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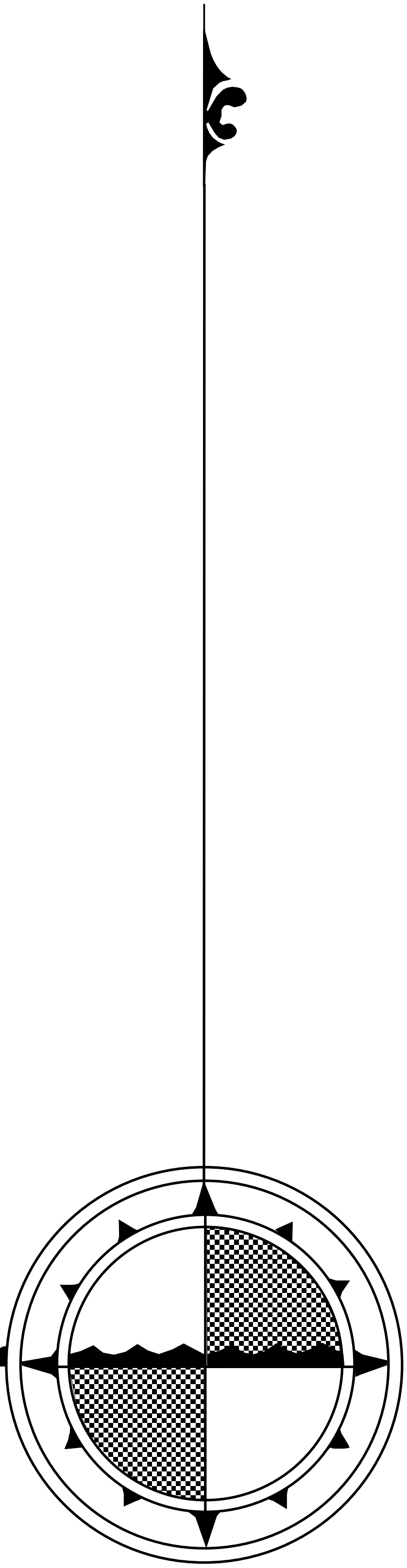
# MANUAL FOR TIDAL CURRENTS ANALYSIS AND PREDICTION

by

M.G.G. Foreman



**INSTITUTE OF OCEAN SCIENCES, PATRICIA BAY**
**Sidney, B.C.**

For additional copies or further information please write to:

Department of Fisheries and Oceans
Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C. V8L 4B2
Canada

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# TIDAL CURRENTS ANALYSIS AND PREDICTION

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M.G.G. Foreman

Institute of Ocean Sciences
Patricia Bay
Sidney, British Columbia

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## 7 APPENDICES

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## ABSTRACT

This report is intended to serve as a user's manual to G. Godin's tidal currents analysis and prediction computer programs. These programs have been revised along the lines suggested by Godin and are consistent in their methodology and constituent information with the similarly revised tidal heights package. In addition to describing input and output of these programs, the report gives an outline of the methods used, a full presentation of which can be found in Godin (1972) and Foreman (1977).

Users who wish to receive updates of these programs and manual should send their names, addresses, and type of computer used, to the author.

# 1 USE OF THE TIDAL CURRENTS ANALYSIS COMPUTER PROGRAM

## 1.1 General Description

This program analyses the hourly current meter data for a given period of time. Current ellipse parameters and Greenwich phase lags are calculated via a least squares fit method coupled with nodal modulation for only those constituents that can be resolved over the length of record. Unless specified otherwise, a standard data package of 69 constituents will be considered for inclusion in the analysis. However, up to 77 additional shallow water constituents can be requested. If the record length is such that certain important constituents are not included directly in the analysis, provision is made for inference of the current ellipse parameters of these constituents from others. A suitable compensation for the smoothing effect that moving average filters may have had on the data prior to input to this program can be made, and a synthesis of hourly tidal current values based on the analysis results and in the same units and format as the input, can be obtained during the same run. Gaps within the tidal record are permitted.

## 2.1 Routines Required

| | | | |
|---|---|---|---|
| (1) | **MAIN** | ...... | reads in some of data, controls most of the output and calls other routines. |
| (2) | **INPUT** | ...... | reads in the hourly current data for the desired time period and checks for errors. |
| (3) | **UCON** | ...... | chooses the constituents to be included in the analysis via the Rayleigh criterion. |
| (4) | **SCFIT2** | ...... | finds the least squares fit to an equally spaced time series using sines and cosines of specified frequencies as fitting functions. |
| (5) | **VUF** | ...... | reads required information and calculates the nodal corrections for all constituents. |
| (6) | **INFER** | ...... | reads required information and calculates the current ellipse and phase parameters of inferred constituents, as well as adjusting those of the constituent used for the inference. |
| (7) | **CHLSKY** | ...... | solves the symmetric positive definite matrix equation resulting from a linear least squares fit. |
| (8) | **GDAY** | ...... | returns the consecutive day number from a specific origin for any given date and vice versa. |

(9) **SCLUP** ...... scales up the least squares fit results to compensate for pre-filtering.

(10) **OUTPUT** ...... writes the hourly current data that has been constructed from analysis results, onto storage files.

(11) **ASTR** ...... calculates ephermides for the sun and moon.

## 1.3 Data Input

For a computer run of the tidal currents analysis program, four files or devices are used for data input. File reference number 8 contains the tidal constituent information, file reference number 4 contains tidal station and analysis type details, and file reference numbers 10 and 11 respectively, contain the hourly north/south and east/west current components. A listing of the standard constituent information for file reference number 8 and a sample set of input for numbers 4, 10 and 11 are given in Appendices 7.1 and 7.2 respectively.

File reference number 8 expects four types of data:

(i) One card each for all possible constituents, `NAME`, to be included in the analysis along with their frequencies, `FREQ`, in cycles/h and the constituent, `KMPR`, with which they should be compared under the Rayleigh criterion. The format used is `(4X,A5,3X,F13.10,4X,A5)`. Unless `NAME` is specifically designated on logical unit 4 for inclusion, a blank data field for `KMPR` results in the constituent not being included in the analysis.

A blank card terminates this data type.

(ii) Two cards specifying values for the astronomical arguments `SO,HO,PO,ENPO,PPO,DS,DH,DP, DNP,DPP` in the format `(5F13.10)`.

`SO` = mean longitude of the moon (cycles) at the reference time origin;
`HO` = mean longitude of the sun (cycles) at the reference time origin;
`PO` = mean longitude of the lunar perigee (cycles) at the reference time origin;
`ENPO` = negative of the mean longitude of the ascending node (cycles) at the reference time origin;
`PPO` = mean longitude of the solar perigee (perihelion) at the reference time origin.

`DS,DH,DP,DNP,DPP` are their respective rates of change over a 365-day period at the reference time origin.

Although these argument values are not used by the program that was revised in October 1992, in order to maintain consistency with earlier programs, they are still required as input. Polynomial approximations are now employed to more accurately evaluate the astronomical arguments and their rates of change.

(iii) At least one card for all the main tidal constituents specifying their Doodson numbers and phase shift along with as many cards as are necessary for the satellite constituents. The first card for each such constituent is in the format `(6X,A5,1X,6I3,F5.2,I4)` and contains the following information:

`KON` = constituent name;
`II,JJ,KK,LL,MM,NN` = the six Doodson numbers for `KON`;
`SEMI` = phase correction for `KON`;
`NJ` = number of satellite constituents.

A blank card terminates this data type.

If `NJ>0`, information on the satellite constituents follows, three satellites per card, in the format `(11X,3(3I3,F4.2,F7.4,1X,I1,1X))`. For each satellite the values read are:

`LDEL,MDEL,NDEL` = the last three Doodson numbers of the main constituent subtracted from the last three Doodson numbers of the satellite constituent;
`PH` = phase correction of the satellite constituent relative to the main constituents;
`EE` = amplitude ratio of the satellite tidal potential to that of the main constituent;
`IR` = 1 if the amplitude ratio has to be multiplied by the latitude correction factor for diurnal constituents,
= 2 if the amplitude ratio has to be multiplied by the latitude correction factor for semidiurnal constituents,
= otherwise if no correction is required to the amplitude ratio.

(iv) One card specifying each of the shallow water constituents and the main constituents from which they are derived. The format is `(6X,A5,I1,2X,4(F5.2,A5,5X))` and the respective values read are:

`KON` = name of the shallow water constituent;
`NJ` = number of main constituents from which it is derived;
`COEF,KONCO` = combination number and name of these main constituents.

The end of these shallow water constituents is denoted by a blank card.

File reference number 4 contains six types of data:

(i) One card for the variables, `RAYOPT,OBSFAC,ICHK,INDPR,NSTRP`, in the format `(F5.2,F10.7, 3I5`.

`RAYOPT` = Rayleigh criterion constant value if different from 1.0;
`OBSFAC` = the scaling factor which will multiply the current observations in order to produce the desired units for the ellipse major and minor semi-axes (e.g. if the hourly observations are in mm/s and the final units are to be in ft/sec, then this variable would be set to 0.0032808);
`ICHK` = 0 if the hourly input data is to be checked for format errors,
= otherwise if this checking to be waived;
`INDPR` = 1 if hourly current component predictions based on the analysis results are to be calculated and written onto file reference numbers 12 and 13. If there is inference, this parameter value will also give the rms residual errors after the inference adjustments,
= 0 if no such predictions are desired;

`NSTRP` = number of successive moving average filters that have been applied to the original current data.

If `NSTRP>0`, then `TIMINT` and `(LSTRP(I),I=1,NSTRP)` will be read on a following card, in the format `(F10.5,10I5)`, and suitable amplitude corrections will be applied to compensate for the smoothing effect of these filters.

`TIMINT` = sampling interval, in minutes, of the original unfiltered record;
`LSTRP(J),J=1,NSTRP` = number of consecutive observations used in computing each of the `NSTRP` moving average filters.

(ii) One card for each possible inference pair. The format is `(2(4X,A5,F13.10),4F10.3)` and the respective values read are as follows:

`KONAN & SIGAN` = name and frequency of the analysed constituent to be used for the inference;
`KONIN & SIGIN` = name and frequency of the inferred constituent;
`RPL & RMIN` = respective ratios of `KONIN` to `KONAN`, for the positive and negative current amplitude components. The positive amplitude component is `0.5*` (major semi-axis length plus minor semi-axis length) and the negative amplitude component is `0.5*` (major semi-axis length minus minor semi-axis length).
`ZETAP & ZETAM` = respective positive and negative Greenwich phases for `KONAN` minus those for `KONIN`.

This inference information is terminated by a blank card.

(iii) One card for each shallow water constituent, other than those in the standard 69 constituent data package, to be considered for inclusion in the analysis. The Rayleigh comparison constituent is also required and the additional shallow water constituent must be found in data type (i) of file reference number 8, but have a blank data field where the Rayleigh comparison constituent is expected. The format is `(6X,A5,4X,A5)` and a blank card is required to terminate data of this type.

(iv) One card in the format `(2X,10I2)` specifying the following information on the period of the analysis:

`IHHA,IDDA,IMMA,IYYA,ICCA` = hour, day, month, year and century of the beginning of the analysis (measured in time `ITZONE` of input data (v));
`IHHB,IDDB,IMMB,IYYB,ICCB` = hour, day, month, year and century of the end of the analysis period.

Zero values for `ICCA` or `ICCB` are reset to 19.

(v) One card in the format `(5X,I4,1X,3A6,A4,A3,1X,2I2,I3,I2,)` containing the following information on the tidal station:

`KSTN` = tidal station number;
`(NA(J),J=1,4)` = tidal station name (22 characters maximum length);
`ITZONE` = time zone of the hourly observations;
`LAD,LAM` = station latitude in degrees and minutes;

`LOD,LOM` = station longitude in degrees and minutes.

If no station latitude is specified, 50°N is assumed for the nodal modulation calculations.

File reference numbers 10 and 11 respectively, contain the north/south and east/west hourly current components. Their input formats are identical and they are read individually via subroutine **INPUT**. For convenience, this format has been made similar to that employed by the tidal heights analysis program. However, if an alternative method is preferable, subroutine **INPUT** and its reference calls may simply be replaced.

The hourly height data cards for each of the current components contain the following information in the format `(I1,1X,I5,7X,3I2,12A5)`.

`KOLI` = 1 or 2 indicates whether this specific card is the first or second one for that day,
= otherwise indicates a non-data card which is ignored;
`JSTN` = tidal station number;
`ID,IM,IY` = day, month and year of the heights on this card;
`(KARD(J),J=1,12)` = hourly observations in integer form. The final constituent major and minor semi-axis lengths are in units `OBSFAC` times those of the hourly observations. Missing values should be specified as a blank field or 99999.

When `KOLI=1`, the first hourly observation on the data card is assumed to be at 0100 h and when `KOLI=2`, it is assumed to be at 1300 h. Since all Greenwich phase angles are relative to the time zone in which the hourly observations are specified, in order to avoid possible confusion when comparing phases for tidal stations in different zones, it is recommended that observations be recorded in Greenwich mean time.

The hourly observation data cards need not begin and end so as to include exactly the analysis period. Subroutine **INPUT** ignores data outside this range.

### 1.4 Output

Four file reference numbers are used for the output of results from the tidal currents analysis program. File 6 is the line printer; 2 is a file that can be used for computer storage of the results, and 12 and 13 respectively, contain the north/south and east/west hourly current values constructed from the analysis results. Files 6 and 2 are required by all program runs, whereas the use of 12 and 13 is controlled by the input variable `INDRP`.

If no inference has been performed, the program will produce two pages of results on the line printer. The first of these gives the tidal station name, number and geographic coordinates; the total number of possible hourly observations in the analysis period and the total number of hourly observations, excluding gaps, in the analysis period; the starting, middle and end points of the analysis period; the sampling interval of the original data and the filters applied, or an acknowledgement that the original data is assumed to be unfiltered; and the Rayleigh criterion parameter. It also lists the constituents included in the least squares fit; their frequencies in cycles/h (although eight decimal places are given, depending on computer accuracy, less than this number may be significant); the cosine and sine coefficient values for the $X$ (east/west) and $Y$ (north/south) current components, along with their respective standard deviation estimates, all measured in units `OBSFAC` times those for the hourly observations; and for each of the $X$ and

$Y$ components, the average and standard deviation of the hourly observations, the rms residual error and the matrix condition number.

The second page repeats the tidal station and analysis period information and specifies the time zone of the Greenwich phases, and if an inference, and/or scaling compensation for pre-filtering, have/has been done. It then follows with the list of constituents included in the analysis, their frequencies and their ellipse parameters: the major and minor semi-axis lengths (measured in the same units as the cosine and sine coefficients), the angle of inclination (measured in degrees counterclockwise from east) and the Greenwich phase angles (degrees) for the current vector and its positively and negatively rotating components.

If inference has been performed in the analysis, then a third page of output is produced which, except for the addition of the inferred constituents and adjustments to those constituents used for the inference(s), is essentially the same as the second page. If the hourly current values based on the analysis results are requested, this page also gives the rms residual errors after the inference adjustments have been made.

Apart from the omission of some titles, the same information as the second (and third) page(s) of the line printer is repeated on file number 2. The list of constituent names, major and minor semi-axis lengths, angle of inclination and the three Greenwich phase lags begins on line 9 of this file, and is in the correct format for input to the tidal current prediction program, namely `(4X,A5,13X,2F8.3,2F7.1)`.

The north/south and east/west hourly currents constructed from the analysis results, are written in the same format expected by subroutine **INPUT**. Values are specified only for the analysis period, including those intervals where there were gaps in the original record, and are in the same measurement units and scaling as the original data.

Appendix 7.3 lists the final page of line printer output resulting from the input variables of Appendix 7.2.

### 1.5 Program Conversion, Modifications, Storage and Dimension Guidelines

The tidal currents analysis source program and constituent data package described in this manual have been tested on various mainframe, PC and workstation computers at the Institute of Ocean Sciences, Patricia Bay. Although as much of the program as possible was written in basic FORTRAN, some changes may be required before the program and data package can be used on other installations. For example,

(i) check that the intrinsic function `INT`, used in subroutine **OUTPUT**, has the following definition for your installation:

`INT(X) = SIGN(X)*N` where `N` is the largest integer less than or equal to `ABS(X)`.

Please write or call the author if any problems are encountered.

The program in its present form requires approximately 72,000 bytes for the storage of its instructions and arrays. A large part of this is due to `X,Y,XP` and `YP`, the arrays of size 9000 each that store the hourly current observations and predictions and `AS`, the array of size 15,000 resulting from the least squares fit for constituent component amplitudes and phases. If memory requirements are restrictive on a particular installation, array storage can be cut by reducing the dimension of `X` and `Y` in the main program to whatever is required for the proposed analysis period, by either similarly reducing `XP` and `YP` or, if there are no predictions, setting their dimension to 2 and by reducing the size of AS in accordance with the number of constituents to be included in the least squares fit.

If additions are made to the standard constituent data package, the dimensions of several arrays may have to be altered. In the event of these or other changes, restrictions on the minimum dimension of all arrays are now given.

Let

| | |
|---|---|
| MTOT | be the total number of possible constituents contained in the data package (presently 146), |
| M | be the number of constituents considered for inclusion in the analysis (presently 69 plus the number of shallow water constituents specifically designated for inclusion, |
| MCON | be the number of main constituents in the standard data package (at present 45), |
| MSAT | be the sum of the total number of satellites for these main constituents and the number of main constituents with no satellites (presently 162 plus 8 for the version of the constituent data package, containing no third-order satellites for both $N_2$ and $L_2$); |
| MSHAL | be the sum for all shallow water constituents, of the number of main constituents from which each is derived (at present 251). |

Then in the main program, arrays NAME,FREQ and KMPR should have minimum dimension M+1; arrays NAMEU,FU,CX,SX,CY,SY,ERCX,ERSX,ERCY,ERSY,AP,AM,EPSP and EPSM should have minimum dimension MU; arrays X,Y,XP and YP should be large enough to contain the hourly current observations (including gaps) and predictions in the proposed analysis period (they are at present set for a maximum of 375 days); array LSTRP should be at least as large as the number of successive moving average filters that were applied to the original current record (at present this is set to 10) and double precision array NA should be large enough to hold the number of characters in the tidal station name (at present 22 characters are expected and the array dimension is 4).

In subroutines **SCLUP** and **UCON**, all arrays are passed through the argument list from the main program and thus need only be dimensioned 2.

In subroutine **GDAY**, arrays NDP and NDM should have minimum dimension 12.

In subroutine **SCFIT2**, arrays X,XP,F,C,S,ERC and ERS are passed in the argument list from the main program and so need only be dimensioned 2; array A should have minimum dimension $((2MU)^2 + 2MU/2)$; arrays CW,SW,RHSC and RHSS should have minimum dimension MU and array RHS should have minimum dimension 2MU. AC and AS should each have minimum dimension $((2MU)^2 + 2MU/2)$ and care should be taken that through their equivalence relationships, neither AC and AS, nor RHSC and RHSS overlap.

In subroutine **CHLSKY**, because arrays A and F are passed in the argument list from SCFIT2, they need only have dimension 2.

In subroutine **VUF**, arrays KON and NJ should have minimum dimension M+1; arrays VU and F should have minimum dimension M; arrays II,JJ,KK,LL,MM,NN and SEMI should have minimum dimension MCON+1; arrays EE,LDEL,MDEL,NDEL,IR and PH should have minimum dimension MSAT and arrays KONCO and CDEF should have minimum dimension MSHAL+4.

In subroutine **INFER**, array KON is passed in the argument list from the main program and so need only be dimensioned 2 and arrays KONAN,SIGAN,KONIN,SIGIN,RPL,RMIN,ZETAP and

`ZETAM` can at present accommodate a maximum of nine inferred constituents.

In subroutine **INPUT**, array `Z` is passed in the argument list from the main program and so need only be dimensioned 2 and arrays `KARD` and `IHT` should have a minimum dimension of 12.

In subroutine **OUTPUT**, arrays `XP` and `YP` are passed in the argument list from the main program and so need only be dimensioned 2; array `MONTH` should have minimum dimension 12 and arrays `ICEW` and `ICNS` should have minimum dimension 24.

## 2 TIDAL CURRENTS ANALYSIS PROGRAM DETAILS

### 2.1 Representation of Tidal Currents

The following presentation is an amalgamation of those found in Godin (1972, 1976), the unpublished notes of J. Taylor on Godin's method and the associated computer program, and Henry and Foreman (1977).

It is customary in tidal observations to measure the vertical displacement or "elevation" of the water surface and the horizontal velocity or "current" at a specified depth. The oscillatory portions of these quantities which can be ascribed to astronomical origins will be referred to as tidal heights and tidal currents[1] respectively.

The decomposition of current observations into north/south and east/west components (where the northern and eastern directions are positive), as is required by this program, is a traditional convenience lending itself to complex variable analysis. The choice of another set of rectangular coordinates would be equally justifiable as long as the positive imaginary axis, $Y$, is 90° counterclockwise from the positive real axis, $X$. This condition is satisfied in our case by setting the north/south components as the imaginary parts and the east/west components as the real parts, of a complex signal, $Z(t)$.

Assuming that each of the current components is comprised of an aperiodic constituent and tidal constituents occurring at the frequencies, $\sigma_j$, (cycles/h) for $j = 1, \ldots, M$, then the complex signal $Z(t)$ can be expressed as

$$Z(t) = X_0(t) + \sum_{j=1}^{M} X_j \cos 2\pi(\sigma_j t - \phi_j) + \left[ Y_0(t) + \sum_{j=1}^{M} Y_j \cos 2\pi(\sigma_j t - \theta_j) \right].$$

Setting $CX_j = X_j \cos 2\pi\phi_j$, $SX_j = X_j \sin 2\pi\phi_j$, $CY_j = Y_j \cos 2\pi\theta_j$ and $SY_j = Y_j \sin 2\pi\theta_j$, this signal can be re-expressed initially as

$$\begin{aligned} Z(t) = X_0 &+ \sum_{j=1}^{M} (CX_j \cos 2\pi\sigma_j t + SX_j \sin 2\pi\sigma_j t) \\ &+ i\left[ Y_0(t) + \sum_{j=1}^{M} (CY_j \cos 2\pi\sigma_j t + SY_j \sin 2\pi\sigma_j t) \right] \end{aligned}$$

and after some algebra as

$$\begin{aligned} Z(t) = X_0(t) + iY_0(t) + \tfrac{1}{2} \sum_{j=1}^{M} \big\{ &[(CX_j + SY_j) + i(CY_j - SX_j)] \exp(2\pi i\sigma_j t) \\ &+ i[(CX_j - SY_j) + i(CY_j + SX_j)] \exp(-2\pi i\sigma_j t) \big\}. \end{aligned}$$

---

[1] Godin (1972, p. 145) used "tidal stream" to indicate what is here termed "tidal current".

Dropping the constituent numbering suffix, $j$, and setting

$$a^{+} = \left[\left(\frac{CX+SY}{2}\right)^2 + \left(\frac{CY-SX}{2}\right)^2\right]^{1/2},$$

$$a^{-} = \left[\left(\frac{CX-SY}{2}\right)^2 + \left(\frac{CY+SX}{2}\right)^2\right]^{1/2},$$

$$\varepsilon^{+} = \arctan\left(\frac{CY-SX}{CX+SY}\right)$$

and

$$\varepsilon^{-} = \arctan\left(\frac{CY+SX}{CX-SY}\right),$$

the tidal currents contribution for any constituent is then seen to be

$$\begin{aligned} Z(t) &= Z^{+}(t) + Z^{-}(t) = a^{+}\exp(i\varepsilon^{+} + 2\pi i\sigma t) + a^{-}\exp(i\varepsilon^{-} - 2\pi i\sigma t) \\ &= \exp\left[i\left(\frac{\varepsilon^{+}+\varepsilon^{-}}{2}\right)\right]\left\{(a^{+}+a^{-})\cos\left[\left(\frac{\varepsilon^{+}-\varepsilon^{-}}{2}\right) + 2\pi\sigma t\right]\right. \\ &\quad \left. + i(a^{+}-a^{-})\sin\left[\left(\frac{\varepsilon^{+}-\varepsilon^{-}}{2}\right) + 2\pi\sigma t\right]\right\}. \end{aligned}$$

Examination of the first of these expressions reveals that this contribution consists of two vectors, $Z^{+}(t)$ and $Z^{-}(t)$, each rotating at the angular speed of $\sigma$ cycles/h. The former vector has length, $a^{+}$, rotates counterclockwise and is at $\varepsilon^{+}$ radians counterclockwise from the positive $X$ (east/west) axis at time, $t = 0$, while the latter has length, $a^{-}$, rotates clockwise and is at $\varepsilon^{-}$ radians counterclockwise from the positive $X$ axis at $t = 0$ (see Figures 1a and 1b). The net rotational effect is that the composite vector, $Z(t)$, moves counterclockwise if $a^{+} > a^{-}$, clockwise if $a^{+} < a^{-}$, and linearly if $a^{+} = a^{-}$. From the second expression, it is seen that over a time period of $1/\sigma$ h, the path of the composite vector traces out an ellipse (or a line segment, in the degenerate case when $a^{+} = a^{-}$) whose respective major and minor semi-axis lengths are $a^{+} + a^{-}$ and $a^{+} - a^{-}$ respectively and whose angle of inclination from the positive $X$ axis is $(\varepsilon^{+} + \varepsilon^{-})/2$ radians.

As an aid to understanding the development and meaning of Greenwich phases for tidal currents, it is convenient to extend the concept of fictitious stars sometimes used in tidal elevation theory. Instead of regarding each tidal constituent as the result of a particular component in the tidal potential, we suppose that each pair of rotating vectors, $Z^{+}$ and $Z^{-}$, is attributable to two fictitious stars which move counterclockwise and clockwise respectively, at the same speed as the constituent in question, around the periphery of a "celestial disk" tangential to the earth at the measurement site. We suppose also that at time, $t_0$, the angular position of the counterclockwise rotating star, $S^{+}$, the star responsible for $Z^{+}$, is $V(t_0)$ radians counterclockwise from the positive $X$ (east) axis, where $V(t_0)$ is the same astronomical argument, relative to Greenwich as occurs for this constituent in the tidal potential (Foreman, 1977, Section 2.3.1). Similarly, at the same time, the angular position of the clockwise rotating star, $S^{-}$, is assumed to be $V(t_0)$ radians clockwise from the positive $X$ axis (see Figure 1c). As a consequence, the constant phase angles, $g^{+}$ and $g^{-}$, by which $S^{+}$ and $S^{-}$ lead (or lag) the respective vectors, $Z^{+}$ and $Z^{-}$, can be termed Greenwich phases and are defined by

$$g^{+} = V(t_0) - \varepsilon^{+},$$

$$g^{-} = V(t_0) + \varepsilon^{-}.$$

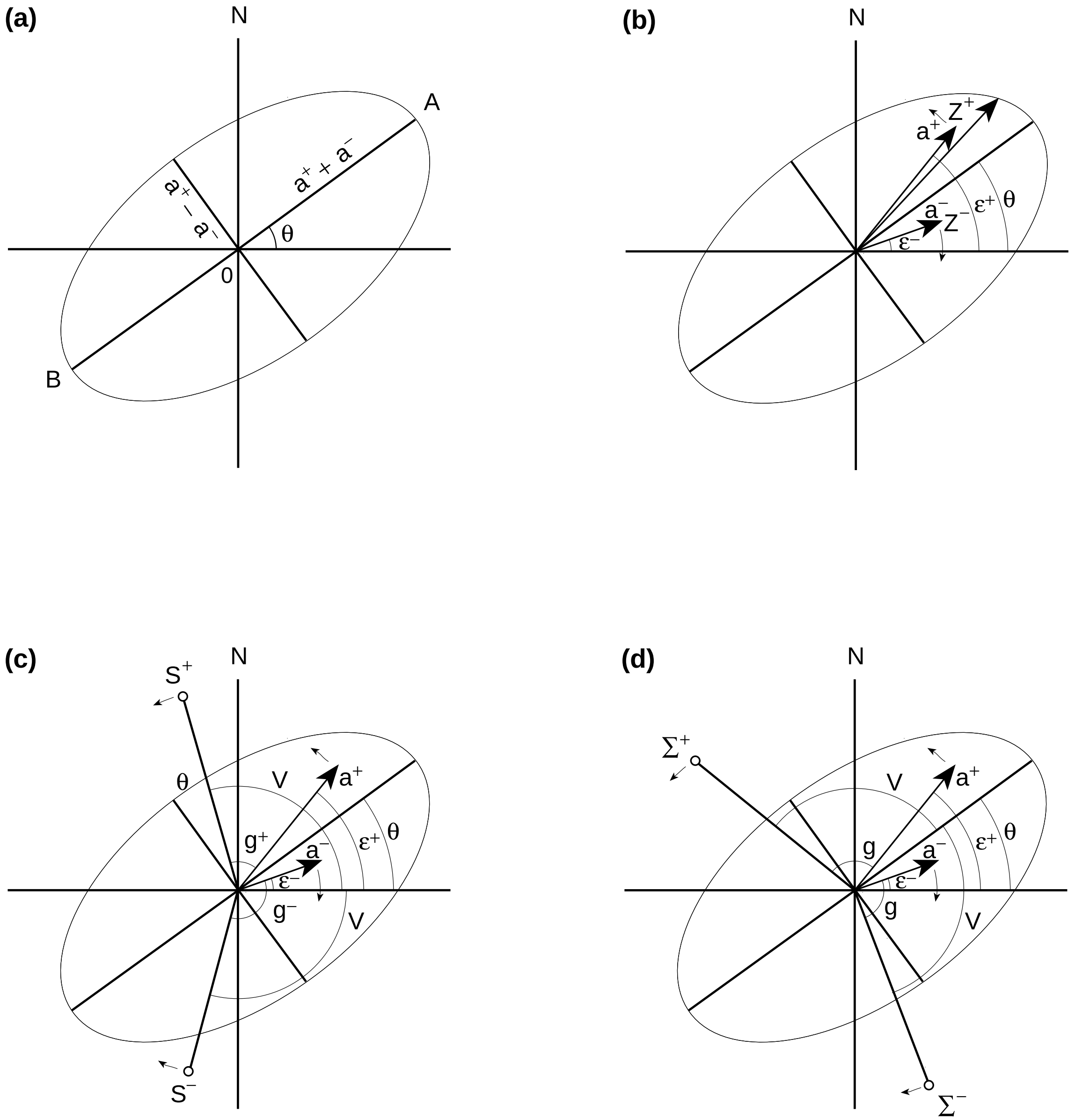

**Figure 1** Delineation of current ellipse notation. (a) Dimensions of a constituent ellipse. (b) Configuration at $t = 0$. (c) Fictitious stars related to the east/west axis. (d) Fictitious stars related to the major semi-axis. (Redrawn from C. Wallace)

As was previously mentioned, provided that the complex variable condition is satisfied, the choice of a rectangular coordinate system for the original current measurements is arbitrary. Since all angles thus far have been specified with respect to the east/west axis, there is a corresponding arbitrariness in the phases of $Z^+$ and $Z^-$. One aim of Godin's analysis is to obtain invariant phases for these vectors by referring angular measurements to a major semi-axis of the constituent ellipse. In order to do this, he employs the construction shown in Figure 1d in which the major semi-axis $OA$ of the constituent ellipse is used as the reference axis.

In particular, two different fictitious stars, $\sum^+$ and $\sum^-$, are now visualized, similar to $S^+$ and $S^-$ respectively, except that their angular positions at $t = 0$ are $V(t_0)$ radians from $OA$ in the appropriate directions. This approach has the advantage that the phase of both rotating vectors relative to their respective stars can now be expressed as a single Greenwich phase angle, $g$, where

$$g = V(t_0) - \left(\frac{\varepsilon^+ - \varepsilon^-}{2}\right).$$

Since, from the definitions of the fictitious stars, $S^+$, $S^-$, $\sum^+$ and $\sum^-$, the astronomical argument, $V(t_0)$, is identical in all the Greenwich phase expressions, $g$ can be calculated terms of $g^+$ and $g^-$ as

$$g = \frac{g^+ + g^-}{2}.$$

Interpreted physically, $g$ can be viewed as the interval by which the instant of maximum current (when $Z^+$ and $Z^-$ coincide along $OA$) lags the simultaneous transit of the fictitious stars, $\sum^+$ and $\sum^-$, at $OA$.

Unfortunately, the factor 2 in the denominators of the expressions for $g$ and $\theta$ can introduce an ambiguity of 180° (= $\pi$ radians) since any of the angles $\varepsilon^+$, $\varepsilon^-$, $g^+$ or $g^-$ can be altered by 360° without changing the representation of the original current. In the present revised computer program version, this ambiguity is avoided by imposing the condition that the northern major semi-axis of the constituent always be used as the reference axis. This condition is expressed through the formula[2]

$$\theta = \frac{\varepsilon^+ + \varepsilon^-}{2} \operatorname{mod}(180^\circ),$$

and is illustrated in Figure 2 with the two basically different configurations that can occur. It is equivalent (see Henry and Foreman, 1977, Appendix 8) to the condition imposed in earlier programs, namely

$$0 \leq g^- - g^+ < 360^\circ,$$

from which $\theta$ was calculated as $(g^- - g^+)/2$ and $g$ as $(g^- + g^+)/2$.

Figures 3 and 4 show separately, the angular relationships for the two rotating vectors, $Z^+$ and $Z^-$, in cases (a) and (b) respectively, of Figure 2. The following formulae for $g^+$ and $g^-$, and the first one specified for $g$, are used in the present computer program.

$$\begin{aligned}
g^+ &= V(t_0) - \varepsilon^+ \operatorname{mod}(360^\circ),\\
g^- &= V(t_0) + \varepsilon^- \operatorname{mod}(360^\circ),\\
g &= g^+ + \theta \operatorname{mod}(360^\circ) = V(t_0) - \varepsilon^+ + \theta \operatorname{mod}(360^\circ),\\
&= g^- - \theta \operatorname{mod}(360^\circ) = V(t_0) + \varepsilon^- - \theta \operatorname{mod}(360^\circ).
\end{aligned}$$

The appearance of $\theta$ in the final expressions for $g$ indicates that if the southern major semi-axis, $OB$, should be chosen as reference axis, the consequent change of 180° in $\theta$ produces a similar change in $g$. This, for example, may occur when comparing the phases, obtained via two analyses at the same tidal station but over different time periods. This might occur, for example, with a constituent such as $K_1$ in Appendix 7.3 whose angle of inclination is near 0° in one case and near 180° in the other. As Godin notes (1976, p. 5) though, such a change of

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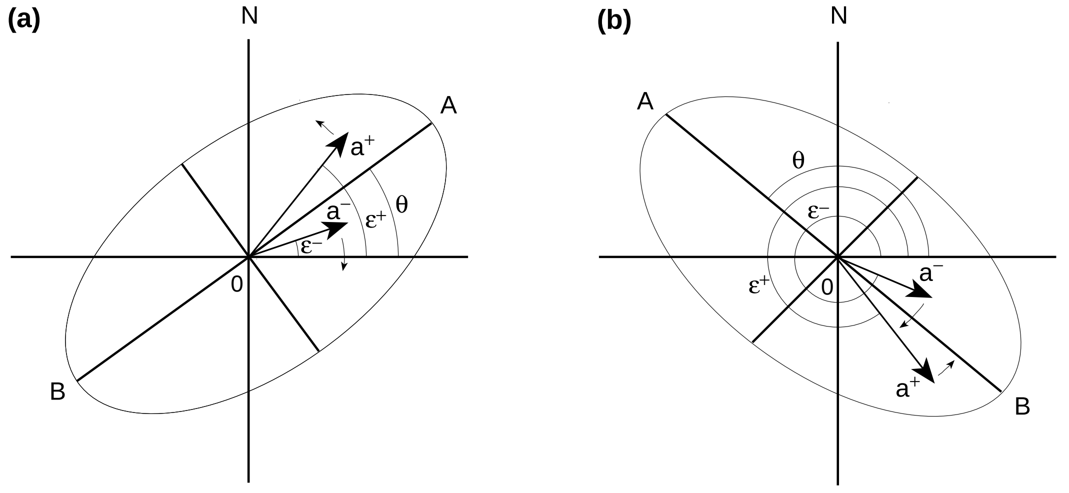
[2] The notation $\phi \operatorname{mod}(N^\circ)$ indicates that a suitable integer multiple of $N$ is added to or subtracted from $\phi$ to bring it into the range $0 \leq \phi < N^\circ$.



$\varepsilon^+ + \varepsilon^- < 360°$, $\theta = \dfrac{\varepsilon^+ + \varepsilon^-}{2}$ $\qquad$ $\varepsilon^+ + \varepsilon^- \geq 360°$, $\theta = \dfrac{\varepsilon^+ + \varepsilon^-}{2} - 180°$

**Figure 2** Definition of semi-axis used as reference axis. (Redrawn from C. Wallace)

the major semi-axis is only in the representation of the constituent ellipse. The ellipse itself is not affected.

From Figures 3 and 4, it can be seen that the maximum current (in the sense that $Z^+$ and $Z^-$ coincide on $OA$), occurs at times

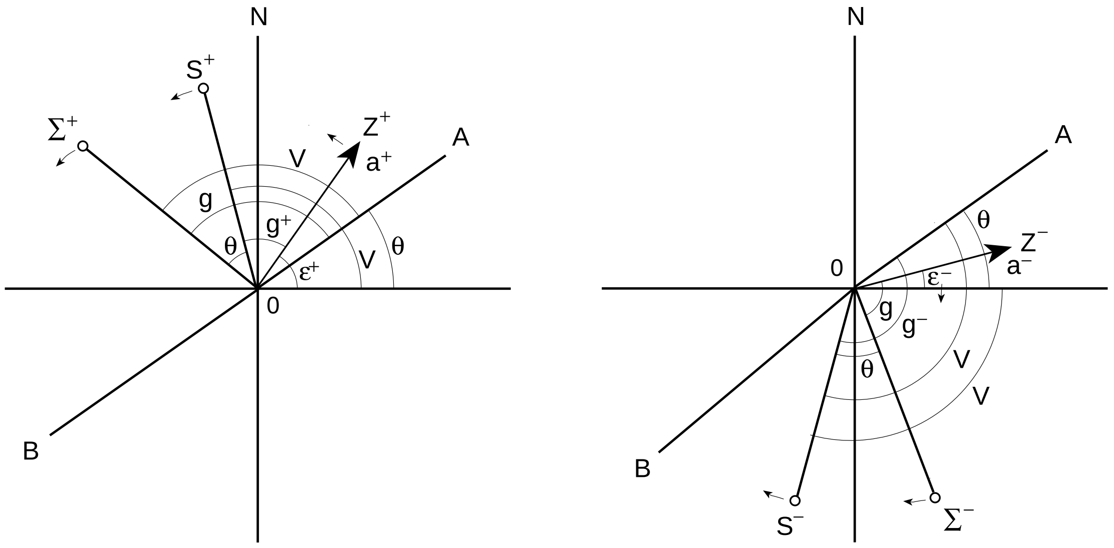
$$t = \frac{g - V(t_0) + n \cdot 360°}{\sigma}, \qquad n = \ldots, -1, 0, 1, \ldots$$

relative to $t = t_0$.

## 2.2 The Analysis Solution

Many of the techniques used in the analysis of tidal currents are the same as those for tidal heights. Rather than repeating here a discussion on topics such as the standard constituent data package (listed in Appendix 7.1), the formation and solution of the least squares matrices, and the calculations of astronomical and nodal modulation variables, we refer you to the *Manual for Tidal Heights Analysis and Prediction* (Foreman, 1977) for details. Instead, a brief description will be given of the steps followed by this analysis program and references to where method or calculation details can be found. In order of operation, these steps are as follows:

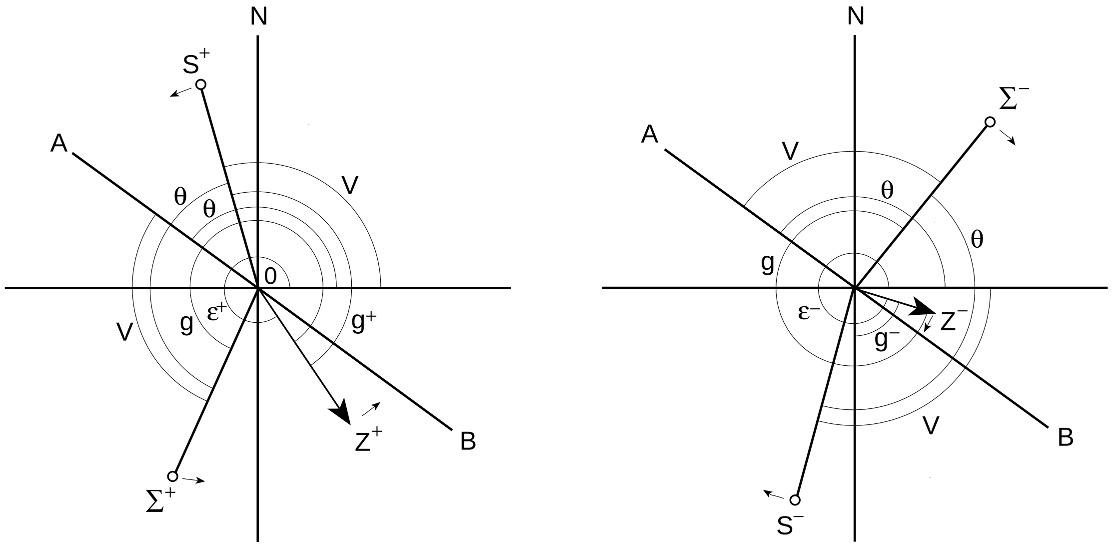
1. Reading all the input parameters, the tidal constituent data package, and the north/south and east/west current components for the proposed analysis period.
2. Calculation of the middle hour, $t_m$, of the analysis period.
3. Calculation at time, $t_m$, of the nodal modulation correction factors, $f$ and $u$, and the astronomical arguments, $V$, for all the constituents in the standard data package. Both the data package and the subroutine that calculates these values are identical to those used in the tidal heights analysis program.



$g = g^{+} + \theta$

$g = g^{-} - \theta$

**Figure 3** Angular relationships when $\varepsilon^{+} + \varepsilon^{-} < 360°$. (Redrawn from C. Wallace)



$g = g^{+} + \theta$

$g = g^{-} + (360° - \theta)$

**Figure 4** Angular relationships when $\varepsilon^{+} + \varepsilon^{-} \geq 360°$. (Redrawn from C. Wallace)

4. Determination via the Rayleigh criterion, of the constituents to be used in the least squares fits. This criterion and the list of prospective candidates and their comparison constituents are again identical to those of the tidal heights method. Tables showing the order of constituent selection, as a function of analysis period length, and in accordance with the Rayleigh criterion, are given in Foreman (1977, pp. 10–13).
5. Construction and solution relative to time, $t_m$, of the least squares matrices for each of the $X$ (east/west) and $Y$ (north/south) current components. Except for the additional feature of being able to calculate hourly predictions based on the results of the foregoing analysis and to recalculate the rms residual error, the subroutine employed here is identical to the one for tidal heights. Hence those output variables which give details of the fit, such as error estimates, average, standard deviation, matrix condition number and rms residual error, will have been calculated in the same manner. The primary outputs however, are the arrays `CX,SX,CY` and `SY`, which are described in Section 2.1 and, if there is to be no inference, the predicted hourly component currents upon request.
6. Writing the preceding preliminary results on the line printer.
7. If so requested, scaling the `CX,SX,CY` and `SY` values to compensate for the application of moving average filters to the current observations prior to submission for analysis. Section 2.3 has details of this calculation.
8. Conversion of the preliminary results into polar coordinates, i.e. calculation of the parameters $a^+$, $a^-$, $\varepsilon^+$ and $\varepsilon^-$ as described in Section 2.1.
9. Inference of the $a^+$, $a^-$, $\varepsilon^+$ and $\varepsilon^-$ values for those designated constituents not included in the least squares fit and the adjustment of these values for those constituents used for the inference(s). Section 2.4 has details of this operation.
10. Calculation, in accordance with the formulae of Section 2.1 and including nodal modulation correction factors and astronomical arguments, of the following ellipse and Greenwich phase parameters: major and minor semi-axis lengths, angle of inclination, $g^+$, $g^-$ and $g$. Note that when the nodal modulation amplitude and phase corrections are included in these formulae, $a^+$, $a^-$ and $V(t_0)$ become $a^+/f(t_0)$, $a^-/f(t_0)$ and $V(t_0) + u(t_0)$ respectively.
11. If there has been inference, calculation, upon request, of the hourly predicted component currents based on least squares and inference results. Any scaling that may have been done to compensate for pre-filtering must initially be reversed though, so that the predicted values will have the same scaling as the original input data.
12. Writing all final results without (and with) inference on the line printer and permanent storage file and the hourly component predictions, if so requested, on their files.

### 2.3 Scaling Compensations for Pre-Filtering

If the sampling interval obtained from a current meter record is other than one hour, Godin (1972, p. 149) recommends that the data be filtered and the hourly values extracted before submission to the tidal currents analysis program. Such an operation will eliminate short-period fluctuations that are related to turbulence and of no relevance to tidal analysis. In particular, he suggests that if the original data were sampled at $n$-minute intervals, and $60/n$ is integer-valued, say $n_0$, then the sequence $(A_{n_0})^2 A_{n_{0+1}}$ moving average be applied if $n_0$ is an even number, and the sequence $A_{n_0}(A_{n_{0+1}})^2$, if $n_0$ is odd.

The definition of the moving average filter, $A_n$, is as follows. Suppose that the original time series of observations is $\{z_k\}$, $k = 1, \ldots, m$, where all the observations are equally spaced in time and $m \geq n$. Then the applications of $A_n$ results in replacing the former sequence with $\{z'_k\}$ for $k = 1, \ldots, m - n + 1$ where

$$z'_k = \frac{1}{n} \sum_{i=k}^{k+n-1} z_i.$$

Assuming that the $k$th element of the original sequence was recorded at time $(k-1)\Delta t$, then in the new sequence it will be at time $[k - 1 + (n-1)/2]\Delta t$. Hence not only has there been a loss of $n - 1$ members from the sequence, but a shift of $(n-1)\Delta t/2$ for the times of corresponding elements. This latter point implies that if $n$ is an even number and the original record included observations on the hour, the filtered record would not have hourly values. Thus, a second $A_n$ filter applied to the results of the first is needed to bring the observation times back into correspondence with those of the original record and so enable the extraction of hourly values. For example, if the original record has $\Delta t = 15$ minutes and the first observation is at 1:00 a.m., then after one pass with an $A_4$ filter, the first observation would be at 1:22:30 a.m., and after a second pass at 1:45 a.m., $\Delta t$ still being 15 minutes.

When there is a sequence of three filters, the second one is applied to the results of the first, and the third to the results of the second. In particular, the application of $(A_n)^2 A_{n+1}$ requires at least $3n - 1$ consecutive observations in the original time series, and results in a loss of $3n - 2$ observations and a shift in time of $(3n-2)\Delta t/2$.

Unfortunately though, the application of moving average filters will affect the entire spectrum of the observations, not solely the high frequency components that we may wish to remove. The nature of this influence is calculated by Godin (1972, p. 54) and summarized as follows.

Given the sequence of numbers $\{f_k\}$, $k = 0, \pm 1, \pm 2, \ldots$[3] and the set of observations $\{z(j\Delta t)\}$, $j = 0, \pm 1, \pm 2, \ldots$, then their convolution is defined to be the sequence

$$\{z_f(j\Delta t)\} = \left\{ \sum_{k=-\infty}^{\infty} f_k z[(j-k)\Delta t] \right\}.$$

If $F(\sigma) = \sum_{k=-\infty}^{\infty} f_k \exp(-2\pi i k \Delta t \sigma)$ is the spectrum of the sequence $\{f_k\}$, then $Z'(\sigma)$, the spectrum of the convoluted values, is related to $Z(\sigma)$, the spectrum of the original observations, via the equation $Z'(\sigma) = F(\sigma)Z(\sigma)$. Hence, a convolution in time is equivalent to a multiplication in frequency.

Now the moving average filter $A_n$ can be defined in terms of a convolution by assigning the following values to the sequence $\{f_k\}$:

$$\begin{aligned} f_k &= \frac{1}{n} \quad \text{if} \quad -\frac{n-1}{2} \leq k \leq \frac{n-1}{2}, \\ &= 0 \quad \text{otherwise,} \end{aligned}$$

where $k = 0, \pm 1, \pm 2, \ldots$ if $n$ is an odd number, and $k = \pm\frac{1}{2}, \pm\frac{3}{2}, \pm\frac{5}{2}, \ldots$ if $n$ is even and, making use of the identity

$$\sum_{k=n_0}^{n_1} \exp(ikx) = \frac{\sin[(n_1 - n_0 + 1)x/2] \exp[i(n_1 + n_0)x/2]}{\sin(x/2)},$$

---

[3] $k = \pm\frac{1}{2}, \pm\frac{3}{2}, \pm\frac{5}{2}, \ldots$ if the sequence is finite and contains an even number of elements.

its spectrum, $F_n(\sigma)$, is calculated as

$$\begin{aligned} F_n(\sigma) &= \sum_{k=-(n-1)/2}^{(n-1)/2} \frac{1}{n} \exp(-2\pi i k \Delta t \sigma) \\ &= \frac{\sin(n\pi\Delta t\sigma)}{n\sin(\pi\Delta t\sigma)}. \end{aligned}$$

Hence one pass of the moving average filter $A_n$ will have the effect of multiplying the response at frequency, $\sigma$, in the original record by $F_n(\sigma)$. Since it follows that the application of three successive moving average filters, $A_n \cdot A_n \cdot A_{n+1}$, results in a net factor of $F_n(\sigma) \cdot F_n(\sigma) \cdot F_{n+1}(\sigma)$, the scaling compensation required to obtain the amplitude response of the original data at frequency $\sigma$ is $1/[F_n(\sigma) \cdot F_n(\sigma) \cdot F_{n+1}(\sigma)]$.

## 2.4 Inference

If the length of a specific tidal record is such that certain important constituents will not be included directly in the analysis, provision is made via the input on file reference number 4 to include these constituents indirectly by inferring their major and minor semi-axis lengths and Greenwich phase lags from neighbouring constituents that are included. If suitable amplitude ratios and phase differences can be specified, inference has the effect of significantly reducing any periodic behaviour in the ellipse parameters and phases of the constituent used for the inference. This is due to the removal of interaction from the neighbouring inferred constituent. If it so happens that a constituent specified for inference is included directly in the analysis, the program will ignore the inference calculations.

The amplitude ratios and phase differences required for inference calculations should be obtained empirically from the results of longer analyses of data at the same or surrounding stations. Tidal current values are preferable but tidal heights results may be used as input by setting each of the two amplitude ratios and the two phase differences equal to the respective values obtained from the tidal heights analysis. However, Godin (1972, p. 212) warns that the latter technique may fail in the vicinity of an amphidromic point.

If the results of a previous tidal currents analysis are used for calculating the inference variables, and it is decided that the two phase differences should be set equal, namely to the difference in the $g$ values, care should be taken to ensure that the angles of inclination of the two constituent ellipses are reasonably close. If their difference is about 180°, then one value and its corresponding Greenwich phase, $g$, should be altered by 180° before calculating the inference phase difference. If this is not done, the subsequent inference adjustments will not have the proper relationship between the constituents, and it may well happen that the rms residual error after inference is higher than before, i.e. inference has not improved the fit.

The actual adjustments are as follows. Assume that the constituent with frequency, $\sigma_2$, is to be inferred from the constituent with frequency, $\sigma_1$, and that the latter's contribution, after conversion of the least squares fit results into polar coordinates (and before nodal modulation), was found to be

$$a_0^+ \exp(\varepsilon_0^+ + 2\pi\sigma_1 t) + a_0^- \exp\left[i(\varepsilon_0^- - 2\pi\sigma_1)\right] .$$

Defining the following variables for the constituents with frequencies, $\sigma_1$ and $\sigma_2$, respectively:

$VU_1, VU_2$ = the astronomical argument plus nodal modulation phase correction;
$g_1^+, g_1^-, g_2^+, g_2^-$ = Greenwich phase lags for the counterclockwise and clockwise rotating component vectors;
$a_1^+, a_1^-, a_2^+, a_2^-$ = amplitudes of the counterclockwise and clockwise rotating component vectors after inference, but before nodal modulation;
$f_1, f_2$ = nodal modulation amplitude correction factors;
$A_1^+, A_1^-, A_2^+, A_2^-$ = amplitudes of the counterclockwise and clockwise rotating component vectors after both inference and nodal modulation;
$\varepsilon_1^+, \varepsilon_1^-, \varepsilon_2^+, \varepsilon_2^-$ = initial phases of the counterclockwise and clockwise rotating component vectors.

Then upon setting $r^+$, $r^-$, $\zeta^+$ and $\zeta^-$ to be the respective variables `RPL,RMIN,ZETAP` and `ZETAM` that are read from file reference number 4, the following relationships can be seen:

$$\begin{aligned}
r^+ &= \frac{A_2^+}{A_1^+} = \frac{a_2^+ f_1}{a_1^+ f_2}, \\
r^- &= \frac{A_2^-}{A_1^-} = \frac{a_2^- f_1}{a_1^- f_2}, \\
\zeta^+ &= g_1^+ - g_2^+ = VU_1 - \varepsilon_1^+ - VU_2 + \varepsilon_2^+, \\
\zeta^- &= g_1^- - g_2^- = VU_1 + \varepsilon_1^- - VU_2 + \varepsilon_2^-.
\end{aligned}$$

Letting $\Delta = \sigma_2 - \sigma_1$, the objective of inference can be stated as decomposing the signal found at frequency, $\sigma_1$, into

$$\begin{aligned}
& a_1^+ \exp(i\varepsilon_1^+ + 2\pi i\sigma_1 t) + a_1^- \exp(i\varepsilon_1^- - 2\pi i\sigma_1 t) + a_2^+ \exp(i\varepsilon_2^+ + 2\pi i\sigma_2 t) + a_2^- \exp(i\varepsilon_2^- - 2\pi i\sigma_2 t) \\
&\qquad = \exp(2\pi i\sigma_1 t)\left[a_1^+ \exp(i\varepsilon_1^+) + a_2^+ \exp(i\varepsilon_2^+ + 2\pi i\Delta t)\right] \\
&\qquad\qquad + \exp(-2\pi i\sigma_1 t)[a_1^- \exp(i\varepsilon_1^-) + a_2^- \exp(i\varepsilon_2^- - 2\pi i\Delta t)] \\
&\qquad = a_1^+ \exp(i\varepsilon_1^+ + 2\pi i\sigma_1 t)\left\{1 + r^+\left(\frac{f_2}{f_1}\right)\exp\left[i(VU_2 - VU_1 + \zeta^+ + 2\pi\Delta t)\right]\right\} \\
&\qquad\qquad + a_1^- \exp(i\varepsilon_1^- - 2\pi i\sigma_1 t)\left\{1 + r^-\left(\frac{f_2}{f_1}\right)\exp\left[i(VU_1 - VU_2 - \zeta^- - 2\pi\Delta t)\right]\right\}.
\end{aligned}$$

Since the constituent with frequency, $\sigma_2$, was not chosen for inclusion in the least squares analysis, $N \cdot |\Delta| < RAY$, where $N$ is the analysis period length in hours, and $RAY$ is the Rayleigh criteria constant (usually 1.0). Assuming in general that $N \cdot |\Delta|$ is small, good approximations to $\exp\left[i(VU_2 - VU_1 + \zeta^+ + 2\pi\Delta t)\right]$ and $\exp\left[i(VU_1 - VU_2 - \zeta^- - 2\pi\Delta t)\right]$ are their average values over the analysis interval, $[-N/2,\ N/2]$, namely

$$\frac{\exp\left[i(VU_2 - VU_1 + \zeta^+)\right]\sin(\pi\Delta N)}{\pi\Delta N} \quad \text{and} \quad \frac{\exp\left[i(VU_1 - VU_2 - \zeta^-)\right]\sin(\pi\Delta N)}{\pi\Delta N}$$

respectively.

Setting

$$T^{+} = 1 + \frac{r^{+}(f_2/f_1)\exp\left[i(VU_2 - VU_1 + \zeta^{+})\right]\sin(\pi\Delta N)}{\pi\Delta N}$$

and

$$T^{-} = 1 + \frac{r^{-}(f_2/f_1)\exp[i(VU_1 - VU_2 - \zeta^{-})]\sin(\pi\Delta N)}{\pi\Delta N},$$

the equation relating the tidal signals before and after inference is then

$$\begin{aligned} a_0^{+}\exp(i\varepsilon_0^{+} + 2\pi i\sigma_1 t) + a_0^{-}\exp(i\varepsilon_0^{-} - 2\pi i\sigma_1 t)& \\ = a_1^{+}\exp(i\varepsilon_1^{+} + 2\pi i\sigma_1 t)T^{+} &+ a_1^{-}\exp(i\varepsilon_1^{-} - 2\pi i\sigma_1 t)T^{-}. \end{aligned}$$

Regrouping similar terms in $\sigma_1 t$, this becomes

$$\begin{aligned} \exp(2\pi i\sigma_1 t)\left[a_0^{+}\exp(i\varepsilon_0^{+}) - a_1^{+}\exp(i\varepsilon_1^{+})T^{+}\right]& \\ + \exp(-2\pi i\sigma_1 t)&\left[a_0^{-}\exp(i\varepsilon_0^{-}) - a_1^{-}\exp(i\varepsilon_1^{-})T^{-}\right] = 0. \end{aligned}$$

Now in order to draw some conclusions from this last equation, let us re-express it in the simpler form

$$\exp(it)(w + ix) + \exp(-it)(y + iz) = 0.$$

Expanding and collecting real and imaginary parts here yields

$$(w + y)\cos(t) + (z - x)\sin(t) = 0$$

and

$$(x + z)\cos(t) + (w - y)\sin(t) = 0.$$

Since these equations must hold for all $t$, it follows that

$$w + y = z - x = x + z = w - y = 0.$$

Hence

$$w = x = y = z = 0.$$

Therefore, setting

$$\begin{aligned} a_0^{+}\exp(i\varepsilon_0^{+}) &= w_0 + ix_0, \\ a_1^{+}\exp(i\varepsilon_1^{+}) &= w_1 + ix_1, \\ a_0^{-}\exp(i\varepsilon_0^{-}) &= y_0 + iz_0, \\ a_1^{-}\exp(i\varepsilon_1^{-}) &= y_1 + iz_1, \\ T^{+} &= c + id, \\ T^{-} &= g + ih \end{aligned}$$

and applying the result of the simplified equation to the last inference equation, gives

$$\begin{aligned} w_0 - w_1 c + x_1 d &= 0, \\ w_0 - w_1 d - x_1 c &= 0, \\ y_0 - y_1 g + z_1 h &= 0, \\ z_0 - y_1 h - z_1 g &= 0. \end{aligned}$$

Solving these simultaneous equations for $w_1$, $x_1$, $y_1$ and $z_1$ yields

$$\begin{aligned}
w_1 &= (w_0 c + x_0 d)/(c^2 + d^2), \\
x_1 &= (x_0 c - w_0 d)/(c^2 + d^2), \\
y_1 &= (y_0 g + z_0 h)/(g^2 + h^2), \\
z_1 &= (z_0 g - y_0 h)/(g^2 + h^2).
\end{aligned}$$

Reconstructing these results into polar coordinate form then gives the following adjusted values for the constituent used for inference:

$$\begin{aligned}
a_1^+ &= \sqrt{w_1^2 + x_1^2}, \\
\varepsilon_1^+ &= \arctan(x_1/w_1), \\
a_1^- &= \sqrt{y_1^2 + z_1^2}
\end{aligned}$$

and

$$\varepsilon_1^- = \arctan(z_1/y_1).$$

And finally, making use of the inference assumptions yields the following values for the inferred constituent:

$$\begin{aligned}
a_2^+ &= r^+ a_1^+ (f_2/f_1), \\
a_2^- &= r^- a_1^- (f_2/f_1), \\
\varepsilon_2^+ &= \zeta^+ + \varepsilon_1^+ + VU_2 - VU_1
\end{aligned}$$

and

$$\varepsilon_2^- = -\zeta^- + \varepsilon_1^- - VU_2 + VU_1.$$

## 3 USE OF THE TIDAL CURRENTS PREDICTION COMPUTER PROGRAM

### 3.1 General Description

This program produces tidal current values at a given location for a specified period of time. For each of the tidal constituents to be used in the prediction, the Greenwich phase lag, and the current ellipse major and minor semi-axis lengths and angle of inclination, are required as input. Output can either be the times, magnitudes and directions of all maximum and minimum currents respectively, or equally spaced values expressed in the form of north/south and east/west components, or vector magnitudes and directions.

### 3.2 Routines Required

(1) **MAIN** ...... reads in tidal station and time period information, ellipse parameters and Greenwich phases of constituents to be used in the prediction and calculates the desired tidal currents.

(2) **SLOPE** ...... calculates for a specific time, the current vector north/south and east/west components, and the derivative of the magnitude squared.

(3) **ASTRO** ...... reads the standard constituent data package and calculates the frequencies, astronomical arguments, and nodal corrections for all constituents.

(4) **PUT** ...... controls the output for maximum–minimum predictions.

(5) **CPUT** ...... controls the output for equally spaced predictions.

(6) **GDAY** ...... returns the consecutive day number from a specific origin for any given date and vice versa.

(11) **ASTR** ...... calculates ephermides for the sun and moon.

### 3.3 Data Input

All input data required by the tidal currents prediction program are read from file reference number 8. A sample set is given in Appendix 7.4. Although data types (i), (ii) and (iii) are identical to types (ii), (iii) and (iv) expected on file reference number 8 by the analysis program, for completeness they are repeated here.

(i) Two cards specifying values for the astronomical arguments `SO,HO,PO,ENPO,PPO,DS,DH,DP,DNP,DPP` in the format `(5F13.10)`.

`SO` = mean longitude of the moon (cycles) at the reference time origin;
`HO` = mean longitude of the sun (cycles) at the reference time origin;

`P0` = mean longitude of the lunar perigee (cycles) at the reference time origin;
`ENP0` = negative of the mean longitude of the ascending node (cycles) at the reference time origin;
`PP0` = mean longitude of the solar perigee (perihelion) at the reference time origin.

`DS,DH,DP,DNP,DPP` are their respective rates of change over a 365-day period at the reference time origin.

Although these argument values are not used by the program that was revised in October 1992, in order to maintain consistency with earlier programs, they are still required as input. Polynomial approximations are now employed to more accurately evaluate the astronomical arguments and their rates of change.

(ii) At least one card for all the main tidal constituents specifying their Doodson numbers and phase shift along with as many cards as are necessary for the satellite constituents. The first card for each such constituent is in the format `(6X,A5,1X,6I3,F5.2,I4)` and contains the following information:

`KON` = constituent name;
`II,JJ,KK,LL,MM,NN` = the six Doodson numbers for `KON`;
`SEMI` = phase correction for `KON`;
`NJ` = number of satellite constituents.

A blank card terminates this data.

If `NJ>0`, information on the satellite constituents follows, three satellites per card, in the format `(11X,3(3I3,F4.2,F7.4,1X,I1,1X))`. For each satellite the values read are:

`LDEL,MDEL,NDEL` = the last three Doodson numbers of the main constituent subtracted from the last three Doodson numbers of the satellite constituents;
`PH` = phase correction of the satellite constituent relative to the phase of the main constituent;
`EE` = amplitude ratio of the satellite tidal potential to that of the main constituent;
`IR` = 1 if the amplitude ratio has to be multiplied by the latitude correction factor for diurnal constituents,
= 2 if the amplitude ratio has to be multiplied by the latitude correction factor for semidiurnal constituents,
= otherwise if no correction is required to the amplitude ratio.

(iii) One card specifying each of the shallow water constituents and the main constituents from which they are derived. The format is `(6X,A5,I1,2X,4(F5.2,A5,5X))` and the respective values read are:

`KON` = name of the shallow water constituent;
`NJ` = number of main constituents from which it is derived;
`COEF,KONCO` = combination number and name of these main constituents.

The end of these shallow water constituents is denoted by a blank card.

(iv) One card with the tidal station information `ISTN,(NA(J),J=1,4),ITZONE,LAD,LAM,LOD,LOM` in the format `(5X,I4,1X,3A6,A4,A3,1X,I2,1X,I2,2X,I3,1X,I2)`.

`ISTN` = station number;
`(NA(J),J=1,4)` = station name;
`ITZONE` = time zone reference for the "Greenwich" phases;
`LAD,LAM` = station latitude in degrees and minutes;
`LOD,LOM` = station longitude in degrees and minutes.

(v) One card for each constituent to be included in the prediction, with the constituent name (`KON`), major and minor semi-axis lengths (`EMAJ` and `EMIN`), ellipse angle of inclination (`EINC`), and Greenwich phase lag (`G`) in the format `(4X,A5,13X,2F8.3,2F7.1)`. (This format is compatible with the analysis program results produced on output device 2.) The units of the predicted currents will be the same as those of the major and minor semi-axis lengths; the angle of inclination should be measured in degrees counterclockwise from east, and the phase lag should be measured in degrees relative to the time zone (`ITZONE`) for which the prediction is desired.

(vi) One card containing the following information on the period and type of prediction desired. The format is `(3I3,1X,3I3,1X,A4,2X,A4,F9.5,2X,2I3)`.

`IDYO,IMOO,IYRO` = first day, month and year of the prediction period;
`IDYE,IMOE,IYRE` = last day, month and year of the prediction period;
`ITYPE` = `'EQUI'` if equally spaced predictions are desired,
= `'EXTR'` if all the high and low tide times and heights are desired;
`IOUT` = `'COMP'` if `ITYPE='EQUI'` and north/south and east/west component predictions are desired,
= otherwise if `ITYPE='EQUI'` and vector magnitude and direction predictions are desired, or if `ITYPE='EXTR'`;
`DT` = time spacing of the predicted values if `ITYPE ='EQUI'`,
= time step increment used to initially bracket a maximum or minimum value if `ITYPE='EXTR'`.
`ICEO,ICEE` = centuries for the beginning and end of the prediction. Zero values are reset to 19.

Equally spaced predictions begin at `DT` hours on the first day and extend to 2400 h (assuming 24 is a multiple of `DT`) of the last day. When `ITYPE='EXTR'`, Godin and Taylor (1973) recommend using the following values for `DT`: 1.5 h for a semidiurnal tide, 3.0 h for a diurnal tide and 0.25 h for a mixed tide.

Type (vi) data may be repeated any number of times. One blank card following a type (vi) record will return the program to type (iv) input while two blank cards will end the program execution.

## 3.4 Output

Up to four file reference numbers are required for the output of results in the tidal currents prediction program. Device number 6 is the line printer, 10 and 11 are data files for the storage of equally spaced predictions and 12 is a data file for the storage of maximum and minimum predictions. All information on files 10, 11 and 12 is written on the line printer in the same format. However, the line printer also records the station name and location, along with the ellipse parameters and phase lags of the constituents used in the prediction. Appendix 7.5 lists the output on files 10, 11 and 12 resulting from the input of Appendix 7.4.

When maximum and minimum current values are desired, the station number, date and a series of up to four current magnitudes along with their directions and occurrence times, are listed on each record. Two and sometimes three records are required per day and the format of these variables on file reference number 12 is `(1X,I4,I3,2I2,4(I5,F6.2,F6.1))`.

When equally spaced currents are requested in component form, file 10 receives the north/south values and 11 the east/west. If the currents are requested in vector form, the magnitudes are on 10 and the directions on 11. In all cases, eight values are listed per record preceded by the station number, the time, day, month and year of the first value and followed by the time increment between values. On both devices, the format for these variables is `(1X,I4,F6.2,I3,2I2,8F7.2,F6.2)`. On the line printer, the component (or vector) values are not listed separately, i.e. one record of north/south components (or current magnitudes) is followed directly by the corresponding east/west values (or current directions).

## 3.5 Program Conversion, Storage and Dimension Guidelines

The source program and constituent data package described in this manual have been tested on various mainframe, PC and workstation computers at the Institute of Ocean Sciences, Patricia Bay. Although as much of the program as possible was written in basic FORTRAN, some changes may be required before the program and data package can be used on other installations. Please write or call the author if any problems are encountered.

The program in its present form requires approximately 37,000 bytes for the storage of its instructions and arrays. As with the analysis program, changing the number or type of constituents in the standard data package may require alteration to the dimensions of some arrays. Restrictions on the minimum dimension of all arrays are now given.

Let

`MTAB` be the total number of constituents contained in the data package (at present 146);

`M` be the number of constituents to be included in the prediction;

`MCON` be the number of main constituents in the standard data package (at present 45);

`MSAT` be the sum of the total number of satellites for these main constituents and, the number of main constituents with no satellites (at present 162 plus 8 for the constituent data package containing no third-order satellites for both $N_2$ and $L_2$);

`MSHAL` be the sum for all shallow water constituents of the number of main constituents from which each is derived (at present 251);

`NITER` be the number of iterations required to reduce the time interval within which it is known that a high or low tide exists, to a desired length (with the largest initial interval size of 3 h and a 6-min final interval, `NITER` is 5).

Then in the main program, array `KONTAB` should have minimum dimension `MTAB+1`; arrays `SIGTAB,V,U` and `F` should have minimum dimension `MTAB`; arrays `KON,EMAJ,EMIN,EINC` and `G` should have minimum dimension `M+1`; arrays `SIG,INDX,ANGO,CMAJ,CMIN,SMAJ,SMIN,CHA,CHB,CHM,SHA,SHB,SHM,C,S,COSE` and `SINE` should have minimum dimension `M` and the two-dimensional array `BTWOC` should have a minimum dimension `M` by `NITER`. Array `COSINE` which stores pre-calculated cosine function values over the range of 0° to 450° and is used as a look-up table, at present has 2501 elements.

In subroutine **SLOPE**, arrays `F,CMAJ,CMIN,SMAJ,SMIN,SIG` and `INDX` are in `COMMON` and should have the same dimensions as in the main program; and arrays `COSE` and `SINE` are passed in the argument list from the main program and so need only be dimensioned 2.

In subroutine **ASTRO**, arrays `KON` and `NJ` should have minimum dimension `MTAB+1`; arrays `FREQ,U,V` and `F` should have minimum dimension `MTAB`; arrays `II,JJ,KK,LL,MM,NN` and `SEMI` should have minimum dimension `MCON+1`; arrays `EE,LDEL,MDEL,NDEL,IR` and `PH` should have minimum dimension `MSAT` and arrays `KONCO` and `COEF` should have minimum dimension `MSHAL+4`.

In subroutine **PUT**, the dimensions of arrays `RK,DIRK` and `ITIME` should be at least as large as the maximum number of extreme current values per day (i.e. at present assumed to be 18).

In subroutine **CPUT**, the dimension of arrays `X` and `Y` should be at least equal to the number of equally spaced tidal current values per output record (at present, this is 8).

In subroutine **GDAY**, both arrays `NDM` and `NDP` should have dimension 12.

# 4 TIDAL CURRENTS PREDICTION PROGRAM DETAILS

## 4.1 Problem Formulation and the Equally Spaced Prediction Method

In Section 2.1 we saw that the tidal current contribution for a constituent with frequency, $\sigma$, can be represented as

$$Z(t) = a^+ \exp(i\varepsilon^+ + 2\pi i\sigma t) + a^- \exp(i\varepsilon^- - 2\pi i\sigma t)$$

where $a^+$, $a^-$, $\varepsilon^+$ and $\varepsilon^-$ are calculated from the least squares analysis. After calculation of the astronomical argument and nodal modulation correction factors at an origin, $t_0$, from which $t$ is measured and substitution of the phase variables, $\theta$ and $g$, this complex-valued tidal contribution can be re-expressed as

$$\begin{aligned} Z(t) &= f(t_0)a^+ \exp\left[i(V(t_0) + u(t_0) - g + \theta + 2\pi\sigma t)\right] \\ &\quad + f(t_0)a^- \exp\left[i(g - V(t_0) - u(t_0) + \theta - 2\pi\sigma t)\right] \\ &= f(t_0)\exp(i\theta)\left[(a^+ + a^-)\cos(V(t_0) + u(t_0) + 2\pi\sigma t - g)\right. \\ &\quad \left. + i(a^+ - a^-)\sin(V(t_0) + u(t_0) + 2\pi\sigma t - g)\right] . \end{aligned}$$

Letting $\phi(t, t_0) = V(t_0) + u(t_0) - g + 2\pi\sigma t$, a further re-arrangement into real (east/west) and imaginary (north/south) parts yields

$$\begin{aligned} Z(t) = f(t_0)&\left[(a^+ + a^-)\cos\theta\cos\phi(t, t_0) - (a^+ - a^-)\sin\theta\sin\phi(t, t_0)\right] \\ &+ if(t_0)\left[(a^+ + a^-)\sin\theta\cos\phi(t, t_0) + (a^+ - a^-)\cos\theta\sin\phi(t, t_0)\right] . \end{aligned} \tag{1}$$

The actual procedure then used to produce equally spaced tidal current predictions is almost identical to that employed in tidal heights prediction (Foreman, 1977, p. 33). Since the data package read from file reference number 8 does not contain constituent frequencies, they must be calculated via the astronomical variable derivatives and the constituent Doodson numbers. Values, $f$, $u$ and $V$ are then calculated for 0000 h of the sixteenth day of the first month of the desired prediction period and updated as required for subsequent months. Tidal current components are then found by summing the contributions from each constituent.

In order to avoid calling a trigonometric library function for each new value of $t$, when a sequence of equally spaced predictions is required, the following formulae are used for each constituent contribution:

$$\cos(\psi + 2\pi\sigma(n + 1)\Delta t) = \cos(\psi + 2\pi\sigma n\Delta t)\cos(2\pi\sigma\Delta t) - \sin(\psi + 2\pi\sigma n\Delta t)\sin(2\pi\sigma\Delta t), \tag{2}$$

$$\sin(\psi + 2\pi\sigma(n + 1)\Delta t) = \sin(\psi + 2\pi\sigma n\Delta t)\cos(2\pi\sigma\Delta t) + \cos(\psi + 2\pi\sigma n\Delta t)\sin(2\pi\sigma\Delta t) \tag{3}$$

where $\psi = V(t_0) + u(t_0) - g$.

### 4.2 The Maximum and Minimum Current Prediction Method

Letting $X$ and $Y$ be the east/west and north/south current components respectively, it is easily seen that the times for which the current magnitude, namely $\sqrt{X^2+Y^2}$, will attain a maximum or minimum value, will be the same as those for the magnitude squared, namely $X^2+Y^2$. Therefore, we can find all maximum and minimum currents by solving the equation that results from setting the derivative of the magnitude squared with respect to time, equal to zero.

Expanding equation (1) of Section 4.1 to include the contributions from $m$ constituents, this result may be written as

$$\left(\sum X_j\right)\frac{\partial}{\partial t}\left(\sum X_j\right)+\left(\sum Y_j\right)\frac{\partial}{\partial t}\left(\sum Y_j\right)=0,$$

where for each constituent

$$\begin{aligned} X(t,t_0) &= f(t_0)\left[(a^+ + a^-)\cos\theta\cos\phi(t,t_0)-(a^+ - a^-)\sin\theta\sin\phi(t,t_0)\right],\\ \frac{d}{dt}X(t,t_0) &= -2\pi\sigma f(t_0)\left[(a^+ + a^-)\cos\theta\sin\phi(t,t_0)+(a^+ - a^-)\sin\theta\cos\phi(t,t_0)\right],\\ Y(t,t_0) &= f(t_0)\left[(a^+ + a^-)\sin\theta\cos\phi(t,t_0)+(a^+ - a^-)\cos\theta\sin\phi(t,t_0)\right] \end{aligned}$$

and

$$\frac{d}{dt}Y(t,t_0) = 2\pi\sigma f(t_0)\left[-(a^+ + a^-)\sin\theta\sin\phi(t,t_0)+(a^+ - a^-)\cos\theta\cos\phi(t,t_0)\right].$$

The method employed to solve this equation is similar to the one used in the prediction of high and low tidal heights (Foreman, 1977, p. 34). We first bracket all extrema by moving forward in time with steps of size $\Delta t$ and comparing signs of the interval endpoints. Once an interval whose endpoints differ in sign has been found, the zero value is located via the method of bisection coupled with linear interpolation.

Because each tidal constituent has two maximum and two minimum values per cycle, as opposed to one of each in the case of tidal heights, the recommended step size values, $\Delta t$, are on half those listed in the tidal heights manual (Foreman, 1977, p. 35), namely:

(i) $\Delta t = 1.5$ h for semidiurnal tide,
(ii) $\Delta t = 0.25$ h for mixed tide,
(iii) $\Delta t = 3$ h for diurnal tide.

Determination of the tidal nature at a particular station may be obtained by calculating the diurnal to semidiurnal ratio of tidal height amplitudes for the major constituents $M_2$, $S_2$, $K_1$ and $O_1$. This value is called the form number (Dietrich, 1963) and is defined precisely as

$$F=\frac{\mathrm{K}_1+\mathrm{O}_1}{\mathrm{M}_2+\mathrm{S}_2}.$$

The tide is then said to be

(i) semidiurnal if $0 \le F \le 0.25$,
(ii) mixed if $0.25 < F \le 3.00$,
(iii) diurnal if $F > 3.00$.

If tidal heights analysis results are not available, $F$ may be approximated using either the $X$ or $Y$ component amplitudes (e.g. using the notation of Section 2.1, the $X$ component amplitude is $\sqrt{(CX)^2 + (SX)^2}$). For Race Rocks, the example used in Appendix 7.4, the east/west and north/south components both yield $F$ values of 0.7.

In more detail, the search algorithm for an extremum is then as follows:

(i) Move forward in time from the origin, or the last extrema, in steps of $\Delta t$ until either a change in sign exists between the derivative values at the endpoints of the interval, $(t_a, t_b)$, or $t_b$ extends beyond the desired prediction period. Each constituent contribution in the summation, $D(t)$ is evaluated by equations (2) and (3) of Section 4.1. When an interval containing an extremum is located, set $k = 1$ and proceed to (ii).

(ii) Calculate $t_k = t_a + \Delta t/2^k$ and for each constituent in the sum, evaluate $D(t_k)$ by using the formulae:

$$\sin(t_k) = \frac{\sin(t_a) + \sin(t_b)}{2\cos \Delta t/2^k},$$

$$\cos(t_k) = \frac{\cos(t_a) + \cos(t_b)}{2\cos \Delta t/2^k}.$$

If $|D(t_k)| \leq 10^{-16}$, set $D(t_k) = 10^{-16}$.

(iii) Re-assign whichever of $t_a$ or $t_b$ has the same derivative sign as $D(t_k)$, by $t_k$. If the new interval length, $t_b - t_a$, is less than 0.1 h, proceed to (iv). Otherwise set $k = k + 1$ and return to (ii).

(iv) Use the following linear interpolation formula to find the extremum $t_E$,

$$t_E = t_a + \frac{D(t_a)(t_b - t_a)}{D(t_a) - D(t_b)},$$

and evaluate the $X$ (real) and $Y$ (imaginary) components of the current at this time via summing the respective constituent contributions given in equation (1) of Section 4.1. For each one, obtain the required sine and cosine values by using a pre-calculated stored table of 2501 cosine values with arguments in the range of $0°$ to $450°$. The current magnitude is then $\sqrt{X^2 + Y^2}$ and its direction measured counterclockwise from east is $\arctan(Y/X)$. Return to (i).

## 5 CONSISTENCY OF THE ANALYSIS AND PREDICTION PROGRAMS AND ACCURACY OF THEIR RESULTS IN RELATION TO THE METHODS EMPLOYED

As in the case of the tidal heights analysis and prediction programs, there is one noteworthy inconsistency between the tidal currents analysis and prediction programs. In particular, if a pseudo-tidal record were synthesized by the prediction program and analysed using the same constituents, the ellipse parameter and phase results given by the analysis program would not be identical to those used as input for the prediction program.

In a small part, this discrepancy is due to round-off accumulated during the calculations and truncation of the synthesized values to conform to input and output formats. However, a test performed on the UNIVAC 1106 at Patricia Bay with a six-month period of synthesized hourly currents indicates that such errors occur no sooner than the fourth digit. The remainder of the difference (which is, at worst, in the third digit) can be attributed to different approximating assumptions for the calculation of $f$ and $u$, the nodal and modulation amplitude and phase correction factors. Whereas the prediction program calculates these values at the sixteenth day of each month in the desired time period and keeps them constant throughout the entire month, the analysis program assumes them to be constant over the entire analysis period and equal to their true values at the central hour of that period. However, if so desired, synthesized values in which the calculation of the nodal modulation factors is consistent with that of the analysis method can be obtained from the analysis program by setting input variable `INDPR` to 1.

As would be expected, the inaccuracy in the nodal modulation calculation for periods longer than two months is worse in the case of the analysis method and becomes more significant as the analysis period increases. In fact, there exists an optimal period length, which Godin estimates to be approximately one year, beyond which the expected accuracy improvement through better resolution of the constituents is overshadowed by this and other nodal modulation assumptions. In particular, once the record length is close to nine years, nodal modulation in its present form breaks down because some constituents, normally considered as satellite, should be resolved directly.

It is also important to note that significantly different results can be expected in a synthesis/analysis test if there is at least one more constituent used in the synthesis than the analysis. This is because the least squares fit technique will adjust the ellipse parameters and phases of constituents included in the analysis to partially account for contributions due to constituents included in the synthesis but not the analysis. In fact, even after the extra constituents have been inferred (e.g. $P_1$ is included in the synthesis and in the analysis via inference from $K_1$) there will still be some discrepancies in the results not only for the inferred and inferee constituents due to small inaccuracies in the approximating inference assumptions, but also for neighbouring constituents whose least squares fit results were affected by the presence of the inferred constituent and whose final results were not adjusted, as were those of the inferee, during inference (e.g. the presence of $P_1$ affects not only $K_1$ but to a lesser extent, neighbouring constituents such as $NO_1$ and $J_1$). However, except for round-off and truncation errors, and the slightly different $f$ and $u$ values, having more constituents in the analysis than the synthesis will not affect the results.

## 6 REFERENCES

Dietrich, G. 1963. General Oceanography. Interscience Publishers, New York. 588 pp.

Doodson, A.T. and H.D. Warburg. 1941. Admiralty Manual of Tides. His Majesty's Stationery Office, London. Reprinted 1946. 270 pp.

Foreman, M.G.G. 1977. Manual for Tidal Heights Analysis and Prediction. Pacific Marine Science Report 77-10, Institute of Ocean Sciences, Patricia Bay, Victoria, B.C. 97 pp. Unpublished manuscript.

Godin, G.G. 1972. The Analysis of Tides. University of Toronto Press. 264 pp.

Godin, G.G. 1976. The reduction of current observations with the help of the admittance function. Technical Note No. 14, Environment Canada, Ottawa. Marine Environmental Data Service. 13 pp.

Henry, R.F. and M.G.G. Foreman. 1977. Numerical Model Studies of Semi-diurnal Tides in the Southern Beaufort Sea. Pacific Marine Science Report 77-11, Institute of Ocean Sciences, Patricia Bay, Victoria, B.C. 71 pp. Unpublished manuscript.

Taylor, J. 1972. The Current Ellipse. 7 pp. Unpublished notes.

## **Appendix 7.1** Standard Constituent Input Data for the Tidal Currents Computer Program. This Data is Read by File Reference Number 8.

```
Z0       0.0             M2
SA       0.0001140741    SSA
SSA      0.0002281591    Z0
MSM      0.0013097808    MM
MM       0.0015121518    MSF
MSF      0.0028219327    Z0
MF       0.0030500918    MSF
ALP1     0.0343965699    2Q1
2Q1      0.0357063507    Q1
SIG1     0.0359087218    2Q1
Q1       0.0372185026    O1
RHO1     0.0374208736    Q1
O1       0.0387306544    K1
TAU1     0.0389588136    O1
BET1     0.0400404353    NO1
NO1      0.0402685944    K1
CHI1     0.0404709654    NO1
PI1      0.0414385130    P1
P1       0.0415525871    K1
S1       0.0416666721    K1
K1       0.0417807462    Z0
PSI1     0.0418948203    K1
PHI1     0.0420089053    K1
THE1     0.0430905270    J1
J1       0.0432928981    K1
2PO1     0.0443745198
SO1      0.0446026789    OO1
OO1      0.0448308380    J1
UPS1     0.0463429898    OO1
ST36     0.0733553835
2NS2     0.0746651643
ST37     0.0748675353
ST1      0.0748933234
OQ2      0.0759749451    EPS2
EPS2     0.0761773161    2N2
ST2      0.0764054753
ST3      0.0772331498
O2       0.0774613089
2N2      0.0774870970    MU2
MU2      0.0776894680    N2
SNK2     0.0787710897
N2       0.0789992488    M2
NU2      0.0792016198    N2
ST4      0.0794555670
OP2      0.0802832416
GAM2     0.0803090296    H1
H1       0.0803973266    M2
M2       0.0805114007    Z0
H2       0.0806254748    M2
MKS2     0.0807395598    M2
ST5      0.0809677189
ST6      0.0815930224
LDA2     0.0818211815    L2
```

| | | |
|---|---|---|
| L2 | 0.0820235525 | S2 |
| 2SK2 | 0.0831051742 | |
| T2 | 0.0832192592 | S2 |
| S2 | 0.0833333333 | M2 |
| R2 | 0.0834474074 | S2 |
| K2 | 0.0835614924 | S2 |
| MSN2 | 0.0848454852 | ETA2 |
| ETA2 | 0.0850736443 | K2 |
| ST7 | 0.0853018034 | |
| 2SM2 | 0.0861552660 | |
| ST38 | 0.0863576370 | |
| SKM2 | 0.0863834251 | |
| 2SN2 | 0.0876674179 | |
| NO3 | 0.1177299033 | |
| MO3 | 0.1192420551 | M3 |
| M3 | 0.1207671010 | M2 |
| NK3 | 0.1207799950 | |
| SO3 | 0.1220639878 | MK3 |
| MK3 | 0.1222921469 | M3 |
| SP3 | 0.1248859204 | |
| SK3 | 0.1251140796 | MK3 |
| ST8 | 0.1566887168 | |
| N4 | 0.1579984976 | |
| 3MS4 | 0.1582008687 | |
| ST39 | 0.1592824904 | |
| MN4 | 0.1595106495 | M4 |
| ST9 | 0.1597388086 | |
| ST40 | 0.1607946422 | |
| M4 | 0.1610228013 | M3 |
| ST10 | 0.1612509604 | |
| SN4 | 0.1623325821 | M4 |
| KN4 | 0.1625607413 | |
| MS4 | 0.1638447340 | M4 |
| MK4 | 0.1640728931 | MS4 |
| SL4 | 0.1653568858 | |
| S4 | 0.1666666667 | MS4 |
| SK4 | 0.1668948258 | S4 |
| MNO5 | 0.1982413039 | |
| 2MO5 | 0.1997534558 | |
| 3MP5 | 0.1999816149 | |
| MNK5 | 0.2012913957 | |
| 2MP5 | 0.2025753884 | |
| 2MK5 | 0.2028035475 | M4 |
| MSK5 | 0.2056254802 | |
| 3KM5 | 0.2058536393 | |
| 2SK5 | 0.2084474129 | 2MK5 |
| ST11 | 0.2372259056 | |
| 2NM6 | 0.2385098983 | |
| ST12 | 0.2387380574 | |
| 2MN6 | 0.2400220501 | M6 |
| ST13 | 0.2402502093 | |
| ST41 | 0.2413060429 | |
| M6 | 0.2415342020 | 2MK5 |
| MSN6 | 0.2428439828 | |
| MKN6 | 0.2430721419 | |
| ST42 | 0.2441279756 | |
| 2MS6 | 0.2443561347 | M6 |
| 2MK6 | 0.2445842938 | 2MS6 |

```
    NSK6     0.2458940746
    2SM6     0.2471780673    2MS6
    MSK6     0.2474062264    2SM6
    S6       0.2500000000
    ST14     0.2787527046
    ST15     0.2802906445
    M7       0.2817899023
    ST16     0.2830867891
    3MK7     0.2833149482    M6
    ST17     0.2861368809
    ST18     0.3190212990
    3MN8     0.3205334508
    ST19     0.3207616099
    M8       0.3220456027    3MK7
    ST20     0.3233553835
    ST21     0.3235835426
    3MS8     0.3248675353
    3MK8     0.3250956944
    ST22     0.3264054753
    ST23     0.3276894680
    ST24     0.3279176271
    ST25     0.3608020452
    ST26     0.3623141970
    4MK9     0.3638263489
    ST27     0.3666482815
    ST28     0.4010448515
    M10      0.4025570033
    ST29     0.4038667841
    ST30     0.4053789360
    ST31     0.4069168759
    ST32     0.4082008687
    ST33     0.4471596822
    M12      0.4830684040
    ST34     0.4858903367
    ST35     0.4874282766

  .7428797055  .7771900329  .5187051308  .3631582592  .7847990160  000GMT 1/1/76
13.3594019864  .9993368945  .1129517942  .0536893056  .0000477414  INCR./365DAYS
      Z0      0  0  0  0  0  0 0.0    0
      SA      0  0  1  0  0 -1 0.0    0
      SSA     0  0  2  0  0  0 0.0    0
      MSM     0  1 -2  1  0  0  .00   0
      MM      0  1  0 -1  0  0 0.0    0
      MSF     0  2 -2  0  0  0 0.0    0
      MF      0  2  0  0  0  0 0.0    0
      ALP1    1 -4  2  1  0  0 -.25   2
      ALP1  -1  0  0 .75 0.0360R1   0 -1  0 .00 0.1906
      2Q1     1 -3  0  2  0  0-0.25    5
      2Q1   -2 -2  0 .50 0.0063    -1 -1  0 .75 0.0241R1  -1  0  0 .75 0.0607R1
      2Q1     0 -2  0 .50 0.0063      0 -1  0 .0  0.1885
      SIG1    1 -3  2  0  0  0-0.25    4
      SIG1  -1  0  0 .75 0.0095R1   0 -2  0 .50 0.0061      0 -1  0 .0  0.1884
      SIG1    2  0  0 .50 0.0087
      Q1      1 -2  0  1  0  0-0.25   10
      Q1    -2 -3  0 .50 0.0007    -2 -2  0 .50 0.0039    -1 -2  0 .75 0.0010R1
      Q1    -1 -1  0 .75 0.0115R1  -1  0  0 .75 0.0292R1   0 -2  0 .50 0.0057
      Q1    -1  0  1 .0  0.0008     0 -1  0 .0  0.1884      1  0  0 .75 0.0018R1
      Q1      2  0  0 .50 0.0028
```

```
RHO1     1 -2  2 -1  0  0-0.25   5
RHO1   0 -2  0 .50 0.0058      0 -1  0 .0  0.1882      1  0  0 .75 0.0131R1
RHO1   2  0  0 .50 0.0576      2  1  0 .0  0.0175
O1       1 -1  0  0  0  0-0.25   8
O1    -1  0  0 .25 0.0003R1    0 -2  0 .50 0.0058      0 -1  0 .0  0.1885
O1     1 -1  0 .25 0.0004R1    1  0  0 .75 0.0029R1    1  1  0 .25 0.0004R1
O1     2  0  0 .50 0.0064      2  1  0 .50 0.0010
TAU1     1 -1  2  0  0  0-0.75   5
TAU1  -2  0  0 .0  0.0446     -1  0  0 .25 0.0426R1    0 -1  0 .50 0.0284
TAU1   0  1  0 .50 0.2170      0  2  0 .50 0.0142
BET1     1  0 -2  1  0  0 -.75   1
BET1   0 -1  0 .00 0.2266
NO1      1  0  0  1  0  0-0.75   9
NO1   -2 -2  0 .50 0.0057     -2 -1  0 .0  0.0665     -2  0  0 .0  0.3596
NO1   -1 -1  0 .75 0.0331R1   -1  0  0 .25 0.2227R1   -1  1  0 .75 0.0290R1
NO1    0 -1  0 .50 0.0290      0  1  0 .0  0.2004      0  2  0 .50 0.0054
CHI1     1  0  2 -1  0  0-0.75   2
CHI1   0 -1  0 .50 0.0282      0  1  0 .0  0.2187
PI1      1  1 -3  0  0  1-0.25   1
PI1    0 -1  0 .50 0.0078
P1       1  1 -2  0  0  0-0.25   6
P1     0 -2  0 .0  0.0008      0 -1  0 .50 0.0112      0  0  2 .50 0.0004
P1     1  0  0 .75 0.0004R1    2  0  0 .50 0.0015      2  1  0 .50 0.0003
S1       1  1 -1  0  0  1-0.75   2
S1     0  0 -2 .0  0.3534      0  1  0 .50 0.0264
K1       1  1  0  0  0  0-0.75  10
K1    -2 -1  0 .0  0.0002     -1 -1  0 .75 0.0001R1   -1  0  0 .25 0.0007R1
K1    -1  1  0 .75 0.0001R1    0 -2  0 .0  0.0001      0 -1  0 .50 0.0198
K1     0  1  0 .0  0.1356      0  2  0 .50 0.0029      1  0  0 .25 0.0002R1
K1     1  1  0 .25 0.0001R1
PSI1     1  1  1  0  0 -1-0.75   1
PSI1   0  1  0 .0  0.0190
PHI1     1  1  2  0  0  0-0.75   5
PHI1  -2  0  0 .0  0.0344     -2  1  0 .0  0.0106      0  0 -2 .0  0.0132
PHI1   0  1  0 .50 0.0384      0  2  0 .50 0.0185
THE1     1  2 -2  1  0  0 -.75   4
THE1  -2 -1  0 .00  .0300     -1  0  0 .25 0.0141R1    0 -1  0 .50  .0317
THE1   0  1  0 .00  .1993
J1       1  2  0 -1  0  0-0.75  10
J1     0 -1  0 .50 0.0294      0  1  0 .0  0.1980      0  2  0 .50 0.0047
J1     1 -1  0 .75 0.0027R1    1  0  0 .25 0.0816R1    1  1  0 .25 0.0331R1
J1     1  2  0 .25 0.0027R1    2  0  0 .50 0.0152      2  1  0 .50 0.0098
J1     2  2  0 .50 0.0057
OO1      1  3  0  0  0  0-0.75   8
OO1   -2 -1  0 .50 0.0037     -2  0  0 .0  0.1496     -2  1  0 .0  0.0296
OO1   -1  0  0 .25 0.0240R1   -1  1  0 .25 0.0099R1    0  1  0 .0  0.6398
OO1    0  2  0 .0  0.1342      0  3  0 .0  0.0086
UPS1     1  4  0 -1  0  0 -.75   5
UPS1  -2  0  0 .00 0.0611      0  1  0 .00 0.6399      0  2  0 .00 0.1318
UPS1   1  0  0 .25 0.0289R1    1  1  0 .25 0.0257R1
OQ2      2 -3  0  3  0  0 0.0    2
OQ2   -1  0  0 .25 0.1042R2    0 -1  0 .50 0.0386
EPS2     2 -3  2  1  0  0 0.0    3
EPS2  -1 -1  0 .25 0.0075R2   -1  0  0 .25 0.0402R2    0 -1  0 .50 0.0373
2N2      2 -2  0  2  0  0 0.0    4
2N2   -2 -2  0 .50 0.0061     -1 -1  0 .25 0.0117R2   -1  0  0 .25 0.0678R2
2N2    0 -1  0 .50 0.0374
```

```
MU2     2 -2  2  0  0  0 0.0    3
MU2   -1 -1  0 .25 0.0018R2  -1  0  0 .25 0.0104R2   0 -1  0 .50 0.0375
N2      2 -1  0  1  0  0 0.0    4
N2    -2 -2  0 .50 0.0039    -1  0  1 .00 0.0008      0 -2  0 .00 0.0005
N2      0 -1  0 .50 0.0373
NU2     2 -1  2 -1  0  0 0.0    4
NU2     0 -1  0 .50 0.0373     1  0  0 .75 0.0042R2   2  0  0 .0  0.0042
NU2     2  1  0 .50 0.0036
GAM2    2  0 -2  2  0  0 -.50   3
GAM2  -2 -2  0 .00 0.1429    -1  0  0 .25 0.0293R2   0 -1  0 .50 0.0330
H1      2  0 -1  0  0  1-0.50   2
H1      0 -1  0 .50 0.0224     1  0 -1 .50 0.0447
M2      2  0  0  0  0  0 0.0    9
M2    -1 -1  0 .75 0.0001R2  -1  0  0 .75 0.0004R2   0 -2  0 .0  0.0005
M2      0 -1  0 .50 0.0373     1 -1  0 .25 0.0001R2   1  0  0 .75 0.0009R2
M2      1  1  0 .75 0.0002R2   2  0  0 .0  0.0006     2  1  0 .0  0.0002
H2      2  0  1  0  0 -1 0.0    1
H2      0 -1  0 .50 0.0217
LDA2    2  1 -2  1  0  0-0.50   1
LDA2    0 -1  0 .50 0.0448
L2      2  1  0 -1  0  0-0.50   5
L2      0 -1  0 .50 0.0366     2 -1  0 .00 0.0047     2  0  0 .50 0.2505
L2      2  1  0 .50 0.1102     2  2  0 .50 0.0156
T2      2  2 -3  0  0  1 0.0    0
S2      2  2 -2  0  0  0 0.0    3
S2      0 -1  0 .0  0.0022     1  0  0 .75 0.0001R2   2  0  0 .0  0.0001
R2      2  2 -1  0  0 -1-0.50   2
R2      0  0  2 .50 0.2535     0  1  2 .0  0.0141
K2      2  2  0  0  0  0 0.0    5
K2    -1  0  0 .75 0.0024R2  -1  1  0 .75 0.0004R2   0 -1  0 .50 0.0128
K2      0  1  0 .0  0.2980     0  2  0 .0  0.0324
ETA2    2  3  0 -1  0  0 0.0    7
ETA2    0 -1  0 .50 0.0187     0  1  0 .0  0.4355     0  2  0 .0  0.0467
ETA2    1  0  0 .75 0.0747R2   1  1  0 .75 0.0482R2   1  2  0 .75 0.0093R2
ETA2    2  0  0 .50 0.0078
M3      3  0  0  0  0  0 -.50   1
M3      0 -1  0 .50  .0564

2PO1 2   2.0 P1        -1.0 O1
SO1  2   1.0 S2        -1.0 O1
ST36 3   2.0 M2         1.0 N2        -2.0 S2
2NS2 2   2.0 N2        -1.0 S2
ST37 2   3.0 M2        -2.0 S2
ST1  3   2.0 N2         1.0 K2        -2.0 S2
ST2  4   1.0 M2         1.0 N2         1.0 K2        -2.0 S2
ST3  3   2.0 M2         1.0 S2        -2.0 K2
O2   1   2.0 O1
ST4  3   2.0 K2         1.0 N2        -2.0 S2
SNK2 3   1.0 S2         1.0 N2        -1.0 K2
OP2  2   1.0 O1         1.0 P1
MKS2 3   1.0 M2         1.0 K2        -1.0 S2
ST5  3   1.0 M2         2.0 K2        -2.0 S2
ST6  4   2.0 S2         1.0 N2        -1.0 M2        -1.0 K2
2SK2 2   2.0 S2        -1.0 K2
MSN2 3   1.0 M2         1.0 S2        -1.0 N2
ST7  4   2.0 K2         1.0 M2        -1.0 S2        -1.0 N2
2SM2 2   2.0 S2        -1.0 M2
```

```
ST38 3   2.0 M2          1.0 S2         -2.0 N2
SKM2 3   1.0 S2          1.0 K2         -1.0 M2
2SN2 2   2.0 S2         -1.0 N2
NO3  2   1.0 N2          1.0 O1
MO3  2   1.0 M2          1.0 O1
NK3  2   1.0 N2          1.0 K1
SO3  2   1.0 S2          1.0 O1
MK3  2   1.0 M2          1.0 K1
SP3  2   1.0 S2          1.0 P1
SK3  2   1.0 S2          1.0 K1
ST8  3   2.0 M2          1.0 N2         -1.0 S2
N4   1   2.0 N2
3MS4 2   3.0 M2         -1.0 S2
ST39 4   1.0 M2          1.0 S2          1.0 N2         -1.0 K2
MN4  2   1.0 M2          1.0 N2
ST40 3   2.0 M2          1.0 S2         -1.0 K2
ST9  4   1.0 M2          1.0 N2          1.0 K2         -1.0 S2
M4   1   2.0 M2
ST10 3   2.0 M2          1.0 K2         -1.0 S2
SN4  2   1.0 S2          1.0 N2
KN4  2   1.0 K2          1.0 N2
MS4  2   1.0 M2          1.0 S2
MK4  2   1.0 M2          1.0 K2
SL4  2   1.0 S2          1.0 L2
S4   1   2.0 S2
SK4  2   1.0 S2          1.0 K2
MNO5 3   1.0 M2          1.0 N2          1.0 O1
2MO5 2   2.0 M2          1.0 O1
3MP5 2   3.0 M2         -1.0 P1
MNK5 3   1.0 M2          1.0 N2          1.0 K1
2MP5 2   2.0 M2          1.0 P1
2MK5 2   2.0 M2          1.0 K1
MSK5 3   1.0 M2          1.0 S2          1.0 K1
3KM5 3   1.0 K2          1.0 K1          1.0 M2
2SK5 2   2.0 S2          1.0 K1
ST11 3   3.0 N2          1.0 K2         -1.0 S2
2NM6 2   2.0 N2          1.0 M2
ST12 4   2.0 N2          1.0 M2          1.0 K2         -1.0 S2
ST41 3   3.0 M2          1.0 S2         -1.0 K2
2MN6 2   2.0 M2          1.0 N2
ST13 4   2.0 M2          1.0 N2          1.0 K2         -1.0 S2
M6   1   3.0 M2
MSN6 3   1.0 M2          1.0 S2          1.0 N2
MKN6 3   1.0 M2          1.0 K2          1.0 N2
2MS6 2   2.0 M2          1.0 S2
2MK6 2   2.0 M2          1.0 K2
NSK6 3   1.0 N2          1.0 S2          1.0 K2
2SM6 2   2.0 S2          1.0 M2
MSK6 3   1.0 M2          1.0 S2          1.0 K2
ST42 3   2.0 M2          2.0 S2         -1.0 K2
S6   1   3.0 S2
ST14 3   2.0 M2          1.0 N2          1.0 O1
ST15 3   2.0 N2          1.0 M2          1.0 K1
M7   1   3.5 M2
ST16 3   2.0 M2          1.0 S2          1.0 O1
3MK7 2   3.0 M2          1.0 K1
ST17 4   1.0 M2          1.0 S2          1.0 K2          1.0 O1
ST18 2   2.0 M2          2.0 N2
```

```
3MN8 2   3.0 M2         1.0 N2
ST19 4   3.0 M2         1.0 N2         1.0 K2        -1.0 S2
M8   1   4.0 M2
ST20 3   2.0 M2         1.0 S2         1.0 N2
ST21 3   2.0 M2         1.0 N2         1.0 K2
3MS8 2   3.0 M2         1.0 S2
3MK8 2   3.0 M2         1.0 K2
ST22 4   1.0 M2         1.0 S2         1.0 N2         1.0 K2
ST23 2   2.0 M2         2.0 S2
ST24 3   2.0 M2         1.0 S2         1.0 K2
ST25 3   2.0 M2         2.0 N2         1.0 K1
ST26 3   3.0 M2         1.0 N2         1.0 K1
4MK9 2   4.0 M2         1.0 K1
ST27 3   3.0 M2         1.0 S2         1.0 K1
ST28 2   4.0 M2         1.0 N2
M10  1   5.0 M2
ST29 3   3.0 M2         1.0 N2         1.0 S2
ST30 2   4.0 M2         1.0 S2
ST31 4   2.0 M2         1.0 N2         1.0 S2         1.0 K2
ST32 2   3.0 M2         2.0 S2
ST33 3   4.0 M2         1.0 S2         1.0 K1
M12  1   6.0 M2
ST34 2   5.0 M2         1.0 S2
ST35 4   3.0 M2         1.0 N2         1.0 K2         1.0 S2
```

## **Appendix 7.2** Sample Tidal Station Input Data for the Analysis Program.

The following sample input for file reference numbers 4, 10 and 11 will produce an analysis of Race Rocks, British Columbia current data for the period 1400 PST February 8, 1972 to 2400 PST March 3, 1972 inclusive. Constituents $P_1$ and $K_2$ will be inferred, shallow water constituent $M_{10}$ is specifically designated for analysis inclusion, a scaling compensation will be made for the application of moving average filters to the original 10-min data and hourly component values based on the analysis results will be produced on file reference numbers 12 and 13. Note that missing hourly observations are denoted by 99999. Final results as given by the line printer are shown in Appendix 7.3.

(i) File reference number 4 input data:

```
1.00 0.010        0    1    3
 10.00       6    6    7
 K1    0.0417807462  P1    0.0415525871  0.311807  0.197553    -4.5       -0.2
 S2    0.0833333333  K2    0.0835614924  0.191983  0.212745   -14.8       27.2

    M10      M8

 14080272  24150372
    7077 RACE ROCKS SMOOTH&PAD PST 481413912
```

(ii) File reference number 10 input data (hourly north/south current components):

```
1  7077         8 272999999999999999999999999999999999999999999999999999999999999999
2  7077         8 27299999  166  262  141  -20 -176  -26   28  128  288  133 -144
1  7077         9 272 -108  -14   60   38  -95  -84   41   83   91   84   30   14
2  7077         9 272   23  110  165   95   25 -107 -143   14  -39   -1  -21 -141
1  7077        10 272 -188 -148   50  124   69  -82 -196 -187  -85  -24   19   17
2  7077        10 272  -84  -95    0   72   48  -56 -115  -74  -45 -159  -73 -116
1  7077        11 272 -134  -27 -125 -114  -12  -18 -127 -131 -169 -154  -49 -110
2  7077        11 272 -230 -345 -223   26  166  133   83   24   92   70  -49  -58
1  7077        12 272 -151 -214 -341 -246  -12   67 -116 -258 -367 -368 -226  -68
2  7077        12 272  -49 -100 -125 -273 -140   82   66   59  -99  -48   88   66
1  7077        13 272 -124 -294 -303 -358 -206    1 -168 -316 -360 -417 -309 -138
2  7077        13 272   57   69  149  -41 -277 -101  178  272  177  -18   62  118
1  7077        14 272   63 -109 -424 -514 -373 -174  -72 -380 -206   76  -78 -230
2  7077        14 272 -187  135  270  328  122 -285   11  146  104  116  -30   48
1  7077        15 272  139  145   30 -226 -405 -237   47   48   -1   52  -42   17
2  7077        15 272  -25  -84  136  265  339  254   -8   -3   15  124   76   67
1  7077        16 272  258  135 -102 -242 -138  181  305  188   84  103  195  193
2  7077        16 272  100   38  202  288   97  164  228  106  250  310  231  266
1  7077        17 272  144   98  133   38  -45   24  300  132    3   59  168  154
2  7077        17 272   85  114  164  131  -18 -116   -5   95  -20  -88  -36   41
1  7077        18 272  126  117   69   37 -156 -350 -285  -50  100  -32   54  116
2  7077        18 272  112   87  131  153   15   55   19    3   -7  -52 -282 -345
1  7077        19 272 -171  162  159   13 -138 -212 -104   -4   87    9   64  114
2  7077        19 272  211   92    0  107  102   60  -15 -265 -179  -68  -45  -47
1  7077        20 272  -22   63  124   81  -69 -136 -128  -84   39   16   70   68
2  7077        20 272   35  184  119   65  156  207   21 -363 -317  -44   43  -58
1  7077        21 272  -91  -48   -4   70  -41 -151 -133  -22    2   16  -26   18
2  7077        21 272  -15    6  125   86   72   55   61  -16 -265 -258    1   36
1  7077        22 272   47   94   89   24   98  126   60   -7   30   91  100   38
2  7077        22 272  -36   57  121  119   31   24   33   92   93 -183  -94  228
1  7077        23 272  327  253  231  150  129  185  180   70  -33  -30   14   80
2  7077        23 272   20  -38  -20  -11  -35   10   52   60  108  112 -131 -320
1  7077        24 272 -151   32   69  156   24 -122 -149 -187  -70   41   45  -31
2  7077        24 272  -74 -150 -120  -54    6  -55  -77  109   73   13  194   32
1  7077        25 272 -195 -253 -168   17  120  -25 -124 -377 -459 -246 -115  -58
2  7077        25 272  -81 -144 -216 -153  -90   18  -30  -78   18    4   32  182
1  7077        26 272   -2 -322 -272  135  255  110 -198 -353 -295 -370 -607 -532
2  7077        26 272 -422 -399 -282 -207 -135 -101  -32    7 -179 -107   40   18
1  7077        27 272  -32 -171 -371 -509 -343  -68 -139 -450 -332 -107  -96 -129
2  7077        27 272 -369 -474 -470 -332 -244 -136  -57   99  184   54  102  147
1  7077        28 272   22 -130 -254 -367 -260  -79   11 -189 -289 -112  -32   35
2  7077        28 272   93  180  233  157   17  -63 -207 -105   66  163   91   76
1  7077        29 272   15 -161 -226 -275 -186   47  -39 -183 -212 -131  -22  -34
2  7077        29 272   18   68   48   66   -4  140   75   42   94  146  173   74
1  7077         1 372  -11   22 -125 -292  -25  236  126   46  104  223  255  202
2  7077         1 372  145  146 -103 -269 -245   81  178  -27 -233  -36  167   78
1  7077         2 372  -11   45   46 -142 -215 -168   30   39  -63  -12   24   29
2  7077         2 372   76  187  114   32   20  -51   68  104   37  -51  -95   26
1  7077         3 372  167  191  190   67  -39  -29   68   96  -69   14  157  113
2  7077         3 372   46  174   46   52   92   27   -6   -5   29   40  -34  -40
1  7077         4 372   36   90  145   -4 -154 -137  -19   27  -50  -96   37  199
2  7077         4 372  203  219  209   71   74   20 -149 -194 -113   62   88  -11
```

```
1  7077        5 372  -24  -16  -91 -187 -182 -128  -42   44   96   59   37  143
2  7077        5 372  150   33    3  129   15   25  -69 -187 -198   -2  142  -17
1  7077        6 372 -253 -204 -149 -154 -154 -115  -40   92  147   28 -132  -62
2  7077        6 3729999999999999999999999999   10   92   10  -58   -1   62   64
1  7077        7 372   -1 -133 -213 -151  -86  -47   -1  -22   -7   -3   -8   32
2  7077        7 372  128  103   14   -4   25  -89   14   90  -18  -53  -14  125
1  7077        8 372  206   50    7  -57  -73  -25   -1   38   73   65  -27  -74
2  7077        8 372  -38   65  -37 -143 -126 -100 -115  -47  -36   12   38    8
1  7077        9 372  -30   46    0 -110  -63  -44   -2   43   17   39   32  -18
2  7077        9 372  -87 -118  108  134  -40  -45  -16  -56   26   34   13   10
1  7077       10 372  -89 -102  -37   61  -80 -265 -213 -127  -86  -36  -10 -121
2  7077       10 372 -182 -171  -67   71   27 -160 -138  -47  -46   28   23 -129
1  7077       11 372 -334 -330 -163 -107 -232 -357 -306 -329 -449 -515 -513 -443
2  7077       11 372 -307 -239 -282 -155   59  -42 -245 -242 -146 -125   34   47
1  7077       12 372  -53 -240 -246 -118  -60 -139 -227 -326 -428 -509 -627 -516
2  7077       12 372 -310 -178 -325 -519 -259  -21  -29  -29  -89  -57  -28  128
1  7077       13 372  148 -131 -320 -235 -121 -160 -287 -358 -479 -283 -197 -172
2  7077       13 372   31  159  142  167  -57 -248  -51  100   23 -111  -46   82
1  7077       14 372  180   39 -105  -76   13   -5 -208 -407 -255 -237  -76  104
2  7077       14 372  176  192   96   45    7  -54 -196 -170  -25  -55  -48   52
1  7077       15 372   76  139  159   62  -77  -68 -211 -519 -308  -75   -7  145
2  7077       15 372   77  140  253  240   -1   34   67   74  105  174  221  240
```

(iii) File reference number 10 input data (hourly north/south current components):

```
1  7077        8 272999999999999999999999999999999999999999999999999999999999999
2  7077        8 27299999 -755 -802 -687 -688 -551 -221   41  301  557  684  633
1  7077        9 272  534  363  203  163   46  -90  -66  -30  -25  -20 -119 -326
2  7077        9 272 -553 -716 -771 -739 -503 -343 -354 -124  135  375  672  813
1  7077       10 272  713  586  379  187  109    4  -81 -178 -234 -278 -350 -519
2  7077       10 272 -693 -767 -738 -863 -961 -882 -705 -422  -39  290  620  845
1  7077       11 272  882  839  518  199   12 -109 -281 -590 -572 -485 -449 -437
2  7077       11 272 -626 -802 -851 -885-1140-1202-1059 -800 -355   88  471  856
1  7077       12 272 1044  887  471   40 -208 -228 -345 -578 -609 -523 -343 -176
2  7077       12 272 -220 -553 -814 -955-1162-1447-1545-1210 -640 -162  354 1092
1  7077       13 272 1454 1338 1020  413 -114 -316 -462 -725 -803 -608 -443 -429
2  7077       13 272 -378 -401 -535 -721 -866-1214-1455-1363-1080 -514   97  579
1  7077       14 272 1122 1542 1248  795  232 -216 -458 -773 -699 -328  -61  -82
2  7077       14 272  -45   41   71 -112 -525 -893-1315-1494-1378 -845 -263  282
1  7077       15 272  820 1282 1525 1294  658  -89 -530 -574 -550 -411 -143  131
2  7077       15 272  452  215   41  -73 -347 -879-1108-1322-1434-1115 -487  180
1  7077       16 272  706 1093 1372 1222  865  376  -48 -401 -583 -600 -465 -101
2  7077       16 272  511  639  617  554  400    9 -320 -732-1120-1230 -919 -228
1  7077       17 272  652 1076 1321 1581 1329  861  317 -156 -517 -636 -638 -397
2  7077       17 272   -7  484  565  658  679  369  -27 -407 -719 -915 -902 -752
1  7077       18 272 -318  319  851 1159 1072  743  370 -158 -653-1108-1294-1121
2  7077       18 272 -861 -460   29  413  710  706  447   97 -202 -518 -766 -737
1  7077       19 272 -539 -124  401  826  859  686  312 -129 -621-1043-1300-1328
2  7077       19 272-1178 -771 -264  196  508  728  721  578  206 -161 -393 -478
1  7077       20 272 -429 -203  184  616  804  725  434   59 -307 -714-1203-1625
2  7077       20 272-1623-1211 -687 -132  220  486  845  897  589  522  428  270
1  7077       21 272  152  132  208  403  592  619  489  320  126 -319 -847-1225
2  7077       21 272-1425-1361-1082 -616   32  471  537  825  950  693  631  597
1  7077       22 272  323   53  -45  -12  111  236  360  336  163  -36 -299 -829
2  7077       22 272-1223-1371-1299 -885 -385  268  465  466  838  990  735  671
1  7077       23 272  564  364   80   -2  -44  -23  110  249  283  161  -88 -404
2  7077       23 272 -636 -812-1102-1227-1073 -528  155  274  589  992 1142 1067
1  7077       24 272  837  605  367   85  -79 -219 -310 -195   38  101  -29 -156
2  7077       24 272 -347 -730-1031-1213-1328-1166 -744  -24  223  440  880 1249
1  7077       25 272 1232  895  409  115  -68 -194 -371 -448 -279  199  430  314
2  7077       25 272    9 -333 -792-1095-1264-1341-1162 -638  -82  271  568  965
1  7077       26 272 1334 1129  699  453  104 -267 -591 -564 -484 -248  -13  306
2  7077       26 272  357   66 -310 -741-1098-1260-1301-1120 -725 -183  271  627
1  7077       27 272 1130 1355  960  273 -214 -468 -625 -830 -619 -236  -11   66
2  7077       27 272  254  249   50 -307 -745-1066-1346-1446-1188 -770 -148  311
1  7077       28 272  796 1182 1135  731  173 -243 -542 -792 -823 -578 -344  -60
2  7077       28 272    0  135  166  -24 -198 -561-1004-1235-1143 -672  -23  463
1  7077       29 272  699  986 1150 1065  567  247  -79 -385 -547 -515 -233  172
2  7077       29 272  296  404  370  235   31  -39 -300 -853 -950 -623  -43  641
1  7077        1 372  965 1128 1293 1219  905  533  173 -243 -504 -388 -136  309
2  7077        1 372  628  744  912  794  362  -62 -309 -601 -881 -891 -502  115
1  7077        2 372  394  542  904  890  536  141 -281 -550 -922-1170-1063 -831
2  7077        2 372 -302  217  341  564  535  293  -72 -336 -582 -782 -728 -444
1  7077        3 372  -64  257  541  698  550  217 -138 -495 -873-1131-1241-1048
2  7077        3 372 -537  140  363  525  699  597  381  140  -59 -313 -586 -572
1  7077        4 372 -271   13  373  719  658  432  140 -201 -583-1008-1195-1060
2  7077        4 372 -705 -194  233  331  610  738  637  357   80 -113 -188 -203
```

```
1  7077         5 372  -52  191  454  605  505  317   49 -302 -653 -896-1140-1286
2  7077         5 372-1049 -660 -228  103  206  458  554  497  261    8  -56   -4
1  7077         6 372  -25  -70   11  197  267  144 -107 -424 -717-1068-1226-1311
2  7077         6 3729999999999999999999999999  178  426  474  308  200  237  134
1  7077         7 372   76   70  138  160  273  385  314   89 -170 -419 -679 -891
2  7077         7 372-1022 -965 -700 -335   -3  180  373  628  758  674  369  151
1  7077         8 372   77   37   23   61   33  -24  -86 -156 -336 -615 -736 -755
2  7077         8 372 -830 -955 -905 -662 -424 -134  108  316  473  506  494  405
1  7077         9 372  226   -5  -95 -185 -253 -298 -342 -357 -348 -403 -479 -621
2  7077         9 372 -748 -757 -794 -875 -740 -484 -157    8  187  400  524  537
1  7077        10 372  418  156 -129 -270 -385 -528 -485 -430 -374 -298 -346 -487
2  7077        10 372 -608 -703 -725 -810 -937 -828 -539 -181   87  405  740  824
1  7077        11 372  657  426  173  -79 -263 -512 -622 -495 -456 -467 -442 -368
2  7077        11 372 -401 -493 -621 -775-1021-1184 -941 -477 -126  164  511  754
1  7077        12 372  896  713  203 -107 -301 -474 -577 -664 -577 -394 -405 -405
2  7077        12 372 -282 -184 -376 -708 -981-1276-1235 -927 -443  -68  242  578
1  7077        13 372  949 1116  789  140 -233 -463 -769 -899 -939 -706 -403 -214
2  7077        13 372  -98  -47  -59 -325 -885-1185-1437-1371 -866 -396  -50  327
1  7077        14 372  767 1107  932  469   30 -357 -775 -979 -974 -629 -310   69
2  7077        14 372  276  416  455  308  -69 -702-1305-1310-1170 -748  -94  223
1  7077        15 372  510  738  890  871  399 -109 -635-1101-1205-1163 -715 -172
2  7077        15 372  132  300  375  347  179 -212 -588 -881-1119 -972 -551    5
```

## **Appendix 7.3** Final Analysis Results Arising from the Input Data of Appendix 7.2 and the Standard Constituent Data Package of Appendix 7.1.

```
FINAL ANALYSIS RESULTS IN CURRENT ELLIPSE FORM
----------------------------------------------

FOR STATION 7077, RACE ROCKS SMOOTH&PAD ,AT THE LOCATION 48 14, 139 12 OVER
THE PERIOD OF 14HR  8/ 2/72  TO  24HR 15/ 3/72

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF MOVING
AVERAGE FILTERS
GREENWICH PHASES ARE FOR TIME ZONE  PST

   NAME      SPEED        MAJOR   MINOR    INC     G      G+     G-
 1 Z0    0.00000000     0.945   0.000   13.5  180.0  166.5  193.5
 2 MM    0.00151215     0.787  -0.072    2.0   85.7   83.7   87.7
 3 MSF   0.00282193     1.087  -0.008   47.2  106.8   59.6  154.0
 4 ALP1  0.03439657     0.113  -0.037  162.3  332.0  169.8  134.3
 5 2Q1   0.03570635     0.442  -0.052    5.1  121.5  116.5  126.6
 6 Q1    0.03721850     0.461  -0.065  175.1  236.9   61.8   51.9
 7 O1    0.03873065     2.410  -0.253  177.5  250.2   72.8   67.7
 8 NO1   0.04026859     0.494  -0.112    6.8   92.2   85.5   99.0
 9 P1    0.04155259     1.272   0.232  178.7  270.5   91.8   89.3 INF FR K1
10 K1    0.04178075     5.043  -0.221    0.9   88.2   87.3   89.1
11 J1    0.04329290     0.142   0.103   22.9  123.9  101.0  146.8
12 OO1   0.04483084     0.455   0.125  125.7  334.4  208.8  100.1
13 UPS1  0.04634299     0.180   0.070  159.3   27.1  227.8  186.4
14 EPS2  0.07617731     0.198  -0.028   41.4  136.8   95.3  178.2
15 MU2   0.07768947     0.409   0.048    8.1  293.2  285.1  301.2
16 N2    0.07899925     1.369  -0.035  173.8  225.2   51.4   39.0
17 M2    0.08051140     6.980  -0.295  178.3  249.2   70.9   67.6
18 L2    0.08202355     0.390  -0.240  174.1  107.1  293.0  281.2
19 S2    0.08333334     2.278  -0.148    5.9   90.6   84.7   96.4
20 K2    0.08356149     0.462  -0.054  164.9  264.4   99.5   69.2 INF FR S2
21 ETA2  0.08507364     0.157  -0.024   76.9   62.8  345.9  139.7
22 MO3   0.11924206     0.343  -0.135   21.4  344.9  323.4    6.3
23 M3    0.12076710     0.265   0.139  155.2   99.3  304.2  254.5
24 MK3   0.12229215     0.346  -0.096  115.0   18.4  263.4  133.4
25 SK3   0.12511408     0.219  -0.179  169.1  321.1  152.0  130.2
26 MN4   0.15951066     0.289  -0.078   49.4  258.5  209.1  307.9
27 M4    0.16102280     0.383   0.182  141.6  114.6  333.1  256.2
28 SN4   0.16233259     0.084  -0.024   34.1  197.6  163.5  231.7
29 MS4   0.16384473     0.366  -0.083   74.0   40.2  326.2  114.2
30 S4    0.16666667     0.089   0.015   91.1   18.1  287.0  109.2
31 2MK5  0.20280355     0.423  -0.072  143.2  129.6  346.4  272.9
32 2SK5  0.20844743     0.154   0.006   61.8  159.3   97.4  221.1
33 2MN6  0.24002205     0.169   0.027  117.2   85.6  328.4  202.8
34 M6    0.24153420     0.350  -0.048  174.1  111.3  297.2  285.4
35 2MS6  0.24435614     0.238  -0.194   95.2  202.8  107.6  298.0
36 2SM6  0.24717808     0.156  -0.120   97.2  184.9   87.6  282.1
37 3MK7  0.28331494     0.145   0.041   25.5  265.7  240.2  291.3
38 M8    0.32204559     0.184  -0.074   18.9  321.7  302.9  340.6
39 M10   0.40255699     0.214   0.087   45.7  322.7  277.0    8.4

AFTER INFERENCE, X RMS(RESID ER)= 1.57687,  AND  Y RMS(RESID ER)= 1.29416
```

## **Appendix 7.4** Sample Input for the Tidal Currents Prediction Program.

The following sample input for file reference number 8 will synthesize three sets of currents at Race Rocks, British Columbia:

(i) the times, magnitudes and directions of all maximum and minimum values for the period 0100 PST July 1, 1976 to 2400 PST July 31, 1976,

(ii) the magnitudes and directions of hourly currents for the period 0100 PST July 1, 1976 to 2400 PST July 5, 1976,

(iii) the north/south and east/west hourly current components for the period 0100 PST July 1, 1976 to 2400 PST July 31, 1976.

Note that the ellipse parameter and phase input values of the constituents to be used in the prediction were selected from the results listed in Appendix 7.3. The number of the constituent, its frequency and its $g^+$ and $g^-$ values are not required.

The output results for file reference numbers 10, 11 and 12 are listed in Appendix 7.5.

```
  .7428797055  .7771900329  .5187051308  .3631582592  .7847990160  000GMT 1/1/76
13.3594019864  .9993368945  .1129517942  .0536893056  .0000477414  INCR./365DAYS
      Z0      0  0  0  0  0  0 0.0    0
      SA      0  0  1  0  0 -1 0.0    0
      SSA     0  0  2  0  0  0 0.0    0
      MSM     0  1 -2  1  0  0  .00   0
      MM      0  1  0 -1  0  0 0.0    0
      MSF     0  2 -2  0  0  0 0.0    0
      MF      0  2  0  0  0  0 0.0    0
      ALP1    1 -4  2  1  0  0 -.25   2
      ALP1  -1  0  0 .75 0.0360R1   0 -1  0 .00 0.1906
      2Q1     1 -3  0  2  0  0-0.25   5
      2Q1   -2 -2  0 .50 0.0063    -1 -1  0 .75 0.0241R1  -1  0  0 .75 0.0607R1
      2Q1    0 -2  0 .50 0.0063     0 -1  0 .0  0.1885
      SIG1    1 -3  2  0  0  0-0.25   4
      SIG1  -1  0  0 .75 0.0095R1   0 -2  0 .50 0.0061     0 -1  0 .0  0.1884
      SIG1   2  0  0 .50 0.0087
      Q1      1 -2  0  1  0  0-0.25  10
      Q1    -2 -3  0 .50 0.0007    -2 -2  0 .50 0.0039    -1 -2  0 .75 0.0010R1
      Q1    -1 -1  0 .75 0.0115R1  -1  0  0 .75 0.0292R1   0 -2  0 .50 0.0057
      Q1    -1  0  1 .0  0.0008     0 -1  0 .0  0.1884     1  0  0 .75 0.0018R1
      Q1     2  0  0 .50 0.0028
      RHO1    1 -2  2 -1  0  0-0.25   5
      RHO1   0 -2  0 .50 0.0058     0 -1  0 .0  0.1882     1  0  0 .75 0.0131R1
      RHO1   2  0  0 .50 0.0576     2  1  0 .0  0.0175
      O1      1 -1  0  0  0  0-0.25   8
      O1    -1  0  0 .25 0.0003R1   0 -2  0 .50 0.0058     0 -1  0 .0  0.1885
      O1     1 -1  0 .25 0.0004R1   1  0  0 .75 0.0029R1   1  1  0 .25 0.0004R1
      O1     2  0  0 .50 0.0064     2  1  0 .50 0.0010
      TAU1    1 -1  2  0  0  0-0.75   5
      TAU1  -2  0  0 .0  0.0446    -1  0  0 .25 0.0426R1   0 -1  0 .50 0.0284
      TAU1   0  1  0 .50 0.2170     0  2  0 .50 0.0142
```

```
BET1    1  0 -2  1  0  0 -.75   1
BET1   0 -1  0 .00 0.2266
NO1     1  0  0  1  0  0-0.75   9
NO1   -2 -2  0 .50 0.0057    -2 -1  0 .0  0.0665    -2  0  0 .0  0.3596
NO1   -1 -1  0 .75 0.0331R1  -1  0  0 .25 0.2227R1  -1  1  0 .75 0.0290R1
NO1    0 -1  0 .50 0.0290     0  1  0 .0  0.2004     0  2  0 .50 0.0054
CHI1    1  0  2 -1  0  0-0.75   2
CHI1   0 -1  0 .50 0.0282     0  1  0 .0  0.2187
PI1     1  1 -3  0  0  1-0.25   1
PI1    0 -1  0 .50 0.0078
P1      1  1 -2  0  0  0-0.25   6
P1     0 -2  0 .0  0.0008     0 -1  0 .50 0.0112     0  0  2 .50 0.0004
P1     1  0  0 .75 0.0004R1   2  0  0 .50 0.0015     2  1  0 .50 0.0003
S1      1  1 -1  0  0  1-0.75   2
S1     0  0 -2 .0  0.3534     0  1  0 .50 0.0264
K1      1  1  0  0  0  0-0.75  10
K1    -2 -1  0 .0  0.0002    -1 -1  0 .75 0.0001R1  -1  0  0 .25 0.0007R1
K1    -1  1  0 .75 0.0001R1   0 -2  0 .0  0.0001     0 -1  0 .50 0.0198
K1     0  1  0 .0  0.1356     0  2  0 .50 0.0029     1  0  0 .25 0.0002R1
K1     1  1  0 .25 0.0001R1
PSI1    1  1  1  0  0 -1-0.75   1
PSI1   0  1  0 .0  0.0190
PHI1    1  1  2  0  0  0-0.75   5
PHI1  -2  0  0 .0  0.0344    -2  1  0 .0  0.0106     0  0 -2 .0  0.0132
PHI1   0  1  0 .50 0.0384     0  2  0 .50 0.0185
THE1    1  2 -2  1  0  0 -.75   4
THE1  -2 -1  0 .00  .0300    -1  0  0 .25 0.0141R1   0 -1  0 .50  .0317
THE1   0  1  0 .00  .1993
J1      1  2  0 -1  0  0-0.75  10
J1     0 -1  0 .50 0.0294     0  1  0 .0  0.1980     0  2  0 .50 0.0047
J1     1 -1  0 .75 0.0027R1   1  0  0 .25 0.0816R1   1  1  0 .25 0.0331R1
J1     1  2  0 .25 0.0027R1   2  0  0 .50 0.0152     2  1  0 .50 0.0098
J1     2  2  0 .50 0.0057
OO1     1  3  0  0  0  0-0.75   8
OO1   -2 -1  0 .50 0.0037    -2  0  0 .0  0.1496    -2  1  0 .0  0.0296
OO1   -1  0  0 .25 0.0240R1  -1  1  0 .25 0.0099R1   0  1  0 .0  0.6398
OO1    0  2  0 .0  0.1342     0  3  0 .0  0.0086
UPS1    1  4  0 -1  0  0 -.75   5
UPS1  -2  0  0 .00 0.0611     0  1  0 .00 0.6399     0  2  0 .00 0.1318
UPS1   1  0  0 .25 0.0289R1   1  1  0 .25 0.0257R1
OQ2     2 -3  0  3  0  0 0.0     2
OQ2   -1  0  0 .25 0.1042R2   0 -1  0 .50 0.0386
EPS2    2 -3  2  1  0  0 0.0     3
EPS2  -1 -1  0 .25 0.0075R2  -1  0  0 .25 0.0402R2   0 -1  0 .50 0.0373
2N2     2 -2  0  2  0  0 0.0     4
2N2   -2 -2  0 .50 0.0061    -1 -1  0 .25 0.0117R2  -1  0  0 .25 0.0678R2
2N2    0 -1  0 .50 0.0374
MU2     2 -2  2  0  0  0 0.0     3
MU2   -1 -1  0 .25 0.0018R2  -1  0  0 .25 0.0104R2   0 -1  0 .50 0.0375
N2      2 -1  0  1  0  0 0.0     4
N2    -2 -2  0 .50 0.0039    -1  0  1 .00 0.0008     0 -2  0 .00 0.0005
N2     0 -1  0 .50 0.0373
NU2     2 -1  2 -1  0  0 0.0     4
NU2    0 -1  0 .50 0.0373     1  0  0 .75 0.0042R2   2  0  0 .0  0.0042
NU2    2  1  0 .50 0.0036
GAM2    2  0 -2  2  0  0 -.50   3
GAM2  -2 -2  0 .00 0.1429    -1  0  0 .25 0.0293R2   0 -1  0 .50 0.0330
```

```
H1      2  0 -1  0  0  1-0.50   2
H1     0 -1  0 .50 0.0224     1  0 -1 .50 0.0447
M2      2  0  0  0  0  0 0.0    9
M2    -1 -1  0 .75 0.0001R2  -1  0  0 .75 0.0004R2   0 -2  0 .0  0.0005
M2     0 -1  0 .50 0.0373     1 -1  0 .25 0.0001R2   1  0  0 .75 0.0009R2
M2     1  1  0 .75 0.0002R2   2  0  0 .0  0.0006     2  1  0 .0  0.0002
H2      2  0  1  0  0 -1 0.0    1
H2     0 -1  0 .50 0.0217
LDA2    2  1 -2  1  0  0-0.50   1
LDA2   0 -1  0 .50 0.0448
L2      2  1  0 -1  0  0-0.50   5
L2     0 -1  0 .50 0.0366     2 -1  0 .00 0.0047     2  0  0 .50 0.2505
L2     2  1  0 .50 0.1102     2  2  0 .50 0.0156
T2      2  2 -3  0  0  1 0.0    0
S2      2  2 -2  0  0  0 0.0    3
S2     0 -1  0 .0  0.0022     1  0  0 .75 0.0001R2   2  0  0 .0  0.0001
R2      2  2 -1  0  0 -1-0.50   2
R2     0  0  2 .50 0.2535     0  1  2 .0  0.0141
K2      2  2  0  0  0  0 0.0    5
K2    -1  0  0 .75 0.0024R2  -1  1  0 .75 0.0004R2   0 -1  0 .50 0.0128
K2     0  1  0 .0  0.2980     0  2  0 .0  0.0324
ETA2    2  3  0 -1  0  0 0.0    7
ETA2   0 -1  0 .50 0.0187     0  1  0 .0  0.4355     0  2  0 .0  0.0467
ETA2   1  0  0 .75 0.0747R2   1  1  0 .75 0.0482R2   1  2  0 .75 0.0093R2
ETA2   2  0  0 .50 0.0078
M3      3  0  0  0  0  0 -.50   1
M3     0 -1  0 .50  .0564

2PO1 2   2.0 P1        -1.0 O1
SO1  2   1.0 S2        -1.0 O1
ST36 3   2.0 M2         1.0 N2        -2.0 S2
2NS2 2   2.0 N2        -1.0 S2
ST37 2   3.0 M2        -2.0 S2
ST1  3   2.0 N2         1.0 K2        -2.0 S2
ST2  4   1.0 M2         1.0 N2         1.0 K2        -2.0 S2
ST3  3   2.0 M2         1.0 S2        -2.0 K2
O2   1   2.0 O1
ST4  3   2.0 K2         1.0 N2        -2.0 S2
SNK2 3   1.0 S2         1.0 N2        -1.0 K2
OP2  2   1.0 O1         1.0 P1
MKS2 3   1.0 M2         1.0 K2        -1.0 S2
ST5  3   1.0 M2         2.0 K2        -2.0 S2
ST6  4   2.0 S2         1.0 N2        -1.0 M2        -1.0 K2
2SK2 2   2.0 S2        -1.0 K2
MSN2 3   1.0 M2         1.0 S2        -1.0 N2
ST7  4   2.0 K2         1.0 M2        -1.0 S2        -1.0 N2
2SM2 2   2.0 S2        -1.0 M2
ST38 3   2.0 M2         1.0 S2        -2.0 N2
SKM2 3   1.0 S2         1.0 K2        -1.0 M2
2SN2 2   2.0 S2        -1.0 N2
NO3  2   1.0 N2         1.0 O1
MO3  2   1.0 M2         1.0 O1
NK3  2   1.0 N2         1.0 K1
SO3  2   1.0 S2         1.0 O1
MK3  2   1.0 M2         1.0 K1
SP3  2   1.0 S2         1.0 P1
SK3  2   1.0 S2         1.0 K1
```

```
ST8  3   2.0 M2         1.0 N2        -1.0 S2
N4   1   2.0 N2
3MS4 2   3.0 M2        -1.0 S2
ST39 4   1.0 M2         1.0 S2         1.0 N2        -1.0 K2
MN4  2   1.0 M2         1.0 N2
ST40 3   2.0 M2         1.0 S2        -1.0 K2
ST9  4   1.0 M2         1.0 N2         1.0 K2        -1.0 S2
M4   1   2.0 M2
ST10 3   2.0 M2         1.0 K2        -1.0 S2
SN4  2   1.0 S2         1.0 N2
KN4  2   1.0 K2         1.0 N2
MS4  2   1.0 M2         1.0 S2
MK4  2   1.0 M2         1.0 K2
SL4  2   1.0 S2         1.0 L2
S4   1   2.0 S2
SK4  2   1.0 S2         1.0 K2
MNO5 3   1.0 M2         1.0 N2         1.0 O1
2MO5 2   2.0 M2         1.0 O1
3MP5 2   3.0 M2        -1.0 P1
MNK5 3   1.0 M2         1.0 N2         1.0 K1
2MP5 2   2.0 M2         1.0 P1
2MK5 2   2.0 M2         1.0 K1
MSK5 3   1.0 M2         1.0 S2         1.0 K1
3KM5 3   1.0 K2         1.0 K1         1.0 M2
2SK5 2   2.0 S2         1.0 K1
ST11 3   3.0 N2         1.0 K2        -1.0 S2
2NM6 2   2.0 N2         1.0 M2
ST12 4   2.0 N2         1.0 M2         1.0 K2        -1.0 S2
ST41 3   3.0 M2         1.0 S2        -1.0 K2
2MN6 2   2.0 M2         1.0 N2
ST13 4   2.0 M2         1.0 N2         1.0 K2        -1.0 S2
M6   1   3.0 M2
MSN6 3   1.0 M2         1.0 S2         1.0 N2
MKN6 3   1.0 M2         1.0 K2         1.0 N2
2MS6 2   2.0 M2         1.0 S2
2MK6 2   2.0 M2         1.0 K2
NSK6 3   1.0 N2         1.0 S2         1.0 K2
2SM6 2   2.0 S2         1.0 M2
MSK6 3   1.0 M2         1.0 S2         1.0 K2
ST42 3   2.0 M2         2.0 S2        -1.0 K2
S6   1   3.0 S2
ST14 3   2.0 M2         1.0 N2         1.0 O1
ST15 3   2.0 N2         1.0 M2         1.0 K1
M7   1   3.5 M2
ST16 3   2.0 M2         1.0 S2         1.0 O1
3MK7 2   3.0 M2         1.0 K1
ST17 4   1.0 M2         1.0 S2         1.0 K2         1.0 O1
ST18 2   2.0 M2         2.0 N2
3MN8 2   3.0 M2         1.0 N2
ST19 4   3.0 M2         1.0 N2         1.0 K2        -1.0 S2
M8   1   4.0 M2
ST20 3   2.0 M2         1.0 S2         1.0 N2
ST21 3   2.0 M2         1.0 N2         1.0 K2
3MS8 2   3.0 M2         1.0 S2
3MK8 2   3.0 M2         1.0 K2
ST22 4   1.0 M2         1.0 S2         1.0 N2         1.0 K2
ST23 2   2.0 M2         2.0 S2
```

```
     ST24 3   2.0 M2         1.0 S2         1.0 K2
     ST25 3   2.0 M2         2.0 N2         1.0 K1
     ST26 3   3.0 M2         1.0 N2         1.0 K1
     4MK9 2   4.0 M2         1.0 K1
     ST27 3   3.0 M2         1.0 S2         1.0 K1
     ST28 2   4.0 M2         1.0 N2
     M10  1   5.0 M2
     ST29 3   3.0 M2         1.0 N2         1.0 S2
     ST30 2   4.0 M2         1.0 S2
     ST31 4   2.0 M2         1.0 N2         1.0 S2         1.0 K2
     ST32 2   3.0 M2         2.0 S2
     ST33 3   4.0 M2         1.0 S2         1.0 K1
     M12  1   6.0 M2
     ST34 2   5.0 M2         1.0 S2
     ST35 4   3.0 M2         1.0 N2         1.0 K2         1.0 S2

    7120 RACE ROCKS BC          PST 48 14  139 12
  1 Z0     .00000000      .945    .000   13.5  180.0  166.5  193.5
  5 2Q1    .03570635      .442   -.052    5.1  121.5  116.5  126.6
  6 Q1     .03721850      .461   -.065  175.1  236.8   61.8   51.9
  7 O1     .03873065     2.410   -.253  177.5  250.2   72.8   67.7
  8 NO1    .04026859      .494   -.112    6.8   92.2   85.5   99.0
  9 P1     .04155259     1.272    .232  178.7  270.5   91.8   89.3 INF FR K1
 10 K1     .04178075     5.043   -.221     .9   88.2   87.3   89.1
 11 J1     .04329290      .142    .103   22.9  123.9  101.0  146.8
 12 OO1    .04483084      .455    .125  125.7  334.4  208.8  100.1
 13 UPS1   .04634299      .180    .070  159.3   27.1  227.8  186.4
 16 N2     .07899925     1.369   -.035  173.8  225.2   51.4   39.0
 17 M2     .08051140     6.980   -.295  178.3  249.2   70.9   67.6
 19 S2     .08333333     2.278   -.148    5.9   90.6   84.7   96.4
 20 K2     .08356149      .462   -.054  164.9  264.4   99.5   69.2 INF FR S2
 21 ETA2   .08507364      .157   -.024   76.9   62.8  345.9  139.7

001007076 031007076 EXTR        0.25
001007076 005007076 EQUI        1.0
001007076 031007076 EQUI  COMP  1.0
```

**Appendix 7.5** Tidal Currents Prediction Results Arising from the Input Data of Appendix 7.4.

(i) File reference number 10 output: the hourly current magnitudes for the period 0100 PST July 1, 1976 to 2400 PST July 5, 1976, followed by the north/south hourly current components for the period 0100 PST July 1, 1976 to 2400 PST July 31, 1976.

```
STN 1ST HR  DATE     1       2       3       4       5       6       7       8   DT HRS

7120  1.00  1 776   4.79    1.99    0.70    2.21    2.09    0.77    3.41    7.22  1.00
7120  9.00  1 776  10.55   12.39   12.08    9.46    4.94    1.02    6.27   10.55  1.00
7120 17.00  1 776  12.74   12.44    9.83    5.61    1.05    3.79    6.73    7.76  1.00
7120  1.00  2 776   6.86    4.52    1.57    1.04    2.45    2.23    0.78    3.04  1.00
7120  9.00  2 776   6.46    9.28   10.62    9.95    7.23    2.94    2.21    6.87  1.00
7120 17.00  2 776  10.22   11.51   10.51    7.48    3.19    1.77    5.61    8.06  1.00
7120  1.00  3 776   8.61    7.33    4.74    1.65    1.03    2.56    2.56    1.18  1.00
7120  9.00  3 776   1.91    4.73    7.05    8.06    7.33    4.87    1.15    3.12  1.00
7120 17.00  3 776   6.89    9.34    9.88    8.36    5.10    1.01    3.81    7.44  1.00
7120  1.00  4 776   9.57    9.84    8.32    5.52    2.21    0.79    2.75    3.29  1.00
7120  9.00  4 776   2.43    0.89    2.22    4.14    5.09    4.63    2.74    0.21  1.00
7120 17.00  4 776   3.53    6.41    8.11    8.10    6.27    2.91    1.54    5.79  1.00
7120  1.00  5 776   9.28   11.27   11.39    9.70    6.63    2.92    0.64    3.28  1.00
7120  9.00  5 776   4.58    4.42    3.07    1.19    1.15    2.29    2.39    1.27  1.00
7120 17.00  5 776   0.82    3.32    5.52    6.72    6.41    4.45    1.10    3.25  1.00
```

```
STN 1ST HR  DATE     1       2       3       4       5       6       7       8   DT HRS

7120  1.00  1 776  -0.15   -0.17   -0.30   -0.48   -0.66   -0.77   -0.76   -0.62  1.00
7120  9.00  1 776  -0.35    0.00    0.34    0.61    0.75    0.71    0.50    0.17  1.00
7120 17.00  1 776  -0.20   -0.55   -0.80   -0.89   -0.83   -0.64   -0.38   -0.14  1.00
7120  1.00  2 776   0.03    0.07   -0.02   -0.21   -0.44   -0.65   -0.76   -0.74  1.00
7120  9.00  2 776  -0.56   -0.28    0.06    0.36    0.55    0.59    0.45    0.17  1.00
7120 17.00  2 776  -0.20   -0.56   -0.84   -0.96   -0.91   -0.70   -0.38   -0.04  1.00
7120  1.00  3 776   0.24    0.39    0.37    0.20   -0.08   -0.39   -0.64   -0.78  1.00
7120  9.00  3 776  -0.75   -0.58   -0.31   -0.01    0.23    0.35    0.31    0.10  1.00
7120 17.00  3 776  -0.21   -0.56   -0.85   -1.00   -0.97   -0.75   -0.40    0.01  1.00
7120  1.00  4 776   0.39    0.65    0.73    0.61    0.33   -0.05   -0.43   -0.73  1.00
7120  9.00  4 776  -0.88   -0.85   -0.68   -0.41   -0.14    0.06    0.12    0.03  1.00
7120 17.00  4 776  -0.19   -0.49   -0.76   -0.94   -0.95   -0.78   -0.44   -0.01  1.00
7120  1.00  5 776   0.42    0.76    0.93    0.89    0.65    0.25   -0.20   -0.61  1.00
7120  9.00  5 776  -0.91   -1.03   -0.97   -0.76   -0.49   -0.23   -0.06   -0.03  1.00
7120 17.00  5 776  -0.13   -0.34   -0.57   -0.76   -0.83   -0.73   -0.48   -0.10  1.00
7120  1.00  6 776   0.32    0.68    0.91    0.95    0.77    0.43   -0.02   -0.48  1.00
7120  9.00  6 776  -0.85   -1.07   -1.11   -0.98   -0.74   -0.45   -0.21   -0.06  1.00
7120 17.00  6 776  -0.04   -0.15   -0.32   -0.50   -0.61   -0.60   -0.46   -0.20  1.00
7120  1.00  7 776   0.12    0.44    0.67    0.76    0.67    0.42    0.05   -0.35  1.00
7120  9.00  7 776  -0.71   -0.97   -1.07   -1.01   -0.82   -0.56   -0.29   -0.09  1.00
7120 17.00  7 776   0.02    0.01   -0.08   -0.22   -0.35   -0.42   -0.39   -0.28  1.00
7120  1.00  8 776  -0.09    0.11    0.29    0.39    0.37    0.24    0.01   -0.26  1.00
7120  9.00  8 776  -0.52   -0.72   -0.83   -0.82   -0.70   -0.52   -0.31   -0.12  1.00
7120 17.00  8 776   0.01    0.06    0.04   -0.04   -0.14   -0.24   -0.30   -0.31  1.00
7120  1.00  9 776  -0.27   -0.20   -0.13   -0.07   -0.04   -0.06   -0.13   -0.22  1.00
7120  9.00  9 776  -0.31   -0.39   -0.43   -0.43   -0.39   -0.32   -0.23   -0.14  1.00
7120 17.00  9 776  -0.07   -0.02   -0.01   -0.03   -0.07   -0.14   -0.21   -0.29  1.00
```

```
7120  1.00 10 776  -0.37  -0.43  -0.48  -0.49  -0.47  -0.42  -0.34  -0.24  1.00
7120  9.00 10 776  -0.13  -0.04   0.03   0.07   0.06   0.01  -0.06  -0.13  1.00
7120 17.00 10 776  -0.19  -0.22  -0.21  -0.19  -0.16  -0.14  -0.17  -0.24  1.00
7120  1.00 11 776  -0.37  -0.52  -0.68  -0.80  -0.84  -0.77  -0.61  -0.35  1.00
7120  9.00 11 776  -0.06   0.23   0.45   0.56   0.55   0.41   0.20  -0.06  1.00
7120 17.00 11 776  -0.29  -0.44  -0.50  -0.46  -0.36  -0.24  -0.16  -0.16  1.00
7120  1.00 12 776  -0.27  -0.46  -0.70  -0.92  -1.06  -1.05  -0.88  -0.55  1.00
7120  9.00 12 776  -0.13   0.32   0.69   0.92   0.95   0.79   0.47   0.07  1.00
7120 17.00 12 776  -0.33  -0.63  -0.78  -0.76  -0.61  -0.39  -0.18  -0.06  1.00
7120  1.00 13 776  -0.09  -0.26  -0.53  -0.84  -1.09  -1.20  -1.10  -0.79  1.00
7120  9.00 13 776  -0.33   0.20   0.70   1.04   1.16   1.03   0.68   0.20  1.00
7120 17.00 13 776  -0.31  -0.73  -0.97  -0.99  -0.82  -0.52  -0.19   0.06  1.00
7120  1.00 14 776   0.15   0.05  -0.22  -0.59  -0.94  -1.18  -1.22  -1.02  1.00
7120  9.00 14 776  -0.61  -0.07   0.47   0.90   1.11   1.06   0.75   0.27  1.00
7120 17.00 14 776  -0.27  -0.75  -1.05  -1.12  -0.95  -0.61  -0.19   0.17  1.00
7120  1.00 15 776   0.39   0.38   0.17  -0.21  -0.64  -1.00  -1.18  -1.14  1.00
7120  9.00 15 776  -0.86  -0.41   0.10   0.56   0.84   0.88   0.66   0.25  1.00
7120 17.00 15 776  -0.26  -0.73  -1.05  -1.15  -1.00  -0.64  -0.18   0.26  1.00
7120  1.00 16 776   0.57   0.67   0.53   0.20  -0.25  -0.69  -1.00  -1.11  1.00
7120  9.00 16 776  -1.00  -0.69  -0.27   0.14   0.44   0.55   0.43   0.13  1.00
7120 17.00 16 776  -0.29  -0.70  -1.00  -1.10  -0.97  -0.64  -0.18   0.28  1.00
7120  1.00 17 776   0.65   0.83   0.79   0.52   0.12  -0.33  -0.71  -0.95  1.00
7120  9.00 17 776  -0.98  -0.83  -0.55  -0.22   0.05   0.18   0.14  -0.06  1.00
7120 17.00 17 776  -0.37  -0.69  -0.92  -1.01  -0.90  -0.61  -0.19   0.25  1.00
7120  1.00 18 776   0.63   0.85   0.88   0.70   0.38  -0.03  -0.41  -0.70  1.00
7120  9.00 18 776  -0.84  -0.81  -0.67  -0.46  -0.26  -0.15  -0.15  -0.26  1.00
7120 17.00 18 776  -0.46  -0.68  -0.84  -0.89  -0.78  -0.54  -0.19   0.20  1.00
7120  1.00 19 776   0.53   0.76   0.82   0.72   0.48   0.16  -0.18  -0.46  1.00
7120  9.00 19 776  -0.64  -0.70  -0.66  -0.56  -0.45  -0.38  -0.37  -0.43  1.00
7120 17.00 19 776  -0.55  -0.67  -0.75  -0.75  -0.64  -0.43  -0.15   0.15  1.00
7120  1.00 20 776   0.42   0.60   0.67   0.61   0.44   0.20  -0.05  -0.29  1.00
7120  9.00 20 776  -0.46  -0.55  -0.58  -0.56  -0.53  -0.51  -0.52  -0.56  1.00
7120 17.00 20 776  -0.61  -0.66  -0.67  -0.61  -0.49  -0.31  -0.08   0.15  1.00
7120  1.00 21 776   0.34   0.46   0.50   0.45   0.33   0.16  -0.02  -0.20  1.00
7120  9.00 21 776  -0.33  -0.43  -0.48  -0.52  -0.54  -0.57  -0.60  -0.64  1.00
7120 17.00 21 776  -0.67  -0.66  -0.62  -0.52  -0.37  -0.20  -0.01   0.16  1.00
7120  1.00 22 776   0.29   0.36   0.36   0.31   0.21   0.09  -0.04  -0.15  1.00
7120  9.00 22 776  -0.24  -0.32  -0.38  -0.44  -0.51  -0.58  -0.64  -0.69  1.00
7120 17.00 22 776  -0.71  -0.69  -0.61  -0.49  -0.33  -0.15   0.02   0.15  1.00
7120  1.00 23 776   0.24   0.28   0.26   0.21   0.13   0.05  -0.03  -0.09  1.00
7120  9.00 23 776  -0.14  -0.19  -0.25  -0.33  -0.42  -0.53  -0.63  -0.71  1.00
7120 17.00 23 776  -0.75  -0.73  -0.66  -0.53  -0.37  -0.20  -0.05   0.08  1.00
7120  1.00 24 776   0.15   0.17   0.16   0.12   0.07   0.04   0.02   0.01  1.00
7120  9.00 24 776   0.00  -0.02  -0.07  -0.15  -0.27  -0.42  -0.56  -0.69  1.00
7120 17.00 24 776  -0.77  -0.79  -0.74  -0.64  -0.49  -0.34  -0.19  -0.08  1.00
7120  1.00 25 776  -0.01   0.02   0.02   0.01   0.01   0.03   0.08   0.13  1.00
7120  9.00 25 776   0.18   0.20   0.18   0.09  -0.05  -0.24  -0.44  -0.62  1.00
7120 17.00 25 776  -0.76  -0.83  -0.83  -0.76  -0.64  -0.50  -0.37  -0.27  1.00
7120  1.00 26 776  -0.20  -0.17  -0.15  -0.13  -0.09  -0.01   0.10   0.23  1.00
7120  9.00 26 776   0.34   0.42   0.43   0.35   0.20  -0.03  -0.28  -0.53  1.00
7120 17.00 26 776  -0.74  -0.87  -0.91  -0.87  -0.76  -0.63  -0.50  -0.40  1.00
7120  1.00 27 776  -0.34  -0.31  -0.30  -0.28  -0.22  -0.11   0.04   0.23  1.00
7120  9.00 27 776   0.41   0.55   0.61   0.57   0.41   0.17  -0.14  -0.45  1.00
7120 17.00 27 776  -0.71  -0.89  -0.97  -0.94  -0.83  -0.67  -0.51  -0.39  1.00
7120  1.00 28 776  -0.32  -0.31  -0.33  -0.35  -0.33  -0.25  -0.10   0.10  1.00
7120  9.00 28 776   0.33   0.53   0.65   0.66   0.53   0.29  -0.04  -0.40  1.00
7120 17.00 28 776  -0.72  -0.94  -1.03  -0.99  -0.84  -0.63  -0.40  -0.23  1.00
```

```
7120  1.00 29 776  -0.13  -0.12  -0.19  -0.28  -0.36  -0.37  -0.30  -0.13  1.00
7120  9.00 29 776   0.10   0.34   0.52   0.59   0.52   0.31  -0.02  -0.39  1.00
7120 17.00 29 776  -0.74  -1.00  -1.11  -1.05  -0.85  -0.55  -0.22   0.05  1.00
7120  1.00 30 776   0.21   0.23   0.13  -0.06  -0.26  -0.42  -0.48  -0.41  1.00
7120  9.00 30 776  -0.23   0.00   0.23   0.38   0.40   0.25  -0.03  -0.40  1.00
7120 17.00 30 776  -0.76  -1.05  -1.17  -1.11  -0.86  -0.49  -0.06   0.32  1.00
7120  1.00 31 776   0.57   0.65   0.53   0.28  -0.06  -0.38  -0.60  -0.68  1.00
7120  9.00 31 776  -0.60  -0.39  -0.14   0.09   0.20   0.16  -0.04  -0.36  1.00
7120 17.00 31 776  -0.72  -1.03  -1.19  -1.15  -0.90  -0.49   0.01   0.49  1.00
```

(ii) File reference number 11 output: the hourly current directions for the period 0100 PST July 1, 1976 to 2400 PST July 5, 1976 followed by the east/west hourly current components for the period 0100 PST July 1, 1976 to 2400 PST July 31, 1976.

```
STN 1ST HR  DATE      1      2      3      4      5      6      7      8  DT HRS

7120  1.00  1 776 181.74 184.94 334.95 347.49 341.67 271.30 192.92 184.90   1.00
7120  9.00  1 776 181.89 180.02 178.38 176.29 171.31  43.97   4.58   0.94   1.00
7120 17.00  1 776 359.08 357.45 355.36 350.86 308.22 189.68 183.27 181.02   1.00
7120  1.00  2 776 179.76 179.08 180.56 348.58 349.62 343.05 283.40 193.98   1.00
7120  9.00  2 776 185.00 181.71 179.69 177.93 175.60 168.44  11.75   1.38   1.00
7120 17.00  2 776 358.87 357.19 355.42 352.60 343.41 203.20 183.87 180.27   1.00
7120  1.00  3 776 178.40 176.98 175.52 173.10 355.62 351.34 345.49 318.93   1.00
7120  9.00  3 776 203.23 187.09 182.52 180.07 178.17 175.86 164.58   1.87   1.00
7120 17.00  3 776 358.24 356.57 355.09 353.14 349.06 311.61 186.04 179.90   1.00
7120  1.00  4 776 177.65 176.20 174.98 173.66 171.47 356.39 350.99 347.23   1.00
7120  9.00  4 776 338.86 287.63 197.81 185.75 181.60 179.32 177.50   7.89   1.00
7120 17.00  4 776 356.85 355.65 354.60 353.34 351.25 344.47 196.80 180.12   1.00
7120  1.00  5 776 177.39 176.11 175.30 174.73 174.41 175.02 341.82 349.21   1.00
7120  9.00  5 776 348.56 346.55 341.67 320.00 205.39 185.82 181.48 181.19   1.00
7120 17.00  5 776 350.89 354.19 354.03 353.48 352.56 350.51 334.47 181.73   1.00
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STN 1ST HR  DATE      1      2      3      4      5      6      7      8  DT HRS

7120  1.00  1 776  -4.78  -1.99   0.63   2.16   1.98   0.02  -3.32  -7.19   1.00
7120  9.00  1 776 -10.55 -12.39 -12.08  -9.44  -4.88   0.73   6.25  10.54   1.00
7120 17.00  1 776  12.73  12.43   9.80   5.54   0.65  -3.74  -6.72  -7.76   1.00
7120  1.00  2 776  -6.86  -4.52  -1.57   1.02   2.41   2.13   0.18  -2.95   1.00
7120  9.00  2 776  -6.43  -9.28 -10.62  -9.94  -7.21  -2.88   2.17   6.87   1.00
7120 17.00  2 776  10.21  11.50  10.47   7.42   3.05  -1.62  -5.60  -8.06   1.00
7120  1.00  3 776  -8.61  -7.32  -4.73  -1.64   1.03   2.53   2.48   0.89   1.00
7120  9.00  3 776  -1.76  -4.69  -7.04  -8.06  -7.33  -4.86  -1.11   3.12   1.00
7120 17.00  3 776   6.89   9.32   9.84   8.30   5.01   0.67  -3.79  -7.44   1.00
7120  1.00  4 776  -9.56  -9.81  -8.29  -5.49  -2.18   0.78   2.71   3.21   1.00
7120  9.00  4 776   2.26   0.27  -2.11  -4.12  -5.09  -4.63  -2.74   0.21   1.00
7120 17.00  4 776   3.52   6.40   8.07   8.05   6.19   2.81  -1.47  -5.79   1.00
7120  1.00  5 776  -9.27 -11.25 -11.35  -9.66  -6.60  -2.91   0.61   3.23   1.00
7120  9.00  5 776   4.49   4.30   2.92   0.91  -1.03  -2.28  -2.39  -1.27   1.00
7120 17.00  5 776   0.81   3.31   5.49   6.67   6.36   4.39   1.00  -3.25   1.00
7120  1.00  6 776  -7.53 -11.01 -12.96 -12.99 -11.09  -7.66  -3.39   0.85   1.00
7120  9.00  6 776   4.28   6.33   6.77   5.76   3.80   1.57  -0.23  -1.09   1.00
7120 17.00  6 776  -0.77   0.59   2.51   4.33   5.34   4.99   3.06  -0.31   1.00
7120  1.00  7 776  -4.58  -8.94 -12.49 -14.47 -14.39 -12.18  -8.24  -3.28   1.00
7120  9.00  7 776   1.75   5.92   8.55   9.30   8.28   5.98   3.15   0.61   1.00
7120 17.00  7 776  -0.98  -1.29  -0.36   1.37   3.18   4.31   4.11   2.27   1.00
7120  1.00  8 776  -1.11  -5.48  -9.98 -13.65 -15.60 -15.30 -12.65  -8.07   1.00
7120  9.00  8 776  -2.41   3.29   7.97  10.81  11.45  10.00   7.04   3.45   1.00
7120 17.00  8 776   0.19  -1.95  -2.55  -1.65   0.24   2.34   3.75   3.73   1.00
7120  1.00  9 776   1.92  -1.56  -6.11 -10.78 -14.49 -16.28 -15.58 -12.36   1.00
7120  9.00  9 776  -7.11  -0.83   5.30  10.11  12.75  12.86  10.66   6.89   1.00
7120 17.00  9 776   2.58  -1.18  -3.53  -4.04  -2.83  -0.51   1.98   3.65   1.00
7120  1.00 10 776   3.70   1.77  -1.94  -6.73 -11.50 -15.09 -16.51 -15.24   1.00
7120  9.00 10 776 -11.33  -5.46   1.26   7.49  12.04  14.07  13.36  10.29   1.00
7120 17.00 10 776   5.75   0.94  -2.98  -5.15  -5.24  -3.50  -0.70   2.10   1.00
7120  1.00 11 776   3.84   3.72   1.48  -2.55  -7.52 -12.23 -15.46 -16.28   1.00
7120  9.00 11 776 -14.27  -9.66  -3.30   3.56   9.54  13.45  14.60  12.94   1.00
7120 17.00 11 776   9.04   3.97  -0.99  -4.69  -6.36  -5.83  -3.53  -0.37   1.00
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7120  1.00 12 776   2.50   4.02   3.50   0.83  -3.49  -8.48 -12.87 -15.48  1.00
7120  9.00 12 776 -15.49 -12.67  -7.46  -0.86   5.79  11.14  14.13  14.25  1.00
7120 17.00 12 776  11.67   7.17   1.90  -2.84  -5.99  -6.96  -5.77  -3.03  1.00
7120  1.00 13 776   0.24   2.89   3.95   2.91  -0.17  -4.61  -9.34 -13.12  1.00
7120  9.00 13 776 -14.88 -13.99 -10.46  -4.90   1.58   7.64  12.02  13.90  1.00
7120 17.00 13 776  12.99   9.67   4.86  -0.24  -4.42  -6.80  -7.00  -5.25  1.00
7120  1.00 14 776  -2.29   0.84   3.06   3.56   2.04  -1.25  -5.53  -9.69  1.00
7120  9.00 14 776 -12.62 -13.43 -11.74  -7.75  -2.22   3.71   8.79  11.98  1.00
7120 17.00 14 776  12.68  10.86   7.07   2.30  -2.30  -5.71  -7.23  -6.72  1.00
7120  1.00 15 776  -4.57  -1.59   1.22   2.94   2.97   1.18  -2.02  -5.81  1.00
7120  9.00 15 776  -9.18 -11.16 -11.12  -8.88  -4.82   0.23   5.21   9.05  1.00
7120 17.00 15 776  10.95  10.56   8.07   4.13  -0.30  -4.20  -6.72  -7.43  1.00
7120  1.00 16 776  -6.36  -3.99  -1.13   1.32   2.64   2.40   0.64  -2.15  1.00
7120  9.00 16 776  -5.23  -7.70  -8.82  -8.17  -5.77  -2.08   2.11   5.89  1.00
7120 17.00 16 776   8.39   9.09   7.85   4.98   1.17  -2.71  -5.81  -7.51  1.00
7120  1.00 17 776  -7.55  -6.10  -3.67  -0.99   1.19   2.30   2.08   0.65  1.00
7120  9.00 17 776  -1.53  -3.80  -5.46  -5.96  -5.07  -2.91   0.08   3.20  1.00
7120 17.00 17 776   5.72   7.02   6.77   4.99   2.04  -1.44  -4.70  -7.07  1.00
7120  1.00 18 776  -8.12  -7.70  -6.05  -3.63  -1.09   0.97   2.12   2.16  1.00
7120  9.00 18 776   1.24  -0.26  -1.83  -2.91  -3.14  -2.36  -0.72   1.41  1.00
7120 17.00 18 776   3.47   4.92   5.32   4.47   2.46  -0.36  -3.43  -6.15  1.00
7120  1.00 19 776  -7.99  -8.61  -7.95  -6.21  -3.81  -1.28   0.87   2.25  1.00
7120  9.00 19 776   2.71   2.33   1.38   0.27  -0.59  -0.88  -0.48   0.52  1.00
7120 17.00 19 776   1.84   3.07   3.79   3.68   2.58   0.58  -2.02  -4.76  1.00
7120  1.00 20 776  -7.14  -8.68  -9.10  -8.31  -6.49  -4.00  -1.30   1.12  1.00
7120  9.00 20 776   2.87   3.74   3.74   3.07   2.06   1.08   0.45   0.35  1.00
7120 17.00 20 776   0.76   1.51   2.26   2.66   2.38   1.28  -0.61  -3.05  1.00
7120  1.00 21 776  -5.63  -7.87  -9.31  -9.63  -8.71  -6.68  -3.90  -0.83  1.00
7120  9.00 21 776   1.98   4.09   5.22   5.30   4.52   3.22   1.81   0.69  1.00
7120 17.00 21 776   0.12   0.15   0.66   1.31   1.73   1.55   0.55  -1.28  1.00
7120  1.00 22 776  -3.72  -6.34  -8.61 -10.02 -10.19  -8.98  -6.51  -3.21  1.00
7120  9.00 22 776   0.37   3.59   5.91   6.99   6.78   5.49   3.56   1.54  1.00
7120 17.00 22 776  -0.08  -0.96  -1.01  -0.40   0.48   1.15   1.14   0.19  1.00
7120  1.00 23 776  -1.74  -4.37  -7.18  -9.54 -10.85 -10.68  -8.91  -5.75  1.00
7120  9.00 23 776  -1.75   2.38   5.88   8.13   8.79   7.88   5.76   3.02  1.00
7120 17.00 23 776   0.35  -1.62  -2.53  -2.34  -1.32  -0.01   0.96   1.06  1.00
7120  1.00 24 776  -0.03  -2.25  -5.23  -8.29 -10.68 -11.70 -10.93  -8.35  1.00
7120  9.00 24 776  -4.32   0.44   5.01   8.54  10.38  10.25   8.34   5.21  1.00
7120 17.00 24 776   1.66  -1.47  -3.51  -4.12  -3.38  -1.77   0.01   1.19  1.00
7120  1.00 25 776   1.19  -0.25  -2.97  -6.39  -9.68 -11.93 -12.43 -10.83  1.00
7120  9.00 25 776  -7.26  -2.31   3.09   7.86  11.08  12.16  10.98   7.94  1.00
7120 17.00 25 776   3.85  -0.30  -3.57  -5.30  -5.28  -3.81  -1.54   0.61  1.00
7120  1.00 26 776   1.80   1.45  -0.58  -3.91  -7.77 -11.15 -13.07 -12.84  1.00
7120  9.00 26 776 -10.27  -5.70   0.03   5.80  10.42  12.99  13.05  10.71  1.00
7120 17.00 26 776   6.63   1.83  -2.55  -5.54  -6.61  -5.74  -3.45  -0.63  1.00
7120  1.00 27 776   1.69   2.63   1.71  -1.02  -4.96  -9.14 -12.42 -13.82  1.00
7120  9.00 27 776 -12.75  -9.22  -3.81   2.41   8.17  12.27  13.90  12.82  1.00
7120 17.00 27 776   9.39   4.52  -0.61  -4.79  -7.14  -7.30  -5.48  -2.44  1.00
7120  1.00 28 776   0.75   3.00   3.49   1.90  -1.51  -5.92 -10.19 -13.15  1.00
7120  9.00 28 776 -13.87 -11.96  -7.63  -1.71   4.58   9.90  13.15  13.67  1.00
7120 17.00 28 776  11.47   7.16   1.84  -3.20  -6.83  -8.29  -7.44  -4.75  1.00
7120  1.00 29 776  -1.15   2.19   4.19   4.16   1.97  -1.90  -6.48 -10.55  1.00
7120  9.00 29 776 -12.98 -12.98 -10.35  -5.55   0.45   6.35  10.86  13.00  1.00
7120 17.00 29 776  12.37   9.20   4.31  -1.10  -5.75  -8.59  -9.10  -7.34  1.00
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7120  1.00 30 776  -3.96  -0.03   3.28   4.98   4.55   2.02  -1.95  -6.34  1.00
7120  9.00 30 776  -9.93 -11.70 -11.06  -8.01  -3.14   2.47   7.56  10.97  1.00
7120 17.00 30 776  11.92  10.23   6.34   1.18  -4.02  -8.08 -10.11  -9.76  1.00
7120  1.00 31 776  -7.30  -3.49   0.59   3.81   5.33   4.75   2.27  -1.42  1.00
7120  9.00 31 776  -5.28  -8.22  -9.38  -8.34  -5.24  -0.76   4.06   8.06  1.00
7120 17.00 31 776  10.26  10.11   7.60   3.30  -1.84  -6.64 -10.06 -11.38  1.00
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(iii) File reference number 12 output: the times, magnitudes and directions of all maximum or minimum current values for the period 0100 PST July 1, 1976 to 2400 PST July 31, 1976.

```
 STN  DATE  TIME   MAG    DIR  TIME   MAG    DIR  TIME   MAG    DIR  TIME   MAG    DIR

7120  1 776  243  0.25 268.7  426  2.38 346.3  600  0.77 269.0 1022 12.56 179.4
7120  1 776 1353  0.72  85.6 1723 12.92 358.4 2109  0.81 265.0
7120  2 776    1  7.75 181.0  334  0.12 278.7  522  2.57 348.2  704  0.76 269.0
7120  2 776 1111 10.65 179.4 1435  0.53  83.0 1804 11.52 357.1 2139  0.79 264.6
7120  3 776   47  8.66 178.7  435  0.05  59.9  630  2.75 349.0  822  0.79 267.9
7120  3 776 1206  8.06 179.9 1516  0.27  79.9 1846  9.93 355.4 2209  0.71 263.0
7120  4 776  138  9.96 176.7  543  0.07  64.8  752  3.30 347.8 1008  0.84 266.0
7120  4 776 1312  5.11 181.1 1556  0.05  46.1 1930  8.33 354.0 2241  0.57 262.3
7120  5 776  234 11.58 175.6  649  0.12 275.2  923  4.68 348.0 1229  0.64 259.9
7120  5 776 1435  2.50 182.7 1639  0.08 278.1 2019  6.79 353.2 2315  0.39 260.5
7120  6 776  331 13.26 175.9  747  0.39 268.5 1046  6.91 350.7 1452  0.24 258.4
7120  6 776 1613  1.12 182.3 1738  0.10 276.0 2117  5.43 353.4 2355  0.23 258.1
7120  7 776  428 14.72 177.1  838  0.59 269.2 1153  9.36 353.7 1618  0.05 248.6
7120  7 776 1743  1.34 179.0 1914  0.11 270.5 2223  4.43 354.6
7120  8 776   43  0.15 255.8  522 15.77 178.8  924  0.62 272.8 1247 11.53 356.3
7120  8 776 1704  0.03 151.3 1853  2.55 179.0 2053  0.13 273.0 2330  3.96 355.5
7120  9 776  136  0.23 262.2  614 16.35 180.3 1008  0.40 277.2 1332 13.13 358.4
7120  9 776 1739  0.05 227.0 1946  4.09 180.3 2212  0.15 270.3
7120 10 776   32  3.93 355.1  232  0.46 267.9  702 16.51 181.2 1049  0.06  21.7
7120 10 776 1414 14.15 360.0 1813  0.22 261.8 2032  5.45 181.8 2314  0.18 274.9
7120 11 776  128  4.07 353.8  324  0.74 269.1  748 16.35 181.4 1129  0.52  84.8
7120 11 776 1454 14.61   0.9 1847  0.50 266.1 2115  6.44 182.9
7120 12 776    7  0.17 276.6  217  4.13 352.7  412  0.96 271.1  830 15.84 181.2
7120 12 776 1207  0.94  87.5 1532 14.55   1.0 1922  0.79 266.6 2155  6.98 183.3
7120 13 776   55  0.08 286.0  303  3.99 352.1  457  1.08 271.7  911 14.91 180.9
7120 13 776 1245  1.15  88.0 1610 13.94   0.4 1957  1.00 267.3 2235  7.20 182.6
7120 14 776  143  0.10  80.6  347  3.65 352.0  539  1.12 272.4  950 13.47 180.7
7120 14 776 1322  1.12  87.7 1646 12.76 359.3 2029  1.07 266.1 2314  7.29 180.7
7120 15 776  233  0.29  80.6  433  3.22 352.0  623  1.10 273.0 1029 11.42 180.8
7120 15 776 1357  0.88  86.5 1720 11.09 357.8 2057  1.01 264.2 2353  7.45 178.4
7120 16 776  327  0.41  80.1  524  2.77 351.0  714  1.05 272.3 1109  8.85 181.3
7120 16 776 1430  0.52  84.2 1752  9.13 355.9 2119  0.89 263.6
7120 17 776   32  7.75 176.3  426  0.37  76.0  624  2.43 348.2  818  0.98 271.6
7120 17 776 1152  5.98 182.5 1459  0.14  78.0 1822  7.16 353.7 2137  0.74 263.8
7120 18 776  113  8.17 175.1  530  0.19  70.2  736  2.35 345.1  952  0.83 266.2
7120 18 776 1243  3.19 185.6 1521  0.18 269.4 1851  5.40 351.2 2154  0.57 261.0
7120 19 776  159  8.65 175.0  634  0.04 300.2  902  2.79 346.7 1220  0.53 262.8
7120 19 776 1354  0.95 203.6 1531  0.40 268.2 1923  3.93 348.9 2215  0.37 259.8
7120 20 776  251  9.13 175.8  730  0.18 268.7 1030  3.89 351.5 1533  0.63 301.2
7120 20 776 2007  2.74 347.3 2243  0.15 256.7
7120 21 776  345  9.68 177.2  817  0.24 271.7 1135  5.42 354.6 1727  0.67 275.4
7120 21 776 2113  1.79 349.2 2321  0.06  94.6
7120 22 776  437 10.29 178.6  854  0.23 273.8 1220  7.07 356.2 1656  0.71 269.2
7120 22 776 1830  1.27 211.0 2032  0.41 280.4 2230  1.25 357.1
7120 23 776    7  0.17  88.4  524 10.97 179.5  925  0.17 279.5 1254  8.81 357.3
7120 23 776 1709  0.75 268.2 1917  2.66 193.7 2202  0.20 280.3 2336  1.16   1.6
7120 24 776   59  0.15  92.2  605 11.71 179.8  955  0.04 339.3 1326 10.57 358.2
7120 24 776 1730  0.79 267.7 1954  4.17 188.9 2300  0.20 281.4
7120 25 776   30  1.36 358.3  153  0.02 141.1  645 12.50 179.7 1026  0.21  74.6
7120 25 776 1358 12.15 358.9 1755  0.83 267.5 2029  5.54 187.3 2342  0.30 276.7
7120 26 776  118  1.88 354.2  247  0.16 262.3  725 13.26 179.3 1100  0.43  82.3
7120 26 776 1431 13.34 359.3 1823  0.89 267.8 2101  6.66 186.6
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7120 27 776   14  0.38 273.5  201  2.65 353.3  341  0.29 265.2  805 13.83 179.0
7120 27 776 1137  0.60  85.5 1506 13.92 359.3 1852  0.97 268.9 2133  7.54 185.6
7120 28 776   45  0.34 272.8  245  3.58 354.8  436  0.35 263.6  847 13.93 178.8
7120 28 776 1216  0.64  85.1 1541 13.82 358.8 1921  1.03 267.6 2207  8.32 184.1
7120 29 776  119  0.12 289.0  329  4.45 357.0  533  0.38 267.5  930 13.32 179.0
7120 29 776 1256  0.54  83.5 1617 13.12 357.8 1948  1.08 265.9 2242  9.20 182.0
7120 30 776  201  0.23  81.9  418  5.09 358.6  632  0.47 267.5 1015 11.78 179.7
7120 30 776 1334  0.34  79.5 1652 11.97 356.6 2014  1.07 265.0 2321 10.25 179.5
7120 31 776  251  0.56  84.0  514  5.38 358.5  738  0.67 267.5 1102  9.39 180.8
7120 31 776 1409  0.14  71.2 1727 10.54 355.3 2039  1.01 265.5
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