THE SCIAMACHY CONSOLIDATED LEVEL 0 DATASET

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ABSTRACT

By the end of the ENVISAT mission, SCIAMACHY had executed 52867 orbits. In most of those SCIAMACHY acquired measurement data. SCIAMACHY's complex measurement schemes are best reflected in the consolidated level 0 products. The cL0 products are the basis for level 0-1b and level 1b-2 processing whenever highest precision is required. It was therefore of paramount importance to develop a cL0 data archive for the entire in-orbit mission lifetime being as complete as possible and containing quality controlled measurement data.

1. INTRODUCTION

Consolidated level 0 (cL0) products are generated from the Near Realtime (NRT) products which are based on raw measurement data. They contain the most accurate auxiliary information in the product headers. Since they span a time range of exactly one orbit starting at the Ascending Node Crossing (ANX) and ending at ANX+1, their contents correspond to what has been planned for this particular orbit.

For SCIAMACHY the rule is that the cL0 product begins with the first state which has been started after ANX and ends with the last state which has been started just before ANX+1. Since SCIAMACHY executes timelines almost continuously from several minutes before sunrise to shortly before the end of eclipse, the cL0 products must usually cover a complete orbital period of about 6036 sec (until October 2010) or 6014 sec (since October 2010). Only in cases of instrument unavailability, either triggered by a planned switch-off or an unexpected platform or instrument anomaly, no raw data have been generated onboard such that a consolidated product could not exist or may deviate from planning.

Because of SCIAMACHY's Announcement of Opportunity (AO) status, DLR as one the AO Providers (AOP) had the right to receive a copy of each cL0 product. For practical reasons the delivery from the ENVISAT Payload Data Segment (PDS) was implemented via an operational interface between the archive area of the D-PAC and the Data Information Management System (DIMS) of the German Remote Sensing Data Center (DFD) at DLR. The transfer from D-PAC to DIMS generated, over the mission lifetime, a complete data set of SCIAMACHY cL0 products serving as a cL0 master data set.

Early in the mission it became apparent that the quality of the cL0 products could be hampered by various inconsistencies. Therefore the SCIAMACHY Operation Support Team (SOST), being responsible for SCIAMACHY mission planning and thus having a detailed insight of the expected state – i.e. measurement data – sequence, established and maintained a dedicated quality control scheme. Every cL0 product had to pass a series of verification checks before being sent to the DIMS master archive. Those products failing the tests were omitted.

In close cooperation with SOST, ENVISAT PDS at ESRIN has adopted a similar verification scheme. This ensures that also the cL0 repository at D-PAC hosts only those products which are required for high quality level 0-1b and level 1b-2 processing campaigns.

2. CONSOLIDATED PRODUCT QUALITY MONITORING

Consolidated products have been generated at LRAC and delivered to D-PAC for parts of the Commissioning Phase and – with the goal of completeness – since 2 August 2002, when a quasi-routine measurement program had started. Since then some of the delivered cL0 products occasionally were erroneous or ambiguous. Such cases included:

- Orbits were not covered by cL0 products although SCIAMACHY was operational.
- cL0 products with incomplete consolidation, i.e. the product duration did not comply with the actually planned and executed instrument operations in that particular orbit.
- For one orbit there could be more than one cL0 product. These products were identical or different in content.
- cL0 products exhibited corrupt data (e.g. exceeding the Reed Solomon correction threshold, sync bit errors).
- cL0 products with incorrectly assigned orbit numbers.

The cL0 verification scheme consisted of a sequence of checks where cL0 information retrieved from the

- filename
- Main Product Header (MPH)
- Secondary Product Header (SPH)
- data format
- product size

was compared with cL0 relevant parameters extracted from SCIAMACHY mission planning information, Operation Change Requests (OCR) and unavailability reports.

The SOST verification accepted only one cL0 product per orbit with the same consolidation flag. Also orbits where the check indicated corrupt measurement data were rejected entirely although operational processing could use part of the orbit up to the elapsed time where the corruption occurs.

The orbits with incomplete consolidation required a particular treatment. As long as their product content did not show any other failure, they were also accepted and transferred to the master archive.

3. CONSOLIDATED LEVEL 0 STATISTICS

Before reaching the final cL0 status of a particular year several verification steps were needed. It started using the continuously delivered cL0 products. Once a year had been completed, up to two re-consolidations were requested for recovering as many products as possible for missing, corrupt or incompletely consolidated orbits.

Applying this verification scheme for the entire in-orbit mission phase August 2002 – April 2012 has yielded more than 46700 fully consolidated level 0 orbits in the master archive. About 780 orbits were only partially consolidated but showed no other anomaly. Finally, in about 1010 orbits the quality of the cL0 data was not acceptable or the data, although acquired, was not available at all (ground segment unavailability or data lost). Overall, between 97%-98% of the orbits with SCIAMACHY operating in MEASUREMENT TIMELINE mode could be processed in consolidated form (Figure 1 and Table 1).

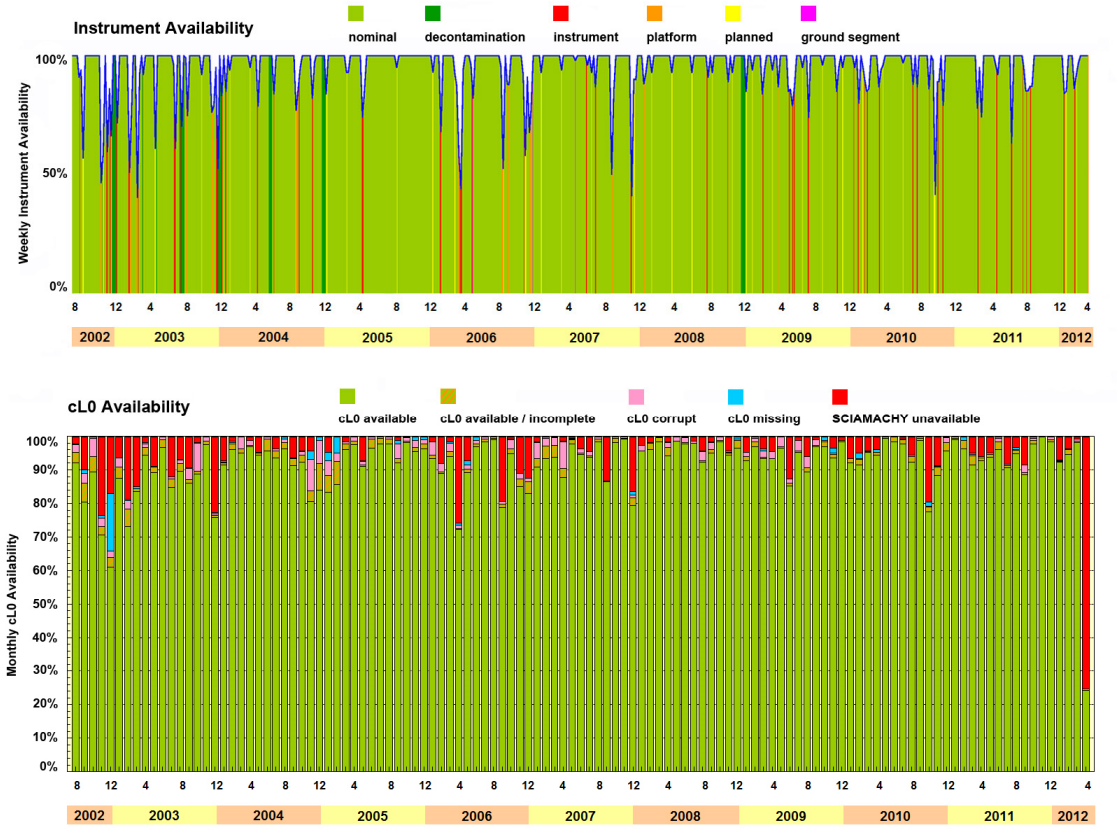

Figure 1. Availability of SCIAMACHY (top) and cL0 products (bottom) for the years 2002-2012. The most frequently occurring anomalies are indicated ('cL0 corrupt' includes Reed Solomon error and 'missing' includes orbits where the downlink was unavailable).

Consolidated Level 0 Statistics - 2002-2012 (Absolute)								
Year	Orbits							
	Total Orbits	SCIAMACHY Unavailable	cL0 Available	cL0 Available / Incomplete	Reed Solomon Error	cL0 Product Corrupt	Downlink Unavailable	Missing Orbits
2002	2176	229	1713	79	39	29	n.a.	87
2003	5224	447	4562	105	47	52	n.a.	11
2004	5239	144	4838	118	46	69	n.a.	24
2005	5225	65	4916	107	48	41	0	48
2006	5225	377	4681	62	19	67	4	15
2007	5224	181	4852	83	21	77	0	10
2008	5240	77	5048	47	17	43	5	3
2009	5224	165	4917	41	12	73	13	3
2010	5229	236	4888	72	7	9	11	6
2011	5243	157	4981	58	15	18	0	14
2012	1415	49	1349	8	3	5	2	1
Total	50664	2127	46745	780	274	483	35	222

Consolidated Level 0 Statistics - 2002-2012 (%)								
Year	Total Orbits	Fraction (%)						
		SCIAMACHY Unavailable	cL0 Available	cL0 Available / Incomplete	Reed Solomon Error	cL0 Product Corrupt	Downlink Unavailable	Missing Orbits
2002	2176	10,52	78,72	3,63	1,79	1,33	n.a.	4,00
2003	5224	8,56	87,33	2,01	0,90	1,00	n.a.	0,21
2004	5239	2,75	92,35	2,25	0,88	1,32	n.a.	0,46
2005	5225	1,24	94,09	2,05	0,92	0,78	0,00	0,92
2006	5225	7,22	89,59	1,19	0,36	1,28	0,08	0,29
2007	5224	3,46	92,88	1,59	0,40	1,47	0,00	0,19
2008	5240	1,47	96,34	0,90	0,32	0,82	0,10	0,06
2009	5224	3,16	94,12	0,78	0,23	1,40	0,25	0,06
2010	5229	4,51	93,48	1,38	0,13	0,17	0,21	0,11
2011	5243	2,99	95,00	1,11	0,29	0,34	0,00	0,27
2012	1415	3,46	95,34	0,57	0,21	0,35	0,14	0,07
Total (%)	50664	4,20	92,26	1,54	0,54	0,95	0,07	0,44

Table 1. Annual SCIAMACHY cL0 statistics for the time period 2 August 2002 – 8 April 2012 with absolute (top) and fractional numbers (bottom) for various types of consolidation or data qualities.

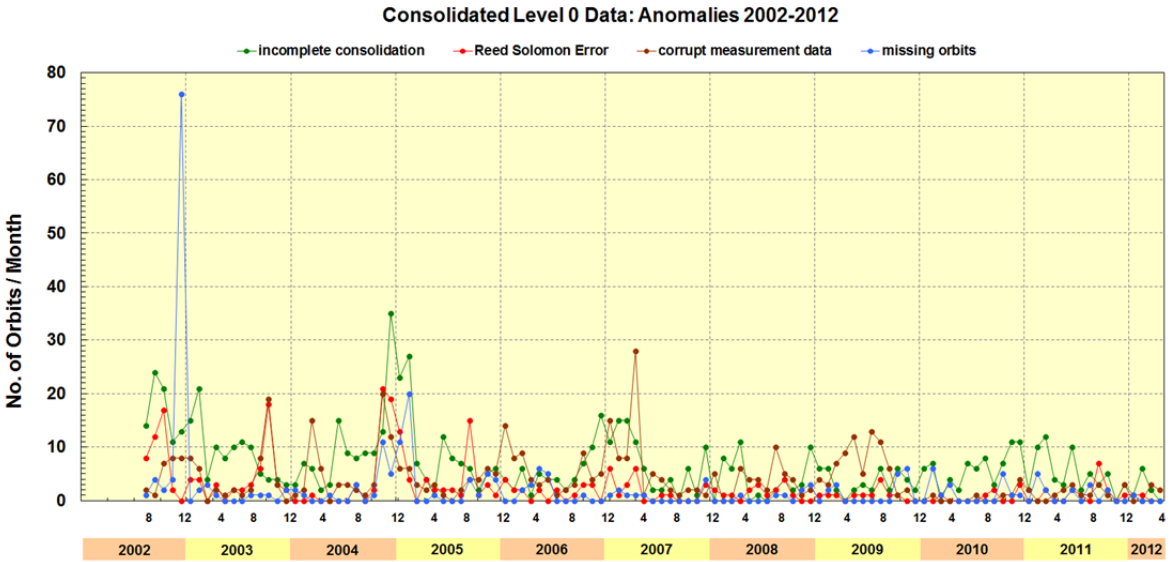

Figure 2. Monthly rate of incompletely consolidated, erroneous and missing cL0 products between 2002 and 2012. When half of the in-orbit mission lifetime was reached, the rate remained about constant.

4. CONSOLIDATED LEVEL 0 ANALYSIS

Although the current cL0 availability is already rather high and matches well the overall instrument performance (see Figure 1), our goal is to recover in phase F as many of the inconsistent orbits as possible. For this purpose a more detailed analysis down to orbit level is required.

It is obvious from Table 1 that over the years the rate of cL0 inconsistencies had decreased. For almost all types of inconsistencies the final figures were considerably lower than in the early mission phase. This can be attributed to an overall improvement in ground segment operations including the consolidation process. How erroneous cL0 orbits developed on a monthly basis is shown in Figure 2.

Individual entries in the cL0 archive content can be characterized by orbit number, product duration and product size. This includes incompletely consolidated orbits accepted, as long as a fully consolidated product is unavailable. Several types of cL0 classes could be identified based on duration and particularly size. They comprised:

Completely consolidated orbits:
They consist mainly of orbits with nominal measurements, i.e. they executed the timeline sequences 1,47,63,53 (sequence 1) or 1,50,63,44 (sequence 2). The state and timeline definitions had changed slightly throughout the SCIAMACHY phase E in response to various Operation Change Requests (OCR). In total 7 timeline sets, starting with t/l set 25 and ending with t/l set 36, were used for nominal measurements. The duration of the entire timeline sequence for a nominal orbit amounted to about 5550 sec (± 20 sec). In each orbit about 500 sec were reserved for idle phases. Two idle gaps were always planned for potential engineering activities, one of about 200 sec duration between the end of an eclipse timeline and the start of the Sun occultation timeline and one of also 200 sec duration between the end of the timeline in the illuminated part of the orbit and timeline 63 when entering the eclipse phase. Additional small gaps were introduced when scheduling a Sun or Moon fixed event because the timelines involved had a fixed length while the occurrence of the Sun/Moon events changed with season along the orbit. The resulting idle periods were of the order of the duration of 1-2 states, i.e. about 100 sec. Because of the early occurrence of orbital sunrise between mid May and the second half of July, a full orbital timeline sequence fits between two consecutive ENVISAT ascending node crossings (ANX to ANX+1). Thus the first limb state in the Sun occultation timeline 1 was started as the first state after ANX and the last state in the planned eclipse timelines (44 or 53) always before ANX+1. The resulting product duration amounted to about 5700 sec (orbital period minus the total duration of the idle phases at the beginning and end of the orbit starting at ANX). All the rest of the year sunrise occurred late in the orbit such that the eclipse timeline had not yet stopped when the next orbit started. A state from the eclipse timeline of the previous orbit (ANX-1) now defined the first state shortly after ANX and one of the states in the eclipse timelines was executed shortly before ANX+1. This yielded a product duration of about the orbital period, i.e. 6000 sec. In summary for most of the fully consolidated orbits two data clusters are expected in the product duration / product size diagram, one at 5700 sec and another at 6000 sec.

Completely consolidated orbits (limb_mesosphere_lower_thermosphere measurements):
This case is identical to the orbits with nominal measurements except that on the dayside of the orbit timelines 14 and 15 were executed. In both the limb_mesosphere_lower_thermosphere state (ID 55) replaced all limb states. Because of the lower radiances at the sensed altitudes and consequently longer exposure times a smaller data volume is expected. The limb_mesosphere_lower_thermosphere measurements started in mid 2008 in response to OCR_036.

Incompletely consolidated orbits:
Sometimes not all acquired measurements of a particular orbit were received on-ground or were used in the level 0 consolidation process. This yielded incompletely consolidated products. The more data exist in a cL0 product, the longer the product duration and the larger the product size. This defined a linear trend.

Monthly calibration orbits:
Monthly calibration orbits executed a predefined timeline sequence which differed from those for nominal measurement orbits. They are expected to group at a certain location in the product duration / product size diagram.

Orbits with start of instrument unavailability:
Whenever an instrument unavailability had occurred, either triggered by an instrument anomaly, a platform anomaly or a planned measurement interrupt, measurements had stopped in an orbit and the scheduled measurement programme for this particular orbit was not entirely executed. Productwise it resembled incompletely consolidated orbits. The sooner the unavailability had occurred, the shorter the product was, i.e. the smaller the product size. Therefore such orbits should follow the size / duration relation as that for incompletely consolidated orbits.

Orbits with end of instrument unavailability: As for the unavailability 'starting' case, the data volume of cL0 products depends on when SCIAMACHY resumed measurements after an unavailability, i.e. how much of the particular orbit could be recovered. The longer the recovered part, the higher the data volume.

Non-nominal orbits due to an OCR:
OCRs implemented operational changes which modified state or timeline definitions or even required modified mission scenarios. In most of the cases the acquired data volume was not affected but certain OCRs indeed resulted in a considerably different data volume (e.g. when the upload of a large amount of CTI parameter tables required the introduction of additional idle gaps).
How the individual cL0 classes appear in the product duration / product size diagram is illustrated in Figure 3 for the year 2010 (the same graph for the entire in-orbit mission period 2002-2012 is displayed in Figure 6). In Figure 3 the two distinct clusters at about 6000 sec and 5700 sec for completely consolidated orbits, as explained in the text due to seasonal variability, are obvious. The classes define a clear pattern. Outliers could be easily identified such they become subject to further investigations.
Figure 4 displays the relation between orbit number and product duration. Again it highlights the seasonal duration pattern. Incompletely consolidated orbits and those related to instrument unavailabilities caused shorter product durations. Orbits with monthly calibrations, limb_mesosphere_lower_thermosphere measurements and implemented OCRs are mainly found at the level of the duration of completely consolidated orbits.

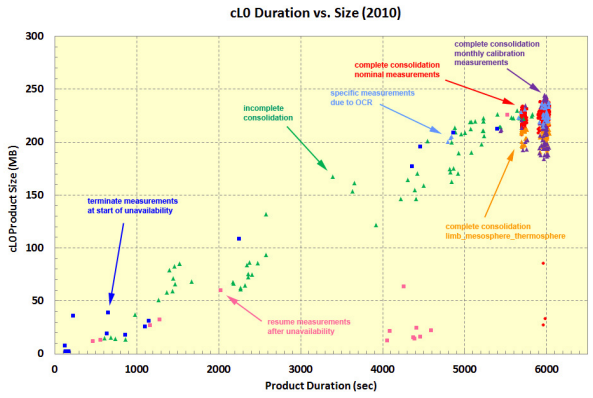

Figure 3. cL0 classes in product duration / product size space for the year 2010.

In October 2010 the ENVISAT orbit altitude had been reduced by 17 km, i.e. the orbital period changed from 6036 sec to a slightly drifting value of 6014 sec. This effect is even visible in Figure 4 around orbit 45000.
Product size as a function of orbit number is given in Figure 5. Now the orbits with monthly calibrations and limb_mesosphere_lower_thermosphere measurements are clearly separated from the fully consolidated orbits with nominal measurements. The latter display no seasonal behavior because for both periods between May and July and for the rest of the year each orbit is covered by the same amount of states and idle phases. The effect described above causing the duration pattern has no effect on product volumes.

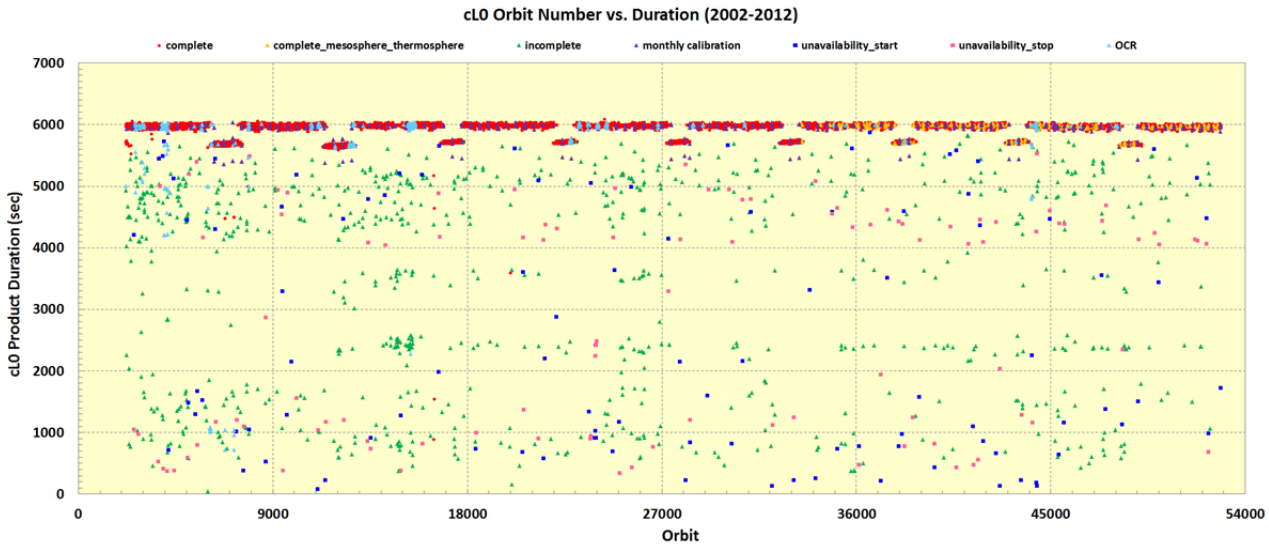

Figure 4. Product duration as a function of orbit number.

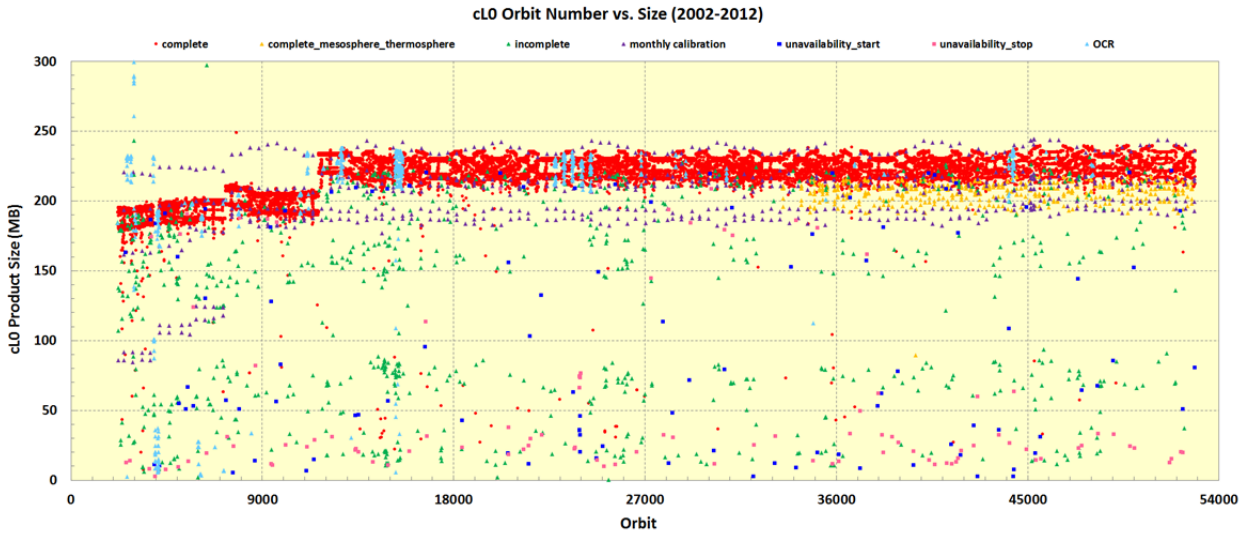

Figure 5. Product size as a function of orbit number.

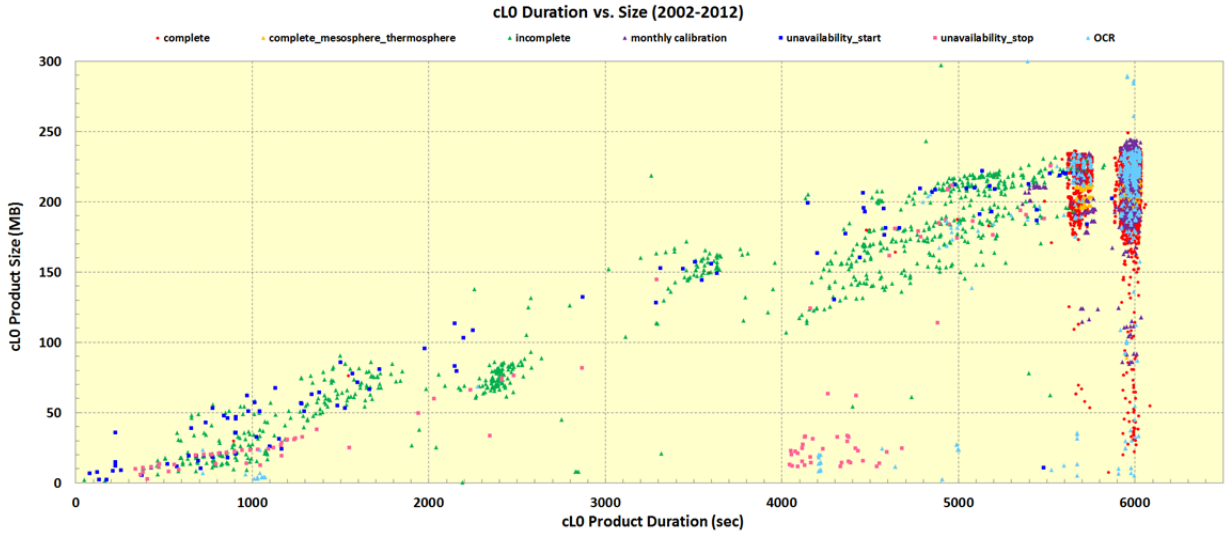

Figure 6. Product size as a function of product duration.

The changes in product size at orbit 7268 and 11639 are triggered by permanently implemented OCRs. From Figure 5 the cL0 product size of nominal measurement orbits can be estimated to amount to 228 ± 8 MB (since 22 May 2004 = orbit 11639).

Figure 6 finally illustrates the product size as a function of product duration. All individual classes from Figure 3 are now shown with even higher significance. Six cL0 products in the early mission phase around orbit 3000 displayed exceedingly high data volumes of about 1000-1300 MB. They have been identified erroneous and are off-scale in Figure 6.

The patterns in Figure 6 can be characterized as follows:

Scatter in product size of about ± 15 MB for completely consolidated products:

Nominal measurement orbits with and without the moon either used the long solar occultation state ID 49 producing measurement data for 130 sec or the short occultation state ID 47 when the orbit_no_moon_daily_calibration_1 scenario was executed. In the latter case two additional solar states, ID 68 (Sun_scanning_fast_sweep) and ID 17 (SUN_ASM_diffuser_calibration) were running in the Sun Occultation & Calibration (SO&C) window. These three solar acquisitions in the first daily calibration orbits resulted in a total measurement duration which

was about 30 sec shorter than in a nominal measurement orbit. Additionally, the ASM diffuser state generated fainter spectra for another 30 sec. It caused smaller level 0 data volumes in the first daily calibration orbit. Thus the cluster of completely consolidated orbits with data volumes between about 215 MB and 245 MB is considered reasonable.

Completely consolidated products with a too small product size < 150 MB:

Whenever the product size falls below about 150 MB (mainly the 'tail' extending below the cluster of red data points at a duration of 6000 sec), actually executed states in the consolidated products are missing. Such 'lost' states never occur at the beginning and end of the orbit, i.e. the product duration is compliant with the expected value but the state sequence does not fully reflect the executed measurements. The number of missing states can range from only a very few up to a considerable amount. The more states are missing, the larger the difference between nominal and actual data volume. For several examples we verified that the states were already missing in the NRT files. Thus level 0 consolidation could not have produced a different result.

Completely consolidated products with a too large product size > 250 MB:

They are off-scale in Figure 6 and represent the opposite case of the previous feature. Only 6 cases could be identified in 2002. An inspection of the corresponding cL0 products revealed that parts of the state sequences were obviously multiplied. This could have occurred in the consolidation process or the corrupt sequences were already present in the NRT products.

Scatter in product size of about ± 20 MB for incompletely consolidated products:

Incompletely consolidated products occur when parts of the executed state sequence at the beginning or end of the orbit were lost in the consolidation or had not been present in the NRT products already. However additional series of missing states may be present within the state sequence thus reducing the product volume even further from what is expected. The observed scatter in product volumes for incompletely consolidated orbits is then simply a result of 'lost' state sequences of various length. As in the case of completely consolidated products with a too small size we had verified whether such states were also missing in the underlying NRT products. They are indeed not present therein such that a re-consolidation could not improve the situation.

Orbits where an instrument unavailability ended:

Whenever an unavailability had ended, scheduled measurements started by executing the first possible MPS driven timeline 63 (executing state ID 65) after the instrument had again achieved MEASUREMENT mode. Therefore the state sequence in the consolidated product in such orbits should start with state ID 65. Before the MPS schedule could be resumed, the recovery procedure required to trigger the execution of timeline 63 manually as part of the Flight Operation Procedure (FOP) for the transfer from HEATER to MEASUREMENT mode. This generated, in addition, state 65 measurement data. Depending on when the FOP driven state ID 65 execution was scheduled – either in the same orbit as the MPS driven state ID 65 execution afterwards or in the previous orbit – two states 65 could appear in the consolidated product. Since a time gap of about 1 hour usually existed between FOP and MPS driven timeline 63 execution, the product duration as calculated from the start times of the first and last state in the cL0 file is much larger than the actual time period spanned by the measurement data, i.e. the product duration does not match the product volume. This is the reason for the cluster of orbits with a duration between 4000-5000 sec and a product size of < 100 MB. For the other orbits of this class, which follow the expected linear duration / size relation, only a single state ID 65 is included in the cL0 file. This was because the FOP was either executed without timeline 63, entirely omitted because SCIAMACHY had remained in IDLE mode or a wider time margin between FOP execution and resuming the MPS schedule was applicable.

CONCLUSIONS

We have developed and implemented a quality control scheme for SCIAMACHY cL0 products. The content of all such products has been compared with mission planning information. In addition, the overall product integrity was verified. This ensured to generate and maintain a data archive with very high coverage of cL0 products for the entire in-orbit mission lifetime 2002-2012 of about 97%-98%.

Orbits with erroneous and inconsistent cL0 data have been identified and are subject to further investigations. Our goal is to re-consolidate as many of these as possible such that the cL0 availability can be increased even further.

Our cL0 verification activities are the basis for level 0-1b and level 1b-2 reprocessing campaigns whenever highest product precision is required. Having achieved a thorough understanding of the cL0 data repository is a pre-requisite for preparing the final SCIAMACHY data products for the envisaged long-term data preservation.