Response of Climate and Water Cycle to Atmospheric CO2; Cretaceous vs. Modern

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The study of paleoclimate during warm periods using climate models is important for the understanding of the Earth system under greenhouse conditions and for verifying model performance.
The Cretaceous is known as one of the warmest periods in the Phanerozoic due to intense volcanic activity and increased levels of greenhouse gases. In particular, the mid-Cretaceous is the warmest during that period, and terrestrial proxy data (e.g., climatically sensitive sediment) from that time show a marked change in the water cycle. For example, mid-Cretaceous strata distributed throughout the low latitudes of Asia include desert deposits or evaporites, indicating aridification during the mid-Cretaceous. It is thought that the cause of the change in the water cycle is the result of increased atmospheric CO2, because within the Cretaceous, mid-Cretaceous CO2 concentration in the atmosphere was especially high. If the water cycle change during the mid-Cretaceous is due to increased atmospheric CO2, then it should be comparable with that associated with global warming predictions as suggested by climate models. However, the water cycle changes in the Asian region are quite different. Thus, it is not obvious whether the change in the water cycle during the mid-Cretaceous can be attributed to increased atmospheric CO2. Even if it can be, it is still not clear why the responses of the water cycle to increased CO2 differ during present day and the Cretaceous.
To resolve this issue, simulations of the Cretaceous climate with different CO2 levels are carried out in this study using the atmosphere-ocean general circulation model MIROC4m. The aim is to investigate the response of the climate and water cycle to increased atmospheric CO2 for a Cretaceous paleogeography and to compare results with Cretaceous proxy data and a present-day warming experiment.
The precipitation change due to increased CO2 in the Cretaceous experiment is consistent with the water cycle change during the mid-Cretaceous, as indicated by geological evidence. With increased atmospheric CO2, the precipitation in the low latitude regions of Asia decreases in the Cretaceous experiment, while it increases in the present-day experiment. The precipitation decreases in southern Europe, but increases in the mid-latitude regions of Asia and North America. This result implies that the water cycle change during the mid-Cretaceous can be explained as a response to increased atmospheric CO2.
Water budget analysis indicates that the difference in the water cycle changes is attributed to the different summer atmospheric circulation responses in Asia. In the Cretaceous experiment, the updraft in the continental interior weakens due to increased atmospheric stability with global warming, resulting in a decrease in the precipitation. On the other hand, in the present-day experiment, it does not fully weaken because diabatic heating over the Tibetan plateau enhances the atmospheric circulation. As a result, the increase in moisture flux due to increased atmospheric moisture overcomes the effect of the atmospheric circulation weakening, resulting in increased precipitation with increased atmospheric CO2.
Additionally, ‘No-Tibet’ experiments, eliminating the Tibetan plateau, are carried out in order to investigate the role of the Tibetan plateau on the water cycle change due to increased atmospheric CO2. In the No-Tibet experiments, the precipitation decreases in low latitude regions of Asia with global warming, which is comparable to the results of the Cretaceous experiment. The summer updraft in Asia becomes weaker than that in the present-day experiment, resulting in decreased precipitation. These results indicate that, in the low latitude regions of Asia, the difference between the precipitation changes of the present day and the Cretaceous is attributed to the Tibetan plateau. This study shows that the

water cycle change due to increased CO_2 is strongly dependent on the geographical conditions.

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