ALSAT-2A TRANSFER AND FIRST YEAR OPERATIONS

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Abstract: *This paper describes the transfer phase, the station keeping and the routine operations performed during the first eight months of the satellite ALSAT-2A after launch. ALSAT-2A is the second Earth Observation spacecraft for Algeria and it is the first satellite of a constellation composed of ALSAT-2A and ALSAT-2B. It has been launched by PSLV-C15 on 12th July 2010 from Sriharikota, Chennaï (India) at 03h52' UT. On 21st July, the satellite has been placed on its mission orbit. This was the starting point of the routine operations to be performed daily by ASAL Flight Dynamics team.*

Keywords: *ALSAT-2A, Transfer, station keeping, MCO*

1 Introduction

ALSAT-2A is the second Earth Observation spacecraft for Algeria and it is the first satellite of a constellation composed of ALSAT-2A and ALSAT-2B. It has been launched by PSLV-C15 on 12th July 2010 from Sriharikota, Chennaï (India) at 03h52' UT. The mission analysis and the transfer phase have been performed by ASAL/Astrium teams. On 21st July, the satellite has been placed on its mission orbit. This was the starting point of the routine operations to be performed daily by ASAL Flight Dynamics team. Alsat-2B is planned to be launched within the two next years and will be phased with ALSAT-2A.

Figure 1. View of ALSAT-2A spacecraft

The reference mission orbit of ALSAT-2A is a phased Sun-synchronous orbit with 14 + 19/29 revolutions per day repetitivity of ground track (altitude over equator around 670 km). In the case of ALSAT-2A, no reference grid was defined, that means that the phasing of the ground track with a reference grid was not considered in the transfer strategies. The reference grid has been defined by the resulting ground track of the satellite observed at the end of the transfer phase. The target orbit to be reached at the beginning of life has been optimised to avoid corrections of the Local Solar Time (out of plane maneuver) during 5 years. This orbit is defined by a semi-major axis of 7048 km and an inclination of 98.23 deg.

The paper presents how the reference orbit has been chosen for ALSAT-2A. Then, the transfer strategy design to reach this mission orbit as well as its operational realization is detailed. In addition, the paper presents the station keeping and routine operations realized by ASAL team. It describes the daily Flight Dynamics activities and also puts forward flight data dealing with operational parameters station-keeping (ground track error at equator and local solar time error evolution) and describes also the activities realized for the first OCM maneuvers.

2. Transfer Phase

2.1 Reference orbit and station keeping definition

The reference mission orbit is a phased Sun-synchronous orbit with a 14 + 19/29 revolutions per day repetitivity of ground track (altitude over equator around 670 km). The mean orbital elements of this reference mission orbit are summarized in Tab. 1.

Table 1. Mean orbital element in Veis reference frame

H over equator (km)	~670
a (km)	7047.805442
Eccentricity	0.00121452
i (deg)	98.0828
w (deg)	90.00
Local Solar Time (D.N.)	09h50 ± 20 mn

As the expected Local Solar time at separation was 09h30 LTDN (+20 mn possible dispersion resulting from the launch window), the reference Local solar time of the mission has been set to 09h50 ± 20 mn, so that the initial inclination and solar time were optimal with respect to the solar time station-keeping window. The initial inclination bias is about 0.1 deg and the resulting initial LST bias is -20 minutes. In the case when the LST at separation would have been delayed, the mission reference LST would have been changed accordingly so that the initial conditions remain optimal with respect to the LST Station-Keeping window.

In that case the mean solar local time can be limited to + or – 20 mn around the mission value over 5 years without any inclination corrections. The local solar time is expected to get out of the window after more than 6 years. Fig. 2 illustrates the predicted evolution of the solar local time.

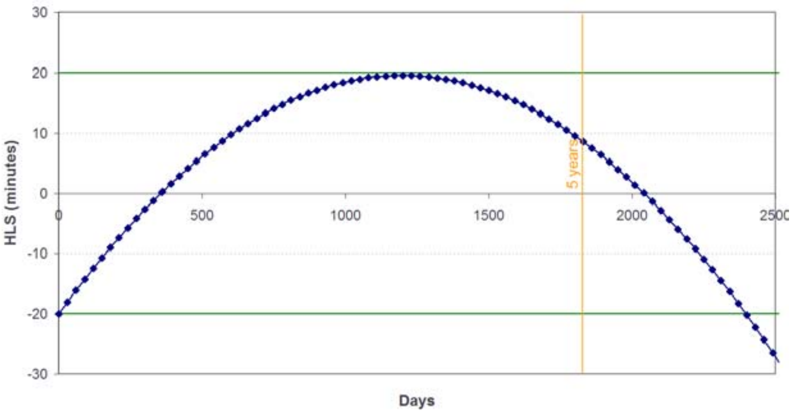

Figure 2. Evolution of the solar local time

2.2. Transfer strategy design

The injection orbit delivered by PSLV-C15 was 33 km and 0.1 deg lower than the target orbit. The transfer phase consisted therefore in increasing the semi-major axis and correcting the inclination to reach the predefined targets while targeting the frozen eccentricity. A generic strategy had been designed during mission analysis to cope with all the cases of dispersions on eccentricity as these were expected to be quite high. The transfer lasted 7 days during which 14 maneuvers have been performed. 2 maneuvers per day of a few m/s have been planned at relevant arguments of latitude to reach the frozen eccentricity. The transfer strategy has been designed to have the first maneuver (calibration maneuver) during a station visibility and to end with small maneuvers to guarantee an accurate arrival on the mission orbit.
In order to fulfill electrical, thermal and SCAO constraints (no saturation of wheels,...) and the minimum delay between two successive manoeuvres (1.5 orbit), the maximum delta V to be used per orbit during transfer is 3 m/s.

As mentioned previously, in case of ALSAT-2A, a predefined reference grid is not needed. That means that the phasing of the ground track with the reference grid was not considered in the transfer strategies. The reference mission orbit, defining the reference ground track phasing and the reference LST was thus defined at the end of the of the transfer phase.

The transfer has been divided in 4 phases:

- The first phase aims at the calibration of manoeuvre through in-plane manoeuvres. This phase also enables starting the correction on the semi-major axis and eccentricity.
- The second phase aims at increasing the semi-major axis up to a few kilometers below the target orbit and to achieve the target inclination through several combined manoeuvres. The eccentricity is also corrected during this phase: allowing a slight AoL shift with respect to the inclination correction optimal AoL enables to correct eccentricity at the same time.
- The third phase aims at reaching the target semi-major axis a few hundred meters below and to achieve to the target eccentricity through several in-plane manoeuvres.
- The last phase corresponds to the last manoeuvres that enable to reach the optimised target semi-major axis for station keeping.

2.3. Transfer realization

The injection of the satellite occurred on 2010/07/12 04:11:09.400. The delta mean parameters observed between the launch bulletin provided by launch authorities and expected nominal parameters are:

- +4.9 km on semi-major axis,
- +0.035 deg on inclination,
- -0.00004 on eccentricity,
- -2 s on HLS.

Theses small dispersions on injection allowed to perform a transfer sequence composed of 7 maneuvers days including 4 days with combined maneuvers as described in Tab. 2.
Maneuvers started on the third day after launch (14th July). The two first days were dedicated to spacecraft initialization. The transfer phase was completed on 21st July, 2010.

Table 2. Computed Transfer Plan

OCM Summary				
	Date	PSO (deg)	ΔV_T (m/s)	ΔV_N (m/s)
OCM1	14/07/2010 12:46:26	167	0.374	0.000
OCM2	14/07/2010 15:40:22	90	0.374	0.000
OCM3	16/07/2010 01:24:02	10	2.670	1.074
OCM4	16/07/2010 03:44:52	170	2.370	-1.074
OCM5	17/07/2010 00:10:18	11	2.783	1.196
OCM6	17/07/2010 02:30:53	169	2.483	-1.067
OCM7	18/07/2010 00:36:09	8	2.420	1.775
OCM8	18/07/2010 02:58:38	172	2.420	-1.775
OCM9	19/07/2010 01:05:40	8	2.420	1.758
OCM10	19/07/2010 03:28:25	172	2.420	1.758
OCM11	20/07/2010 00:22:15	90	0.770	0.000
OCM12	20/07/2010 03:38:39	90	0.770	0.000
OCM13	21/07/2010 00:30:00	-4.35	0.320	0.000
OCM14	21/07/2010 03:13:08	-126.58	0.346	0.000

The 14 Orbit Control Maneuvers (OCM) corrected 33 km of semi-major axis (Fig. 2), +0.1 deg of inclination (Fig. 3), and achieved the frozen eccentricity (Fig. 4).
The maneuvers have been calibrated during the transfer. The calibration coefficient was set to 0 for OCM 1&2 (no knowledge of calibration).

As expected, a strong over-efficiency was observed for very small OCM as the propulsion model was known to be less accurate for small maneuvers. However, it did not prevent to reach accurately the mission orbit as it has been anticipated.

- +5.4% for OCM 1&2
- +14.9% for OCM 11&12
- +25.4% for OCM 13&14
- A slight over-efficiency is observed for long OCM, as expected.

Tab. 3 summarizes the calibrated maneuvers realized during LEOP.

Table 3. Realized Transfer Plan

OCM Summary - Observed				
	Date	PSO (deg)	ΔV_T (m/s)	ΔV_N (m/s)
OCM1	14/07/2010 12:46:26	167	0.390	-0.098
OCM2	14/07/2010 15:40:22	90	0.394	0.026
OCM3	16/07/2010 01:24:02	10	2.499	1.053
OCM4	16/07/2010 03:44:52	170	2.279	0.921
OCM5	17/07/2010 00:10:18	11	2.780	1.210
OCM6	17/07/2010 02:30:53	169	2.516	1.026
OCM7	18/07/2010 00:36:09	8	2.439	1.709
OCM8	18/07/2010 02:58:38	172	2.451	1.774
OCM9	19/07/2010 01:05:40	8	2.435	1.813
OCM10	19/07/2010 03:28:25	172	2.478	1.760
OCM11	20/07/2010 00:22:15	90	0.882	0.000
OCM12	20/07/2010 03:38:39	90	0.882	0.000
OCM13	21/07/2010 00:30:00	-4.35	0.353	0.033
OCM14	21/07/2010 03:13:08	-126.58	0.378	-0.007

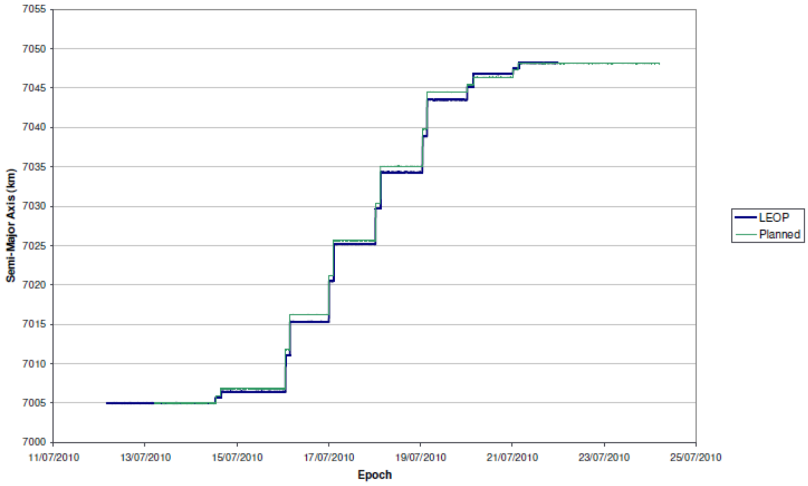

Figure 2. Semi-major axis raising sequence

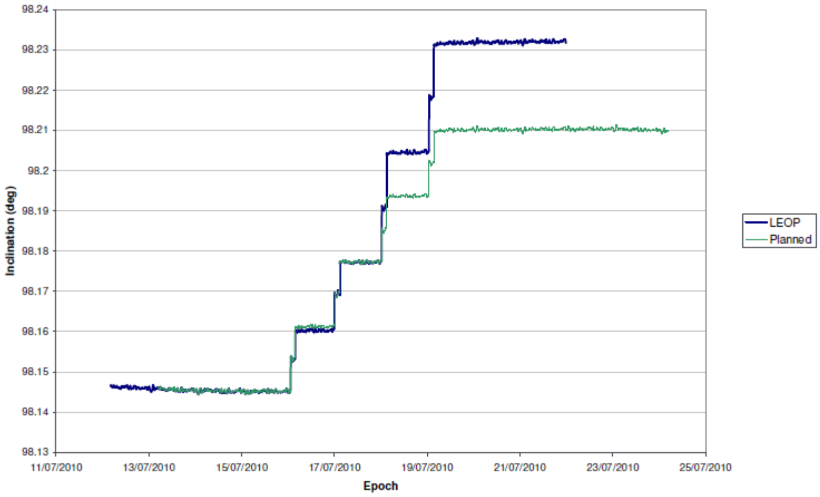

Figure 3. Inclination raising sequence

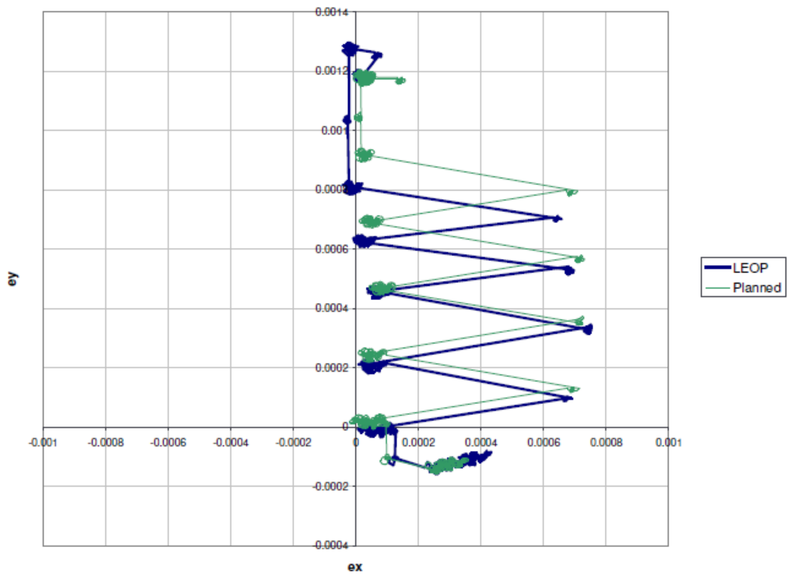

Figure 4. Eccentricity raising sequence

The difference between planned inclination evolution and actual evolution is not due to dispersions. Indeed, the target inclination was refined during transfer in order to be optimal regarding actual injection conditions.
At the end of the transfer and the initialization of the station keeping, the first station-keeping maneuvers were expected to occur by mid-December 2010 (Fig. 5).

Fig. 6 illustrates the evolution of the local solar time. The local solar time is maximum end of 2013 (LST = 22:07:42) and left the window in October 2016, thus more than one year after the expected end of mission (5 years nominal lifetime).

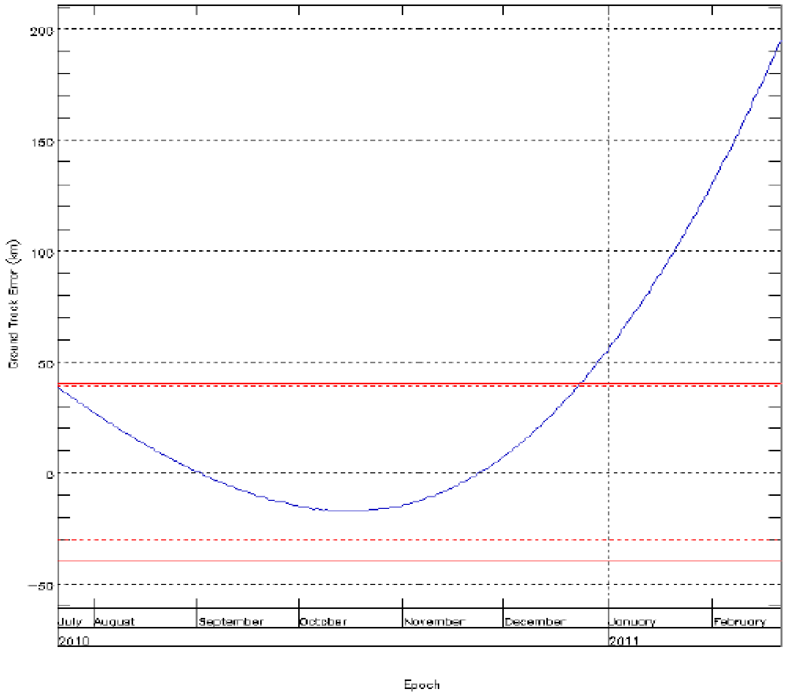

Figure 5. Ground track error evolution prediction at the end of the transfer

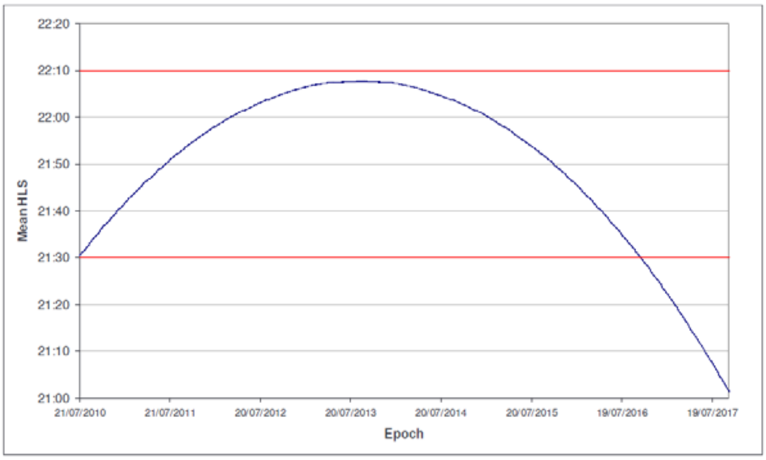

Figure 6. Local Solar Time evolution prediction at the end of the transfer

3. First year of operations as seen by CTS/ASAL

The operations are performed from ALSAT-2 ground segment located in Ouargla (Algeria). The CTS/ASAL operation team is now fully autonomous to control and monitor nominally ALSAT-2A and is also able to handle anomaly situation, analyze telemetry, and correct the anomalies. The control ground segment is composed of the Flight Dynamics Centre, the Satellite Control Centre, and the Mission Planning Centre. The image ground segment is composed of an X-band station and a Data Processing Facility to process the images.

3.1. Flight Dynamics routine activities

The daily routine activities for Flight Dynamics team start when the GPS and Doppler data are available after the first satellite contact in the morning. All the activities are performed with the operational software package QUARTZ developed by Astrium Satellites. The routine activities consist in:

- Orbit determination (OD): The operational orbit determination is based on a batch weighted least square (WLS) using GPS based navigation solutions from dumped telemetry or by using Doppler measurements. The result of operational orbit determination is the estimation of spacecraft orbit for a specific epoch. Solar flux and drag error can be estimated when needed. QUARTZ determines the orbit precisely.
- Events prediction, Station Keeping parameters evolution monitoring and UTC time reference update. The main perturbations taken into account are: geo-potential, solar radiation pressure, Sun/Moon attraction, drag and earth tides
- Generating files for Mission Planning Center as Orbit Ephemeris for mission planning purpose and Transponder activation plan to generate a TC file to activate spacecraft transponder when the spacecraft is in geometrical visibility of the ground stations.
- Generating Antenna pointing file for S band station and an orbit in TLE format for X band station

3.2. Orbit Maintenance Strategy

The orbit maintenance strategy shall not disturb the payload operation. Therefore, the SK shall be optimized to plan only necessary maneuvers. The two parameters to be considered for SK are Ground Track error and Local Solar Time error.
Ground Track of the orbit is defined as the locus of points projected on the Earth's surface directly "beneath" the spacecraft orbit.
Due to the time varying nature of the perturbations on the orbit, deviations from the reference orbit lead to ground track drift. To understand this, consider the orbit as it crosses the equator (called ground track error), as the earth rotates from one node crossing to the next the ground track moves westward. If the orbital period is exactly right, successive node crossings match successive reference nodes. If the period is too short, the Earth does not rotate quite far enough, and the true node falls eastwards of the reference node. If the period is too long, the earth rotates too far, and the true node falls westwards. After several orbits, the ground track moves further and further to one direction or another and a ground track drift develops. Ground track maintenance maneuvers must be performed to maintain the ground track within a predefined control window around the reference ground track. For ALSAT-2A, this window is ±40 km. as shown in “Fig. 7.”

For the Local Solar Time, no corrections of inclination will be performed as explained above.

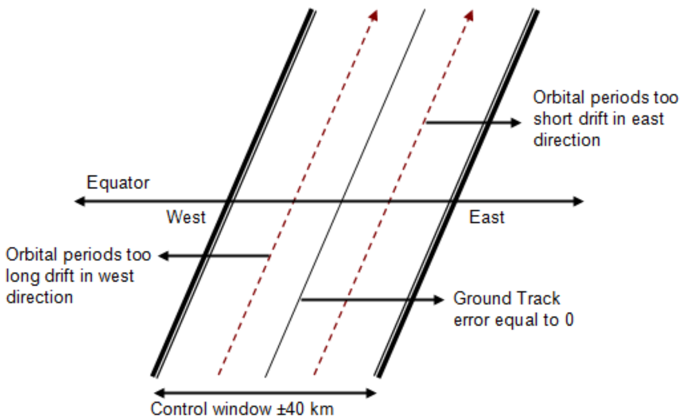

Figure 7. Ground track drift, measured at the equator

3.2. Orbit Maintenance OCM

The operators performed SK long-term prediction based on weekly basis to check evolution of ground track and local solar time. The ground track and local solar time real evolutions since the LEOP have demonstrated that with the real solar activity and the others perturbations, the first station keeping maneuvers should be performed at the end of October 2010. More than one month before the date predicted at the end of transfer. In fact the semi-major axis decrease was not as fast as expected. Therefore a maneuver to decrease semi-major axis was necessary to prevent ALSAT-2A from exiting the Ground Track window on the west side.
The date selected to perform the correction on the semi-major axis is November 4th, 2010.

Once the need of a maneuver has been established, the maneuver shall be computed in terms of size, start date, duration and all the related constraints shall be checked. Then the corresponding satellite Tele-command plan shall be generated and uploaded.

In order to maintain the ground track within a predefined control window around the reference ground track, a correction of -50 m on the semi-major axis has been performed. The programmed maneuvers are:

As observed during LEOP phase for the short maneuvers, an over-efficiency shall be considered for the station keeping maneuvers. The up to date value of the calibration coefficient considered is 25.4%.

	Centroid epoch	ΔV_T (m/s)	ΔV_W (m/s)	Declination (deg)
OCM1	2010/11/04 01:09:47.907	0.0663971779	0.0000000000	0.00000
OCM2	2010/11/04 03:37:11.903	-0.093106435	0.0000000000	0.00000

As post maneuvers activities, the efficiency of the maneuvers based on the localization measurements are estimated. The calibration coefficient is then used for the computation of the next

OCM. Also the remaining propellant mass after thrust is estimated. The remaining propellant is currently around 3 kg which is sufficient for orbit maintenance over 10 years.

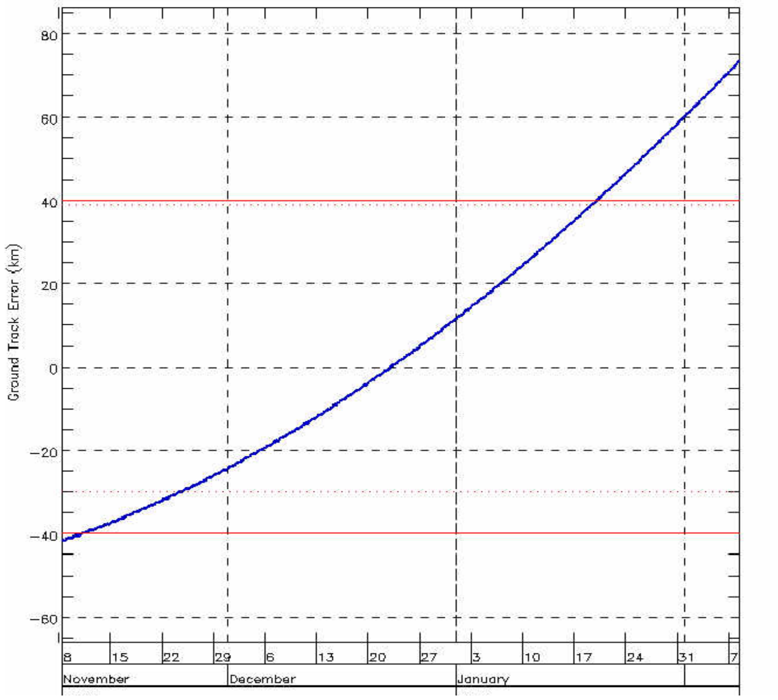

Figure 8. Evolution of ground track error after orbit maintenance OCM

Currently the ground track error at equator and local solar time are respectively more than 20 km (Ground track error window is +/-40 km) and 21:45:50 (LST window is 21:50±20 mins). The next foreseen OCM should occur in end January 2011 and is an in-plane maneuver.

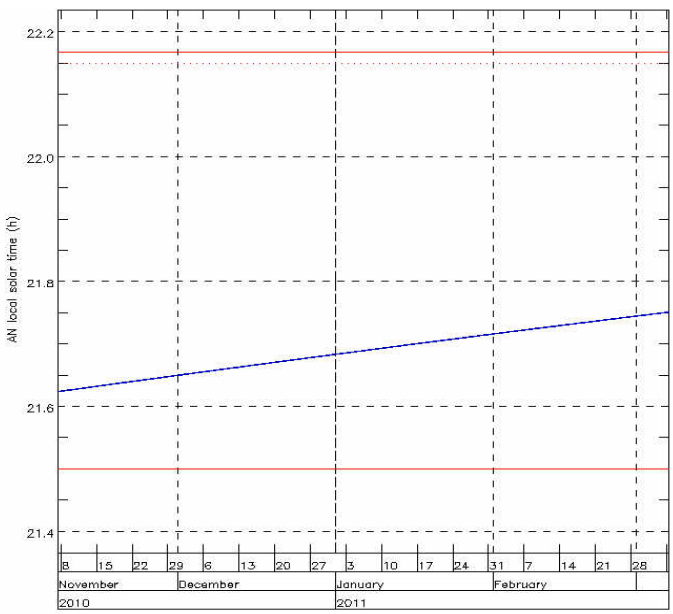

Figure 9. Actual evolution of Local Solar Time

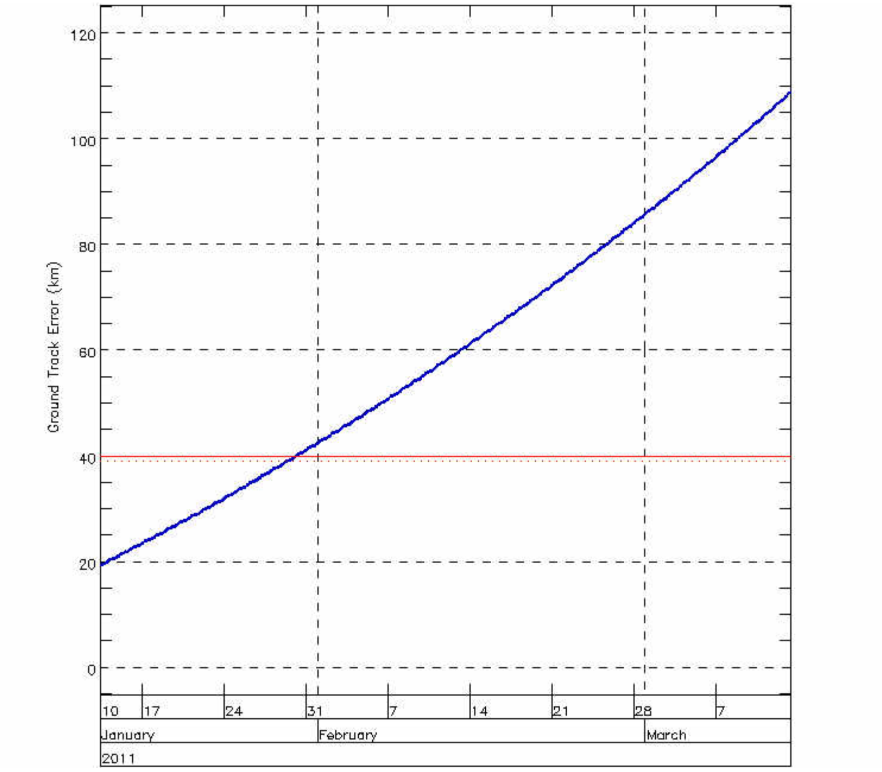

Figure 10. Actual evolution of ground track error

4. Conclusion

ALSAT-2A satellite and ground segment are now functioning nominally and are now fully operated by CTS/ASAL. The entire ALSAT-2A system has been tested, monitored, calibrated and validated and is now ready to operationally deliver imaging products to world wide customers. The daily routine Flight Dynamics activities are now handled by CTS/ASAL FD operators. They have already performed the first OCM activity on 4th of November 2010 and will perform the next orbit maintenance OCMs around end of January 2011.

5. References

[1] CNES, " Mécanique Spatiale", 1995 – Ed. Cepadues.