Diverse response of global terrestrial vegetation to astronomical forcing, CO2 and ice sheets from orbital to millennial timescales

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During the Quaternary glacial-interglacial cycles, the spatial distribution of major vegetation types on the globe was strongly affected by the astronomically-induced changes in latitudinal-seasonal distributions of insolation and by the changes in atmospheric CO2 concentration and ice sheets. However, the relationship between vegetation and different forcing factors remains complex and not necessarily well understood. In this study, we investigate the vegetation variations on orbital and millennial timescales and their relationship with different factors by combining proxy reconstructions and model simulations. Three representative glacial-interglacial (G-IG) periods, i.e. MIS19-18, MIS13-12 and MIS11-10, which are characterized by different variations of precession, obliquity, CO2 and ice volume, are chosen. Our results show that the relative effect of precession and obliquity on vegetation strongly depends on regions and also varies between the G-IG periods. For example, in the subarctic and Mediterranean regions and over most of the mid-latitude lands, obliquity is more important than precession during MIS11-10 due to large variations of obliquity and small variations of precession, whereas by contrast, precession is more important than obliquity in these regions during MIS13-12. Over eastern Africa, Indian subcontinent and East Asia, precession is more important during both MIS11-10 and MIS13-12. Our results show that astronomical forcing plays a dominant role on regional vegetation evolution as compared to CO2. As quite expected, large Laurentide and Eurasian ice sheets suppress forest and favor grass development over many regions, but exceptions exist and the sensitivity of vegetation response to ice sheets strongly depends on regions. Our transient simulations also reveal the subharmonics of precession signal in the vegetation evolution in the tropics and some extra-tropical regions such as the Mediterranean, but the occurrence and strength of these signals depend on regions and vary in time. In addition to orbital and sub-orbital scale variations, the astronomically-induced slow variation of insolation could induce abrupt changes and multi-centennial variations in the forest and grass compositions especially in the northern mid-high latitudes. When boreal summer insolation decreases to a threshold, it induces abrupt changes in the AMOC, which in turn affects the climate and vegetation at large continental scale.