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Solar cycle evolution of the Sun's shadow in 10 TeV cosmic ray intensity observed with the Tibet air shower array

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In this paper, we report for the first time a clear solar cycle variation of the Sun's shadow in the 10 TeV cosmic-ray intensity observed over an entire period of the Solar Cycle 23 between 1996 and 2009. In this variation, the average intensity deficit in the shadow changes in a high negative correlation with the Heliocentric Current Sheet (HCS) tilt-angle, i.e. the intensity deficit decreases (increases) in the solar activity maximum (minimum) period. The amplitude of the variation is as large as one half of the deficit intensity expected when all cosmic rays arriving from the optical Sun disk are excluded from the observation. Based on numerical simulations of the trajectory of antiparticles ejected from the earth to the Sun in the model magnetic field, we find that the Sun's shadow diminishes during the solar activity maximum period due to antiparticles' orbits being deflected in the complicated and disordered coronal field and excluded from hitting the photosphere. During the solar minimum period, on the other hand, we find trajectories in the solar polar region being focused and guided toward the photosphere resulting in the enhancement of the shadow. We also find the Geocentric Solar Ecliptic (GSE) longitude of the shadow center changing in two succeeding solar minimum periods. The average GSE longitude in 1996-1997 is +0.039+-0.038 deg, while it is -0.49+-0.036 deg in 2007-2009 being 25 % larger than the geomagnetic deflection of the Moon's shadow. This is due to the poloidal component of the ordered coronal field deflecting cosmic ray trajectories in an opposite sense to the geomagnetic deflection in 1996-1997, while it deflects trajectories in the same sense in 2007-2009.

Keywords: Sun's shadow, solar magnetic field, solar cycle variation, galactic cosmic rays, air shower