Technical memo: Model for the correction of DORIS/Jason USO frequency

Reference document RD1:

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LIST OF ACRONYMS

USO	Ultra Stable Oscillator
SAA	South Atlantic Anomaly
UTC	Universal Time Coordinate
TAI	Temps Atomique International (International Atomic Time)

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1. INTRODUCTION

All receivers on-board the different satellites equipped with DORIS display fluctuations of their actual frequency with respect to their nominal frequency, at different time scales. The behaviour of these frequency offsets can be split into long, medium and short term. The last one will interest us more particularly; the long and medium term offsets being absorbed by empirical parameters (frequency biases / pass).

The sensitivity of the ultra stable oscillator (USO) of DORIS/Jason-1 to solar radiative phenomena was demonstrated a few months after the start up of the instrument. This sensitivity causes a fluctuation of the frequency when the satellite crosses the area of the South-Atlantic Anomaly (SAA). The principal consequence is the impossibility of using the measurements of the DORIS beacons located in the SAA for cm-precision positioning since the real frequency of the on-board oscillator is varying rapidly in that area. Moreover, these DORIS measurements do not contribute (or little) to the determination of the orbit of Jason-1 because they are eliminated during the pre-processing on residuals criteria.

To correct for this sensitivity to the effects of solar radiation, a model of frequency evolution of the USO was designed and validated by CNES (RD1). This model of frequency correction makes a significant improvement in the orbit adjustment. It takes into account the geographical characteristics of the SAA region (1x1 degree SAA grid) as well as parameters of the USO's response to this external stimulation: an amplitude, a relaxation time-constant and a memory effect of the SAA disturbance. This model was optimized and documented in order to be able to deliver an operational module (software) that will be used by the processing centers of DORIS data. The purpose of this document is to give the principle of the model and to allow its implementation and its use.

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2. DESCRIPTION OF THE MODEL

2.1. OBJECTIVE

The model of frequency correction of the DORIS/Jason's USO will determine the temporal evolution of the short-term frequency correction on the 2 GHz channel for a chosen period. The necessary input can either be a time interval, a series of dates or a DORIS measurements file in CDDIS 2.1 format.

Additionally, and for information purposes, an approximate value of the long-term evolution of the frequency is also given, based on a polynomial regression.

2.2. PRINCIPLE OF THE MODEL

The model is based on the numerical integration of the amount of radiation received and released by the USO during its flight in orbit, particularly when crossing the SAA where most of the high-energy protons are located. The frequency offset is considered proportional, by a variable factor, to the integrated amount of radiation received.

To calculate this short-term frequency correction it is necessary to know the geographical position of the satellite at each instant for the required period, but this position does not need to be known with great accuracy. Taking the mean orbit ground track of Topex (identical to Jason's) is sufficient for the purpose, if it is given with a time-step not greater than 10 seconds. This time-step is then taken as the integration step. The short-term correction is first calculated for an integer number of cycles covering the required period and stored in an array; it is then interpolated at the dates of the measurements found in the input file.

Important notice:

- since the short-term frequency correction is the result of an integration process, two runs of the model starting at two different dates will give different (but similar) results. The difference between the results will be a small constant bias and some discrepancy at the start of the integration process. The bias will be absorbed by the usual empirical parameters (frequency biases per pass); the discrepancy at the start of the integration process will vanish after approximately 60 minutes.
- there are two DORIS chains aboard Jason-1 for redundancy reasons. From launch, on December 7, 2001, until June 25, 2004, it was the redundant chain (chain n°2) that was active. Then on June 25, 2004 a switch from the redundant to the nominal instrument was carried out and it is now chain n°1 which is active, until the present day. Then, an impotant notice is: Input file has to correspond either to the chain 2 period (before June 25, 2004, cycle number 91) or to the chain 1 period (after July 3, 2004, cycle number 92), it cannot cover the transition period June 25 to July 3, 2004.

2.3. SOFTWARE ARCHITECTURE

The software consists of a main program calling several subroutines. A functional description of the subroutines is given in Appendix A.

In the input directory, the program needs an input file and asks for the type of data contained in that file: CDDIS or list of dates in free format. This input file has to correspond either to the chain 2 period or to the chain 1 period.

The program extracts the first and last dates of the input file, determines the number of cycles covered by this time span, computes the short-term frequency corrections over the entire number of cycles and interpolates the correction at the dates of the measurements.

In the output directory, the program writes the files:

- OUTPUT/jason_position.dat: date (points of the orbit file), approximate latitude and longitude
- OUTPUT/jason_df.orbit.dat: date (points of the orbit file), short-term and long-term frequency corrections
- OUTPUT/jason_df.measu.dat: date (points of the measurement file), short-term and long-term frequency corrections

And if input file is in CDDIS format:

- OUTPUT/jason_df.measu2.dat: CDDIS format file corrected by short-term correction

The input and output files are described in more detail below.

2.4. INPUT FILES

2.4.1. User-provided input file

This file has to be named ANNEXE/MESURE/Input. The model accepts two types of format, the CDDIS format and a free format.

2.4.1.1. CDDIS DORIS 2.1 format

DORIS 2.1 format is the format of the Doris measurement files available at CDDIS. A description of this format can be found at ftp://ftp.cls.fr/pub/ids/data/doris21.fmt and an example is given in Appendix B. The time scale is TAI (Temps Atomique International). The computation of the short and long-term frequency correction is done at the middle of the Doris count interval. And as this input file has to correspond either to the chain 2 period or to the chain 1 period, the CDDIS DORIS 2.1 files corresponding to 90 and 91 cycles cannot take into account (the name of theses files are "ja1data090.001" and "ja1data091.001" on the following address: ftp://cddis.gsfc.nasa.gov/doris/data/ja1/).

2.4.1.2. Free format

The model can accept a measurement file containing only dates, expressed in TAI, for instance dates of the middle of Doppler count intervals. These dates are defined by four integers separated by a space. The first corresponds to the year indicated by two or four digits (02 or 2002), the second integer to the day of the year, the third to seconds, and the last to microseconds. This file, of which an example is presented in Appendix B, is read in free format and has to correspond either to the chain 2 period or to the chain 1 period.

2.4.2. Model-provided input files

2.4.2.1. Jason cycle dates: file ANNEXE/CYCLE/jason_cycle_dates

This file contains, for each Jason cycle, the cycle number and the begin date of the cycle in CNES Julian day (cf. Appendix B). The end date of the current cycle is the begin date of the following one. These dates are expressed in UTC (Universal Time Coordinate). Since the model works in TAI, they are converted from UTC to TAI in the program.

This file has to be changed regularly.

2.4.2.2. Average orbit ground track: file ANNEXE/ORBITE/topex_mean_track

This file contains the date, the latitude and longitude of the reference track, in 9,702 seconds steps, for the total duration of a reference cycle. The begin date is zero and the end date is the cycle duration (cf. Appendix B).

The average orbit ground track was obtained by the Space Oceanography department of CLS, based on seven years of Topex data.

2.4.2.3. South Atlantic Anomaly grid: file ANNEXE/TABSAA/SAA_grid_CH2 and SAA_grid_CH1

This grid defines the geographical pattern and amplitude of the SAA extension, as perceived by Jason's USO. It is used to determine the short-term frequency correction. There is one grid for each chain. As shown in figure 1 for chain 1, the grid provides a dimensionless amplitude per square degree.

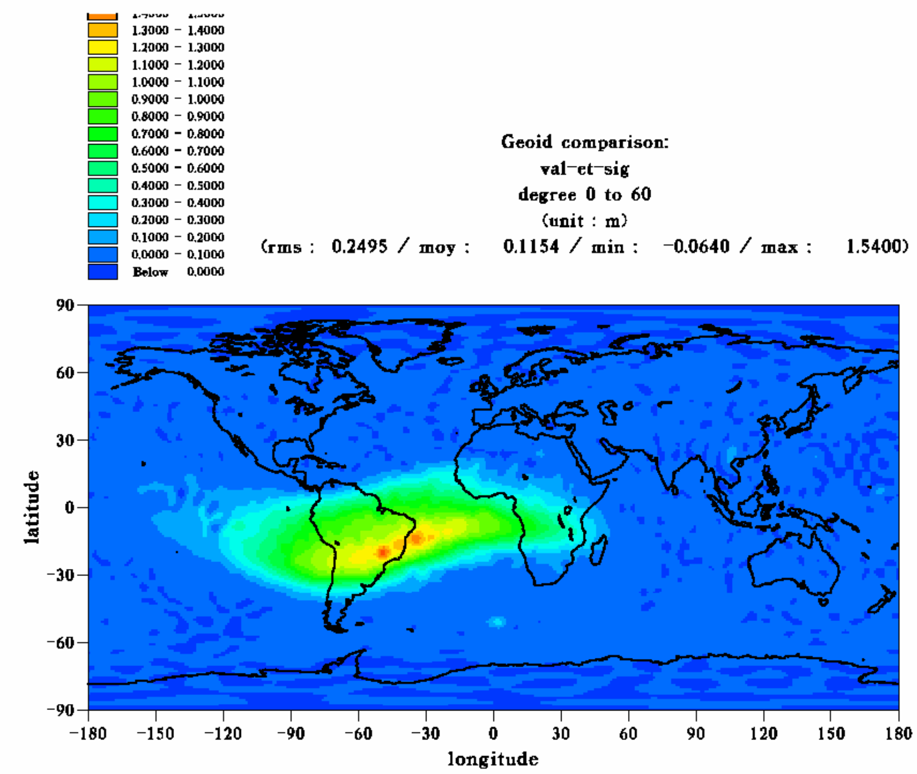

Figure 1: SAA grid of chain 1

2.5. OUTPUT FILES

2.5.1. Frequency correction at the dates of the orbit file: file OUTPUT/jason_df.orbit.dat

This file contains the results of the computation of the short and long-term frequency corrections, on the 2.03625 GHz channel of Jason's USO, for each 9.702 second step of the orbit of all the cycles covering the required time-span. The date is in CNES decimal Julian day, in the TAI scale. The frequencies are in Hz.

CNES Julian day 19000 ⇔ calendar date January 8, 2002

The results are written with Fortran format: (f17.11,2f12.6). An example is given in Appendix C.

2.5.2. Frequency correction at the dates of the measurement file: file OUTPUT/jason_df.measu.dat and file OUTPUT/jason_df.measu2.dat

This file contains the results of the computation of the short and long-term frequency corrections, on the 2.03625 GHz channel of Jason's USO, for each point of the measurement file /ANNEXE/MESURE/Input. The dates are in the TAI scale. The frequencies are in Hz.

Depending on the type of input file, the results can be written with two different Fortran formats (examples are given in Appendix C):

- if the input file is in free format, the output file will contain the date in free format, the date in CNES decimal Julian day and the short and long-term frequency corrections, written with format: (i4.2,1x,i3.3,1x,i5,1x,i6,1x,f17.11,2f12.6)

- if the input file is in CDDIS format, the first output file will contain the original measurement in CDDIS format, followed by the date in CNES decimal Julian day (at the middle of the count interval) and the short and long-term frequency corrections, written with format: …,1x,f17.11,2f12.6). The second ouput file, jason_df.measu2.dat, will contain the original measurement in CDDIS format corrected by short-term frequency.

2.5.3. Jason approximate latitude and longitude position: file OUTPUT/jason_position.dat

This file contains the approximate latitude and longitude of Jason track for each 9.702 second step of the orbit of all the cycles covering the required time-span. The date is in CNES decimal Julian day, in the TAI scale. The latitude and longitude are in degrees.

The results are written with Fortran format: (f17.11,2f11.6)

3. IMPLEMENTATION AND USE OF THE MODEL

To implement the model in the UNIX environment, it is necessary to carry out a certain number of steps that will be described below. We will then see how to use the model.

3.1. IMPLEMENTATION OF THE MODEL

The model and all its components are contained in the compressed file "modele.tar.gz". The size of this file is around 4 Mo.

3.1.1. Installation

One makes a copy of the file "modele.tar.gz" (4 Mo) in his work directory. Initially, it is necessary to decompress this file by the shell command "gunzip - D modele.tar.gz". The file "modele.tar" of size 14,5 Mo is created. Then, one de-tars the file by the shell command "tar – xvf modele.tar".

The MODELE directory contains all the source files: f90_kind.f90, lecture_doris_file_init.f90, jul.f90, date_cycle.f90, cortai.f90, calcul_dfsat.f90, hf_jason_doris_freq.f90, modele_fsat_doris.f90 and interpol_datemes.f90. MODELE directory also contains directories ANNEXE and OUTPUT. The OUTPUT directory is empty and the ANNEXE directory contains directories: MESURE, CYCLE, ORBIT, TABSAA. The MESURE directory contains the file "Input", CYCLE the file "jason_cycle_dates", ORBIT the file "topex_mean_track", and TABSAA the file "SAA_grid".

MODELE/ : *f90, ANNEXE, OUTPUT

MODELE/OUTPUT/ : No file

MODELE/ANNEXE/: MESURE, CYCLE, ORBITE, TABSAA

MODELE/ANNEXE/MESURE/Input

MODELE/ANNEXE/CYCLE/jason_cycle_dates

MODELE/ANNEXE/ORBITE/topex_mean_track

MODELE/ANNEXE/TABSAA/SAA_grid_CH2 or SAA_grid_CH1

3.1.2. Compilation

One can compile directly the main program: "modele.f90". The compilation of the module and the routines is done automatically. The executable file is then generated and the model can be used.

3.2. USE OF THE MODEL

3.2.1. Pre-processing

A file named "Input" has to be placed in the directory ANNEXE/MESURE. It can either be a CDDIS Doris 2.1 data file or a free format file of dates that the user has created (see Appendix B). This input file has to correspond either to the chain 2 period (before June 25, 2004, cycle number 91) or to the chain 1 period (after July 3, 2004, cycle number 92), it cannot cover the transition period June 25 to July 3, 2004.

3.2.2. Processing

The model asks for the type of measurement file, 1 for CDDIS, 2 for the free format (year, day of year, seconds, and microseconds). At the end of the job, the messages "End of Calculation" and "Output Files: jason_df.orbit.dat, jason_df.measu.dat, jason_position.dat and if input file is in CDDIS format, jason_df.measu2.dat " are posted on the screen.

The results "jason_df.orbit.dat", "jason_df.measu.dat", "jason_position.dat" and "jason_df.measu2.dat" (if input file is in CDDIS format) are in the OUTPUT directory. An example of those files is given in Appendix C.

Important notice: two runs of the model starting at two different dates will give different (but similar) results (see chapter 2.2).

APPENDIX A DESCRIPTION OF SUBROUTINES

LECTURE_DORIS_FILE_INIT

This routine looks for the begin and end dates and the number of measurements in the measurement file. The input argument is the format of the measurement file and the output arguments are the begin and end dates, and the number of measurements. The input file ("Input") is opened in order to read the first date, a reading loop counts the number of measurements, and the last date is read. The calendar dates are converted into CNES Julian day for future use using the "jul" function whose input arguments are the day, the month and the year.

DATE_CYCLE

The purpose of this routine is to find the begin and end dates of the cycle containing the begin date of the measurements. The input arguments are the begin and end dates of the measurements and the output arguments are the begin and end dates of the cycle. Theses dates are read in UTC. Using the "cortai" function, the conversion into TAI is done.

CALCUL_DFSAT

The purpose is the calculation of the frequency corrections for one cycle, by steps of 9.702 seconds and the storage of the obtained values (dates and short-term correction) in an array. The input arguments are the begin and end dates of the cycle, the maximum size of the frequency correction array and the current number of values in that array. The output argument is the array of the dates and the frequency corrections.

Working cycle by cycle, this routine computes the approximate position of the satellite thanks to the mean ground track, computes every 9.702 s the short-term frequency correction using the routine hf_jason_doris_freq, and the long-term correction with the routine modele_fsat_doris. The results are stored in an array, together with the date in CNES Julian day. The date and position (latitude and longitude) is simultaneously written in the output file "jason_position.dat".

HF_JASON_DORIS_FREQ

This routine is the model of High-Frequency fluctuations of the DORIS 2 GHz oscillator on-board JASON. It calculates the frequency correction (short-term time evolution) from date and position. The input arguments are the date in CNES Julian day and the position (latitude and longitude). One input/output argument is the logical variable (l_initialiser) for the initialization at the first call of the subroutine. On output the routine provides the short-term frequency correction. Following is a brief description of the model’s constituents.

The model is defined by three fundamental parameters, whose value varies slowly with time over the whole lifetime of the instrument in the case of the chain 2, and whose value considered constant in the case of the chain 1:

- a "sensitivity factor" (or "amplitude of response") of DORIS/Jason to the SAA, in unit of Hz per day on the 2 GHz channel. In the case of the chain 2, the amplitude varies with time like a polynomial of order two. In the case of the chain 1, the amplitude is varies with time like a linear regression,

- a time constant corresponding to a relaxation effect after a pass in the SAA, approximated by an exponential decay for the chain 2, and constant for the chain 1,

- a "memory effect" corresponding to the fact that the frequency does not come back to its initial value after an SAA "boost" but remains at an intermediate level. The memory effect decreases by an exponential decay (chain 2). In the case of the chain 1 this parameter is constant.

An SAA 1 degree square grid, which represents the geographical dependence of the SAA, supplements this model. By multiplying the amplitude, at the time of computation, by the value of the SAA grid at the satellite's location, one obtains the flux of SAA radiation received by the satellite. At the same time the satellite releases part of its accumulated dose according to the second parameter: the time constant. The sum of the radiation received and released forms the instantaneous total dose flux, which has been found to be analogous to the time derivative of the frequency of DORIS/Jason-1 oscillator in units of Hz/day on the 2 GHz channel. By integrating the total dose flux with time, one obtains the current dose and by integrating only the received dose flux with time, one obtains the cumulated dose.

The short-term frequency correction will be equal to the sum of the current dose and the cumulated dose, weighted by the memory effect.

MODELE_FSAT_DORIS

In this routine, the calculation of the long-term frequency correction is done at the date given in input. The output argument of the routine is the long-term frequency correction. The model is a polynomial of degree 2 plus an exponential decay (different for the chain 1 and 2) to account for the warm-up phase at the instrument's switch-on.

INTERPOL_DATEMES

This routine computes the short-term frequency correction at the measurement date by interpolating in the array of frequency corrections computed by the subroutine "calcul_dfsat". It also computes the long-term frequency correction at the date of measurement. The input arguments are the type of measurement file, the number of measurements, the array of dates and short-term frequency corrections and the number of calculated corrections.

First, the output file "jason_df.orbit.dat" is written, containing the dates and the long and short-term frequency corrections at the orbit points.

Then, for each measurement, the following actions are carried out:

- reading of the measurement date from the Input file and conversion into CNES Julian day with the "jul" function,

- calculation of the short-term frequency correction by interpolation at the date of measurement,

- calculation of the long-term correction at the date of measurement by calling the "modele_fsat_doris" routine,

- writing of the results (date of measurement in CNES Julian day and short and long-terms corrections) to the output file "jason_df.measu.dat” and if input file is in CDDIS format, "jason_df.measu2.dat” which contains measurements file in CDDIS format corrected by short-term frequency.

APPENDIX B INPUT FILES

I) Examples of measurement files

Name of file: ANNEXE/MESURE/Input

I.1) CDDIS format:

```
JASON13935MARB 0334426921864217110  70000005-33186809071016279 68   300   -3065  22732101   295
JASON13935MARB 0334426928864217110 100000007-32462274451016279 68   300   -2460  21483101   276
JASON13935MARB 0334426938864218110 100000007-31581171931016279 68   300   -2306  20104101   307
```

I.2) Free format:

```
03 344 26921 864217
03 344 26928 864217
03 344 26938 864218
```

or

```
2003 344 26921 864217
2003 344 26928 864217
2003 344 26938 864218
```

II) Example of Jason cycles file

Name of file: ANNEXE/CYCLE/jason_cycle_dates

```
 1  19007.2158717129641445
 2  19017.1315117939811898
 3  19027.0471389120357344
 4  19036.9627861342596589
 5  19046.8784264236128365
…
```

III) Example of the average orbit ground track

Name of file: ANNEXE/ORBITE/topex_mean_track

```
.00000000000000000E+00  -66.147567   17.087164
.11229166666666668E-03  -66.141687   18.320223
.22458333333333325E-03  -66.125348   19.552168
.33687499999999983E-03  -66.098544   20.781950
.44916666666666640E-03  -66.061354   22.008546
```

APPENDIX C EXAMPLES OF OUTPUT FILES

I) jason_df.orbit.dat

Date in CNES Julian day, short and long-term correction in Hz

```
19701.31137929437  -0.000013 -133.544338
19701.31149158642  -0.000031 -133.544355
19701.31160387847  -0.000051 -133.544372
19701.31171617053  -0.000071 -133.544390
19701.31182846258  -0.000085 -133.544407
```

II)

a) CDDIS format:

- jason_df.measu.dat

CDDIS measurements + date in CNES Julian day, short and long-term correction in Hz

```
 JASON13935MARB 0334426921864217110  70000005-33186809071016279 68   300   -3065  22732101   295
19701.31159565066  -0.000050 -133.544371
 JASON13935MARB  0334426928864217110  100000007-32462274451016279  68     300     -2460    21483101     276
19701.3116766918  -0.000064 -133.544384
 JASON13935MARB  0334426938864218110  100000007-31581171931016279  68     300     -2306    20104101     307
19701.31179240993  -0.000081 -133.544401
```

- jason_df.measu2.dat

CDDIS measurements + corrected by short term

```
JASON13935MARB 0334426921864217110  70000005-33186808991016279 68   300   -3065  22732101   295
JASON13935MARB 0334426928864217110 100000007-32462274351016279 68   300   -2460  21483101   276
JASON13935MARB 0334426938864218110 100000007-31581171801016279 68   300   -2306  20104101   307
```

b) FREE format

jason_df.measu.dat

Date in free format, date in CNES Julian day, short and long-term correction in Hz

```
 03 344 26921 864217 19701.31159565066   -0.000050 -133.544371
 03 344 26928 864217 19701.31167666918   -0.000064 -133.544384
 03 344 26938 864218 19701.31179240993   -0.000081 -133.544401
```

III) jason_position.dat

Date in CNES Julian day, latitude and longitude in degrees

```
19701.31137929437 -66.141687  18.320223
19701.31149158642 -66.125348  19.552168
19701.31160387847 -66.098544  20.781950
19701.31171617053 -66.061354  22.008546
19701.31182846258 -66.013788  23.230931
```