

ENVISAT**CLS-DOS-NT-05-218****Version : 1rev1 of the 17 February 2006****Nomenclature : -****Envisat MWR drift evaluation and correction**

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CHRONOLOGY ISSUES			
Control Initials	ISSUE	DATE	REASON FOR CHANGE
	1REV0	03/01/2006	Creation of the document
	1REV1	17/02/2006	Accounting for ESA remarks and addition of the chapter describing the tool that computes the wet tropospheric range correction

D : page deleted

I : page inserted

M : page modified

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APPLICABLE DOCUMENTS / REFERENCE DOCUMENTS

- RD 1:** Eymard L., E. Obligis, N. Tran, F. Karbou, and M. Dedieu: Long-term stability of ERS-2 and TOPEX microwave radiometer in-flight calibration, IEEE Trans. Geosci. Remote Sens., 43 (5), 1144-1158, 2005.
- RD 2:** E. Obligis, N. Tran, and Eymard L.: An assessment of Jason-1 microwave radiometer measurements and products, Mar. Geod., 27, 255-277, 2004.
- RD 3:** N. Tran, E. Obligis, and L. Eymard: Evaluation of Envisat MWR 36.5 GHz drift, CLS-DOS-NT-05-073, 20 April 2005.
- RD 4:** M. Ablain, S. Philipps, J. Dorandeu : TOPEX/Poseidon validation activities 13 years of T/P data (GDR-Ms), CLS-DOS-NT-05, available soon at http://www.jason.oceanobs.com/documents/calval/validation_report/tp/annual_report_tp_2005.pdf
- RD 5:** Obligis E., L. Eymard, N. Tran, S. Labroue and P. Femenias, 2005, First three years of the Microwave Radiometer Aboard ENVISAT : In-flight calibration, Processing and Validation of the geophysical products, Journal of Atmospheric and Oceanic Technology, in press.

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1. INTRODUCTION

The statement of work for the 2005 new calibration/validation and expertise activities for the ENVISAT microwave radiometer (MWR) by CETP, LOCEAN and CLS (CCN 2 of the contract RA-2 ocean and MWR measurement performance long-term monitoring 17293/03/I-OL) includes the following issues:

- **WP 1 : In-depth analysis of the MWR 36.5 GHz brightness temperature drift impact;**
- **WP 2 : New MWR calibration based on improved models;**
- **WP 3 : Update of the level 2 MWR neural network algorithms;**

Considering the continuous drift of the 36.5 GHz channel of the MWR sensor, a new expertise activity is required to propose suitable brightness temperature drift correction that could be rapidly used by the users to get a stable time series of brightness temperature and wet tropospheric correction. This activity dedicated to the formulation of a correction is performed in place of the WP2 and WP3 tasks of the present CCN 2. It consists in an update of the evaluations gathered in RD3 (April 2005) as report of WP1 task, to conclude on the value of the drift at low brightness temperatures (coldest ocean TBs) and at high brightness temperatures (over tropical rain forest). These two evaluations will allow (assuming a linear drift) a global correction expressed as $TB_corr = f(t, TB_Product)$, a function of the date and TB value, suitable for any TB in the ocean range. Note that the present WP2 and WP3 tasks will be performed in the framework of a new CCN that will follow.

The following report summarizes the work performed in the framework of this contract and dedicated to the evaluation and correction of the drift observed on the 36.5 GHz brightness temperatures of the Envisat microwave radiometer. The data come from both the available

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GDRs at this time (cycle 09-40) and the prototype chain at CETP for the instrumental parameters monitoring (from launch up to cycle 42). The work performed is divided into the following topics:

- **Instrumental parameters monitoring**
- **36.5 GHz brightness temperatures drift evaluation**
- **Correction proposed to the users and validation**
- **Impact on retrieved path delay**

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2. INSTRUMENTAL PARAMETERS MONITORING

Cyclic reports on the behavior of the ENVISAT/MWR in terms of instrumental characteristics and quality of the brightness temperatures are regularly sent to ESA and point out an abnormal behavior (drift) for the 36.5 GHz channel. Its impact on brightness temperatures and wet tropospheric corrections will be evaluated in the next sections. We recall here its main characteristics in term of instrumental parameters.

The instrumental parameters monitoring is performed from the MWR level 0 data product (MWR_NL_OP) at a cycle periodicity. The decoding and the pre-processing are done with the MWR level 1B reference processing chain located at CETP. The data are from the ESA's ground stations in Kiruna, Sweden, and at ESRIN, Italy. The objectives of the cyclic reports are:

- to provide an instrumental status;
- to check the stability of the instrument;
- to report any change at the instrumental level that could impact the quality of the brightness temperatures.

To monitor the instrument behavior during its lifetime (here up to cycle 42), 4 key parameters are under surveillance and are plotted in figures 1-4: gain (after correction of the thermal variations, modeled as a parabolic function), sky horn and hot load counts, and residual term TE. The instrument stability is ensured if none of these parameters do vary with time.

The Figure 1 shows the gains of the two channels 23.8 and 36.5 GHz. As observed the gain in the 23.8 GHz channel remains stable around 9.6 while for the second channel, the evolution shows two decreasing trends, small at the beginning (starting around day 25) and a stronger one since days around 150 after launch. The total decrease is about -16.8 %. The sky horn counts on Figure 2 exhibit similar features than the gain for both channels. The counts present a very slight increase with time for the first channel. For the second channel, the values drop

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from 3600 to 3075 (-14.6 %). The hot load counts on Figure 3 are stable for the first channel, around 553. They decrease for the second channel from 660 at launch time to about 635 (-3.8 %). Finally, the last parameter that is monitored, the residual temperature, is presented in Figure 4. Since launch the observed values are higher than evaluated from ground testing. The residual temperatures were expected to be around 0.5 K for the first channel and a bit higher, 0.5-0.7 K for the second one, i.e. close to the ERS ones. They vary around 1 for the first channel while the values for the 36.5 GHz channel are now 3.6 times larger in magnitude than the ones observed just after launch.

The source of these abnormal behaviors has not been completely identified yet, so the impact on brightness temperatures has been evaluated through monitoring of TB values over reference areas and through comparison with other measurements as reported in RD3.

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3. ANALYSIS OF 36.5 GHZ TB DRIFT

To evaluate the effect of the instrumental drifts on the 36.5 GHz brightness temperatures, different methods have been used. Some of them (coldest TB over ocean, TB over continental targets, inter-comparison between channels and instruments) were developed and tested on TOPEX and ERS-2 radiometer measurements as part of their long-term monitoring activities (RD1). Others represent adapted methods (survey of the differences between measurements and simulated TB) from calibration activities to provide additional independent information on the drift. Estimation of the drift at low and high brightness temperatures from RD3 is presently updated with :

- **Monitoring of coldest ocean TB;**
- **Monitoring of TB over hot reference areas (nighttime data):**
 - o Amazon and Congo rain forests

3.1. MONITORING OF COLDEST OCEAN TB

Following the method developed for the long-term monitoring of ERS-2 and also applied on TOPEX radiometer, the coldest ocean measurements are selected as follows: a first step consists in the filtering of measurements higher than a fixed threshold (150 and 170 K for the 23.8 and 36.5 GHz channels respectively) simultaneously for the two channels and of latitude location greater than 70° (N and S) to remove possible values over ice. The second step consists in the computation of the mean and standard deviation of the remaining data population of each channel for each 35-day cycle. Finally, the third and last step consists in filtering out the measurements warmer than the threshold defined as the cyclic mean minus the associated standard deviation simultaneously for the two channels within each cycle. The left out coldest ocean TB measurements (daily means) are plotted in Figures 5-6 for the 23.8 and 36.5 GHz channels respectively. Overlaid is the linear regression fit. Although the time series exist since the launch, we evaluate the drift only from cycles 09 (from 24 September

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2002) to 40 (ending on 19th September 2005) which represents a time period of almost 3 years of data and correspond to the period over which the GDR products are available to users. This limitation was applied in order to compare the different drift estimates from the different methods. This allows also to work with a whole number of year and thus decreases the impact of the annual TB variation on the estimates.

The 23.8 GHz trend is small with a variation of -0.11 K/year. The 36.5 GHz trend is in magnitude more than 2 times larger than for the first channel with a variation of +0.25 K/year. Note that even if the stability of the 23.8 GHz channel seems to be questionable, we think that even three complete years of data are not enough to get ride completely of the inter-annual variability of the brightness temperatures from each channel. The main result lies in the factor ~2 observed between the two channels.

3.2. MONITORING OF TB OVER HOT REFERENCE CONTINENTAL AREAS

As showed in RD1, there are a few locations over the globe, where the atmosphere conditions and/or surface emissivity stability are sufficient to be used as hot continental targets to allow drift estimation if any. They are exactly the same ones used in RD3 and only nighttime data were used over these areas to minimize the variability due to the diurnal cycle. Their geographical locations are as follows:

- Amazon rain forest area: [294, 295]° of longitude by [-5.2, -4.3]° of latitude
- Congo rain forest area: [18.5, 21.4]° of longitude by [-3.5, -2.8]° of latitude

Over Amazon and Congo rain forests (Figures 7-8) where the annual cycle of variation is weak, the 23.8 GHz channel TB show small trends (-0.03 K/year when mixing the two time series) when compared to the 36.5 GHz TB ones (+0.47 K/year) that are positive and quite large in magnitude.

The present analyses focus on the coldest and hottest brightness temperatures to bracket the range of ocean TB measured by ENVISAT.

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5. VALIDATION OF THE CORRECTION

To validate the proposed correction, we applied it on the previous coldest ocean points and hot rain forest brightness temperatures time series provided as Figures 5-8 in Figure 9. The trends decrease significantly and are now of +0.022 K/year (compared to +0.248 K/year) and +0.022 K/year (compared to +0.470 K/year) respectively for the two time series. Also provided is the change that the application of the correction term causes on the daily mean brightness temperature time series, we observe a decrease from 0.341 K/year to 0.088 K/year. Remaining trend might be attributed to a potential climatic signal that would be interested to analyze in finer detail.

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6. IMPACT ON PATH DELAY

Finally, the change causes by the application of this 36.5 GHz drift correction has been evaluated on the retrieved wet path delay (positive quantity) through two approaches:

- **Comparison with ECMWF wet path delay estimates;**
- **Comparison with radiosonde measurements.**

6.1. GLOBAL OCEAN PATH DELAY MONITORING

The use of ECMWF estimates was proved to be useful to survey the stability of the radiometer products from Jason-1 radiometer by comparing them at a daily time-scale as shown in RD2 to detect anomalies and drifts. However, the use of such a method is based on a good knowledge of any change in the ECMWF model, since it could have an impact on the path delay estimation and so in the computed difference. Since January 2002, there was no significant big change in the ECMWF model, so over ENVISAT cycles 09-401, these path delay estimates can be considered as a stable reference to compare with. Figure 10 shows the daily difference between ENVISAT and ECMWF path delays as a function of time before and after application of the corrective term on 36.5 GHz brightness temperatures. Overlaid is the linear regression fit. The early daily difference displays a decreasing trend of -0.082 cm/year with a mean bias of -0.486 cm and a standard deviation of 0.115 cm. When the correction is applied, the wet tropospheric difference displays smaller decreasing trend of -0.023 cm/year, a mean bias of -0.40 cm and a standard deviation of 0.094 cm. Comparison of stability is performed with daily difference between TOPEX (after correcting for the 18 GHz TB drift and correction of the yaw effects as indicated by RD4) and ECMWF path delays as a function of time over the same Envisat period. This latter displays a little bit less variability with time.

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Comparison with either Jason-1 or ERS-2 data has not been provided because of unavailability of reprocessed Jason-1 data corrected for different features such as jumps, drift, yaw effects at this time. Due to a failure of the ERS-2 tape recorder on 22 June 2003, the recording capabilities are permanently unavailable and the ERS-2 Low Rate mission goes on within the visibility of ESA ground stations over Europe, North Atlantic, the Arctic and western North America. This reduced area exhibits large annual variation of the TBs and thus interpretation of the differences with Envisat does not come out very well.

The proposed Envisat 36.5 GHz brightness temperature correction represents only a rough one, improved correction would come when identification of the source of the instrumental parameter drift will be assessed.

6.2. COMPARISON WITH RADIOSONDE MEASUREMENTS

The most conventional method for the validation of the radiometer path delays is the comparison with in-situ measurements that are humidity measurement profiles provided by radiosondes. This accumulation of collocated measurements can also be used to detect potential drift of the radiometer measurements as shown in RD2 in the case of TOPEX radiometer over 11 years of data. Figure 12 provides the difference between ENVISAT and radiosonde measurements with respect to time since launch. The data are daily averages. Overlaid are the 90-day moving average curve and the linear regression fit. The difference displays an increasing trend of +0.06 cm/year from the GDR products and of +0.11 cm/year when one recomputed the wet path delay after correcting the 36.5 GHz brightness temperatures. This result is in opposition with the results based on ECMWF path delay estimates. We have to be careful when using this last result because of the limited distribution of the situations analyzed as shown in Figure 13 and of the large uncertainties on the slope determination as revealed by the large interval obtained for the confidence interval of the slope. The curve of the difference over the three years displays annual and inter-annual variations (see the resulting time series for TOPEX wet path delay in RD2 with 90-day and 360-day averaging windows respectively) and leads us to conclude that a longer time series is

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needed before exploiting this comparative method to detect accurately potential drift in ENVISAT path delay measurements.

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7. SUMMARY AND CONCLUSION OF THE STUDY

In this analysis, we focused on evaluations of the 36.5 GHz brightness temperatures drift associated to the observed drift of the main instrumental parameters from this channel. As shown through Figures 1-4, the drift of all the instrumental parameters monitored are continuing. All internal parameters at 36.5 GHz are drifting in parallel with a -16.8 % decrease on the gain for instance since launch. Three years of Envisat GDR data (cycles 09-40) are analyzed to determine a drift correction on the 36.5 GHz brightness temperatures.

The impact on the wet path delay has been reduced by comparing Envisat with ECMWF estimates. Finally, these results represent only a rough correction. A tool has been developed for ENVISAT users to correct the TB 36.5 GHz and recompute the different radiometer product parameters (wet tropospheric correction, water vapor content, integrated liquid water, backscatter attenuation in Ku and S band). This tool is described in the next chapter.

At this stage, it seems to us that explanations of the causes of the drift of the 4 instrumental parameters is the major point that is needed to be elucidated to properly correct the restituted 36.5 GHz brightness temperatures.

Note that although the 23.8 GHz brightness temperatures seems to display a small drift (Figure 5), there are inconsistencies in the trends between the coldest, hot, and mean brightness temperatures (i.e. they are opposite in sign, coldest and hot data show a negative drift while mean values show positive drift) so it would not be possible to suppose a correction expressed as a linear function of time and of the TB value. More data are needed to state if a correction of these measurements is really required or not.

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8. DESCRIPTION AND USAGE OF THE DH_NEURAL TOOL

As already mentioned in the previous section, a tool has been developed for ENVISAT users to compute the ENVISAT MWR wet tropospheric range correction and related parameters (water vapor content, integrated liquid water content, attenuation in Ku and S band) using a neural network algorithm with corrected brightness temperatures as inputs.

This tool, “**dh_neural.pl**”, has been developed with the Perl language to insure its portability on any computer system. Indeed it has been developed under the Windows system and successfully tested on both the Windows and the Unix system.

In order to ease the implementation of the tool within the ENVISAT users programs, three examples of encapsulation are also provided : one in Fortran, one in Matlab and one in PV-Wave.

8.1. DESCRIPTION OF THE DH_NEURAL PROGRAM

The description of this program is given through the following rubrics : function, inputs, outputs, algorithms and implementation.

8.1.1. Function :

To correct the 36.5 GHz brightness temperature and to compute the wet tropospheric range correction using a neural network.

8.1.2. Inputs

The inputs to the tool can be given through two different ways : by passing the parameters themselves or by passing the name of the file containing rows of parameters.

Parameters inputs

- Tb1 : 24GHz brightness temperature (10-2 K)

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- Tb2 : 36GHz brightness temperature (10-2 K)
- SigKu : Ku Sigma0 (10-2 dB)
- AttKu : Ku atmospheric attenuation (10-2 dB)
- AttS : S atmospheric attenuation (10-2 dB)
- Day : day expressed in MJD2000 (day)

All the parameters (Tb1 Tb2 SigKu AttKu AttS Day) have to be extracted from the RA2 MDS of the NRT or OFL product.

Filename input :

- The name of a file. This file contains a set of input parameters. Each line of the input file contains (cf. description above): Tb1 Tb2 SigKu AttKu AttS Day

8.1.3. Outputs

- FileOut : Name of the result file. Each line contains the result of the computation for the corresponding set of input parameters: Tb1Corr Tb2Corr DhCalc WvCalc WcCalc AttKuCalc AttSCalc

where :

- Tb1Corr : 24GHz corrected brightness temperature (10-2 K) (1)
- Tb2Corr : 36GHz corrected brightness temperature (10-2 K)
- DhCalc : wet tropospheric range correction (mm)
- WvCalc : water vapor content (10-2 g/cm²)
- WcCalc : water liquid content (10-2 kg/m²)
- AttKuCalc : atmospheric attenuation on Ku band (10-2 dB)
- AttSCalc : atmospheric attenuation on S band (10-2 dB)

(1) Actually the 24GHz brightness temperature does not need to be corrected.

Nota: if FileOut is set to "-", the results are printed on the standard output.

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8.1.4. Algorithms

The 36.5 GHz brightness temperature is corrected using the equations given in the paragraph “Correction for the 36.5 GHz TB”.

The wet tropospheric range correction, the water vapor content, liquid water content and the atmospheric attenuation in Ku and S band are computed using a neural network as described in RD5.

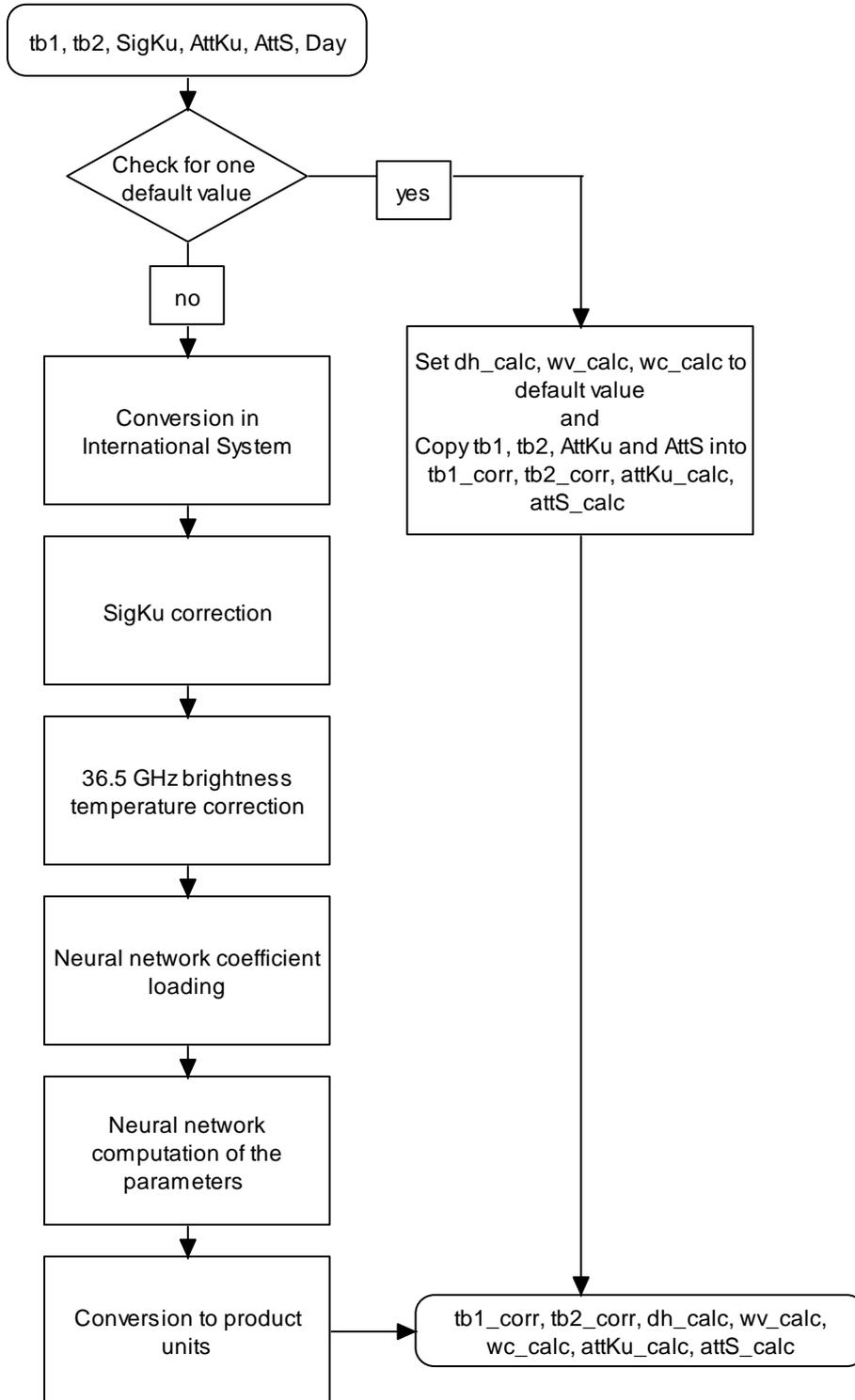
8.1.5. Implementation

The functions that have been implemented with Perl language are the following :

- Usage : Print the script usage
- CLS_ArretBrutal : Print an error message and exit the program
- round : Round the data to the nearest integer
- calcul_TB_corr : Computation of the corrected brightness temperature
- load_RN_coeff : Loading of the neural network coefficient in the tables
- calcul_envisat_RN : Computation of the output by the neural network algorithm
- algo_NN : Computation of the ENVISAT RA-2 wet tropospheric range correction using a neural network algorithm with brightness temperature as inputs
- main : main

with the following architecture for the algo_NN function which is the major function :

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8.2. USAGE OF THE DH_NEURAL PROGRAM

For usage and help about this programs, type the following command on a command line :

perl dh_neural.pl --help

As already mentioned in the previous section, the input parameters can be called using two different ways :

- by passing the values of the input parameters
- by passing the name of the file that contains on each line the values of input parameters

The outputs are stored in a file that you need to read to get them back in your program

The commands are then :

perl dh_neural.pl Tb1 Tb2 SigKu AttKu AttS Day FileOut

or

perl dh_neural.pl FileIn FileOut

This input ASCII file contains on each line the values of the input parameters ordered as follow :

Tb1 Tb2 SigKu AttKu AttS Day

and the output ASCII file contains on each line the output parameters ordered as follows :

Tb1_corr Tb2_corr dh_calc wv_calc wc_calc attKu_calc attS_calc

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Since this program only edits on default values, it is assumed that the user will have performed the necessary editing on the input data in order to have meaningful parameter value as input.

If you do not have Perl module, you can find it at the following web address :

<http://www.activestate.com/Products/Download/Download.plex?id=ActivePerl>

for Windows system, download the MSI file

8.3. CALLING EXAMPLES

Three calling examples of the perl program are proposed to help the users integrating this tool within their own programs. They are :

- test_dh_neural.f : example of Fortran program that encapsulates the PERL program
- test_dh_neural.m : example of Matlab program that encapsulates the PERL program
- test_dh_neural.pro : example of PV-Wave program that encapsulates the PERL program

They have the same program structure :

- Variables declaration
- Building of the perl command
- Running of the perl command
- Recovery of the output parameters
- Printing of the output parameters

These examples can be run with in the two calling configuration of the perl program, thanks to the parameter “config”, if set to :

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- 1 : will build the perl command as to call the perl program using the parameter values
- another value : will buikd the perl command as to call the perl program using a filename

details are provided in previous paragraphs

For each of the calling examples, the values of the input parameters are passed trough :

- the parameters, which are declared at the beginning of the calling example

or

- trough the ASCII file : TDS_dh_neural.data (see description in previous paragraph)

according to the value of the parameter “config” and the output parameters are recorded in the output file.

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9. FIGURES

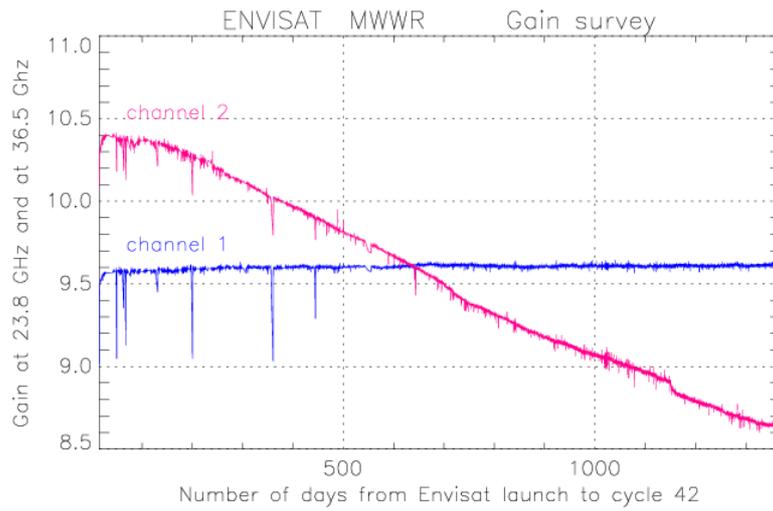


Figure 1: Monitoring of the gains in both channels since Envisat launch.

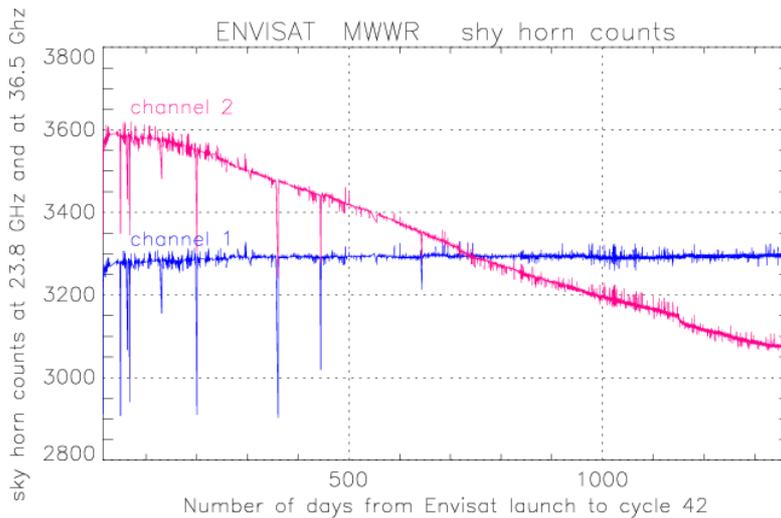


Figure 2: Monitoring of the sky horn counts in both channels since Envisat launch.

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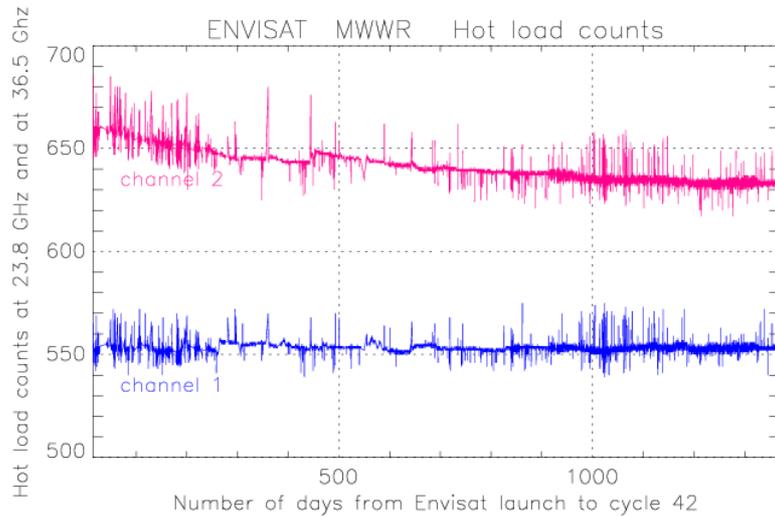


Figure 3: Monitoring of the hot load counts in both channels since Envisat launch.

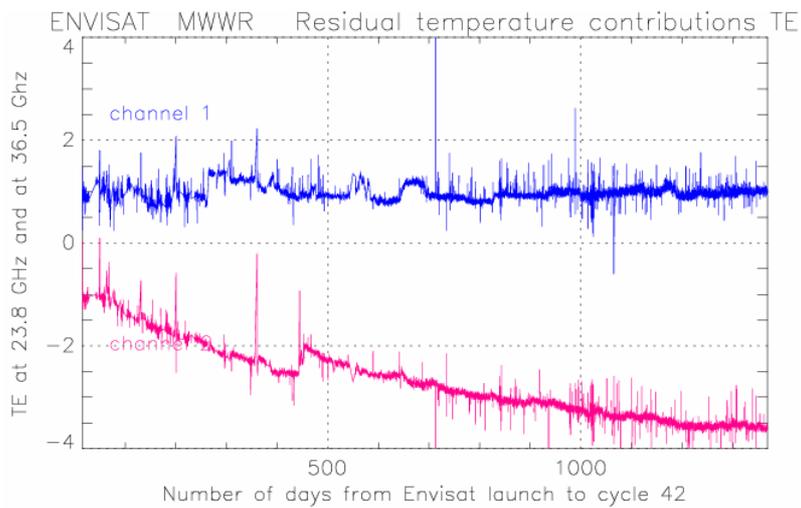


Figure 4: Monitoring of the residual temperature terms in both channels since Envisat launch.

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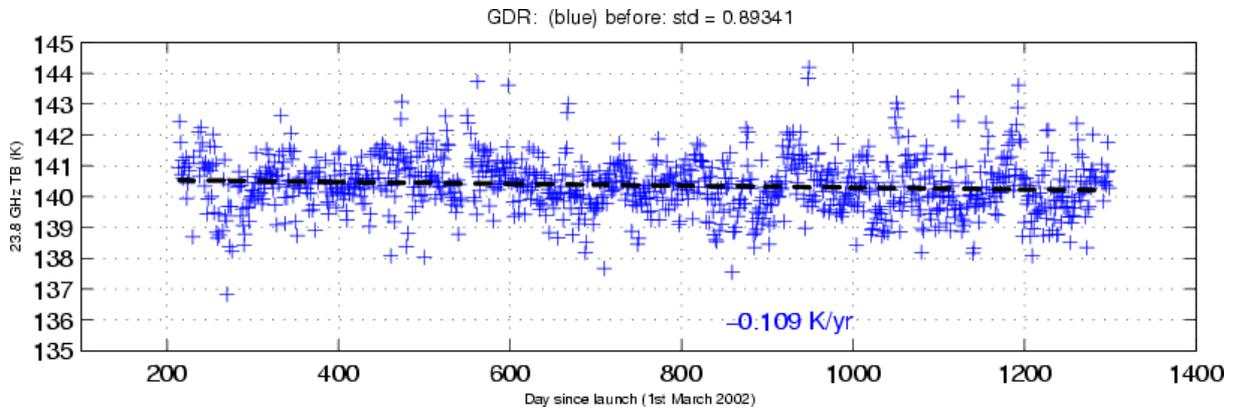


Figure 5: Variation of the coldest brightness temperatures at 23.8 GHz, averaged per day. The black line is the regression fit.

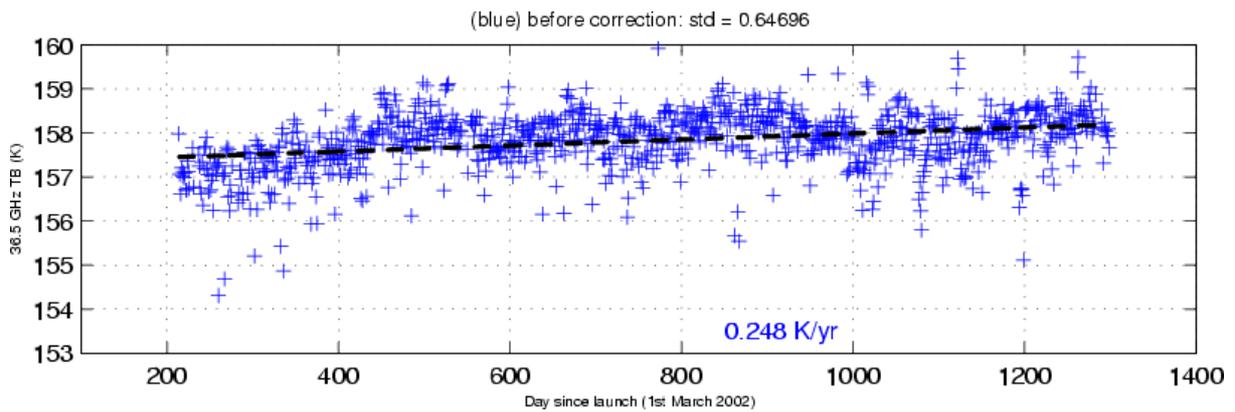


Figure 6: Same as Figure 5 at 36.5 GHz.

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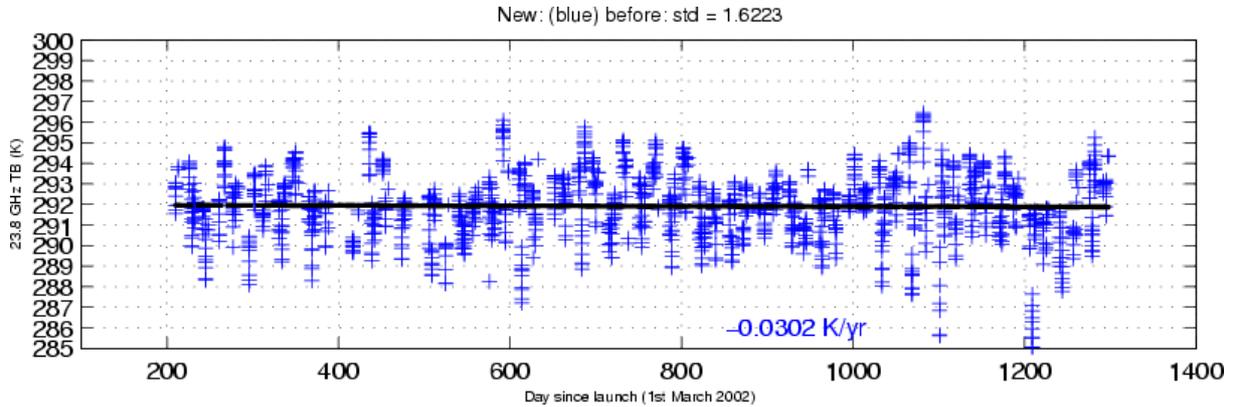


Figure 7: 23.8 GHz Brightness temperature time series over Amazon and Congo rain forest areas.

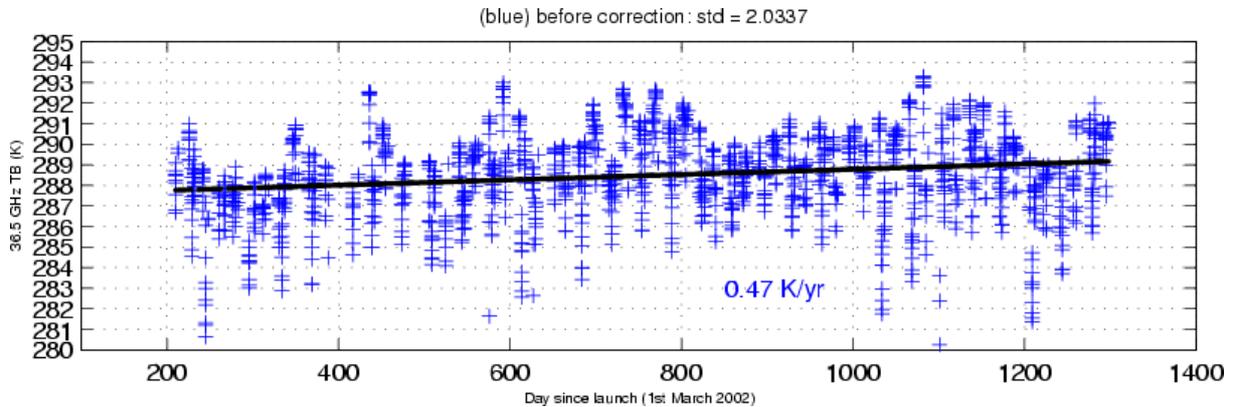


Figure 8: 36.5 GHz Brightness temperature time series over Amazon and Congo rain forest areas.

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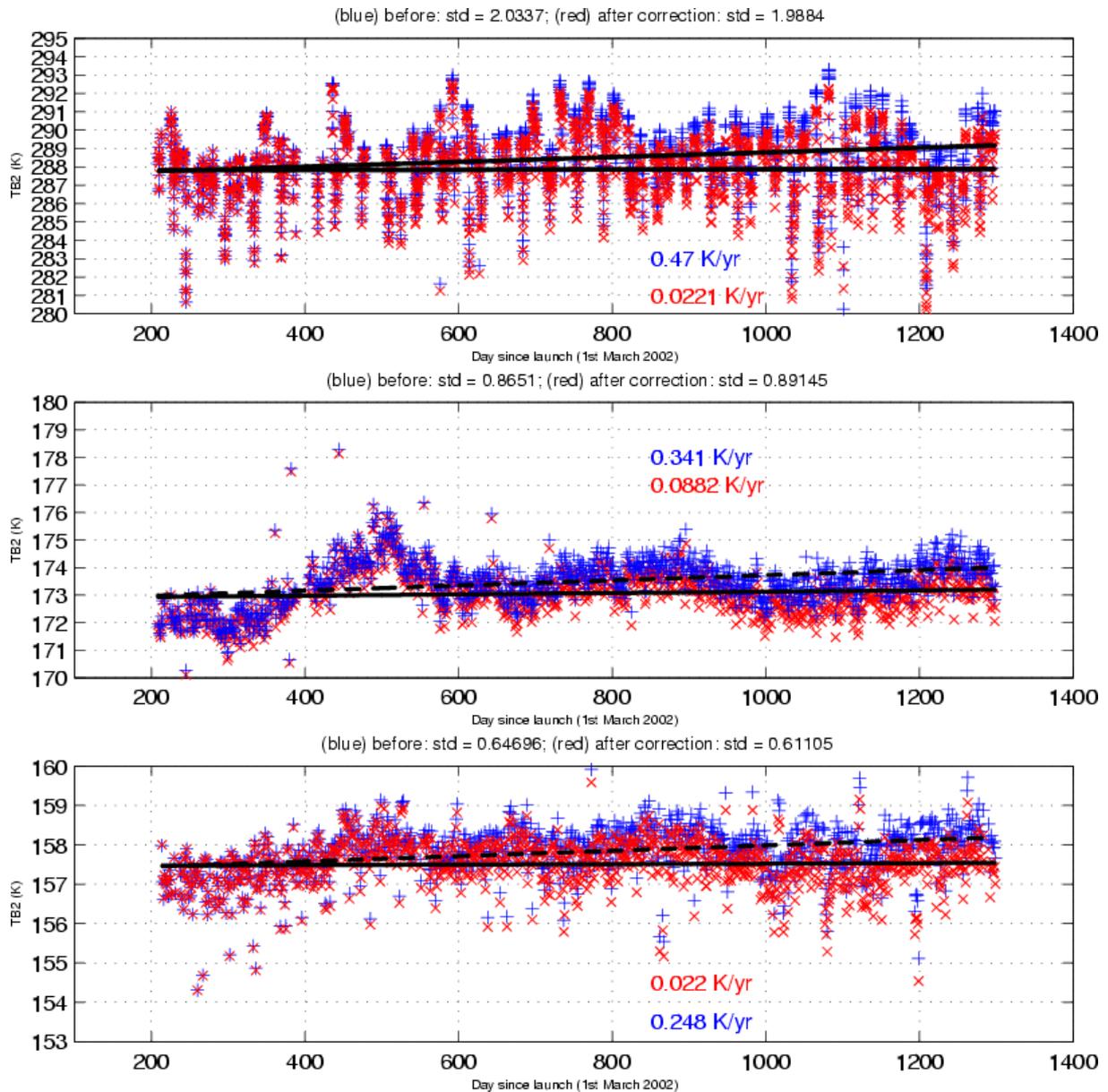


Figure 9: Time series of 36.5 GHz brightness temperatures from GDR products (in blue) and re-computed with the proposed correction (in red). (top) over the rain forest areas, (middle) for daily mean ocean measurements, and (bottom) for the coldest ocean data.

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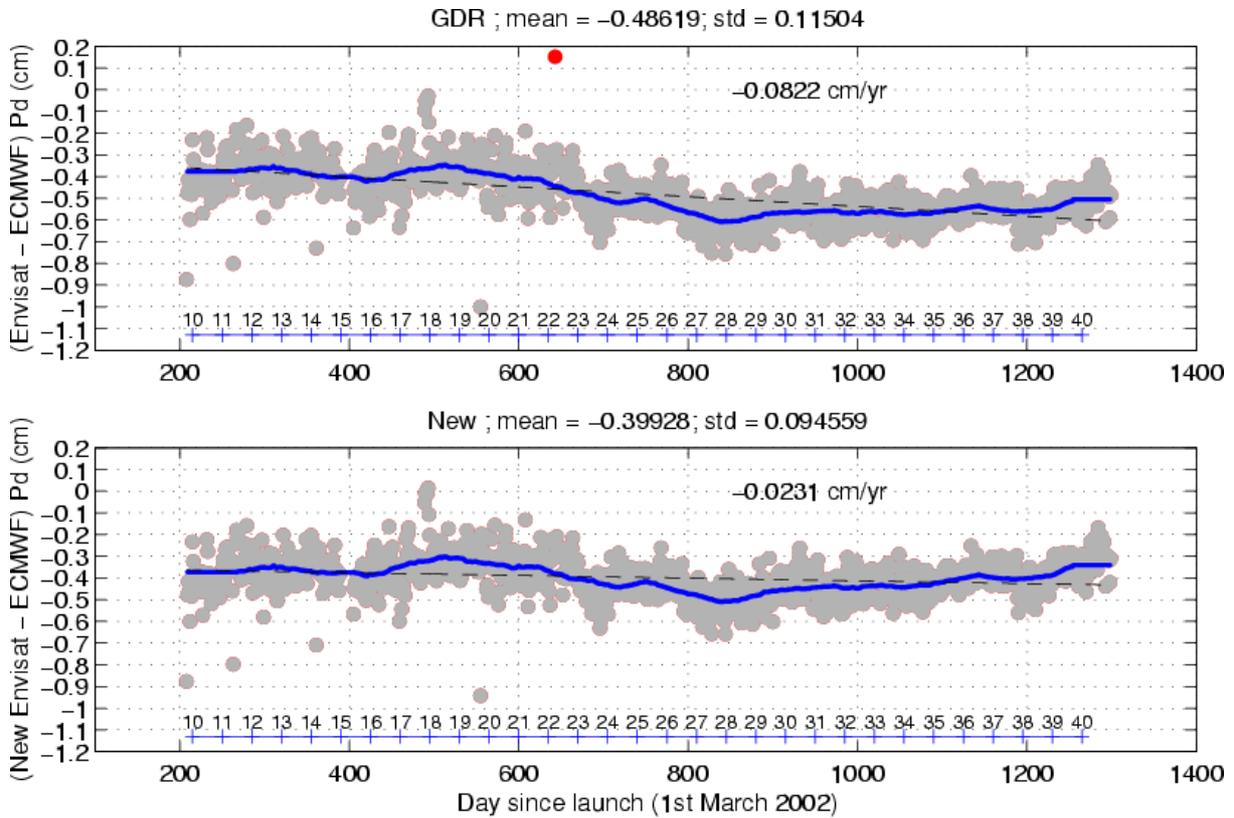


Figure 10: Daily mean difference (grey) between Envisat and ECMWF path delays as a function of time. Overlaid are the 90-day running averages time series (blue) and the black line the regression fit. (top) from the GDR products and (bottom) when using the corrected 36.5 GHz brightness temperatures and re-computation of the wet path delays. Red points indicate daily averages that are outside the 3σ interval of variation and are not taken into account to compute the statistical indicators.

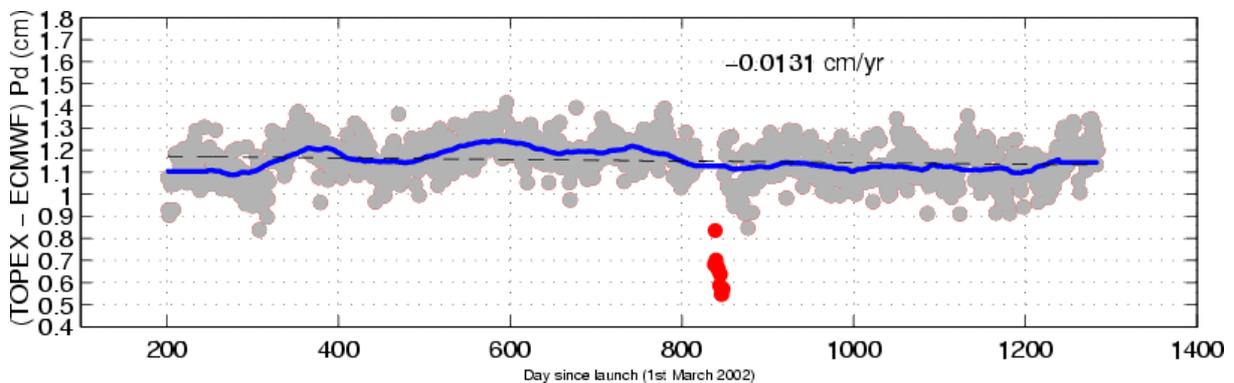


Figure 11: Daily mean difference (grey) between Topex and ECMWF path delays as a function of time over the same Envisat period. Overlaid are the 90-day running averages time series (blue) and the black line the regression fit.

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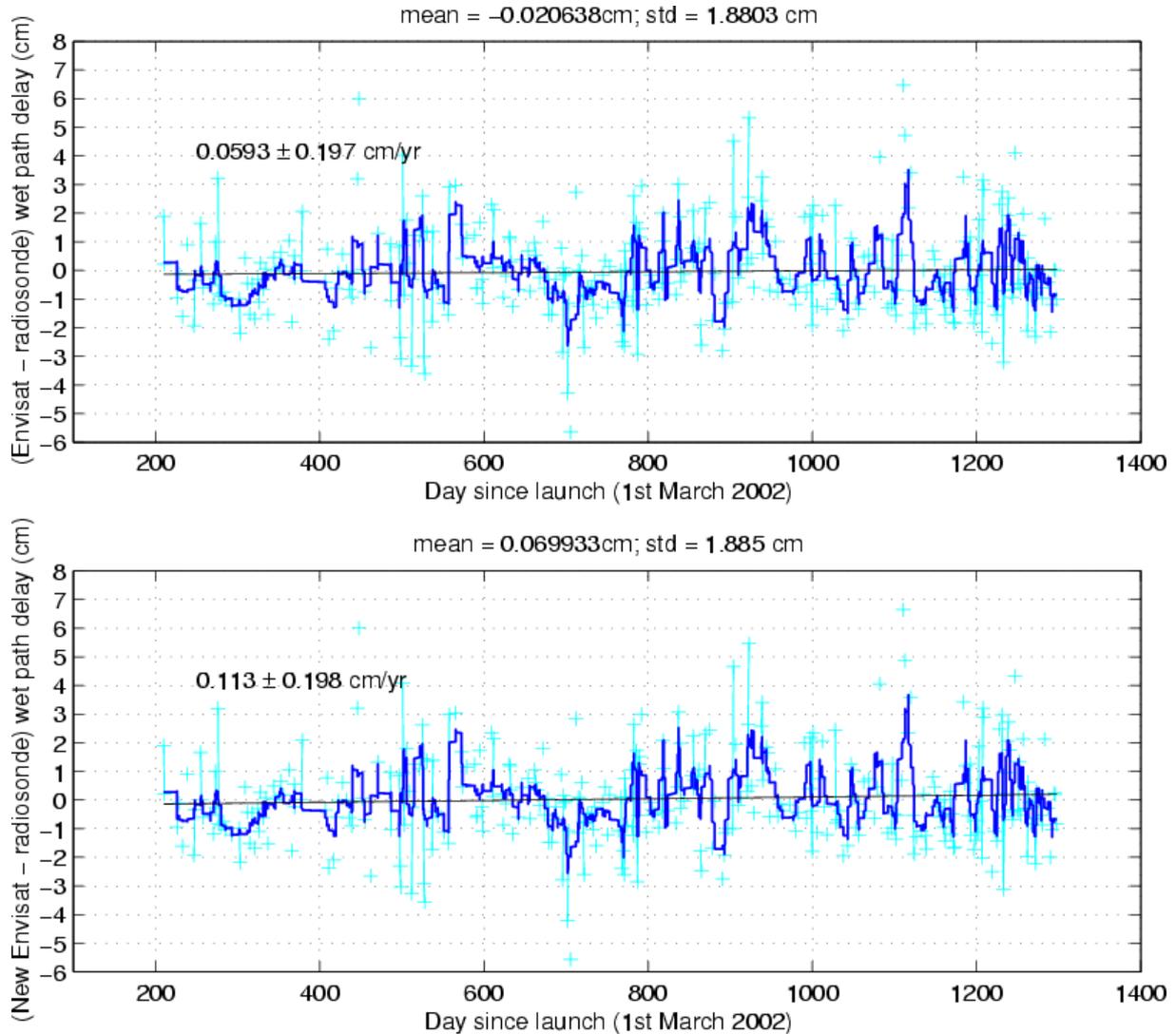


Figure 12: Variation of the daily mean difference between Envisat and radiosonde path delays. The solid dark blue curve indicates 90-day running averages time series and the black line the regression fit. (top) from the Envisat GDR products and (bottom) when using the corrected 36.5 GHz brightness temperatures and re-computation of the wet path delays.

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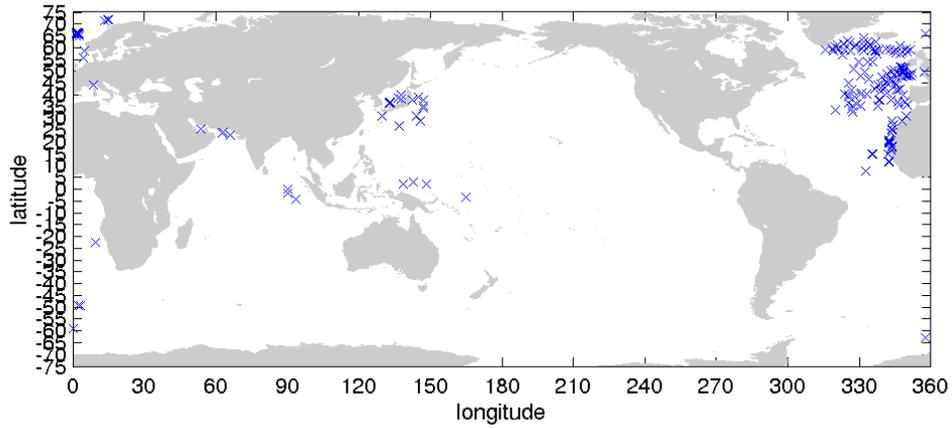


Figure 13: Spatial distribution of the radiosonde measurements.