Baytap08 User's Manual

Original BAYTAP-G Manual by

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1   Introduction

Baytap08 is a modified version of the BAYTAP-G [1] program developed by M. Ishiguro, Y. Tamura, T. Sato and M. Ooe. This program uses a Bayesian modeling procedure (based on work by H. Akaike) to analyze time series that contain both tidal and other variations: this includes tidal gravity, ocean tides, and strain and tilt data. BAYTAP-G was originally released on March 26, 1985; the most recent release was on November 15, 1999. Baytap08 is basically the same program, but has been modified (by D. C. Agnew) to make it somewhat easier to use.

The original application of Akaike's method (known as ABIC, for Akaike Bayesian Information Criterion) to tidal and crustal deformation modeling was described by Ishiguro *et al.* (1981); Ishiguro (1981); Ishiguro *et al.* (1984). Ishiguro and Tamura (1985), which includes a program listing, is meant mostly to introduce program libraries for a time series analysis package. The fullest description of the current version is by Tamura *et al.* (1991), which should be cited in any publication that uses results found through BAYTAP-G or baytap08.

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[1] Bayesian Tidal Analysis Program - Grouping Model

The program can:

1. Estimate tidal amplitudes and phases.

2. Determine a long-period component of the data (the "drift" or "trend") and calculate its power spectrum using an ARMA model.

3. Interpolate missing data and estimate sizes of known offsets.

4. Perform a rough search for abnormal data.

5. Calculate the Akaike Bayesian Information Criterion (ABIC), to find the goodness of fit of the model.

1.1   Program Installation

Baytap08 is a stand-alone program written in Fortran-77 [2]. The only system-dependent features are calls to the Unix functions *argc* and *getarg* to get arguments from the command line, and *fdate* to get the current time (for timestamping the output file). On most systems the program can simply be compiled and the resulting executable run directly. It may be necessary to specify a compiler option that makes all variables static; for the *g77* compiler this is `-fno-automatic`.

It is possible (though unlikely) that the array dimensions set in the program as distributed will need to be increased to handle large datasets; and also possible (though even more unlikely) that they would need to be decreased to fit into memory. See Section 11.1 for further discussion.

1.2   Versions

Bug fixes subsequent to the release in July 2008 are:

1. January 1, 2009: fixed line 1664, for reading names of more than three files.

2. April 16, 2013: fixed internal mapping of variable `igrp` so that `igrp=1` and `igrp=2` gave appropriately different actions, instead of both giving the action for `igrp=2`. (Thanks to Mai-Linh Doan).

1.3   Modifying the Program

If you modify the source code, please change the version name in subroutine `verstr`, and replace the source institution names "NAO, Mizusawa" and "IGPP/Scripps/UC San Diego" with the name

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[2]The only departure is the use of `enddo` for ending a `DO` loop. While nonstandard in Fortran77, this usage is supported by most compilers.

of your organization. [3]

2   Method of Analysis

The program analyzes a data series, y_i, for which the i-th value is at time $t_i = t_0 + (i - 1)\Delta$; this series is assumed to be a combination of

1. Tidal variations, which can be related to the tidal potential through some kind of admittance function, and described by the amplitude and phase (the "tidal constants") of different tidal constituents. The model for this portion of the series can be written as

$$v_i = \sum_{m=1}^{M} (A_m C_{mi} + B_m S_{mi}) \tag{1}$$

   where C_{mi} and S_{mi}, are the cosine and sine parts of the theoretical values of different tidal components, and A_m and B_m. are the tidal constants to be solved for.

2. A *"drift"*, d_i, which includes any long-term changes that would include temporal correlation. This component may have any functional form, though with a constraint discussed below.

3. Offsets (steps) of unknown amplitude but known times.

$$s_i = \sum_{l=1}^{L} h_l H(t_i - T_l) \tag{2}$$

   where h_l is the unknown offset value at time T_l; H is the Heaviside step function.

4. A component that is correlated with some other series, called the *auxiliary series* x_i. This might, for example, be the local air pressure. There may be as many as three auxiliary series; for each one the model for the correlated part is

$$c_i = \sum_{k=0}^{K-1} b_k x_{(i-k)} \tag{3}$$

   where the b_k are the weights in a moving average (or FIR) filter that allows the transfer function between x and c to have some frequency response. These weights are called the *response weights* and are what are solved for.

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[3]This software is provided "as is", without warranty of any kind, express or implied, including but not limited to the warranties of merchantability, fitness for a particular purpose and noninfringement. In no event shall the authors or copyright holders be liable for any claim, damages or other liability, whether in an action of contract, tort or otherwise, arising from, out of or in connection with the software or the use or other dealings in the software.
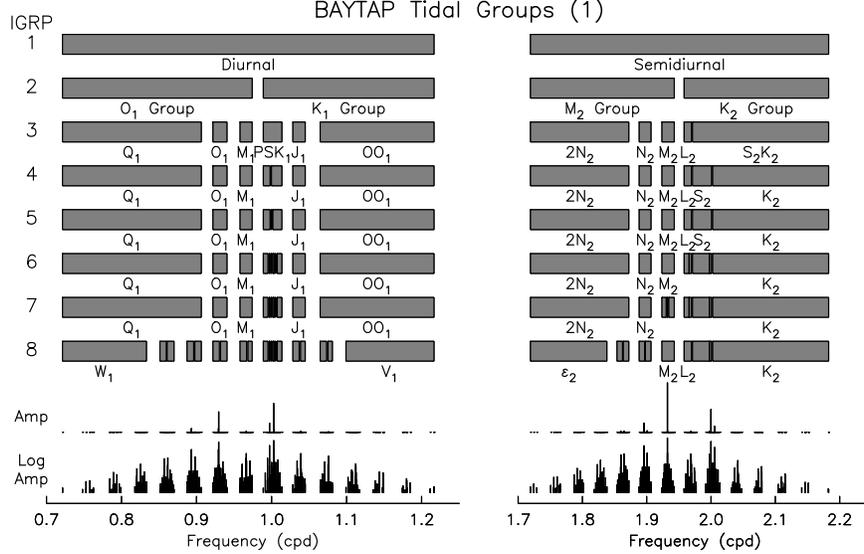
Figure 1: Diurnal and semidiurnal tidal groups available with the default option in Baytap, shown on a linear frequency axis. Labels omitted if they would overlap. The two lines below the groups show the amplitude spectrum of tidal harmonics, in both linear and log amplitude.

The *residual series*, $r_i = y_i - (v_i + s_i + d_i + s_i + c_i)$, is the misfit of the model to the data. For the assumptions underlying least-squares fitting to be valid, this series should have little or no temporal correlation. If you are interested in variations unrelated to the tides or other phenomena, the nontidal series $d_i + r_i$ best represents the "remainder".

The program solves for all the parameters by minimizing S, which combines the square of the misfit to the model with constraints on the model parameters:

$$
\begin{aligned}
S = & \sum_{i=1}^{N} \left[y_i - (v_i + s_i + d_i + s_i + c_i) \right]^2 \\
& + D^2 \sum_{i=1}^{n} (d_i - 2d_{i-1} + d_{i-2})^2 \\
& + W^2 \sum_{m=2}^{M} (A_m - A_{m-1})^2 + (B_m - B_{m-1})^2
\end{aligned}
\tag{4}
$$

D and W are additional parameters, called hyperparameters because they are not parameters of the model, but rather parameters which apply constraints to it. The hyperparameter D is multiplied by the second difference (or optionally third difference) of the drift terms; including this in the minimization creates a smoothness constraint on d_i, which could otherwise absorb all the variation in the series. The larger the value of D, the smoother the series; for D very large, the second difference term would dominate the sum, and would force d to be a linear drift. This smoothness
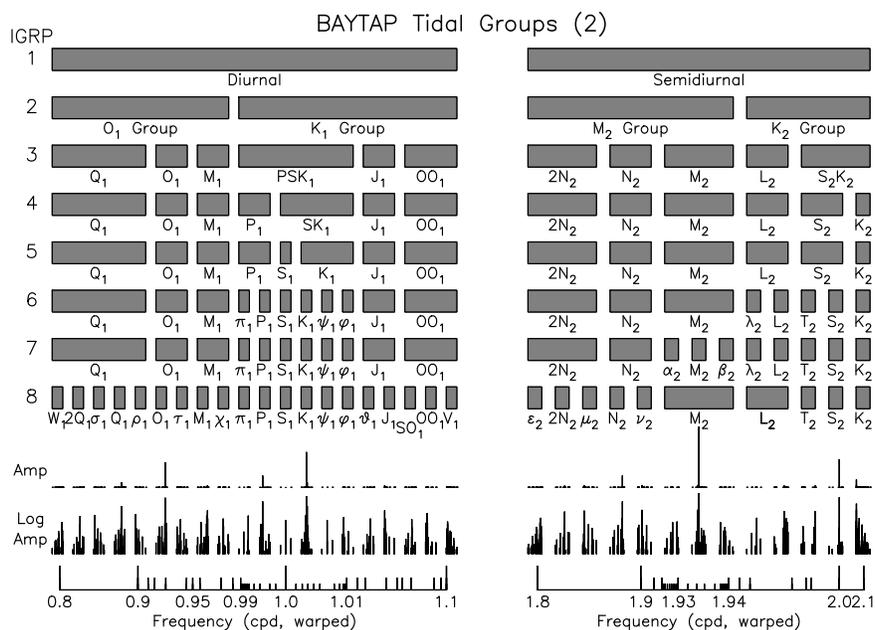
Figure 2: Diurnal and semidiurnal tidal groups available with the default option in Baytap, shown with the frequency axis warped to make each of the groups (in the finest subdivision) equal in size; the ticks at the bottom are for 0.1, 0.01, and 0.001 cycles/day, chosen to avoid crowding. The two lines below the groups show the amplitude spectrum of tidal harmonics, in both linear and log amplitude.

constraint allows the drift to vary in ways not easily expressed by polynomial or periodic functions.

The hyperparameter W likewise controls the smoothness of the tidal admittance: that is, how rapidly it can vary with frequency. For simplicity, equation (4) does not include one refinement actually present: the smoothness condition is not applied at the edges of the tidal bands for each tidal species. W is usually fixed to 1, but sometimes, as when analyzing a short data sequence, W must be modified manually to select the most suitable model.

The Akaike Bayesian Information Criterion (ABIC) is a statistical measure of model fit for the case in which both regular parameters and hyperparameters are present; D is varied by Baytap08 to find the value that minimizes the ABIC.

2.1 Grouping Tidal Constituents

If the sum for the tidal series (equation 1) included all tidal constituents, the inversion for amplitudes and phases would be unstable because of constituents spaced too closely in frequency. For this reason, each of the C_m and S_m is actually the sum of constituents close together in frequency that are grouped together; M is the total number of groups. Therefore, the tidal constants found are those for each group. There are a total of 8 possible arrangements of groups; which one is used can be set manually or chosen automatically, based on the timespan covered by the data. While the hyperparameter W stabilizes the analysis even if many tidal constituents are estimated from a short window of data, it is advisable to select the number of groups considering the quality and length of the data.

Figure 1 shows the different groups that are chosen for different settings of the parameter `igrp` in the control file. In this figure the frequency axis is linear; in Figure 2 this axis has been warped to separate all the groups. (Neither figure includes the additional group that covers the terdiurnal tides). The very large number of groups around 1 cycle/day exists because of interest in measuring the core-resonance effect, which is confined to this band. Looking at the spectrum of tidal amplitudes on a linear scale shows that only a few groups contain constituents with large amplitudes; the rest can be estimated precisely only with large amounts of data and low noise.

If `igrp` is set to zero, the grouping is chosen automatically, according to the following rule: For T in days:

Range of T	1–8	8–16	16–180	180–364	364-2000	>2000
`igrp`	1	2	3	4	5	6

Setting `igrp` to 7 or 8 would be done only for special tidal studies: 7 to look at the annual sidebands to the M_2 tide (which are sometimes anomalously large), and 8 for high resolution at the edges of the tidal bands.

3   Program Usage

Baytap08 accepts from one to four data files as input, reads a control file for instructions, and writes out either one file or two. All files are ASCII.

The input files are:

1. The *data file*, which contains the time series itself, along with (in some formats) additional information. This file is read from standard input.

2. The *control file* [4], which contains instructions for the processing. The name of this file is the first argument on the command line.

3. Optionally, up to three *auxiliary files*, which contain auxiliary data. The names of these files are read from the command line,

The output files are:

1. The *results file*, which contains the results of the tidal analysis, a spectrum of the drift (if asked for), and the statistical parameters. The name of this series is the second argument on the command line.

2. The *output series file*, which contains the individual series r_i, v_i, d_i, c_i and s_i. This file is written to standard output, though there is an option available not to write it at all.

An example of using the program would thus be

```
cat input-file | baytap08 control-file results-file
```

if you do not need the output series, or

```
cat input-file | baytap08 control-file results-file > output-file
```

if you do. If you had an auxiliary series, and wanted the output, the usage would be

```
cat input-file | baytap08 control-file results-file aux-file > output-file
```

4   Input File Formats

The input file and the auxiliary files may have one of four formats; for each file the format must be specified by an integer set in the control file (parameter `inform`). The possible values of this are

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[4]Formerly called the *parameter file.*

3, for a *data-only* free format (the default); 1, for *fixed/free* format (fixed header and free-format data); and 0, −1, or 2 for three types of *fixed* format. The fixed format is rather restrictive, but is the only one that can provide information on times of steps, and on calibrations. The fixed and fixed/free format (values −1 through 2) are all legacy formats from BAYTAP-G.

4.1 Data-only Format

This format is very simple: one title line at the start, followed by one data value per line, in either integer or floating-point format. In this case information about the station location, start time, sample interval, and number of terms must all be set in the control file. If the number of terms is absent, or larger than the number of data, the program will read to the end of the file, and take the number of lines to be the number of terms.

4.2 Fixed/free Format

This file format begins with a 5-line header:

```
title of dataset
latitude² longitude altitude gravity
year³ month day hour
number of obs⁴ sample interval⁵ missing data flag⁶
format of input data⁷
```

where the quantities read are

1. Title of dataset; this is free-format.

2. Coordinates of site: latitude and longitude in decimal degrees (spaces 1–10 and 11–20) and altitude in meters (21–30); also local gravity in cm/s^2 (spaces 31–40). If the gravity is set to 0.0, normal gravity is used. A mean value, 982.024 cm/s^2, is acceptable.

3. Time of first observation, given as `YYYY MM DD HHHH.HHHHH` where `YYYY` is the year, `MM` is the month, `DD` is the day of the month and `HHHH.HHHHH` is the decimal hour. The first three are 5 spaces each (spaces 1–15 in all) and the last is spaces 16-25.

4. Number of observations: spaces 1–5.

5. Sample interval in decimal hours: spaces 6–10.

6. Missing data flag, either positive or zero: spaces 11-25. If this is positive, the program ignores data with larger absolute values; if it is zero, all observations are used.

7. Format of the input data, given as a Fortran77 format statement; for example, `(10f8.2)` would imply 10 values per line, each eight characters long and with two decimal places.

An example of this format would be:

```
Esashi Earth Tide Station   Esashi, NS Extensometer (Free End)
    39.148    141.335      393.0    980.122
 1992   12    1  0.0
 2160  1.0    9000.D0
(6F10.2)
     -8.91    -10.23   9999.99     -9.79     -8.62     -6.87     921201
     -5.99     -4.53     -4.38     -5.84     -7.45     -9.93
    -12.13    -13.73    -14.32    -12.86    -11.10     -9.06
     -7.31     -5.84     -5.84     -7.31     -9.06    -11.83
    -14.32    -16.66    -17.39    -17.53    -16.07    -14.46     921202
   9999.99   9999.99   9999.99     -4.09     -3.36     -4.53
     -6.43     -8.47     -9.50     -9.93     -9.06     -7.89
     -4.68     -2.19     -0.15      1.17      1.17     -0.29
      1.17     -2.48     -4.82     -8.04   9999.99   9999.99     921204
```

Note that in this example the date indicators at the right-hand side of every fifth line are not read, since they are to the right of space 60.

4.3   Fixed Format

In this format the sample interval must be 30 minutes. Format types 0 and -1 differ only in the number of digits allowed for the data values: 4 digits for type 0 and 5 for type -1. Format type 2 allows 7 digits, and also is arranged in a different order.

The header starts with information about the site, which is followed by calibration information, and then the data—which includes timing information. The format looks like:

```
title of dataset[1]
latitude longitude altitude gravity[1]
number of calibrations[2]
year[3] month day hour calibration value[4])
year month day hour calibration value
d1[5] d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 J[6] S[7] yr[8] mon dy m[9]    Type 0
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 J S yr mon dy m        Type -1
yr mon dy m d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 J S        Type 2
```

where the quantities read are

1. Title of dataset; this is free-format.

2. Coordinates of site: latitude and longitude in decimal degrees (spaces 1–10 and 11–20) and altitude in meters (21–30); also local gravity in cm/s^2 (spaces 31–40). If the gravity is set to 0.0, normal gravity is used. A mean value, 982.024 cm/s^2, is acceptable.

3. The number of calibrations, which must be at least 2 and no more than 50: spaces 1–5.

4. The times of the calibration values, given as `YYYY MM DD HH.HH` where `YYYY` is the year, `MM` is the month, `DD` is the day of the month and `HH.HH` is the decimal hour. The first three are 5 spaces each (spaces 1–15 in all) and the last is spaces 16-20.

5. Calibration value: spaces 21–30. The calibration value at each observation time is found by linear interpolation between the calibrations given. The first calibration must be before the first observation and the last one must be after the last observation. If the sensitivity varies gradually, the calibration time may be on the hour or half-hour; if the sensitivity changes abruptly, you should give two calibration values at times between the half-hour interval; for example, one with the old sensitivity at (say) 23.8 hours, and the one with the new sensitivity at 23.9 hours. If the calibration value changes abruptly and there are no missing observations, you should designate a offset at that time to counteract the offset created with the zero level of the data is multiplied by the new calibration value.

6. Observations. Each line contains 12 data points (6 hours, given the sample interval). The observation time of the first data point on each line must be 0, 6, 12 or 18 hours. Blanks indicate missing data; for hourly data, put a blank at time corresponding to half-hours and set the resampling interval `delta` to 1 or 2 hours (Section 5.1.1). The end of the data is marked by a `9999` (type 0 data) or `99999` (type −1 data) in the leftmost spaces. The program will also stop reading at the end of the file.

7. Location of offset, given by an integer j, which indicates an offset between the $j − 1$th and jth datum. (Only one offset is allowed per line). If $j = 1$, the offset occurs between the last value of the previous line and the first value of the current one. A blank means no offsets.

8. Size of offset, to be added to all values following the $j − 1$-th. Blank spaces indicate an unknown offset to be estimated. While baytap08 does not estimate offsets in the auxiliary data, their size can be entered here; if you indicate an offset in an auxiliary series but do not give the size, that data point is treated as missing, and a warning message will be printed.

9. Time, in year month and day, of the data

10. Continuation number, from 1 to 4; the first data value of a line numbered m occurs at $6(m−1)$ hours.

The spaces used depend on the format type. For type 0, the data take spaces 1–48 (4 spaces/datum), the offset integer spaces 49–51, the offset size spaces 52–56, the year month and day spaces 74–79 (two-digit year), and the continuation space 80. For type −1, the data take spaces 1–60 (5 spaces/datum), the offset integer spaces 61–63, the offset size spaces 64–68, the year month and day spaces 74–79 (two-digit year), and the continuation space 80. For type 2, the year month and day take spaces 1–6 (two-digit year), the continuation space 7, the data spaces 8–14, 16–23, 24–31, ..., 96–103, the offset integer spaces 104–105, and the offset size spaces 106–113.

5   Control File

This file describes the analysis options, and provides information about the data and auxiliary files. An example (to be used in Section 8.2) is

```
&param
kind=8,
span=11000, shift=11000,
dmin=0.50d0,
order=3,
lat=48.6536 , long=-123.4515 ,ht=0,grav=0,
lpout=0,   filout=1,
lagp=3,
timsys=0.0d0
maxjmp=0,
igrp=5,
year=2005,mon=1,day=30,hr=0,min=0,sec=0,
ndata=11000,delta=1.0,
inform=3,
rlim=9999,
spectw=3,
nsine=10,
&end
0.935012       2000 01 01 00 00 00        0.0000000d0        MP1
1.0000000000   2000 01 01 00 00 00        0.0000000d0        S1
1.070464       2000 01 01 00 00 00        0.0000000d0        SO1
1.929535       2000 01 01 00 00 00        0.0000000d0        MTS2
2.861809       2000 01 01 00 00 00        0.0000000d0        MO3
2.935012       2000 01 01 00 00 00        0.0000000d0        MK3
3.0027379067   2000 01 01 00 00 00        0.0000000d0        SK3 (190.46+3l)
3.8645472267   2000 01 01 00 00 00        0.0000000d0        M4  (248.56+4l)
3.932273       2000 01 01 00 00 00        0.0000000d0        MS4
4.0000000000   2000 01 01 00 00 00        0.0000000d0        S4


                   Ocean Tide


Patricia Bay tide gauge (7277), located on the west side of the Saanich
Penninsula, in Saanich Inlet at Patricia Bay, at the Pacific Geoscience
Center.
----
Patricia Bay                           station name
Tide Gauge                             instrument name
----
```

```
cm of sea level                         unit of tidal data
Vancouver Internat Apt, sea-level press  title of assosiated dataset
```

The file opens with a *parameter section*: all lines between `&param` and `&end`. The parameter section is followed by `nsine` lines of information about other sinusoids to fit (see the discussion under `nsine` in Section 5.1.2). There are then up to 10 lines (of at most 80) characters; these are printed in the results file as title information. The `----` is the end of this information, and is followed by one line which gives the station name (40 characters, meaning that the `STATION NAME` shown in the example above is not printed), and up to 10 lines of 40 characters that describe the instrument. The second `----` is followed by one line that gives the units used (40 characters), and as many lines as there are auxiliary datasets, each line giving information about the auxiliary dataset (40 characters).

5.1   Parameter Section

Parameters are set using the syntax `keyword`=value. Each such entry must be separated from the next one by a comma, but there may be more than one entry per line. The `keyword` may be in all lowercase (as used in the examples here) or all uppercase. Parameters not set will assume their default values; all parameter values are printed in the results file.

In the descriptions of the keywords below, a $\Rightarrow$ symbol is used to flag those that are more commonly set; a $\bullet$ is used for those (newly introduced into baytap08) that provide information needed if the data is read using the free-format option (`inform`=3). The descriptions are grouped roughly by area of relevance.

5.1.1   Data Information

$\Rightarrow\bullet$`year`, `mon`, `day hr`: These give the start time of the nalysis, in year, month, day, and decimal hour.

$\Rightarrow\bullet$`ndata`: The number of data to be analyzed.

$\Rightarrow\bullet$`delta`: The sample interval for the analysis, in hours; this may be longer than the sample interval of the data, but should be an integer multiple of it.

$\Rightarrow\bullet$`lat`, `long`, `ht`: These are the N latitude and E longitude (in degrees) and elevation (m) where the data were collected.

`grav` is the gravity at the site, needed for tilt computations. If set to 0.0 (the default) it will be taken to be the normal gravity for the latitude and height given.

5.1.2 Analysis

⇒`kind`: (Default 7) This defines the kind of theoretical tide against which the data are compared. Setting `kind`=7 uses the tide-generating potential divided by the acceleration due to gravity and the mean earth radius (6371023.6 m), to form a nondimensional tide. This setting may be used for any tidal data; the estimated amplitudes and phases will be correct, but the tidal factors will not be.

It is common in earth-tide studies to express the results as ratios between the tide on a rigid (or purely elastic) Earth, and the tides observed, to compare with the relevant combinations of Love numbers. This corresponds to `kind` being set to 1 through 6. For 1, the theoretical tide is the gravity tide, with units of microgal, and increased gravity positive. For 2 or 3, the theoretical tide is assumed to be north or east tilt respectively, units milliarcseconds [5] with positive tilt being equivalent to subsidence to the north or east [6] If `kind` is 4–6, the tide is assumed to be linear strain, in units of 10^{-9}, with extension positive; 4, 5, and 6 give NS, EW, and NE linear strain, respectively.

If `kind`=8, the theoretical tide is assumed to be the tidal potential divided by a mean gravity of 982.024 cm/s² [7] to give a height in cm, so that this would be suitable for analyzing ocean tides.

`az`: (Default 0). The instrument azimuth, in degrees clockwise from north. For tilt or strain, this may be used to set the direction: if `kind`=2 or 4, and `az`=n, the direction of tilt (or strain) is along azimuth n. Thus `kind`=2 and `az`=90 is equivalent to `kind`=3, and `kind`=4 and `az`=90 is equivalent to `kind`=5.

⇒`span`: (Default 744) This is the number of observations to process as a unit; since baytap08 treats the drift value at each observation time as an unknown parameter, the length may need to be limited to keep the matrix inversion computable. If the drift is not solved for, baytap08 can process very long spans of data. To process a long span of data with the drift included, the analysis period can be shifted (see `shift`). The exact upper limit of `span` depends on the total number of parameters to be solved for, including tidal constituents, response weights, and steps.

`shift`: (Default 720) If multiple spans of data are being analyzed, this is the number of points the data window will be shifted by each time; for example, if `span`=744 and `shift`=720, 744 points will be processed, then the analysis window will be moved by 720 points, giving an overlap of 24 points. In this case, if `filout`=1, the results of the first 720 points of each data window will be printed and all 744 are printed in the last block. If `shift` is greater than `span` some data will be skipped. If `shift`=0 the drift is not solved for and `span` will be ignored: the program will process the entire data set.

⇒`dmin`: (Default 0.25) The lower limit of the hyperparameter D. baytap08 searches for a value of

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[5]A milliarcsecond is 4.848 nanoradian.

[6]That means that for a pendulum tiltmeter the bob moves in that direction, while for a water tube tiltmeter the water level rises at the north (or east) end.

[7]This gravity value, and that used for `kind`=7, is chosen to be compatible with Venedikov's method used in NAO Mizusawa.

D that minimizes the ABIC value; the range searched is from `DMIN` to 1000. Four times `dmin` is the initial value of D. If you are analyzing long spans of data, it is useful to first analyze two or three months of data to find a good initial value for D (which is given in the results file); setting `dmin` to be 0.25 of this D will minimize computation time in the full analysis.

⇒`igrp` (Default 0). This parameter is described in Section 2.1; if it is 0, the number of groups is selected automatically as described there. The existence of the hyperparameter W stabilizes the tidal analysis if many groups estimated from a short window of data; but it remains advisable to select the number of groups appropriately given the data quality and record length.

`lagp`: Maximum lag allowed in estimating the response weights for auxiliary data; If `lagp`=k, then $k+1$ response weights will be found; `lagp`=0 would be used if there is only one coefficient, as when the series are simply proportional.

`lagint`: (Default 0) Lag interval Δ. The response part of equation (3) can be written more precisely as

$$\sum_{k=0}^{K} b_k x_{i-k\Delta} \tag{5}$$

where b_k are the response weights and x_k is the auxiliary data. For example, if the sampling interval is 1.0 hour and `lagint`=2, the weights are 2 hours apart.

⇒`nsine`: (Default 0) If this is nonzero, and less than or equal to 10, `nsine` lines will be read from the control file immediately following the `&end` line. Each line specifies a sinusoid to be fit to the data, in addition to all the other parameters. This is useful for fitting nonlinear tides or meteorological tides. Each line should contain the frequency, in cycles/day (spaces 1-15); the epoch for a given phase (year, month, day, hour, minute, second, spaces 16 through 34), and the phase at that epoch, in degrees (spaces 35 through 46). See Section ??? for an example.

`order`: (Default 2) Defines the order of differencing is used to measure the roughness of the drift function d_i (equation 4), which must be 2 or 3.

`weight`: (Default 1.0) This is the value of the hyperparameter W described in Section 2.

5.1.3   Input and Output

`filout`: (Default 0) Baytap assumes the input data can be decomposed into four parts: tides, drift, the response to auxiliary data, and the residual. `filout`=1 will write these series to standard output, in the order given.

`inform`: (Default 3) The format for the data and auxiliary files, as described in Section 4.

`lpout`: (Default 0) This specifies the tidal analysis output. If `lpout`=0 the program prints the
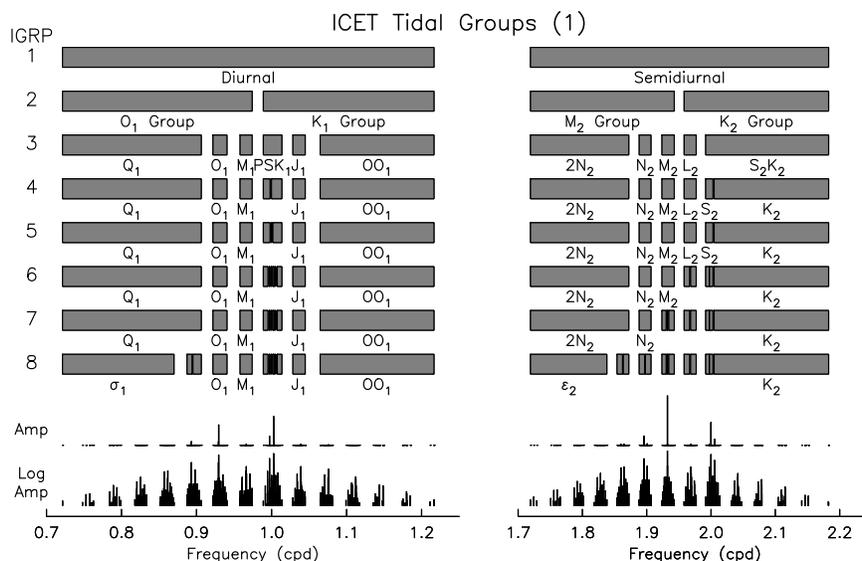
Figure 3: Diurnal and semidiurnal tidal groups available with the `icetgr=2` option in baytap08, shown on a linear frequency axis. Labels omitted if they would overlap. The two lines below the groups show the amplitude spectrum of tidal harmonics, in both linear and log amplitude.

estimated tidal factors and the frequency response for the auxiliary data.

`rlim`: (Default 10^{25}) Values whose absolute value exceeds this will be treated as missing data, and not used in the analysis. In the decomposed series, any flagged points will have a value of 10^{30} in the residual and original series. The flagging will not appear in the drift, the tidal part, or the estimate of the part correlated with auxiliary series. In the nontidal series (residual plus trend) the residual will be assumed to be zero for any flagged data.

`spectw`: (Default 0) Resolution for plotting the power spectrum of the drift. If this is set to zero and the entire series is being analyzed, the spectrum is not plotted. *Note* that the drift spectrum is computed by fitting an ARMA model to the time-series values, and then computing the spectral response of this model. The normalization of this is somewhat different from that usually used for power spectra.

5.1.4   Miscellaneous and Special-Purpose

`iback`: (Default 0) If this is set to a nonzero value, the program will be run in backwards-compatible mode, described in more detail in Section 10

`icetgr`: (Default 1) If this is set to 2, the tides are grouped somewhat differently than the default shown in Figures 1 and 2. Figures 3 and 4 show the alternative grouping.

`ifcr`: (Default 0) Flag to include the free core resonance effect in the theoretical tides; the default is that it is not. See Section 9.3 for details.
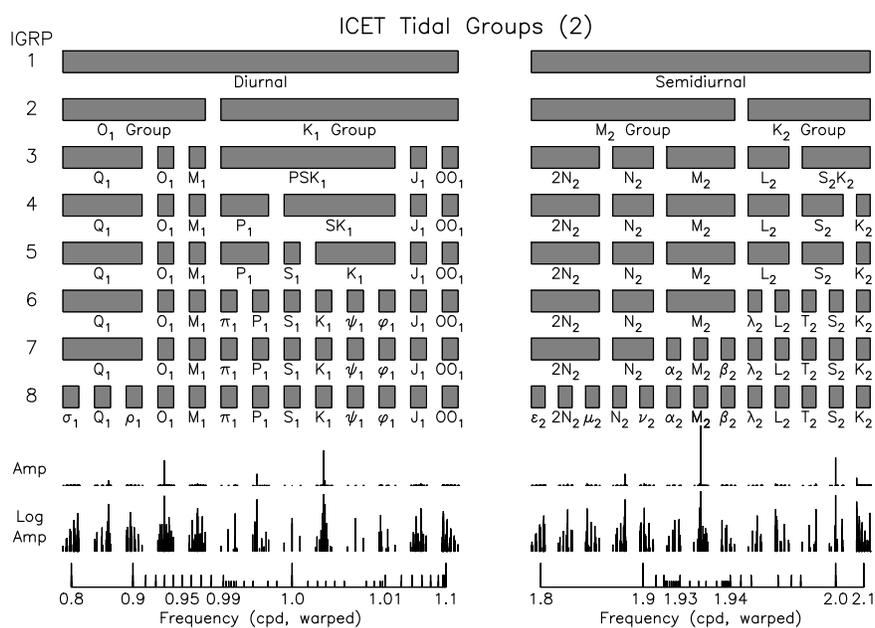
Figure 4: Diurnal and semidiurnal tidal groups available with the `icetgr`=2 option in baytap08, shown with the frequency axis warped to make each of the groups (in the finest subdivision) equal in size; the ticks at the bottom are for 0.1, 0.01, and 0.001 cycles/day, chosen to avoid crowding. The two lines below the groups show the amplitude spectrum of tidal harmonics, in both linear and log amplitude.

ipoten: (Default 1) The default uses the Cartwright, Tayler and Edden table (Cartwright and Tayler, 1971; Cartwright and Edden, 1973) for the theoretical tide calculation. If **ipoten**=2, Tamura's table (Tamura, 1987), with 909 tidal constituents, is used instead.

ith: (Default 1) If **ith**=1, theoretical tides are included; if **ith** = 0, they are not. This flag should be used if you are analyzing very noisy data and the tides may or may not be present; see Section refsec-bresp.

lovenm: (Default 2)

maxitr: (Default 21) Maximum number of iterations allowed in searching for the minimum ABIC.

maxjmp: (Default 5) Defines the maximum number of steps in one analysis period. This parameter is used to check the size of working storage. Do not set **maxjmp** too large unnecessarily, since a large value will increase memory needed and the computation time.

p4flag: (Default 1)

paglen: (Default 66)

prepro: (Default 0) If **prepro**, **shift**, and **lpout** are all greater than zero, the interpolated values of the missing observations will be printed out, with the number of decimals (1, 2, or 3) equalling the value of **prepro**.

qval: (Default 1150) This sets the value of Q used for the core resonance (equation 6).

s1wave: (Default 0) Normally, the S_1 tide group is represented by several sinusoids with frequencies close to 1 cycle/day, since this is what the tidal potential looks like. If **s1wave**=1 these are replaced by a single sinusoid at exactly 1 cycle/day.

timsys: (Default 0) Amount by which to adjust time system to UTC. For example, if the data are observed in UTC, **timsys**=0.0. If the time system is Japanese Standard Time (JST), **timsys** = -9.0. The difference between ephemeris time (dynamic time) and universal time is fixed to 51 seconds.

6   Output Files

As noted in Section 3, baytap08 produces two output files: the results file, giving the results of the analysis, and the output series file, giving the different time series produced by the baytap08 analysis.

6.1 Results File

The results file begins with the version of baytap08, array dimensions used, the parameter settings, the title, longitude and latitude of the tidal data set, the date of the first data point, the results of a memory check, and information from the auxiliary data sets. For each data window analyzed the program always prints

1. Information on the search for the minimum ABIC as the hyperparameter D is varied, with the best value of D corresponding to a minimum ABIC. If there are auxiliary datasets, the raw values of the response weights are also given. Note that while the auxiliary data are normalized against the range of the tide for processing, the output values are for un-normalized data.

2. Tidal factors, amplitudes, and phases, with errors. For ease in extraction, these lines begin with a >. An example would be

grp		symbol	factor	rmse	phase	rmse	amplitude	rmse
					(local, lags negative)			
1	1-143:	Q1	3.82893	0.22804	-127.960	3.412	7.333	0.437
2	144-201:	O1	4.30927	0.04006	-134.739	0.533	43.107	0.401
3	202-249:	M1	4.04779	0.38037	-142.332	5.383	3.184	0.299
4	250-266:	P1	5.09743	0.08385	-156.486	0.943	23.726	0.390
5	267-270:	S1	5.26553	1.40200	-156.730	15.256	0.579	0.154
6	271-305:	K1	5.43406	0.02448	-156.963	0.258	76.450	0.344
7	306-345:	J1	6.26571	0.37251	-177.244	3.405	4.929	0.293
8	346-450:	OO1	6.54658	0.38289	153.666	3.351	2.818	0.165
9	451-549:	2N2	5.07205	0.16434	-45.339	1.856	1.372	0.044
10	550-599:	N2	6.76238	0.03322	-101.277	0.282	13.829	0.068
11	600-655:	M2	5.73293	0.00597	-126.305	0.060	61.232	0.064
12	656-681:	L2	4.37565	0.12412	165.144	1.626	1.321	0.037
13	682-710:	S2	3.02664	0.01245	-151.049	0.226	15.040	0.062
14	711-827:	K2	2.89533	0.03163	-152.590	0.625	3.911	0.043
15	828-909:	M3	4.33865	0.35811	-98.571	4.725	0.401	0.033

Here the numbers in the second column show the harmonics used: 909 total. The fourth and fifth columns give the factors relative to the reference tide (in this case, the tidal potential height) and the errors. note that these values vary relatively smoothly with frequency, as do the phases (sixth column). The amplitudes are in the eighth column. The standard deviations for the factors, the phases, and the amplitudes, all include the variation of D, and cannot be compared to other analysis methods directly. If the auxiliary data influence tidal variation greatly, a larger D will be obtained compared to the analysis without auxiliary data. In this case, the standard deviation and the hyperparameter D often become larger. Usually the

data quality is judged by the magnitude of the standard deviation; in baytap08, the value of D may be a better measure. A large D (linear drift) indicates good data.

In addition, the following may be printed:

1. If there are auxiliary data the frequency response for these is printed next. For ease in extraction, these lines begin with a `>R`. For atmospheric pressure data, only the response at long periods and for the S_1 and S_2 pressure tides are likely to be meaningful. For example, an amplitude response of 0.882 with phase shift 147° for the S_2 tide means that in (say) an the ocean tide analysis, the uplift of the ocean surface is $0.882cos(\phi_{S_2} + 147°)$, where ϕ_{S_2} is the phase of the S_2 tide; at this frequency, 147° is a delay of 1.1 hours compared to an ideal inverted barometer.

2. The power spectrum of the drift. For ease in extraction, these lines begin with a `>S`. This shows the noise level of the data and the residual noise in the tidal bands. To increase the resolution of this figure use the optional parameter, `spectw=n`, where n is the magnification. Setting `spectw=3` is usually adequate for hourly data.

3. Optionally, the nontidal time series may be displayed as a printer-plot. In preprocessing, the values which are excluded from the original data are printed with this figure with the option `prepro=1`.

4. Finally, the program gives a summary of the search for abnormal data and a list of steps (for `inform` -1, 0, and 2). The ABIC of each analysis block, the differences in the drift, and the magnitude of the residual, can be used to investigate abnormal values. The estimated step sizes are already multiplied by the sensitivity; they must be divided by this to get the corrections to the original data (which can be then added to the input file if the right format is used). If `prepro=1`, this division is done automatically and both values are printed. These values should be added to input data for step correction. Note that the positions of steps printed in the summary output may differ by a few hours from the positions pointed in the original dataset because of resampling. Since this summary section can be at most 100 lines; abnormal data and steps may not print even if present. You should then repeat the preprocessing for the time periods in question or process with a shorter data window.

6.2   Output Series File

This file prints the decomposition of the series into (A) a residual series (which should look like "white noise"; (B) a smooth "drift" or "trend"; (C) a part that is correlated with the auxiliary series; and (D) a tidal part. The first column in the file is the time of the data value, given in ISO 8601 style, e.g., `2005-06-20T19:00:00`; this is suitable for use in the GMT plotting package. (Or in *gnuplot*, using the command `set timefmt %Y-%m-%dT%H:%M:%S`). The next four columns are (A) through (D), which is followed by the sum of (A) and (B), which is called the "nontidal" series": this is the best approximation to a series "cleaned" of tidal and auxiliary effects. The remaining columns of each line contain the values of the original input data to be analyzed, and of the auxiliary series: in these, missing data have been replaced by a value of 10^{30}.

7 Typical Uses

How baytap08 is used depends on whether the aim is to find the precise tidal constants or the nontidal part. In the former case, it is not necessary to obtain the drift, but attention has to be paid to the calibration, rejection of abnormal data, parameters settings and preparation of the auxiliary dataset. For finding nontidal parts, the parameter settings are less constrained.

7.1 Precise Determination of Tidal Constants

As stated above, before doing a tidal analysis you should first clean the data, removing bad observations and unusual data. Quite often you will get better results by deleting poor data rather than by correcting them or interpolating over data gaps.

Setting `shift=0` will use all the data; in this case `span` is ignored, and the drift is not estimated. Also, the spectrum of the drift and summary output are not printed. Options `lpout=1` and `filout=1` are also ignored. If you are trying to identify a variation of tidal constants with time, set `shift` >0 to process the data using a sliding window.

Pay attention to the rejection of data, collection of auxiliary data and choice of maximum lag (`lagp`) in the precise decision of tidal constants. A tidal signal will remain in the drift component if the instrument sensitivity varies with time; this will also cause the tidal parameters to vary with time.

7.2 Ocean Tides

Sea level changes roughly opposite to changes of atmospheric pressure, with a ratio of about 1 cm/mb. A measurement of air pressure is needed for precise analysis of the ocean tide. The response can be estimated by setting `lagp=3` and `lagint=1`. The theoretical value of ocean tide (`kind=8`) contains only equilibrium tides; it does not have either long-period tides (e.g. S_a, M_f) or compound tides (e.g. S_3, MK_3). Baytap08 may therefore not be suitable for the analysis of tides in shallow water. Peaks of S_3 and S_4 often stand out in the spectrum of the drift; Section 8.2 shows an example. But if the amplitude of the compound tide is small, baytap08 can be used in ocean tide analysis.

If analyzing a long period tide, set `shift` >0 and `filout=1` to save the determined drift and analyze that as the drift contains the long period change of the ocean surface. If analyzing short period tides, examine the synthesized data, which are the sum of the drift and residual because the power from short-period tides may remain in the residual. For precise analysis, use the nontidal series.

7.3   Preprocessing of Datasets

Baytap08 can be used to pre-process tidal data. Preprocessing includes the rejection of abnormal data (but not abnormal phenomena), estimation of steps (type 0 and 1 format), tracing the change of instrument sensitivity and checking the variation of data quality.

For preprocessing, the analysis interval (`span`) should be short and the data analyzed using a sliding window. For example, for 1 hour sampling use one month data windows, and a 1 day overlap, `span`=744 and `shift`=720. For 0.5 hour sampling and 10-day data windows overlapping by 1 day the parameters would be `span`=480, `shift`=432. If an auxiliary dataset exists, set `lagp`=0, `lagint`=1 to decrease processing time. The grouping of tidal constituents can be done automatically or can be set to 3 or 12 groups.

After questionable data have been identified in an initial processing run it is advisable to set `lpout` to 1 and verify the drift and residual part in subsequent preprocessing runs.

If the calibrations are not good, a change of tidal factors will appear across the various data windows. If the change is considered to be a result of bad calibration and not real phenomena, the calibration values must be corrected before precise analysis. Otherwise, a tidal signal will remain in the estimated drift and in the worst case; a winding drift, which imitates the original data, is obtained if the analysis period is long.

To interpolate missing data and correct bad data set `lpout`=1, `shift` > 0 and `prepro`=1. If the option `prepro`=1 (or 2 or 3) is given, the predicted values of "drift + tidal part + correlated part" are printed at the right side of the printer-plot of the drift. These values do not include the residual part. and are not multiplied by the sensitivity. The predicted values are corrected for known steps, so they may not be used directly to replace bad data points. If steps are being estimated as part of the preprocessing however, the estimated step values are not added to the predicted data values. In this case, the predicted values can be used to replace missing or abnormal data. If there are auxiliary data sets, the above prediction is not done at the beginning of the data window or where there are missing auxiliary data because the response cannot be calculated at those points. If there are missing auxiliary data points, perform the preprocessing without the auxiliary dataset to get the expected values for the entire period.

7.4   Determination of Trend and Search for Abnormal Data

Initially check the parameter settings are good by using only two to three months of data and vary the parameters in these first runs. For example, vary the parameter `lagp` from 3 to 12 for auxiliary data sets. The estimation of the drift across a data gap should be examined carefully. A few abnormal data before or after some hours of missing observation can sometimes create an abnormal drift. This often occurs after maintenance at the site. Removal of these data can sometimes make the drift smoother. The same attention should be paid to the evaluation of steps in a period of missing data. Sometimes a rapid drift is obtained if the parameter settings are extremely wrong or there is an unexpected change of sensitivity. In this case, power remains in

tidal bands. Check this has not happened by examining the power spectrum of the drift once with the parameter `lpout=1`.

For the actual analysis the whole period of data should be processed with a sliding window of two or three months in length. For example,

```
lpout=0, filout=1, lagp=3, lagint=1, span=1488, shift=1440
```

If you expect changes in sensitivity, first set the data length processed to be a few weeks to get a smooth drift.

A summary of the search for abnormal data is listed in the output file. Though this list of unusual data is found through a rough search, in most cases they are really irregular data and baytap08 points out almost all irregular observations and phenomena. Irregular data might arise from instrument failure, a large disturbance of the surroundings or real abnormal phenomena. The last case occurs rarely, even though many observers try to detect unusual movements of the Earths crust.

8 Examples

This section discusses and illustrates several examples of applying baytap08 to various tidal series. All the files needed to run these examples are included in the distribution.

8.1 Esashi Strain Data

This dataset (one of the samples distributed with BAYTAP-G) is about three months of data from a quartz-bar strainmeter in Esashi, Japan, an installation described in detail by (Sato and Harrison, 1990). The beginning of these data are shown in Section 4.2 as an example of fixed/free input format. The control file is

```
&param
kind=7,
span=2160, shift=2160,
dmin=0.50d0,
lpout=0,   filout=1,
lagp=3,
timsys=0.0d0
maxjmp=2,
igrp=4,
year=1992,mon=12,day=1,hr=0,min=0,sec=0,
ndata=2160,delta=1.0,
```
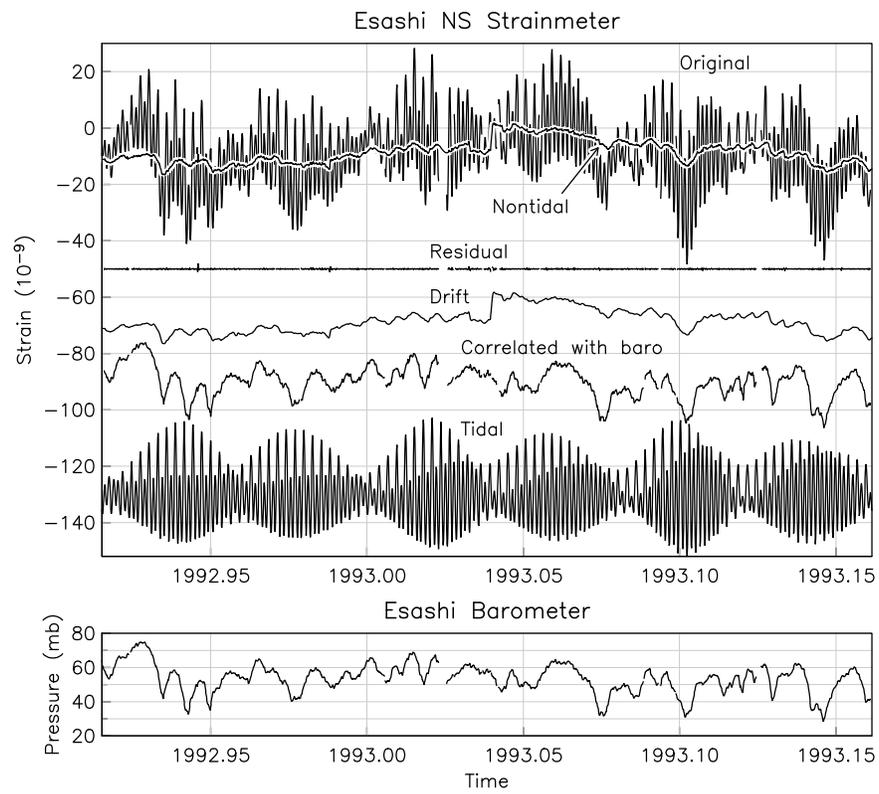
Figure 5: Strainmeter data from Esashi, Japan, as processed by baytap08
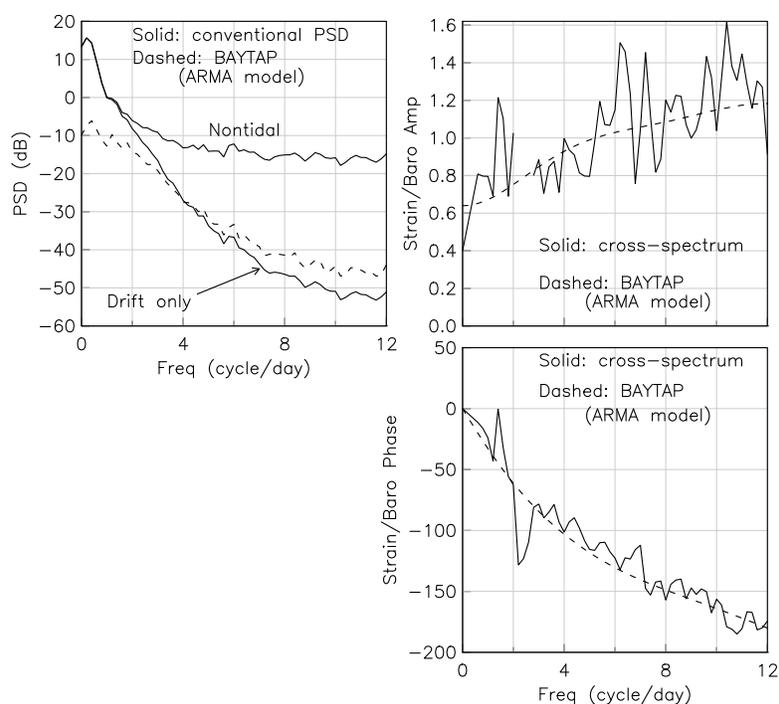
Figure 6: Spectra of the drift and nontidal data from Esashi, and the transfer function from air pressure to strain.

```
inform=1,
rlim=9000,
spectw=1,
&end
                    NS Strain


----
Esashi Earth Tide Station                 station name
quartz tube extensometer                   instrument name
----
10**(-9) strain                           unit of tidal data
Atmospheric pressure                      title of assosiated dataset
```

Figure 5 shows the time series, overlain by the nontidal component found by baytap08. Below this are shown the four series that are actually found: the residual, the drift (the sum of these is the "nontidal" series), the part correlated with the air pressure (with a response of about 10^{-9} strain per millibar), and the tidal part. The air pressure is shown in a separate frame. Figure 6 shows the spectrum of the drift as estimated by baytap08 and also by more conventional means (a section-averaged power spectrum), and also the transfer function between air pressure and strain, estimated by a cross-spectrum and by baytap08. Especially in the second case, the agreement is very good.
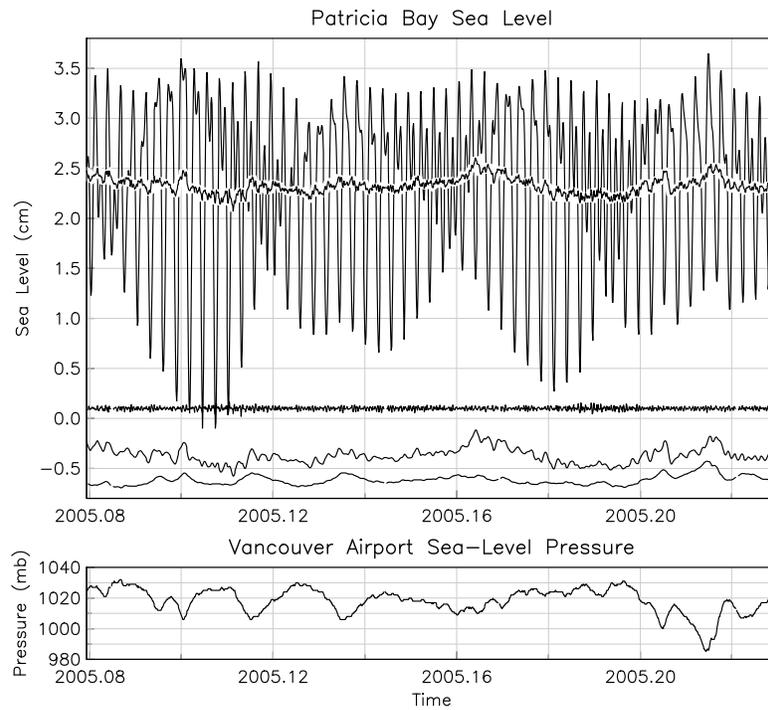
Figure 7: Sea-level data from Patricia Bay, Canada (adjacent to the Pacific Geoscience Center) as processed by baytap08
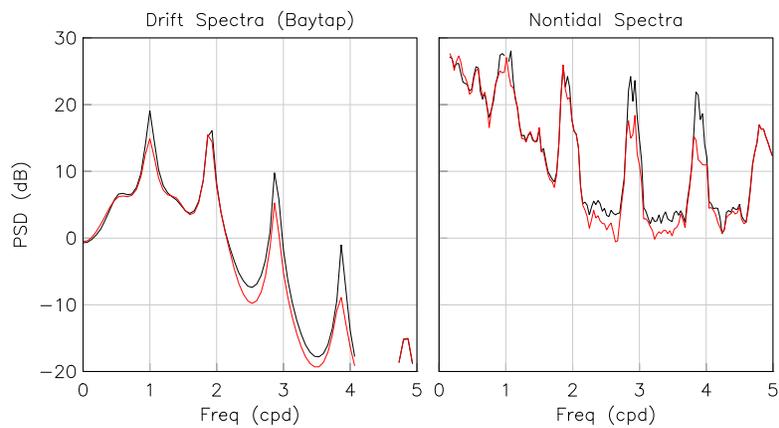
Figure 8: Spectra of the drift and nontidal data from Patricia Bay. Red is after fitting the extra sinusoids.

8.2   Patricia Bay Sea Level

In this example, chosen for its proximity to a set of PBO strainmeters, there were about 18 months of data available from a tide gauge. Hourly pressure data were available from a nearby airport. The analysis parameters have already been shown in Section 5. Figure 7, which shows the first part of the data and series, shows the effectiveness of the program at removing the tidal and pressure signals; the latter is only removed in part, probably because the transfer function from pressure to sea level changes with the season.

In this case, extra sinusoids were included; the frequencies of these were chosen by looking at a high-resolution spectrum of the nontidal series from an analysis in which these were not used; peaks in this could be matched to various tidal frequencies expected to appear with nonlinear behavior—something not unexpected at this site, which is not open-ocean. Figure 8 shows the effect of including these sinusoids, in the frequency domain. Their amplitudes are:

Frequency (cpd)	Amp (cm)	Err (cm)
0.935012	1.87	0.46
1.000000	2.41	0.40
1.070464	2.04	0.32
1.929535	1.12	0.06
2.861809	1.57	0.03
2.935012	1.19	0.03
3.002738	0.41	0.03
3.864547	1.25	0.03
3.932273	0.79	0.03
4.000000	0.20	0.03

Even after these are removed, the spectra still show significant energy in these bands; it seems likely that a time-domain fit in the style of Cartwright (1968) would be needed to remove all this energy.

9   Special Features

This section covers special features of baytap08: smoothing input data, using baytap08 to implement the "response method" of tidal analysis, and including the free core resonance in theoretical tides.

9.1   Smoothing Input Data

Input data can be smoothed without estimating tidal constants if the theoretical tides are not included (`ith=0`) and the lower limit of hyperparameter D is set to a low value (e.g., `dmin=0.01`), baytap08 smoothes the input data without determination of tidal constants. The spectrum of the smoothed input data instead of the spectrum of the drift is then printed (`filout=1`). The spectrum obtained cannot be used as a precise analysis of the input data, however, because the spectrum is a lowpassed one and the frequency resolution is not good. But, this result is useful to confirm the spectral structure of the input data before tidal analysis.

9.2   Using baytap08 as a Response Method

If there is an auxiliary dataset and the theoretical tides are not included in the analysis (`ith=0`), baytap08 can be used to estimate the response. Though the standard analysis model of baytap08 is a harmonic one, this usage is actually useful. In the analysis of nontidal data or noisy data which are not certain to contain tidal components, use baytap08 as a response method with the option `ith=0`. To determine tidal constants using the response method, prepare the theoretical tides as an auxiliary dataset and for one hour interval data, for example, set `lagp=16` or 24, `lagint=2` and `ith=0`. Though the standard usage is advisable for the precise estimation of tidal constants this method is used as a test of the program.

9.3   Including the Free Core Resonance

There is little experience so far in analyzing data with this option; we suggest extreme caution when trying this option.

Theoretically there are 205 tidal constituents in the diurnal band. Baytap08 usually combines the diurnal constituents into 6 or 11 groups, depending on the length of the analysis period. However, if `ifcr=1`, baytap08 creates a new group using all diurnal constituents; this is expressed as:

$$\sum_{l=1}^{205} \frac{1}{2\pi f - \left(2\pi f_0 + \frac{i}{2Q}\right)} \cos(2\pi f t + \phi) \tag{6}$$

where f_0 is 1.004913 cycles/day (15.0737 °/hr, which is the frequency of the resonance caused by the ellipticity of the core-mantle boundary; we assume that this resonance has a Q of 1150. The first part of this equation expresses the resonance and the last part expresses the time variation of the theoretical tides. The rapid variation of the tidal admittance around $mathrmK_1$, ψ_1 and ϕ_1 should be handled appropriately by this modification.

If `ifcr=1`, the three groups K_1, ψ_1 and ϕ_1 should be given the same admittance, so these form a new group R. Since the K_1, ψ_1 and ϕ_1 constituents can only be separated with one year of

observations, this process is meaningless for short periods of data. You should set `igrp`=5, and set `weight` to a value greater than 1, to make an even smoother tidal admittance. The coefficient of the group R is printed separately in cosine and sine parts. To alter the value assumed for Q, use the parameter `qval`.

10   Backwards Compatibility

If the parameter `iback` is set to 1 In the control file, baytap08 will attempt to emulate the behavior of BAYTAP-G as much as possible. The calling syntax is unaltered, but the format of the control file and the two output files is different, and input format `inform`=3 is not supported.

10.1   Control File

The file after the `&end` of the parameter section contains more information, and is more strictly formatted.

First, there has to be a line specifying the start date of the analysis,, the number of samples to be used (total) and the time interval to be used. The format is:

```
YYYY   MM   DD H.HHH NNNN S.S
(3I5,F5.0,I5,F10.0).
```

Where `YYYY` is the year, `MM` the month, `DD` the day of the month, and `HH` the hour of the day (which may be real). `NNNN` is the number of samples and `S.S` is the sample interval in hours. For `inform` set to 0 or -1, the new interval can be 0.5, 1.0, 1.5, 2.0, 3.0 or 6.0 hours; if it is 1.0, every other datum is read. For `inform` set to 1, the interval given here is ignored, and the one used in the data input file is used.

This line may be followed by up to 10 lines in which spaces 1-5 contain the string `cos` or `COS` followed by two blanks; these lines will be treated as descriptions of sinusoids to be fit (see `nsine` in Section 5.1.2). For each sinusoid, the line should contain its frequency in degrees/hour, the epoch time for its phase (in year, month, day, and decimal hour), and the phase at that epoch, in degrees; the line will be read with a Fortran format of `(5x,d15.8,3i5,f5.1,d15.8)`

The next line gives the tidal grouping to be used. If this is 0, the series length will be used, as described in Table 2.1. Otherwise, the value set maps to `igrp` as follows:

Value	-2	-1	1	2	3	4	5	6
igrp	1	2	3	4	5	6	7	8

The next line specifies the format for the tidal series, using a number between -1 and 2; and also a flag to indicate if steps should be estimated (0 not to, 1 to do so). The format is `(5x,2i5)`.

This line is followed by up to three lines, similarly formatted, for the auxiliary series; for all of these the step variable should be set to zero, but the formats may be different.

This section of the results file is terminated by a `9999` in the first four spaces of a line. This delimiter is followed by the same ASCII information that follows the `&end` statement in the usual control file (Section 5), except that the `----` delimiters are `9999` instead.

10.2 Results File

In general, the output will be similar to that in baytap08, except that times will in general be given in decimal hours rather than hours, minutes, and seconds; and frequencies will be in degrees/hour (15 degrees/hour is 1 cycle/day). In addition, the response to the auxiliary file, and the residual spectrum, are given as printer plots rather than just as lists.

10.3 Output Series File

Three comment records are printed first. Then, the sequence number, residual, drift, correlated part (if relevant), tidal part, and original data (corrected for known steps, and multiplied by sensitivity) are printed with a format `1X,i5,5(1pd13.5)`. One record is printed for each observation.

11 Miscellaneous Notes

11.1 Internal Array Sizes

Dimension sizes are declared to analyze several years of data without estimating the drift or three month's data with estimation of drift. The dimensions are defined using **parameter** statements in the source code In the present version, the parameters are: `maxhc=7500000`, `maxdc=320000`, `maxout=100000`, `maxaux=3`, `maxgrp=31`, and `lbuff=50000`. If only about one month of data is processed or baytap08 is used as a preprocessing tool, the program size can be reduced substantially. For example, setting `maxhc=25000`, `maxdc=2500`, `maxout=1000`, `maxasc=1`, `maxgrp=12`, and `lbuff=500` in the main program and subroutines will reduce the program size to about 700 KBytes. For these settings one can divide tidal constituents into at most 12 groups and can apply one auxiliary dataset in the analysis. In this case, `maxjmp` should be set to the smallest possible value.

11.2 Static Variables

The subroutines `subsea` and `tide` contain local variables that must retain the values defined at the previous call; these should have `save` statements included, or else use a `save` option when

compiling. In subroutine `subsea`, the `dmin` may be pointed to as an undefined variable by the Fortran77 compiler. Since its value is used only for second and subsequent calls this is acceptable.

11.3   In Case of Problems

To report bugs or ask questions, contact Duncan Agnew at the address given above.

References

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