

SpaceOps-2025, ID # 335

## The Surface Water Ocean Topography Mission an exciting CNESNASA experience of operations

Saïd Haouchine<sup>a\*</sup>

<sup>a</sup> *Centre National d'Etudes Spaciales (CNES), Toulouse - France, said.haouchine@cnes.fr*

\* Corresponding Author

### Abstract

We share here our joint CNES/NASA experience of operations for SWOT mission including very critical operations during 9 days in 24/7 (LEOP) followed by the first two years of regular operations and their lessons learnt. This adventure started decades ago with the goal to improve significantly the altimetry resolution after more than 25 years of cumulative experience thanks to Jason and Sentinel family missions. SWOT performs for the first time global survey of Earth's surface water as lakes, observes the fine details of the ocean's surface topography, and measures how water bodies change over time. SWOT is an earth observation satellite, operating in a nearly circular non sunsynchronous orbit at an altitude of 890 km and an orbital inclination of 77.6°. During the six first months of the mission, SWOT was flying in a one-day cycle orbit at an altitude of 857 km. The SWOT flight system is the spaceborne element of the mission. It is composed of the spacecraft bus supplied by CNES, and the two payload modules (KaRIn and nadir). The bus provides basic services to the payload modules and includes AOCS, Electrical power, data handling and radio frequency communication subsystems. The spacecraft's mass at launch was roughly 2000 kg. The satellite has been jointly developed by NASA/JPL and Centre National D'Etudes Spatiales (CNES) with contributions from the Canadian Space Agency (CSA) and United Kingdom Space Agency. SWOT is operated together by CNES and NASA/JPL space agencies. CNES, from its control centre in Toulouse, operates the spacecraft platform (including flight dynamics operations); while JPL, from its premises in Pasadena CA, carries out Karin payload operations to be uploaded by CNES. CNES mission center is in charge of science data product and delivery to the science community and JPL ground data segment in charge of re-processing campaigns. This paper examines our joint experience of operations starting from the preparation phase including dress rehearsals, LEOP, commissioning ops phase until the two first years of regular operations. It will focus on the main chosen drivers which contributed to build a solid operational concept based on a high level of automation with the feedbacks after launch and during the current period of operations. Finally, it provides some impressive results of data thanks to the exceptional performances of the satellite and a very active scientific community.

### Keywords:

SWOT, LEOP, operations, deployment, cooperation

### Acronyms/Abbreviations

**SWOT:** Surface Water and Ocean Topography

**Karin:** Ka band, interferometric radiometer

**CNES:** Centre National d'Etudes Spaciales

**JPL:** Jet propulsion Laboratory

**NASA:** National Aeronautics and Space Administration

**DORIS:** Doppler Orbitography and Radiopositioning Integrated by Satellite

**GPS:** Global Positioning System

**LEOP :** Launch and Early Operations

**OCG :** Operational Coordination Group

## 1. Introduction

The CNES/NASA Surface Water and Ocean Topography program is an important cooperation based on decades of lesson learnt in altimetry since Topex Poseidon mission, followed by Jason and Sentinel family satellites. With an initial mission duration of three + two years, SWOT has already shown impressive results. The mission will be probably extended as the satellite is working perfectly with all its redundancies available.

SWOT has been launched on December 17<sup>th</sup> 2022 from Vandenberg Space Force Base through SpaceX falcon 0 rocket. It is collecting a huge amount of science data and first results shown a real revolution regarding the impact of lakes and ocean on the climate change.

The mission is jointly operated by CNES and NASA/JPL space agencies. CNES is in charge of platform operations while JPL operates the payload.

The satellite carries a novel, Ka band, interferometric radiometer (Karin) to capture from which maps of more than 90% of lakes. By consistently mapping two important thematises in the water cycle (ocean and lakes) it is advancing weather and climate models.

SWOT satellite is composed of a payload module and spacecraft bus whose assembly has been led by the NASA Jet propulsion laboratory (JPL) and CNES, respectively.

The Payload has components contributed by NASA, CNES, and the Canadian Space Agency. The primary payload is KaRIn that has been developed by JPL. The Canadian Space Agency provided a high-power assembly component for KaRIn. CNES built the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) Antenna and the nadir altimeter. JPL also provided a Global Positioning System (GPS) science receiver, a Laser Retroreflector and a two-beam Microwave Radiometer.

**Karin** measures ocean and surface water levels over a 120-km (75-mi) wide swath with a ~20 km (~12 mi) gap along nadir. It is operated in two modes:

- Low-Resolution over the ocean with significant onboard processing to reduce data volume.
- High-Resolution over broad, primarily continental, regions defined by the SWOT Science Team, focusing on hydrology studies

**Jason-class Altimeter** collects data in the gap between the KaRIn swaths. It is used to determine Sea Surface height.

**DORIS Antenna** picks up signals from 50-60 ground-based radio beacons, equally distributed over Earth to ensure good coverage.

**Microwave Radiometer** measures the amount of water vapor between SWOT and Earth's surface. More water vapor means slower radar signals.

**X-band Antenna** is used for high-rate data downlink.

**Laser Reflector Assembly** is an array of mirrors that provide a target for laser tracking measurements from the ground.

**Global Positioning System (GPS) Receiver** picks up tracking signals from the constellation of GPS satellites.

Mounted below the payload module, the bus is composed of two S-Band antennas which are used for the commands and telemetry reception, the Attitude and Orbit Control System with a multi-head startracker, reaction wheels, magnetic torquer bars and GPS, the power subsystem including huge solar panels, and finally, the propulsion system which is design to ensure a controlled re-entry using 8 thrusters.

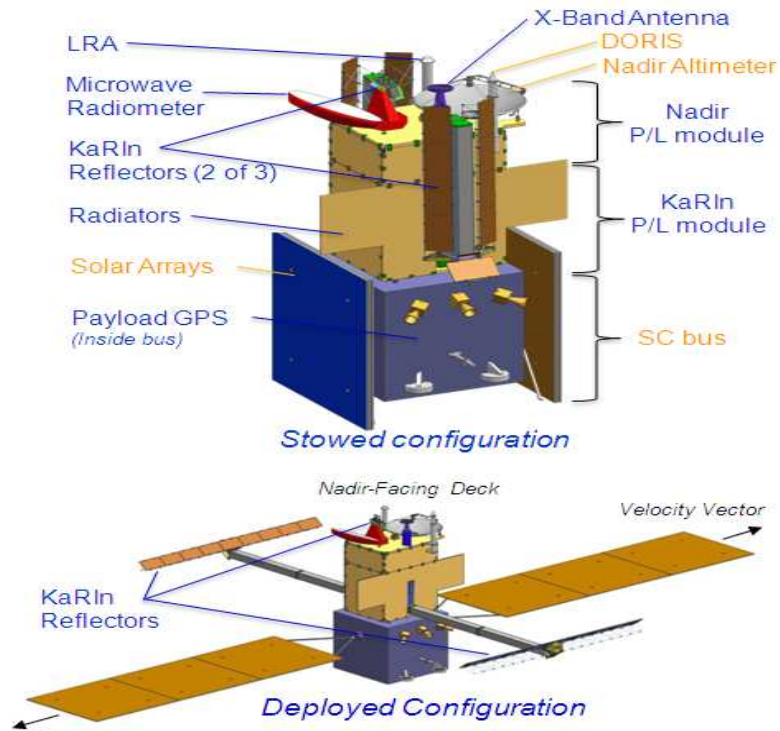


Fig. 1. SWOT satellite component

SWOT is operated as a collaboration between CNES, which controls the spacecraft bus and the French payloads and NASA JPL which plans and controls the American Payloads. The French Ground Segment is composed of the control center, the French mission center and the S+X Band station network. Its functionality comprises telecommanding, orbit and attitude processing, and the monitoring of platform housekeeping telemetry. All the telecommands are up-linked via the S band ground station network provided by CNES; the network acquires the housekeeping telemetry too. The science data is downloaded via the X-Band ground station network provided by CNES. The data are processed by the CNES SWOT mission center and delivered to JPL.

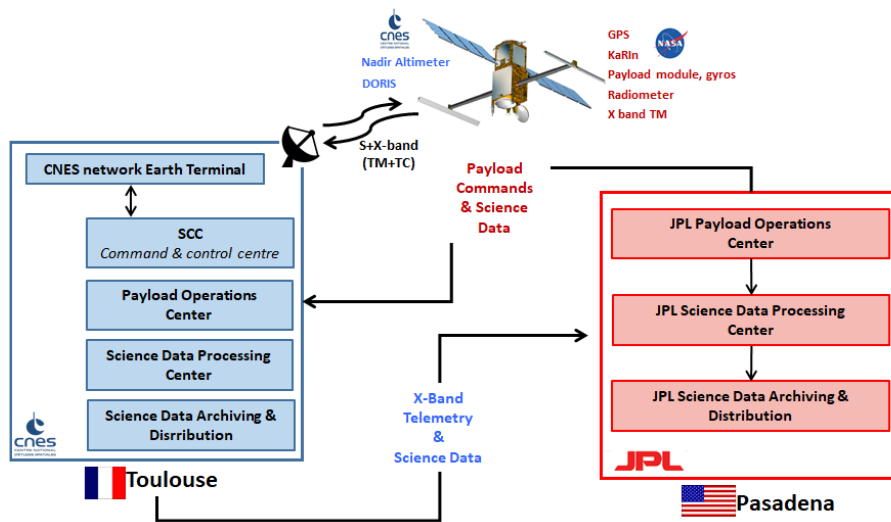


Fig. 2. SWOT ground segment

SWOT started its life in a one-day cycle calibration orbit (857 km of altitude) for 6 months and has been moved to a 21-days cycle orbit for the science phase (891 kms of altitude). The first orbit (one day-cycle) was interesting for calibration using in-situ data for some dedicated sites. The cycle also allowed to observe some short phenomena as mesoscales (an intermediate scale between those of weather systems and of microclimates, on which storms and other phenomena occur) as their duration is around 3 days. After six months of calibration, the main interest of the science mission is to have a global coverage of the earth. The twenty-one-days cycle orbit is very well adapted for that. So one of the critical operations after the calibration phase consisted in moving the satellite from 857 to 891 kms. It has been performed during ten days of operations on extended hours organization including week-ends.

The paper is divided into 4 chronological parts. First, it describes the tests phase preparation activities to qualify the system and design the ops concept, then it highlights the LEOP joint operations by CNES and JPL for 10 days followed by a 6 months of calibration and checkout operations. The third part shows the nominal operations chronology and describes especially how the time shift between France and USA has been used to optimize the operations during the week. And finally, it shows some data results which makes us sense of this work.

## 2. Pre-Launch phase

The pre-launch phase is a very exiting phase when all project members work together with a common goal: be prepared for the launch and make everything to build a success.

In term of operations, our main objective is to produce the entire operational documentation including end of life operation during this phase to be ready at the launch. This process implies to include the operational team participation very early during the project development. This organization ensure to have constituency between design and ops concept taking into account constraints coming from the platform design and others coming from ops organization (working during business hours, working days for example). For decades, CNES ops concept is based on a huge experience of automation. The command route from ground to the satellite through the CNES station network is fully automated. So based on that, it's very important to take into account this way to perform operations during the satellite development phase dealing with command and control subsystem design.

The picture below illustrates the process to build the operational documentation using inputs from the design phase:

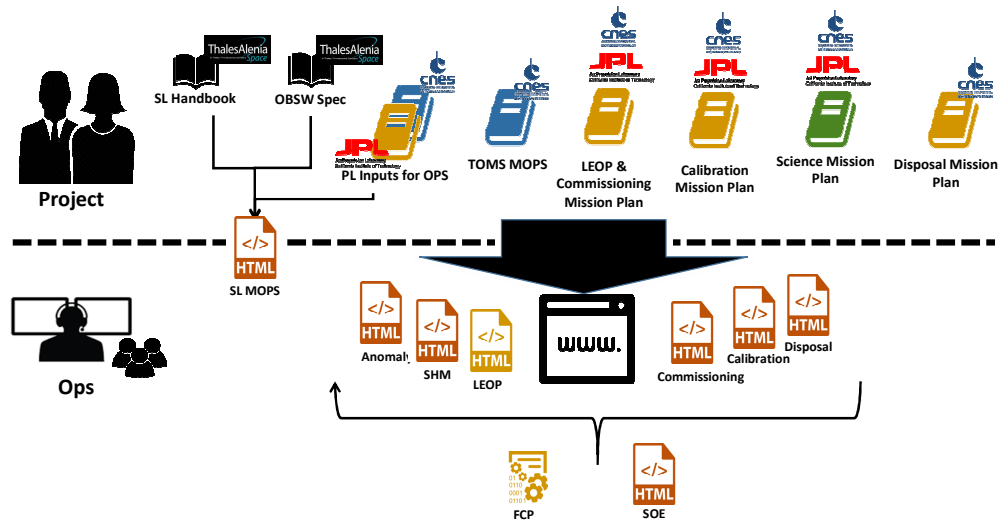


Fig. 2. Operational documentation production process

As many projects in cooperation between several agencies, a good coordination is the key of success. In particular, the schedule must be well defined and shared by the different parts with transparency. Another key to ensure design stability is to define precisely the interfaces between the different parts, giving the freedom for each to manage their project internally and independently knowing that reducing interfaces number is a good goal for schedule optimization.

The CNES was responsible of the global system and the spacecraft design. We focus here on the French contribution part to describe how we managed the system qualification.

First, we defined the qualification test process and highlighted the major milestones. During this phase, the difficulty was to imagine a new way to validate the system knowing that we faced constantly schedule evolutions. Classically, we divide the schedule into different chorological parts. We know now that this way to work is not really adapted in the current context when everything has to be quickly adapted with moving needs.

So we choose to define the main milestones that could be re-qualified many time during the project development with a high level of formalism and quality management. To prepare these milestones, in parallel we organized different workshops that were closely managed by the operational team in cooperation with the system team. These workshops were defined according to the global system schedule and adapted every week taking into account schedule adjustments in real time. That method was a success because every week, we coordinated the activities to come knowing the previous week's activities status. The figure below illustrates this method:

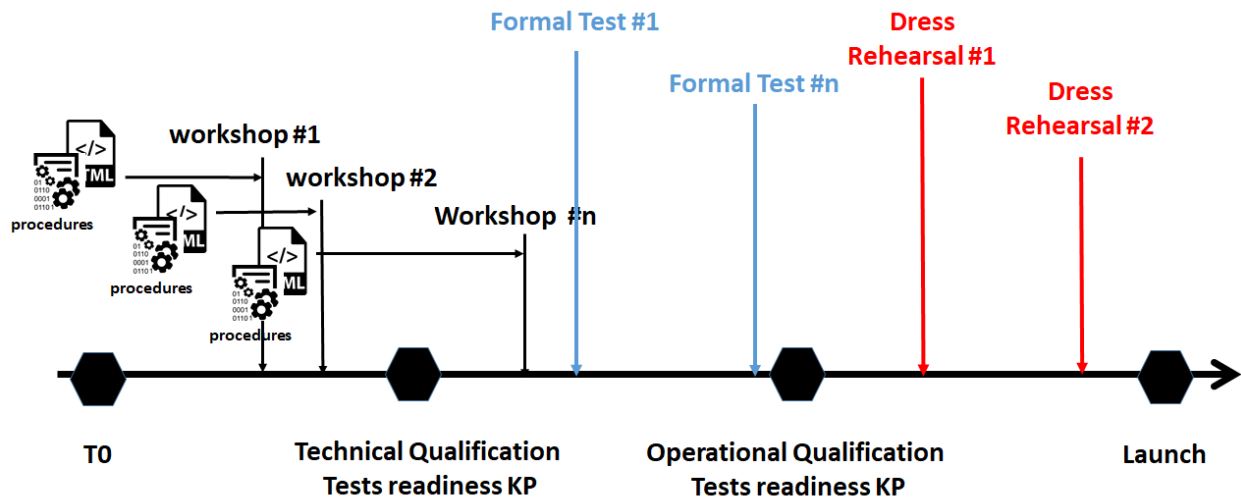


Fig. 3. System qualification method

As we can see on the previous figure we have several kinds of milestones. We classically divided the schedule into different parts to organize reviews between each one. However, after the technical qualification readiness review, some technical tests have been re-executed or adapted in order to ensure the quality of the system after each new delivery (could be linked to a ground or an on-board component). The Operational Qualification Readiness Review goal is to ensure that the quality level of the entire system is enough and then, permits to the operational team the execution of several dress rehearsals in real conditions. That method doesn't avoid the possibility to perform ground or on board evolution continuously. There is a part of risk in this flexible method. That's why to reduce the risk, we closely managed each test according to each new delivery milestone.

We can also see in the figure that to prepare the main milestones, a huge work has been performed by executing tests validation in a workshop way with a lighter formalism. The teams worked very closely (ops team, ground or satellite experts) to ensure a high level of reactivity during test execution.

Finally, this method imposes to have a very strict configuration management cycle through a well-known quality process by each member of the different teams. This phase was very intense but has been a real success for launch preparation.

### 3. Launch and very early operations phase

One of the important points for launch satellite operations is to be ready on time and to be able to adapt the chronology in case of launch delay. That was a driver to build a flexible process for operation preparation (including the operations documentation). The SWOT launch have been delayed by one day and the new operations sequence was refreshed in one hour (checks included). This reactivity has been ensured thanks to the high level of automation on ground control tools used for preparation and execution. It's the main driver of the control center operational concept. We will understand on the next part that the common factor for all phases is automation and reusability.

All the teams were organized to ensure ten days of operations on a 24/7 basis. We used two separated rooms for these operations: one called Main control room which has been used by CNES and NASA experts for checks and GO/NOGO (for critical operations when needed), and another room (in a separate building) which is the SWOT control center where the operational team sends the commands to the satellite. This organization ensures calm and maximum concentration in the room.

The two rooms were connected via a voice loop. Real time and recorded telemetry were relayed from the control center to the main control room and some cameras were installed in the two rooms to be able to see each other and know which is the adequate moment to contact a dedicated person between critical activities.

The voice loop was also connected to NASA JPL mission center in Pasadena for listening only to permit the remote team in California to follow the operations. It was a 'listen only' link in order to avoid any disturbance in the loop as we agreed to have all required NASA experts presents in the main control room and authorized to speak in the voice loop.

Here after you can see a picture of the two rooms:



Fig. 4. Main control room used by CNES and JPL experts



Fig. 5. SWOT control center used by the CNES Operations team

Classically, LEOP operations duration for low earth observation mission is around 2-3 days. However, for SWOT mission, as we had critical operations consisting in deploying the payload antenna, the duration was much more longer.

After each step of deployment, the satellite restarts a safe mode sequence to ensure the sun pointing because, its inertia changes after each step.

During the launch preparation phase, we had a request from our NASA partners to ensure a real time visibility for all critical operations. Actually, it is a global requirement applicable to all NASA projects containing critical steps.

On CNES side, we have a requirement which imposes a backup pass for command upload. And if a go/no go has to be done, it must be at the latest in the beginning of the pass in order to ensure enough remaining time before the end of real-time link.

First of all, we identified which operations are critical. It consisted in the four main steps of the Payload antenna deployment as described in the figure below:

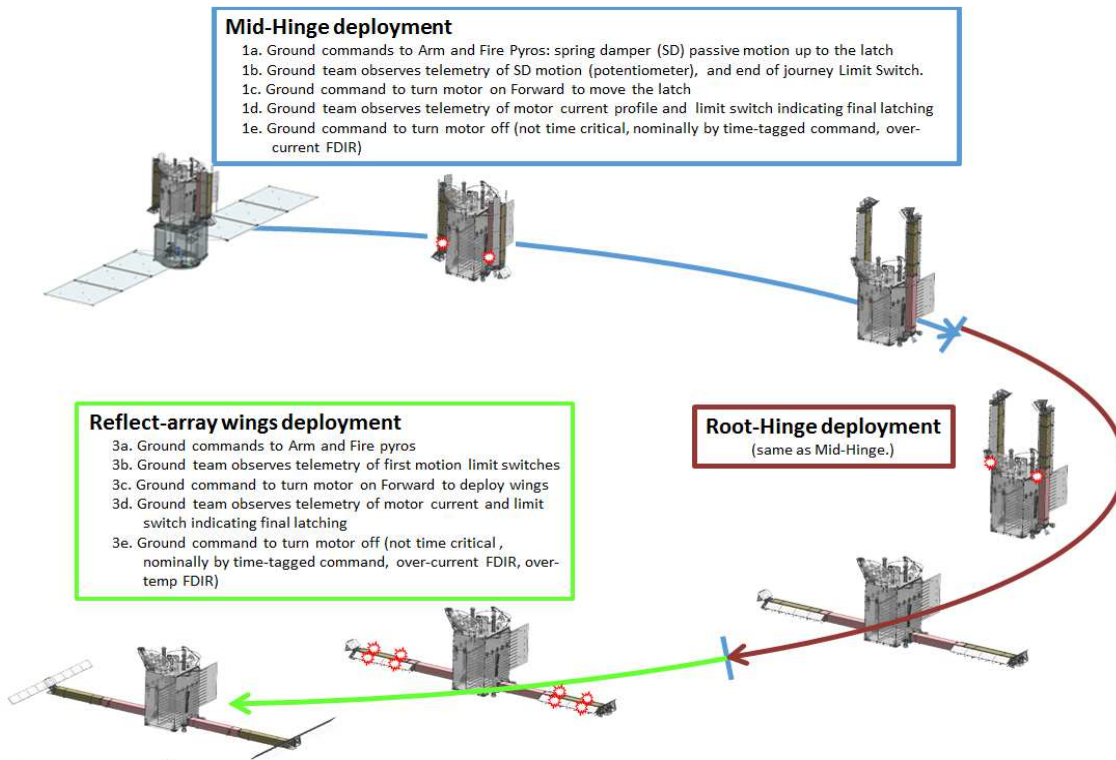


Fig. 6. Payload antenna deployment sequence

To be compliant with both CNES and NASA requirement, we agreed to use back to back passes (passes with an overlap of visibility) in order to increase the contact duration by using three consecutive passes. The only available configuration to have three consecutive passes was a sequence 'Inuvik Canada, followed by Kiruna Sweden and finally Toulouse France station'. This sequence ensures 38 minutes of visibility which give the time to have enough time after a GO/NO GO very early in the pass. These passes occurred around 01:00Z every day.



Fig. 7. Sequence of 3 consecutive passes

However, this solution has a drawback. In order to mitigate a possible issue in one of the two first antenna, we were obliged to set the time execution only starting at the third pass as illustrated in the following figure:

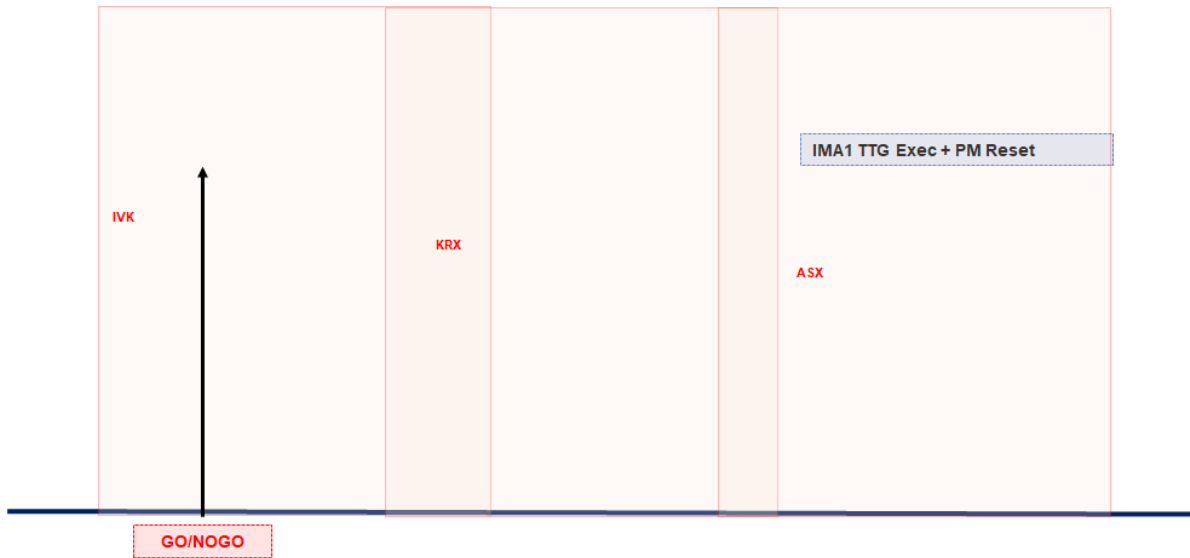


Fig. 8. Time-tagged execution sequence

The previous figure shows the on board sequence to be executed. Of course, to be executed, it must be already uploaded before. To upload it we use two booked passes (a nominal and a backup one).

It is easy to understand that having the execution time starting at the third pass of the sequence is not optimal to maximize the visibility! So we, had to implement a smart mechanism consisting in sending a dedicated command just after the GO done by the expert to anticipate the execution of the on board sequence. This command changes the execution date of each command using a negative timeshift as follow:



Fig. 9. Negative time-shift of the execution sequence

Another important point for these early operation was the collision risk management. As the operations sequence duration was longer than usual, the nominal maneuver capacity was reached only after 9 days instead of 3 days classically. During the deployment sequence (as it is done in a safe mode state), it was impossible to ensure a possible maneuver to mitigate a collision risk with a debris. Knowing that, it was not acceptable by the French space traffic management office to stay 10 days as a non-maneuverable satellite. So, we decided accordantly, to declare the satellite maneuverable from day #2 to day #3, then non-maneuverable between day #3 and day #8 with a GO/NOGO key point to start the deployment sequence on day #2 depending on the collision risk situation for the coming days.

Finally, no risk has been identified during SWOT LEOP and all operations have been performed successfully according to the defined sequence.

#### 4. From LEOP to nominal operations

When we speak about nominal operations, the first feeling is to think about routine. Our experience shown that for space operations nominal operation is never routine which is a good news actually!

As soon as LEOP operations were completed, we had a period of several months with exceptional operations. However, we tried to implement the nominal timeline as soon as we can. The nominal timeline will be presented later.

First, to start the mission, we need to switch-on all needed instruments and calibrate them. Again, for SWOT mission, a dedicated team of NASA experts came to participate to the operations. The main instrument Karin must be calibrated before using it in a nominal way and delivering science data with the required level of quality.

Following the first step (switch-on instruments), we performed a set of exceptional operations to align the two payload detectors.

We successfully performed all alignment operations during 14 days with a closed collaboration having NASA experts presents in Toulouse. This organization helped us to save time for this critical operation which is directly linked to mission performances.

In parallel, the spacecraft performed orbit acquisition maneuvers. It consisted in performing a set of movements to reach the calibration orbit. As described previously, the SWOT mission uses two different orbits. For the first six months, the satellite was flying in a high repetitive orbit near 857 km to allow a one-day cycle. This orbit has been used to calibrate the instrument with in-situ data for dedicated targets. As the other altimetry missions, we must have a very precise orbit to ensure performances requirements. The strategy to reach the one-day cycle orbit was to perform a set of six maneuvers as described in the following figure:

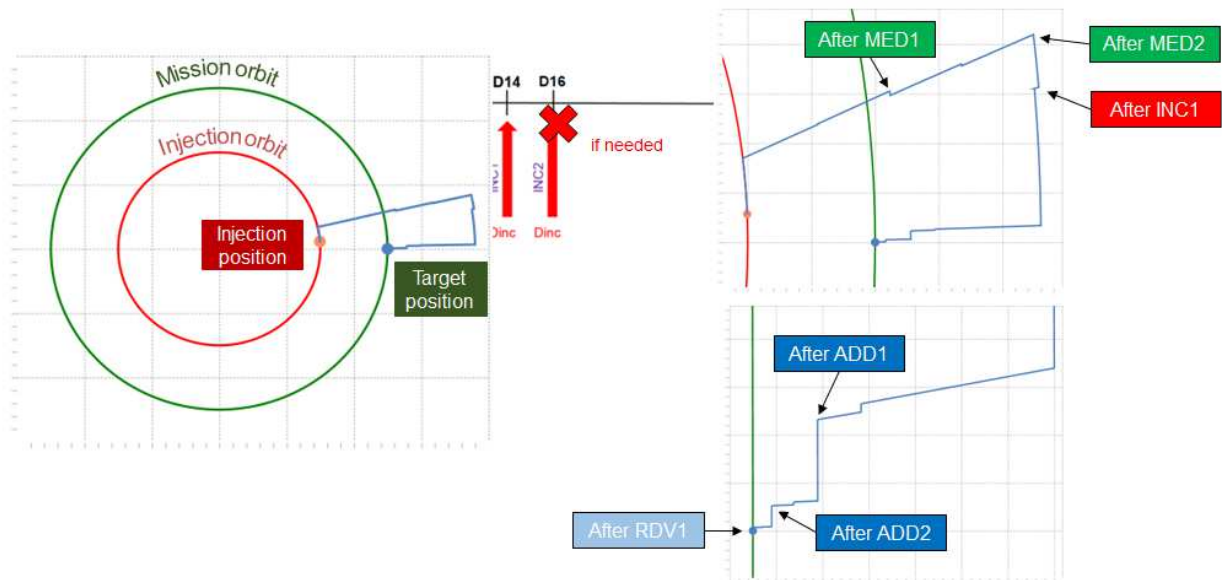


Fig. 10. Orbit acquisition strategy

The previous picture shows the six different maneuvers to reach the targeted orbit. The two last maneuvers are performed only for small corrections. The duration of these operations was 23 days. It has been performed on a 24/7 organization basis.

To save time, and to start acquiring science data as soon as possible, we switched ON in parallel all payload instruments and checked their good behavior. Finally, at the end of the maneuver operations period, all payloads were ON and started science data acquisition.

The SWOT mission requires on board parameters updates every three weeks to ensure the required performances. In order to have margins and to simplify the timelines, we decided to design a concept of operations based on 'update slots' every two weeks. Another input was to perform all operations during working days and business hours (French time). On JPL side, the organization is similar, so, we must imagine a timeline which respects the two organization constraints. We decided to use the timesheet between Toulouse (France) and Pasadena (California) to optimize the operations and be able to reproduce the same schema every two weeks. The following pictures illustrate this timeline:

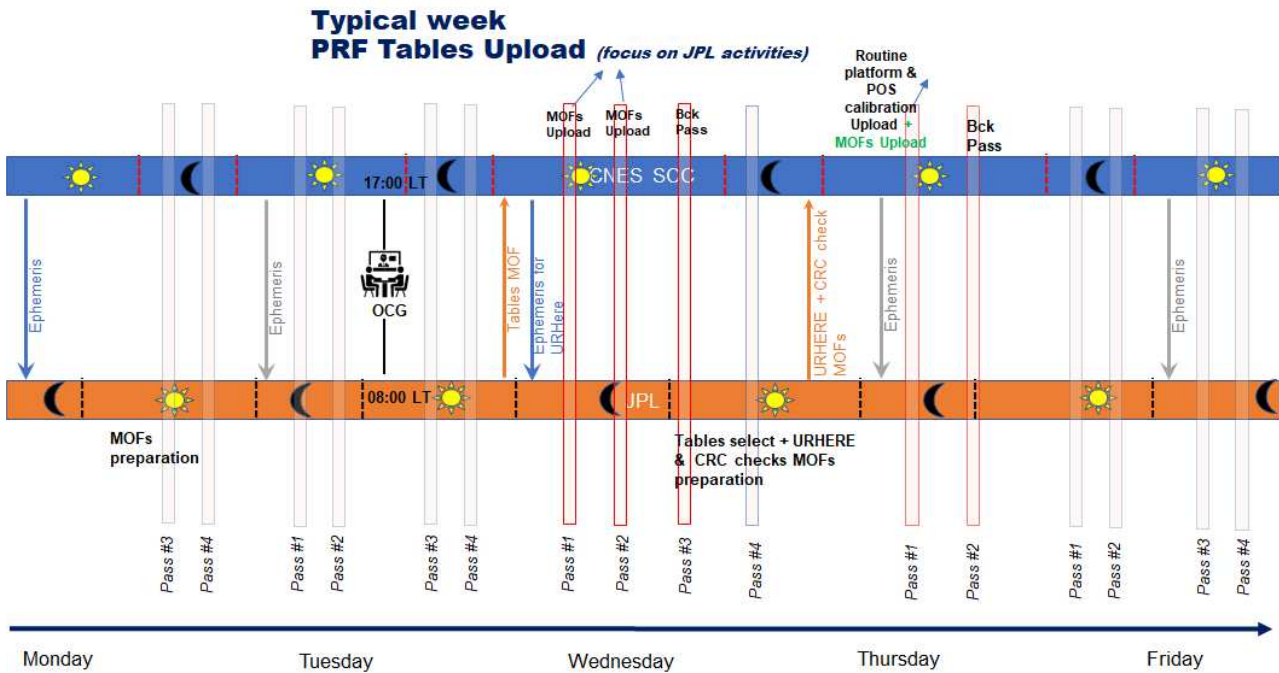


Fig. 11. Typical week using time-shift between US and France

During the first weeks and before switching ON the main payload instrument, all the passes were used for checkout and maneuvers activities. However, as soon as the Main Payload (Karin) was switched ON, we had to managed the other exceptional activities to be planned between the nominal slots in the weekly schedule. On the nominal schedule, we agreed to have a joint videoconference called OCG meeting (Operational Coordination Group) once a week to give a status on the previous operations and define the upcoming activities.

The transition between checkout, maneuver and nominal activities had to be daily adapted. To avoid any misunderstanding, we organized a coordination meeting every day with all the teams (maneuver execution, instrument experts, operators and NASA partners). This period was very rich in term of lessons learnt, team spirit and schedule flexibility.

During these daily meetings, we presented a status for previous operations and agreed about the upcoming activities. In case of new procedures to upload to the spacecraft, we agreed to take the required time for validation using a flight simulator. This period was very intense as we had to plan the satellite activities, validate the adapted procedure and compute, perform and analyze the maneuvers in a daily basis. The team was organized in an extended hours basis including week-ends. Knowing that the first science data were really amazing and we had a kind of pressure to optimize the duration of checkout activities and start the science mission as soon as possible.

Following this intensive period of checkout activities, we had to plan the nominal activities based on the weekly timeline as described in figure 11. The transition was checked manually in order to ensure the consistency of activities configuration.

As described in the introduction, the ops concept is based on a high level of automation by using rules to generate the weekly planning. A rule could be very simple as 'at 08:00Z connect to JPL server to send an interface' or more complex like based on orbit events, taking into account days off to automatically postpone some activities etc. The picture below shows a set of rules used for SWOT. Note that this concept is use for all in-flight earth observation science mission operated in CNES.

Priority	Category	Description
10	CCC_COMMUN	Initialiser Z_NEWDAY : Initialiser Z_NEWDAY à minuit d'aujourd'hui et de demain
20	CCC_COMMUN	Propagate Z_NEWDAY : Propagate Z_NEWDAY de minuit aujourd'hui à minuit demain
10	CCC_COMMUN	Déclencheur basé sur le calendrier : GND_OP_ZDAYNAME
11	CCC_COMMUN	Déclencheur basé sur le calendrier : GND_OP_ZDAYOFF
15	CCC_COMMUN	Variables contenant les JARTT et ponts : GND_OP_ZDAYOFF
19	CCC_COMMUN	Déclencheur basé sur le calendrier : GND_OP_ZPREVIOUSDAYISOFF and GND_OP_ZNEXTDAYISOFF
20	CCC_COMMUN	Déclencheur basé sur le calendrier : GND_OP_ZWORKINGHOUR
70	CCC_COMMUN	Variable de déclenchement des appels astreintes : ZCALLHOUR
20_OCC_MANAGEMENT		
50_FDS		
70_MUM_INTERFACES		
80_MC_INTERFACES (Generic: SATELLITE in [SWOT])		
10	MC_INTERFACES	Déclencheur des envois au CNESMC et JPLGDS : GND_OP_ZMCEXCHANGE : HKTМ-PARAM et IF_FDS
11	MC_INTERFACES	Déclencheur de la reception des donnees TMX DORIS depuis CNESMC : GND_OP_ZMCEXCHANGE : TMX-TMPACK
15	MC_INTERFACES	Déclencheur pour le management des MOFs MC et JPL : GND_OP_ZMOFMNGT
20	MC_INTERFACES	Envoi au CNESMC : STA-PLAN vers CNESMC
30	MC_INTERFACES	Envoi au JPLGDS : STA-PLAN vers JPLGDS
40	MC_INTERFACES	Réception et import MOF CNESMC dans le SCC : MOF CNESMC
50	MC_INTERFACES	Réception et import des MOF JPLGDS dans le SCC : MOF JPLGDS
60	MC_INTERFACES	Extraction de paramètres SOLAR-PANEL TM de J-1 à J : HKTМ-PARAM
70	MC_INTERFACES	Envoi de paramètres TM SOLAR-PANEL de J-1 à J au CNESMC : HKTМ-PARAM
80	MC_INTERFACES	Envoi de paramètres TM SOLAR-PANEL de J-1 à J au JPLGDS : HKTМ-PARAM
90	MC_INTERFACES	Envoi des interfaces au CNESMC : CONSTRAINTS, ECLIPSE, POST-PROC-EPHEM, HISTO_OEF, MAN_COM_MASS

Fig. 12. Set of rules used to generate the weekly operations schedule

A tool called automation computes all the rules to generate a planning which is executed in real time. This planning contains all automated activities which must be performed in the control center. These activities could be a pass management (antenna connection, sending commands to the spacecraft and receiving the real time telemetry), or downloading the recorded telemetry from the earth terminal, sending data to JPL, activating the flight dynamic software to compute a maneuver and many other needed tasks to operate a mission. Here after, a picture of the generated schedule:

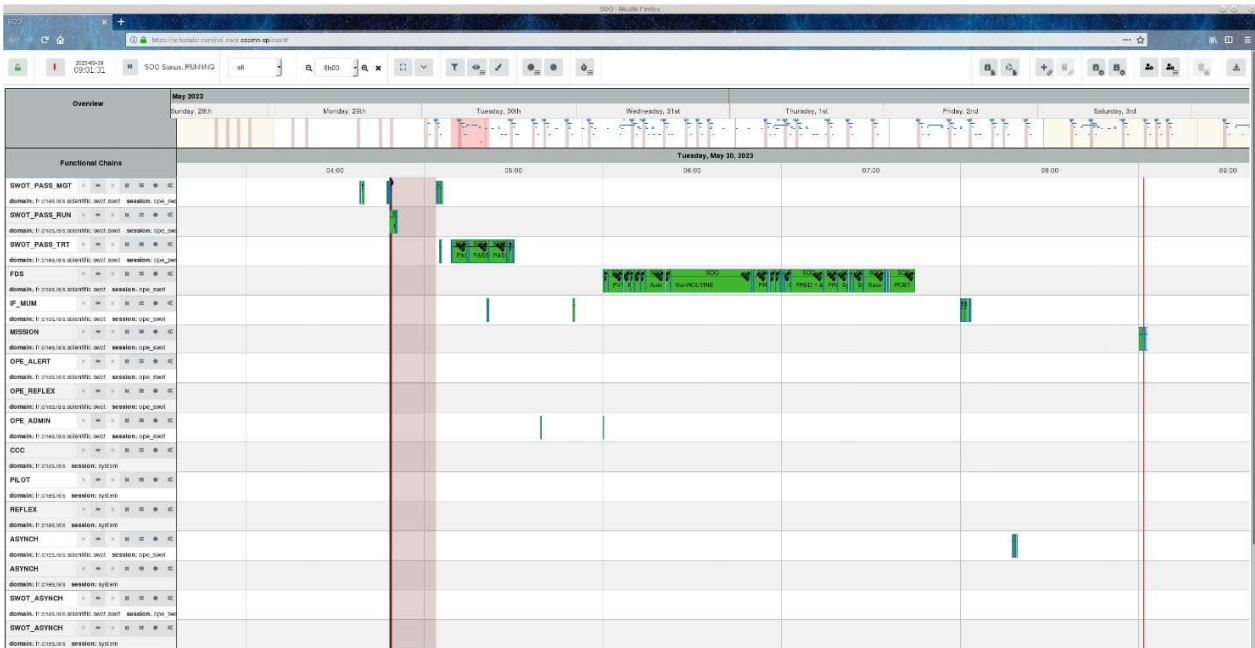


Fig. 13. Automated activities schedule

This automated schedule is generated every Monday for a week and can be adapted following the coordination meeting. Some extra activities could be added if needed. Our objective is to optimize the chronology, and to secure the operations by using an automated process. This concept is also compatible with flexibility! Even if the rules are quite stable, we can also adapt the schedule by adding or modifying some activities if needed. We defined the concept of pass type to assign a kind of activity for a pass. The default value of a pass is defined by rules.

For example, if we want to send a procedure P to the satellite on the first business hours pass on Monday, we assign a dedicated value to the variable which manage the pass activity (add the value 'P' to PASS\_TYPE variable). Then, we execute again the rules computation and the planning will be updated by adding the procedure P for the first pass on next Monday.

The figure here after shows a set of extra activities which could be added to the schedule. The list is configurable:

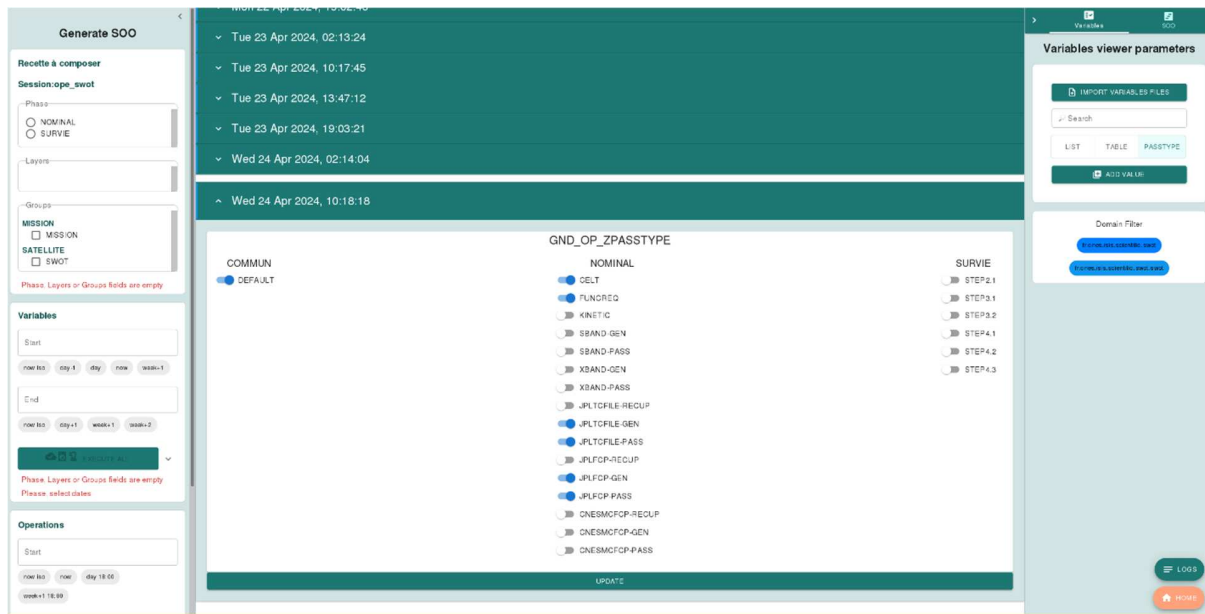


Fig. 14. Extra-activities to plan for a pass

This function allows us a high level of flexibility which is very appreciated by our JPL partners. They could ask us to add a specific payload operation and it could be instantaneously inserted to the nominal schedule.

During the calibration phase, we optimized this weekly timeline based on the lessons learnt.

At the end of the calibration phase, we had a key point to decide the beginning of the ‘science’ phase. To start this phase, we must perform some maneuvers in order to increase the altitude from 857 to 891 km as described previously. Calibration data acquisition has been stopped during the orbit change operation phase.

To reduce the mission interruption, we optimized the maneuver strategy and it consisted in performing four maneuvers every two working days. The whole duration was ten days. So since the twenty first of July 2023, SWOT is flying in its science orbit delivering amazing data and the results far exceeded scientist’s expectation.

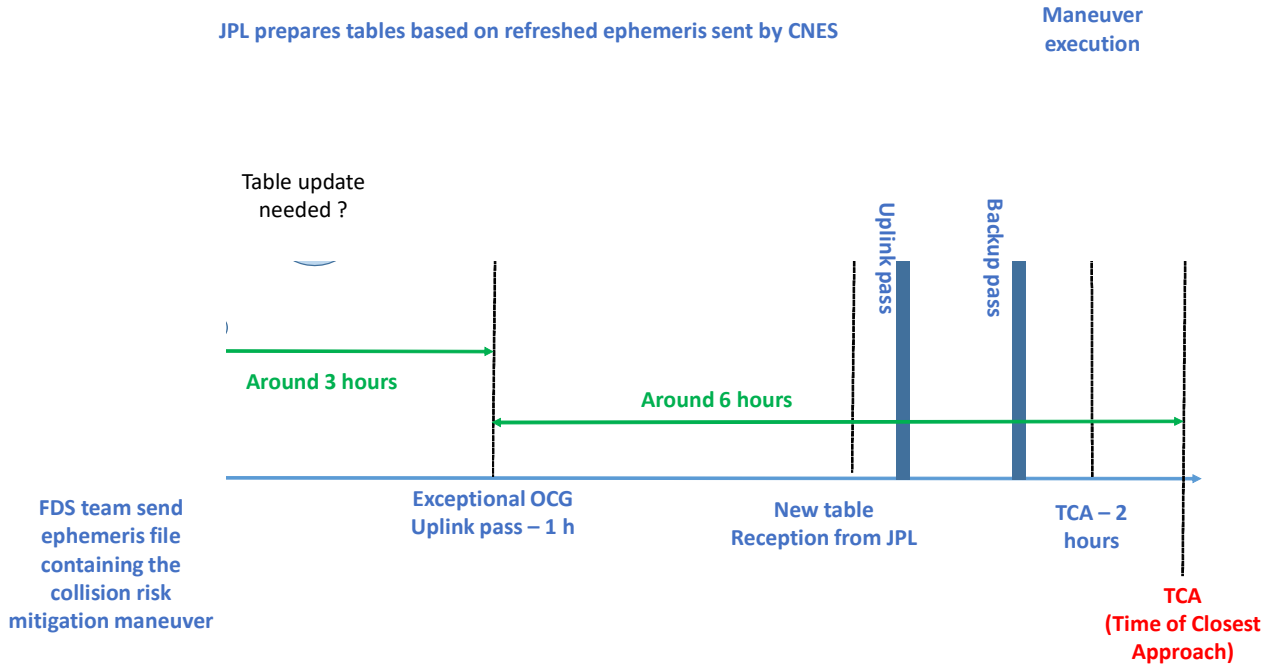
The current status of the satellite is excellent despite some ground issues (fire on Inuvik station on summer 2023, South Africa internet link issue on 2024) and it’s still a real pleasure and source of pride to operate this mission for all CNES and JPL teams.

## 5. Collision risk management

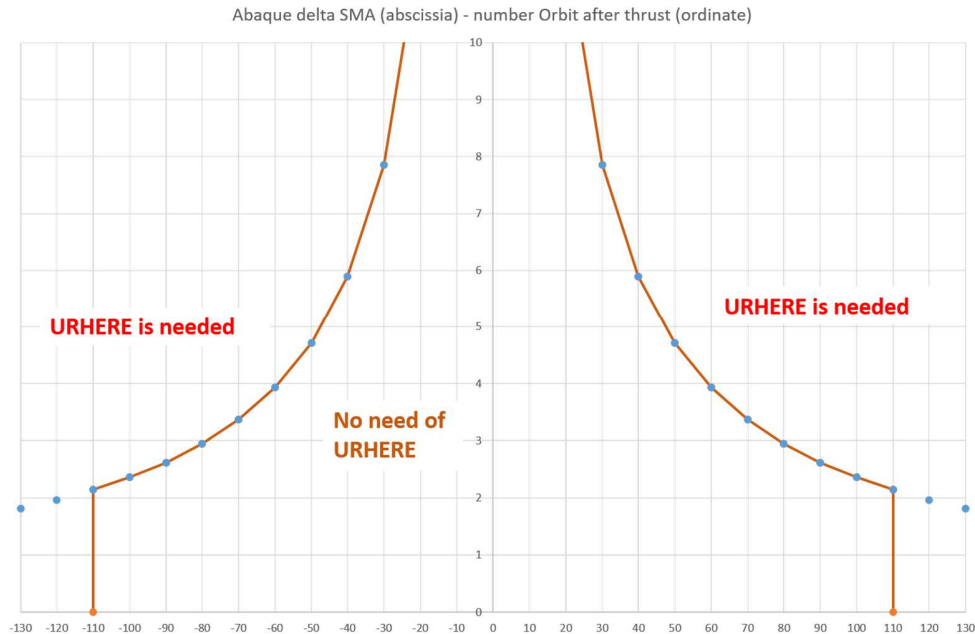
As mentioned on section 4, to ensure SWOT mission requirement, we need to update a table containing some parameters every three weeks. Actually, this requirement is linked to the constituency between the orbit and the parameter we upload. After three weeks, and due to the orbit drift (in term of altitude) we must refresh on board those parameters. Three weeks corresponds to 100 meters in altitude. We can easily understand that each time we perform a maneuver; we need also to refresh this set of parameters on board to be consistent with the new orbit. This operation is integrated into routine operations and optimized taking into account the time shift between France and US as described previously. However, when we have to manage a collision risk, this operation has also to be added into the risk mitigation maneuver process. Before launch, we decided only to perform back and forward maneuver in order to avoid this extra-operations consisting in setting these parameters and improving mission interruption. However, as soon as we performed the first collision risk mitigation maneuver, we observed that some onboard parameters had to be quasi-systematically performed. So we adapted the timeline and defined two different cases:

- A collision risk far from the next table update (due to table ageing or station keeping maneuver): Then the maneuver to perform is a back and forward maneuver.
- A collision risk that occur on the same week of a planned station keeping maneuver or a tables update: Then the maneuver to perform is combined with the upcoming station keeping maneuver.

These two cases implied to define a dedicated timeline for the on call team. As the table of parameters must be computed using the “refreshed” orbit, we need to send the orbit maneuver computation to JPL in order to allow them generating the new table based on the future orbit. The following picture shows the chronology of the operations:



The flight dynamics teams created a tool to help the ops by knowing the need of refreshing the data depending on the amplitude of maneuver and time between the two burns (for a back and forward maneuver) as follow :



## 6. Some science data results

Even if it is not a scientific article, I thought interesting to share some first results. Thanks to CNES team, we could have some picture to feel the amazing capability of the SWOT mission.

The following picture shows how using SWOT data, we can multiply by ten the resolution compared to an assembly of seven satellites. This first picture is a compilation of data provided by seven altimetry mission. The result is already impressive and delivered a lot of information about the sea surface temperature anomaly.

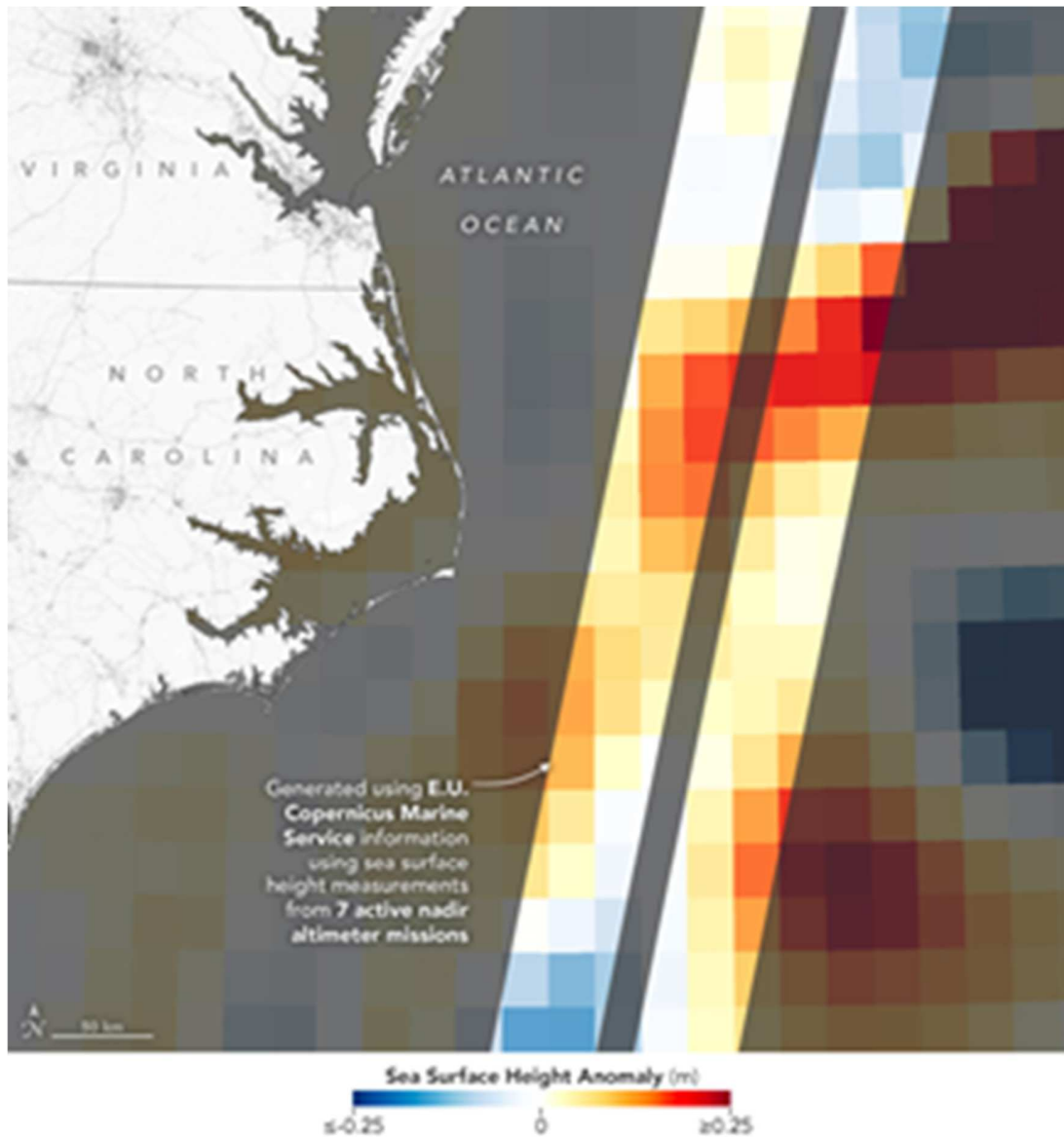


Fig. 15. 1D altimetry (7 satellites)

CNES teams wanted to use this image to compare SWOT results with their current knowledge. What was the surprise when the first SWOT data of the same area has been computed! On the next figure, we can easily understand the power of SWOT in term of resolution but also in term of coverage. After 21 days, the coverage was more than 90% of the earth and in a better resolution than previously! It has never been covered by all other missions we operated before. This resolution permitted to improve significantly our knowledge in water cycle and climate change.

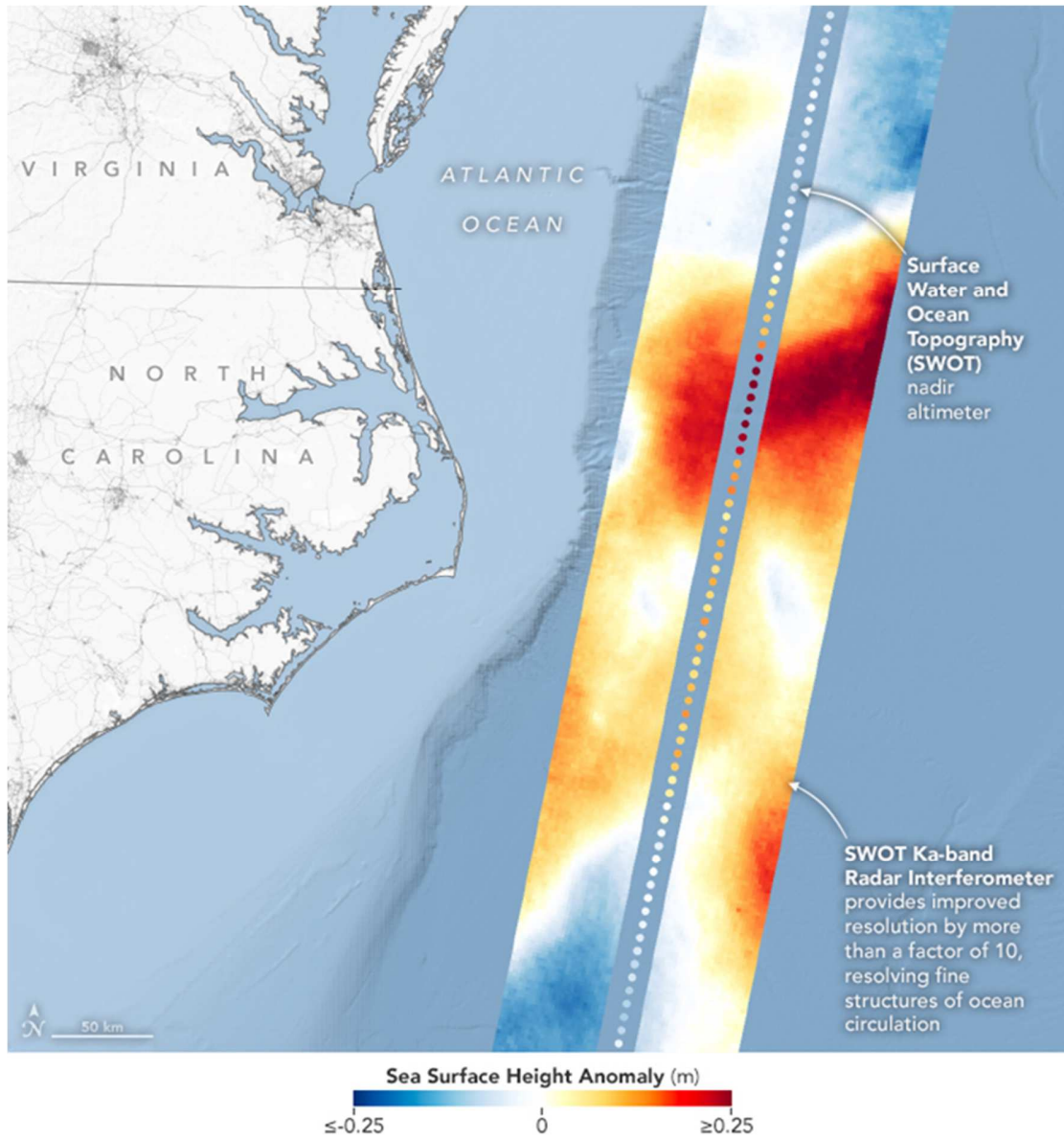


Fig. 16. 2D altimetry (SWOT)

Finally, and to summarize what we observed with the first result, we can easily understand that the SWOT exceeded its objectives in term of resolution compared to requirement defined before launch as we can see in this comparison of SWOT data with an optical image of Toulouse city:

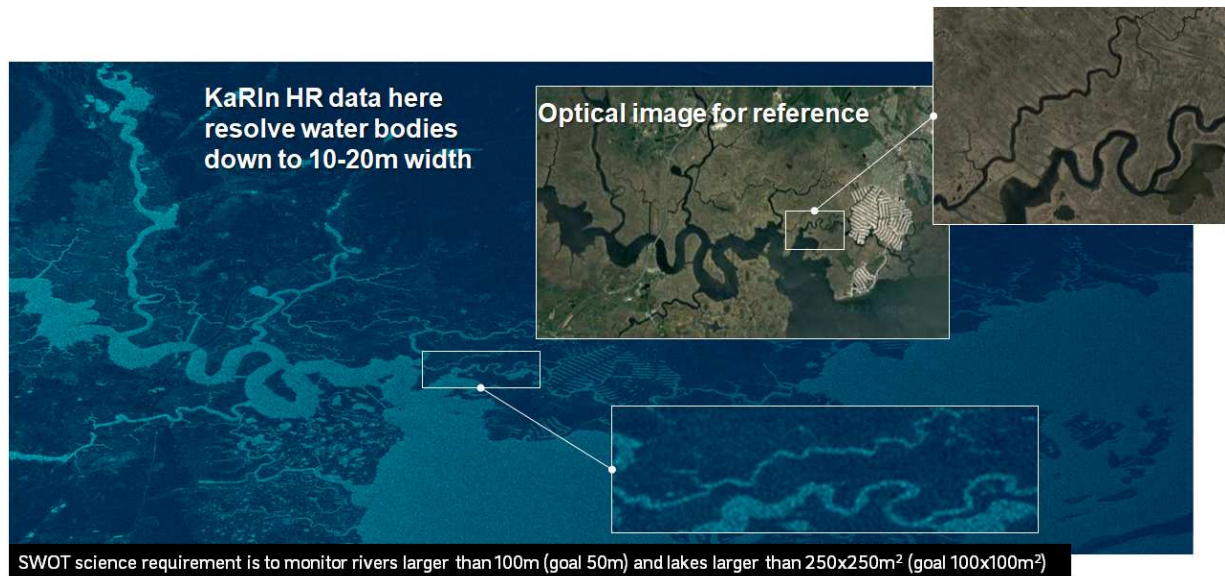


Fig. 17. SWOT compared to an optical image

## 7. Conclusions

As a conclusion, everyone who involved on SWOT knew that mission objectives were challenging. The schedule was very intense and has been adapted regularly according to all actors' constraints. The Covid was another point which implied a high level of flexibility. Thanks to automation and flexibility, operations were secure, easy to manage and gave a lot of lessons learnt applied for the followed CNES.

## Acknowledgements

I would like to thank CNES giving me the opportunity to be manage SWOT operations, my CNES colleagues during the development phase, the CNES operational team, my colleagues from NASA JPL who are always enable me to work every day in an exceptional atmosphere of trust.