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# Orbitally-forced *Azolla* blooms and middle Eocene Arctic hydrology; clues from palynology

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The presence of high abundances of the freshwater fern *Azolla* in the early Middle Eocene central Arctic Ocean sediments recovered from the Lomonosov Ridge during IODP Expedition 302, have been related to the presence of a substantial freshwater cap. *Azolla* massulae, belonging to the newly described Eocene species *Azolla arctica* Collinson et al., have been found over at least a ∼4 m-thick interval. There are strong indications that *Azolla* has bloomed and reproduced *in situ* in the Arctic Ocean for several hundreds of thousands of years. Possible causes for the sudden demise of *Azolla* at ∼48.1 Ma include salinity changes due to evolving oceanic connections or sea-level change.

Distinct cyclic fluctuation in the *Azolla* massulae abundances have previously been related to orbitally forced climate changes. In this study, we evaluate the possible underlying forcing mechanisms for these freshwater cycles and for the eventual demise of *Azolla* in an integrated palynological and cyclostratigraphical approach.

Our results show two clear periodicities of ∼1.3 and ∼0.7 m in all major aquatic and terrestrial palynomorph associations, which we can relate to obliquity (41 ka) and precession (∼21 ka), respectively. Cycles in the abundances of *Azolla*, freshwater-tolerant dinoflagellate cysts, and swamp vegetation pollen show co-variability in the obliquity domain. Their strong correlation suggests periods of enhanced rainfall and runoff during *Azolla* blooms, possibly associated with increased summer season length and insolation during obliquity maxima. Cycles in the angiosperm pollen record are in anti-phase with the *Azolla* cycles. We interpret this pattern as edaphically drier conditions on land and reduced associated runoff during *Azolla* lows, possibly corresponding to obliquity minima. The precession signal is distinctly weaker than that for obliquity, and is mainly detectable in the cold-temperate Larix and bisaccate conifer pollen abundances, which is interpreted as a response to stronger seasonality with colder winters and warmer summers during precession minima.

Together with the *Azolla* demise at 48.1 Ma, a concurrent decline of swamp vegetation suggests drier local conditions on land, saltwater intrusion, and possibly decreased runoff into the Arctic Ocean, causing salinity changes which could have been fatal for *Azolla* blooms.
After the *Azolla* demise, the cyclic distribution of freshwater tolerant dinoflagellate cysts suggests that runoff cycles continued to influence the central Arctic although at decreased intensity.