T A B O O

User guide

Giorgio Spada

Istituto di Fisica - Universita' di Urbino
Via Santa Chaiara, 27
I-61029 Urbino

spada@fis.uniurb.it

other investigators:

Andrea Antonioli, Lapo Boschi, Valter Brandi
Spina Cianetti, Gabriele Galvani, Carlo Giunchi
Bruna Perniola, Nicola Piana Agostinetti
Antonio Piersanti, Paolo Stocchi

Second Edition

February 8, 2005

Contents

Chapter 1

Introduction

In this manual we describe the general purpose of TABOO, its structure, and its applications. A very basic knowledge of the Fortran 90 language and of Unix is required. The mathematical theory behind TABOO is given in a separate theory document (hereafter referred as to TD) which is released with these instructions.

TABOO has been mainly written for students at their first approaches to the postglacial rebound problem. We hope that it will also be useful for more experienced investigators.

1.1 What is TABOO ?

TABOO is a postglacial rebound calculator.

TABOO can be used to compute the response of the Earth to loads of various shapes and time–histories. Although it is especially oriented to loads of glacial origin, it can be used or adapted to model the effects of tectonic loads or of any perturbation that can be described by means of a pressure applied to the external surface of the Earth.

TABOO has the purpose of collecting in a single, quite general, and portable code the procedures and knowledge that we have developed since we began to investigate the postglacial rebound problem. The implementation in TABOO of all of the required formulas took us a long time, but the result now is that anyone can obtain predictions in a very easy way and check and/or modify this freely available code.

TABOO *is not* a Sealevel equation solver! The solution of the sealevel equation is being implemented in the companion software SELEN, which will be freely released as soon as possible by my group.

1.2 Main assumptions

In this section we list explicity the assumptions regarding the Earth structure and the glacial loads. Some of these assumptions can be easily relaxed in future versions of `TABOO`, some others constitute a more severe obstacle. The formal implications of the assumptions listed here are illustrated in the TD.

1.2.1 On the Earth structure

`TABOO` is based on a number of assumptions regarding the internal structure of the Earth. The Earth is:

- layered,
- non-rotating,
- incompressible,
- self–gravitating,
- Maxwell viscoelastic,
- spherically symmetric.

Within each layer:

- the density,
- the shear modulus,
- and the Maxwell viscosity

are constant.

The program can handle several built–in input models (see Appendix D). For all of the currently available models:

- the inner core is not included,
- the core is homogeneous and inviscid,
- a perfectly elastic lithosphere is included.

`TABOO` is written in such a way that the user can easily change the features of the existing models or add new ones to the library.

1.2.2 On the glacial models

TABOO can handle ice loads characterized by various geometries and time-histories. They are discussed in detail in §3.2. We only mention here that the user can build an *ad hoc* ice load model or, alternatively, he can use ice models taken from the existing literature. To date, TABOO includes the ICE1, ICE2, and ICE3G glacial models of W. R. Peltier and co–authors (see the footnote to page 71), but others can be easily implemented.

1.2.3 Units and constants

Units

- TABOO employs SI units. However, *time* is always expressed in the more convenient unit 'kyr', where 1 kyr = 1000 years.

- The *angles* are always expressed in degrees (deg). We normally use longitude and colatitude but in some output file we employ latitude instead of colatitude (the convention adopted is always clearly stated). Longitude and colatitude must always be given in the range [0:360] and [0:180] deg, respectively.

- Any component of the *displacement field* and the *geoid height* is expressed in units of meters (m) in all of the output files of TABOO (see Appendix B).

- The components of the *velocity field* and the *rate of geoid change* are expressed in units of millimeters per year (mm/yr) in all of the output files of TABOO (Appendix B).

- The *lithospheric thickness* and the *radii of the interfaces* between the internal layers of the Earth are expressed in units of km.

- The *inertia tensor variations* are given in output in units of MR**2, where M is the Earth mass, and R its average radius (the default values of these constants are given below). The time *derivative of the inertia tensor*, normalized by the same factor, is given in output in units of yrs^{-1}.

- In output, the *variations of the Stokes coefficients*, being them fully normalized or not, are given multiplied by the factor 10^6. The *time–*

derivatives of the Stokes coefficients, expressed in units of yr^{-1}, are given in output multiplied by the factor 10^{11}.

Constants

Here we give the numerical values of the physical constants and relevant geophysical parameters used in `TABOO`.

- Gravity constant = 0.667×10^{-10} Nm**2/kg**2
- Average radius of the Earth = 6371.0 km
- Radius of the core–mantle boundary (CMB) = 3480.0 km
- Earth mass = 5.97×10^{24} kg
- Earth mean density = 5.51×10^{3} kg/m**3
- Ice density = 1000.0 kg/m**3
- Number of seconds in 1 year = $365.25 \times 24 \times 3600$

1.3 Things that `TABOO` can do

`TABOO` can compute physical quantities (or variables) which are of one of three kinds. We have conventionally classified them as:

- Spectral,
- Local,
- Global.

1.3.1 Spectral variables

`TABOO` can compute these spectral variables:

- Relaxation spectrum of a given model,
- Load-deformation coefficients (ldcs),
- Tidal Love numbers (tLns).

The relaxation spectrum is load-independent. The ldcs and the tLns are conventionally specified for an impulsive (delta–like) point load. Their amplitudes depend on the chosen Earth model.

1.3.2 Local variables

The available local variables are

- 3D displacement,
- 3D velocity,
- Changes and rates of changes of geoid height,
- Baselines evolutions.

Local variables can be computed at a given point on the Earth's surface as a function of time, or at a given time at various locations. They are load- and rheology-dependent.

1.3.3 Global variables

TABOO can compute these global variables:

- Mass of the glacial load,
- Changes and rates of change of the Stokes coefficients,
- Changes and rates of change of the inertia tensor.

Global variables do not have a spatial dependence; they can only be computed at a given time or for a suite of times. They are in general load- and rheology-dependent.

1.4 How to tell TABOO to do those things

In this section we briefly describe how the User can supply TABOO with the information needed to perform a given task.

1.4.1 The tasks of TABOO

To simplify the user approach to the program, we have organized the structure of the TABOO input files into three separate and independent tasks. At the time of this writing, TABOO only allows *one* and only *one* task to be executed at a time. A fully detailed description of the three tasks of TABOO is given in Chapters 2, 3, and 4, respectively. Each task requires the configuration of appropriate input text files, conventionally called task_1.dat, task_2.dat, and task_3.dat. The taboo.zip archive already includes samples of the task_*.dat files, which can be easily modified to schedule the desired outputs. These sample input files also contain brief explanations on how to configure TABOO. Of course, TABOO also requires other input files to run. These files, which need not to be modified by the user, are listed and described in Appendix A.

The three tasks of TABOO have the following aim:

- **task#1**: The user can perform a study of spectral variables: the relaxation spectrum, the load–deformation coefficients (ldcs) or the tidal Love numbers (tLns) for a specific Earth model, and other related quantities. The input file for this analysis is task_1.dat.
- **task#2**: This task concerns the study of the response of the Earth to a single glacial load evolving according to a specific time-history. Both local and global studies are possible, but by default TABOO also computes some spectral variables. To execute this task, the input file task_2.dat must be configured.
- **task#3**: By this task it is possible to deal with complex aggregates of ice loads taken from the literature, or built *ad hoc* by the Users. Local and global variables can be computed, but also some basic spectral variables. The input file for this analysis is task_3.dat.

Regardless of the type of task, TABOO reports on the default file taboo.log all the major events occurred during execution. Short versions of these messages can also be optionally directed to the monitor. TABOO also report error and warning messages, with very brief explanations of their causes.

1.4.2 Form of the task_*.dat files

Any of the task_*.dat (*=1, 2, or 3) input files has the following form:

`Active` ⟵ first line of file task_*.dat

```
        ...
        ...
keyword_1
        parameters
        ...
        ...
        ...
keyword_2
        parameters
        ...
        ...
        ...
keyword_n
        parameters
        ...
        ...
        ...
```

Notes:

1. The word `Active` (upper–case `A`) aligned left in row 1 of task_*.dat (* = 1, 2, or 3) is a *keyword* that tells `TABOO` that the file is active, so that it can be employed to perform specific operations. The keywords must obey the rules given in note 5 below.

2. If any other string of characters is found in the place of `Active`, the file task_*.dat are considered as *not* active. For instance, if the word `!Active` is detected in row 1, `TABOO` consider task_*.dat as an invalid input file.

3. At the time of this writing, `TABOO` only allows *one* and only *one* task to be accomplished at a time. Thus, if more than one input file is found to be active, the entire process is stopped and an error message is reported on the file taboo.log. The same happens if no valid input file is detected.

4. `TABOO` reads sequentially all of the lines of the input file task_*.dat, provided that this is recognized as active. Only the lines containing keywords or keywords parameters are read (see below).

5. A keyword is a special string of characters which precede a list of alphanumeric parameters. In the following we will use the abbreviation kw for keyword. The basic rules for the kws are: (1) they are *case sensitive*, (2) they must be aligned left on file task_*.dat, (3) they must appear once in task_*.dat, (4) the various kws appearing in task_*.dat must follow a natural sequence, that must *not* be modified, (5) the kw `Active` must always be written in the first row of task_*.dat. The simplest way to *disactivate* a keyword is to put one or more characters in front of it. If `keyword` is a kw, among the following lines only the first is interpreted by `TABOO` as a valid active kw:

   ```
   keyword
     keyword
   KEYWORD
   !keyword
   ```

6. In general, in order that the activation of a kw is fully effective, one or more previous kws along the natural sequence must also be active. These kw chains are described explicitly in the following.

7. Each kw enables `TABOO` to perform computations which are specified by a list of parameters. Once a kw is recognized as active, `TABOO` reads the list of parameters which follow the kw. Typically, the form is:

   ```
   keyword
   parameter_1 parameter_2 ...
   parameter_n
   ...
   ...
   ```

   Certain kws, such as `Active`, have no parameters. The parameters, of INTEGER or REAL type, can be generally supplied in free format. If a parameter is of type CHARACTER, the syntax rules (1) and (2) given in note 5 above apply. The sequence of the parameters cannot be modified, and no extra lines can be inserted between two lines of parameters. It is care of the user to input exactly the required number of parameters. The extra parameters are generally ignored, while less parameters than required may result in unpredictable effects. Since no really exhaustive checks are currently made by TABOO on the syntax of the parameters sections, the user must be particularly careful.

8. The function of certain kws may depend on the context in which they appear. For instance, the kw Harmonic_Degrees takes different forms in task#1 and #3. These differences are described in detail where necessary.

9. If one or more kw parameters are found to be out of bounds, this produces a warning or a job aborted message in the file taboo.log, which also reports benign messages indicating the succesfull execution of the tasks required by the user and–or special events. If the verbose mode is selected, some of these messages are also sent on the monitor (see also §1.4.1).

10. In the sample task_*.dat files which come with TABOO, we have used the character '!' in column one to emphasize that the corresponding line contains comments. We also use ! in front of a kw to disactivate it. Any other choice or convention is possible: TABOO only gives attention to the lines containing properly written and aligned kws, and to the ensuing parameters.

1.5 Technical issues

TABOO requires modest resources. You essentially need a Fortran 90 compiler and a moderate disk space, as illustrated in the following.

1.5.1 Hardware and Software requirements

In addition to the source code, the archive taboo.zip contains all of the files needed for the configuration of the tasks of TABOO, other input files with information on the ice aggregates and more (Appendix A), and the output files for the examples given in §2.5, 3.5 and 4.5. Once decompressed, the TABOO files will occupy a few mb on your hard disk. Some of the computations need up to 40 mb of disk space to store the data during execution (see §4.2.3). This is due to the memory limitations of the Alpha Server on which TABOO has been first developed. Future releases of the code will be designed to reduce the amount of disk space required.

A `Fortran 90` compiler is strictly required. Since some parts of `TABOO` are written in REAL*16 precision, the compiler must support it. In the course of the development of `TABOO` we have made use of these two compilers:

- The DIGITAL UNIX F90 compiler installed both on Alpha and HP systems.
- The Lahey/Fujitsu Compiler F95 ver. 5.50 installed on both Linux and Windows XP systems.

It is recommended to have gnuplot[1] and GMT[2] installed (Unix, Linux and Windows versions of these programs are available). The output files of `TABOO` have a format which is compatible with the default input data files of both gnuplot and GMT (see Appendix B).

1.5.2 Optimization and portability

`TABOO` is *not* fully optimized. `TABOO` is a melange of `Fortran 90` and `FORTRAN 77` routines developed by the authors of this manual in the course of the years or taken from existing sources, such as Numerical Recipes[3]. Where it was possible, we have taken care to optimize the performances of the various components, but we acknowledge that a significant amount of work is still to be done. For instance, large parts of the code are now implemented in REAL*8 precision, while it is certain that they can be re-written in single precision, thus improving the overall performance. These and other optimizations will be implemented in the future releases of `TABOO`.

Until now, `TABOO` has been installed and successfully employed on the following systems:

- A DIGITAL Unix Alpha Server,
- A HP Unix Workstation,
- My home PC, running Windows XP,
- A Linux PC.

[1] Gnuplot is a copyright of Colin Kelley and Thomas Williams.

[2] Wessel, P. and W. H. F. Smith, Free software helps map and display data, EOS Trans. AGU, *72*, 441, 1991.

[3] W. H. Press et al., Numerical Recipes in Fortran 77: the art of scientific computing, second edition, Cambridge University Press, 1992.

Careful, thought not exhaustive tests, have shown that the results obtained on these systems are generally compatible within three significant digits. The examples given in §2.5, 3.5, and 4.5 are provided to allow the user to check his own numerical results against ours. Any significant discrepancy should be reported to GS (email: `spada@fis.uniurb.it`).

1.5.3 Installation, compilation and execution

In order to install, compile, and execute `TABOO` you should follow these simple instructions.

Installation

The `TABOO` package comes as a zipped file named taboo.zip. Just copy it in a selected directory and unzip it. The source code is taboo.f90. It contains all of the modules and routines which are needed for the execution of the various tasks. All of the output files will be found after execution in the same directory where `TABOO` has been installed. See Appendix A for a list of all of the files contained in the taboo.zip archive and Appendix B for details on the `TABOO` output files.

Compilation and execution (Unix)

Invoke the DIGITAL F90 compiler with

% f90 taboo.f90 -o taboo.exe

The input files of `TABOO` task_*.dat (see §2.1, 3.1, and 4.1) can be configured in such a way that `TABOO` may run in verbose or silent modes. If the first mode has been selected, some output is sent on the monitor. In this case, you can execute `TABOO` with:

% taboo.exe

If the silent mode has been chosen, you may want to send the execution in the background with:

% taboo.exe &

or

% nohup taboo.exe &

Compilation and execution (Linux)

Invoke the Lahey/Fujitsu F95 compiler typing

% lf95 taboo.f90 -o taboo.exe

and execute with the same commands given above for Unix.

Compilation and execution (Windows XP)

The Lahey/Fujitsu F95 compiler can be invoked from the DOS prompt using exactly the same commands as described above for Linux. In execution, as far as we know (but we may be wrong), there is no way to send `TABOO` in the background.

Under Windows, the Lahey ED4W developer can be used to perform the compilation-execution tasks clicking on appropriate buttons on the right side of the developer window (the first from top for compilation, and the third for execution).

As a final note, we must admit that we did not perform any serious study of the various optimization options offered by the DIGITAL and Lahey/Fujitsu compilers. This is completely left to the User.

1.5.4 Distribution

The code we have written is freely available to anyone. The only condition for the users is to reference the two booklets which come with `TABOO`:

- G. Spada, A. Antonioli, L. Boschi, V. Brandi, S. Cianetti, G. Galvani, C. Giunchi, B. Perniola, N. Piana Agostinetti, A. Piersanti, and P. Stocchi, `TABOO`, *User Guide*, Samizdat Press, Golden - White River Junction, 2003.
- G. Spada, *The theory behind* `TABOO`, Samizdat Press, Golden - White River Junction, 2003.

`TABOO` is released on an *as it is* basis, with no warranty of being free from errors both in its theoretical structure and in its implementation. The Users are kindly asked to report problems encountered with the code and/or any error in the theory behind `TABOO`. Future releases of the code will take advantage from all of the suggestions and criticisms received.

To download the code and the documentation, which includes the two booklets above, point your browser to:

`http://samizdat.mines.edu`

You can obtain help writing to

`spada@fis.uniurb.it`

1.6 Acknowledgments

TABOO could not have been written without the generous aid of several people. We gratefully acknowledge Enzo Boschi, Roberto Sabadini, David Yuen and Yanick Ricard who first encouraged me (GS) and others among the authors of TABOO to undertake the research in the field of global geodynamics. In the course of the years we have benefited by discussions and exchange of opinions with many scientists involved in the research on postglacial deformations. We mention Bert Vermeersen, Detlef Wolf, Jerry Mitrovica, Ondrej Cadek and his group of the Charles University in Prague, Gabriella D'Agostino, Luce Fleitout, Claude Froidevaux, Ilaire Legros, Giorgio Ranalli, Roberto Casadio, Paolo Gasperini, Patrick Wu, Gianluca Maria Guidi, Marianne Gregg–Lefftz, Paul Johnston, Paul Morin, and many others. We particularly benefited by comments from Ondrej Cadek, who has provided benchmark computations to test the consistency of TABOO against independent results. We finally acknowledge the referees of our research papers, since thanks to their comments and suggestions we have improved our knowledge on the postglacial rebound problem.

This work has been mainly funded by the Faculty of Environmental Sciences of the University of Urbino, Italy, with grants "Ex 60%", and by the MIUR (Ministero dell' Istruzione, dell' Università e della Ricerca) by a FIRB project (Fondo per gli Investimenti della Ricerca di Base).

Chapter 2

Spectral analysis (task#1)

The task#1 of TABOO allows for the computation of the following spectral variables, and of particular combinations of them:

- the relaxation spectrum,
- the load-deformation coefficients (hereafter 'ldcs'),
- the tidal Love numbers ('tLns').

The computations must be planned by means of the input file task_1.dat. This file contains the following keywords, listed below in their natural sequence:

- `Active`
- `Harmonic_Degrees`
- `Make_Model` (or `External_Model`)
- `Normalized_Residues`
- `El_Fluid_Viscel`
- `Heaviside_th`

where

- `Active` activates the input file task_1.dat (see §1.4.2).

- Harmonic_Degrees must be used to define basic parameters which control the execution, including the range of harmonic degrees, the kind of problem (loading or tidal), and the way TABOO communicates with the user (see §2.1.1 for the details).

- Make_Model is to be used to input the rheological profile of the model, including the thickness of the lithosphere and the viscosity of the various layers. The activation of this kw allows for the computation of the relaxation spectrum of the selected Earth model, which is the minimal task that can be performed by TABOO within task#1. Details on the configuration of this kw are given in §2.2.1. The list of available models is given in Appendix D.

- External_Model is alternative to Make_Model, since with this kw a test non-self-gravitating Earth model can be selected. This kw is described in §2.2.2 below.

- Normalized_Residues is an optional kw which can be employed to compute the 'normalized residues' of the ldc of the chosen Earth model. It is described in §2.4.1.

- El_Fluid_Viscel is another optional kw that can be used to produce tables of the elastic, fluid, and viscoelastic ldc as a function of the harmonic degree, as described in §2.4.2.

- Heaviside_th allows for the computation of the time–evolution of the ldc when the Earth is perturbed by a point mass characterized by an Heaviside time–history. It is an optional kw, described in §2.4.3 below.

This chapter is organized as follows: §2.1, 2.2 and 2.4 illustrate the use of the task#1 kws, §2.3 describes the way TABOO prepares the relaxation spectrum of a given Earth model, and finally §2.5 provides an example of spectral analysis planned using task#1. The output files produced by TABOO are listed and briefly described in Appendix B.

2.1 Basic settings for task#1

The kw Harmonic_Degrees of task#1 allows to input basic parameters which control the execution of TABOO. Using this kw, the User can define the range of harmonic degrees to employ in the spectral study, to choose between verbose and silent execution modes, and to specify the particular type of study (loading or tidal), as described below.

2.1.1 Keyword `Harmonic_Degrees`

The kw `Harmonic_Degrees` has the following form:

```
...
...
Harmonic_Degrees
l_min l_max
verbose
i_loading
...
...
```

where:

- `Harmonic_Degrees` is the kw for this subtask.
- `l_min l_max` [INTEGER] are the minimum and maximum harmonic degrees, with $2 \leq$ `l_min` $\leq$ `l_max` ≤ 128 (see note 2 below).
- `verbose` [INTEGER=0/1] determines if messages are to be sent to the monitor (`verbose`=1) or not (=0) during the execution of task#1. More detailed messages are written by default on file taboo.log.
- `i_loading` [INTEGER=0/1] controls whether the forcing is of loading (1) or tidal type (0). For `i_loading` = 1, `TABOO` computes the ldcs, otherwise it computes the tLns (this option is not available for task#2, where only loading problems can be solved).

Notes:

1. If the kw `Harmonic_Degrees` is not active, *none* of the remaining kws of task_1 are executed.
2. The range of harmonic degrees $2 \leq$ `l_min` $\leq$ `l_max` ≤ 128 *generally* ensures that the models available in the library of `TABOO` (Appendix D)

run safely, in the sense that the numerical procedures employed to solve the secular equation *generally* provide the number of roots expected, all characterized by having a negative real part, and a (numerically) vanishing imaginary part. In the following, for practical purposes, we define 'non–physical' those viscoelastic modes associated with a root of the secular polynomial with real part ≥ 0 and/or with imaginary part with modulus larger than 1.E-30 kyrs**(-1). When a non–physical mode is detected, a short message is issued on the monitor and a more detailed one is printed on file taboo.log. However, no action is taken, in the sense that the non–physical modes will be included in all of the spectral computations done. The User is warned about possible anomalies in the results obtained (a look to taboo.log and good sense are always recommended before drawing geophysical implications from the output files of `TABOO`). We anticipate that in task#2 `TABOO` can optionally exclude from the computation of local and global variables the non–physical modes (see §2.1.1).

3. In general, models with a limited number of viscoelastic layers (≤ 3) can run safely on a range of harmonic degrees largely exceeding the `TABOO` default $2 \leq$ `l_min` $\leq$ `l_max` ≤ 128. The user can convince himself by modifying the parameter `llmax` in the module named COMMON of taboo.f90 and compiling again (see §1.5.3 for the instructions). It should however be noted that if `llmax` is pushed above the current value of 128, some functions of `TABOO` will not work properly. In particular, it will not be possible to execute the tasks involving the ocean function, since its expansion in spherical harmonics is presently limited to degree and order 128 (see description of file oceano.128, Appendix A).

4. At this level of development, the degree one harmonics are not included in `TABOO`, i.e., the spectrum of the various geophysical quantities that can be computed by the program will not contain a degree $l = 1$ component. The only exception is constituted by the spherical harmonics expansion of the ice thickness that can be computed in task#3 (see §4.3). Physically, the absence of the degree $l = 1$ in the displacement field means that it is assumed that the center of mass of the system (Earth + glacial load) always coincides with the origin of the reference frame. Since it is known that the degree 1 fields have a non–negligible amplitude, it is hoped that the future releases of `TABOO` will include a self–consistent treatment of this harmonic component.

5. The degree 0 (zero) is not relevant as far as we are concerned with the deformations of an incompressible model, as it is done here. This does not mean that the degree $l = 0$ harmonics do not play any role at all. In fact, the spherical harmonics decomposition of the surface load may indeed contain a degree 0 (and a degree 1) component (the latter is *ignored* by `TABOO` as explained at point 4 above). If the surface load is balanced, the degree zero component of its spherical harmonics expansion is equal to zero (see the TD). Examples of these loads are given in §3.2.1. If the load is not balanced, the degree zero component of the surface load function is not zero, but nevertheless it does not produce any deformation, due to the assumed Earth incompressibility. Thus, in both cases, there will be no degree zero deformations.

2.2 Choosing the Earth model

Using kw `Make_Model` of task#1 the user can input the properties of the Earth model. All of the models available by means of `Make_Model` are self–gravitating. As an alternative to this kw, the user may want to employ `External_Model`, which gives access to a test non–self–gravitating Earth model (see Appendix D). These two kws are described in what follows.

2.2.1 Kw `Make_Model`

The kw `Make_Model` has the following form:

```
...
...
Make_Model
NV
CODE
lt
ilm
eta_1
eta_2
...
...
eta_NV
...
...
```

where:

- `Make_Model` is the kw for this subtask. As an alternative to `Make_Model`, the kw `External_Model` can be supplied. One of these two kws must necesserely be given (see also §2.2.2). `Make_Model` require that these kws have been previously activated:

  - `Active`
  - `Harmonic_Degrees`

- `NV` [INTEGER] is the number of viscoelastic layers. For *viscoelastic layer* we mean a layer with Maxwell rheology and with all of the material parameters distinct from those of the immediately adjacent layers. At the time of this writing, the admissible values of `NV` are: 1, 2, 3, 4, 7, and 9 (Appendix D). Any other input value is rejected by `TABOO`.

- `CODE` [INTEGER] Given `NV`, `CODE` must be used to select a specific `NV` –layers model from a list of models published in the literature or built *ad hoc* for `TABOO`. `CODE` indirectly controls the numerical values of the density and shear moduli of each of the `NV` viscoelastic layers and the depth of the interfaces between the various mantle layers. In the present version of `TABOO`, the library contains 23 distinct models (i. e., distinct combinations of the parameters `NV` and `CODE`), plus an external test model (see Appendix D). For each of them, the user has further degrees of freedom which allow to select specific viscosity values for the mantle layers and for the thickness of the lithosphere, as explained below.

- `LT` [REAL] is the thickness of the elastic lithosphere, conventionally expressed in units of km. The value of `LT` or its admissible range depends on the chosen values of `NV` and `CODE` (see Appendix D). In the case it is possible to choose `LT` within a certain interval, `TABOO` checks that the given `LT` value fits the interval. For certain combinations (e.g. `NV` = `CODE` = 1 and others, see Appendix D), only a specific `LT` value is allowed. If the user inputs a different value, `TABOO` will change it to the only permitted value.

- `ilm` [INTEGER=0/1]. This parameter controls the thickness of the lower mantle layers for models with `NV` =7 and `NV` =9. If the option ilm=1 is chosen, the lower mantle layers will all have the same thickness, otherwise (ilm=0) their thickness will increase smoothly with depth. The parameter ilm is ignored for NV $\neq 7$ and $\neq 9$.

- eta_1, eta_2, ..., eta_NV [REAL] are the Maxwell viscosities of the various layers, ordered from *bottom* (i.e. immediately above the Core Mantle Boundary) to *top* (i.e. immediately below the lithospheric layer), and in units of 10**21 Pa.s. There are not a–priori bounds on the viscosity values and no check is performed by TABOO. However, it is possible that overflow occurs when *too low* viscosity values are chosen (typically below 10**20 Pa.s or so). The code is generally more stable when *large* viscosity values are employed (10**23 Pa.s or larger).

Notes:

1. TABOO reports on taboo.log the details of the model which has been selected by the kw Make_Model. These details include: the radii of the interfaces between the various layers (km) and the thickness of the lower mantle layers (km) (this is done for NV =7 and 9), the thickness of the lithosphere (km), the material properties (density, rigidity, and viscosity of each layer), and the values of the gravity field at each interface (SI units).

2. The density profile is checked to find possible density inversions (a high-density layer on top of a low- density layer). If one is found, a warning message is issued on file taboo.log. The job is not stopped, although the presence of exponentially increasing terms in the relaxation spectrum may cause overflow.

2.2.2 Kw External_Model

This kw forces TABOO to use a predefined non–self–gravitating test model with NV =1 instead of one of those available using the kw Make_Model (see §5.4.1). If this kw is activated, only the ldcs h and l can be studied, and no tidal study is possible. The kws Make_Model and External_Model are mutually exclusive: if the second is active, the first must be not, and vice versa. The kw External_Model has no parameters. It simply takes the form:

```
...
External_Model
...
```

. . .

The kw `External_Model` requires that these two kws have been previously activated:

- `Active`

- `Harmonic_Degrees`

Notes:

1. The test model employed when the kw `External_Model` is active is described in Appendix D.

2. The relaxation spectrum and the ldcs are not computed by `TABOO`, but are taken by the files external_spectrum.dat, external_h.dat, and external_l.dat. The spectrum and the ldcs are given in the range of harmonic degrees [2:128].

3. The inclusion of this external model in `TABOO` gives the possibility of comparing the output of a self-gravitating model with that of a simply gravitating one. This can be done by using first `Make_Model` with the parameters `NV` =1, `CODE`=4, `LT`=100, `eta_1`=1.0, and then running `TABOO` with the `External_Model` kw active.

2.3 The relaxation spectrum

Once the `Make_Model` parameters of task#1 have been read, the relaxation spectrum is computed for harmonic degrees in the range [`l_min:l_max`] (see §2.1.1). If the `External_Model` kw is active instead of `Make_Model`, the spectrum is read from file external_spectrum.dat. In both cases, by default `TABOO` reports the spectrum on the output file spectrum.dat (see Appendix B for the details and §2.5 for an example).

At a given harmonic degree, the relaxation spectrum for a model with `NV` viscoelastic incompressible layers with distinct material properties contain NR= 4*`NV` relaxation times, provided that an elastic incompressible lithosphere is present, and a fluid, homogeneous, inviscid core is also included (this is always true for the models included by default in `TABOO`, see Appendix D). This number also includes `NV` relaxation times identical to the intrinsic Maxwell times of each layer. The amplitudes of the viscoelastic residues associated with these latter relaxation times is however negligible if compared to that of the 3*NV 'genuine' ones.

The computation of the relaxation spectrum requires that these three kws are active:

- Active
- Harmonic_Degrees
- Make_Model (or External_Model).

2.4 More task#1 keywords

In addition to the relaxation spectrum, TABOO can optionally compute a suite of other spectral variables. They include the (normalized) residues of the ldcs (tLns), their elastic, fluid and viscoelastic components, and finally the ldcs (or tLns) corresponding to an Heaviside time history. These outputs are made available by means of specific kws, as illustrated in the following.

2.4.1 Kw Normalized_Residues

This keyword can be used to compute the "normalized residues" $-h_i/s_i$, $-l_i/s_i$, $-k_i/s_i$, where h_i, l_i, and k_i are the viscoelastic amplitudes of the ldcs (or of the tLns) for i=1, ..., NR, and s_i is the i-th root of the secular polynomial. Since both the viscoelastic amplitudes (h_i, l_i, k_i) and the roots (s_i) have dimensions of a frequency, the normalized residues are non-dimensional. The input records for this kw are

```
...
...
Normalized_Residues
IH
IL
IK
...
```

where:

- Normalized_Residues is the kw for this subtask. It requires that these three kws have been previously activated:

- `Active`
- `Harmonic_Degrees`
- `Make_Model` (or `External_Model`)

- `IH IL IK` [INTEGER=0/1] determine if $-h_i/s_i$, $-l_i/s_i$, or $-k_i/s_i$ are to be computed (1) or not (0), respectively. If the kw `External_Model` is active (see §2.2.2), `IK` is reset to zero if it is found equal to 1, since for non–self–gravitating models the k ldc is identically equal to zero.

Notes:

1. The default output files for the normalized residues $-h_i/s_i$, $-l_i/s_i$ and $-k_i/s_i$ are ih.dat, il.dat, and ik.dat, respectively (Appendix B). If the kw `External_Model` is active (§2.2.2), the file ik.dat is not created.

2.4.2 Kw `El_Fluid_Viscel`

The activation of this optional kw allows the user to save on appropriate files the elastic, fluid, and viscoelastic amplitudes of the ldcs (or the tLns) as a function of the harmonic degree. The kw `El_Fluid_Viscel` can be employed independently from the status of `Normalized_Residues`. The input records are

```
...
...
El_Fluid_Viscel
IH
IL
IK
...
...
```

where:

- `El_Fluid_Viscel` is the kw for this subtask. It requires that these three kws have been previously activated:

  - `Active`
  - `Harmonic_Degrees`

- Make_Model (or External_Model)

- IH IL IK [INTEGER=0/1] are switches that determine if the elastic, viscoelastic and fluid components of the h, l, or k ldc (or tLn) are to be computed (=1) or not (=0), respectively. If the kw External_Model is active (see §2.2.2), IK is reset to zero if it is found equal to 1, since for non–self–gravitating models the k ldc is identically equal to zero.

Notes:

1. The default output files for the three ldcs (or tLns) h, l, and k are h.dat, l.dat, and k.dat, respectively (see Appendix B). If External_Model is active (see §2.2.2), the file k.dat is not created.

2.4.3 Kw Heaviside_th

Using the optional kw Heaviside_th, the user can compute the time- evolution of the ldcs (or tLns) in response to a point load characterized by a step (Heaviside) time history activated at time t=0 kyrs, for a set of harmonic degrees. The kw can be employed independently from the status of Normalized_Residues and El_Fluid_Viscel. The input format for this kw is:

```
...
...
Heaviside_th
n
l_1 l_2 ...l_n
tmin
tmax
IH
IL
IK
...
...
```

where:

- Heaviside_th is the kw for this subtask. It requires that these three kws have been previously activated:

- Active
- Harmonic_Degrees
- Make_Model (or External_Model)

- n [INTEGER] is the number of degrees for which the Heaviside ldcs (tLns) must be computed ($1 \leq$ n ≤ 6).
- l_1 l_2 ...l_n [INTEGER] are the selected harmonic degrees. They must be included in the range specified by Harmonic_Degrees: l_min $\leq$ l_k $\leq$ l_max, for any k (see §2.1.1).
- tmin [REAL] is the lower bound of the time- window considered, expressed in kyrs (tmin > 0.0 kyrs).
- tmax [REAL] is the upper bound of the time- window considered, expressed in kyrs (tmax $>$ tmin).
- npt [INTEGER] is the number of intermediate points between tmin and tmax ($1 \leq$ npt ≤ 2001).
- IH IL IK [INTEGER=0/1] are the switches that allows to select the ldc(s) (or tLns) that are required in output. If the kw External_Model is active (see §1.2.2), IK is reset to zero if it is found equal to 1, since for non–self–gravitating models the k ldc is not defined. No tLn can be computed if External_Model is active.

Notes:

1. By default, the output files for the three ldcs (tLns) are h_heav.dat, l_heav.dat, and k_heav.dat (see Appendix B). If External_Model is active (see §2.2.2), the file k_heav.dat is not created.
2. While the l and k ldcs (tLns) are printed on the respective output files as they stand, $h/(2n+1)$ is printed instead of h, where n is the harmonic degree.

2.5 An example for task#1

We provide here an example on how to configure and run TABOO for task#1. There are two subsections. The first concerns the kws configuration in task_1.dat, the second shows the corresponding outputs of TABOO.

Kw configuration

We want to study the spectral properties of the model by Cianetti et al., [2002][1]. It is a model with three viscoelastic mantle layers (shallow upper mantle, transition zone and lower mantle). The lithospheric thickness is `LT`= 120 km. We first activate the input file task_1.dat:

```
Active
```

Then we ask `TABOO` to work in the range of harmonic degrees $2 \leq l \leq 100$, to report messages on the monitor during execution and to compute the ldcs:

```
Harmonic_Degrees
2 100
1
1
```

From Appendix D, `NV` =3 and `CODE` = 2 for the Cianetti et al. model. We decide to adopt a viscosity profile where the viscosity is 2 in the lower mantle, and 1 above (in units of 10**21 Pa.s). We configure the kw `Make_Model` accordingly:

```
Make_Model
3
2
120.
1
2.0
1.0
1.0
```

The kw `Make_Model` enables `TABOO` to compute the most basic spectral quantity, i.e., the relaxation spectrum of the selected Earth model. The spectrum is printed by default on file spectrum.dat (see Appendix B). Since we want `TABOO` to compute also the normalized residues $-h_i/s_i$ (by default, `TABOO` writes the results on the file ih.dat, see Appendix B), we configure `Normalized_Residues` as follows:

[1] S. Cianetti, C. Giunchi, and G. Spada, Mantle viscosity beneath the Hudson Bay: an inversion based on the Metropolis algorithm, JGR, *102*, 12, 2002.

```
Normalized_Residues
1
0
0
```

Another request for `TABOO` is the computation of the elastic, fluid, and viscous components of the ldc k as a function of the harmonic degree. They are printed on k.dat (Appendix B). This is done with:

```
El_Fluid_Viscel
0
0
1
```

Finally, we ask `TABOO` to compute the h Heaviside ldc in the time range [1.E-3:1.E5] kyrs on 11 time steps, for degrees l=2 and l=26. `TABOO` writes the result on file h_heav.dat. The input is:

```
Heaviside_th
2
2 26
1.e-3
1.e+5
11
1
0
0
```

The file task_1.dat is now ready to be processed. See §1.5.3 for the instructions on how to compile and to execute `TABOO`.

Output data

After execution, taboo.log contains a report showing the basic step of the process. The first lines should look like this:

```
# 2002.10.14 time=18.45.37
Detecting the Active INPUT file !
task_1.dat is active
```

```
task_2.dat is NOT active
task_3.dat is NOT active
Opening file task_1.dat ...
Reading file task_1.dat ...
# task#1 of TABOO on 2002.10.14 time=18.45.37
> found KEYWORD Harmonic_Degrees
Lmin and Lmax 2 100
> found KEYWORD Make_Model
Building the model
...
...
```

The section concerning the basic features of the chosen model is:

```
...
...
Mantle viscosity from BOTTOM to TOP (/1E21)
Viscosity of layer 1 = 2.0000
Viscosity of layer 2 = 1.0000
Viscosity of layer 3 = 1.0000
3-- layer mantle model by CIANETTI et al.  [2002]
---------------------------------------------------------------
Radii, densities, shear moduli & viscosity from bottom to top
SI units:  m, kg/m**3, Pa, Pa.s, respectively
---------------------------------------------------------------
0 0.34800000E+07 0.10925000E+05 0.00000000E+00 0.00000000E+00
1 0.57010000E+07 0.45080000E+04 0.20000000E+12 0.20000000E+22
2 0.59510000E+07 0.42200000E+04 0.11000000E+12 0.10000000E+22
3 0.62510000E+07 0.41200000E+04 0.95000000E+11 0.10000000E+22
4 0.63710000E+07 0.41200000E+04 0.73000000E+11 0.00000000E+00
Litho.  thickness employed (km) = 120.0000 km
Looking for density inversions...
No density inversions found
-----------------------------------
Gravity at the interfaces (m/s/s)
(from bottom to top)
-----------------------------------
0 0.10622216E+02
```

```
1 0.95051939E+01
2 0.95709959E+01
3 0.96614344E+01
4 0.97075475E+01
...
...
```

The last lines of taboo.log are:

```
...
...
# task#1 of TABOO closed on 2002.10.14 time=18.45.48
# Closing this file (taboo.log) on2002.10.14 time=18.45.48
```

The first four lines of the segments of the file spectrum.dat corresponding to degrees l=2 and l=81 (only the first four columns are shown here), should be:

```
...
...
2 0.3010300E+00 -0.6588956E-05 -0.5181183E+01 0.1517691E+09 ...
2 0.3010300E+00 -0.3681758E-03 -0.3433945E+01 0.2716094E+07 ...
2 0.3010300E+00 -0.8165014E-01 -0.1088043E+01 0.1224738E+05 ...
2 0.3010300E+00 -0.2832764E+00 -0.5477896E+00 0.3530121E+04 ...
...
...
...
81 0.1908485E+01 -0.5241824E-03 -0.3280518E+01 0.1907733E+07 ...
81 0.1908485E+01 -0.1020107E-02 -0.2991354E+01 0.9802893E+06 ...
81 0.1908485E+01 -0.2255408E-01 -0.1646775E+01 0.4433788E+05 ...
81 0.1908485E+01 -0.6081394E+00 -0.2159969E+00 0.1644360E+04 ...
...
...
```

The segments of the file ih.dat, containing the normalized residues corresponding to degrees l=2 and l=35 are shown here:

```
...
...
2 -0.1633115E-01
2 -0.1448393E+00
2 -0.1549434E+00
2 -0.7669515E+00
2 -0.5883387E+00
2 -0.1112921E-25
2 -0.7216891E-04
2 -0.2722385E-05
2 -0.2418370E-26
2 -0.2223286E-04
2 -0.1648983E-03
2  0.2259053E-27
...
...
35 -0.1498487E-01
35 -0.1160999E-01
35 -0.8773378E-14
35 -0.1452553E+02
35 -0.2703098E-01
35  0.4819768E-23
35 -0.2612473E-03
35  0.1265178E-20
35 -0.4835296E-03
35 -0.3857967E-05
35 -0.1278950E-04
35  0.2130399E-22
```

It should be observed that the output for the normalized residues corresponding to the Maxwell roots (the sixth entry for l=2 is an example) may be different on different computers, due to its small numerical value.

After execution, the file k.dat contains the elastic, fluid, and viscoelastic components of the ldc k. The file is partly shown here:

```
# File k.dat, created by task#1 of TABOO on 2002.10.14 t...
2 -0.26142268E+00 -0.97659822E+00 -0.58893162E-08 ...
```

```
3 -0.17853455E+00 -0.97874475E+00 -0.14303395E-07 ...
5 -0.10505179E+00 -0.98005513E+00 -0.44705932E-07 ...
6 -0.91809427E-01 -0.97994717E+00 -0.66624816E-07 ...
7 -0.83632501E-01 -0.97936610E+00 -0.92636289E-07 ...
8 -0.77951823E-01 -0.97825152E+00 -0.12228334E-06 ...
9 -0.73650521E-01 -0.97651205E+00 -0.15497980E-06 ...
...
...
95 -0.16448553E-01 -0.34694461E-01 0.57772950E-11 ...
96 -0.16310008E-01 -0.33778060E-01 0.49897698E-11 ...
97 -0.16173813E-01 -0.32901456E-01 0.43082804E-11 ...
98 -0.16039900E-01 -0.32062515E-01 0.37188679E-11 ...
99 -0.15908202E-01 -0.31259237E-01 0.32093371E-11 ...
...
```

Finally, the file h_heav.dat contains, after execution, the following records:

```
# File h_heav.dat, created by task#1 of TABOO on 2002.10.14 ti...
2 0.1000000E-02 -0.9729916E-01
2 0.6309573E-02 -0.9834625E-01
2 0.3981072E-01 -0.1048197E+00
2 0.2511886E+00 -0.1408675E+00
2 0.1584893E+01 -0.2588534E+00
2 0.1000000E+02 -0.3765835E+00
2 0.6309573E+02 -0.3996875E+00
2 0.3981072E+03 -0.4031584E+00
2 0.2511886E+04 -0.4167331E+00
2 0.1584893E+05 -0.4284075E+00
2 0.1000000E+06 -0.4297445E+00


26 0.1000000E-02 -0.1942110E-01
26 0.6309573E-02 -0.1969521E-01
26 0.3981072E-01 -0.2141843E-01
26 0.2511886E+00 -0.3204755E-01
26 0.1584893E+01 -0.9066297E-01
26 0.1000000E+02 -0.2684659E+00
```

```
26 0.6309573E+02 -0.3284747E+00
26 0.3981072E+03 -0.3291739E+00
26 0.2511886E+04 -0.3298746E+00
26 0.1584893E+05 -0.3301566E+00
26 0.1000000E+06 -0.3301581E+00
```

Chapter 3

Response to a single load (task#2)

Task#2 allows for the computation of the following spectral, local and global variables:

- Relaxation spectrum,
- Load-deformation coefficients (ldcs),
- 3D displacement,
- 3D velocity,
- Mass and thickness of the ice load,
- Change and rate of change of geoid height,
- Change and rate of change of the Stokes coefficients,
- Change and rate of change of the inertia tensor.

In all of the computations made accessible by task#2, a *single* load is acting, which may be accompanied by a secondary load to mimic mass conservation (see §3.2.1). The case of complex aggregates of loads is considered separately in task#3.

The file task_2.dat is characterized by the following keywords, which are listed here in their natural sequence:

- `Active`

- Harmonic_Degrees
- Make_Model
- External_Model
- Load_Geometry
- Load_History
- Local_Study
- Global_Study

where

- Active is the kw which activates the file task_3.dat. Its description is given in §1.4.2.
- Harmonic_Degrees defines the range of harmonic degrees for the analysis and determines if some output is to be sent on the monitor during execution. These two functions of Harmonic_Degrees have been already described in §2.1. However, in task#2 this kw may be also employed to suppress the viscous components of the ldcs and possible undesired 'non–physical' modes (see §2.1.1). The use of Harmonic_Degrees for task#2 is described in deeper detail in §3.1.1.
- Make_Model defines the Earth model to be employed in the computations. The form of this kw has been already described in §2.1.1. We only notice that in task#2 Make_Model causes the computation of the relaxation spectrum *and* of the ldc of the model selected. The ldc are written on the default files h.dat, l.dat, and k.dat as it is (optionally) possible in task#1 by means of kw El_Fluid_Viscel.
- External_Model is an alternative to Make_Model. See §2.2.2 for its description.
- Load_Geometry allows to describe the geometry of the surface load. The present version of TABOO includes seven different surface loads. The kw is described in §3.2.1.
- Load_History is to be employed to input the time–history of the ice load. Nine different time–histories are available, as described in §3.2.3.

- `Local_Study` specifies the kind of local study to be performed. There are five options currently available, as described in §3.3. The local variables involved are the components of the displacement vector, the components of the velocity vector, and the geoid height at given points on the Earth surface.

- `Global_Study` is the kw that must be configured to perform global studies, such as the computation of the Stokes coefficients of the gravity field, or of the inertia tensor. The three options available are described in §3.4.

This chapter is organized as follows: §3.1 to 3.4 illustrate the use of the task#2 kws, and in §3.5 we give examples of postglacial rebound problems solved using task#2. For a description of the output files for task#2 the reader is referred to Appendix B.

3.1 Basic settings for task#2

The basic settings of task#2 can be configured using `Harmonic_Degrees`, which however differs from its task#1 counterpart (§2.1) as explained below. As in task#1, the Earth model and the viscosity profile of the mantle are determined by the parameters of kw `Make_Model` (or, alternatively, of `External_Model`). Since the use of these kws is identical to that in task#1, the user is referred to §2.2.1 and §2.2.2 for instructions on their configuration.

3.1.1 Keyword `Harmonic_Degrees` for task#2

The use of kw `Harmonic_Degrees` is slightly different with respect to the use made in task#1:

- Since in task#2 only loading studies can be performed, the old switch Loading/Tidal of task#1 is no more available (see §2.1.1).

- In task#2 it is possible to force `TABOO` to disregard the viscous component of the Maxwell rheology. The analysis in this case is restricted to elastic fields.

- Acting on a switch, in task#2 it is possible to exclude from the computation of local and global variables the 'non physical' modes which sometimes may appear in the relaxation spectrum (see note 2 of §2.1.1).

The kw `Harmonic_Degrees` for task#2 has the following form:

```
...
...
Harmonic_Degrees
l_min l_max
verbose
only_elastic
drop_modes
...
...
```

where:

- `l_min l_max` and `verbose` have the same meaning as in task#1 (see §1.1.1).

- `only_elastic` [INTEGER=0/1] is a switch that controls the elastic and viscoelastic components of the Maxwell rheology: If `only_elastic` = 0 *both* the elastic *and* the viscous components of the rheology are included in the computations that are scheduled by `Local_Study` or `Global_Study` (see §3.3 and §3.4). On the contrary, if `only_elastic` = 1, only the elastic component of the Maxwell rheology are retained. Since for `only_elastic` = 1 the Earth does not relax to the load, the spectrum of relaxation is not computed, and consequently not reported on file spectrum.dat (see §2.3).

- `drop_modes` [INTEGER=0/1] is another switch. If `drop_modes` = 1, `TABOO` excludes from the computations programmed by means of `Local_Study` and `Global_Study` the 'non–physical' relaxation modes (see note 2 of §2.1.1 for a definition of 'non–physical' viscoelastic modes). If `drop_modes` =0, `TABOO` includes all of the modes in its computations. It should be remarked that, due to the finite resolving power of our (*of any*) root–finder algorithm, it is indeed possible that some 'physical' modes have erroneous amplitudes. The value of the switch `drop_modes` given in input is ignored if `only_elastic` = 1. The switch `drop_modes` has no effect if the kw `External_Model` has been configured instead of `Make_Model`.

3.2 Choosing the load geometry and time–history

This section shows how to select the load geometry and the load time–history from the default set of TABOO. Most of the conventions adopted are also extended to task#3, where aggregates of ice loads can be modeled (see Chapter 4). In the present version of TABOO the User has seven geometries and nine time-histories at his disposal. The keywords which allow to configure the spatio–temporal features of the surface load are Load_Geometry and Load_History.

3.2.1 Kw Load_Geometry

The kw Load_Geometry is to be employed to input the geometric properties of the ice load which remain constant during its time evolution. To configure Load_Geometry the user must supply the following records:

```
...
...
Load_Geometry
CL
IOC p_1 p_2 ...
...
...
```

where:

- Load_Geometry is the kw for this subtask. It requires that these three kws have been previously activated:
  - Active
  - Harmonic_Degrees
  - Make_Model (or External_Model)
- CL [INTEGER] is the code which identifies the load. The following options are currently available:
  - CL=10: Disc load. A disc load is a load with uniform thickness and a circular base. Its center can be placed anywhere on the Earth surface.

- `CL`=11: Two loads are acting: a primary and a secondary load. The primary is a disc load (the same as for `CL` =10). The secondary is a complementary disc load, i.e., a load with uniform thickness distributed over the region outside the primary so that (mass of the primary load) + (mass of the secondary) = 0 at any time. The center of the primary load can be placed anywhere on the Earth surface.
- `CL`=20: Parabolic load. A parabolic load is a load with parabolic cross–section and a circular base. Its center can be placed anywhere on the Earth surface.
- `CL`=21: Two loads are acting: a primary parabolic load (the same as for `CL` = 20) and a secondary complementary disc load, i.e., a load with uniform thickness placed in the region outside the parabolic load so that (mass of the primary load) + (mass of the secondary) = 0 at any time. The center of the primary load can be placed anywhere on the Earth surface.
- `CL`=30: Point load. A point load is a load with no lateral extent. It has no thickness, just a mass. It can be placed anywhere on the Earth surface.
- `CL`=40: Harmonic zonal load. An harmonic load is a load which covers the entire Earth surface. It exerts a pressure which varies in space as a prescribed surface zonal harmonic function. This is just defined by the mass per unit surface exerted at its pole (i.e. at the point where its axis of symmetry cuts the sphere), and by a given harmonic degree. The load pole can be placed anywhere on the Earth surface. If an harmonic zonal load is selected, `TABOO` expects that the kw `Harmonic_Degrees` is configured with `l_max=l_min` (see §3.1.1).
- `CL`=50: This load has a uniform thickness, and a spatial extent limited by two meridians and two parallels. Sometimes we will refer (improperly) to this load as to "rectangular" load.

• `IOC` [INTEGER=0/1] is a switch which may take one of two values:

- `IOC`=1. Using this option, the loads selected by `CL` = 10, 20, 30, or 50 may be argumented by a secondary load uniformly distributed over the oceans to mimic mass conservation. The oceans have approximatively their real shape (the ocean function developed at degree `l_max` is employed to this purpose). No check is made to test whether a given load is partly or totally superimposed to the ocean surface. The option `IOC` = 1 must *not* be used for `CL` = 11, 21, or 40 since these loads are already accompanied by their own secondary loads (11 and 21), or cover the entire Earth surface with a zero average (40) so that they already conserve mass. For `CL` = 11, 21, or 40 only the option `IOC` = 0 is allowed.

  – `IOC`=0. The load chosen is *not* argumented by any secondary load over the oceans. Mass conservation is violated, unless the user has chosen `CL` = 11, 21, or 40.

• `p_1 p_2 ...` [REAL] are parameters defining the geometrical features of the loads selected by `CL`. Their number and meaning depend on `CL` as described below. All of the `p_k` parameters are to be given in units of degrees. The allowed ranges of `p_k` are given in brackets.

  – `CL`=10:

    `p_1` = Longitude of the load center]0:360[deg.
    `p_2` = Colatitude of the load center]0:180[deg.
    `p_3` = Half–amplitude of the load]0:180[deg.

  – `CL`=11: see `CL`=10.

  – `CL`=20: see `CL`=10.

  – `CL`=21: see `CL`=10.

  – `CL`=30:

    `p_1` = Longitude of the load]0:360[deg.
    `p_2` = Colatitude of the load]0:180[deg.

  – `CL`=40:

    `p_1` = Longitude of the load pole]0:360[deg.
    `p_2` = Colatitude of the load pole]0:180[deg.

  – `CL`=50:

    `p_1` = Longitude of the load centroid [`p_3`/2:360-`p_3`/2] deg.
    `p_2` = Colatitude of the load centroid [`p_4`/2:180-`p_4`/2] deg.
    `p_3` = Width of the load in longitude [0.25:90.0] deg.
    `p_4` = Width of the load in colatitude [0.25:90.0] deg.

3.2.2 Kw Load_History (I)

The kw `Load_History` is to be employed to input the load time–history. If the load is accompanied by a secondary load (see §3.2.1), `TABOO` assigns to the latter the same time–history of the primary, but with the sign reversed. In the following, we first describe the general form of `Load_History`. Then, we illustrate the form that it takes for any of the currently available load time-histories.

The general input format of `Load_History` is:

```
...
...
...
Load_History
LH
p_1
p_2
...
...
...
p_n
...
...
```

where:

- `Load_History` is the kw for this subtask. The use of `Load_History` requires that the following four keywords are active:

  - `Active`
  - `Harmonic_Degrees`
  - `Make_Model` (or `External_Model`)
  - `Load_Geometry`

- `LH` [INTEGER] is the code which identifies the particular time–history to be employed. Its range is [0:8]. For some `LH` values (namely, `LH`= 6, 7, and 8), the kw `Load_History` also requires, in addition to the parameters, an user-supplied text file containing the details of the time–evolution of the load (see §3.2.3 below).

- `p_1 p_2 ... p_n` are the parameters required to specify the time-history selected above by `LH`. Their meaning is described in §3.2.3.

3.2.3 Kw `Load_History` (II)

Depending on the specific value of `LH`, the kw `Load_History` may assume various forms. In the present version of `TABOO` the User can dispose of nine time- histories, which are described below. If not stated differently, with the term "load" we indicate the primary load (see §3.2.1).

In task#2, the origin of time is dictated by a conventionally chosen, specific feature of the load time-history. For instance, for the time-history of type `LH` = 3 (simple deglaciation), time t = 0 (kyrs) marks the beginning of deglaciation. Time is positive after the beginning of deglaciation, and negative before. Other time histories use different conventions, as explained below. Notice that in task#3 the origin of the time axis is placed at present time (see also §3.1).

`LH = 0`: "Heaviside", or "Instantaneous loading"

The load is activated at time t=0 kyr and kept constant thereafter (see the TD for further details). The kw must be configured as follows:

```
Load_History
0
PRM
```

where the meaning of `PRM` depends on the value of the `CL` parameter of kw `Load_Geometry` in the following way:

- If `CL = 10`: `PRM` (≥ 0) = load thickness for t$\geq$ 0 (m).
- If `CL = 11`: see `CL = 10`.
- If `CL = 50`: see `CL = 10`.
- If `CL = 20`: `PRM` (≥ 0) = Load thickness at its center for t$\geq$ 0 (m).
- If `CL = 21`: see `CL = 20`.

- If `CL = 30`: `PRM` (≥ 0) = load mass for t$\geq$ 0 (kg).
- If `CL = 40`: `PRM` (≥ 0) = mass/surface at the load pole for t$\geq$ 0 (kg/m**2).

`LH = 1`: **"Instantaneous Unloading"**

The load is kept constant for time $-\infty \leq t < 0$ kyrs, and is zero for $t \geq 0$ kyrs (see the TD for further details). The kw must be configured as follows:

```
Load_History
1
PRM
```

where the meaning of `PRM` depends on the value of the `CL` parameter of kw `Load_Geometry` in the following way:

- If `CL = 10`: `PRM` (≥ 0) = load thickness for $-\infty \leq t < 0$ (m).
- If `CL = 11`: see `CL = 10`.
- If `CL = 50`: see `CL = 10`.
- If `CL = 20`: `PRM` (≥ 0) = load thickness at its center for $-\infty \leq t < 0$ (m).
- If `CL = 21`: see `CL = 20`.
- If `CL = 30`: `PRM` (≥ 0) = load mass for $-\infty \leq t < 0$ (kg).
- If `CL = 40`: `PRM` (≥ 0) = mass/surface at the load pole for $-\infty \leq t < 0$ (kg/m**2).

`LH = 2`: **"Loading and Unloading"**

The load is kept to zero for $-\infty \leq t <$ `-TAU` kyrs. At time t= `-TAU` kyrs, the load is activated and kept constant until it is disactivated at time t=0 kyrs (see the TD and the examples below for further details). The kw must be configured as follows:

```
Load_History
```

```
2
TAU
PRM
```

where:

- If `CL = 10`: `PRM` (≥ 0) = load thickness for `-TAU` $\leq t < 0$ kyrs (m).
- If `CL = 11`: see `CL = 10`.
- If `CL = 50`: see `CL = 10`.
- If `CL = 20`: `PRM` (≥ 0) = load thickness at its center for `-TAU` $\leq t < 0$ kyrs (m).
- If `CL = 21`: see `CL = 20`.
- If `CL = 30`: `PRM` (≥ 0) = load mass for `-TAU` $\leq t < 0$ kyrs (kg).
- If `CL = 40`: `PRM` (≥ 0) = mass/surface at the load pole for `-TAU` $\leq t < 0$ kyrs (kg/m**2).

`LH = 3`: **"Simple deglaciation"**

The load is kept constant for $-\infty \leq t < 0$ kyrs. For times $0 \leq t <$ `TAU` kyrs the load is deglaciated at the constant rate (1/`TAU`) kyrs**(-1), with `TAU` $>$ 0 kyrs. For t $\geq$ `TAU` kyrs, no load is acting (see the TD for further details). The kw must be configured as follows:

```
Load_History
3
TAU
PRM
```

where:

- `TAU` (>0) is the length of the deglaciation phase.

and where the meaning of `PRM` depends on the value of the `CL` parameter of kw `Load_Geometry` in the following way:

- If `CL = 10`: `PRM` (≥ 0) = load thickness for $-\infty \leq t <0$ kyrs (m).
- If `CL = 11`: see `CL = 10`.
- If `CL = 50`: see `CL = 10`.
- If `CL = 20`: `PRM` (≥ 0) = load thickness at the center for $-\infty \leq t <0$ kyrs (m).
- If `CL = 21`: see `CL = 20`.
- If `CL = 30`: `PRM` (≥ 0) = load mass for $-\infty \leq t <0$ kyrs (kg).
- If `CL = 40`: mass/surface at the load pole for $-\infty \leq t <0$ kyrs (kg/m**2).

`LH = 4:` "Saw tooth"

The load is characterized by a periodic saw–tooth time–history in which loading and melting phases occur at constant rates. The length of each loading phase is `TAUC` (>0) kyrs, and the length of the melting phase is `DINC` (>0) kyrs. The time-history includes `NPH` phases of loading and unloading in addition to the more recent (always included), so that the total number of phases is `NPH+1` (`NPH` must be an INTEGER with 0≤ `NPH` ≤5). The end of the last loading phase (i.e. the beginning of the last deglaciation phase) is placed at time t=0 kyrs (see the TD and the examples below for further details). The kw `Load_History` must be configured as follows:

```
Load_History
4
NPH
TAUC
DINC
PRM
```

where:

- `NPH` [INTEGER] is the number of (loading + unloading) phases in addition to the last. The range is [0:5].
- `TAUC` (REAL, >0) is the length of each loading phase (kyrs).
- `DINC` (REAL, >0) is the length of each un-loading phase (kyrs),

and where the meaning of `PRM` depends on the value of the `CL` parameter of kw `Load_Geometry` in the following way:

- If `CL = 10`: `PRM` (≥ 0) = load thickness for t=0 kyrs (m).
- If `CL = 11`: see `CL = 10`.
- If `CL = 50`: see `CL = 10`.
- If `CL = 20`: `PRM` (≥ 0) = load thickness at the center for t=0 kyrs (m).
- If `CL = 21`: see `CL = 20`.
- If `CL = 30`: `PRM` (≥ 0) = load mass for t=0 kyrs (kg).
- If `CL = 40`: `PRM` (≥ 0) = mass/surface at the load pole for t=0 kyrs (kg/m**2).

`LH = 5:` **"Sinusoidal Loading"**

The load is characterized by a sinusoidal time–history for $-\infty \leq t \leq \infty$, with period equal to `T` (> 0) kyrs. The sinusoid oscillates between 0 and 1. The kw must be configured as follows:

```
Load_History
5
T
PRM
```

where:

- `T` (REAL, >0) = period of the sinusoid (kyrs).

and where the meaning of `PRM` depends on the value of the `CL` parameter of kw `Load_Geometry` in the following way:

- If `CL = 10`: `PRM` (≥ 0) = peak value of the primary load thickness (m).
- If `CL = 11`: see `CL = 10`.
- If `CL = 50`: see `CL = 10`.
- If `CL = 20`: `PRM` (≥ 0) = peak value of the thickness at the primary load center (m) kyrs (m).
- If `CL = 21`: see `CL = 20`.
- If `CL = 30`: `PRM` (≥ 0) = peak value of the primary load mass (kg).
- If `CL = 40`: `PRM` (≥ 0) = peak value of the mass/surface at the load pole (kg/m**2).

`LH = 6`: "Piecewise Linear"

The load is characterized by a piecewise continuous, linear time-history. For $0 = t_0 \leq t < t_N$ the time- history is linear over the (non necessarily identical) intervals $t_{k-1} \leq t < t_k$, with k=1, 2,..., N ($1 \leq N \leq 100$). This phase is referred as to the PLP (Piecewise Linear Phase). For $t < 0$ kyrs and $t \geq t_N$ kyrs the load is constant (see the TD and the examples below for further details). The kw `Load_History` must be configured as follows:

```
Load_History
6
```

The user must also provide a two–columns free format text file with default name 'timeh_6.dat' of the form:

6
t_0 y_0
t_1 y_1
t_2 y_2
$\cdots$

t_k y_k
...
...
...
t_N y_N

where:

- `6` [INTEGER] is the label of this time-history.
- t_k (REAL, $\geq$0) are the times which bound the intervals during which the time-history is linear (kyrs). Notice that t_0 must be equal to 0.0 by convention. The t_k must form a strictly increasing sequence from t_0 to t_N. The range of N is [1:100].

The meaning of y_k depends on the value of the `CL` parameter of kw `Load_Geometry` in the following way:

- If `CL = 10`: y_k (≥ 0) = Thickness of the load (m) at time t_k. Notice that y_0 indicates the constant value of the thickness taken for $-\infty \leq t < 0$ kyrs, and that y_N is the constant value of the thickness taken for $t \geq t_N$ kyrs.
- If `CL = 11`: see `CL = 10`.
- If `CL = 50`: see `CL = 10`.
- If `CL = 20`: y_k (≥ 0) = Thickness of the load (m) at its center at time t_k. Notice that y_0 indicates the constant value of the thickness at the center of the load for $-\infty \leq t < 0$ kyrs, and that y_N is the constant value of the thickness at the center of the load for $t \geq t_N$ kyrs.
- If `CL = 21`: see `CL = 20`.
- If `CL = 30`: y_k (≥ 0) = Mass of the load (kg) at time t_k. Notice that y_0 indicates the constant value of the mass taken for $-\infty \leq t < 0$ kyrs, and that y_N is the constant value of the mass for $t \geq t_N$ kyrs.
- If `CL = 40`: y_k (≥ 0) = Mass per unit surface at pole of the load (kg/m**2), at times t_k. Notice that y_0 indicates the constant value of the mass/surface taken for $\infty \leq t < 0$ kyrs, and that y_N is the constant value of the mass/surface for $t \geq t_N$ kyrs.

`LH = 7:` **"Piecewise Constant"**

For $t_0 = 0 \leq t < t_N$ this time–history is piecewise constant over N identical time intervals (we refer conventionally to this phase as to the PCP, or Piecewise Constant Phase: the PCP is therefore composed of N time steps). For $-\infty \leq t < 0$ the load has a constant value (we refer to this phase of infinite length as to step#0). Finally, also for $t \geq t_N$ (step#N+1) the load is constant, with an amplitude equal to that assumed over the N–th step, i.e. over the last step of the PCP (see the TD for further details). The kw `Load_History` must be configured as follows:

```
Load_History
7
```

The user must also provide a two–columns free format text file with default name 'timeh_7.dat' of the form:

7
DELTA
0 y_0
1 y_1
2 y_2
...
k y_k
...
...
...
N y_N

where:

- `7` [INTEGER] is the label of this time-history.
- `DELTA` [REAL] is the length (in kyrs) of each time step during the PCP. It must be in the range [0.001:1000] kyrs.
- `0, 1, ...N` [INTEGER] are the steps labels, with $1 \leq$ `N` ≤ 100,

and where the meaning of y_k depends on the value of the `CL` parameter of kw `Load_Geometry` in the following way:

- If `CL = 10`: y_k (≥ 0) = Thickness of the primary load (m) at step #k. Notice that y_0 indicates the constant value of the thickness before the PCP (i.e. during step#0), and that during step#N+1 the primary load thickness is the same as during step#N.
- If `CL = 11`: see `CL = 10`.
- If `CL = 50`: see `CL = 10`.
- If `CL = 20`: y_k (≥ 0) = Thickness of the primary load (m) at its center at step #k. Notice that y_0 indicates the constant value of the thickness at the load center before the PCP (i.e. during step#0), and that during step#N+1 the primary load thickness at its center is the same as during step#N.
- If `CL = 21`: see `CL = 20`.
- If `CL = 30`: y_k (≥ 0) = Mass of the primary load (kg) at step #k. Notice that y_0 indicates the constant value of the mass before the PCP (i.e. during the step#0), and that during step#N+1 the primary load mass is the same as during step#N.
- If `CL = 40`: y_k (≥ 0) = Mass/surface at the load pole (kg/m**2) at step#k. Notice that y_0 indicates the constant value of the mass/surface before the PCP (step#0), and that during step#N+1 the mass/surface at the load pole is the same as during step#N.

`LH = 8:` **"Piecewise Constant with loading phase"**

For $t > 0$ kyrs the load history is identical to that for `LH` = 7 "Piecewise Constant" (see above). The phase of constant load which characterizes `LH` =7 for $-\infty \leq t < 0$ is replaced here by a phase of linearly increasing loading in the interval `-TAU` $\leq t < 0$. This represents step#0 for `LH`=8. Before time t=-`TAU` the load is zero (see the TD for further details). The kw `Load_History` must be configured as follows:

`Load_History`

```
8
```

It is also necessary to provide a two-columns text file with free format and default name 'timeh_8.dat' of the form:

`8`
`DELTA`
`TAU`
$0\ y_0$
$1\ y_1$
$2\ y_2$
$\ldots$
$k\ y_k$
$\ldots$
$\ldots$
$\ldots$
$N\ y_N$

where:

- `8` [INTEGER] is the label of this time-history.
- `DELTA` [REAL] is the length (in kyrs) of each time step which characterize the piecewise phase of the time-history. It must be in the range [0.001:1000] kyrs.
- `0, 1, .. N` [INTEGER] are the steps labels, with $1 \leq$ `N` ≤ 100,

and where the meaning of y_k depends on the value of the `CL` parameter of kw `Load_Geometry` in the following way:

- If `CL = 10`: y_k (≥ 0) = Thickness of the primary load (m) at step #k. Notice that y_0 indicates the value of the thickness at t=0 kyrs (i.e. at the end of step#0), and that during step#N+1 the load primary thickness is the same as during step#N.
- If `CL = 11`: see `CL = 10`.

- If `CL = 50`: see `CL = 10`.
- If `CL = 20`: y_k (≥ 0) = Thickness of the primary load (m) at its center at step #k. Notice that y_0 indicates the value of the thickness at the load center at time t=0 kyrs (i.e. at the end of step#0), and that during step#N+1 the primary load thickness at its center is the same as during step#N.
- If `CL = 21`: see `CL = 20`.
- If `CL = 30`: y_k (≥ 0) = Mass of the load (kg) at step #k. Notice that y_0 indicates the constant value of the mass taken for $-\infty \leq t < 0$ kyrs (i.e. during step#0), and that during step#N+1 the load mass is the same as during step#N.
- If `CL = 40`: y_k (≥ 0) = Mass per unit surface at pole of the load (kg/m**2), at step#k. Notice that y_0 indicates the constant of the mass/surface at t=0 kyrs (i.e. at the end of step#0), and that during step#N+1 the mass/surface at the load pole is the same as during step#N.

3.3 Local analysis

Using `Local_Study` it is possible to input the parameters describing the particular type of local study to be performed by `TABOO` in task#2. In the following pages, we describe the five options currently available for this kw. The reader is referred to the comments in the sample file task_2.dat supplied with `TABOO` for further details.

3.3.1 Kw `Local_Study` (I)

The general input format for kw `Local_Study` is:

```
...
...
Local_Study
IS
p_1
p_2
...
```

```
...
...
p_n
...
...
```

where:

- `Local_Study` is the kw for this subtask. It must be written beginning by column one. It is case–sensitive, as all of the kws of `TABOO`. The use of `Local_Study` requires that the following five keywords are active:

  - `Active`
  - `Harmonic_Degrees`
  - `Make_Model` (or `External_Model`)
  - `Load_Geometry`
  - `Load_History`

- `IS` [INTEGER] is the code which identifies the particular local study to be performed. The range of `IS` is [1:5]. See §3.3.2.

- `p_1 p_2 ... p_n` are other parameters required to specify the type of local study selected above by means of the `IS` parameter. We notice that for `IS` = 2 `Local_Study` requires an user–supplied file in addition to these parameters (see §3.3.2 below).

3.3.2 Kw `Local_Study` (II)

According to the value of `IS`, the kw `Local_Study` may assume five different forms, which are described in the following pages. We recall that the time variable in task#2 is measured with respect to specific features of the load time–history (see §3.2.3). Another convention applies to task#3 (see the introductory notes to Chapter 4).

`IS = 1`: "One observer, various times"

This type of analysis allows to compute a given local variable at a point P ("observer") on the Earth's surface for times ranging in a prescribed interval.

The default output files for this analysis (disp.his and rate.his) also contain a global variable, i.e., the mass of the (primary) load as a function of time (or, alternatively, the mass/surface at the load pole for harmonic loads). The format of the output files disp.his and rate.his is described in Appendix B.

The kw `Local_Study` must be configured as follows:

```
Local_Study
1
IR IT IG DIR DIT DIG
LON COL
TMIN TMAX DELTAT
Isub
```

where:

- `IR IT IG DIR DIT DIG` [INTEGER=0/1] are the switches which determine the particular local variable to be computed:

  - `IR` = 1: the radial displacement is computed at P,
  - `IT` = 1: the two components of the tangential displacement (along the colatitude and the longitude unit vectors, respectively) are computed at P,
  - `IG` = 1: the geoid height is computed at P,
  - `DIR` = 1: the radial velocity is computed at P,
  - `DIT` = 1: the two components of the tangential velocity (along the colatitude and the longitude unit vectors, respectively) are computed at P,
  - `DIG` = 1: the rate of change of the geoid height is computed at P.

- `LON COL` [REAL] are the longitude and co–latitude of point P. Their ranges are [0:360] deg and [0:180] deg, respectively.

- `TMIN TMAX DELTAT` [REAL] are the time parameters for this analysis, expressed in units of kyrs. The local variables selected by the switches `IR, ..., DIG` are computed at point P for times ranging between `TMIN` and `TMAX` with increment `DELTAT`, with `TMIN` $\leq$ `TMAX` and `DELTAT` > 0.

- `Isub` [INTEGER=0/1] is a switch that allows to select the routine to be used to compute the local variables. This switch is ignored (but it must be equally given) if the `CL` parameter of the kw `Load_Geometry` is set to 50, i.e. if a load with "rectangular" base has been selected (see §3.2.1). For `Isub` = 0, `TABOO` uses the subroutine AXIS_DISP0, which takes advantage from the axial symmetry of the loads with `CL` ≤ 40. For `Isub` = 1, `TABOO` uses instead the routine ESSA_IEZI0, which implements a general spherical harmonics expansion without invoking any symmetry to simplify the computations (this is significantly more time consuming with respect to the case `Isub` = 0). The results obtained using the two `Isub` options should be virtually identical, as the user should verify.

`IS = 2`: "More observers, various times"

This type of analysis allows to compute a given local variable at a set of points P_k (observers) on the Earth's surface for times ranging in a prescribed interval. As for `IS` = 1, the local variables computed are written on the default files disp.his and rate.his together with the load mass (or the mass/surface at the load pole if `CL` = 40). The format of the output files is described in Appendix B.

The User must first configure the kw as follows:

```
Local_Study
2
IR IT IG DIR DIT DIG
Filename
TMIN TMAX DELTAT
Isub
```

where:

- `IR IT IG DIR DIT DIG` [INTEGER=0/1] have the same meaning as for `IS` = 1.

- `Filename` [CHARACTER*20] is the name of a free–format user supplied file containing the coordinates of the observers P_k. In each row, `Filename` simply contains the longitude (deg) and the colatitude of (deg) of P_k. The maximum allowed number of observers is 16200. This default can be easily changed modifying subroutine TASK_2 of the program taboo.f90. We recall that for `Filename`, as well as for all of the parameters of type CHARACTER, the same syntax rules as for the kws apply (see §1.4.2). A sample of this file is contained in the taboo.zip archive with name sparsi.dat.

- `TMIN TMAX DELTAT` [REAL] are the time parameters for this study. See the description made above for `IS` = 1.

- `Isub` [INTEGER=0/1] has the same meaning as for `IS` = 1.

`IS = 3`: "Along a meridian, at a given time"

Using `IS` = 3 one can compute local variables on a set of evenly spaced points (observers) P_k placed along a meridian on the Earth surface, at a given time. The local variables computed for `IS` = 3 are written on the default files disp.pro and rate.pro, as described in Appendix B. The user must configure the kw as follows:

```
Local_Study
3
IR IT IG DIR DIT DIG
LONG C1 C2 EPC
GIVEN_TIME
Isub
```

where:

- `IR IT IG DIR DIT DIG` [INTEGER=0/1] have the same meaning as for `IS` = 1.

- `LONG C1 C2 EPC` [REAL] are the angular parameters of this type of study. They must be all given in degrees. `LONG` is the longitude of the chosen meridian (the range is [0:360] deg), `C1` and `C2` define the range of colatitudes for the observers P_k (their range is [0:180] deg) (`C2`>`C1`), and `EPC` (>0) is the increment in colatitude.

- `GIVEN_TIME` [REAL] is the time at which the study must be performed (kyrs).

- `Isub` [INTEGER=0/1] has the same meaning as for `IS` = 1.

`IS = 4`: "Along a parallel, at a given time"

Using `IS`=4 one can compute the local variables on a set of evenly spaced points (observers) P_k placed along a parallel on the Earth surface, at a given time. As for `IS` = 3, the output local variables are written on the default files disp.pro and rate.pro, which are described in Appendix B. The user must configure the kw as follows:

```
Local_Study
4
IR IT IG DIR DIT DIG
COLA L1 L2 EPL
GIVEN_TIME
Isub
```

where:

- `IR IT IG DIR DIT DIG` [INTEGER=0/1] have the same meaning as for `IS` = 1.
- `COLA L1 L2 EPL` [REAL] are the angular parameters for this type of study. `COLA` is the colatitude of the chosen parallel ([0:180] deg), `L1` ([0:360] deg) and `L2` ([0:360] deg) define the range of longitudes of the observers P_k (`L2`>`L1`), and `EPL` (>0) is the increment in longitude.
- `GIVEN_TIME` [REAL] is the time at which the study must be performed (kyrs).
- `Isub` [INTEGER=0/1] has the same meaning as for `IS` = 1.

`IS = 5`: "On a map"

With `IS` = 5 it is possible to compute the local variables on a set of points (observers) P_k evenly distributed on the region between to meridians and two parallels on the Earth surface, at a given time. The local variables computed for `IS` = 5 are written on the default files A_geo.dat, A_lat.dat, A_lon.dat, A_rad.dat, Ad_geo.dat, Ad_lat.dat, Ad_lon.dat, Ad_rad.dat (see Appendix B). The User must configure the kw as follows:

```
Local_Study
5
IR IT IG DIR DIT DIG
L1 L2 EPL
C1 C2 EPC
GIVEN_TIME
Isub
```

where:

- `IR IT IG DIR DIT DIG` [INTEGER=0/1] have the same meaning as for `IS` = 1.
- `L1 L2 EPL` [REAL] are angular parameters of this type of study. `L1` ([0:360] deg) and `L2` ([0:360] deg) define the East–West range of the map (`L2`>`L1`), and `EPL` (>0) is the longitude increment.
- `C1 C2 EPC` [REAL] are more angular parameters of this type of study. `C1` ([0:180] deg) and `C2` ([0:180] deg) define the North–South range of the map (`C2`>`C1`), and `EPC` (>0) is the colatitude increment.
- `GIVEN_TIME` [REAL] is the time at which the study must be performed (kyrs).
- `Isub` [INTEGER=0/1] has the same meaning as for `IS` = 1.

3.4 Global analyses

Using the kw `Global_Study` it is possible to input the parameters concerning the desired global analysis. The kws `Global_Study` and `Local_Study` are mutually exclusive. In the following pages, we describe the three options currently available for this kw.

3.4.1 Kw Global_Study (I)

The general input format for kw Global_Study is:

```
...
...
Global_Study
ES
p_1
p_2
...
...
...
p_n
...
...
```

where:

- Global_Study is the kw for this subtask. It requires that the following five keywords are active:
  - Active
  - Harmonic_Degrees
  - Make_Model (or External_Model)
  - Load_Geometry
  - Load_History
- ES [INTEGER] is the code which identifies the particular global study to be performed. The range of the parameter ES is [1:3]. See §3.4.2.
- p_1 p_2 ... p_n are other parameters required to specify the particular local study selected above. See §3.4.2 below.

3.4.2 Kw Global_Study (II)

According to the value of ES, the parameters of Global_Study may assume various meanings, as described in the following pages.

`ES = 1`: "Stokes coefficients vs time"

Setting `ES`=1 it is possible to compute the variations of the Stokes coefficients corresponding to a specific degree and order and their time derivatives as a function of time (see also the TD). The cosine and sine Stokes coefficients computed for `ES`=1 are written on the default files stokes.his and stoked.his. These files also report the mass of the (primary) load as a function of time, or, alternatively, the mass/surface at the load pole for `CL` = 40 (see Appendix B).

The kw must be configured as follows:

```
Global_Study
1
L M
Inorm
TMIN TMAX DELTAT
```

where:

- `L M` [INTEGER] are the harmonic degree and order of the Stokes coefficient to be computed, and of its time-derivative. The restrictions on these parameters are: `l_min` ≤ `L` ≤ `l_max`, 0 ≤ `M` ≤ `L`, 2 ≤ `L` ≤36, where `l_min` and `l_max` are defined by kw `Harmonic_Degrees` (see §3.1.1 and 2.1.1).

- `Inorm` [INTEGER=0/1]. For `Inorm` = 1, the Stokes coefficients are fully normalized. For `Inorm` = 0, they are not (see the TD for details on this point).

- `TMIN TMAX DELTAT` [REAL] are the time parameters for this analysis, in units of kyrs. The changes in the Stokes coefficients and their time-derivatives are computed for times ranging between `TMIN` and `TMAX` with increment `DELTAT` (`TMIN` ≤ `TMAX` and `DELTAT` > 0).

`ES = 2`: "Stokes coefficient vs degree"

Setting `ES` = 2 it is possible to compute the variations of the Stokes coefficients and their time derivatives in the range of harmonic degrees `[LDE1:LDE2]`, at a given time. The global variables computed for `ES` =

2 are written on the default files stokes.pro and stoked.pro (see Appendix B).

The kw must be configured as follows:

```
Global_Study
2
LDE1 LDE2
Inorm
GIVEN_TIME
```

where:

- `LDE1 LDE2` [INTEGER] are the harmonic degree and order of the Stokes coefficient to be computed, and of its time-derivative. The restrictions on these parameters are: `l_min` $\leq$ `LDE1` $\leq$ `l_max`, `l_min` $\leq$ `LDE2` $\leq$ `l_max`, `LDE1` $\leq$ `LDE2`, 2 $\leq$ `LDE1` $\leq$ `36`, 2 $\leq$ `LDE2` $\leq$ `36`, where `l_min` and `l_max` are defined by kw `Harmonic_Degrees` (see §3.1.1 and 2.1.1).
- `Inorm` [INTEGER=0/1]. For `Inorm` = 1, the Stokes coefficients are fully normalized. For `Inorm` = 0, they are not (see the TD for further details on this point).
- `GIVEN_TIME` [REAL] is the time at which this global study must be performed (kyrs).

`ES` = 3: "Inertia tensor vs time"

With `ES` = 3 it is possible to compute the variations of the inertia tensor and their time-derivatives as a function of time. These quantities are written on the default files iner.pro and ined.pro, respectively. For `ES`=3 `TABOO` also computes the mass of the (primary) load vs time (for `CL` =10, 11, 20, 21, or 50), or the mass/surface at the load pole vs time for `CL`=40. The output files are load_mass.dat and load_pole.dat (see Appendix B). For `ES` = 3 `TABOO` expects that `Harmonic_Degrees` is configured with `l_max=l_min`=2 (see §3.1.1).

The kw `Global_Study` must be configured as follows:

```
Global_Study
3
TMIN TMAX DELTAT
```

where:

- `TMIN TMAX DELTAT` [REAL] are the time parameters for this analysis, expressed in kyrs. The change of the inertia tensor and their time-derivatives are computed for times ranging between `TMIN` and `TMAX` with increment `DELTAT` (`TMIN` $\leq$ `TMAX` and `DELTAT` > 0).

3.5 Worked examples for task#2

In this section we present examples on how to configure the task#2 of `TABOO` to obtain the response of the Earth to a given ice load. The explicit output files instead of plots are made available in the taboo.zip archive. This allows more precise comparisons between what is presented here and what anyone can obtain running `TABOO` on his own computer. The geophysical relevance of the numerical results obtained in the following examples if not of concern here.

3.5.1 Example #1 (Laurentian ice load)

In this example we consider an ice load which mimics the Laurentian. Our intention is to compute the local variables at given places and times. We begin activating file task_2.dat:

```
Active
```

The second step consists in the setting of the basic parameters of task#2. This is done using `Harmonic_Degrees`, where we state the range of harmonic degrees, we select the verbose mode (some output is be sent on the monitor), we express our intention to include both the elastic and the viscoelastic rheology, and we decide to exclude from the computations the 'non-physical' modes (if some of these modes arise from the determination of the relaxation spectrum):

```
Harmonic_Degrees
2 72
1
0
0
```

For our study we decide to adopt the Earth model by Bills and James (1997) (`NV` =2, `CODE`=2). It includes a two-layers mantle, and a 100–km thick lithosphere (see Appendix D). We adopt a viscosity of 2×10^{21} Pa.s in the lower mantle, and of 1×10^{21} Pa.s in the upper mantle. We therefore add these lines:

```
Make_Model
2
2
100.0
0
2.
1.
```

We approximate the Laurentian ice dome to a disc load with an half–amplitude of 15 degrees. This load, which is placed to the north pole of our Earth model, is not accompanied by any secondary load. Thus we configure `Load_Geometry` as follows:

```
Load_Geometry
10
0    0.0   0.0    15.0
```

The load thickness evolves according to a saw–tooth time–history, in which loading and unloading phases are 90 and 10 kyrs long, respectively. We include 5 cycles of loading and unloading in addition to the more recent, and we set the maximum ice thickness to 2080 m, which gives a realistic mass for the Laurentian ice dome. All this is done with:

```
Load_History
4
5
90.0
10.0
2080.
```

Due to the load symmetry and to its geographical location, it may appear convenient to compute the local variables along a meridian. Any meridian would provide the same results. Here we choose the reference meridian, and compute all of the available local variables at points separated by 1 deg in colatitude. We use subroutine AXIS_DISP0, which takes advantage from the load symmetry. Assuming that 18 kyrs have elapsed since the beginning of the last unloading episode, we write:

```
Local_Study
3
1 1  1    1    1  1
0.0   0.0   180.0    1.0
18.0
0
```

This concludes the configuration of the keywords for this study. In the taboo.zip archive we have placed the following output files:

- spectrum_e21.dat (the relaxation spectrum for example #1 of task#2),
- h_e21.dat, l_e21.dat, k_e21.dat (ldcs),
- load_coeff_e21.dat (the load coefficients),
- taboo_e21.log (log file),
- disp_e21.pro, rate_e21.pro (local variables and their time-derivatives).

A variant of Example #1

Suppose that we are not fully satisfied with the results obtained above and that we want to continue our investigation modifying the ice geometry. We can replace the disc load with one of parabolic cross section by simply modifying the kw `Load_Geometry` as:

```
Load_Geometry
20
0    0.0   0.0    15.0
```

where we have left unchanged the half–amplitude of the load with respect to the previous disc configuration. We also leave unchanged the configuration of kw `Load_History`, so that the value of 2080. m has now the meaning of load thickness at the center (notice that mass of the load diminishes significantly, due to the smaller volume of the new parabolic load).

In this variant of Example#1 we turn our attention to what happens on a specific point of the Earth surface for various times. For this reason we configure the kw `Local_Study` in this manner:

```
Local_Study
1
1 1  1    1  1  1
12.0 45.0
-10.0 20.0 0.5
0
```

where the local variables already selected in the first part of this example are computed at the point of longitude 12.0 deg and colatitude 45.0 deg for times ranging from 10 kyrs before the beginning of deglaciation to 20 kyrs after, with time increments of 0.5 kyrs.

The spectral outputs of `TABOO` are unchanged, since the model has not been modified. Our choice of a `Local_Study` of type #1 has made the following new files available:

- load_coeff_e21v.dat (the new load coefficients),
- disp_e21v.his, rate_e21v.his (local variables and derivatives vs. time).

3.5.2 Example #2 (snow load in Siberia)

We consider the following problem: what is the effect of a snow load on the Stokes coefficients of the Earth gravity field ? We take the case of Siberia, which is a candidate to produce significant effects due to its large size.

Since we are concerned with a seasonal surface load, characterized by a short time scale if compared to the mantle relaxation time scales, there is no need to compute the viscoelastic components of the global variables. We thus configure the first lines of task_2.dat as

```
Active
```

```
Harmonic_Degrees
2 72
1
1
0
```

The model we want to use includes a PREM-averaged uniform mantle, a 80–km thick lithosphere, and a fluid homogeneous core (`NV` =1, `CODE` = 0) (see Appendix D). The viscosity of the mantle plays no role, but it must nevertheless be specified. The `ilm` parameter is ignored since `NV` $\neq$ 7 and `NV` $\neq$ 9. We write:

```
Make_Model
1
0
80.0
0
1.
```

Using the kw `Load_Geometry`, we define the type of load. In this case, we consider a large rectangular load, with centroid placed at the point of longitude 95.0 deg and colatitude 30.0 deg. The region covered by snow spans 70.0 degrees in longitude and 20.0 degrees in colatitude:

```
Load_Geometry
50
95.0  70.0   30.0    20.0
```

We assume an instantaneous loading, with a load thickness of 20 m:

```
Load_History
0
20.0
```

Finally, we ask TABOO to compute the fully–normalized Stokes coefficients in the range of degrees [2:12] at time 10 kyrs after the loading has been placed on site. Since the Earth responds elastically, any other positive value would produce the same effect:

```
Global_Study 2
2    12
1
10.0
```

With the above configuration, we have obtained the output files below, which are contained in the taboo.zip archive:

- h_e22.dat, l_e22.dat, k_e22.dat (elastic ldcs),
- load_coeff_e22.dat (the rectangular load coefficients),
- taboo_e22.log (log file),
- stokes_e22.pro, stoked_e22.pro (Stokes coefficients and their time–derivatives).

Chapter 4

Response to complex loads (task#3)

The third and last task of `TABOO` allows for the computation of the same spectral, local and global variables which can be obtained in task#2. They are listed here:

- Relaxation spectrum,
- Load-deformation coefficients (ldcs),
- 3D displacement,
- 3D velocity,
- Mass and thickness of the ice load,
- Change and rate of change of geoid height,
- Change and rate of change of the Stokes coefficients,
- Change and rate of change of the inertia tensor.

However, in task#3 it is possible to solve problems in which a number ≥ 1 of distinct ice loads are acting at the same time. Since using task#3 it is possible to obtain the same results that we can achieve with task#2, one may wonder why we have maintained the latter. The reason is that task#2 is simply structured, whereas in task#3 we have been forced to build a more complicated code to allow for the possibility of using ice loads with different geometries and time-histories at once. While in task#2 the user can simply specify the load geometry directly on the input file task_2.dat, in task#3 there is the need to provide an external file with its own, not so intuitive, format (see §4.2.1 and 4.2.2). In task#2 the number of allowed geometries is larger (the harmonic zonal load is not included in task#3), and the number of admissible local studies is also larger (see §3.3.2). These features make task#2 more efficient, general, and friendly when the user is concerned with a single ice load. Of course, when task#3 is configured for a single load, it *must* provide exactly the same results that it is possible to obtain with task#2.

To understand clearly the following pages on the configuration of task#3, the reader should give before a look to Chapter 3 of this manual, dedicated to task#2. In fact, the parts of task#3 which are similar to parts of task#2 are not be described in detail here, to avoid redundancy.

File task_3.dat is characterized by the following keywords, listed here in their natural sequence:

- `Active`
- `Harmonic_Degrees`
- `Make_Model` (or `External_Model`)
- `Ad_Hoc` (or `Ice_k`, with $k = 1, 2$, or 3)
- `Local_Study`
- `Global_Study`

where

- `Active` is the kw which activates file task_3.dat. It is described in note 1 of §1.4.2.
- `Harmonic_Degrees` is to be used to input basic parameters which control the execution. In task#3, this kw has the same format as in task#2 (see §3.1.1).
- `Make_Model` is the kw that determines the model to be employed and its viscosity profile. It is described in §2.2.1. In task#3 `Make_Model` forces automatically the computation of the relaxation spectrum and of ldc of the model selected. The ldc are written on the default files h.dat, l.dat, and k.dat as it is (optionally) possible in task#1 by means of kw `El_Fluid_Viscel`.

- External_Model is alternative to Make_Model, and allows to select a non-self-gravitating test model. See §2.2.2.

- Ad_Hoc allows to build an *ad hoc* surface load. It has the same functions of the task#2 kws Load_Geometry and Load_History, but it allows to build an aggregate of ice loads. This kw is described in §4.2.

- Ice_k ($k = 1, 2, 3$), which constitutes an alternative to Ad_Hoc (see above), allows to employ the ICE_k ice aggregates by W. R. Peltier and coworkers[1], or parts of them. These kws are described in §4.2.3.

- Local_Study is to be used to input the parameters which define the type of local analysis. The use of this kw, described in §4.3, is very similar to that of task#2.

- Global_Study allows to input the details on the global study to be performed. Its configuration follows almost exactly that of task#2. It is described in §4.4.

We remark that the time convention for task#3 differs from that of task#2. In the kws of task#3 time is in fact measured with respect to present time, and not with respect to features of the load time–history. Time is counted as positive if it is time before present (BP), and negative if time is future time. This convention is adopted since it is obviously impossible to employ a load–dependent origin of time when various loads are present, possibly with distinct kinds of time evolutions.

This chapter is organized as follows: §4.1 and 4.2 show how to provide the basic settings for TABOO and the spatio–temporal features of the load(s). In §4.3 and §4.4 we describe the local and global analyses available via task#3, and finally two worked examples are given in §4.5.

4.1 Settings and model selection for task#3

As in task#2, some important settings of TABOO can be defined using kw Harmonic_Degrees. Since the use of this kw in task#3 is identical to that of task#2, the reader is referred to §3.1.1 for the instructions. We only

[1]For ICE1, see W. R. Peltier and J. T. Andrews, Geophys. J. R. Astron. Soc., *46*, 605–646, 1976. The ICE2 deglaciation chronology is given in P. Wu and W. R. Peltier, ibid., *74*, 377–449, 1983. For the description of the ICE3G model, see A. M. Tushingham and W. R. Peltier, J. Geophys. Res., *96*, 4497–4523, 1991.

recall here that `Harmonic_Degrees` must be used to define the range of harmonic degrees for the analysis, to choose between silent and verbose mode, to possibly suppress the viscous component of the Maxwell rheology, and to manage the 'non–physical' viscoelastic modes which may come out from the numerical procedure.

In task#3, the Earth model to be employed can be selected from the `TABOO` library of models using kws `Make_Model`, `External_Model`. The use of these kws is exactly the same as in task#2. The user can find detailed instructions in §2.2.1 and 2.2.2.

4.2 Load geometries and time histories for task#3

In task#3, the information on the geometry of the ice load and on its time–history can be provided in two mutually exclusive ways:

1. If the user wants to build its own aggregate of ice loads, he must supply the specific kw `Ad_Hoc` in task_3.dat and provide an external file containing both the spatial and the temporal parameters of all of the single ice loads of the aggregate. The form of the external file provided must be coherent with a set of rules that are presented in §4.2.1.

2. If, on the contrary, there is the need to use one of the deglaciation models proposed by W. R. Peltier and coworkers (or parts of them), the user can provide one of the three kws `Ice_k` (k=1, 2, or 3) and a set of control parameters directly on file task_3.dat (the kw `Ice_3` selects the aggregate ICE3G, where G is dropped to simplify the notation). Other ice melting chronologies taken from the literature can be simply implemented in `TABOO` following the procedure that we have implemented for ICE*k*. The only restriction is that the entire ice aggregate must be given as an ensemble of simple elements of kind `CL`=10 (i.e., discs) or `CL`=50 ("rectangles" on the sphere) (see §3.2.1), and that the thickness of the ice elements varies with time according to one of the time–histories already implemented in `TABOO`. The files ice*k*.* are briefly described in Appendix A, where * is a string of three characters which may denote a single part of ICE*k* or the entire ICE*k*. Each of the subparts of ICE*k* corresponds to a well defined geographical region. The instructions on how to configure the kws `Ice_k` are given in §4.2.3.

The approach outlined in the two above points differs from that of task#2, in which the user needs to configure `Load_Geometry` and `Time_History` and to provide their parameters directly on file task_2.dat. In task#3 these two kws are not needed.

4.2.1 Kw `Ad_Hoc` (I)

This section shows how to input an user–defined aggregate of ice elements using the kw `Ad_Hoc` . This kw, coupled with an user–supplied file, includes all of the features of the kws `Load_Geometry` and `Load_History` which are in use with task#2. To activate `Ad_Hoc` the following records must be supplied:

```
...
...
Ad_Hoc
Filename
...
...
```

where:

- `Ad_Hoc` is the kw for this subtask. It requires that these three kws have been previously activated:
  - `Active`
  - `Harmonic_Degrees`
  - `Make_Model` (or `External_Model`)
- `Filename` [CHARACTER*30] is the name of the user–supplied file containing the parameters needed to specify the spatio–temporal attributes of each element of the aggregate (see §4.2.2 below). Two samples of valid input files are included in the taboo.zip archive with names complex_e31.dat and complex_e31v.dat (see §4.5.1 and §4.5.2, respectively).

4.2.2 Kw `Ad_Hoc` (II)

The kw `Ad_Hoc` must be accompanied by the user–supplied file `Filename`, which is written in free format according to the rules illustrated in the following. The general form of `Filename` is:

```
N .....................................first record of Filename
CL IOC LH .....first line of the parameters list for element #1
s_1 s_2 ...
PRM
p_1 p_2 ...
f_0 f_1 f_2
g_0 g_1 g_2 .....last line of the parameters list for element #1
...
...
...
...
CL IOC LH .....first line of the parameters list for element #N
s_1 s_2 ...
PRM
p_1 p_2 ...
f_0 f_1 f_2
g_0 g_1 g_2 .....last line of the parameters list for element #N
[EOF]
```

where:

- `N` [INTEGER] is total the number of ice elements which compose the user–supplied aggregate. It may vary in the range [1:809] (the upper bound coincides with the number of elements of the aggregate ICE3G plus one). The group of records between the first and the last line of the parameters list must be repeated for each of the `N` elements which compose the ice aggregate.

- `CL` [INTEGER] is the code which identifies the type of load. In task#3 valid `CL` values are: 10, 11, 20, 21, and 50 (notice that the option `CL`=40 is not permitted in task#3). The meaning of each `CL` value is explained in §3.2.1. Codes `CL`=11 and `CL`=21 are only allowed for `N`=1 since when more than one element is present the complementary load of a given element would overlap the regions occupied by the others.

- `IOC` [INTEGER=0/1] is the 'ocean' switch. For `IOC`=1, the load is balanced on an ocean with realistic shape, whereas for `IOC`=0 it is not. If `N`=1 (i.e., when a single element is included in the aggregate), the condition `IOC`=1 is not allowed for `CL`=11 or `CL`=21, since these types of load are already balanced on their own secondary loads. This also holds for task#2 (see §3.2.1).

- `LH` [INTEGER] is the code that identifies the time–history of the element. The range is [0:8]. The meaning of each of `LH` values is given below, but see also the descriptions of the time–histories given in §3.2.3.

- `s_1 s_2` ...and `PRM` [REAL] are the geometrical attributes of the load. Their meaning depend on the value of `CL` in the following manner:

  - `CL`=10:

    `s_1` = Longitude of the load center [0:360] deg.

    `s_2` = Colatitude of the load center [0:180] deg.

    `s_3` = Half–amplitude of the disc [0:180] deg.

    `PRM` = Maximum thickness of the (primary) disc load in the course of its time–evolution (m).

  - `CL`=11: see `CL`=10.

  - `CL`=20:

    `s_1` = Longitude of the load center [0:360] deg.

    `s_2` = Colatitude of the load center [0:180] deg.

    `s_3` = Half–amplitude of the parabolic load [0:180] deg.

    `PRM` = Maximum thickness at the center of the (primary) disc load in the course of its time–evolution (m).

  - `CL`=21: see `CL`=20.

  - `CL`=30:

    `s_1` = Longitude of the load [0:360] deg.

    `s_2` = Colatitude of the load [0:180] deg.

    `PRM` = Maximum mass of the point load in the course of its time–evolution (kg).

  - `CL`=50:

    `s_1` = Longitude of the load centroid [`s_3`/2:360-`s_3`/2] deg.

    `s_2` = Colatitude of the load centroid [`s_4`/2:180-`s_4`/2] deg.

s_3 = Load size in longitude [0.25:90.0] deg.

s_4 = Load size in colatitude [0.25:90.0] deg.

PRM = Maximum thickness of the rectangular load in the course of its time–evolution (m).

- p_1 p_2 ...f_1 f_2 ...g_1 g_2 are other temporal attributes of the load. Their meaning depends on the value of LH as explained in the following (notice that the f_k parameters are only defined for LH=6, 7, and 8; the g_k parameters only for LH=6 and that the p_k parameters are needed for any value of LH). For any LH value, the parameter p_1 represents the time elapsed since the occurrence of a given conventionally chosen episode in the course of the time–history (for instance, this episode is the epoch of loading for LH=0 - instantaneous loading -, and the beginning of the last deglaciation episode for LH=4 (saw-tooth time history). The parameter p_1 is positive if the event occurred before present (BP), negative if it will occur in the future.
  - LH=0 ("Heaviside" or "instantaneous loading"):

    p_1 = Time since loading (kyr).
  - LH=1 ("instantaneous unloading"):

    p_1= Time since unloading (kyr).
  - LH=2 ("loading and unloading"):

    p_1= Time since unloading (kyr).

    p_2= Lapse of time between loading and un-loading (> 0 kyrs).
  - LH=3 ("simple deglaciation"):

    p_1= Time since the beginning of deglaciation (kyrs).

    p_2= Duration of the phase of deglaciation (> 0 kyrs).
  - LH=4 ("saw tooth"):

    p_1= Time since the beginning of the last deglaciation (kyrs).

    p_2= Duration of each loading episode (> 0 kyrs).

    p_3= Duration of each unloading episode (> 0 kyrs).

p_4= [INTEGER] Number of (loading+unloading) phases in addition to the last [0:5].

- LH=5 ("sinusoidal loading"):

  p_1= Time since time t=0 (kyrs) (at time t=0 the value of the time-history is 1/2 of the peak value).

  p_2= Period of the sinusoid (> 0 kyrs).

- LH=6 ("piecewise linear"):

  p_1= Time since the beginning of the Piecewise Linear Phase (PLP) (kyr).

  p_2= NNS [INTEGER] = number of time intervals characterizing the PLP, with $0 \leq$ NSS ≤ 24.

  f_k= t_k (k=0,...,NNS), t_0 $\equiv 0.0$, see §3.2.3. All of the t_k's (i.e., f_k) must be positive and given in a strictly increasing sequence.

  g_k= Load thickness (> 0 m) (or load mass, > 0 kg) at times t_k. Notice that (i) the PRM parameter is superseded by Max(g_k) and that (ii) the f_k's and the g_k's must be given in one single row.

- LH=7 ("piecewise constant"):

  p_1= Time since the beginning of the piecewise constant phase (PCP) (kyr).

  p_2= Duration of each time step during the PCP (> 0 kyrs).

  p_3= NS [INTEGER] = Number of steps during the PCP, with $0 \leq$ NS ≤ 24.

  f_k= Load thickness (> 0 m) (or mass, > 0 kg) at step#k (k=0,..., NS). Notice that: (i) by convention, f_0 refers to the period before the PCP (also called step#0), (ii) after the PCP (step#NS+1): f_(NS+1)=f_NS, (iii) the PRM parameter is superseded by MAX(f_k), (iv) and that the f_k's must be given in one row. See also §3.2.3.

- LH=8 ("piecewise constant with loading phase"):

  p_1= Time since the beginning of the piecewise constant phase (PCP) (kyr).

`p_2`= Duration of each time step during the PCP (> 0 kyrs).

`p_3`= `NS` [INTEGER] = Number of steps during the PCP, with $0 \leq$ `NS` ≤ 24.

`p_4`= Duration of the loading phase prior to the PCP (> 0 kyrs).

`f_k`= Load thickness (> 0 m) (or mass, > 0 kg) at step #k (k=0,...,`NS`). Notice that: (i) by convention, `f_0` refers to the period before the PCP (also called step#0), (ii) after the PCP (step#`NS+1`): `f_(NS+1)=f_NS`, (iii) the `PRM` parameter is superseded by MAX(`f_k`), (iv) and that the `f_k`'s must be given in one row. See also §3.2.3.

Notes:

1. During execution, `TABOO` finds the maximum thickness for each ice element, and normalizes the individual time–histories dividing for that maximum. Details on the time–histories of the ice elements before and after normalization are reported on file taboo.log (Appendix B).

4.2.3 Kws `Ice_1`, `Ice_2`, and `Ice_3`

In this section we give the instructions in how to configure the kws `Ice_1`, `Ice_2`, and `Ice_3`, which are to be used to perform computations with the ICE*k* deglaciation models (k =1, 2, or 3(G)). The User must supply the following records in the input file task_3.dat:

```
Ice_k
IOC
FRTD
F7T8 tau
Scale
KS
sub_1
sub_2
...
...
...
sub_KS
```

where:

- `Ice_k` (k=1, 2, or 3) is the kw for this subtask. Notice that kws `Ice_k` and `Ad_Hoc` (§4.2.1) are mutually exclusive. If `Ice_1` or `Ice_2` are given, `TABOO` implicitly assumes that the ice elements are of type `CL` =50 (i.e. "rectangles" of uniform thickness on the sphere), whereas for `Ice_3` it assumes a type `CL`=10 (the default for `Ice_1` and `Ice_2` can be changed acting on the switch `FRTD`, as explained below). The default time–histories are of type `LH`=7 for all of the `Ice_k` kws, with the possibility of modifying them to type `LH`=8 by means of the switch `F7T8` (see below). The time steps during the PCP are 2 kyrs long for `Ice_1` and 1 kyr long for both `Ice_2` and `Ice_3`. Kw `Ice_k` requires that the following kws have been previously activated along the natural sequence of kws for task#3:

  - `Active`
  - `Harmonic_Degrees`
  - `Make_Model` (or `External_Model`)

- `IOC` [INTEGER=0/1] is the 'ocean' switch for this kw. For `IOC`=1, *every single constituent* of ICEk is compensated on an ocean with realistic shape, whereas for `IOC`=0 it is not. This default differs from that in use for kw `Ad_Hoc` (§4.2.1), where each ice element may have or not his own ocean compensation.

- `FRTD` [INTEGER=0/1] is a switch that, if set to 1, allows to transform the rectangular elements (`CL`=50) of aggregates ICE1 and ICE2 into discs (`CL`=10). The choice `FRTD`=0 leaves the elements unaltered. The transformation operates in such a way that the discs have the same mass, the same thickness, and the same center of the rectangles (as well as the same time–history). The introduction of discs obviously alters the details of the surface mass distribution. While a coverage made of rectangles leaves no spacing between the various elements, when transformed into discs the same elements does not cover uniformly the region, and overlaps also occur. In `TABOO` there is no way to optimize the discs coverage. Results obtained using the two surface distributions may give significantly different results especially if the observer is placed close to the margins of the ice sheet. Less serious discrepancies should be found on the geophysical observables of large wavelength, such as the Stokes coefficients of low harmonic degree. The use of discs allows for significant savings of execution time, as the user can easily verify. When the elements of the aggregate are of type `CL`=50 (rectangles on the sphere), `TABOO` stores the spectral coefficients of each load on an auxiliary unformatted file called coeff.tmp. The maximum size of this file is $\sim$ 40 mb. The limitations of the Alpha server on which `TABOO` has been first developed has forced us to employ file coeff.tmp since the early steps of work. If the size of coeff.tmp may constitute a problem, the User can modify the code so that to keep all the needed coefficients in memory instead of using disk space. For disc models such as ICE3 (or for the converted ICE1 and ICE2 models), this file is not created by `TABOO`.

- `F7T8 TAU`. Setting the switch `F7T8` [INTEGER=0/1] to 1, the user can change the time-history of the ice aggregates ICE1, ICE2, or ICE3 from type `LH` = 7 ("piecewise constant") to type `LH` = 8 ("piecewise constant with loading phase"). The switch must be followed by the parameter `TAU` [REAL > 0], which represents the length of the loading phase which comes before the PCP of time-history `LH`=8 (see §3.2.3), in units of kyrs. The `TAU` parameter is ignored if `F7T8` = 0. We remark that the choice `F7T8` = 1 is not affect in any way the geometrical features of the ice elements, but only their time–history.

- `Scale` [REAL] is a scaling factor which allows to magnify or to reduce the thickness of *all of the elements* which compose the aggregate. The range of `Scale` is [0.01:100.0].

- `KS` [INTEGER] is the number of sub–aggregates of ICEk that the user wants to include in his simulation. The range of `KS` is [1:3] for ICE1 and ICE2, and [1:9] for ICE3 (see below and Appendix A).

- `Sub_n (n=1,2,...KS)` [CHARACTER*8] are the names of the sub–aggregates to be included in the ICEk model. The list of available sub–aggregates is given in Appendix A. Here we only mention that if the whole ICEk ice model is to be employed, the user must supply `KS`=1 (see above) and `sub_1` = ice$k$.dat.

4.3 Local analyses

In order to schedule a study of local type the User must configure the kw `Local_Study`. The instructions for this kw follow largely those already given for task#2 (see §3.3). There are however differences, that are discussed when necessary in this chapter, and a totally new kind of analysis that allow to compute the rates of deformations of baselines connecting two sites on the Earth surface.

It should be recalled that for the analyses of task#3, time is meant as 'time before present' (BP). Thus, time is positive if it refers to a past event, and negative if it refers to a future event. This time convention differs from that for task#2 (§3.2.3), where the origin of time is defined by a conventionally chosen feature of the time history of the (unique) surface load. From §3.3, we recall that the general format of kw `Local_Study` is

```
...
...
Local_Study
IS
p_1
p_2
...
...
...
p_n
...
...
```

where the integer parameter `IS`, which identifies the particular kind of local study to be performed, varies in the range [1:4] (in task#2 the range is [1:5]), and with `p_k` are parameters of `Local_Study`. According to the value of `IS`, `TABOO` can be programmed to perform the local investigations which follow.

`IS = 1`: "One observer, various times"

This type of analysis allows to compute a given local quantity at a point (observer) P on the Earth's surface for times ranging in a prescribed interval. The configuration of the parameters for `IS`=1 follows almost exactly the scheme that we have described for task#2. One difference is that now the time variable is to be referred to the present time, so that 'time' is 'time BP' (Before Present). Another difference is that the `Isub` switch is not available here (see §3.3). The default names of the output files are the same as in task#2, i. e., disp.his and rate.his. Their format is described in detail in Appendix B.

The full set of parameters for `IS=1` has the form:

```
Local_Study
1
IR IT IG DIR DIT DIG
LON COL
T1 T2 DTI
```

where the meaning of `IR, IT, IG, DIR, DIT, DIG, LON, COL` has been explained in §3.3.2, and

- `T1 T2 DTI` [REAL] are the time parameters for this analysis, in units of kyrs. `T1` and `T2` are times BP, with `T1` < `T2`, and `DTI` > 0. Negative values of `T1` (or `T2`) indicate future times.

`IS = 2`: "More observers, various times"

Setting `IS`=2 the User can compute a local variable on a set of points for times ranging in a prescribed interval. The configuration follows almost exactly that for `IS`=2 in task#2 (see §3.3.2 for the instructions). The two only differences are that here 'time' is meant as 'time BP', and that the `Isub` switch of task#2 is not available here. The default names of the output files are the same as in task#2, i. e., disp.his and rate.his (see Appendix B). The full set of parameters for `IS`=2 has the form

```
Local_Study
2
IR IT IG DIR DIT DIG
Filename
T1 T2 DTI
```

where the meaning of `IR, IT, IG, DIR, DIT, DIG, Filename` is explained in §3.3.2, and the time parameters `T1, T2, DTI` have the same meaning as for `IS`=1 (see above). A sample of `Filename` is included in the taboo.zip archive with name sparsi.dat.

`IS = 3`: **"On a map"**

With `IS`=3, it is possible to compute local variables on a set of points (observers) evenly distributed on a specified rectangular portion of the Earth surface. The use is almost identical to that of `IS`=5 for task#2 (§3.3.2) to which the User is referred for detailed instructions. The differences are that here 'time' is meant as 'time BP', the `Isub` switch of task#2 is no more available, and that with `IS`=3 is now possible to prepare a map of the primary ice thickness. The local variables computed for `IS`=3 are written on the same default files of task#2, i. e., A_geo.dat, A_lat.dat, A_lon.dat, A_rad.dat, Ad_geo.dat, Ad_lat.dat, Ad_lon.dat, Ad_rad.dat. The default output file for the ice thickness is named load_thick.dat (see Appendix B).

For `IS`=3, the kw must be configured as follows:

```
Local_Study
3
IR IT IG DIR DIT DIG
L1 L2 EPL
C1 C2 EPC
GIVEN_TIME
I_THI
```

where the meaning of `IR, IT, IG, DIR, DIT, DIG, L1, L2, EPL, C1, C2, EPC` has been explained in §3.3.2, and

- `GIVEN_TIME` represents the time BP at which the local variables are to be computed (kyrs).
- `I_THI` [INTEGER=0/1] is a switch that, if set to 1, allows to produce a map of the thickness of the primary load. It can be activated only in the case that the load is *not* compensated on a realistic ocean (`IOC`=0 in kw `Ice_k`, see §3.3.2).

`IS = 4`: **"Baselines rates at a given time"**

This analysis concerns the rates of deformation of the baseline connecting two sites on the Earth surface. The rates are projected along the conventional

VLBI components L, T, and V. The User is referred to the Theory Document of `TABOO` for details on how the L, T, and V rates are defined. The default output file for the current type of analysis is ltv_rates.dat (Appendix B).

The user must supply the following records:

```
Local_Study
4
Filename
GIVEN_TIME
```

where:

- `Filename` [CHARACTER*30] is the user–supplied file containing information on the sites connecting the various baselines. The admissible baselines must be at least 1000.0 m long. `Filename` may take two different forms:

  1. If code '1' is found in the first line, the lines which follow contain the names of the two sites of the couple, in the form: site#1 site#2 where site#1 and site#2 are names of the two sites. They must be given as two CHARACTER*8 constants aligned left and separated by two blank characters (the format is '(A8,2X,A8)'). A maximum of 300 couples of sites can be given, the extra couples are simply ignored. A sample of valid input file is included in the taboo.zip archive, with name nomi_siti.dat. The names of the sites (e.g., ALGOPARK, RICHMOND, BREST...) are listed in the file site_locations.2001cn.1 which has been downloaded from the web site of the Goddard Geodetic VLBI Group[2] and is also contained in the archive taboo.zip. TABOO reads the two character constants, copies from the NASA file the coordinates of the two sites, and performs a transformation from the original DMS to the decimal form. These coordinates are used to compute the L, T, and V components of the velocity of site#2 w.r.t. site#1 at the time `GIVEN_TIME` provided by the user (see below).

[2]NASA Goddard Space Flight Center VLBI Group, 1999. Data products available electronically at `http://lupus.gsfc.nasa.gov/vlbi.html`.

2. If the code '2' is found in the first line of the user- supplied file `Filename`, those which follow contain the coordinates expressed in degrees (decimal form). The coordinates are `LONG_1, COLA_1, LONG_2, COLA_2`, where `1` and `2` refer to the sites, and `LONG` and `COLA` stand for longitude and colatitude, respectively (these coordinates of course need not to be those of a real VLBI or GPS antenna). A sample of valid input file is included in the taboo.zip archive, with name site_couples.dat. The coordinates of the two sites, which can be given in free format, are used to compute the L, T, and V components of the velocity of site#2 w.r.t. site#1 at the time `GIVEN_TIME` provided by the user (see below). A maximum of 300 couples of sites can be given (the extra couples are simply ignored).

- `GIVEN_TIME` [REAL] represents the time BP (kyrs) at which the baselines rates are to be computed.

4.4 Global analyses

By means of `Global_Study`, `TABOO` can be programmed to compute global variables. Two types of studies are available, which have a direct counterpart in task#2. These two types are briefly described here. The User is referred to §3.4 for the details of the kw configuration. We start recalling that the general format of kw `Global_Study` is

```
...
...
Global_Study
ES
p_1
p_2
...
...
...
p_n
...
...
```

where the integer `ES`, which identifies the particular kind of global study to be performed, varies in the range [1:2] (in task#2 the range was [1:3]), and where `p_k` are parameters of `Global_Study`. According to the value of `ES`, it is possible to perform the following local investigations.

`ES = 1`: "Stokes coefficient vs. time"

This analysis allows to compute the variations of the Stokes coefficients of a given degree and order and their time derivatives as a function of time. The scheme is virtually identically to that of `ES`=1 for task#2 (§3.4.2), but in task#3, 'time' is meant as 'time BP'. The default names of the output files (i.e., stokes.dat and stoked.dat), are also the same as in task#2 (Appendix B).

The kw must be configured as follows:

```
Global_Study
1
L M
Inorm
T1 T2 DTI
...
...
```

where

- `L M` [INTEGER] are the harmonic degree and order of the Stokes coefficient, and `Inorm` allow to specify the type of normalization (see §3.4.2 for details).

- `T1 T2 DTI` [REAL] are the time parameters for this analysis, in units of kyrs. `T1` and `T2` are times BP, with `T1` < `T2`, and `DTI` > 0. Negative vales of `T1` (or `T2`) indicate future times.

`ES = 2`: "Inertia tensor vs. time"

With `ES`=2 it is possible to compute the changes of the Earth inertia tensor and their time–derivatives as a function of time. This study is essentially the same as for `ES` =3 of task#2 (see §3.4.2), but notice that here 'time' is meant as 'time BP'. The default names of the output files (i.e., iner.dat, ined.dat, and load_mass.dat), are the same as in task#2 (Appendix B). The kw must be configured as follows:

```
Global_Study
2
T1 T2 DTI
...
...
```

where `T1 T2 DTI` have the same meaning as for `ES`=1 (see above).

4.5 Two worked examples for task#3

In this section we give two examples on how to configure the task#3 of `TABOO` to compute the response of the Earth to an aggregate of ice loads. The explicit output files are made available in the taboo.zip archive to allow comparisons between what is presented here and what anyone can obtain running `TABOO` on his own computer. The geophysical relevance of the numerical results obtained in the following examples if not of concern here.

4.5.1 Example #1 (Laurentide, Fennoscandia, and Antarctica)

In this example we consider the three largest Holocene ice–sheets with the purpose of computing a global map of all of the geophysical variables that can be obtained `TABOO`. The ice loads parameters given in the following are not perfectly representative for the actual Laurentide, Fennoscandia, and Antarctica ice aggregates, since our purpose here is simply to show how to configure the input files. We decide to perform our computations at the largest spatial resolution allowed by `TABOO`, to use the verbose execution mode, to account for the viscous component of the Maxwell rheology, and to exclude from the analysis the 'non–physical' modes which may arise. We thus activate file task_3.dat and we configure kw `Harmonic_Degrees` as follows:

```
Active

Harmonic_Degrees
2 128
1
```

```
0
1
```

We employ the model by Yuen, Sabadini and Boschi (1982) (`NV`=1, `CODE`=1) (see Appendix D). The lithosphere has a thickness of 100 km, and the uniform mantle is characterized by a viscosity of 10^{21} Pa.s:

```
Make_Model
1
1
100.0
0
1.
```

The description of the three loads acting in this example is given in the user–supplied file complex_e31.dat:

```
Ad_Hoc
complex_e31.dat
```

File complex_e31.dat is contained in the archive taboo.zip, but it is also reported here to better discuss its features:

```
3
10 0 4
270.0 25.0 15.0
2000.0
18.0 90.0 10.0 3
20 0 4
20.0 25.0 8.0
1000.0
18.0 90.0 10.0 2
10 0 3
0.0 180.0 20.0
700.0
18.0 12.0
```

In words, the above list of parameters describes the three loads as follows:

1. The Laurentide ice load is described as a disc load (CL=10) with no ocean loading (IOC=0). Its evolution follows a saw–tooth time–history (LH=4), its center is placed at longitude 270.0 deg and colatitude 25.0 deg, the half–amplitude of the load is 15.0 deg, and the maximum load thickness is of 2000.0 m. The last glacial maximum occurred 18.0 kyrs BP. The length of the loading and unloading phases during the load history were of 90.0 and 10.0 kyrs, respectively. The number of (loading + unloading) phases in addition to the most recent is 3.

2. The Fennoscandia ice load is modeled as a load with parabolic profile (CL=20) with center at longitude 20.0 deg and colatitude 25.0 deg. The time–history is the same as for the Laurentian, but here we consider only 2 (loading + unloading) phases in addition to the most recent. The half– amplitude of the load is 8.0 deg, and its maximum thickness is of 1000.0 m. As for the Laurentide, the last glacial maximum is placed at 18 kyrs BP.

3. Antarctica has followed an hypothetical time–history of type LH=3 ("simple deglaciation"), in which the ice melting begun 18.0 kyrs BP and lasted for 12.0 kyrs. The disc load which mimics Antarctica, exactly centered at the South pole, has an half–amplitude of 20.0 deg and a maximum thickness of 700.0 m.

Our intention is to perform a local study of all of the physical variables on a map with resolution $2^\circ \times 2^\circ$ and to compute these variables at time 0 BP. We do not need a map of the ice thickness. We thus configure Local_Study as follows:

```
Local_Study
3
1 1 1 1 1 1 1
1.0 359.0 2.0
1.0 179.0 2.0
0.0
0
```

After execution, the user can access the files taboo.log, A_rad.dat, A_lon.dat, A_lat.dat, A_geo.dat, Ad_rad.dat, Ad_lon.dat, Ad_lat.dat, and Ad_geo.dat which contain the eight maps required (see Appendix B for a description of their format). In the archive taboo.zip, we have placed the outputs of the current example so that the user can check the consistency between ours and his own results. The archive files corresponding to those above are taboo_e31.log, A_rad_e31.dat, A_lon_e31.dat, A_lat_e31.dat, A_geo_e31.dat, Ad_rad_e31.dat, Ad_lon_e31.dat, Ad_lat_e31.dat, and Ad_geo_e31.dat.

A variant of Example #1

As a variant of the above example, we consider the case in which the three loads are compensated on a ocean with realistic shape. The only required modification concerns the user–supplied filename (which is now called complex_e31v.dat), in which the `IOC` parameter is now set to 1:

```
3
10 1 4
270.0 25.0 15.0
2000.0
18.0 90.0 10.0 3
20 1 4
20.0 25.0 8.0
1000.0
18.0 90.0 10.0 2
10 1 3
0.0 180.0 20.0
700.0
18.0 12.0
```

The file taboo.zip contains both complex_e31v.dat and the output files of this variant of Example#1, with names taboo_e31v.log, A_rad_e31v.dat, A_lon_e31v.dat, A_lat_e31v.dat, A_geo_e31v.dat, Ad_rad_e31.dat, Ad_lon_e31v.dat, Ad_lat_e31v.dat, and Ad_geo_e31v.dat.

4.5.2 Example #2 (working with the ICEk aggregates)

In this second example we illustrate how to use the ICEk ice aggregates taken from the literature (see the introductory notes to Chapter 4). We consider a bunch of variants of a main problem to show how the ice load affects the numerical results obtained.

In our main example, the kws of task#3 are configured as follows:

```
Active


Harmonic_Degrees
2 72
1
0
1


Make_Model
3
2
120.0
0
2.
1.
1.


Ice_3
1
0
0 100.
1.0
1
ice3.dat


Local_Study
1
```

```
1 1 1 1 1 1
12.2 45.8
0.0 0.0 0.1
```

With the above kws and parameters, the problem consists in the computation of the TABOO geophysical variables at time 0 BP at the point with longitude 12.2 deg and colatitude 45.8 deg (these coordinates correspond to the town of Ravenna, northern Italy), assuming the deglaciation model ICE3G. We use a truncation degree of 72, and the Cianetti et al. (2002) model with a viscosity of 2.0 in the lower mantle and 1.0 both in the transition zone and in the shallow upper mantle (see Appendix D). The ice elements of the aggregate ICE3G are compensated on a realistic ocean.

After execution, the user should verify that the TABOO default output files disp.his, rate.his, and taboo.log are identical to those that we have obtained running this example, which are named disp_e32.his, rate_e32.his, and taboo_e32.log in the taboo.zip archive.

Variants of Example #2

In the *first variant* of Example#2 we modify ICE3G substituting the loading phase of infinite length which is the default for this ice aggregate with a 100 kyrs long finite loading phase. We therefore only modify the part concerning the kw Ice_3 as follows:

```
Ice_3
1
0
1 100.
1.0
1
ice3.dat
```

The output files corresponding to this computation are disp_e32v1.his, rate_e32v1.his in archive taboo.zip. As the user can notice, the differences with respect to the case of an infinitely long loading phase are not negligible, after all.

In the next example, which constitutes the *second variant* of Example#2, we turn our attention to the ocean loading. We repeat Example_2 but imposing no compensation on a realistic ocean. Mass conservation is thus explicitely violated. To this purpose, we configure the kw `Ice_3` as follows:

```
Ice_3
0
0
0 100.
1.0
1
ice3.dat
```

The user can judge the role played by mass conservation comparing the output files of this case (i.e., disp_e32v2.his, rate_e32v2.his) with those originally obtained imposing mass conservation (disp_e32.his and rate_e32.his).

As a final case study, in the *third variant* of this example, we substitute the ICE3G ice chronology with that of ICE1:

```
Ice_1
0
0
0 100.
1.0
1
ice1.dat
```

The two files disp_e32v3.his and rate_e32v3.his contain the results for this last computation. The ice load makes a difference, as one can realize by a comparison with the previous variant of Example_2.

Chapter 5

Appendices

5.1 Appendix A: TABOO input files

In addition to the three input files task_*.dat, which represent the interface between TABOO and the users, the program needs also other input files. All of them are contained in the archive taboo.zip. For a normal functioning of TABOO these files need not to be manipulated nor modified.

Here we give a list of all of the TABOO input files and a short description of their content. The taboo.zip archive also includes samples of user–supplied files that must be given to execute certain tasks, and the output files for the TABOO examples given in this manual (see §2.5, 3.5, and 4.5). The numbers in parentheses given for each filename indicate the tasks which make use of that file. The files are listed in alphabetical order.

- **ice1.dat** (3). This file contains the complete ICE1 deglaciation model by Andrews and Peltier (GJRAS, *46*, 605–646, 1976). The data are taken directly by their paper. ICE1 is discretized in 153 simple ice elements of type CL=50 of size $5° \times 5°$ (§2.2.1) and with time history of type TH=7 with DELTA = 2 kyr (§2.2.3).

- **ice1.eup, ice1.gro, ice1.nam** (3). These input files contain ice1.dat subparts. They correspond to the European ice aggregate (.eup, 38 elements), to Greenland (.gro, 26), and to the North America aggregate (.nam, 89).

- **ice2.dat** (3). This file contains the ICE2 deglaciation model of Wu and Peltier (GJRAS, *74*, 377–449, 1983). The Antarctic component of ICE2 *is not* included. Model ICE2 is discretized in 154 simple ice elements of type `CL`=50 of size $5° \times 5°$ (§3.2.1), and with time history of type `TH`=7 with time steps of `DELTAT` = 2 kyrs (§3.2.3).

- **ice2.eup, ice2.gro, ice2.nam** (3). These are the available subcomponents of ice2.dat. They correspond to the European ice aggregate (.eup, 38 elements), to that of Greenland (.gro, 26 elements), and to North America (.nam, 90 elements).

- **ice3.dat** (3). This file contains the complete ICE3G deglaciation model of Tushingham and Peltier (JGR, *96*, 4497–4523, 1991) which also includes an Antarctic component. ICE3 is discretized in 808 elementary ice elements of type `CL`=10 with various half–amplitudes (see §3.2.1) and with time history of type `TH`=7 with `DELTAT` = 1 kyr (§3.2.2 and 3.2.3).

- **ice3.and, ice3.ant, ice3.bal, ice3.bri, ice3.gro, ice3.ike, ice3.nam, ice3.pol, ice3.sib** (3). These are the 9 subparts of model ICE3G. They represents the ice loads of the Andes (.and, 10 elements), Antarctica (.ant, 174), the Baltic region (.bal, 49), British Isles (.bri, 3), Greenland (.gro, 125), Iceand (.ike, 4), North America (.nam, 235), the region to the East of the Baltic, including the Barents Sea (.pol, 173), and Siberia (.sib, 35).

- **external_spectrum.dat, external_h.dat, external_l.dat** (1, 2, 3). These files contain the relaxation spectrum and the ldcs h and l in the range of degrees [2:128] for the non–self–gravitating model by Giunchi and Spada (GRL, *27*, 2065–2068, 2000). It is employed by `TABOO` if the kw `External_Model` is found to be active in task_*.dat (see §2.2.2).

- **nomi_siti.dat** (3). This file is a sample of the user supplied file that must be given to configure the kw `Local_Study` with `IS`=4 in task#3. The format of this file is the first of the two possible formats available (see §4.3).

- **oceano.128** (2, 3). File oceano.128 contains the harmonic coefficients of the ocean function at degree and order 128. The coefficients, which are written on the base of the real spherical harmonics, are read by subroutine READ_OCEAN with format '(2(1X,I3),2(1X,E14.8))'.

- **prem200.dat, prem1.dat** (1, 2, 3). File prem200.dat is employed by subroutine prem of TABOO to compute PREM[1]–averaged values of the layers density and shear moduli. This file contains the PREM values at the reference period of 200 s. The User can use prem1.dat (at the reference period of 1 s) instead of prem200.dat by simply modifying the subroutine PREM of taboo.f90. Files prem1.dat and prem200.dat, as well as subroutine PREM were provided to us by Bert Vermeersen some years ago.

- **site_locations.2001cn.1** (3). This file contains the coordinates and names of VLBI stations worldwide. Its origin and format is explained in §4.3.

- **sites_couples.dat** (3). This file is a sample of the user supplied file that must be given to configure the kw `Local_Study` with `IS`=4 in task#3. The format of this file is the second of the two possible formats available (see §4.3).

- **sparsi.dat** (2, 3) This is a sample of the user–supplied file that must be given to execute a local analysis with `IS`=1 in task#2 or in task#3 (see §3.3.1 and 4.3).

- **timeh_6.dat, timeh_7.dat, timeh_8.dat** (3). These are the files that the user must provide to configure the kw `Load_History` for `LH` =6, 7, or 8. Samples of these files are contained in the taboo.zip archive.

5.2 Appendix B: TABOO output files

After a succesfull execution of any of the tasks of TABOO, the User can access the output files in the same directory where it has been installed. All of the output files are in plain text format. Here we summarize the names and the content of each of them, also giving instructions on how to obtain these output files and on their format.

A_rad.dat, A_lon.dat, A_lat.dat, A_geo.dat, Ad_rad.dat, Ad_lon.dat, Ad_lat.dat, Ad_geo.dat

General description. These are the default names for the files containing maps of local variables on the sphere (but see also the description

[1]A. M. Dziewonski and D. L. Anderson, PEPI, *25*, 297–356, 1981.

of file load_thick.dat given below). All of the files are in the 3–columns format '(3(1X,F14.5))'. An header shows the creation date and time and the time at which the local variables have been computed. The first column is longitude (in degrees), the second is *latitude*, and the third is the desired geophysical quantity. This format is suitable for the use of GMT. The labels "rad", "lon", and "lat" refer to the radial, longitudinal, latitudinal components of displacement, while "geo" refers to the geoid height. The letter "d" in some file names indicates that the corresponding quantity is derived with respect to time. Units are m (meters) for the displacement components and for the geoid height, and mm/yr for the derived quantities.

task#1: N/A.

task#2: The map files are created if the User has set the parameter `IS`=5 in the kw `Local_Study`. For loads of type `CL` $\neq$ 40, the header shows the mass of the primary load at the chosen time. If `CL`=40, the mass/surface at the load pole is reported.

task#3: The map files are created if the User has set the parameter `IS`=3 in the kw `Local_Study` of this task. The header shows the mass of the primary load at the time (BP) to which the file refers.

coeff.tmp

General description. This file is used by `TABOO` to store the harmonic coefficients of surface loads of type `CL`=50.

task#1 and #2: N/A.

task#3: See the description of parameter `FRTD` (§4.2.3).

disp.his, rate.his

General description. The files disp.his and rate.his contain the time-*his*tories of local variables and of their time–derivatives. The two files are composed of as many blocks as the number of observers. Within each block, the first two rows report the longitude and colatitude of the observer (in degrees). The rest of the data are in the 6–columns format '(5(1X,F9.4),1X,E14.5)'. The first five columns of disp.his contain: time (kyrs), the radial displacement (m), the component of the displacement along colatitude (m), the component of the displacement along longitude (m), and the the geoid height (m). In rate.his, the first five columns contain the time-derivatives of the quantities reported in disp.his, in units of mm/yr. The content of the sixth column of disp.his and rate.his depends on the current task (see below).

task#1: N/A.

task#2: Files disp.his and rate.his are made available setting `IS`=1 or `IS`=2 in kw `Local_Study` of task#2 (see §3.3.2). To make file disp.his (rate.his) available, at least one among `IR (DIR), IT (DIT)`, or `IG (DIG)` must be set to 1. The sixth column of disp.his and rate.his gives the mass of the primary load (kg) *or* the mass/surface at the load pole if an harmonic load of type `CL`=40 has been selected. If one among `IR, IT, IG (DIR, DIT, DIG)` is set to 0, the corresponding column in disp.his (rate.his) is filled by zeroes too.

task#3: Files disp.his and rate.his for task#3 are also made available setting `IS`=1 or `IS`=2 in kw `Local_Study` (see §3.3.2 and 4.3). The only difference with respect to task#2 is the sixth column, which always contains the mass of the primary load (the type of load `CL`=40 is not allowed in task#3).

disp.pro, rate.pro

General description. The files disp.pro and rate.pro contain spatial *pro*files of local variables at a given time. An header shows the date and time of creation of the files, the time at which the variables are computed (kyrs), the longitude of the meridian (or alternatively the colatitude of the parallel), and the mass of the primary load at the time chosen by the user for the local study. The body of the files is in the 6-columns format '(6(1X,F9.4))'. For an analysis along a meridian, the first columns of disp.pro and rate.pro contain the colatitude of the observers, in degrees. For a study along a parallel the first column reports the longitude. The four last columns of disp.pro contain the radial displacement, the component of the displacement along colatitude, the component of the displacement along longitude, and the geoid height (all in units of m). In file rate.pro, the four last columns report the time–derivatives of the corresponding variables of disp.pro, in units of mm/yr.

task#1: N/A

task#2: Files disp.pro (rate.pro) are created setting `IS` = 3 (4) in kw `Local_Study` of task#2 (§3.3.2). To make file disp.pro (rate.pro) available, at least one of the switches `IR (DIR), IT (DIT)`, or `IG (DIG)` must be set to 1. If one among `IR, IT, IG, (DIR, DIT, DIG)` is set to 0, the corresponding column in disp.pro (rate.pro) is filled by zeroes too.

task#3: N/A

h.dat, l.dat, k.dat

General description. The files h.dat, l.dat, k.dat contain the h, l, and k ldcs (or tLns), respectively. Files h.dat, l.dat, and k.dat have the multi–column format '((I3,1X,96(1X,E20.8)))', with column #1: Harmonic degree, column #2: Elastic ldc (tLn), column #3: Fluid ldc, column #4 to column #4+NR-1: Viscoelastic ldc (tLn), where NR is the number of viscoelastic modes. An header helps to identify the origin and the nature (loading or tidal) of the data.

task#1: In task#1, files h.dat, l.dat, and k.dat are created when the kw `El_Fluid_Viscel` is active (§2.4.2). If `External_Model` is active, the k.dat file is not created, independently from the status of the switch `i_loading` of kw `Harmonic_Degrees`, and none among h.dat, l.dat, and k.dat are created if `i_loading` = 0 (§2.2.2 and 2.4.2).

task#2 and #3: For these tasks the files h.dat, l.dat, and k.dat are created whenever the kw `Harmonic_Degrees` is found to be active. However, if `External_Model` is also active, file k.dat will not be available. If the user has set `only_elastic`=1 in kw `Harmonic_Degrees`, the form of files h.dat, l.dat, and k.dat will be in a simpler two–columns format, due to the absence of the viscoelastic modes.

h_heav.dat, l_heav.dat, k_heav.dat

General description. These files report the time–evolution of the ldcs (tLns) in the case of a point mass characterized by an Heaviside time–history. Each file is composed by two– column segments, where each segment refers to a specific value of the harmonic degree among those chosen. The three columns of each segment report the value of the harmonic degree, time (in kyrs) and the ldcs or the tLns (non- dimensional). For each line, the format is '(I4,1X,2(E15.7,1X))'. An header helps to identify the origin and the nature (loading or tidal) of the file content.

task#1: In order to create files h_heav.dat, l_heav.dat, and k_heav.dat, the kw `Heaviside_th` needs to be active in task#1 of `TABOO`. In the case kw `External_Model` is active, file k_heav.dat is not created independently from the status of parameter `i_loading` of kw `Harmonic_Degrees`, and none among h_heav.dat, l_heav.dat, and k_heav.dat is created for `i_loading` = 0 (§2.2.2 and 2.4.3).

task#2 and #3: N/A.

ih.dat, il.dat, ik.dat

General description. These files are used by `TABOO` to report the normalized viscoelastic residues $-h_i/s_i, -l_i/s_i, -k_i/s_i$. Each of them is composed by two– column segments. Within each segment the harmonic degree l is constant, and each row reports l and the corresponding normalized residue. Each segment has thus NR lines, where NR is the number of viscoelastic modes. For each line, the format is '(2(E15.7,1X))'. An header helps to identify the origin and the nature (loading or tidal) of the data.

task#1: The creation of files ih.dat, il.dat, ik.dat is only possible via the activation of kw `Normalized_Residues` (§2.4.1). If the kw `External_Model` is active, file ik.dat is not created independently from the status of the parameter `i_loading` of kw `Harmonic_Degrees`, and none among ih.dat, il.dat, ik.dat is created if `i_loading` = 0 (§2.2.2 and 2.4.1).

task#2 and #3: N/A.

iner.his, ined.his

General description. Files iner.his and ined.his contain the time-history of the change of the inertia tensor and of its time-derivative. Time (in kyrs) is given in column #1 of both files. In iner.his, the six columns which follow contain the xz, yz, zz, xy, yy, and xx components of the inertia tensor variation, normalized by MR**2, where M is the

Earth mass and R its radius. The values given in file ined.his are to be multiplied by the same factor to obtain the rates of change of the inertia tensor in units of kg*m**2/yr. For both files, the format is '(F9.4,2X,7(E12.5,1X))'.

task#1: N/A.

task#2: In task#2 the two files iner.his and ined.his are created if `ES`=3 is set in kw `Global_Study` (see §3.4).

task#3: The files iner.his and ined.his are created if `ES`=2 is set in kw `Global_Study`. Time (column #1) is time BP.

load_coeff.dat

General description. This multi–column file contains the harmonic coefficients of the load function (see the TD) as a function of degree (for axis-symmetric loads) or as a function of degree and order (for non–axisymmetric loads). If `CL`=10, 20, or 50, the coefficients are those of the primary load, regardless of the value of `IOC`. If `CL`=11 or 21 a secondary load is included, and the coefficients account for it. The coefficients are always given in units of kg/m**2. A short header gives information on the kind of primary load in use (see §3.2.1).

task#1: N/A.

task#2: In order to create load_coeff.dat the User must configure the kw `Load_Geometry` (§3.2.1).

task#3: N/A.

load_mass.dat

General description. This file contains the mass of the (primary) load as a function of time in the two-columns format '(2X,F9.4,1X,E20.8)'. The mass is given in units of kg.

task#1: N/A.

task#2: File load_mass.dat is made available by default when the user selects `ES`=3 for kw `Global_Study` (§3.4) and `CL` is $\neq$ 40 in kw `Load_Geometry` (§3.2.1).

task#3: In order to create load_mass.dat, the User must set `ES`=2 in kw `Global_Study` (see §4.4).

load_pole.dat

General description. This file contains the mass/surface at the pole of the load as a function of time in the two-columns format '(2X,F9.4,1X,E20.8)'. The mass/surface is given in units of kg/m**2, time is in units of kyrs.

task#1: N/A.

task#2: File load_pole.dat is made available by default when the user selects `ES`=3 for kw `Global_Study` (§3.4) and `CL` is = 40 in kw `Load_Geometry` (§3.2.1).

task#3: N/A.

load_thick.dat

General description. This file contains a map of the primary load thickness. Its format follows that already described for the map files A*.dat (see the first entry of this list of files). The load thickness is given in units of m.

task#1 and #2: N/A.

task#3: The file is only created if the User has set the parameter `IS`=3 in the kw `Local_Study` of this task (§4.3.2). An header shows the mass of the primary load (kg) at the time (BP) to which the data refer.

ltv_rates.dat

General description. This file contains the `TABOO` output for the L, T, and V components of the baselines rates of deformation (mm/yr), as well as the coordinates of the couples of sites for each baseline. The format of this file is '(2(A9,1X,2(F6.2)),3(F6.2))'.

task#1 and #2: N/A.

task#3: In order to create file ltv_rates.dat, the user must set `IS`=4 in `Local_Study` of task#3 (§4.3).

spectrum.dat

General description. File spectrum.dat contains the relaxation spectrum of the Earth model in a 6–columns format. An header explains the meaning of each column, as follows. 1st column: l = Harmonic degree, 2nd column = LOG10 (l), 3rd column: s (kyrs**(-1)), 4th column: LOG10(-s) (with s in kyrs**(-1)), 5th column: Relaxation time = -1000.0/s (yrs), and 6th column: LOG10 (Relaxation time (yrs)), where with s we indicate one of the roots of the secular polynomial at harmonic degree l. The header is followed by a file segment for each harmonic degree, from `l_min` to `l_max`. Each segment is composed by NR lines with format '(I4,1X,5(E15.7,1X))', where NR is the number of viscoelastic modes. An explicit example is given in (§2.5). See also §3.5.1.

task#1: File spectrum.dat is created if `Make_Model` (`External_Model`) are found to be active.

task#2 and #3: For these tasks, spectrum.dat is only made available if `Make_Model` (`External _Model`) are active, provided that `only _elastic`=0 in kw `Harmonic_Degrees`.

stokes.his, stoked.his

General description. These files are used to record the change of the Stokes coefficients and their time–derivatives as a function of time. An header shows the date and time, the current harmonic degree and order, and the kind of normalization adopted. The body of these files is in the four columns format '(F9.4,3(E14.5))'. The first column reports time in kyrs, the second and third report the (non-dimensional) changes in the cosine and sine Stokes coefficients multiplied by the factor 1.E6. In stoked.his, the time- derivatives of the changes in the Stokes coefficients in units of yr**(-1) can be obtained by dividing the second and third column by the factor 1.E11.

task#1: N/A.

task#2: The `Global_Study` kw must be configured with `ES`=1 to create the files stokes.his and stoked.his (§3.4.2). For loads of type `CL` $\neq$ 40 the fourth column of both files shows the mass of the (primary) load in units of kg as a function of time. If CL=40, the quantity shown is the mass/surface at the load pole in units of kg/m**2.

task#3: The files are created if ES=1 in kw Global_Study (see §4.4). The fourth column of the files shows the mass of the primary load (kg) as a function of time (kyrs).

stokes.pro, stoked.pro

General description. These files report the cosine and sine Stokes coefficients for a suite of harmonic degrees at a given time. An header shows the current time value and the kind of normalization. Both files, with format '(I4,1X,2(1X,I3),2(E14.5))', report indx(l,m), l, and m in their first three columns (indx(l,m) is defined as l*(l+1)/2+m+1, where l and m are the degree and the order, respectively). In stokes.pro, the fourth and fifth columns represent the (non-dimensional) changes in the cosine and sine Stokes coefficients multiplied by the factor 1.E6. In stoked.pro, the time- derivatives of the changes in the Stokes coefficients in units of yr**(-1) can be obtained by dividing the fourth and fifth column by the factor 1.E11.

task#1: N/A.

task#2: The files stokes.pro and stoked.pro are created if Global_Study is configured with ES=2 in task#2 (§3.4.2).

task#3: N/A.

taboo.log

General description. This file contains a summary of the configurations of the TABOO tasks and of all of the major events occurred during execution. It also reports warning and error conditions, with a brief explanation of their causes. In some cases, the CPU time required for the computations is also reported. This file is written for *any* of the three TABOO tasks. If the verbose mode has been selected (see §2.1.1, 3.1.1, and 4.1) some of the messages reported on taboo.log are also directed on the monitor.

5.3 Appendix C: TABOO SUBROUTINES and FUNCTIONS

We give here a synthetic description of the work done by each of the TABOO subprograms. More detailed comments are written in the source code. In the following NR stands for Numerical Recipes (see footnote to page 10). The list is in alphabetical order.

FUNCTION subprograms

- CHEB: Chebichev polynomials of the 1st kind.
- DED: Determinant of a 2x2 table.
- d_Load_History : Derivative of the load history wrt time.
- FUNCP: Function $-P_{lm}(x)$.
- GPROD: Computes $(l-m)!/(l+m)!$, l=degree, m=order.
- INDX: Gives $l*(l+1)/2+m+1$, l=degree, m=order.
- LEG: REAL*8 version of the routine PLGNDR by NR.
- LEGDEV1: REAL*8 derivative of $P_{lm}(\cos\theta)$ wrt θ.
- Load_History : Load time–history at a given time.
- th_0: Time-history #0
- th_1: Time-history #1
- th_2: Time-history #2
- th_3: Time-history #3
- th_4: Time-history #4
- th_5: Time-history #5
- th_6: Time-history #6
- th_7: Time-history #7
- th_8: Time-history #8

SUBROUTINE subprograms

- AXIS_DISP0: Displacements, geoid, and their rates at a point (axis–symmetric load)
- AXIS_INER: Inertia tensor for an axis–symmetric load
- AXIS_LOAD: Harmonic coefficients of an axis–symmetric load
- AXIS_STOK: Stokes coefficients for an axis–symmetric load
- AXIS_Pressure : Load (kg/m**2) at a point (axis–symmetric load)
- balanc: Dependency of zrhqr (adapted from NR)
- BASE_RATES: Provides the L, T, and V rates of site#2 wrt site#1
- bf: Surface boundary conditions
- change_time: Changes from local time to time BP
- convol_0_new: Convolution for time-history #0
- convol_1_new: Convolution for time-history #1
- convol_2_new: Convolution for time-history #2
- convol_3_new: Convolution for time-history #3
- convol_4_new: Convolution for time-history #4
- convol_5_new: Convolution for time-history #5
- convol_6_new: Convolution for time-history #6
- convol_7_new: Convolution for time-history #7
- convol_8_new: Convolution for time-history #8
- CONVOL_Load_History: Convolution of a generic time–history
- COREBO: CMB boundary conditions
- DEFPA: Normalization scheme
- det_tu: Computes the secular determinant

- diretta: Fundamental matrix
- ESSA_IEZI0: Local quantities at a point without the aid of symmetry
- Find_Station: Finds a VLBI station in the NASA site locations file
- hqr: Dependency of zrhqr (adapted from NR)
- inversa: Inverse of the fundamental matrix
- Matprod: A direct matrix multiplied by an inverse
- M_2: A collection of warning and error messages for task#3
- M_3: A collection of warning and error messages for task#2
- Ocean_correction: Corrects for the oceanic uniform load
- PREM: Computes the PREM–averaged values of density and shear moduli
- Printdue: Prints headers and more on output files for task#2
- Printtre: Prints headers and more on output files for task#3
- PROMAT: Product of propagators
- qgaus: Gauss integration (adapted from NR)
- READ_OCEAN: Reads the ocean function coefficients from ocean.128
- RECT_DISP0: Displacements, geoid, and their rates rates at a point (`CL`=50)
- RECT_LOAD0: harmonic coefficients of a rectangular load (`CL`=50)
- RECT_Pressure : Load (kg/m**2) at a point (`CL`=50)
- RECT_STOK: Stokes coefficients for a rectangular load (`CL`=50)
- RECT_INER: Inertia tensor for a rectangular load (`CL`=50)
- SPEC: Model library of `TABOO`
- Spectrum: Computes the relaxation spectrum and ldcs (tLns)

- TASK_1: Reads file task_1.dat
- TASK_2: Reads file task_2.dat
- TASK_3: Reads file task_3.dat
- zrhqr: REAL*16 Root finding algorithm (adapted from NR)

5.4 Appendix D: Earth models library

In this Chapter we give more information about the set of Earth models that can be used with `TABOO`. As stated above (see §2.2.1), an Earth model must be specified giving the parameters `NV` and `CODE`. We recall that with `NV` we indicate the number of *mantle viscoelastic layers*, and that `CODE` indicates a particular Earth model with a given `NV` value, normally taken from the literature. The set of models that can be used with `TABOO` is quite limited (see below), but it is easy to enlarge the list of admissible models modifying the subroutine SPEC of taboo.f90.

Here we adopt the following conventions regarding the parameters which define the various models (the user is also referred to §1.2.1 for the general conventions regarding the Earth models currently available using `TABOO`):

1. With r_k (k=0, 1, ...`NV`+1) we denote the radii of the interfaces between the various layers which compose the model. Thus r_0 is the radius of the core–mantle boundary, and r_{NV+1} is the radius of the Earth. These radii are usually given in units of km. In all of the models listed here, r_0 = 3480.0 km, and r_{NV+1}=6371.0 km.

2. With ρ_k (k=0, 1, ...`NV`+1) we indicate the density of a given layer. Thus ρ_0 is the density of the (uniform) core, and ρ_{NV+1} is the density of the (elastic) lithosphere.

3. In the following, μ_k (k=0, 1, ...`NV`+1) is the shear modulus of a given layer. Therefore μ_0 is the shear modulus of the (uniform) core, and μ_{NV+1} refers to the (elastic) lithosphere.

4. We use the term 'Prem–Averaged' (abbreviated as P–A) to indicate the volumetric average of a specific parameter, such as the density or the shear modulus (see A. M. Dziewonski and D. L. Anderson, PEPI, *25*, 297–356, 1981). In `TABOO` the PREM averages are computed by subroutine PREM using files prem1.dat and prem200.dat (see Appendix

A), to which the reader is referred for further details. Some facts about the PREM model are reported in the comments of subroutine SPEC.

5.4.1 Models with `NV`=1

`CODE`=	0	1	2	3	4
LT (km)	[30:300]	100.	70.	200.	[30:300]
r_2 (km)	6371.	6371.	6371.	6371.	6371.
r_1 (km)	r_2–LT	6271.	6301.	6171.	r_2–LT
r_0 (km)	3480.	3480.	3480.	3480.	3480.
ρ_2 (kg/m^3)	P–A	2689.	4500.	4500.	3300.
ρ_1 (kg/m^3)	P–A	4314.	4500.	4500.	4518.
ρ_0 (kg/m^3)	10931.7 (P–A)	10927.	10927.	10927.	10977.
μ_2 (Pa*10^{11})	P–A	0.28	1.45	1.45	0.28
μ_1 (Pa*10^{11})	P–A	1.45	1.45	1.45	1.45
μ_0 (Pa*10^{11})	0.0	0.0	0.0	0.0	0.0

Table 5.1: Details about the available models for `NV`=1. With P–A we denote Prem–Averaged values. Not all the P–A parameters are explicitely given, since some of them depend on the choice of the lithospheric thickness, that is left to the Users. We recall that the explicit values of all of the parameters used in the computations, including those computed as P–A by `TABOO` are always reported on file taboo.log after execution.

Notes and references for `NV`=1

`CODE`=0: Fully P–A model, expressly built for `TABOO`, but notice that the shear modulus in the core is set to zero (the PREM–average is not zero in this region, due to the presence of the inner solid core).

`CODE`=1: Taken from Table 1 (entry N=3) of the the paper by Yuen Sabadini and Boschi (JGR, *87*, 10,745–10,762, 1982).

`CODE`=2: This model, and the following, has been recently used to test `TABOO` against independent predictions provided by Ondrej Cadek.

`CODE`=3: As for `CODE`= 2.

`CODE`=4: Model with the same density and rigidity profile as the 'three–layer test model' in Giunchi and Spada (GRL, *27*, 2065–2068, 2000) (but notice that here the model is self-gravitating, in Giunchi and Spada it was simply gravitating). If `External_Model` kw is active in task_*.dat, the non–self–gravitating model by Giunchi and Spada is used (see §2.2.2).

5.4.2 Models with NV=2

CODE=	0	1	2	3	4
LT (km)	[30:300]	[30:300]	100.0	100.	150.
r_3 (km)	6371.	6371.	6371.	6371.	6371.
r_2 (km)	r_3−LT	r_3−LT	6271.	6271.	6221.
r_1 (km)	r_3−670.	r_3−670.	r_3−670.	r_3−670.	r_3−670.
r_0 (km)	3480.	3480.	3480.	3480.	3480.
ρ_3 (kg/m^3)	P–A	P–A	2689.	2771.	3232.
ρ_2 (kg/m^3)	P–A	3988.1 (see note)	4430.	4120.	3666.
ρ_1 (kg/m^3)	4877.9 (P–A)	4396.6 (see note)	4919.	4508.	4904.
ρ_0 (kg/m^3)	10931.7 (P–A)	10927.	10927.	10925.	10987.
μ_3 (Pa*10^{11})	P–A	0.28	0.282	0.315	0.6114
μ_2 (Pa*10^{11})	P–A	0.28	0.837	0.954	0.9169
μ_1 (Pa*10^{11})	2.19 (P–A)	1.45	2.17	1.99	2.225
μ_0 (Pa*10^{11})	0.0	0.0	0.0	0.0	0.0

Table 5.2: This Table shows the available models with NV=2. See also the caption of Table 5.1 above and the notes given below. This Table is continued in the following page.

`CODE`=	5	6
LT (km)	80.	100.
r_3 (km)	6371.	6371.
r_2 (km)	6291.	6271.
r_1 (km)	$r_3-670.$	$r_3-670.$
r_0 (km)	3480.	3480.
ρ_3 (kg/m^3)	3115.	4120.
ρ_2 (kg/m^3)	3614.	4120.
ρ_1 (kg/m^3)	4878.	4508.
ρ_0 (kg/m^3)	10932.	10926.
μ_3 (Pa*10^{11})	0.5597	1.38
μ_2 (Pa*10^{11})	0.8464	1.38
μ_1 (Pa*10^{11})	2.171	1.51
μ_0 (Pa*10^{11})	0.0	0.0

Table 5.3: Other available models with `NV`=2. See also the caption of Table 5.1 and the notes given below.

Notes and references for `NV`=2

`CODE`=0: Fully P–A, expressly built for `TABOO`, but notice that the shear modulus in the core is set to zero (the PREM–average is not zero in this region, due to the presence of the inner solid core).

`CODE`=1: All of the densities and shear moduli are P–A, but ρ_2 and ρ_1 have the PREM values just below and just above the 670 km depth discontinuity. This ensures that at this depth the ratio $(\rho_2 - \rho_1)/\rho_1$ is the same as that of the PREM model (~ 10 %).

`CODE`=2: Taken from Table 1 (entry N=4) of the the paper by Yuen Sabadini and Boschi (JGR, *87*, 10,745–10,762, 1982).

`CODE`=3: Taken from the paper by Bills and James (JGR, *102*, 7579–7602, 1997). Notice however that here the lithosphere is perfectly elastic, whereas in the above study the lithosphere has the viscosity of 10^{10} in units of 10^{21} Pa.s (however, this should imply an almost perfectly elastic behavior).

`CODE`=4: This model is taken from Table 2 of Lefftz Sabadini and Legros (GJI, *117*, 1–18, 1994).

`CODE`=5: This model has been suggested by Antonio Piersanti. It is in use in his group for predictions of postseismic deformations.

`CODE`=6: Taken from Table 1 (model h) of Ricard Sabadini and Spada (JGR, *97*, 14,223–14,236, 1992).

5.4.3 Models with NV=3

Notes and references for NV=3

CODE=0: Fully P–A model, expressly built for TABOO, but notice that the shear modulus in the core is set to zero (the PREM–average is not zero in this region, due to the presence of the inner solid core).

CODE=1: This model is only partially P–A, in the sense that follows: (1) the lower mantle density (ρ_3) is that taken from the PREM model just below the 670 km depth discontinuity, (2) the shallow upper mantle density is that of PREM just above the depth of 400 km, (3) the transition zone density is P–A, (4) the shear moduli of all of the layers are P–A.

CODE=2: This model is the same adopted by Cianetti Giunchi and Spada (JGR, *102*, 12, 2002).

CODE=3: 'Reference' model by James and Morgan (GRL, *17*, 1990, see their Table 1). Notice however that in their paper the fluid portion of the core has a finite viscosity of 10^{18} Pa.s.

CODE=4: This model is very similar to that by Peltier (JGR, *90*, 1985). Here the values of the lithospheric and core parameters are P–A. In Peltier, the lithosphere is composed of two layers, and the core density is continously varying with depth.

CODE=5: This model is one of those employed by the GIA Benchmark group (`http://wwwrser.anu.edu.au/geodynamics/GIA_bechmark/participants.html`).

CODE=	0	1	2	3	4	5
LT, (km)	[30:300]	[30:300]	120.	120.	120.	70.
r_4 (km)	6371.	6371.	6371.	6371.	6371.	6371.
r_3 (km)	r_4−LT	r_4−LT	6251.	6251.	6251.	6301.
r_2 (km)	r_4−400.	r_4−400.	5951.	5951.	5951.	5951.
r_1 (km)	r_4−670.	r_4−670.	5701.	5701.	5701.	5701.
r_0 (km)	3480.	3480.	3480.	3486.	3480.	3480.
ρ_4 (kg/m^3)	P–A	P–A	4120.	2900.	3233.6 (P–A)	3037.
ρ_3 (kg/m^3)	P–A	P–A	4120.	3550.	3959.	3438.
ρ_2 (kg/m^3)	3857.7 (P–A)	3529.8 (see note)	4220.	3800.	4100.	3871.
ρ_1 (kg/m^3)	4877.9 (P–A)	4396.6 (see note)	4508.	4900.	4372.	4978.
ρ_0 (kg/m^3)	10931.7 (P–A)	10931.7 (P–A)	10925.	11110.	10931.7 (P–A)	10750.
μ_4 (Pa*10^{11})	P–A	P–A	0.73	0.40	0.706 (P–A)	0.50605
μ_3 (Pa*10^{11})	P–A	P–A	0.95	0.71	ρ_3* $5219^2/10^{11}$	0.70363
μ_2 (Pa*10^{11})	0.735 (P–A)	0.735 (P–A)	1.10	1.45	ρ_2* $5475^2/10^{11}$	1.0549
μ_1 (Pa*10^{11})	1.064 (P–A)	1.064 (P–A)	2.00	2.30	ρ_1* $6117^2/10^{11}$	2.2834
μ_0 (Pa*10^{11})	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.4: This Table shows the available models with NV=3. See also the caption of Table 5.1 and the notes below.

5.4.4 Models with NV=4

Here we give details on models characterized by NV=4. The three models available have been built *ad hoc* for TABOO, none comes from the literature. The numerical values of the properties of the model (radii, shear moduli, and densities) are reported on file taboo.log after execution. See also the subroutine SPEC of the taboo.f90 program.

CODE=0: The model, which is essentially P–A, has the following features:

1. The lithospheric thickness LT may vary in the range [40:150] km. The properties of the lithosphere (shear modulus and density) are P–A.
2. The *shallow upper mantle* is subdivided into two layers (SUM1 and SUM2, respectively). Both have P–A properties.
3. The base of layer SUM1 is placed are the depth of 220 km, where the PREM model shows a discontinuity.
4. The thickness of SUM2 is of 180 km, so that its base is at the depth of 400 km, where the PREM model shows another discontinuity.
5. The P–A transition zone (TZ) thickness is of 270 km. Its base is thus at the depth of 670 km, and coincides with one of the PREM discontinuities.
6. The lower mantle density and shear moduli are P–A.
7. The core shear modulus is =0, as usual in TABOO. The core density is P–A.

CODE=1: The model with CODE= 1 is largely a P–A model, similar to that with CODE=0 described above, but with a substantial difference in the lower mantle structure. In fact, the lower mantle density *is not* P–A, but rather it has the density of the PREM model at a depth immediately below the 670 km depth discontinuity. According to file prem1.dat (see Appendix A), the lower mantle density is thus 4396.56 kg/m**3. The lower mantle shear modulus is P–A.

CODE=2: The model with CODE=2 is basically the same as CODE=1, but with only a minor difference, since now the lower mantle shear modulus *is not* P–A. The value of the shear modulus in the lower mantle is that of PREM just below the 670 km depth discontinuity, i.e., 1.61 $\times 10^{11}$ Pa. Thus, for `CODE`=2, the lower mantle density *and* the lower mantle shear modulus have the values taken by the PREM model just below the 670 km discontinuity.

5.4.5 Models with NV=7

Here we give details on the only model characterized by NV=7. This model have been built *ad hoc* for TABOO. The numerical values of the properties of the model (radii, shear moduli, and densities) are reported on file taboo.log after execution. See also the subroutine SPEC of the taboo.f90 program.

CODE=0: The model has the following features:

1. The model structure in the lithosphere, in the two shallow upper mantle layers (SUM1 and SUM2), and in the transition zone is exactly the same as for NV=4.
2. The lower mantle is fully P–A. The user can control the thickness of the four lower–mantle layers acting on switch `ilm` of kw `Make_Model` (see §2.2.1). Details on how the thickness of the lower mantle layers are computed can be obtained by inspection of subroutine SPEC of taboo.f90.
3. As for NV=4, the core shear modulus is =0, as usual in TABOO. The core density is P–A.

5.4.6 Models with NV=9

Details on the only model characterized by NV=9 are given here. This model have been built *ad hoc* for TABOO. The numerical values of the properties of the model (radii, shear moduli, and densities) are reported on file taboo.log after execution. See also the subroutine SPEC of the taboo.f90 program.

CODE=0: The model has the following features:

1. The model structure in the lithosphere, in the two shallow upper mantle layers (SUM1 and SUM2), and in the transition zone is `exactly` the same as for NV=4 and NV=7 (see above).
2. The lower mantle is fully P–A. The user can control the thickness of the six lower–mantle viscoelastic layers acting on the switch `ilm` of kw `Make_Model` (see §2.2.1). Details on how the thickness of the lower mantle layers are computed can be obtained by inspection of subroutine SPEC of program taboo.f90.
3. The core shear modulus is =0 and the core density is P–A.