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Role of Mediterranean SST in enhancing the European heat wave of summer 2003

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[1] During summer 2003 Europe was affected by one of the driest and most persistent heat waves. During this event, the Mediterranean Sea surface temperature (SST) was exceptionally warm (SST anomalies of 2–4°C). We investigate the possible role of the Mediterranean SST in enhancing the amplitude of the heat wave. Several Atmospheric General Circulation Model (AGCM) sensitivity experiments were conducted with and without Mediterranean SST anomalies. First it was found that the AGCM was able to simulate the evolution and structure of the heat wave using observed global SST anomalies. The experiment with SST anomalies over the Mediterranean only was also able to simulate the upper level anticyclone over central Europe, even though it was weaker, and about half of the amplitude of the heat wave of the global SST anomaly experiment. **Citation:** Feudale, L., and J. Shukla (2007), Role of Mediterranean SST in enhancing the European heat wave of summer 2003, *Geophys. Res. Lett.*, *34*, L03811, doi:10.1029/2006GL027991.

1. Introduction

[2] The European summer of 2003 was exceptionally warm and dry [*Schär et al.*, 2004; *Luterbacher et al.*, 2004], affecting a spatial area of more than $2.25 \cdot 10^6$ Km^2. The largest positive anomalies of 2 m air temperature were observed in the months of June and August in the southern part of France, although maximum temperature records were broken in many parts of western and central Europe [*Black et al.*, 2004]. At the same time, record-breaking positive SST anomalies were recorded throughout the entire Mediterranean Sea basin [*Grazzini and Viterbo*, 2003]. Analyses of the historical reconstructed SST [*Reynolds et al.*, 2002] since 1854 for the June–July–August (JJA) season indicate that the summer 2003 SST over the Mediterranean and Black Sea was the warmest on the record. The goal of this work is to investigate whether this high positive SST anomaly in the Mediterranean had a strong impact on the surface temperature in Europe. Some idealized sensitivity experiments were performed with the AGCM of the Center for Ocean-Land-Atmosphere Studies (COLA), prescribing, as boundary conditions, observed SSTs only over the Mediterranean and climatological SSTs elsewhere. The experiments show that the Mediterranean SST was responsible for more than half of the amplitude of the global SST effect.

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2. Model

[3] The COLA AGCM version V2.2.7 was used for this investigation [*Kinter et al.*, 1997]. It is a spectral model that includes the NCAR CCM3 dynamics, run at T63 horizontal resolution (about 1.875° grid resolution) with 18 unevenly spaced sigma layers in the vertical, Relaxed Arakawa-Shubert convection (RAS) [*Moorthy and Suarez*, 1992] and the land surface is represented by the Simplified Simple Biosphere Model (SSiB) [*Xue et al.*, 1991]. Ten ensemble members were performed for each experiment for the period 1 January to 30 September 2003. The model was initialized with the global atmospheric and surface NCEP/NCAR reanalysis at 2.5° horizontal resolution [*Kalnay et al.*, 1996; *Kistler et al.*, 2001] for the dynamical parameters and the GOLD Climatological Soil Wetness [*Dirmeyer and Tan*, 2001] for the soil moisture. The SST was updated daily during the whole period with the global OISST [*Reynolds et al.*, 2002]. Since the event was exceptional not only in terms of intensity and duration but also in spatial extent (more than $2.25 \cdot 10^6$ Km^2), the resolution of this GCM was adequate to address the scale of the heat wave.

3. Observations of SST

[4] The positive SST anomaly in the Mediterranean Sea during JJA 2003 was not uniformly distributed (shown in Figure 1a), but affected mainly the western part of the Mediterranean basin. A linear interpolation from weekly to daily OISST V2 data [*Reynolds et al.*, 2002] shows that a noticeable warm positive SST anomaly built up rapidly, especially in the western Mediterranean (see rectangle in Figure 1a), starting from the second half of April and persisting until the end of the summer. We used the 1982–2003 as the period for calculating the anomaly. The anomaly, after a slow increase in the middle of May, grew further in the first two weeks of June, reaching a maximum in mid-June (Figure 1b). The solid line represents the time-series of averaged SST anomaly over the entire Mediterranean basin and Black Sea and the dashed line represents the averaged SST anomaly over the area that exhibited the largest anomaly during the entire JJA season (the area between 2.8°E–12°E of longitude and 39.2°N–45°N of latitude, enclosed in the box shown in Figure 1a).

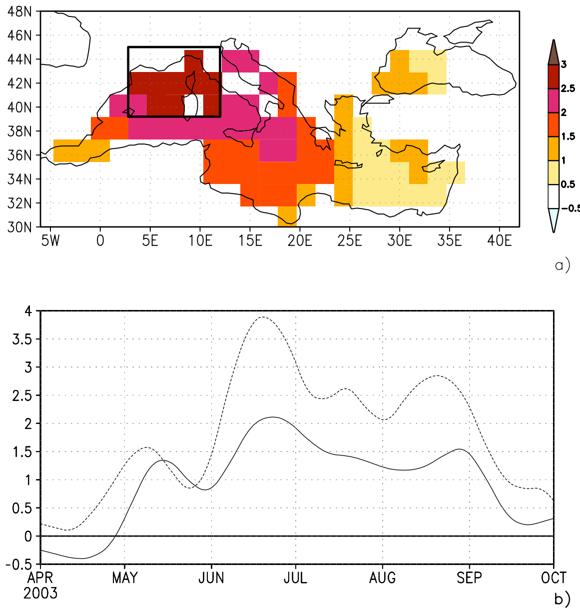

Figure 1. (a) JJA 2003 SST anomaly (°C) in the Mediterranean basin and Black Sea. The rectangle in the region (2.8°E–12°E, 39.2°N–45°N) shows the area with the highest SST anomalies. (b) Time-series of SST anomaly (°C) for the Mediterranean and Black Sea (solid) and for the rectangle shown in Figure 1a (dashed).

The SST anomaly in this area reached the maximum value of 4°C in the middle of June, which is a record for the previous 150 years.

4. Results

[5] The COLA AGCM was integrated for 9 months, from 1 January to 30 September, and, for each experiment, 10 ensemble members were run and the ensemble mean was analyzed. In order to assess the model's ability to reproduce the event, at first the heat wave was simulated using the global observed SST as boundary conditions (GLOBAL SST experiment). Then a run with climatological SST was performed for the same period in order to calculate the model anomaly of the 2003 event (CLIM. SST experiment). The difference between the two results (GLOBAL SST minus CLIM. SST) is shown in Figure 2b. Figure 2a shows the observed JJA maximum temperature (T_{max}) anomaly. The structure of the observed T_{max} anomaly for JJA is simulated reasonably well by the model, especially over western and central Europe, but the amplitude is only about half of the observed. The local maximum in south-western France, close to Switzerland, was also well simulated. A t-test demonstrates that this result is statistically significant above the 90% level.

[6] To investigate if the exceptional Mediterranean and Black Sea SST anomaly had a major influence on the evolution of the heat wave, a simulation was performed with observed SSTs over the Mediterranean and Black Sea (MED. SST experiment) and climatological SSTs over the rest of the global ocean. The difference between the ensemble mean of the MED. SST experiment and the CLIM. SST experiment is shown in Figure 2c. With the exception of Spain, the Mediterranean SST anomaly alone can produce the same structure of land surface temperature anomaly as the GLOBAL SST experiment. The atmospheric response to these anomalous SSTs is shown in terms of geopotential height anomalies at 500 hPa (Z500 anomalies). Over central Europe the geopotential height field at low (not shown) and mid tropospheric levels (Figure 3a) was dominated by a strong positive anomaly. This positive and persistent anomaly was reproduced by both GLOBAL SST (Figure 3b) and MED. SST (Figure 3c) experiments, although the amplitude was not as strong as in the observations. This Z500 anomaly is connected to an anticyclonic circulation, suggesting a dominant adiabatic descending motion, resulting in a cloud free sky and an increase in incoming solar radiation warming the surface.

[7] Figure 4 shows the time-series of a 7-day-running-mean T_{max} anomaly of the area that was most affected by the heat wave (1°W–10°E, 43°N–50°N): the solid line represents the T_{max} anomaly for the global SST (GLOBAL SST minus CLIM. SST), and the dashed line shows the effect due to the Mediterranean and Black Sea SSTs (MED. SST minus CLIM. SST). The timeseries of T_{max} due to the Mediterranean SST compares very well with the T_{max} from the global SST experiment, capturing the two large intraseasonal events, one starting in June and the other one in August. Results show that more than half of

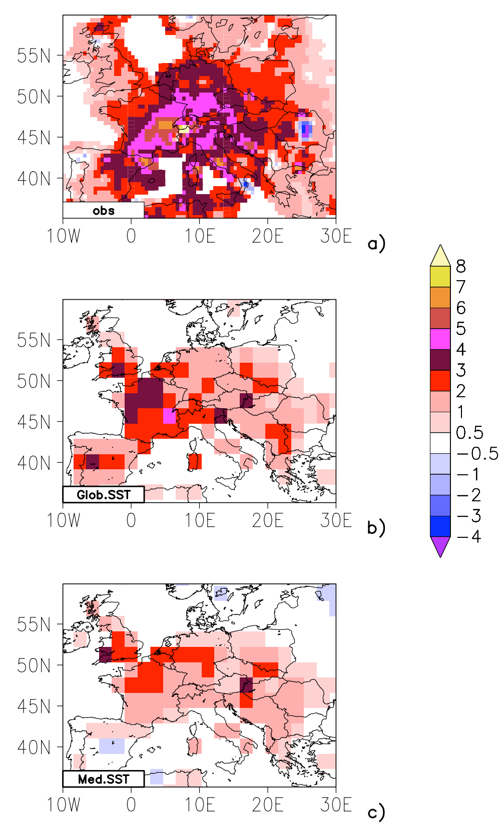

Figure 2. JJA 2003 T_{max} anomaly (°C) at 2m: (a) observed, (b) from global SST experiment, and (c) from Mediterranean experiment.

the global SST effect is captured by the Mediterranean and Black Sea SST effect.

5. Discussion and Concluding Remarks

[8] A comprehensive analysis of the global SST experiment showed [*Feudale*, 2006] that, consistent with observations, the primary reason for the persistence of the heat wave was the presence of a long-lasting upper tropospheric anticyclonic circulation. The AGCM sensitivity experiment suggested that the global SST was mainly responsible for the persistent anticyclonic simulation over Europe. A warm SST anomaly in the North Atlantic Ocean modified the air temperature field in the mid-high latitudes, leading to a reduction of the absolute value of the meridional gradient. This resulted in a northward shift of the polar jet, allowing the expansion of the anticyclone over central Europe. We suspect that this anomalous circulation was also responsible for exceptional Mediterranean SSTs. Forcing the model with just the observed Mediterranean and Black Sea SSTs (MED. SST) showed that the anomalous SSTs were still able to simulate and maintain the anticyclonic circulation over central Europe. Generally the warm Mediterranean SST do not persist for the entire season because atmospheric fluctuations rapidly can cool the Mediterranean SST due to sea-water mixing and enhanced evaporation. However during this heat wave the transient weather events coming from the Atlantic Ocean were displaced northward and could not cool the Mediterranean Sea. In addition, there was an enhanced downward motion which suppressed convection and increased incoming solar radiation over the Mediterranean Sea. The combining effect of these processes was that the very warm Mediterranean SST persisted for more than a season.

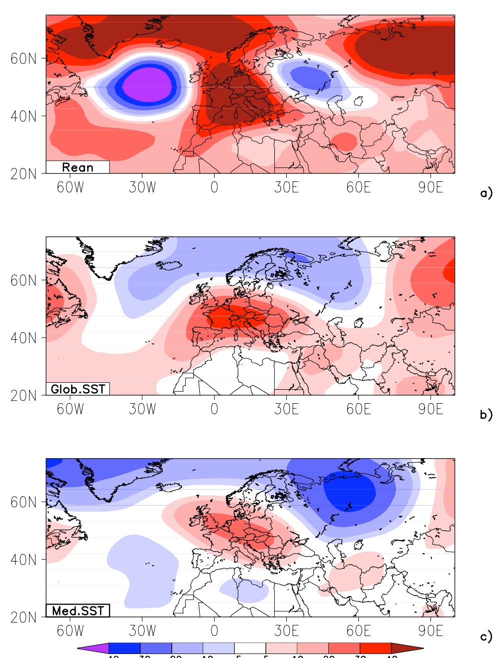

Figure 3. JJA 2003 geopotential height anomaly (m) at 500 hPa from (a) NCEP reanalysis, (b) global SST experiment, and (c) Mediterranean experiment.

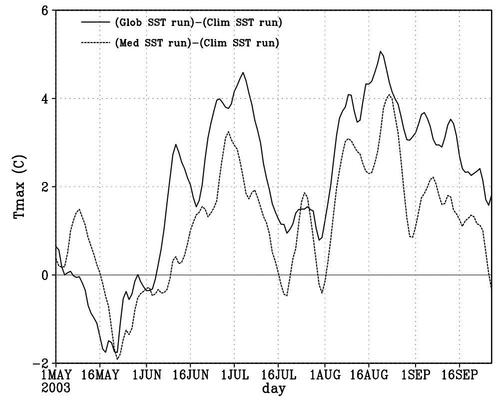

Figure 4. Time-series of 7-day average simulated T_{max} anomaly (°C) from global SST experiment (solid) and from Mediterranean experiment (dashed) averaged over (1°W–10°E, 43°N–50°N).

[9] Therefore, our interpretation of the results is as follows: the global SST and the accompanying circulation produced a very warm Mediterranean SST. The upper level anticyclone and the associated downward motion could suppress cooling mechanisms of the Mediterranean Sea and increase the downward solar radiation. This could further increase the Mediterranean SST and amplify the heat wave. The mechanism through which SST anomalies produce an anticyclone over the Mediterranean region, and also the possible role of a very warm Mediterranean Sea in enhancing and maintaining the anticyclonic circulation are important questions that we propose to investigate in a future study.

[10] The amplification of the heat wave was caused by two important factors. First, the exceptional warm Mediterranean Sea caused the anomalous sensible heating of the atmosphere over the Mediterranean basin and the surrounding regions. Second, the Mediterranean SST, as shown by the model experiment, also produced the upper level anticyclone although not as strong as in the global SST experiment. Perhaps the land-atmosphere interaction also further amplified the heat wave [*Seneviratne et al.*, 2006], but our study has not addressed that question.

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