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Comment on "Donders, T.H. 2014. Middle Holocene humidity increase in Florida: Climate or sea-level? Quaternary Science Reviews 103: 170–174"

Donders (2014) has recently proposed that the climate of Florida became progressively wetter over the past 5000 years in response to a marked strengthening of the El Niño regime. This reconstruction is largely based on a re-analysis of pollen records from regions north of Lake Okeechobee (Fig. 1) using a new set of pollen transfer functions. Donders concluded that a latitudinal gradient in precipitation prevailed across Florida since the mid Holocene, but the overall trend was toward progressively wetter conditions from 5000 cal BP to the present.

Donders (2014) also proposed that this climatic trend extended across South Florida despite contrary paleo-records from the Everglades. In particular he singled out the Northeast Shark River Slough (NESRS) record of Glaser et al. (2013) as an atypical local signal of paleo-environmental change that was biased by a misinterpretation of the ecology of pine and Amaranthaceae (Amaranth family). In response to this direct critique of our paleo-environmental interpretation, we wish to point out that:

1) Our interpretation of the NESRS sedimentary sequence (site 4, Fig. 1A) was based on multiple lines of evidence that all indicate a shift from wetter to drier (i.e. less wet) conditions that occurred after 2800 cal BP.
2) A similar climatic shift from wetter to less wet conditions was reported for this time interval from other sites in the Everglades (Willard et al., 2006; Willard and Bernhardt, 2011) and also from the Caribbean region to the east (Hodell et al., 1991, 1995; Higuera-Gundy et al., 1999).
3) The NESRS site is located in an area where runoff collected from a 10,000 km^2 wetland prior to 1900 AD when most of the drainage from the Everglades was channeled to the sea through the narrow Shark River Slough. The sedimentary sequence at the NESRS site should therefore contain an integrated record of hydrological change across the pre-historical Everglades (Glaser et al., 2012). In addition this essentially non-forested wetland is well suited to accumulate a representative sample of the regional pollen rain in its sediments (e.g. Jacobson and Bradshaw, 1981; Prentice, 1985).

Since Donders (2014) only presents analyses for pollen sites located north of Lake Okeechobee we fail to understand the basis for extending his climatic reconstruction to the lowland regions of South Florida (Fig. 1). Donders appears to rely heavily on the pollen record from the Fakahatchee Strand in Southwest Florida (site 6, Fig. 1A; Donders et al., 2005) and either ignores or assumes that the contrary records from the Everglades region are atypical. However, in addition to the findings of Glaser et al. (2013), Willard and Bernhardt (2011) noted: *Pollen from a peat core collected in central Taylor Slough* (site 5: Fig. 1A) *indicates persistence of slough vegetation and long hydroperiods from ~3.8–3 ka, before-shifting to sawgrass marshes and moderate hydroperiods* (Willard et al., 2001). *A peat core collected from a cypress strand in Fakahatchee Strand Preserve State-Park* (site 6: Fig. 1A) *also indicates vegetation changes between 3.5 and 2 ka, but the change from mixed prairie and pinelands to cypress forest is interpreted as a shift to wetter conditions* (Donders et al., 2005).

The most likely explanation for these opposing climatic interpretations may be Donders's reliance on pollen transfer functions without giving proper consideration to the roles of fire and rising sea level in shaping the paleo-vegetation patterns of South Florida during the late Holocene. The pinelands of Florida, for example are fire dependent ecosystems in which the individual pine taxa are distributed across a disturbance gradient according to their varying tolerances to ground fires, soil moisture, and competing species (Myers and Ewel, 1990). Slash pine (*Pinus elliottii* var. *elliotti*), for example grows on swampy and streamside sites in the northern portions of its range in Florida where it competes directly with several other pine species (e.g. *Pinus palustris*, *Pinus clausa*) that are more tolerant of ground fires (Gordon, 1963; Lohrey and Kossuth, 1990). In these areas slash pine is restricted by ecological competition to moister refugia that provide more effective fire protection for its seedlings (Hubbell et al., 1956; Monk, 1968) rather than functioning as an obligate mesic or wetland indicator as implied by Donders (2014).

Moreover, in South Florida, the southern variety of slash pine (*P. elliottii* var *densa*) is more tolerant to both droughts and fires (Ketcham and Bethune, 1963) and once formed pure stands on the uplands of Southeast and Southcentral Florida before they were nearly eliminated by recent logging and urbanization (Myers and Ewel, 1990). In these settings *P. elliottii* var. *densa* was not exposed to competition from other pine taxa but still depended on periodic fires to avoid being replaced in time by shade-tolerant hardwoods of the subtropical hammocks (Davis, 1943; Gordon, 1963; Wade et al. 1980; Myers and Ewel, 1990). Although slash pine also occurs in the forested swamps of Southwest Florida it is generally not a dominant in these settings and even here it depends on fire for its regeneration and long-term persistence (Wharton et al., 1977; Ewel, 1990). Our interpretation of the conspicuous increase in the abundance of pine pollen in the NESRS record after

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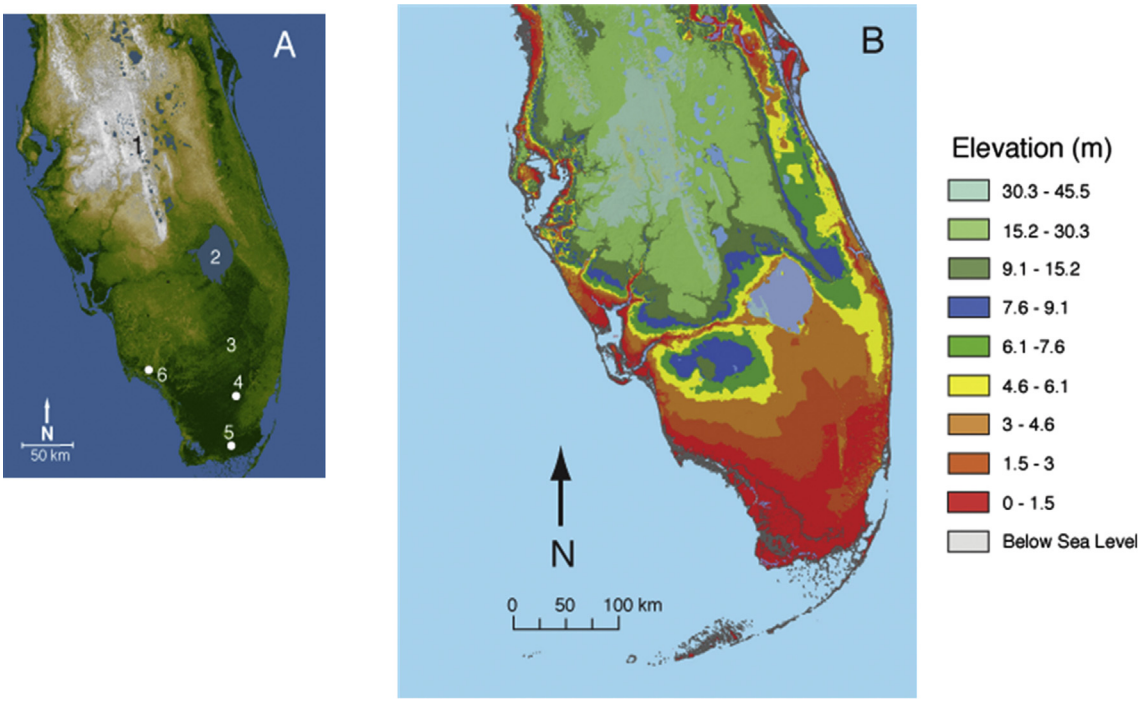

Fig. 1. South Florida. The SRTM (Shuttle Radar Topography Mission) image on the left (A) shows the location of the Lake Wales Ridge (1), Lake Okeechobee (2), Everglades (3), NESRS coring site (4), Taylor Slough (5), and Fakahatchee Strand (6). The finer scale digital elevation model (United States Geological Survey) on the right (B) shows the very low relief of the lowlands that extend across most of South Florida.

2800 cal BP is therefore consistent with an inferred shift to drier (i.e. less wet) conditions that would promote a more favorable fire regime to support slash pine on nearby uplands (Glaser et al., 2013).

This interpretation is also consistent with the corresponding decline in Amaranthaceae pollen at the NESRS site after 2800 cal BP, since the only likely source for this pollen type would be *Amaranthus australis*, which is a native wetland plant in South Florida. We do not agree with Donders (2014) interpretation of this pollen type as a drought indicator *sensu stricto* because there was no corresponding rise in Amaranthaceae pollen at the NESRS site when pervasive drainage operations lowered water levels across the Everglades after 1900 AD. In addition, our interpretation of a climatic shift to more moderate hydroperiods after ca. 2800 BP is supported by the close correspondence between the local and regional pollen assemblages of the NESRS record to coincident shifts in the lithology, mineralogy, and elemental composition of the sediment, all of which were assessed by Glaser et al. (2013).

It is surprising that Donders (2014) recognizes that rising sea levels had a strong impact on late-Holocene pollen records from the coastal lowlands of north and central Florida, while ignoring any similar effect of sea level on the lowlands that extend across most of South Florida (Fig. 1). Vegetation patterns are strongly related to moisture gradients, which are dependent not only on climatic variables but also on the local and regional hydrogeologic setting. Model simulations based on the Dupuit assumptions show that the topography of the water table is a function of 1) recharge (precipitation minus evapotranspiration and runoff), 2) hydraulic conductivity of the surficial materials, and 3) the boundary conditions (e.g. geometry and hydraulic head of water bodies) that define any groundwater flow domain (e.g. Glaser et al., 2004). The hydrological impacts of this later factor has been demonstrated for paleorecords from lakes on sand plains (Almendinger, 1993) and also from peatlands on coastal lowlands (Glaser et al., 2004; Dommain et al., 2011, 2014).

Rising sea level should have had a much stronger effect on the regional hydrology of South Florida than on the inland sites of central and northern Florida because of their contrasting topographic relief and geomorphology (Fig. 1). There is a growing body of evidence that rising sea levels impeded drainage across the lowlands of South Florida since the mid Holocene, raising the regional water table (Glaser et al., 2012; Dekker et al., 2015), and driving the landward migration of mangroves and salt marshes (e.g. Parkinson, 1989; Ross et al., 2000). Ross et al. (1994), for example, has related the recent decline of slash pine in the Florida Keys since 1935 AD to rising sea level and salinization of the shallow groundwater system. The late Holocene decline in pine and corresponding rise in cypress at the Fakahatchee site of Donders et al. (2005) could similarly be the result of rising sea level at least in part given the site's low elevation (<1 m above modern sea level) and close proximity to the sea (<1 km from the sea). Moreover, the slow rise in sea level under a moist climatic regime since 4000 cal BP has been identified as the major contributing driver for the formation and accumulation of peat in the large Everglades basin (Wanless et al., 1994; Willard and Bernhardt, 2011; Glaser et al., 2012) rather than being the result of climatic change alone as suggested by Donders (2014).

Although it is tempting to dismiss discordant records from the Everglades as “atypical” they are more likely to provide insights on the combined effects of changing sea level and climate on paleo-vegetation patterns. Teasing out these opposing signals from pollen records is unfortunately limited by the low resolution of late-Holocene sequences of South Florida. These records are largely restricted to wetland deposits, which are generally subject to slow rates of sediment accretion, the creation of sedimentary gaps by episodic drying, and multiple issues that complicate radiocarbon dating (e.g. Glaser et al., 2012).

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The critical time interval between 3700 and 850 yr BP, for example, which lies at the heart of the discrepancy between the NESRS and Fakahatchee records appears to be a problematic interval in the Donders et al. (2005) age model. Ultimately their smoothed age vs depth model is anchored by a complex set of radiocarbon dates of bulk sediment that include: identical radiocarbon dates between 119 and 140 cm (3719 ± 36 and 3719 ± 39 yr BP respectively), an inverted sequence of ages between 56, 70, and 80 cm (936 ± 33, 850 ± 35, 650 ± 35 yr BP respectively), and two very compressed chronological depth intervals between 80 and 90 cm (650 ± 35 to 1792 ± 100 yr BP) and 160–180 cm (4169 ± 36 to 4290 ± 60 yr BP) that may be indicative of sedimentary gaps.

In contrast our chronology for the NESRS record (Glaser et al., 2012, 2013) is based on a single linear progression of radiocarbon dates of fossil gastropod shells, that were corrected for the hard-water effect and free from other apparent dating problems. This chronology indicates a slow but relatively continuous rate of local sediment accretion that closely corresponded to the slow rise in sea level over the past 4600 years. It also provides a reliable date for the reported shift to a drier (less wet) climate and the cessation of aeolian P-fertilization after 2800 cal BP that we proposed was probably responsible for the origin of surface patterning in the Everglades. A shift to wetter conditions at this time as suggested by Donders (2014), however, would have submerged this 1 million ha wetland under deeper surface waters and thereby prevented the development of the ridge and tree island patterns that characterize the modern Everglades. Moreover, our timing for the cessation of dust deposition at the NESRS site matches the chronology for the final transition to an arid Sahara (Kröpelin et al., 2008). By 2800 cal BP, the soils of this large region had probably been largely depleted in the fine-grained fraction that was most rich in nutrients and susceptible to aeolian transport across the Atlantic Ocean.

In conclusion we urge a more cautious, integrative approach for reconstructing paleo-climate across the broad lowlands of South Florida. Interpretive problems arise because dating issues in this region obscure inter-site comparisons and their relationship to sub-centennial modes of climatic variability. In addition, the effect of rising sea level and changing disturbance regimes on paleo-vegetation patterns would most likely have varied across the region in relation to local changes in the geomorphic setting. Consequently the strongest approach for resolving these uncertainties in our opinion is the development of robust age models for high quality sedimentary sequences. These age models can then firmly anchor regional and local pollen assemblages to a site's depositional history as reflected in its sediment lithology, mineralogy, and elemental composition.

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