Analysis of Envisat orbit maintenance strategies to improve/increase Envisat ASAR interferometry opportunities.

D.Kuijper[(1)], M.A. Garcia Matatoros[(2)]

[(1)]*LogicaCMG c/o ESA-ESOC, Robert-Bosch-Str. 5, D-64293 Darmstadt, Germany, E-mail: Dirk.Kuijper@esa.int*
[(2)] *ESA-ESOC, Robert-Bosch-Str. 5, D-64293 Darmstadt, Germany, E-mail:*
Marco.Antonio.Garcia.Matatoros@esa.int

ABSTRACT

The biggest and most advanced Earth Observation Satellite in-orbit, developed by the European Space Agency (ESA) and its member states, is Envisat. It was launched on March 1, 2002 by an Ariane V from French Guyana and holds a total of 10 multi-disciplinary Earth observation instruments, among which an Advanced Synthetic Aperture Radar (ASAR).

The ASAR user community requested the Flight Dynamics division of the European Space Operations Centre (ESOC) to investigate how the orbit control maintenance strategy for Envisat could be changed to optimise ASAR interferometry opportunities overall and in addition support the International Polar Year 2007/2008 initiative. The Polar Regions play a pivotal role in understanding our planet and our impact on it as they are recognized as sensitive barometers of environmental change. One of the main themes of the International Polar Year 2007/2008 is therefore the study of Earth's changing ice and snow, and its impact on our planet and our lives. Naturally, ESA would like to support this very important initiative.

This paper presents the investigations that have been conducted to support these requests in the best possible way. It discusses the orbit maintenance strategy that has been in place since its launch, ensuring the actual orbit to be within 1 km of a so-called reference orbit, and presents the new orbit maintenance strategy that is aimed at improving/increasing the opportunities for Envisat ASAR interferometry, while preserving the fuel on board the spacecraft. The hydrazine on-board Envisat happens to be a precious resource as only approximately 300 kg of it was available at launch, like ERS-2. The difference being however that the mass of Envisat is approximately 3.2 times that of ERS-2.

The old orbit maintenance strategy effectively resulted in ASAR interferometry baselines of 2000 meters maximum. The new strategy on the other hand, by performing more regular orbit inclination manoeuvres, will reduce the baselines down to 250 metres over the polar region between certain repeat cycles, making a valuable contribution to the International Polar Year initiative. To extend the reduced baseline opportunities all over the orbit, the orbit altitude maintenance has also been improved.

The new orbit maintenance strategy was adopted by ESA at the start of 2007, and will be maintained for the next 2 years. This paper will also include some first ASAR interferometry results of the new orbit maintenance strategy.

1. INTRODUCTION

One of the major challenges facing the human race today is to understand the impact of mankind's activities on the Earth environment. The effects of man-made pollution or natural disasters often reach across national borders and even develop a global scale, like the global warming, the hole in the ozone layer, destruction of forests, flooding, and man made natural disasters. The most effective way to observe such global scale phenomena is by the watchful eye of remote sensing satellites.

To this end the European Space Agency (ESA) and its member states developed a series of satellites, of which Envisat is the biggest and most advanced European Earth observation satellite in-orbit (see Figure 1). It was launched on March 1, 2002 by an Ariane V from Kourou in French Guyana into a sun-synchronous low Earth orbit with the following orbital characteristics:

- semi-major axis = 7159.5 km,
- inclination = 98.55 deg,
- mean local solar time = 10:00 A.M. (at the descending node)
- repeat cycle of 35 days (or 501 orbits) with 14 11/35 orbits/day

The spacecraft accommodates a total of 10 multi-disciplinary Earth observation instruments, among which the Advanced Synthetic Aperture Radar (ASAR).

Figure 1: Artist impression of Envisat in-orbit

The ASAR user community requested to investigate possible orbit control maintenance strategy for Envisat that would:

a) reduce/minimise the average baseline values anywhere in the orbit and throughout the mission in the future (see Figure 2 for baseline definitions).

b) reduce/minimise the baseline values to less than 200-250 m over the Poles for about 3 consecutive cycles during southern Polar winter (i.e. European summer) and repeat this the next 3 years.

The investigations concentrated on how to best accommodate these requirements, but not to neglect the fact that fuel is a precious commodity on-board Envisat that needs to be preserved wherever possible to maximise mission lifetime.
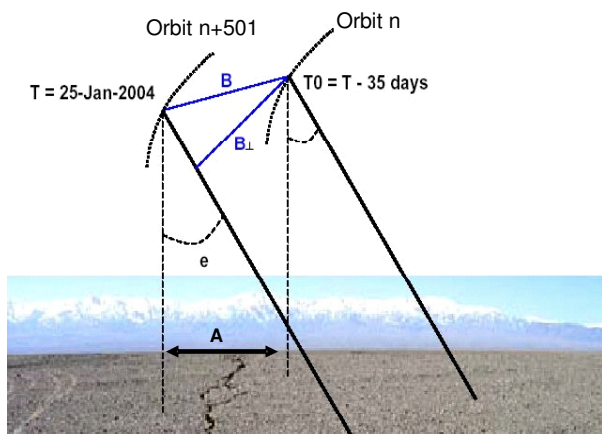

Figure 2: *Definition of the perpendicular baseline B⊥ and across–track baseline B (from reference 1)*

The next paragraph presents the general orbit control maintenance strategy in place for Envisat since its launch. The following paragraph explains how this strategy can be changed to accommodate the requirements of the ASAR user community as best as possible while avoiding or limiting as much as possible the impact on the fuel consumption. The subsequent paragraph discusses the orbit control maintenance investigations in detail, followed by a summary of the selected orbit control maintenance strategy and some baseline results that have been achieved so far.

2. GENERAL ENVISAT ORBIT CONTROL MAINTENANCE STRATEGY

The general Envisat orbit control maintenance strategy in place since the launch of Envisat in 2002 is based on the frozen eccentricity reference orbit control concept that was already applied successfully on ERS-1 & -2 (see reference 1.). In this concept, the orbit of the satellite is controlled such that its ground track is maintained within 1 km of a reference ground track. The reference ground track is based on a reference orbit that has an exact 35 days / 501 orbits repeat cycle and is computed without taking into account the perturbing forces by sun and moon gravitation, air drag, and solar radiation pressure. These perturbing forces do exist however, and therefore an exact repeat orbit cannot be maintained without orbit control. The orbit control strategy therefore aims at compensating the effect of these forces (in particular the first two forces) as far as possible to achieve the ground track control requirement of ± 1 km[1].

The major effect of the solar gravity perturbations on the orbit of Envisat is a secular decrease in inclination. The Moon induces an additional periodic perturbation on the inclination with a period of half a month. The rate of inclination change depends on the Sun-Earth distance. As the Earth moves closer to the Sun (closest distance during wintertime) the torque on the orbital plane increases and therefore increases the inclination change rate. Figure 3 illustrates the effects of these forces on the orbital plane. Shown are the actual deviations of the ground track from the reference ground track at the most northern point on the orbits.

---

[1] *This requirement was originally driven by the needs of the altimetry instrument to overfly the same ground track with this accuracy*
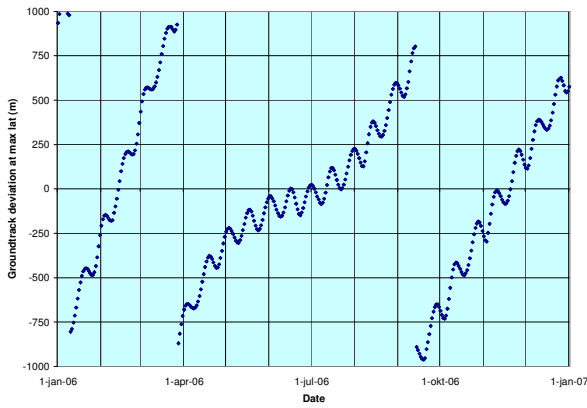
Figure 3: The deviation (km) of the actual ground track from the reference ground track at the most northern point on each orbit for 2006.

The increase in ground track deviations corresponds to a decrease of the inclination w.r.t. to the nominal sun synchronous inclination, i.e. a gradual drift towards the pole. To move the ground track away from the pole again, i.e. increase the inclination again, out-of-plane Orbit Control Manoeuvres (OCMs) are executed, preferably centred around the Equator, at the ascending node (an operational requirement to execute the manoeuvre in eclipse). In order to meet the 1 km ground track requirement, around 3 OCMs are performed per year like in 2006 (see Figure 3). The manoeuvres are represented by the sharp changes (decrease in y-axis value) in the graph. The seasonal effect by the Moon is also evident in the varying rate of the ground track deviation drift. During northern summer the perturbing effect of the Sun is minimum.

The air drag has a significant influence on satellites flying at low altitude. At the altitude of Envisat, variations in air density by a factor 1000 can take place in short periods of time, which makes this force an unpredictable one. The level of air density and thus air drag mainly depends on the level of solar activity. As air drag is a non-conservative force, it continuously takes away energy from the orbit and thus gradually decreases the orbit semi-major axis and thus the orbital period. Figure 4 illustrates the effect of air drag on the satellite orbit in terms of deviation of altitude (vertical axis) and across-track position (horizontal axis) relative to the reference orbit. At an altitude above nominal, the satellite has a westward drift, which is reduced by the air drag decay until the nominal altitude is reached and then turns into an eastward drift below the nominal altitude, which can only be stopped by a semi-major axis raising manoeuvre. For an optimal control cycle, the satellite has to start at a certain altitude above nominal. Assuming a predicted level of solar activity, the ground track error is kept just within the western limit. If, however, the assumed level of solar activity turns out to be lower than expected, the orbital decay will be slower and the satellite will exit the western limit if the drift is not stopped at this limit by a manoeuvre against the flight direction. If the assumed level of solar activity on the other hand turns out to be higher than expected, the orbital decay will be faster and hence the western limit will not be reached, whereas the east-most boundary will be reached earlier than expected.
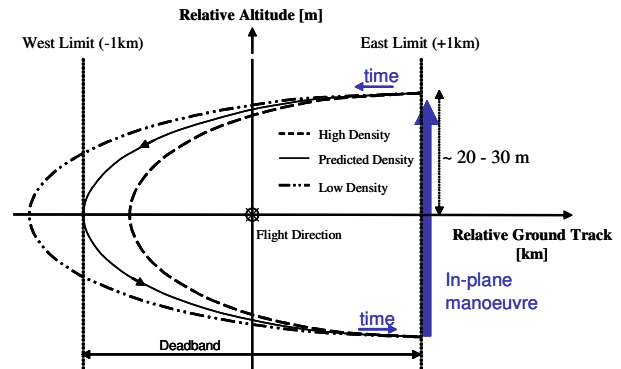

Figure 4 Evolution of the satellite orbit relative to the reference orbit in a vertical plane perpendicular to the flight direction.

The semi-major axis of the satellite is controlled by in-plane manoeuvres, i.e. the thrusters fire along or against the flight direction in order to have the desired increase or decrease in semi-major axis respectively. This type of manoeuvre is referred to as a Stellar Fine Control Manoeuvre (SFCM) and is performed every 30-50 days, depending on the level of solar activity and thus the rate of orbital decay.

3. FULFILLING THE ASAR INTERFEROMETRY REQUIREMENTS

The general orbit maintenance strategy in place since the launch of Envisat, as described in the previous paragraph, effectively results in interferometry baselines of a maximum 2000 meters. Although the collected ASAR data so far have an average baseline value of around 750 m and provide useful data for most interferometric applications, a significant percentage of the collected data have very large (more than 800 m and up to 2000 m) baselines.

To decrease this percentage, i.e. reduce/minimise the average baseline values anywhere in the orbit and throughout the mission in the future, the orbit control strategy in place needs to change. To create as many good ASAR interferometry opportunities as possible, the orbits of a 35-day repeat cycle need to be as close as possible to the ones some multiple 35-day cycle before during the complete orbit revolutions. This can be achieved by phasing the OCMs such that the time interval between OCMs is an integer number of cycles, i.e. 1 OCM every M repeat cycles, and increasing the frequency of the in-plane manoeuvres to reduce the

(equatorial) across-track differences. The ground track deviations at middle latitudes are a combination of the deviation at the pole and at the Equator.

The investigations focused on determining the factor M. There is however one aspects to consider when making the final choice of M. An out-of-plane OCM requires an attitude change of plus or minus 90° about the z axis before execution and a slew back to nominal attitude position after execution of the burn. The slews are thruster based and therefore an associated hydrazine consumption of about 0.7 kg is required per OCM, which in terms of orbital correction is a loss to be taken into account when selecting M.

The second requirement of the ASAR user community can be fulfilled by introducing one small OCM during northern summer, but due to the slews, associated with each OCM, this will be at the cost of some extra fuel.

4. ORBIT CONTROL MAINTENANCE INVESTIGATIONS

Two issues have been looked at. One concerns the optimal duration of an out-of-plane manoeuvre and the other concerns the phasing of the out-of-plane manoeuvres.

4.1 Optimal out-of-plane manoeuvre duration

The availability of hydrazine is an important aspect of the Envisat mission and since the out-of-plane OCMs are the biggest consumers of this commodity, it is of interest to find the optimal duration for these OCMs to limit the impact on the fuel consumption. The factors that affect the optimal duration are on the one hand that these manoeuvres have a constant propellant cost contribution as Envisat needs to be rotated by 90° twice per manoeuvre, as described in the previous section, and on the other hand the efficiency of an out-of-plane thrust to change the inclination is reduced by the cosine of the latitude, i.e. the efficiency of the manoeuvre decreases with it duration.

4.1.1 Theory

The function to optimise is the change in inclination that can be achieved per kilogram of fuel, taking into account that the change in inclination is not linear dependant with the manoeuvre duration and the manoeuvre duration (without the slews) is restricted to the orbit eclipse times (see reference 2. for more details).

Taking the Gauss equation and assuming a circular orbit, the change in inclination can be expressed as follows:

$$\frac{di}{dt} = \frac{A_n \cos(\alpha)}{na}, \qquad \qquad \text{[eq. 1]}$$

where

- A_n is the orbit-normal acceleration of the applied force
- a is the semi-major axis
- n is the mean motion
- α is the true latitude

The total change in inclination per OCM is given by the integration of the above equation. Considering A_n, n and a to be constant along the duration of the burn, and for circular orbits $d\alpha$ equals ndt, and assuming out-of-plane OCMs can be performed symmetrically around the node (see reference 3.), the change of inclination as a function of the manoeuvre duration t can be expressed as follows:

$$\Delta i = \frac{2 A_n \sin\left(\frac{nt}{2}\right)}{n^2 a} \qquad \qquad \text{[eq. 2]}$$

The total hydrazine required to perform the manoeuvre is the sum of the fuel required for the slews (M_T) and the fuel required for the actual burn, which equals the mass flow rate (M_{FR}) times the duration t of the manoeuvre. The aim of the optimisation is to achieve a maximum change in inclination per kg of hydrazine, i.e. find the maximum of the next equation:

$$\frac{\Delta i}{M} = \frac{2 A_n \sin\left(\frac{nt}{2}\right)}{n^2 a [M_T + M_{FR} t]} \qquad \qquad \text{[eq. 3]}$$

Differentiating this equation provides the following condition for an optimum manoeuvre duration, i.e maximum inclination change per propellant mass:

$$\frac{n}{2}[M_T + M_{FR} t]\cos\left(\frac{nt}{2}\right) - M_{FR} \sin\left(\frac{nt}{2}\right) = 0 \quad \text{[eq. 4]}$$

Note that the optimal duration only depends on the mean motion, mass required to rotate the spacecraft and the mass flow rate. Using the above equation we can get a first approximation of the optimal manoeuvre duration t as a function of these parameters:

$$t = \sqrt[3]{\frac{11 M_T}{n^2 M_{FR}}} \qquad \qquad \text{[eq. 5]}$$

To find out about the optimal manoeuvre durations for future out-of-plane OCMs, it is important to find out how the mass flow rate has decreased over time and extrapolate that for future OCMs.

4.1.2 Practise

Up to the end of 2006 a total of 16 OCMs have been successfully performed. The first 2 manoeuvres were executed to manoeuvre Envisat into its operational orbit, phasing it to ERS-2. The other 14 manoeuvres were orbit control maintenance manoeuvres. The next graph represents the mass flow rate for each of these 14 manoeuvres.
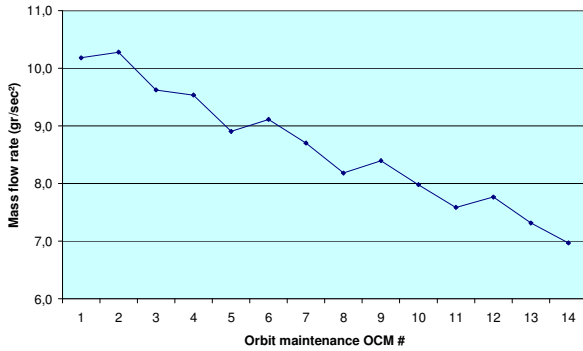
Figure 5: Mass flow rate values for each orbit maintenance OCM that has been executed since operations started, until the end of 2006.

Note that the mass flow rate is not linearly decreasing. This is the result of switching tanks every other OCM, to balance the pressure in the two tanks. To be able to compute the fuel required for future OCMs a linear decrease in mass flow rate is assumed however.

The orbit-normal accelerations of the OCMs also decreased over time due to the depletion of the tanks with every manoeuvre. Table 1 Gives an overview of all the orbit maintenance OCMs that have been executed up to the end of 2006.

Table 1: Overview of orbit maintenance OCMs that have been performed by Envisat up to the end of 2006.[2]

Start time burn	T	M_{FR}	M_T	M_{TOT}	A_n	ΔV	T_{opt}
	(sec)	(gr/s)	(gr)	(kg)	(mm/s^2)	(m/s)	(sec)
10-09-2002 00:35	624	10,2	631	6,984	2,85	1,782	859
18-12-2002 05:27	508	10,3	642	5,867	2,86	1,458	861
21-02-2003 04:42	627	9,6	623	6,657	2,70	1,692	872
20-05-2003 05:11	698	9,5	644	7,303	2,68	1,873	884
28-10-2003 05:55	806	8,9	629	7,804	2,49	2,005	897
04-02-2004 05:46	687	9,1	621	6,881	2,54	1,747	887
14-04-2004 05:42	718	8,7	630	6,882	2,41	1,734	905
21-09-2004 05:14	882	8,2	618	7,835	2,27	2.000	918
07-01-2005 05:24	815	8,4	615	7,460	2,35	1,915	908
17-03-2005 05:50	906	8,0	627	7,854	2,23	2,016	930
07-09-2005 06:19	998	7,6	630	8,202	2,10	2,102	947
10-01-2006 05:53	1020	7,8	632	8,548	2,15	2,198	941
28-03-2006 05:32	1130	7,3	628	8,892	2,02	2,284	958
13-09-2006 05:21	1091	7,0	623	8,226	1,92	2,093	971

With the information from the table above and equation 3, the change in inclination per kg of propellant as a function of manoeuvre duration can be computed for

---

[2] *T is the duration of the actual burn and T_{opt} would have been the optimal burn duration for the OCM, computed from equation 5.*

each of the orbit maintenance OCMs. The result is depicted in Figure 6.
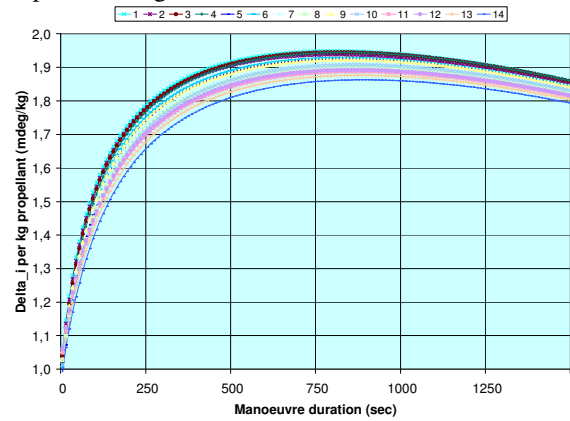

Figure 6: Change of inclination per kg of propellant as a function of manoeuvre duration for all orbit maintenance OCMs executed up to the end of 2006.

This plot shows that the change in inclination per kg of fuel has been decreasing over time due to the depletion of the tanks. At the same time the optimal duration for an OCM has been increasing from 860 to 970 seconds and will increase further in the future. Also note that at the maximum, the function is quite flat, which gives a reasonable margin in manoeuvre durations (say between 800 and 1200 seconds) without significant fuel loss.

4.2 Phasing of Out-of-plane Manoeuvres

The other part of the investigation concentrated on phasing the out-of-plane manoeuvres with the 35 days repeat cycle, i.e. determining factor M as discussed earlier in section 3. Three orbit control strategies were looked at:

1. The orbit control strategy that has been in use since the launch of Envisat and introduce in-plane manoeuvres at the start of every cycle, with an occasional touch up in between to keep a 200 m deadband at the Equator.
2. The same orbit control strategy as 1, but introduce one small OCM during summer to support the International Polar Year initiative.
3. An orbit control strategy, where an OCM is scheduled every other cycle (M=2), i.e. every 70 days, fitting in the small OCM during summer to support the International Polar Year initiative.

These orbit control strategies can be analysed by using the ground track deviation at maximum latitude from the past, shifting them to the future and introducing inclination changes, i.e. ground track deviations jumps at the preferred times. Although the inclination change rate varies considerably over the year, the pattern is quite repetitive and can therefore actually be used for this purpose (see reference 2.).

Using this approach, all three strategies were analysed for the period 2007 to 2008. The analyses showed that introducing an OCM every other cycle does not cost more fuel than following the old orbit control strategy, but does reduce the baselines between alternating cycles overall. It was therefore decided to follow strategy 3 for the next 2 years, including the small OCM during summer at the small extra cost of a bit less than 500 grams of fuel.

Figure 7 represents the predicted ground track deviation at maximum latitude for the next 2 years, using the selected orbit control strategy.
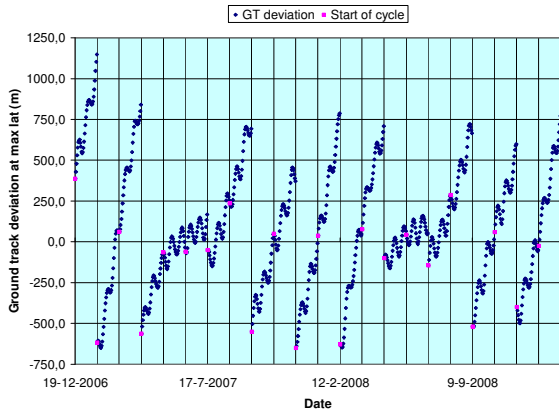
Figure 7: Expected ground track deviations at maximum latitude for 2007 and 2008, following the selected orbit control strategy.

The start of each cycle is indicated by cyan dots. The first cycle in the plot is cycle 54. These predicted ground track deviations can be used to compute the expected baselines at maximum latitude for each day in the cycle for each possible cycle combination. Figure 8 presents the expected baseline results of cycle combinations of the cycles that cover our northern Summer of both 2007 and 2008.
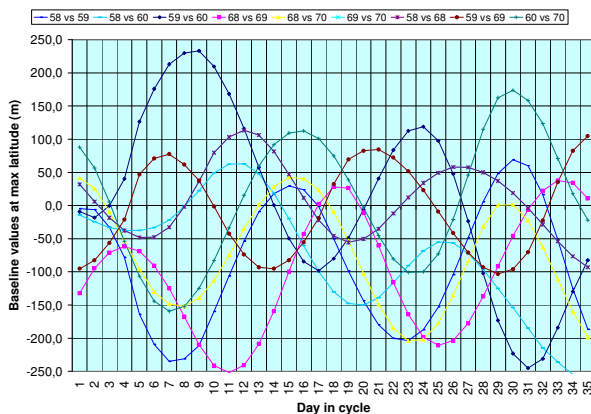

Figure 8: Expected perpendicular baseline values at maximum latitude for all cycle combinations of the

cycles that cover the northern Summer of both 2007 and 2008.

Figure 9 shows the expected baseline results at maximum latitude between the cycles where the inclination of the orbit is higher than the nominal (reference) one, i.e. west of the reference at the northern hemisphere. Note that the baseline values are less than 250 m for most cycle combinations. The number of combinations, where the baseline values reside within 250 m is higher than for the other 2 strategy cases.
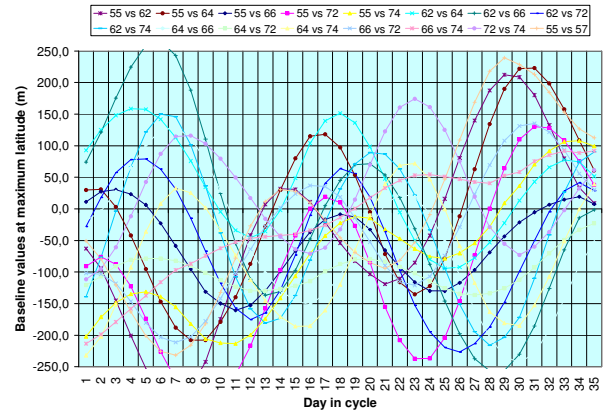

Figure 9: Expected perpendicular baseline values at maximum latitude for all cycle combinations of the cycles where the inclination of the orbit is higher than the reference

A similar plot can be presented for the cycle combinations of the cycles where the inclination of the orbit is lower than the reference one.

During the investigations the same approach was also used to look at using OCMs with an optimal duration, i.e. maximum inclination change per kg of fuel. This strategy was about 300 grams more fuel efficient than strategy 1, but the ASAR interferometry opportunities were far worse than strategy 3, so this strategy was not an option.

In addition, the same approach was used to investigate performing OCMs every cycle (M=1), which implies an inclination correction of less than 5 mdeg is required every cycle, which in turn requires OCMs with a burn duration of less than 500 seconds. A 500 second burn represents a fuel loss of more than 200 grams compared to the optimal and since the number of OCMs would increase to 10 per year and cause an additional operational overhead, this strategy was not an option either.

5. ADOPTED ORBIT CONTROL MAINTENANCE STRATEGY

The new orbit maintenance strategy has been introduced in January 2007, and is to be executed during 2007 and 2008.

5.1   In-plane manoeuvres:

At the Equator the orbit is allowed to drift 200 meters w.r.t. to the reference, i.e. a 200 meter deadband is maintained. Effectively the number of (smaller) in-plane manoeuvres increases, but this does not affect the overall annual propellant consumption for in-plane manoeuvres.

5.2   Out-plane manoeuvres:

Every 2 cycles, an inclination correction is performed at the same relative orbit within the cycle. The only exception has been made for the OCM after cycle 58 (see Figure 7), which has been delayed by one cycle due to the requirement to support the International Polar Year initiative. So, the following orbit maintenance OCMs are scheduled for 2007 & 2008:

- 2007: 23 Jan, 3 Apr, 17 Jul, 25 Sep, 4 Dec.
- 2008: 12 Feb, 22 Apr, 1 Jul, 9 Sep, 18 Nov.

The OCMs are always performed in the early hours of the day (see Table 1). Note that with this strategy 5 orbit maintenance OCMs are executed each year, with an additional fuel cost of a bit less than 500 grams per year. The first 3 OCMs have already been successfully executed.

The expected baselines using the described orbit control maintenance strategy are as follows
- For the polar regions:

0 m - 250 m	Northern Summer
500 m – 750 m	Northern Winter, for baselines with **odd** cycle difference
0 m - 250 m	Northern Winter, for baselines with **even** cycle difference

- For tropical and mid latitudes:

max @ 32.0 deg < 472 m	Northern Summer
max @ 61.9 deg < 850 m	Northern Winter, for baselines with **odd** cycle difference
max @ 32.0 deg < 472 m	Northern Winter, for baselines with **even** cycle difference
@ 0.0 deg < 400 m	all baselines

These expected baselines could be used in the ordering process of ASAR observations, depending on the anticipated ASAR interferometric application.

6.   BASELINE RESULTS

At the time of writing (August 2007), almost 6 cycles have been flown since the introduction of the new Envisat orbit control maintenance strategy, and the initial interferometric baseline results look very promising:

- For the polar regions:

500 m - 900 m	Northern Winter, for baselines with **odd** cycle difference, "consecutive"
0 m - 250 m	Northern Winter, for baselines with **even** cycle difference, "alternate"

- In between 60S – 60N:

0 m - 800 m	Northern Winter, for baselines with **odd** cycle difference, "consecutive"
0 m - 300 m	Northern Winter, for baselines with **even** cycle difference, "alternate")

The next 4 graphs illustrate the baseline results that have been obtained so far (courtesy of Betlem Rosich from ESA-ESRIN).
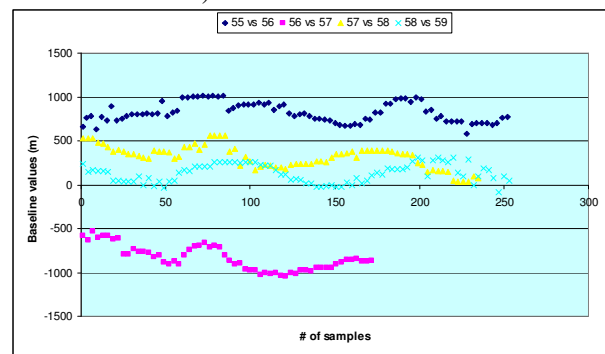

Figure 10: Actual perpendicular baseline values over the North Pole region for consecutive cycles 55 through 59.

Note that the cycle combination 58-59 shows baseline values that are in line with the expected baseline values for this combination (see Figure 7). The others however are not, e.g. Figure 7 shows that the ground track deviations between cycle 55 and 56 can not be more than about 750 meters. The perpendicular baselines between these cycles should even be less, whereas the above plot shows values of up to a 1000 meters. This needs further investigation.
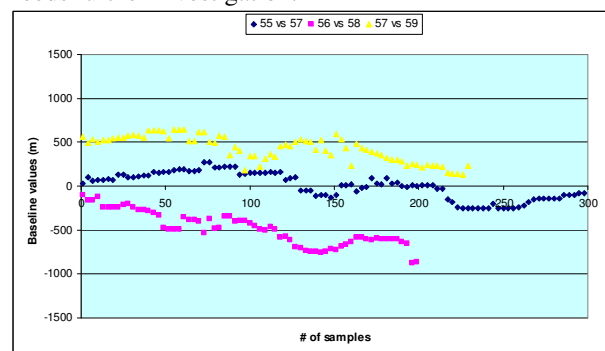

Figure 11: Actual perpendicular baseline values over the North Pole region for alternating cycles 55 through 59.

The results between alternating cycles in the above plot are more in line with the expected baseline values as can be seen from Figure 7.
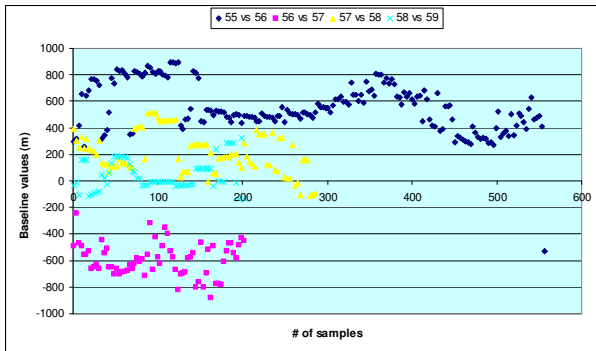

Figure 12: Actual perpendicular baseline values over the Europe area for consecutive cycles 55 through 59.

The results over Europe for consecutive cycles look better than over the North Pole region as these are a combination of the deviations at maximum latitude and Equator, where a deadband is maintained of 200 meter.
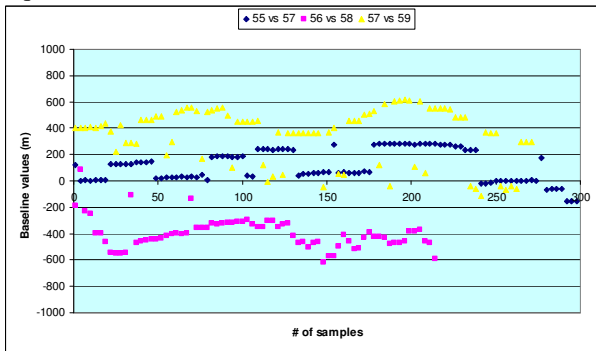

Figure 13: Actual perpendicular baseline values over the Europe area for alternating cycles 55 through 59.

Again the results over Europe for alternating cycles look better than over the North Pole region for the same reason as above.

7. CONCLUSIONS

The International Polar Year initiative triggered some investigations on how the orbit control maintenance strategy of Envisat could be changed to support this initiative and on top to improve overall ASAR interferometry opportunities.

The investigations focused on finding the optimal burn duration, i.e. maximum inclination change per kg of hydrazine, and on phasing the out-of-plane manoeuvres with a 35-day repeat cycle, i.e. determining the best integer number of cycles between manoeuvres.

The investigations showed that concerning the optimal manoeuvre duration there is some margin of ± 200 seconds around the optimal burn duration. A burn duration selected within this range can be executed

without any significant fuel losses. Furthermore, the investigations demonstrated, concerning the phasing of the out-of-plane manoeuvres, that most ASAR interferometry opportunities are provided by an orbit control strategy where out-of-plane manoeuvres are executed every 70 days and this at no significant additional fuel cost compared to the optimal strategy.

To support the International Polar Year initiative, each northern Summer a small out-of-plane manoeuvre is executed to reduce the baselines between consecutive Summer cycles and also between years below the 250 meter level. This support however comes with a additional fuel cost of a bit less than 500 grams per manoeuvre.

The new orbit maintenance strategy has been introduced in January 2007, and is to be executed during 2007 and 2008. First baseline results after almost 6 cycles already look very promising, but it is expected that results will improve even more for future cycles to come.

REFERENCES

1. Rosengren M., *Orbit Control of ERS-1, ERS-2 and ENVISAT to support SAR Interferometry*, ERS and Envisat Szmposium, Gothenburg, 16-20 October 2000.
2. Rudolph A. et al., *ENVISAT Orbit Control – Philosophy, Experience and Challenges*, ERS and Envisat symposium, Salzburg/Austria, September 2004.
3. Milligan D. et al., *ENVISAT Platform Operations: Providing a Platform for Science*, 2007 Envisat Symposium, Montreux/Switzerland, 23-27 April 2007.