Temperature variability over Greece: Links between space and time

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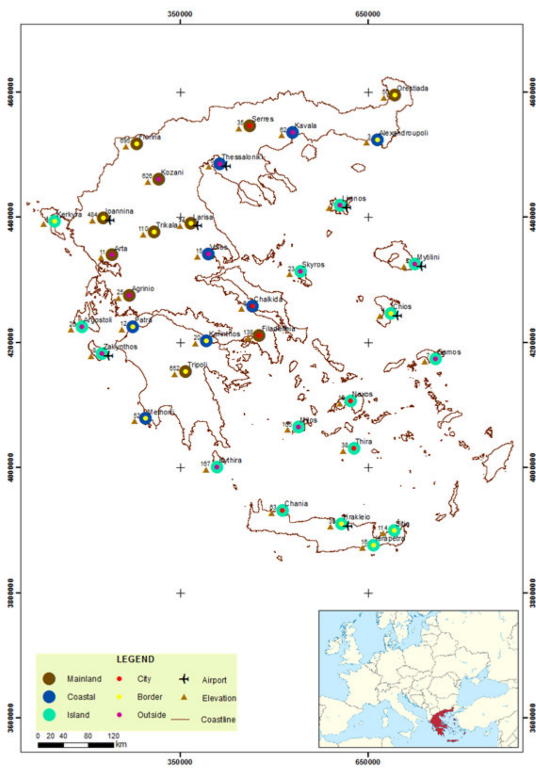
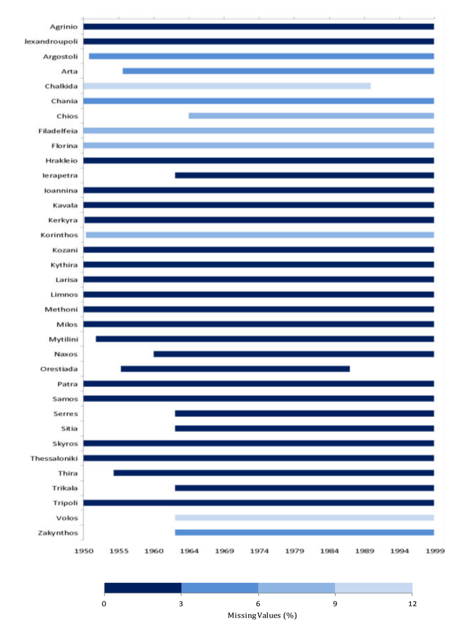
1. Abstract

Temperature is strongly linked to the hydrological cycle in numerous ways and mainly with the evapotranspiration. Our aim here is to examine the possible influence of spatial characteristics on the temperature temporal variability of the monthly absolute maxima/minima and the monthly means over Greece. To achieve this, the temperature records of the Hellenic National Meteorological Service station network, which date back to 1950, are analysed. The analysis involved two steps: the determination of regions with similar climatic properties and the investigation of the possible correlations of temperature in time. Thus, the time series are classified in three groups based on their location (continental, coastal and island) and four types regarding the proximity of the station to a city (at the city centre, near the city border, far away from city border) or to an airport. Each one of the time series is then examined for (a) the influence of the city heat island as Greek cities expanded in time, (b) the effect of the general atmospheric circulation (NAO phase), (c) its correlation to the global temperature record and (d) the implied change on evapotranspiration in the area.

2. The data set (study area)



Data from 35 stations of HNMS were used, with a rather uniform spatial distribution as it can be seen in the map and at least 40 years of data and 12% missing values.



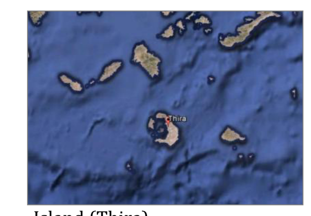
3. Station classification

In order to investigate the role of the sea to temperature variability and the effect of the thermal heat island the stations were classified:

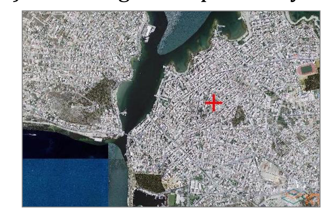
i) according to their location


Continental (Larisa)

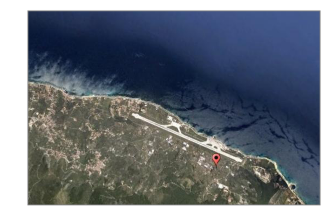

Coastal (Alexandroupoli)


Island (Thira)

ii) according to the proximity of the station to a city


City Center (Chalkida)


Near the city border (Tripoli)


Far away from the city (Mytilini)

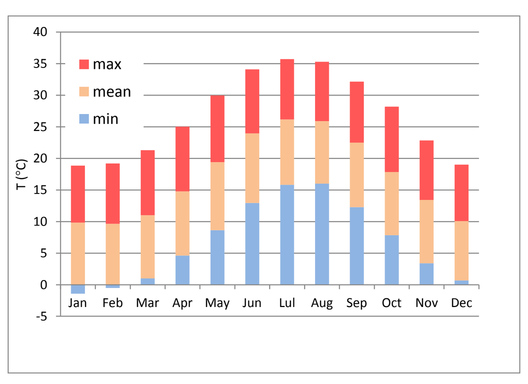
		Location			City proximity		
	Total	Continental	Coastal	Island	Center	Border	Away
number of Stations	35	11	8	16	6	15	14
mean record length (years)	43,11	43,05	43,22	43,10	39,50	42,62	45,18
mean elevation (m)	107,63	263,64	21,88	43,25	48,33	155,27	82,00

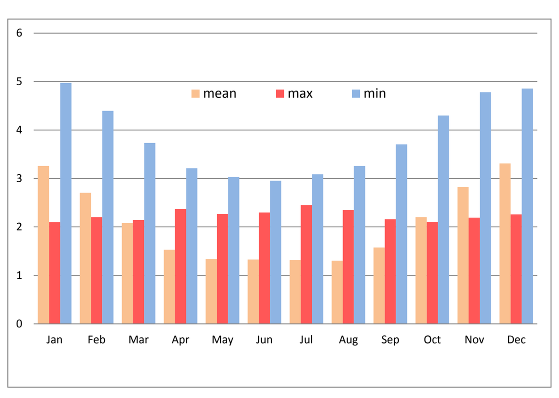
4. Temperature characteristics

The software used for the statistical analysis was R programming language.

Three variables were examined: monthly mean and monthly (absolute) maximum/ minimum (seen on the right).

Mean monthly values that deviated more than 6 degrees from overall monthly mean were omitted as outliers, as well as minimum values that deviated more than 10 degrees



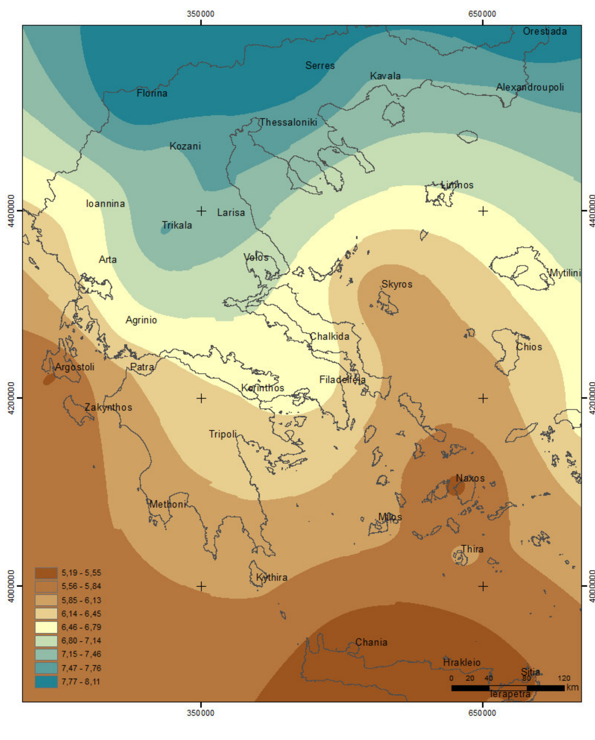


The figure on the left, shows the mean standard deviations amongst all stations for each month.
The standard deviations of mean and min temperatures exhibit the same pattern, increasing on winter months and decreasing on summer.
Maximum temperatures demonstrate the least variability and remains uniform throughout the year.

5. Inter-annual variability

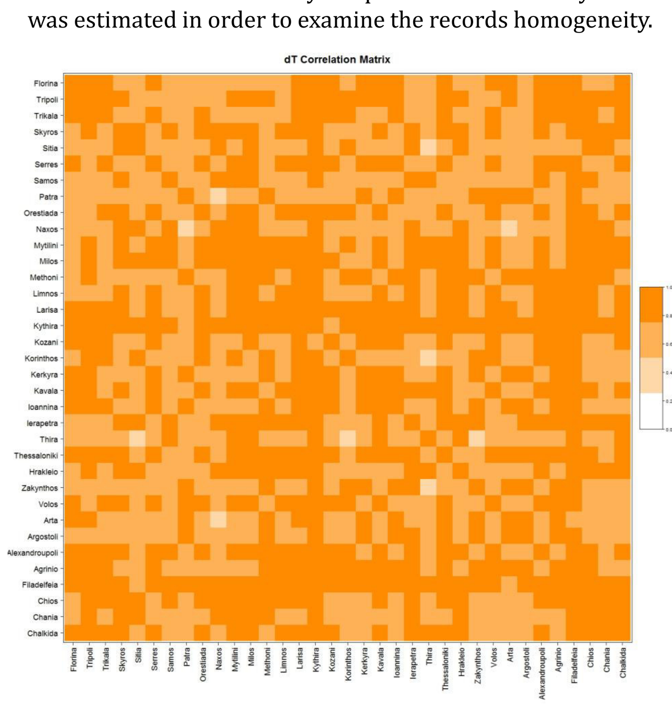
The map of inter-annual variation (i.e. the mean standard deviation of the monthly temperatures of each year) shows that the variability of temperature parameters is higher to continental stations than to coastal or island regions, which is in accordance with the findings of Stathopoulos *et al.*, 2012.
This result shows the effect of the proximity to the sea to a region, which can only be seen in the table below for each of the corresponding station categories.

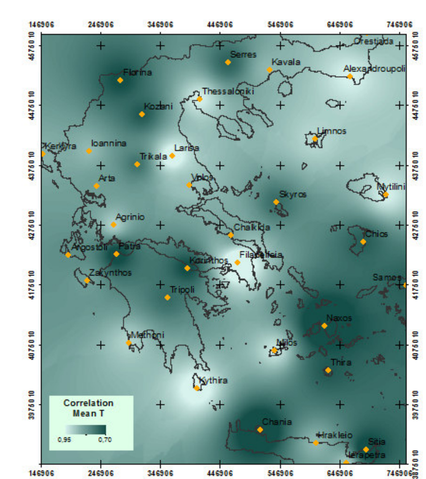
Standard deviation			
Type of area	T mean	T max	T min
mainland	7,55	7,79	7,19
coastal	6,81	6,82	6,84
islands	5,71	6,38	5,91



6. Correlations

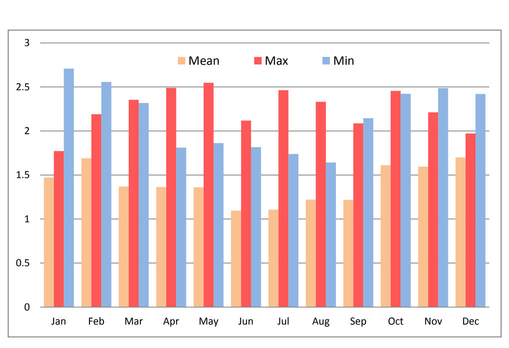
The cross-correlation coefficient matrix of the temperature difference between monthly temperature and monthly mean was estimated in order to examine the records homogeneity.

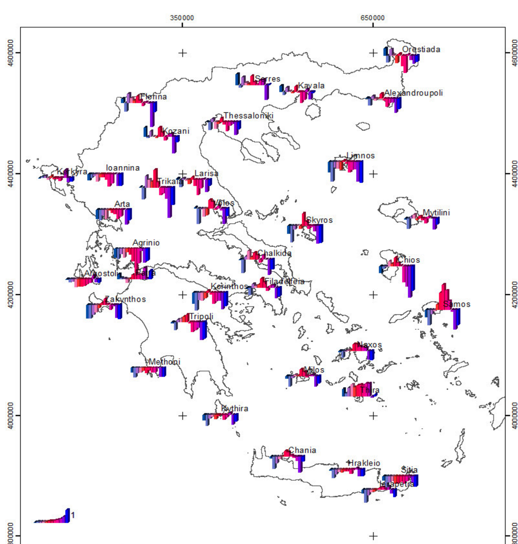




The correlation matrix of dT demonstrates that the set of mean temperature values is homogenous (most values above 0.7). This justifies the use of an aggregated mean temperature record for the whole study area. No lower scale spatial correlations were found, as it can be seen at the map above.

7. Change over time



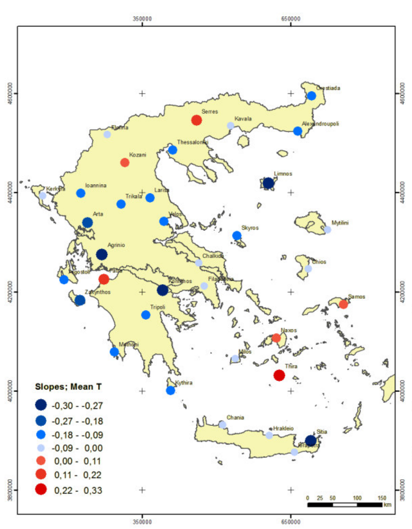


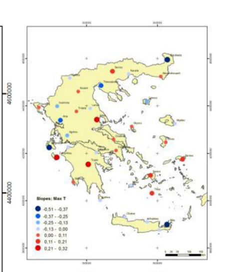
The time series do not vary significantly over time. When we estimated the mean standard deviation for each month (e.g. all Octobers), we found out that mean temperature standard deviation varies between 1-1.5 degrees, while the other variables show higher variance as expected.

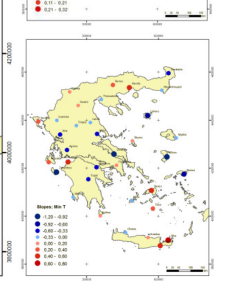
This change were further analyzed by calculating the difference of the average mean, maxima and minima temperatures between the periods 1975/2000 and 1950/1975 for each month (shown in the map above for temperature mean).
The overall picture shows a slight cooling in the winter and an ever more modest increase in the summer temperatures, which is in accordance with the findings of Marougianni *et al*, 2012. However, if compared with the standard distribution neither of them can be regarded as statistically significant, as suggested also by Feidas *et al.*, 2004.

8. Change over time (continued)

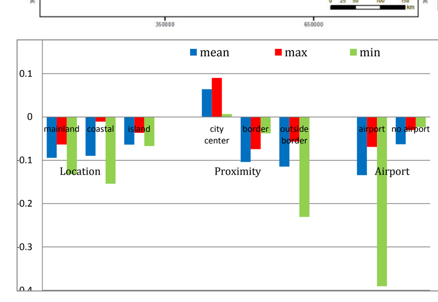
The next step of our analysis involved the determination of slopes for each time series. As it can be seen on the maps to the right, there is a minor cooling trend in temperature with a mean value of approximately 0.1°C per decade, and opposing trends between maxima and minima.
Furthermore, each category was examined separately. Interestingly, the records of stations near city center demonstrated rising slopes. The effect of city heat island phenomenon could lead to a plausible explanation, but as discussed above the overall change is relatively small when compared to the standard deviation.
The presence of an airport near the station does not seem to have an impact to the slope.







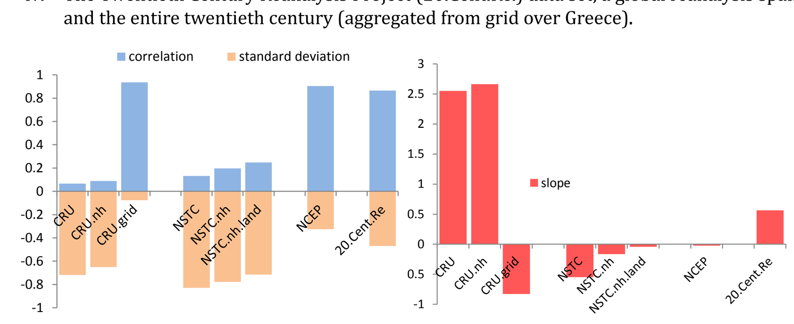
Slopes of Minimum, Mean and Maximum temperatures



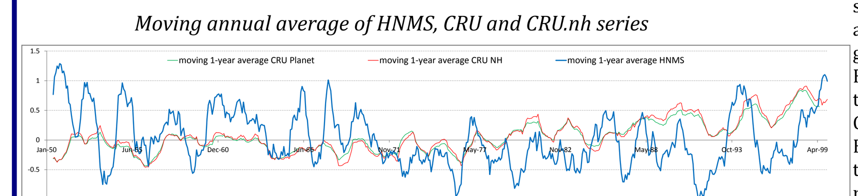
9. Comparison to global and regional temperature records

A comparison was held between HNMS data and other widely-used temperature time series:

i. The Climatic Research Unit HadCRUT4 dataset for global (CRU) and northern hemisphere (CRU.nh) means, as well as the mean for CRU grid over Greece (land stations only).
ii. National Space Science and Technology Center (NSSTC) data for global (NSSTC), northern hemisphere (NSSTC.nh) and northern hemisphere land stations (NSSTC.nh.land).
iii. The National Centers for Environmental Prediction (NCEP) Reanalysis data set, which incorporates observations and numerical weather prediction model output dating back to 1948 (aggregated from grid over Greece).
iv. The Twentieth Century Reanalysis Project (20.Cent.Re.) data set, a global reanalysis spanning portion of the nineteenth century and the entire twentieth century (aggregated from grid over Greece).



Moving annual average of HNMS, CRU and CRU.nh series

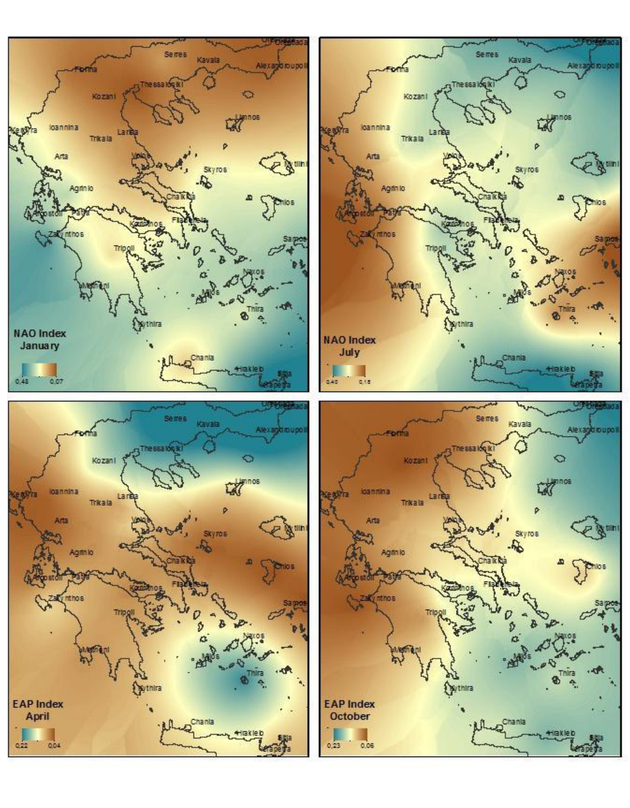


The time series were compared in terms of cross-correlation, standard deviation and slope and our findings are shown on the left. Only gridded data correlate to the aggregated dT mean of the records and only CRU.grid data agree on standard deviation. A similar picture holds also for slopes. It is obvious that aggregated temperature over Greece is not correlated with the observed increase on global and hemisperic scales, also deomstrated on the adjacent figure. Our findings are in good agreement with the findings of Feidas *et al*. (2004), which suggest that there is a different pattern for Greece compared to the rest of the Europe, and that surface air temperature in Greece shows a slight negative trend over the 20th century.

10. Correlations with climatic indexes

The aggregated mean of dT was also compared with four climatic indices of northern hemisphere atmospheric circulation:
i.The North Atlantic Oscillation (NAO), which demonstrates the difference in atmospheric pressure at sea level between the Azores high (HP) and the Icelandic low (LP).
ii.The East Atlantic pattern (EAP) ,which is similar to NAO index, and consists of a north-south dipole of anomaly centers connecting the North Atlantic from east to west.
iii.The Scandinavia pattern (SCAND), consists of a primary circulation center over Scandinavia, with weaker centers of opposite sign over western Europe and eastern Russia/ western Mongolia.
iv.The East Atlantic/ West Russia pattern (EATL/WRUS) is located over Europe, northern China, central North Atlantic and north of the Caspian Sea.

Very weak correlations were found, with NAO and EAP showing a more uniform spatial distribution illustrated on the maps to the right, which is in agreement with the findings of Markonis *et al.* (2013). More specifically, in January, NAO index correlates to the Western Greece and Central Aegean regions, while on the summer (July) this relationship is reversed geographically, i.e. the most correlated area is the Eastern Continental Greece, Western Aegean and Crete. Spring and autumn correlations are even smaller, as well as the rest of the indices.

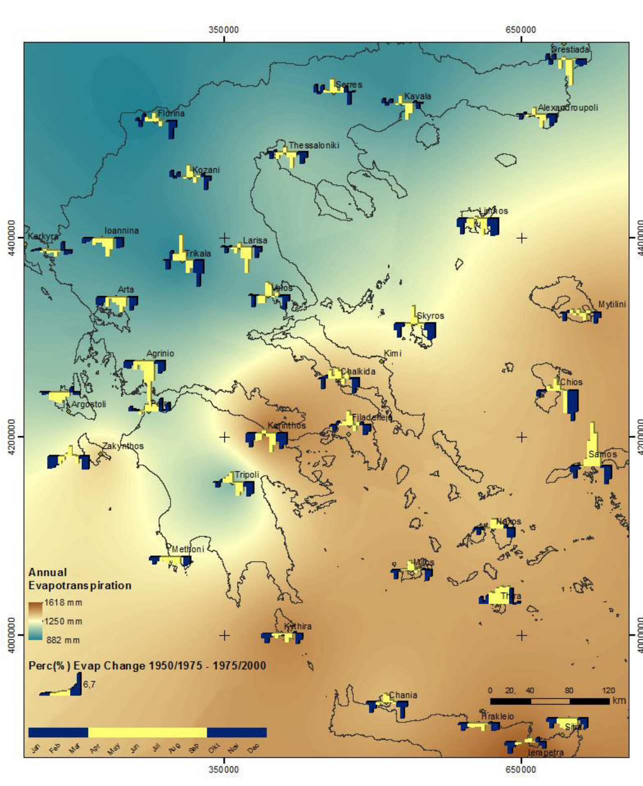


11. Potential Evapotranspiration (PET)

Monthly potential evapotranspiration for each station was estimated by a new parametric model (Tegos *et al.* 2013):

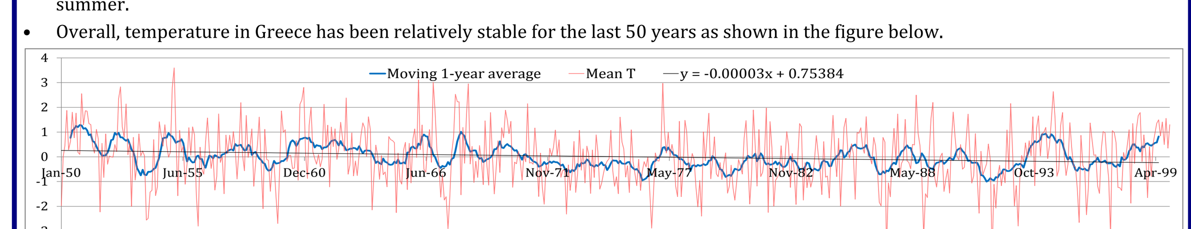
$$E = \frac{aR_a}{1 - cT_a}$$

dependent only to temperature T_a and incoming solar radiation R_a and two coefficients, a (kg/kJ) and c (C^{o-1}). Values for a follow a geographical distribution between 0,00001 (NW Greece) and 0,000073 (SE Greece), used by the same study and value of c is estimated as 0.00234.
Our results are at the map on the right, which include both annual PET (background coloring) and monthly change over the examined period (bars). We can see that PET has been declining during the last 50 years, which is expected as it follows the temperature decrease. It must be noted though that some station in Eastern Greece show increase during the summer.



12. Conclusions

- The classification revealed that places close to the sea demonstrated lesser inter-annual standard deviation and smaller range of minimum and maxima.
- There is some evidence of the influence of city heat island found in the slope of temperature records near to the city centers . The exact effect needs to be further investigated because the number of stations was not large enough.
- All stations in Greece showed strong correlation between them, which justifies the use of an aggregated temperature record over space.
- Climatic indexes do not correlate with temperature in terms of monthly mean, maxima and minima. NAO has the greatest impact, which is still weak and can be regarded significant only for specific months and areas.
- The correlation between our data set and global temperature data is not considerable, especially, when slopes and standard deviations are concerned. Reanalysis data seem to underestimate the actual climatic variability.
- The potential evapotranspiration has decreased in winter all over Greece, and has increased only in a few Aegean islands during summer.
- Overall, temperature in Greece has been relatively stable for the last 50 years as shown in the figure below.



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Tegos, A., Efstratiadis, A. and Koutsoyiannis, D. A parametric model for potential evapotranspiration estimation based on a simplified formulation of the Penman-Monteith equation, Evapotranspiration-An Overview, edited by S. Alexandris, 143–165, doi:10.5772/52927, InTech, 2013 (dx.doi.org/10.5772/52927)

Data used from:
http://www.cru.uea.ac.uk/cru/data/temperature/
http://www.nsstc.uah.edu/
http://rda.ucar.edu/datasets/ds131.1/#description
http://www.cpc.ncep.noaa.gov/data/