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Satellite observed thermospheric impact of solar flares and possible implications for the early Earth

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1. Introduction

The evolution of planetary atmospheres depends sensitively on the radiation and particle environment of the planet's hoststar. Atmospheric escape rates are strongly related especially to the soft X-ray (SXR) and extreme and far ultraviolett (EUV and FUV) parts of the solar spectrum. By means of observational data from low Earth orbiting (LEO) satellites it is possible to study the response of the earths thermosphere on enhanced EUV radiation events caused by solar flares. This enables one to estimate exobase temperatures and thermospheric particle densities under different radiation environments. So the flare events can be used as proxies for early Earth studies and for Earth-like atmospheres of potential exoplanets which are exposed to higher stellar EUV fluxes.

2 The impact of the EUV flux

The main part of the EUV radiation on Earth is absorbed in the region from 90 km to 500 km. There exist several theoretical models in order to understand the possible impact of a stronger EUV radiation on a terrestrial atmosphere and its enhanced erosion due to atmospheric loss processes during the early stages of the solar evolution [6, 9, 10]. A validation of these models could be achieved by studying the response of the Earth's thermosphere on higher EUV radiation by observational data from LEO satellites. GRACE (Gravity Recovery and Climate Experiment) is a twin satellite system with an orbit at about about 500 km. Data from the onboard accelerometer can be used to derive neutral particle densities for an altitude of 490 km [5]. Data were analyzed for the quiet Sun and compared to the empirical Jacchia-Bowman 2008 model (JB08, [1]) and to the NRLMSISE-00 model (MSIS00, [7]).

It was found, that an increased EUV flux, as caused by the X17.2 flare during the so called Halloween period in October 2003, leads to an increase of the exobase temperature and to an expansion of the thermosphere, hence to higher neutral particle densities. [8] established a relation between the intensity flux in the EUV and the ages of solar analogs. Based on this relation the EUV flux of the X17.2 flare corresponds to the Sun at an age of about 2.3 Gyr.

The JB08 and the NRLMSISE-00 models cannot predict the atmospheric densities during the maximum of the X17.2 flare because they use averaged daily and 81-day solar indices, which are not sensitive for an event lasting about 90 minutes. In order to reproduce the observed densities at 490 km, so called pseudo indices are introduced, which replace the averaged daily and 81-day solar indices and reflect an analogue solar-like star at the age of 2.3 Gyr. With these pseudo indices the predicted neutral densities agree rather well with the observed densities.

3 Studies of the early Earth

Multi-wavelength observations and studies of solar analogs show, that the solar flux in the SXR and EUV region integrated over 0.1 - 120 nm was about a factor of 6 higher $\approx$ 3.5 Gyr ago, compared to the present Sun ([11, 4, 2, 8, 3]). With the pseudo indices as input for the theoretical models it is now possible to estimate the exobase temperature and thermospheric densities for EUV fluxes during earlier epoches of Earth's evolution.

Additional flare events are studied in order to reevaluate and validate the introduced pseudo indices.

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