Characterization and monitoring of space radiation in LEO orbit by the SATRAM/Timepix payload on board the ESA Proba-V satellite

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The compact spacecraft payload SATRAM, operating in LEO orbit since 2013 on board the Proba-V satellite from ESA, provides comprehensive and high resolution radiation monitoring in the satellite environment. Equipped with the hybrid semiconductor pixel detector Timepix, the technology demonstration payload determines the composition and spectral characterization of the mixed radiation field with quantum imaging sensitivity, charged particle tracking, energy loss and directionality capability. With a polar orbit (sun synchronous, 98° inclination) and altitude of 820 km the space radiation field is visualized and continuously sampled essentially over the entire planet. In this contribution we present the resulting spatial and time distributions of dose rates and particle fluxes produced in wide dynamic range.

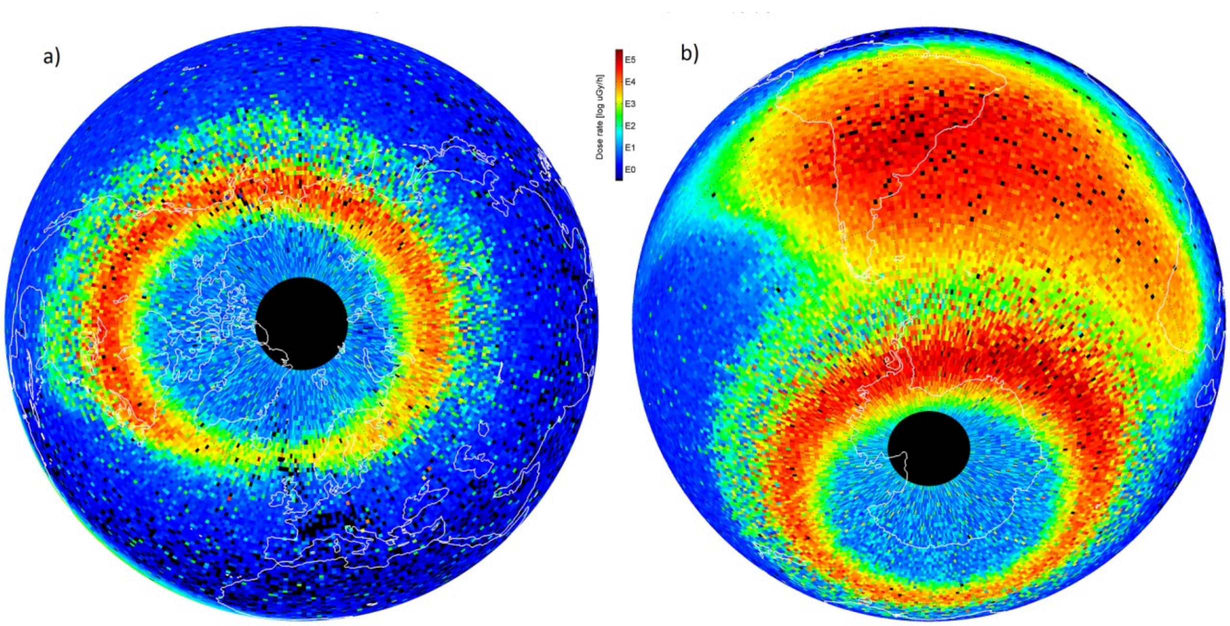

Fig. 1. *Earth map of space radiation in LEO orbit at 820 km measured by SATRAM/Timepix payload on board the Proba-V satellite. The total dose rate is shown (in units uSv/h displayed in color in log scale) for the Northern (a) and Southern (b) hemispheres. The polar horns of the radiation belts are revealed together with the South Atlantic Anomaly (b). Data displayed for the period January-July 2015. Regions and bins in black correspond to locations not covered by the satellite, or where data was not collected, respectively.*

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The SATRAM Timepix spacecraft payload in open space on board the Proba-V satellite for wide range radiation monitoring in LEO orbit

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ABSTRACT

The Space Application of Timepix based Radiation Monitor (SATRAM) is a spacecraft platform radiation monitor on board the Proba-V satellite launched in an 820 km altitude low Earth orbit in 2013. The is a technology demonstration payload is based on the Timepix chip equipped with a 300 μm silicon sensor with signal threshold of 8 keV/pixel to low-energy X-rays and all charged particles including minimum ionizing particles. For X-rays the energy working range is 10–30 keV. Event count rates can be up to 10^6 cnt/(cm^2 s) for detailed event-by-event analysis or over 10^{11} cnt/(cm^2 s) for particle-counting only measurements. The single quantum sensitivity (zero-dark current noise level) combined with per-pixel spectrometry and micro-scale pattern recognition analysis of single particle tracks enables the composition (particle type) and spectral characterization (energy loss) of mixed radiation fields to be determined. Timepix's pixel granularity and particle tracking capability also provides directional sensitivity for energetic charged particles. The payload detector response operates in wide dynamic range in terms of absorbed dose starting from single particle doses in the pGy level, particle count rate up to 10^{6-10} /cm^2/s and particle energy loss (threshold at 150 eV/μm). The flight model in orbit was successfully commissioned in 2013 and has been sampling the space radiation field in the satellite environment along its orbit at a rate of several frames per minute of varying exposure time. This article describes the design and operation of SATRAM together with an overview of the response and resolving power to the mixed radiation field including summary of the principal data products (dose rate, equivalent dose rate, particle-type count rate). The preliminary evaluation of response of the embedded Timepix detector to space radiation in the satellite environment is presented together with first results in the form of a detailed visualization of the mixed radiation field at the position of the payload and resulting spatial- and time-correlated radiation maps of cumulative dose rate along the satellite orbit.

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http://satram.utef.cvut.cz/

SATRAM

Institute of Experimental and Applied Physics, Czech Technical University in Prague

The compact SATRAM spacecraft payload equipped with the Timepix semiconductor pixel detector is operating in LEO orbit at 820 km altitude onboard ESA's Proba-V satellite launched on 7th May 2013. The technology demonstration payload was successfully commissioned and has been providing continuous time-stamp monitoring of the space radiation field in the satellite environment along its orbit.

The instrument was designed and constructed by CSRC, Brno with with the Institute of Experimental and Applied Physics (UTEF) of the Czech Technical University (CTU) in Prague with funding by the European Space Agency, Grant No. 4000105089/11/NL/CBi.

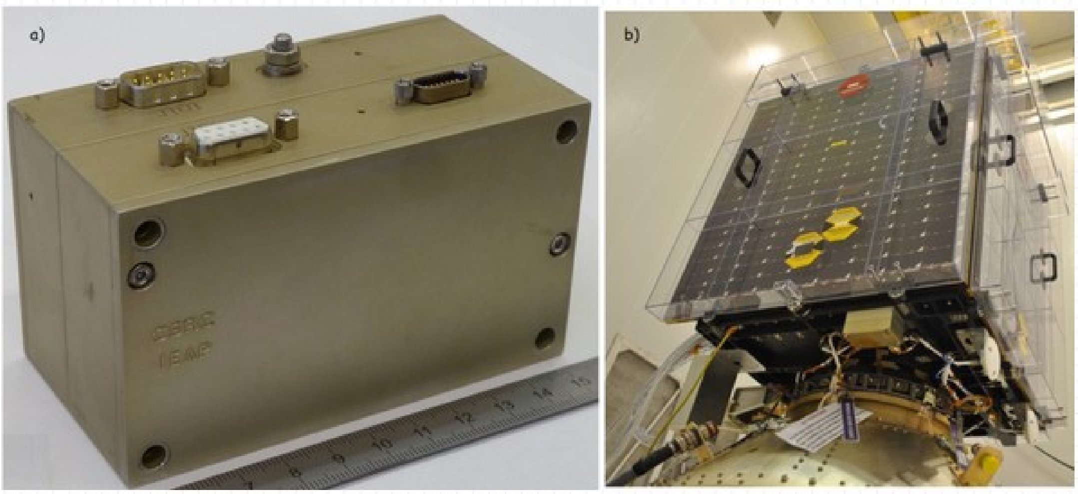

FIG. 1: SATRAM engineering model (EM) (a) and the QFM payload (b) attached to ESA's Proba-V satellite external bottom side(b) prior launch by Vega-2 rocket. SATRAM payload size: 55.5 mm (height), 62.1 mm (width) and 107.1 mm (length); mass including shielding box 380 g. Proba-V satellite size: 80 cm × 80 cm × 100 cm; mass 138 kg.

Space Application of Timepix based Radiation Monitor (SATRAM)

SATRAM is a technology demonstration device carrying the Timepix position-sensitive semiconductor pixel detector. On board ESA's Proba V satellite, (see Fig. 1). Since launch on the 7th May 2013, SATRAM has been continuously operating in open space. The payload has the capability to read up to several frames per second (fps), with adjustable frame length (from μs up to arbitrarily long acquisition times (e.g. few s and longer)).

Data products

Measurement of spectral characteristics and composition of mixed radiation field in the satellite environment. Spatial- and time-distributions of radiation maps along the satellite orbit. Data products:

- Particle count rates
- Particle fluxes (*)
- Dose rate [uSv/h]
- Directional distributions of energetic charged particles (evaluation in progress)

* on the detector. external field require satellite environment correction and numerical/MC simulations.

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Fig. 2. Quantum imaging detection of space radiation by the SATRAM payload on board the Proba-V satellite in an 820 km altitude LEO orbit. The data are position- and time-stamped. Frames shown were acquired on (a) 11th Nov 2013 over the Korea peninsula; and on 23rd April 2014 over (b) the Southern Indian Ocean, (c) the South Pole, and (d) the South Atlantic anomaly (SAA). Data displayed in Timepix counting mode. Frame acquisition time: 1s (a) and 10 ms (b,c,d). The whole Timepix sensor is shown (matrix 256 × 256 pixels, total size 14 × 14 mm^2 = 2 cm^2).

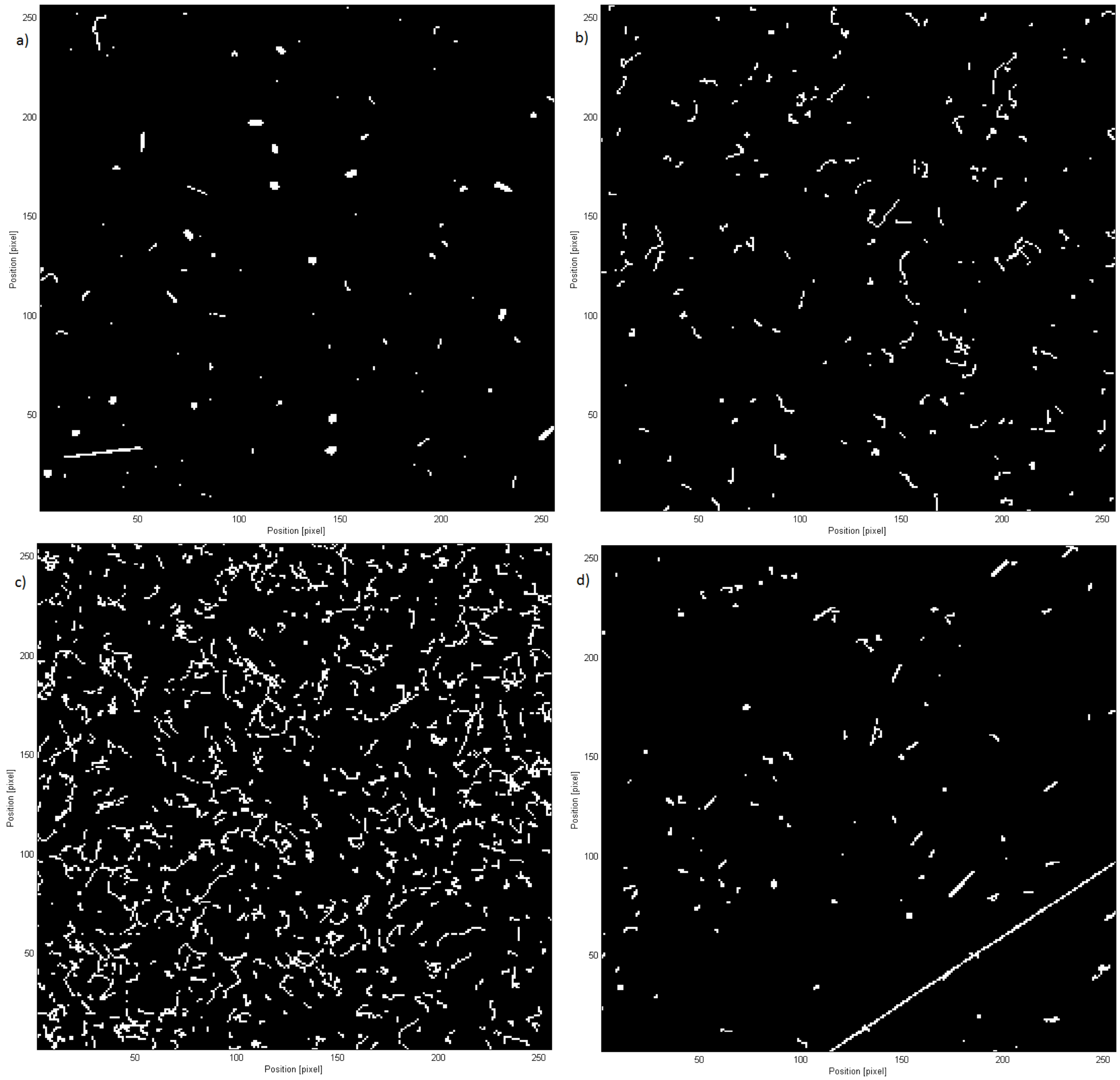


Fig. 3. Similar to Fig. 2 with Timepix data displayed in energy (ToT) mode where the per-pixel energy response is shown in color (see vertical bar with varying range scale for each frame). Frames collected in 200 ms (a,b) and 20 s (c) exposure times for distinct radiation regions along Proba-V's LEO orbit containing a dominant component of (a) light and (b) heavy charged particles. The track of a single (c) highly energetic high-Z ion with associated delta electrons is shown. Only parts of the whole sensor area are displayed.

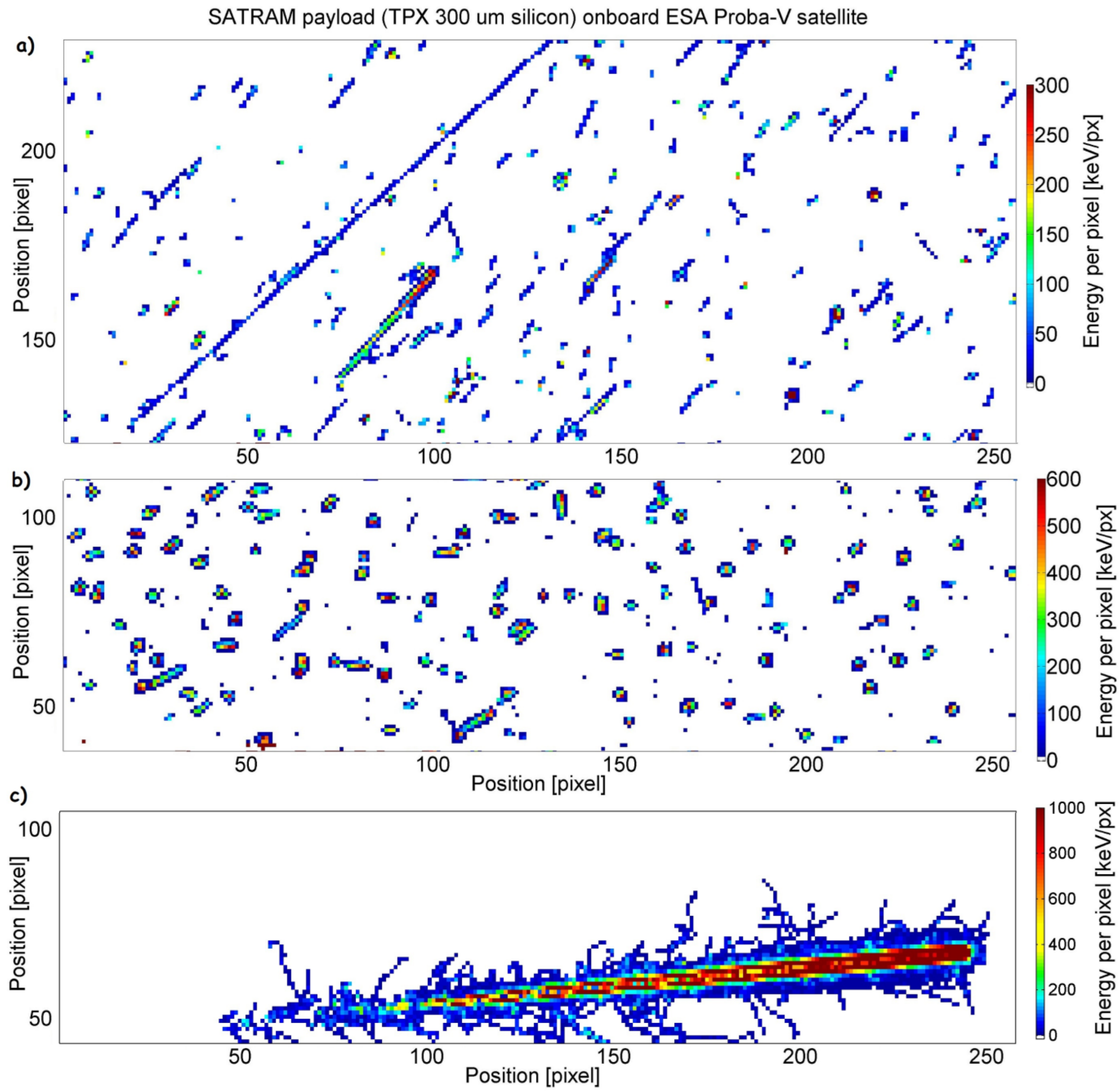
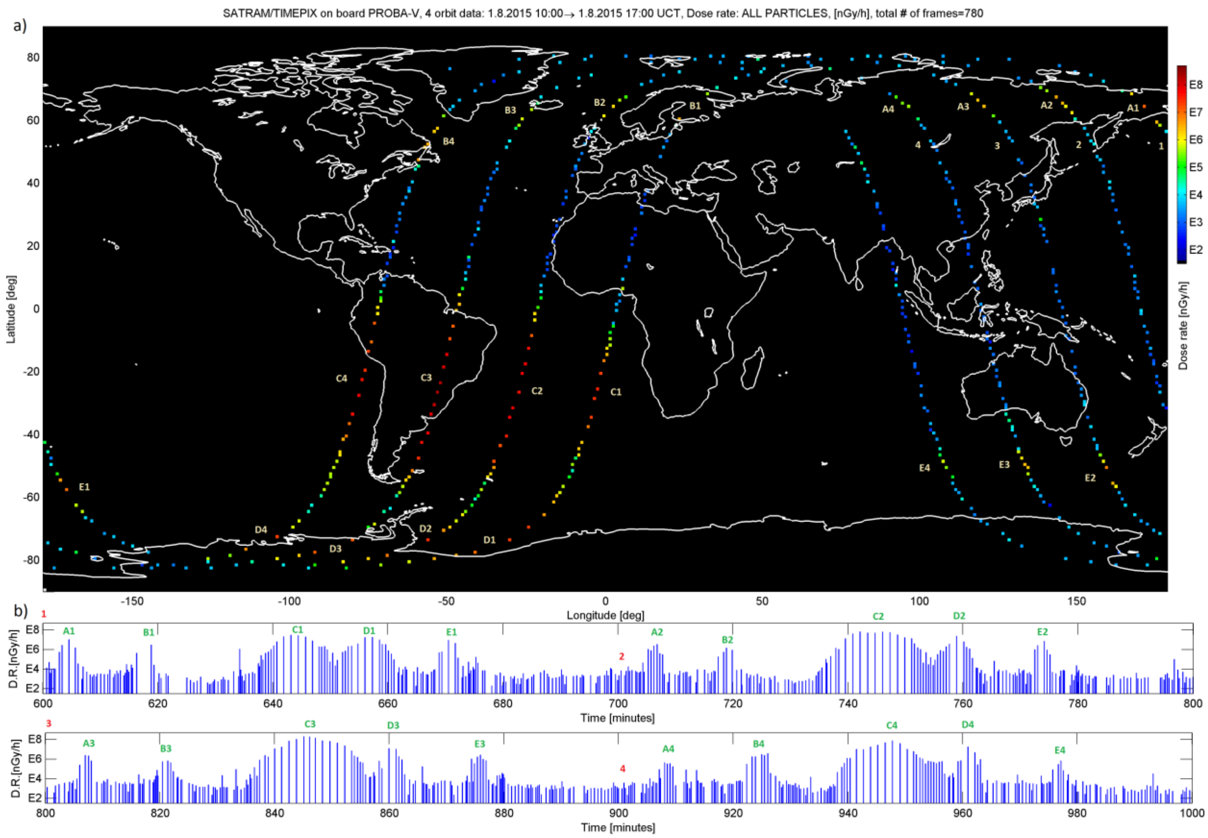


Fig. 4. Spatial (a) and time (b) distributions of total dose rate (sum of all particle components) measured by SATRAM along the 820 km LEO orbit of Proba-V. Results are shown for a 7 h period comprising 4 orbits on 1st August 2015 from 10:00 h thru 17:00 h (UCT time). Data shown were acquired from a total of 780 data frames. The quantity displayed (total absorbed dose, displayed in nGy/h) span overs six orders of magnitude (color bar and vertical axis in the histograms given in log scale). For orientation, the start of the orbits are labeled (1 thru 4) as well as few regions of high radiation intensity (A thru E).



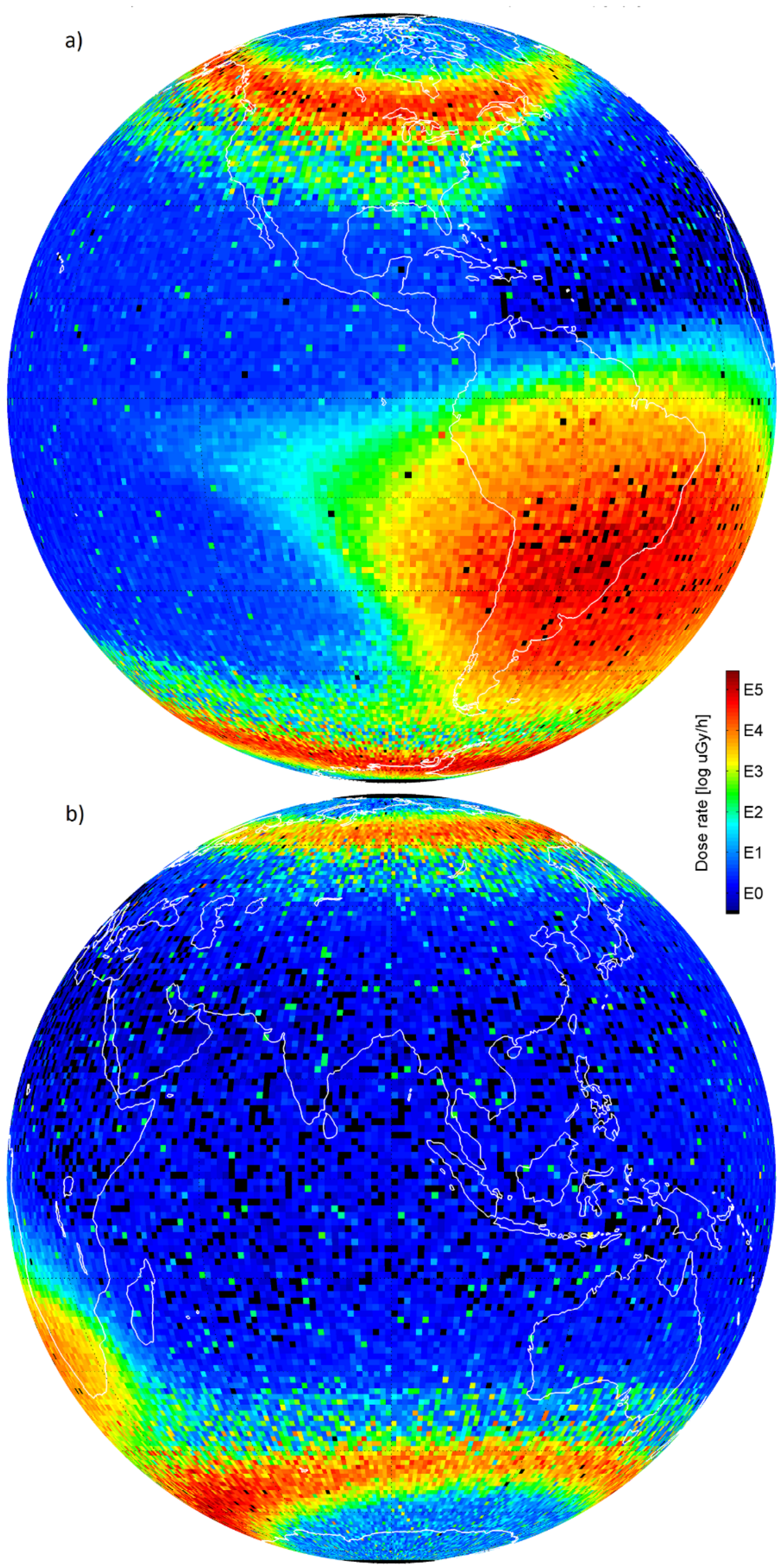


Figure 5. Map of space radiation registered by SATRAM on board Proba-V in a nine month period from 1st January till 9th August 2015 showing the (a) Western and (b) Eastern hemispheres. The evaluated quantity (total dose rate (all particles)) is displayed in spatial bins of 1° with values averaged over the whole period. Bins without data appear as empty cells (in black).

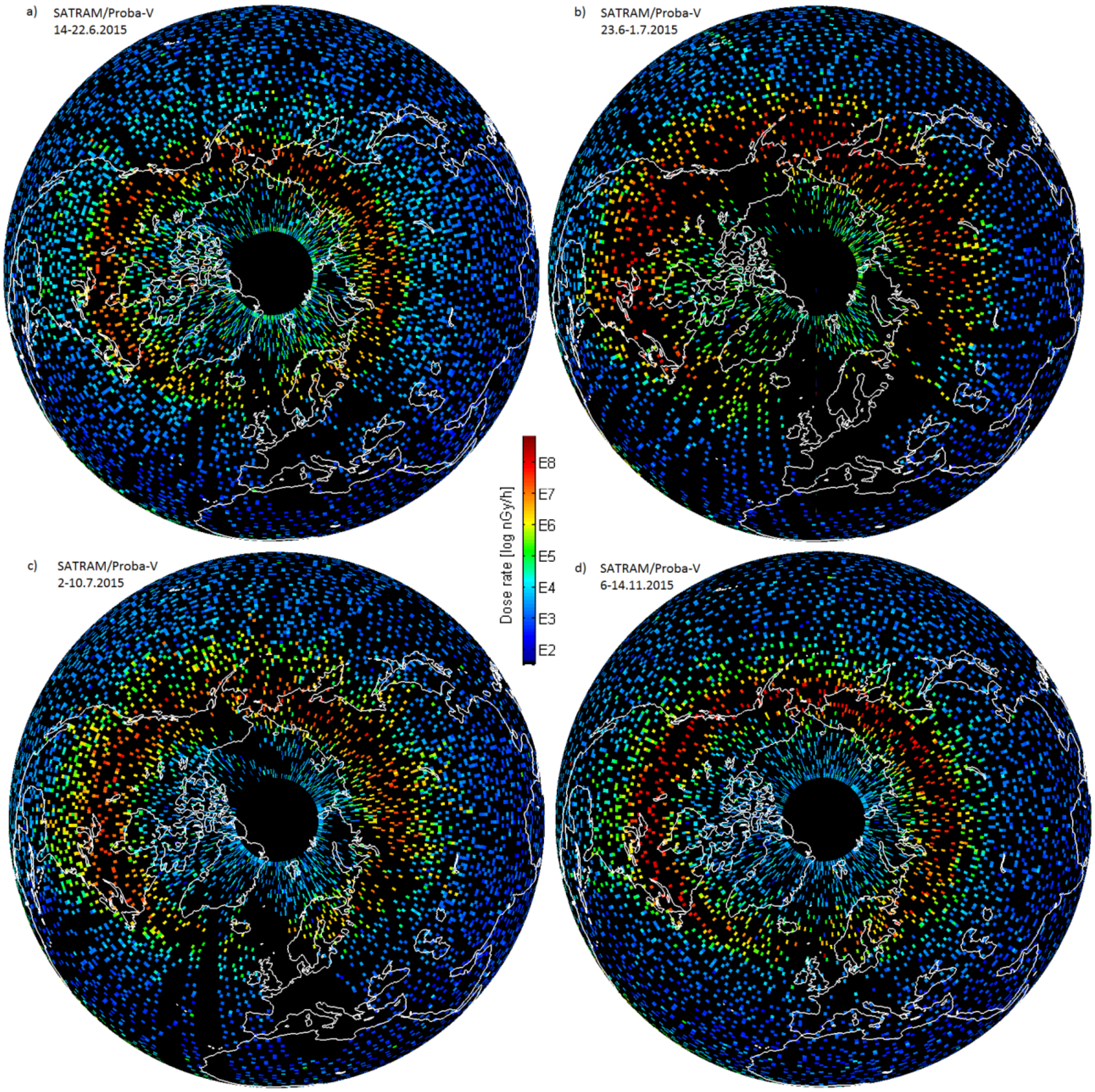


Figure 6. Same as Fig. 5 for different 9-day periods: (a) 14-22 June, (b) 23 June – 1 July (SPE period), (c) 2-10 July, and (d) 6-14 November 2015. The maps over the northern hemisphere are displayed. The resulting spatial pattern of the quantity displayed (dose rate) exhibit values spanning over seven orders of magnitude. Differences among the different periods are apparent. The local intensity and spatial pattern distribution exhibit largest variability, of over two orders of magnitude, comparing the SPE period (b) with the quiescent periods (a,d) and follow-up interval (c).

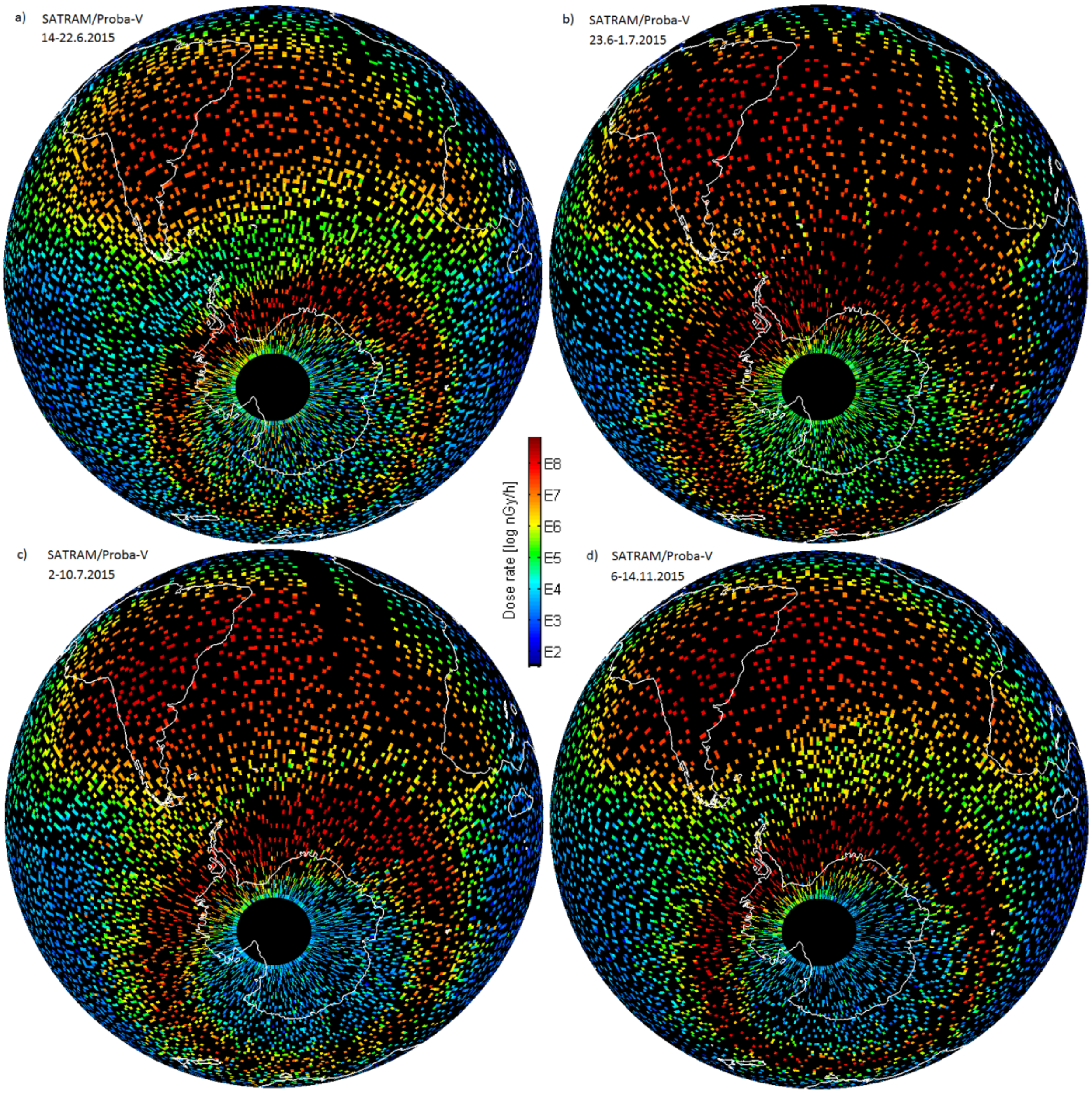


Figure 7. Same as Fig. 6 showing part of the southern hemisphere and the South Atlantic Anomaly.