Eight Years MOS-IRS – Summary of Calibration Activities

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ABSTRACT

After eight successful years of operation in orbit the mission of the Modular Optoelectronic Scanner (MOS) on board the Indian Remote Sensing Satellite (IRS-P3) ended in May 2004. Being the first imaging spectrometer in the Earth's orbit and due to the long lifetime it allowed extensive calibration and inter-calibration studies. The paper will give a summary on the results of in-orbit calibrations (internal lamps, sun, vicarious and moon) and inter-comparisons with other missions using ground targets and derived geophysical products. Conclusions are drawn for future improvements of inter-calibration strategies.

Keywords: In-orbit calibration, ground target based calibration, inter-calibration, imaging push broom scanner, VIS/NIR remote sensing, earth observation

1. INTRODUCTION

For the last 8 years the Modular Optoelectronic Scanner MOS has been delivering valuable findings of the qualitative and quantitative determination of characteristic parameters to determine the ecological changes of the oceans, especially of the coastal zones. The MOS mission is the longest and the most successful environmental remote sensing mission of the German Aerospace Center (DLR), where the MOS VIS/NIR imaging spectrometer was developed and built. The satellite orbited the earth about 42,000 times on its 820 km sun synchronous orbit. Fundamental problems did not occur during this long term mission, all detector elements are still working now. Some difficulties and the failure of the on board calibration equipment caused by the failure of its power supply could be overcome only by using alternative methods and the instrument performance data that had been established by the lab measurements as well as by the in orbit calibrations.
Only in this way it was possible to maintain the high data quality which is necessary for deriving the desired ecological parameters and their time trends. About 4,700 lamp calibrations, 70 sun calibrations, 36 ground target based (vicarious) calibrations and 9 moon calibrations are the basis for the knowledge of the behaviour and the changes of the MOS sensor components and the total time trend of the responsivity of the different spectral channels during the last 8 years in orbit.
Table 1 gives an overview of the performance data of the MOS sensor and fig. 1 shows the optical design of MOS-B.

Performance data: Modular Optoelectronic Scanner MOS-IRS
(orbit: altitude 817 km; 10:45 AM equator crossing time, descending node, sun synchroneous polar)

Parameter	MOS-A	MOS-B	MOS-C
Spectral range [nm]	755 - 768	408 - 1010	1550-1650
No. of channels	4	13	1
Centre wavelengths [nm]	756.7; 760.6; 763.5; 766.4	408; 443; 485; 520; 570; 615; 650; 685; 750; 815; 870; 945; 1010	1600
Spectral FWHM [nm]	1.4	10	93
Swath width [km]	187	200	192
No. of pixels	420	384	299
Pixel size x*y [km^2]	4.9 x 0.45	1.34 x 0.52	0.74 x 0.74
Measuring range $L_{min}...L_{max}$ [$\mu Wcm^{-2}nm^{-1}sr^{-1}$]	0.1 .. 40	0.2 .. 48	0.5 .. 8
Accuracy $\Delta L/L$ at L_{min} [%]	0.3	1.0	2.0
Dynamic range [bit]	16	16	16

Tab. 1: MOS Performance data

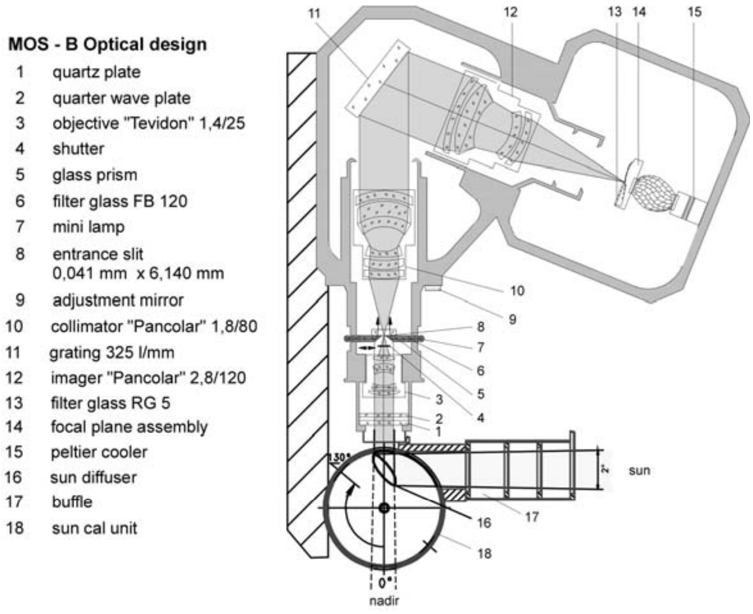

Fig. 1: Optical design and in-orbit calibration equipment MOS-B

2. IN-ORBIT CALIBRATION

The data quality during the mission time has been checked by different methods and also different equipment for each of the three MOS instruments.

The **internal lamp calibration** is a relative check. It was done at the beginning of each measuring cycle in 4 different radiation levels. The light of the two mini lamps (7) passed the glass prisms (5) and entered the spectrometer via two separate slits beneath the spectrometer slit. Only the following opto-electronical components could be checked by the internal lamps: The collimator (10), the grating (11), the imager (12), filter glass for second order spectrum suppression (13), CCD focal plane (14) and the sensor electronics.

The **sun calibration** permitted an absolute radiometric recalibration of the instruments. It was done periodically every 14 days when the satellite passed the terminator. Then the spectralon sun diffuser (16) was turned into the FOV of the spectrometer. The sun light passed the baffle (17) and fell under an angle of 40° onto the diffuser. The diffused sun light illuminated the TFOV of the instrument and now all opto-electronical components could be checked. That means we could check the quartz plate (1), the quarter wave plate (2), the entrance optics (3), the spectrometer slit (8) and additionally we could check the same components as the internal lamps but in a different way. This enabled us also to check the internal lamps and to find out in many cases which optical component generates observed changes in the response of the instrument.

For the **ground target based or vicarious calibrations** we have chosen a region near the border between Tunisia and Algeria south of Chott el Djerid, part of the Great Eastern Erg, a largely sandy desert. This is an area with good homogeneity, high reflection degree and with stable surface and atmospheric conditions which lies in the receiving area of the DLR satellite ground station Neustrelitz.

The vicarious calibration data have been corrected with respect to sun zenith angle at the centre of the test site and the distance between sun and earth. Atmospheric corrections were not taken into account. But we selected from the received spectrometer data of the test site only those which were taken at cloudless conditions also in the surrounding area and at sun zenith distance angles smaller than 50°. That means that we did not use measurements in wintertime and thus we can also exclude hoar frost effects at the surface.

The **moon calibration** served as a relative check of the calibration of the MOS sensors without atmospheric effects. It was evident especially for comparison between the different MOS-A channels inside and outside the O_2A-absorption band and the 750nm channel of MOS-B.

The history of MOS in orbit calibration started shortly after the launch on 21st March, 1996. The first what we found were some small changes in the internal lamp calibration data[1]. The internal lamps, for example, showed changes of the data taken before and after launch in the order of 2 to 4%. The in orbit sun calibration data indicated changes of the vignetting curves in the same order especially at one end of the CCD lines. Some of these effects were obviously caused by mechanical manoeuvres of the satellite. That means small particles seem to have been transported into the spectrometer slit plane and into the calibration slit plane where they changed the transmission of these slits. But after this time in the middle of April 1996 the instruments reached a new stable state for some years.

The next event was a small change of the vignetting curves of MOS-B in February 1999. Approximately the last 40 pixels of all spectral channels suffered a wavelength dependent decrease of responsivity up to 4%, the longer the wavelength the smaller the decrease. We found this effect only in the sun calibration data and in the ground target based calibration data, but not in the internal lamp calibration data. Taking into account the design of the on board calibration equipment the only explanation for this behaviour was a shadowing effect in front of the entrance optics. This change of the vignetting was a stable effect without variations up to the mission end.

In September 2000 the most dramatic occurrence during the whole mission time happened: the power supply of the internal lamp calibration and of the complete sun calibration equipment dropped out. That means also the dark signal measurement by using the shutter failed. Fortunately the nadir looking remote sensing measurements could be continued and were not affected in any way. The in orbit calibration based on lamp and sun calibration could be replaced and continued by the ground target based calibration using our test site of the Great Eastern Erg in the Sahara.

The dark signals needed for all measurements and for the calibration data too as from now were obtained by nadir measurements at the night side of the earth over the dark ocean during new moon.

The next two years mission time was without any problem. But in November 2002 we had to meet a new challenge. The thermo-electrical cooling of the CCD sensors did not work. Normally the detectors were stabilised to 5.0°C. But as from now the temperature decreased up to 20°C when the satellite moved from the dark to the illuminated side of the earth. To get accurately calibrated data we had to take into account the temperature dependence of the dark signals on the one hand and the temperature dependence of the responsivity on the other hand.

Fig. 2…4 show the data and the trend curves of the internal lamp calibration, the sun calibration and the ground target based calibration for 3 typical examples: the 408nm, the 685nm and the 1010nm channel. The last four data points of the ground target based calibration (bij_vic) after November 2002 are shown for two cases: a) the temperature correction is applied for 15°C (◆) and b) without temperature correction (o). From the 500…700nm spectral channels, which are unaffected by temperature variations practically (see fig. 3), we can see that the time trend must be a continuous function for all channels. The best indicator for the right temperature correction of the data is the 1010nm channel 13 because of its strong responsivity variation with temperature (see fig.4).

In spite of all the different events in orbit we always were able to derive actual recalibration data of high accuracy from the ground target based calibrations during the whole mission time without any break.

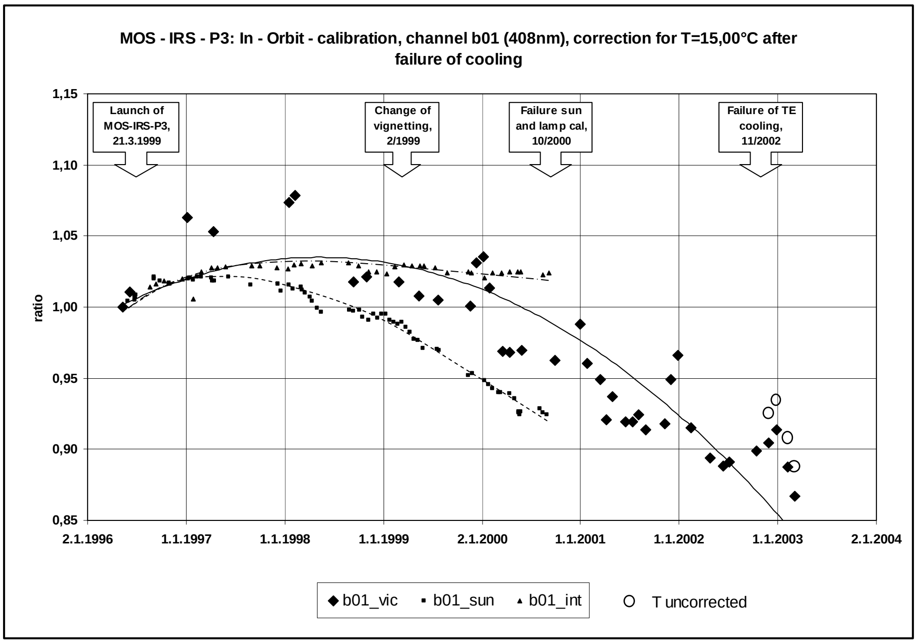

Fig. 2: Time trend of MOS in-orbit calibrations (vic: ground target based calibration, sun: sun calibration, int: internal lamp calibration), channel 01 (408nm)

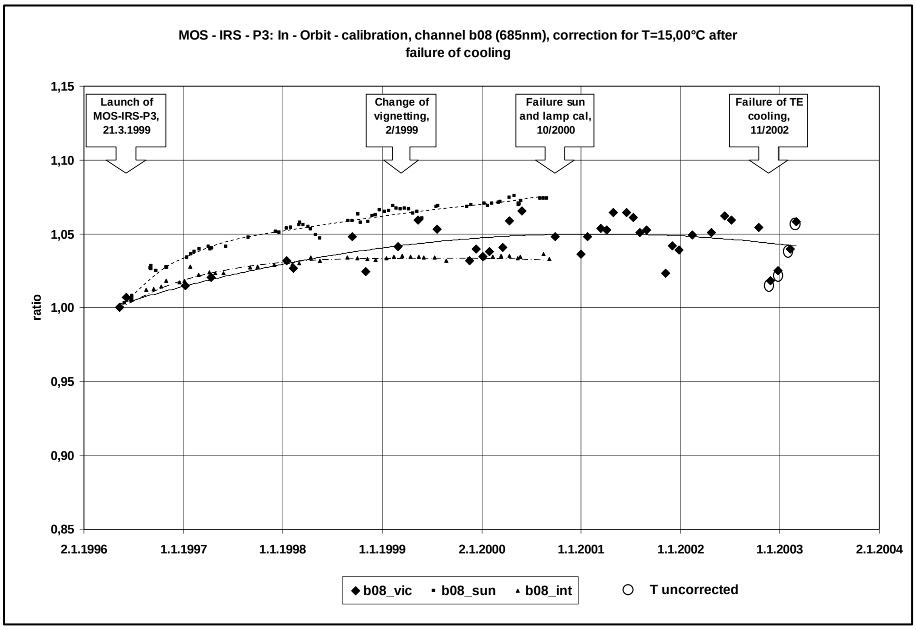

Fig. 3: Time trend of MOS in-orbit calibrations (vic: ground target based calibration, sun: sun calibration, int: internal lamp calibration), channel 08 (685nm)

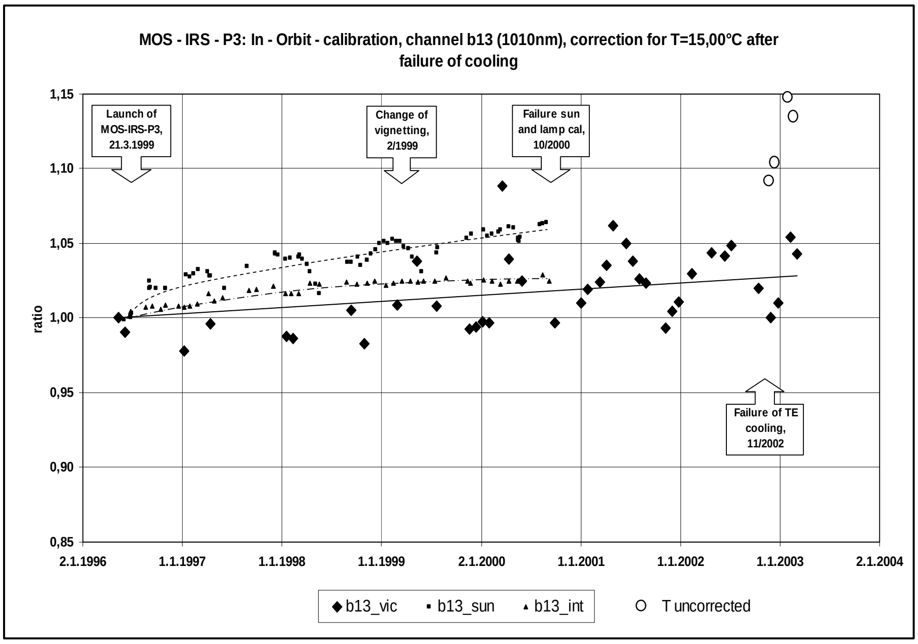

Fig. 4: Time trend of MOS in-orbit calibrations (vic: ground target based calibration, sun: sun calibration, int: internal lamp calibration), channel 13 (1010nm)

The different contributions of different MOS opto-electronical components to the total change of spectral responsivity of the MOS channels 7 years after launch are shown in fig.5. These results could be obtained by an intensive analysis of the different in-orbit calibration methods.

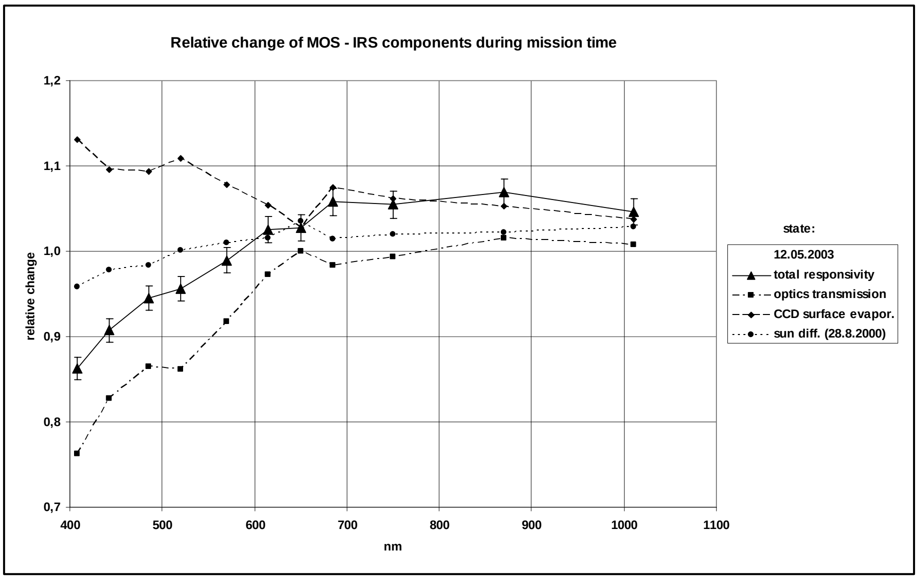

Fig. 5: Wavelength dependent change of optical and electronic MOS components in orbit

For the reason of an independent check of the calibration of MOS sensors some moon measurements were carried out in the year 1999. They were realised in the full moon phase at three different dates in August, October and December in 1999. Within 1 or 2 orbits per night the moon was scanned by the MOS instruments. Therefore it was necessary to carry out a manoeuvre with the satellite IRS-P3 to orientate MOS to the moon. While passing the moon, the pitch angle of the satellite was changed to get an image of the moon. With help of this operation it was possible to get 2-3 scans of the moon in one orbit.

The objective of the moon measurements was relative check of the calibration of the MOS instrument. It was assumed, that the spectral reflectivity of the moon surface is a smooth function over the wavelength interval of MOS instrument (400 – 1020 nm).

A mean value of selected pixels (bright pixels, not at the border of the moon) of each moon scan was determined and normalized to the wavelength of MOS-B-channel 8 (685 nm) after a resampling of the measured data (because of different scan velocities at different scans).

A definite difference of the smoothed function of normalized reflectivity could be used to derive a correction factor. Knowing, that the PRNU (Photo Response Non Uniformity) within one wavelength channel didn't change significantly, this correction factor is to apply to all pixels of a wavelength channel.

In the scatterplots of MOS-A channels (758, 760, 763 and 766 nm) in fig. 6 the correct calibration of MOS-A is confirmed (no O_2-absorption like on earth). The comparison of MOS-B-channel 9 (750 nm) and MOS-A-channel 1 (758 nm) confirmed corrections, which were derived from earlier sun calibration measurements for MOS-B instrument (see fig. 8).

So the moon measurements gave an additional approval for MOS calibration derived from sun measurements

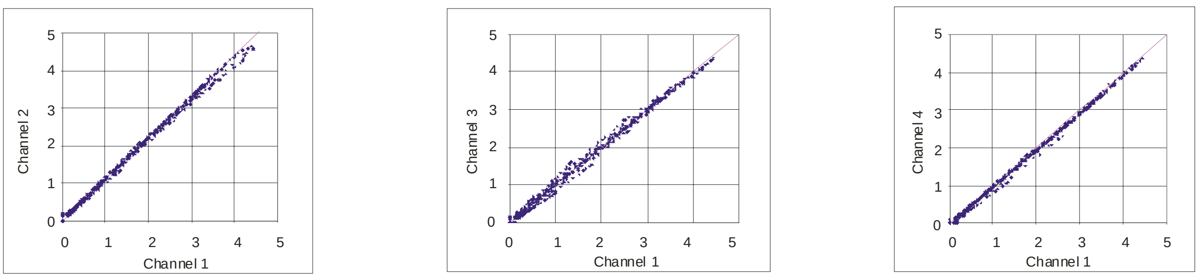

Fig. 6: Scatterplots of MOS-A channels (all radiances in µW/cm² nm sr)

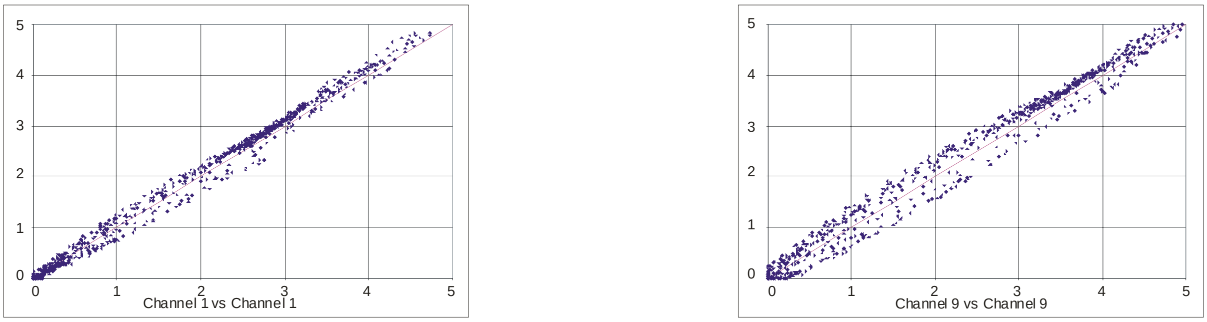

Fig. 7: MOS-B Scatterplots of different records and same channels (all radiances in µW/cm² nm sr)

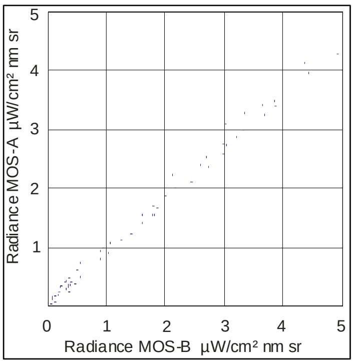

Fig. 8: Scatterplot of MOS-B vs MOS-A at 750nm

3. INTERCOMPARISON OF DERIVED PRODUCTS

Having different instruments in orbit for similar applications raises the question of intercomparison of derived products. For MOS an algorithm using Principal Component Inversion (PCI) was developed to compute water constituents directly from top-of-atmosphere radiances[2]. The inversion scheme accounts for aerosols internally and generates also a map of aerosol-optical thickness. The existing algorithm has been modified for SeaWiFS and MODIS respectively. Due to some reasons no intercomparison was made for large amounts of data. However, several samples of (nearly) synchronous overpasses of MOS, SeaWiFS and MODIS were processed, mainly in the North Sea, Baltic Sea, Black Sea and the Mediterranean. The results were analysed with respect to:

- intercomparison of SeaWiFS chlorophyll computed by SeaDAS with PCI-derived MOS chlorophyll
- intercomparison of PCI-derived chlorophyll, suspended sediment and aerosol-optical thickness both for SeaWiFS and MOS.

The analysis showed:

- good agreement for chlorophyll and aerosol-optical thickness in general, with clear differences for very small and very large values
- for most cases the PCI-derived values for all instruments agreed very good
- in turbid case-2 waters the better spectral resolution of MOS allowed a better distinction between chlorophyll, sediment and aerosol, the derived SeaWiFS products still show cross-influence between single parameters.

The latter is illustrated in Fig. 9, showing PCI-derived parameters for MOS and SeaWiFS over the German Bight.

Additional, very detailed intercomparisons have been made by the SIMBIOS project[3].

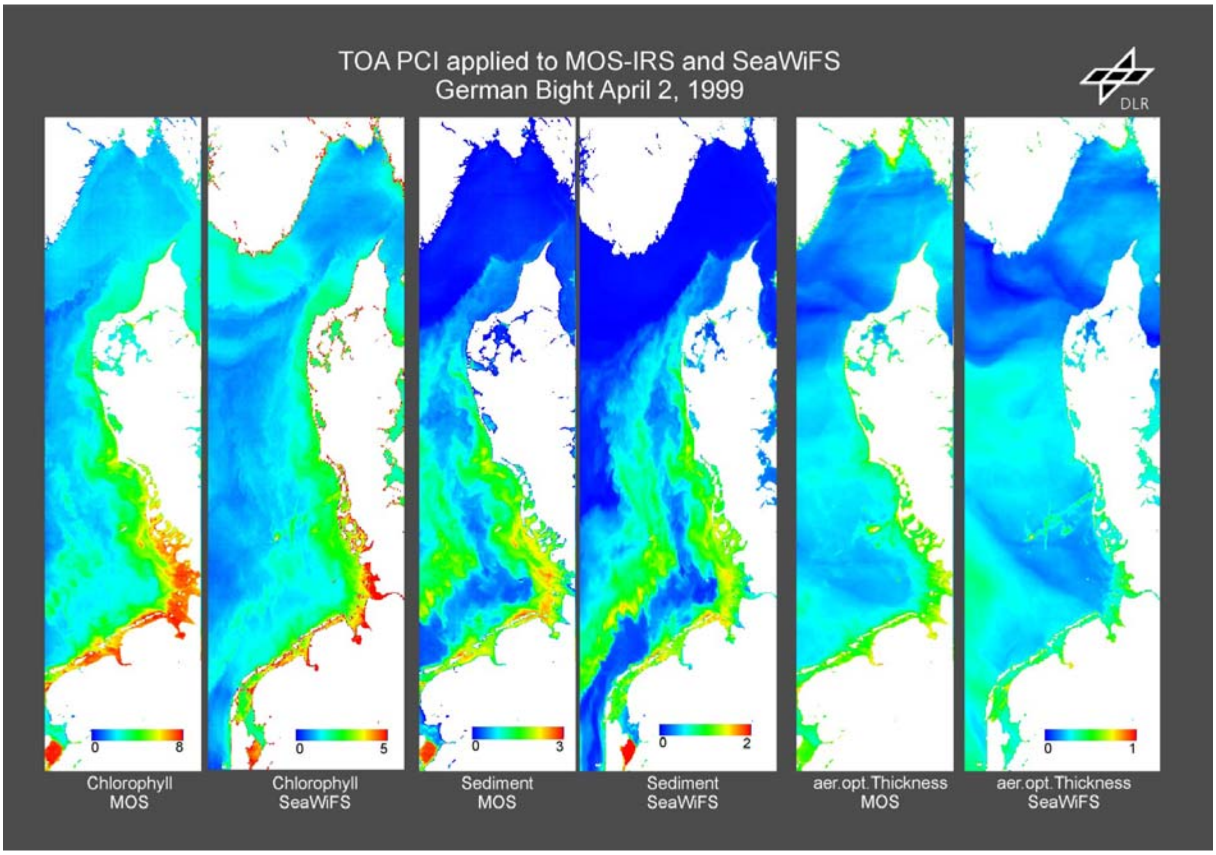

Fig. 9: PCI-derived parameters for MOS and SeaWiFS over the German Bight

4. CONCLUSIONS

The 8 years of in-orbit calibration of MOS was a very successful story. In spite of some critical events with respect to the in-orbit calibration such as changes of the vignetting, the failure of the sun and lamp calibration equipment after 4 years and the failure of the TE cooling of the detectors in 2002, we found solutions to continue the relative in-orbit calibration with very high accuracy without any break during the whole mission time. The changes of the relative calibration factors were caused by the aging of some opto-electronical components under the hard orbit conditions and by evaporation effects of the CCD surfaces. The changes of vignetting may have been caused by satellite manoeuvres especially at the beginning of the mission.

The good results of the in-orbit calibration based on the appropriate calibration concept, on the precise lab calibration and adjustment and on the precise knowledge of the instrument behaviour under different environmental conditions.

Using different and independent methods of in-orbit calibration often affords to get continuously recalibration data in spite of failure of instrument components. This also gives the possibility of discrimination and identification of different sources and reasons for changes in the calibration data.

Relative accuracy of about 1...2% for the recalibration data is achievable.

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