J10.5

HEAT WAVES IN THE MEDITERRANEAN REGION: ANALYSIS AND MODEL RESULTS

Marina Baldi*, Massimiliano Pasqui, Francesco Cesarone, Giovanna De Chiara
Institute of Biometeorology - CNR, Rome, Italy

1. INTRODUCTION

Heat-wave events have a high cost in terms of damage to the agriculture, forest-fires, and, also, in term of human health and death loss. Initial estimates of the economic loss (more than $13 Billion) place the summer 2003 European heat wave on top of all natural disasters of the year. In this respect, these events represent one of the worst weather-related catastrophes, therefore an appropriate forecast leading to an efficient early warning system (EWS) is highly desirable.

Heat-waves are a familiar feature of the Mediterranean summer (Colacino and Conte, 1995). Several anomalous warm summers occurred in the Mediterranean and southern Europe in the last 50 years, with heat-wave events of different intensity and length. However, the heat-wave occurred in 2003 (the most extreme in 500 years) was the longest and warmest event occurred, with more than 30,000 fatalities in Western Europe, and it has been viewed by some Authors as part of the expected global signal of warming. Other Authors (see Schar *et al.*, 2004) remark that events like that of summer 2003 are statistically extremely unlikely, and linked to an increased variability of temperatures (in addition to increases in mean temperature), more than to the observed warming. Beniston and Stephenson (2004) shows that extreme climatic events in the Mediterranean-European Region are due to particular significant changes in the trends of quantiles in the course of the 20th century, and an increase in the Temperature in the course of the XXI Century is likely to produce an increase in the frequency of severe heat wave episodes.

It is arguable that the event resulted from a direct of lower tropospheric global warming, or more likely, it has been a regional climate event.

In an attempt to support this last hypothesis, and taking into account the fact that the time series of air temperature at the surface in the Mediterranean region show a positive trend during the summer (Maugeri and Nanni, 1998; Brunetti *et al.*, 2000), while precipitation time series show an increase of long dry spells (Brunetti *et al.*, 2002), we examine the recent 50 summers in the Mediterranean and south Europe region in order to know if heat wave events show any long term variation in frequency and/or intensity. We analyse the climatology and the anomalies and we extract the length and the intensity of those hot events. Furthermore, we classify the episodes in short and long lasting, depending on the duration, and we examine the large scale configurations relatively to the two classes. Few particular short and long lasting heat wave events are compared, in order to give an explanation of the mechanisms. Surface observations are used to identify the events, to quantify their intensity, and to classify them in terms of duration. The NCEP-NCAR Reanalysis have been extensively used to quantify the extent and significance of the global and regional atmospheric anomalies in causing these periods of extreme heat, and find patterns associated and/or preceding the Mediterranean heat-waves.

In particular, as a case study, we analyze the summer 2003 heat-wave event, being not only the longest and warmest detected, but also the most damaging and costly, using NCEP/NCAR reanalysis and surface observations. We also modelled this particular event using RAMS (Regional Atmospheric Modelling System) in order to capture the mechanisms driving such anomalous episode.

* *Corresponding author address:*
Marina Baldi CNR - IBIMET
Via dei Taurini, 19, 00185 - Roma, Italy.
Phone: +39 06 4993-7680 ; FAX: +39 06 4993-7685;
Email: m.baldi@ibimet.cnr.it

Analysis and model results show that heat waves in western Europe and Mediterranean, although presenting a distinct trend in the last 50 years, are mostly the result of regional climate fluctuation, weakly linked to large scale climate events, as monsoons and SSTAs, (Baldi *et al.*, 2004; Raicich *et al.*, 2001), rather than a direct result of lower tropospheric global warming, which, however, may play a role in enhancing their strength and frequency.

A further possible mechanism, still under evaluation, contributing to the enhancement of hot periods, i.e. large soil moisture deficits, accrued in the region due to exceptionally early and warm spring, may have intensified most of the subsequent summer heat waves.

2. DATA AND MODELLING TOOL

In order to perform a detailed analysis of the heat waves events in the Mediterranean Basin, we analyzed surface data (T_{max}, T_{mean}, T_{min}) covering the period 1951-2003 (June to September), collected at several stations located in North, Central, and South Italy, and provided by the Laboratory for Meteorology and Environmental Modeling (L.a.M.M.A., Florence-Italy) (http://www.lamma.rete.toscana.it) and by Ufficio Centrale di Ecologia Agraria (UCEA, Rome - Italy).

Using the NCEP/NCAR reanalysis (Kalnay *et al.*, 1996; *Kistler et al.*, 2001), we compute the large scale field and derived fields such as Geopotential anomalies, Temperature thickness anomaly, etc, for selected events.

For the modelling of the summer 2003 heat wave the Regional Atmospheric Modelling System (RAMS) has been used. A general description of the model can be found in Pielke et al. (1992), while a technical description can be found on the ATMET web site (http://www.atmet.com). Today RAMS represents the state-of-the-art in the atmospheric numerical modelling and it is continuously improved on the basis of a multi-disciplinary work both at Colorado State University and at several other research laboratories worldwide.

Authors have used RAMS in the past extensively for regional scale modelling at several time scales from few days to climatological, and it is being used for forecast purposes, i.e. operationally, by one of the Authors at La.M.M.A, the regional meteorological service of Tuscany (Italy) since 1999 in collaboration with the Institute of Biometeorology of National Research Council (http://www.ibimet.cnr.it).

3. DISCUSSION OF THE RESULTS

3.1 *Trends and variability*

A short-lasting heat wave is defined as an event more intense than normal daily mean (base period 1961-1990) of one or more standard deviations (from normal daily mean) computed for the period 1961-1990. This event has usually a duration of 3 to 6 days.

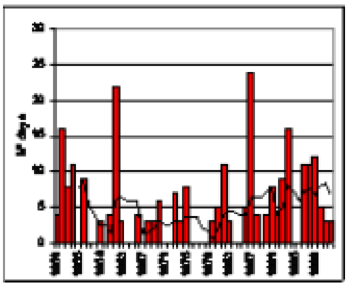
During the long-lasting heat waves events the air temperature is larger than the normal daily mean of one or more standard deviations (evaluated relatively to the normal daily mean) for 7 days or more.

Same results shown in this paper are obtained if the IPCC 2001 definition of extreme event is used: "An extreme weather event is an event that is rare within its statistical reference distribution at a particular place. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called extreme weather may vary from place to place.

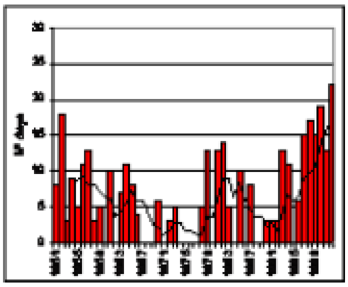
An extreme climate event is an average of a number of weather events over a certain period of time, an average which itself is extreme (e.g. rainfall over a season)."

In the period considered (1951-2003) the total number of summer-time days influenced by short or long lasting heat waves are 1282. Since the total number of days in June, July, August and September (summer season) in the examined 53 years is 6466, about 20% of the summer period in the central Mediterranean in the last 50 years has being influenced by exceptional warming due to heat waves. This is an appreciable fraction and indicates that the phenomenon is not very infrequent or exceptional for the Region and it should be considered as a phenomenon occurring rather frequently in the Mediterranean summer.

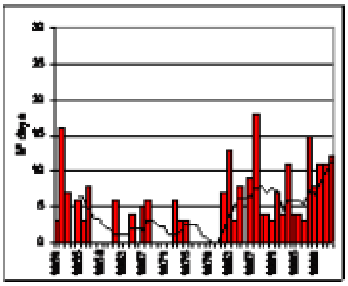
However, a significant positive change in the frequency of occurrence of hot summer episodes and an increase of the total number of hot days is evident in Figure 1, showing the number of hot days per month in the period 1951-2003.



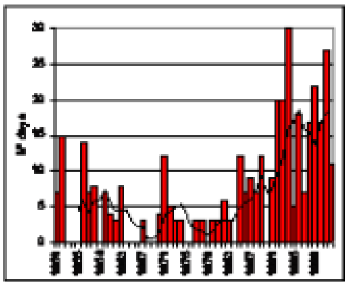
June



July



August



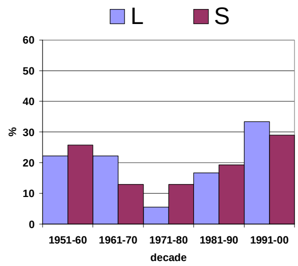
September

Figure 1: Number of heat wave days in the period 1951-2002

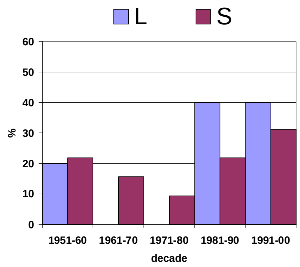
Table 1 summarizes the monthly distribution of the events, of the days influenced by heat waves, and of their relative percentages. It emerges that more than half of heat events occurs in June and August, 55 and 65, respectively. In the month of August we detected a total number of 402 hot days, due, mainly, to short lasting events. A high number of hot days is also detected in June (371) comparable to the August number.

Summary of the heat waves events						
Month	***Short***	***Long***	***Nr of events***	***%***	***Nr of days***	***% days***
June	35	20	55	26	371	29
July	35	12	47	22	254	20
August	48	17	65	31	402	31
Sept	37	9	46	22	255	20
Total	**155**	**58**	**213**		**1282**	

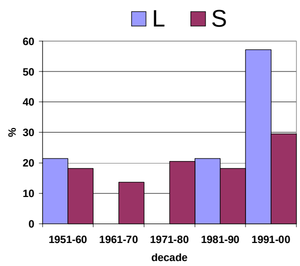
Table 1: Summary of the heat waves events



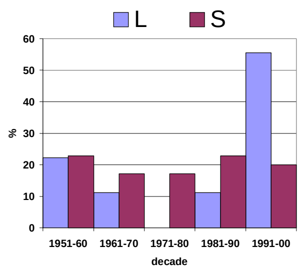
June



July



August



September

Figure 2: Decadal distribution of short and long-lasting heat-waves (%) in the period 1951-2000

Figure 2 show, for each decade, the percentage of days contributing to the short and long lasting events. It is evident how the long lasting events are predominant in August and September and show a dramatic increase in the last decade, while, although an increase in the two kinds of events is detected in June and July, during those two months the relative contribute of long and short episodes is comparable.
The distribution of heat wave days in the five decades 1951-1960, 1961-1970, 1971-1980, 1981-1990 and 1991-2000 is reported in the following Table 2, showing an increase in the total number of days affected by heat waves in the last two decades of the 20th century.

Decadal distribution of heat wave days		
Decade	***N° days***	***%***
1951-1960	227	21
1961-1970	134	12
1971-1980	91	8
1981-1990	234	21
1991-2000	413	38
Total	**1099**	**100**

Table 2: Decadal distribution of heat wave days

3.2 *Short lasting heat waves*

Looking for characterizing weather patterns, the geopotential field, wind vector, air temperature, temperature thickness associated to short and long lasting episodes occurred in the last 3 years (2001-2003) have been analyzed.
During Short lasting heat waves (Slhw), it is not evident "omega wave" configuration in the 300 hPa geopotential height field (Figure 3a). It induces to suppose that temperature anomalies are caused by other mechanisms in the lower troposphere (relative maximum of HGT 850 hPa on North Africa, Figure 3b). As said before, Slhw episodes last from 3 to 6 days. The analysis of the 850hPa geopotential height field show, in correspondence with the occurrence of Slhw episodes, a persistent high pressure center over Libya. The short duration of hot episodes is probably due to the fact that the Libyan relative pressure maximum is not reinforced by the Azores high, and the Mediterranean basin is (weakly) under the influence of an Asian low center.
Slhw 850hPa vector wind maps (Figure 3c) show that the air travelling along the Azores high pressure isobars is bent from a relative pressure minimum near the Gibraltar strait. The westerlies are guided by Libyan high pressure, over the North Africa desert and over the Italian peninsula. Usually, under these conditions, hot air advection reaches in Italy from south-west.

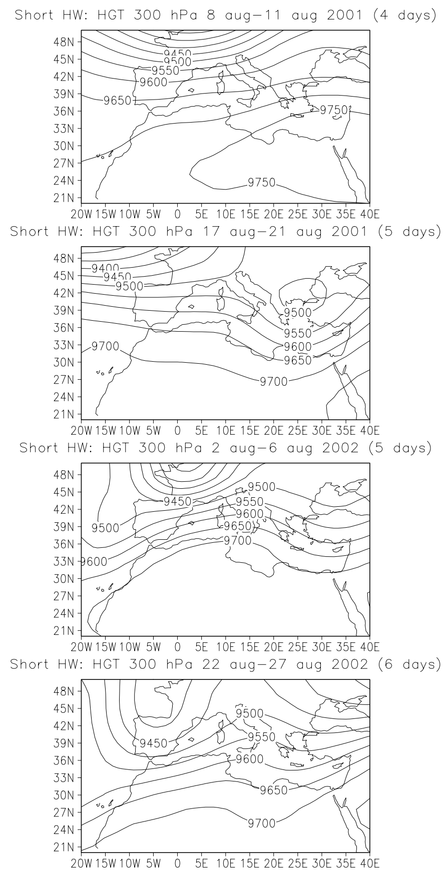


Figure 3a: Geopotential height at 300 hPa for selected short lasting heat waves events NCEP/NCAR Reanalysis

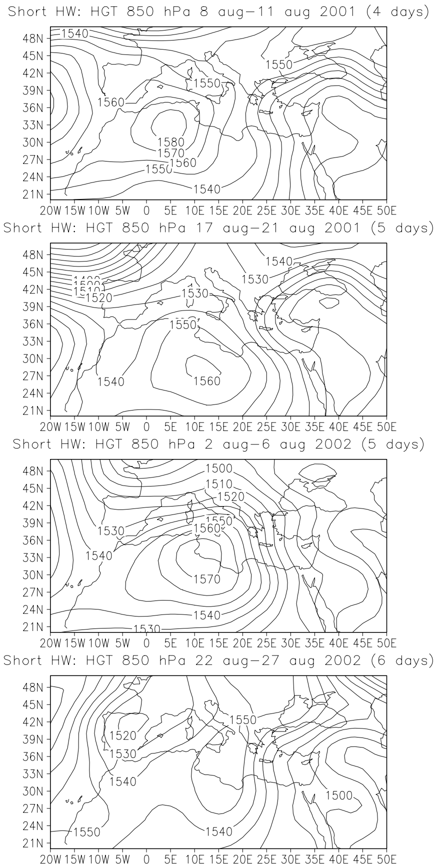


Figure 3b: Geopotential height at 850 hPa for selected short lasting heat waves events NCEP/NCAR Reanalysis

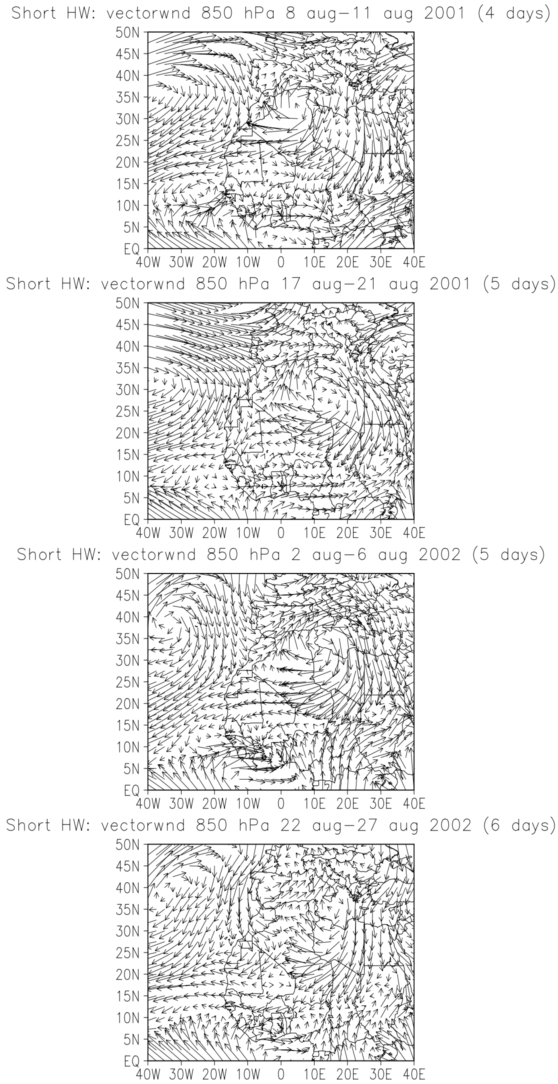


Figure 3c: Wind vector for selected short lasting heat waves events NCEP/NCAR Reanalysis

3.3 *Long lasting heat waves*

During Long lasting heat waves (Llhw), 300 hPa geopotential height patterns confirm the presence of an "omega wave" configuration, i.e. there is a through on Portugal coast (around 20°W), a ridge on the Italian peninsula and a through on the East Mediterranean Basin (Figure 3d).

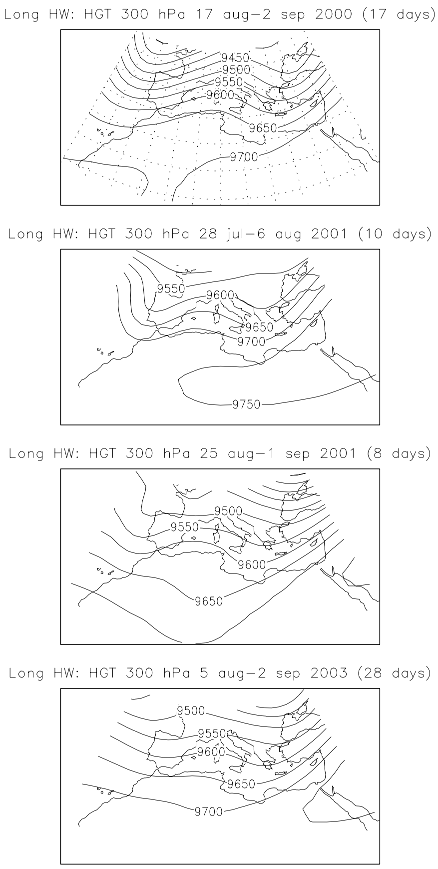


Figure 3d: Geopotential height at 300 hPa for selected long lasting heat waves events NCEP/NCAR Reanalysis

The 850hPa geopotential height field shows that Azores high pressure stretches all over the Mediterranean basin. In this configuration, we note a relative maximum pressure over Libya region. It reinforces the hot air advection towards Italian peninsula. More likely, the combination of two anticyclones determines the prolonged heat events, i.e. the action of the Libya high pressure center is stabilized and combined with the wider Azores high pressure system (Figure 3e).

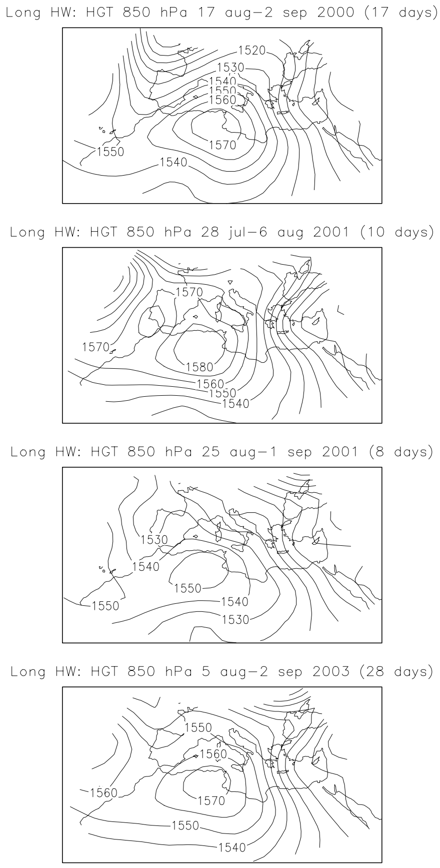


Figure 3e: Geopotential height at 850 hPa for selected long lasting heat waves events NCEP/NCAR Reanalysis

Llhw 850hPa vector wind maps (Figure 3f) show an analogous configuration to Slhw patterns.

850hPa meridional wind field shows positive (from south to north) values over the west Mediterranean basin. By comparing south Italian temperature profile with the 850hPa meridional wind averaged on west Mediterranean basin (10°W 15°E, 30°N 50°N), we obtain same pattern.

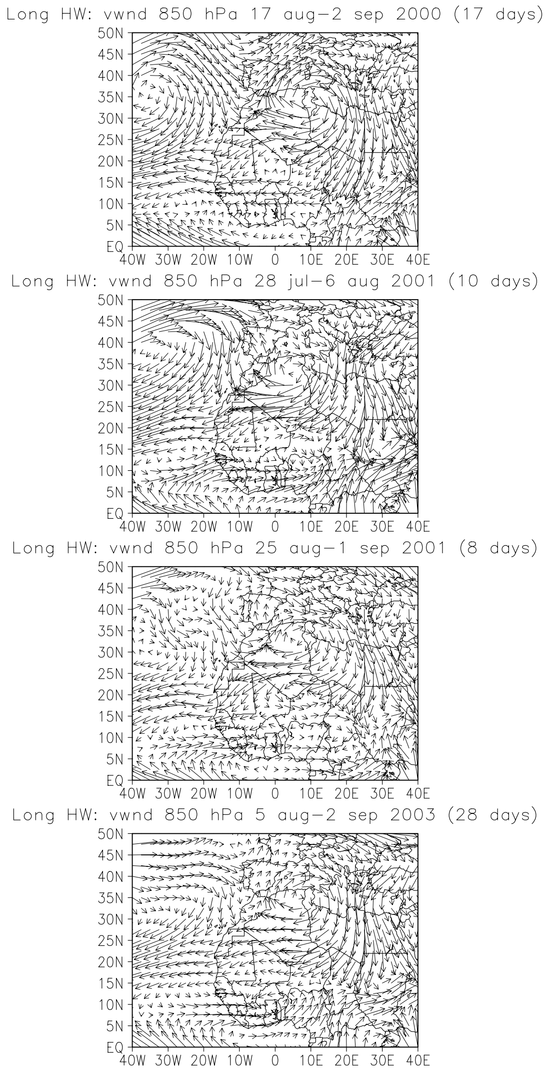
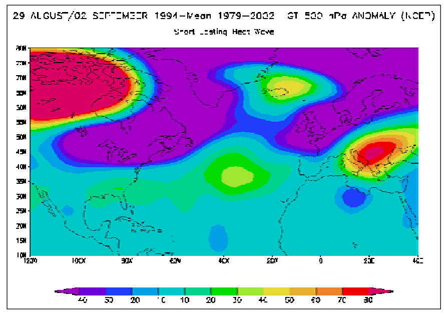
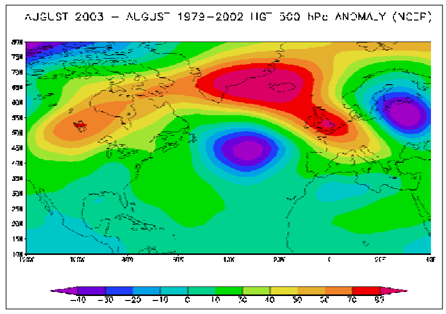


Figure 3f: Wind vector for selected long lasting heat waves events NCEP/NCAR Reanalysis

As stated in a pioneer work by Colacino and Conte (1995), we can say that the short-lasting heat wave is determined by downward flux, associated with latitudinal oscillations of STJ, although the adiabatic compression is exerted on a dome of warm air of African type. Since the latitudinal oscillations of the STJ are rapid and short lasting, the associated heat waves present the same characteristics. The long-lasting events are instead produced by horizontal motions, also if temporary and brief incursions of the STJ can reinforce the phenomenon by adiabatic compression. For these events, Colacino and Conte observe a typical pressure configuration denominated "omega wave", in which, from the west to east, through-ridge-through are alternated over Mediterranean Basin.

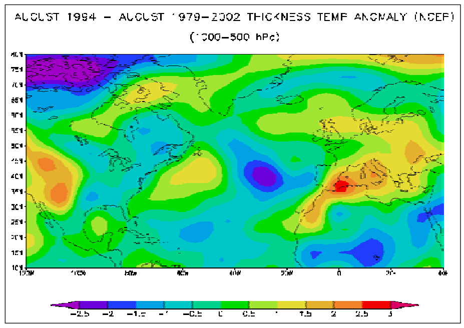


Geo 500hPa anomaly
1994 – (1979-2002)



Geo 500hPa anomaly
2003 – (1979-2002)

Figure 4a: Geopotential field at 500 hPa anomalies in the selected events: 1994 (short lasting) in the upper panel, and 2003 (long lasting) in the lower panel NCEP/NCAR Reanalysis



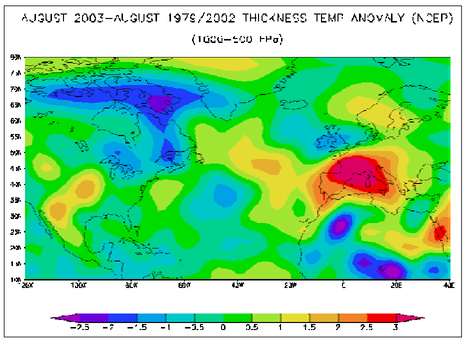


Figure 4b: (1000-500) hPa temperature thickness anomaly for the selected events: 1994 (short lasting) in the upper panel, and 2003 (long lasting) in the lower panel. Base period: (1979-2002). NCEP/NCAR Reanalysis

Subtropical Jet Stream is a current of very strong winds in the upper troposphere whirling from west to east. A strong circulation corresponds to a compressed circumpolar vortex: a weak circulation corresponds to a highly irregular and undulating Jet Stream. Such configurations severely affect the climate in the Northern Hemisphere. In fact, when the circumpolar vortex is intense, and the Jet Stream blows strong, it follows a path approximately parallel to the Polar Regions. The southern climatic regions have more space to move north, monsoons arrive with regularity, and the temperate regions are characterized by mild climate without great temperature or rain extremes. When the vortex becomes weak, it flows on pronounced undulating path (see the sketch in Figure 5).

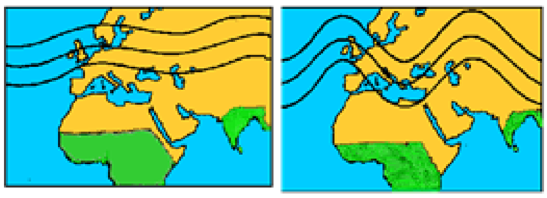


Figure 5: Schematic picture showing the undulating path

The influence of SJT arrives to lower latitude, compressing climatic areas towards the equator and limiting the penetration of the monsoon to the north. Moreover, heat wave configurations are associated with progressive increase in the frequency and persistence of Azores anticyclones over Mediterranean Basin in recent decades (Brunetti *et al.*, 2002).

The mentioned undulating path in the geopotential field is evident for the selected events, the long and the short lasting respectively, although some differences can be observed: a shift in the phase of the wave and a deeper through in the long lasting case, which is even more clear in the geopotential anomaly field, and reflected in the (1000-500) hPa temperature thickness anomaly field (Figures 4a, 4b).

Another large scale feature, candidate for driving the heat wave episode is the West African Monsoon (WAM). In particular, a strong influence is detected on the Geopotential field at 500hPa due to strong WAM, which is, in turn, associated to anomalous SST in the Guinea Gulf. In fact, an interannual climate analysis shows that the sea surface temperatures (mean and anomalous SST) in the Gulf of Guinea, through their effect on the West African monsoon, influence the central-western Mediterranean summer climate (Baldi *et al.*, 2004). Specifically, a southward shift of the monsoonal activity is related to cooler and wetter conditions over the central and western Mediterranean Sea in mid-late summer. Conversely, when the West African monsoon reaches further north and is more intense than average, the summer tends to be hotter and drier than average in the western portion of the Mediterranean region. This is evident in the composite differences of geopotential at 500 hPa (Fig 6a), calculated for summer, over the period 1979-2003. The intensity of the monsoon has been evaluated using the outgoing longwave radiation anomalies over a region including the Sahel (8 cases of weak and 8 cases of strong monsoon). In particular, the large area of negative anomalies over central and north Europe, and the positive centers over the Mediterranean, and over north-western Atlantic are significant at the 90% level, according to the Wilkoxon-Mann-Whitney test.

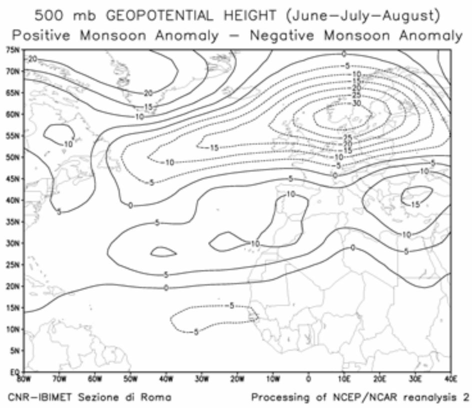


Figure 6a: Composite differences of geopotential anomaly field at 500 mb (summer mean) due to years with strong minus weak west African Monsoon (NCEP/NCAR Reanalysis) calculated over the period 1979-2003.

Using the Regional Atmospheric Modelling System (RAMS) and the NCEP-NCAR reanalysis, Baldi et al. (2004) have demonstrated that a latitudinal northward shift of the West African monsoon is related to observed SST anomalies in the Gulf of Guinea. In an idealized simulation, Baldi *et al.* (2004) perturbed the climatological SST in the first half of the summer, specifically in May-June, introducing a colder dipole in the Gulf of Guinea which in turn favoured a deeper inland northward penetration of the oceanic moisture, while warm SSTAs, in the second half of the summer, provided additional moisture which enhanced the strength of the monsoon, which, through its thermodynamics and the dynamics, resulted in stronger subsidence over the Mediterranean Sea. Figure 6b shows the effect of colder SST in the Guinea Gulf on the Geopotential height at 500hPa, simulated by RAMS, obtained forcing the whole system by introducing a cold SST anomaly.

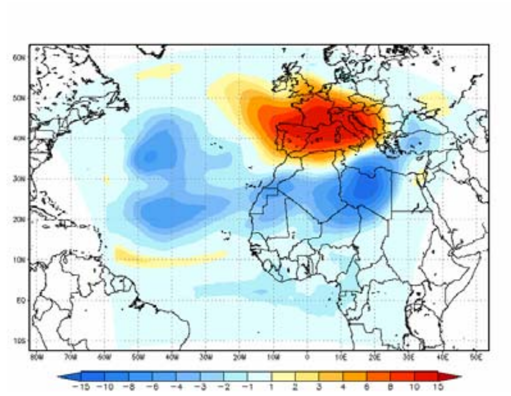


Figure 6b: Effects of cold June SSTAs in the Gulf of New Guinea on the Geopotential Height at 500 mb in August (RAMS sensitivity run).

4 The anomalous summer 2003 event

4.1 *Analysis of the Summer 2003 event*

The long-lasting heat wave of summer 2003 started in June, and, after a short break in July, it rose again in August until beginning of September. The minimum temperatures remained anomalously high during the whole period, as shown in Figure 8 for selected stations in Italy (Turin: North Italy, Roma: Center, Palermo: South).

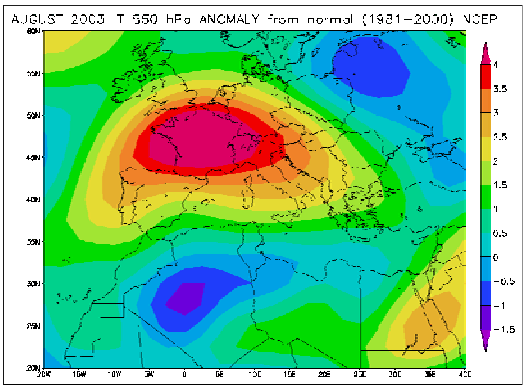


Figure 7: 850hPa Temperature anomaly during August 2003 (base period 1981-2000) NCEP/NCAR Reanalysis

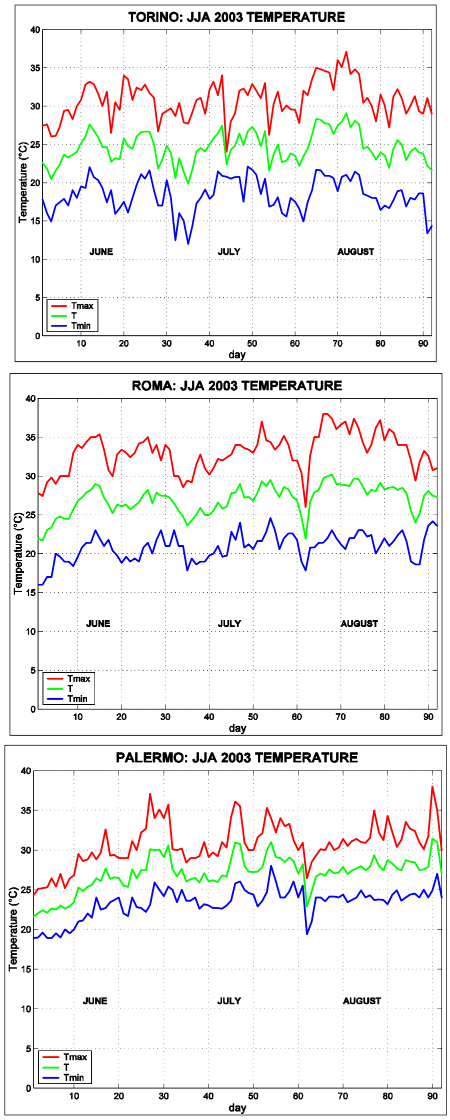


Figure 8: Tmin, Tmax, T mean time series in three selected cities in Italy (Turin, Roma, Palermo) in the period June 1st – August 31st, 2003.

During the summer of 2003, above average precipitation was recorded over the Sahel and below average along the Guinea coast for the whole rainy season (not shown here), clearly marking this case as a more intense and northward-reaching monsoon season. The SST anomalies in the Gulf of Guinea were slightly negative in May and June and positive in July and August, with absolute anomalies between 0.5 and 1.0°C. We consider this sufficient to influence the position and strength of the West African Monsoon. For the same time period seasonal mean SST time series in the Western Mediterranean show an historic maximum of June-August 2003, in the whole Mediterranean basin, the anomalies were about 5°C above the climatological mean, with the monthly mean exceeding 25°C in July and August (not shown). These SST anomalies directly mirror the air temperatures registered at the surface and aloft.
The geopotential field at 300 and 500 hPa, show both the so-called "omega" pattern characterizing the extremely hot episodes, as discussed above, and a large anomaly compared to the climatology (not shown here).

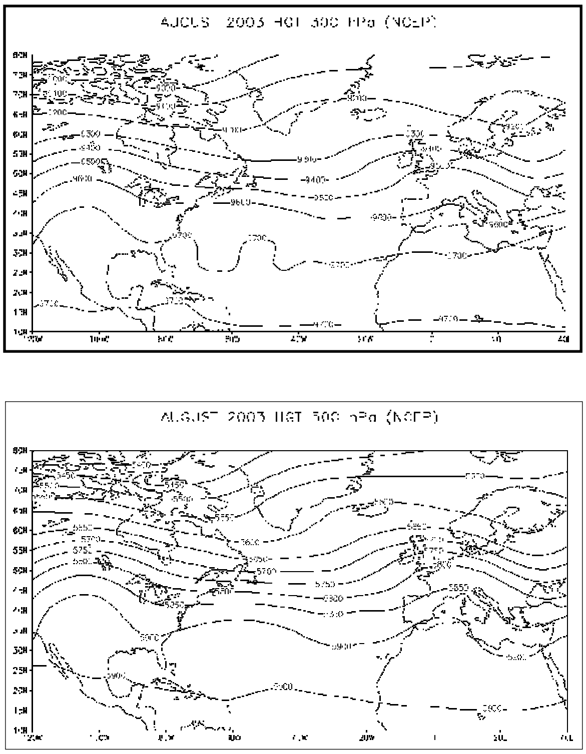


Figure 9: August 2003: Mean Geopotential height at 300 hPa (upper panel) and at 500 hPa (lower panel) NCEP/NCAR Reanalysis

4.3 *Simulation results*

The simulation, started on April 1st 2003, lasted until end of September 2003, in order to capture the main features of the exceptionally long heat wave of summer 2003. The domain (Figure 10a) extends from central Europe to the Gulf of Guinea and, longitudinally, it includes the Atlantic Ocean, the whole Mediterranean Basin and it extends eastward to the Balkans. The SST has been updated weekly during the whole period, while a monthly average is used for the soil moisture (Figure 10a, 10b).

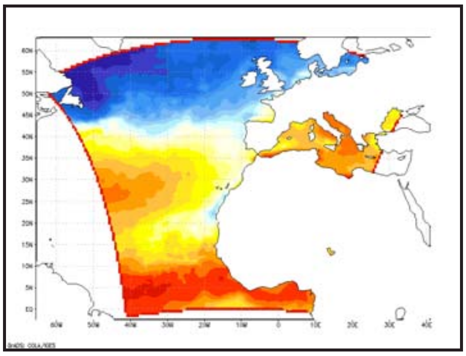


Figure 10a: Simulation domain and SST used in the simulation (June 1st, 2003)

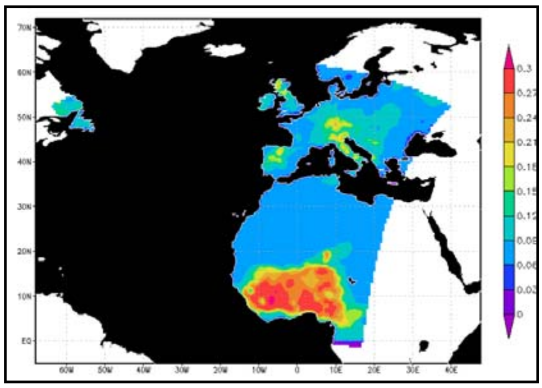


Figure 10b: Soil moisture used in the simulation (June 1st, 2003)

Results of the simulation, in terms of Geopotential field at 850 and 500 hPa and the air Temperature at 850 hPa are well reproducing the corresponding maps obtained from the NCEP/NCAR reanalysis, for the month of August 2003 (Figure 11). In particular, the use of weekly SST, instead of monthly mean, increases the performance of the model in reproducing the weather patterns. A further improvement can be obtained if finer (spatial and temporal) resolution soil moisture data will be used, being, the lack of moisture and of convective precipitation in the region key players of this severe episode.

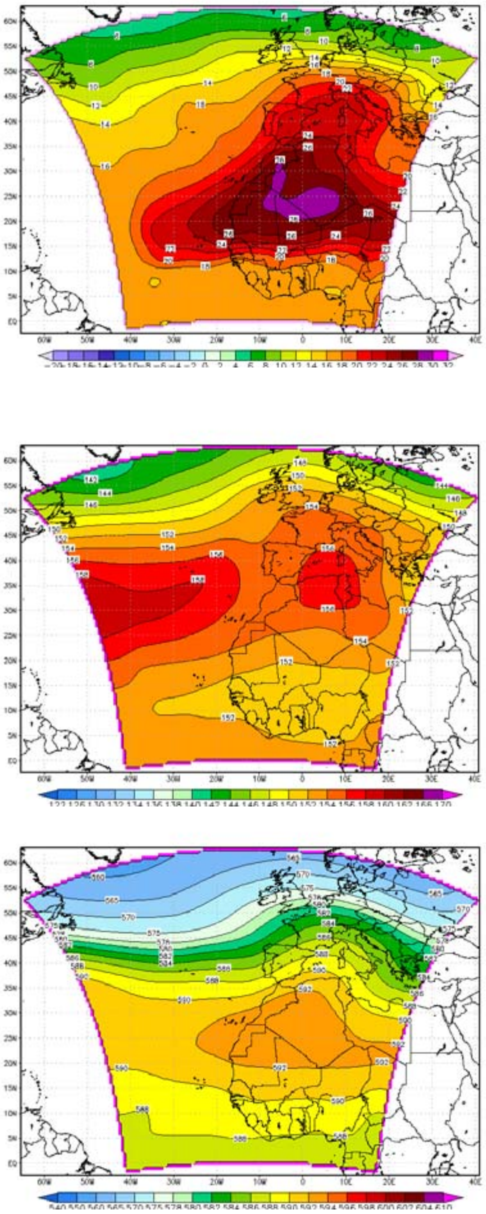


Figure 11: August 2003 – Model Results: Mean Air T at 850hPa (upper panel), Geopotential at 850 hPa (center) and at 500 hPa (lower)

5. CONCLUSIONS

Using the NCEP/NCAR reanalysis and the station data, 53 summers have been analyzed, looking for short and long lasting hot episodes in the Mediterranean. The main results can be summarized as follows:

- In july the short-lasting episodes are prevailing.
- In august the long-lasting episodes are prevailing.
- The total number of heat wave days (Long and Short Events) is dramatically increased in the last 10 years.
- In the same period, the long lasting heat waves are percentually contributing more to the extremely hot events than the short lasting.

The inter-annual variability of the Mediterranean summer climate is linked to the strength and position of the Atlantic sub-tropical anticyclone, whose structure is in turn connected to the northern hemisphere summer monsoons: Asian, North-American and West African.

As first shown by model results, a key role is certainly played by a positive feedback on the temperatures, by a low convective rainfall activity, and by the large soil moisture deficits, accrued in the region due to an exceptionally early and warm spring, which may have intensified most of the subsequent summer heat waves. Moreover the use of weekly versus monthly SST in the whole domain indeed improved the performance of the model, as well as more accurate soil moisture data at finer resolution can certainly do (results under investigation).

The Guinea Gulf SST, and, thus, the West African Monsoon, contribute significantly to the hot episodes triggering, and to the inter-annual variability of the central-western Mediterranean summer climate (Baldi *et al.*, 2004).

The analysis performed and the simulation results are a major starting point for a better understanding of the physical mechanisms yielding to such severe events, and will improve the forecast of these phenomenon (expected to occur more frequently in the course of the 21st century, as suggested by regional climate scenarios, see Beniston, 2004), as needed for an efficient early warning systems. In particular, through numerical simulations, it is possible to distinguish the role played by each of the different physical processes (soil moisture depletion, positive feedback on summer temperatures, and lack of convective rainfall) characterizing severe episodes such as the summer 2003.

Acknowledgements

The Authors thank the Climate Diagnostic Center (NOAA, Boulder, CO) for providing the NCEP/NCAR Reanalysis dataset and L.a.M.M.A. and UCEA for station data.

The work has been funded by the Italian Projects CLIMAGRI (MIPAF) and "*Effetti dei cambiamenti climatici sugli ecosistemi costieri: la Tenuta Presidenziale di Castelporziano come caso di studio*".

M. Baldi acknowledges the support of the Italian CNR Short-Term Mobility Program.

REFERENCES

Baldi M., F. Meneguzzo, G.A. Dalu, G. Maracchi, M. Pasqui, V. Capecchi, A. Crisci, and F. Piani, 2004: Guinea Gulf SST and Mediterranean summer climate: analysis of the interannual variability. Proceedings of the 84th AMS Conference, Seattle, WA. US.

Beniston, M., 2004. The 2003 heat wave in Europe: a shape of things to come? Geophys. Res. Lett. 31, L02022.

Beniston M., D. B. Stephenson, 2004: Extreme climatic events and their evolution under changing climatic conditions. Global and Planetary Change, *in press*

Brunetti M., L. Buffoni, M. Maugeri, and T. Nanni, 2000: Trends of Minimum and Maximum Daily Temperatures in Italy from 1865 to 1996 Theor. Appl. Climatol. **66**, 49-60

Brunetti M., Colacino M., Maugeri M., Nanni T., 2001: Trends in the daily intensity of precipitation in Italy from 1951 to 1996. Int. J. Climatol. **21**, 299-316.

Brunetti et al., 2002: Atmospheric circulation and precipitation in Italy for the last 50 years, Int. J. Climatol. **22**, 1455-1471.

Brunetti M., L. Buffoni, F. Mangianti, M. Maugeri, and T. Nanni, 2004: Temperature, precipitation and extreme events during the last century in Italy. Global and Planetary Change, **40**, 141-149.

Conte and Colacino, 1995: Heat waves in the central Mediterranean. A Synoptic climatology. Il Nuovo Cimento, **18 C**, 295-304.

Intergovernmental Panel on Climate Change: Third Assessment Report 'Climate Change 2001: The Scientific Basis'; http://www.ipcc.ch/

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, G. White, J. Woolen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. Mo, and D. Joseph, 1996: NCEP/NCAR 40-year reanalysis project. *Bull. Am. Soc.*, **77**, 437-471.

Kistler, R.E., and coauthors, 2001: The NCEP-NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation. *Bull. Am. Met. Soc.*, **82**, 247-268.

Maugeri M., T. Nanni, 1998: Surface Air Temperature Variations in Italy: Recent Trends and an Update to 1993. Theor. Appl. Climatol. **61**, 191-196

Pielke, R. A. & Coauthors, 1992: A comprehensive meteorological modelling system-RAMS. Meteor. Atmos. Phys., 49, 69–91.

Raicich, F., N. Pinardi, and A. Navarra, 2001: Teleconnections between Indian monsoon and Sahel rainfall and the Mediterranean. Archo Oceanogr. Limnol., 22, 9-14.

Schaer C., P.L. Vidale, D. Luthi, C. Frei, C. Haberli, M.A. Linigier, C. Appenzeller, 2004: The role of increasing temperature variability in European summer heatwaves. Nature, **427**,332-336