Temperature Variability in Apulia Region (Italy) and its Impact on the Reference Evapotranspiration: Seasonal Based Analysis of the Period 1950 to 2003

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***Abstract*—** The minimum, maximum, mean temperatures and reference evapotranspiration were considered in this paper for the purpose of trend analysis. The study, which was based on 38 monitoring stations, was carried out at a sub-national scale throughout Apulia region (Italy). The methodology of the non-parametric Mann-Kendall test and the progressive trend analysis were used for the trend detection. The second half of the 20th century (1950-2003) was investigated on seasonal and annual scales.

The results generally showed a warming process, which has taken place especially from the mid-1970s, and an acceleration of the atmospheric evaporative demand thereafter. The latter had a significant positive trend, while the period before the break point of the 70s had a cooling effect. Finally, the warming was more pronounced in the case of minimum temperature.

***Keywords*—**Air temperature, climate change, Evapotranspiration, trend analysis.

I. INTRODUCTION

THE common conclusion of a wide range of fingerprint studies conducted over the past one or two decades isthat climate changes can't be explained by natural factors alone (Santeret al., 1995 and 1996a,b,c; Hegerlet al., 1996, 1997 and 2000; Hasselmann, 1997; Barnett et al., 1999; Tettet al., 1999; Stott et al., 2000). As climate science and the Earth's climate have continued to evolve over recent decades, increasing evidence of anthropogenic influences on climate change has been found and the Intergovernmental Panel on Climate Change (IPCC) has made increasingly more definitive statements about human impacts on climate (Le Treutet al., 2007).

The overall effect of human activities on climate since the start of the industrial era has been a warming influence (Forster et al., 2007). However, the warming has been neither steady nor the same in different seasons or in different locations and recent observations have showed that surface temperatures have risen globally, with important regional variations (Trenberthet al., 2007).

From 1950 to 2004, the annual trends in minimum and maximum land-surface air temperature averaged over regions with data available were 0.20°C and 0.14°C per decade, respectively, with a trend in diurnal temperature range (DTR) of –0.07°C per decade (Voseet al., 2005). In addition, an increasing rate of warming has taken place especially over the last 25 years (1979-2004), and 11 of the 12 warmest years on record have occurred in the last 12 years (Trenberthet al., 2007). The corresponding linear trends for the land areas where data are available were 0.29°C per decade for both maximum and minimum temperature .

Italy, which lies in the middle of the Mediterranean region, has been identified as one of the most sensitive areas to greenhouse gas (GHG)-induced global warming (Giorgi, 2006; Coppola and Giorgi, 2010). Brunettiet al., (2006)stated that the situation about mean temperaturein Italy was quite uniform in the different regions. In southern Italy, the temperature trend is homogeneous everywhere and a temperature increase seems to prevail, especially from about 1980 (Polemio and Casarano, 2008).

The present study investigated the case of Apulia region (Lat 39.75-41.9 N; Long 14.9-18.5 E) in southern Italy. It wasaimedatinvestigating the spatiotemporal variability of temperature and evaluatingits impact on reference evapotranspiration. The study was carriedout on a seasonal scale andit investigated the second half of the 20th century (1950-2003).

II. DATASET

The analyzed data series are available on the web site of "*Regione Puglia*". The monitoring stations are managed by the hydrographic office of the region and an average monthly database was provided.

The analyzed data set, for a period of 54years (1950-2003), covered 71 stations and included both average maximum and minimum temperature. In the present study, only stations that had less than 15% of missing data (38 stations) were considered. Density and distribution of the selected stations (Fig. 1) over the study area were acceptable.

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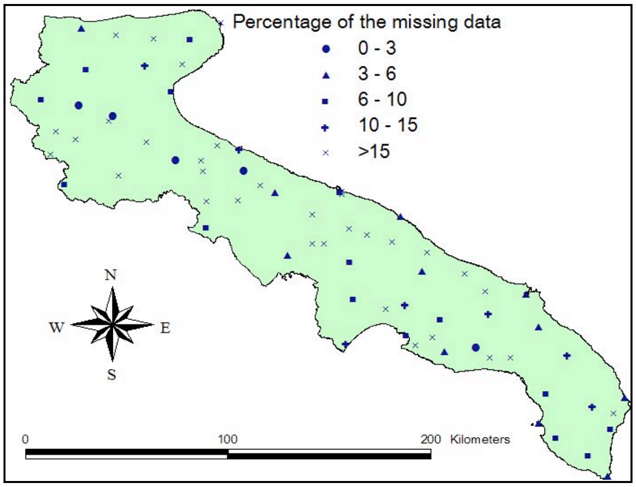


Fig. 1 Distribution of the monitoring stations over the study area.

The missing data were generated using the Inverse Distance Weighted methodology with the power 2 and a fixed search radius. In addition, the lapse rate (-0.65 °C per hundred meters) was considered in estimating missing data (Edmonds, 2009).

III. METHODOLOGY

A. Trend Detection

The trend analysis was performed using the non-parametric Mann-Kendall test and the simple linear regression model. The analysis was carried out on a seasonal scale considering mainly two periods: the overall period (1950-2003) and the last three decades (1974-2003).

The test of Mann-Kendall is simple, robust and can cope with missing values and values below the detection limit (Smadi, 2006; Toros, 2011). This test was found to be useful and it has been extensively used to detect trends in hydro-meteorological time series (Yu *et al.,* 2002; Domroes and El-Tantawi, 2005; Brunetti*et al.,* 2006; Chen *et al*., 2007; Moderres and Da Silva, 2007; Panda *et al*., 2007; Bartolini*et al.,* 2008; Hamed, 2008 and 2009; Chen and Grasby, 2009; Tayanç*et al.,* 2009; Xu*et al*., 2010). Moreover, the Mann-Kendall test has a predictive power comparable to its parametric competitors (Liu *et al*., 2008). According to a certain confidence level, the trend may belong to one of the following significance classes:

NSNT: Non-Significant Negative Trend;
SNT: Significant Negative Trend;
NSPT: Non-Significant Positive Trend;
SPT: Significant Positive Trend.

In order to demonstrate the trend dependency on the selected period of analysis and detect variations inside the overall period, the progressive trend analysis was performed on the average time series and two time directions were considered:

The direct time direction

In this case, 1950-1979 represents a common period for a 25 sub-series. The first sub-series is 1950-1979, the second one is 1950-1980. By iteration, the last sub-series will be 1950-2003.

The opposite of the time direction:

In this case, 1974-2003 represents a common period for a 25 sub-series. The first sub-series is 1974-2003, the second one is 1973-2003. By iteration, the last sub-series will be 1950-2003.

Thus, the progressive trend analysis allows investigating different sub-series of at least 30-year length to evaluate the year-by-year trend.

B. Parameters of Study

Investigated parameters were maximum temperature (*Tmax*), minimum temperature (*Tmin*), mean temperature (*Tm*) and reference evapotranspiration (*ETo*).

The Blaney-Criddle (1950) model was used to estimate the impact of temperature variability on reference evapotranspiration. The usual form of the Blaney-Criddle equation converted to metric units is written as:

$$ET_0 = p\left(0.46 \cdot Tm + 8.13\right) \tag{1}$$

ETo is the reference crop, clipped grass, evapotranspiration (in mm/day); Tm is the average temperature over the period (in °C); p is the average daily percentage of total annual daylight hours for the period.

IV. RESULTS AND DISCUSSION

In terms of mean temperature and considering the overall period, most of the stations showed a positive trend for all the seasonsand, thus , for the annual scale (92% of the stations). The maximum percentage of stations that showed a negative trend was observed in summer (26.3%). At 95% confidence level (Fig. 2(a)), results showed the predominance of the NSPT-class and a quiet high percentage of the SPT-class. Only 2.6% of the stations showed an SNT. At 1% significance level, percentage of the SNT-class was Zero on a seasonal scale and remained 2.6% on annual scale.

During the last three decades of the covered period, the warming process was more evident (100% of analyzed stations in terms of Tm) and was dominated, in general, by the SPT. Percentage of the SPT-class remains highfor most of the stations even at 1% significance level, especially in summer (about 87% of the stations).

By considering the overall period, *Tmin* was at the origin of the warming process in the study area (Fig. 2(b),2(c)) while *Tmax* trend was not evident (almost equal percentage of the positive and negative trend). Butduring the last three decades, both *Tmax* and *Tmin* significantly participated in that warming.

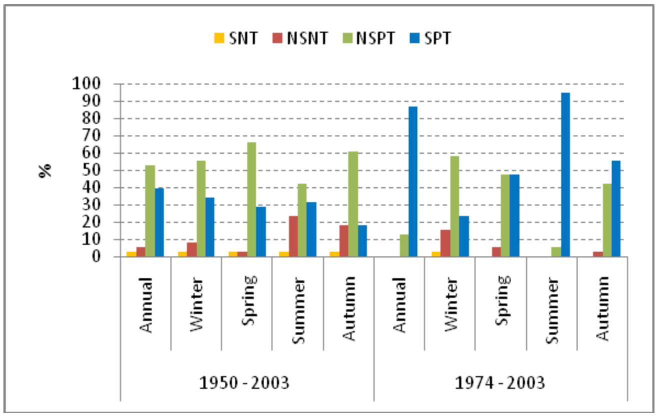


Fig. 2(a) Temperature trend significance at 95% confidence level- Mean temperature (*Tm*)

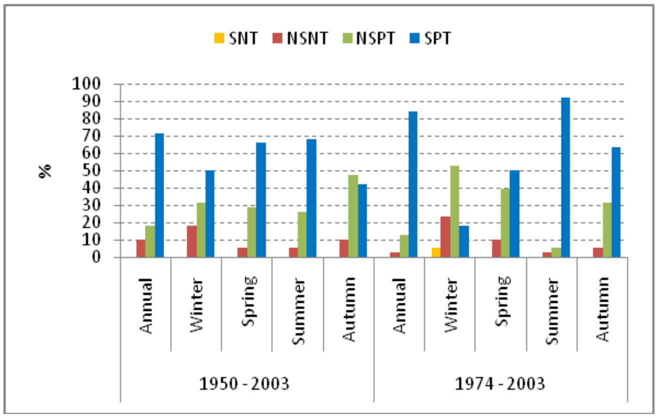


Fig. 2(b) Temperature trend significance at 95% confidence level- Minimum temperature (*Tmin*)

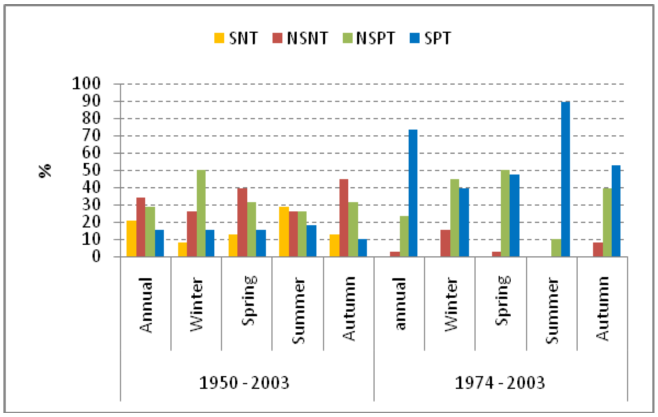


Fig. 2(c) Temperature trend significance at 95% confidence level- Maximum temperature (*Tmax*)

Table I recapitulates the average trend value in the study area, expressed in °C/decade. In addition to the observed dominance of the SPT-class during the last three decades, the seasonal trend magnitudes, but winter season, were notable. In particular, summer season showed an average trend of 0.91°C/decade in terms of Tm. These trends were much higher than the trend magnitudes of the overall period.

As previously saidabout the contribution of *Tmin* (and not of *Tmax*) to the warming, if we consider the overall period, all average trends were significant at 99% confidence level, whereas average trend magnitudes of *Tmax* were not significant and were closed to Zero °C/decade.

TABLE I

AVERAGE TRENDS IN THE STUDY AREA

(Significance levels: *** <1% ;** 1–5% ; * 5 –10%)

	1950 – 2003			**1974 – 2003**		
	Tmax	**Tmin**	**Tm**	**Tmax**	**Tmin**	**Tm**
Annual	-0.01±0.07	0.25±0.06***	0.11±0.04	0.52±0.07***	0.52±0.09***	0.52±0.07***
Winter	0.02±0.05	0.19±0.07***	0.11±0.04**	0.23±0.08*	0.15±0.09	0.19±0.08*
Spring	0.00±0.07	0.26±0.06***	0.14±0.04*	0.54±0.08***	0.44±0.09**	0.49±0.08**
Summer	-0.06±0.10	0.29±0.05***	0.12±0.05	0.90±0.09***	0.92±0.11***	0.91±0.08***
Autumn	-0.04±0.06	0.21±0.06***	0.08±0.04	0.41±0.08**	0.53±0.09***	0.46±0.07***

Spatial interpolation of the *Tm* trend magnitude on a seasonal scale in the study area is shown in Fig 3. In addition to the evident warming, aclear spatial pattern was observed during the last three decades.

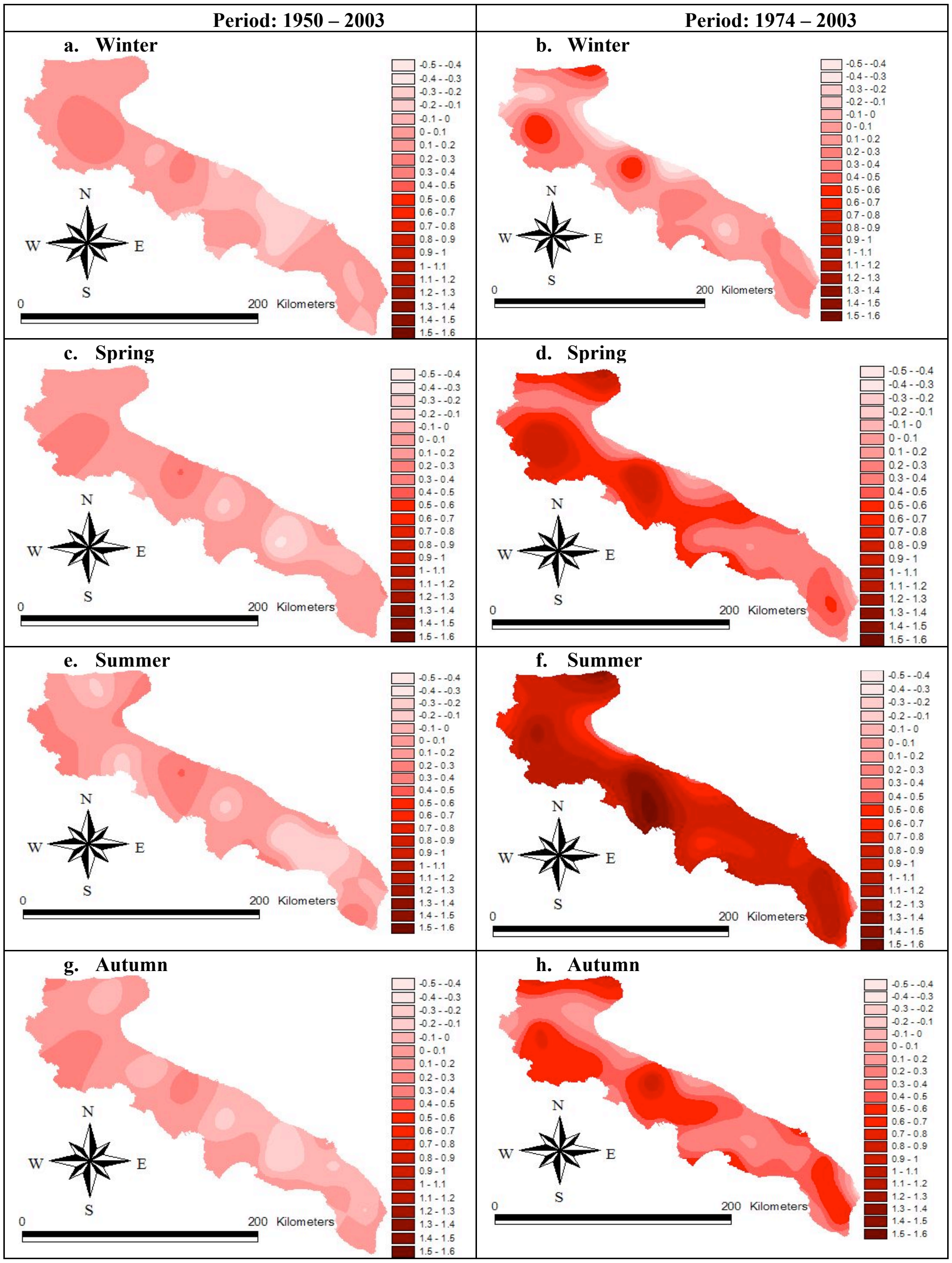


Fig. 3. Spatial interpolation of the trend in °C/decade on a seasonal scale: case of the mean temperature

Trends in the study area were not linear, as demonstrated in Table II by the average determination coefficient (R^2) of the simple linear regression model, whereas in the last three decades $R^2$was quiet high especially for *Tmin* in summer season.

TABLE II

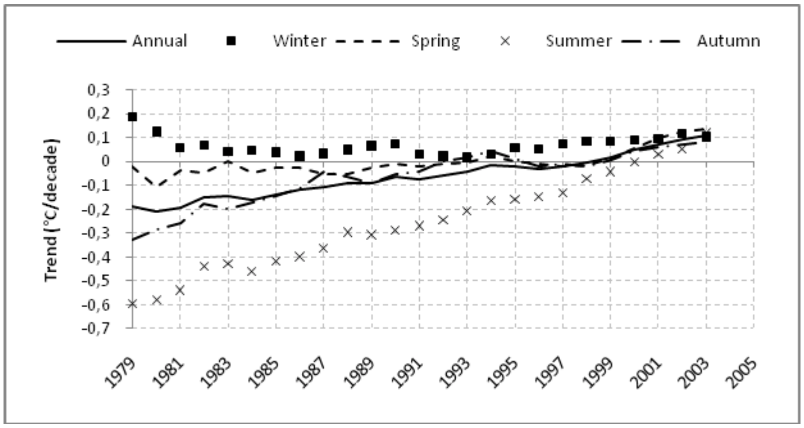
TEMPERATURE AVERAGE DETERMINATION COEFFICIENT

	1950 - 2003			1974 – 2003		
	Tmax	**Tmin**	**Tm**	**Tmax**	**Tmin**	**Tm**
Annual	0.10±0.03	0.23±0.06	0.10±0.03	0.29±0.05	0.37±0.07	0.34±0.06
Winter	0.05±0.02	0.13±0.04	0.06±0.02	0.11±0.03	0.09±0.03	0.09±0.03
Spring	0.06±0.02	0.18±0.05	0.07±0.02	0.14±0.03	0.16±0.04	0.16±0.03
Summer	0.09±0.03	0.17±0.04	0.07±0.02	0.34±0.04	0.45±0.05	0.41±0.04
Autumn	0.06±0.02	0.11±0.04	0.04±0.01	0.13±0.03	0.19±0.04	0.15±0.03

Since the trend was generally non-linear, the trend significance and magnitude thus depended on the selected period of analysis. This result was previously demonstrated by considering only two periods: the overall period (1950-2003) and the last three decades (1974-2003).

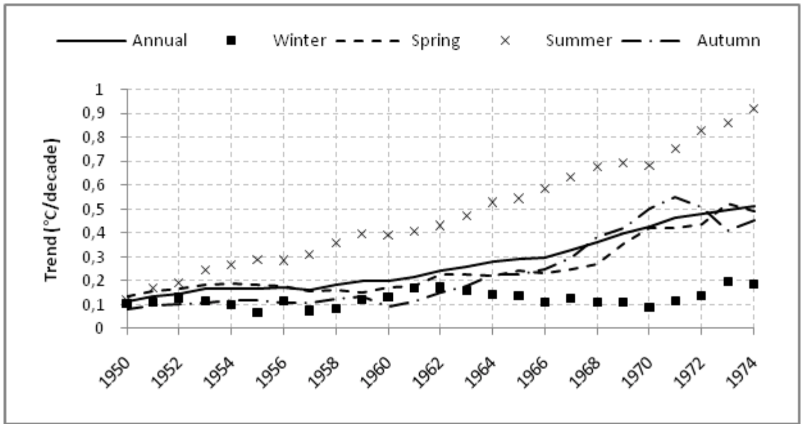
To demonstrate effectively the trend dependency on the selected period, the progressive trend analysis was performed on the average time series and the results are shown in Fig. 4 and 5. These results showed that the observed positive trend of Tm in the study area (Fig. 4a) was determined by the last 5 years (1998 to 2003). Furthermore, the warming is generally due to *Tmin* (Fig. 5). In fact, the *Tmin* trend was generally positive with some exception in summer and autumn seasons (Fig. 5c, d).

a- Direct time direction



In this figure, 1979 represents the period 1950-1979,…, and 2003 represents the period 1950-2003.

b- Opposite of the time direction



In this figure, 1974 represents the period 1974-2003,…, and 1950 represents the period 1950-2003.

Fig 4 Progressive trend analysis of the average mean temperature

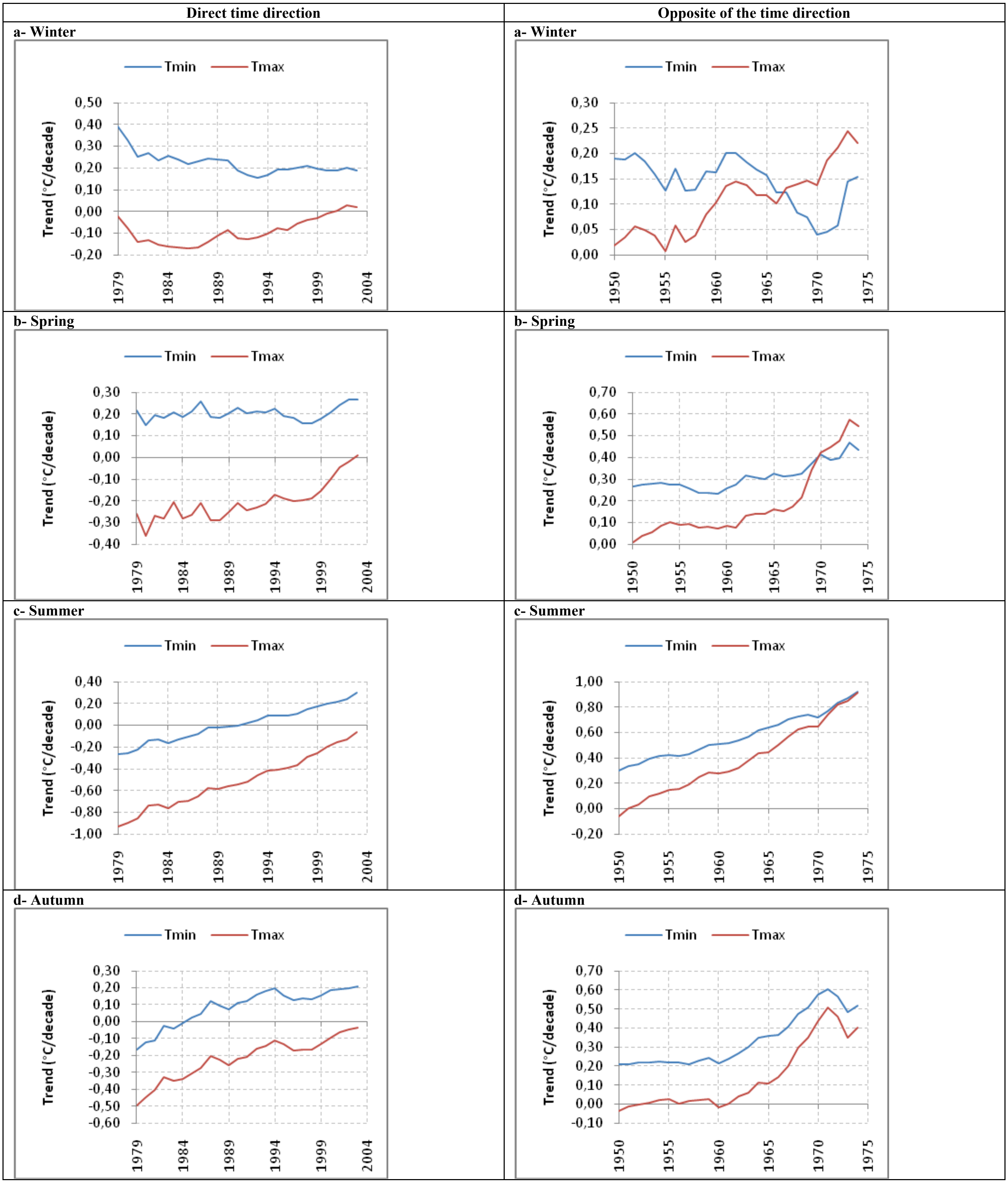


Fig. 5 Progressive trend analysis of the average maximum and minimum temperature (*Tmax ;Tmin*).

Reference evapotranspiration followed approximately the same behavior of the mean temperature and this is due to the high correlation between them. Thus, a significant acceleration of the atmospheric evaporative demand was observed especially during the last three decades, in particular in summer and spring seasons (Fig. 6). Trend of *ETo* in summer remains significant for most of the stations (about 87%)even at 99% confidence level.

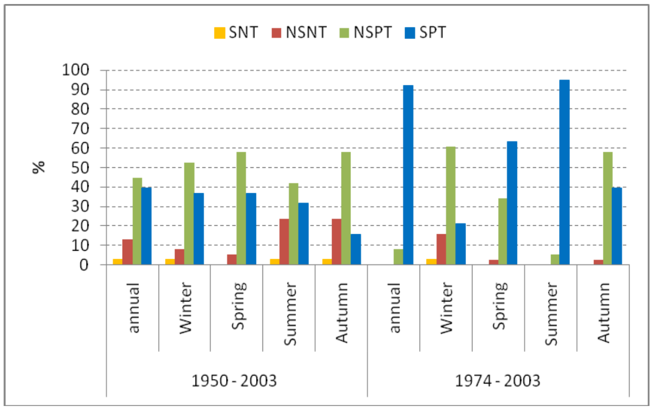


Fig. 6 Trend significance at 95% confidence level of the reference evapotranspiration

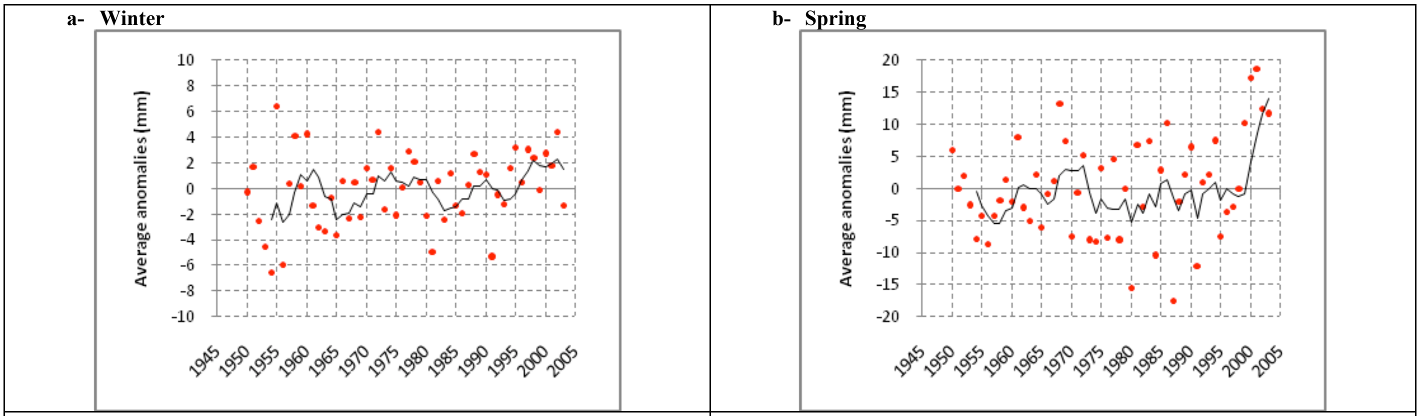
Table III gives a summary of the average trend magnitudes in the study area, expressed in mm/decade. The same as for temperature, trends were not linear and, therefore, they depended on the selected period of analysis as demonstrated in Fig. 7. The solid black lines represent the 5-year moving average curves of the series and results were presented in terms of anomalies with respect to the 1961-1990 mean.

TABLE III

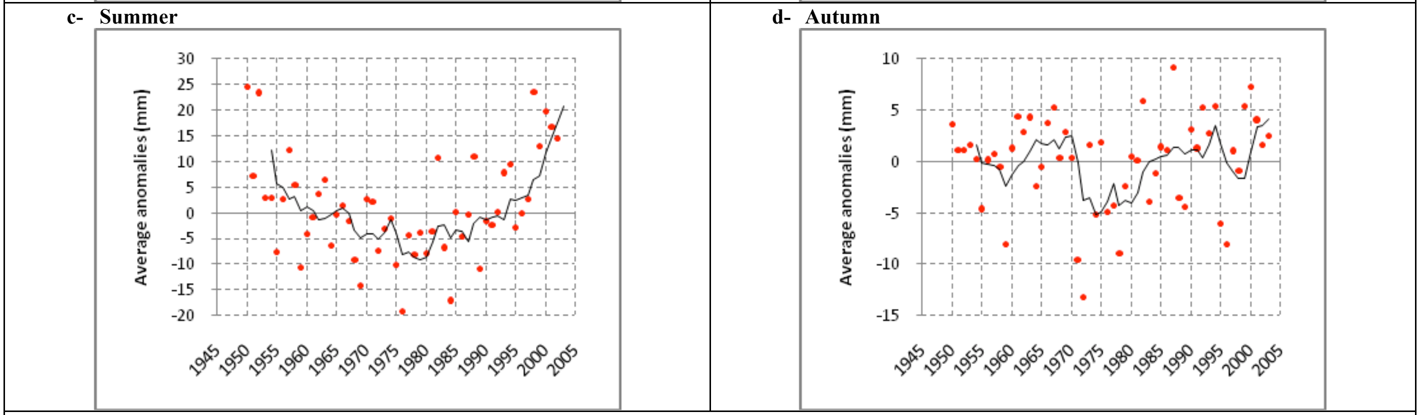
TEMPERATURE AVERAGE DETERMINATION COEFFICIENT

(Significance levels: *** <1% ;** 1–5% ; * 5 –10%)

Average trend (mm/decade)					
(mm/decade)	**Annual**	**Winter**	**Spring**	**Summer**	**Autumn**
1950-2003	3.5±1.2	0.4±0.2**	1.3±0.4*	1.4±0.0	0.3±0.2
1974-2003	18.6±2.2***	0.8±0.3	4.9±0.7**	10.8±1.0***	2.1±0.4**


a- Winter

b- Spring


c- Summer

d- Autumn

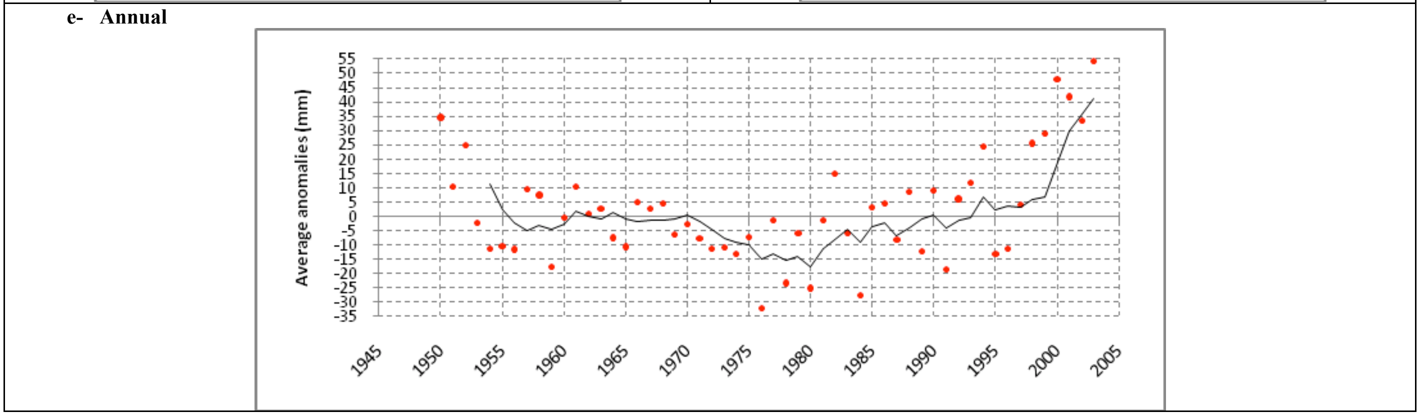

e- Annual

Fig. 7 Anomalies of *ETo* with respect to the 1961-1990 mean

Referring to the overall period, the impact of the warming process in terms of magnitude of *ETo*was not important. However, the impact was more evident during the last three decades, especially in summer season and on annual scale.

Considering the similarity between the *Tm* and *ETo*behaviors, the period between 1950 and 1980 had a cooling effect especially on annual scale (Fig. 7e) and in summer season (Fig. 7c).

V.CONCLUSION

The present study confirms that the warming was more pronounced for the minimum temperature and the 1970s presented a break period from which the increasing rate has taken place. This is in line with the results obtained by Vos*et al.,* (2005), Brunetti*et al*., (2006),Trenberth*et al.,(2007) and* Polemio and Casarano(2008). Nevertheless, trend magnitude in the study area during the last three decades is approximately double of the global trend magnitude found by Trenberth*et al.,* (2007) in analysis of the period 1979-2004.

The notable seasonal warming that was observed starting from the mid-1970s was significant at least at 90% confidence level. In particular, trend in summer was highly significant (<1%) with a trend magnitude of 0.91±0.08 °C/decade. The average annual trend was 0.52±0.07 °C/decade, whereas the period before the end of 1980 showed a cooling effect.

Furthermore, the last five years (1998 to 2003) had a major influence on the trend of the overall period. If they are not considered, unimportant warming occurs only in winter but the trend is negative for the other seasons and also on annual scale (Fig. 4 (a)).

The impact on reference evapotranspiration is quiet important only in the last three decades, in particular, it is highly significant (<1%) in summer (10.8±1.0 mm/decade) and also on annual scale (18.6±2.2 mm/decade).

REFERENCES

[1] Blaney H. F.,Criddle W. D. (1950). Determining water requirements in irrigated area from climatological irrigation Data. US Department of Agriculture, Soil Conservation Service, Technical paper No. 96, 48 PP.

[2] Barnett T. P., Hasselmann K., Chelliah M. et al.,(1999). Detection and attribution of recent climate change: A status report. Bulletin of the AmericaMeteorological Society, V.80: 2631–2660

[3] Bartolini G.,Morabito M., Crisci A.et al., (2008). Recent trend in Tuscany (Italy) summer temperature and indices of extremes. International journal of climatology, V.28: 1751-1760.

[4] Brunetti M., Maugeri M., Monti F., Nanni T., (2006). Temperature and precipitation variability in Italy in the last two centuries from homogenized instrumental time series. Journal of climatology, V.26 (3): 345-381.

[5] Chen Z.,Grasby S. E. (2009). Impact of decadal and century-scale oscillations on hydroclimate trend analyses. Journal of hydrology, V.365 (1-2): 122-133.

[6] Chen H.,Guo S.,Xu C Y., Singh V. P. (2007). Historical temporal trends of hydro-climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin.Journal of hydrology, V.344 (3-4): 171-184.

[7] Coppola E.,Giorgi F. (2010). An assessment of temperature and precipitation change projections over Italy from recent global and regional climate model simulations. Journal of climatology, V.30 (1), 11-32.

[8] Domroes M., El-Tantawi A., (2005). Recent temporal and spatial temperature changes in Egypt. International journal of climatology, V.25: 51-63.

[9] Edmonds I. (2009). Hot air balloon engine.Renewable Energy, V.34 (4): 100–1105.

[10] Forster P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[11] Giorgi F. (2006). Climate change Hot-spots. Geophysical research letters, 33: L08707, 4 PP.

[12] Hamed K. H. (2008). Trend detection in hydrologic data: the Mann–Kendall trend test under the scaling hypothesis. Journal of hydrology, V.349 (3–4): 350–363.

[13] Hamed K. H. (2009). Exact distribution of the Mann–Kendall trend test statistic for persistent data. Journal of hydrology, V.365 (1-2): 86-94.

[14] Hasselmann K (1997). Multi-pattern fingerprint method for detection and attribution of climate change.Climatedynamics, V.13: 601–612

[15] Hegerl G. C., Storch V. H., Hasselmann K. et al., (1996). Detecting greenhouse-gas-induced climate change with an optimal fingerprint method. Climate, V.9: 2281–2306

[16] Hegerl G. C., Hasselmann K., Cubasch U. et al., (1997). Multi-fingerprint detection and attribution of greenhouse-gas and aerosol-forced climate change. Climate Dynamics, V.13: 613–634.

[17] Hegerl G. C., Stott P., Allen M. et al., (2000). Optimal detection and attribution of climate change: Sensitivity of results to climate model differences. Climate dynamics, V.16: 737–754.

[18] Le Treut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson and M. Prather, 2007: Historical Overview of Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[19] LiuQ., Yang Z., Cui B., (2008). Spatial and temporal variability of annual precipitation during 1961–2006 in Yellow River Basin, China.Journal of hydrology, V.361 (3-4): 330-338.

[20] Moderres R., Vicente de Paulo Rodrigues da Silva. (2007). Rainfall trends in arid and semi-arid regions of Iran. Journal of Arid Environments, V.70 (2): 344-355.

[21] Panda D. K., Mishra A., Jena S. K., James B. K., Kumar A. (2007). The influence of drought and anthropogenic effects on groundwater levels in Orissa, India. Journal of hydrology, V.343 (3-4): 140-153.

[22] Polemio M.,Casarano D. (2008). Climate change, drought and groundwater availability in southern Italy. Geological society, London, Special publications, V.288: 39-51.

[23] Santer B. D., Boyle J. S., Parker D.E. (1996a). Reply to: Human effect on global climate?.Nature 384, 524

[24] Santer B. D., Taylor K. E.,Wigley T. M. L.et al., (1996c): A search for human influences on the thermal structure of the atmosphere. Nature, V.382 : 39–46

[25] Santer B., D., Taylor K. E., Penner J. E. et al.,(1995). Towards the detection and attribution of an anthropogenic effect on climate. Climate dynamics, V.12: 77–100

[26] Santer B. D.,Wigley T. M. L., Barnett T. P.,Anyamba E., (1996b). Detection of climate change, and attribution of causes. In: Climate Change 1995: The Science of Climate Change [Houghton, J.T., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA: 407–443.

[27] Smadi Mahmoud M. (2006). Observed Abrupt Changes in Minimum and Maximum Temperatures in Jordan in the 20th Century. American Journal of Environmental Sciences, V.2 (3): 114-120.

[28] Stott P. A., Tett S. F. B., Jones G. S. et al., (2000). External control of 20th century temperature by natural and anthropogenic forcings.Science, V.290 :2133–2137.

[29] Tayanç M., Im U., Dogruel M., Karaca M., (2009). Climate change in Turkey for the last half century. Climate change, V.94: 483-502.

[30] Tett S. F. B., Stott P. A.Allen M. R.et al., (1999). Causes of twentieth century temperature change. Nature, V.399: 569–572

[31] Toros H. (2011). Spatio-temporal variation of daily extreme temperatures over Turkey.International journal of climatology. DOI: 10.1002/joc.2325.

[32] Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai, 2007: Observations: Surface and Atmospheric Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[33] Vose R. S.,Easterling D. R., Gleason B., (2005). Maximum and minimum temperature trends for the globe: An update through 2004. Geophys. Res. Lett., 32, L23822, doi: 10.1029/2004GL024379.Yu P-S; Yang T-C; Chou C-C (2002). Effects of climate change on evapotranspiration from paddy fields in southern Taiwan. Climatechange, V.54: 165-179.

[34] XuZ.,Liu Z., Fu G., Chen Y., (2010). Trends of major hydroclimatic variables in the Tarim River basin during the past 50 years. Journal of Arid Environments, V.74 (2): 256-267.

[35] Yu P-S., Yang T-C., Chou C-C. (2002). Effects of climate change on evapotranspiration from paddy fields in southern Taiwan. Climate change, V.54: 165-179.