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# SOLAR Predictor: A Knowledge Management Tool Supporting Long-Term Console Operations

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**The Solar Monitoring Observatory (SOLAR) is a payload of the European Space Agency (ESA) mounted on the zenith-pointing external platform of the Columbus module of the International Space Station (ISS) and is designed to track the Sun in order to perform quasi-continuous measurements of the solar irradiance. SOLAR is operational and returning science since February 2008 and its mission is supported until February 2017. This paper presents the "SOLAR Predictor", a web-based knowledge management tool. The tool has been developed by the operator team at the Belgian User Support and Operations Centre (B.USOC) in 2012 to support the operations of SOLAR within the team and it was further fine-tuned in 2013. The SOLAR Predictor aims to collect and combine all the latest information relevant to SOLAR operations at a single location, in order to support and facilitate routine operator tasks The SOLAR Predictor tool automatically fetches and parses information from a series of sources relevant to SOLAR Operations, like real-time planning, attitude timeline and vehicle traffic, orbit-related data and of course the SOLAR telemetry data. The tool also links to a database containing SOLAR specific command schedules. These command scripts are used on-board to execute the science activities. The implementation in the Predictor is as such that it provides a means of configuration control, on-board file management, and support for file uplink and transfer. The algorithms implemented in the Predictor tool process the data feed in order to provide predictions of Sun observation conditions and operations constraints based on the latest available information. The information is graphically visualised, highlighting possible conflicts in the planning, allowing the operators to easily fine-tune the planning. The tool facilitates the long-term planning and real-time rescheduling of the science activities, based on the input from the science teams. At the time of activity execution, the operator is warned through an audible alarm. The daily timeline reviews are supported by automatically checking the differences between the desired planning and the published Onboard Short Term Plan data, and by automatically generating the input files for the various operational counterparts. Finally, the tool automatically creates detailed and accurate Daily Operations Reports, which are distributed to the SOLAR stakeholders. The SOLAR Predictor tool helps maximizing the scientific return of operations within the existing**

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**external constraints impacting SOLAR operations, such as loss of signal, South Atlantic Anomaly passes, Sun Visibility Windows, attitude control and orbital control of the station using propellant, visiting vehicles, etc.. On console, the tool provides support for the real-time operations as well as to routine tasks that used to involve a lot of repetitive manual cut-and-/paste and comparison work. As a result, the amount of operator inaccuracies and errors in routine tasks is dramatically reduced.**

## I. Introduction

The Belgian User Support Operations Centre (B.USOC) is responsible for the planning and execution of the science activities performed by the Solar Monitoring Observatory (SOLAR) on-board the International Space Station (ISS). SOLAR is operational since February 2008, and although the mission was initially foreseen to last 1.5 years, mission duration has been extended in the meantime till 2017. The SOLAR payload is mounted on one of the external platforms of the Columbus module, and contains three Sun observing instruments. Due to the specificity of the ISS orbit and the design of the SOLAR mechanical structure, observations of the Sun are not continuously possible. In order to optimise the operational and scientific return, accurate knowledge of the possible measurement intervals is crucial. Therefore, the B.USOC team decided to develop a web-based tool, the SOLAR Predictor, that allows the prediction of the upcoming Sun observation windows for SOLAR, based on the ISS orbit and attitude data. The SOLAR Predictor tool developed into a complete operations support tool, tailored to the SOLAR and ISS operations, taking into account the SOLAR specific operational rules and guidelines. It serves as a supporting tool for both long-term planning and real-time rescheduling of the SOLAR science activities, for resource planning, for daily reporting to the stakeholders, it allows configuration control and links to the SOLAR telemetry archive.

This paper presents the operational and technical aspects of the SOLAR Predictor tool. In section II, the SOLAR Payload and the operational concept are described, as well as the SOLAR Predictor's functionalities to support these SOLAR operations. Section III then provides the technical details of the SOLAR Predictor. The possible further development into a more generic tool is discussed in section IV.

## II. The SOLAR Operations

### A. The SOLAR Payload

SOLAR is an integrated platform accommodating three instruments complementing each other (Figure 1). The SOLAR mission has the aim to provide accurate measurements of the Solar Spectral Irradiance, covering a wide spectral range from the Infra-Red (IR) to the Extreme Ultra-Violet (EUV). The scientific objectives of the SOLAR mission cover different fields of research, such as solar physics, atmospheric physics, and climatology[1, 2]. The SOLAR payload contains three instruments, each designed to observe the Sun in a specific wavelength range. The Solar Variability Irradiance Monitor (SOVIM) was focusing on Total Solar Irradiance (TSI) data. Unfortunately, the SOVIM instrument was lost after a fatal hardware failure in the first year of the mission. The SOLar SPECtrum (SOLSPEC) instrument measures the Solar Spectral Irradiance (SSI) in three different channels: UV, visible and IR. Measurements of the SSI in the EUV part of the solar spectrum are made by the SOLar Auto-Calibrating EUV/UV Spectrometers (Sol-ACES). The SOLAR instruments are mounted on a Coarse Pointing Device (CPD), a two-axes movable platform providing Sun pointing and tracking capabilities. The SOLAR Control Unit (CU) provides power, collects, formats, and dispatches to ground the telemetry and science data generated by the platform and the instruments in dedicated telemetry packets. It receives ISS ancillary data and processes the ground issued telecommands..


**Figure 1: SOLAR Payload** *(courtesy NASA)*

## B. SOLAR Operational Constraints[5]

Throughout the six years of SOLAR Operations, all B.USOC operators have gone through a learning phase on how to operate the payload in the best way. To maximize the science return, many aspects of SOLAR had to be included in the operations concept, and require specific attention during operations. The most important characteristics of SOLAR operations and how these are included in the SOLAR Predictor are summarized below:

### 1. *Defining Sun Visibility Windows[3]:*

Due to ISS orbital mechanics and due to the mechanical range of the SOLAR CPD, the Sun is not always observable by SOLAR. The visibility is mainly dependent on the ISS β-angle, which is the angle between the Sun-Earth vector and its projection on the ISS orbital plane, that varies slowly over time due to the precession of the ISS orbit and the seasonal movement of the Earth around the Sun. In the nominal ISS Torque Equilibrium Attitude (TEA), SOLAR observations are possible when the β-angle is between -24° and +24°, due to the CPD rotation limits. In practice, this leads to so-called Sun Visibility Windows (SVW) lasting typically 10 to 15 days (Figure 2). During these days, SOLAR is able to track the Sun with its instruments and can perform measurements according to the inputs from the SOLAR science team.

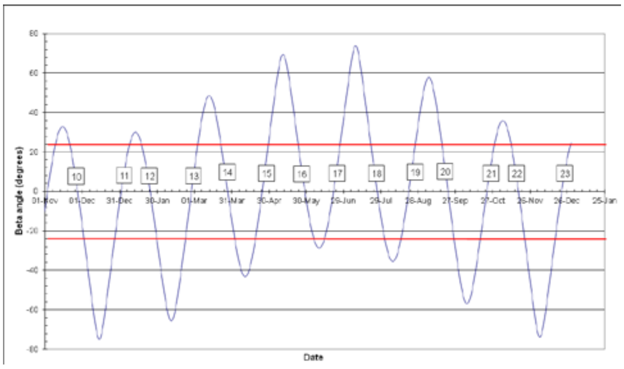



**Figure 2: Sun Visibility Windows: the Sun is only observable by SOLAR when the beta angle is between the red lines.**

The ISS attitude influences the Sun Visibility Window: a yaw or roll different from zero will impact the duration of the tracking and shift the start and end times of the Sun Visibility Window. A good and precise prediction of the ISS attitude is therefore important to accurately predict a Sun Visibility Window in order to correctly plan the science activities. To allow successful operations, the operator team has to set-up a detailed planning for each science period based on the prediction of the Sun Visibility Window, the operational constraints, and the inputs from the scientists. The planning should be adaptable at all times following the real-time operations. This requirement from the operators team was the initial trigger for the development of the SOLAR Predictor tool.

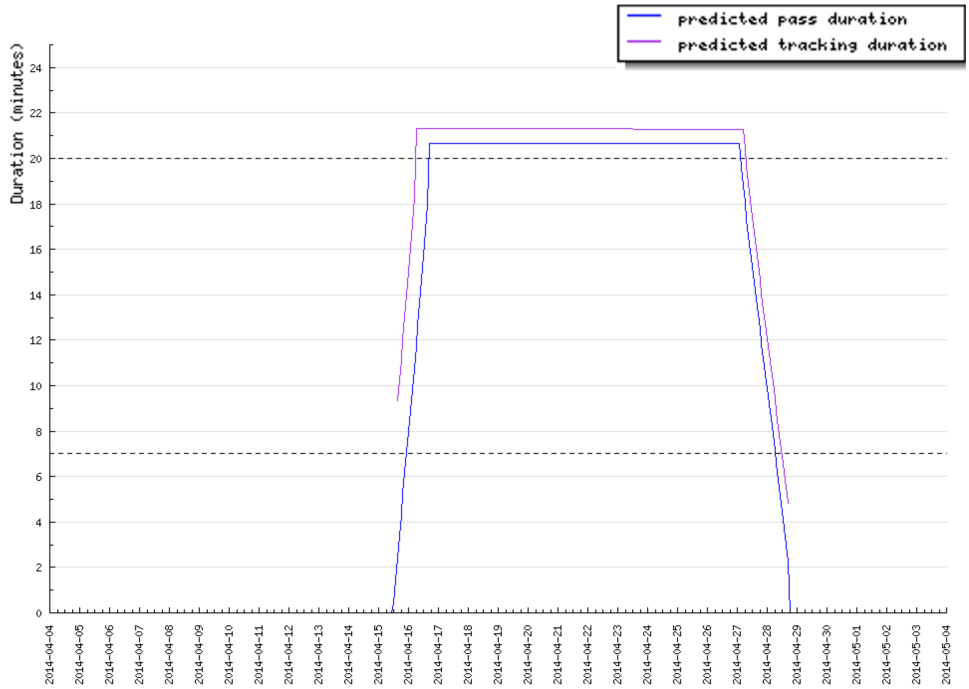
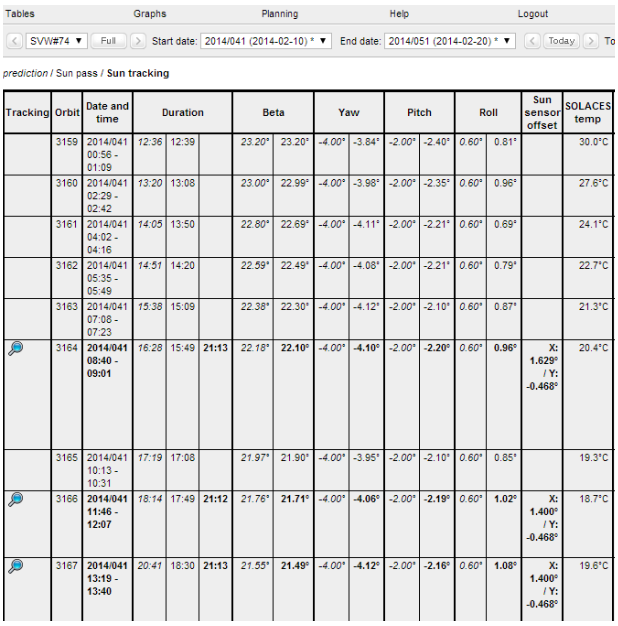



**Figure 3: Graphical view of the tracking prediction.**

Based on the known mechanical range of the CPD, the on-orbit related data fetched from the Trajectory OPerations Officer (TOPO) team, and the Two Line Elements (TLE), the SOLAR Predictor provides a detailed overview of the prediction of the Sun Visibility Window, both graphical and numerical (Figures 3 and 4).



Tables Graphs Planning Help Logout

SVW#74 Full Start date: 2014/041 (2014-02-10) * End date: 2014/051 (2014-02-20) * Today To

*prediction* / Sun pass / **Sun tracking**

| Tracking | Orbit | Date and time | Duration | | | Beta | | Yaw | | Pitch | | Roll | | Sun sensor offset | SOLACES temp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3159 | 2014/041 00:56 - 01:09 | *12:36* | 12:39 | | *23.20°* | 23.20° | *-4.00°* | -3.84° | *-2.00°* | -2.40° | *0.60°* | 0.81° | | 30.0°C |
| | 3160 | 2014/041 02:29 - 02:42 | *13:20* | 13:08 | | *23.00°* | 22.99° | *-4.00°* | -3.98° | *-2.00°* | -2.35° | *0.60°* | 0.96° | | 27.6°C |
| | 3161 | 2014/041 04:02 - 04:16 | *14:05* | 13:50 | | *22.80°* | 22.69° | *-4.00°* | -4.11° | *-2.00°* | -2.21° | *0.60°* | 0.69° | | 24.1°C |
| | 3162 | 2014/041 05:35 - 05:49 | *14:51* | 14:20 | | *22.59°* | 22.49° | *-4.00°* | -4.08° | *-2.00°* | -2.21° | *0.60°* | 0.79° | | 22.7°C |
| | 3163 | 2014/041 07:08 - 07:23 | *15:38* | 15:09 | | *22.38°* | 22.30° | *-4.00°* | -4.12° | *-2.00°* | -2.10° | *0.60°* | 0.87° | | 21.3°C |
| | 3164 | **2014/041 08:40 - 09:01** | *16:28* | 15:49 | **21:13** | *22.18°* | **22.10°** | *-4.00°* | **-4.10°** | *-2.00°* | **-2.20°** | *0.60°* | **0.96°** | **X: 1.629° / Y: -0.468°** | 20.4°C |
| | 3165 | 2014/041 10:13 - 10:31 | *17:19* | 17:08 | | *21.97°* | 21.90° | *-4.00°* | -3.95° | *-2.00°* | -2.10° | *0.60°* | 0.85° | | 19.3°C |
| | 3166 | **2014/041 11:46 - 12:07** | *18:14* | 17:49 | **21:12** | *21.76°* | **21.71°** | *-4.00°* | **-4.06°** | *-2.00°* | **-2.19°** | *0.60°* | **1.02°** | **X: 1.400° / Y: -0.468°** | 18.7°C |
| | 3167 | **2014/041 13:19 - 13:40** | *20:41* | 18:30 | **21:13** | *21.55°* | **21.49°** | *-4.00°* | **-4.12°** | *-2.00°* | **-2.16°** | *0.60°* | **1.08°** | **X: 1.400° / Y: -0.468°** | 19.6°C |

**Figure 4. SOLAR Predictor Sun Passes**

The graphical view provides a bird's eye view on the up-coming SVW. The prediction in Figure 3 also takes into account the fact that at the end of a Sun tracking, the CPD keeps on moving along with the Sun even though its tracking precision requirements are not met anymore. The tracking duration is thus longer than the useful pass duration with correct pointing accuracy. The graphical view of the SOLAR Predictor displays this deviation with two lines: (a) a purple line indicating the total tracking duration, (b) a blue line indicating the actual useful pass duration (Figure 4 ).

The transition into a SVW occurs gradually over several hours because the nominal ISS TEA is not perfectly aligned with the flight direction of the ISS[4]. The tracking duration is therefore shorter at the beginning and end of the SVWs.

A more detailed prediction is provided to the operator team through the numerical overview (Figure 4). The prediction consists of the exact time of the start and end of Sun tracking, providing the correct duration. This overview is used when the operator is requesting planning inputs from the scientists, allowing them to tailor their requested measurements to the predicted useful pass duration.

2. *Thruster events:*

On a regular basis, the ISS thrusters or the thrusters of a visiting vehicle need to be activated. This can be the case for: a re-boost, testing a thruster, changing the ISS attitude, or the execution of a Debris Avoidance Maneuver. During these events science activities should not be performed by SOLAR, as disturbances in the micro-g environment will influence the observations. Moreover, there is a concern on possible contamination by thruster gasses, especially for the SolACES instrument. Therefore, the instruments need to be configured in a safe mode, with SOLSPEC powered off, and SolACES preferably heated up and shutters closed to protect the optics. The Predictor tool retrieves the start and end times of the thruster events from the webpage mastered by the Attitude Determination and Control Officer (ADCO), showing the ISS Attitude Timeline (ATL), and saves the data in a database. The list of upcoming and past thruster events can be consulted by the "special events" tab in the web-interface of the Predictor. The operator has the possibility to add manually to this list any events that requires the attention of the operator.

3. *South Atlantic Anomaly*

For the SOLSPEC instrument, the South Atlantic Anomaly (SAA) has to be taken into account when planning the measurements. When the ISS is crossing this region of increased flux in energetic particles, SOLSPEC should be off as the detectors are influenced by the enhanced radiation. The SAA passes are automatically retrieved from the TOPO website by the SOLAR Predictor.

4. *Offset for each payload*

The alignment of the instruments with the CPD is not perfect, and differs from one instrument to the other. A maneuver called "criss-cross" is available in the command set of the SOLAR Application software. From this maneuver, the offset angles for each instrument were determined in the early stage of the mission. Because of this difference in instrument alignement, parallel execution of Sun observations with both instruments is to be avoided. The SOLAR Predictor retrieves from the SOLAR telemetry the offset angle applied during each orbit, and includes this information in the tabular overview of the tracking duration. A future development will provide warnings to the operator whenever two measurements with different offset requirements would be overlapping.

5. *Staff availability*

Another relevant constraint is the staff availability. The SOLAR Predictor tool provides a view of who is covering each of the shifts. This allows the operator to choose whether an activity will be properly covered by the required specialist or not. The information is retrieved from another internal tool called "Shiftplanner". The Shiftplanner tool contains all shift information of the SOLAR operator team and allows visualizing and managing this information in different ways for team management purposes.

Detailed information of some of the above constraints are available from different web-based sources. Specifically, thruster events and visiting vehicles information is retrieved from the ISS Altitude Timeline (ATL). SAA passes are retrieved from the TOPO website, and shift coverage from the Shiftplanner tool. Data retrieval from these sources are performed automatically on a regular basis to ensure all changes are timely captured. Moreover the operator also has the ability to launch the retrieval manually or to manually insert external occurrences which impact on-going operations, such as Ku-band or S-band outages impacting the monitoring and commanding capability of the SOLAR operator.

### C. SOLAR Operations Execution

The B.USOC SOLAR operators are on console 24/7 to monitor and control the payload, following the science requests of the scientists.. Payload downstream data, or SOLAR telemetry, from the ISS allows real-time monitoring of SOLAR by the operator. These so-called housekeeping data provide the overall status of the payload, consisting of SOLAR temperatures, instrument temperatures, voltages, current consumption, operational status, command execution reports, etc.

Based on the input from the scientists, B.USOC executes science measurements through telecommanding. Telecommanding can either be done by direct ground commands or by executing a so-called Command Schedule (CS). A CS is a dedicated pre-programmed time-ordered sequence of time-tagged commands to be sent to the SOLAR instruments or the CPD system.

Since 2009, SOLAR Payload commanding is done through the so-called Payload Real-Time Commanding Window[5]. An activity called SOL-REAL-CMD lasting 24 hours is planned in the Onboard Short Term Plan Viewer (OSTPV) whenever SOLAR is powered. It gives the B.USOC operator an immediate access to command SOLAR upon the go of the Columbus Flight Director (Col-FD). It should be mentioned that operations covered by the real-time commanding window are activities which should only affect the payload itself and not affect other payloads or subsystems, and the commanding and monitoring of these activities is completely B.USOC's responsibility. Activities that involve the Columbus subsystems, such as powering up the instrument or a file upload, fall outside the real-time command window. Those activities are separately defined in the OSTPV in order to ensues the resources are available. The Predictor tool is capable to obtain the SOLAR related activities from the OSTPV tool, in order to provide a graphical overview of the planning, showing only the information relevant to SOLAR operations.

*1. SOLAR File Transfers*

The uplink of the CSs is done from ground to the Columbus Mass Memory Unit (MMU), from where the files are transferred to the SOLAR payload. As it involves the Columbus MMU, the uplink of the file has to follow the Columbus File Transfer process which means that only specific and a limited number of filenames can be used. Moreover, the file has to be available to the Columbus Flight Control Team (FCT) at least 8 hours prior to the uplink to the Columbus MMU. Additionally, for the transfer from the B.USOC premises to the Columbus dropbox, the filename and corresponding checksum (a unique identifier of the file generated from its content) has to be provided to the FCT. Figure (Figure 5) provides an overview of the process.

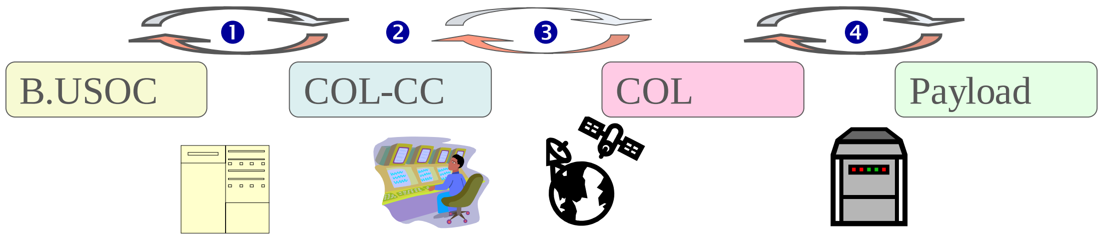



**Figure 5: Columbus Payload File Transfer Process**

After 4 years of operating SOLAR, more than 120 different CSs had been uplinked to SOLAR. In case such a file transfer fails, which had happened several times, the traceability of these files and their location on the MMU is of essential relevance for the operator. The process was very error prone and required a strict system of configuration control. The Predictor Tool provides a supporting function to the file transfer process.

The Predictor tool connects to the database containing all the different CSs for SOLAR, and it is possible to add a new CS to the database via the Predictor tool. When inserting a CS file into the SOLAR Predictor, it is under configuration control, meaning that it is not possible to replace a file already in the tool or to rename a file to an already existing filename. The SOLAR Predictor automatically generates the checksum, records the file size and derives CS execution information such as duration, timing and constraints relevant to the planning of the CS.

The preparation of the actual file transfer is also performed through the SOLAR Predictor. After uplinking the CS in the tool, the operator can indicate that the file is ready for transfer to SOLAR by linking it to a predefined and available position of the Columbus MMU and the corresponding OSTPV file uplink and transfer activities. This action then automatically generates the textual information, such as listing the filename, the file size, the checksum and the time of uplink and transfer from ground to SOLAR, which is to be provided to the FCT. At any given time, a SOLAR operator can obtain from the SOLAR Predictor an overview of the files on SOLAR, the SOLAR files on the Columbus MMU, and which files have ever been inserted into the SOLAR predictor tool. Consequently, in case of a reboot of the SOLAR Control Unit, which erases all files on SOLAR, the SOLAR operator can easily retrieve an overview from the SOLAR predictor of which files are available on the Columbus MMU and which files are need to be transferred to SOLAR in order to resume the operations.

*2. SOLAR Operations Planning and Execution*

The planning of the SOLAR activities is done on an operational level as well as on a science execution level. The SOLAR Predictor tool allows the SOLAR operator to choose which kind of timeline has to be used on a daily basis during the preparation of the SOLAR activities to be scheduled in OSTPV:

1. Sun Observation Day for which SOLAR resources are scheduled for continuous power as well as the 24 hour real-time commanding window and the activities required for a file transfer from ground to SOLAR. This timeline is used during the SVW.

2. No-Sun Observation Period or Idle Mode, where SOLAR resources for continuous power are scheduled as well as the 24 hour real-time commanding window. This timeline is used outside the SVW.
3. Idle Mode and file transfer, which consists of the same timeline as at point 2 with the addition of the file transfer activities. This timeline is used once a week, outside the SVW.
4. Survival Mode where only the survival heating power resources are scheduled. This timeline is rarely used, when SOLAR is powered off except for its survival heaters.

Following the generic Columbus operations planning preparation and the prediction of the SVWs, the SOLAR Predictor is populated with the suitable timeline for each day giving a full overview of how the OSTPV activities should be scheduled. This planning (Figure 6) is used as an input to the Columbus planning team for the Weekly Look-ahead Plan (WLP).

**SVW#74 OSTPV activities overview**

Number of weeks: 4 ▼ Apply

nominal timeline / slip timeline - desired / **implemented** - past / future - SVW / Idle

| Week | Day | | | Beta | DMS-SOL FILE-D/L | SOL-LOG-TRCE | SOL-RES-F1+F2 | SOL-RES-F2 | SOL-FEED1-ACT | SOL-CU-REBOOT | SOL-R/T ACQ-START | SOL-PWR-ON | SOL-PREP-SURV | SOL-RT ACQ-STOP | SOL-FEED1-DEACT | SOL-FEED2-ACT | SOL-FEED2-DEACT | SOL-REAL-CMD | DMS-SOL FILE-U/L | MMU-SOL-XFER | SOL-SW-UPGD1 | SOL-SW-UPGD2 | Special events |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2014/06 inc37/38 W21 | Mon | 2014/034 | 2014-02-03 | 35.0° — 34.9° | | | 06:00 | | | | | | | | | | | 06:00 | | | | | 15:30-17:10: 52P Undocking (thruster/vehicle event) |
| | Tue | 2014/035 | 2014-02-04 | 34.9° — 34.1° | | | 06:00 | | | | | | | | | | | 06:00 | | | | | |
| | Wed | 2014/036 | 2014-02-05 | 34.1° — 32.9° | | | 06:00 | | | | | | | | | | | 06:00 | 01:40 | 08:15 | | | 20:30-23:20: 54P Docking (thruster/vehicle event) |
| | Thu | 2014/037 | 2014-02-06 | 32.9° — 31.1° | | | 06:00 | | | | | | | | | | | 06:00 | | | | | 04:08-06:05: OPM to +XVV (thruster/vehicle event)<br>10:15-11:45: MSL-MICAST-EVAC (venting) |
| | Fri | 2014/038 | 2014-02-07 | 31.1° — 28.9° | | | 06:00 | | | | | | | | | | | 06:00 | | | | | 10:40-11:25: GFI Test (SUP3J03 off) (for info only) |
| | Sat | 2014/039 | 2014-02-08 | 28.9° — 26.3° | | | 06:00 | | | | | | | | | | | 06:00 | | | | | |
| | Sun | 2014/040 | 2014-02-09 | 26.3° — 23.3° | | | 06:00 | | | | | | | | | | | 06:00 | 01:35 | 08:15 | | | |
| 2014/07 inc37/38 W22 | Mon | 2014/041 | 2014-02-10 | 23.3° — 20.1° | | | 06:00 | | | | | | | | | | | 06:00 | 01:00 | 06:30 | | | 13:19-15:42: SOLACES not initialising (AR-993) (anomaly) |
| | Tue | 2014/042 | 2014-02-11 | 20.1° — 16.6° | | | 06:00 | | | | | | | | | | | 06:00 | 01:45 | 07:20 | | | 15:00-01:00: Possible Shadowing (shadowing)<br>17:20-17:33: Robot arm shadow aborting on-going SOLAR |
| | Wed | 2014/043 | 2014-02-12 | 16.6° — 12.8° | | | 06:00 | | | | | | | | | | | 06:00 | 01:35 | 06:30 | | | 15:00-01:00: Possible Shadowing (shadowing)<br>14:00-23:00: Possible Shadowing (shadowing)<br>01:00-14:00: ROBO Shadowing (shadowing) |
| | Thu | 2014/044 | 2014-02-13 | 12.8° — 8.9° | | | 06:00 | | | | | | | | | | | 06:00 | 02:20 | 05:30 | | | 07:00-11:30: DaSS Ops migration (TC/TM outage (idle))<br>11:30-16:00: testing period DaSS migration (TC/TM outage (<br>19:00-03:15: Possible Shadowing (shadowing) |
| | Fri | 2014/045 | 2014-02-14 | 8.9° — 4.8° | | | 06:00 | | | | | | | | | | | 06:00 | 01:35 | 06:30 | | | 19:00-03:15: Possible Shadowing (shadowing)<br>03:15-18:00: ROBO Shadowing (shadowing)<br>18:10-22:15: Possible Shadowing (shadowing) |
| | Sat | 2014/046 | 2014-02-15 | 4.8° — 0.7° | | | 06:00 | | | | | | | | | | | 06:00 | 01:45 | 06:50 | | | |
| | Sun | 2014/047 | 2014-02-16 | 0.7° — -3.6° | | | 06:00 | | | | | | | | | | | 06:00 | 01:35 | 09:10 | | | 08:05-11:20: Solar Array Efficiency Test (thruster/vehicle e |
| 2014/08 inc37/38 W23 | Mon | 2014/048 | 2014-02-17 | -3.6° — -8.0° | | | 06:00 | | | | | | | | | | | 06:00 | 01:00 | 08:20 | | | 10:30-12:00: MSL-CETSOL-EVAC CMD (venting)<br>01:37-02:30: SOLSPEC anomaly (anomaly) |
| | Tue | 2014/049 | 2014-02-18 | -8.0° — -12.4° | | | 06:00 | | | | | | | | | | | 06:00 | 02:25 | 06:30 | | | 10:50-12:40: Cygnus Release (thruster/vehicle event)<br>09:40-11:10: MSL-GSD-BLEED CMD (venting) |
| | Wed | 2014/050 | 2014-02-19 | -12.4° — -16.8° | | | 06:00 | | | | | | | | | | | 06:00 | 01:40 | 09:00 | | | |

**Figure 6. WLP Planning from SOLAR Predictor timelines.**

Once the planning is available in OSTPV, the SOLAR Predictor regularly fetches the relevant SOLAR activities from OSTPV and compares it with the B.USOC initial input, supporting the daily timeline reviews for 7, 3, and 1 day ahead planning. In case of a discrepancy, the SOLAR Predictor automatically generates the textual input in the correct format that needs to be provided to the Columbus FCT for further processing. All inputs provided to the Columbus FCT are logged within the SOLAR Predictor providing the operator with full follow-up capabilities. Moreover, the tool provides a merged overview of the operational planning from OSTPV and the actual science schedule.

Based on the scientists input, the scientific measurements during the Sun Visibility Window are also prepared through the SOLAR Predictor. The sequence of CSs is entered for every day and each instrument according to the requested science measurements. The SOLAR Predictor shows

**CS sequence planning for SVW#76**

SOLACES | SOLSPEC | SOVIM | SYSTEM

| Actions | CS name | Requested start | Use activity | Abort after orbit # | Planned start/end | | CS info | Planning info | MMU | SOLAR |
|---|---|---|---|---|---|---|---|---|---|---|
| | IAEEH22.DAT | 105/22:39 | SOL-ACE-NOM | no abort | 105/22:39 | 105/22:49 | | Duration: 0:10:28 | SOLAR18.DAT | IAEEH22.DAT |
| | IAC72.DAT | 106/17:08 | SOL-INST-CS START | no abort | 106/17:08 | 106/22:09 | | Min. 0:04:00 Sun track / 4 orbits | DOSTEL.IOP | IAC72.DAT |
| | IAC74.DAT | 107/15:00 | SOL-INST-CS START | no abort | 107/15:00 | 108/00:29 | | Min. 0:10:00 Sun track / 7 orbits | EXPOSE.IOP | IAC74.DAT |
| | IAC74.DAT | 108/10:00 | SOL-INST-CS START | no abort | 108/10:00 | 108/20:36 | | Min. 0:10:00 Sun track / 7 orbits | EXPOSE.IOP | IAC74.DAT |
| | IAC74.DAT | 109/09:00 | SOL-INST-CS START | no abort | 109/09:00 | 109/19:50 | | Min. 0:10:00 Sun track / 7 orbits | EXPOSE.IOP | IAC74.DAT |

**Figure 7. SOLAR Predictor CS sequence.**

whether the file was already uploaded in the SOLAR Predictor, uplinked to the Columbus MMU and/or available on SOLAR (**Figure 7**). This overview allows the SOLAR operator to easily identify the files that need to be uplinked and by when the files are needed.

The graphical daily planning overview, as shown in Figure 8, helps the operator to fine-tune the planning as it provides a complete overview of the selected day and graphically highlights identified conflicts. This overview includes:

1. The predicted Sun observation passes.
2. Operational constraints such as possible thruster events from the ATL, Acquisition Of Signal (AOS) / Loss Of Signal (LOS) prediction from OSPTV, manually entered events, SAA passes from TOPO.
3. SOLAR related OSTPV activities.
4. Science activities for each instrument individually and the status of the platform.
5. The operators who will be supporting the activities.

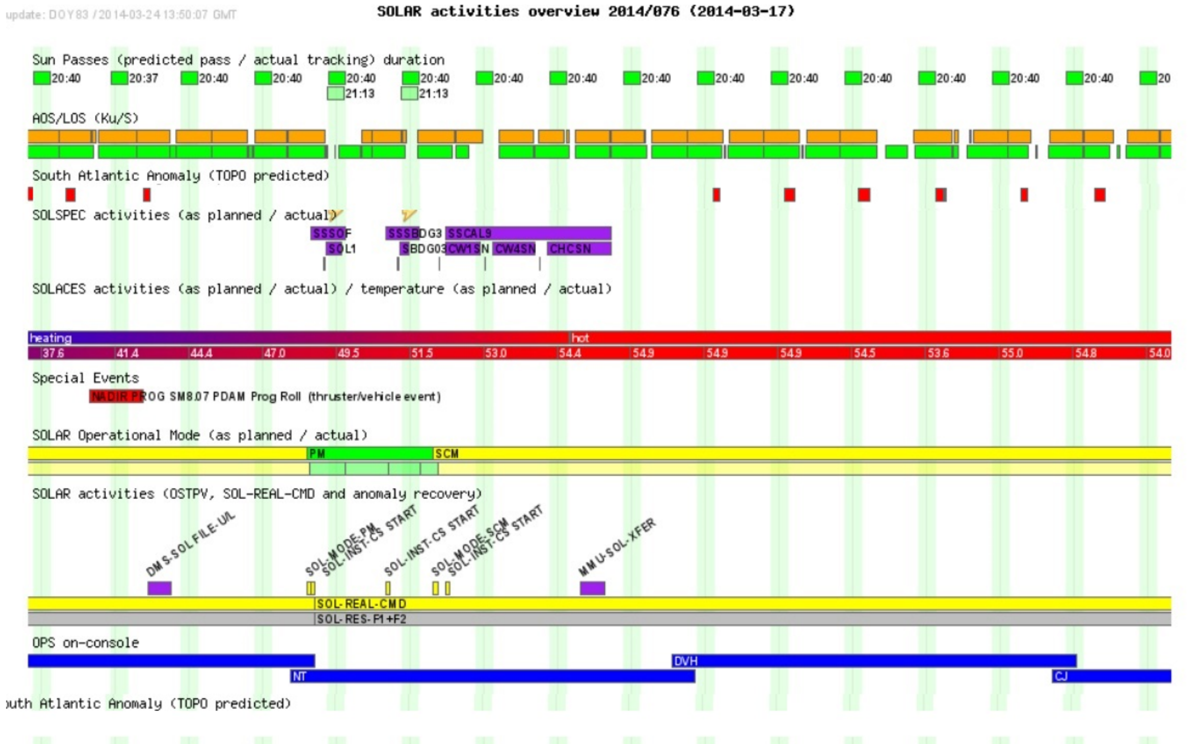
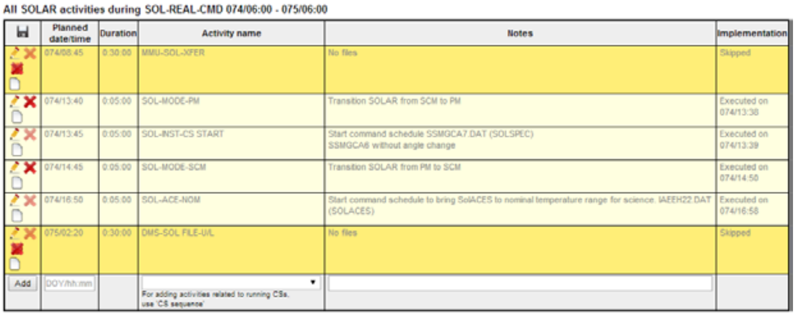



**Figure 8. Daily Graphical Planning overview**

The user interface also provides detailed timing information through tooltip indications when hovering over the individual activities with the mouse.

Apart from the graphical planning overview, also a listing of the activities is available (Figure 9). In the list view it is possible to add, delete, or shift SOLAR related activities. Those activities not included in the real time command window are coloured differently. An Excel sheet can be generated, providing all the activities B.USOC would like to execute during the SOLAR real-time command window. This information needs to be provided to Col-FD.



All SOLAR activities during SOL-REAL-CMD 074/06:00 - 075/06:00

| | Planned date/time | Duration | Activity name | Notes | Implementation |
|---|---|---|---|---|---|
| | 074/08:45 | 0:30:00 | MMU-SOL-XFER | No files | Skipped |
| | 074/13:40 | 0:05:00 | SOL-MODE-PM | Transition SOLAR from SCM to PM | Executed on 074/13:38 |
| | 074/13:45 | 0:05:00 | SOL-INST-CS START | Start command schedule SSMGCA7.DAT (SOLSPEC) SSMGCA6 without angle change | Executed on 074/13:39 |
| | 074/14:45 | 0:05:00 | SOL-MODE-SCM | Transition SOLAR from PM to SCM | Executed on 074/14:50 |
| | 074/16:50 | 0:05:00 | SOL-ACE-NOM | Start command schedule to bring SolACES to nominal temperature range for science. IAEEH22.DAT (SOLACES) | Executed on 074/16:58 |
| | 075/02:20 | 0:30:00 | DMS-SOL FILE-U/L | No files | Skipped |
| Add | DOY/hh:mm | | For adding activities related to running CSs, use 'CS sequence' | | |

**Figure 9. SOLAR Ground activities overview**

From the operations execution this overview is the main sequence of activities for the operator on console. An audible alarm can be activated five minutes prior the activity, reminding the operator of the upcoming ground commanding. Execution times are to be added to confirm the successful execution, but anomalies can also be inserted, whether a new anomaly or a reoccurrence of a known one with known recovery. In case of an anomaly, the tool allows flexible re-planning with the possibility to enter comments to properly document the rescheduling.

*3. SOLAR Daily Reporting*

During periods of science measurements, the scientists receive a Daily Operations Report (DOR) of the SOLAR operations. This report consists of a detailed description of the executed activities, as well as an overview of the planned activities during the on-going SVW and external events possibly impacting the SOLAR operations. The daily report is automatically generated by the SOLAR Predictor reducing considerably the workload of the operators and it provides accurate and up-to-date information. The backbone of the DOR is the graphical overview which provides visual and detailed information of the executed activities. In addition to that, the relevant status information of the covered period is also available such as onboard software version, applied offset, tracking accuracy, as well as file status and versions. Throughout a Sun Visibility Window, the DOR contains all the information to allow manual continuation of operations of the Sun Window in case problems with the tool, from the planning to the file transfer to the latest available information on the external constraints.



## III. Technical aspects of the Predictor Tool

The aim was to develop an integral and interactive tool, that should capable to centralise and store the relevant data in a long-term manner, to process them, and to present the information to the operator in an intuitive and meaningful way. It was chosen to use well known and supported open source software.

### A. Database

The software was designed on top of a well-known ACID (Atomicity, Consistency, Isolation, Durability) compliant relational database to handle the large amount of data, concurrent multi-user capabilities, configuration control, and to meet functional requirements. The decision was to use MySQL for its proven performance and reliability. A complex relational table schema was designed to cope with all the possible operational scenarios.

### B. Programming language

The applications backend was developed in the PHP web scripting language. The client side interfacing the user is a web-based platform built using a conjunction of World Wide Web (WWW) standards including HTML, CSS and JS/AJAX technologies. These technologies are all widely used and supported, and provided us with the short development time we required. High performance and scalability, something that was key to deal with real-time operations, was also provided by using these Web standards.

### C. External sources of information

The external sources accessed by the SOLAR Predictor are various. They are implemented using scripts coded in the PHP language. Most of them are triggered automatically at a preconfigured daily time by the use of cronjob, which is a job scheduler built in most Linux-based operating systems.

An enumeration of the external data sources follows:

1) *ATL*: The ISS Attitude data are parsed automatically from the ATL website, accessed through a web proxy. The operator using the tool has to provide his NDC account credentials to start this process.

2) *OSTPV*: The timeline and AOS/LOS data are also parsed automatically from the OSTPV web interface, accessed through a web proxy, but on a scheduled six hour basis.

3) *TOPO*: SAA and accurate orbital prediction data are parsed automatically from the TOPO website.

4) *TLE*: Orbital data are accessed by interfacing the REST (REpresentational State Transfer) interface available on the Internet, on an hourly basis.

5) *Shiftplanner*: Shiftplanner is a web based Planning Tool used internally to assign Operators to shifts. The information is fetched by the SOLAR Predictor tool over the Internet by importing the related tables directly into its own database.

6) *TM*: Telemetry data is captured by the use of a parameter extractor that interfaces the data archive.

### D. Algorithms

The tool implements numerous algorithms that, before the Predictor was developed, were calculated either manually or using rudimentary spreadsheets. One good example of this are the SVW predictions, which are based on the forecast of the solar β-angle parameter and the orbital data of the ISS. These data are fetched from an external source of information that is updated frequently and becomes more accurate the closer one gets to the predicted time. The SOLAR Predictor tool, by automating this process, is able to deliver precise up-to-date SVW predictions and therefore improves the planning process.

Most of the constraints described in Section II were added to the tools intelligence and are nowadays being checked automatically giving warnings to the operators when a certain condition is not met.

### E. Internet Protocol (IP) security

The SOLAR Predictor was placed inside the Demilitarized Zone (DMZ) network of B.USOC. Operators can access it from computers connected to a secured VPN connection over the Internet. Having the need to interface several external sources of information, some of them available on the Internet, and due to the criticality of some of the other sources of information accessed and contained in this tool, the host machine needed to implement the proper preventive countermeasures. A firewall performing stateful packet inspection was put in place to monitor and secure the whole system from potential threats.

### F. Scalable environment

The SOLAR Predictor tool runs on a scalable Linux Ubuntu Server Long Term Support 12.04 32 bit hosted on a VMware ESXi 5 virtual machine. This environment provides redundant high availability ensuring that the application is hardware fault tolerant and available 24/7, to cope with B.USOC continuous operations.

By using VMware's virtualization technology, if an extraordinary increase in processing power is suddenly needed by the SOLAR Predictor tool, it is possible to quickly allocate more resources to the guest virtual machine hosting the SOLAR Predictor tool.

## IV. Summary and outlook

The SOLAR Predictor tool, originally developed to predict the observation windows of the SOLAR payload, developed into a complete operations support tool, tailored to the SOLAR and ISS operations, taking into account the SOLAR specific operational rules and guidelines. It serves as a supporting tool for both long-term planning and real-time rescheduling of the SOLAR science activities, for resource planning, for daily reporting to the stakeholders, it allows configuration control and links to the SOLAR telemetry archive. As the tool was initiated and developed by the operators on console, it is fully tailored to the operator's needs and the SOLAR payload operations and constraints. It provides a unified and single interface to the operators, with all the latest information required to perform the SOLAR operations. Moreover, this software support tool improved the processes established, ensures quality and configuration control within the SOLAR operations execution.

Although the SOLAR Predictor emerged from SOLAR specific problems or issues encountered on console, many features, such as planning, file transfer or orbital constraints will be very valuable for future or other ISS payloads, either integrated or separate.

From the experience of the development and use of the SOLAR Predictor tool, the B.USOC team will certainly include the development of further tailoring of the tool for its future payloads.

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