The Status of the SCIAMACHY Active Thermal Control (ATC)

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Abbreviations and Acronyms

ANX	Ascending Node Crossing
ASM	Azimuth Scan Mechanism
ATC	Active Thermal Control
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ENVISAT	Environmental Satellite
ESA	European Space Agency
ESM	Elevation Scan Mechanism
HK	Housekeeping
IOM	Instrument Operation Manual
KBS	Ka-band Subsystem
OBM	Optical Bench Module
PMD	Polarization Measurement Device
RAD A	Radiator A
RD	Reference Document
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
TN	Technical Note
UV	Ultraviolet

Reference Documents

[RD1] ATC Adjustment Preparations, DLR, 31 July 2008
[RD2] SCIAMACHY Mission Extension Performance Verification, PO-TN-DLR-SH-0030, Issue 1, Rev. 0, 30 April 2011
[RD3] IOM: chapter 12 (P-I-N 402)
[RD4] Power Distribution between ATC Loops (TN-SCIA-1000FO/233)
[RD5] ATC adjustment in the Operational Phase (TN-SCIA-0000FO/236)
[RD6] Inputs for PIN-402: ATC Adjustments (SE-SCIA-0319FO/02) with associated Excel tool

1. Introduction

The Active Thermal Control System (ATC) is providing thermal stability to SCIAMACHY's optical bench module (OBM). Over the past 10 years in-orbit mission lifetime the ATC has proven extremely reliable. Although regular monitoring has revealed some degradation – less than what was predicted before launch – only a single adjustment was necessary so far to keep the OBM temperature within the specified limit. The ATC adjustment occurred in October 2008 in orbit 34643 [RD1 with referencing RD3-RD6]. It changed the ATC setpoints and gain factors as listed in table 1.

	Applicable Period	
	10-JUN-2002 to 15-OCT-2008	**since 15-OCT-2008**
Setpoints		
RAD A	-21.60 °C	-21.60 °C
Nadir	-16.40 °C	-16.25 °C
Limb	-15.00 °C	-15.15 °C
Gain Factor *		
RAD A	-0.092	-0.092
Nadir	-1.120	-1.135
Limb	-1.200	-1.183

* the sign of the gain factors is 'as commanded'

Table 1: Current and past ATC settings

Because SCIAMACHY has meanwhile doubled the in-orbit lifetime, it becomes more likely that due to the degradation of the ATC, the OBM has to be operated closer to the specified thermal limits. Extending the mission to the period 2014+ could even require violating some of these settings since the ATC heater margins have expired.

This TN tries to summarize the present status of the ATC. It addresses

- orbital mean ATC parameters as specified in the IOM for routine monitoring purposes as a function of mission duration and annual phase
- orbital variations of ATC parameters as a function of mission duration
- seasonal orbital variations of ATC parameters

The findings of this analysis could help to modify the ATC monitoring procedures and facilitates preparations for instrument operations in the 2014+ timeframe [RD2].

2. OBM/ATC Status Information

Operationally the OBM thermal status is monitored via the procedure P-I-N 402 [RD3] as described in the IOM. It is based on the HK telemetry readings

- I0773D: ATC nadir sensor temperature derived from HK parameter I0136 (ATC nadir YSI sensor readout)
- I0772D: ATC limb sensor temperature derived from HK parameter I0134 (ATC limb YSI sensor readout)
- I0799D: ATC nadir heater power derived from HK parameter I0143 (ATC nadir heater control)
- I0798D: ATC limb heater power derived from HK parameter I5340 (ATC limb heater control)
- I0800D: RAD A heater power derived from HK parameter I0144 (ATC RAD A heater control)

In addition, ATC information is also obtained via the HK reading I0774D (ATC RAD A sensor temperature) which is derived from HK parameter I0135 (ATC RAD A YSI sensor readout).

Nadir and limb sensor temperatures yield the OBM temperature according to

$$T_{OBM} = 0.5 \times (T_{LIMB} + T_{NADIR}) - 2.2\ °C, \quad -17.6\ °C \geq T_{OBM} \geq -18.2\ °C \qquad (1)$$

with T_{LIMB} = I0772D and T_{NADIR} = I0773D. The constant term in eq. 1 has been derived using information from the HK parameter I0165 (RAD A HK temperature). Being subject to radiation degradation it was only used in the early phase of the mission. Although the sensor is termed 'RAD A' the corresponding sensor is located on the OBM (see fig. 3).

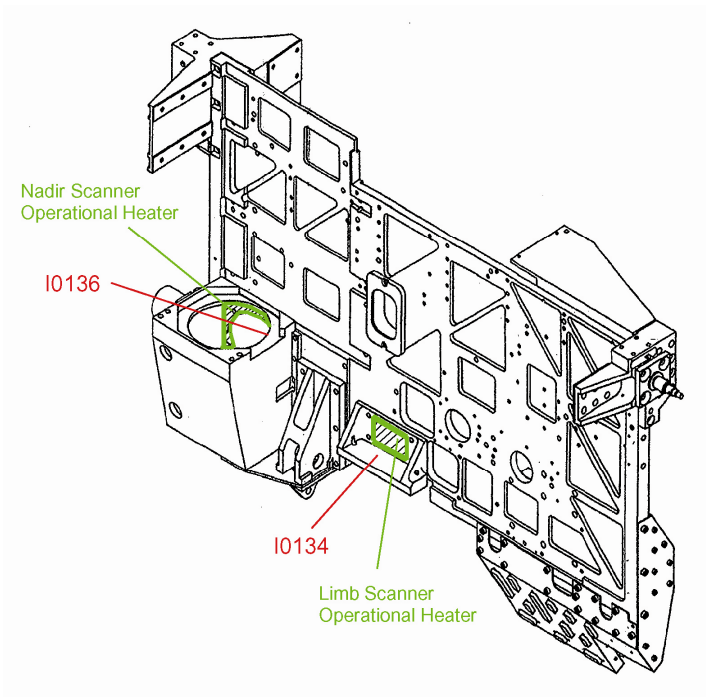


Fig. 1: Location on the OBM of the sensors providing I0134 and I0136 HK information together with the corresponding ATC heaters.

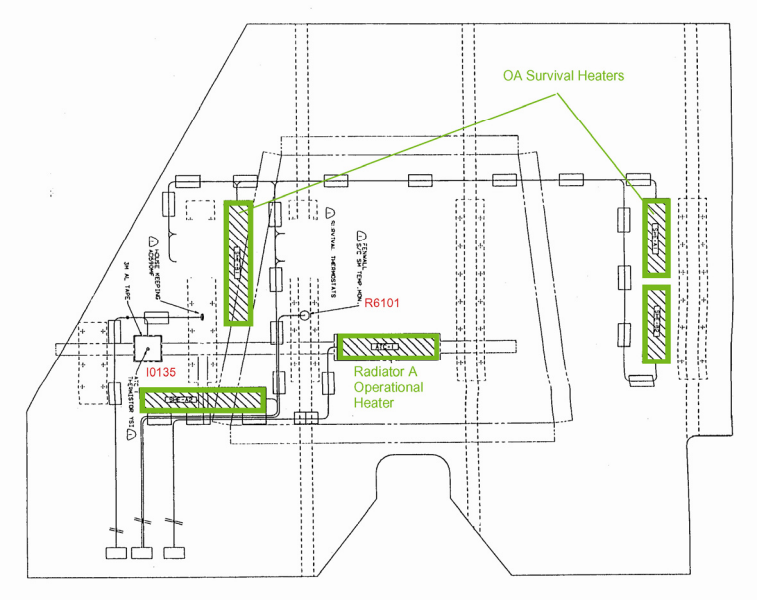


Fig. 2: Location on RAD A of the sensor providing I0135 HK information together with the corresponding ATC heater.

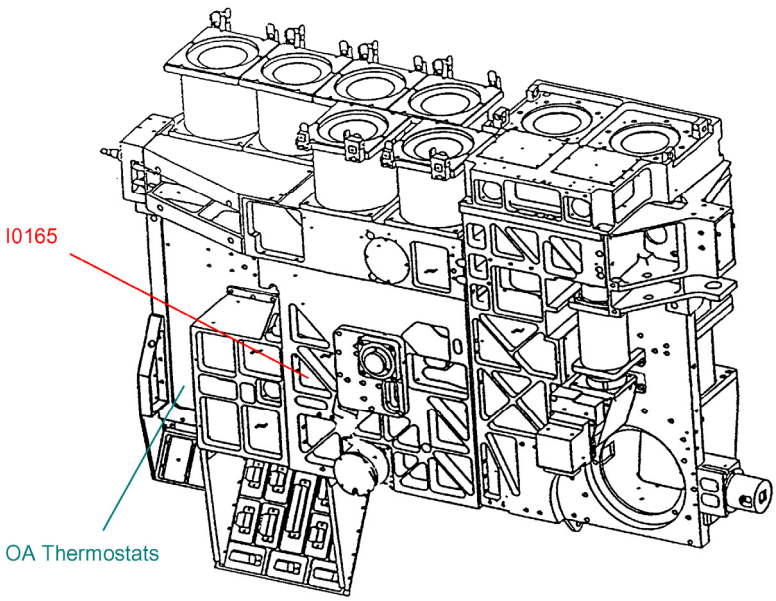


Fig. 3: Location on the OBM of the sensor providing I0165 HK information.

3. Thermal and Optical Changes

By chance coincidence the ENVISAT orbit manoeuvre to lower the platform orbit end of October 2010 occurred almost at the same time when an anomaly in the Ka-band antenna subsystem (KBS) required to switch from KBS-2 to KBS-3 and to change its operating procedure. While KBS-2 was intermittently turned 'on' and 'off', for safety reasons KBS-3 remains 'on' the whole time. Therefore about 120 W more energy is dissipated and the thermal environment of ENVISAT, including the payload instruments has changed since then. The effect on SCIAMACHY [RD2] can be described by

- stable ATC temperatures
- reduced ATC heater powers (-0.1 W to -0.5 W, heater dependent)
- increased detector temperatures (0.3 K to 0.5 K, channel dependent)
- increased PMD temperature (0.1 °C)
- increased Electronic Assembly subsystem temperatures (1.1 to 2.7 °C, subsystem dependent)

For the ATC system the reduction in heater powers has an impact which enhances the degradation trend. Therefore the KBS-3 related thermal effect can be treated as a singular 'degradation event'.

In early February 2011, the optical throughput began to increase in channels 1-5 indicating a recovery of the corresponding optical trains. It is most pronounced in both UV channels where the throughput (optical train: Sun via ASM and ESM mirror) changed from 26% (orbit 46000) to 60% (orbit 52000) in channel 1 and from 54% to 71% in channel 2. A likely explanation is that the amount of contaminants on the optical surfaces has been reduced. The exact mechanism is, however, unknown, Since contamination and thermal status are interrelated, it is therefore necessary to study whether the throughput recovery can be explained by a change in the thermal behaviour. The ATC controlling the optical bench with associated optical components (e.g. scan mirrors) is a prime target in such investigations.

4. Mean Orbital ATC Temperatures and Heater Powers

Overall the ATC degradation is well compensated by the control loops such that the OBM temperature remained stable since June 2002. Fig. 4 displays the average OBM temperature as specified in the OBM temperature monitoring procedure of the IOM (P-I-N 402) for orbits with 50% and 90% HK telemetry coverage.

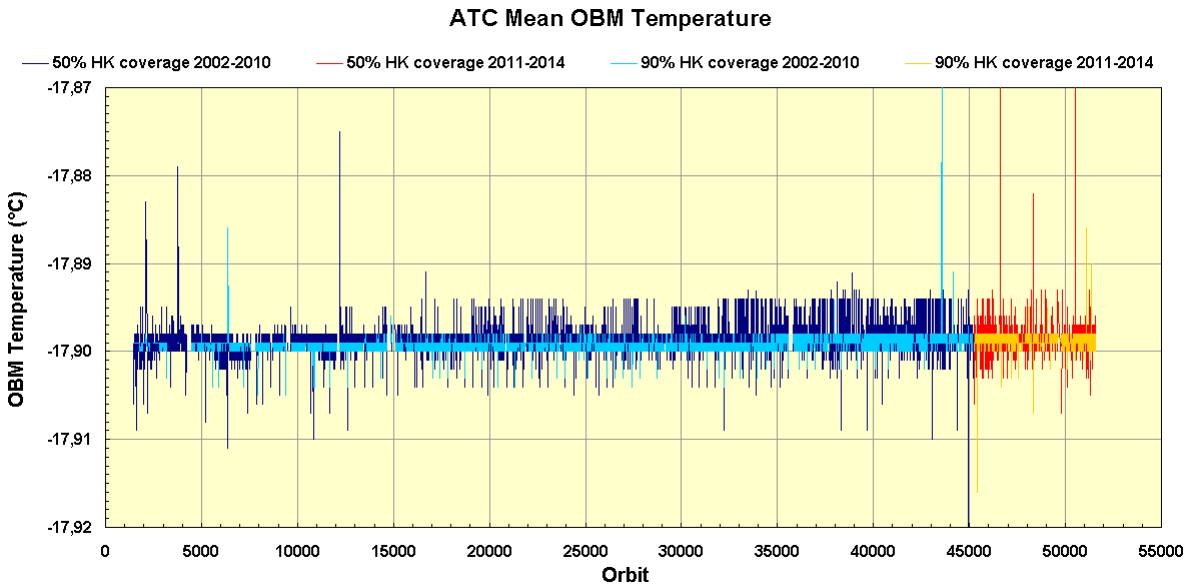


Fig. 4: Mean OBM temperature derived from orbits with 50% (dark) and 90% (light) HK telemetry. In blue is the period before the October 2010 orbit manoeuvre, in red that since then.

Monitoring of the RAD A, nadir and limb heater powers reveals the degrading ATC system. All three heaters dissipate less power as compared to the beginning of ATC operations (fig. 5). The decrease is most pronounced for the nadir heater while limb and RAD A heater show smaller effects. The two glitches just before orbit 35000 and after orbit 45000 are caused by the ATC adjustment in October 2008 and the switching to KBS-3 in October 2010, respectively.

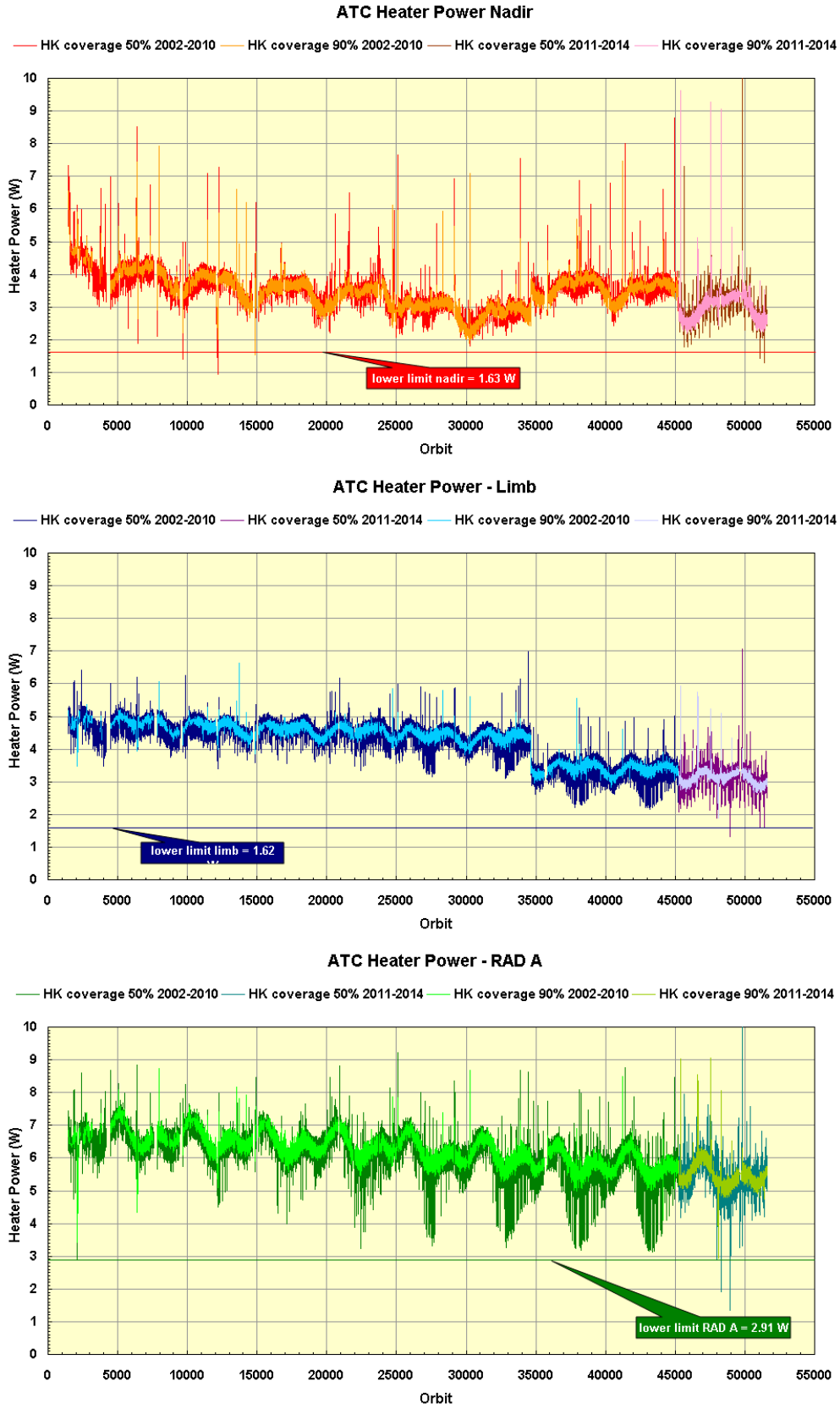


Fig. 5: Mean ATC heater powers for the years 2002 to early 2012. Dark and light curves stand for 50% and 90% HK coverage. The lower limits as specified by the IOM (15% duty cycle) are indicated.

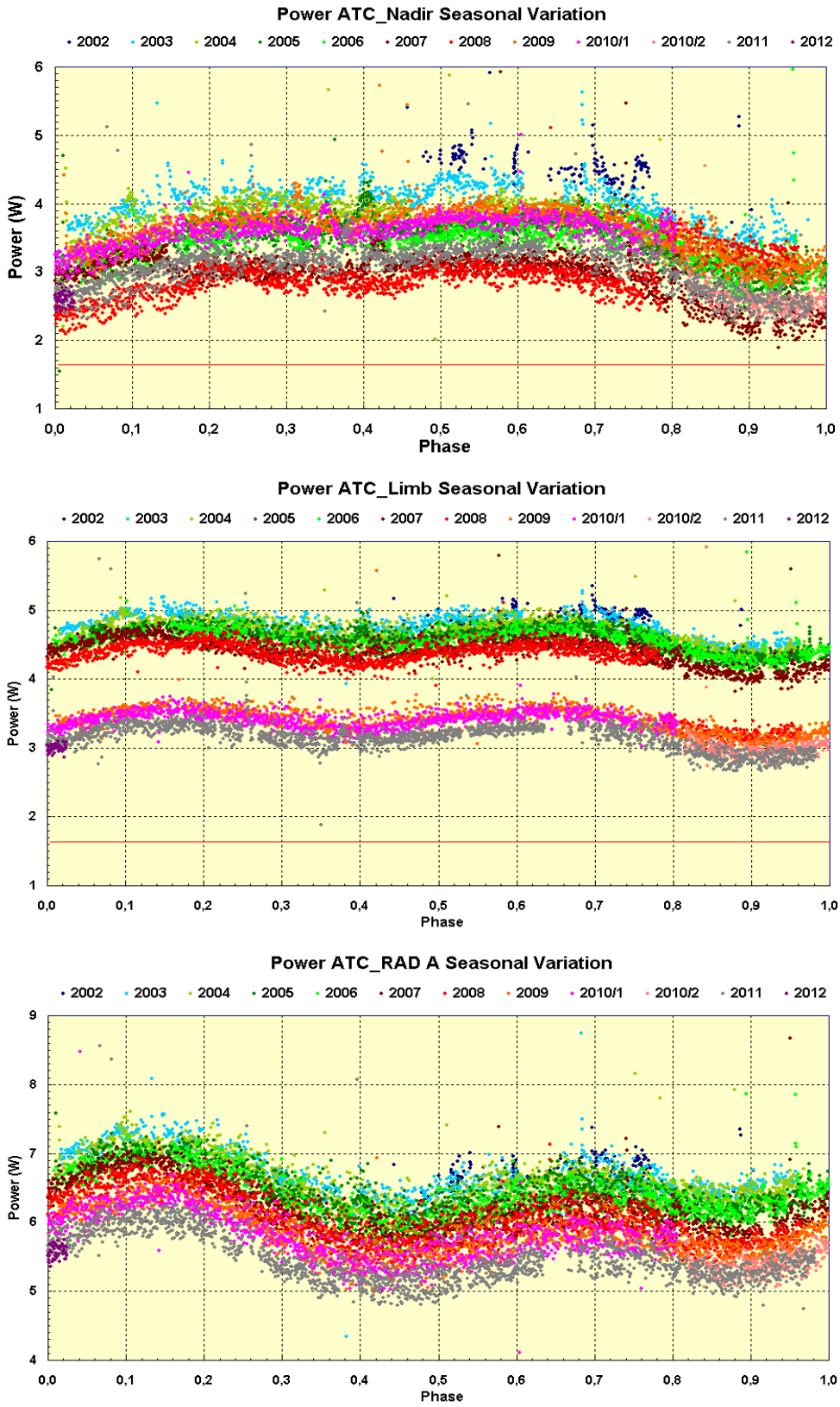


Fig. 6: Mean ATC heater powers for the years 2002 to early 2012 as a function of annual phase. 2010/1 and 2010/2 stand for the part of 2010 before and after the orbit manoeuvre.

While fig. 5 displays heater power as a function of orbit number, fig. 6 presents the same parameters related to the annual phase. The seasonal power minimum, i.e. the phase with closest approach to their lower limits, occurs for the nadir and limb heater in December and November each year, for the RAD A heater around June. The maximum is broader. It is reached in September for the nadir and limb heater and in February for the RAD A heater. Degradation can cause slight shifts in these periods.

In the ATC limb display of fig. 6 the ATC adjustment from October 2008 is obvious as two distinct power levels. In the ATC nadir part the thermal impact of the KBS-3 operations has smeared out both levels. For the RAD A power only the elevated heat dissipation of KBS-3 has caused a change.

From the results presented in fig. 5 and 6 the average ATC heater degradation can be deduced. It amounts to

- nadir heater = -0.25 W/year
- limb heater = -0.11 W/year
- RAD A heater = -0.15 W/year

with the absolute values being shifted by -0.5 W end of October 2010 for the nadir heater and -0.1 W for the limb and RAD A heater.

In summary the orbital mean OBM temperature and ATC heater powers do not show different behaviour since early 2011. The degradation follows a linear trend since June 2002, only modified by two singular events (ATC adjustment and external heat input).

5. Orbital ATC Temperatures and Heater Powers as a Function of Mission Duration

Further judging the ATC status requires investigation of the orbital variations[1], both for the temperatures and the heater powers. Most critical are phases when ATC heaters dissipate closest to their assigned lower limits. This occurs at different annual phases. Representative orbits are listed in table 2.

Nadir		Limb		RAD A	
Orbit	**Date**	**Orbit**	**Date**	**Orbit**	**Date**
4200	19-DEC-2002	3788	20-NOV-2002	1470	11-JUN-2002
9400	17-DEC-2003	8981	18-NOV-2003	6721	13-JUN-2003
14660	19-DEC-2004	14224	18-NOV-2004	11989	15-JUN-2004
19938	22-DEC-2005	19441	18-NOV-2005	17189	13-JUN-2005
25167	23-DEC-2006	24671	18-NOV-2006	22420	14-JUN-2006
30393	23-DEC-2007	29892	18-NOV-2007	27645	14-JUN-2007
35552	17-DEC-2008	35139	18-NOV-2008	32882	14-JUN-2008
40842	22-DEC-2009	40345	17-NOV-2009	38100	13-JUN-2009
46074	22-DEC-2010	45586	18-NOV-2010	43325	13-JUN-2010
51314	22-DEC-2011	50824	18-NOV-2011	48570	14-JUN-2011

Table 2: Orbits for ATC analysis (mission duration).

[1] Orbital phase = 0 refers to Ascending Node Crossing (ANX)

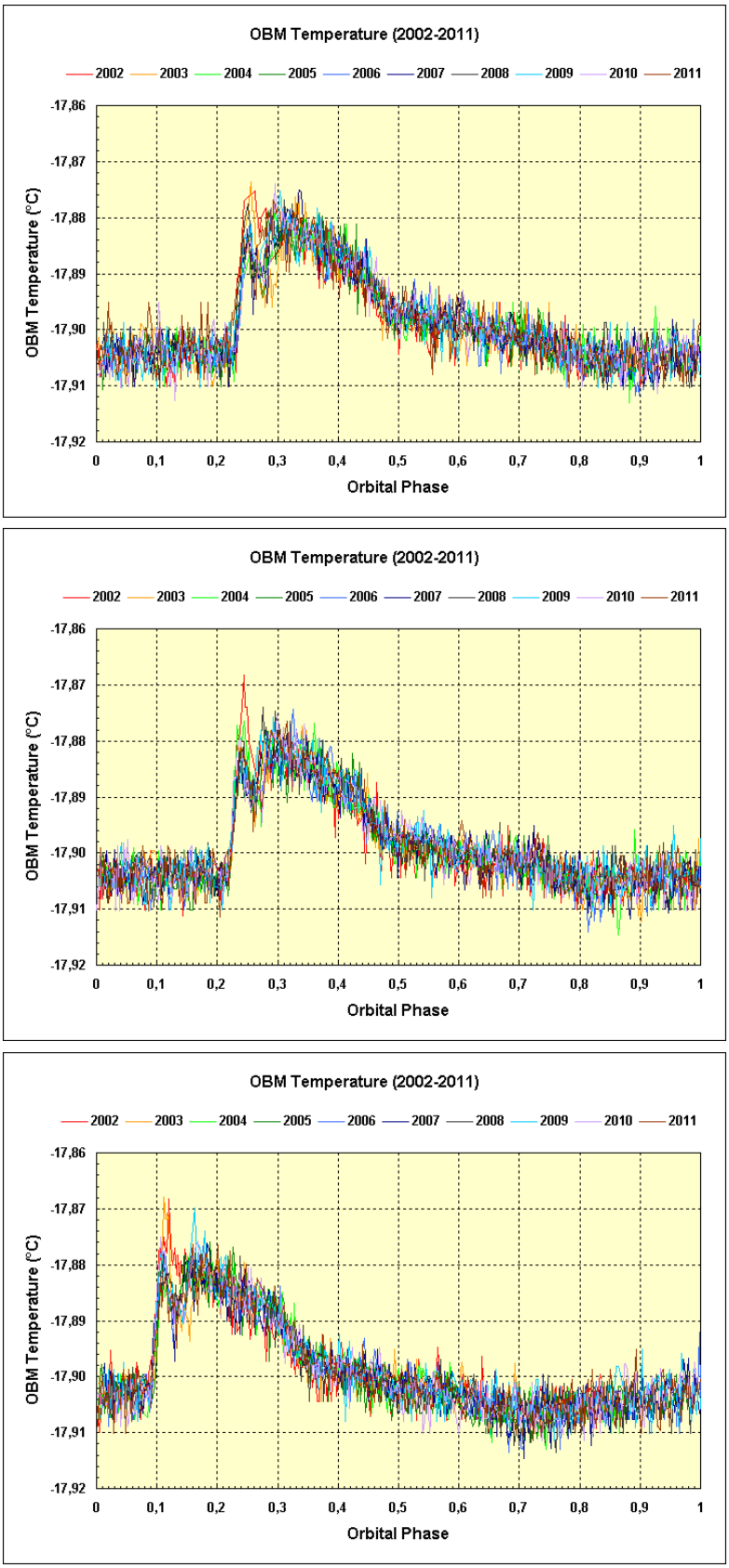


Fig. 7: Orbital OBM temperature profiles for the years 2002 to 2011 at phases when the ATC nadir (top), limb (middle) and RAD A (bottom) heaters reach their orbital mean minima (see table 2).

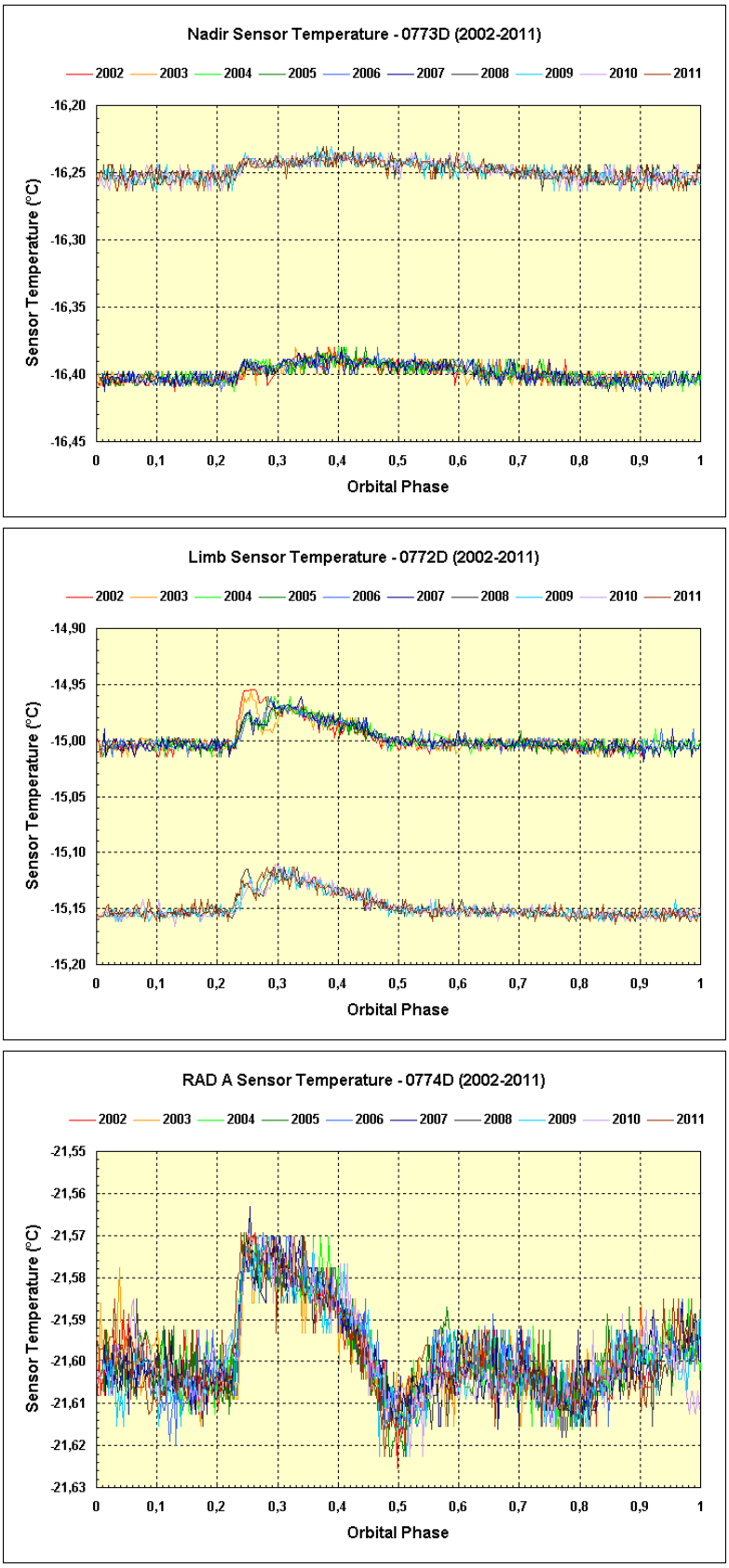


Fig. 8: Orbital ATC sensor temperature profiles for the years 2002 to 2011 at phases when the dissipated ATC nadir heater reaches the orbital mean minimum (December each year). The two levels for the nadir and limb heaters are due to the ATC adjustment in October 2008.

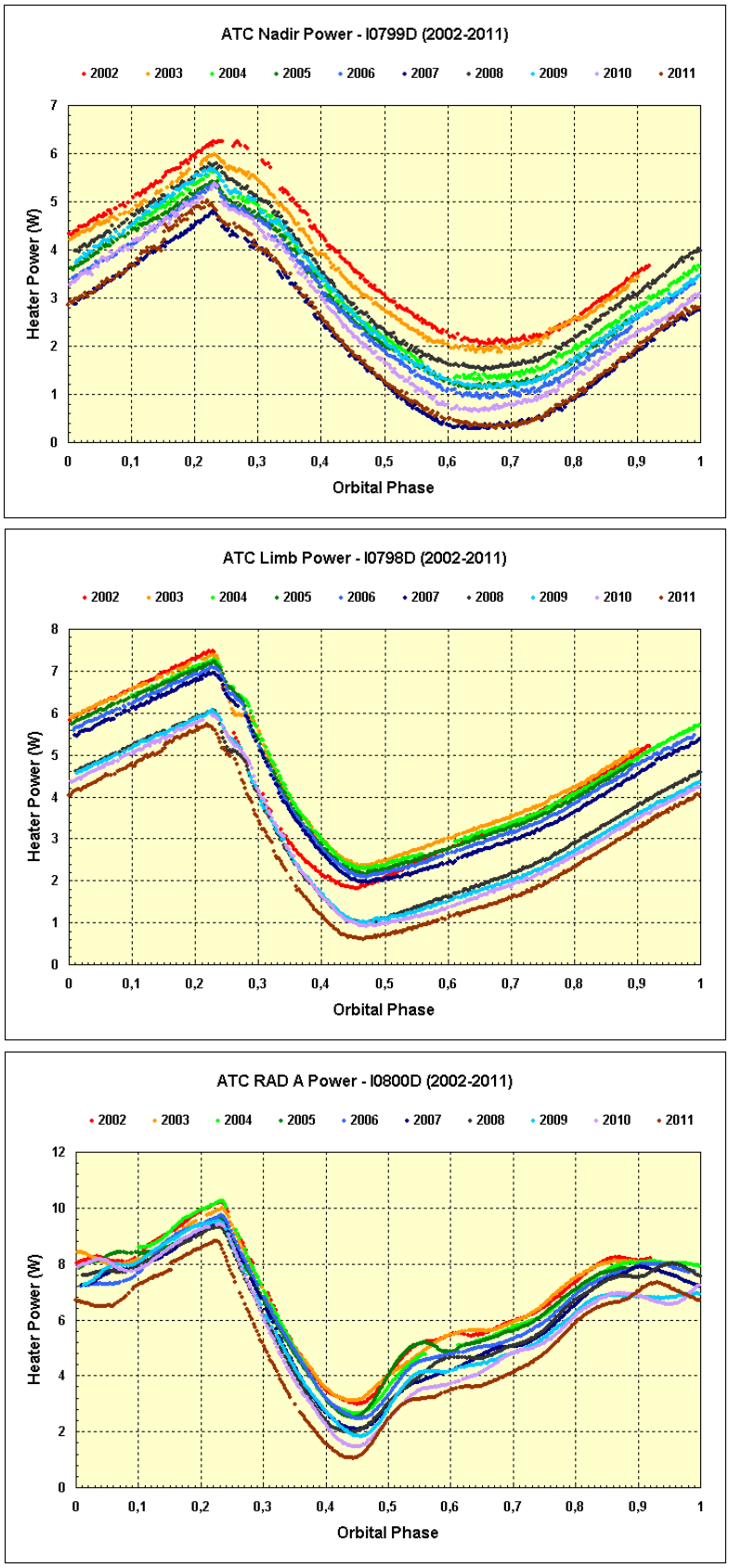


Fig. 9: Orbital ATC heater power profiles for the years 2002 to 2011 at phases when the dissipated ATC nadir heater reaches the orbital mean minimum (December each year).

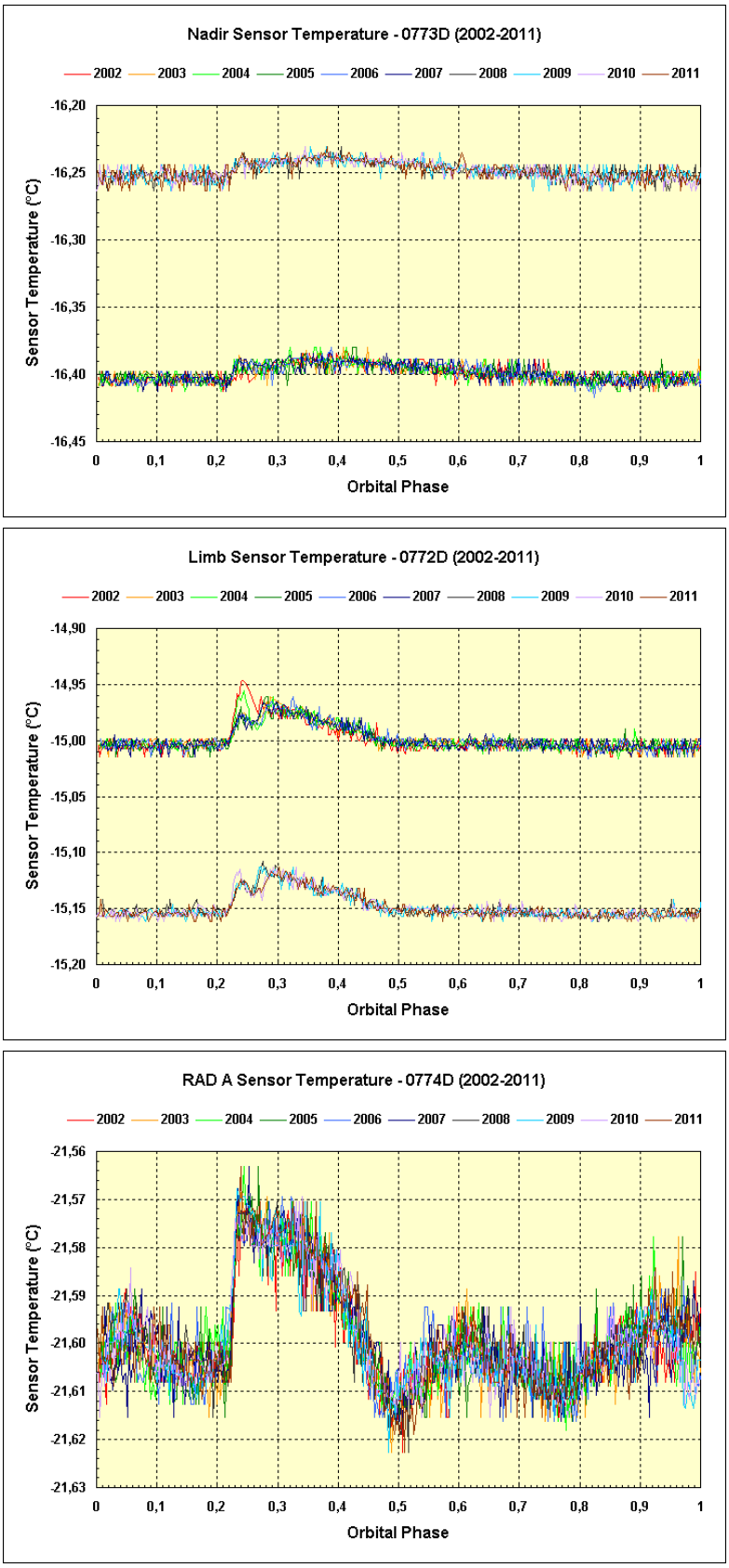


Fig. 10: Orbital ATC sensor temperature profiles for the years 2002 to 2011 at phases when the dissipated ATC limb heater power reaches the orbital mean minimum (November each year). The two levels for the nadir and limb heaters are due to the ATC adjustment in October 2008.

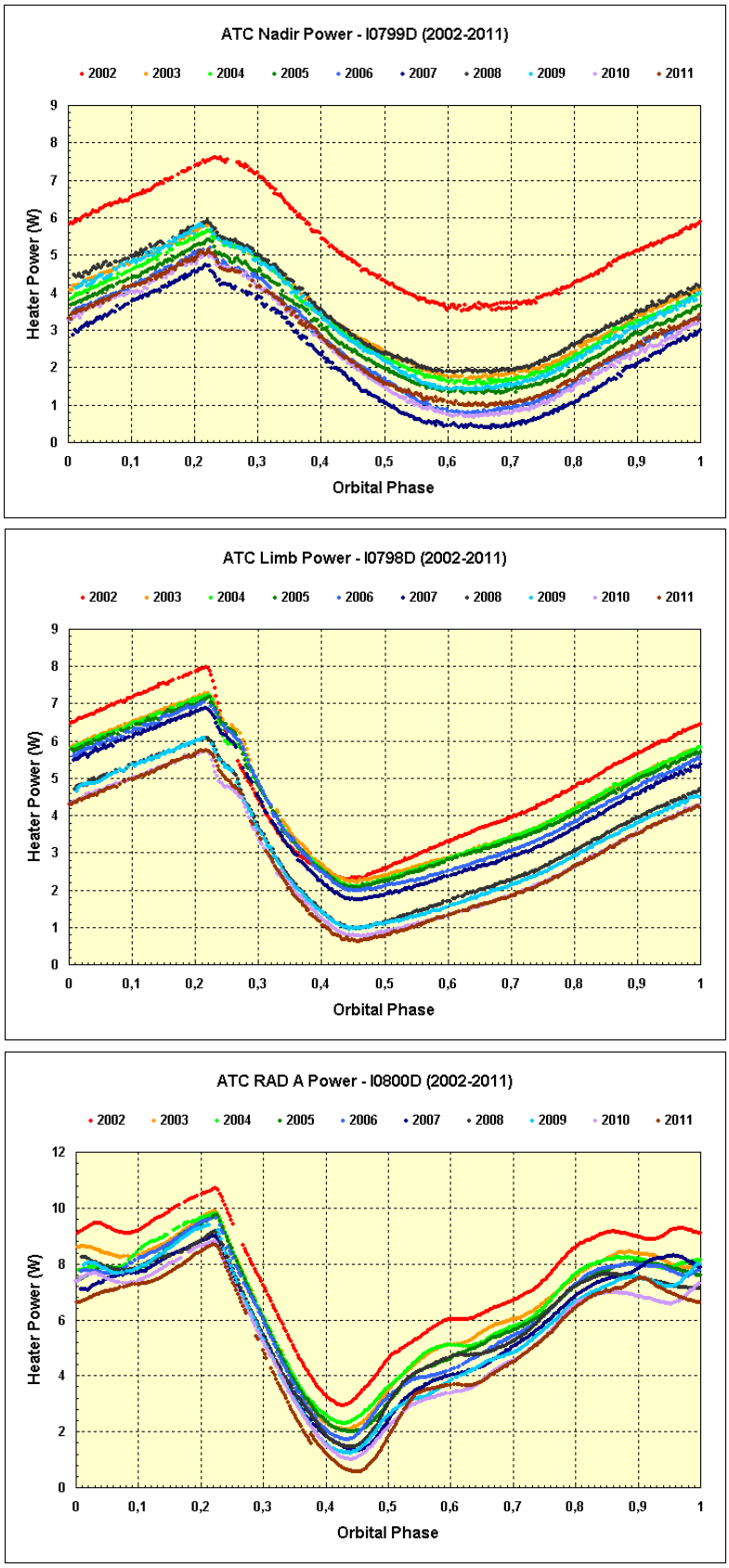


Fig. 11: Orbital ATC heater power profiles for the years 2002 to 2011 at phases when the dissipated ATC limb heater reaches the orbital mean minimum (November each year).

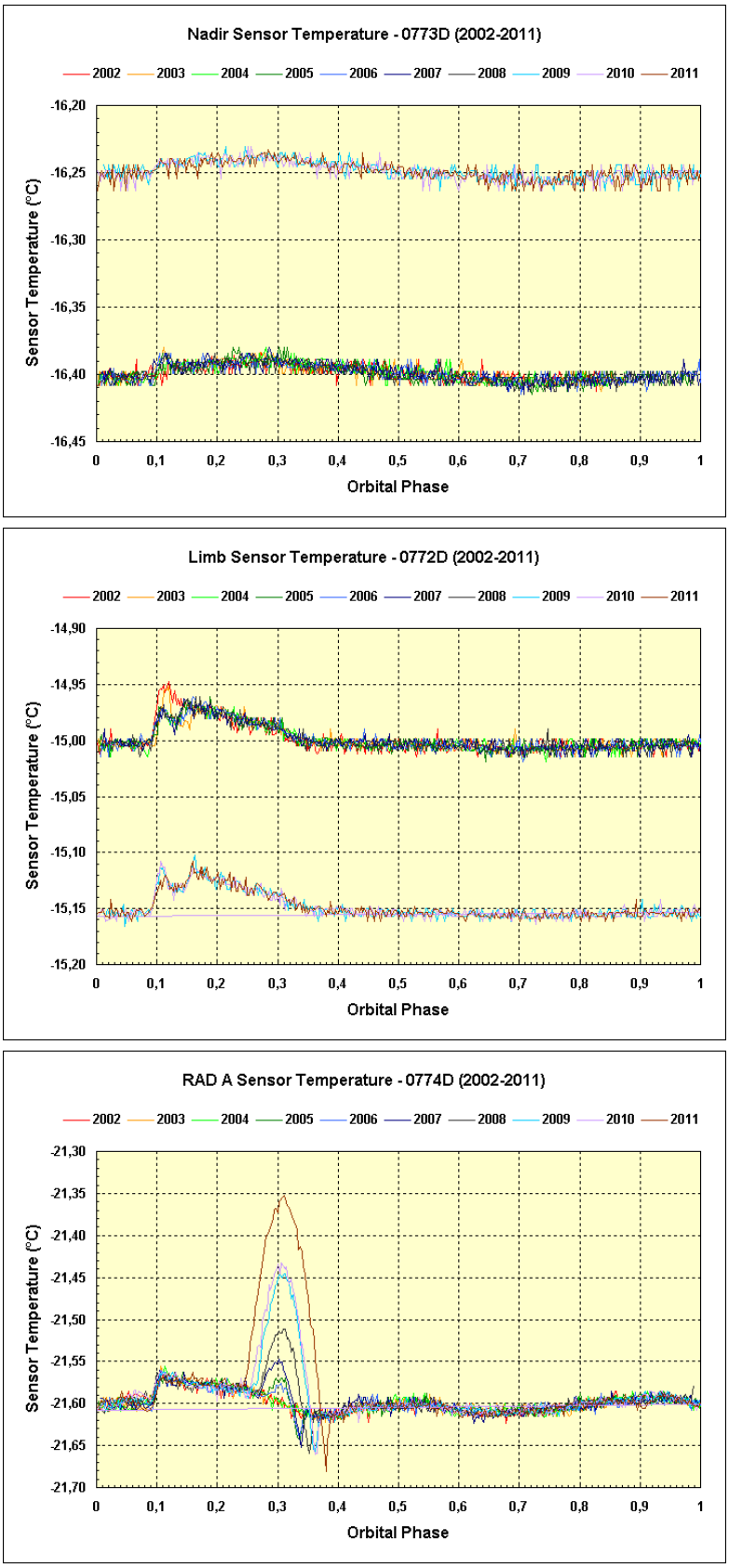


Fig. 12: Orbital ATC sensor temperature profiles for the years 2002 to 2011 at phases when the dissipated ATC RAD A heater power reaches the orbital mean minimum (June each year). The two levels for the nadir and limb heaters are due to the ATC adjustment in October 2008.

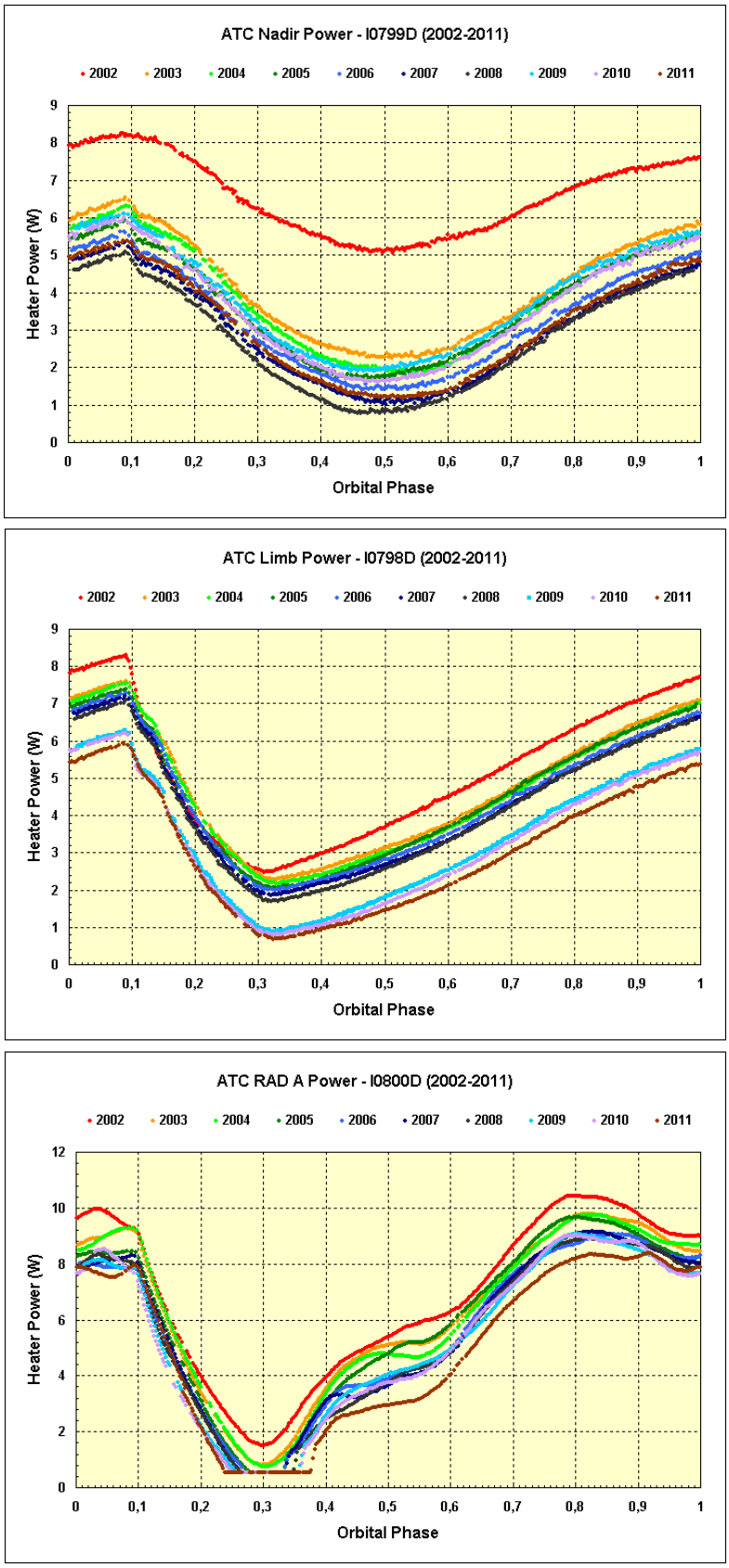


Fig. 13: Orbital ATC heater power profiles for the years 2002 to 2011 at phases when the dissipated ATC RAD A heater reaches the orbital mean minimum (June each year).

Overall the derived OBM temperature shows an almost identical orbital variation from 2002 to 2011 in the periods selected (fig. 7). The orbital temperature profiles match nicely with a variation of about 0.025 °C. This variation starts at Sunrise (occurring at elapsed time = 500 sec, i.e. orbital phase = 0.1 in summer and at elapsed time = 1300 sec, i.e. orbit phase = 0.21 in winter) when the control loops take some time to compensate for elevated temperatures. The horizontal temperature levels at the beginning and end of the orbit are about identical to the selected setpoints in the ATC system.

As expected, the nadir and limb sensor temperatures appear in two distinct temperature levels due to the ATC adjustment in October 2008 (fig. 8 top and middle graph, fig. 10 top and middle graph). Permanently operating KBS-3 does not manifest in the temperature graphs since the ATC compensates for that via adapting the power consumption. As can be expected from the stable OBM temperatures, both the nadir and limb sensor temperature profiles do not change over the mission lifetime. This is also true for the RAD A sensor temperatures which are unused in OBM temperature calculations (fig. 8 bottom graph, fig. 10 bottom graph).

All ATC degradation effects are obvious, however, in the orbital variations of the nadir, limb and RAD A ATC powers (fig. 9 and 11). They illustrate the continuously occurring reduction of heater power because of the slowly increasing inefficiency of the ATC system. In addition the KBS-3 phenomenon reduced the power readings for the nadir heater in 2010 and 2011 (December) to a level which is similar to that before the ATC adjustment in 2008 (fig. 9 top graph). For the limb heater the minimum is reduced even further (November 2010 and 2011) as compared to the readings after the ATC adjustment in 2008. Extrapolating the minimum readings of the orbital variations of the nadir (fig. 9) and of the limb (fig. 11) heater powers to the near future indicate that the absolute limit of 0 W could be reached either in 2012 or 2013 for part of the orbit. Then we expect that the nadir and limb sensor temperature profiles become ‘disturbed’ in that part and the derived OBM temperature would no longer fall into the specified tolerance range.

The effect of an ATC heater power reaching its lower limit for part of the orbital variation can be seen for the RAD A heater. Although regular ATC monitoring according to the IOM does only require the regular monitoring of orbital mean parameters without using the RAD A sensor temperature readings in the OBM temperature calculation, understanding how RAD A parameters behave orbit-wise can help elaborating the optimum settings for future ATC adjustments when also the nadir and limb heaters approach their 0 W limits. Fig. 12 (bottom) shows the RAD A sensor temperature profiles at the time of the seasonal orbital mean RAD A heater power dissipation. This occurs in June each year. Starting about 2006 the temperatures began to deviate from the common orbital profile for a short while at an orbital phase of 0.3 (phase 0 = ANX, i.e. the feature occurred after the SO&C window in the northern hemisphere). This period grew larger in the following years. In 2011 it span about 10% of the orbital phase with the temperature being higher by about 0.25 °C. Both the nadir and limb sensor temperature readings display no unusual behaviour at the same time. The elevated RAD A temperatures are caused by the RAD A heater which reaches its absolute lower limit of 0 W. However surprisingly it does not fully approach this value but instead operates at a constant value of 0.54 W (note: if the RAD A heater would indeed reach a minimum power of 0 W, the observed effect would have become obvious only in the 2010/2011 timeframe). What causes this plateau is not understood.

The RAD A power reading (I0800D) is a derived parameter. It is calculated from the HK parameter I0144 (RAD A ATC heater control) according to

$$I0800D = (I0144 \times I0144)/25.21 \qquad \text{with } I0144 = 0 - 22.11 \text{ (engineering units)} \qquad (2)$$

Since eq. (2) does not introduce an offset we would expect to obtain 0 W as the lowest RAD A heater power. However checking the values of the parameter I0144 at times when the RAD A power has reached the lower limit ≠ 0 W revealed that also the RAD A ATC heater voltage (I0144) operates at a

value ≠ 0 in accordance with the observed I0800D parameter. This points to a lower limit in the corresponding controller settings and not to an erroneous calibration of the I0144 raw telemetry.

If both the nadir and limb heater would also exhibit such a feature, the corresponding lowest limits could be hit earlier than expected during the corresponding seasonal minima. Also note that the orbital mean heater powers as monitored according to P-I-N 402 of the IOM give no indication for reaching the lowest limit. Even in June 2011 the orbital mean RAD A heater power amounted to about 4.5-5 W, i.e. well above the 15% duty cycle limit of 2.91 W.

6. Orbital ATC Temperatures and Heater Powers as a Function of Season

For understanding how the orbital variations of ATC parameters evolve with season we derived the ATC parameters for each month of 2011. The results are presented in fig. 14 (derived OBM temperatures), fig. 15 (sensor temperatures) and fig. 16 (heater powers).

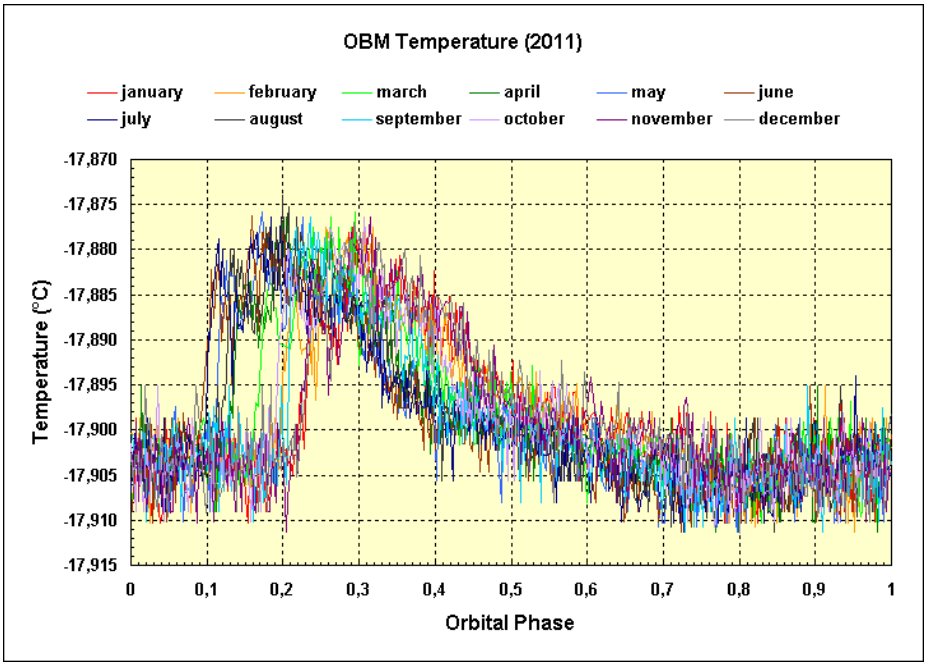
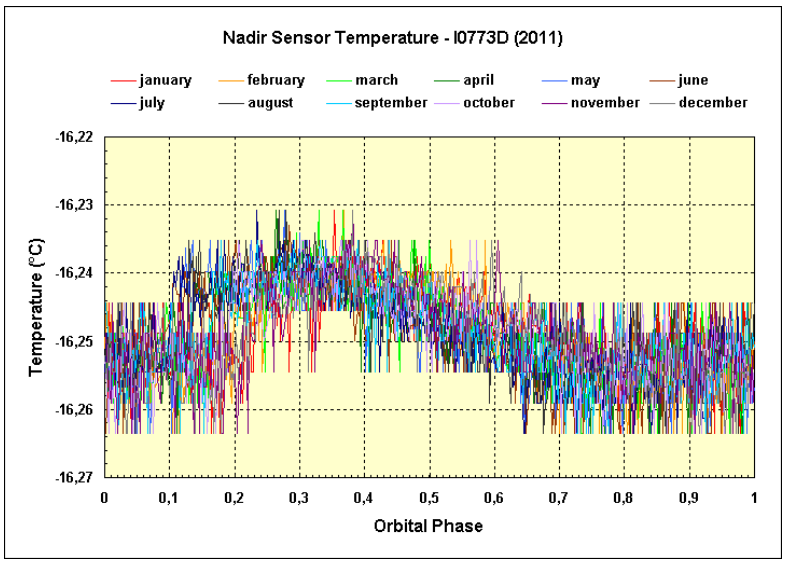
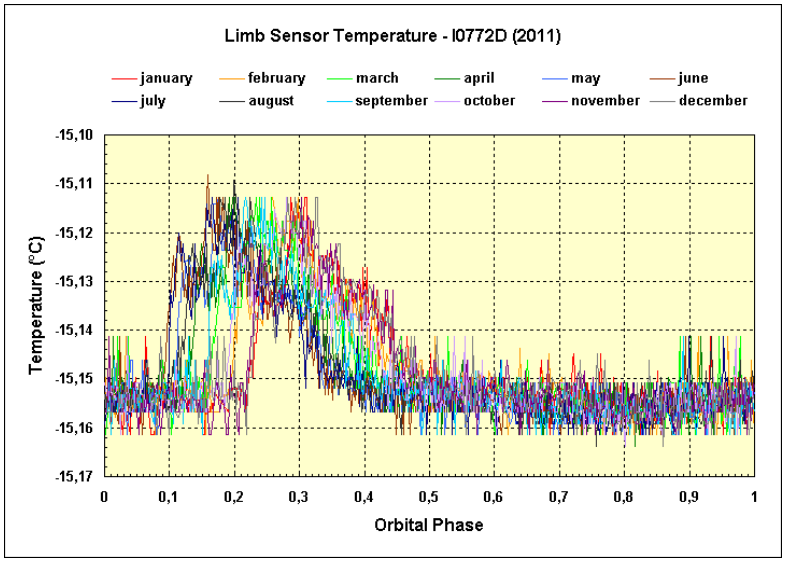


Fig. 14: Orbital OBM temperature profiles for the year 2011. The shift of the profile is due to the varying elapsed time when sunrise occurs in the ENVISAT orbit. The Sun can be observed earliest after ANX in summer (phase = 0.1) and latest in winter (phase = 0.2).

Fig. 14 indicates that presently the change of the OBM temperature with season does only reflect the varying illumination conditions, i.e. dayside/nightside of orbit, over a year. This is also obvious in the nadir and limb sensor temperature profiles (fig. 15 top and middle graph). The corresponding nadir and limb heater powers (fig. 16 top and middle graph) display very similar profiles each month, again only shifted in phase. Note that the very low minimum of the nadir heater power in December 2011 is a clear sign for the need to execute an ATC adjustment in the course of 2012.

The RAD A parameters display the fact that the heater power cannot be reduced any further. From May to July the sensor temperature increased by up to 0.25 °C between orbital phases 0.25-0.35 (fig. 15 bottom). In the corresponding heater power graph (fig. 16 bottom) the plateau is clearly visible for the same months even with an indication that it also began to develop in August.





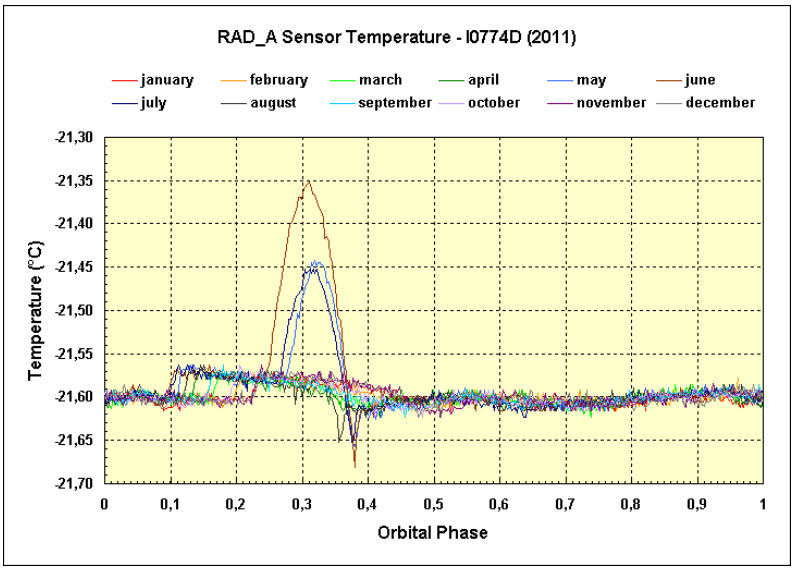


Fig. 15: Orbital ATC sensor temperature profiles for the year 2011.

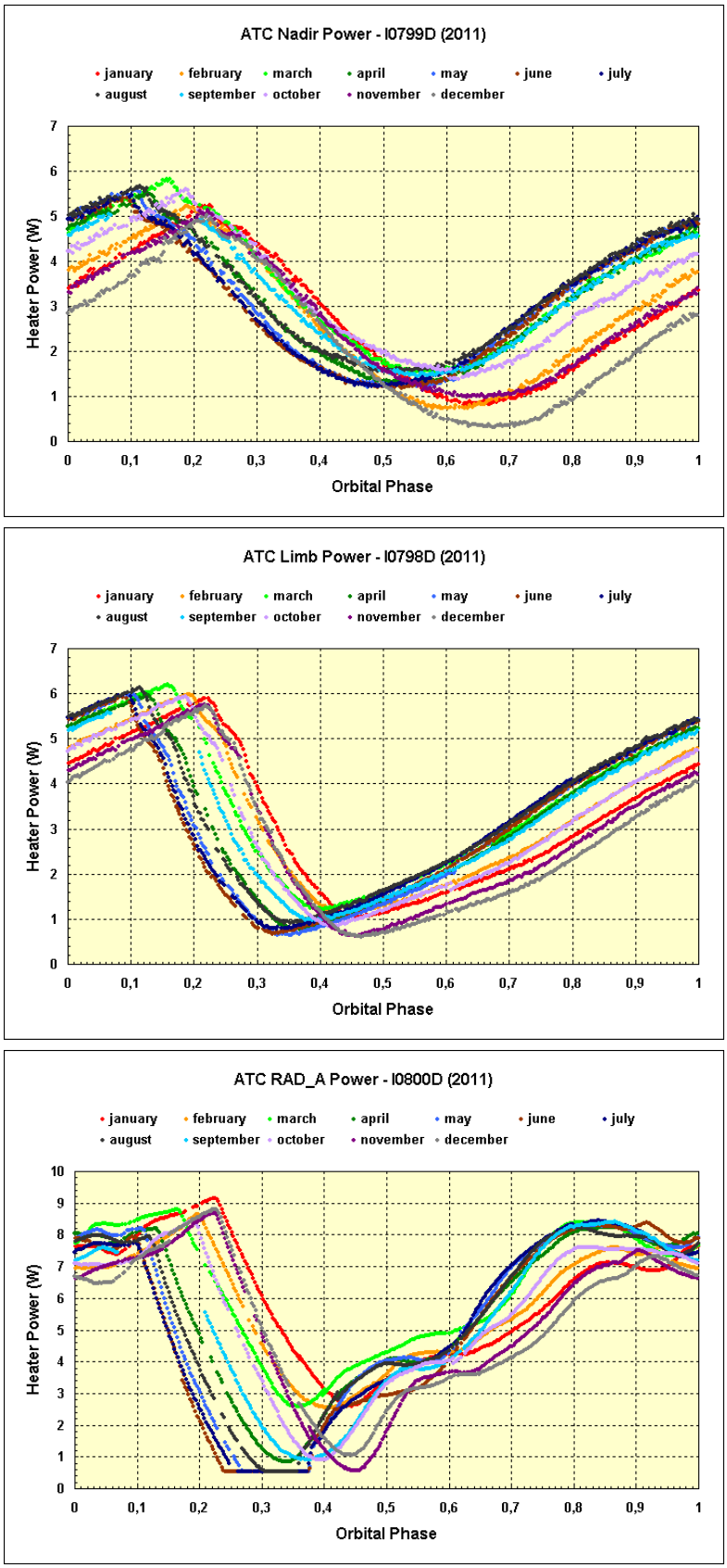


Fig. 16: Orbital ATC heater power profiles for the year 2011.

7. Summary

Even after 10 years in orbit the SCIAMACHY ATC system shows a very stable behaviour keeping the derived OBM temperature well in the specified limits. Degradation over the mission lifetime persists but is lower than expected. A modification of operating a Ka-band antenna subsystem on the platform (KBS-3) has resulted in an additional warming of the instrument which had to be successfully compensated by the ATC.

The monitoring procedure outlined in the IOM is used for regularly monitoring the status of the OBM and for deciding on needed ATC adjustments. In this TN we show that, although this procedure obviously fulfils the requirement for maintaining a stable OBM temperature, on orbit-level the picture can be more complex. Whether this can become critical in terms of the OBM temperature has to be discussed among calibration & monitoring experts as well as supporting industry (thermal subsystems). The following topics should be addressed

- criticality of RAD A heater reaching a low limit with corresponding increase of RAD A sensor temperature for a fraction of the orbit (presently May – July timeframe, but increasing)
- offset (plateau) of minimum RAD A heater power
- compensation options (ATC adjustments, could even be season-dependent) when nadir and/or limb heaters reach low limit (taking potential offsets into account)
- impact on calibration and retrieval when compensation options are no longer possible

For the nadir and limb heater power an ATC adjustment is very likely required in the second half of 2012. How the corresponding setpoints and gain factors have to be selected depends on the outcome of the discussion mentioned above.