Study of OMI row anomaly during the OMI roll maneuver of January 29 2010

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1 Introduction

1.1 OMI row anomalies

A row anomaly is an anomaly which affects all wavelengths for a particular viewing direction of OMI. This corresponds to a binned row on the CCD detectors, and hence the term 'Row Anomaly'. Several row anomalies have occurred in the recent past. These anomalies affect the quality of the Level 1B and Level 2 data products.

- Anomaly 1: Since June 25th, 2007, cross-track scenes 53-54 (0-based).
- Anomaly 2: Since May 11th, 2008, cross-track scenes 37-44 (0-based)
- Anomaly 3: Since January 24th, 2009, cross-track scenes 27-44 (0-based).

Since "anomaly 3" the row anomaly exhibits a more dynamic behavior than before. Which rows are affected and to what extent varies with time.

The row anomalies have four distinct effects on the OMI radiance spectra:

1. Blockage effect

   A decrease in the radiance level for several viewing directions. It is currently assumed that this is caused by a partial blocking of the OMI nadir port. The blocking object is assumed to be opaque. This is effectively a multiplicative error on the radiances with a factor smaller than unity.

2. Solar radiation

   An increase in the radiance level for the northern part of the orbit. This type of anomaly occurs when the part of OMI containing the nadir port is directly illuminated by the sun. This is assumed to be caused by reflection of sunlight into the nadir port via the blocking object (outside of OMI). This is an additive error on the radiances. This increase in the radiance level is not observed for the first anomaly in rows 53-54 (0-based).

3. Wavelength shift

   The blocking object causes an inhomogeneous illumination of the spectral slit in OMI. This causes a change in the slit function, shifting the center of weight away from the nominal center. This causes light of a specific wavelength to hit the detector in a slightly different location than expected with a fully illuminated entrance slit.

   In the OMI Level 0 to Level 1 software in release 1.1.2 and before, the wavelengths are not fitted but assigned. Corrections are made based on the homogeneity of clouds and the temperature of the optical bench. Therefore the effect of an object blocking part of the incoming light is not included in the nominal level 1B wavelength assignment.

   The OMI Level 0 to Level 1 software version 1.1.3 adds a field with fitted wavelengths. If these fields are used, then this third effect mostly vanishes. Developers are referred to the Level 1B documentation for details on these new fields.

4. Earth radiance from outside nominal field of view

   Light reflected by the earth from outside the nominal field of view is coupled into the nadir port. This light is collected over a large area, giving an additive error on the radiances, with a term which is not constant.

The anomalies are known to the OMI team and are currently under investigation to examine whether corrections for the effects can be implemented in the Level 1b data. Also the OMI team would like to understand what causes the row anomalies.

1.2 OMI roll Maneuver

On request of the OMI Instrument Operations Team as part of the row anomaly investigation an OMI roll Maneuver was performed on January 29 2010. The maneuver consisted of a +10-degree roll for 2 orbits where Aura initiated the roll before Aura moved out of eclipse and ended the roll 2 orbits later after Aura had entered eclipse. During the 2 rolled orbits and one orbit before and one orbit after the roll OMI used the special Daily_ext_arctic orbit-type activity. This orbit-type activity is the same as a normal Nominal_1 orbit-type

activity, but with extended arctic measurements to fill the gaps between the radiance measurements and the dark measurements to monitor part of the row anomaly effect that went unobserved until January 28 2010. From this day onward this special orbit-type activity is part of the nominal operations baseline and is run once a day for monitoring purpose.
A difference in Aura attitude might shed some (new) light on the OMI row anomaly and could possibly point in the direction of the cause(s) of the OMI row anomalies.
The analysis of the data of the two rolled orbits and the two un-rolled (normal) orbits before and after the maneuver is discussed in section 2. Section 3 discusses a possible simple explanation at the south side of the orbit. The conclusions are drawn in section 4.

2 Comparison rolled and unrolled orbits

Comparison of the L0 data of the unrolled orbits (29479 and 29482) and the rolled orbits (29480 and 29481) shows that there is no difference in row number of the rows that are affected by reflected sunlight. Discussed here is UV1 data, but the conclusions also apply to UV2 and VIS data. As can be seen in Figure 1 the impact on radiance level due to reflected sunlight in rows 23 - 26 in UV1 during the south arctic measurements starts at the same point in the orbit, when Aura exits eclipse, and ends at a later point in the orbit for the rolled orbits compared to the unrolled orbits. The impact lasts about 1 minute 30 seconds longer in the rolled orbits with respect to the unrolled orbits

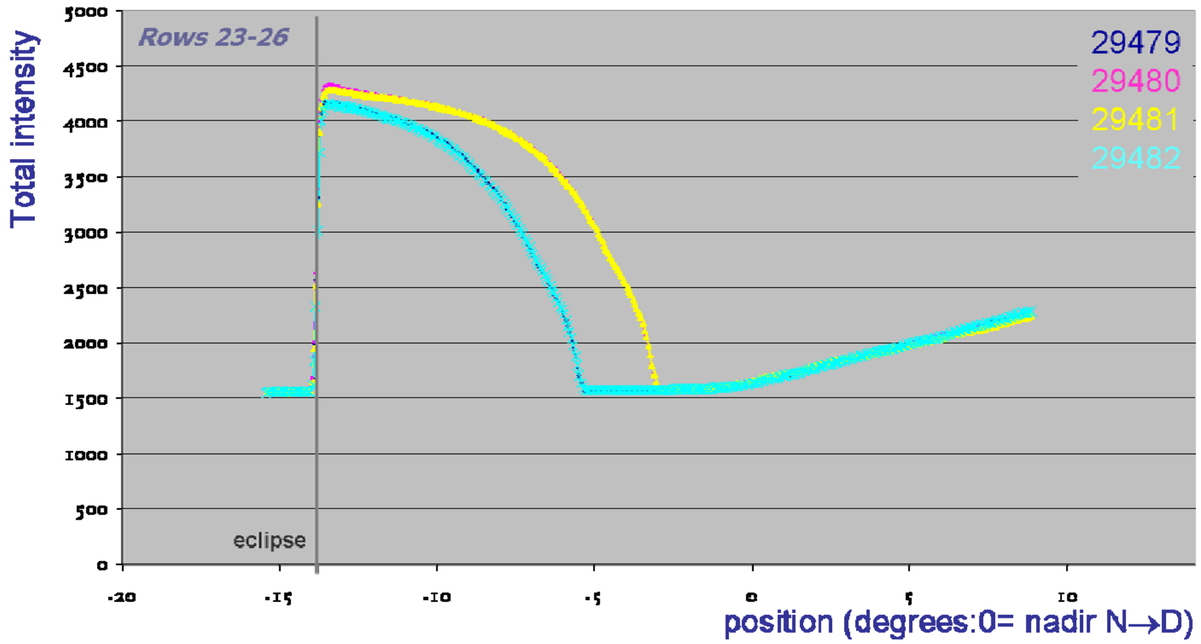

Figure 1. Total L0 radiance versus orbit position (in degrees), where 0 degree corresponds to the nadir night to day transition, for UV1 (rows 23 - 26). These are the rows that are affected by reflected sun light. The sharp rise in intensity around -14 degrees is caused by Aura moving out of eclipse. The impact due to reflected sun light starts for all orbits at the same point along the orbit (when Aura moves out of eclipse), but lasts longer for the rolled orbits.

Reflected sun light in UV1 also affects rows 14 - 21 at the north side of the orbit and starts for the rolled orbits earlier than for the unrolled orbits. As can be seen in Figure 2 the effect ends in both cases at the same point in the orbit when Aura enters eclipse. Again the impact starts about 1 minute 30 seconds earlier in the rolled orbits with respect to the unrolled orbits. Note: this shift in time of start of the reflected sunlight is only visible in UV1. For UV2 and VIS the reflected sunlight effect/signal is initially 'swamped' by the earthlight signal and can only be observed at a later point in the orbit. In both cases, at the south side of the orbit and at the north side of the orbit, the row anomaly effect of reflected sunlight lasts longer for the rolled orbits.

An interesting feature in UV1 is the appearance of an area of low intensity right in the middle of the rows that suffer from reflected sunlight. This 'hole' appears at some time during the north arctic measurements.

Figure **3** shows this dark feature for orbit 29479 728 seconds after the start of the north arctic measurements. The 'hole' appears in the rolled orbits immediately at the start of the north arctic measurements and for the unrolled orbits 41 s after the start of the north arctic measurements (see **Figure 4**).

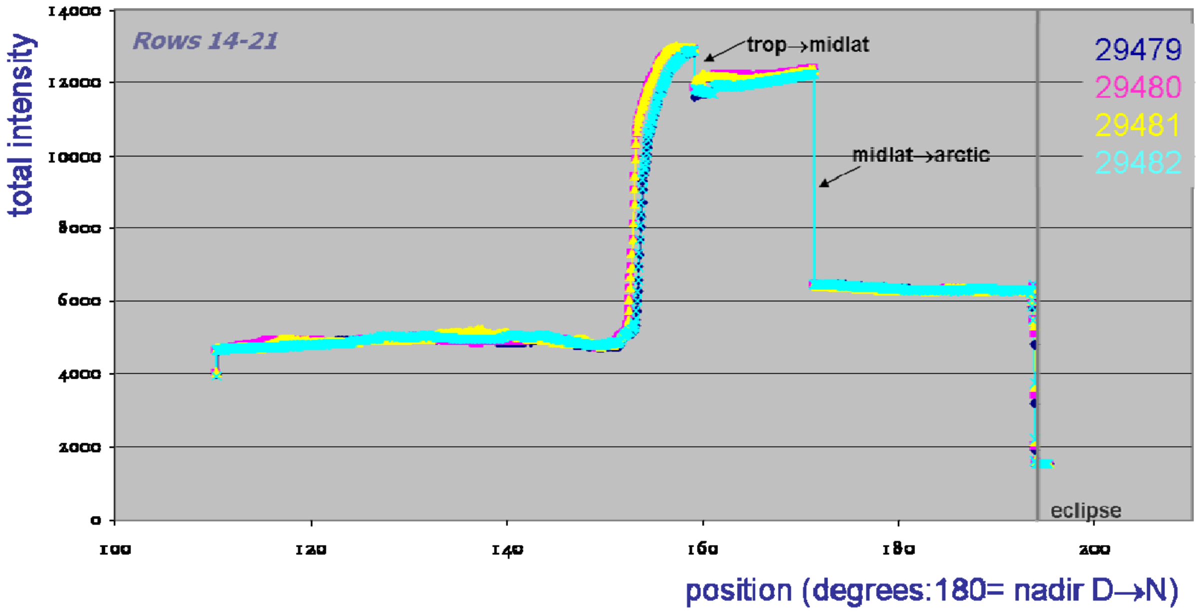

Figure 2. Total L0 radiance versus orbit position (in degrees), where 180 degrees corresponds to nadir day to night transition, for UV1 (rows 14 - 21). These are the rows that are affected by reflected sun light. The sudden drop in intensity near 160 degrees and near 170 degrees is caused by a change in CCD gain settings from tropics to midlat and from midlat to arctic settings. The third drop in intensity at the end is caused by Aura moving into eclipse. The impact due to reflected sun light starts for the rolled orbits at a point earlier along the orbit, but the impact subside for all orbits at the same point along the orbit (when Aura moves into eclipse). The duration of the reflected sunlight lasts longer for the rolled orbits.

There appears no 'hole' feature in the north midlat measurements. This is due to the fact that the midlat measurements have a lower gain factor than the arctic measurements. Further analysis indicates that this dark feature shows up for the first time January 24 2009. This goes inside with a change in the row anomaly behaviour (see section 1.1). The low pixel values are actually underflows that are caused by too much light somewhere (not necessarily the same pixels) on the CCD. This underflow problem is a complicated problem and is well described in TN-OMIE-KNMI-630: "Clipped signals in high gain areas". Unfortunately it can not help us understand (better) the row anomaly as the pixels that suffer from too much light might not be the same pixels that suffer from the underflows and therefore can not give any clue as to for instance what material the reflective material is made of.

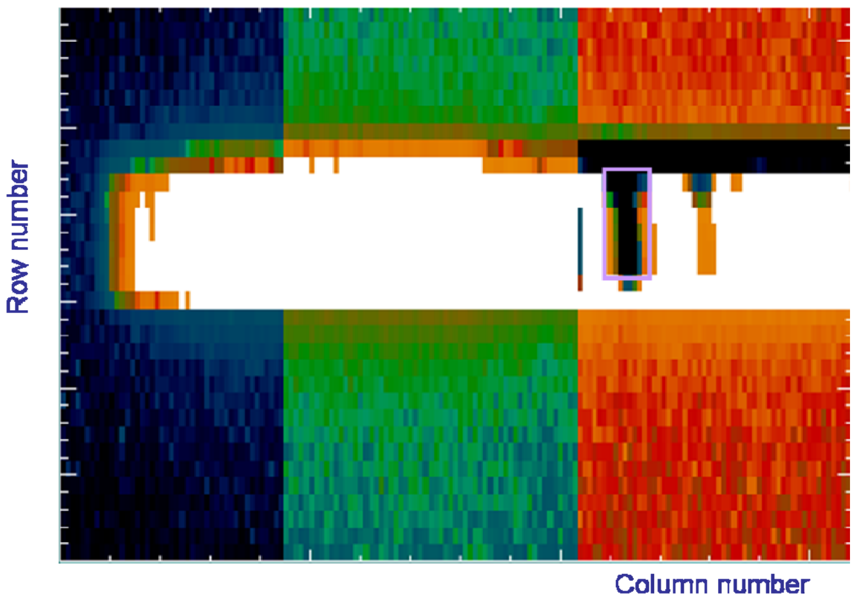

Figure 3. Row (Xtrackposition) versus column (wavelength) for UV1 for orbit 29479 728s after the start of the north arctic measurements. Clearly an area of low intensity has developed in the middle of the rows with high intensities due to the reflected sun light.

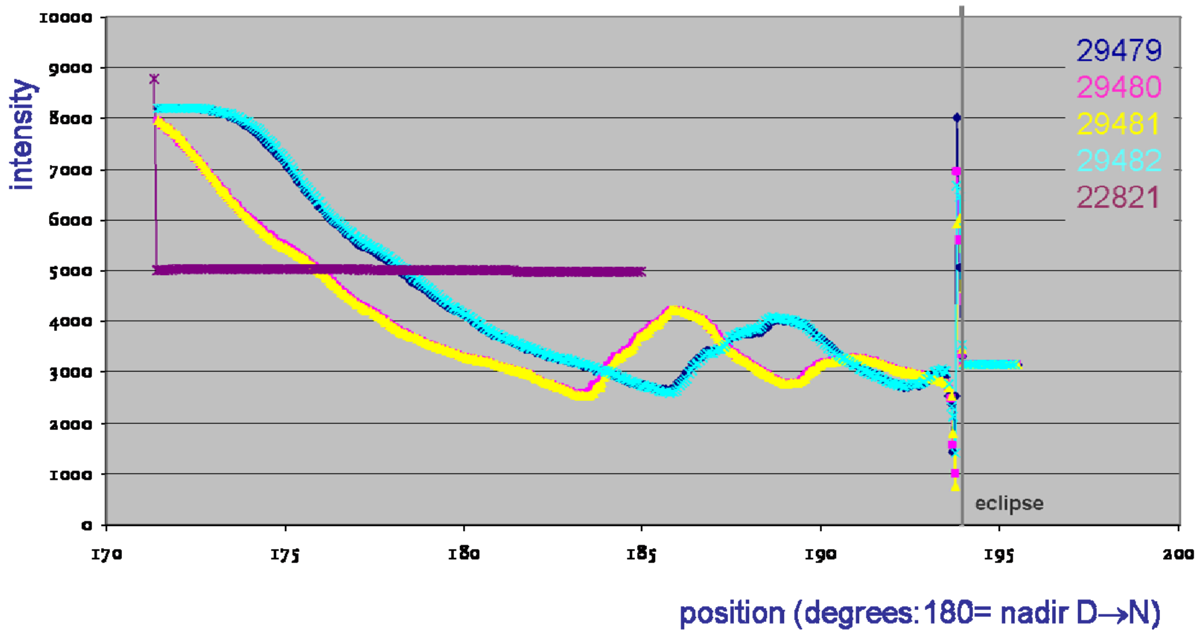

Figure 4. L0 radiance versus orbit position (in degrees), where 180 degrees corresponds to nadir day to night transition for a certain pixel box in UV1 (rows 17-21 and column 109-119 (UV1 coordinates)). The pixels in this box go from very high intensities (reflected sunlight) to very low intensities during the north arctic measurements. For the rolled orbits the lowering of pixel intensities (start of the 'hole') starts immediately when the north arctic measurements start. For the unrolled orbits it starts later. Just before Aura enters eclipse the intensity of the pixels in the pixel box first decreases sharply. This sharp decrease is followed by a

sharp increase when the 'hole' disappears. This is followed by a sharp decrease of intensity when Aura enters eclipse. As a reference the data from orbit 22821 (October 29 2008) has been added. For this date there is no 'hole' in UV1. Note that orbit 22821 was a normal N1 orbit-type activity without extended arctic measurements and therefore ends before the end of the extended arctic measurements used just before, after and during the roll.

3 Attempt to understand reflection on the south side of the orbit

The most puzzeling row anomaly effect is the reflected sunlight that occurs during the extended south arctic measurements, since Aura just comes out of eclipse and the sun is at the wrong position with respect to the OMI aperture. Note however that normal (i.e. without arctic measurement extension) orbit-type activities start at a later point in the orbit and are not troubled by this puzzeling effect.
Since we lack the possibility to model this in 3D we have to make do with trying to picture the situation in 2D. For a simple single scattering solution to the problem we need to place a piece of reflective material R somewhere in the field of view as drawn in Figure 5. Also drawn are the sun rays incident at 15 degrees and 5 degrees. Note: at 5 degrees the reflection effect has disappeared for the unrolled orbits. The reflective piece of material R as drawn in Figure 5 might explain this situation. However, we don't understand how it is possible for a roll of 10 degrees around the x-axis to cause the effect of reflected sun light to last longer in the rolled orbits. Here we assume (as we must) that the piece of reflective material is attached to the Aura satellite. This suggests that the row anomaly effect is caused by a more complicated double/multiple scattering problem.
Furthermore, the piece of reflective material, as placed in Figure 5, fails to explain the reflectance effect at the north side of the orbit and also fails to explain other aspects of the row anomaly.

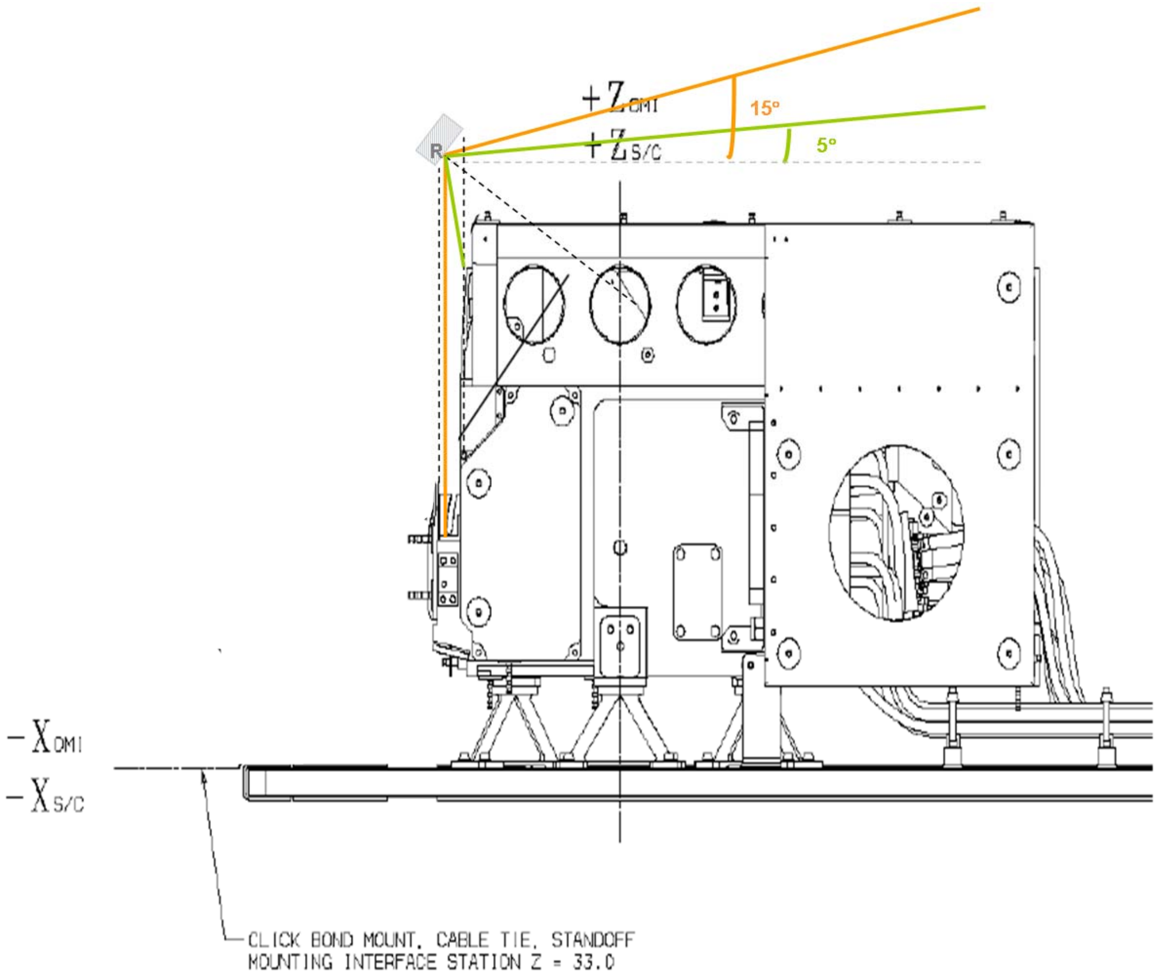

Figure 5. A schematic view of the OMI aperture and solar rays incident at 15 and 5 degrees on Aura and a piece of imaginary reflective material R. This is the most simple way to observe reflections when Aura is out of eclipse, but has not yet crossed the terminator.

4 Summary and Conclusions

- An OMI roll maneuver was performed on January 29 2010. Aura was rolled by +10 degrees during two orbits.
- The L0 data was analyzed for the rolled (29480 and 29481) and the unrolled orbits (29479 and 29482).
- A roll of 10 degrees did not result in a shift in row number for the rows that were affected by the reflected sunlight.
- The duration of the row anomaly effect (reflected sun light) in the arctic measurements is longer for the rolled orbits in comparison to the unrolled orbits. For the south arctic measurements the effect starts at the same moment in the orbit (when Aura moves out of eclipse) and for the rolled orbits lasts about 1.5 minutes longer. This is true for VIS, UV2 and UV1.
- The reflected sun light effect at the north side starts during the tropical measurements and starts for the rolled orbits about 1.5 minutes earlier than for the unrolled orbits. This effect ends for both the unrolled and rolled orbits at the same moment in the orbit (when Aura enters eclipse).
- The fact that there is a change of the effect in case of rolled orbits tells us that the row anomaly is caused by something on the satellite (which does not tell us anything new).

- An interesting feature appears in the north arctic measurements when for a certain group of pixels in UV1 the high values (due to sunlight reflection) drop to very low values and a 'hole' appears in the middle of the rows that are affected by reflected sun light. This feature appeared for the first time on January 24 2009. It is the effect of underflows that appear when there is too much light, possibly somewhere else, on the CCD and, therefore, it can not teach us anything about for instance the kind of material that is reflecting/blocking the light.
- It is not possible to explain the reflection effect at the south side of the orbit in terms of a simple single scattering event. We therefore conclude that the row anomaly is caused by a double/multiple scattering effect which makes it very difficult to figure out what is the cause of the row anomaly and what to expect for the rolled orbits.