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DSN ODF (Orbit Data File) Calibration Software:
Doppler Level 1b to Level 2
Software Design Specifications

Issue:	**4**
Revision:	**0**
Date:	**05.04.2007**
Document:	**MEX-MRS-IGM-DS-3038** **ROS-RSI-IGM-DS-3128** **VEX-VRA-IGM-DS-5009**

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Document Change Record

Issue	Rev	Sec	Date	Changes	author
Draft	0	All	29.11.2003	first version	mpa
1	0	2.1 2.5 2.6	12.02.2004	ODF-DOP-SPEC-2180 updated ODF-DOP-SPEC-2550 corrected ODF-DOP-SPEC-2560 corrected ODF-DOP-SPEC-2622 included ODF-DOP-SPEC-2630 revised	mpa
2	0	all	23.09.2004	document split Here only Doppler processing	mpa
2	1		24.10.2004		mpa
2	2	1.3 1.4 2.3.2 3.2 4	13.03.2005	After review: New section 1.3: software control New section 1.4: action item list New section 2.3.2 New section 3.2 New tables 4-2 and 4-3	mpa
3	0	all	16.11.2005	Complete revision	T.A.
4	0	5.1	05.04.2007	Changes in GUI-section	M.H.

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ACRONYMS

A/D	Analog/Digital
AGC	Automatic Gain Control
AGVTP	Archive Generation, Validation and Transfer Plan
AOL	Amplitude Open Loop
ATDF	Archival Tracking Data Format
CD-ROM	Compact Disk - Read Only Memory
CL	Closed-Loop
DDS	Data Delivery System
DSN	Deep Space Network
DVD	Digital Versatile Disk
ESA	European Space Agency
ESOC	European Space Operation Center
ESTEC	European Space Technology Center
FOL	Frequency Open Loop
G/S	Ground Station
HGA	High Gain Antenna
ODF	Intermediate Frequency Modulation System
JPL	Jet Propulsion Laboratory
LCP	Left Circular Polarization
LGA	Low Gain Antenna
LOS	Line Of Sight
MaRS	Mars Express Radio Science Experiment
MGA	Medium Gain Antenna
MGS	Mars Global Surveyor
NASA	National Aeronautics and Space Administration
ODF	DSN Original Data File
ODR	Original Data Record
OL	Open-Loop
ONED	one-way dual-frequency mode
ONES	One-way single-frequency mode
PDS	Planetary Data System
POL	Polarization Open Loop
RCP	Right Circular Polarization
RSR	Radio Science Receiver
RX	Receiver
S/C	Spacecraft

SIS	Software Interface Specification
S-TX	S-Band Transmitter
SPICE	Space Planet Instrument C-Matrix Events
TBC	To Be Confirmed
TBD	To Be Determined
TWOD	Two-way dual-frequency mode
TWOS	Two-way single-frequency mode
USO	Ultra Stable Oszillator
X-TX	X-band Transmitter

Contents

1 INTRODUCTION

1.1 SCOPE

This document specifies the requirements for the development of the Orbit data File (ODF) calibration software, transferring Level 1b ODF Doppler data towards Level 2. The software shall analyze radio Doppler tracking data recorded at the DSN ground stations.

1.2 REFERENCED DOCUMENTS

	Reference Number	Title	Issue Number	Date
[1]	MEX-MRS-IGM-IS-3016	Radio Science File naming Convention	11.0	24.10.2004
[2]	TRK-2-18	Orbit Data File Interface	change 3	15.06.2000
[3]	MEX-MRS-IGM-DS-3037	ODF Processing Software: L1a to L1b	3.4	08.11.2005

1.3 SOFTWARE CONFIGURATION CONTROL

This document addresses the software package

DSN_ODF_PROC_DOP_L1B_TO_L02

Version 1.2

After release, the software is under configuration control which will be documented in this section.

Version number	Changes/Action	New version	Release date
V1.0	First working release	V1.1	24.05.2005
V1.1	Impact Parameter for Phobos and Solar corona implemented Generation of L1B directory implemented Modification of the log file (now similar to that of the IFMS Doppler processing software)	V1.2	30.08.2005
V1.2	Automatisation of getting the names of the input files Automatic processing implemented		15.11.2005

2 SPECIFICATIONS FOR LEVEL 1B TO LEVEL 2 CALIBRATION

2.1 MAIN PROGRAM SPECIFICATIONS

2.1.1 General specifications

ODF-DOP-SPEC-2110: This software shall

- Read Level 1b ODF data
- Apply Earth troposphere calibration to the Doppler data
- Compute differential Doppler values if two frequencies are available and the sample interval of S-band and X-band is equal
- Apply plasma calibration to the Doppler data either by using differential frequency data or by using a so called Klobucher Modell for the ionosphere of the earth (see section 3.4.4 for more information)
- Apply the Doppler predicts in order to compute residuals
- Output the results as level 2 data
- Generate PDS label files for the output files

ODF-DOP-SPEC-2120: the software language is FORTRAN and Perl.

ODF-DOP-SPEC-2122: The data processing options are

(a) occultation
(b) global gravity,
(c) target gravity
(d) solar corona
(e) Phobos

is selected via a graphical user interface. This graphical user interface will be described in section 5.1.

2.1.2 Modules

The main program uses a number of modules

1. M_READ_ODF_INPUT
2. M_ODF_SETTINGS
3. M_PREDICT
4. M_CALIBRATION
5. M_IONO_CALIB
6. M_OUTPUT
7. M_TRACKING_TIME
8. M_GLOBAL_VAR
9. M_DOPPLER

and some general modules, wherein shared subroutines and functions are provided

10. M_FILE_UTILITIES
11. M_SPICE
12. M_ERROR
13. M_UTILITIES
14. M_FILE_NAMING_CONVENTION
15. M_LABEL
16. M_INTERPOL
17. M_SEARCH
18. M_TYPE_PARAMETER

The software describing flow diagram is shown in Figure 2-1. There are only shown the internal dependencies in the stand alone Fortran software. No interdependencies between the Fortran software and the graphical user interface are shown. The only interaction between the Fortran and the Perl software is done by the odf_process_option.txt file which is produced by the Perl graphical user interface and contains processing information. A detailed description of the odf_process_option.txt file is given in section 5

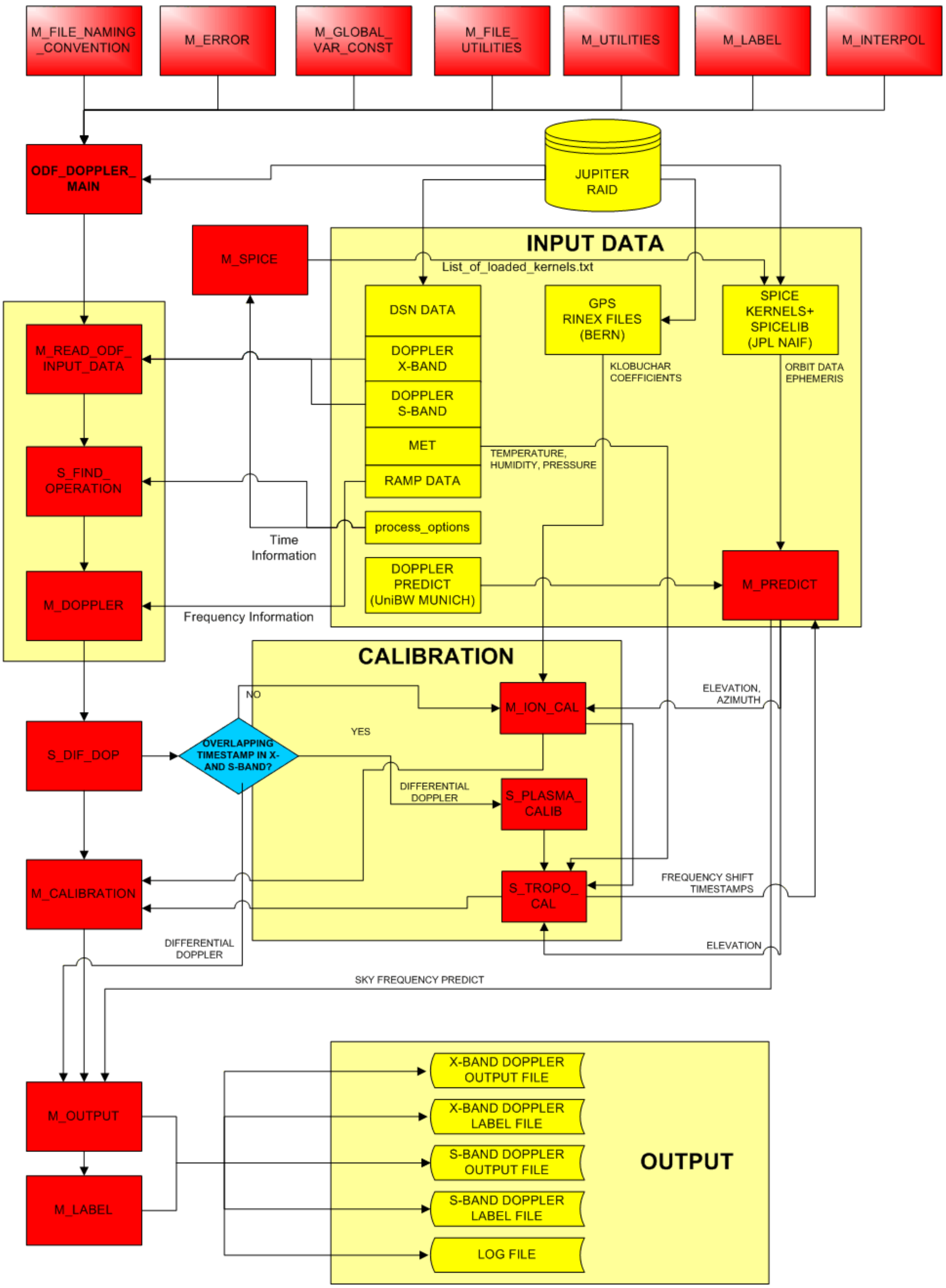
M_FILE_NAMING_CONVENTION
M_ERROR
M_GLOBAL_VAR_CONST
M_FILE_UTILITIES
M_UTILITIES
M_LABEL
M_INTERPOL
ODF_DOPPLER_MAIN
JUPITER RAID
INPUT DATA
M_SPICE
List_of_loaded_kernels.txt
DSN DATA
DOPPLER X-BAND
DOPPLER S-BAND
MET
RAMP DATA
process_options
DOPPLER PREDICT (UniBW MUNICH)
GPS RINEX FILES (BERN)
SPICE KERNELS+ SPICELIB (JPL NAIF)
KLOBUCHAR COEFFICIENTS
ORBIT DATA EPHEMERIS
TEMPERATURE, HUMIDITY, PRESSURE
M_READ_ODF_INPUT_DATA
S_FIND_OPERATION
M_DOPPLER
Time Information
Frequency Information
M_PREDICT
CALIBRATION
NO
YES
M_ION_CAL
ELEVATION, AZIMUTH
S_DIF_DOP
OVERLAPPING TIMESTAMP IN X- AND S-BAND?
DIFFERENTIAL DOPPLER
S_PLASMA_CALIB
M_CALIBRATION
S_TROPO_CAL
FREQUENCY SHIFT TIMESTAMPS
ELEVATION
DIFFERENTIAL DOPPLER
SKY FREQUENCY PREDICT
M_OUTPUT
M_LABEL
X-BAND DOPPLER OUTPUT FILE
X-BAND DOPPLER LABEL FILE
S-BAND DOPPLER OUTPUT FILE
S-BAND DOPPLER LABEL FILE
LOG FILE
OUTPUT

Figure 2-1: Flowchart for evaluation software for the ODF Doppler data

2.1.3 Input files

2.1.3.1 Data file types

ODF-DOP-SPEC-2130: the following table defines the input file types and the logical file names used in this specification and within the software:

File Description	Logical name within program
S-band Doppler file	ODF_DOP_S
X-band Doppler file	ODF_DOP_X
Uplink ramp rate file	ODF_RAMP
DSN Media calibration	DSN_MET_MOD
Doppler predict file	PREDICT_FILE
Klobuchar coefficients for Earth ionosphere calibration	ION_COEFF
SPICE Kernels	N/A

ODF-DOP-SPEC-2135: input file names will be selected automatically based on information given in the graphical interface described in section 0 via a Windows interface if the processing should be done manually and if the processing should be done automatically via a log file described in section 4.3.1.1.

ODF-DOP-SPEC-2140: Klobuchar coefficients are only needed if X-band and S-band Doppler files have no overlapping timestamp or the kind of data processing is occultation

2.1.3.2 File names

ODF-DOP-SPEC-2145: Level 1b file names are defined in [1] section 4.1

For the Doppler files:

If the sample interval is 60 seconds:

r00ODF0L1B_DPS_yydddhhmm_qq.TAB
r00ODF0L1B_DPX_yydddhhmm_qq.TAB

and if it is 1 second:

rggODFsL1B_DPS_yydddhhmm_qq.TAB
rggODFsL1B_DPX_yydddhhmm_qq.TAB

where s can be X for a X-band file and S for a S-band file and serves as identifier for files with 1 second sample interval.

for the ramp rate file:

rg00DSN0_L1B_RMP_yydddhhmm_qq.TAB

for the meteorological file:

rggDSN0L1B_MET_yydddhhmm_qq.TAB

For the predict file:

rggUNBWL02_RTW_yydddhhmm_qq.TAB

2.1.3.3 File Formats

ODF-DOP-SPEC-2150: File formats are defined in [1] and [3].

2.1.4 Definition of constants

ODF-DOP-SPEC-2160: ASTRONOMICAL UNIT (AU)

1 AU = 149,597,870 kilometers

ODF-DOP-SPEC-2165: SPEED OF LIGHT

c = 299,792,458 m/s

ODF-DOP-SPEC-2170: RANGE UNIT (RU)

1 RU = 0.30 m

ODF-DOP-SPEC-2175: PHYSICAL CONSTANTS

Constant		Value	SI units
Electron charge	e	$1.6022\ 10^{-19}$	A s
Electron mass	m_e	$9.1094\ 10^{-31}$	kg
Electric field constant	ε_0	$8.8542\ 10^{-12}$	$s^4\ A^2\ m^{-3}\ kg^{-1}$
Plasma constant	$\frac{1}{2}\frac{1}{4\pi^2}\frac{e^2}{m_e\varepsilon_0}$	40.30924	$m^3\ s^{-2}$

ODF-DOP-SPEC-2180: CARRIER FREQUENCIES Mars Express

Mars Express:

frequency band	uplink	downlink
S-band	2114.676 MHz	2296.482 MHz
X-band	7116.936 MHz	8420.432 MHz

ODF-DOP-SPEC-2185: Transponder constants and ratios

Mars Express:

frequency band uplink	transponder ratios downlink/uplink	
	S-band	X-band
S-band	240/211	880/211
X-band	240/749	880/749

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3 LEVEL 1B TO LEVEL 2 SOFTWARE SPECIFICATIONS

3.1 MODULE M_READ_ODF_INPUT

Module M_READ_ODF_INPUT contains subroutines and functions in order to read data from ODF_DOP_S, ODF_DOP_X, ODF_RAMP and DSN_MET_MOD. All data are read in from ODF_DOP_S, ODF_DOP_X, ODF_RAMP and DSN_MET_MOD. ODF_DOP_S, ODF_DOP_X and ODF_RAMP can contain data from several ground stations and timestamps with different sample intervals.

ODF_DOP_SPEC-3100: The data in ODF_DOP_S, ODF_DOP_X and ODF_RAMP are stored in arrays and transferred to M_TRACKING_TIME to analyze it and find the appropriate data of predetermined operations.

ODF_DOP_SPEC-3110: The data in DSN_MET_MOD are stored in an array an transferred to M_CALIBRATION in order to compute the tropospheric calibration

3.2 MODULE M_TRACKING_TIME

Module M_TRACKING_TIME provides routines in order to analyze the data contained in ODF_DOP_S, ODF_DOP_X and ODF_RAMP and find the appropriate data of predetermined operations.

ODF-DOP-SPEC-3200: Subroutine S_FIND_OPERATION accepts the start time, stop time and the respective ground station of one or more operations from the odf_process_options.txt file. For more details on the odf_process_options.txt file see section 5.

ODF-DOP-SPEC-3210: Subroutine S_FIND_OPERATION find in the arrays containing the data from ODF_DOP_S, ODF_DOP_X and ODF_RAMP the respective start index and stop index of the array for the predetermined operations defined in the odf_process_options.txt file.

ODF-DOP-SPEC-3220: The start and stop index of one ore more operations are stored in the self defined data type t_log and transferred to M_DOPPLER.

ODF-DOP-SPEC-3230: The arrays containing the data from ODF_DOP_S, ODF_DOP_X and ODF_RAMP are transferred to M_DOPPLER in order to compute the received antenna frequency and to reconstruct the uplink frequency for the specified operations.

3.3 MODULE M_DOPPLER

Module M_DOPPLER provides several subroutines and functions in order to compute the received antenna frequency and to reconstruct the uplink frequency.

ODF-DOP-SPEC-3300: Subroutine S_CALC_REC_FREQ accepts each array containing the data from ODF_DOP_S or ODF_DOP_X and the respective start and stop index of one specified operation.

ODF-DOP-SPEC-3310: The received antenna frequency $f_{antenna}$ is computed in subroutine S_CALC_REC_FREQ according to the following equation and transferred to M_OUTPUT.

$$f_{antenna}\left(t_i\right) = k \cdot f_{ref}\left(t_i\right) - f_{obs}\left(t_i\right)$$

Whereas

k the transponder ratio depending on the uplink and downlink frequency (see ODF-DOP-SPEC-2185 for available values),

f_ref the reference frequency, column 13 in ODF_DOP_S or ODF_DOP_X and

f_obs the observed Doppler, column 12 in ODF_DOP_S or ODF_DOP_X indicates.

Reconstruction of the uplink frequency

This is done for each frequency band.

ODF-DOP-SPEC-3320: Subroutine S_REC_UP_FREQ accepts the array containing data from ODF_RAMP and the respective start and stop index of one specified operation.

ODF-DOP-SPEC-3330: The uplink frequency *f_up* is computed in subroutine S_REC_UP_FREQ via the following equation.

$$f_{up}\left(t_i\right) = \Delta t \cdot f_{rate}\left(t_i\right) + f_{ramp}\left(t_i\right) \quad \text{with} \quad \Delta t = t_i - t_{start,f_{ramp}}$$

Whereas

t_i the current time stamp,

f_{rate} the ramp rate, column 9 in ODF_RAMP,

f_{ramp} the ramp start frequency, column 10 in ODF_RAMP, and

$t_{start,framp}$ the ramp start time, column 2 in ODF_RAMP, indicates.

3.4 MODULES M_CALIBRATION AND M_IONO_CALIB

Module M_CALIBRATION provides several subroutines in order to correct for the contribution by the propagation through the plasma and the neutral Earth troposphere.
Module M_IONO_CALIB provides several subroutines to compute the correction for the Earth ionosphere, i.e. the ionospheric delay in nanoseconds, using the so called Klobuchar model for the Earth ionosphere.
Plasma media correction can only be performed if two downlink frequencies have been recorded and is done only for gravity observations. If only one frequency is available or for occultation observations, the Earth ionosphere is corrected via the Klobuchar model.

3.4.1 Tropospheric calibration

Subroutine S_TROP_CALIB uses the meteo data observed at the respective ground station to compute the path delay (unit is meter) of the dry and wet component of the Earth troposphere and calculate from the path delay the total correction for the Earth troposphere in Hz.

ODF-DOP-SPEC-3405: Troposheric calibration
The path delay (unit is meter) of the dry and wet component of the Earth troposphere is (Hofmann-Wellenhoff et al., Global Positioning System, 4th Ed.):

$$\begin{aligned}\Delta_{dry}(E) &= \frac{10^{-6}}{5}\frac{77.64\frac{p}{T}}{\sin\left(\sqrt{E^2+6.25}\right)}\left[40136+148.72(T-273.16)\right]\\ \Delta_{wet}(E) &= \frac{10^{-6}}{5}\frac{-12.96T+3.718\cdot 10^5}{\sin\left(\sqrt{E^2+2.25}\right)}\frac{e}{T^2}11000\end{aligned} \tag{1.1}$$

where *p*, *T* and *e* are the atmospheric pressure, Temperature and partial water vapour pressure, respectively, as observed at the ground station site.
These values are given in the ODF_METEO file. The elevation angle E (unit in degrees) is provided by M_PREDICT.
The following transformations have to be applied:

	equation (20)	ODF_METEO	M_PREDICT
pressure *p*	mbar	hPascal	-
Temperature *T*	Kelvin	°Celsius	-
Water vapour partial pressure *e*	hPascal	-	-
humidity *h*	-	% humidity	-
elevation *E*	degrees	-	radian

The relation between the water vapour partial pressure and the humidity given in ODF_METEO is:

$$e = 6.108 \cdot 10^{-2} \cdot humidity[\%] \cdot \exp\left\{\frac{17.393(T-272.15)}{T-33.95}\right\} \qquad (1.2)$$

The total tropospheric calibration expressed as delay time in seconds is:

$$\tau_{tropo} = \frac{2}{c}\left\{\Delta_{dry}(E) + \Delta_{wet}(E)\right\} \qquad (1.3)$$

for the two-way radio link where c is the speed of light with definition given in ODF-DOP-SPEC-2165 and

$$\tau_{tropo} = \frac{1}{c}\left\{\Delta_{dry}(E) + \Delta_{wet}(E)\right\}$$

for the one-way radio link.

ODF-DOP-SPEC-3410: The correction for the Earth troposphere is then for one-way radio link:

$$m_{ONE} = \tau_{tropo} \cdot f_{down} \qquad (1.4)$$

and for the two-way radio link:

$$m_{TWO} = \tau_{tropo} \cdot \left(f_{down} + f_{up}\right) \qquad (1.5)$$

where m is the cycle advance and the shift in frequency is:

$$\Delta f_{ONE,tropo} = \frac{dm_{ONE}}{dt} \qquad (1.6)$$

and for the two-way radio link:

$$\Delta f_{TWO,tropo} = \frac{dm_{TWO}}{dt} \qquad (1.7)$$

This is done for each frequency band.

ODF-DOP-SPEC-3415: The result from ODF-DOP-SPEC-3410 is transferred to M_OUTPUT, added to the respective plasma correction described below and the sum is stored in column 11.

ODF-DOP-SPEC-3420: The result from ODF-DOP-SPEC-3410 is transferred to M_OUTPUT and added to the predicted Doppler data (see section 3.6)

3.4.2 Differential Doppler

Subroutine S_DIFF_DOP finds out whether ODF level 1a Doppler data at X-band and S-band are overlapping in time. If this is the case and the ODF level 1a Doppler data at X-band and S-band having the same sample interval the differential Doppler is computed.

ODF-DOP-SPEC-3425: Differential Doppler
The result from ODF-DOP-SPEC-2363 is taken to compute the differential Doppler

$$\delta f = f_{S,antenna} - \frac{3}{11} f_{X,antenna} \tag{1.8}$$

ODF-DOP-SPEC-3426: The result from ODF-DOP-SPEC-3425 is transferred to M_OUTPUT and stored in column 14.

3.4.3 Plasma calibration using the differential doppler

Subroutine S_PLASMA_CALIB calculates the temporal change in electron content from the differential Doppler and the according frequency-shift in antenna frequency at X-band and S-band

ODF-DOP-SPEC-3430: Plasma calibration
Derive the temporal change in electron content from the differential Doppler and computes the dispersive frequency shift for each frequency band. f_s and f_x are downlink carrier frequencies and *c* is the speed of light, all defined in section 1.

$$\begin{aligned} \delta f &= -\frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e\varepsilon_0}\left\{\frac{1}{f_S^2}-\frac{1}{f_X^2}\right\} f_S \frac{dI}{dt} \\ \Rightarrow \frac{dI}{dt} &= -\left\{\frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e\varepsilon_0}\right\}^{-1}\frac{\delta f}{f_S}\left\{\frac{1}{f_S^2}-\frac{1}{f_X^2}\right\}^{-1} \end{aligned} \tag{1.9}$$

ODF-DOP-SPEC-3431: Plasma correction
The temporal change in electron content will be used to correct for the downlink plasma propagation for gravity observations only:

$$\Delta f_{S,plasma,cal} = \frac{40.31}{c}\frac{1}{f_S}\frac{dI}{dt}$$
$$\Delta f_{X,plasma,cal} = \frac{40.31}{c}\frac{1}{f_X}\frac{dI}{dt} \qquad (1.10)$$

If equation (1.9) is applied to equation (1.10), the plasma correction is than

$$\Delta f_{S,plasma,cal} = \delta f \frac{121}{112}$$
$$\Delta f_{X,plasma,cal} = \delta f \frac{33}{112} \qquad (1.11)$$

For further details see APPENDIX B

ODF-DOP-SPEC-3432: The result from ODF-DOP-SPEC-3431 is transferred to M_OUTPUT added to the tropospheric correction described above and the sum is stored in column 11

ODF-DOP-SPEC-3433: The result from ODF-DOP-SPEC-3431 is transferred to M_OUTPUT and added to the predicted Doppler data (see section 3.6)

3.4.4 Plasma calibration using the Klobuchar model

If only one frequency is available or the kind of data processing is Occultation, the Earth ionosphere plasma has to be modeled. Module M_IONO_CAL contains subroutines in order to provide a model of the electron content of the Earth ionosphere and will be described below in detail.

3.4.4.1 The Klobuchar model

Module M_IONO_CALIB contains several subroutines to provide a model of the electron content of the Earth ionosphere at any local time and pointing direction of the ground station antenna and determines the path delay. This is done using the Klobuchar model introducing the Klobuchar coefficients from GPS measurements of the International GPS Service (IGS). The IGS is based on about 200 globally distributed permanent GPS tracking sites. The coefficients used by module M_IONO_CALIB come from one of the seven IGS Analysis Center: the Center for Orbit Determination in Europe (CODE) of the Astronomical Institute of the University of Berne (AIUB), Switzerland.

CODE generates Global ionosphere maps (GIM) on a daily basis using data from about 200 GPS/GLONASS sites of the IGS and other institutions. The vertical total electron content (VTEC) is modelled in a solar-geomagnetic reference frame using a spherical harmonics expansion up to degree and order 15. Piece-wise linear functions are used for representation in the time domain. The time spacing of their vertices is 2 hours, conforming with the epochs of the VTEC maps. Instrumental biases, so-called differential P1-P2 code biases (DCB), for all GPS satellites and ground stations are estimated as constant values for each day, simultaneously with the 13 times 256, or 3328 parameters used to represent the global VTEC distribution. The DCB datum is defined by a zero-mean condition imposed on the satellite bias estimates. P1-C1 bias corrections are taken into account if needed. To convert line-of-sight TEC into vertical TEC, a modified single-layer model mapping (MSLM) mapping function approximating the JPL extended slab model mapping function is adopted. The global coverage of the GPS tracking ground stations considered at CODE is shown figure 3.5.1 including abbreviations for station identification.

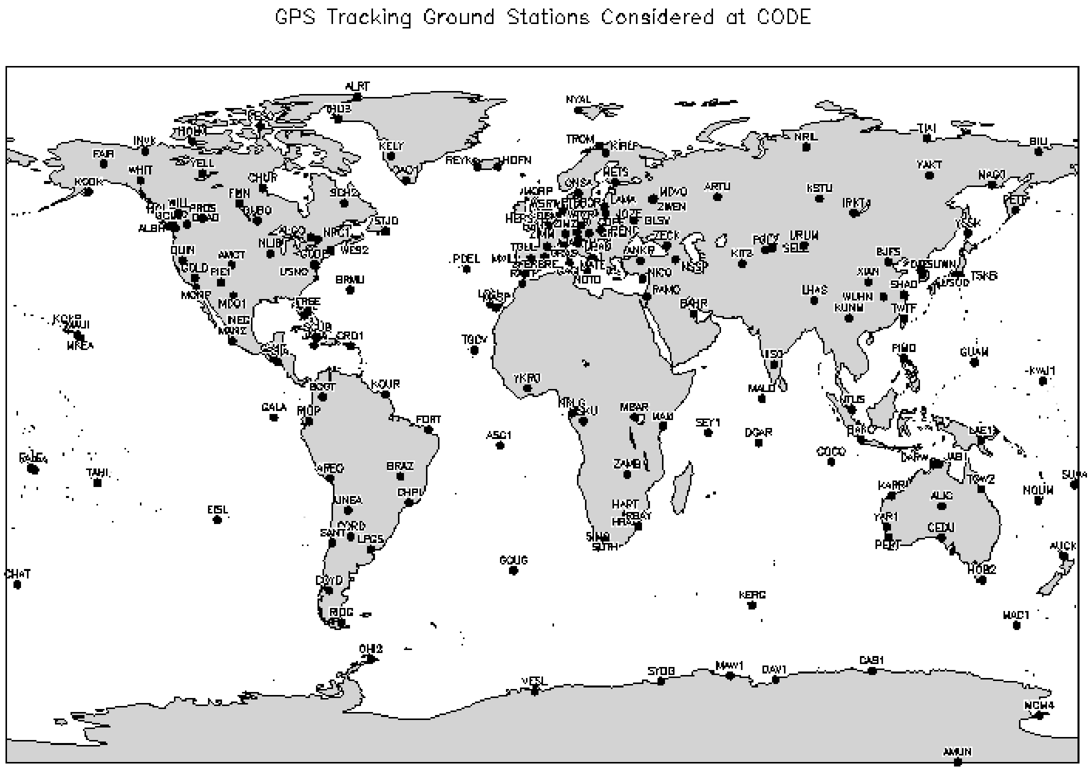

Figure 3-1: GPS Tracking Ground Stations

CODE computes Klobuchar-style ionospheric coefficients (alphas and betas) best fitting the IONosphere map EXchange data (IONEX) on a regular basis. The description how the Klobuchar coefficients are computed and on which ionopsheric model they are based on can be found in ANNEX B.

The data files containing the Klobuchar coefficients are named `CGIMddd0.yyN`, where `ddd` and `yy` substitute doy and 2-digit year. Those coefficients derived from a final IONEX product are stored under `ftp://ftp.unibe.ch/aiub/CODE/` in `yyyy`-specific subdirectories as of 1995. For the few days where the final product is not yet available, rapid as well as predicted coefficients serving real-time applications may be found generally at `ftp://ftp.unibe.ch/aiub/CODE/`. CGIM2410.04N_R contains the latest set of rapid coefficients; `CGIM2420.04N_P` and `CGIM2430.04N_P2` contain the current 1-day and 2-day predicted coefficients, respectively.
Unlike the original Klobuchar ionosphere model which is based on a total of 370 possible sets of base coefficients and which is therefore of discrete nature, the model derived by CODE is not subject to a similar restriction. All the night-time TEC level of this type of ionosphere model is hard-wired to 5 nanoseconds of ionospheric delay on the first GPS frequency (corresponding to approximately 9 TECU). Because the Klobuchar-style TEC parameterization may be unpleasant at the polar caps and especially at the poles, CODE displays a corresponding warning in the RINEX navigation data files in case the TEC above a latitude of 75 degrees reaches day-time level. The format of RINEX data files is described in ANNEX C.

The module is currently only valid for the NNO ground station.

ODF-DOP-SPEC-3440: Module M_IONO_CALIB accepts the actual needed Klobuchar coefficients (described above) from input file ION_COEFF. The input file can be downloaded from

ftp.unibe.ch/aiub/CODE/

M_IONO_CALIB needs several input parameters, which are listed in the table below.

Parameter	Description	Unit
Phi	Geodetic latitude of receiver	Degree
Lambda	Geodetic longitude of receiver	Degree
TOW	Time of Week	Degree
Beta	The coefficients of a cubic equation representing the amplitude of the vertical delay	
Alpha	The coefficients of a cubic equation representing the period of the model	

Table 3-1: Input parameter of M_IONO_CALIB

ODF-DOP-SPEC-3441: The output of Module M_IONO_CALIB is the ionospheric slant range correction τ_{iono}. The unit of τ_{iono} is seconds. The calculation of τ_{iono} is described in ODF-DOP-SPEC-3442**.**

ODF-DOP-SPEC-3442: The computation of the ionospheric slant range correction $\boldsymbol{\tau_{iono}}$ depends on the local time at the ground station side. For the calculation of $\boldsymbol{\tau_{iono}}$ the following parameters are used:

1. **Local Time t:**

   t = 4.32·long_i + TOW

2. **Azimuth a (in radian):**

   a = azimuth·pi /180
   !

3. **Elevation angle e (in semicircles):**

   e = elev·1./180
   !

4. **Earth Centered angle psi:**

   psi = 0.0137/ (e+0.11) - 0.022

5. **Subionospheric longitude long_i :**

   long_i = lambda·1./180.+ (psi·DSIN(a)/DCOS(lat_i·pi))

6. **Subionospheric latitude lat_i :**

   lat_i = phi·1./180+ psi·DCOS(a)

7. **Time of the Week TOW (output of the subroutine S_GPSTIME)**

   t = DMOD(t,86400.) !

8. **Slant factor sf:**

   sf = 1. + 16. · $(0.53\text{-e})^3$!

9. **Period of model PER:**

   If PER less than 72000.D0

PER = 72000.

Else

PER = beta(1) + beta(2) ·lat_m + beta(3) ·lat_m^2 +beta(4) ·lat_m^3

10. **Phase of the model x (Maximum at 14.00 =! 50400 sec local time):**

x = 2.·pi·(t-50400.) / PER !

11. **Amplitude of the model AMP:**

AMP = alpha (1) + alpha (2) ·lat_m + alpha (3) ·lat_m^2 +alpha(4) ·lat_m^3

12. **Ionospheric slant correction τ_{iono}:**

Night (DABS(x) greater Than 1.57):

τ_{iono} = sf · (5.D-9)

Day:

τ_{iono} = sf · (5.D-9 + AMP*(1.D0 – x^2/2. + x^4/24.))

at any local time and pointing direction of the ground station antenna and determines the path delay. This is done using the Klobuchar model introducing the Klobuchar coefficients from GPS measurements.

3.4.4.2 Plasma calibration of the antenna frequency

Subroutine S_PLASMA_CALIB_MOD corrects for the contribution by the propagation through the earth ionosphere by using the model for the earth ionosphere defined in module M_ION_CALIB.

ODF-DOP-SPEC-3444: Subroutine S_PLASMA_CALIB_MOD accepts the ionospheric slant correction τ_{iono} from module M_IONO_CALIB

ODF-DOP-SPEC-3445: The correction for the Earth ionosphere is then

$$m = \tau_{iono} \cdot f_{down}$$

where *m* is the cycle advance and the shift in frequency is:

$$\Delta f_{iono} = \frac{dm}{d\tau_{iono}}$$

This is done for each frequency band
.
ODF-DOP-SPEC-3450: The result from ODF-DOP-SPEC-3445 is transferred to M_OUTPUT added to the tropospheric correction described above and the sum is stored in column 11

ODF-DOP-SPEC-3455: The result from ODF-DOP-SPEC-3445 is transferred to M_OUTPUT and added to the predicted Doppler data (see section 3.6)

3.5 MODULE M_PREDICT

M_PREDICT accepts a Doppler predict file: the predict file PREDICT_FILE considers all possible perturbing forces as the best known gravity field and solar and albedo radiation pressure. For more details about the PREDICT_FILE see document [3]. M_PREDICT interpolates for a given time stamp between the predicted Doppler shift for the uplink and the predicted Doppler shift for the downlink respectively for each observed time stamp. M_PREDICT also computes with the interpolated values the predicted antenna frequency depending on the uplink frequency provided by subroutine S_REC_UP_FREQ and returns an estimated parameter for each observed time stamp. This is done for each frequency band.

ODF-DOP-SPEC-3510: M_PREDICT accepts input data from PREDICT_FILE with the file name format defined in [1] section 8.1 or in [1] section 8.2 for the predicted orbit or the reconstructed orbit file, respectively. PREDICT_FILE contains both the Doppler uplink and downlink data.

ODF-DOP-SPEC-3515: M_PREDICT accepts predicted Doppler data from PREDICT_FILE (file name specified in ODF-DOP-SPEC-2210) formatted as defined in [1] section 8.1 or in [1] section 8.2 for the predicted orbit or the reconstructed orbit file, respectively.

ODF-DOP-SPEC-3520: M_PREDICT_FILE contains predicted Doppler data with a time period that covers one entire operation.

ODF-DOP-SPEC-3525: M_PREDICT accepts from subroutine S_REC_UP_FREQ the reconstructed uplink frequency f_{up}.

ODF-DOP-SPEC-3530: M_PREDICT accepts from S_CALC_REC_FREQ the transponder ratio *k*.

ODF-DOP-SPEC-3535: Subroutine S_DOP_PRED_ODF accepts from M_READ_ODF_INPUT the array TIME_DOPPLER representing the observed Doppler time stamps.

ODF-DOP-SPEC-3540: Subroutine S_DOP_PRED reads predicted Doppler data from PREDICT_FILE and interpolates between the predicted Doppler shift for the uplink and the predicted Doppler shift for the downlink respectively for each observed time stamp given as TIME_DOPPLER.

ODF-DOP-SPEC-3545: S_DOP_PRED computes for each frequency band the predicted antenna frequency $f_{pred,antenna}$ received at a given ground station via

$$f_{pred,antenna}(t_i) = k \cdot f_{up}(t_i)\left(1 + P_{up} + P_{down} + P_{up} \cdot P_{down}\right)$$

where $P_{up} = \frac{\Delta f_{up}}{f_{up}} = \frac{v_{r,up}}{c}$ and P_{down} is the predicted Doppler shifts of the uplink and the downlink path, respectively. The result is stored in the array DOPPLER_PREDICT_SKY. For more details about the computation see Appendix A.

ODF-DOP-SPEC-3550: The array DOPPLER_PREDICT_SKY is transferred to the module M_OUTPUT. This is done for each frequency band.

ODF-DOP-SPEC-3555: M Subroutine S_DOP_PRED reads time values of the two way light time from PREDICT_FILE and interpolates between each value of the two way light time for each observed time stamp given as TIME_DOPPLER. This is done for each frequency band.

ODF-DOP-SPEC-3560: The resulting values are subtracted from TIME_DOPPLER at each time stamp in order to compute the transmit frequency ramp reference time.

ODF-DOP-SPEC-3565: The result from ODF-DOP-SPEC-3560 is transferred to M_OUTPUT and stored in column 6.

3.6 MODULE M_OUTPUT

Module M_OUTPUT provides routines to create the output files for each frequency band and the log file containing processing information.

ODF-DOP-SPEC-3610: As many output files are created as many individual tracking time ranges have been selected. The start date and time of the input data are used as the time in the output file name defined in ODF-DOP-SPEC-4110.
The individual tracking time ranges are selected in Modul M_TRACKING_TIME.

ODF-DOP-SPEC-3615: Subroutine S_DOPPLER_OUTPUT accepts the interpolated values for the received antenna frequency f_{pred} from M_PREDICT.

ODF-DOP-SPEC-3620: Subroutine S_DOPPLER OUTPUT adds the troposheric calibration and the plasma correction to the interpolated predicts and stores the result in column 10.

$$f_{pred,calib} = f_{pred} + \Delta f_{iono} + \Delta f_{tropo}$$

This is done for each frequency band

ODF-DOP-SPEC-3625: Subroutine S_DOPPLER OUTPUT computes for each frequency band the frequency residuals Δf_{res} by subtracting the interpolated and corrected, predicted antenna frequency $\Delta f_{pred,calib}$ from the received antenna frequency $f_{antenna}$ and stores the result in column 12.

$$\Delta f_{res} = f_{antenna} - f_{pred,calib}$$

This is done for each frequency band.

ODF-DOP-SPEC-3630: output files
For each selected individual activity an output file is created (for each downlink frequency). The format of the output files is specified in ODF-DOP-SPEC-4210 and ODF-DOP-SPEC-4230.

ODF-DOP-SPEC-3635: log file
Subroutine S_WRITE_OPT_FILE creates a log file that contains information about the processing operation e.g. file names of the files used during the processing start and stop time of all processed operations, which calibration was applied, standard deviation of the residuals and so on. A detailed description of the format of the log file is given in section 4.3.1.1.

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4 OUTPUT FILES

4.1 FILE NAMES

ODF-DOP-SPEC-4110: The DOPPLER_OUTPUT file names are defined as

rggODF0L02_sss_yydddhhmm_qq.TAB

The definitions are given in Table 2-1.

Table 4-1: DOPPLER_OUTPUT file name Definition

Acronym	Description	Examples
r	Spacecraft (Raumsonde) name R = Rosetta M = Mars Express V = Venus Express	M
gg	Ground station ID: DSN complex Canberra 34 = 34 m BWG 43 = 70 m 45 = 34 m HEF DSN complex Goldstone: 14 = 70 m 15 = 34 m HEF 24 = 34 m BWG 25 = 34 m BWG 26 = 34 m BWG 27 = 34 m HSBWG DSN complex Madrid: 54 = 34 m BWG 55 = 34 m BWG 63 = 70 m 65 = 34 m HEF	43
tttt	data source identifier Level 2 ODF0 = DSN ODF closed-loop file with 60 seconds sample interval ODFX = ODFS =	ODF0
lll	Data archiving level L02 = Level 2	L2
sss	data type	DPS

	data level 2: DPS S-band Doppler DPX X-band Doppler	
yy	Year	04
ddd	Day of the year	153
hhmm	Sample hour , minute (Start time)	1135
qq	Sequence or version number	01
eee	.TAB ASCII data files	

4.2 FILE FORMATS

ODF-DOP-SPEC-4210: The format of the DOPPLER_OUTPUT_X file is defined in Table 4-2

ODF-DOP-SPEC-4220: if only X-band Doppler data exist, the differential Doppler cannot be computed and is set to “-9999.999”.

ODF-DOP-SPEC-4230: The format of the DOPPLER_OUTPUT_S file is defined in Table 4-3.

ODF-DOP-SPEC-4240: if only S-band Doppler data exist, the differential Doppler cannot be computed and is set to “-9999.999”.

ODF-DOP-SPEC-4250: All data that are not available in the data file are set to a default value corresponding to their format description. For example data with format F10.3 are set to -99999.999. This default value indicates that the data is not a valid number and can not be used for further computations. For details see Table 4-2 and Table 4-3.

ODF-DOP-SPEC-4260: The first and the last value of column 11 of the DOPPLER_OUTPUT_X file and DOPPLER_OUTPUT_S_file (calibration) is set to his default value due to the way of computation.

Table 4-2 Definition of DOPPLER_OUTPUT_X file format

column	description	unit	resolution
1	Sample number		
2	Ground received time *as UTC in ISO format*		
3	Ground received time *as UTC in fractions of day of year starting with the first day of the year the data was recorded at 00:00.000*	day	10^{-10} day
4	Ground received time *as elapsed terrestrial barycentric dynamic time (TDB) time since noon of the first calendar day of year 2000 (12:00 1 January 2000 TDB)*	second	10^{-6} sec
5	Distance *Propagation experiments: approximate value of the closest approach of a downlink geometric ray path to the center of the reference body (Sun, planet, minor object). When two-way, the value is approximate average of uplink and downlink rays* *Gravity observations: geometric distance of the s/c from the center of mass of referenced body*	kilometer	10^{-3} m
6	Transmit frequency ramp reference time *UTC in ISO format* *The time (t0) at which the transmitted frequency would have been f_0 using the coefficients f_0 (column 7) and df (column 8). At any time t within the interval when those coefficients are valid, the transmitted frequency f_t may be calculated from* $$f_t = f_0 + df \cdot (t - t_0)$$ *For DSN two-way measurements:* *f_t is the uplink frequency of the ground transmitter; the f_t photon will reach the receiver one RTLT later.* *For DSN one-way measurements:* *f_t is the downlink frequency of the spacecraft transmitter; the f_t photon will reach the receiver OWLT later. In both cases, f_0 and df may change; but f_t is always continuous, and changes in the coefficients occur only on integer seconds.* *For ODF measurements:* $$f_t = f_0$$		

	because df=0.		
7	Transmit frequency corresponding to time in column 6 *Two-way coherent modes:* *Uplink frequency of ground station* *S-band order of 2100 MHZ* *X-band order of 7100 MHz* *One-way mode:* *S/C transmission frequency* *X-band order of 8400 MHz* *S-band order of 2300 MHz*	Hertz	10^{-6} Hz
8	Uplink frequency ramp rate *DSN two-way coherent:* *Time derivative of uplink frequency in column 7* *DSN one-way downlink mode:* *Value of spacecraft frequency drift, if known and/or meaningful; -99999.999999* *ODF measurements:* *Ramp rate is always zero; df=0*	Hertz/sec	10^{-6} Hz/sec
9	Observed X-band antenna frequency *Frequency of the signal at the terminals of the receiving antenna structure at UTC TIME columns 2 to 4 (t_r). Set to -9999999999.999999 for missing or corrupted data.*	Hertz	10^{-6} Hz
10	Predicted X-band antenna frequency *Based on the ESOC reconstructed orbit file or SPICE kernels* *Expected frequency of the signal at the terminals of the receiving antenna structure at UTC TIME in columns 2 to 4 (t_r). The calculation includes geometrical effects (relative positions and motions of ground station and spacecraft, including Earth rotation and light time adjustments), tuning of both the transmitter and receiver and a model-based correction for one- or two-way (as appropriate) propagation through the Earth's atmosphere.*	Hertz	10^{-6} Hz
11	Correction of Earth atmosphere propagation Correction term for the propagation of the signal in the Earth atmosphere, based on meteorological data observed at the ground station site (MET-files)	Hertz	10^{-6} Hz
12	Residual calibrated X-band frequency shift *column 9 minus 10*	Hertz	10^{-6} Hz
13	Received signal level	dBm / dB	0.1 dB

	<u>Closed-loop data:</u> *Signal level from AGC in decibels relative to one milliwatt (dBm).* *<u>Open-loop (RSR):</u>* *Signal level in decibels (dB) relative to an arbitrary reference.*		
14	Differential Doppler $f_S - \frac{3}{11} f_X$ *Where f_S and f_X are the received S-band and X-band frequencies* *If* BAND_NAME = X *(from the label file), f_X comes from column 9 in this table and f_S comes from column 9 in the file identified by* SOURCE_ID *(from the label file).* *If* BAND_NAME = S *(from the label file), f_S comes from column 9 in this table and f_X comes from column 9 in the file identified by* SOURCE_ID *(from the label file).* *if either band is not available, this column is set "-99999.999"*	Hertz	10^{-6} Hz
15	standard deviation of the observed antenna frequency X-band in column 9 (open-loop only) *for closed-loop this value is set "-99999.999"*	Hertz	10^{-6} Hz
16	Received X-band signal quality (open-loop only) *Ratio of observed received signal strength to the statistical standard deviation of the measurement, column 15 devided by column 19* *For closed-loop this is value is set "-999.9"*	dB	0.1 dB
17	standard deviation of received signal level at X-band (open-loop) *A statistical measure of the error in determining SIGNAL LEVEL (column 15) based on fit of a data spectrum to a sinc function. Uses the same arbitrary scale factor as column 15; units of dB.* *for closed-loop this is set "-999.9"*	dB	0.1 dB

Table 4-3: Definition of DOPPLER_OUTPUT_S file format

column	description	unit	resolution
1	Sample number		
2	Ground received time *as UTC in ISO format*		
3	Ground received time *as UTC in fractions of day of year starting with the first day of the year the data was recorded at 00:00.000*	day	10^{-10} day
4	Ground received time *as elapsed terrestrial barycentric dynamic time (TDB) time since noon of the first calendar day of year 2000 (12:00 1 January 2000 TDB)*	second	10^{-6} sec
5	Distance *<u>Propagation experiments:</u> approximate value of the closest approach of a downlink geometric ray path to the center of the reference body (Sun, planet, minor object). When two-way, the value is approximate average of uplink and downlink rays* *<u>Gravity observations:</u> geometric distance of the s/c from the center of mass of referenced body*	kilometer	10^{-3} m
6	Transmit frequency ramp reference time *UTC in ISO format* *The time (t0) at which the transmitted frequency would have been f_0 using the coefficients f_0 (column 7) and df (column 8). At any time t within the interval when those coefficients are valid, the transmitted frequency f_t may be calculated from* $f_t = f_0 + df \cdot (t - t_0)$ *<u>For DSN two-way measurements:</u>* *f_t is the uplink frequency of the ground transmitter; the f_t photon will reach the receiver one RTLT later.* *<u>For DSN one-way measurements</u>:* *f_t is the downlink frequency of the spacecraft transmitter; the f_t photon will reach the receiver OWLT later. In both cases, f_0 and df may change; but f_t is always continuous, and changes in the coefficients occur only on integer seconds.* *<u>For ODF measurements:</u>*		

	$$f_t = f_0$$ *because df=0.*		
7	Transmitted frequency corresponding to time in column 6 *<u>Two-way coherent modes:</u>* *Uplink frequency of ground station* *S-band order of 2100 MHZ* *X-band order of 7100 MHz* *<u>One-way mode:</u>* *S/C transmission frequency* *X-band order of 8400 MHz* *S-band order of 2300 MHz*	Hertz	10^{-6} Hz
8	Uplink frequency ramp rate *<u>DSN two-way coherent:</u>* *Time derivative of uplink frequency in column 7* *<u>DSN one-way downlink mode:</u>* *Value of spacecraft frequency drift, if known and/or meaningful; -99999.999999* *<u>ODF measurements:</u>* *Ramp rate is always zero; df=0*	Hertz/sec	10^{-6} Hz/sec
9	Observed S-band antenna frequency *Frequency of the signal at the terminals of the receiving antenna structure at UTC TIME columns 2 to 4 (t_r). Set to -9999999999.999999 for missing or corrupted data.*	Hertz	10^{-6} Hz
10	Predicted S-band antenna frequency *Based on the ESOC reconstructed orbit file or SPICE kernels* *Expected frequency of the signal at the terminals of the receiving antenna structure at UTC TIME in columns 2 to 4 (t_r). The calculation includes geometrical effects (relative positions and motions of ground station and spacecraft, including Earth rotation and light time adjustments), tuning of both the transmitter and receiver and a model-based correction for one- or two-way (as appropriate) propagation through the Earth's atmosphere.*	Hertz	10^{-6} Hz
11	Correction of Earth atmosphere propagation *Correction term for the propagation of the signal in the Earth atmosphere and ionosphere, based on meteorological data observed at the ground station site (MET-files)*	Hertz	10^{-6} Hz

12	Residual calibrated X-band frequency shift *column 9 minus 10*	Hertz	10^{-6} Hz
13	Received S-band signal level <u>*Closed-loop data:*</u> *Signal level from AGC in decibels relative to one milliwatt (dBm).* <u>*Open-loop (RSR):*</u> *Signal level in decibels (dB) relative to an arbitrary reference.*	dBm / dB	0.1 dB
14	Differential Doppler $$f_S - \frac{3}{11} f_X$$ *Where f_S and f_X are the received S-band and X-band frequencies* *If* BAND_NAME = X *(from the label file), f_X comes from column 9 in this table and f_S comes from column 9 in the file identified by* SOURCE_ID *(from the label file).* *If* BAND_NAME = S *(from the label file), f_S comes from column 9 in this table and f_X comes from column 9 in the file identified by* SOURCE_ID *(from the label file).* *if either band is not available, this column is set "-99999.999"*	Hertz	10^{-6} Hz
15	standard deviation of the observed antenna frequency S-band in column 9 (open-loop only) *for closed-loop this value is set "-99999.999"*	Hertz	10^{-6} Hz
16	Received S-band signal quality (open-loop only) *Ratio of observed received signal strength to the statistical standard deviation of the measurement, column 15 devided by column 19* *For closed-loop this is value is set "-999.9"*	dB	0.1 dB
17	standard deviation of received signal level at S-band (open-loop) *A statistical measure of the error in determining SIGNAL LEVEL (column 15) based on fit of a data spectrum to a sinc function. Uses the same arbitrary scale factor as column 15; units of dB.* *for closed-loop this is set "-999.9"*	dB	0.1 dB

4.3 ADDITIONAL OUTPUT FILES

4.3.1.1 Log file

The Module M_OUTPUT generates an additional output file a so called log file. This file contains the processing mode, the whole path of all input files, additional information like downlink and uplink frequency in Hz, the sample rate in samples per seconds, statistical data about the processed data like average value and standard deviation, version of the processing software and error messages.
The log file will not be distributed and is only intended for internal use. Therefore the filename of the log file is not complying with [1]. But in order to relate the log file with the corresponding data files the log file gets the file name of the corresponding DOPPLER_OUTPUT_X_file but instead of the ending .tab the ending .log is used. If a log file is already existing in the processing folder and the date are not automatically processed the log file gets the file name of the corresponding DOPPLER_OUTPUT_S_file with ending .log. An example of a log file is shown in Figure 4-1.

ODF-DOP-SPEC-4310: The average values of the residuals of S-Band data and X-Band data are computed only for the first 40% of the data. The computation is done via the following formulation

$$\overline{f}_{res} = \frac{1}{N}\sum_{i=1}^{N} f_{res_i}$$

ODF-DOP-SPEC-4320: The standard deviation of the residuals of S-Band data and X-Band data are computed only for the first 40% of the data. The computation is done via the following formulation

$$f_{res,std} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(f_{res_i} - \overline{f}_{res}\right)^2}$$

```
MEX

OC

OCCULTATION

FLAGS FROM PROCESS_OPTIONS FILE:
--------------------------------
T      Processing with Predict
F      Processing with AGC
063      Groundstation
2004-08-29T13:58:00.000     Start time
2004-08-29T17:56:00.000     Stop time

NUMBER OF INPUT FILES:
----------------------
01      Number of doppler S-band files
01      Number of doppler X-band files
01      Number of Meteo files
00      Number of AGC S-Band files
00      Number of AGC X-Band files

FILES USED FOR PROCESSING:
--------------------------
Z:\ddswork\DSN_data\odf_processed\MEX\2004\242\L1B\M00ODF0L1B_DPS_042421
400_02.TAB
Z:\ddswork\DSN_data\odf_processed\MEX\2004\242\L1B\M00ODF0L1B_DPX_042421
400_01.TAB
Z:\ddswork\DSN_data\odf_processed\WEA\M60ODF0L1B_MET_040010000_00.TAB
Z:\ddswork\DSN_data\odf_processed\MEX\2004\242\L1B\M00ODF0L1B_RMP_042421
400_02.TAB
Z:\unibw\Predicts\MarsExpress\2004\Predicts_GS63_SCO_242\M63UNBWL02_PTW_
042421335_00.TAB
```

```
FILES CREATED DURING PROCESSING:
--------------------------------
Z:/Processed_temp/MEX/Orbit/2005/DOY_002_1_MEX/NN13_NN11/D1/M32ICL3L02
_D1S_050020542_00.TAB
Z:/Processed_temp/MEX/Orbit/2005/DOY_002_1_MEX/NN13_NN11/D1/M32ICL1L02
_D1X_050020542_00.TAB
Z:/Processed_temp/MEX/Orbit/2005/DOY_002_1_MEX/NN13_NN11/D1/M32ICL3L02
_D1S_050020542_00.LBL
Z:/Processed_temp/MEX/Orbit/2005/DOY_002_1_MEX/NN13_NN11/D1/M32ICL1L02
_D1X_050020542_00.LBL

CONFIGURATION INFO:
--------------------
UPLINK-FREQUENCY X-BAND:   7166619369.9976720809936523
DOWNLINK-FREQUENCY X-BAND:   8420060140.9852495193481445
SAMPLE-INTERVAL X-BAND:            1.0000000000000000
TRANSPONDER-RATIO X-BAND:880/749
UPLINK-FREQUENCY S-BAND:   7166619369.9976720809936523
DOWNLINK-FREQUENCY S-BAND:   2296380038.4505224227905273
SAMPLE-INTERVAL S-BAND:            1.0000000000000000
TRANSPONDER-RATIO S-BAND:240/749

PROCESSING INFO
 ---------------
AVERAGE S-BAND RESIDUALS IN mHZ:            -6.94218
STANDARD DEVIATION S-BAND RESIDUALS IN mHZ:            4.39143
AVERAGE X-BAND RESIDUALS IN mHZ:             9.68471
STANDARD DEVIATION X-BAND RESIDUALS IN mHZ:           14.90616
PLASMA-CORRECTION DONE WITH DIFFERENTIAL DOPPLER
FILES OVERLAPPING IN TIME
X-BAND-MODE: TWO-WAY
S-BAND-MODE: TWO-WAY

SOFTWARE INFO:
--------------
SOFTWARE NAME: DSN_ODF_PROC_DOP_L1A_TO_L2_V1.2
CREATION TIME: 2005-11-07T16:24:09.000
PROCESSED BY: andert
ERRORS:
 -------
```

Figure 4-1: Example of a log file

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5 USAGE OF THE SOFTWARE

The above described software is embedded in a PERL script that calls the Fortran software.

One ODF data file of level 1b can contain more than one operation i.e. data from more than one ground station and over a long time period. Therefore before processing the level 1b data file start time, stop time and the respective ground station for each operation have to selected. This can be done by using a graphical interface (see

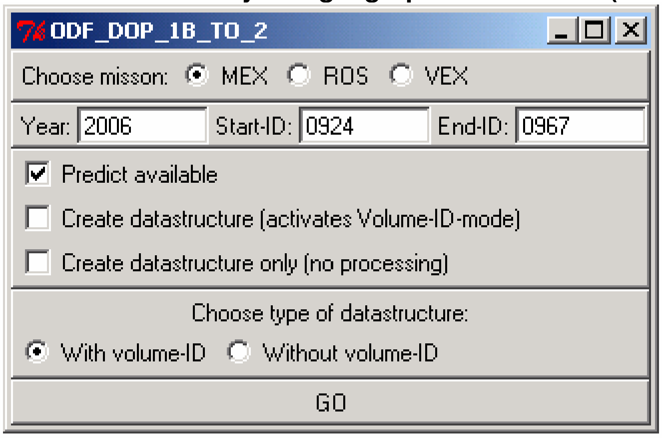

Figure 5-4 and section **Fehler! Verweisquelle konnte nicht gefunden werden.** for a detailed description).

The processing options like mission, observation type or availability of files can be adjusted by means of another graphical interface (see and section 0 for a detailed description).

If all this information are filled in the graphical interfaces and the software starts to work the Perl script creates a file named odf_process_options.txt and writes all necessary information into this file. This odf_processing_options.txt file is read in from the Fortran software and serves as a data interface between the graphical interfaces and the Fortran software.

Therefore the Fortran software can be used by editing the odf_process_options.txt and filling the necessary information by hand in. An example of a odf_process_options.txt file is shown in Figure 5-1.

Figure 5-1: Example of a odf_process_options.txt file

```
MEX                     ! Mission
NO                      ! Autoprocessing
GR                      ! Processing Mode
YES                     ! Processing with predict
YES                     ! Processing with agc
1                       ! Number of X-band files
1                       ! Number of S-band files
1                       ! Number of meteo files
1                       ! Number of AGC X-band files
1                       ! Number of AGC S-band files
SOLAR                   ! Observation Type
Andert          ! login
1                       ! Number of operations
63                                      ! Station ID
2004-242::14:45:00          ! Start time of the operation
2004-242::16:00:00          ! Stop time of the operation
```

Usually the Fortran software finds the files to process automatically based on the information in the odf_process_options,txt file but if the files can not be found the files must be selected by hand. The selection of the respective files for processing is done via another graphical interface shown below in Figure 5-2. The simultaneously arising DOS window (see Figure 5-3) indicates what kind of file is needed and shows subsequently the processing status.
In addition there is a possibility provided to process an amount of data automatically. But for this a log file (see section 4.3.1.1) must exist, i.e. the files have to be processed one time before by hand.

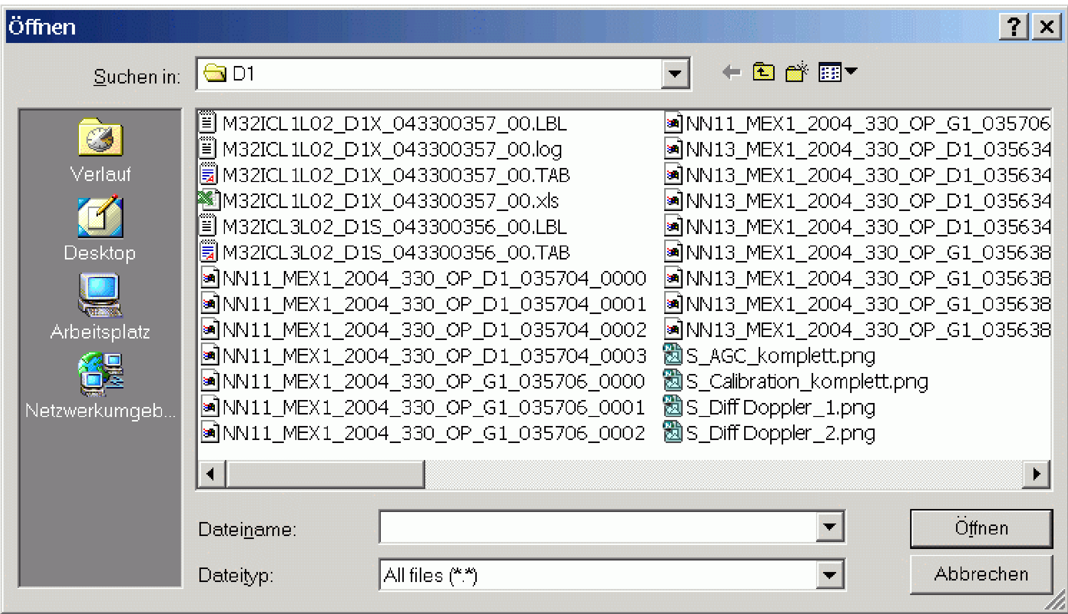

Figure 5-2: Graphical interface for selection of the input files.

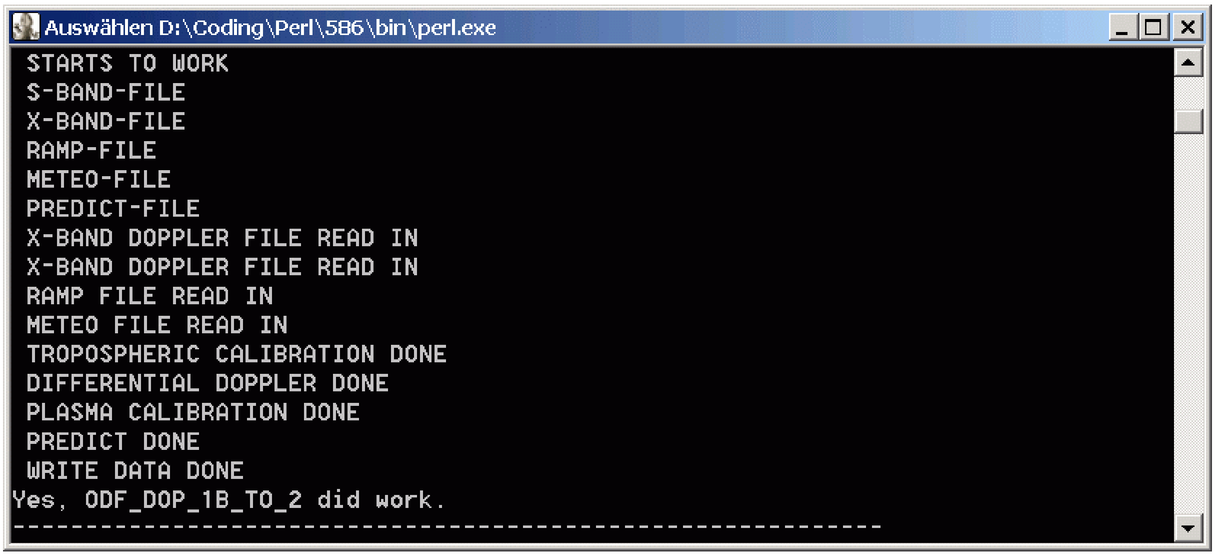

Figure 5-3: DOS window showing information about the kind of file needed to be inputted and processing status.

5.1 GRAPHICAL INTERFACE

In order to process the data some information are needed. For this job an graphical user interface is developed and will be described in detail below.

5.1.1 <u>Selection of operations</u>

The selection of the operations to process can be done via a graphical interface (see

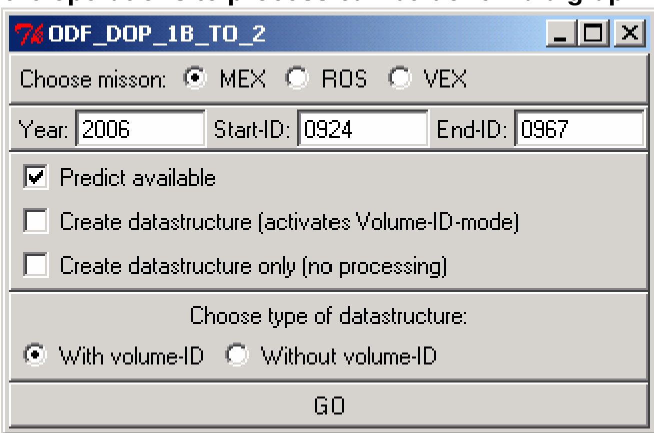

Figure 5-4). The mission and the year have to be filled in the graphical interface. Pressing return starts to search for all DSN operations between the selected volume-IDs in the current version of the logbook. There are several options to be selected. Processing with or without a predict file is possible. Creating of the data structure is

possible to be switched off. Also its possible to let the script create these data structures without L2-processing. Two types of data structures are available.
Pressing the GO-button starts processing. All information necessary for processing are read from the current version of the logbook by the PERL-script.

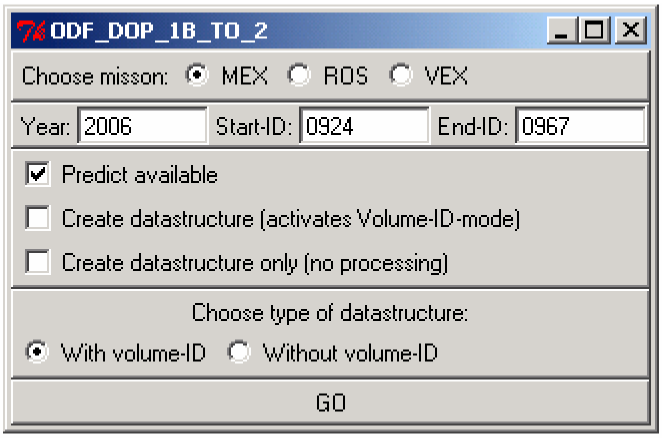

Figure 5-4: Selection of operations to be processed

5.2 ADDITIONAL OUTPUT FILES

Several files with additional information about the processed data are produced during the processing operation by means of a PERL script which is called by the main script.

5.2.1 Data validation Excel sheet

An Excel sheet is automatically generated during the processing operation. The information contained in the Excel sheet is read in from the above described log file. This Excel sheet is used for data validation aims and is complemented with additional information during data validation and can accordingly be copied into a log book comprising processing information about all level 2 data.
The excel sheet will not be distributed and is only intended for internal use. Therefore the filename of the Excel sheet is not complying with [1]. But in order to relate the Excel sheet with the corresponding data files the Excel sheet gets the file name of the corresponding DOPPLER_OUTPUT_X_file but instead of the ending .tab the ending .xls is used.

5.2.2 Data illustration

During the processing operation a number of plots illustrating the processed data are automatically generated.

- **Correction of the earth atmosphere propagation** (column 11 in the data file of level 2) in Hz is plotted over the entire time period. This is done for S-band and X-band Doppler data.
- **Residual calibrated data** (column 12 in the data file of level 2) in Hz is plotted over the entire time period for S-band and X-Band Doppler data. In addition partial plots are generated. If the total number of sample points is bigger than 3600 the data to illustrate is divided into subintervals with 3600 data points or less for the remaining data points and plotted. If the total number of sample points is smaller than 3600 the data to illustrate is divided into subintervals with 600 data points or less for the remaining data points and plotted.
- **Received signal level** (column 13 in the data file of level 2) in dBm is plotted over the entire time period for S-band and X-Band Doppler data.
- **Differential Doppler** (column 14 in the data file of level 2) is plotted over the entire time period for S-band and X-Band Doppler data if it is available. In addition partial plots are generated. If the total number of sample points is bigger than 3600 the data to illustrate is divided into subintervals with 3600 data points or less for the remaining data points and plotted. If the total number of sample points is smaller than 3600 the data to illustrate is divided into subintervals with 600 data points or less for the remaining data points and plotted.

5.3 ERROR MESSAGES

The following describes some errors that maybe occur during the processing operation.

- A kernel defined in the list of loaded kernels is not available in the folder where all kernels for processing are stored. Therefore the missing kernel has to be copied into the kernel folder. An example of the error message is shown in Figure 5-5.

```
D:\Coding\Perl\586\bin\perl.exe
Start:365 Ende:365

DOY_365_MEX
find_log done!!
 STARTS TO WORK

 ==============================================================================

 Toolkit version: N0053

 SPICE(NOSUCHFILE) --

 The tenth file
 'Z:\ddswork\process_data\Soft_Doppler_L2\Kernels\ORMM__041201000000_00105.BSP'
 specified by KERNELS_TO_LOAD in the file
 Z:\ddswork\process_data\Soft_Doppler_L2\Kernels\List_of_loaded_kernels.txt
 could not be located.

 A traceback follows.  The name of the highest level module is first.
 FURNSH --> ZZLDKER

 Oh, by the way:  The SPICELIB error handling actions are USER-TAILORABLE.  You
 can choose whether the Toolkit aborts or continues when errors occur, which
 error messages to output, and where to send the output.  Please read the ERROR
 "Required Reading" file, or see the routines ERRACT, ERRDEV, and ERRPRT.

 ==============================================================================
Return code 1
Sorry, an error occurred! No output produced!
------------------------------------------------------------
```

Figure 5-5: Example of an error message if a kernel file is missing.

- A wrong kernel file containing ephemeris data with inappropriate time stamps is loaded. This has to be corrected in the module M_SPICE. An example of the error message is shown in Figure 5-6

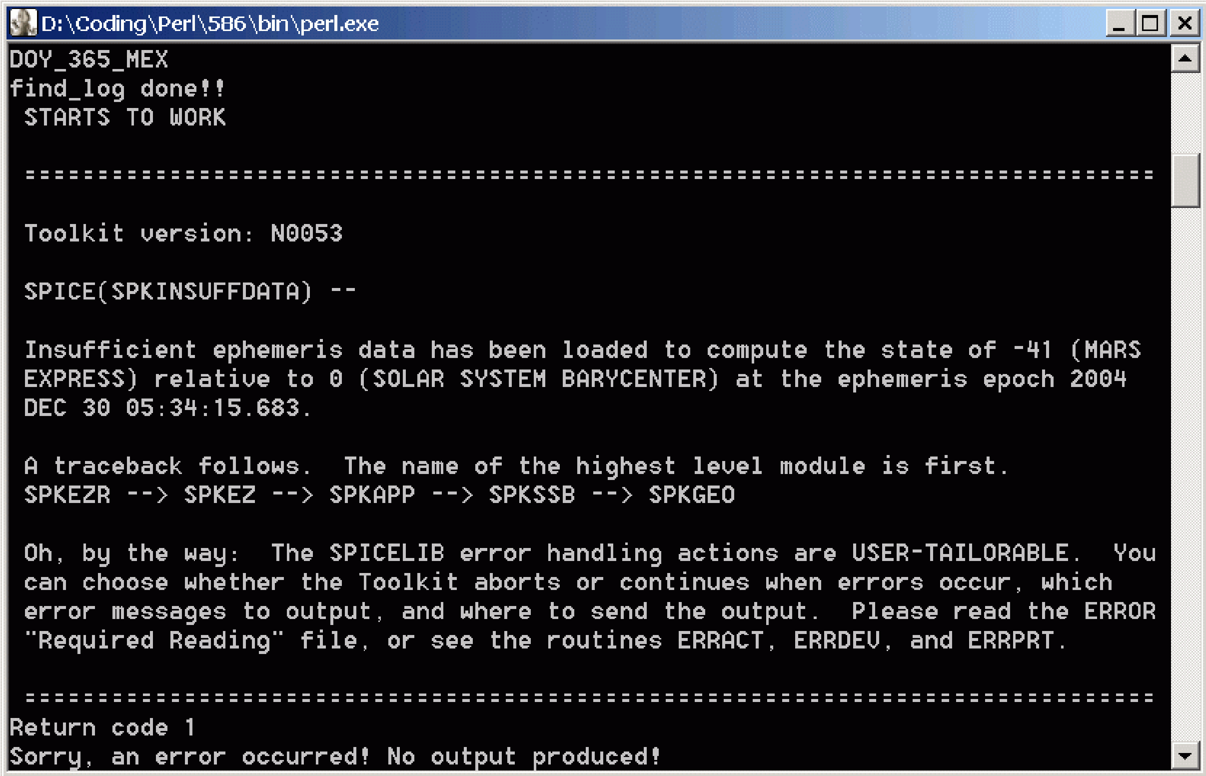

Figure 5-6: Example of an error message if a wrong kernel file is loaded.

- Two or more identical lines in the data file are existing and therefore the interpolation routine is not working. Consequently the redundant information has to be erased. This can happen in the meteo file of level 1a and the predict file. An example of the error message is shown in Figure 5-7. If the meteo file contains redundant data the terminal error arises after READ DOPPLER DONE.

```
D:\Coding\Perl\586\bin\perl.exe

Start:365 Ende:365

DOY_365_MEX
find_log done!!
 STARTS TO WORK
 READ DOPPLER DONE
 READ METEO DONE
 TROPO CALIBRATON DONE
 DIFFERENTIAL DOPPLER DONE
 PLASMA CALIBRATION DONE

 *** TERMINAL ERROR 2 from DC1SOR.  Points in the data point abscissas array,
 ***          XDATA, must be distinct, but XDATA(2) = XDATA(3) =
 ***          1.576555624123737D+08.
     Here is a traceback of subprogram calls in reverse order:
     Routine name                    Error type  Error code
     ------------                    ----------  ----------
     DC1SOR                               5           2    (Called internally)
     DC2DEC                               0           0    (Called internally)
     DC2INT                               0           0    (Called internally)
     DC2IEZ                               0           0    (Called internally)
     DCSIEZ                               0           0
     USER                                 0           0
Kein Logfile
```

Figure 5-7: Example of an error message if redundant data is contained in the predict file.

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APPENDIX A

Computation of the sky frequency received at ground station from doppler predicts

Acronyms:

fs_{gs} = frequency emitted from ground station
fs_{sc} = frequency emitted from spacecraft
fr_{sc} = frequency received at spacecraft
fr_{gs} = frequency received at ground station

Δf_{sc} = frequency shift received at spacecraft in the uplink signal emitted from groundstation
Δf_{gs} = frequency shift received at groundstation in the downlink signal emitted from the spacecraft
K = transponder conversion ratio

P_{UL} = doppler predict of the uplink signal independent from frequency
P_{DL} = doppler predict of the downlink signal independent from frequency

General relations:

$$P_{UL} = \frac{\Delta f_{sc}}{fs_{gs}}$$

$$P_{DL} = \frac{\Delta f_{gs}}{fs_{sc}}$$

<u>One-way case</u>

$$\Delta f_{gs} = fs_{sc} \cdot P_{DL}$$

it is needed

$$fr_{gs} = \Delta f_{gs} + fs_{sc}$$

therefore the sky frequency is

$$fr_{gs} = fs_{sc} \cdot P_{DL} + fs_{sc}$$

or

$$fr_{gs} = fs_{sc} \cdot \left(P_{DL} + 1\right)$$

Two-way case:

$$\Delta f_{sc} = fs_{gs} \cdot P_{UL}$$
$$\Delta f_{gs} = fs_{sc} \cdot P_{DL}$$

needed is

$$fr_{gs} = \Delta f_{gs} + fs_{sc}$$

therefore

$$fr_{gs} = fs_{sc} \cdot P_{DL} + fs_{sc}$$

or

$$fr_{gs} = fs_{sc} \cdot (P_{DL} + 1)$$

with

$$fs_{sc} = K \cdot fr_{sc}$$
$$\Rightarrow \quad fr_{gs} = K \cdot fr_{sc} \cdot (P_{DL} + 1)$$
$$\Rightarrow \quad fr_{gs} = K \cdot (fs_{gs} + \Delta f_{sc}) \cdot (P_{DL} + 1)$$
$$\Rightarrow \quad fr_{gs} = K \cdot fs_{gs} \left(1 + \frac{\Delta f_{sc}}{fs_{gs}}\right) \cdot (P_{DL} + 1)$$
$$\Rightarrow \quad fr_{gs} = K \cdot fs_{gs} (1 + P_{UL}) \cdot (1 + P_{DL})$$

and therefore the sky frequency is

$$fr_{gs} = K \cdot fs_{gs} (1 + P_{UL} + P_{DL} + P_{UL} \cdot P_{DL})$$

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APPENDIX B

Computation of the plasma correction using the differential doppler

The differential doppler is computed via

$$\delta f = f_{S,antenna}\Big|_{tropo\_corrected} - \frac{3}{11} f_{X,antenna}\Big|_{tropo\_corrected} \tag{1.12}$$

or

$$\delta f = -\frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e \varepsilon_0}\left\{\frac{1}{f_S^2} - \frac{1}{f_X^2}\right\} f_S \frac{dI}{dt} \tag{1.13}$$

therefore the temporal change in electron content is

$$\frac{dI}{dt} = -\left\{\frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e \varepsilon_0}\right\}^{-1} \frac{\delta f}{f_S}\left\{\frac{1}{f_S^2} - \frac{1}{f_X^2}\right\}^{-1} \tag{1.14}$$

the plasma correction for S-Band is

$$f_{S,antenna,cal} = f_{S,antenna}\Big|_{tropo\_corrected} + \frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e \varepsilon_0}\frac{1}{f_S}\frac{dI}{dt} \tag{1.15}$$

and for X-Band

$$f_{X,antenna,cal} = f_{X,antenna}\Big|_{tropo\_corrected} + \frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e \varepsilon_0}\frac{1}{f_X}\frac{dI}{dt} \tag{1.16}$$

If equation (1.14) is inserted into (1.15)

$$f_{S,antenna,cal} = f_{S,antenna}\Big|_{tropo\_corrected} + \frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e \varepsilon_0}\frac{1}{f_S}\left(-\left\{\frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e \varepsilon_0}\right\}^{-1}\frac{\delta f}{f_S}\left\{\frac{1}{f_S^2} - \frac{1}{f_X^2}\right\}^{-1}\right)$$

$$\Rightarrow \quad f_{S,antenna,cal} = f_{S,antenna}\Big|_{tropo\_corrected} - \delta f\left\{\frac{f_S^2}{f_S^2} - \frac{f_S^2}{f_X^2}\right\}^{-1}$$

and with the general relations

$$f_X = \frac{11}{3} f_S \quad \Leftrightarrow \quad \frac{f_X}{f_S} = \frac{11}{3} \quad \Leftrightarrow \quad \frac{f_S}{f_X} = \frac{3}{11} \tag{1.17}$$

follows than

$$f_{S,antenna,cal} = f_{S,antenna}\Big|_{tropo\_corrected} - \delta f \left\{ 1 - \frac{9}{121} \right\}^{-1}.$$

Therefore equation (1.15) ca be written as

$$\boxed{f_{S,antenna,cal} = f_{S,antenna}\Big|_{tropo\_corrected} - \delta f \frac{121}{112}} \quad (1.18).$$

A similar computation can be done for equation (1.16).

$$\Rightarrow \quad f_{X,antenna,cal} = f_{X,antenna}\Big|_{tropo\_corrected} - \delta f \left\{ \frac{f_X f_S}{f_S^2} - \frac{f_X f_S}{f_X^2} \right\}^{-1}$$

Using equation (1.17)

$$\Rightarrow \quad f_{X,antenna,cal} = f_{X,antenna}\Big|_{tropo\_corrected} - \delta f \left\{ \frac{11}{3} - \frac{3}{11} \right\}^{-1},$$

therefore equation (1.16) can be written as

$$\boxed{f_{X,antenna,cal} = f_{X,antenna}\Big|_{tropo\_corrected} - \delta f \frac{33}{112}} \tag{1.19}$$

APPENDIX C

Earth Klobuchar Ionosphere Model (see attached document CGIM_ANNEX_C.pdf)

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APPENDIX D

Klobuchar File Format Description (see attached document CGIM_ANNEX_D.pdf)