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Climatic impact of spectrally resolved irradiances during the late Archean as modeled with EMAC-FUB

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Abstract

Investigating the faint young Sun problem we have performed simulations with a 3-dimensional general circulation model. We can show that in an anoxic environment with irradiances valid for the Archaean at 2.5 Ga (i.e. 82% present TSI), a global ocean, and present day greenhouse gases, it is still possible to have liquid water in tropical latitudes, even though the global, annual mean surface temperature is below the freezing point of water.

1. Introduction

During the Archaean aeon the surface temperature is supposed to be high enough to support liquid water, although the luminosity of the young Sun was reduced. This fact, known as the faint young Sun paradox [1], can be explained by assuming higher concentrations of greenhouse gases during the early stages of the Earth. But there is still an ongoing debate about the possible range of greenhouse gas concentrations that are consistent with the geologic evidence [2].

We present a study in which we investigate this problem using the Chemistry Climate model EMAC-FUB (ECHAM/MESSy Atmospheric Chemistry) [4] with a constructed, spectrally resolved irradiance dataset valid for the Archean. We analyse the climatic impact of the reduced solar luminosity, an anoxic environment, an increased CO_2 concentration, and the land mass.

2. Model and experimental setup

The EMAC-FUB consists of the modular Earth submodel system (MESSy) and uses ECHAM5 as a base model [3]. It is used in a configuration with a highly resolving shortwave radiation parametrisation [5], and a mixed layer ocean [6], where the sea surface temperatures and ice thicknesses are derived from the thermodynamics of an ocean layer.

In total six simulations have been performed, where two simulations only differ by the O_2 and O_3 content and otherwise have present day conditions. Four simulations use a global ocean, as the distribution and fraction of the continents are highly uncertain during the Archaean, and anoxic conditions. Three simulations use a reduced solar luminosity, where two CO_2 scenarios are tested (3 $\times$ PAL and 10 $\times$ PAL). As proxy for the early Sun during the late Archaean at 2.5 Ga (10^9 years ago) we take the dwarf star β Com. The spectrally resolved irradiances are compiled from measurements taken from the IUE satellite archive and a synthetic NextGen model spectrum and scaled to get a total solar irradiance (TSI) of 82 % the present TSI (i.e. 1121 W m^{-2}) [7].

3. Main Results

We can show that in an anoxic environment with reduced solar luminosity at 2.5 Ga (i.e. 82% present TSI), a global ocean, and present day greenhouse gases, it is still possible to have liquid water in tropical latitudes, even though the global, annual mean surface temperature is below 0°C. When the CO_2 concentration is increased, the regions of open water widens. The removal of O_2 and O_3 has a large impact on the thermal structure of the upper atmosphere (cooling by 140 K).

The polar night jet vanishes and the Hadley circulation intensifies. At the surface the temperatures are only slightly higher (0.6 K, global, annual mean) due to the decreasing total cloud cover (-2%). Under anoxic conditions with 2.5 Ga irradiances the near surface meridional temperature gradient is increased, and the Hadley circulation is further intensified, but less extended vertically. Despite this strong Hadley cell, the precipitation is not increased, due to the low water vapour concentrations. With 10 $\times$ CO_2 the intensifi-

cation of the meridional temperature is less strong, as well as the intensification of the Hadley circulation.

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