

## Description of keywords of VTD (VLBI Time Delay) control file language

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### *Abstract:*

*This document provides detailed description of syntax of the language used for specification of control file for the package VTD (VLBI Time Delay).*

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### 1 General rules

Control file for VTD consists of lines of variable length. Lines which starts from characters # or \* are considered as comments and ignored by parsing software. Each line consists of a keyword and the value. All keywords must be specified, no defaults are allowed. A value should be separated the keyword by one or more delimiters. Valid delimiters: blank (decimal code 32), tabulation (decimal code 9) and binary zero. The first line of the control file should have the label of the format version. The current label version is  
# VTD Control file. Format version of 2009.02.21

If the file does not have correct format label, VTD library will issue and errors message.

### 2 Description of keyword

#### 2.1 LEAP\_SECOND:

**LEAP\_SECOND: [leap\_second\_file\_name or NERS]**

leap\_second\_file\_name is the name of the file in LEAP\_SECOND format which tabulates epochs of discontinuities of the function  $UT1 - TAI(t)$  and values of discontinuities.

If NERS is specified, the leap second is downloaded automatically using the Network Earth Rotation Service

#### 2.2 DE\_EPHEMERIDES:

**DE\_PHEMERIDES: planetary\_ephemerides\_file\_name**

Planetary\_ephemerides\_file\_name is the name of the DE ephemerides file.

## **2.3 STATION\_DESCRIPTION:**

**STATION\_DESCRIPTION: station\_description\_file\_name**

Station\_description\_file\_name is the name of the file in STADESC format. That file contains information about all stations which participated in the experiment: IVS station name, antenna mounting type, antenna axis offset, tectonic plate. This file may contain information about other stations which did not participated in the analyzed experiment. All stations which participated in the experiment must be listed in this file.

## **2.4 STATION\_COORDINATES:**

**STATION\_COORDINATES: station\_coordinates\_file\_name**

Station\_coordinates\_file\_name is the name of the file either in GETPAR\_STA format  
( [http://astrogeo.org/psolve/doc/getpar\\_02.html#section3.1](http://astrogeo.org/psolve/doc/getpar_02.html#section3.1) )  
or in SIT-MODFILE format. That file contains information about all stations which participated in the experiment: IVS station name, station coordinates and epoch for coordinates of those stations which had episodic motion. This file may contain information about other stations which did not participated in the analyzed experiment. All stations which participated in the experiment must be listed in this file.

## 2.5 STATION\_VELOCITIES:

**STATION\_VELOCITIES: station\_velocities\_file\_name**

Station\_velocities\_file\_name is the name of the file either in GETPAR\_VEL format  
( [http://astrogeo.org/psolve/doc/getpar\\_02.html#section3.2](http://astrogeo.org/psolve/doc/getpar_02.html#section3.2) )  
or in VEL-MODFILE format. That file contains information about all stations which participated in the experiment: IVS station name, station velocities. This file may contain information about other stations which did not participated in the analyzed experiment. All stations which participated in the experiment must be listed in this file.

## 2.6 STATION\_ECCENTRICITIES:

**STATION\_ECCENTRICITIES: station\_eccentricities\_file\_name**

Station\_eccentricities\_file\_name is the name of the file with eccentricity vector in ECC-FORMAT. It contains IVS station name, CDP monument number, starting date of validity of the eccentricity vector, end date of validity of the eccentricity vector, eccentricity vector for each station each period of validity defined as the vector from the monument point for which station coordinates are referred to, to the reference point on the antenna, defined as a point on the fixed axis which is located at the closest distance to the moving axis.

## 2.7 SOURCE\_COORDINATES:

**SOURCE\_COORDINATES: source\_coordinates\_file\_name**

The qualifier Source\_coordinates\_file\_name is the name of the file either in GETPAR\_SOU format

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( [http://astrogeo.org/psolve/doc/getpar\\_02.html#section3.3](http://astrogeo.org/psolve/doc/getpar_02.html#section3.3) )  
or in SOU-MODFILE format. That file contains information the sources which participated in the experiment: IVS source name, source coordinates. This file may contain information about other source which were not observed in the analyzed experiment.

### 2.8 SOURCE\_COORDINATES\_2ND:

**SOURCE\_COORDINATES: [source\_coordinates\_file\_name\_2 or NONE]**

The qualifier source\_coordinates\_file\_name is the name of the file either in GETPAR\_SOU format  
( [http://astrogeo.org/solve\\_root/help/getpar\\_02.html#section3.3](http://astrogeo.org/solve_root/help/getpar_02.html#section3.3) )  
or in SOU-MODFILE format. This is the secondary catalogue used by VTD. It might be convenient to keep coordinates of source in more than one file. That file contains information the sources which participated in the experiment: IVS source name, source coordinates. This file may contain information about other source which were not observed in the analyzed experiment.

### 2.9 SOURCE\_COORDINATES\_3RD:

**SOURCE\_COORDINATES: [source\_coordinates\_file\_name\_3 or NONE]**

The qualifier source\_coordinates\_file\_name is the name of the file either in GETPAR\_SOU format  
( [http://astrogeo.org/psolve/doc/getpar\\_02.html#section3.3](http://astrogeo.org/psolve/doc/getpar_02.html#section3.3) )  
or in SOU-MODFILE format. This is the ternary catalogue used by VTD. It might be convenient to keep coordinates of source in more than one file. That file contains information the sources which participated in the experiment: IVS source name, source coordinates. This file may contain information about other source which were not observed in the analyzed experiment.

## 2.10 SOURCE\_COORDINATES\_4TH:

**SOURCE\_COORDINATES:** [source\_coordinates\_file\_name\_4 or NONE]

The qualifier source\_coordinates\_file\_name is the name of the file either in GETPAR\_SOU format

( [http://astrogeo.org/psolve/doc/getpar\\_02.html#section3.3](http://astrogeo.org/psolve/doc/getpar_02.html#section3.3) )

or in SOU-MODFILE format. This is the fourth catalogue used by VTD.

It might be convenient to keep coordinates of source in more than one file.

That file contains information the sources which participated in the

experiment: IVS source name, source coordinates. This file may contain

information about other source which were not observed in the analyzed experiment.

## 2.11 SOURCE\_PRLX\_PRP\_MOTION:

**SOURCE\_PRLX\_PRP\_MOTION:** [source\_parallax\_and\_proper\_motion\_file or NONE]

The qualifier source\_parallax\_and\_proper\_motion\_file specifies the name of the file with a priori source proper motions and parallaxes. Each line of

that file contains IVS source name J2000 source name, proper motion over

right ascension without scaling  $\cos(\delta)$  factor, proper motion over

declination, annual parallax, and comment. See file prlx\_prp\_format.txt

in the documentation directory for the format description.

## 2.12 DIR\_BTX:

**DIR\_BTX:** [directory\_name or NONE]



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Directory with files with phase center offsets in bintex format for both space-born and ground based antennas. Files in bintex format are created by utility vtd\_antex\_to\_bintex that processes an input file in the IGS ascii format ANTEX into output files. VTD searches for phase center offsets in the directory tree specified by DIR\_BTX keyword.

### 2.13 DIR\_NZO:

**DIR\_NZO: [directory\_name or NONE]**

Directory with files with orbits of near-zone objects. Supported formats for orbit files are:

NZO -- Internal VTD ascii format that tabulates time series of positions and velocities.

ORM -- The Consultative Committee for Space Data Systems orbit messages, CCSDS 502.0-B-3, <https://ccsds.org/Pubs/502x0b3e1.pdf>

TLE -- the two line element format, <https://www.celestrak.org/columns/v04n03/>

SP3 -- The Extended Standard Product 3 Orbit Format (SP3-c) <https://files.igs.org/pub/data/format/sp3c.txt>

### 2.14 AEM\_FILE

**AEM\_FILE: aem\_file\_name or NONE**

Keyword AEM\_FILE specifies the name of the file with the a priori Earth rotation model. This file is one of the three files that describes the Earth's rotation in accordance to the empirical Earth rotation model formalism. The file should conform specifications of the AEM files. The AEM file defines values of "large" parameters, i.e. those parameters which squares are not-negligible. These are parameters for precession, several terms in nutation and several terms in the Earth's axial rotation.

## 2.15 ERM\_FILE

**ERM\_FILE: erm\_file\_name or NONE**

Keyword ERM\_FILE specifies the name of the file with the a priori Earth rotation model. This file is one of the three files that describes the Earth's rotation in accordance to the empirical Earth rotation model formalism. The file should conform specifications of the ERM files. The ERM file defines coefficients that describe long periodic, "small" variations in Earth's rotation, i.e. those parameters variations which squares are negligible. The coefficients of B-spline allows to compute the instantaneous vector of perturbations to the Earth's rotation. These file describes the slowly varying component of the Earth rotation.

## 2.16 HARMONIC\_EOP\_FILE:

**HARMONIC\_EOP\_FILE: [NONE or NERS or file\_name]**

Keyword HARMONIC\_EOP\_FILE specifies the name of the file with the harmonic Earth Orientation model. This models describes perturbation in the Earth orientation with respect to the a priori model specified by the a priori EOP files, a priori nutation, precession and built-in expression for the UT1 angle. The model is in the form

$$\sum (a + b*t)*\{\sin/\cos\}(\theta/2*t^2 + \omega*t + \text{phase})$$

The purpose of this model is to correct a priori EOP model specified in EOP\_SERIES, PRECESSION\_EXPRESSION, NUTATION\_EXPANSION, GEODESIC\_NUTATION keywords.

NERS -- the harmonic EOP variations are taken using the Network Earth Rotation Service (NERS) automatically. The NERS client control file specified by EOP\_SERIES keyword is used.

file\_name -- name of the file with the model in HEO format.

## 2.17 EOP\_SERIES:

**EOP\_SERIES: [NONE or NERS or ners\_configuration\_file or earth\_orientation\_parameters\_file]**

Earth\_orientation\_parameters\_file is the name of the file of the Earth orientation parameters either in EOP-MOD or NERS EOP series format, or NERS configuration file or NERS. The file with the Earth Orientation Parameters contains values of X-coordinate of the pole coordinate, Y-coordinate of the pole coordinate, and UT1 angle at the equidistant grid of time epochs.

NONE -- No external file with EOP series.  
(Supported when ERM formalism was chosen)

NERS -- The EOP data are taken using NERS. Default NERS client control file is used.

ners\_configuration\_file -- name of the control file for NERS client

earth\_orientation\_parameters\_file -- name of the file with Earth orientation parameters

VTD analyzes the first line of the file in order to determine whether it is the file with the Earth orientation parameters or the NERS configuration file.

## 2.18 EOP\_TIME\_SCALE:

**EOP\_TIME\_SCALE: time\_scale\_of\_eop\_table**

Time\_scale\_of\_eop\_table defines the time scale used for time tags in the table of the input Earth orientation series specified in the value of the keyword EOP\_SERIES. Supported values:

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TAI  
TDT  
TDB  
UTC  
UT1  
NERS -- the same as TAI  
NONE -- (Supported when ERM formalism was chosen)

### 2.19 UZT\_MODEL:

**UZT\_MODEL: [NONE or NERS or DICKMAN1993 or DICKMAN1993\_PRINCIPAL or DICKMAN1993\_SHORT]**

UT1\_zonal\_tides\_model\_name is the name of the model of UT1 variations induced by zonal tides. Supported values:

NONE -- no model is used.  
NERS -- the same as NONE  
DICKMAN1993 -- model of Dickman, 1993, all terms  
DICKMAN1993\_PRINCIPAL -- model of Dickman, 1993, only principal term and 14 terms which contributes to UT1 rate greater than 1.0D-14 rad/s  
DICKMAN1993\_SHORT -- model of Dickman, 1993, only terms with periods shorter than 60 days

### 2.20 UZT\_USE:

**UZT\_USE: [NONE or NERS or ADD or INTERPOLATE or SUBTRACT]**

The way how to apply the mode of UT1 variations induced by zonal tides.

NONE -- not to apply contribution of UT1 variations induced by zonal tides;  
NERS -- the same as NONE

## VTD keywords

**ADD** -- add contribution to UT1 caused by zonal tides to apriori EOP;

**SUBTRACT** -- subtract contribution to UT1 caused by zonal tides from a priori EOP;

**INTERPOLATE** -- the model is used for subtracting contribution to UT1 due to zonal tides before computation of interpolating coefficients, and then contribution of UT1 are added to final a priori UT1 values after interpolation.

### 2.21 EROT\_COMPAT:

**EROT\_COMPAT:** [NONE or NERS or CALC10 or NO\_SANG]

If specified, adds corrections to the a priori Earth rotation angles to be compatible with Calc10. It can be used for testing in order to precisely emulate values computed by Calc. These corrections DO NOT improve VLBI path delay prediction. This option is intended for tests only.

NONE (recommended) means that no emulation is performed.

NERS the same as NONE

### 2.22 PRECESSION\_EXPRESSION:

**PRECESSION\_EXPRESSION:** precession\_model\_name

Keyword PRECESSION\_EXPRESSION specifies the name of the precession model. Supported expansions:

**LIESE\_1977** -- Values of precession parameters from Lieske 1976.

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SIMON\_1994 -- Values of precession parameters from Simon 1994.  
IERS\_1996 -- Values of precession parameters from IERS 1996.  
CAPITAINE\_2003 -- Values of precession parameters from Capitaine 2003  
CAPITAINE\_2005 -- Values of precession parameters from Capitaine 2005  
NERS -- Precession is computed by the NERS. The NERS client  
control file specified by EOP\_SERIES keyword is used.  
NONE -- No precession (Supported when ERM formalism was chosen)

### 2.23 NUTATION\_EXPANSION:

**NUTATION\_EXPANSION: nutation\_expansion\_name**

Keyword NUTATION\_EXPANSION specifies the name of the nutation expansions.  
Supported expansions:

WAHR1980 -- Wahr 1980 nutation expansion. Expansion for Doodson  
arguments referred to at that paper are used.  
IERS1996 -- Empirical nutation expansion computed by T. Herring  
and presented in the IERS 1996 Conventions. Expansion  
for Doodson arguments referred to at that paper are used.  
REN2000 -- Theoretical expansion of the rigid Earth model by  
J. Souchay  
MHB2000 -- MHB2000 expansion according coefficients presented in  
the program which T. Herring posted on the Web.  
MHB2000\_TRANSF -- REN2000 expansion with the transfer function from  
Mathews et al, 2002 paper.  
MHB2000\_ADDON -- REN2000 expansion with the transfer function from  
Mathews et al, 2002 paper and all add-on terms listed  
at that paper.  
MHB2000\_PETA -- Simplified expansion to nutation with only three non-linear  
terms.  
NERS -- Nutation is computed by the NERS. The NERS client  
control file specified by EOP\_SERIES keyword is used.  
NONE -- No nutation (Supported when ERM formalism was chosen)

### 2.24 GEODESIC\_NUTATION:

### GEODESIC\_NUTATION usage\_flag

Keyword NUTATION\_EXPANSION specifies whether geodesic nutation should be modeled.

usage\_flag -- one of  
    YES -- to model geodesic nutation  
    NONE -- not to model geodesic nutation

## 2.25 SOLID\_EARTH\_TIDES\_ZERO\_FREQ:

### SOLID\_EARTH\_TIDES\_ZERO\_FREQ: Love\_model\_name

Keyword SOLID\_EARTH\_TIDES\_ZERO\_FREQ specifies the name of the model of Love numbers for the zeroth frequency. Unfortunately, several erroneous papers and thoughtless resolution of scientific societies created a great confusion about the issues of so-called "permanent tide". VTD allows a user to specify the model for computation of the zonal tides of the zero-th frequency.

Love\_model\_name -- model code. One of  
  
    MDG97AN -- Mathews, Dehant, Gipson 1997, anelastic  
                variant.  
    NONE -- consider Love numbers for the tides of  
            the second degree as zero.

## 2.26 SOLID\_EARTH\_TIDES\_2ND\_DEGREE:

### SOLID\_EARTH\_TIDES\_2ND\_DEGREE: Love\_model\_name

## VTD keywords

Keyword `SOLID_EARTH_TIDES_2ND_DEGREE` specifies the name of the model of Love numbers of the second degree as a function of frequency.

`Love_model_name` -- model code. One of

`MDG97EL` -- Mathews, Dehant, Gipson 1997, elastic variant.  
`MDG97AN` -- Mathews, Dehant, Gipson 1997, anelastic variant.  
`DDW99EH` -- Dehant, Defraigne, Wahr 1999, elastic, hydrostatic variant.  
`DDW99IN` -- Dehant, Defraigne, Wahr 1999, inelastic, non-hydrostatic variant.  
`LOVE` -- Love, 1923 model  
`MATHEWS_2000` -- Mathews, 2000 model  
`MATHEWS_2001` -- Mathews, 2001 model  
`NONE` -- consider Love numbers for the tides of the second degree as zero.

### 2.27 `SOLID_EARTH_TIDES_3RD_DEGREE`:

**`SOLID_EARTH_TIDES_3RD_DEGREE: Love_model_name`**

Keyword `SOLID_EARTH_TIDES_2ND_DEGREE` specifies the name of the model of Love numbers of the third degree.

`Love_model_name` -- model code. One of

`MDG97EL` -- Mathews, Dehant, Gipson 1997.  
`NONE` -- consider Love numbers for the tides of the second degree as zero.

### 2.28 `POLE_TIDE_MODEL`:



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### POLE\_TIDE\_MODEL: Love\_model\_name

Keyword POLE\_TIDE\_MODEL specifies the name of the model of Love numbers used for computation of the pole tide.

Love\_model\_name -- model code. One of

MDG97EL -- Mathews, Dehant, Gipson 1997, elastic  
variant.  
MDG97AN -- Mathews, Dehant, Gipson 1997, anelastic  
variant.  
DDW99EH -- Dehant, Defraigne, Wahr 1999, elastic,  
hydrostatic variant.  
DDW99IN -- Dehant, Defraigne, Wahr 1999, inelastic,  
non-hydrostatic variant.  
LOVE -- Love, 1923 model  
MATHEWS\_2000 -- Mathews, 2000 model  
MATHEWS\_2001 -- Mathews, 2001 model  
NONE -- consider Love numbers for the pole tides  
as zero.

## 2.29 MPL\_FILE:

### MEAN\_POLE\_MODEL: expression\_id

Keyword MEAN\_POLE\_MODEL MPL\_FILE specifies the name of the expression for the mean pole positions.

expression\_id -- one of

NONE -- mean pole positions is zero.

IERS2010 -- expression for pole tide following IERS2010 conventions.  
NB: THIS EXPRESSION IS WRONG!! It was included only  
for tests.

IERS2022 -- expression for pole tide following IERS2022 conventions.

## 2.30 POSVAR\_FIL:

**POSVAR\_FIL: model\_index model\_file\_name**

Keyword POSVAR\_FIL specifies the name of the file with the model of position variations.

model\_index -- the index of the model. Should be 1 if only one model of position variations is in use. Of more than one model is in use, then the models are numbered consecutively from 1 to the last model. Maximum 8 models can be specified.

model\_file\_name -- the name of the file with the model.

## 2.31 POSVAR\_MOD:

**POSVAR\_MOD: model\_index model\_type**

Keyword POSVAR\_MOD specifies the model type. Two types are supported: time series and harmonic site position variations model.

model\_index -- the index of the model. Should be 1 if only one model of position variations is in use. Of more than one model is in use, then the models are numbered consecutively from 1 to the last model. Maximum 8 models can be specified.

model\_type -- one of  
HARMONIC\_MODE -- the file is in HARPOS format:  
[http://astrogeo.org/psolve/doc/harpos\\_format.txt](http://astrogeo.org/psolve/doc/harpos_format.txt)  
TIME\_SERIES -- the file is in BINDISP format:  
[http://astrogeo.org/psolve/doc/bindisp\\_format.txt](http://astrogeo.org/psolve/doc/bindisp_format.txt)  
B\_SPLINE -- ...

## 2.32 POSVAR\_INT:

**POSVAR\_INT: model\_index interpolation\_type**

Keyword POSVAR\_MOD specifies the type of interpolation. The values of the position variations models are first read at several epoch around the time range of the experiment, then interpolation polynomials are computed. Position variations at the epoch of the observation are computed on the basis of this polynomial. Two interpolation types are supported: LINEAR and SPLINE

model\_index      -- the index of the model. Should be 1 if only one model of position variations is in use. Of more than one model is in use, then the models are numbered consecutively from 1 to the last model. Maximum 8 models can be specified.

interpolation\_type -- one of  
                     LINEAR  
                     SPLINE

## 2.33 POSVAR\_USE:

**POSVAR\_USE: model\_index usage\_flag**

Keyword POSVAR\_INT specifies the action of position variations model is not available for the requested station, requested epochs. An alternative is either issue a warning and continue or print the fatal error message and stop.

model\_index      -- the index of the model. Should be 1 if only one model of position variations is in use. Of more than one model is in use, then the models are numbered consecutively from 1 to the last model. Maximum 8 models can be specified.

interpolation\_type -- one of  
                     REQUIRED    -- if position variation model is not available for a requested station, requested epoch, then stop.

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IF\_AVAILABLE -- if position variation model is not available for a requested station, requested epoch, then print a warning, set variations to zero and continue.

### 2.34 AXIS\_OFFSET\_MODEL:

**AXIS\_OFFSET\_MODEL: usage\_flag**

usage\_flag -- the flag. Supported values:

YES -- (recommended) means that the contribution to delay due to antenna axis offset is taken into account.

NONE -- means that the contribution to delay caused by the antenna axis offset is ignored. It is used for tests only.

CALC9 -- forces VTD to emulate a bug in Calc9. This option is for tests only.

### 2.35 ANTENNA\_DEFORMATIONS\_FILE:

**ANTENNA\_DEFORMATIONS\_FILE: [NONE or agd\_file]**

Keyword ANTENNA\_DEFORMATIONS\_FILE specifies the file name that keeps parameters of the models of antenna deformation caused by gravity. The file should conform AGD specifications. The current model tabulates the change of the focal length as a function of elevation for each antenna. Some antenna may be missing from the agd\_file file. The contribution to delay caused by antenna deformations for these antenna will be set to zero.

### 2.36 ANTENNA\_THERMAL\_EXPANSION

**ANTENNA\_THERMAL\_EXPANSION NONE or [MODEL antenna\_information\_file  
INSITU [NONE or insitu\_file]  
TEMPERATURE [METEO or SPD]  
LAG time\_in\_seconds]**

Keyword ANTENNA\_THERMAL\_EXPANSION defines the mode for computing the contribution to time delay caused by antenna structures thermal expansion. The 1st qualifier may be NONE or MODEL. If the 1st qualifier is MODEL, then VTD expects to read 8 qualifiers. The second qualifier is the name of the antenna information file in the ANTI format. The antenna information file defines the type of each antenna, dimensions of the antenna structure and their coefficient of thermal expansion, reference temperature. Some antennas may be missing from this file. Contribution to path delay caused by antenna deformations of these antennas will be set to zero. The 3rd qualifier is INSITU. The 4th qualifier is the name of the file with information about antennas that have available data of their thermal height variation measurements with the invar rod. These stations will be excluded from computation of contribution due to antenna thermal deformation according to the model of thermal expansion. Position variations of the reference point for these antennas should be included to the model specified by POSVAR\_MOD, POSVAR\_FIL, POSVAR\_INT, POSVAR\_USE.

The antenna deformations caused by thermal expansion depend on the effective temperature of elements of antenna structure. The 5th qualifier is TEMPERATURE. It defines the source of temperature data defined in the 6th qualifier METEO or SPD. If METEO, then temperature is supplied with VTD\_METEO\_IN subroutine. These are usually data collected by local meteorological sensor. If SPD, then air temperature is supplied in SPD (slant path delay) data files. It is computed from the output of the global numerical weather model. The 7th qualifier is LAG. The 8th qualifier defines the lag of antenna temperature with respect to air temperature. Antenna temperature at time  $t$  is computed as air temperature at time  $t - \text{lag}$ .

Restrictions: TEMPERATURE SPD requires EXTERNAL\_DELAY\_DIR directory names be defined that supplied the source of information about expansion coefficients via 3D B-splines.

## 2.37 METEO\_DEF

### **METEO\_DEF model**

Qualifier METEO\_DEF defines the model that is used for computing missing meteorological parameters. If the atmospheric pressure and/or air temperature are negative, they are interpreted as missing.

default\_model:

IMA -- the model of the International Meteorological Association  
ISO Standard atmosphere 1976.

CALC -- Undocumented model that Calc uses. This model is for  
test only.

NONE -- not to change meteorological parameters. Keep in mind,  
that if NONE specified, subsequent computation of zenith  
path delay using SAASTAMOINEN model will be  
\_\_completely wrong\_\_.

## **2.38 HYDROSTATIC\_ZENITH\_DELAY:**

**HYDROSTATIC\_ZENITH\_DELAY: [NONE or zenith\_delay\_path\_model\_name or  
MMF mmd\_model\_file ]**

Keyword HYDROSTATIC\_ZENITH\_DELAY specifies the name of the a priori model for the hydrostatic component zenith path delay.

zenith\_delay\_path\_model\_name -- the name of the model. One of

NONE -- do not model hydrostatic path delay

SAASTAMOINEN -- Saastamoinen model

MMF -- the Mean Mapping Function mode (Petrov (2009), in  
preparation). Requires the name of the file with  
the MMF model in the following qualifier.

## **2.39 WET\_ZENITH\_DELAY:**

**WET\_ZENITH\_DELAY: [NONE or zenith\_delay\_path\_model\_name]**

Keyword WET\_ZENITH\_DELAY specifies the name of the a priori model for the non-hydrostatic component of the zenith path delay.

zenith\_delay\_path\_model\_name -- the name of the model. One of  
NONE -- do not model non-hydrostatic path delay  
MMF -- the Mean Mapping Function mode (Petrov (2009), in preparation). Requires the name of the file with the MMF model in the following qualifier.

## 2.40 HYDROSTATIC\_MAPPING\_FUNCTION:

**HYDROSTATIC\_MAPPING\_FUNCTION: [NONE or mapping\_function\_name or [MMF mmf\_mode file] ]**

Keyword HYDROSTATIC\_MAPPING\_FUNCTION defines the model for the mapping function for the hydrostatic component of the path delay -- dependence of the hydrostatic component of the atmospheric path delay with elevation. NB: the argument of the mapping function is so-called vacuum elevation: the elevation which the source would have in the absence of refractive atmosphere.

mapping\_function\_name -- the name of the mapping function. One of  
NMFH -- Niell 1996 mapping function.  
MMF -- the Mean Mapping Function mode (Petrov (2009), in preparation). Requires the name of the file with the MMF model in the following qualifier.

## 2.41 WET\_MAPPING\_FUNCTION:

**WET\_MAPPING\_FUNCTION: [NONE or mapping\_function\_name or [MMF mmf\_mode file]**

or external\_delay\_dir ]

Keyword WET\_MAPPING\_FUNCTION defines the model for the mapping function for the non-hydrostatic component of the path delay -- dependence of the non-hydrostatic component of the atmospheric path delay with elevation. NB: the argument of the mapping function is the so-called vacuum elevation: the elevation which the source would have in the absence of refractive atmosphere.

mapping\_function\_name -- the name of the mapping function. One of  
NMF -- Niell 1996 mapping function.  
MMF -- the Mean Mapping Function mode (Petrov (2009), in preparation). Requires the name of the file with the MMF model in the following qualifier.

## 2.42 ATMOSPHERE\_TILT\_PARTIALS:

**ATMOSPHERE\_TILT\_PARTIALS: tilt\_partials**

Keyword ATMOSPHERE\_TILT\_PARTIALS defines the model for partial derivatives of the atmospheric tilt, or using another words, atmospheric gradients.

tilt\_partials -- the name of tilt\_partials model.  
Currently, only one value is supported:  
MACMILLAN\_1995

## 2.43 SLANT\_PATH\_DELAY\_MODEL

**SLANT\_PATH\_DELAY\_MODEL [SPD\_3D or NONE]**

Keyword SLANT\_PATH\_DELAY defines that the path delay through the neutral atmosphere for a given elevation, azimuth, time for a given station should be computed by three-dimensional B-spline interpolation



## VTD keywords

of the time series of slant path delays. These time series of path delays are supposed to have been computed at an elevation/azimuth grid for each station using a standalone program SPD\_3D by solving numerically a system of non-linear differential equations of wave propagation through the 4D, heterogeneous atmosphere (L. Petrov, 2009, in preparation) represented by the 4D field of atmospheric parameters that are the output of a numerical weather model. NB: the contribution of the neutral atmosphere can be computed either by using mapping function approach (keywords HYDROSTATIC\_ZENITH\_DELAY, HYDROSTATIC\_MAPPING\_FUNCTION, WET\_MAPPING\_FUNCTION, WET\_ZENITH\_DELAY) or by SLANT\_PATH\_DELAY.

SPD\_3D -- slant path delay will be computed by interpolation of time series of B-spline coefficients stored in files that are kept directory EXTERNAL\_DELAY\_DIR (or EXTERNAL\_DELAY\_DIR\_2, EXTERNAL\_DELAY\_DIR\_3, EXTERNAL\_DELAY\_DIR\_4 if defined )

NONE -- algorithm for computing slant path delay by interpolation of time series of B-spline coefficients will be disabled.

In a case if slant path delay is not available for one or more stations, the a priori path delay is computed in accordance with values of keywords HYDROSTATIC\_ZENITH\_DELAY and HYDROSTATIC\_MAPPING\_FUNCTION.

### 2.44 SLANT\_PATH\_DELAY\_BIAS\_FILE

**SLANT\_PATH\_DELAY\_BIAS\_FILE [File or NONE]**

File with a constant bias in the slant path delay.

### 2.45 ATMOSPHERE\_PATH\_DELAY\_PARTIAL

**ATMOSPHERE\_PATH\_DELAY\_PARTIAL [NONE or NMW or NMF or IONO\_350 or IONO\_400 or IONO\_450 or IONO\_500 or TOTAL\_SCALE or TOTAL\_WATER or (GAUSSIAN\_LAYER [layer\_height layer\_fwhm])]**

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Keyword `ATMOSPHERE_PATH_DELAY_PARTIAL` defines partial derivative of slant path delay with respect to the path delay in zenith direction. This partial derivatives is not used for computing a priori path delay, but is supposed to be used for parameter estimation. The partial derivatives are placed in arrays `DER_DEL`, `DER_RAT`, in slots `VTD__DER_AT1` (partial derivatives for station #1) and `VTD__DER_AT2` (partial derivatives for station #2).

`NONE` -- no partial is computed

`NMFH` -- Niell (1996) hydrostatic mapping function

`NMFW` -- Niell (1996) wet mapping function

`IONO_350` -- mapping function for the case when residual atmosphere is described as a thin shell at height 350 km. Such a model is suitable for characterizing residual ionosphere.

`IONO_400` -- mapping function for the case when residual atmosphere is described as a thin shell at height 400 km. Such a model is suitable for characterizing residual ionosphere.

`IONO_450` -- mapping function for the case when residual atmosphere is described as a thin shell at height 450 km. Such a model is suitable for characterizing residual ionosphere.

`IONO_500` -- mapping function for the case when residual atmosphere is described as a thin shell at height 500 km. Such a model is suitable for characterizing residual ionosphere.

`TOTAL_SCALE` -- mapping function for the case when residual atmosphere is considered proportional to the total atmosphere. The partial derivative is defined as a ratio of the total slant path delay to the total path delay in the zenith direction. NB: this partial derivative requires

## VTD keywords

computation of a priori slant path delay  
(SLANT\_PATH SPD\_3D).

WATER\_SCALE -- mapping function for the case when residual atmosphere is considered proportional to the water vapor contribution to the atmosphere. The partial derivative is defined as a ratio of the water vapor contribution of slant path delay to the water vapor contribution to path delay in the zenith direction. NB: this partial derivative requires computation of a priori slant path delay (SLANT\_PATH SPD\_3D).

GAUSSIAN\_LAYER -- layer\_height layer\_fwhm -- mapping function for the case when the dependence of concentration of the residual atmosphere is described with the Gaussian model with the specified height and the specified full width half maximum (FWHM). The height of the layer in meters is specified in the 3rd qualifier and the FWHM in meter is specified in the 4th qualifier.

## 2.46 EXTERNAL\_DELAY\_DIR

**EXTERNAL\_DELAY\_DIR [NONE or directory\_name]**

Keyword EXTERNAL\_DELAY\_DIR specifies the directory name of files with external path delays. The format of these files is defined by SLANT\_PATH\_DELAY keyword. If SLANT\_PATH\_DELAY is SPD\_3D, then the files in the EXTERNAL\_DELAY\_DIR directory should satisfy spd\_3d\_bin specification. Each file contains the time series of the B-spline coefficients for a specific station.

## 2.47 EXTERNAL\_DELAY\_DIR\_2ND

**EXTERNAL\_DELAY\_DIR\_2ND [NONE or directory\_name]**

Keyword EXTERNAL\_PATH\_DELAY\_FILE specifies the secondary directory name of files with external path delays. Each file contains the time series of B-spline coefficients for a specific station. If a file for a given station is not found in directory EXTERNAL\_DELAY\_DIR, it is sought in directory EXTERNAL\_DELAY\_DIR\_2ND.

## **2.48 EXTERNAL\_DELAY\_DIR\_3RD**

**EXTERNAL\_DELAY\_DIR\_3RD [NONE or directory\_name]**

Keyword EXTERNAL\_PATH\_DELAY\_FILE specifies the name of third directory of files with external path delays. Each file contains the time series of B-spline coefficients for a specific station. If a file for a given station is not found in directories EXTERNAL\_DELAY\_DIR, EXTERNAL\_DELAY\_DIR\_2ND, it is sought in directory EXTERNAL\_DELAY\_DIR\_3RD.

## **2.49 EXTERNAL\_DELAY\_DIR\_4TH**

**EXTERNAL\_DELAY\_DIR\_4TG [NONE or directory\_name]**

Keyword EXTERNAL\_PATH\_DELAY\_FILE specifies the name of fourth directory of files with external path delays. Each file contains the time series of B-spline coefficients for a specific station. If a file for a given station is not found in directories EXTERNAL\_DELAY\_DIR, EXTERNAL\_DELAY\_DIR\_2ND, and EXTERNAL\_DELAY\_DIR\_3RD, it is sought in directory EXTERNAL\_DELAY\_DIR\_4TH.

## 2.50 IONOSPHERE\_MODEL:

**IONOSPHERE\_MODEL:** [NONE or GNSS\_TEC\_MAP]

Keyword IONOSPHERE\_MODEL specifies the ionospheric model for computation of path delay. Accepted values:

NONE      -- no ionosphere path delay is applied.

GNSS\_TEC\_MAP -- apply ionospheric path delay computed using GNSS TEC maps.

## 2.51 IONOSPHERE\_SCALE:

**IONOSPHERE\_SCALE:** value

Keyword IONOSPHERE\_SCALE specifies the scale factor. The ionospheric contribution computed from TEC maps is multiplied by that parameter.

## 2.52 SOU\_DEBIAS\_MODEL:

**SOU\_DEBIAS\_MODEL:** [None value]

Keyword SOU\_DEBIAS\_MODEL specifies the name of the source position de-bias model. It is for compensation of the source position bias caused by the the deficiency of an ionospheric model or other models. The contribution of the de-bias model to path delay is computed on the basis of an empirical model that describes the position bias in declination as a function of declination. Supported models: NONE, MAP\_850N, MAP\_750R, MAP\_780S.

## **2.53 IONOSPHERE\_DATA\_FILE:**

**IONOSPHERE\_DATA\_FILE: [NONE or file name]**

Keyword IONOSPHERE\_DATA\_FILE specifies a binary file ion viono format that keeps GNSS TEC maps for some period of time.

## **2.54 IONOSPHERE\_DATA\_FILE\_2ND:**

**IONOSPHERE\_DATA\_FILE\_2ND: [NONE or file\_name]**

Keyword IONOSPHERE\_DATA\_FILE\_2ND specifies a binary file ion viono format that keeps GNSS TEC maps for some period of time.

## **2.55 IONOSPHERE\_DATA\_FILE\_3RD:**

**IONOSPHERE\_DATA\_FILE\_3RD: [NONE or file\_name]**

Keyword IONOSPHERE\_DATA\_FILE\_3RD specifies a binary file ion viono format that keeps GNSS TEC maps for some period of time.

## **2.56 IONOSPHERE\_DATA\_FILE\_4TH:**

**IONOSPHERE\_DATA\_FILE\_4TH: [NONE or file\_name]**

Keyword IONOSPHERE\_DATA\_FILE\_4TH specifies a binary file ion viono format that keeps GNSS TEC maps for some period of time.

## **2.57 IONOSPHERE\_DATA\_FILE\_5TH:**

**IONOSPHERE\_DATA\_FILE\_5TH: [NONE or file\_name]**

Keyword IONOSPHERE\_DATA\_FILE\_5TH specifies a binary file ion viono format that keeps GNSS TEC maps for some period of time.

## **2.58 IONOSPHERE\_DATA\_FILE\_6TH:**

**IONOSPHERE\_DATA\_FILE\_6TH: [NONE or file\_name]**

Keyword IONOSPHERE\_DATA\_FILE\_7TH specifies a binary file ion viono format that keeps GNSS TEC maps for some period of time.

## **2.59 IONOSPHERE\_DATA\_FILE\_8TH:**

**IONOSPHERE\_DATA\_FILE\_8TH: [NONE or file\_name]**

Keyword IONOSPHERE\_DATA\_FILE\_8TH specifies a binary file ion viono format that keeps GNSS TEC maps for some period of time.

## **2.60 IONOSPHERE\_DATA\_FILE\_9TH:**

**IONOSPHERE\_DATA\_FILE\_9TH: [NONE or file\_name]**

Keyword IONOSPHERE\_DATA\_FILE\_9TH specifies a binary file ion viono format that keeps GNSS TEC maps for some period of time.

## **2.61 GRS\_METRIC:**

**GRS\_METRIC: metric\_identifier**

Keyword GRS\_METRIC specifies the name of the metric tensor for the geocentric reference system.

metric\_identifier -- Identifier of the metric tensor. Supported values:

IAU2000 -- the metric tensor proposed by Kopeikin and Brumberg. recommended by IAU2000 resolution.

ITRF2000 -- the metric tensor which was implicitly used in data analysis in the 20-th century, which was used for constructing the ITRF2000 catalogue of station positions and velocities.

Comment: recommendation of IERS2003 is contradictory: in one place the authors of Conventions claimed that they compliant with the IAU2000 recommendation, at another place they propose formulae based on ITRF2000 metric.

## **2.62 TROP\_AXOF\_COUPLING:**

**TROP\_AXOF\_COUPLING: usage\_flag**



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The keyword TROP\_AXOF\_COUPLING specifies whether to compute contribution to delay due to coupling of the troposphere path delay and antenna axis offsets. By another words TROP\_AXOF\_COUPLING takes into account additional troposphere path delay due to motion of the reference point.

usage\_flag -- the flag. Supported values:

- YES -- to compute contribution due to coupling of the troposphere path delay and antenna axis offsets.
- NO -- not to compute contribution due to this coupling.

### 2.63 TROP\_GEOMETRIC\_COUPLING:

**TROP\_GEOMETRIC\_COUPLING: usage\_flag**

The keyword TROP\_GEOMETRIC\_COUPLING specifies whether to compute the contribution to delay due to coupling of the troposphere path delay and geometric delay.

usage\_flag -- the flag. Supported values:

- YES -- to compute contribution due to coupling of the troposphere path delay and geometric delay.
- NO -- not to compute contribution due to this coupling.

### 2.64 PARALLACTIC\_ANGLE:

**PARALLACTIC\_ANGLE: usage\_flag**

The keyword PARALLACTIC\_ANGLE specifies whether to compute the contribution to phase delay and phase delay rate due to the parallactic angle. NB: the contribution of the parallactic angle to group delay is zero.

usage\_flag -- the flag. Supported values:

- YES -- to compute contribution to phase delay due

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parallactic angle  
NO -- not to compute contribution due to parallactic angle.

### 2.65 GALACTIC\_ABERRATION:

**GALACTIC\_ABERRATION:** *usage\_flag*

The keyword GALACTIC\_ABERRATION specifies whether to compute the contribution to delay caused by the galactic aberration.

*usage\_flag* -- the flag. Supported values:  
YES -- to compute contribution to phase delay due  
parallactic angle  
NO -- not to compute contribution due to parallactic angle.

### 2.66 GEOM\_EXPR\_FAR\_ZONE:

**GEOM\_EXPR\_FAR\_ZONE:** *model\_name*

The keyword GEOM\_EXPR\_FAR\_ZONE specifies the name of the expression for geometric delay in far zone (larger than 10 pc) in vacuum based on general relativity.

*model\_name* -- the name of the expression. Supported values:  
KS\_1999 -- expression Kopeikin and Schaefer, 1999  
PK\_2001 -- expression Petrov and Kopeikin, 2001 (recommended)

### 2.67 GEOM\_EXPR\_NEAR\_ZONE:

**GEOM\_EXPR\_NEAR\_ZONE:** *model\_name*

## VTD keywords

The keyword `GEOM_EXPR_NEAR_ZONE` specifies the name of the expression for geometric delay in the near zone (from Earth's satellite to 10 pc) in vacuum based on general relativity.

`model_name` -- the name of the expression. Supported values:

`LIGHT_TIME` -- iterative solution of the light equation

`JN_2019` -- Jaron, Nothnageeel expersion

### 2.68 SOURCE\_STRUCTURE:

**SOURCE\_STRUCTURE:** `control_file_name`

The keyword `SOURCE_STRUCTURE` specifies the control file for modeling contribution to delay due to source structure.

`control_file_name` -- the name of the control file or

`NO` -- contribution to delay due to source structure  
will not be computed.

This option is currently being tested.

### 2.69 DOPPLER\_EXPR:

**DOPPLER\_EXPR:** `model_name`

The keyword `DOPPLER_EXPR` specifies the name of the expression for computation of the Doppler frequency shift for an object within the Solar system based on general relativity.

### 2.70 DELAY\_RATE:

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### DELAY\_RATE: YES or NONE

The keyword DELAY\_RATE specifies whether to compute delay rate.  
If DELAY\_RATE is NONE computation runs faster.

YES -- to compute delay rate using analytical expressions.

NO -- not to compute delay rate.

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Questions and comments about this guide should be directed to:

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