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Changes in solar radiation arising from changes in the orientation of the earth's axis had pronounced effects on tropical monsoons and mid-latitude climates as well as on ice-sheet configuration during the last 18,000 years. COHMAP (Cooperative Holocene Mapping Project) has assembled a global array of well-dated paleoclimatic data and used general-circulation models to identify and evaluate causes and mechanisms of climatic change. For the northern tropics, particularly in Africa and Asia, data and model results show that the orbitally induced increase in solar radiation in summer 12,000 to 6,000 years ago enhanced the thermal contrast between land and sea and thus produced strong summer monsoons, which raised lake levels in regions that are arid today. In middle to high latitudes the climatic response to both the insolation changes and to the retreating ice sheets led to readjustments in the vegetation in both the Northern and Southern hemispheres. Model results show that the large North American ice sheet split the westerly jet stream into northern and southern branches over North America. An increase in storms associated with the southern branch helps explain high lake levels and increased woodlands in the southwestern United States during full-glacial conditions. Comparisons of paleoclimatic data with the model simulations are important because models provide a theoretical framework for evaluating mechanisms of climatic change, and such comparisons help to evaluate the potential of general circulation models for predicting future climates.

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Pollen and foraminifera were analyzed from identical samples in two marine cores taken from the upper and lower continental rise between Cape Hatteras and Chesapeake Bay. Down-core variations in percent abundance of pollen taxa permit the identification of three floral events. These floral events are comparable to and isochronous with changes in polleniferous sediments from the adjacent continental United States through the last 20,000 y, the time interval represented in these cores. A transfer function was used to obtain sea surface paleotemperature estimates from planktonic foraminifera. These estimates indicate that surface waters were relatively warm at the site of both cores from 8,000 y BP to present. Between 12,400 and 8,000 y BP the nearshore core continued to record warm temperatures whereas the offshore core, which should be closer to warm Gulf Stream waters, seems to have recorded significantly colder temperatures. These temperature discrepancies appear to result from severe carbonate dissolution in the offshore core. Temperature estimates are lowered by dissolution of the less resistant tropical species leaving resistant transitional and subpolar forms. This dissolution event coincides with the maximum upslope movement of the Western Boundary Undercurrent as indicated by changes in sedimentation rate. As shown by the nearshore core, in which dissolution was not severe, surface temperatures in this area increased abruptly about 12,000 y BP and remained relatively warm until 4,000 y BP when they decreased slightly. These changes in sea surface temperature appear to be related to the position of the Gulf Stream as indicated by percent abundance of *Globigerinoides sacculifer*. The Gulf Stream moved into this area about 12,000 y BP and attained its maximum northward penetration about 8,000 y BP. Marine and terrestrial paleoclimatic changes in this area are not synchronous. Sea surface temperatures increased about 12,000 y BP whereas the change from a glacial to an interglacial forest occurred several thousand years later, about 10,000 y BP.

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flora suggest that late-glacial forest refugia were more developed here at middle altitude, rather than at higher altitude as previously suggested. The forest developed after 9800 yr B.P., while the water level remained high in the Korçë basin until 5000 yr B.P. Different environmental conditions, characterized by lower available moisture and warmer winters, progressively took place after this date. Human activity in the Korçë basin ca. 4500 yr B.P. was coeval with conditions characterized by an increase in winter temperatures and a decrease in summer moisture. © 2000 University of Washington.

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Percentage, concentration and accumulation pollen data together with diatom and non-siliceous microfossil data are presented for the site of Golhisar Golu (37°8'N, 29°36'E; elevation 930 m), a small intramontane lake in Burdur Province, southwest Turkey. Microfossil assemblages from the longest sediment core (GHA: 813 cm) record changes in local and regional vegetation and lake productivity over the last ~9500 years. Pollen spectra indicate that vegetation progressed from an open landscape with an increase in arboreal pollen occurring ~8500 BP to mixed forest comprising oak, pine and juniper until around 3000 BP (Cal ~ 1240 BC) when a human occupation phase becomes discernible from the pollen spectra. This occurs shortly after the deposition of a volcanic tephra layer which originated from the Minoan eruption of Santorini (Thera) and radiocarbon dated to 3330 ± 70 yr BP (Cal ~ 1600 BC). This human occupation phase is comparable to the Beyşehir Occupation phase recorded at other sites in southwest Turkey and involved forest clearance and the cultivation of fruit trees such as *Olea*, *Juglans*, *Castanea* and *Vitis* together with arable cereal growing and pastoralism. The presence of pollen types associated with the Beyşehir Occupation phase in deposits above the Santorini tephra layer confirms a Late Bronze Age/early Anatolian Dark Age date for its commencement. Since ~ 3000 BP notable changes in aquatic ecology associated with tephra deposition and subsequent nutrient and sediment flux from the lake catchment are recorded. The Beyşehir Occupation phase at Golhisar Golu came to an end around 1300 BP (Cal AD ~700) when pine appears to have become the dominant forest tree.

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The post-glacial history of two adjacent sites in the Harvard Forest, a 10-ha swamp (Black Gum Swamp) and a 0.006-ha hollow (Hemlock Hollow) in a *Tsuga canadensis* forest were investigated using pollen analysis. The sites were selected in order to contrast the regional vegetation history revealed from the swamp sediments with the local history of the *Tsuga* forest reconstructed from the Hollow sediments. Specific objectives were (1) to document the natural and anthropogenic disturbance history, (2) to examine the long-term vegetation dynamics of the two sites resulting from environmental change, species migration, and disturbance, especially with respect to *Tsuga*, and (3) to contrast the pre- and post-settlement vegetation and environments. The Swamp and Hollow cores contain continuous sediment records covering the past 12 300 and 9500 yr, respectively. Regional vegetation changes are delimited in six pollen zones: I, Herb zone (12 500-11 800 yr BP); II, *Picea* zone (11 800-9500 yr BP); III, *Pinus-Quercus* zone (9350-8350 yr BP); IV, *Tsuga*-northern hardwoods zone (8350-1750 yr BP); V, *Tsuga-Castanea*-hardwoods zone (1750-200 yr BP); and, VI Post-settlement zone (200 yr BP-present). No disturbances are detected in the periods of tundra or boreal vegetation from 12 500 to 8 350 yr BP. Since 8350 yr BP three distinct disturbance processes are detectable: (1) fires recorded in discrete charcoal horizons, (2) the apparent pathogenic decline of *Tsuga* (4700-3500 yr BP) and the blight of *Castanea* (? 1915 A.D.), and (3) post-settlement forest cutting, burning, land clearance, and cultivation (1750 A.D. to present). Log-ratio diagrams facilitate the differentiation of local vegetation history in the *Tsuga* forest from the regional upland history. *Tsuga* has been the dominant taxon at the Hollow for the last 8000 yr although its abundance has fluctuated with disturbance. *Tsuga*, *Ulmus*, *Populus*, *Acer rubrum*, *A. saccharum*, *Betula*, and *Castanea* apparently are more abundant locally than in the regional vegetation, which has a larger component of *Pinus*, *Quercus*, and *Carya*. Post-disturbance vegetation dynamics in the *Tsuga* forest are controlled by the type and intensity of disturbance and the pool of available species, determined by species migration and climate change. *Tsuga* decreases and subsequently recovers in 300-1200 yr following most disturbances. Northern hardwood taxa (*Acer*

saccharum, Fagus, Betula spp., Ulmus, Fraxinus) generally decrease after fire and human activity and recover with Tsuga. For the period 8000-3000 yr BP Pinus, Quercus, and occasionally Populus and Nyssa increase following fire and the Tsuga decline at 4700 yr BP. However, since its immigration at ~3000 yr BP Castanea has been the major species to increase upon disturbance of the Tsuga-northern hardwood forest. The study documents the long-term dominance of a forest stand by Tsuga canadensis and northern hardwood species despite repeated infrequent disturbances. The ability of these taxa to gradually reassume their former abundance following disturbance is presumably a consequence of their shade tolerance and longevity and the low frequency of disturbance.

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We present directly correlative, high-resolution pollen and isotopic data from marine isotope stage (MIS) 5 from a marine core taken on the continental margin off the southeastern United States (31[deg]40'N, 75[deg]24'W, 2985 m). These data provide the first chronostratigraphically controlled pollen data for the last interglacial from this region. Comparison of the pollen- and benthic isotope stratigraphies demonstrate that vegetation and climate development in southeastern United States did not always coincide with global ice volume changes. Deglacial terrestrial climate amelioration, which was nearly synchronous with ice decay, peaked slightly before the ice volume minimum in MIS 5e. Cooling in the latter part of the last interglacial began at C27, prior to ice growth. Vegetation and climate were not stable during MIS 5e. Suborbital climate oscillations persisted throughout MIS 5 both onshore and in the subtropical Atlantic offshore. The largest correlative suborbital oscillations in the *Pinus* (pine) and *Quercus* (oak) forests of coastal Georgia and South Carolina and sea surface variability correspond to stadial/interstadials documented in Greenland ice cores; however, coupled oscillations also occur more frequently.

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Lake Tulane provides one of the few continental sediment records beyond the late glacial period (~ 15,000 cal years B.P.) for eastern North America. Its continuous, organic-rich sediment has yielded pollen assemblages that date back 62,000 years. Here we report the first organic geochemical characterization of the sediment core from Lake Tulane based on compound-specific carbon isotopic analyses of higher plant leaf waxes. Our millennium-resolution carbon isotope data allow us to quantitatively assess the variations in the relative abundances of C3 and C4 plants in Central Florida under contrasting climate conditions and different atmospheric pCO<sub>2</sub> levels during the last glacial-interglacial cycle. Specifically, our results indicate large changes in the relative abundance of C3 and C4 plants, with ~ 40% higher input from C4 plants during the last glacial maximum (LGM) than during the Holocene. During the last glacial period, C4 plant abundance decreased dramatically during the pine phases when precipitation increased, indicating that increasing precipitation overrode the impact of low atmospheric pCO<sub>2</sub>, leading to expansions of C3 plants. Our results provide new insights on the forcing mechanisms and first quantitative estimates on the C3 and C4 plant variation in central Florida for the last 62,000 cal years.

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Oxygen isotope variations spanning the last glacial cycle and the Holocene derived from ice-core records for six sites in Greenland (Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP) show strong similarities. This suggests that the dominant influence on oxygen isotope variations reflected in the ice-sheet records was regional climatic change. Differences in detail between the records probably reflect the effects of basal deformation in the ice as well as geographical gradients in atmospheric isotope ratios. Palaeotemperature estimates have been obtained from the records using three approaches: (i) inferences based on the measured relationship between mean annual

$\delta^{18}\text{O}$  of snow and of mean annual surface temperature over Greenland; (ii) modelled inversion of the borehole temperature profile constrained either by the dated isotopic profile, or (iii) by using Monte Carlo simulation techniques. The third of these approaches was adopted to reconstruct Holocene temperature variations for the Dye 3 and GRIP temperature profiles, which yields remarkably compatible results. A new record of Holocene isotope variations obtained from the NorthGRIP ice-core matches the GRIP short-term isotope record, and also shows similar long-term trends to the Dye-3 and GRIP inverted temperature data. The NorthGRIP isotope record reflects: (i) A generally stronger isotopic signal than is found in the GRIP record; (ii) several short-lived temperature fluctuations during the first 1500 yr of the Holocene; (iii) a marked cold event at ca. 8.2 ka (the '8.2 ka event'); (iv) optimum temperatures for the Holocene between ca. 8.6 and 4.3 ka, a signal that is 0.6‰ stronger than for the GRIP profile; (v) a clear signal for the Little Ice Age; and (vi) a clear signal of climate warming during the last century. These data suggest that the NorthGRIP stable isotope record responded in a sensitive manner to temperature fluctuations during the Holocene. Copyright © 2001 John Wiley and Sons, Ltd.

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We present oxygen and carbon isotope records of benthic foraminifera from the glacial stage 6 through interglacial substage 5e (Eemian) sections of several cores from the subpolar North Atlantic. The cores range in water depth from 1451 to 2658 m. In one core, we generated estimates of sea surface temperature (SST) and of ice-rafted detritus (IRD) delivery for all of stage 5. We reconstruct bathymetric profiles of  $\delta(13)C$  for stage 6, Termination II, and three time slices of substage 5e. The  $\delta(13)C$  profiles indicate that local deep water geometry during stage 6 was similar to that of the last glaciation, with glacial North Atlantic Intermediate Water (GNAIW) overlying deeper waters partially of southern origin. An anomalously large peak in IRD, coupled with planktonic  $\delta(18)O$  evidence for iceberg melting immediately precedes Termination II and is otherwise similar to stage 2 and 3 Heinrich events. During the termination, low  $\delta(13)C$  values are observed in cores near and above 2 km, providing evidence of reduced GNAIW production in association with deglacial melting. In the shallowest cores, low  $\delta(13)C$  values persist into early

substage 5e, indicating that the southward retreat of southern-source waters was not completed until well after the beginning of the substage. In contrast to Termination I, SSTs remained cold until the end of the deglaciation; this may be why there is little evidence from marine and terrestrial sequences for a pronounced climate reversal on Termination II despite what is now clear evidence of a significant reduction in ocean ventilation. The faunal data suggest that SSTs during early 5e were about 7 degrees C warmer than during the glaciation. SST rose several degrees from early to middle substage 5e, peaked in middle substage 5e at about 10 degrees C above glacial values, and then gradually declined by about 5 degrees C. These changes were linked to variations in water mass configuration, as interpreted from benthic  $\delta^{13}C$  evidence. Most of the evidence suggests that oscillations superimposed on the gradual SST trend were 1 degrees-2 degrees C, in contrast to the larger SST changes (3 degrees-4 degrees C) documented for substage 5d.

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Accurate reconstructions of late-Quaternary land-cover change are needed to better understand past interactions of the terrestrial biosphere with other components of the earth system. This paper presents a sequence of reconstructed needleleaved and broadleaved tree-cover densities for North America since the last glacial maximum, generated from fossil-pollen data and present-day tree-cover estimates derived from the Advanced Very High Resolution Radiometer (AVHRR). For this study, a refined form of the modern analog technique was developed, called the hierarchical analog technique, which can constrain paleoenvironmental properties even for fossil-pollen assemblages without close analogs in the modern-pollen record. Pollen taxa from samples that are

compositionally unlike any modern-pollen samples are regrouped into plant functional categories based upon phenology, life form, leaf shape, and climatic tolerances, and the analog analysis rerun. Reclassifying individual pollen taxa into broader functional categories enables analogs to be found when no compositional analogs exist, but at a cost of increased uncertainties in the analog estimates. Tests of the hierarchical analog technique shows that it accurately reconstructs present-day tree-cover densities. The median standard deviation for each individual estimate is 2 concentrations. By 14 ka, broadleaved tree-cover densities had begun to rise in the southeastern US and needleleaved forests grew in the western US, southeastern US, and as a belt along the southern margin of the Laurentide Ice Sheet. By the mid-Holocene, the northern and western needleleaved forests had joined. Needleleaved and broadleaved tree densities continued to increase until European settlement. Mapping percent tree-cover represents a useful alternative to biome-based classification schemes, enabling a fuller representation of vegetational gradients in space and time, and can be directly compared to the tree distributions simulated by dynamic global vegetation models. In effect, by calibrating the modern-pollen data against the AVHRR-derived estimates of tree-cover, the fossil-pollen data are applied to extrapolate satellite-based observations into the Quaternary, enabling study of vegetation dynamics and land-cover change at timescales beyond the period of direct observation by engineered remote sensors. Analog-based approaches, however, require extensive networks of surface and fossil-pollen samples, making further data collection a priority in sparsely sampled regions of the world.

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