Comment on Russo & Cubasch, ***Mid-to-late Holocene Temperature Evolution and Atmospheric Dynamics over Europe in Regional Model Simulations***

By Basil Davis

I would just like to reply to a number of comments made by Reviewer 2 with respect to the reconstruction of Mauri et al. (2015), and the data-model discrepancies highlighted by Russo & Cubasch in their paper.

In the first instance I would encourage all of the reviewers to read the original Mauri et al. (2015) paper, where we have gone to some lengths to address the kind of concerns expressed by the climate modeling community that are also expressed here.

I will start with a general overview, and then move to the specific comments.

The reconstruction of Mauri et al. (2015) is based on over 800 well-dated pollen-based quantitative climate records from throughout Europe, many hundreds of which come from Southern Europe. This data has been projected onto a uniform spatial grid that is consistent with, and appropriate to, the spatial resolution used by climate models. The method derives a regional climate record from a dense network of local site records, thereby minimizing the role of local climatic factors that may not be represented at the scale of most models. Uncertainties for the reconstruction have been fully documented and the reconstruction successfully evaluated against other reconstructions based on other proxies and methods (Chironomids being a notable and previously documented exception). Similar pollen-based climate reconstructions have been extensively used for data-model comparisons, and most recently for the evaluation of the PMIP3/CMIP5 climate models included in the last IPCC report (Stocker et al. 2013, Harrison et al. 2015). Cooler summer temperatures over much (but by no means all) of Southern Europe in the early-mid Holocene have been a feature of all pollen-based climate reconstructions since the seminal work of Huntley & Prentice (1988) almost 30 years ago.

Reviewer #2: Paleoclimate reconstructions based on pollen rely on the assumption that changes in the vegetation were driven by the parameter to be reconstructed (i.e. summer temperature). In the Mediterranean region, vegetation distribution is mainly limited by effective precipitation, rather than by summer temperature (e.g. Osborne et al. 2000).

Effective precipitation is an important factor in determining the distribution of the Mediterranean vegetation, but temperatures are also important through thermic responses such as metabolic processes and frost tolerance. No vegetation model would be able to successfully predict the distribution of the Mediterranean vegetation based on effective precipitation alone.

The reference cited by the reviewer (Osborne et al., 2000) uses a vegetation model to highlight the sensitivity of Mediterranean vegetation to changes in CO_2. The effect of CO_2, and the relative importance of temperature and precipitation in determining past vegetation change in the Mediterranean have already been comprehensively investigated by Wu et al. (2007) using inverse modeling. Usually, climate is used as an input into a vegetation model to arrive at a vegetation. In inverse modeling, the vegetation (in this case determined from pollen data) is used as an input to arrive at a climate. This method therefore reconstructs climate from pollen data in an entirely independent way from the modern analogue method used by Mauri et al. (2015). It also means that CO2 can also be included as an independent input and its effects included in the analysis. The results of inverse modeling by Wu et al. (2007) show however the same mid-Holocene summer cooling reconstructed by Mauri et al. (2015) (Figure 1), indicating that irrespective of change in precipitation and CO2, it is still necessary to have cooler summers in order to explain the vegetation shown in the pollen record.

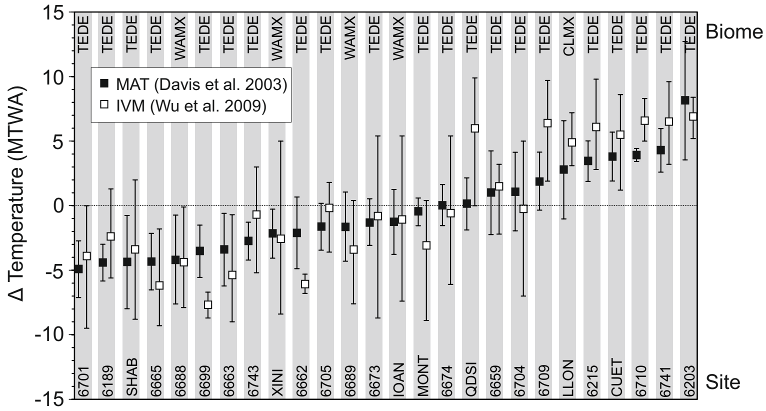

Figure 1. Comparison of mid-Holocene summer temperature anomalies reconstructed from pollen data using the Modern Analogue Technique (MAT) and Inverse Modeling Method (IVM). Results are shown for all sites in Southern Europe that were used by both Wu et al. (2009/7) and Davis et al. (2003). The comparison shows how similar summer temperature anomalies are reconstructed by both MAT and IVM. MTWA: Mean Temperature of the Warmest Month. TEDE: Temperate Deciduous Forest, WAMX: Warm Mixed Forest, CLMX: Cool Mixed Forest.

The reviewer appears to suggest that the reconstruction of Mauri et al. (2015) is somehow biased because of the insensitivity of Mediterranean vegetation to temperature. Putting aside whether this is a real problem or not, Mediterranean vegetation is not actually the underlying cause of the reconstructed early-mid Holocene summer cooling that the models are unable to reproduce. The summer cooling comes instead from the expansion of temperature deciduous vegetation south into the Mediterranean, the same temperature deciduous vegetation that also expands north into Scandinavia at this time. In the north of Europe this is the result of warmer summer temperatures, and in the south of Europe the result of cooler summer temperatures. It is the same vegetation in both cases and the reconstruction has the same confidence in both regions. There is therefore no methodological reason to both accept the reconstruction for Northern Europe that agrees with the models, while at the same time rejecting the reconstruction for Southern Europe because it does not agree with the models. It should also be noted that the cooling in summer that is reconstructed over Southern Europe is also independently replicated over the same latitudes of the Southern USA (Viau et al. 2006) (Figure 2), while similarly not being shown in model simulations for the region (eg. Sawada et al. 2004, Renssen et al 2009).

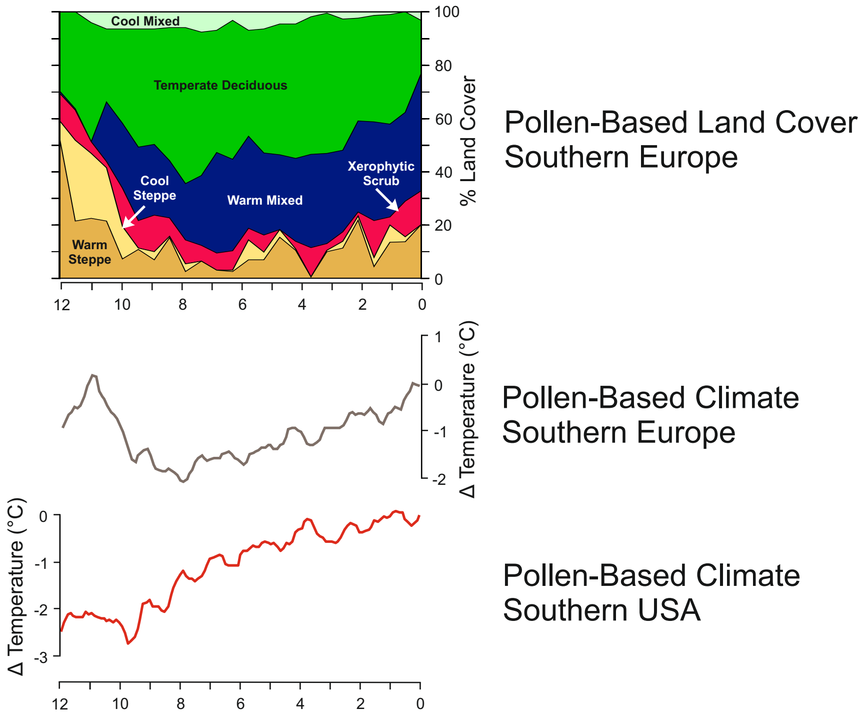

Figure 2. The top panel shows the proportional change in land cover (pollen-biomes) for Southern Europe (south of 45N) for the Holocene (From Davis et al. 2015). Note that the early-mid Holocene is characterized by an expansion of Temperate Deciduous Forest with little change in the area of Xerophytic Mediterranean scrub. The expansion of cooler temperate taxa is what drives the cooler summer temperatures shown in pollen-based climate reconstructions at the same regional scale (in this case from Davis et al. 2003). These cooler summer temperatures are also reproduced in regional pollen-based climate reconstructions for the same latitudes (south of 45N) across the Southern USA (again based on many hundreds of sites), despite being based on an entirely different modern and fossil pollen dataset (Viau et al. 2006).

Even if we reject all pollen-based climate reconstructions, we can still show that the discrepancy between pollen data and models over Southern Europe is real. In this approach the climate model output is used as an input into a vegetation model, and the resulting climate model derived vegetation is compared to the pollen record. Here again, the data-model discrepancy does not go away. The climate models all suggest summer temperatures were even higher than today in the early-mid Holocene, with summer precipitation either similar or less than today. This results in greater summer aridity than today with a prolonged summer drought and a large decrease in effective moisture for plant growth. The vegetation simulated by climate models is much too dry than that suggested by the pollen data, with an expansion of Mediterranean and steppe/desert vegetation and contraction in forest cover (Prentice et al. 1998, Wohlfart et al. 2004, Gallimore et al. 2005, Garzon et al. 2007, Kleinen et al. 2010) (Figure 3)

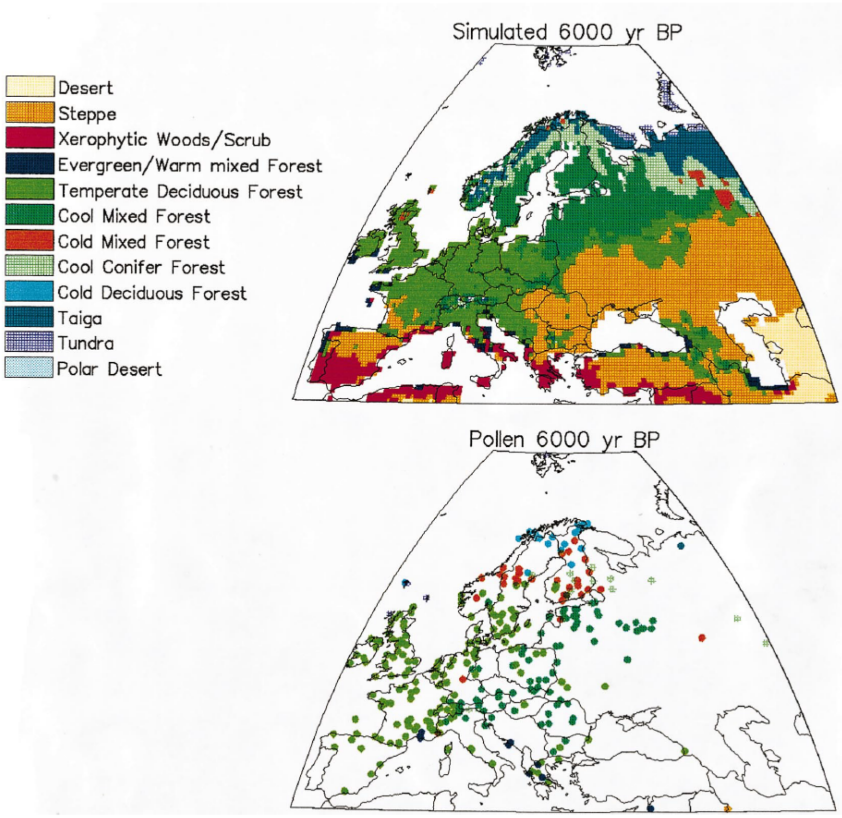

Figure 3. A comparison of biomes simulated by a vegetation model driven by a mid-Holocene climate model simulation, and biomes reconstructed from pollen data (from Prentice et al. 1998).

The warmer climate simulated by the models also results in a large increase in evaporation in the early-mid Holocene, making it difficult for climate models to explain the near equilibrated hydrological budget of the Mediterranean Sea at this time (Duplessy et al. 2005), which led to stratification and sapropel formation. Similarly, and for the same reason, models have difficulty reproducing evidence of higher lake levels (Harrison et al. 1993, Magny et al. 2013). Higher lake levels suggest a more favourable moisture balance that is entirely consistent with the expansion of temperature deciduous and drought intolerant taxa shown in the pollen data.

Reviewer #2: For instance, summer temperature reconstructions from the S Europe domain based on Chironomids, show a clear Holocene cooling (Heiri et al. 2015; Toth et al. 2015) that actually support the presented modelling results.

The reconstruction of Mauri et al. (2015) is based on many hundreds of individual temperature reconstructions from sites across Southern Europe assimilated onto a uniform spatial grid that is consistent with the spatial resolution of a climate model. The reconstruction shows regional and local variability in temperature trends that can be clearly seen in the spatial pattern of anomalies shown in the paper. This includes warming at altitude in the Alps and Carpathian mountains in agreement with the trends at the sites cited by the referees, although it is true that in general Mauri et al. (2015) show that Chironomid records are not generally replicated by pollen-based records. This is consistent with other studies that have compared pollen and chironomid based reconstructions (Velle et al. 2010). For instance, while hundreds of pollen-based climate reconstructions from sites in Northern Europe show early-mid Holocene warming (Mauri et al. 2015) in agreement with climate models (Renssen et al. 2009), it is also possible to find Chironomid records from the region that show cooling at this time that is contrary to climate model simulations (Figure 4).

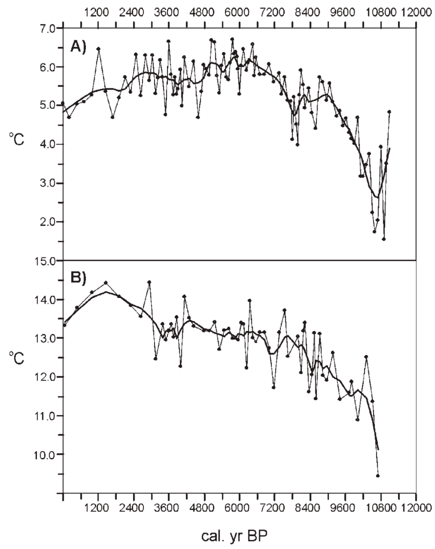

Figure 4. Comparison of a pollen-based reconstruction (A) and chironomid-based reconstruction (B) from Lake Gilltjarnen, northern Central Sweden (from Antonsson et al. 2006). The pollen record shows mid-Holocene warming while the Chironomid record shows mid-Holocene cooling.

Southern Europe in particular is topographically diverse, with many mountain ranges, islands, inlets and other geographic features that can have an important impact on local climate but which are not represented at the grid box scale of a climate model. Consequently changes in prevailing wind direction, air masses, lapse rates and other dynamic components of the climate system at the regional scale may have local impacts that are recorded at individual sites, but which are not representative of climate change at the regional or grid box scale. For instance, the pollen-based reconstruction by Cheddadi et al. (1998) at the site of Tigalmamine in the Atlas Mountains of Morocco shows early-mid Holocene warming which appears to contradict the general cooling reconstructed by Mauri et al. (2015). However, the study by Mauri et al. (2015) included the same data from this site, and the same warming was reconstructed. What the Mauri et al. (2015) reconstruction shows is that the temperature changes recorded at the Tigalmamine site are not representative at the regional scale when all sites in the region are considered. The regionally anomalous nature of the Tigalmamine site is also clear from the precipitation reconstruction published alongside the temperature reconstruction, which shows early-mid Holocene aridity at a time when most of North Africa was experiencing a pronounced humid period (Figure 5).

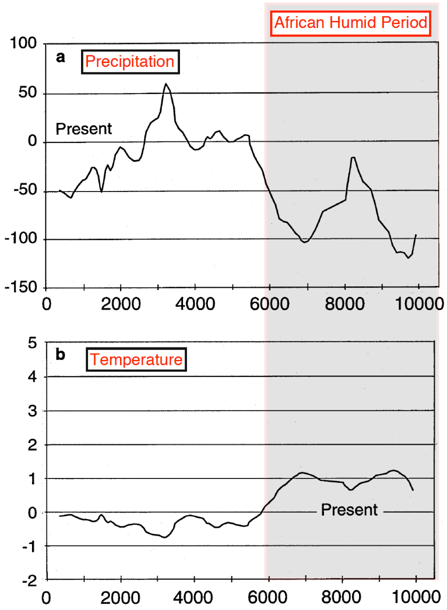

Figure 5. The pollen-based climate reconstruction by Cheddadi et al. (1998) at the site of Tigalmamine in the Atlas Mountains of Morocco shows two regionally anomalous features during the early-mid Holocene. The first is the early Holocene warming shown in the temperature record, which is not reproduced in other sites in the region (Mauri et al. 2015). The second is the early Holocene aridity shown in the precipitation record, which occurs at a time when precipitation increased regionally during the 'African Humid Period' (de Monecal et al. 2000).

The interpretation of individual sites and small site networks as regionally representative should be treated with caution, especially in heterogeneous regions such as Southern Europe. Even during the widespread warming of the Twentieth Century it is still possible to find sites that show a contrary cooling trend (Figure 6), and small site networks that happen to be based on these sites will provide a very different impression of climate change than a large site network similar to the one we have used in Mauri et al. (2015).

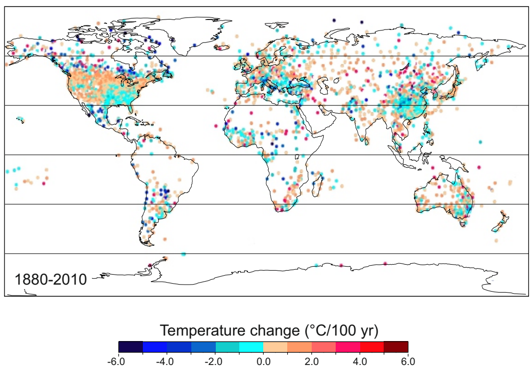

Figure 6. Even during the widespread warming of the Twentieth Century it is still possible to find a few sites that show a contrary cooling trend.

In addition, Holocene SST reconstructions from the Mediterranean Sea show a similar cooling trend (e.g. Marchal et al. 2002).

As with the pollen-based climate reconstructions, evidence from SST reconstructions in the Mediterranean region show both warmer and cooler temperatures during the Holocene. For instance, cooling has been found in the following studies; Kallel et al. 1997, Emeis et al. 2000, Siani et al. 2001, Sbaffi et al. 2001, Melki et al. 2009, Adloff et al. 2011. Attempts to understand Holocene SST conditions at regional spatial scales have been limited because the multi-site record is more complex than it often appears from individual site records. This complexity has revealed itself when attempts are made to compare closely located sites based on the same proxy, or records from the same or closely located sites based on different proxies, or to establish modern baseline SST's in order to calculate anomalies to show actual warming/cooling as opposed to simple trends (Hessler et al. 2014). The authors of the Marchal et al. (2002) paper cited by the reviewer also present similar conclusions.

For instance the site of D13822 near the coast of Portugal shows strong early-mid Holocene warming, but the nearby site of SU81-18 does not (Figure 7). As we have already mentioned, it is important not to assume that a single site that reflects local conditions is representative of climate change at a regional or grid-box scale, particularly given clear evidence from Mauri et al. (2015) of local climate variability in the Mediterranean region.

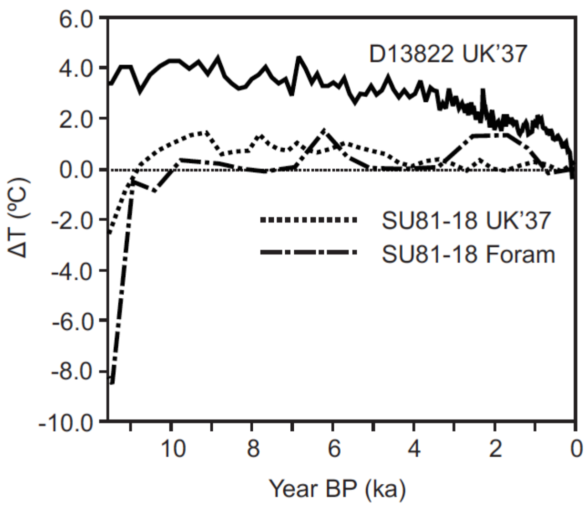

Figure 7. A comparison of the Holocene SST alkenone (UK'37) record from site D13822 off the coast of Portugal (Rodrigues et al.2010) with SST records from the nearby site SU81-18. Both alkenone (UK'37) (Bard et al. 2000) and foraminifera (Waelbroeck et al. 2001) SST reconstructions from site SU81-18 fail to reproduce the strong warming seen in site D13822.

Many of the marine sites that show the strongest early-mid Holocene SST warming in the Mediterranean region are based on alkenones. Process studies have shown that SST reconstructions based on this proxy can be subject to bias due to sensitivity to changes in river discharges and surface mixing (Versteegh et al. 2007, Abrantes et al. 2009; Grauel et al. 2013). It has also been suggested that alkenones may be less reliable in low salinity conditions (Bendle and Rosell-Mele, 2004).

It is not clear what effects, if any, these possible sources of bias may have had on the SST record, but we do know that the Mediterranean Sea has undergone profound changes during the Holocene. For instance, river discharges into the Mediterranean have varied considerably through the Holocene, being largely responsible for the development of an equilibrated hydrological budget in the early-mid Holocene that decreased salinity and allowed stratification and sapropel formation (Rohling et al. 2015).

Lastly, in considering the reliability of the reconstruction by Mauri et al. (2015) we can also mention plausibility. Importantly, the spatial patterns of anomalies that we reconstruct do not appear to be randomly distributed within their uncertainty bounds, but have a spatial coherence that varies systematically through time. In Mauri et al. (2014) we show that these spatial patterns of temperature changes are entirely plausible based on changes in atmospheric dynamics. These changes in atmospheric dynamics are not shown in climate models, but have been suggested by other authors based on many different lines of evidence. These include changes in the Norwegian and Arctic Ocean currents, Norwegian glacier mass balance, the salinity of the Baltic, isotopic composition of lake sediments in Sweden and groundwater fed lakes in Spain.

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