ENVISAT RA2 DRY TROPOSPHERE CORRECTION FOR ICE SHEETS

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ABSTRACT

The LEGOS based OSCAR project (observing continental surfaces with radar altimetry) delivers a validation of the ENVISAT RA2 altimetry, in particular over Antarctic and Greenland. We investigated the stability and reliability of every correction on the altimetric measurements. Here we show the investigations on the dry troposphere correction. Although the overall trend in this correction is difficult to qualify, we found large unreliability of this correction at smaller scale on the Antarctic icecap. Large jumps are observed at cycle 40 and 55 of the satellite's life local trends of very significant and suspect values are found as well. We show the results of our investigations and map the impact this suspect correction has on the surface height changes. The impact is found to be non negligible and locally very significant. We investigate the possibility to re-compute a correction with the ECMWF pressure fields and show the improvement on the height recovery and height change surveys.

1. OBSERVATIONS OF THE DRY TROPOSPHERE CORRECTION

For this study, we used data from cycles 9 to 82 (September 2002 to September 2009) of ENVISAT RA-2. We computed the dry troposphere correction for the ascending and descending tracks at each crossover point.

The map in Figure 1 presents the dry troposphere correction trend calculated from these time series at crossovers and shows the position of certain selected crossovers. Figure 2 shows time series for crossover points selected on Antarctica.

First of all, from the map in Figure 1, we remark there are two main wide areas, one with positive trend in dome of Valkyrie and another one with negative trend at the east of the Ronne Ice-shelf. The other smaller areas are mainly localized on the coast and along the trans-Antarctic mountain. All these areas are formed of crossovers which are impacted by jumps in their time series of the dry troposphere correction. These two maps as well show that there is no difference between the values from the ascending and descending track.

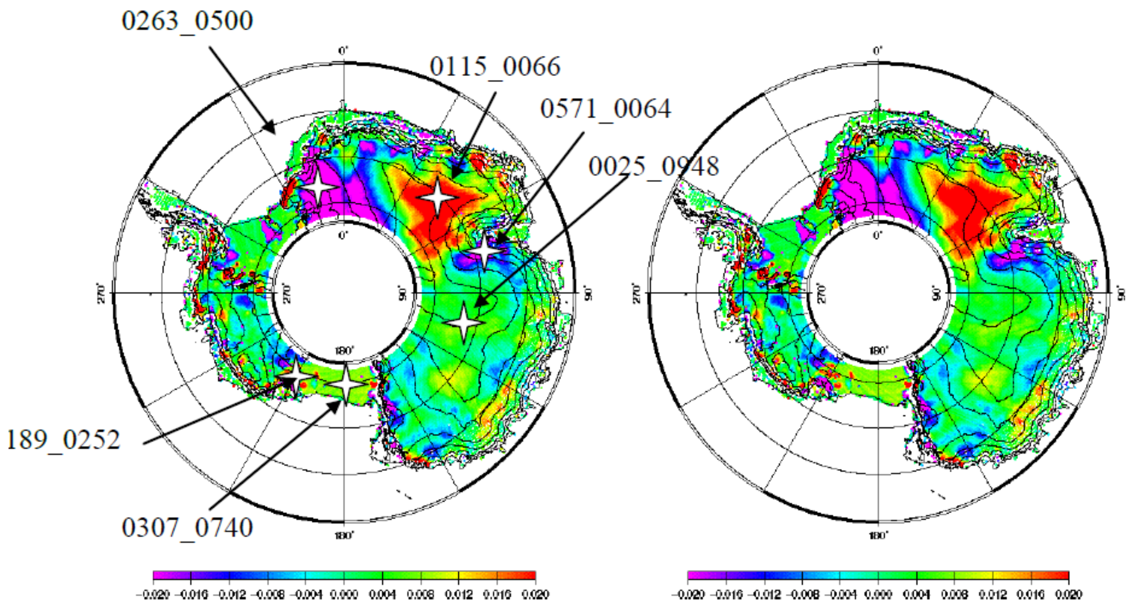

Figure 1 : Map of dry troposphere correction trend (m/year) at crossover point for ascending (left) and descending (right) tracks over the time period from cycle 9 to 79.

We also note, Figure 2, that some time series present sometimes one or two jumps at cycle 40 and cycle 55 (Figure 2 crossover: 0115_0066, 0571_0064 and 0189_0252). These jumps are either positive (the correction value increases brutally) or negative (the correction value decreases brutally). We also observe from the map that the crossovers, which have these jumps in their time series, have strong trends of dry troposphere correction. And finally, we note that some time series present clearly a drift from cycle 40 (Figure 2 crossover: 0025_948 and 0307_0740).

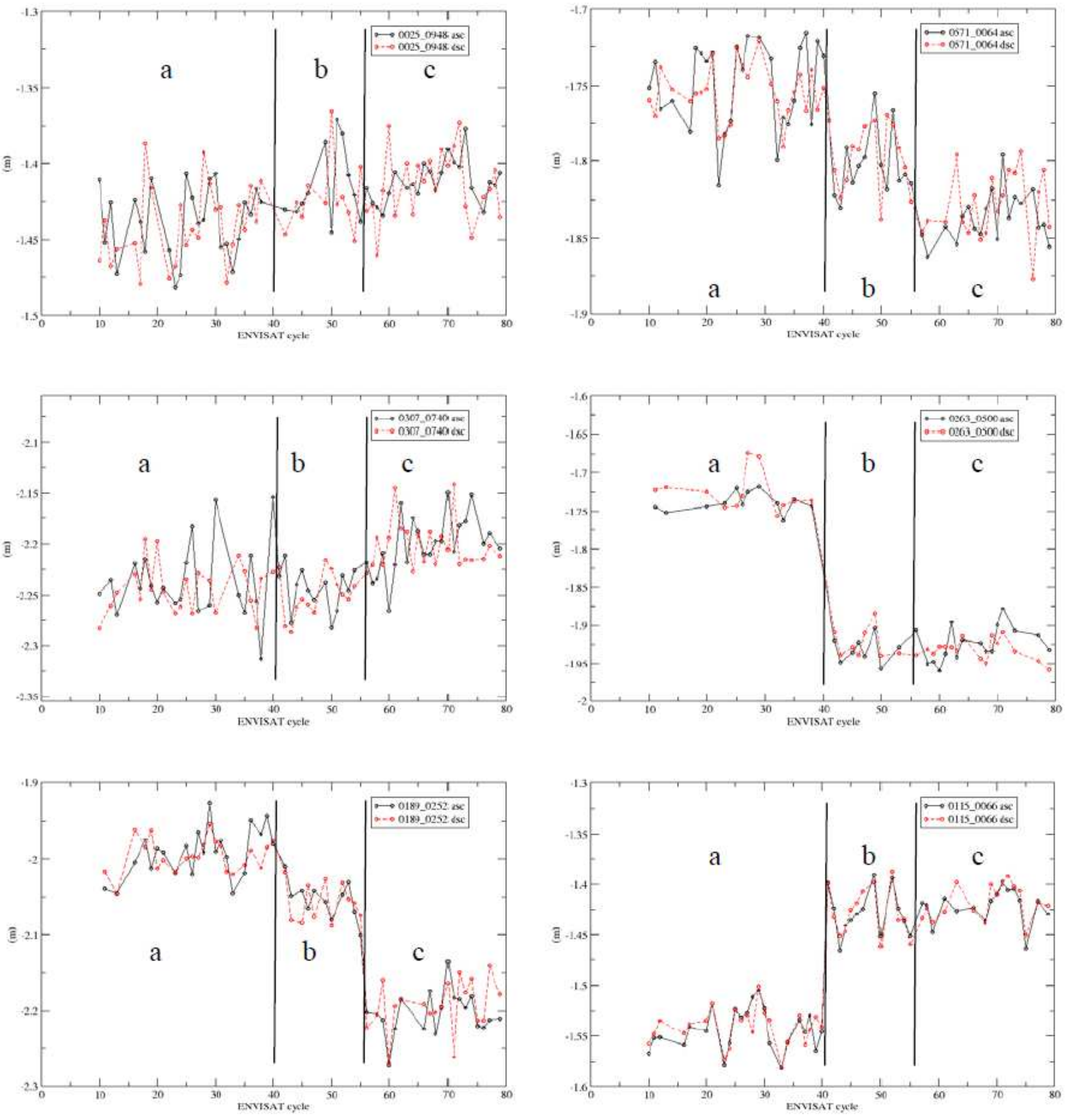

Figure 2: The times series of the dry troposphere correction for 6 different crossover points (ascending track and descending track): 0307_0740, 0571_0064, 0189_0252, 0115_0066, 0263_0500 and 0025_0948 (from cycle 9 to cycle 79).

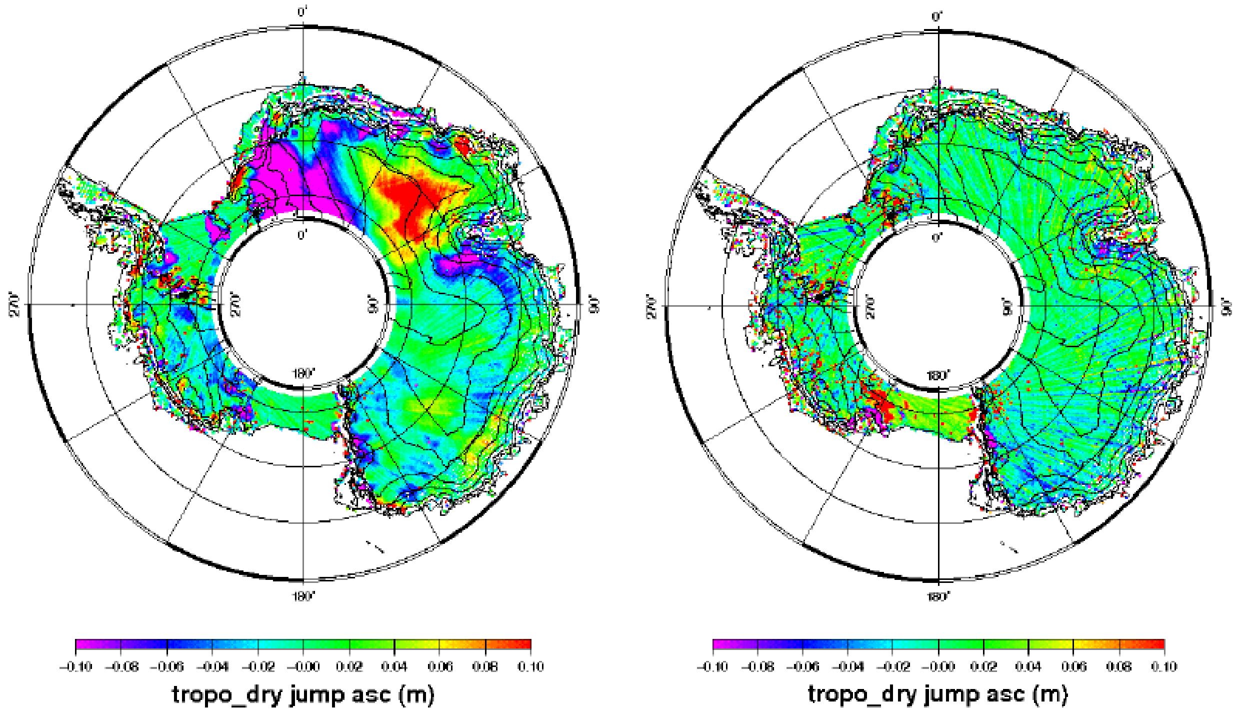

Figure 3: Jump amplitude at cycle 40 (left) and cycle 55 (right).

Figure 3 shows the amplitude of the jump at cycle 40 (map on the left) and cycle 55 (map on the right). We observe, at the cycle 40 that the jump appears in the same wide areas over all Antarctica as we have seen for the map in figure 2. For the jump cycle 55, the map shows little areas around the Ross ice-shelf region. The absolute value of the jump amplitude reaches around 10 cm in many areas. We remark that the jump at cycle 40 is the main event which produces the trend measured on the maps in figure 2.

In order to understand and to better characterise these jumps and drift, we have plotted the distribution for three different time periods in Figure 4. These time periods have been chosen so as to see the evolution of the shape of the distribution in the time. The first period just before the jump at cycle 40 (cycle 9 to 40: corresponding to the *a* in the time series Figure 2). The second period includes the jump at cycle 40 and terminates before the cycle 55 (cycle 9 to 55: corresponding to the *a* and *b* in the time series), and the last period for the whole duration (cycle 9 to 82: corresponding to the *a, b* and *c* in the time series).
The second period includes the jump at cycle 40 and terminates before the cycle 55 (cycle 9 to 55: corresponding to the *a* and *b* in the time series), and the last period for the whole duration (cycle 9 to 82: corresponding to the *a, b* and *c* in the time series).

For first time period, the distribution is Gaussian and become less as the time period is getting longer. The different histograms highlight two phenomena which occur at each step of the time. The first one, the distribution becomes wide due to the jump at cycle 40 which increases strongly the trend of several crossover points in the areas impacted by the jump. It appears, in the distribution, new classes of large positive and negative trend. The second one, the maximum of the distribution shifts to the positive value. The drift which appears on all time series after the cycle 40, shifts the whole distribution to a positive and global trend.

The statistical study confirms and quantifies our observation of the distribution. From the table n°1, we observe that the median value increases and the RMS grow as the time period gets longer. These two statistical values report well the two phenomena. The median value shows that for the first time period (cycle 9 to 40) the distribution was centred close to zero. As the time period is getting longer, the distribution moves to a significant trend of 1.8 mm/year. The RMS value increases from 5.52mm/year to 13.00mm/year and shows that the spreading of the distribution mainly comes from the jump at cycle 40. But we also observe that the average value does not change too much and does not give a good idea of what is going on.

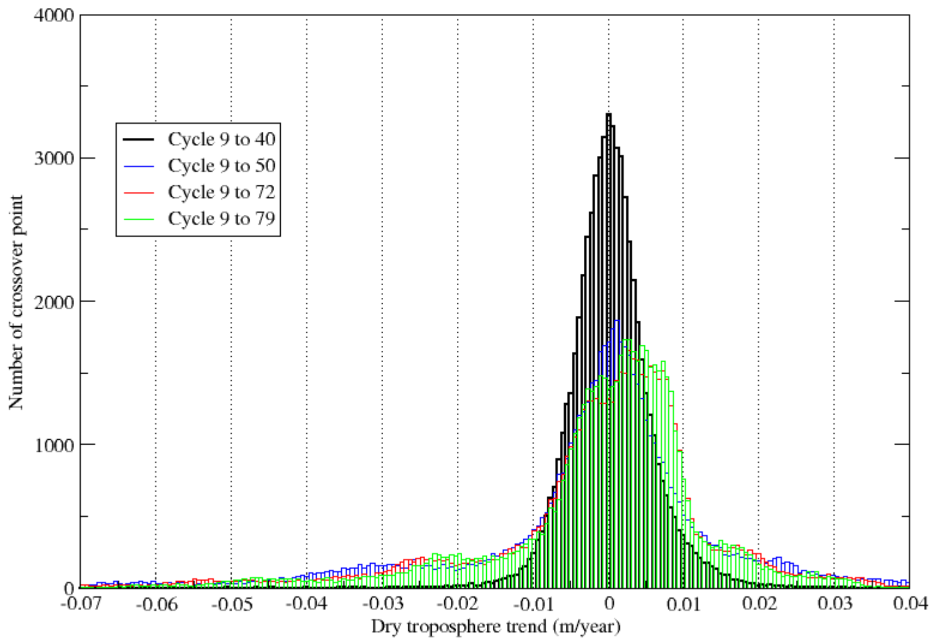

Figure 4: Distribution of the trend of the dry troposphere correction over all Antarctica for three different time period, black: cycle 9 to cycle 40, blue: cycle 9 to cycle 55 and red: cycle 9 to cycle72

	Distribution Figure n°4		
Time period interval (cycle)	Median value (mm/y)	Mean Value (mm/y)	rms (mm/y)
9 to 40 (black)	0.25	0.42	5.52
9 to 55 (bleu)	0.18	-0.76	14.68
9 to 72 (red)	1.40	-0.11	13.43
9 to 79 (green)	1.58	-0.21	13.00

Table 1 : The dry troposphere correction trend characterisation for each period considered.

The phenomenon of drift in the dry troposphere correction appears here clearly and it was not detect before. This table clearly illustrates that we do not see a significant impact by just monitoring the global average value and confirm that there are two phenomena introduced by this correction: a jump and a drift.

2. ATMOSPHERIC SURFACE PRESSURE

The dry troposphere correction is mainly governed by the atmospheric pressure. In this section, we study the atmospheric pressure, first, the one given by the GDR product (figure 5 black curve) and second, the one directly derived from the ECMWF ERA Interim re-analysis archive (figure 5 red curve).

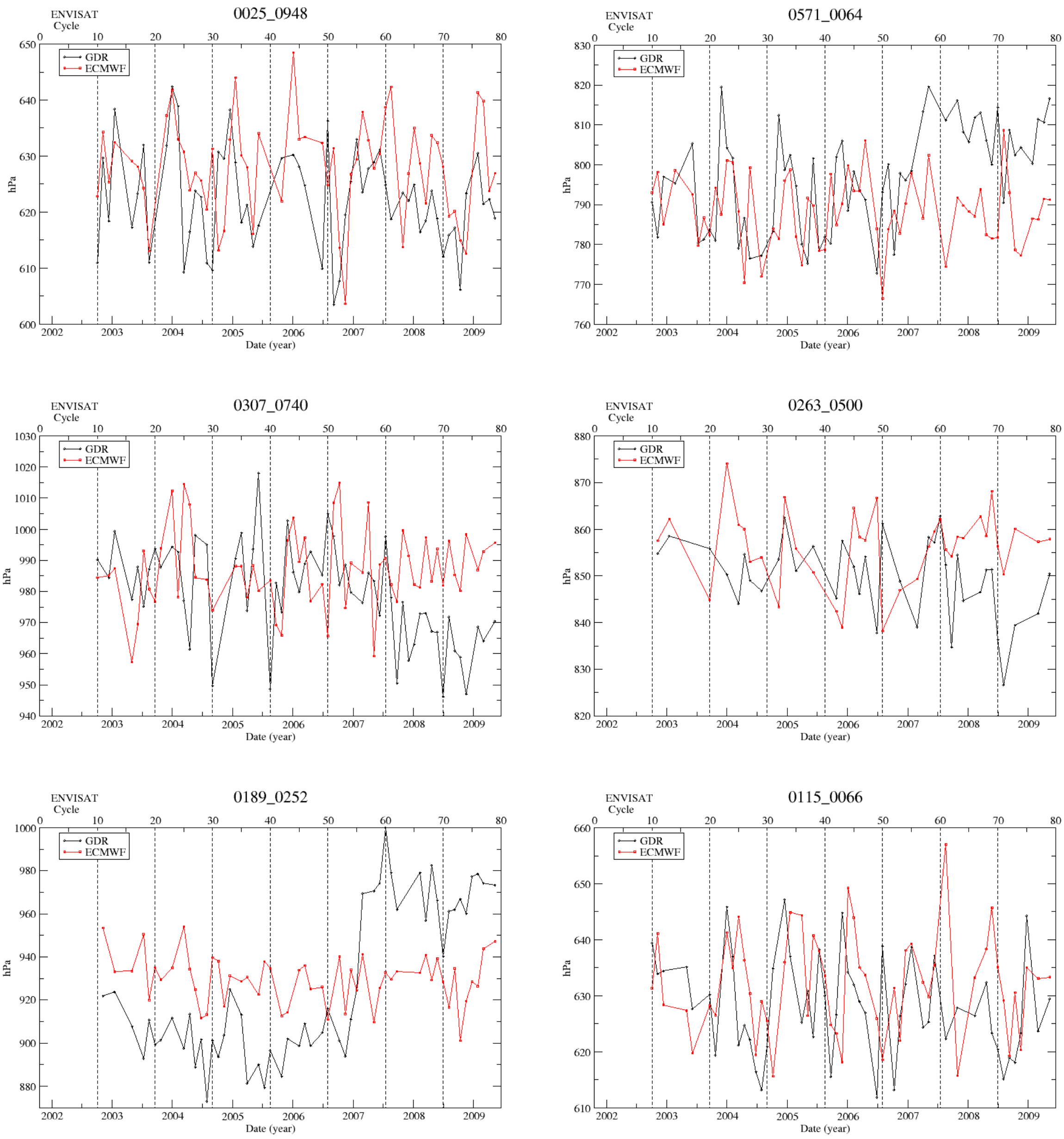

Figure 5: The atmospheric surface pressure time series for the six crossovers points in Antarctica (The positions are given in map figure n°1). The black line corresponds to the surface pressure from the GDR and the red line to the surface pressure from the ECMWF ERA interim re-analysis.

We note first of all that atmospheric surface pressure from ENVISAT GDR data (figures n°5 black curve) contains just one jump at cycle 55. It is clearly observed for the crossovers 0189_0252, 0307_0740 and 0571_0064. The jump amplitude of surface pressure explains definitely the dry troposphere correction jump as using the *Saastamoinen(1972)* formula.

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

where P_{surf} is the surface pressure in millibars and ϕ the latitude.

For the atmospheric surface pressure from ECMWF reanalysis (figures n°5 blue curve), we do not observe any jump. We note that the crossovers time series are in quite good agreement between GDR and ECMWF if we take into account the reanalysis effect (jump). The GDR pressure data are less consistent due to the regular CMA (Multimission Altimetry Center) upgrade or GDR a, b and c upgrade done over time which could explain the jump at cycle 55. The CNES/CMA confirmed that the jump in the surface pressure data is linked to a topography evolution at that time (end of December 2006).

It remains the jump at cycle 40 which is not explained by a surface pressure jump. But the introduction of the S1S2 waves in the computation of the surface pressure could explain this jump [1]. We are currently investigating and testing the impact of these S1S2 waves on the surface pressure. It is also appearing that impact of this evolution is less sensitive over ocean than continental surfaces.

3. *IMPACT AND SOLUTIONS*

It appears that the dry troposphere correction and the surface pressure in the ENVISAT GDR are not consistent. This correction is applied on the range and used to calculate the surface height and its trend to evaluate the masse balance of Antarctica. Here we study the impact of the dry troposphere correction over the surface height trend. We also study a solution to compute a new correction of dry troposphere over Antarctica using the mean sea level pressure from ECMWF and the topography supplied by OSCAR.

Potential impact of dry troposphere correction on ENVISAT altimetric trends

To evaluate the impact of this correction to the surface height trend, we plot the ratio of the correction trend versus the surface height trend. Although dry troposphere correction patterns are not visible on the map of the surface height trend (figure n°6 left), the impact is clear. In some areas the impact of the jump yields to 50% of the height trend in areas of very small trends.

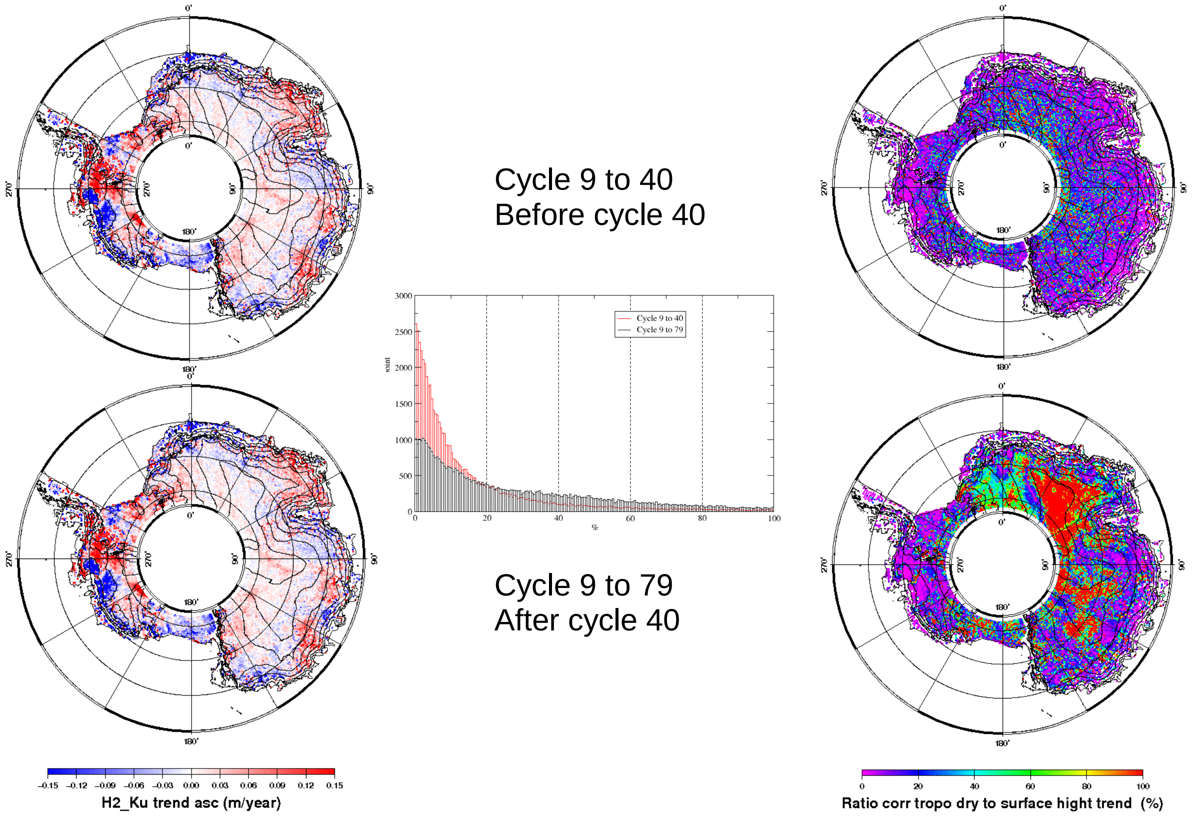

Figure 6 : On the left hand side the surface height trend and on the right hand side the percentage of this trend attributable to the dry troposphere correction, the surface height trend before cycle 40 (top) and after.

New surface pressure and new dry troposphere correction

From this observation, we see that it is important to get a better dry troposphere correction. As illustrated in the first part of this report this correction is given as a function of surface pressure. The surface pressure over continental surface depends of the forecast model but also on the topography. We do not know a lot about the topography used by ECMWF in the forecast model and over this kind of surface such as cryosphere, it is always difficult to have a precise topography in the forecast model.

For this reason we choose to calculate our own surface pressure from our OSCAR topography and using mean sea level pressure supplied by ECMWF (ERA interim re-analysis). We compare this “OSCAR surface pressure” with ECMWF surface pressure (ERA interim re-analysis).

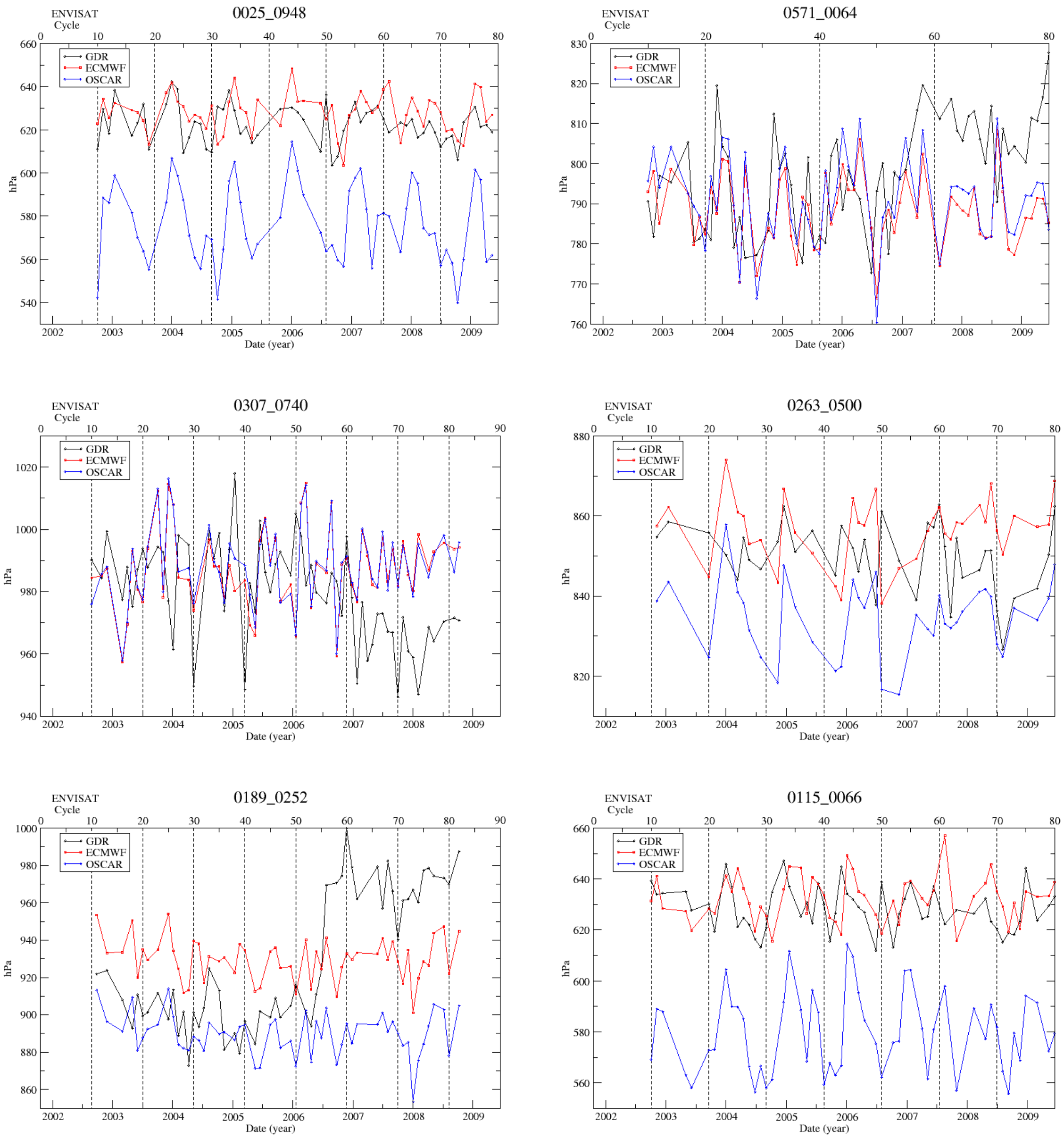

Figure 7 : The atmospheric surface pressure time series for the six crossover points in Antarctica (The positions are shown in figure 1). Black line is surface pressure data from GDR, the red line is the surface pressure from ECMWF ERA interim re-analysis and the blue line is the surface pressure calculated from the equation 2 using OSCAR topography, ECMWF mean sea level surface pressure and ECMWF temperature at 2 meters.

For the calculation of the so-called “OSCAR surface pressure”, we follow the same way as it is done by Météo-France to estimate the Surface pressure (eq 2) and to generate a new dry troposphere correction based on *Saastamoinen 1972*(eq 1).

$$P_{surf} = P_{sea} \cdot \left(\frac{T_{2m} + \gamma H_{oscar}}{T_{2m}} \right)^{-\frac{Ma\, g}{R\, \gamma}} \qquad \text{eq.2}$$

Where γ is the mean vertical gradient of the temperature equal to 6.5°/km, R is the universal gas constant equal to 8.31434 J.mole^{-1}.K^{-1}, M_d and M_w are the molar masses of dry (28.9644 10^{-3} kg/mole) and water vapor (18.0153 10^{-3} kg/mole) respectively and g is the acceleration of gravity equal to 9.783 m/s^2 in average.

The plots in figure 7 show, for the same selected crossovers, the time series of GDR (black), ECMWF (red) and OSCAR (blue) surface pressure.

When, we compare the ECMWF and the OSCAR surface pressure. We observe for the crossover point time series at low altitude a good agreement (Figure n°7: 0307_0740 and 0571_0064) but we note a strong difference for the crossover time series at high altitude (Figure n°7: 0025_0948 and 0115_0066). This difference can reach 90 hPa equivalents to a topography difference of about 300 meters. This is too large for cryospheric studies. To carry on this study, we have to investigate by checking the difference between the ECMWF and OSCAR topography. For this report, we choose to keep the dry troposphere correction calculated from OSCAR topography because we are more confident with it.

Figure 8 shows the trend of this new dry troposphere correction. We clearly see that the trend observed in figure 1 has definitely disappeared. In the same as we did for figure 6, we evaluate the impact of this new dry troposphere correction (figure 9).

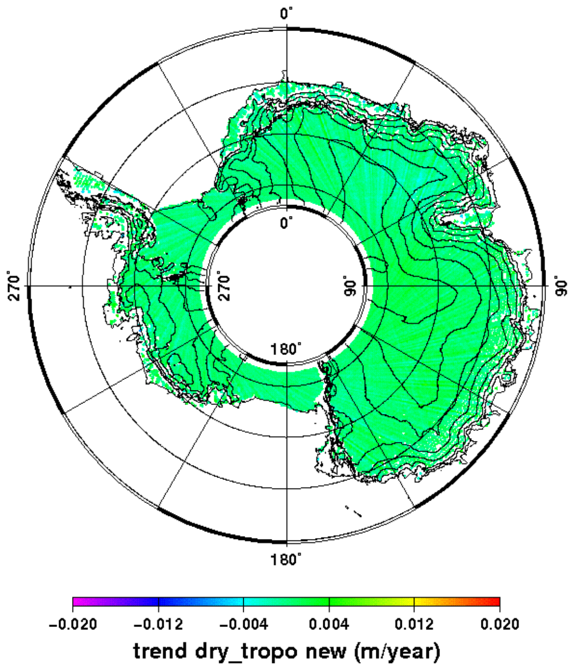

Figure 8 : Map of dry troposphere correction trend at crossover point for ascending track over the time period from cycle 9 to 79 with the new OSCAR calculation.

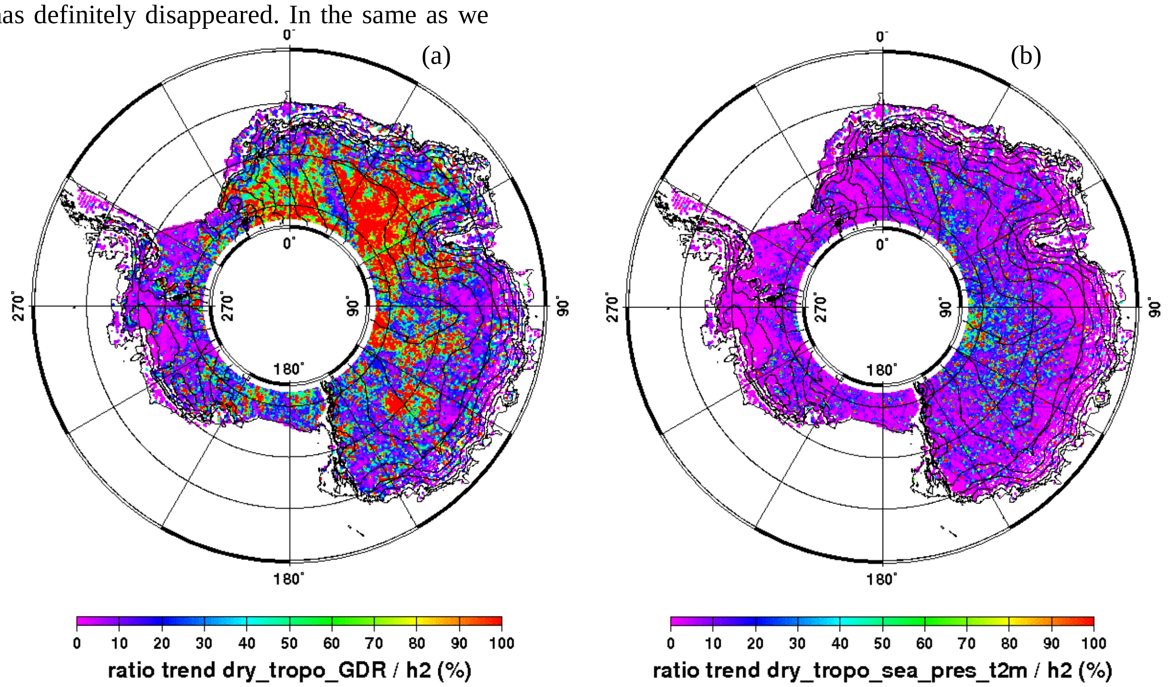

Figure 9 : As in figure 6 these map show the impact of the dry troposphere correction on the surface height trend for using the GDR correction (a) and the ECMWF sea level pressure and 2m temperature corrected for the OSCAR topography (following eq 1 and 2).(b)

Figure 9 shows also that the impact of the dry troposphere correction had definitely disappeared (from left to right hand side).
We are then confident that this new dry troposphere correction we have calculated using ECMWF ERA interim data and OSCAR topography is appropriate for use.

4. *CONCLUSION*

In this study we monitor the dry troposphere correction on ENVISAT altimeter time series, before the whole re-processing of ENVISAT mission (due by the mid 2011). It is highlighted that this correction during this mission was affected by CMA and ECMWF model upgrades which have produced significant jumps in the time series.
This correction errors impact strongly the surface height trend due to the two jumps at cycle 40 and cycle 55.We investigated several ways to explain the cause of theses jumps. But we can partly conclude. The jump at cycle 40 appears at the same period when the S1 and S2 waves have been changed in the dry troposphere correction computation in the CMA evolution. We also note that this evolution impacts more over the continents than over the ocean. More investigation is needed to test and understand it. The jump at cycle 55 is completely explained by surface pressure jump in the GDR data. CNES/CMA confirmed that this jump in the surface pressure is linked with a topography evolution at that time (end of December 2006).
We also tried several ways to compute a consistent dry troposphere correction. We found good results with the ECMWF ERA interim data archive using *Saastamoinen* formula (eq 1) and Meteo France. But, we note difference between ECMWF (using directly the surface pressure from ERA interim re-analysis in *Saastamoinen* formula) and OSCAR (using our own topography) correction. It is probably due to the topography difference and constant parameter difference between ECMWF and OSCAR.

The solution we chose to have a consistent dry troposphere correction over the whole ENVISAT mission and over cryospheric surfaces is the correction using our own topography (OSCAR). This solution had been successfully tested over Antarctica.

We recommend for the re-processing (REAPER project…) to add fields in the GDR re-processed to have an alternative surface pressure from ECMWF ERA Interim re-analysis and an alternative dry troposphere correction computed from this surface pressure.

We have already reprocessed ourselves a correction. It is available on demand via the OSCAR project web site: http://oscar.legos.obs-mip.fr/.

5. ACKNOWLEDGEMENTS

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We would like to thank CNES and CLS for their useful advises.

6. REFERENCES

[1] A. Ollivier and Y. Faugere, Envisat RA2/MWR ocean data validation and cross-calibration activities. Yearly report 2009. CLS.