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Model simulated climate and biogeochemistry variations in the Indian Ocean from the early Holocene into the future

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The climate and marine biogeochemistry of the Indian Ocean are simulated with a global coupled atmosphere-ocean model (KCM-PISCES). Forcing is by orbital parameters and greenhouse gas concentrations for the Holocene from 9.5ka B.P. (9500 model years) and an idealized 1% p.a. atmospheric CO_2 increase until two times CO_2 and stabilization thereafter for a further 1000 years. The analysis focuses on the long term changes for the Indian Ocean and the comparison of natural (Holocene) and anthropogenic (CO_2 increase experiment) variability. Changes in interannual and seasonal variability as well as remote influence from the global ocean are also addressed. Climatic conditions for the Holocene are fairly stable, with relatively low temperatures during the mid-Holocene and a modest warming during the late Holocene. With regard to biogeochemistry, an expanding oxygen minimum zone in the Indian Ocean is simulated during the Holocene in both the Arabian Sea and the Bay of Bengal. The decreasing oxygen concentrations can be attributed mainly to a slowdown in large scale circulation as indicated by increasing water mass ages and a corresponding increase in apparent oxygen utilization (AOU). Marine primary and export production remain fairly stable. Doubling the atmospheric CO_2 results in a rapid warming of up to 5^oC in the surface Indian Ocean followed by a further increase of 1-2^oC during stabilization. Surprisingly, when the climate warms in response to the atmospheric CO_2 increase, O_2 concentrations in the subsurface northern Arabian Sea do initially increase, due to local changes in circulation resulting in younger water mass ages. This behaviour is different from further south in the Arabian Sea and the Bay of Bengal and other oxygen depleted regions of the global ocean, where, more expected, O_2 concentrations decrease rapidly for the future scenario and oxygen minimum zones expand. During stabilization, also the northern Arabian Sea loses oxygen as solubility decreases with increasing temperatures.