INVESTIGATIONS ON THE ENVISAT RA2 TROPOSPHERIC CORRECTION

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ABSTRACT

The Center for the Topography of Oceans and the Hydrosphere (CTOH), the Altimeter Data Service of the LEGOS laboratory pursue an effort to validate and improve ENVISAT RA2 altimetry. We investigate the stability and reliability of different corrections for the altimetric measurements. With the one before last ENVISAT RA2 processing (v1.0), the ICE Validation chain of the CTOH detected some issues with the Dry Tropospheric Correction (DTC) over the Cryosphere. Here we present the validation of the latest reprocessing (v2.1) of ENVISAT data. We observe the limitation of this re-processed DTC, especially the jump observed at cycle 44 over Antarctica which causes significant local trend and suspect changes in the variability of this correction over time. We investigated a solution and re-compute this correction all over the globe with the ERA Interim ECMWF pressure fields and using directly the altimetric range measurement rather than any external digital elevation model (DEM). We present the results of this investigation, the statistics of previous (DTC_v2.1) and new corrections (DTC_ctoh) and in the context of different surfaces. The improvement is significant, and we discuss the aspects and impacts of this improvement, in terms of meteorological-fields, procedure, and location.

1. INTRODUCTION

The CTOH had developed a ICE Validation Chain to monitor the altimetric mission and advise the users of the assessment of the data. This validation is base on crossover difference statistic where each ICE2 parameters [1] and corrections are assessed. We use these various outputs available to monitor the behavior of all parameters and corrections in time, in space and as a function the surface slope. We already and specifically do this work for the cryosphere field for the missions ERS2 and ENVISAT [2]. The assessments raise some times problems for which we make particular investigations. Here, in the case of ENVISAT, it was observed for the previous release GDR data a serious problem for the Dry Tropospheric Correction (DTC) over Antarctica. In two mains wide area, in Dronning Maud Land and Dome Fuji, at the east of the Ronne Ice-shelf, the time series of DTC show large jump of more of 10 cm at cycle 40 [3].

Since the beginning of 2012, the ENVISAT mission is completely reprocessed (called release v2.1). And we have assessed the new GDR (v2.1) using our ICE Validation Chain. We found that the new release solve many issues [4]. For example, the homogeneity of the GDR dataset is improved because the whole mission is consistent to a homogeneous algorithms release (IPF Version 6.04, CMA processor version 9.3, and GDR-C precise orbits) [From ESA web site]. And we also note that the Doppler slope correction is also better in some continental area but remains unreliable in coastal and transition areas as well on other continents [5].
However it remains some corrections which did not pass satisfactorily the assessment. In the ICE Validation result of ENVISAT v2.1, we note that the time series of the RMS of DTC_v2.1 shows a jump cycle 44 (see Fig.1-b) for Antarctica. While the Greenland, this RMS appears normal [4]. In this study, we investigate and we compare it with the alternative Dry Tropospheric Correction (DTC_ctoh) base on the altimetric height measurement that we have developed to solve the same issue for the previous assessment of the ENVISAT precious release[3].

2. DATA SETS AND VALIDATION FIGURES

For this study, we used ENVISAT reprocessed (release v2.1) data from cycles 6 to 94 (Jun 2002 to October 2010). This dataset cover the exact repeat period until the orbit change in October 2010. The DTC_v2.1 is extracted directly from the GDR v2.1 re-processed. And the DTC_ctoh is updated using the range and orbit from the GDR v2.1 and the last release of ERA Interim ECMWF data. In section 3, we detail their computation. Both corrections are validated over the cryosphere by using the Ice Validation Chain [2].
The figures in this paper are calculated using crossover point statistics form the validation process. Here are the steps to compute the regional time series which we used in the figures:

- For each crossover a mean and a difference of the dry troposphere correction is calculated using the ascending and descending value within each repeat cycle.
- For each cycle the anomaly is calculated by subtracting the average value of the time series at each crossover. Then, for each crossover, the

anomaly of the mean dry troposphere correction and the anomaly (CM_ANO) of the dry troposphere correction difference (CD_ANO).
- From these two anomalies we can compute the anomaly averaged along the orbit and the anomaly averaged over geographical area (Antarctica in our case). We also compute the RMS variability of the mean (CM_RMS)and difference (CD_RMS).

The figures presented here are the anomaly averaged over Antarctica for the mean DTC and the dry troposphere correction difference (Fig.1). The maps are obtained by doing statistic (mean, RMS, trend) on the crossover time series.

3. DRY TROPOSPHERIC CORRECTION

3.1. General

The DTC is very important in radar altimetry over ocean and continental surfaces. It is applied to correct the effect of the dry gas of the atmosphere refraction on the path delay of the radar echo. Its magnitude depends of the thickness of the atmosphere crossed by the radar signal. Its temporal variations are relatively small but its spatial variations are very important due to the relief over continental surface. It is about 2.3m over ocean and gradually less as a function of the surface height over continental surfaces (e.g. down to 1.3m at 3500 m of altitude in Antarctica).

3.2. DTC from the ENVISAT GDR and recomputed by CTOH

The DTC is calculated from the surface pressure given by the relationship of Staastamoinen [6].

$$\delta h_{dry} = -0.002277\, P_{surf} \cdot (1 + 0.0026 * \cos(2\phi)) \quad Eq.\ 1$$

Where P_{surf} is the surface pressure in millibars and ϕ the latitude. The surface pressure is supplied by the ECMWF meteorological model and interpolated along the pass.

The DTC_v2.1 computed by ESA uses the Surface Pressure Model (SPM_v2.1 supplied in the GDR v2.1) and an external or auxiliary Digital Elevation Model (DEM).

The DTC_ctoh calculated by the CTOH do not use any DEM. The Surface Pressure Model (SPM_ctoh) is computed according to the Météo-France relationship given by:

$$P_{surf} = P_{sea} \cdot \left(\frac{T_{2m} + \gamma H_m}{T_{2m}} \right)^{-\alpha} \quad Eq.\ 2$$

Where γ is the mean vertical gradient of the temperature equal to 6.5°/km, α is constant value given by Météo-France for dry gas equal to 5,255. P_{sea} and T_{2m} taken from the ECMWF ERA Interim data and the surface height H_m from the radar altimetric data itself [3].

$$H_m = H_{sat} - Range - H_{geoid} \quad Eq.\ 3$$

where H_{sat} is the satellite orbit above the ellipsoid, *Range* the altimetric range from the satellite to the ground echoing point and H_{geoid} height of the geoid above the ellipsoid.

This alternative way to proceed avoids relying on external or auxiliary DEM (which are often found to be the source of unreliable or irrelevant surface heights) and takes the surface height “as seen by the satellite” and better reflect the atmospheric layer crossed by the radar waves. It is not of the best possible accuracy, but all errors from corrections not applied on the height measurement impact on the inferred DTC are negligible. When the impact of corrections is not negligible correspond to cases where the radar altimetric measurement is unreliable as for instance when the altimeter is tracking a target far off nadir which falls away from the antenna aperture main lobe. Proceeding this way ensures a consistent computation of the DTC for the whole mission and all surfaces.

4. OBSERVATIONS OF THE VALIDATION RESULTS

In the validation report of ENVISAT v2.1, we plot the time series of the DTC over Antarctica as shown in Fig.1.

The amplitude of the CM_ANO in Fig.1a appears normal (+/-0,04m) for the Antarctic continent and a clear annual cycle is observed.

We can see that the CM_RMS of DTC_v2.1 (Fig.1b) presents a jump at cycle 44. The CM_RMS of DTC_v2.1 is higher before than after the jump and changes from more than 4 cm to 3 cm. While the CM_RMS of DTC_ctoh is consistently smaller and stays consistently around 1.5 cm for the whole time series.

For the CD_ANO (Fig.1-c) the two time series of the DTC do not have the same level of seasonal amplitude. The DTC_v2.1 has very low amplitude without much seasonal variations while the DTC_ctoh shows 3 mm seasonal variations. This difference between the DTC is difficult to interpret but we suspect that this issue comes from the SPM_v2.1.

The disagreement between SPM_v2.1 and SPM_ctoh come from the difference of the ECMWF meteorological fields releases and from the difference of the altitude estimation between the DEM and the radar altimetry measurement.

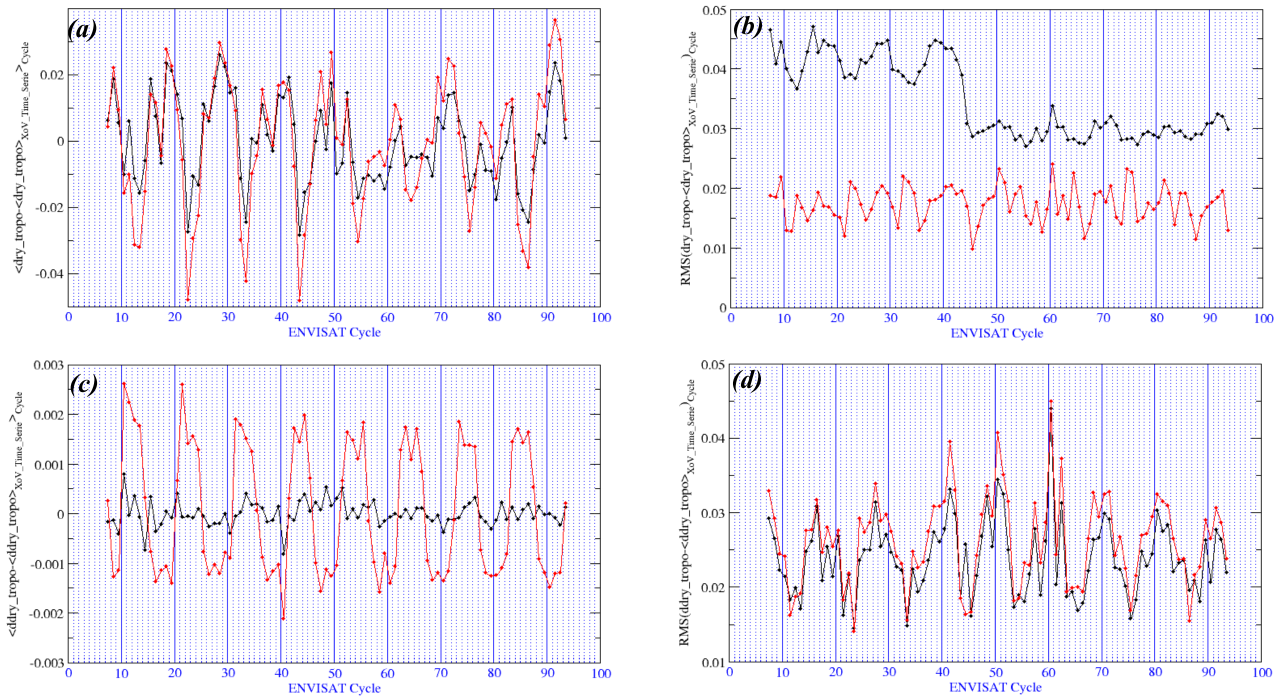

Figure 1: Time series of the Dry Troposphere Correction as function of ENVISAT cycle number over Antarctica: (a) anomaly at crossover (CM_ANO) (c) crossover difference anomaly (CD_ANO) (b) the spatial RMS of crossover anomaly (CM_RMS) and (d) the spatial RMS of the crossover difference anomaly (CD_RMS). In ***black*** *is done with DTC re-processed GDR v2.1 and in* ***red*** *is done with DTC computed by the CTOH. Unit: meter.*

We focus our analysis to observe the consequence of the issue to the DTC_v2.1 and the assessment of the DTC_ctoh.

5. ANALISYS OF THE VALIDATION RESULTS

In order to extend this analysis of the validation results done in the previous section, we also look at the spatial extent of these variations.

On Fig.2 we map the crossover mean RMS of DTC calculated by doing the RMS on the DTC crossover mean time series. The map Fig.2-a shows a number of areas where the RMS is particularly strong. The two most important areas are located in Est Antarctica close to Dome Fuji and East of the Ronne ice shelf. None of these variations seems correlated with the topography of Antarctica.

For the DTC_ctoh, Fig.2-b, no areas having strong RMS anomaly is observed. At higher altitude the RMS become stronger but never like the DTC_v2.1. The RMS of DTC_ctoh shows a correlation to the surface elevation. It is also consistent with the SPM which shows larger amplitude at higher than at lower altitude.

The DTC crossover differences averaged on each crossover time series (cycles 6 to 94) from the validation report, is also plotted Fig.3. The average difference remains small. We can see the nested marks of the tracks in both maps showing positive and negative difference of DTC. It appears also that the difference at crossover is more positive in East Antarctica for the DTC_ctoh. The systematic difference may come for the systematic local time difference at crossover point as ENVISAT is sun-synchronous, aliasing the daily pressure and temperature cycle for example.

The histograms below present the distributions of the crossover difference plotted in the map. We observe that the distribution of the DTC_v2.1 is well centered to zero while the DTC_ctoh shows a slight bias around 1 mm. By analyzing this bias at crossover difference with each parameters involved in the computation of the DTC_ctoh and SPM_ctoh (Eq.1 and Eq.2), surface height (H_m), Temperature at 2 meter (*T2M*) and Mean Sea Level Pressure (*MSLP*), we see, Fig.4, a clear mean bias of -0,5 degrees Kelvin over Antarctica. Fig.3, the histogram of the DTC_ctoh has a more Gaussian distribution than the DTC_v2.1.

An other aspect of this DTC investigation is to check the artifact trends which could be introduced. Fig.5 shows the map of the trend for both DTC calculated using the complete exact repeat mission over Antarctica. It appears that the jumps at cycle 44 in the time series for the DTC_v2.1 produce trends in the same areas

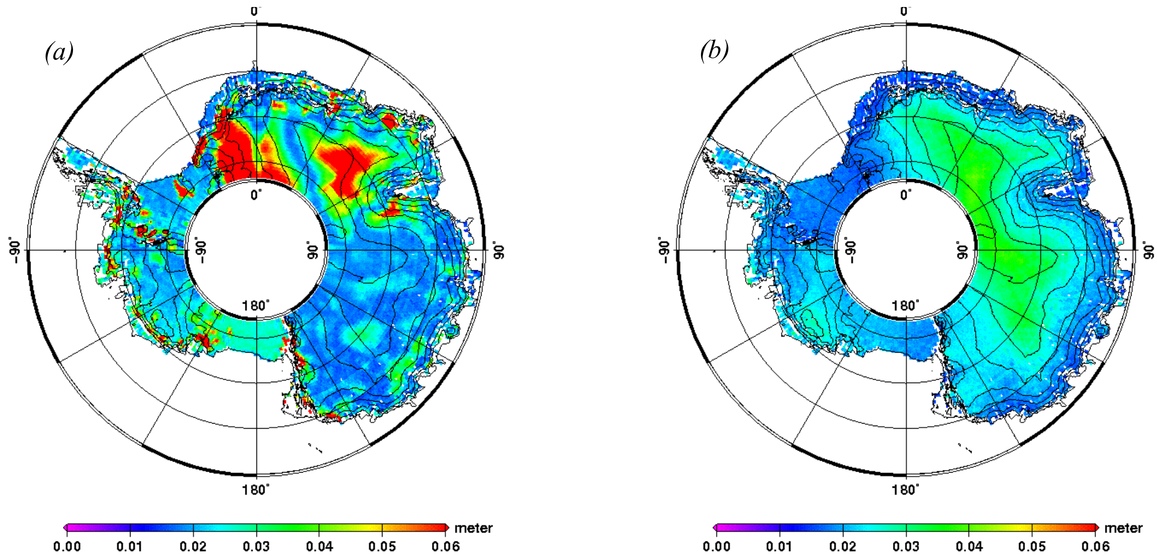

Figure 2: Spatial distribution of the RMS of the DTC (CM_RMS) calculated from the time series of the DTC crossovers anomalies for DTC_v2.1 on the left, DTC_ctoh on the right hand side.

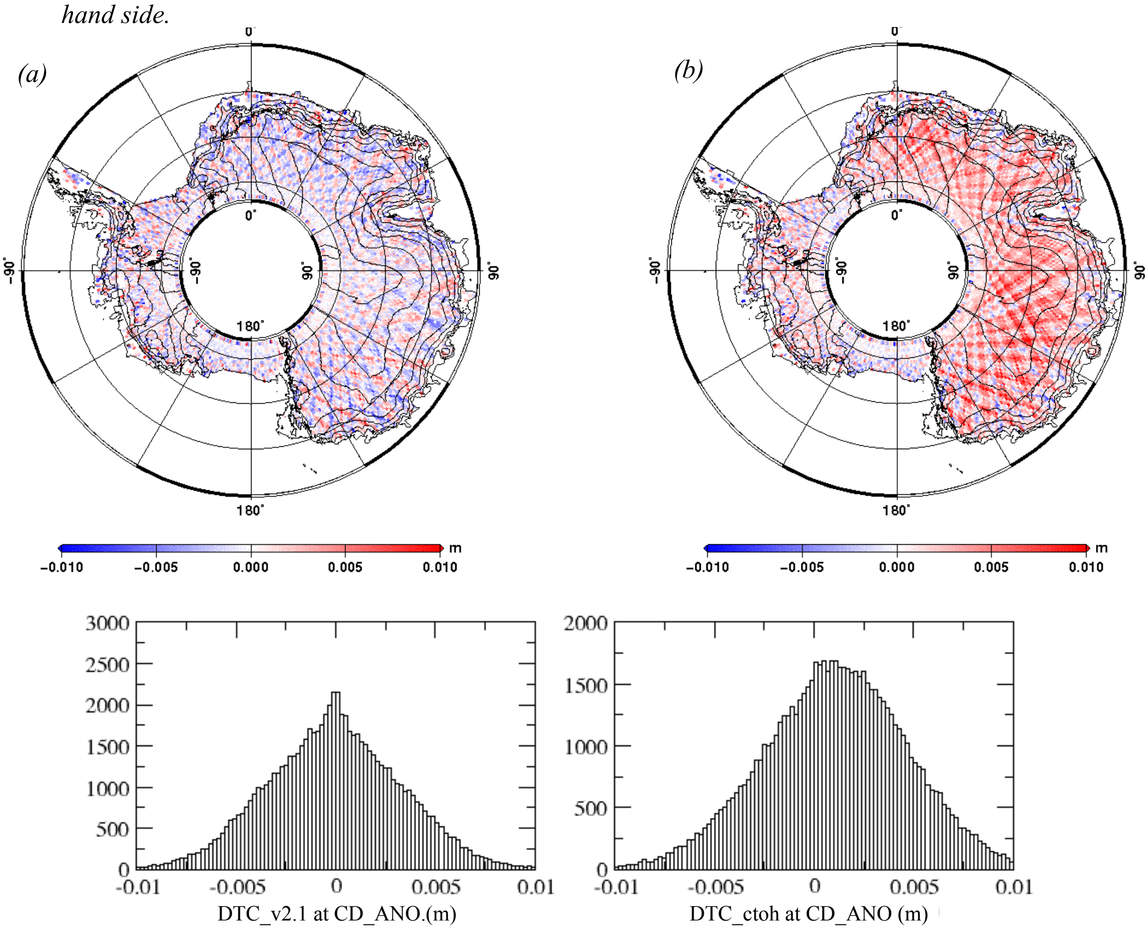

Figure 3: DTC difference at crossovers (CD_ANO) over Antarctica for DTC_v2.1 (a) and DTC_ctoh (b) processing (averaged over all repeat cycles). Below each maps, the distribution of the DTC difference at crossovers.

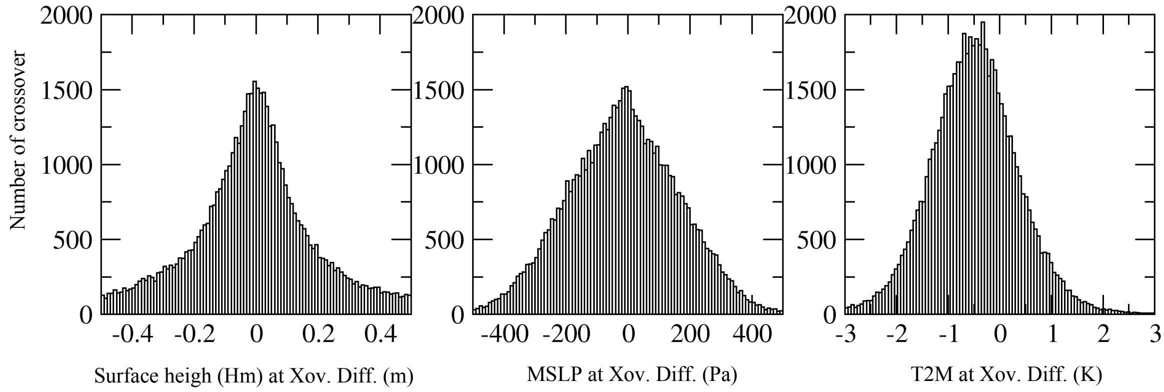

Figure 4: Distributions of the Surface heigh (Hm), MSLP and of the T2M at crossover difference over Antarctica. These meteorological-fields, MSLP and T2M, are supplied by the ECMWF RA Interim and used to compute DTC_ctoh (Eq.1) with a re-calculated Surface Pressure Model (Eq.2)

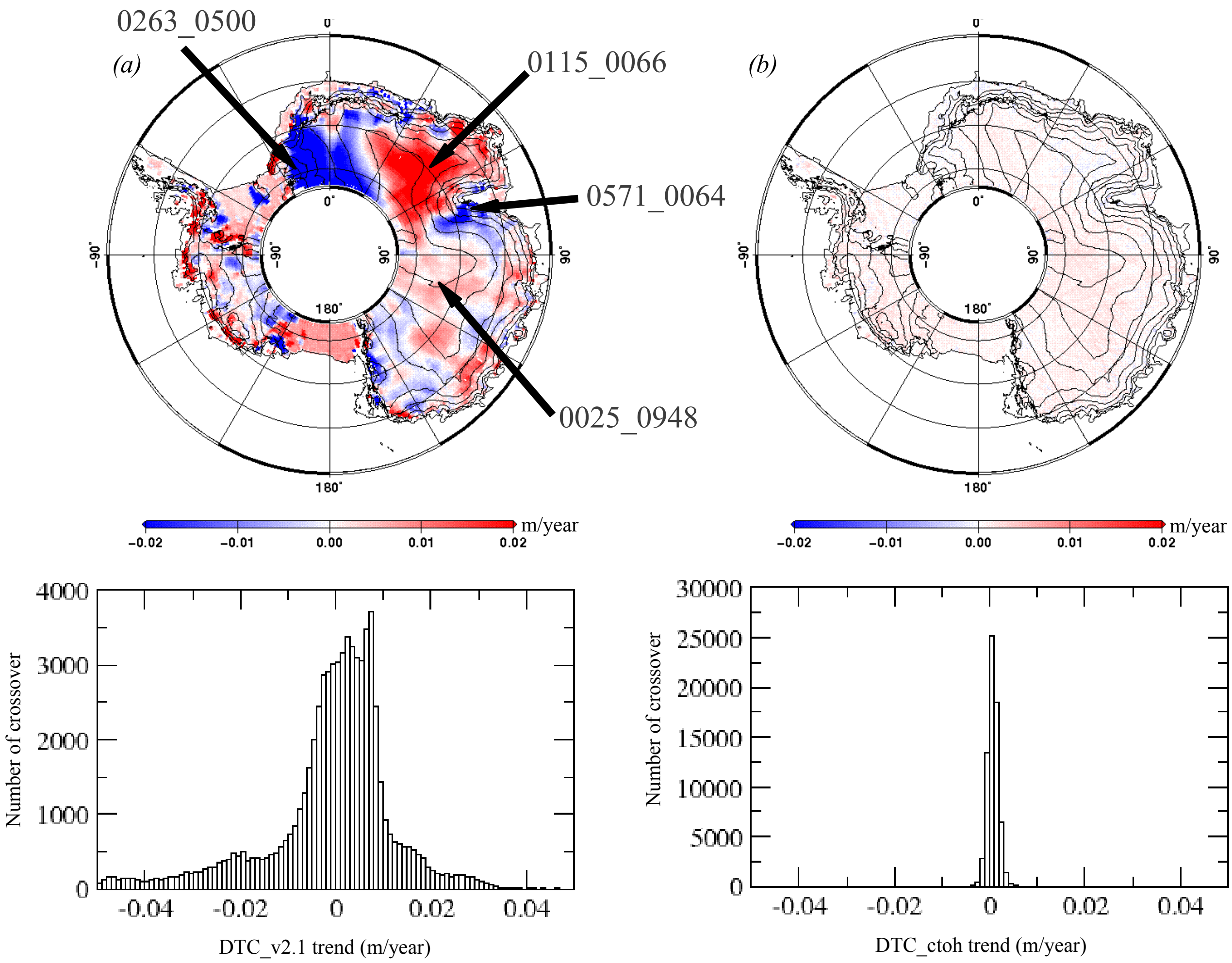

Figure 5: Trend of DTC (m/year): the DTC_v2.1 on the left hand side and the DTC_ctoh on the right hand side. Below each maps, the distribution of the DTC trend.

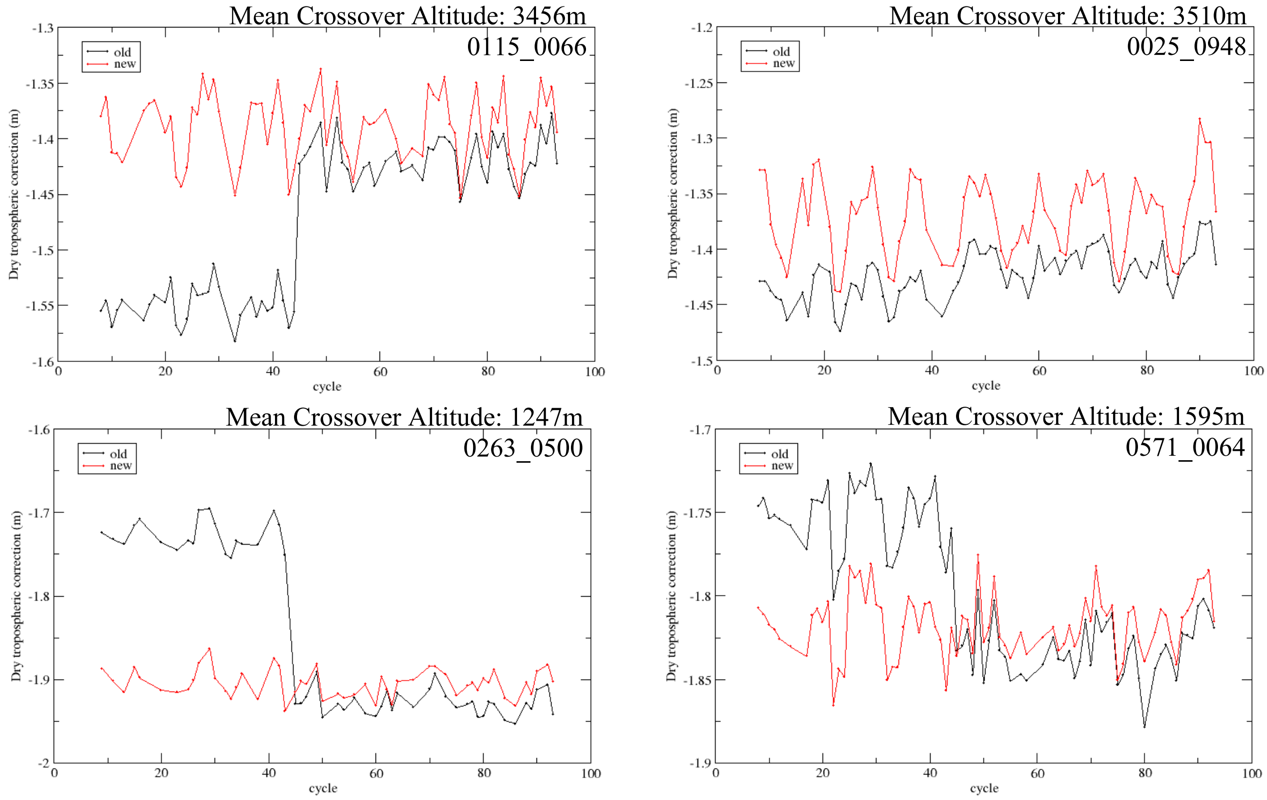

*Figure 6: Time series for **DTC_v2.1** (black) and **DTC_ctoh** (red) at four individual crossovers as function of ENVISAT cycle number. The crossover positions are indicated on the map given Fig.5.*

where the RMS is strong (Fig.2). Fig.6 shows the time series of DTC at crossover mean for some crossovers points selected Fig.5-a. We can see a clear transition jump for the DTC_v2.1 (black curve) at cycle 44 for the crossovers 0263_0500, located in the negative area trend, and the crossover 0115_0066, located in the positive area trend. In other parts the jump is less important, for example in the Vostok lake area for the crossover point 0025_0948. The DTC_ctoh is free of jump and is close to DTC_v2.1 for the second part of the time series after the transition jump at cycle 44. It looks like that there is an improvement of DTC_v2.1 during the mission lifetime. This improvement is still consolidated for the begin mission in the last reprocessing (v2.1). Fig.5, the histogram below the DTC_v2.1 trend map is large and disymmetric. While the DTC_ctoh distribution is Gaussian with a slight bias trend observed. For DTC_ctoh, we find a positive trend of 0,73 mm/year in average with a RMS of 1,1 mm/year over Antarctica. This trend is low in comparison to the surface elevation trend observed in regional areas in Antarctica. For DTC_v2.1 it is -1.33 mm/year in average with a RMS of 14.3 mm/year across Antarctica. The relative impact on the surface height trend is evaluated in the next section.

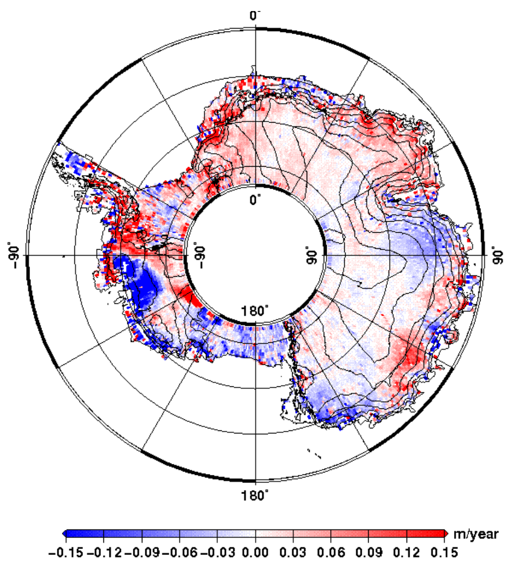

Figure 7: Surface height trend calculated for the complete ENVISAT mission in repeat mode.

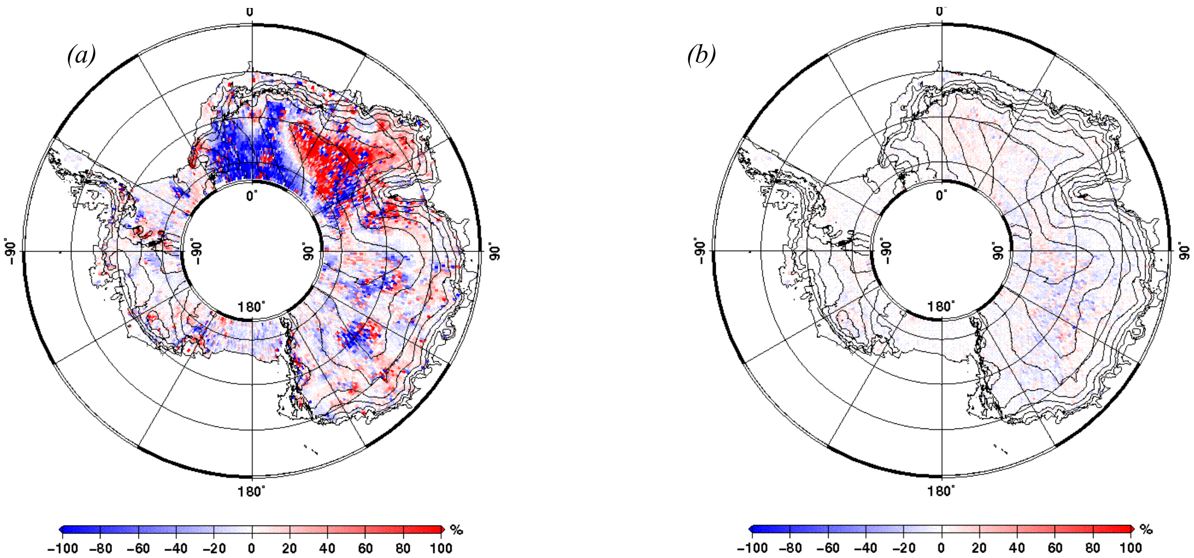

Figure 8: The ratio (%) of the impact of the dry troposphere correction on the surface height trend for the complete ENVISAT mission in repeat mode: the DTC_v2.1 on the left hand side and the DTC_ctoh on the right hand side.

6. IMPACT OF THE DTC ON THE ENVISAT ALTIMETRIC TREND

This DTC applied to the range to calculate the surface height may impact on the surface height trend (Fig.7). In order to evaluate the impact of the DTC trend in the regional trends we calculate for each crossover the ratio of the correction versus the surface height trend.

Fig.8-a is drawn the trend impact for the DTC_v2.1. It shows again the same two large main areas: one positive and other one negative. They are impacted by the trend of DTC_v2.1 for more of 80%.

Fig.8-b, the trend impact of the DTC_ctoh is reduced in particular in the Dronning Maud Land – Dome Fuji area in East Antarctica. Where the surface height trend is low. The impact of the correction appears stronger for some sparse crossovers. The color pattern of these sparse crossovers looks like noise instability due to the very low surface height trend and that the DTC trend has the same order of magnitude as the surface height trend.

Finally, we can see that the impact on the surface height trend is strongly reduced with the DTC_ctoh. It passes from 12,5% in average with the DTC_v2.1 to less of 0,01% with the DTC_ctoh over Antarctica.

7. HISTOGRAM

We know the strong dependency of the altimeter measurement to the ground surface slope. The alternative method to calculate the DTC_ctoh use directly the altitude measurement H_m (Eq.3). Here we check its slope dependence which should be small.

In order to evaluate it, we plot histograms by class of slope. The histogram, from the validation report (Fig.9)

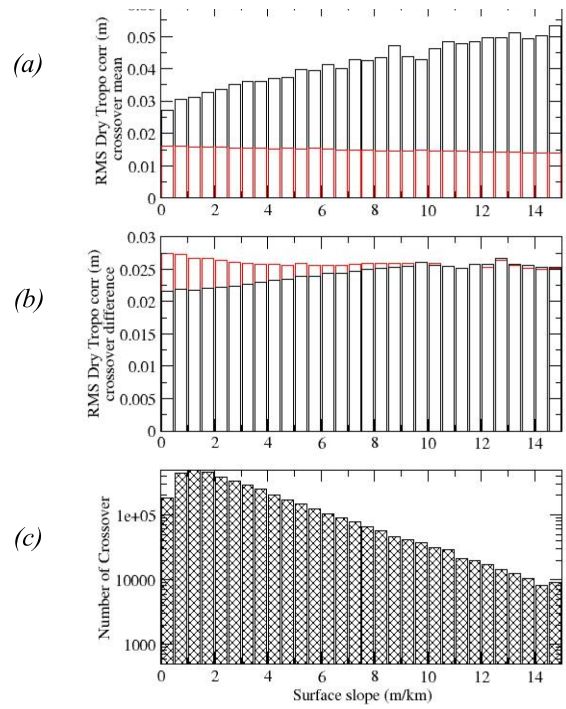

*Figure 9: RMS of the **DTC_v2.1** and **DTC_ctoh** by class of surface slope: crossover mean (a), crossover difference (b) and crossover distribution (c). These histograms are done using crossovers in Antarctica over 200 meter altitude.*

shows the RMS of the DTC as function of class of surface slope: for the crossover mean (Fig. 9-a) and for the crossover difference (Fig. 9-b). The distribution of the number of crossovers is plotted in the histogram (Fig. 9-c).

From the histograms (Fig. 9-a) and (Fig. 9-b), it is observed that the RMS level increases as the surface slope increases for the DTC_v2.1 (black). While the DTC_ctoh (red) is more stable to about 16 mm for the crossover mean and to about 28 mm for the crossover difference. The RMS histograms then show that the DTC_v2.1 had surface slope dependence while the DTC_ctoh hasn't got a significant slope dependence.

We also observe that the RMS level for the crossover mean is higher than the RMS level for the crossover difference for the DTC_v2.1 while it is inverse for the DTC_ctoh.

8. CONCLUSION

This particular investigation on DTC with the ICE validation chain shows that this DTC_v2.1 has some issues: RMS at crossover mean change during the mission life, time series show a jump at cycle 44, the impact to the surface height trend is not negligible and

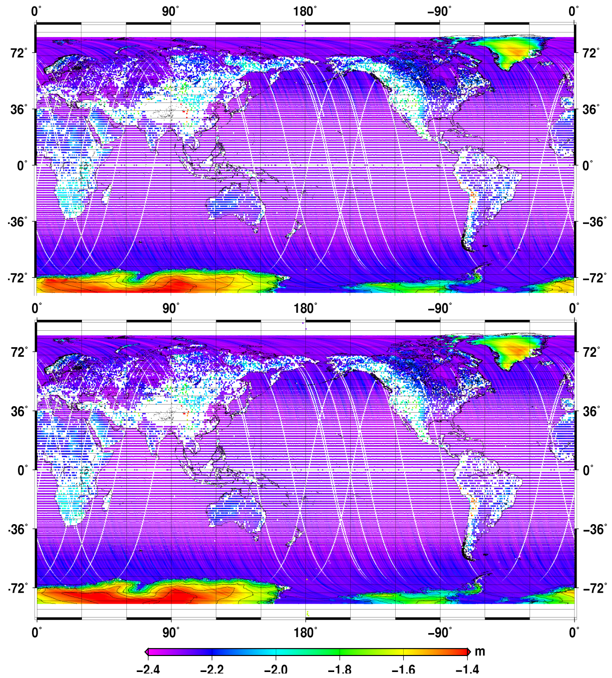

Figure 10: Global map of DTC_v2.1 (top) and DTC_ctoh for ENVISAT cycle 12.

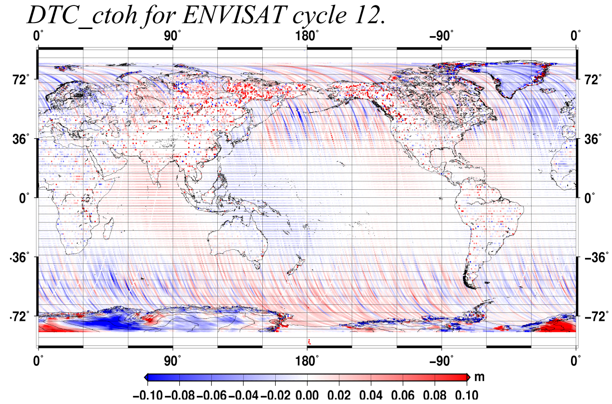

Figure 11: Global map of the difference between DTC_v2.1 and DTC_ctoh at crossover plotted above Fig.10. We find again the strong disagreement across Antarctica but also some tracks in open ocean and over the continents.

its surface slope dependency. The auxiliary DEM and pressure fields are the source of the DTC_v2.1 inconsistencies.

We developed the DTC_ctoh computed using the ERA-interim and using the altimetric radar measurements them selves instead of an auxiliary DEM. This solves the jump issue found in the ENVISAT GDR v2.1 over Antarctica.

The DTC_ctoh has no surface slope dependence and has a better correlation to the surface elevation unlike the DTC_v2.1. And also the DTC_ctoh has a consistent RMS level at crossovers.

This DTC_ctoh is fully validated over the cryosphere and we strongly recommend to the users to use it as new Dry Tropospheric Correction.

Finally, this new Dry Tropospheric Correction has the advantage of being valid directly all over the world and to be computed (where the range is available) without any external DEM (Fig.10).

The CTOH plans to evaluate and assess this new DTC for ocean and hydrology needs (Fig.11). This new correction is already available for ENVISAT v2.1 (cycle 6 to 94) and will soon be available for ERS-2 re-processed and other altimetry mission on the web site (http://ctoh.legos.obs-mip.fr/).

9. REFERENCES

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