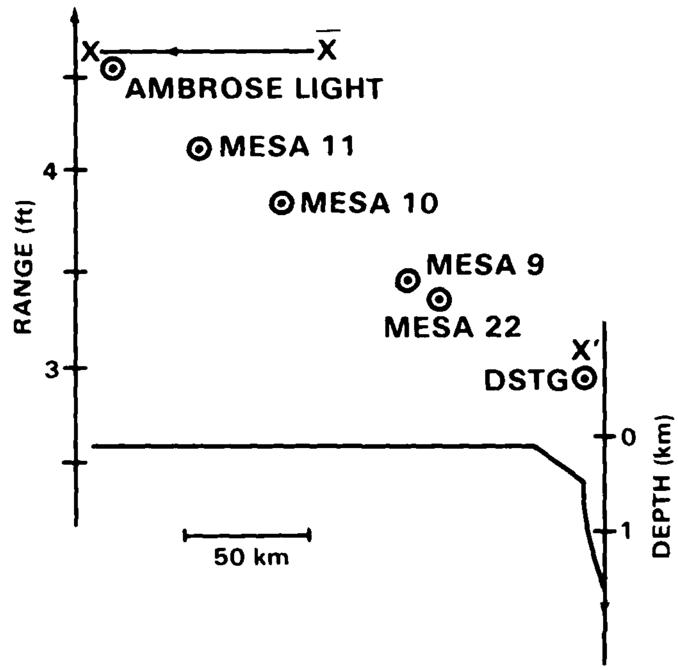


Figure 2. Sharp Decay of Tidal Ranges Across the Continental Shelf of New York Bight: ⊙ Gill-Porter Measurements, ($\bar{x}$, x') NSWC Tide Model, x Replaced Empirical Boundary Datum $\bar{x}$)

(d) **Future Improvements:** Refined local tide models are presently under consideration by the author. The results of those models will subsequently be used in connection with forthcoming new and better empirical data to improve the global NSWC tide models. An error reduction from 10 cm to 3 cm is already being called for in various applications. Of course, a model of this accuracy will require more and better measured and analyzed empirical data especially in critical areas.

4. NSWC GLOBAL OCEAN TIDE DATA (GOTD) TAPE

The NSWC GOTD-1981 tape contains the amplitudes $\xi^i_{m,n}$ (in meters) and Greenwich phases $\delta^i_{m,n}$ (in degrees, $0° = 360°$) of the leading harmonic ocean tidal modes (M_2, S_2, K_1, O_1, N_2, P_1, K_2, Q_1, Mf, Mm, Ssa) on a 1° x 1° spherical grid system. This GOTD-1981 tape is identical to the earlier GOTD -1980 tape, which did not contain the Mm and Ssa data.

The entire data set ($\xi^i_{m,n}$, $\delta^i_{m,n}$) is arranged by modes according to the mode number i = 1, 2, 3, ... , 11 as defined in Table 2, which also lists the corresponding species number ν (compare also Table 1).

Table 2. Entire Data Set (see Table 1)

Tidal Symbol	M_2	S_2	K_1	O_1	N_2	P_1	K_2	Q_1	Mf	Mm	Ssa
Mode Number: i	1	2	3	4	5	6	7	8	9	10	11
Species Number: ν	2	2	1	1	2	1	2	1	0	0	0

In each mode (i = 1, 2, ... , 11), the data are arranged by colatitude numbers n = 1, 2, ... , 168 (see Equation 2) in consecutive pairs of blocks each of which contain 361 words of amplitudes or phases arranged by longitude numbers m = 1, 2, ... , 360 (see Equation 1) with the last (361-st) word indicating the colatitude number n. The first block in each pair contains the amplitudes $\xi^i_{m,n}$ in Format F5.3 and the second one the phases $\delta^i_{m,n}$ in Format F5.1. The data have been blockwise generated by the BUFFER-OUT statement on the CDC 6700 computer. The magnetic tape has the following properties: seven track, BCD form, even parity, 556 bpi, and unlabeled.

The tidal constants ($\xi^i_{m,n}$, $\delta^i_{m,n}$) are representative for the 1° x 1° square with the geographical center point (λ_m, θ_n), where

$$\lambda_m = (m - 0.5)° = \text{longitude east } (m = 1, 2, \ldots, 360) \quad (1)$$

$$\theta_n = (n - 0.5)° = \text{colatitude } (n = 1,2, \ldots, 168) \quad (2)$$

On land (continental or large islands; see Schwiderski 1978c) all tidal constants have been set to:

$$\xi^i_{m,n} = 9.999, \quad \delta^i_{m,n} = 999.9 \text{ for land} \quad (3)$$

The precise definition of those data, their accuracy and limitation, and their proper application and improvement has been discussed in Sections 2 and 3. To avoid possible misleading conclusions any application of those data *must* evaluate realistically the listed features and suggestions.

The instantaneous ocean tide ζ_i (in meters) of any model i (= 1, 2, ..., 11) can be found at any given instant (y = year, d = day number of year y, and t = universal time of day d in seconds) and any given ocean point (λ, θ) by linearly interpolating the amplitude ξ_i and phase δ_i belonging to the point (λ, θ) in the corresponding *partial tide tables* and computing

$$\zeta_i = \zeta_i\,(\lambda, \theta, t) = \xi_i \cos\,[\sigma_i\, t + \pi\,(\chi_i - \delta_i)/180] \tag{4}$$

In this formula σ_i and χ_i denote, respectively, the frequency and the astronomical argument of the partial tide listed in Table 1.

The corresponding instantaneous astronomical partial equilibrium tide η_i (or tide-generating potential G_i; see Schwiderski 1978a, 1979c, d, or 1980a) is determined by

$$\eta_i = \eta_i\,(\lambda, \theta, t) = K_i\, f_{\nu i}\,(\theta) \cos\,[\sigma_i\, t + \pi\,(\chi_i + \nu_i\, \lambda)/180] \tag{5}$$

where $K_i = K$ and $\nu_i = \nu$ denote, respectively, the tidal amplitude and species number listed in Table 1. The species function of colatitude θ is defined by

$$f_\nu\,(\theta) = \begin{cases} \sin^2\theta \text{ for } \nu = 2 \\ \sin 2\theta \text{ for } \nu = 1 \\ \frac{1}{2}(3\sin^2\theta - 2) \text{ for } \nu = 0 \end{cases} \tag{6}$$

In a simple second-order Love-number approximation, the corresponding solid-earth tide ζ_i^e is given by (see Schwiderski 1978a, 1979c, d, or 1980a)

$$\zeta_i^e = \zeta_i^e\,(\lambda, \theta, t) \approx 0.612\, \eta_i \tag{7}$$

Similarly, in a simple Accad-Pekeris approximation (see Schwiderski 1978a, 1979c, d, or 1980a), the corresponding dip (yielding) of the solid earth ζ_i^{eo} in response to the oceanic tidal load ζ_i is given by

$$\zeta_i^{eo} = \zeta_i^{eo}\,(\lambda, \theta, t) \approx -\,0.0667\, \zeta_i \tag{8}$$

Thus, the corresponding instantaneous geocentric partial tide ζ_i^c (relative to the geoidal sea surface at rest) is determined by linear superposition to

$$\zeta_i^c = \zeta_i^c\,(\lambda, \theta, t) = \zeta_i + \zeta_i^e + \zeta_i^{eo} \tag{9}$$

Finally, by linear superposition of all corresponding partial tides, one finds the instantaneous local tides:

$$\zeta = \zeta(\lambda, \theta, t) = \sum_i \zeta_i = \text{total oceanic tide} \tag{10a}$$

$$\zeta^c = \zeta^c(\lambda, \theta, t) = \sum_i \zeta_i^c = \text{total geocentric tide} \tag{10b}$$

Note to Users: Copies of the NSWC GOTD tape in its discribed standard format (or any other desired format) may be requested from the authors:

E. W. Schwiderski, Code K104, Tel. (703) 663-8406
L. T. Szeto, Code K14, Tel. (703) 663-7741
NSWC, Dahlgren, Virginia 22448

5. NSWC RANDOM-POINT TIDE PROGRAM (RPTIDE)

The following NSWC RPTIDE computes from the harmonic tidal constants listed on the NSWC GOTD 1981 (or GOTD 1980) tape (Section 4) the instaneous oceanic and/or geocentric tides at given random points and instances. The corresponding Users' Guide and Program Listing are given in Appendixes A and B. A fast program to compute geocentric tides along satellite tracks is described in Schwiderski, E. W. and Szeto, L. T. 1981.

1) Input Data

(1) $(\xi^i_{m,n}, \delta^i_{m,n})$ = ocean tide amplitudes (in m) and Greenwich phases (in deg) from GOTD 1981 (or 1980) tape, where

$i = 1, 2, 3, \ldots, 11$ = mode numbers for GOTD 1981 ($0 < i < 10$ for GOTD 1980)

$m = 1,2, \ldots, 360 \ (=0)$ = longitude numbers

$n = 1,2, \ldots, 168$ = colatitude numbers

Note: $\xi^i_{m,n} = 9.999$, $\delta^i_{m,n} = 999.9$ on land

$\delta^i_{m,n} = 360° = 0°$ (phase jump)

(2) y = year $\geqslant 1975$ (fixed for one run!)

(3) d = day of year y ($d = 1$ for January 1st, also fixed for *one run!*)

(4) t_j = specified instances (in sec after Greenwich midnight of day d, where $j = 1, 2, 3, \ldots, J$

(5) (λ_j, θ_j) = longitudes (East) and latitudes (+ North, - South) in deg. of random points corresponding to instances t_j

(6) J = number of random points

(7) I = number of superposed tidal modes if $1 \leqslant I \leqslant 11$ with option $-1 \leqslant I \leqslant -11$ for computation of single tidal mode $i = |I|$, $|I| < 10$ for GOTD 1980 tape)

(8) $\alpha = 0$ or $= 1$ = earth tide parameter ($\alpha = 1$ earth tide included, $\alpha = 0$ earth tide excluded)

(9) $\beta = 0$ or $= 1$ = ocean load parameter ($\beta = 1$ ocean load included, $\beta = 0$ ocean load excluded)

(10) $\gamma = 0$ or $= 1$ = ocean tide parameter ($\gamma = 1$ ocean tide included, $\gamma = 0$ ocean tide excluded)

II) Preliminary Computations

With the tidal parameters $\nu = \nu_i$, $\sigma = \sigma_i$, $K = K_i$, h_o, s_o, p_o specified in Tables 1 and 2 compute:

$$h = \pi h_o/180, \qquad s = \pi s_o/180, \qquad p = \pi p_o/180$$

$$\chi = \chi_i \text{ for } i = 1, 2, 3, \ldots, 11$$

and set ($E_i = 0.612\ K_i$)

$$\begin{array}{lll} E_1 = 0.148\ 308, & E_2 = 0.069\ 059, & E_3 = 0.086\ 638, \\ E_4 = 0.061\ 515, & E_5 = 0.028\ 396, & E_6 = 0.028\ 668, \\ E_7 = 0.018\ 791, & E_8 = 0.011\ 785, & E_9 = 0.025\ 546, \\ E_{10} = 0.013\ 480, & E_9 = 0.011\ 901, & \end{array}$$

also

$$\bar{\gamma} = \gamma - 0.0667\,\beta$$

III) Main Computation

(1) Set $j = 1$

(2) Set $\zeta_j = 0$ and

$$i \begin{cases} = 1 \text{ for } I > 0, \\ = |I| \text{ for } I \not> 0 \text{ (single mode!)} \end{cases}$$

(3) Compute:

$$m = \text{Int}\,[\lambda_j + 0.5] + 1, \; \psi = m - (\lambda_j + 0.5)$$

$$n = \text{Int}\,[90.5 - \phi_j] + 1, \; \theta = \bar{\theta} = n - (90.5 - \phi_j)$$

and transfer to core memory

$$\begin{array}{ll} (\xi^i_{m-1,\,n-1}, \delta^i_{m-1,\,n-1}); & (\xi^i_{m,\,n-1}, \delta^i_{m,\,n-1}) \\ (\xi^i_{m-1,\,n}, \delta^i_{m-1,\,n}); & (\xi^i_{m,\,n}, \delta^i_{m,\,n}) \end{array} \qquad (*)$$

where m - 1 = 0 → 360

Check for land points and replace

(a) if $\xi^i_{m,n-1} = 9.999$, replace $\theta \to 0$

(b) if $\xi^i_{m,n} = 9.999$, replace $\theta \to 1$

(c) if (a) and (b) hold, replace $\psi \to 1$

(d) if $\xi^i_{m-1,n-1} = 9.999$, replace $\bar{\theta} \to 0$

(e) if $\xi^i_{m-1,n} = 9.999$, replace $\bar{\theta} \to 1$

(f) if (d) and (e) hold, replace $\psi \to 0$

(4) Interpolate ξ^i_j or the ruled second-order surface in ψ and θ:

$$\xi^i_j = (1-\psi)\,[\theta\,\xi^i_{m,n-1} + (1-\theta)\,\xi^i_{m,n}] + \psi\,[\bar{\theta}\,\xi^i_{m-1,n-1} + (1-\bar{\theta})\,\xi^i_{m-1,n}] \qquad (**)$$

Test for 360° phase jumps and replace

$$\text{if } \delta^i_{m,n-1} - \delta^i_{m,n} \begin{cases} > 180, \text{ replace } \delta^i_{m,n-1} \to \delta^i_{m,n-1} - 360 \\ < -180, \text{ replace } \delta^i_{m,n} \to \delta^i_{m,n} - 360 \end{cases}$$

$$\text{if } \delta^i_{m-1,n-1} - \delta^i_{m,n} \begin{cases} > 180, \text{ replace } \delta^i_{m-1,n-1} \to \delta^i_{m-1,n-1} - 360 \\ < -180, \text{ replace } \delta^i_{m,n} \to \delta^i_{m,n} - 360 \end{cases}$$

$$\text{if } \delta^i_{m-1,n} - \delta^i_{m,n} \begin{cases} > 180, \text{ replace } \delta^i_{m-1,n} \to \delta^i_{m-1,n} - 360 \\ < -180, \text{ replace } \delta^i_{m,n} \to \delta^i_{m,n} - 360 \end{cases}$$

$$\text{if } \delta^i_{m-1,n-1} - \delta^i_{m,n-1} \begin{cases} > 180, \text{ replace } \delta^i_{m-1,n-1} \to \delta^i_{m-1,n-1} - 360 \\ < -180, \text{ replace } \delta^i_{m,n-1} \to \delta^i_{m,n-1} - 360 \end{cases}$$

$$\text{if } \delta^i_{m-1,n} - \delta^i_{m,n-1} \begin{cases} > 180, \text{ replace } \delta^i_{m-1,n} \to \delta^i_{m-1,n} - 360 \\ < -180, \text{ replace } \delta^i_{m,n-1} \to \delta^i_{m,n-1} - 360 \end{cases}$$

$$\text{if } \delta^i_{m-1,n} - \delta^i_{m-1,n-1} \begin{cases} > 180, \text{ replace } \delta^i_{m-1,n} \rightarrow \delta^i_{m-1,n} - 360 \\ < -180, \text{ replace } \delta^i_{m-1,n-1} \rightarrow \delta^i_{m-1,n-1} - 360 \end{cases}$$

Use adjusted δs to interpolate δ^i_j by formula (**) with ξ replaced by δ.

Now, compute and replace

$$\zeta_j \rightarrow \zeta_j + \overline{\gamma}\, \xi^i_j \cos\left[\sigma_i t_j + \chi_i - \pi\, \delta^i_j/180\right]$$
$$+ \alpha\, E_i(\phi_j) \cos\left[\sigma_i t_j + \chi_i + \pi\, \nu_i \lambda_j/180\right]$$

where

$$E_i(\phi_j) = \begin{cases} E_i \cos^2 \phi_j \text{ for } \nu_i = 2 \\ E_i \sin 2\phi_j \text{ for } \nu_i = 1 \\ \frac{1}{2} E_i (3\cos^2 \phi_j - 2) \quad \text{for } \nu_i = 0 \end{cases}$$

If $i < |I|$, replace $i \rightarrow i + 1$, transfer to core memory new data (*), and repeat routine (4).

If $i \nless |I|$, print λ_j, ϕ_j, t_j, and ζ_j.

If $j < J$, replace $j \rightarrow j + 1$ and repeat (2) through (4).

If $j \nless J$ stop program.

Note: This program does not consider any special features or suggestions made in Sections 2 and 3. Hence, if a higher accuracy near coastal boundaries is needed, an appropriate local computation should be used following the suggestions of Section 2.

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APPENDIX A

RPTIDE PROGRAM USER'S GUIDE

APPENDIX A

RPTIDE PROGRAM USER'S GUIDE

The Random-Point Tide (RPTIDE) program computes instantaneous oceanic and/or geocentric tides at randomly given geographical points and specified instances as described in Section 5. The program listing in Appendix B shows RPTIDE written in FORTRAN IV extended for the CDC 6700 computer under the SCOPE 3.4 operating system. The BUFFER IN statement buffers in GOTD 1980 or 1981 tide constants (Section 4), which are in binary mode. The GOTD magnetic tape is in coded mode; its files are attached as follows for the example I = 6, L = IT1 (see Sections 4 and 5):

ATTACH, TAPE L	$\xi^1_{m,n}$	GOTD files
ATTACH, TAPE L + 1,	$\delta^1_{m,n}$	
ATTACH, TAPE L + 2,	$\xi^2_{m,n}$	
ATTACH, TAPE L + 3,	$\delta^2_{m,n}$	
⋮		
ATTACH, TAPE L + 10,	$\xi^6_{m,n}$	
ATTACH, TAPE L + 11,	$\delta^6_{m,n}$	

All other input data are entered using data cards consisting of one type A data card one or more type B data cards. The type A card contains 8 right-justified integers with the format of 8I5. The integers represent the following ordered variables (Section 5 symbols in parentheses):

YEAR = (y) = year > 1975 (fixed for one run!)

DAY = (d) = day of YEAR (d = 1 for January 1st, also fixed for one run!)

JPTS = (J) = total number of random points or instances with same YEAR and DAY

MTIDE = (I) = total number of tidal modes to be superposed ($1 \leqslant i \leqslant I$ where $I < 10$ for GOTD 1980 and $I < 12$ for GOTD 1981). Option if MTIDE = − N with $0 < N < 10$ or 12, the computed tide is the single partial tide i = N

ETINC = (α) = earth tide parameter (ETINC = 0 excludes and ETINC = 1 includes earth tide)

LOAD = (β) = ocean load parameter (LOAD = 0 excludes and LOAD = 1 includes ocean load)

OCEAN = (γ) = ocean tide parameter (OCEAN = 0 excludes and OCEAN = 1 includes ocean tide)

IT1 = beginning unit number of 2 * |MTIDE| consecutive unit numbers to which GOTD files are attached (see example above)

Each type B data card contains three numbers with the format 3F20.8. These numbers are, respectively:

TIME = (t) = time (in sec) of given instant after Greenwich midnight of day DAY (may be several days later)

LONG = (λ) = Longitude (East; in degrees)

LAT = (ϕ) = Latitude (+ North, - South; in degrees)

Other major notations corresponding to Section 5 are:

D = (δ) = Oceanic tidal phase

X = (ξ) = Oceanic tidal amplitude

T = (ζ) = instantaneous tidal height

NU = (ν) = tidal species number

FREQ = (σ) = tidal frequeancy

ASTRO = (χ) = astronomical argument

ETIDE = (E) = earth tide constant amplitude

ET = ($E(\phi)$) = earth tide geographical amplitude

Note: For land points in squares with 9.999 vertex amplitudes only the earth tide is meaningful if ETINC = 1, LOAD = OCEAN = 0. For improved accuracy in coastal waters, special computations should incorporate the suggestions of Section 3 c and d.

APPENDIX B

RPTIDE PROGRAM LISTING

```
      PROGRAM WPTIDE(INPUT,OUTPUT
     * ,TAPE11=0,TAPE12=0,TAPE13=0,TAPE14=0,TAPE15=0,TAPE16=0
     * ,TAPE17=0,TAPE18=0,TAPE19=0,TAPE20=0
     * ,TAPE21=0,TAPE22=0,TAPE23=0,TAPE24=0,TAPE25=0,TAPE26=0
     * ,TAPE27=0,TAPE28=0,TAPE29=0,TAPE30=0,TAPE31=0,TAPE32=0
     * )
      REAL LONG, LAT
      INTEGER ETINC,OCEAN
      INTEGER YEAR, DAY
      DIMENSION ASTRO(11),X(360),D(360),XN(360),DN(360)
     * , FREQ(11), ETIDE(11),NU(11)
      DATA NU/2, 2, 1, 1, 2, 1, 2,1, 0, 0, 0/
      DATA FREQ/1.40519E-4, 1.45444E-4, 0.72921E-4, 0.67598E-4,
     * 1.37880E-4, 0.72523E-4, 1.45842E-4, 0.64959E-4,
     * 0.53234E-5, 0.26392E-5, 0.39821E-6/
      DATA ETIDE/ .148308, .069059, .086635, .061515, .028396
     * ,        .028608, .018791, .011785, .025546, .013480, .011901/
C     READ IN INPUT FROM DATA CARDS.
      READ50,YEAR,DAY,JPTS,MTIDE,ETINC,LOAD,OCEAN,IT1
   50 FORMAT( 8I5)
C
C     INITIAL COMPUTATIONS(ASTRONOMICAL ARGUMENT AND OTHER VALUES)
      CALL INCOM
     * ( YEAR, DAY, ASTRO
     * )
      GAMMAR=OCEAN-0.0667*LOAD
C
      NMTIDE=MTIDE
      MTIDE=IABS(MTIDE)
     PRINT51,YEAR,DAY,JPTS,MTIDE,ETINC,LOAD,OCEAN,IT1,NMTIDE
   51 FORMAT(*0*,9I5)
C
C     GENERATE TIDE FOR EACH POINT.
      J=0
C     DOUNTIL ALL THE POINTS ARE PROCESSED
  100       CONTINUE
            J=J+1
C           INITIALIZE TIDE TO 0.0 AND COMPUTE OTHER VALUES.
C           OBTAIN THE NEXT POINT J
             READ52,TIME, LONG, LAT
C            LONG AND LAT ARE IN DEGREES.
   52        FORMAT( 3F20.8)
C           CORRECTION TO P-4- OF FORMULATIONS(11-1-80)
            M= LONG+ .5+1
            N= 90.5- LAT
            N= N+1
            TJ= 0.0
            DT=0.
            DL=0.
            ETD=0.
C
C           COMPUTE TIDE FOR EACH OF THE TIDAL COMPONENTS.
            DO  I=1,MTIDE
 ...
```

```
            *          ( N, L, X, D, XN, DN
            *          ,IT1)
        C
        C              COMPUTE TIDE FOR THIS MODE
                       CALL COMPUT
            *          ( M, X, D, XN, DN, LONG
            *          , NU, TIME, ASTRO, N,L,ETINC ,GAMMAB
            Y          ,DTT, OLL, ETT
            *          , FREQ, LAT, ETIDE, T)
        C
        C              SUM TIDES OF THE DIFFERENT MODES.
                       TJ=TJ+T
                       DT=DT+ DTT
                       OL=OL+ OLL
                       ETD= ETD+ETT
          800          CONTINUE
        C
        C          ENDDO
        C
        C          PRINT OUT TIDE FOR THIS POINT
                   CALL PRINTD
            *      ( T, LONG, LAT, J, TJ ,TIME
            G      , DT, OL, ETD
            *      , MTIDE)
        C
        C          CHECK IF THIS IS THE LAST POINT
                   IF( J.LT. JPTS) GOTO 100
        C
        C      ENDDO
               END
```

```
      SYMBOLIC REFERENCE MAP (R=3)

ENTRY POINTS     DEF LINE     REFERENCES
 5466  RPTIDE         1

VARIABLES     SN  TYPE          RELOCATION
 5727  ASTRO      REAL      ARRAY            REFS     10     23     62
 6512  D          REAL      ARRAY            REFS     10     57     62
 5703  DAY        INTEGER                    REFS      9     23     30  DEFINED    19
10032  DN         REAL      ARRAY            REFS     10     57     62
 5721  ETD        REAL                       REFS     72     78  DEFINED     50     72
10615  ETIDE      REAL      ARRAY            REFS     10     62  DEFINED     16
 5700  ETINC      INTEGER                    REFS      8     30     62  DEFINED    19
 5725  ETT        REAL                       REFS     62     72
10602  FREQ       REAL      ARRAY            REFS     10     62  DEFINED     13
 5710  GAMMAB     REAL                       REFS     62  DEFINED     26
 5707  IT1        INTEGER                    REFS     30     57  DEFINED     19
 5712  J          INTEGER                    REFS     37     78     84  DEFINED    34     37
 5704  JPTS       INTEGER                    REFS     30     84  DEFINED     19
 5722  L          INTEGER                    REFS     55     57     62  DEFINED    53
 5677  LAT        REAL                       REFS      7     45     62     78  DEFINED    40
 5706  LOAD       INTEGER                    REFS     26     30  DEFINED     19
```

```
      SUBROUTINE COMPUT
     * ( M, X, D, XN, DN, LONG
     * , NU, TIME, ASTRO, N,L,ETINC ,GAMMAR
     Y , OTT, OLL, ETT
     * , FREQ, LAT, ETIDE, T)
      DIMENSION ASTRO(11),X(360),D(360),XN(360),DN(360)
     * , FREQ(11), ETIDE(11),NU(11)
      INTEGER ETINC
      REAL LONG,LAT
      DATA DTR/0.01745329252/
      XLAND=9.999
      MM1=M-1
      IF(M.EQ.1) MM1=360
C
C     CORRECTION TO P-4- OF FORMULATIONS(11-1-80)
      P= M-(LONG+.5)
      TB= N*1.0-( 90.5-LAT)
      TE=TB
      IF( XN(  M).EQ.XLAND) TE=0
      IF(  X(  M).EQ.XLAND) TE=1
      IF( XN(MM1).EQ.XLAND) TB=0
      IF(  X(MM1).EQ.XLAND) TB=1
      IF( XN(  M).EQ.XLAND.AND. X(M).EQ.XLAND) P=1
C
      IF( XN(MM1).EQ.XLAND.AND. X(MM1).EQ.XLAND) P=0
C     INTERPOLATE
            XLJ=(1-P)*(XN(M)*TE+ (1-TE)*X(M))
     *      + P*( XN(MM1)*TB   + (1-TB)*X(MM1))
      DMN1= DN(M)
      DMN=  D(M)
      DM1N1= DN(MM1)
      DM1N=  D(MM1)
      D1= DN(M)- D(M)
      D2= DN(MM1)- D(M)
      D3= D(MM1)-  D(M)
      D4= DN(MM1)- DN(M)
      D5= D(MM1)- DN(M)
      D6= D(MM1)- DN(MM1)
      IF(D1.GT. 180.0) DMN1 =DMN1 -360.0
      IF(D1.LT.-180.0) DMN  =DMN  -360.0
      IF(D2.GT. 180.0) DM1N1=DM1N1-360.0
      IF(D2.LT.-180.0) DMN  =DMN  -360.0
      IF(D3.GT. 180.0) DM1N =DM1N -360.0
      IF(D3.LT.-180.0) DMN  =DMN  -360.0
      IF(D4.GT. 180.0) DM1N1=DM1N1-360.0
      IF(D4.LT.-180.0) DMN1 =DMN1 -360.0
      IF(D5.GT. 180.0) DM1N =DM1N -360.0
      IF(D5.LT.-180.0) DMN1 =DMN1 -360.0
      IF(D6.GT. 180.0) DM1N =DM1N -360.0
      IF(D6.LT.-180.0) DM1N1=DM1N1-360.0
C     INTERPOLATE
            DLJ=(1-P)*( DMN1*TE+ (1-TE)*DMN)
     *      +P*( DM1N1*TB+ (1-TB)*DM1N)
C     COMPUTE EARTH TIDE
      COSLAT= COS(LAT*DTR)
      COS2= COSLAT*COSLAT
      ET=COS2
```

```
                   IF( NU(L).EQ.1) ET=SIN((LAT+LAT)*DTR)
                   IF( NU(L).EQ.0) ET=(3.0*COS2-2.0 )/2.0
 60                ET=ETIDE(L)*ET
           C
                   STX=FREQ(L     )*TIME+ ASTRO(L      )
                   DTT= XLJ*COS(STX- DLJ*DTR)
                   DLL= -.0667*DTT
 65                ETT= ET*COS(STX+ NU(L)*LONG*DTR)
                   T= GAMMAB*DTT + ETINC*ETT
                   RETURN
                   END
```

SYMBOLIC REFERENCE MAP (R=3)

```
ENTRY POINTS      DEF LINE      REFERENCES
   3  COMPUT          1            67

VARIABLES      SN   TYPE            RELOCATION
    0  ASTRO       REAL       ARRAY     F.P.       REFS        6       62    DEFINED      1
  322  COSLAT      REAL                            REFS     2*56  DEFINED       55
  323  COS2        REAL                            REFS       57       59    DEFINED     56
    0  D           REAL       ARRAY     F.P.       REFS        6       30       32       33        34     2*35      37
                                                     38  DEFINED        1
  321  DLJ         REAL                            REFS       63  DEFINED       52
  310  DMN         REAL                            REFS       40       42       44       52   DEFINED       30      40
                                                     42       44
  307  DMN1        REAL                            REFS       39       46       48       52   DEFINED       29      39
                                                     46       48
  312  DMIN        REAL                            REFS       43       47       49       52   DEFINED       32      43
                                                     47       49
  311  DMIN1       REAL                            REFS       41       45       50       52   DEFINED       31      41
                                                     45       50
    0  DN          REAL       ARRAY     F.P.       REFS        6       29       31       33        34     2*36      37
                                                     38  DEFINED        1
  266  DTR         REAL                            REFS       55       58       63       65   DEFINED       10
  313  D1          REAL                            REFS       39       40    DEFINED     33
  314  D2          REAL                            REFS       41       42    DEFINED     34
  315  D3          REAL                            REFS       43       44    DEFINED     35
  316  D4          REAL                            REFS       45       46    DEFINED     36
  317  D5          REAL                            REFS       47       48    DEFINED     37
  320  D6          REAL                            REFS       49       50    DEFINED     38
  324  ET          REAL                            REFS       60       65    DEFINED     57        58       59      60
    0  ETIDE       REAL       ARRAY     F.P.       REFS        6       60    DEFINED      1
    0  ETINC       INTEGER              F.P.       REFS        8       66    DEFINED      1
    0  ETT         REAL                 F.P.       REFS       66  DEFINED        1       65
    0  FREQ        REAL       ARRAY     F.P.       REFS        6       62    DEFINED      1
    0  GAMMAB      REAL                 F.P.       REFS       66  DEFINED        1
    0  L           INTEGER              F.P.       REFS       58       59       60     2*62        65
                                                DEFINED        1
    0  LAT         REAL                 F.P.       REFS        9       17       55     2*58   DEFINED        1
    0  LONG        REAL                 F.P.       REFS        9       16       65  DEFINED         1
    0  M           INTEGER              F.P.       REFS       12       13       16       19        20     2*23    2*27
                                                     29       30     2*33       34       35        36       37
```

```
                  SUBROUTINE INCOM
               *  ( YEAR,DAY
               *  , ASTRO)
                  INTEGER YEAR, DAY, YB, Y2B, DB
                  DIMENSION ASTRO(11)
                  DATA PI/3.1415926535/
         C        PERFORM INITIAL COMPUTATIONS
         C        AND GENERATE THE ASTRONOMICAL
         C        ARGUMENT FOR EACH OF THE 11
         C        TIDAL MODES.
         C
                  YB= YEAR-1975
         C
         C        Y2B IS TRUNCATED.
                  Y2B=(YB+2)/4
                  DB= DAY+365*YB+ Y2B
                  R= (27392.500528+1.0000000356*DB)/ 36525.0
                  R2=R*R
                  R3=R2*R
                  PII= PI/180.0
                  H=PII*(279.69668+36000.768930485*R+3.03E-4*R2)
                  S=PII*(270.434358+481267.88314137*R
               *  -1.133E-3*R2+ 1.9E-6*R3)
                  P=PII*(334.329653+ 4069.0340329575*R
               *  -1.0325E-2*R2- 0.12E-4*R3)
                  H2=H+H
                  S2=S+S
                  S3=S2+S
                  PI2= PI/2.0
                  ASTRO( 1)= 2*(H-S)
                  ASTRO( 2)= 0.0
                  ASTRO( 3)= H+ PI2
                  ASTRO( 4)= H- S2- PI2
                  ASTRO( 5)= H2- S3  + P
                  ASTRO( 6)= -H- PI2
                  ASTRO( 7)= H2
                  ASTRO( 8)= H- S3  + P- PI2
                  ASTRO( 9)= S2
                  ASTRO(10)= S-P
                  ASTRO(11)= H2
                  RETURN
                  END
```

```
      SYMBOLIC REFERENCE MAP (R=3)

ENTRY POINTS     DEF LINE     REFERENCES
   3  INCOM          1           41

VARIABLES     SN  TYPE          RELOCATION
    0  ASTRO      REAL      ARRAY    F.P.      REFS      5    DEFINED     1     30     31     32     33
                                                 34     35       36     37     38     39     40
    0  DAY        INTEGER            F.P.      REFS      4       16   DEFINED    1
  113  DB         INTEGER                      REFS      4       17   DEFINED   16
```

```
                 SUBROUTINE INDATA
               * ( N, L, X, D, XN, DN
               * ,IT1)
                 DIMENSION X(360), D(360), XN(360), DN(360)
      C          OBTAIN THE AMPLITUDES(X,XN)
      C          AND PHASES(D,DN) THAT ARE NEEDED.
      C
      C          COMPUTE TAPE UNIT NUMBER W.R.T. MODE L
                 II=(L-1)*2
                 ITX= IT1+ II
                 ITD=ITX+1
                 NM1=N-1
                 REWIND ITX
                 REWIND ITD
      C
                 DO 30  I=1,NM1
                    BUFFER IN(ITX,1) ( XN(1), XN(360))
                    BUFFER IN(ITD,1) ( DN(1), DN(360))
                    IF(UNIT(ITX)) 26,12,13
           26       IF(UNIT(ITD)) 28,12,13
           28       CONTINUE
           30       CONTINUE
      C          ENDDO
      C          CHECK TAPE UNITS INSURE DATA
      C          TRANSFER HAVE BEEN COMPLETED.
                 IF(UNIT(ITX)) 34,12,13
           34    IF(UNIT(ITD)) 36,12,13
           36    BUFFER IN(ITX,1) ( X(1), X(360))
                 BUFFER IN(ITD,1) ( D(1), D(360))
                 IF(UNIT( ITX)) 40,12,13
           40    IF(UNIT( ITD)) 42,12,13
           42    CONTINUE
                 GOTO 46
           12    STOP  "STOP 12"
           13    STOP  "STOP 13"
           46    RETURN
                 END
```

SYMBOLIC REFERENCE MAP (R=3)

```
ENTRY POINTS     DEF LINE     REFERENCES
   3  INDATA         1           36

VARIABLES     SN  TYPE            RELOCATION
    0  D          REAL         ARRAY     F.P.       REFS       4   DEFINED      1       2*29
    0  DN         REAL         ARRAY     F.P.       REFS       4   DEFINED      1       2*18
  113  I        * INTEGER                        DEFINED      16
  107  II         INTEGER                           REFS      10   DEFINED      9
  111  ITD        INTEGER                           REFS      20        27     31    DEFINED      11
                                                I/O REFS      14        18     29
  110  ITX        INTEGER                           REFS      11        19     26        30    DEFINED      10
                                                I/O REFS      13        17     28
    0  IT1        INTEGER                F.P.       REFS      10   DEFINED      1
```

```
                SUBROUTINE PRINTO
         *          ( T, LONG, LAT,J, TJ  ,TIME
         G      , DT, OL, ETD
         *      ,MTIDE)
                REAL LONG,LAT
                IF(.NOT.(J.EQ.1)) GO TO 200
                    PRINT10C
    100             FORMAT(*1*, T20,*(DEGREES      )*       ,T42,*TOTAL*
         *          , T82,*TOTAL TIDE*
         *          ,T96,*OCEAN TIDE   OCEAN LOADING  EARTH TIDE*
         *          )
                    PRINT104
    104             FORMAT(* *, T17,*LONG*, T34, *LAT*
         *          , T42, *COMPONENT TIDES*,T63,*TIME*
         *          ,T85,*(  METERS*,T126,*)*
         *          )
    200             CONTINUE
C               ENDIF
                PRINT300,LONG, LAT,     MTIDE,TIME,TJ ,DT,OL,ETD
    300         FORMAT(*0*, 2F20.6, I5,F20.2,9X,4F14.4)
                RETURN
                END
```

```
  SYMBOLIC REFERENCE MAP (R=3)

ENTRY POINTS     DEF LINE     REFERENCES
   3 PRINTO          1           21

VARIABLES     SN  TYPE            RELOCATION
    0  ETD        REAL                   F.P.      REFS       19   DEFINED      1
    0  J          INTEGER                F.P.      REFS        6   DEFINED      1
    0  LAT        REAL                   F.P.      REFS        5       19   DEFINED      1
    0  LONG       REAL                   F.P.      REFS        5       19   DEFINED      1
    0  MTIDE      INTEGER                F.P.      REFS       19   DEFINED      1
    0  OL         REAL                   F.P.      REFS       19   DEFINED      1
    0  CT         REAL                   F.P.      REFS       19   DEFINED      1
    0  T          REAL        *UNUSED    F.P.    DEFINED       1
    0  TIME       REAL                   F.P.      REFS       19   DEFINED      1
    0  TJ         REAL                   F.P.      REFS       19   DEFINED      1

FILE NAMES       MODE
     OUTPUT      FMT                   WRITES        7        12        19

STATEMENT LABELS              DEF LINE     REFERENCES
   21  100     FMT                8            7
   40  104     FMT               13           12
   13  200                       17            6
   66  300     FMT               20           19

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  PROGRAM LENGTH                73P          59
```

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