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Key Points:
- A simplified approach for annual evapotranspiration predictions accounting for the seasonality of meteorological conditions is proposed
- Evapotranspiration is insensitive to future scenario changes of vapor pressure deficit, but sensitive to seasonal precipitation changes
- Greatly reduced future runoff scenarios are predicted, requiring new strategies and designs in water resources planning and management in Sardinia

Supporting Information:
- Supporting Information S1

Correspondence to:
N. Montaldo,
nmontaldo@unica.it

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Changing Seasonal Rainfall Distribution With Climate Directs Contrasting Impacts at Evapotranspiration and Water Yield in the Western Mediterranean Region

Nicola Montaldo[1] and **Ram Oren**[2,3]

[1]Dipartimento di Ingegneria civile, ambientale e architettura, Università di Cagliari, Cagliari, Italy, [2]Nicholas School of the Environment and Pratt School of Engineering, Duke University, Durham, NC, USA, [3]Department of Forest Sciences, University of Helsinki, Helsinki, Finland

Abstract Over the past century, climate change has been reflected in altered precipitation regimes worldwide. Because evapotranspiration is sensitive to both water availability and atmospheric demand for water vapor, it is essential to assess the likely consequences of future changes of these climate variables to evapotranspiration and, thus, runoff. We propose a simplified approach for annual evapotranspiration predictions, based on seasonal evapotranspiration estimates, accounting for the strong seasonality of meteorological conditions typical of Mediterranean climate, still holding the steady state assumption of basin water balance at mean annual scale. Sardinian runoff decreased over the 1975–2010 period by more than 40% compared to the preceding 1922–1974 period. Most of annual runoff in Sardinian basins is produced by winter precipitation, a wet season with relatively high evaporation rates. We derived linear seasonal evapotranspiration responses to seasonal precipitation, and, in turn, a relationship between the parameters of the linear functions and the seasonal vapor pressure deficit (*D*), accounting for residuals with basin properties. We then used these relationships to predict evapotranspiration and runoff using future Intergovernmental Panel on Climate Change climate scenarios, considering changing precipitation and *D* seasonality. We show that evapotranspiration is insensitive to *D* scenario changes. Although both evapotranspiration and runoff are sensitive to precipitation seasonality, future changes in runoff are related only to changes of winter precipitation, while evapotranspiration changes are related to those of spring and summer precipitation. Future scenario predicting further runoff decline is particularly alarming for the Sardinian water resources system, requiring new strategies and designs in water resources planning and management.

1. Introduction

Over the past century, climate change has been manifested in alteration of precipitation regimes worldwide (Giorgi & Lionello, 2008; Knapp et al., 2015). In the Mediterranean regions there is a clear trend of decreasing precipitation and runoff (Altin & Barak, 2014; Boithias et al., 2014; Brunetti et al., 2002; Ceballos et al., 2004; Garcia-Ruiz et al., 2011; Klein-Tank & Können, 2003; Lopez-Moreno et al., 2011; Martinez-Fernandez et al., 2013; Ventura et al., 2002; Vicente-Serrano & López-Moreno, 2006; Vicente-Serrano et al., 2011), triggering desertification with deleterious impacts on agricultural and water resources sustainability. Climate change projections point to further strengthening of the observed changes in global precipitation (Giorgi & Lionello, 2008), with increasing drought severity and water supply in the Mediterranean area (Cayan et al., 2008; Mariotti et al., 2008; Mastrandrea & Luers, 2012; May, 2008; Ozturk et al., 2015).

At coarse temporal scales (e.g., annual or multiannual), water yield is roughly the balance between precipitation, *P*, and evapotranspiration, *ET*. Climate factors control *ET* by affecting both atmospheric demands for water vapor and moisture supply to meet that demand. Air temperature affects *ET* by regulating the moisture holding capacity of the air, thus determining the potential for water flux from the soil to the atmosphere (Brutsaert, 1982). At the same time, precipitation affects *ET* by controlling soil water content, and the resistance to water uptake by plants and its use in transpiration, and the direct diffusion of vapor to the atmosphere as evaporation (Brutsaert, 1982; Jung et al., 2010; Montaldo et al., 2008). Although a large variation in temporal trends of *ET* has been observed across the globe, ranging from increasing to decreasing (Wang et al., 2010), using FLUXNET observation sites, Jung et al. (2010) detected a rising trend in mean global *ET* from 1982 to 1997, but a decreasing trend over the following decade, especially in regions where *ET* was limited by soil moisture. Similar average trends have been confirmed using satellite observations from 1980

(Miralles et al., 2014), highlighting the key role of soil moisture in eastern and central Australia, southern Africa, and eastern South America. Such findings have been expanded to predictions based on a land ecosystem model (the Dynamic Land Ecosystem Model) driven by 2007 Intergovernmental Panel on Climate Change (IPCC) future scenarios (Intergovernmental Panel on Climate Change, 2007; Pan et al., 2015); these predictions show varied future *ET* trends over the globe, yet mostly trending upward by up to 14% increase of *ET* by the 2090s, owing to projected increases of both mean temperature and precipitation (up to 16.9%). Indeed, *ET* declined only in regions in which *P* is projected to decrease (e.g., North Africa and the Mediterranean region). Further decreases in *ET* in the Mediterranean region are expected with predicted increases of El Niño impacts (Miralles et al., 2014).

Mediterranean regions pose a particularly interesting challenge to prediction of how future climate will affect the partitioning of *P* between *ET* and water yield. In these regions, water yield is sensitive to two asynchronous forcing, precipitation and evaporative demand, and changes in the seasonality of these variables alter runoff production. The region contains high spatiotemporal variability of environmental conditions (Doblas-Miranda et al., 2015), owing in part to the seasonal climate, which is also highly affected by the dynamics of general atmospheric circulation (Giorgi & Lionello, 2008). Giorgi (2006) classified the Mediterranean Sea region as one of the most pronounced “hot spots” in the world, highly sensitive to climate change with predicted (for 2080–2099) large decrease in mean precipitation (− 9.7% in the wet season and −21.6% in the dry season) and increase in precipitation variability (+24.9% in the wet season and +40% in the dry season).

Mediterranean basins are typically characterized by strong seasonality of the climate, with relatively dry summer months in which most of the rainfall is consumed by evapotranspiration, contrasting the wetter seasons, in which various proportions of the precipitation contribute to runoff. Thus, a decrease of winter precipitation, when soil is fairly saturated and precipitation comfortably exceeds evapotranspiration, will exert a similar decrease of runoff. In Sardinia, Montaldo and Sarigu (2017) showed that runoff decreased drastically over the 1975–2010 period, with mean annual values 40% lower than the 1922–1974 period (with Mann-Kendall τ values ranging from −0.39 to −0.2). The same study also showed that, as expected, most of the yearly runoff in Sardinian basins (averaging ~70%) is generated by winter precipitation and that changes of the North Atlantic Oscillation (NAO) index cause reductions in winter precipitation. Given the *observed past* changes in winter precipitation and their strong impact on water yield in recent decades, it is necessary to assess how *predicted future* changes in both precipitation and vapor pressure deficit will affect the partitioning of precipitation between evapotranspiration and runoff, with consequences to surface energy partitioning and temperature, vegetation performance, and water yield to downstream ecosystems and water users.

To better understand the behavior of *ET*, match historical trends, and predict future quantities of *ET* and water yield at an annual time scale, key elements of climate change (e.g., precipitation and vapor pressure deficit) and basin physiographic properties can be used to account for the variability of annual evapotranspiration (ET_y). Beginning with the steady state assumption of basin water balance at mean annual scale (Donohue et al., 2007), thus neglecting seasonality, most existing approaches for estimating ET_y are based on Budyko’s model (Choudhury, 1999; Roderick & Farquhar, 2011; Xu et al., 2014; Zhang et al., 2001, 2008). However, precipitation seasonality may affect Budyko’s model estimates (Potter et al., 2005; Ye et al., 2015). Recent efforts (Ye et al., 2015; Zeng & Cai, 2015; Zhang et al., 2016), elaborating on Budyko’s model, depart from the steady state assumption of the basin water balance and account for intraannual (e.g., monthly) changes in basin soil moisture storage through coupled hydrologic models. We propose a simplified approach for ET_y estimates, still using common meteorological conditions (precipitation and vapor pressure deficit, both monitored worldwide over almost a century), but at seasonal rather than annual scale, incorporating commonly available basin physiographic properties (vegetation cover, soil depth, and slope). Note that the steady state assumption of basin water balance at mean annual scale is a reasonable assumption in the Mediterranean Sea region, where the soil is usually dry at the end of the hydrologic year (i.e., end of summer), such that annual soil moisture changes are negligible.

Our proposed approach allows predicting ET_y and water yield using future climate scenarios. We use the future climate scenarios predicted by global climate models (GCM) in the Fifth Assessment Report of the IPCC (Flato et al., 2013) and selected the most reliable model after testing the GCM predictions of past conditions against observed data. From future predictions of precipitation and evapotranspiration, water yield can be estimated using the steady state assumption of the basin water balance at annual scale. We

Table 1
For the 10 Sardinian Basins Used in the Trend Analysis, the Mann-Kendall τ of the Yearly Runoff (τ_{Qy}) and its P Value, the Mann-Kendall τ of the Yearly Precipitation (τ_{Pyb}) and its P Value, and the Mann-Kendall τ of the Yearly Evapotranspiration (τ_{ETy}) and its P Value

Basin name	Basin code	τ_{QY} (−)	p of τ_{QY} (−)	τ_{PYb} (−)	p of τ_{PYb} (−)	τ_{ETy} (−)	p of τ_{ETy} (−)
Fluminimaggiore	1	−0.250	0.004	−0.175	0.045	−0.004	0.971
Coghinas a Muzzone	2	−0.266	0.000	−0.285	0.000	−0.168	0.034
Coghinas a Buttule	3	−0.249	0.011	−0.179	0.068	−0.010	0.925
Coghinas a Berchidda	4	−0.193	0.029	−0.142	0.109	−0.028	0.755
Coghinas a Concarabella	5	−0.284	0.000	−0.271	0.001	−0.124	0.141
Tirso a Rifornitore Tirso	6	−0.316	0.000	−0.222	0.003	−0.032	0.677
Araxisi	7	−0.387	0.000	−0.112	0.168	0.330	0.000
Flumendosa a Monte Scrocca	8	−0.248	0.002	−0.226	0.004	0.075	0.346
Fluminimannu a Is Barrocus	9	−0.198	0.116	−0.036	0.784	0.193	0.124
Leni a Villacidro	10	−0.458	0.000	−0.471	0.000	−0.140	0.279

used Sardinia as a case study representing typical conditions of the western Mediterranean Sea basin, endowed with extensive and long hydrological database. Furthermore, having relatively low urbanization and human activity makes Sardinia an excellent reference condition for Mediterranean hydrological studies.

2. Methods

2.1. Setting and Hydrologic Data

The island of Sardinia (24,100 km^2) is in the center of the western Mediterranean Sea. The island has ancient conformation (Ghiglieri et al., 2014) and is not earthquake-prone. Sardinia is mainly mountainous (mean elevation of 338 m above sea level [asl], highest elevation of 1,834 m asl in the center of the island), with only two main flat areas in the northwest and in the south (see Figure 1 of Montaldo & Sarigu, 2017). The climate regime (mean yearly rainfall of 733.3 mm, ranging 433 to 1,206 mm; Figure S1) is typically maritime Mediterranean, with wet autumn and winter (October–March; maximum monthly precipitation in December, averaging 113.3 mm) contrasting dry summer (June–September; minimum monthly precipitation in July of 6.9 mm). Snowmelt and groundwater are negligible, so that surface runoff is the predominant water contribution to the island water resources. Due to the strong seasonality, surface runoff is stored in 54 main reservoirs, the key resource of the Sardinian water management system (Vinelli, 1926).

Daily rain data from 206 stations of the Sardinian Regional Hydrographic Service, some over a period lasting from 1921 to 2011, were used (Montaldo & Sarigu, 2017). Note that in the following analyses, yearly estimates of hydrologic variables are computed for the hydrologic year, beginning in October (when runoff usually resumes) and ending in September of the following year (when the dry season usually ends). We used daily and monthly runoff data of 28 stations (data from 1922 to 2011 and with at least 20 years of data; Table S1), and for evaluating historical runoff trends, we further selected 10 basins with at least 40 years of complete data, including data from the last 10 years (Table 1, Figure S1, and Figure 1 of Montaldo & Sarigu, 2017). Daily maximum and minimum air temperatures (T_{max} and T_{min}, respectively) of 228 stations are available. We estimated basin topographic properties (basin area, slope, and elevation) from a digital elevation model at 10 m spatial resolution. Soil characteristics (soil depth and texture) and land cover maps are also available at 250 m spatial resolution. Sardinian soils are typically clay loam (49%), loamy sand (21%), sandy clay loam (16%), sand (10%), and clay (4%), with average depth of 0.35 m (standard deviation [*SD*] of 0.3 m, the depth of 66% of soils $<$0.3 m), average saturated moisture of 0.44 (*SD* of 0.02), and average field capacities of 0.24 (*SD* of 0.07). The soils of the 28 basins have similar characteristics (Table S1). More details on the Sardinian hydrologic database are provided in Montaldo and Sarigu (2017).

We computed a vapor pressure deficit (D) proxy value of the basins from observed T_{max} and T_{min} time series. D was calculated assuming that the air was saturated at T_{min} and that the absolute moisture content of the air did not increase with air temperature, thus estimating the relative humidity at T_{max}. Based on T_{max} and T_{min}, and the corresponding humidity, we calculated one D value for each day. We tested this method for estimating D using data from the Orroli flux site (39°41′12.57″N, 9°16′30.34″E, 500 m asl; Detto et al., 2006; Montaldo et al., 2008, 2013) located in the center of Sardinia, where an eddy-covariance-based land surface fluxes of energy, water, and CO_2 were monitored from 2003 at the top of a 10 m micrometeorological tower. The daily D proxy values were highly (Pearson correlation coefficient of 0.94) and linearly related (D = 0.703 D_{act}, coefficient of determination r^2 = 0.87) with those based on observed actual daily vapor pressure deficit (D_{act}), confirming the reliability of D as representative term of the vapor pressure deficit. Finally, we computed potential evapotranspiration (*PET*) monthly time series using the Thornthwaite equation (Thornthwaite, 1948), requiring only mean daily air temperature, estimated as the average of T_{max} and T_{min}.

2.2. Historical Annual and Seasonal Evapotranspiration

We computed annual estimates of *ET* from *P* and runoff based on basin water balance, assuming negligible annual changes in the basin soil water storage, thus assuming that, annually, catchments were at steady state (e.g., Donohue et al., 2007; Roderick & Farquhar, 2011; Zhang et al., 2004). The assumption is considered acceptable in semiarid regions (Zhang et al., 2001), like Sardinia.

Because seasonality is very strong in the Mediterranean climate, and changes in seasonal *P* have been detected in the past (from 1922 to 2010; Montaldo & Sarigu, 2017), we estimated seasonal evapotranspiration (ET_s) from seasonal precipitation (P_s) and runoff using the basin water balance, but accounting for changes in soil moisture storage. We use the redefined hydrologic seasons of Montaldo and Sarigu (2017) for better aggregating months into seasonal scale in relation to their runoff contribution in Sardinia. On average, runoff values are high and relatively invariable in December through March (mean of 49 mm/month and *SD* of 13.2 mm/month, "extended winter"), while runoff values are negligible and nearly invariable in June through September (mean of 3.4 mm/month and *SD* of 2.2 mm/month, "extended summer"). Between these two extended seasons, a period of increasing runoff occurs in October and November ("shortened autumn") and decreasing runoff in April and May ("shortened spring"). In general, changes in basin soil water storage are nearly negligible in winter and summer. In contrast, during the short transition seasons of autumn and spring, soil water changes of opposite signs (positive in autumn versus negative in spring) violate the steady state assumption of the basin water balance (see, for instance, soil moisture observations at Sardinia case studies by Reichstein et al., 2003 [clay loam soil with water content changes between 0.08 and 0.28], Montaldo et al., 2008 [silt loam changing between 0.08 and 0.48], Niedda & Pirastru, 2014 [loam soil changing between 0.15 and 0.43], and Spano et al., 2009 [clay loam soil in which plant available water changed between 10% and 100%]). During these seasons, ET_s cannot be simply estimated as the difference between *P* and runoff. Thus, we introduce a simple approach accounting for the contribution of soil moisture to ET_s.

In *autumn* (October–November), we estimate a positive Δs_a soil water storage change (mm):

$$\Delta s_a = \begin{cases} \Delta s_{\max,} & \text{if } P_{s,a} > PET_a \\ \dfrac{P_{s,a}}{PET_a}\Delta s_{\max,} & \text{if } P_{s,a} \le PET_a \end{cases} \tag{1}$$

where $P_{s,a}$ is the total precipitation in autumn, PET_a is the autumn PET, $0 \le \Delta s_a \le \Delta s_{max}$, and Δs_{max} is the maximum soil water storage change ($\Delta s_{max} = ds\ \Delta\theta_{max}$, where ds is the mean basin soil depth and $\Delta\theta_{max}$ is the maximum soil moisture change of the basin). Because basin-specific soil moisture observations are rarely available, we hypothesized and tested an inverse relationship between $\Delta\theta_{max}$ and ds, expecting that shallower soils will undergo more drastic changes in moisture during the transition period. Using literature from studies in Mediterranean ecosystems (Arca di Noè, Puechabon, and Castelporziano sites from Reichstein et al., 2003; Orroli site from Montaldo et al., 2008; Balsa Blanca site from Morillas et al., 2013; Amoladeras site from FLUXNET database; and Baratz catchment site from Niedda & Pirastru, 2014), we found the following relationship: $\Delta\theta_{max} = -0.05 \log (ds/10) + 0.35$ (with ds expressed in mm; r^2 = 0.43, p = 0.04).

Because ds ranged among basins from 0.1 to 0.7 m (mean and *SD* of 0.3 ± 0.14 m), $\Delta\theta_{max}$ ranged 0.1–0.3 (0.2 ± 0.03) and Δs_{max} 9–56 mm (30 ± 11 mm). Accounting for autumn Δs_a, a gross autumn evapotranspiration ($ET_{s,a}$*) can be estimated based on the basin water balance as $ET_{s,a}^* = P_{s,a} - Q_a - \Delta s_a$. Because the actual evapotranspiration cannot be greater than the PET, we also account for autumn basin leakage (L_a), which equals zero unless $ET_{s,a}^* > PET_a$; in that case, $L_a = ET_{s,a}^* - PET_a$. Hence, the actual autumn evapotranspiration ($ET_{s,a}$) is estimated as

$$ET_{s,a} = P_{s,a} - Q_a - \Delta s_a - L_a \tag{2}$$

where Q_a is the autumn runoff.

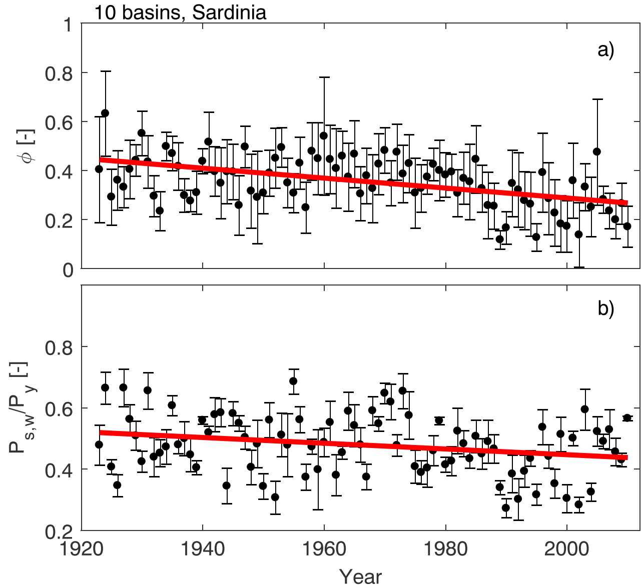

Figure 1. Trends for the 10 Sardinian basins (listed in Table 1) of (a) mean annual basin runoff coefficient (ϕ; trend line estimated by Theil-Sen method of $\phi = -0009\ y + 2.177$, where y is the year) and (b) the mean ratio between winter precipitation ($P_{s,w}$) and yearly precipitation (P_y; trend line estimated by Theil-Sen method of $P_{s,w}/P_y = -0.002\ y + 4.252$).

In *winter* (December–March), actual evapotranspiration ($ET_{s,w}$) was estimated accounting in addition for a possible residual soil moisture change ($\Delta s_{a,res} = \Delta s_{\max} - \Delta s_a$) in years and basins in which Δs_a was less then $\Delta s_{\max}$ in autumn, meaning when autumn precipitation was not sufficient to bring the soil moisture from the summer minimum to saturation. Hence, $ET_{s,w}$ is estimated as

$$ET_{s,w} = P_{s,w} - Q_w - \Delta s_{a,res} - L_w \tag{3}$$

where $P_{s,w}$ is the winter precipitation, Q_w is the winter runoff, and L_w is the winter basin leakage, which is equal zero unless $ET_w^* = P_{s,w} - Q_w - \Delta s_{a,res} > PET_w$ (PET_w is the winter PET); in that case $L_w = ET_w^* - PET_w$, similar to L_a.

In *spring* (April–May) the actual evapotranspiration ($ET_{s,s}$) is estimated based on the basin water balance accounting for the decrease of Δs_s (mm; with $0 \leq \Delta s_s \leq \Delta s_{\max}$), estimated as

$$\Delta s_s = \begin{cases} \Delta s_{\max}, & \text{if } P_{s,s} > PET_{s,s} \\ \left(1 - \dfrac{P_{s,s} - PET_{s,s}}{PET_s}\right)\Delta s_{\max}, & \text{if } P_{s,s} \geq PET_{s,s} \end{cases} \tag{4}$$

where $P_{s,s}$ is the spring precipitation and $PET_{s,s}$ is the spring PET. Hence, $ET_{s,s}$ is estimated through:

$$ET_{s,s} = P_{s,s} - Q_s + \Delta s_s - L_s \tag{5}$$

where Q_s is the spring runoff and L_s is the spring basin leakage, which is equal zero unless $ET_s^* = P_{s,s} - Q_s + \Delta s_s > PET_s$; in that case $L_s = ET_s^* - PET_s$.

Finally, in *summer* (June–September), in estimating the actual evapotranspiration ($ET_{s,su}$), we accounted for a potential residual soil moisture change ($\Delta s_{s,res} = \Delta s_{\max} - \Delta s_s$) in years and basins in which Δs_s was less then $\Delta s_{\max}$ in spring, occurring when spring evapotranspiration was not sufficient to utilize the accessible soil moisture storage. Hence, $ET_{s,su}$ is estimated through

$$ET_{s,su} = P_{s,su} - Q_{su} + \Delta s_{s,res} \tag{6}$$

where $P_{s,su}$ is the summer precipitation and Q_{su} is the summer runoff.

We note that while spring and summer discharges and autumn and winter recharges thus estimated are only rough estimates, these estimates have no effect on the annual estimates, because the seasonal changes are of opposite signs and thus balanced at the annual time scale, consistent with the observation that soil moisture changes over the hydrologic year are negligible. Ultimately, it is the estimate of ET_y that is of concern for projection of annual water yield.

2.3. IPCC Model Historical and Future Projections

For future climate scenario, we have considered the IPCC scenario in the Fifth Assessment report, focusing on the climate models of Flato et al. (2013). Flato et al. (2013) evaluated the climate models at the global scale (Atmosphere-Ocean General Circulation Models, AOGCMs) and for numerous variables, compared model predictions of past conditions with observed data. We selected the climate models for future scenarios after comparing the models' outputs with the observed data, but only for Sardinia. Concentrating on the 12 AOGCMs (MPI-ESM-LR, CMCC-CMS, CNRM-CM5, GFDL-ESM 2G, GFDL-ESM 2M, HadCM3, HadGEM2-CC, HadGEM2-ES, MPI-ESM-MR, NorESM1-M, NorESM1-ME, and HadGEM2-AO) of Flato et al. (2013), for which analyses produced predictions for Sardinia for the period 1951–2000, we aimed at choosing the model(s) that best simulates past precipitation and air temperature changes over the island. Thus, we compared the observed (206 stations) changes in mean precipitation and air temperatures from the period 1951–1975

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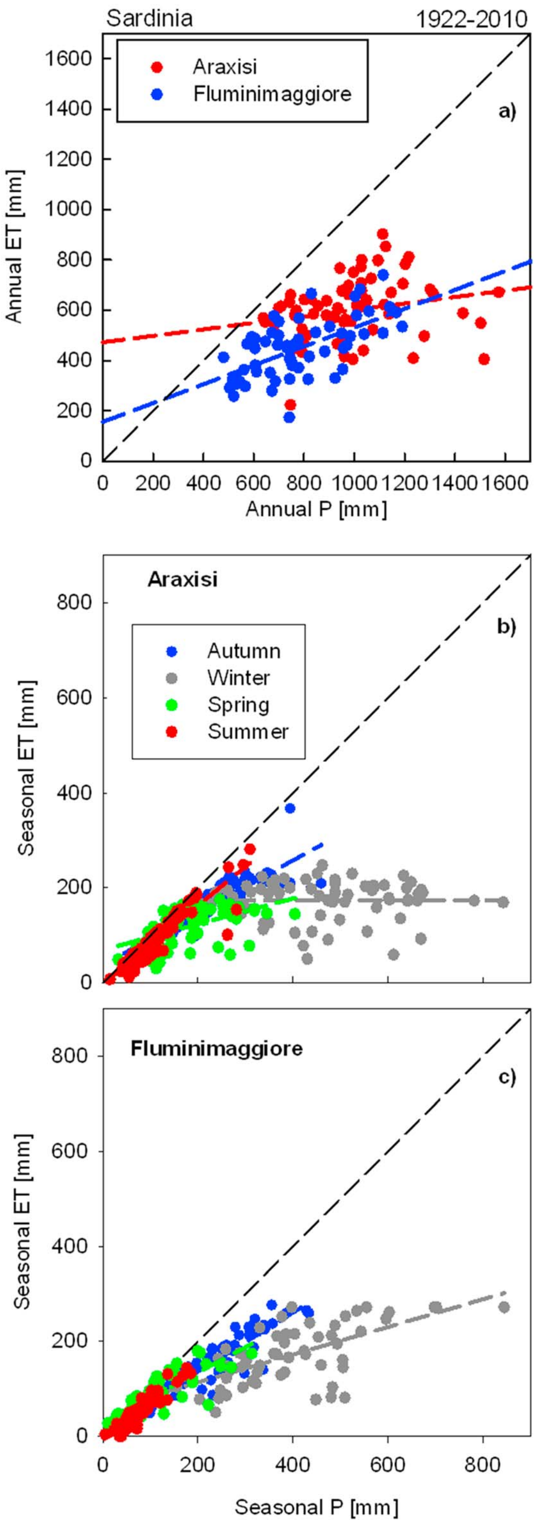

Figure 2. Comparison of historical evapotranspiration (ET) estimate versus precipitation (*P*) in Araxisi and Fluminimaggiore basins: (a) annual *ET* and *P* of both basins (the red and blue dashed lines are the fitted lines for the Araxisi basin and Fluminimaggiore basin respectively); (b) seasonal *ET* and *P* for the Araxisi basin (the fitted dashed lines for each season are with the same colors of the legend); (c) seasonal *ET* and *P* for the Fluminimaggiore basin (same fitted lines as in panel b).

with that of 1976–2000, with the changes predicted by the model for the same period in the cells overlaying Sardinia. Only one model (HadGEM2-AO) was able to capture past climate changes in Sardinia, with differences in predicted changes of P_s, typically the most uncertain among the predicted variable (e.g., Giorgi & Lionello, 2008), of less than 19% of the observed changes of P_s. Scenarios based only on this model were used in predictions of likely effects of future climate change on *ET* and, thus, water yield.

3. Results

All 10 basins showed a decreasing trend of yearly precipitation (P_y) and, even more, of annual runoff (Table 1; Montaldo & Sarigu, 2017). The greater decrease of runoff relative to that of *P* is reflected in a large decrease of the mean annual basin runoff coefficient (ϕ, ratio between runoff and precipitation; Figure 1a; Mann-Kendall τ value of -0.32, $p < 0.0001$) with a trend line slope, estimated by the Theil-Sen method (Sen, 1968; Theil, 1950), of -0.002/year. Over the 87-year record, ϕ decreased from 0.43 (in 1923) to 0.26 (in 2010). The large decline of ϕ is the result of reduction, in all basins, of the fraction of P_y occurring in winter (Figure 1b; Mann-Kendall τ value of -0.15, $p = 0.035$), the key season for runoff production in Sardinia's basins (Montaldo & Sarigu, 2017), and a quantity decreasing at a higher rate than the annual precipitation rate.

While the decrease of annual *P* and runoff is general for the 10 basins, the trends of annual *ET* (ET_y) are not (3 positive and 7 negative), with only two basins showing a significant trend $p < 0.05$ (Table 1), and only one basin showing $|\tau| > 0.2$ and five showing $|\tau| > 0.1$ (Table 1).

Investigating the reasons of such contrasting ET_y trends, we analyze the effect of P_y on ET_y at the 28 Sardinian basins. ET_y to P_y relationship is potentially a key to understanding precipitation impact on evapotranspiration dynamics and amounts. However, the response of ET_y to P_y were different, even in two basins under similar climate and sharing like physiographic characteristics (Figure 2a). In Araxisi, ET_y shows low sensitivity to P_y (fitted line equation of $ET_y = 0.12$, $P_y + 472.9$ mm; $r^2 = 0.05$, $p = 0.06$), despite P_y values ranging widely from 638 to 1,574 mm around a mean of 978 mm (*SD* = 213 mm). In contrast, in Fluminimaggiore, ET_y is much more sensitive to P_y ($ET_y = 0.4$, $P_y + 138.5$ mm; $r^2 = 0.40$, $p < 0.0001$), perhaps because the range of P_y, while still wide (ranging from 480 to 1,191 mm; mean of 783 ± 189 mm), occupied a lower interval.

A closer look, however, shows that the difference in the sensitivity of annual *ET* to P_y between the two basins is caused by somewhat different seasonal distribution of precipitation and evapotranspiration. Using equations (2), (3), (5), and (6), we estimate seasonal *ET* contributions and compare ET_s of the two basins (Figures 2b and 2c). In summer, precipitation is almost entirely lost to evapotranspiration, so ET_s-P_s slopes are high in nearly all basins (=0.83); the slopes of the ET_s-P_s relationships decrease and become more variable in the other seasons. Despite the similarity in the ET_s-P_s relationship in summer, the ET_s-P_s slope in winter is 0.28 in Fluminimaggiore showing greater sensitivity than that in Araxisi (=0.00). In spring ET_s-P_s slope in

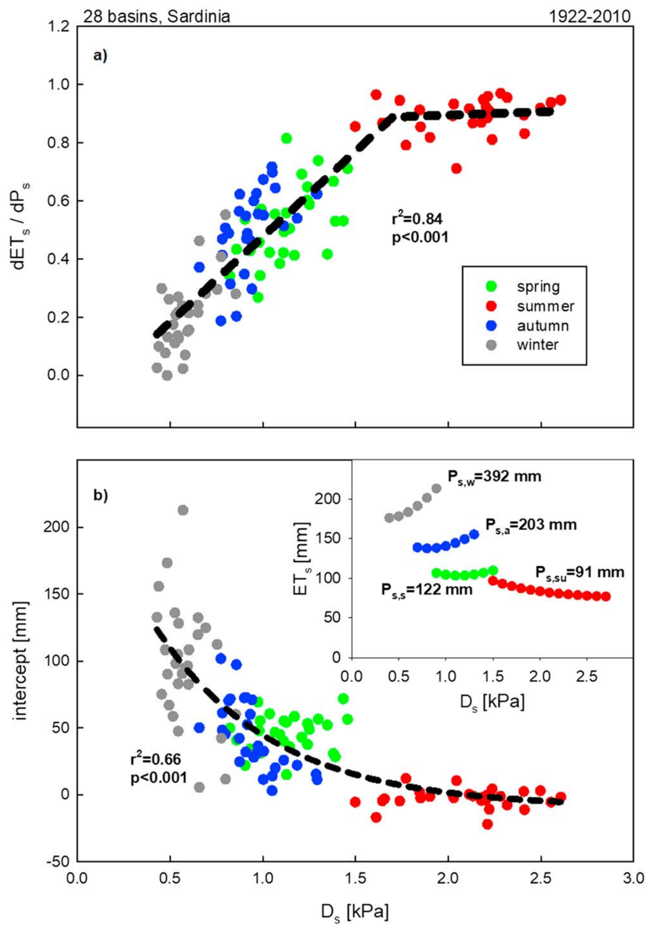

Figure 3. (a) Slope (dET_S/dP_S) and (b) intercept of the seasonal evapotranspiration-precipitation relationships versus vapor pressure deficit (D_S) of the 28 Sardinian basins. The equations of the fitted two-segment linear piecewise function in (a) and exponential function in (b) are (8) and (9) reported in the text respectively. The inset of (b) shows the sensitivity of the seasonal evapotranspiration (ET_S) to the range of D_S observed in each season using a mean seasonal precipitation.

Fluminimaggiore (=0.53) is much steeper than that in Araxisi (=0.27), remaining slightly steeper in autumn (0.62 in Fluminimaggiore versus 0.51 in Araxisi). Note that the ET_s-P_s slopes of spring and autumn are intermediate in sensitivity to those of the summer and winter seasons. We find this to be a general behavior for all the 28 basins (see Table S2 statistics of the goodness of fit for all the seasons and basins), so that a relationship between seasonal evapotranspiration and seasonal precipitation in each basin may be described as

$$ET_s = s_{ET,P}P_s + i_{ET,P} \tag{7}$$

where $s_{ET,P}$ and $i_{ET,P}$ are the slope and the intercept of the seasonal *ET-P* relationship, respectively. The variation of seasonal *ET-P* slopes and intercepts among the 28 basins are explainable based on the seasonal mean of one climate variable, the vapor pressure deficit (Figure 3), and a few physiographic basin properties (slope of the basin, fraction of woody vegetation cover, and soil depth). Higher seasonal *D* is associated with increasing sensitivity of seasonal *ET* to *P* ($s_{ET,P}$), and decreasing baseline *ET* (the *ET-P* intercepts, $i_{ET,P}$).

Before moving to synthesizing information over all available basins, we evaluated our estimates of winter and spring ET_s comparing to their corresponding *PET* at the Orroli flux site. The mean over years of ET_s/PET_s in winter (1.05, SD = 0.21) and spring (0.95, SD = 0.22) were, as expected, similar to 1.0 ($p > 0.05$). Furthermore, despite accounting for leakage, our estimate of winter *ET*, relative to that from the direct flux measurement, was 1.11 (SD = 0.11), not significantly greater than 1.0 ($p > 0.05$). These comparisons suggest that our seasonal estimates of *ET* and thus runoff are reasonable.

Combining the information shown in Figure 2 (but for all 28 basins) and Figure 3, it is possible to predict seasonal *ET* based on the respective *P* and *D*. We thus fit (1) a two-segment linear piecewise function describing the sensitivity of *ET* to *P* based on the variation of *D* (r^2 = 0.84, $p < 0.001$; Figure 3a)

$$s_{ET,P} = \frac{dET}{dP} = \begin{cases} -0.143 + 0.599D & \text{if } D \leqq 1.706 \text{ MPa} \\ 0.841 + 0.022D & \text{if } D > 1.706 \text{ MPa} \end{cases} \tag{8}$$

and (2) an exponential function for the baseline *ET* with respect to *P* (the intercepts), also in relations to variation of *D* (r^2 = 0.66, p $<$ 0.001; Figure 3b):

$$i_{ET,P} = -9.105 + 277\ e^{-1.575\ D} \tag{9}$$

We have considered 22 basins (Table S1) for fitting (8) and (9) as a calibration phase of the approach, and we used the remaining six basins (Table S1) for assessing the approach. We expected that some of unexplained variation may be related to physiographic basin properties. Indeed, the residuals of $s_{ET,P}$ sensitivity to *D* in autumn and spring were significantly explained by the basin's slope (*sl*), and in winter by the basin's woody vegetation cover fraction (f_{wv}); the residuals of *ET-P* intercept sensitivity to *D* in autumn and winter were significantly explained by the basin's slope and, in spring, by the basin's mean soil depth (Figure 4). Considering the 22 basins only (Figure 4):

$$\varepsilon_{s,a} = -0.56\ sl + 0.18;\ \varepsilon_{i,a} = 86.67\ sl - 27.19 \tag{10}$$

$$\varepsilon_{s,w} = -0.38\ f_{wv} + 0.16;\ \varepsilon_{i,w} = 183.7\ sl - 35.94 \tag{11}$$

$$\varepsilon_{s,s} = -0.69\ sl + 0.10;\ \varepsilon_{i,s} = 90.60\ sd - 13.66 \tag{12}$$

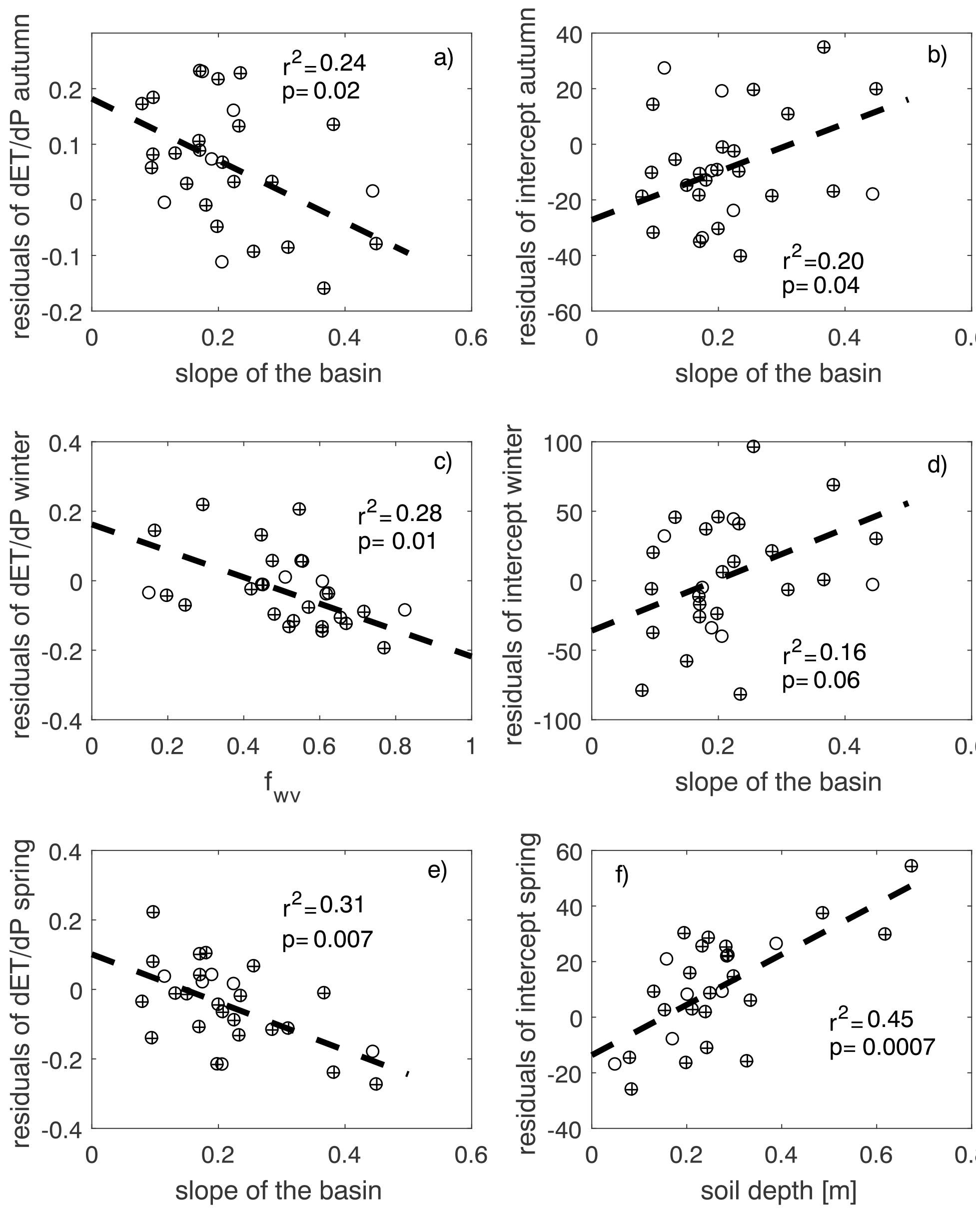

Figure 4. The residuals of the slopes of the evapotranspiration-precipitation relationships with vapor pressure deficit in (a) autumn, (c) winter, and (e) spring versus the slope of the basin, fraction of forest (f_{wv}), and slope of the basin, respectively; the residuals of the intercepts of the evapotranspiration-precipitation relationships with vapor pressure deficit in (b) autumn, (d) winter, and (f) spring versus the slope of the basin, slope of the basin, and basin soil depth, respectively. The equations of the fitted linear functions are (10)–(12) reported in the text with statistics of the goodness of fit (coefficient of determination, r^2, and P value).

where $\varepsilon_{s,a}$, $\varepsilon_{s,w}$, and $\varepsilon_{s,s}$ are the residuals of $s_{ET,P}$ sensitivity to D in autumn, winter, and spring respectively, and $\varepsilon_{i,a}$, $\varepsilon_{i,w}$, and $\varepsilon_{i,s}$ are the residuals of $i_{ET,P}$ sensitivity to D in autumn, winter, and spring, respectively. Note that we were not able to identify physiographic properties for explaining significantly the residuals of $s_{ET,P}$ and $i_{ET,P}$ sensitivity to D in summer, a season of low variation in both quantities.

In this way, seasonal ET can be estimated from seasonal P and D observations, and additional information on the fractional cover of woody vegetation, basin soil depth, and basin slopes can be used to further reduce the unexplained variation. Thus, annual ET can be predicted by summing the seasonal ET estimates, using ET_s estimated based on equations (7)–(12).

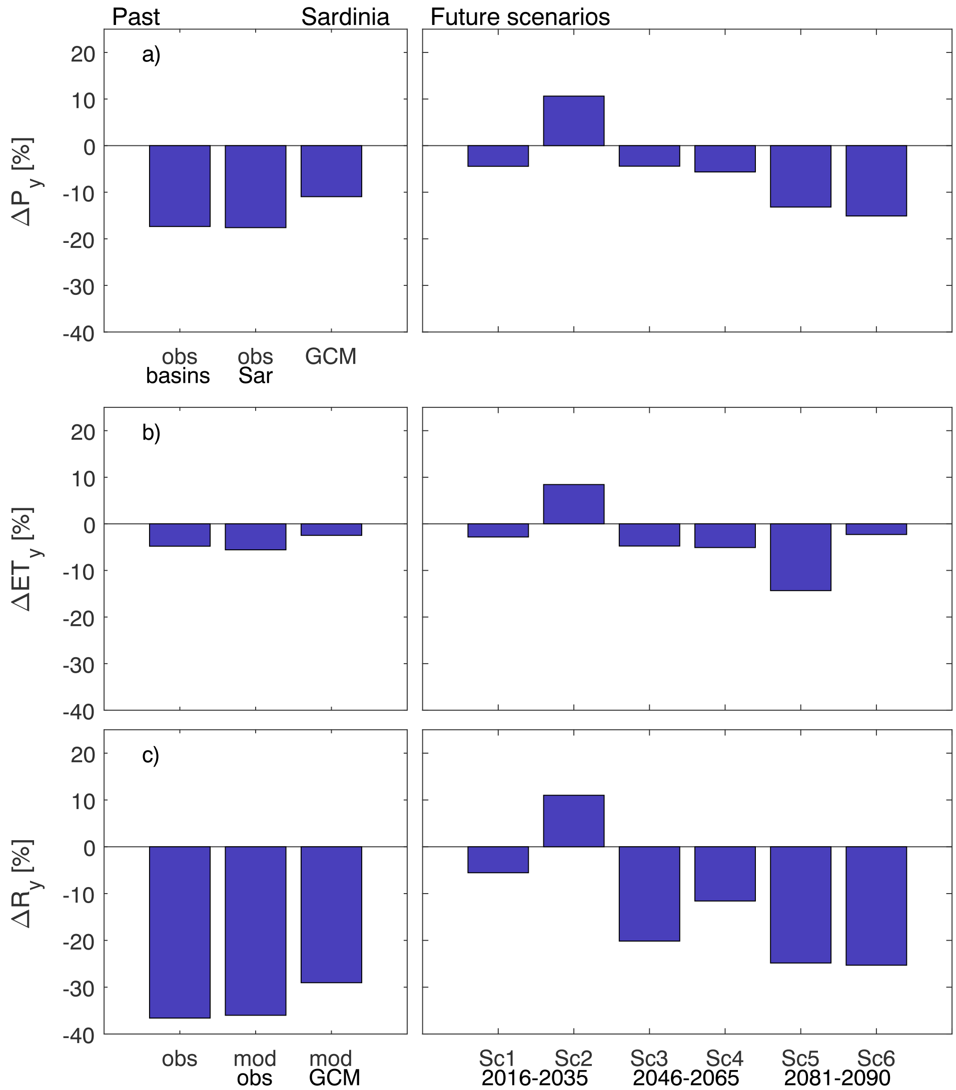

Figure 5. Mean changes of (a) annual precipitation (ΔP_y), (b) annual evapotranspiration (ΔET_y), and (c) annual runoff (ΔR_y) in Sardinia. Left panels are for mean observed changes in the past (1976–2000 compared with 1951–1975), and right panels are for mean predicted changes in the six future scenarios of Table 2 by the AOGCM (Table S3). For past ΔP_y, mean observed changes in the basins (obs, basins) and in the Sardinian rain gage system (obs, Sar) and mean predicted changes by the AOGCM are reported. For past ΔET_y and ΔR_y, mean observed changes in the basins (obs) and mean predicted changes using observed P_s and D_s (mod, obs) and using predicted P_s and D_s by the AOGCM (mod, GCM) are reported.

Historical values of annual *ET* were predicted reasonably well. Averaged annually for the 22 basins used to fit the empirical model, mean annual modeled ET_y of 512 mm (±30.1 mm *SD*) was similar to the mean annual observed ET_y of 533.9 mm (±67.8 mm *SD*; two-tailed *t* test $p = 0.17$) with root-mean-square error (rmse) of 56.5 mm, and Pearson correlation coefficient of 0.65. Similar comparisons for the six basins used for independent assessment of the model performance produced modeled mean ET_y of 522.2 mm (±68.2 mm *SD*) versus averaged observed mean ET_y of 545.8 mm (±93 mm *SD*; two-tailed t test $p = 0.63$; rmse = 49.3 mm; Pearson correlation coefficient of 0.87). Note that not using equations (10)–(12) for ET_s estimates (i.e., using only equations (7)–(9), and not correcting for basin-specific factors) reduced the accuracy of ET_y estimates (rmse of 62.8 mm; Pearson correlation coefficient of 0.54).

From the 12 AOGCMs of Flato et al. (2013), we selected the AOGCM (HadGEM2-AO) that simulates reasonable approximation of observed past seasonal precipitation and air temperature changes (1976–2000 compared with 1951–1975) in Sardinia (Figure 5a and Table S3). Using the AOGCM predictions of precipitation and

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Table 2
The Six IPCC Future Scenarios of the Fifth Assessment Report (Flato et al., 2013)

Future scenario	Representative Concentration Pathways	Period
Sc1	RCP 4.5	2016–2035
Sc2	RCP 8.5	2016–2035
Sc3	RCP 4.5	2046–2065
Sc4	RCP 8.5	2046–2065
Sc5	RCP 4.5	2081–2090
Sc6	RCP 8.5	2081–2090

minimum and maximum temperatures of the past (1951–2000), and six future scenarios, we simulate ET_y using equations (7)–(12). The future scenarios, chosen from the IPCC scenarios of the Fifth Assessment Report (Flato et al., 2013), are shown in Table 2. The AOGCM predictions produced a slight reduction in Sardinian average ET_y (= −2.5%), comparable with the observed low values (≈4.7%; Figure 5b; ET_y observed and modeled are not significantly different, p = 0.47), and consistent with the results of ET_y trends, showing small and insignificant temporal trends in all but two of the 10 basins (Table 1). This is in contrast with the more significantly decreasing trend of P_y (≈17.5%), a variable somewhat underestimated in past predictions of the AOGCM (−10.9%, Figure 5a, left). Note that the ET_y predictions for Sardinia are the averaged model results of the 10 basins, weighed by the basin area. Yearly runoff (R_y) is calculated for all scenarios as the balance of P_y-ET_y. The strong reduction (−36%) of R_y observed in the past (1951–2000) is well estimated using the past scenario of the AOGCM (−29%, Figure 5c, left; R_y

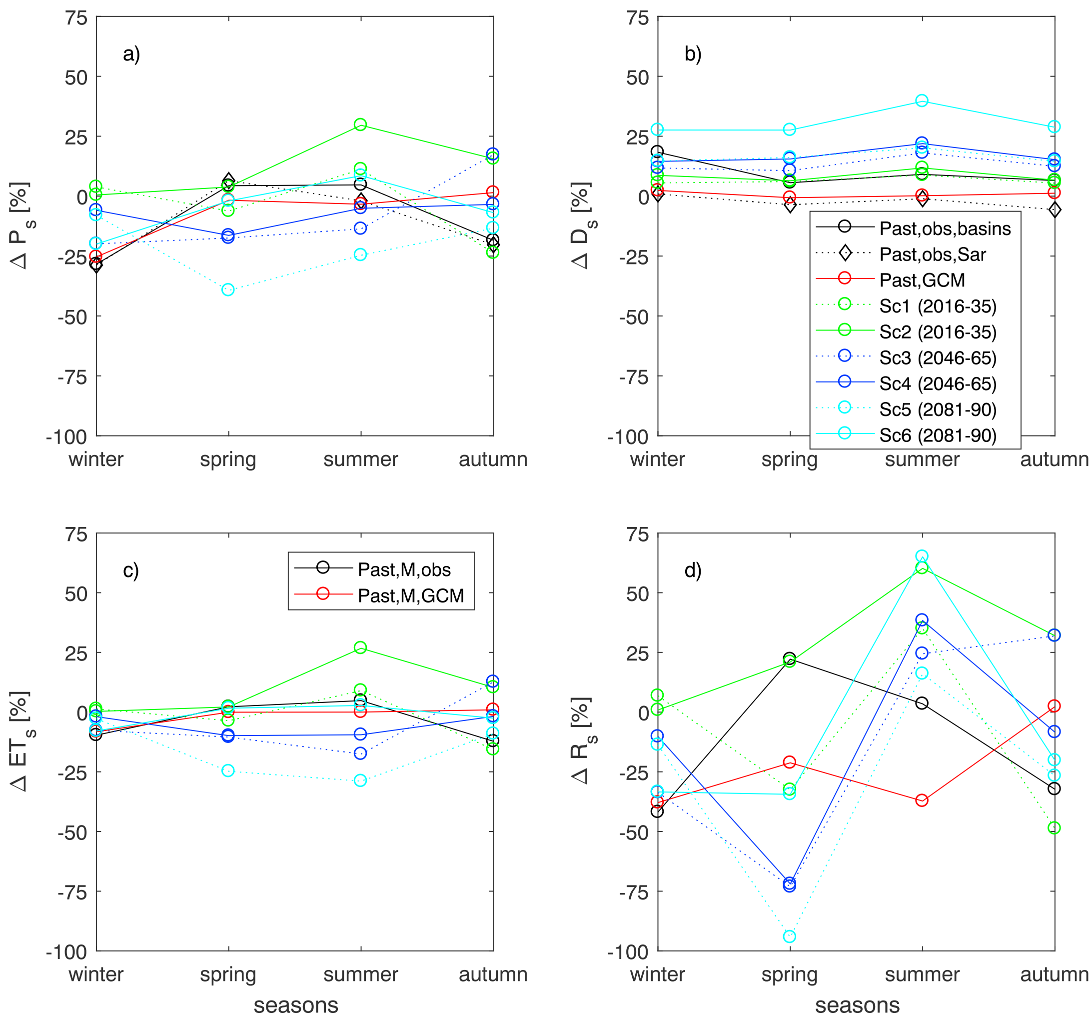

Figure 6. Mean observed changes in the past (1976–2000 compared with 1951–1975) in the basins (Past, obs, basins) and in all the Sardinian meteorological network (Past, obs, Sar), mean of the changes predicted in the past (Past, GCM) by the AOGCM (Table S3), and mean of the changes predicted by the AOGCM in the six future scenarios of Table 2 of (a) seasonal precipitation (ΔP_s) and (b) seasonal vapor pressure deficit (ΔD_s); mean changes of (c) seasonal evapotranspiration (ΔET_s), and (d) seasonal runoff (ΔR_y) in the past (1976–2000 compared with 1951–1975) using observed P_s and D_s (Past, M, obs) and predicted P_s and D_s by the AOGCM (Past, M, GCM) and in the six future scenarios of Table 2.

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observed and modeled are not significantly different, $p = 0.26$), although, as expected, R_y was slightly underestimate, consistent with the slight underestimation of P_y simulated by the AOGCM (Figure 5a, left).

Different changes of precipitation, in both amounts and signs, are predicted by the six future scenarios (Figure 5a, right). Two scenarios, Sc2 and Sc6, predict higher change rate ($>|10|\%$) but with opposite signs owing to opposite predictions of winter and autumn precipitations (Figure 6), the main seasons of P_y in Sardinia (Montaldo & Sarigu, 2017). In general, the changes in precipitation predicted by the six scenarios produced significant changes ($p < 0.1$) in both ET_y (Figure 5b, right) and R_y (Figure 5c, right). Evapotranspiration is sensitive to intra-annual rainfall distribution. ET_y decrease differently for Sc5 and Sc6 (14% and 2% respectively; Figure 5b, right), although the decrease of P_y is high in both scenarios (13% for Sc5 and 15% for Sc6; Figure 5a, right). In Sc5, P_s is predicted to decrease in all seasons, but especially in spring (39%) and summer (24%), two seasons in which *ET* consumes much of precipitation, reducing predicted ET_s (29% in summer and 25% in spring). In contrast, Sc6 predicts lower P_s in winter (20%) and slightly in autumn (7%), but higher P_s in summer (9%), greatly impacting annual *P* but not ET_s, which decreased only 8% in winter and 3% in autumn, and slightly increased (3%) in summer (Figure 6).

Similar to changes in P_y, changes in R_y are mainly related to those of $P_{s,w}$, as can be readily observed when comparing Sc1 and Sc3 scenarios. Both scenarios predict small decreases in P_y (4.4%) but different reductions of R_y (5% and 20%, respectively). This is because $P_{s,w}$ changes are larger in Sc3 (−20%) than in Sc1 (+4%), compensating for the reductions in P_s predicted for other seasons (Figure 6).

Although seasonal changes in *D* are positive for all six scenarios and all seasons (up to the highest scenario, Sc6, for which *D* increased ~40%, Figure 6), ET_y was insensitive to these changes.

4. Discussion and Conclusion

The analyses of data from the 28 Sardinian basins showed that warming climate and increasing vapor pressure deficit will likely not have a large effect on evapotranspiration, meaning *ET* and, thus runoff, is mostly affected by the amount and distribution of precipitation (Figures 2 and 3). Future scenarios that alter the amount of *P*, especially during the winter months, suggest the greatest impact on future water yields in Sardinia. One scenario (Representative Concentration Pathway [RCP] 8.5; see Table 2) predicts changes in precipitation making water more available in the near future, but less available further on. Following we evaluate the approach and predictions.

4.1. Seasonal Estimates of Evapotranspiration

Most existing approaches for estimating ET_y based on Budyko's model (Choudhury, 1999; Roderick & Farquhar, 2011; Xu et al., 2014; Zhang et al., 2001; Zhang et al., 2008) neglect seasonality, and thus the need to account for changes in soil moisture. In addition, these studies to not specifically treat the likelihood that leakage may be incorrectly assigned to *ET*, estimated as the difference between the annual values of precipitation and runoff. Our approach allows estimating annual evapotranspiration while accounting for the impact of seasonality of precipitation on evapotranspiration and water yield. The approach forced us to allocate some of the P_s to leakage when the storage capacity of the relatively thin soil, which we must explicitly treat, is exceeded, and the estimate of ET_s is greater than PET_s. This may not be entirely correct. Some studies show that water can be stored within the underlying rock, and be accessible for tree water uptake and transpiration (e.g., Schwinning, 2010; Witty et al., 2003). This shortcoming, however, reflects a pervasive lack of information about the contribution of this storage compartment to ET_s, contribution ignored in most hydrological models. Adjusting for such storage will improve our estimates of ET_s; however, at this time we have no information to account for this pool in any defensible way. Nevertheless, we note that annually, our estimate of leakage relative to annual *P* amounted to only 2.0% (S.D. 1.9%) and that in wet winters and springs, our estimates of ET_s were similar to PET_s and *ET* at the Orroli flux site.

Both seasonal and annual *ET* varied greatly within each watershed, in part reflecting the variation in precipitation among years (Figure 2). Decreasing *P* may be associated with increasing *D*, but only when soil moisture decreases below a level where stomata conductance is reduced (Oishi et al., 2010); however, the opposite responses of *D* and stomatal conductance to decreasing soil moisture produce negligible effect on transpiration (Montaldo & Oren, 2016; Oishi et al., 2010). Thus, *D* may have a larger effect on ET_s during periods in which soil moisture is sufficiently high to have no effect on stomatal conductance. This may be reflected in the larger variance of ET_s in winter than in other seasons, but this idea was not supported when relating the residuals of the relationships between ET_s and P_s to D_s, the seasonal vapor pressure deficit (Table S2). Another cause for the large unexplained variation especially in annual and winter ET (see examples in Figure 2 and Table S1) is the uncertainty of estimated amount of soil moisture stored in the soil at the end of each season. However, we note again that despite the uncertainty injected by estimates of changes of soil moisture (and of leakage), winter ET_s estimates are close to the eddy-covariance based estimates at the Orroli site. Overall, as can be expected, P explained most of the temporal variation of ET_s in spring, summer, and autumn.

In modeling the effect of future climate on evapotranspiration, and consequently water yield, we used space-for-time substitution (Crimmins et al., 2011; Lenoir et al., 2008). The spatial variation in ET_s among watersheds was explained by their prevailing seasonal D, excluding the summer when the variation among watersheds was very small (nearly all P was converted to ET in all watersheds and all years; Figure 3 and Table S2). With increasing prevailing D_s among basins, here a surrogate to Budyko's available energy, the slope of the ET_s-P_s increased, while the intercept decreased. Note that conveniently, the intercept roughly formed a continuous relationship with D_s across seasons, but this coincidental outcome of the particular partitioning selected in this study to represent specific soil moisture conditions. Expressing ET_s (as in Figure 2) on a daily instead of a seasonal scale would alter the relationship shown in Figure 3 for the intercept (there will be small difference among the seasons except for the summer), but not the slope, thus requiring a different approach to predicting the intercept. The outcome of the opposite directional change of the slopes and intercepts is shown as inset in Figure 3b, where a mean seasonal precipitation is used with the range of D_s observed in each season, and the corresponding sensitivity of ET_s to P_s and the intercept. The analysis shows that although there are some effects of differing basin D_s on ET_s in all seasons, the canceling effects of the slope and intercept in relations to basin D_s result in a fairly conservative ET_s, ranging <20 mm among watersheds, except in winter. In winter, basins with higher D_s, mostly representing lower elevations, are likely to use more of the precipitation in evapotranspiration. We suggest that this spatial variation is a reasonable representation of the response to temporally changing D_s with climate.

The variations from the trend lines of the sensitivity of ET_s to D_s, observed in all seasons but the summer, were related to a greater or lesser extent to basin properties, and mostly to the slope. This is not surprising because slope angle affects the energy input under identical climate conditions and aspect, and often reflect a set of other variables, such as vegetation and rock content, soil depth, and species composition. Soil depth and the fractional vegetation cover (f_{WV}) were useful in explaining some of the variation remaining after the effect of D_s was accounted for. We used the combined information in these set of relationships (Figures 3 and 4) to predict how ET_s of these 28 basins will respond to future changes in P_s and D_s, assuming that the basin properties will not change. Thus, an underlying assumption in these predictions is that changes in vegetation function upon changing climate are instantaneous, but that vegetation cover remains the same, thus reflecting the upward migration of species observed over the past 100 years in the region (Lenoir et al., 2008).

We propose a simplified approach for estimating evapotranspiration at an annual time scale, accounting for seasonal variations in commonly available meteorological variables (precipitation and vapor pressure deficit), thus avoiding the computationally intensive approach based on hydrologic model running at finer time scales (e.g., Ye et al., 2015). The approach can be directly used across the Mediterranean region. Indeed, the wide range of annual precipitation in Sardinia (Figure S1) is typical of both the western and eastern Mediterranean Sea basin (Philandras et al., 2011), and Sardinian climate categories according to Deitch et al. (2017) classification, which considers also the seasonality of rainfall, are representative of ~50% of the Mediterranean basin. Where runoff and precipitation time series and physiographic basin properties are available, site-specific estimates of (8)–(12) can be refined using the proposed approach. Indeed, because our approach is based on simple criteria and a few rules (equations (1)–(6)) accounting for seasonal soil moisture changes and likely leakage, it can be readily adapted to, and tested in other systems.

4.2. The Likely Impacts of Future Climate on Evapotranspiration and Water Yield

Our 28 basins captured well the changes in seasonal precipitation of Sardinia from the early to the later period of observation (Figure 6a) but produced a greater increase in D_s than was observed in the larger measurement network (Figure 6b). In fact, the GCM estimates of these past changes were closer to the Sardinian mean, with only one obvious deviation—not capturing the large decrease in $P_{s,a}$. This produced an underestimation of the decrease in autumn ET_s (Figure 6c), with a complimentary effect on the decrease of autumn runoff (Figure 6d). The relative effects on runoff are naturally larger, because this flux is smaller than ET_s in all seasons except winter. Thus, a small underestimation of spring and summer P_s translated into a large underestimation of spring and summer runoff.

The future scenarios of the AOGCM were made for three periods of increasing distance into the future (Table 2), each with two different atmospheric CO_2 concentrations (Flato et al., 2013). We note that there is little evidence of direct CO_2 effect on the hydrological budget of forests (Schäfer et al., 2002; Tor-ngern et al., 2015). Two scenarios (Sc1 and Sc2) predicted more precipitation in winter, bucking the trend observed in the past data (Figure 1a), but the increase may reverse further into the future (Figure 6a). Because the sensitivity of ET_s to P_s is highest in summer and lowest in winter, and available energy (indicated by D_s) is already high in summer, changes in P_s impact summer ET_s the most and winter ET_s the least (Figure S2). In effect, changes in D_s offer only a small modification of the strong effect on ET_s exerted by changes in P_s (Figure S2). Water yield in these basins, however, is a smaller component of the hydrological budget, nearing ET_s only in winter. Therefore, changes in P_s trigger larger relative effects on R_s than ET_s, but the direction of the effect is similar in all but the summer period (Figure S2). In the summer, runoff is so low, that relative changes in this quantity reflect essentially noise.

The approach we used allowed assessing the effects of changes in both total precipitation and their seasonal distribution on the annual quantities of ET_y and R_y in the future (Figure 5). Sc3 and Sc4 scenarios do not predict high changes of P_y but predict decreasing spring and summer precipitation, the two seasons contributing the highest proportion but lowest quantity to ET_y. Winter is the season in which most precipitation (48% of the yearly precipitation) and runoff production (averaging ~70%) occur in Sardinia's basins. However, the variation in winter P_s has little effect on ET_s; thus, even without changes in annual precipitation, a change in its seasonal distribution will impact ET_y. Overall, predicted ET_y changes are negative for five of the six scenarios (Figure 5b, right); Sc2 predicts a positive P_y change, much of it associated with increased autumn precipitation, a season contributing the lowest proportion of P_s to ET_s and most of R_s (Figure 6). This positive effect is in contrast to published predictions for the Mediterranean region, as is the size of the change (+10% ET_y). Another scenario (Sc5) produced a negative, yet still a large change of ET_y (−15%). Previous studies in the Mediterranean region predicted negative changes of ET_y, ranging from near zero (2011–2040) to −4.2% (2071–2098; Stefanova et al., 2017) in Spain, and 3–4% (2035–2065) in Spain and Greece (Gampe et al., 2016), consistent with predictions for the region from a global-scale perspective (under B1 scenario, by 2090; Pan et al., 2015).

Although in all 10 Sardinian basins annual precipitation and, even more strongly, annual runoff decreased over the 1922–2011 period due to the negative trend of the winter precipitation (Figure 1), the yearly ET trends are not always significantly negative (Table 1), confirming the uncertainty on historical ET trends, a phenomenon observed worldwide (Jung et al., 2010; Miralles et al., 2014; Wang et al., 2010). In contrast, to the sensitivity of ET_y to seasonal changes in the distribution of precipitation, this quantity is insensitive to D changes. This is consistent with finding at daily scale in the summer during a period in which soil moisture at a midelevation Sardinian site was low and constant, and latent heat flux was unrelated to large variation in D (Montaldo & Oren, 2016).

Thus, predicted changes in R_y are strongly related to those of $P_{s,w}$. The two most contrasting scenarios for runoff production were Sc2 and Sc6, in which Sc2 predicts a reversal of the past precipitation trend and Sc6 (as did Sc5) predicts further large decreases of precipitation and runoff. The results (except from Sc2) are consistent with previous studies on future climate impacts on runoff in Mediterranean regions (D'Agostino et al., 2010, −25% by 2050 in Italy; Morán-Tejeda et al., 2015, −15% for 2021–2050; and Stefanova et al., 2017, −1% to −11% over ~85 years beginning in 2011, both in Spain). Indeed, only one study, using previous IPCC climate scenarios, predicted an increase in winter surface flow (as is implied in Sc2), but the annual water yield decreased nearly 50% (2081–2100; Molina-Navarro et al., 2014). Here we used the most recent Fifth IPCC Assessment Report (Flato et al., 2013) and limited our analysis to the only model of 12 showing reasonable approximation of past precipitation and vapor pressure deficit observations in Sardinia.

The approach proposed here can be utilized to estimate the effect of P_s on seasonal runoff, allowing better tailoring of reservoir capacity to the timing of supply of, and demand for water. In general, the relative changes of R_y are greater than P_y. This is because, Sardinian basins in general show high degree of precipitation elasticity of streamflow (Montaldo & Sarigu, 2017), a parameter reflecting the sensitivity of streamflow to changes in climate (Andreassian et al., 2016; Schaake & Chunzen, 1989). Thus, although in the near future Sc2 suggests some relief from water shortage, in the more distant future Sc3 to Sc6 predict decreases in water yield (up to −25%) relative to current yields, a large decrease for a water resources management system that already has difficulties meeting the needs of the island for over a decade (Montaldo & Sarigu, 2017; Statzu & Strazzera, 2009). To the degree that the Sc2 proves accurate, it suggests some relief for a period of time. Rather than squandering this repose, policies empowering enhanced strategies for water resources management (e.g., increasing the number of low capacity reservoirs, reservoirs interconnectedness, and desalinization) should begin immediately in preparation for a drier future condition.

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