ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/281435502

Revisiting the Priestley-Taylor method for the assessment of reference crop evapotranspiration in Italy

Article in Italian Journal of Agrometeorology · June 2015

CITATIONS
20

READS
1,928

5 authors, including:

Vassilis George Aschonitis
Hellenic Agricultural Organization - Demeter
116 PUBLICATIONS 1,503 CITATIONS

SEE PROFILE

Kleoniki Demertzi
Greek Biotope/Wetland Centre
21 PUBLICATIONS 155 CITATIONS

SEE PROFILE

D. M. Papamichail
Aristotle University of Thessaloniki
73 PUBLICATIONS 1,381 CITATIONS

SEE PROFILE

Nicolò Colombani
Università Politecnica delle Marche
236 PUBLICATIONS 3,099 CITATIONS

SEE PROFILE

All content following this page was uploaded by Nicolò Colombani on 02 September 2015.

The user has requested enhancement of the downloaded file.

Revisiting the Priestley-Taylor method for the assessment of reference crop evapotranspiration in Italy

Vassilis Aschonitis[1,2,], Kleoniki Demertzi[1], Dimitris Papamichail[1], Nicolò Colombani[3], Micòl Mastrocicco[4]*

Abstract: *Aim of the study is to test the Priestley-Taylor (P-T) method for the assessment of reference crop evapotranspiration ET_o in the Italian territory using as a base the ASCE standardized Penman-Monteith method (ASCE). Monthly averages of daily mean climatic data which cover the period 1950-2000 were used in this study. Analysis was performed on the spatial variability of the seasonal difference between ASCE and P-T method using the typical value 1.26 for the advection coefficient a_{pt}. The results showed that the surface coverage of the Italian territory, with acceptable ±10% difference using a_{pt}=1.26, was 24.9% in Spring, 41.4% in Summer, 34.3% in Autumn and 11.9% in Winter. The recalculation of a_{pt} using the ASCE method showed high spatial and temporal variability of the coefficient. Regression analysis showed that more than 90% of the spatial variability of the seasonal a_{pt} is explained by the spatial variability of vapour pressure deficit DE (positive correlation). The rate of a_{pt} variation per unit DE was found significantly different between seasons and it was negatively correlated to net solar radiation R_n and consequently temperature. The general trends of the a_{pt} coefficient led to the conclusion that colder-drier environments due to low net radiation and high vapour pressure deficit tend to increase its values.*
Keywords: *Priestley-Taylor, ASCE standardized Penman-Monteith, advection coefficient, GIS, Italy.*

Riassunto: *Lo scopo dello studio è di verificare il metodo di Priestley-Taylor (P-T) per la valutazione dell'evapotraspirazione di riferimento nel territorio Italiano utilizzando come base l'equazione standardizzata ASCE di Penman-Monteith (ASCE). In questo studio sono state utilizzate le medie mensili derivate dai dati climatici medi giornalieri del periodo 1950-2000. L'analisi è stata eseguita sulla variazione spaziale della differenza stagionale tra ASCE e P-T utilizzando il valore tipico 1.26 per il coefficiente di advezione a_{pt}. La copertura della superficie del territorio Italiano, con una differenza accettabile di ± 10%, utilizzando a_{pt} = 1.26, è stata di 24,9% in primavera, 41,4% in estate, 34,3% in autunno e 11,9% in inverno. Il calcolo di a_{pt} è stato effettuato utilizzando il metodo ASCE ed i risultati hanno mostrato un'elevata variazione spaziale e temporale del coefficiente. L'analisi di regressione ha mostrato che oltre il 90% della variabilità spaziale dell'a_{pt} stagionale è spiegata dalla variabilità spaziale del deficit di pressione di vapore DE (correlazione positiva). Il tasso di a_{pt} per unità di DE (pendenza della retta di regressione) è stato trovato significativamente differente tra le stagioni ed è stato correlato negativamente alla radiazione solare netta e di conseguenza alla temperatura. Le tendenze generali riscontrate per il coefficiente a_{pt} hanno portato alla conclusione che gli ambienti più freddi e asciutti tendono ad aumentarne il valore, in quanto caratterizzati da una bassa radiazione netta e una pressione di vapore alta.*
Parole chiave: *Priestley-Taylor, ASCE Penman-Monteith standardizzato, coefficiente di advezione, GIS, Italia.*

1. INTRODUCTION

The reference evapotranspiration ET_o is defined as the sum of evaporation from soil and transpiration from a reference crop selected for comparative purposes (grass or alfalfa), with adequate fetch to make edge effect unimportant. It is used for standardizing the hydro-climatic regime of a region based on the reference crop (Katerji and Rana, 2011). ET_o is an essential parameter for water balance estimations and irrigation planning of crops (Rana and Katerji, 2009; Zottele *et al.*, 2010; Lazzara and Rana, 2010; Mastrocicco *et al.*, 2010; Tabari, 2010; Diamanto-poulou *et al.*, 2011; Aschonitis *et al.*, 2012). The ASCE-standardized Penman-Monteith method has been proposed by the ASCE-EWRI Task Committee (Allen *et al.*, 2005) as an accurate operational method for ET_o estimations and it is an update of the FAO-56 Penman-Monteith (Allen *et al.*, 1998). The update concerns improvements on hourly ET_o estimations for two reference crops. However, several researchers criticized this method for several faults in the basic biophysical hypothesis of applicability (Douglas *et al.*, 2009; Katerij and Rana, 2011; 2014). In cases where the climatic parameters of wind speed and humidity are missing an alternative solution to estimate ET_o is the use of Priestley-Taylor method (P-T) (Priestley and Taylor, 1972).

* Corresponding author's e-mail: schvls@unife.it
[1] Department of Hydraulics, Soil Science and Agricultural Engineering, Aristotle University of Thessaloniki, Greece.[1]
[2] Department of Life Sciences and Biotechnology, University of Ferrara, Italy.
[3] Department of Earth Sciences, Sapienza University of Rome, Italy.
[4] Department of Physics and Earth Sciences, University of Ferrara, Italy.
Received 06 October 2014, accepted 03 February 2015.

The Priestley-Taylor method requires only temperature and radiation data and it is considered as one of the most precise among the simplified methods with reduced parameters (Xu and Singh, 1998; Sumner and Jacobs, 2005). The method includes a correction factor known as advection coefficient a_{pt}. The value of the factor a_{pt} is usually considered equal to 1.26 (Priestley and Taylor, 1972) generally ranging between 1.08 and 1.34 for agricultural lands (Tateishi and Ahn, 1996; Xu *et al.*, 2013). Studies for various climatic conditions have shown that the a_{pt} factor presents significant spatial and temporal variability (Castellvi *et al.*, 2001; Xu and Singh, 2002; Moges *et al.*, 2003; Pereira, 2004). Weiß and Menzel (2008) used the value 1.26 for wet and the value 1.75 for dry climatic conditions in an attempt to calculate the evapotranspiration at a global scale. The value a_{pt}=1.26 has been verified experimentally for bare irrigated soil (Eichinger *et al.*, 1996). Theoretical simulations for the case of the reference crop in saturated soil have verified the a_{pt}=1.26 only for the case of non or restricted advection effects (Lhomme, 1997a; McMahon *et al.*, 2013). Low values of the advection coefficient (~1.14) have been reported by Singh and Irmak (2011) for Nebraska (USA), while high values ranging between 1.82 and 2.14 have been reported for cold-dry lands of Iran (Tabari and Talaee, 2011).

Although, the typical P-T method (for a_{pt}=1.26) has been used to estimate irrigation water requirements at different spatial scales and climatic environments (Morari and Giardini, 2001; Heinemann *et al.*, 2002, Utset *et al.*, 2004), the observed high spatio-temporal variability of a_{pt} coefficient suggests a significant restriction in the applicability of a unique a_{pt} value for such purposes. Analysis on the operational limits of the typical P-T method was made by McAneney and Itier (1996) who showed that the typical P-T method provides satisfactory results in more humid regions where the daytime mean saturation deficit is smaller than 10 g m^{-3}. The authors concluded that the use of more data-demanding methods (e.g. Penman-Monteith P-M) under these conditions will not be rewarded with a better estimate, while significant limitations of the typical P-T method are expected in semi-arid and arid environments. Analysis on water use and irrigation options for maize under Mediterranean semi-arid conditions (North Spain) showed that the typical P-T method provided significantly smaller ET_o estimations from P-M but non statistically significant differences were found between their respective modeling results derived by irrigation decision-making scenarios (Utset *et al.*, 2004).

The aim of this study is a) to estimate the differences of ET_o between the original Priestley-Taylor method (P-T) (with a_{pt}=1.26) and the ASCE standardized Penman-Monteith method for short reference crop in the Italian territory and b) to recalibrate a_{pt} coefficient for estimations of reference crop using as a base the ASCE method. Italy was considered an optimum candidate to test the Priestley-Taylor method since it is located between the European and the African plates displaying seven different climatic types of temperate zones (i.e. Temperate mountain, Warm Temperate sub-continental, Temperate sub-oceanic, Mediterranean mountain, Mediterranean sub-oceanic, Mediterranean sub-continental and Mediterranean sub-tropical) (Costantini *et al.*, 2009). The analysis was performed using gridded mean monthly averages of daily mean climatic data which cover the period 1950-2000.

2. EFFECTS OF SPACE, TIME STEP AND OTHER ASSUMPTIONS IN ET_O ESTIMATIONS

ET_o is an instantaneous phenomenon, as the actual crop evapotranspiration, and it is regulated by the respective interactions of the reference crop with the climatic conditions (Baldocchi *et al*., 2001). The description of ET_o using mathematical expressions is based on averaged climatic variables based on specific time intervals and their calibration and validation are usually performed using experimental data by weighing lysimeters (Hargreaves, 1989; Rana *et al*., 1994; Hunsaker *et al*., 2002; Garcia *et al*., 2004; Walter *et al.*, 2004). Calculations based on hourly step are considered the most suitable to describe the bio-physical background of ET_o based on measurements from agro-meteorological stations located to well-watered, flat, homogeneous and large areas covered by reference grass (Rana and Katerji, 2009). Hourly step ET_o estimations can not be performed for the case of watershed, country-scale or larger territories over a long period of time due to data and computational power limitations. For this reason daily or monthly steps are adopted in order to overcome such problems but with an analogous loss of precision. The loss of precision due to the use of larger time step intervals and other assumptions which accompany the methods of ET_o are summarized in the following:

- Extreme peaks and lows of climatic variables captured in hourly step are smoothed when larger time steps are used (Katerji and Rana, 2011; 2014; Sun *et al*., 2011).
- The aerodynamic and canopy resistance of the reference crop are usually considered constant while in reality they show diurnal/seasonal variations which regulate eddy covariance of heat and vapour (Rana and Katerji, 1998; Katerji *et al*., 2011).
- The transpiration rate of the reference crop (e.g. grass or alfa-alfa) and the evaporation from soil depend on physical soil properties. The amount of available water under well-watered conditions (field capacity) and the respective water potential which regulates water uptake

by plants and evaporation from soil differs significantly between different textured soils (Ascho-nitis *et al.*, 2013a,b). Ritchie (1972) proposed a modelling approach which includes the effects of soil but it is only applied in the calculation of real crop evapotranspiration and not of ET_o (Knisel and Davis, 2000).

- The theoretical concept of ET_o assumes full cover soil. Total coverage with 12 cm height grass is usually assumed to be succeeded for leaf area index (*LAI*) values above 3. Further increase of *LAI* corresponds to full coverage but also increases transpiration rates (Aschonitis *et al.*, 2014) while evaporation from soil reaches an asymptotic low value. *LAI* values are usually taken into account in the case of real crop evapotranspiration (Rithcie, 1972) but not in the calculations of ET_o.
- The albedo of the reference crop is usually considered constant while in reality may show a diurnal/seasonal variation due to variability in chlorophyll content and leaves orientation. This assumption affects the net radiation factor of ET_o (Fritschen, 1967).
- Stomatal conductance is considered constant while in reality it shows diurnal/seasonal variation (Jarvis, 1976; Rana *et al.*, 2012; Bonan et *al.*, 2014).
- ET_o methods assume flat topographic conditions. Topographic variability of the surrounding environment and sloppy topographies affect net radiation and eddy covariance of heat and vapour (Rana *et al.*, 2011).
- For site-specific ET_o estimations, the interactions between adjacent sites are suppressed based on the assumption of homogeneous large territories. In reality the climatic conditions of a site are the result of the interaction between its climatic environment with the ones of the adjacent territories.

The above assumptions suppress significantly the effects of the factors related to plant, soil and topography, converting ET_o to a more climatic rather than a bioclimatic parameter. These assumptions are prerequisite when mean ET_o estimations have to be performed for large territories over a long period of time (Droogers and Allen, 2002; Weiß and Menzel, 2008; Zomer *et al.*, 2008; Demertzi *et al.*, 2013). The above assumptions are used in this study for the description of the mean ET_o conditions in the Italian territory for the period 1950-2000.

3. METHODS AND DATA

3.1. The ASCE standardized Penman-Monteith

The calculation of ASCE method in daily step is performed by the following equation (Allen *et al.*, 2005):

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + \dfrac{\gamma u_2(e_s - e_a)C_n}{\left(T_{\mathrm{mean}} + 273.16\right)}}{\Delta + \gamma(1 + C_d u_2)} \tag{1}$$

where ET_o: the daily reference crop evapotranspiration (mm d^{-1}), R_n: the daily net radiation at the crop surface (MJ m^{-2} d^{-1}), u_2: the mean daily wind speed at 2 m height above the soil surface (m s^{-1}), T_{mean}: the mean daily air temperature (^{o}C), G: the daily soil heat flux density at the soil surface (MJ m^{-2} d^{-1}), e_s: the mean daily saturation vapour pressure (kPa), e_a: the mean daily actual vapour pressure (kPa), Δ: the slope of the saturation vapour pressure-temperature curve (kPa ^{o}C^{-1}), γ: the psychometric constant (kPa ^{o}C^{-1}), C_n and C_d: constants, which vary according to the time step and the reference crop type and describe the bulk surface resistance and aerodynamic roughness. The coeffi-cient 0.408 was derived by $1/\lambda$ where λ: is the latent heat of vaporization equal to 2.45 MJ kg^{-1}. The short reference crop corresponds to clipped grass of 12 cm height and surface resistance of 70 s m^{-1} where the constants C_n and C_d have the values 900 and 0.34, respectively (equivalent to FAO-56) for daily step calculations. The tall reference crop corresponds to full cover alfalfa of 50 cm height and surface resistance of 45 s m^{-1}, where the constants C_n and C_d have the values 1600 and 0.38, respectively (Allen *et al.*, 2005). In this study, the ET_o is estimated using Eq. 1 for the commonly used short reference crop. The equations used for inter-calculations in ASCE are given in Allen *et al.* (2005) and Demertzi *et al.* (2013).

3.2. The Priestley-Taylor method

The calculation of P-T method in daily step is performed by the following equation (Priestley and Taylor, 1972):

$$ET_o = a_{pt}\frac{\Delta}{\lambda(\Delta + \gamma)}\left(R_n - G\right) \tag{2}$$

where ET_o: the daily potential evapotranspiration (mm d^{-1}), R_n: the net solar radiation (MJ m^{-2} d^{-1}), G: the daily soil heat flux density at the soil surface (MJ m^{-2} d^{-1}), Δ: the slope of the saturation vapour pressure-temperature curve (kPa ^{o}C^{-1}), γ: the psychometric constant (kPa ^{o}C^{-1}), λ: the latent heat of vaporization (MJ kg^{-1}) and a_{pt}: the Priestley-Taylor advection coefficient which is considered equal to 1.26. Eq. 1 strictly refers to the reference crop evapotranspiration (i.e. short or tall grass), whereas Eq. 2 has been used for the calculation of evapotranspiration under non-limiting water conditions of the reference crop, bare soil or open water surface (Priestley and Taylor, 1972). The P-T method has been used for estimations of the reference crop evapotranspiration in many works (McAneney and Itier, 1996; Morari and Giardini, 2001; Heinemann *et al.*, 2002; Utset *et al.*, 2004) and for this reason is tested as a reference crop evapotranspiration method versus the

ASCE method. The equations used for inter-calculations in P-T method were the same ones used for the respective parameters of ASCE method.

3.3. Analysis on ET_o % difference of P-T versus ASCE and reassessment of the a_{pt} coefficient for short reference crop

Analysis of the % difference in the ET_o estimations using the P-T method for a_{pt}=1.26 versus ASCE was performed for each month i according to the following:

$$\% D_i = 100 \times \frac{\left(ET_{o(P-T, apt=1.26)}\right)_i - \left(ET_{o(ASCE)}\right)_i}{\left(ET_{o(ASCE)}\right)_i} \quad (3)$$

Eq. 3 was also applied to assess the spatial variation of the % seasonal difference. The range of ±10% of the mean seasonal difference was used as a base to identify the regions where the original P-T method can be applied safely without significant deviations from the ASCE method. The value of ±10% was adopted taking into account the mean seasonal (3-months) ET_o of winter (coldest season) and summer (warmer season) estimated by ASCE for the whole Italian territory. The mean ET_o values for the period 1950-2000 were estimated at 80 mm for the winter and 399 mm for the summer season where the ±10% mean seasonal error corresponds to ±8 mm and ±39.9 mm, respectively. Converting the values of seasonal error to daily values, the daily acceptable error falls below 0.1 mm d^{-1} for winter and below 0.5 mm d^{-1} for summer.

The reassessment of the mean daily value of the Priestley-Taylor coefficient for each month for the Italian territory was performed according to the following:

$$a_{pt\,i} = \left(ET_{o(ASCE)}\right)_i \times \frac{\lambda(\Delta+\gamma)}{\Delta(R_n - G)} \quad (4)$$

The vapour pressure deficit and the wind speed do not participate in Eq. 2. For this reason a regression analysis was performed in order to describe the effects of these two parameters on the seasonal-spatial variability of the a_{pt} coefficient.

3.4. Data

Two different climatic databases were used in this study for the estimation of reference crop evapotranspiration. The first database is the one of Hijmans *et al.* (2005), which provides mean monthly values for the parameters of precipitation, maximum, minimum and mean temperature at 30 arc-sec (~1×1 km) spatial resolution. The original data are given directly as grids of mean monthly values for the period 1950-2000 (http://www.worldclim.org/). The first database also includes a corrected digital elevation model DEM at 30 arc-sec (~1×1 km) spatial resolution, based on GTOPO30 and SRTM models, which was used for the estimation of the atmospheric pressure.

The second database is the one of Sheffield *et al.* (2006), which provides mean monthly values of parameters such as wind speed at the height of 10 m above the ground surface, incoming short and long-wave solar radiation, specific humidity, precipitation and temperature for the period 1948-2006 at 0.5 degrees (~50×50 km) spatial resolution. The original data are given as netcdf files of monthly values for each year over the period 1948-2006 (http://hydrology.princeton.edu/data.pgf.php). These data were converted to grids of mean monthly values for the period 1950-2000.

The monthly averages of daily mean values of maximum, minimum and mean temperature were obtained from the first database, whereas wind speed, specific humidity and solar radiation were obtained from the second database. Actual vapour pressure was estimated from specific humidity and atmospheric pressure using the function Peixoto and Oort (1996) while wind speed was adjusted at 2 m (Allen *et al*., 2005; Demertzi *et al*., 2013). The resolution of the second database was converted from 0.5 degrees to 30 arc-sec in order to be consistent with the first one using the bilinear resampling interpolation technique. The conversion of the second database to finer resolution was based on the fact that the net radiation R_n and the vapour pressure deficit $DE=e_s-e_a$ in Eq. 1 and 2 are also functions of temperature and atmospheric pressure which are already at 30 arc-sec spatial resolution. All the grids were produced and elaborated using GIS (ArcGIS 9.3 software).

3.5. Statistical analysis

The software Sampling Design Tool, which has been developed by NOAA (National Oceanic and Atmospheric Administration of USA http://ccma.nos.noaa.gov/products/biogeography/sampling/), was used to create a shapefile of 10,000 randomly distributed positions inside the entire Italian territory. The mean seasonal values of the wind speed and vapour pressure deficit (which do not participate in the P-T method) and the respective mean seasonal a_{pt} values where extracted from these positions in order to be used in the following statistical procedures.

Simple-multiple linear regression analysis was performed in order to describe the effects of the aforementioned two parameters on the spatial and temporal variation of the seasonal a_{pt} coefficient. The ln(x+1) transformation was applied for all the variables to avoid normality deviations. Outliers were not removed due to the large number of data (there is no automatic procedure to remove outliers) and for this reason the Cochrane-Orcutt procedure (Cochrane and Orcutt, 1949) with optimization of the auto-regressive coefficient ρ was used during the multiple regression in order to compare serial correlation of the residuals. Autocorrelation of the residuals was tested using the Durbin-Watson test (Durbin and Watson 1950, 1951), which provides values between 0 and 4; the optimum value for no autocorrelation is equal to 2. The statistical analysis which is presented in this study was conducted using Statgraphics Centurion (StatPoint Technologies 2009).

4. RESULTS

4.1. Analysis of P-T performance versus ASCE using a_{pt}=*1.26* and reassessment of a_{pt} coefficient

Twelve rasters representing the mean monthly averages of daily mean ET_o of the Italian territory for the period 1950-2000 were produced using the ASCE and the P-T for a_{pt}=1.26 methods. The mean annual values of ET_o estimated by the two methods are given in Figg. 1a,b. The mean monthly values of ET_o and the % mean monthly difference (using Eq. 3) for the whole Italian territory are given in Fig. 2a, while the respective mean monthly recalculated a_{pt} coefficient (using Eq. 4) is given in Fig. 2b.

A first finding by the comparison of Figs. 1a and 1b is that the original P-T method reduces the difference in the estimations of ET_o between adjacent highland and lowland regions in comparison to ASCE. This response of the original P-T method is clearly evident for example between the lowland and the upland region around Etna Mountain (Sicily), in the region around the Punta la Marmora Mountain (Sardinia) and in the Alpine valleys. Since the value of a_{pt}=1.26 has been generally tested and calibrated for flat regions, significant deviation of P-T results from ASCE are expected in mountainous areas or transitional regions between mountains and plains due to the steep temperature changes along the altitudinal gradient. These changes lead to significant changes in vapour pressure deficit which affects the results of ASCE but not the results of the original P-T method.

Regions with extremely low values of ET_o (<500 mm/year) cover ~3.5% of the Italian territory and belong to mountain areas above 2500 m altitude. On the other hand extremely high values of ET_o (>1300 mm/year) cover ~1.5% of the Italian territory and belong to the lowlands of Catania (east Sicily) and the lowlands of the eastern coast of the Calabria region. Averaging the ASCE ET_o grid based on administrative regions gave similar results with those derived by Venezian-Scarascia *et al.* (2006).

According to Fig. 2a, the mean monthly ET_o for the whole Italian territory is overestimated using the P-T method for a_{pt}=1.26 during the period March-August (positive difference), while it is underestimated during the period September-February (negative difference) in comparison to ASCE. The maximum positive and

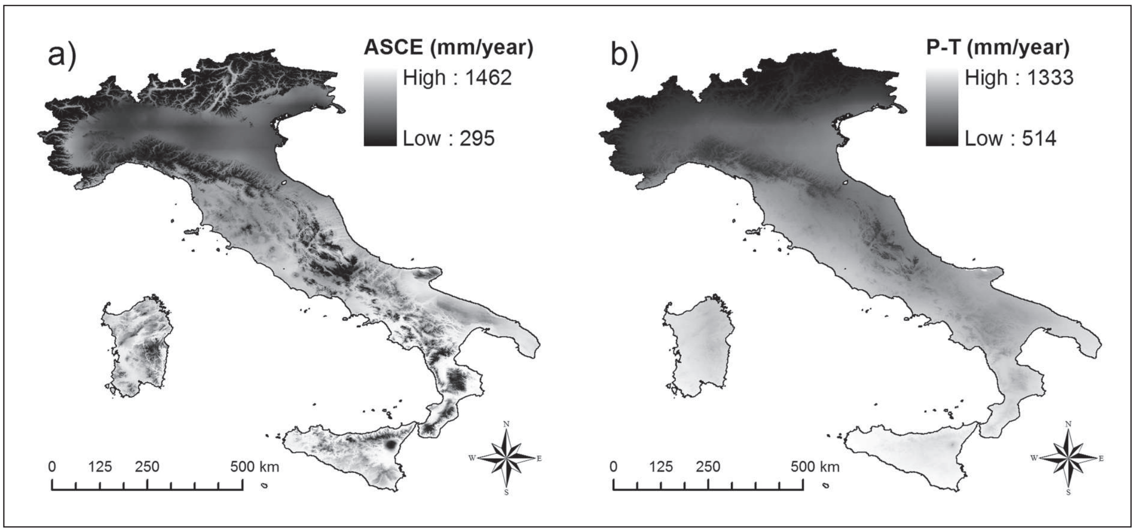

Fig. 1 - Mean annual ET_o for the period 1950-2000 estimated using a) the ASCE standardized Penman-Monteith method for short reference crop and b) the Priestley-Taylor method for a_{pt}=1.26.
Fig. 1 -ET_o media annuale per il periodo 1950-2000 stimata utilizzando a) il metodo ASCE Penman-Monteith standardizzato per la coltura di riferimento bassa e b) il metodo di Priestley-Taylor per a_{pt}=1.26.

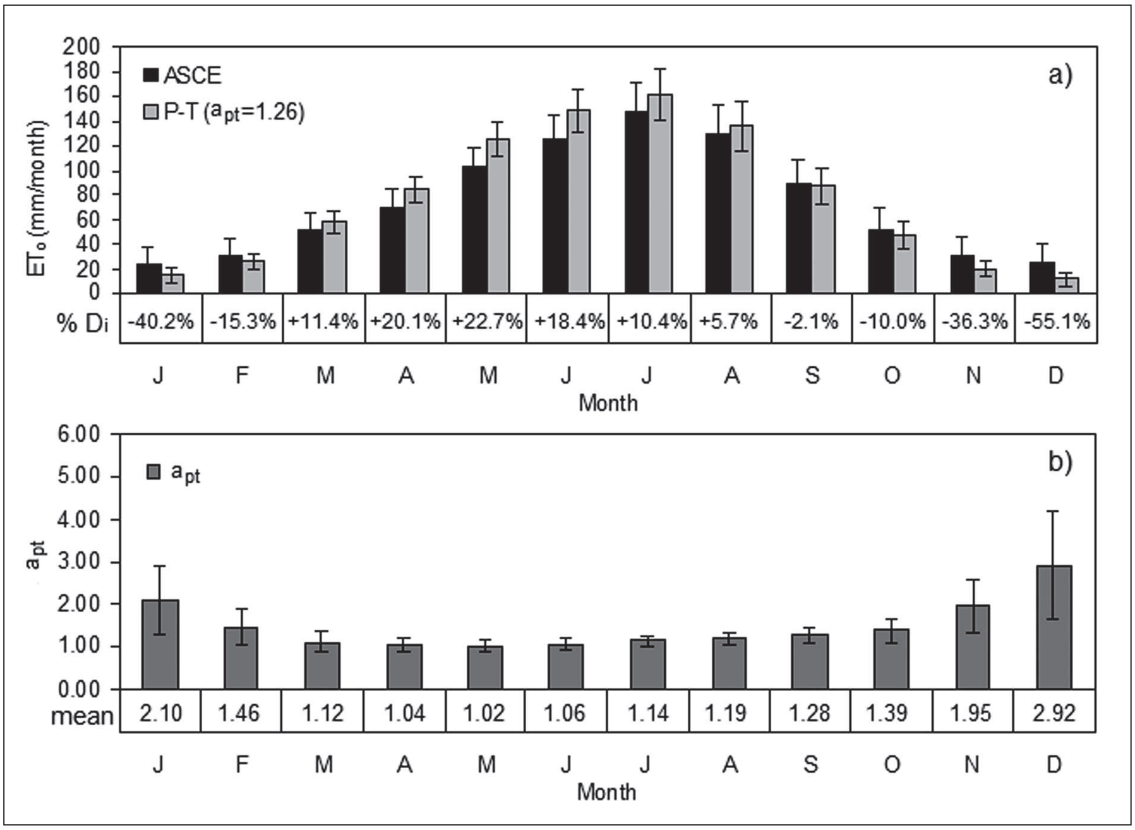

Fig. 2 - a) Mean monthly ET_o estimated using the ASCE method and the P-T method for a_{pt}=1.26, and % monthly difference (% D_i) of P-T versus ASCE, b) mean monthly values of the recalculated a_{pt} coefficient in the Italian territory for the period 1950-2000 (means and standard deviations in both figures are calculated for N=473694 pixels of 1×1 km surface coverage).
Fig. 2 - a) ET_o media mensile stimata utilizzando il metodo ASCE e il metodo PT originale per a_{pt}=1.26, e la differenza percentuale mensile (% D_i) tra P-T e ASCE, b) valori medi mensili del coefficiente a_{pt} ricalcolato nel territorio italiano per il periodo 1950-2000 (medie e deviazioni standard in entrambe le figure sono calcolate per N=473694 pixel di 1×1 km di superficie).

negative differences are observed in May (+22.7%) and December (-55.1%), respectively, while the minimum difference was observed in September (-2.1%) (Fig. 2a). Fig. 2b highlights the temporal variation of the recalculated a_{pt} coefficient which follows the same patterns observed by Castellvi et *al.* (2001) in stations located in regions of Spain which belong to continental and Mediterranean climatic zones. The variation of the a_{pt} coefficient presents a relative stability during the period March-September while steep changes are observed in the period October-February reaching maximum values in December.

The spatial variation of the mean seasonal % *D* of the original P-T method is given in Fig. 3. As indicated by the four seasonal maps of Fig. 3, acceptable ±10% *D* values correspond to a surface coverage equal to 24.9% in Spring, 41.4% in Summer, 34.3% in Autumn and 11.9% in Winter. These percentages can be re-adjusted to 29.7% in Spring, 49.4% in Summer, 40.9% in Autumn and 14.2% in Winter, if we consider only the regions below 1000 m altitude, which include more than 95% of the agricultural land and natural shrublands/grasslands (information was obtained by the land use grid GlobCover2009 database - http://due.esrin.esa.int/globcover/). The results of Fig. 3 show that the original P-T method can be considered an acceptable approach for ET_o estimations during the Spring and Summer seasons only for the lowland regions of Catania (east Sicily), Piemonte (north-west Italy) and central Italy. Acceptable results during Autumn and Winter are observed only in the regions of Pianura Padana (Po valley in northern Italy).

The spatial variations of the mean seasonal recalculated a_{pt} coefficients are given in Fig. 4, while frequency graphs of the estimated mean seasonal values of a_{pt} coefficient for the whole Italian territory are given in Fig. 5.

Since vapour pressure deficit $DE=e_s-e_a$ and wind speed u_2 are not included in P-T method, the results of Eq. 2 are expected to deviate significantly from those of Eq. 1 during the cold periods because the values of net radiation are significantly minimized and the final calculations of ET_o become very sensitive to DE and u_2 variability. This is verified by the results of Figs. 4 and 5 where the spatial variability of seasonal a_{pt} and the range of a_{pt} values during the warm season (i.e. Summer) is smaller in comparison to the cold season (i.e. Winter) which is significantly higher. During the cold season when mean monthly averages of daily mean ET_o fall below 0.5 mm d^{-1}, the differences between Eq. 1 and 2 are small in terms of mm per day but may be extremely high in terms of % D and a_{pt} since both parameters are ratios. For example, in Figs. 4d and 5d extremely high values of a_{pt} (above 4) are observed in the Alpine valleys during Winter. These values can be justified as follows:

a) these valleys presented the lower values of net radiation R_n because the presence of the surrounding mountains probably increases radiation blocking which is also enhanced by the diminished solar declination during Winter.

b) they also presented high diurnal variation of temperature (T_{max}-T_{min}) which increases significantly

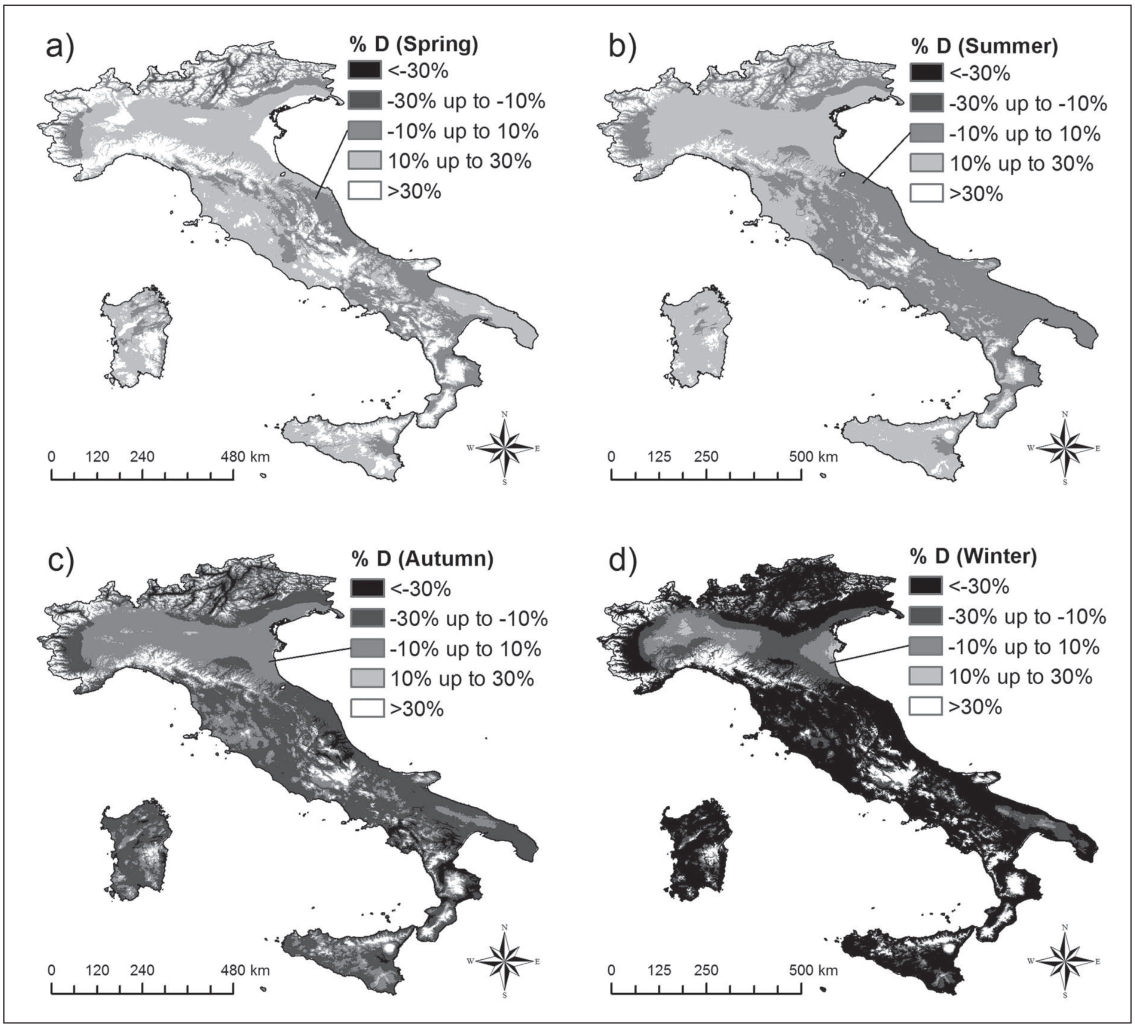

Fig. 3 - Mean seasonal difference % of the P-T method for a_{pt}=1.26 versus ASCE of the period 1950-2000 in the Italian territory a) Spring, b) Summer, c) Autumn and d) Winter.

Fig. 3 - Differeza media stagionale % del metodo P-T per a_{pt}=1.26 rispetto ad ASCE del periodo 1950-2000 nel territorio italiano in a) Primavera, b) Estate, c) Autunno e d) Inverno.

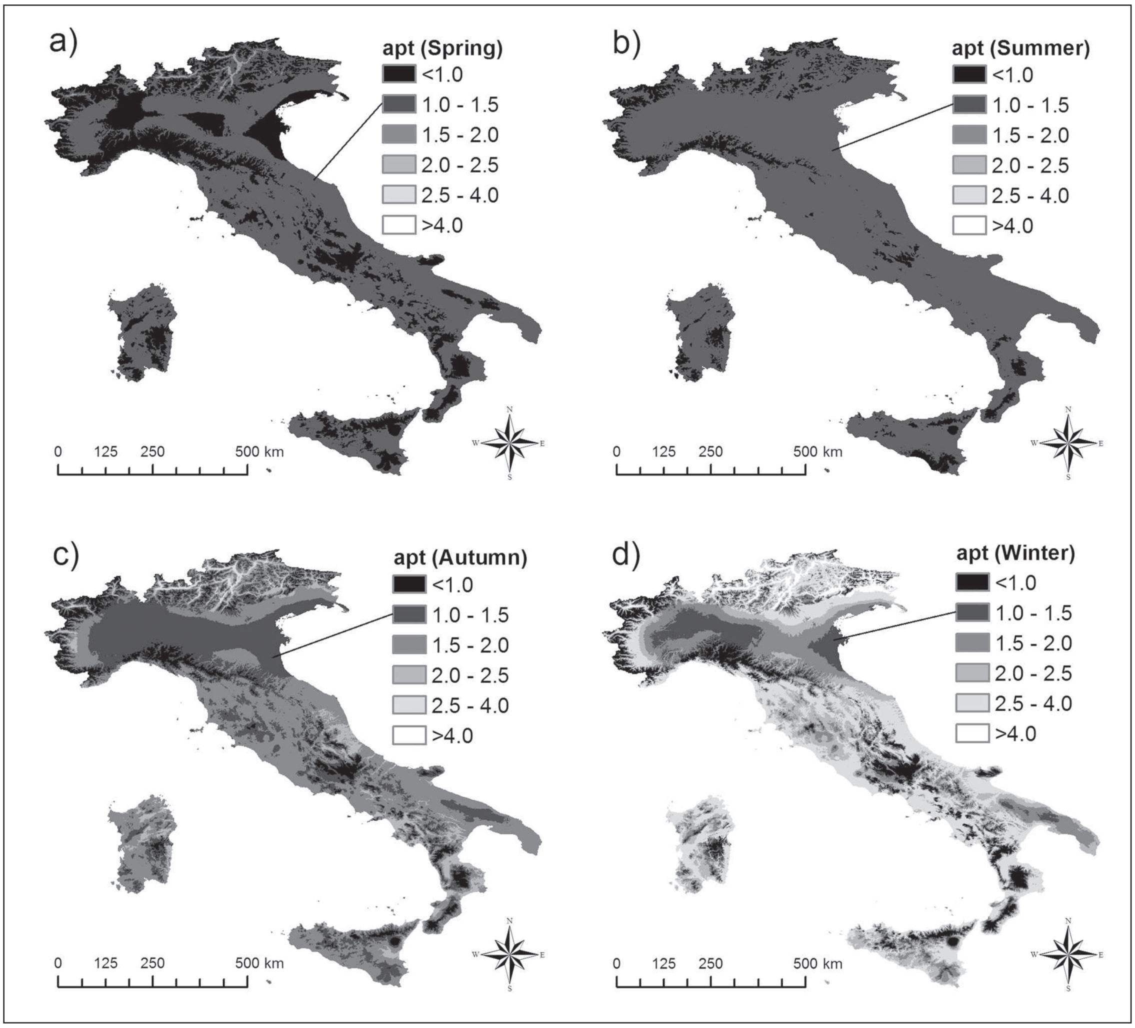

Fig. 4 - Mean seasonal recalculated values of a_{pt} coefficient of the period 1950-2000 in the Italian territory a) Spring, b) Summer, c) Autumn and d) Winter.
Fig. 4 - Valori medi stagionali ricalcolati del coefficiente a_{pt} per il periodo 1950-2000 nel territorio Italiano in a) Primavera, b) Estate, c) Autunno e d) Inverno.

the values of *DE*. This variation can be attributed to the fact these valleys are transitional regions between the massive mountain blocks of Apls and the extensive lowland plain of Pianura Padana. These specific territories create one of the most extensive and steepest altitudinal gradients in Europe where the transitional valleys are affected by both the cold mountains and the warmer lowlands.

Another finding is that the a_{pt} coefficient showed values <1 in high altitude areas where seasonal *DE* is lower than 0.2 kPa. This finding is opposite to the theoretical basis reported by many authors (Lhomme, 1997; Pereira, 2004) that the a_{pt} coefficient can not be <1. This concept is based on the theory of decoupling factor or similar approaches which consider that a_{pt} can be substituted by a function which includes the psychometric constant, the slope of the saturation vapour pressure-temperature curve, the aerodynamic resistance to heat-water vapour transfer through the surface layer and the bulk surface resistance to water vapour transfer. These functions have the special characteristic that provide minimum values equal to 1 even though other authors justify in detail the case of a_{pt}<1 (De Bruin, 1983; Flint and Childs, 1991; Sumner and Jacobs, 2005). Taking into account the forms of Eq.1 and 2, it is possible to occur a_{pt} <1 in regions with very small values of *DE*. In this case, the numerator of Eq. 1 approximates the numerator of Eq. 2 (without

a_{pt}), while its denominator is always higher than the denominator of Eq. 2 due to the inclusion of wind speed. Thus, small values of DE in combination with higher values of u_2 can reduce a_{pt} below 1 especially in low R_n conditions.

4.2. Factors affecting the seasonal and spatial variation of a_{pt} coefficient

A first step analysis was performed using multiple linear regression in order to test the effects of seasonal DE and u_2 on the seasonal a_{pt} variation while a second step analysis was performed using simple linear regression separately for each of the two parameters versus a_{pt}. The above combinations showed that the inclusion of u_2 in the multiple linear regression showed negligible improvement on the results (less than 1% improvement in R^2) while the vapour pressure deficit DE alone using the simple regression explained more than 90% of the spatial variation of seasonal a_{pt}. From the above combinations, the results of the regression between the seasonal a_{pt} and DE was selected to be presented in this study (Tab. 1 and Fig. 6). Using the models of Tab.1, the variation of a_{pt} versus DE for the four seasons was plotted and it is given in Fig. 7a. Both Figg. 6 and 7a indicate the positive correlation between DE and a_{pt} coefficient but Figs. 7a also shows how the rate of a_{pt} variation per unit DE is differentiated between seasons. Taking into account the results of Tab. 1 and Fig. 7a, the intercepts a of the seasonal models present small variability ranging between 0.5-0.6 and they do not follow the variation of other climatic variables. On the other hand, the slopes b of the seasonal models show a transitional seasonal increase following the order Summer<Spring<Autumn<Winter (Tab. 1 and Fig. 7a). Further analysis of the slope b using different climatic parameters showed that it is correlated to net radiation R_n (Fig. 7b) (b was also correlated to temperature but R_n provided better results). Figs. 7a,b show that the rate of a_{pt} variation per unit DE (slope b) is decreased when R_n is increased suggesting that drier (in terms of vapour pressure deficit) and colder conditions (sites with lower R_n are generally colder) lead to higher a_{pt} values. These findings verify the high observed a_{pt} values of Tabari and Talaee (2011) for the cold-dry lands of Iran. The strong effects of DE and R_n in the seasonal

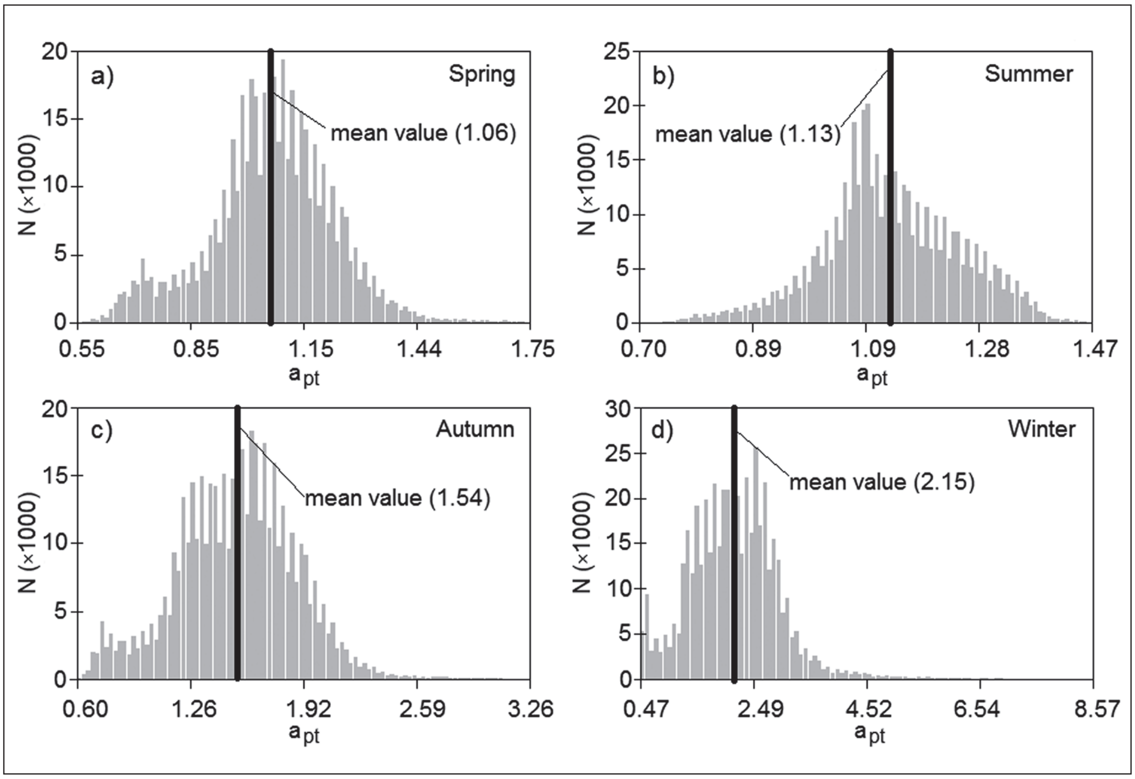

Fig. 5 - Frequency analysis of the mean seasonal recalculated values of a_{pt} coefficient of the period 1950-2000 in the Italian territory a) Spring, b) Summer, c) Autumn and d) Winter (Analysis on 473694 pixels of 1×1 km surface coverage).
Fig. 5 - Analisi di frequenza dei valori medi stagionali ricalcolati del coefficiente a_{pt} per il periodo 1950-2000 nel territorio Italiano in a) Primavera, b) Estate, c) Autunno e d) Inverno (Analisi su 473694 pixel di 1×1 km di superficie).

Season Coefficient	Spring Mean ± S.E.	Summer Mean ± S.E.	Autumn Mean ± S.E.	Winter Mean ± S.E.
a (intercept)	0.524*±0.0006‡	0.573*±0.0005	0.513*±0.0022	0.599*±0.0073
b (slope)	0.762*±0.0012	0.334*±0.0006	1.277*±0.0025	3.399*±0.0113
R^2 (adj.df)	0.976†	0.967†	0.963†	0.900†
Durbin-Watson test	2.350	2.104	2.364	2.557
Cochrane-Orcutt ρ	0.728	0.779	0.866	0.881

‡ S.E.: standard error for N=10,000 observations
* p<0.001 according to t-test
† p<0.001 according to ANOVA

Tab. 1 - Results of the regression analysis between seasonal a_{pt} and vapour pressure deficit *DE* (kPa) using the model $\ln(a_{pt}+1)= a+b\cdot\ln(DE+1)$.
Tab. 1 - Risultati dell'analisi di regressione tra a_{pt} stagionale e deficit della pressione di vapore DE (kPa) utilizzando il modello $\ln(a_{pt}+1)= a+b\cdot\ln(DE+1)$.

variation of a_{pt} can also explain the respective spatial variation of the coefficient due to the spatial variations of the aforementioned parameters. The spatial variation of a_{pt} can also be partially justified by theoretical concepts such as the equilibrium potential evaporation in a convective boundary layer with entrainment (Lhomme, 1997a,b) after loosening some of its assumptions. According to this concept, the additional energy (implied by $a_{pt} > 1$) has a double origin: the feedback of areal evaporation on local potential evaporation and the entrainment effects. In our case, it was observed an inverse relation between

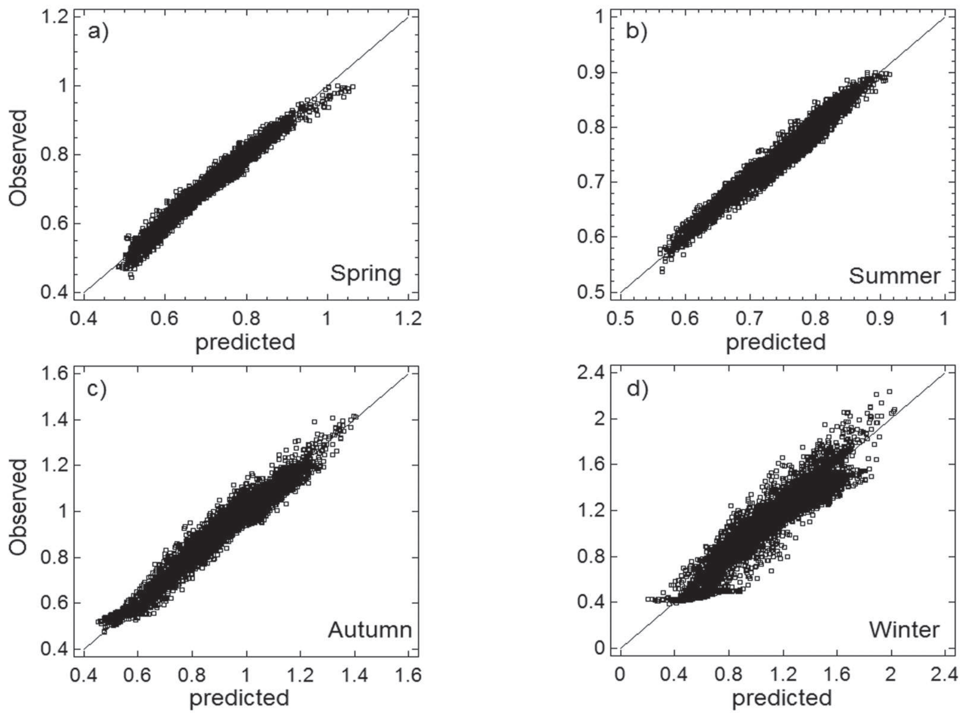

Fig. 6 - Observed vs. predicted values of the mean seasonal $\ln(a_{pt}+1)$ of the period 1950-2000 in the Italian territory using the linear models of Tab. 1 for a) Spring, b) Summer, c) Autumn and d) Winter.
Fig. 6 - Confronto tra valori osservati e previsti della media stagionale $\ln(a_{pt}+1)$ per il periodo 1950-2000 nel territorio italiano utilizzando i modelli lineari della Tab. 1 per a) Primavera, b) Estate, c) Autunno e d) Inverno.

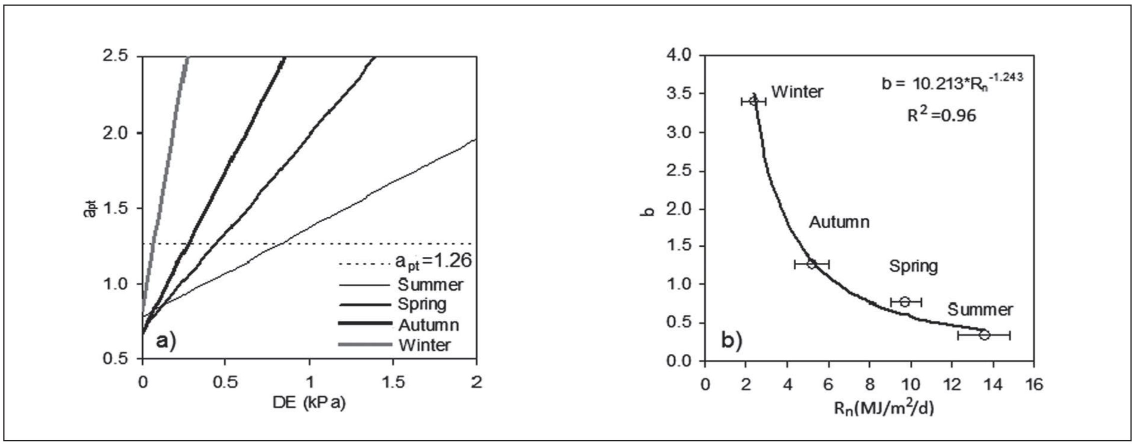

Fig. 7 - a) Variation of the a_{pt} coefficient based on *DE* for each season using the models of Tab. 1 and b) variation of seasonal slope *b* (slope coefficient from Tab. 1) based on net seasonal radiation R_n.
Fig. 7 - a) Variazione del coefficiente a_{pt} sulla base di DE per ogni stagione, calcolato utilizzando i modelli di Tab.1. e b) la variazione dei valori medi stagionali di pendenza b (coefficiente di pendenza dalla Tab. 1) basato sulla radiazione netta stagionale R_n.

altitude/slope and a_{pt} where sloppy areas and mountain tops showed in many cases values of a_{pt} < 1, while the adjacent lowlands showed values of a_{pt} > 1. We can attribute this spatial variation to the fact that the *a posteriori* climate conditions of each site (the ones we use in ET_o calculations) are the result of interaction of the *a priori* climate conditions between adjacent lowland and upland sites. The interactions between adjacent territories are regulated by many factors such as the changes of topography (differences in surface resistance of sites due to differences in surface slope), the downward movement of colder aerial masses from uplands to lowlands or the opposite movement of warmer aerial masses which is very common in regions close to the sea etc. Suggestions and interpretations of the physical meaning of the a_{pt} coefficient can not be robustly supported by the data of this study because there are multi-scale areal effects such as the effects of local topography, the geographical location, the climatic zone of the studied sites and the seasonal trends of air masses circulation (heat and vapour transfer) regulated by wind direction. Such information can be derived only by global climate circulation models (Voldoire *et al*., 2013).

5. CONCLUSIONS

The results of the study illustrated that the P-T method using a_{pt}=1.26 shows a moderate performance during Summer and poor performance during the other seasons and especially during Winter for the assessment of reference crop evapotranspiration in the Italian territory. The recalculation of a_{pt} coefficient using as a base the ASCE method showed significant spatial and temporal variation of the coefficient. The regression analysis showed that more than 90% of the spatial variability of the seasonal a_{pt} is explained by the spatial variability of vapour pressure deficit *DE* with a positive correlation between the two variables. The rate of seasonal a_{pt} variation per unit *DE* showed a transitional seasonal increase following the order Summer<Spring<Autumn<Winter and it was negatively correlated to net solar radiation R_n. The general trends of the a_{pt} coefficient leaded to the conclusion that cold and dry conditions, explained by low R_n and high *DE* values, respectively, tend to increase the values of a_{pt}. The study also revealed the different response of the a_{pt} coefficient between lowland and upland regions where in the second case the original P-T using a_{pt}=1.26 significantly deviates from ASCE. The results of this study can provide a general indication of the spatial and temporal variation of a_{pt} in areas of the temperate zone, since Italy is located between the European and the African plates displaying a great variety of climatic types. The products of the study can significantly contribute to future hydro- and agro-meteorological applications for the Italian territory as follows:

a) The mean monthly values of ET_o from the ASCE method can be used to develop general irrigation management plans especially in regions where data availability for ET_o estimations is restricted.

b) The produced linear models of a_{pt} which use *DE* as explanatory variable can be used to construct adjusted datasets of a_{pt} coefficient for a specific location improving significantly the performance of P-T method at local scale.

c) The produced raster datasets of the mean monthly adjusted a_{pt} coefficient can improve the estimations of ET_o using the P-T method and consequently the water balance estimations at watershed scale.
d) the overall results provide significant information about the ET_o conditions in the Italian territory for the period 1950-2000 and can be used in future climate change studies.

ACKNOWLEDGEMENTS
We would like to thank Dr. Gianfranco Rana for his valuable comments which significantly improved this paper.

REFERENCES
Allen R.G., Pereira L.S., Raes D., Smith M., 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome.
Allen R.G., Walter I.A., Elliott R., Howell T., Itenfisu D., Jensen M., 2005. The ASCE standardized reference evapotranspiration equation. Final Report (ASCE-EWRI). Pr. In: Allen R.G., Walter I.A., Elliott R., Howell T., Itenfisu D., Jensen M. (Eds.), Environmental and Water Resources Institute, 2005. Task Committee on Standardization of Reference Evapotranspiration of the Environmental and Water Resources Institute.
Aschonitis V.G., Antonopoulos V.Z., Papamichail D.M., 2012. Evaluation of pan coefficient equations in a semi-arid Mediterranean environment using the ASCE standardized Penman-Monteith method. Agricultural Sciences, 3(1): 58-65.
Aschonitis V.G., Antonopoulos V.Z., Lekakis E.H., Litskas V.D., Kotsopoulos S.A., Karamouzis D.N., 2013a. Estimation of field capacity for aggregated soils using changes of the water retention curve under the effects of compaction. European Journal of Soil Science, 64(5): 688-698.
Aschonitis V.G., Lithourgidis A.S., Damalas C.A., Antonopoulos V.Z., 2013b. Modelling yields of non-irrigated winter wheat in a semi-arid mediterranean environment based on drought variability. Experimental Agriculture 49(3): 448-460.
Aschonitis V.G., Papamichail D.M., Lithourgidis A., Fano E.A., 2014. Estimation of leaf area index and foliage area index of rice using an indirect gravimetric method. Communications in Soil Science and Plant Analysis, 45(13): 1726-1740.
Baldocchi D., Falge E., Wilson K., 2001. A spectral analysis of biosphere-atmosphere trace gas flux densities and meteorological variables across hour to multi-year time scales. Agricultural and Forest Meteorology, 107(1): 1-27.
Bonan G.B., Williams M., Fisher R.A., Oleson K.W., 2014. Modeling stomatal conductance in the earth system: Linking leaf water-use efficiency and water transport along the soil-plant atmosphere continuum. Geoscientific Model Development, 7(5): 2193-2222.
Castellvi F., Stockle C.O., Perez P.J., Ibanez M., 2001. Comparison of methods for applying the Priestley-Taylor equation at a regional scale. Hydrological Processes, 15: 1609-1620.
Cochrane D., Orcutt G.H., 1949. Application of least squares regression to relationships containing autocorrelated error terms. Journal of the American Statistical Association, 44: 32-61.
Costantini E.A.C., Urbano F., Aramini G., Barbetti R., Bellino F., Bocci M., Bonati G., Fais A., L'Abate G., Loj G., Magini S., Napoli R., Nino P., Paolanti M., Perciabosco M., Tascone F., 2009. Rationale and methods for compiling an atlas of desertification in Italy. Land Degradation and Development, 20: 261-276.
De Bruin H.A.R., 1983. A model for the Priestley-Taylor parameter a. Journal of Climate ad Applied Meteorology, 22: 572-578.
Demertzi K., Aschonitis V., Papamichail D., 2013. Analysis of Priestley-Taylor method for the assessment of reference evapotranspiration in Greece. Hydrotechnica, 22: 1-14.(in Greek)
Diamantopoulou M., Georgiou P.E., Papamichail D.M., 2011. Performance evaluation of artificial neural networks in estimating reference evapotranspiration with minimal meteorological data. Global Nest Journal, 13: 18-27.
Douglas E.M., Beltràn-Przekurat A., Niyogi D., Pielke R.A., Vorosmarty C.J., 2009. The impact of agricultural intensification and irrigation on land – atmosphere interactions and Indian monsoon precipitation – a mesoscal modeling perspective. Global and Planetary Change, 67(1–2): 117–128.
Droogers P., Allen R.G., 2002. Estimating reference evapotranspiration under inaccurate data conditions. Irrigation and Drainage Systems, 16: 33-45.
Durbin J., Watson G.S., 1950. Testing for serial correlation in least squares regression, I. Biometrika, 37(3-4): 409-428.
Durbin J., Watson G.S., 1951. Testing for serial correlation in least squares regression, II. Biometrika, 38(1-2): 159-179.
Eichinger W.E., Parlange M.B., Strickler H., 1996. On the concept of equilibrium evaporation and the value of the Priestley-Taylor coefficient. Water Resources Research, 32: 161-164.

Flint A.L., Childs S.W., 1991. Use of the Priestley-Taylor evaporation equation for soil water limited conditions in a small forest clearcut. Agricultural and Forest Meteorology, 56: 247-260.

Fritschen L.J., 1967. Net and solar radiation relations over irrigated field crops. Agricultural Meteorology, 4(1): 55-62.

Garcia M., Raes D., Allen R., Herbas C., 2004. Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano). Agricultural and Forest Meteorology, 125(1-2): 67-82.

Hargreaves G.H., 1989. Accuracy of estimated reference crop evapotranspiration. Journal of Irrigation and Drainage Engineering, 115(6): 1000-1007.

Heinemann, A.B., Hoogenboom, G., de Faria, R.T., 2002. Determination of spatial water requirements at county and regional levels using crop models and GIS: An example for the State of Parana, Brazil. Agricultural Water Management, 52(3): 177-196.

Hijmans R.J., Cameron S.E., Parra J.L., Jones P.G., Jarvis A., 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology, 25: 1965-1978.

Hunsaker D.J., Pinter Jr. P.J., Cai H., 2002. Alfalfa basal crop coefficients for FAO-56 Procedures in the Desert Regions of the Southwestern U.S. Transactions of the American Society of Agricultural Engineers 45(6): 1799-1815.

Jarvis P.J., 1976. The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field. Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences, 273: 593-610.

Katerji N., Rana G., 2011. Crop reference evapotranspiration: a discussion of the concept, analysis of the process and validation. Water Resources Management, 25:1581-1600.

Katerji N., Rana G., Fahed S., 2011. Parameterizing canopy resistance using mechanistic and semi-empirical estimates of hourly evapotranspiration: critical evaluation for irrigated crops in the Mediterranean. Hydrological Processes, 25(1): 117-125.

Katerji N., Rana G., 2014. FAO-56 methodology for determining water requirement of irrigated crops: critical examination of the concepts, alternative proposals and validation in Mediterranean region. Theoretical and Applied Climatology, 116(3-4): 515-536.

Knisel W.G., Davis F.M., 2000. GLEAMS, Groundwater loading effects from agricultural management systems V3.0. Publ. No. SEWRL-WGK/FMD-050199, U.S.D.A., Tifton, Georgia.

Lazzara P., Rana G., 2010. The use of crop coefficient approach to estimate actual evapotranspiration: A critical review for major crops under Mediterranean climate. Italian Journal of Agrome-teorology 2: pp. 25.

Lhomme J.-P., 1997a. A theoretical basis for the Priestley-Taylor coefficient. Boundary-Layer Meteorology, 82: 179-191.

Lhomme J.-P., 1997b. An examination of the Priestley-Taylor equation using a convective boundary layer model. Water Resources Research, 33(11): 2571-2578.

Mastrocicco M., Colombani N., Salemi E., Castaldelli G., 2010. Numerical assessment of effective evapotranspiration from maize plots to estimate groundwater recharge in lowlands. Agricultural Water Management, 97(9): 1389-1398.

McAneney K.J., Itier B., 1996. Operational limits to the Priestley-Taylor formula. Irrigation Science, 17(1): 37-43.

McMahon T.A., Peel M.C., Lowe L., Srikanthan R., McVicar T.R., 2013. Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis. Hydrology and Earth System Sciences, 17: 1331-1363.

Moges S.A., Katambara Z., Bashar K., 2003. Decision support system for estimation of potential evapotranspiration in Pangani Basin. Physics and Chemistry of the Earth, 28: 927-934.

Morari F., Giardini L., 2001. Estimating evapotranspiration in the Padova Botanical Garden. Irrigation Science, 20(3): 127-137.

Peixoto J.P., Oort A.H., 1996. The climatology of relative humidity in the atmosphere. Journal of Climate, 9: 3443-3463.

Pereira A.R., 2004. The Priestley–Taylor parameter and the decoupling factor for estimating reference evapotranspiration. Agricultural and Forest Meteorology, 125: 305-313.

Priestley C.H.B., Taylor R.J., 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review, 100: 81-92.

Rana G., Katerji N., Mastrorilli M., El Moujabber M., 1994. Evapotranspiration and canopy resistance of grass in a Mediterranean region. Theoretical and Applied Climatology, 50(1-2): 61-71.

Rana G., Katerji N., 1998. A measurement based sensitivity analysis of the Penman-Monteith actual evapotranspiration model for crops of different height and in contrasting water status. Theoretical and Applied Climatology, 60: 141-149.

Rana G., Katerji N., 2009. Operational model for direct

determination of evapotranspiration for well watered crops in Mediterranean region. Theoretical and Applied Climatology, 97(3): 243-253.
Rana G., Katerji N., Ferrara R.M., Martinelli N., 2011. An operational model to estimate hourly and daily crop evapotranspiration in hilly terrain: Validation on wheat and oat crops. Theoretical and Applied Climatology, 103 (3-4): 413-426.
Rana G., Katerji N., Mastrorilli M., 2012. Method for automatic determination of soybean actual evapotranspiration under open top chambers (OTC) subjected to effects of water stress and air ozone concentration. Environmental Monitoring and Assessment, 184(10):6377-6394.
Ritchie J.T., 1972. A model for predicting evaporation for a row crop with incomplete cover. Water Resources Research, 8(5): 1204-1213.
Sheffield J., Goteti G., Wood E.F., 2006. Development of a 50-yr high-resolution global dataset of meteorological forcings for land surface modeling. Journal of Climate, 19(13): 3088-3111.
Singh R.K., Irmak A., 2011. Treatment of anchor pixels in the METRIC model for improved estimation of sensible and latent heat fluxes. Hydrological Sciences Journal, 56: 895-906.
StatPoint Technologies, 2009. Statgraphics Centurion XVI, user manual. StatPoint Technologies Inc.
Sumner D.M., Jacobs J.M., 2005. Utility of Penman-Monteith, Priestley-Taylor, reference evapotranspiration, and pan evaporation methods to estimate pasture evapotranspiration. Journal of Hydrology, 308(1-4): 81-104.
Sun G., Alstad K., Chen J., Zhang Y., Zhang Z., 2011. A general predictive model for estimating monthly ecosystem evapotranspiration. Ecohy-drology, 4(2): 245-255.
Tabari H., Talaee P.H., 2011. Local calibration of the Hargreaves and Priestley–Taylor equations for estimating reference evapotranspiration in arid and cold climates of Iran based on the Penman–Monteith model. Journal of Hydrologic Engineering, 16: 837-845.
Tabari H., 2010. Evaluation of reference crop evapotranspiration equations in various climates. Water Resources Management, 24: 2311-2337.
Tateishi R., Ahn C.H., 1996. Mapping evapotranspiration and water balance for global land surfaces. ISPRS Journal of Photogrammetry and Remote Sensing, 51: 209-215.
Utset A., Farré I., Martínez-Cob A., Cavero J., 2004. Comparing Penman-Monteith and Priestley-Taylor approaches as reference-evapotranspiration inputs for modeling maize water-use under Mediterranean conditions. Agricultural Water Management, 66(3): 205-219.
Venezian Scarascia M.E., Di Battista F., Salvati L., 2006. Water resources in Italy: availability and agricultural uses. Irrigation and Drainage, 55: 115-127.
Voldoire A., Sanchez-Gomez E., Salas y Mélia D., (...), Chauvin F., 2013. The CNRM-CM5.1 global climate model: description and basic evaluation. Climate Dynamics, 40(9): 2091-2121.
Walter I.A., Allen R.G., Elliott R., Jensen M.E., Itenfisu D., Mecham B., Howell T.A., Snyder R., Brown P., Echings S., Spofford T., Hattendorf M., Cuenca R.H., Wright J.L., Martin D., 2004. ASCE's standardized reference evapotranspiration equation. Watershed Management and Operations Management 2000, pp. 105.
Weiß M., Menzel L., 2008. A global comparison of four potential evapotranspiration equations and their relevance to stream flow modelling in semi-arid environments. Advances in Geosciences, 18: 15-23.
Xu C.-Y., Singh V.P., 1998. Dependence of evaporation on meteorological variables at different time-scales and intercomparison of estimation methods. Hydrological Processes, 12: 429-442.
Xu C.-Y., Singh V.P., 2002. Cross Comparison of Empirical Equations for Calculating Potential Evapotranspiration with Data from Switzerland. Water Resources Management, 16(3): 197-219.
Xu J.-Z., Peng S.-Z., Ding J.-L., Wei Z., 2010. Evaluation of methods for estimating daily reference crop evapotranspiration based on lysimeter grass experiments. Journal of Hydraulic Engineering, 41(12): 1497-1505.
Xu J., Peng S., Ding J., Wei Q., Yu Y., 2013. Evaluation and calibration of simple methods for daily reference evapotranspiration estimation in humid East China. Archives of Agronomy and Soil Science, 59(6): 845-858.
Zomer R.J., Trabucco A., Bossio D.A., van Straaten O., Verchot L.V., 2008. Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation. Agric. Ecosystems and Envir. 126: 67-80.
Zottele F., Toller G., Eccel E., 2010. Irri4web: Crop water needs definition by webgis. Italian Journal of Agrometeorology 3: pp. 5.

View publication stats