MISSION DESIGN FOR THE "SWOT" MISSION

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Abstract: *SWOT (Surface Water and Ocean Topography) is a joint CNES/NASA mission that extends the series of altimetry missions (Topex-Poseidon, Jason 1/2/3...) with more stringent accuracy requirements and a wider spectrum of scientific objectives.*
The SWOT mission is composed of a single spacecraft equipped with a Ka-band SAR interferometer. The satellite will operate in a near-polar Earth orbit for about 3 years from end of 2020.
The paper provides an overview of the analyses related to space flight dynamics conducted at CNES during phase A.
The paper first shows the results of the orbit selection process. The objective was to select an orbit meeting both the scientific requirements (relative to aliasing and coverage in particular) and the requirements relative to the mission system (download capability, orbit control performance…).
Then, various results related to the orbit are shown, beginning by the effects of perturbations. The orbit is subject to a resonance effect due to the coupling between Earth gravity (J2/J3 mainly) and solar radiation pressure. The paper will detail this resonance effect as well as many other aspects that had to be evaluated to prove that all the mission requirements are effectively met.

Keywords: *SWOT, mission design, orbit, system performance*

Acronyms:

CNES	*Centre National d'Etudes Spatiales* - French Space Agency
CAL/VAL	Calibration / Validation
CNES	*Centre National d'Etudes Spatiales* - French Space Agency
DV	Delta-V (velocity change)
LEO	Low Earth Orbit - apogee altitude less than 2000 km (IADC definition)
MLTAN	Mean Local Time of Ascending Node
RAAN	Right Ascension of Ascending Node
SRP	Solar Radiation Pressure
STELA	Semi-analytic Tool for End of Life Analysis (CNES tool for orbit long-term propagation)
SWOT	Surface Water and Ocean Topography
sma	Semi-major axis
ecc	Eccentricity

1. Introduction

SWOT (Surface Water and Ocean Topography) is a joint CNES/NASA mission (with also a contribution from the Canadian space agency) whose objective is to characterize the ocean mesoscale and sub-mesoscale circulation at spatial resolutions of 15 km and greater, and to provide a global inventory of all terrestrial water bodies whose surface area exceeds 250 m2, and rivers whose width exceeds 100 m.
The SWOT mission is composed of a single spacecraft equipped with a Ka-band SAR interferometer called KaRin and an altimeter (among other instruments). The satellite will operate in a near-polar (not Sun-synchronous) Earth orbit for about 3 years. SWOT extends the series of altimetry missions (Topex-Poseidon, Jason 1/2/3...) with more stringent accuracy requirements and a wider spectrum of scientific objectives, serving both the oceanography and land hydrology communities.

SWOT is planned to be launched at the end of 2020. The expected mission lifespan is 3.5 years, including 6 months at the beginning of the mission for validation and calibration purposes.

One of the main objectives of the mission design was to select an orbit meeting the science, mission system and instrument/satellite requirements.
The orbit presently selected for the science mission is a 21 day (more accurately: 20.86 days) repeat orbit. For the first 6 months the orbit is a one day (more accurately: 0.99 day) repeat orbit.

The mission timeline contains the following major events:
- launch (various launchers are possible from various launch sites),
- LEOP and acquisition of the 1 day repeat orbit for CAL/VAL,
- after about 6 months: move from CAL/VAL to science orbit,
- departure from the science orbit at end of mission to comply with end of life requirements.

The paper presents a selection of the mission design aspects that have been studied at CNES during phase A. Only the most specific aspects will be detailed.

2. Orbit trades

The initial scientific requirements regarding the orbit were:
- altitude between 800 and 1000 km,
- inclination between 70 and 80 deg.

The range for the inclination was driven by the need to observe arctic rivers (that is to say regions at high enough latitudes) and by aliasing constraints which become severe above 80 deg.
Altitude was also chosen in relation to the swath size (around 120 km) and the necessity for (nearly) global coverage in the accessible latitude range.
This first analysis led then to a 22 day repeat orbit (altitude ~970 km) and an inclination of 78 deg. The altitude was later lowered to 873 deg during phase 0 to be more compliant with the anticipated available Delta-V.

At the beginning of 2013, a new orbit selection process was started off so as to satisfy oceanography and land surface hydrology communities best. The main drivers and conclusions that led to the currently selected orbit are detailed below.

The study started by first selecting a set of potential (science) candidate orbits not too far from the previously selected one (highlighted in red in Figure 1).

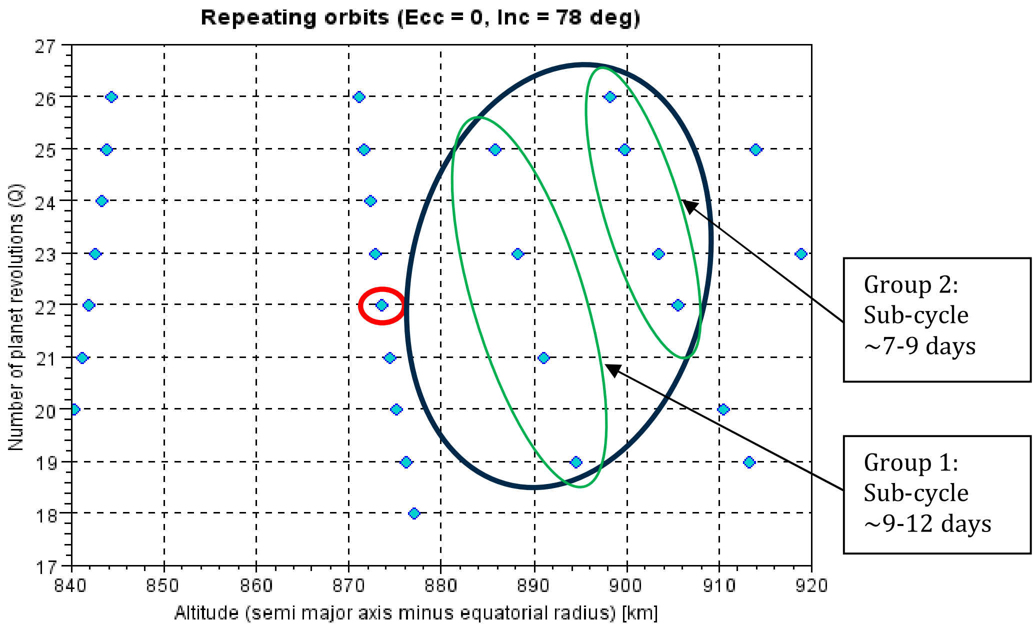


Figure 1. Orbit search space

The orbits are supposed frozen (in order to minimize changes in swath size along the orbit path) and the ground tracks are repeating after a so-called repeat cycle (or period), which is between 19 and 26 days (see y-axis in Figure 1).
The selected candidates belong to 2 groups, even 3 if the previously selected orbit is also considered. The orbits in each group share the same sampling pattern. Altitude is limited to approximately 900 km to minimize deorbit cost as the satellite has to comply with the French Space Operations Act (the requirement then was to put the satellite in a disposal orbit with a 25-year life time at end of mission).

The main drivers considered were tidal aliasing, coverage and sampling / mapping errors. They are detailed hereafter.

Tidal aliasing:
The analysis performed was a classical one, considering one observation per repeat period.
The criteria used are those from Richard Ray (see [5] for additional details):

- Set of tidal waves:

Number	Name	Period (days)	
1	S1	1.0	
2	S2	0.5	
3	K1	0.99727	
4	K2	0.498635	
5	M2	0.517525	
6	N2	0.527431	
7	P1	1.002745	
8	O1	1.075806	
9	Q1	1.119515	
10	Mf	13.660791	
11	Mm	27.554551	
12	Ssa	182.621095	
13	Sa	365.2594	
14	M4	0.2587625	2*M2
15	M6	0.172508333	3*M2
16	MS4	0.254305791	M2+S2

- Aliasing periods should be less than 1 (or maybe 2) years.

- The waves from the main tier (Sa, SSa, Q1, O1, K1, N2, M2, S2, K2) must be separable within a time period shorter than the mission lifespan.

- The number of inseparable pairs (w1, w2) where w1 belongs to the main tier and w2 belongs to (P1, M4, MS4, M6) has to be minimized.

The application of these criteria has a strong impact on the orbit (that's why aliasing criteria should be selected with care): candidate orbits either cannot be retained or the inclination that meets the criteria is limited to a very small range. The results are shown in Table 1, where (N,P,Q) are the 3 integers that characterize the repeat characteristics (Q = repeat period, N*Q+P = number of orbits per repeat period):

Table 1. Result of the application of aliasing criteria

Orbit Number	Repeat characteristics (N,P,Q)	Altitude (km) (for inclination = 78 deg)	Acceptable inclination range (deg)
1	13 21 22	873.6	77-78
2	13 23 25	885.7	None
3	13 21 23	888.1	~77.4
4	13 19 21	891.0	76.5- 78
5	13 17 19	894.6	~75
6	13 23 26	898.1	None
7	13 22 25	899.8	None
8	13 20 23	903.5	~77.3
9	13 19 22	905.6	76.7-77.8

Coverage:
Coverage did not have a strong impact on the orbit selection.
The following figure shows the ratio of not covered area to the whole area between –inclination and +inclination (latitude range). The ratio is computed for the orbits that meet the aliasing criteria assuming a fixed swath size. The ratio is between 3% and 6.5% which satisfies the requirement.

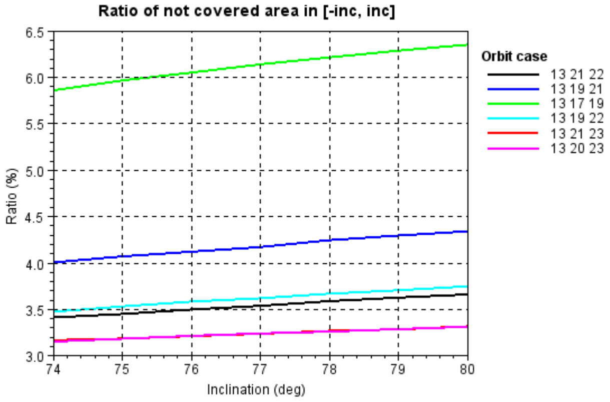


Figure 2. Not covered area ratio

There are some differences though pertaining to the coverage at low latitudes (differences that mostly concern the hydrology community), as can be shown in Figure 3. But these differences were considered as negligible enough.

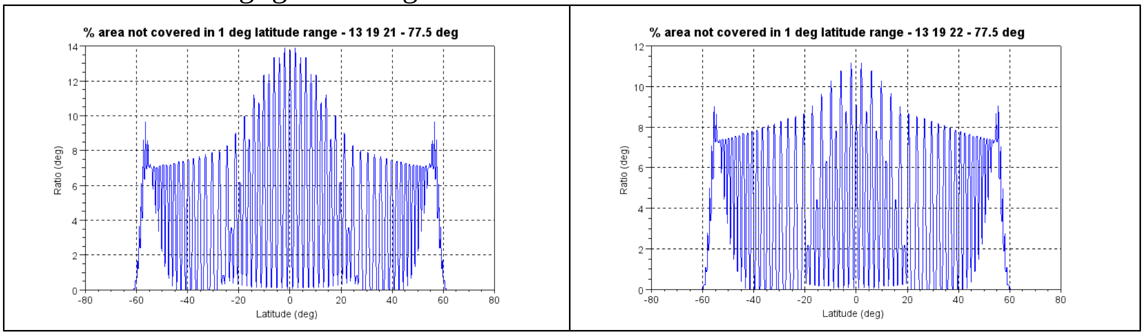


Figure 3. Covered area as a function of latitude

Sampling mapping errors:
The conclusions concerning this point (closely related to measurements processing) were in fact borrowed from Dudley Chelton (see [4]). How good an orbit is depends on how the ground tracks repeat and fill the Earth surface (sampling pattern). It followed from that analysis that the orbits belonging to group 1 tend to be preferred.
Even better orbits (according to Dudley Chelton's criteria) exist but are out of the search domain (altitude above 900 km).

Other aspects:
Other aspects have been studied in detail, particularly the data download capacity and the effect of perturbations on the orbit (and the orbit corrections that have to be performed). They were

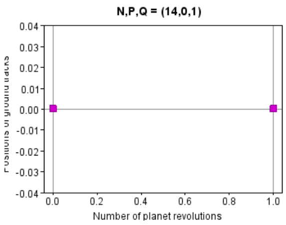
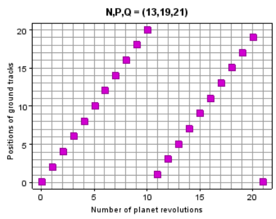
considered as satisfactory and manageable respectively. These aspects will be detailed in other sections of the paper.
The final orbit results are summarized in the table below.

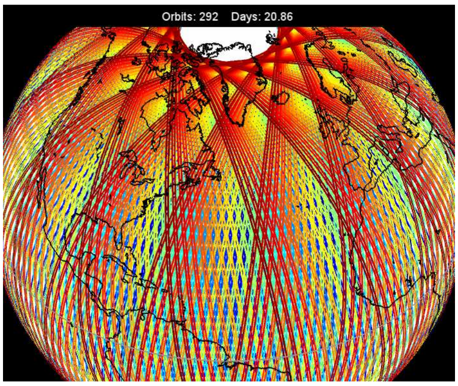
Table 2. Final orbit trade results

Orbit Number	Repeat characteristics (N,P,Q)	Approx alt. (km)	Inc (deg) (Aliasing)	Chelton's classification (order of preference)	Coverage ratio	All criteria
1	13 21 22	873	77-78	3	OK	
2	13 23 25			1 - Preferred	OK	
3	13 21 23	885	75.2-75.8	1 - Preferred	OK	OK
4	13 19 21	890	77-78	1 - Preferred	OK	OK
5	13 17 19	890	74-75	1 - Preferred		
6	13 23 26			2	OK	
7	13 22 25			2	OK	
8	13 20 23	900	75-75.7	2	OK	
9	13 19 22	905	76.7-77.8	2	OK	

The selected orbit is the highlighted one (13, 19, 21), with a repeat period close to 21 days. In addition to the science orbit, a 1 day repeat cycle is chosen for calibration and validation purposes.
Table 3 gives a synthesis of the main orbital characteristics of the selected orbits. The results were computed with a model limited to J2-J6.

Table 3. Orbital characteristics

	Fast sampling orbit	"Mission" orbit
Repeat orbit parameters	14 + 0 / 1	13 + 19 / 21
Mean semi-major axis (m)	7235379.8	7268718.9
Altitude (km) (mean sma minus equ. radius)	857.244	890.582
Inclination (deg)	77.6	77.6
Mean Eccentricity (frozen)	0.00105	0.00105
Number of orbits per cycle	14	292
Nodal period (sec)	6131.25	6173.62
Exact repeat cycle duration (days)	0.99349	20.86455
Longitude gap between 2 consecutive ground tracks (deg)	25.714	25.890
Longitude gap between 2 adjacent ground tracks (deg)	25.714	1.233
Drift of RAAN local time (minutes/day)	-9.44	-9.35
Duration for 24h RAAN local time change (days)	152.6	154.0
Chronology of ground tracks in the cycle	 (No sub-cycle)	 Sub-cycle ~10 days



The figure on the left shows the ground track over one repeat period (20.86 days). In red: most recent passes and in blue: older ones.
One can clearly see the 2 sub-cycles (of about 10 days each). Hardly visible are the tiny white dots that correspond to the areas that are not observed by the interferometer (mostly at low latitudes, and in the nadir direction at crossovers).

3. Flight system

The flight system is depicted in Figure 4.
The 2 reflectors are situated on each side of the ground track. The solar arrays may rotate or not in the final design, but are considered fixed in the present analysis. They contain the velocity vector thus minimizing the effect of atmospheric drag. The solar array normal is oriented at a ~20 degree angle to the orbital plane in order to maximize lighting (not as shown in the figure).

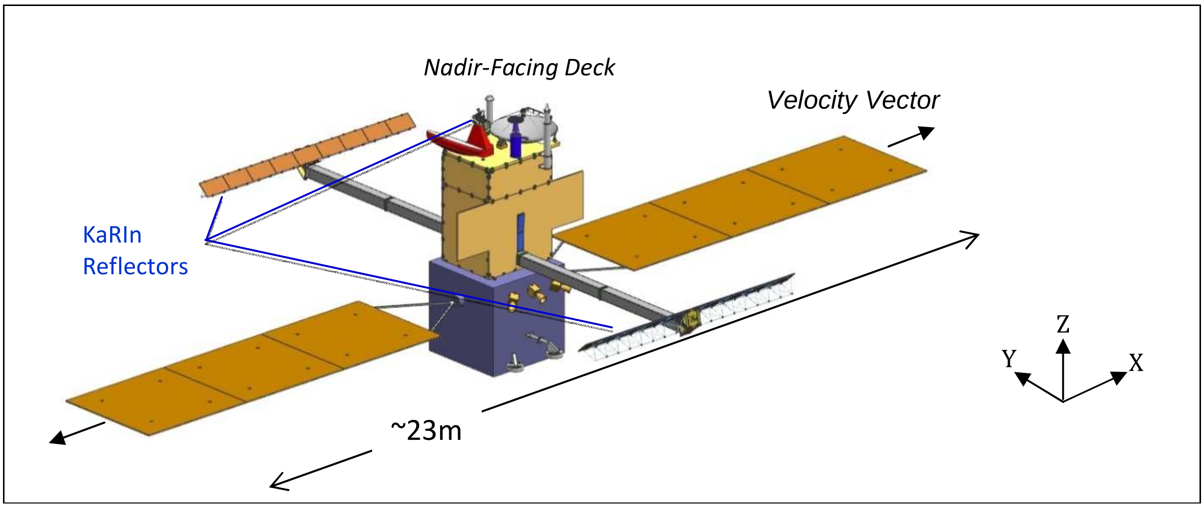


Figure 4. Satellite in deployed configuration

Some characteristics used in the analysis are the following:

- Areas as seen from the X,Y,Z axes: respectively 7.7, 20, 35.9 m^2 (X,Y,Z axes: ~tangential, normal, radial directions).
- Mass: around 1700 kg (it might be slightly greater in the final design).

The areas above lead to (approximate) average areas of:

- 27.5 m^2 along a random direction (tumbling mode),
- 31.1 m^2 along a direction perpendicular to the Sun direction (not considering eclipses),
- 7.7 m^2 along the velocity direction.

Yaw flip maneuvers are performed each time the Sun lies in the orbit plane, thus making the solar panels always directed towards the Sun.

4. Study of orbit motion, perturbations that affect the orbit

4.1 Resonance effect, evolution of eccentricity

When propagating the orbit, an unusual phenomenon appears: eccentricity varies with a long term period that depends on inclination.

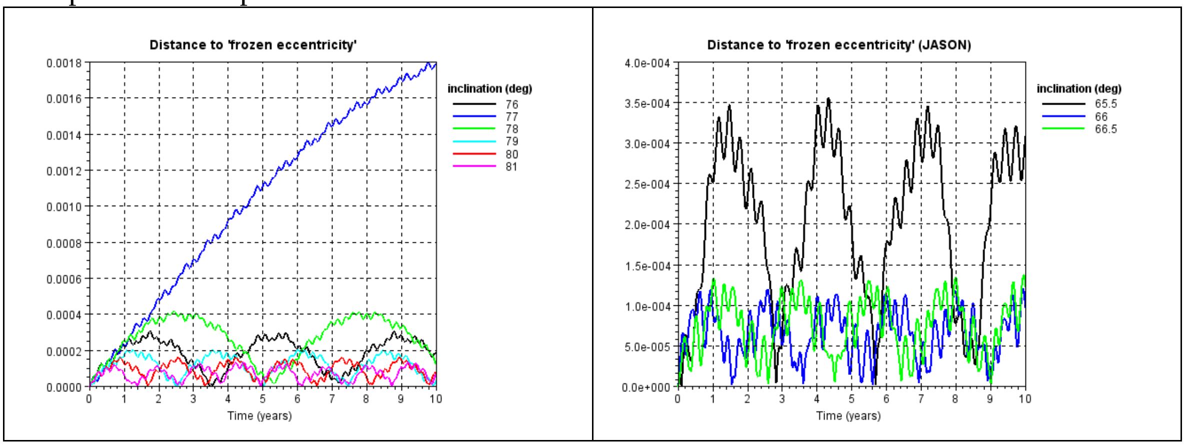


Figure 5. Evolution of eccentricity

Figure 5 (left) shows the norm of the eccentricity vector difference between the nominal (constant) value and the actual one. One observes that for an inclination of about 77 deg, the evolution is nearly secular. The results are the same whatever the initial MLTAN (Mean Local Time of Ascending Node).
For comparison purposes, the right figure shows the same evolution for a JASON-like orbit for the same area to mass ratio. In fact a resonance effect exists at the critical inclination (63.4 deg). But the JASON inclination (66 deg) is far enough from the critical inclination so that the amplitude of the periodic oscillations is limited to about 1.e-4.

The simulation results were obtained with the STELA tool (semi analytical propagator) [6] [7], considering a (constant) mean value for the area to mass ratio. In reality, the mean value of the area over one orbit varies as a function of MLTAN (approximately ±15% around the mean value). The variation is small enough and has been neglected as it is not supposed to change the evolution of eccentricity much.

The reason for the evolution of the eccentricity vector for the SWOT orbit is a resonance effect due to SRP: the argument of perigee rotates at about the same rate as the MLTAN. Comprehensive theoretical developments are given in [3]:
The angle $\Omega - \Omega_{sun} - \omega$ (MLTAN minus argument of perigee, called resonance angle) appears to be nearly constant for an inclination close to 78 deg (see Figure 6). Moreover, that angle is present in the development of de/dt (e being the usual eccentricity) under the effect of SRP. A value of 0 for the time derivative of the resonance angle means that de/dt can potentially grow very large.

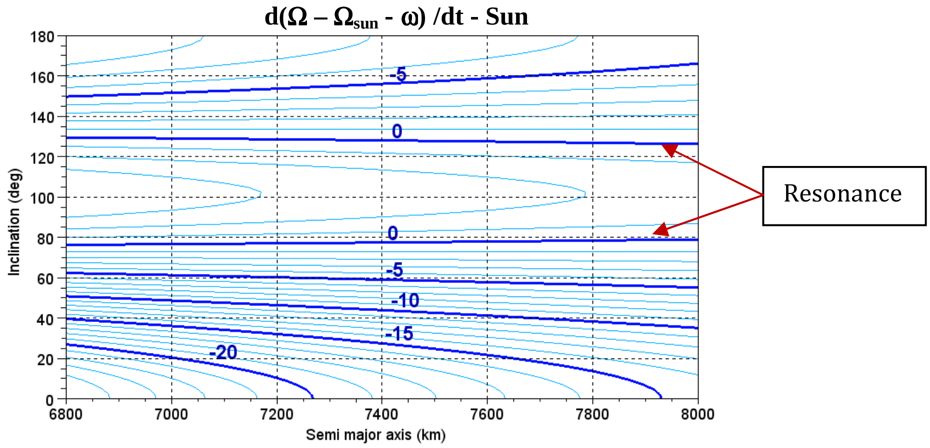


Figure 6. Resonance angle time derivative (effect of J2)

The theoretical developments in [2] led to the conclusion that the resonance effect is maximized for an inclination of 77.1 deg. This is consistent with the results obtained above. Eclipses were not taken into account in [2], but their impact appears negligible enough.

The selected inclination for SWOT (77.6 deg) thus leads to variations with an amplitude close to 1.e-3 (in-between the green and blue curves in Figure 5 (left). The amplitude does not really matter because the slope at the origin is nearly always the same whatever the inclination: the evolution appears approximately secular for the first 3.5 years (nominal SWOT mission life time).

4.2 Effect of atmospheric drag

At the altitude of 890 km, atmospheric drag is small but not completely negligible.
For the estimation of the effect of drag, we consider the following hypotheses:

- Ballistic coefficient: 0.0122 m^2/kg (Cd = 2.7)
- Constant (high) solar activity with flux (F10.7 cm) = 200, Ap = 15
- Atmospheric model used: NRLMSISE-00

These assumptions lead to a variation of the semi major axis of around 420 m per year and a correction cost of about 0.2 m/s per year.
The correction cost is thus very small, and it would be so even if more stringent solar activity conditions had been considered. Recent Marshal prediction of solar activity (Figure 7) shows that a value of 200 for the flux is a reasonable value in the year range [2022, 2025].
Atmospheric drag will in fact mostly have an impact on the frequency of orbit corrections (to meet the desired station keeping window) and on orbit prediction accuracy.

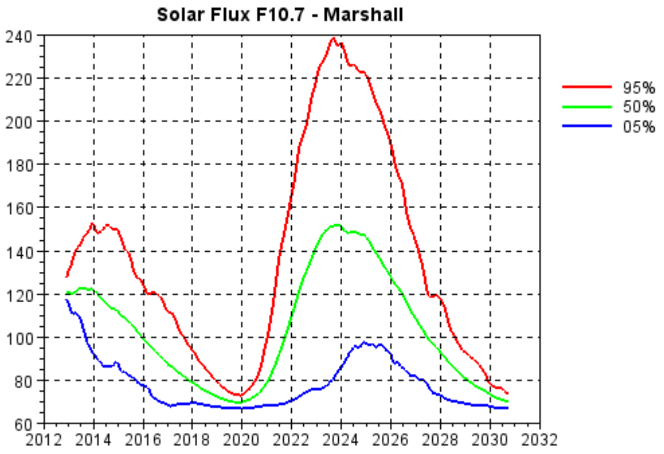


Figure 7. Marshall predicted solar activity (Flux F10.7)

4.3 Other perturbing effects

One other major perturbing effect that affects the orbit is the Sun and Moon gravity.
Because the orbit is not Sun-synchronous there are no secular effects but only periodic ones.
Orbit simulation using STELA software [6] [7] reveal periodic variations of inclination up to ±0.004 deg (±450 m on the ground track at the maximum latitude) and ±600 m on the longitude of the ground track at equator (see Figure 8).

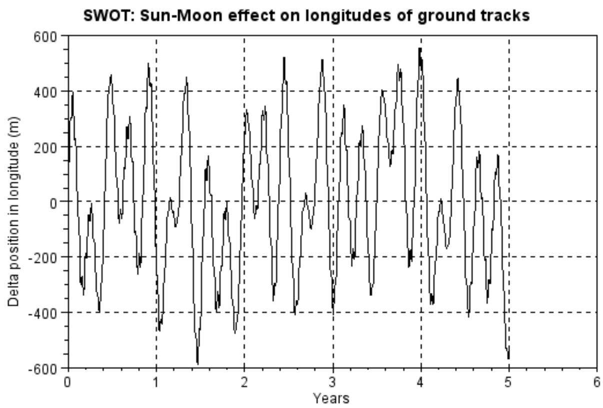


Figure 8. Sun/Moon effect on ground track longitude

The signature is very irregular as it results from a combination of effects involving the Sun declination and the local time of the ascending node. The amplitude is not negligible compared to the station keeping window size on the ground track (see 5.3).

5. Timeline, maneuver sequences

One main aspect of the mission design has been the evaluation of the various orbit maneuver sequences necessary for all the mission phases: LEOP, orbit change (from the 1 day to the 22 day repeat orbit) and at end of life.

5.1 LEOP

The main objective of the LEOP phase is to correct the injection errors and to acquire the nominal longitude of the CAL/VAL orbit. The LEOP phase potentially includes inclination, semi-major axis and eccentricity vector maneuvers.

In order to evaluate the required maneuvers, a simplified strategy has been studied, consisting of 2 semi-major axis maneuvers only (each maneuver consisting itself in 2 burns so that eccentricity remains unchanged).

The first maneuver alters the semi major axis and changes the injection orbit into a drift orbit. The 2nd maneuver stops the drift and enables the acquisition of the CAL/VAL orbit.

The injection errors (15km, 3σ) on the perigee and apogee altitudes have been turned into semi-major axis errors only (15 km, 3σ) for simplification reasons, as it can be shown that the correction costs are maximized in this case.

As the target longitude as well as the injection trajectory are not well known at this stage, 3 hypotheses have been considered regarding how close the injection ground track is relative to the nominal one: the closest, the farthest, or "unknown". Other hypotheses relate to the timeline: the assumptions are: 7 days minimum from injection to first maneuver and 30 days at most between injection and acquisition of the CAL/VAL orbit.

The results are shown in Figure 9.

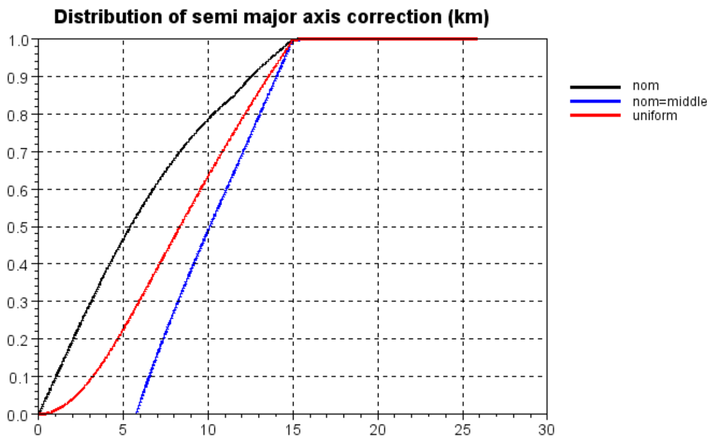


Figure 9. Semi major total change for acquisition of CAL/VAL orbit

The required ΔV (with a high enough confidence level) is the same whatever the hypothesis: the total semi-major axis change is around 15 km, and the corresponding DV close to 7.5 m/s.

This simple strategy enables a quick evaluation of the impact of a change in the timeline. Choosing 20 days instead of 30 for the total duration increases the DV by about 5 m/s (Figure 10, left). It can also be proved that changing the nominal injection semi-major axis does not reduce the DV (Figure 10, right).

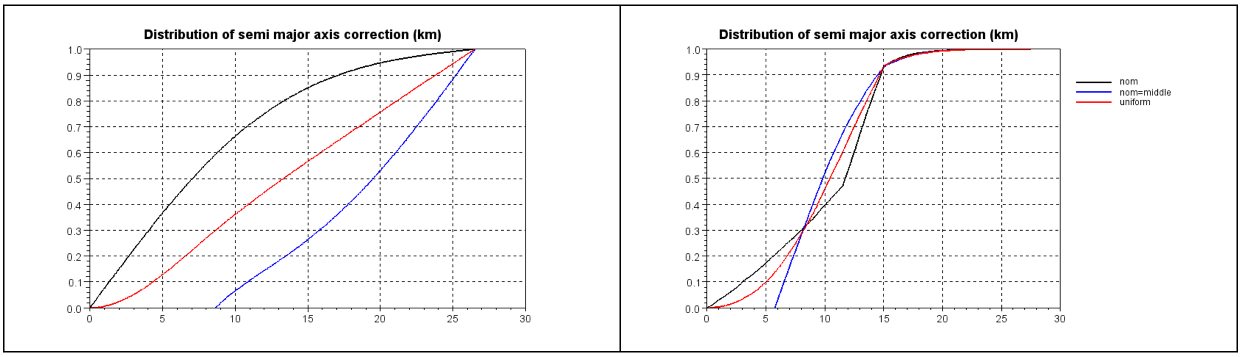


Figure 10. LEOP semi major total change
(left: total duration = 20 days, right: injection sma reduced by 7.5 km)

The simple 2-maneuver sequence had then to be changed into a more realistic one considering errors on all orbital elements (including eccentricity) and realistic operational hypotheses. Additional hypotheses are then required: maximum achievable DV (2.5 m/s for one burn), maximum maneuver execution error (10%), targeted accuracy, and whether inclination is partially or totally corrected. Using all these additional inputs a sequence of about 6 maneuvers has been retained.

5.2 Orbit change (1-day to 22-repeat orbit)

This maneuver sequence aiming to change the semi major axis is a rather standard one. It will not be detailed here.

5.3 Station keeping

The main objective was to evaluate the station keeping cost, and to determine the maneuver frequency so that the ground track longitude remains in the specified range, approximately ±1km around the nominal ground track.
Because of the perturbing effects as shown above, both semi-major axis and eccentricity vector maneuvers are required. The retained maneuver strategy results from the fact that only "pure" semi major axis maneuvers (2 opposite burns) are proved to be achievable at any time (see section about power limitation). It has then been decided to perform dedicated eccentricity maneuvers only occasionally (that is, when needed).
The following effects on the ground track longitude have been obtained:

Table 4. Effect of perturbations on ground track

Perturbing source	Max effect on ground track at equator	
Atmospheric drag	1km	1 km = window size. Corresponds to 1 maneuver every ~35 days (1)
SRP (eccentricity)	250m	1 dedicated maneuver every year (2)
Third body (Sun and Moon)	600 m	600m is the maximum effect. See Figure 8.

(1) Using hypotheses from paragraph 4.2, assuming a constant solar activity. Considering the Marshall prediction (Figure 7) leads to a maneuver frequency that varies as shown in Figure 11. Constant geomagnetic coefficients values are considered in the simulation (Ap = 15).

(2) Estimated by $\Delta L = 2\Delta e / 14$, with ΔL: variation in ground track longitude (rad), Δe: variation in norm of eccentricity vector

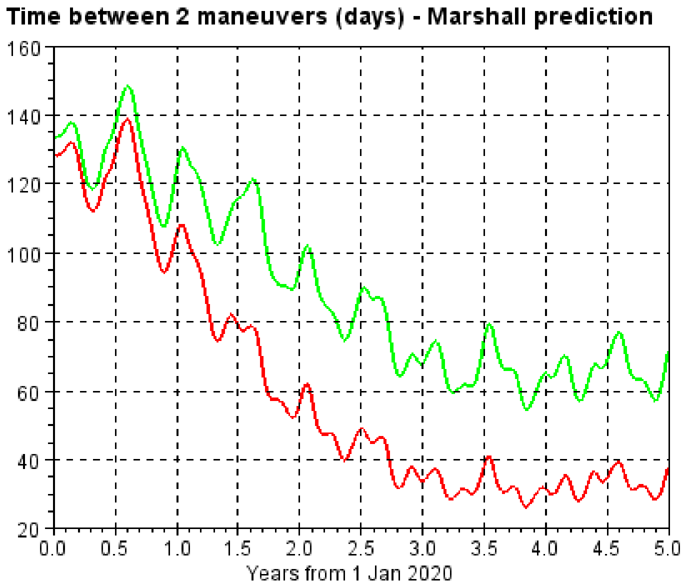
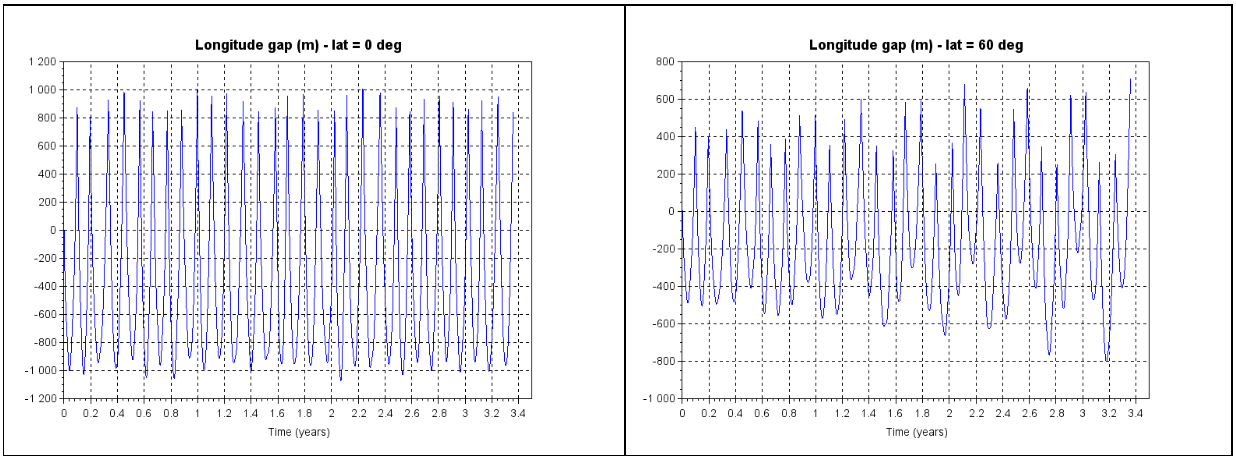


Figure 11. Estimated maneuver frequency – drag only
(no propagation errors considered)

A possible approach would have been to reduce the window size so that there is enough margin for the cumulated effects of 3rd body and SRP perturbations. But the window size would shrink to close to 0, and the maneuver frequency to compensate for the effect of drag would be too high. Only a more realistic simulation could prove than the 1 km window is achievable.
Some results are shown below.



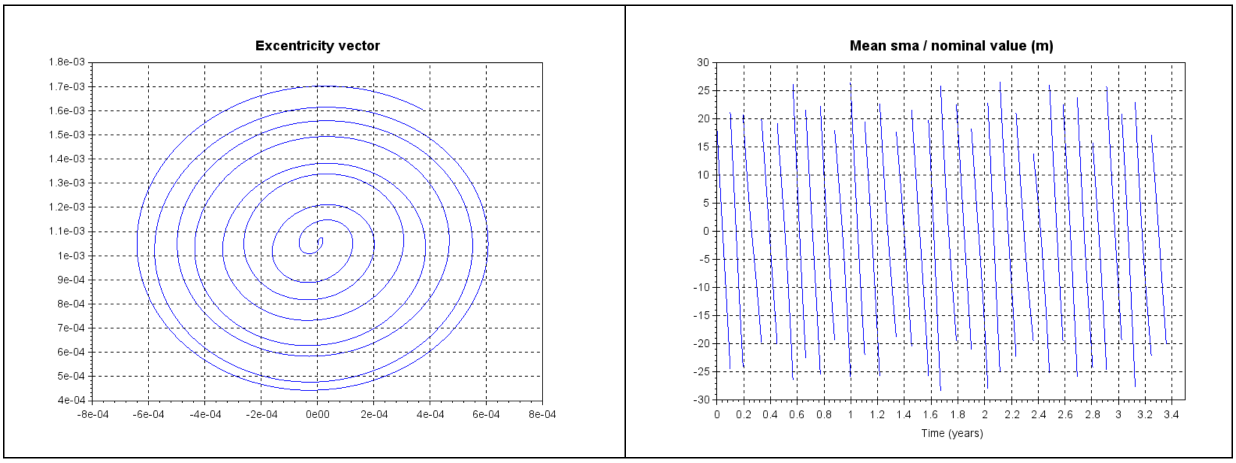


Figure 12. Simulation of station keeping

The simulation as implemented is quite simple, but it was useful to assess the performance.
The method has consisted in controlling the longitude of the ground track at the equator only; the longitude at other latitudes is simply checked within the desired bounds. A parabola fitting the predicted evolution of the longitude gap over an adequate period (close to the expected time between 2 maneuvers) is determined and a semi-major axis maneuver (equivalent to a change of slope on the longitude as a function of time) is computed so that the minimum value coincides with the bottom edge of the control window.
The maneuver then partially “absorbs” the effects of perturbations other than drag (hence the slightly irregular shape). Solar activity is constant in the simulation, so the results are somewhat theoretical. In reality the time between maneuvers will vary, and the window size will have to be slightly reduced by an adequate margin to take into account drag prediction uncertainties. The impact of drag uncertainty on the maneuver frequency is estimated around 10%, so that the simulation is representative enough at this stage.
The simulation is based on STELA [6][7] extended by a simple analytical model for the computation of the crossing points at the equator or other latitudes. Calculation is consequently particularly efficient.
The simulation also shows that specific eccentricity maneuvers might not be necessary after all.

5.4 End of life

Maneuvers at end of life are designed to achieve an uncontrolled reentry in order to put the satellite in a disposal orbit with an expected lifetime of 25 years. It was a procedure considered as compliant with the French Space Operations Act at that time (the situation is now different: the new baseline is to perform a controlled reentry to ensure a probability of casualty less than 2.e-5).
The effect of finite burn durations was estimated to increase the (impulsive) DV by 1.5%. This is because each burn (spread over an arc almost ¼ of the orbit span) causes the perigee to decrease less than expected (and the apogee to slightly increase) whereas the semi major axis value at the end of burn almost reaches the expected value.
The number of burns for an uncontrolled re-entry is quite high: more than 30.

5.5 Dealing with power limitation

One important issue that had to be resolved is whether or not the necessary maneuvers could be achieved despite energy constraints (that is, with the main instrument remaining ON). As a matter of fact, the available power is a function of the beta angle (angle between the Sun and the orbit plane). When the beta angle is close to 0, the available power is at its minimum. This can potentially affects the feasibility of performing maneuvers, particularly the eccentricity maneuvers.

As a matter of fact, orbit maneuvers require slew maneuvers that change the orientation of the solar array. Depending on the position of the slew maneuver in the orbit, the solar array can be better oriented towards the Sun or not. Figure 11 shows the regions when power limitation may be a concern (blue area) for positive DVs. For negative DVs, the figure is symmetrical with respect to the line X=0.

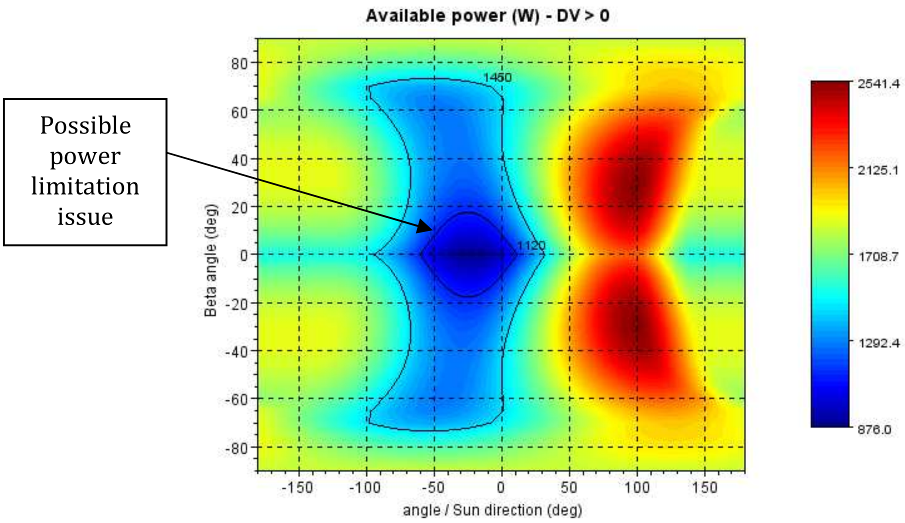


Figure 13. Estimation of available power

The logic has been to try to devise what could happen and look for possible workarounds: delay the maneuvers if possible, choose the position of the first burn adequately, change the angular separation between burns, evaluate the probability that an unwanted situation occurs. Considering all these possibilities for all the maneuver sequences, power limitation has been proved not to be an issue: all necessary maneuvers can be performed one way or another.

5.6 Ground orbit prediction accuracy

One of the requirements is that the difference between the predicted altitude and the real one (above the ellipsoid, at a given latitude) has to be less than 100 m otherwise new data tables have to be uploaded.

This aspect is not critical as new tables can always be uploaded when required. But it is desirable to increase the time between 2 uploads as much as possible.

A rough analysis has shown that the 100m accuracy should be easily met between station keeping (semi-major axis) maneuvers. Assuming the same hypotheses as in 4.2, one gets:

- Change of semi major axis between maneuvers (around 35 days): ~25 m
- Effect of eccentricity change on altitude ~1.8 km / year, that is ~180 m between 2 maneuvers.

A prediction error on drag and SRP of around 50% is then enough to meet the requirement.

5.7 DV budget

For completeness, the DV budget is given hereafter.

Table 5. DV budget

	DV (m/s)
Injection errors and orbit acquisition	18.2
Orbit change (CAL/VAL => Science orbit)	16.8
Station keeping (3.5 years)	4.7
Debris avoidance (3.5 years)	0.7
End of life disposal maneuver	85.6
Total	**126**

It is then clear that the DV budget is dominated by the maneuver at end of life. The DV will be even bigger for a controlled re-entry. A small gain can be expected if the injection inclination errors are not or only partially corrected.

6. Download capability

An important aspect of the mission design has been the evaluation of the downlink performance. Given a network of ground stations (and assumptions on visibility passes: 8 deg minimum elevations, no more than 26 min cumulated visibility per orbit) and hypotheses on:

- ground station selection strategy,
- data acquisition and download rates (considering ocean and land modes for the instrument),
- areas of interest (known as the "mask") as delivered by the science teams,
- swath size and acquisition modes (high rate mode if the swath intersects the mask),

simulations were performed to check that all the data recorded onboard could be downloaded without exceeding the available memory.

The "mask" represents the areas for which the instrument records data at high rate. The last version (June 2013) as produced by the SWOT science teams is shown in Figure 14.

Figure 14. Mask = high rate areas (in black)

The main result of the simulation is the "download margin", that is to say, the margin between what can be downloaded and what is recorded on board. The computed margin was considered satisfactory ((Available- Required)/Available = 13%), as well as the memory usage.
Simulation is quite demanding as it requires a good modeling of the mask (with a sufficient accuracy) and of the instrument swath. The mask and the swath were sampled with a definition of 1 pixel every 5km at the equator, which was considered sufficient. Some results are given in Figure 15.

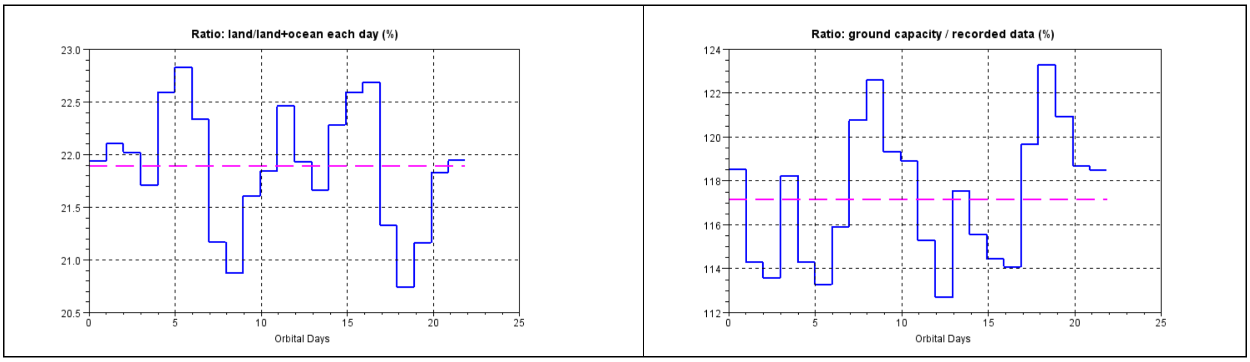


Figure 15. Downlink simulation results

The sub-cycle (about half the repeat period) is clearly visible: the grounds tracks are nearly the same after 1 sub-cycle hence the nearly 10-day period for the results.

The results in fact depend on the pass selection strategy which is supposed representative of the operational one. Still, the simulation results show that at least one solution meeting the requirements exists; Figure 16 shows for instance the cumulated visibility length per orbit, which is less than ~26 mn as expected.

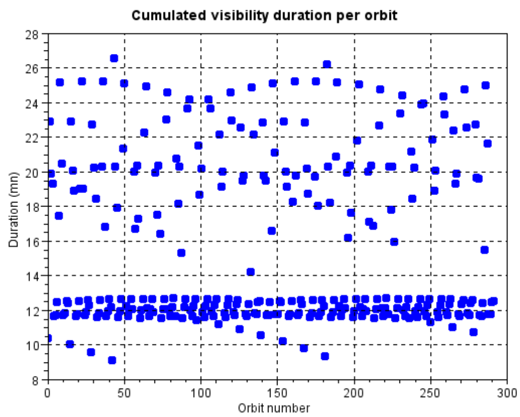


Figure 16. Cumulated visibility per orbit

Memory usage (not shown) was computed to be within the acceptable limits.

It can also be noted that similar simulation results were obtained independently by the JPL project team.

7. Conclusion

The paper has shown some of the main aspects of the SWOT mission design: orbit selection process, evaluation of maneuver sequences (from injection to end of life), downlink capability, among other features.

The objective was not to cover everything in detail, but to illustrate some of the main issues, and there were a few tricky ones: aliasing criteria in the orbit selection process, impact of the evolution of eccentricity, assessment of station keeping performance, power constraints issues are some of them.

The mission design activity is still on-going, and some aspects are still under analysis.

But the main conclusion is that the orbit as presently selected meets all the requirements, either scientific or related to the mission system.

8. Acknowledgments

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9. References

[1] Ernesto Rodríguez et al, SWOT Science Requirements Document,
http://swot.jpl.nasa.gov/files/swot/SWOT_science_reqs_release2_v1.14.pdf

[2] SWOT web sites: *http://smsc.cnes.fr/SWOT/index.htm,*
http://www.aviso.altimetry.fr/en/missions/future-missions/swot.html,
http://swot.jpl.nasa.gov/mission

[3] Lamy A. et al “Resonance Effects on Lifetime of Low Earth Orbit Satellites”, ISSFD 2012

[4] Dudley Chelton, Summary of SWOT Orbit Scenarios, note for June 2013 SDT meeting, 21 May 2013.

[5] Richard D. Ray, SWOT Orbits and Tidal Aliasing Issues, NASA Goddard Space Flight Center, 29 January 2013

[6] Fraysse et al., Long Term Orbit Propagation Techniques Developed in the Frame of the French Space Act, ISSFD 2011

[7] STELA software download site: *http://logiciels.cnes.fr/STELA/en/logiciel.htm*