4. Instrument Operations

SCIAMACHY's measurement operations concept required combining the prerequisites of the ENVISAT environment – both space and ground segment, the challenging scientific needs and the characteristics of the sensor. Finally a building block concept was developed which permitted full utilisation of the instrument's flexibility without using too many resources of the ENVISAT mission or violating the requirements of the atmospheric science user community *(EADS Astrium 2003)*.

The characteristics of a polar orbiting platform with short telemetry coverage at the high latitude stations Kiruna or Svalbard demanded highly autonomous on-board operations. This comprises not only on-board anomaly detection and initiating corrective actions as part of the instrument control but also the ability to configure the instrument status and to execute measurements without direct manual intervention from ground. Thus the pre-planned measurement schedule must be executed on-board in a time tagged way.

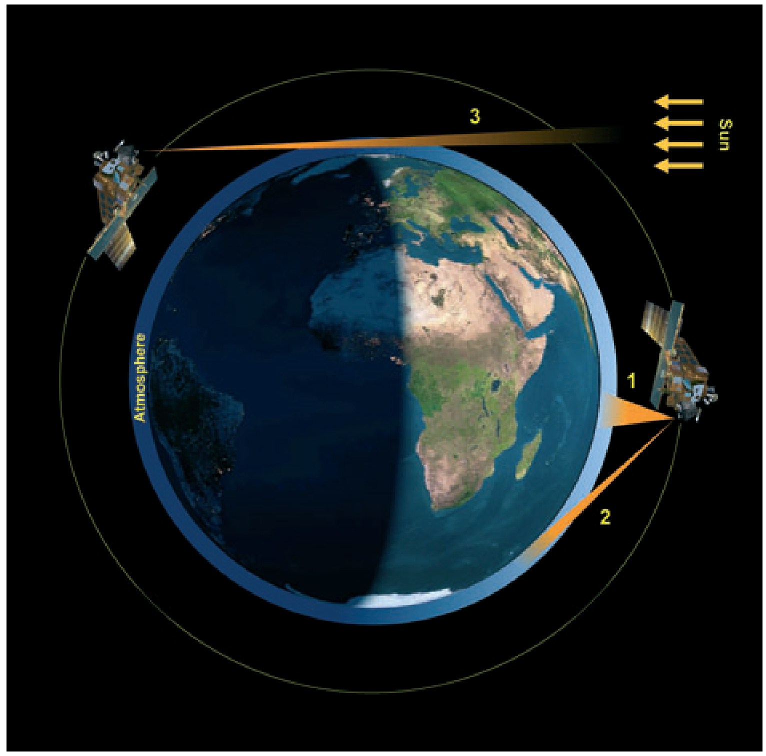

Fig. 4-1: SCIAMACHY's scientific observation modes: 1 = nadir, 2 = limb, 3 = occultation. (graphics: DLR-IMF)

Scientific requirements include viewing geometries for atmospheric measurements of nadir, limb, sun occultation and moon occultation. In addition, external (e.g. dark current, sun reference) and internal (calibration lamps) observations supplement the measurement schedule. One of SCIAMACHY's main objectives is to measure the same atmospheric volume both in nadir and limb within one orbit, i.e. limb/ nadir matching. This can be achieved by first observing an atmospheric volume at the horizon by looking slightly off the flight direction towards Earth's rotation. Later in orbit, after a time interval Δt = 430 sec, the same volume of air crosses the sub-satellite point and can be observed under nadir conditions. The interval of Δt = 430 sec is

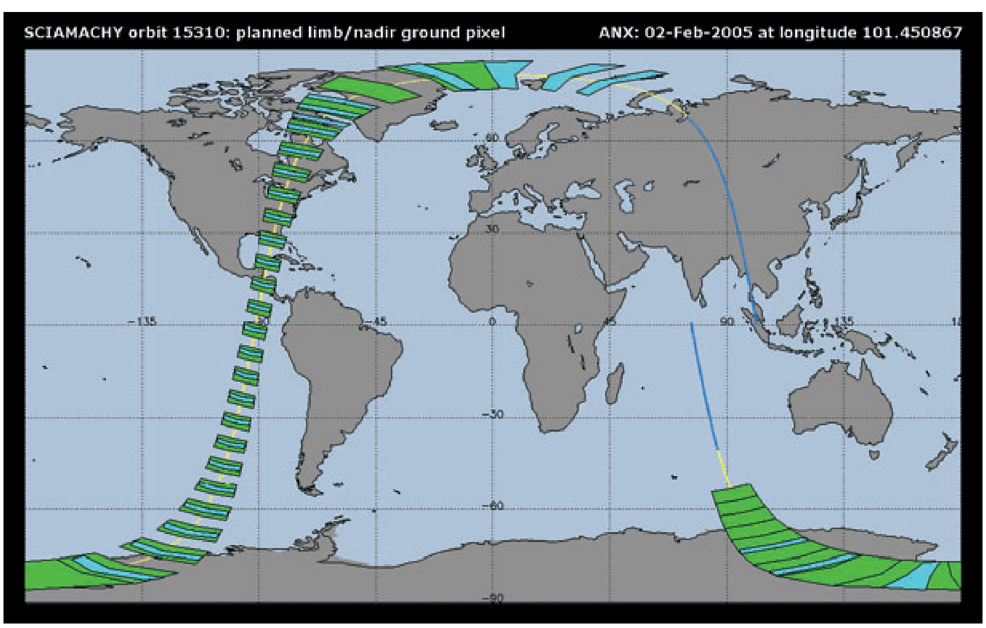

Fig. 4-2: An orbit with planned limb/nadir matching on the dayside of the orbit. The sequence of nadir and limb states in a timeline is arranged so that limb ground pixels (blue), defined by the line-of-sight tangent point, fall right into a nadir ground pixel (green). At the beginning and end only limb or only nadir measurements are executed. (graphics: DLR-IMF)

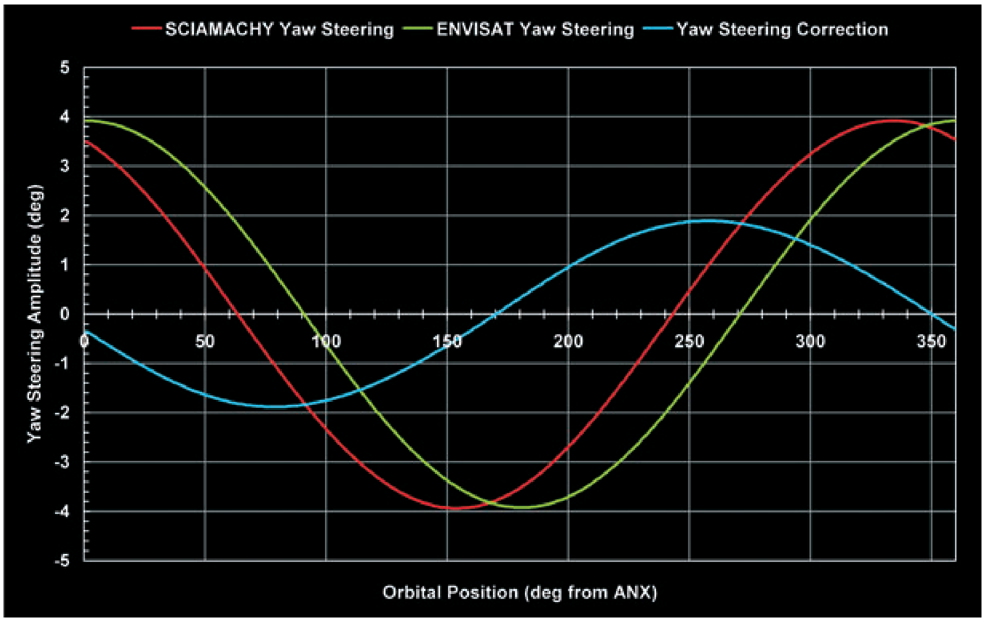

Fig. 4-3: ENVISAT's yaw steering, the yaw steering correction of limb states and the resulting SCIAMACHY yaw steering. Between ENVISAT and SCIAMACHY yaw steering an orbital shift of 27° exists which reflects the observation geometry when looking to the horizon in flight direction. (graphics: DLR-IMF)

the result of the angular velocities of Earth and spacecraft platform. In limb mode, SCIAMACHY observes the horizon 3280 km ahead of the instrument close to flight direction. Because the spacecraft's yaw steering is determined by the Earth's angular velocity at the instantaneous sub-satellite point, the line of sight does not intercept the horizon at a point where the Earth's and spacecraft's angular velocities lead to limb/nadir matching. Therefore, an instrument yaw steering correction is implemented in SCIAMACHY's on-board software to compensate for the phase shift between local yaw steering and instrument line of sight in limb observations. It reflects the angular difference of approx. 27° between local sub-satellite point during limb measurement and line of sight interception at the Earth's horizon (fig. 4-3).

4.1 Sun and Moon Observation

All measurement activities are planned relative to solar and lunar constellations. SCIAMACHY operations are either sun or moon fixed, but not Earth fixed *(SOST 1996)*. Since solar and lunar constellations, as viewed from ENVISAT's orbit, are determined by the orbital motion of the platform, the orientation of the orbital plane, the lunar motion around Earth and the Earth's movement around the sun, the observing conditions can be completely predicted by careful orbit analysis. These predicted conditions are then translated into configurable instrument states and timelines.

Sun Occultation

The mean local time of 10 a.m. during descending node crossing leaves the sun always to the left of the flight direction, i.e. at azimuth angles > 180°. The elevation of the sun varies between approx. -70° and +70°. Sunrise occurs after ascending node crossing when ENVISAT moves towards the North Pole on the eclipse side of the orbit. The sun becomes visible at the Earth's limb left of the flight direction at medium to high geographic latitudes. The exact latitude is dependent on the actual position of the *true* sun relative to the Earth (*true* sun reflects the actual annual orbital motion of the Earth contrary to the *mean* sun which is characterised by assuming a constant Earth orbital velocity). In summer, sun occultation measurements start when the spacecraft has reached geographic latitudes of about 27° north while in winter the sub-satellite point moves up to about 75° north. At sunrise the solar elevation is identical to the elevation of the Earth's limb, i.e. approx. 27.2°. The azimuth angle at sunrise has a mean value of 330°, corresponding to the mean local time at descending node crossing of 10 a.m. and changes over a year due to the apparent motion of the true sun. Caused by the orbital motion of ENVISAT, the sun rises almost vertically through SCIAMACHY's limb TCFoV. In an occultation measurement, the ASM has to acquire the sun at an angle of about 330° and to follow the slightly changing azimuth as the sun moves higher. In the elevation direction the sun must be tracked by the ESM up to the maximum elevation angle of 19.5°, limited by the TCFoV. From the Earth's limb up to an elevation angle of 25.2°, corresponding to an altitude of 100 km, the sunlight is absorbed by the Earth's atmosphere. Thus the sun serves both as a target for probing the atmospheric trace gas constituents (altitude < 100 km) and for calibration and monitoring measurements (altitude > 100 km). Therefore the total time of the sunrise in the limb TCFoV is referred to as *Sun Occultation & Calibration (SO&C)* window.

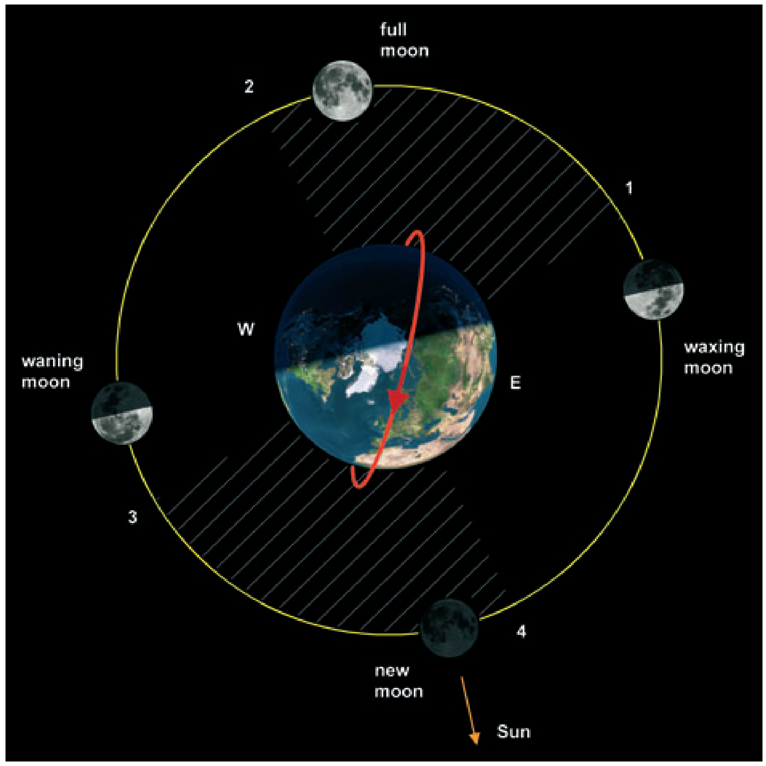

Fig. 4-4: SCIAMACHY's monthly lunar visibility occurs between 1 and 2 over the southern hemisphere (lunar phase > 0.5). The hatched area illustrates the limb TCFoV of 88°. Visibility at smaller lunar phases over the northern hemisphere between 3 and 4 is not used because it coincides with solar occultation. (graphics: DLR-IMF)

Sub-solar Observations

The sub-solar port above the ESM provides additional access to the sun above the atmosphere. Because sun viewing in this configuration does not involve the ASM, measurements of this kind can be used to monitor the behaviour of the ASM mirror. The sun is visible through the sub-solar port when the sun has reached its highest elevation. This occurs at an azimuth angle of 270°. The sub-solar elevation angle changes continuously with season. Therefore the sun moves up and down over a year along the elongated dimension of the sub-solar TCFoV when passing through the window. The duration of a sub-solar measurement is defined by the time it takes the sun to pass through the azimuth dimension of the sub-solar port, reduced by the small aperture stop to only 0.72°. This interval amounts to 21 sec, with the sun being fully visible for a short period of only 3.5 sec.

Moon Occultation

Individual observations of the moon follow the same principles as described for the sun. The lunar disk is acquired by the ASM and ESM and tracked as the moon rises through the limb TCFoV. As in the case of the sun, the moon acts both as a target for scientific and for calibration & monitoring measurements. The corresponding time interval is named *Moon Occultation & Calibration (MO&C)* window. Predicting lunar occultation measurements requires analyses of the viewing conditions as a function of the monthly lunar motion. For a full orbit the moon moves in *direct motion* within a *synodic month* of 29.53 days. The moon's orbital plane is inclined by 5.1° to the ecliptic. Thus, to a first order, the moon's orbital plane lies perpendicular to ENVISAT's orbital plane. Whenever the lunar orbit crosses the limb TCFoV of SCIAMACHY, moonrise can be observed. With a total azimuth size of 2 × 44° for the limb TCFoV, the monthly time interval when lunar measurements can be executed is

$$\Delta_{moon} = \frac{88°}{360°} \cdot 29.5\, days \approx 7.2\, days$$

The duration of each monthly observation opportunity displays a seasonal variation of between 5.5-8 days. Due to the lunar orbital motion, the first moonrise in a monthly period occurs on the left side of the limb TCFoV (azimuth = -44°). Each orbit moonrise progresses with an azimuth rate of about 1°/orbit to the right side of the limb TCFoV. At the end of the monthly visibility, the moon has reached the right edge of the TCFoV (azimuth = +44°). The lunar phase changes continuously within each monthly period. At the beginning of the visibility, the phase amounts to about 0.6–0.7. Full moon can be observed close to the end of the monthly cycle because the 10 a.m. descending node crossing time criterion of ENVISAT's sun-synchronous orbit only allows full illumination of the lunar disk when the moon lies at an azimuth of about 30°. Moonrise occurs over a large range of geographic latitudes. Different to sunrise, where the geographic latitude of the sub-satellite point (and thus also the geolocation of the tangent point where the atmosphere is probed) changes slowly over a year, the latitude of the sub-satellite point at moonrise varies significantly within a monthly period. This fact is particularly interesting for the occultation measurements because it allows studying the atmosphere at various latitudes. Moonrise at lunar phases > 0.5 can only be observed over the southern hemisphere. This complements solar occultations which are restricted to the northern hemisphere.

Fig. 4-5: The rising moon seen from a spacecraft in a low-Earth orbit. Differential refraction distorts the lunar disk. (photo: NASA)

Refraction

Observation of sunrise and moonrise from a spacecraft is affected by the refractive properties of the Earth's atmosphere. Because the sun and moon have almost the same apparent size of 31.5 arcmin the effect of refraction is identical for both. The refraction angle depends on the Earth's radius, the scale height of the exponentially decreasing refractivity profile, the refractivity and the height of the tangent point of the incident rays. For visible light the refraction angle amounts to approx. 70 arcmin at the horizon (h = 0 km), i.e. SCIAMACHY can observe the first solar/lunar photons when the sun/moon is still well below the geometric horizon. As the unrefracted sun/moon rises, the refracted image of the disk is distorted by differential refraction (fig. 4-5). At an altitude of h ≈ 17 km refraction has become so small that refracted image and solar/lunar disk overlap. Below this height the angular rate of the rising sun/moon as defined by the moving spacecraft is larger than the variable rate of their refracted images. At low altitudes, measuring the sun or the moon can become difficult due to obscuration by or reflected radiation from clouds. On-board control of the scan mirrors during occultation uses the Sun Follower with its relatively wide field of view of 2.2° × 2.2°. Since the brightness of the lunar disk can be insufficient to exceed that of an illuminated cloudy atmosphere, moon occultation measurements are only possible when the moon rises on the night side beyond the terminator.

4.2 Reference Measurement Orbit

A typical SCIAMACHY orbit starts above the northern hemisphere with an observation of the rising sun. In order to acquire also light from the sparsely illuminated atmosphere at the limb in the direction of the rising sun, a sequence of limb measurements precedes each sun occultation measurement. Once the sun has risen, it is tracked by the ESM for the complete pass through the SO&C window. After about 175 sec the sun leaves the limb TCFoV at the upper edge. In order to fully exploit the high spatial resolution during occultation, measurement data readout with a high rate is required in the SO&C window. Until the passage of the sub-solar point, a series of matching limb/nadir observations are executed. At the sub-solar point the sun, generally close to descending node crossing, has reached its highest elevation relative to ENVISAT. Whether a sub-solar measurement is actually executed depends on whether a sub-solar calibration opportunity has been assigned by ENVISAT. Because of the vignetting of the sub-solar TCFoV by the Ka-band antenna in operational position, only 3 orbits per day with sub-solar opportunities are possible, of which nominally one has to be selected. Another sequence of matching limb/nadir measurements follows. Above the southern hemisphere, the moon becomes visible during the monthly moon visibility period, otherwise matching limb/nadir observations continue. The rising moon is observed similarly to the rising sun from bottom to top of the limb TCFoV. A series of limb/nadir observations concludes the illuminated part of the SCIAMACHY orbit. Because the instrument is still viewing sunlight while the projected ground-track in the flight direction will already have seen sunset, the final measurements in this phase are only of the nadir type. When ENVISAT enters the eclipsed part of the orbit, dedicated eclipse observations can be executed until SCIAMACHY moves towards another sunrise and the orbit sequence starts again (fig. 4-6). Ascending node crossing occurs always in eclipse phase. The reference orbit nicely illustrates the sun/moon fixed concept. While sun fixed events show a relatively stable temporal behaviour over a year, orbital segments related to moon occultation measurements do not. They exhibit strong variability both within a monthly moon observation period and over a year.

4.3 Mission Scenarios

It has proven useful to structure SCIAMACHY operations in the form of *mission scenarios (SOST 2001a)*. These define in a top-down approach objectives on various planning levels. The mission scenarios lead finally to a scenario for a single orbit, i.e. an orbital mission scenario that is the basis for continuous mission planning and scheduling. For nominal operations the orbital mission scenario is as follows:

- swath width of ± 480 km relative to ground track in nadir and limb scans for global coverage within 6 days (taking the alternating limb/nadir measurements into account)
- matching limb/nadir measurements in the illuminated part of the orbit
- sun occultation measurements each orbit
- moon occultation measurements whenever possible (moonrise on nightside of Earth)
- calibration & monitoring measurements on a daily (every 14th orbit), weekly (every 98th orbit) and monthly basis

The simplest orbital mission scenario is executed whenever the moon is not visible and no regular calibration & monitoring tasks have to be performed. This scenario occurs about 90 % of the time during a month and can be accommodated by 4 timelines (see below). The most complex scenario is defined when implementing monthly calibration & monitoring requirements. This consists of a series of 5 consecutive orbits filled with calibration & monitoring activities.

4.4 Parameter Tables

Utilising the high degree of flexibility in the instrument design can only be accomplished through parameterisation of on-board operations. For the execution of scientific and calibration & monitoring measurements this means that associated functions must be predefined and stored on-board with ground control having the capabilities to modify the instrument configuration by commanding. Changing the instrument status includes software updates via patching as well as parameter settings via commanding. Those sets of parameters which are associated with basic instrument properties, e.g. scanner, thermal and mechanism control definitions are termed *engineering* parameters. More than 4600 engineering parameters exist. Most of them have been defined prior to launch and were verified during the Commissioning Phase. During routine operations, engineering parameters are usually not subject to modifications. Parameters relating to the configuration of the spectrometer while measuring, the so-called *measurement* parameters, have also been defined prior to launch. However, changing scientific requirements

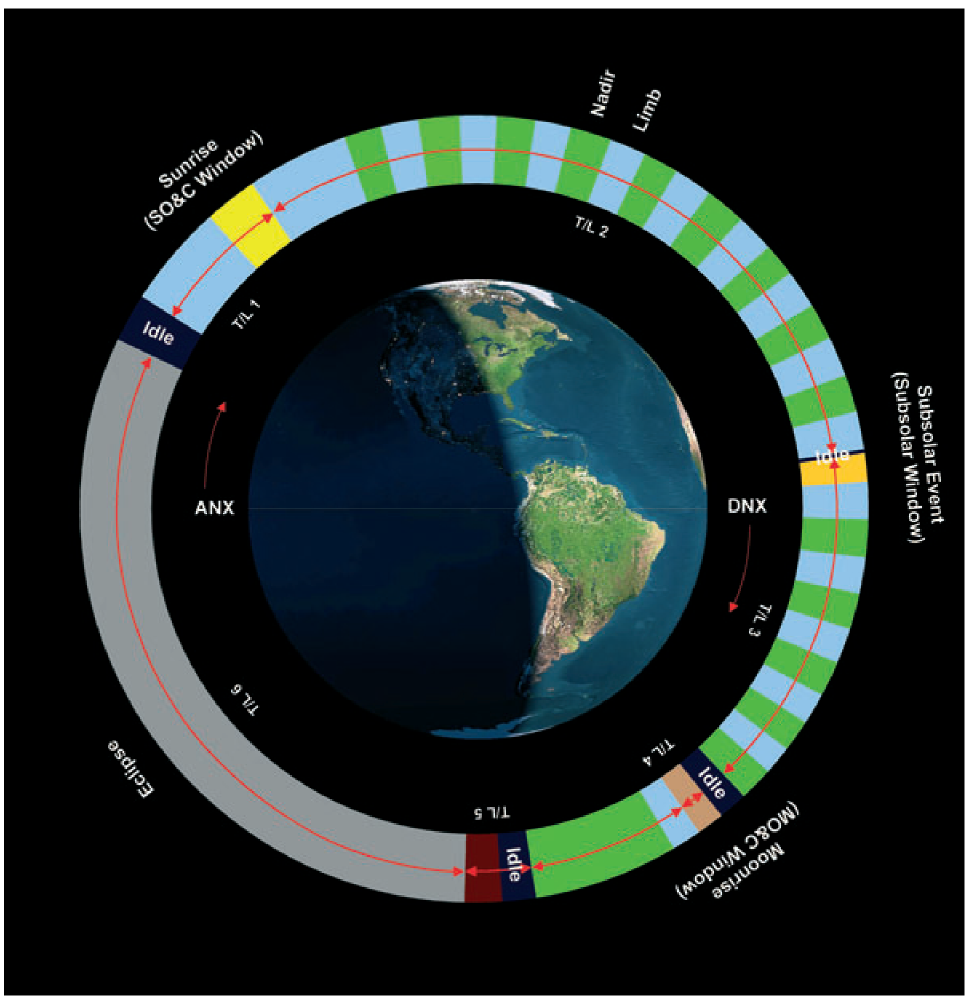

Fig. 4-6: SCIAMACHY reference orbit with sun/moon fixed events along the orbit. The events define orbital segments which are filled with timelines. State duration is not to scale. (graphics: DLR-IMF)

Type	*Table*	*Number of Used Parameters*
State	Scanner State	1820
	Pixel Exposure Time	140
	Hot Mode	70
	State Index	70
	State Duration	70
	Co-Adding	1120
	Detector Cmd Words	8
	DME Enable	8
Common	Basic Scan Profile	14
	Relative Scan Profile	48
	Cluster per Channel	4
	Cluster Definition	160

Table 4-1: Measurement parameter tables

and following lessons learned about actual instrument behaviour during the Commissioning Phase, have made it necessary to update measurement parameters occasionally. Both types of parameters were burnt into the EEPROM (Electrical Erasable Programmable Read Only Memory) unit during instrument development. Whenever the ICU is initialised or reset, the EEPROM content is loaded and expanded into the ICU RAM (Random Access Memory). A copy of this content is then further loaded into the work area of the RAM and this part of the ICU RAM can be accessed by macrocommands in order to update parameters as required. Engineering and measurement parameters are organised in a series of parameter tables defining common functional tasks.

Each table contains a number of parameters which can have several instances, e.g. more than 20000 measurement parameters are specified to execute all the required measurements. Spectrometer settings, both for the detectors and the scanners, are provided via measurement parameters (table 4-1). Tables usually relate to individual measurement states (see below) but 'common' tables serve all states. Particularly, the values of the pixel exposure times and the co-adding factors ensure, in conjunction with the definition of wavelength clusters, optimised signal-to-noise ratios over the complete orbit. The product of PET and co-adding factor yields the integration time, which defines the read-out frequency (see chapter 3.2). In the case where SWIR channels run into saturation, the so-called *Hot Mode* parameters allow decreasing the exposure times in channels 6-8 below the minimum PET of 31.25 msec. The characteristics of the ASM/ESM rotations are defined via the Scanner State, Basic Scan Profile and Relative Scan Profile parameters. The Basic Scan Profile specifies the underlying standard motion of the respective mirror whereas the Relative Scan Profile is a mirror movement superimposed onto the Basic Scan Profile, e.g. fast upward/downward scans in elevation while the ESM is basically slowly moving in elevation.

4.5 Measurement States

The individual functions to operate SCIAMACHY in measurement modes are defined as *states (SOST 2003)*. A state is a sequence of activities for a particular measurement task, e.g. nadir observations with certain pixel exposure times, sun occultation with certain scan geometry, etc. In total 70 states can be defined on-board. There they are stored as part of the Relative Time Command Sequence (RTCS) table which is also contained in the EEPROM and transferred to the ICU RAM. The entries in the RTCS table determine the execution of each state as a series of *primitive commands* which are activated sequentially once the first primitive command has been started. The parameters in the measurement tables control the execution of the primitive commands, i.e. of the state.

Definition

SCIAMACHY's scientific measurement objectives and requirements have necessitated the definition of the 70 individual states as listed in table 4-2. 34 states implement scientific requirements, 26 are for the purpose of in-flight calibration, 4 for in-flight monitoring and the data from 6 states can be used for scientific and calibration analyses. The high number of calibration & monitoring states is the result of the thorough and complex in-flight calibration & monitoring concept.

The definition of each state requires the translation of scientific requirements into instrument functions, configurable via parameter settings. Once a state has been specified, its configuration is frozen thus establishing the state final flight status. The corresponding parameter tables are uploaded on-board so that routine operations can execute the associated measurements whenever required. Changes to final flight definitions are possible but require consistency with the Operation Change Request (OCR) procedure.

Nadir and Limb States

Continuous observations of the illuminated atmosphere occur in a sequence of matching limb/nadir states. The standard setting requires a wide swath

State ID	State	Measurement Type	Remark
1 - 7	nadir 960 km swath	science	all orbital positions
8, 26, 46, 63, 67	dark current	calibration	pointing at 250 km
9 - 15	nadir 120 km swath	science	all orbital positions
16	NDF monitoring, NDF out	monitoring	
17 - 21	sun ASM diffuser	calibration	sun above atmosphere
22	sun ASM diffuser atmosphere	monitoring	various azimuth angles
23 - 25, 42 - 45	nadir pointing	science	all orbital positions
27	limb mesosphere	science	scanning 150 - 80 km
28 - 33	limb 960 km swath	science	all orbital positions
34 - 37, 40, 41	limb no swath	science	all orbital positions
38	nadir pointing left	monitoring	
39	dark current Hot Mode	calibration	
47	SO&C scanning/pointing	science, calibration	sun through and above atmosphere
48	NDF monitoring, NDF in	monitoring	
49	SO&C nominal scanning, long duration	science, calibration	sun through and above atmosphere
50	SO&C fast sweep scanning	calibration	
51	SO&C pointing	science, calibration	sun through and above atmosphere
52	sun ESM diffuser, NDF out	calibration	sun above atmosphere
53	sub-solar pointing	calibration	
54	moon nominal scanning	calibration	moon above atmosphere
55	moon pointing troposphere	science, calibration	moon through atmosphere
56	moon pointing	science, calibration	moon through atmosphere
57	moon pointing, long duration	science, calibration	moon through and above atmosphere
58	sub-solar pointing/nominal scanning	calibration	
59	SLS	calibration	
60	sub-solar fast sweep scanning	calibration	
61	WLS	calibration	
62	sun ESM diffuser, NDF in	calibration	sun above atmosphere
64	sun extra mirror pointing	calibration	sun above atmosphere
65	ADC, scanner maintenance	calibration	
66	sun extra mirror nominal scanning	calibration	sun above atmosphere
68	sun extra mirror fast sweep scanning	calibration	sun above atmosphere
69	SLS ESM diffuser	calibration	
70	WLS ESM diffuser	calibration	

Table 4-2: Measurement state definition

geometry both in nadir and limb geometry. This enables global coverage within 3 days in nadir only mode or 6 days when running matching limb/nadir sequences. At medium to high latitudes, complete coverage is achieved earlier.

For a nadir state, the instrument Instantaneous Line of Sight (ILoS) is pointed, via the ESM, to the sub-satellite point. Starting left of the flight direction, the ESM is then moved during 4 sec across track to the right with an angular rate yielding the required

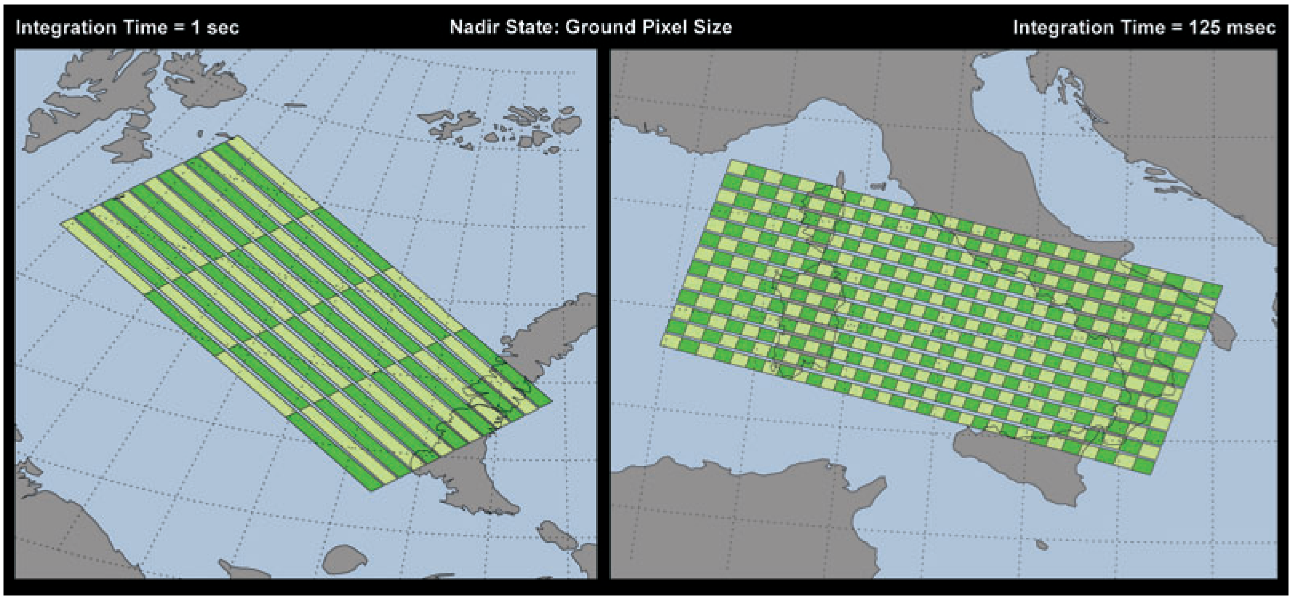

Fig. 4-7: The pattern of ground pixels in a nadir measurement for an integration time of 1 sec (left) and 125 msec (right). Only the forward scans are shown. This causes the along-track gaps between consecutive scans which vary in width due to a projection effect. Across-track extent is defined by the integration time while along track the size reflects the dimension of the IFoV with only a small contribution of the integration time. (graphics: DLR-IMF)

swath width on the ground. Having reached the turnaround on the right side, the ESM returns in 1 sec across track back to the left side. For each integration time, a channel dependent readout of the spectrum occurs. Depending on the measurement duration of the nadir state, a series of forward/backward scans cover a ground scene of typically 400 km along track. Within the ground scene, individual ground pixels have a size which is defined by the selected integration time. They vary from about 26 km × 30 km (along-track × across-track) up to 32 km × 930 km for wide swath settings (see fig. 4-7).

While a nadir state requires operation of the ESM only, a limb state has to acquire light from the Earth's limb via the ASM. This light is reflected onto the ESM and then further into the spectrometer. Routine limb observations start with a horizontal scan 3 km below the horizon from the right to the left side. A vertical step of 3 km moves the ILoS upwards and another horizontal scan of the selected width is executed in opposite direction. In a sequence of vertical steps and horizontal scans the full range of the atmosphere is observed nearly up to its top at about 100 km. When the last horizontal scan has finished, the ILoS is moved to an altitude of 250 km to obtain a short dark current measurement whilst pointing into open space. The IFoV at the distance of the Earth's limb corresponds to a ground pixel size of 103 × 2.6 km (across-track × height). As in the case of nadir states, the integration time determines the area covered by the readout, i.e. by the scanning IFoV. Largest limb ground pixels span 1060 × 3.6 km (across-track × height, including step height error), smallest 230 × 2.6 km across-track × height).

A limb state executes one of the most complex measurement functions defined for SCIAMACHY. This is due to the fact that ASM and ESM movements have to be synchronised with the channel readouts in the horizontal scans. The ground scene of a limb scan is usually defined by the geolocation of the line of sight tangent point at the start and end of the state. Due to the elevation steps executed, the tangent point of the line of sight moves towards the spacecraft as the platform moves along the orbit. This results in a rather narrow appearance of the along track extent of the limb pixels.

Since atmospheric illumination conditions vary along the orbit as a function of the solar zenith angle, maximum spectral signal-to-noise ratios require selection of pixel exposure times as a function of orbital position. Therefore science oriented states do exist for different orbital positions. In total 7 nadir states, each for wide and small swath settings, execute the same scanning trajectory but with different pixel exposure times. The same is true for limb states. Here 6 states each for wide and small swath cover all orbit positions.

Occultation States

While nadir, limb and those calibration & monitoring states which are using the internal calibration units, can be defined by selecting appropriate positions and scan ranges for the ESM and ASM, the states observing sun or moon require dynamic control of the scanners. Sun- and moonrise is affected by refraction, as mentioned above. This leads to different rates of the rising solar/lunar disks at the start of the occultation measurement. One rate results from refraction, the other from the platform's orbital motion. Scanner control via the Sun Follower would be able to compensate for this but cloud coverage may prevent the Sun Follower from successfully acquiring the solar or lunar disk. The control loop via the ICU works with a single scan rate only and is unsuitable for tracking the rising sun/moon in the early occultation phase. Therefore the corresponding states implement a dedicated sun/moon occultation procedure. At an altitude of about 17 km, refracted and geometrical images overlap significantly and rise with an almost constant rate. The ESM is rotated to this elevation and performs continuous vertical scans of 2 sec each with a vertical range of ±0.33°. The ASM is rotated to an azimuth angle which ensures that the sun or moon is within the field of view of the Sun Follower when their refracted disk appears at the limb. Because of the scan motion of the ESM, the object is detected at an altitude lying between the horizon and 17 km. Once the sun/moon has reached an altitude of 17 km above the horizon, control is switched either to the SF or ICU. In the latter case a single rate for the ESM is sufficient because from that elevation onwards refraction can be neglected. The ESM tracks the upward motion of the sun/moon in pointing or one of the scanning modes. Nominal scanning moves the ESM in 2 sec ±0.33° around the centre of sun or moon. Because the integration times are shorter than 2 sec, the light can be analysed in horizontal slices of the disk. The fast sweep is a 2.1° wide scan over the solar disk in 0.125 sec. The sweep is centered in the sun. The spectrometer records the integrated intensity at one sweep over the full disk.

Calibration & Monitoring States

Usually, calibration and monitoring states operate either the internal calibration lamps SLS and WLS, measure the dark signal from deep space or observe sun and moon. As long as the line of sight during solar or lunar sunrise traverses the atmosphere, i.e. below an altitude of 100 km, the data serve scientific requirements. Above 100 km, they support calibration & monitoring. Sun measurements above the atmosphere can either observe the solar disk via the scan mirrors or reflect the light via one of the two diffusers. By selecting different light paths – e.g. using the extra mirror – and scanning properties, analysis of solar and lunar states is not only able of providing sun reference spectra for data processing but also information about the status of various optical components.

	Calibration & Monitoring Measurement																								
Calibration & Monitoring Timescale	Sun nominal scan	Sun nominal scan/pointing	Sun fast sweep scan	Sun over ESM diffuser (NDFM in)	Sun over ESM diffuser (NDFM out)	Sun over ASM diffuser	Sun over extra mirror fast sweep scan	Sun over extra mirror pointing	Sun over extra mirror nominal scan	Sun over ASM diffuser through atmosphere	Sub-solar fast sweep scan	Sub-solar pointing/nominal scan	Sub-solar pointing	Moon pointing	Moon nominal scan	Dark current	WLS	SLS	WLS over ESM diffuser	SLS over ESM diffuser	NDFM monitoring (NDFM in)	NDFM monitoring (NDFM out)	Nadir pointing left	Nadir pointing	ADC
Window	SO&C										Sub-solar			MO&C											
Orbital																									
each orbit	49													57		8,26,46,63,67									65
Daily																									
1st orbit		47	50	62							60			56	54	8,26,46,63,67									65
2nd orbit		47				17-21	68							57		8,26,46,63,67									65
Weekly																									
1st orbit		47	50	62							60			56	54	8,26,46,63,67	61	59							65
2nd orbit		47				17-21	68							57		8,26,46,63,67									65
Monthly																									
1st orbit		47	50	62							60			56	54	8,26,46,63,67	61	59							65
2nd orbit		47			52		68					58				8,26,46,63,67			70						65
3rd orbit		47				17-21		64					53			8,26,46,63,67				69	48	16			65
4th orbit		47							66							8,26,46,63,67							38		65
5th orbit										22						8,26,46,63,67								23-25,42-45	65

Fig. 4-8: Calibration & monitoring scenarios from orbital to monthly timescales. In the top row the individual measurements and their targets, e.g. sun, moon, lamps, are listed. The states used in each calibration orbit, referring to the definitions in table 4-2, are outlined below. All states unrelated to the sun or the moon can be executed several times at any position along the orbit. (graphics: DLR-IMF)

Knowledge of the dark current signal is a prerequisite for successful interpretation of data from all measurement states. Therefore 5 dark current states are specified which cover all relevant integration times. Dark states are executed on the eclipse side during measurement orbits and along the whole orbit during special, monthly calibration orbits. In a dark current state, the line of sight is directed to and maintained at an altitude of 250 km. It corresponds to pointing into deep space well above the atmosphere. No Earthshine light is expected at this altitude and only the detector dark signal should be recorded.

SLS and WLS states are required to derive further pixel-dependent detector properties and to monitor the instrument's stability. Whenever one of these states is operated, the ESM is rotated to the position where its mirror reflects light from the lamps onto the entrance slit of the spectrometer. Orbital variations may be detected by running SLS or WLS states several times during an orbit. Since each lamp dissipates heat when operated, thermal perturbations have to be kept to a minimum.

The mission scenarios described in chapter 4.3 specify the execution of calibration & monitoring states on orbital, daily, weekly and monthly timescales. How frequently one of these states is scheduled depends on its specific measurement goal. The completed calibration & monitoring measurement plans have to ensure that all aspects of in-flight instrument characterisation are met. Fig. 4-8 depicts the associated measurements on orbital, daily, weekly and monthly timescales. State IDs refer to the definitions in table 4-2.

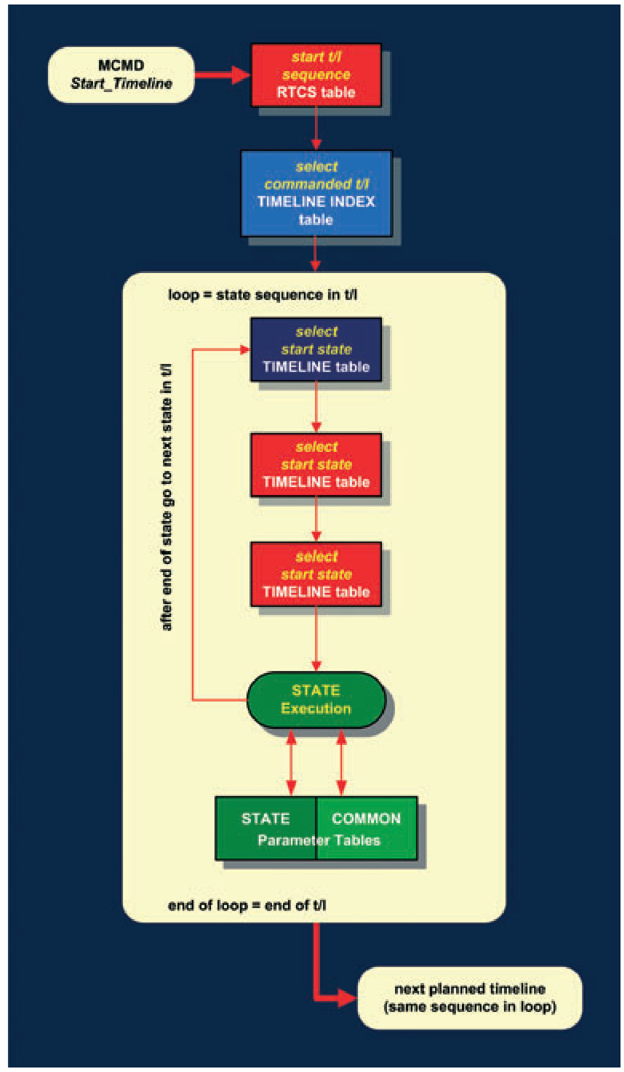

Fig. 4-9: Information flow during timeline execution. Timelines are started by macrocommand and end when the last state in the timeline has run to completion. (graphics: DLR-IMF)

4.6 Timelines

Concept

The execution of single states is possible. However, with an average state duration of about 60 sec, commanding a complete orbit, state by state, is cumbersome, both for the ENVISAT ground segment and for operations planning. Therefore, SCIAMACHY allows execution of predefined state sequences. These sequences are called *timelines (SOST 2001b)*. A total of 63 timelines can be stored on-board in the TIMELINE table of the ICU RAM.

Each timeline is characterised by the chronological sequence of states and its total duration. Once the timelines are stored in the TIMELINE table, they can be started via MCMD. This MCMD provides the scheduled timeline start time. If the timeline includes a state executing a sun or moon measurement, e.g. sunrise at a given altitude, sub-solar event or moonrise at a given altitude, additional position parameters specifying the solar or lunar celestial positions, are uploaded with the MCMD. They are used by the instrument to correctly position the scan mirrors at the beginning of the particular state to initially acquire the target. Execution of the timeline is a complex interaction between various parameter tables as depicted in fig. 4-9. From triggering the first timeline related commands in the RTCS table until the sequence of states has finally run to completion, information is extracted from tables and used to control instrument measurement activities. It is a prerequisite for successful operations that the content of the associated tables is consistent and conflict free. The timeline definition ensures that sun or moon states in the timeline observe their target at the right time and location to meet the scientific requirements. Since the start timeline MCMD can provide only one set of position parameters for one solar or lunar event, there can only exist one sun or moon related state in a timeline. Thus timelines including a sun or moon state are fixed in time and are called *sun fixed* or *moon fixed*. All other timelines without a sun or moon state are scheduled relative to sun or moon fixed timelines.

Definition

Based on the objectives of each orbital mission scenario and the occurrence of sun and moon fixed events along the orbit, timelines can be built from the set of 70 states. Each timeline corresponds to an orbit interval with start/stop being related to a sun or moon fixed event. Timelines can be assigned to the following orbit intervals:

- SO&C window
- MO&C window
- eclipse
- end of SO&C window to start of eclipse
- end of SO&C window to start of sub-solar window
- end of sub-solar window to start of eclipse
- end of SO&C window to start of MO&C window
- end of sub-solar window to start of MO&C window
- end of MO&C window to start of eclipse

A complete orbital mission scenario is implemented by assembling a sequence of timelines which covers the full orbit and executes those states required in the scenario. This is an efficient building block approach which reduces the command load drastically. The most frequent scenario executes 4 timelines only – a SO&C timeline, followed by a long limb/nadir sequence and two calibration timelines in eclipse. Because the sequence of limb/nadir states generates a ring-like pattern of nadir and limb ground pixels, it has been decided to switch between two limb/nadir sequences in consecutive orbits. At latitudes where nadir ground pixels exist in one orbit, limb ground pixels are thus generated in the following orbit. The result is a chessboard type pattern better suited for global value added data processing. In order to obtain Earthshine spectra with a signal-to-noise ratio as high as possible, the sequence of nadir and limb states in a timeline for execution on the illuminated side of the orbit needs to reflect the relation between pixel exposure times and orbital position. For a selected swath setting, usually all defined nadir and limb pixels are required to cover the interval from sunrise to sunset.

All timelines starting or ending with the MO&C window have to accommodate the strong temporal variability of lunar events within a monthly visibility period. Therefore several versions of moon related timelines with different lengths do exist for the same segment. Triggered by mission planning, they are exchanged on-board whenever required by lunar position.

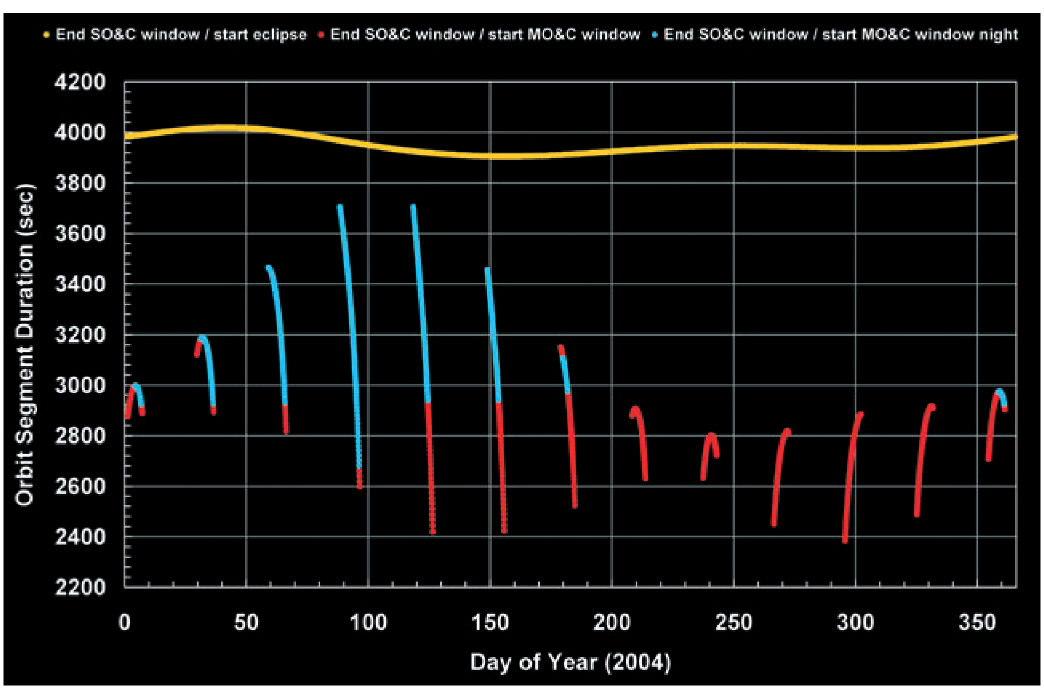

Fig. 4-10: Example of the seasonal temporal variability of orbital segments. The time interval between end of SO&C window and start of eclipse varies only slightly over a year (yellow). In the monthly moon visibility periods, the time between end of MO&C window and start of eclipse shows a much higher variation (red curves). The blue segments indicate lunar visibility phases where moonrise occurs on the nightside, i.e. those which can be used for occultations. (graphics: DLR-IMF)

This is different from timelines allocated to sun related orbit segments which require only single instances due to the moderate seasonal changes (fig. 4-10).

As in the case of states, a final flight configuration exists which reflects the currently agreed and verified set of 63 timelines. Its configuration controlled status can be modified via the OCR procedure.

4.7 SCIAMACHY Operations Setup

Operations of the instrument include mission planning, configuration control of the on-board measurement status and instrument monitoring. Due to its status as an AO instrument, operational responsibilities for SCIAMACHY were split between ESA and DLR/NIVR. Agreements define that FOCC executes daily SCIAMACHY flight operations as for all other ENVISAT instruments but based on input from the AOP, whereas operationally offline tasks are assigned to DLR/NIVR. On the AOP side, the SCIAMACHY Operations Support Team (see chapter 3.5) interfaces with ESA, particularly FOCC, to fulfil these functions in order to accomplish safe operations and generation of high quality measurement data.

SCIAMACHY mission planning has the task to generate and plan timelines around solar and lunar events in each orbit. Since the occurrence of such events depends purely on orbital and celestial mechanics it is predictable. Well in advance of actual operations, orbit analysis determines the properties of sun and moon related orbit segments. Timelines are then generated ensuring that the complete orbit is covered with measurements – scientific on the illuminated side of the orbit and mostly calibration & monitoring in the eclipse phase when the Earth's atmosphere appears dark. Regular mission planning consists of defining the measurement programme for time slices of several weeks by SCIAMACHY Operations Support. This programme is translated into timeline sequences for each orbit and provided to ENVISAT's mission planning system (MPS). The sequences must yield maximum orbital coverage, permit conflict free instrument operations and comply with the overall ENVISAT flight operation rules. ENVISAT MPS allocates absolute timeline start times. In order to inform validation users well in advance of actual operations about planned measurements, Operations Support determines the geolocation of planned nadir and limb ground pixels based on an orbital simulation of the schedule.

The control task of the on-board measurement status is responsible for the final flight status of states and timelines. A database of engineering, measurement parameters and timelines is maintained on the SCIAMACHY side by Operations Support. Whenever required, modified tables are generated, translated into the MCMD format and sent to FOCC. FOCC integrates SCIAMACHY's input into the overall ENVISAT command database and uploads it according to the specified validity time.

Instrument monitoring includes several operations related aspects. Both the monitoring at FOCC and SCIAMACHY Operations Support uses HK telemetry and report formats to compare executed with planned operations for detecting anomalies. While FOCC focuses on the day-by-day operations following the procedures specified in the Instrument Operation Manual (IOM), Operations Support monitoring covers also long-term aspects. This includes e.g. the regular weekly checking of the thermal status of the detectors and the OBM to ensure that temperature limits are not violated and data quality remains unaffected.

The past, present and planned status of SCIAMACHY mission planning, instrument configuration and long-term monitoring results are reported by SCIAMACHY Operations Support via its dedicated website at http://atmos.caf.dlr.de/projects/scops/. This site includes not only dynamic information but informs also about orbit properties and the overall operations and mission planning concept. A comprehensive description of the final flight states, the corresponding valid parameter settings and a list of timelines supplement the website.