3.3. Auroral lights

Auroral lights visible in the FoV of the detector with very high probability restrain EAS measurements. Conservatively, they should be excluded from the observational duty cycle. Method to evaluate a auroral lights influence to observational duty cycle is described in Appendix A.

The influence to observational duty cycle year by year since 2000 till 2011 is presented in the left panel of Figure 3. The value of the observational duty cycle has an absolute reduction going from 2.46% in year 2003 to 0.12% in year 2009.

Because the effect clearly depends on time, specifically on solar cycle, the influence is estimated also in 3 years moving time windows, i.e. periods 2000– 2002, 2001–2003, till 2009–2011. We selected 3 years long periods because we estimate similarly long measurements of JEM-EUSO on ISS in years 2017– 2019. The effect of auroras presented in the right panel of Figure 3 is the highest for periods 2002–2004 and 2003–2005 when the observational duty cycle diminishes by 1.6% and it is lowest in periods 2008–2010 and 2009–2011 with value 0.3%.

To evaluate the influence in years 2017–2019 we should estimate geomagnetic conditions during such period. The conservative estimation is, that JEM-EUSO will face declining solar activity and solar minimum somewhere during measurement period. In that case we estimate an effect of auroral lights to the observational duty cycle to be close to ~1% which has to be added to the other factors quantified in this section.

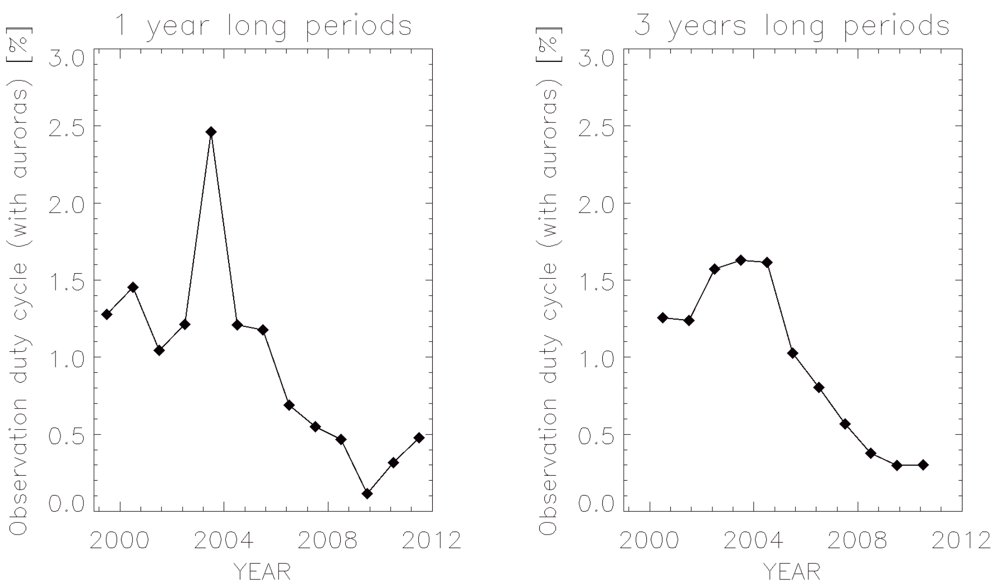

Figure 3: Left panel: Effect of auroras to JEM-EUSO observational duty cycle for one year long periods from 2000 to 2011. The value of absolute reduction varies from 2.46% in year 2003 to 0.12% in year 2009. Right panel: The effect of auroras is highest for periods 2002–2004 and 2003–2005 when the observational duty cycle diminishes by 1.6% and it is lowest in periods 2008–2010 and 2009–2011 with value 0.3%.

Appendix A.

The position of auroral oval depends on the magnetosphere disturbance. With increasing level of the magnetospheric disturbance equatorward border of the auroral oval move closer to geomagnetic equator. Level of magnetospheric disturbance can be described by Kp index. Equatorward border position of auroral oval as funcion of Kp index is usually fitted by linear functions (J.A.Whalen, 1985). Fits are evaluated for different magnetic local times with one hour steps. Table 1App describes the position of equatorward border geomagnetic latitude dependency on Kp index for midnight local magnetic time. Because at midnight is equatorward auroral boundary position one of the closest to the equator, we use these values as conservative estimation of auroras possible appearance. Because inclination of ISS orbit is 51.6^{o} we cannot see auroras during period with Kp index less then 3. Latitudinal thickness of auroral oval is approximately 10 degree in narrowest region for Kp = 3 and increase to 20 degree for Kp = 8 (S.E.Milan, 2010). In conclusion we can assume that ISS trajectory does not cross the poleward border of auroral oval during the period 2000 till 2011, what keep our model conservative.

Table 1App: Equatorward auroral boundary position dependence on Kp index

Geomagnetic Latitude	Kp index
66.5	0
64.5	1
62.4	2
60.4	3
58.3	4
56.3	5
54.2	6
52.2	7
50.1	8
48.1	9

To estimate the influence of the auroral lights to the observational duty cycle of JEM-EUSO experiment we evaluated the geomagnetic coordinates of the ISS real trajectory (one minute steps taken from NASA SSC locator) together with adequate Kp index. We assume that auroral light is visible in JEM-EUSO nadir mode of observation if it is located inside auroral boundaries. In the model we excluded all ISS positions with geomagnetic latitude higher that latitude of equatorward auroral boundaries from the observational duty cycle.

The method is verified by the NASA video (NASA Video Gallery) taken on September 17, 2011, on an ascending pass from south of Madagascar to north of Australia over the Indian Ocean. Part of the video shows the ISS flight over aurora australis, when auroral light is visible in nadir observational mode.

The record presented in NASA video starts at 17:22:27 and ends at 17:45:12 GMT. From NASA video can be seen that ISS passed over Aurora approximately from 17:26 till 17:33 GMT. This is the time range predicted by our method. Positions of aurora visibility predicted by our method also approximately fits positions with aurora visibility in the video as showed at figure 1App. The video starts south of Madagascar and during 4 minutes ISS passes almost 1700 km and moves eastward by ~15 degrees what agrees with first point predicted by the estimation method. Reading from the video is of course not very precise due to tilt of camera at ISS and unknown completeness of time coverage of movie slides, hovewer aurora visibility is predicted precisellly in time scale with one minute steps. Because this, we do not take the video as a proof of the method validity but as a supporting argument to validity.

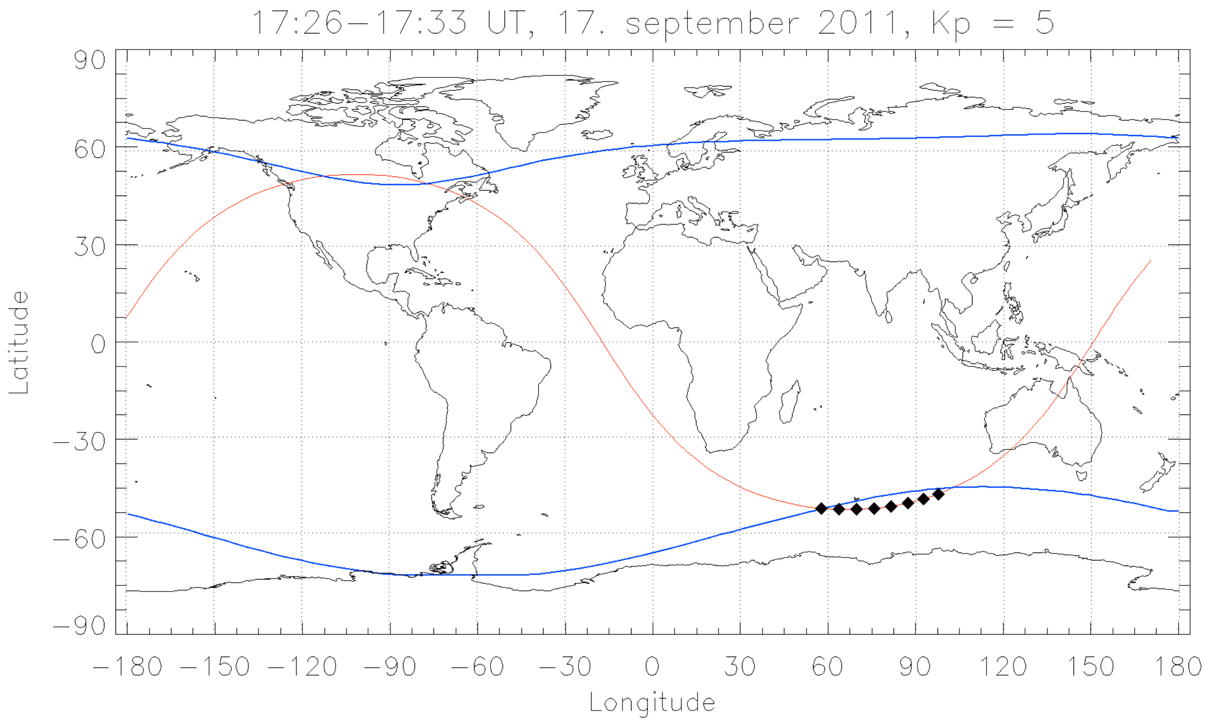

Figure Apendix 1: Red line represent trajectory of the ISS, blue lines are equatorward boundaries of the auroral oval for magnetosphere disturbed at levele Kp = 5. Diamons on ISS trajectories are points on ISS trajectory with one minute step (from 17:26 till 17:33 GMT, 17 september 2011) excluded from operational duty cycle visible on NASA video [citation].

Parts of the ISS trajectory excluded from duty cycle for year 2003 when magnetopshere was most disturbed and for year 2009 when situation was most quiet during researched preriod can be seen at figure 2App. For year 2003 we exclude 12913 minutes, in 2009 only 608 minutes. Different levels of Kp indexes are signed by different colors on excluded space station minute positions. It is clearly seen that with higher Kp we stay longer in regions where during night auroras can restrain measurements of JEM-EUSO detector. But those periods are less frequent with Kp index increasing. Histograms showing distribution of Kp indexes during year 2003 and 2009 (upper right corner of figures 2App). We do not observe auroras inside equatorward border along the ISS trajectory in nadir observation mode for Kp index equal two or lower value. While for most disturbed year 2003 we have 36% of time on orbit Kp at levels 0, 1 or 2, for most quiet year 2009 it is 94%. Looking to periods where we can see auroras more offenly, during 2003 we have 1.4% of time Kp at levels 7, 8, 9, for year 2009 there are not disturbances at this levels at all.

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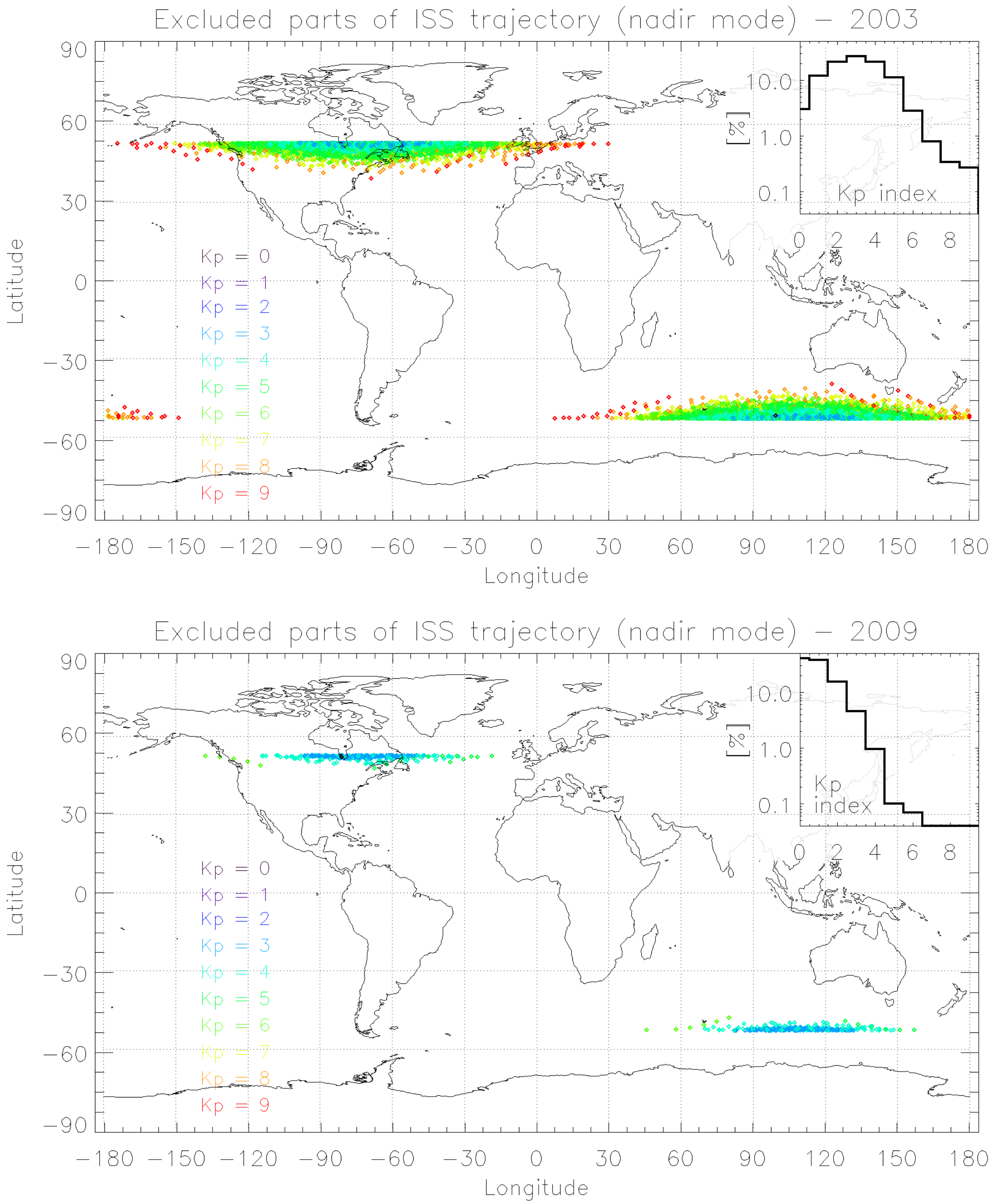

Figure Apendix 2: Upper panel: Excluded parts of ISS trajectory during year 2003 due to auroras. One minute steps of trajectories are in color describing a Kp ingex of geomagnetic activity. Upper left included figure show a histogram of Kp index measured along ISS trajectory during the year 2003. Bottom panel: Excluded parts of ISS trajectory during year 2009 due to auroras. One minute steps of trajectories are in color describing a Kp ingex of geomagnetic activity. Upper left included figure show a histogram of Kp index measured along ISS trajectory during the year 2009.