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Hydrology and Earth System Sciences Discussions

Spatio-temporal trends in the hydroclimate of Turkey for the last decades based on two reanalysis datasets

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Abstract. We present a regional assessment of the spatiotemporal trends in several hydro-climate variables from 1979 to 2010 in Turkey, one of the vulnerable countries of the Eastern Mediterranean to climate change, using the two reanalysis products of ECMWF: ERA-Interim and ERA-Interim/Land, namely. The trend analysis revealed that an average warming of 1.26 °C occurred in Turkey from 1979 to 2010, with high confidence intervals (95 to 99%) mostly. Geographically, the largest warming (up to 1.8 °C) occurred in the Western coastal areas next to Aegean Sea and in the South-East regions. The increasing trend of air temperature was confirmed by the comparisons with the measurements from several meteorological stations. With respect to the regional trends in hydrological variables, ERA-Interim and ERA-Interim/Land revealed quite different pictures: the ERA-Interim dataset indicated that there have been significant decreasing trends of precipitation, snow water equivalent and runoff in some parts of inner/South-eastern Anatolia (up to 250 mm decrease totally in the upstream of Euphrates, Kizilirmak and Seyhan basins), while ERA-Interim/Land showed none or minor trends in the same areas. Comparison of the precipitation trends by the two datasets with some rain gauge data distributed over Turkey revealed that none of the products is consistently closer to the observations. Based on the trend assessment of the hydrological trends by the two datasets and the comparisons with the observation data and other trend studies in the study area we can conclude that, except for some evapotranspiration trends over Mediterranean and Black Sea, there have not been clear and considerable trends of precipitation, snow water equivalent and runoff quantities over Turkey from 1979 to 2010, despite the considerable warming for the same period throughout the country. In this respect, we can suggest that, the impacts of global warming on the water cycle are rather unpredictable especially at regional scale.

1 Introduction

The future climate simulations show that the Mediterranean region is one of the most vulnerable zones in the world. The climate models consistently predict that Mediterranean basin will be affected adversely by climate change in the future (Giorgi and Lionello 2008; Lelieveld et al. 2012; Ozturk et al. 2014; Türkeş et al. 2011), while IPCC reports (2007, 2014) indicating significant increases in temperatures besides considerable reductions in precipitation throughout Mediterranean and the Middle East by the end of the twenty-first century. Observational records and climate projections provide abundant

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evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems (Yücel et al., 2014). Milly et al (2005) report 10-30% reductions in runoff in the Middle East by the year 2050.

Apart from the future simulations, several studies show that climate and water cycle of the Mediterranean and the Middle East have already undergoing significant changes in the recent decades whether they are due to climate change and/or direct human influences. Using observations from the Gravity Recovery and Climate Experiment (GRACE) satellite mission, Voss et al. (2013) indicated an alarming rate of decrease in total water storage in the north-central Middle East from 2003 to 2009. Yucel et al. (2014) investigated the regional trends in hydroclimatic variables in the eastern Anatolia, Turkey between 1970 and 2010 based on the streamflow and meteorological point measurements. The seasonal snowmelt runoff in the mountainous basins of eastern Turkey has experienced changes over the past several decades (Sen et al., 2011; Sönmez et al., 2013). Sen et al (2011) indicate that streamflow timings of the Euphrates and Tigris rivers shifted to the earlier days between two consecutive 17-year periods (i.e. 1972-88 and 1990-2006).

Detection of trends and their significance with confidence generally requires consistent and long-term records of variables considered, especially in the case of detecting climate change driven trends (Gokmen et al., 2013). As stated by Leroy et al. (2008), it is obvious that the longer the time series, the easier it should be to distinguish a trend from natural variability (and measurement uncertainty), because shorter periods of record generally have small signal-to-noise (S / N) ratios (Allen et al., 1994). Based on a hypothetical data set with certain statistical characteristics, Leroy et al. (2008) determined the minimum detection time as about 33 yr for detecting a global warming signal of 0.2K decade^{-1}. Similarly, assessing the trend consistency over a range of timescales (from 10 to 32 yr), Santer et al. (2011) states that multi-decadal records are required for identifying the human effect on the climate variables (e.g. temperature) with high statistical confidence.

The time series of temperature data from meteorological stations are widely used to assess the historical trends, however, as highlighted by Sen et al (2011), point measurements of temperature come with important shortcomings such as inadequate representation of mountainous areas and contamination by urban heat island effects as most stations are located in cities (e.g. Ezber et al., 2007).

Reanalysis products provide invaluable temporally and spatially continuous information on various atmospheric variables ranging from near-surface temperature, wind and solar radiation components to hydrological parameters including precipitation, evapotranspiration and runoff. Besides the weather forecast services, one of the primary aims of the reanalysis product by The European Centre for Medium-Range Weather Forecasts (ECMWF) is stated to construct a long-term homogeneous record of the atmosphere, which is achieved by systematic assessment, inter-calibration, and integration of the observational record in the context of physical models (Dee et al. 2011). Simmons et al. (2010) show that surface temperature and humidity trends from 45-yr ECMWF Re-Analysis (Era-40; Uppala et al. 2005) and ERA-Interim are in excellent agreement with estimates obtained from climatological land station data from Hadley Centre. Balsamo et al. (2010) evaluated the suitability of ERA-interim precipitation estimates for land applications at various timescales from daily to annual over the conterminous US. Decker et al. (2012) showed that the land surface evaporation of ERA-Interim compared

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favorably with the flux tower observations and with other reanalysis. The results of the studies based on reanalysis were also used in 5th Assessment Report (IPCC, 2014), which state that adequacy of trend detection using reanalysis data depends on the variable under consideration, the time period and the region of interest. For example, surface air temperature and humidity trends over land in the ERA-Interim reanalysis compare well with observations (Simmons et al., 2010), but polar tropospheric temperature trends in ERA-40 disagree with trends derived from radiosonde and satellite observations (Bitz and Fu, 2008; Grant et al., 2008; Graversen et al., 2008; Screen and Simmonds, 2011). Recently, ECMWF has introduced a new product, namely ERA-Interim/Land, which incorporates the up-to-date land model developments via combining near-surface meteorological fields from ERA-Interim with the latest version of the HTESSEL land surface model (Hydrological Tiled ECMWF Scheme for Surface Exchanges over Land), which is an extension of the TESSEL scheme (van den Hurk et al., 2000) used in ERA-Interim. Balsamo et al. (2015) states the added-value components of The ERA-Interim/Land as soil, snow and vegetation description upgrades, as well as a bias correction of the ERA-Interim monthly-accumulated precipitation based on GPCP v2.1.

In this study, we utilized reanalysis datasets of ECMWF (both ERA-Interim and ERA-Interim/Land) to analyze the spatiotemporal trends in several hydro-climate variables (i.e. near-surface air temperature, precipitation, snow water equivalent, runoff and evapotranspiration) at regional scale. More specifically, this study aims at;

- determining the significance and magnitude of the hydro-climatic trends over the last decades (from 1979 to 2010) in a spatially distributed manner,
- and inter-comparing the trends detected by ERA-Interim and ERA-Interim/Land datasets

in Turkey, one of the vulnerable countries of the Eastern Mediterranean to climate change. The Anatolian peninsula not only shows high gradients of topography (from sea level to above 5,000 m) and hydro-climate (yearly average total precipitation ranging from around 400 mm in the semi-arid inner Anatolia plateau to above 2,000 mm in the humid Northeastern Black Sea coast), but also has been undergoing severe human interferences through land use changes due to deforestation, conversion to agricultural lands, expansion of urban lands, building of dams, among others.

2 Materials and Methods

2.1 The study area

Turkey is situated in Anatolia (97%) and the Balkans (3%), bordered by the Black Sea in the North, the Aegean Sea and the Mediterranean Sea in the west and the south (Fig. 1). Due to its complex terrain and the long land-sea boundary interactions, the climate of the country varies from the Mediterranean (in the coastal areas in the West and South) to the continental climate in the inner Anatolian plateau, while the Black Sea coast in the North is humid due to the orographic effect by the steep topography.

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Annual precipitation is relatively low (around 400 mm) in the semi-arid Central Anatolia plateau, it varies from 600 to 1,300 mm in the Aegean and Mediterranean coasts, while eastern coast of the Black Sea receives the greatest amount with over 2,000 mm annual rainfall (Bozkurt and Sen, 2011).

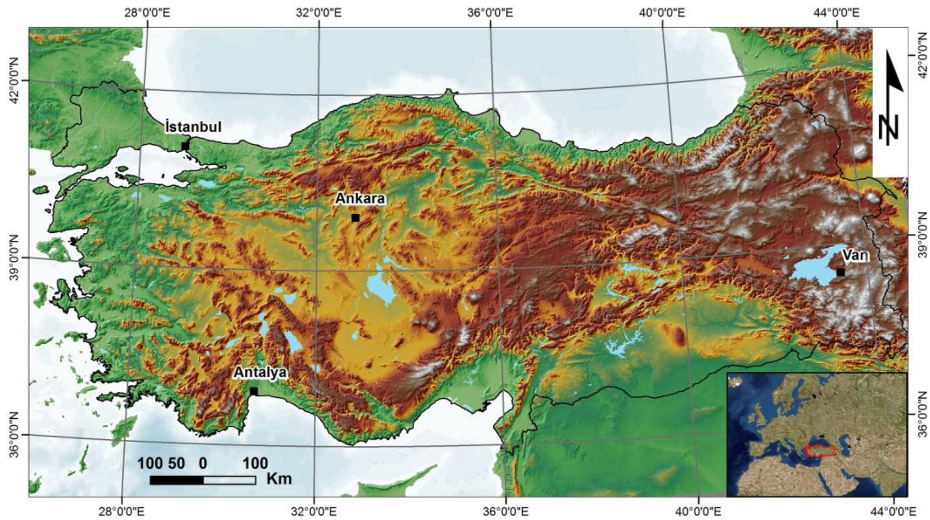

Figure 1. The geographic location and the topography of the study area.

2.2 Methods

The time series of temperature and all the hydrologic variables were analysed using the Mann-Kendall non-parametric test for detecting the significance and the direction of the trend. Mann (1945) originally used this test and Kendall (1975) subsequently derived the test statistic distribution. The Mann-Kendall test has two parameters that are of importance for trend detection: the significance level that indicates the trend's strength (p value), and the slope magnitude (Kendall's Tau) estimate that indicates the direction as well as the magnitude of the trend. After detecting the significance level and the direction of trends by the Mann-Kendall test, the magnitude (slope) of trends were determined using linear models.

In order to apply the trend analysis in a spatially distributed manner, the Mann-Kendall test was applied using the R software and the Kendall package for R (http://cran.r-project.org/web/packages/Kendall/Kendall.pdf).

2.3 Data

In this study, we used two different reanalysis products by ECMWF: The ERA-Interim and ERA-Interim/Land, namely. Table 1 provides a summary of the variables that were considered for the trend analyses.

The ERA-Interim atmospheric reanalysis is built upon a consistent assimilation of an extensive set of observations (typically tens of millions daily) distributed worldwide (from satellite remote sensing, in situ, radio sounding, profilers, etc). Besides ERA-Interim, we also used a new product by ECMWF, namely ERA-Interim/Land. Balsamo et al. (2015) indicate that the ERA-Interim/Land is produced by combining near-surface meteorological fields from ERA-Interim with the latest version of

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the HTESSEL land surface model. HTESSEL is an extension of the TESSEL scheme (van den Hurk et al., 2000) used in ERA-Interim. HTESSEL includes an improved soil hydrology (Balsamo et al., 2009), a new snow scheme (Dutra et al., 2010), a multiyear satellite-based vegetation climatology (Boussetta et al., 2013), and a revised bare soil evaporation (Balsamo et al., 2011; Albergel et al., 2012).

The original ERA-Interim is produced at T255 spectral resolution (about 80 km) and covers the period from January 1979 to present. While ERA-Interim/Land covers the period between 1979 and 2010. To allow comparison, we used 1979-2010 as the study period for both datasets. Also, we used a spatially rescaled version (0.25X0.25 degrees) of the datasets as provided by ECMWF.

Table 1. The summary of the data used in the study

Variable	Source	Spatial resolution	Temporal coverage
Air temperature	ERA-Interim	0.25 degrees	1979 – 2010
Total precipitation	ERA-Interim ERA-Interim/Land	0.25 degrees	1979 – 2010
Snowmelt	ERA-Interim ERA-Interim/Land	0.25 degrees	1979 – 2010
Evapotranspiration	ERA-Interim ERA-Interim/Land	0.25 degrees	1979 – 2010
Surface runoff	ERA-Interim ERA-Interim/Land	0.25 degrees	1979 – 2010

3 Hydro-climate trends

3.1 Air temperature

As the ERA-Interim/Land product mainly focused model updates related to the hydrological variables and did not include an air temperature output, here only the results from ERA-Interim are presented. Figure 2a shows that, apart from a minor region at the very Eastern border of the country, Turkey has experienced significant increases of air temperature from 1979 to 2010. The significance level for the increasing temperature trends was high ($p<0.01$-0.05) in most of the country. During the 32 years study period, the magnitude of the temperature increase generally ranged between 0.8 (about 0.25 degrees per decade) and 1.8 degrees (about 0.56 degrees per decade) totally: the highest increases occurred in the Western coastal areas next to Aegean Sea and in the South-East regions (and in other Middle East countries including Iraq and Syria).

According to Yucel et al. (2014), the daily average temperature in the eastern Anatolia was increased by 1.3 ^{o}C between 1970 and 2010, which corresponds to an increasing rate of about 0.32 degrees per decade, confirming the similar rate of increases in the Eastern regions shown in Figure 2b. Also, assessing 850 hPa temperature differences between 1990-2006 and 1972-1988 periods, Sen et al. (2011) indicated that the largest warming (over 2 ^{o}C) occurred over the Aegean Sea and Western Turkey, due to the propagation of warmer air from over the Balkans and Aegean Sea toward eastern Anatolia after about 25 February.

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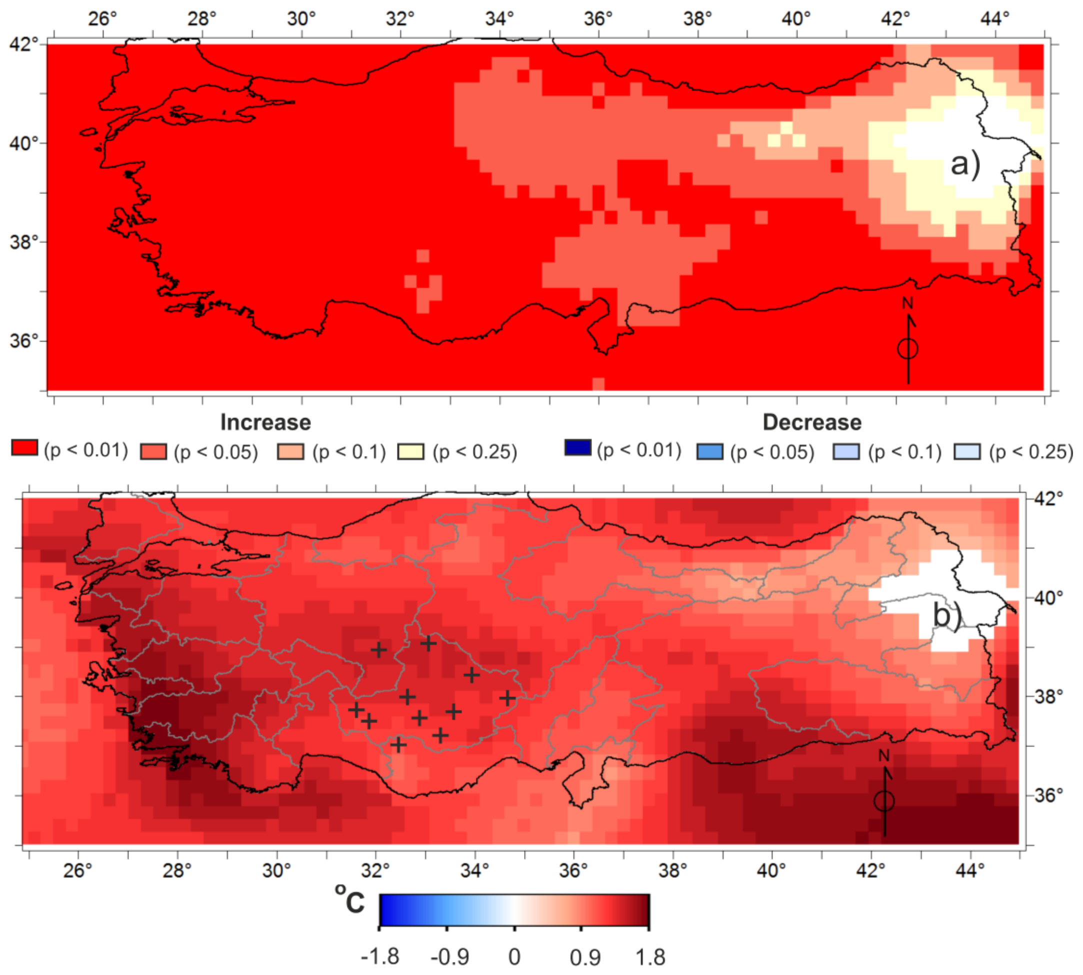

Figure 2. The distribution of a) the presence of the significant Air Temperature trends at different levels of statistical significance and b) the magnitudes of the total trends in the Air Temperature for the 32-years study period (1979-2010) from ERA-Interim dataset. The plus signs indicate the locations of the meteorological stations used for the comparison.

Showing the comparison of the yearly average air temperature estimates by ERA-Interim (overall average for the country) with the average of meteorological measurements from several stations, Figure 3a indicates that both the stations and ERA-Interim data shows very similar yearly changes, confirmed by the slope of the fitted trend lines. Analyzing the measurements of 249 stations (1970-2014) distributed over the country, Meteorology Service of Turkey indicated 1992 as the coldest year (avg. 11.4 ^{o}C) and 2010 as the warmest year (avg. 15.1 ^{o}C). In addition, Figure 3b shows that the overall increase of air temperature was relatively higher in the lowlands compared to the high mountainous regions.

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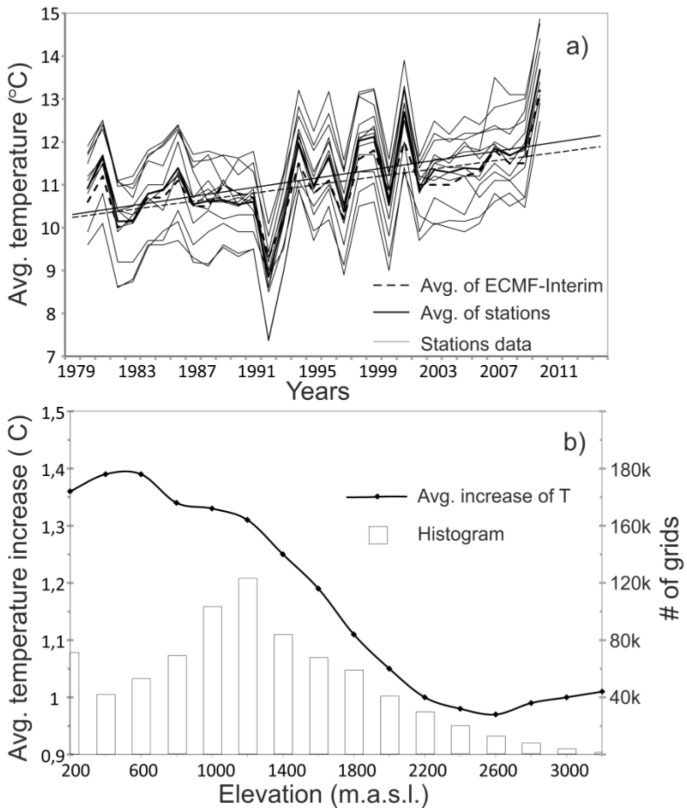

Figure 3a. The comparison of the yearly country-averaged air temperature estimates by ERA-Interim with the yearly average temperatures from the meteorological stations shown in Figure 2b. **3b)** The distribution and the histogram of the average temperature increases (over study period) with respect to elevation.

3.2 Total precipitation

According to the comparison of Figures 4a and 4b, the significance level and the direction of the total precipitation trends by ERA-Interim (Fig. 4a) and ERA-Interim/Land (Fig. 4b) are distributed quite differently: except for the Western part and some of the South-eastern regions, ERA-Interim and ERA-Interim/Land reveal contradicting precipitation trends in most of the study area. While ERA-Interim indicated highly significant decreasing trends of total precipitation in some parts of inner/South-eastern Anatolia and at the very North-Eastern part, ERA-Interim/Land showed either weak increasing trend or no-trend in the same areas. In terms of the magnitude of trends, ERA-Interim indicated as high as 250 mm decrease of precipitation totally over the 32-years period in some parts of Euphrates and Tigris River Basins (Fig. 4c), ERA-Interim/Land either showed no-trend in most of the upstream parts of Euphrates and Tigris or only less than 100 mm decrease totally in some downstream parts of the same basins. Analyzing the meteorological data from 10 stations distributed over Eastern Anatolia, Yucel et al. (2014) indicated that there are generally no statistically meaningful trends in annual total precipitation over the study period (1970-2010), which is generally more in line with the trends detected by ERA-Interim/Land than ERA-Interim data.

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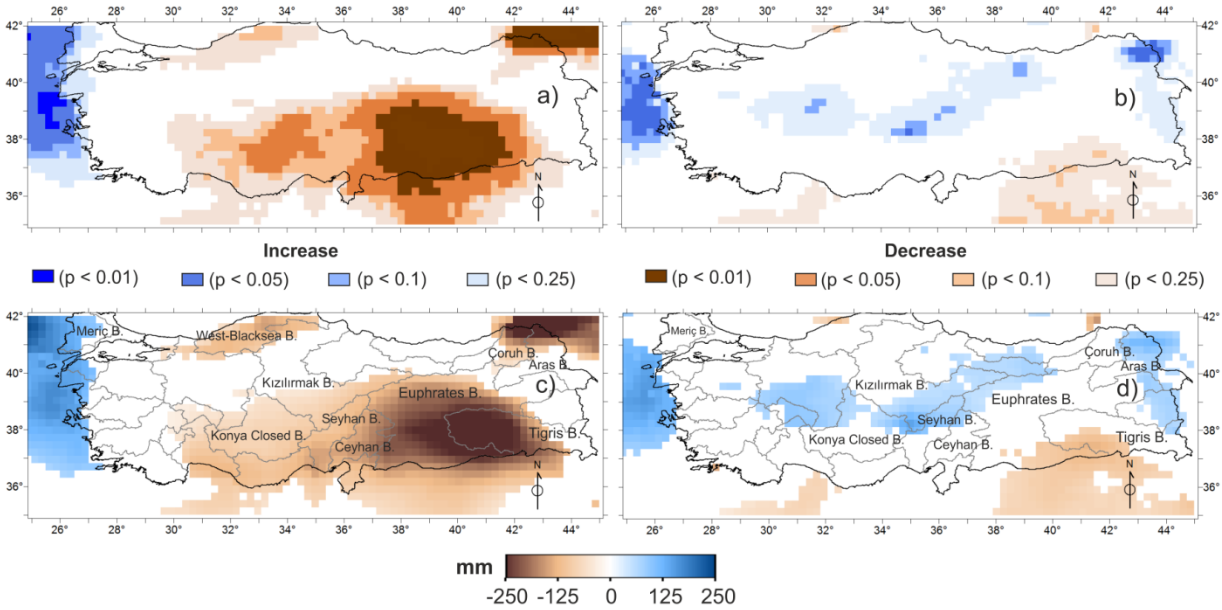

Figure 4. The distribution of **a)** the presence and the direction of Total Precipitation trends by ERA-Interim, **b)** the magnitudes of the Total Precipitation trends by ERA-Interim, **c)** the presence and the direction of Total Precipitation trends by ERA-Interim/Land, **d)** the magnitudes of the Total Precipitation trends by ERA-Interim/Land over the 32-years period.

Figure 5a shows the distribution of the difference between the average yearly total precipitation estimations by ERA-Interim/Land and ERA-Interim for the study period. The difference map indicates a distinctive pattern that the total precipitation is estimated higher by ERA-Interim/Land in more than half of the country in the West (more than 250 mm yr^{-1} in certain coastal areas), while ERA-Interim estimated higher total precipitation in North-eastern and South-eastern parts. The two estimates are generally matching over the Mediterranean and Aegean seas and in some Eastern regions. Figures 5b to 5h shows how the yearly total precipitations by ERA-Interim/Land and ERA-Interim products compare with some meteorological observations distributed over Turkey. Overall, none of the products is consistently closer to the observations: For example, in a highly ERA-Interim/Land overestimate area such as Mugla station, ERA-Interim/Land was much closer to the observations over the study period, but in Sakarya station, ERA-Interim yearly precipitations was much closer to the observations especially before the year 1999. In some stations like Edirne and Mardin, both products were consistent with the observations in terms of magnitude and inter-annual pattern. While in some regions where the precipitation is lowest in the country (e.g. Karaman), ERA-Interim performed better in estimating the inter-annual pattern of total precipitation. It should be noted that, in some mountainous terrain such as Ardahan, both ERA-Interim/Land and ERA-Interim were largely overestimate than the station observation, which is possibly due to non-representativeness of the point precipitation measurements in highly varying complex terrains. Still, in Ardahan, though ERA-Interim/Land looked a large overestimate, the slopes of the increasing trends over the study period were very similar between the ERA-Interim/Land and the station data.

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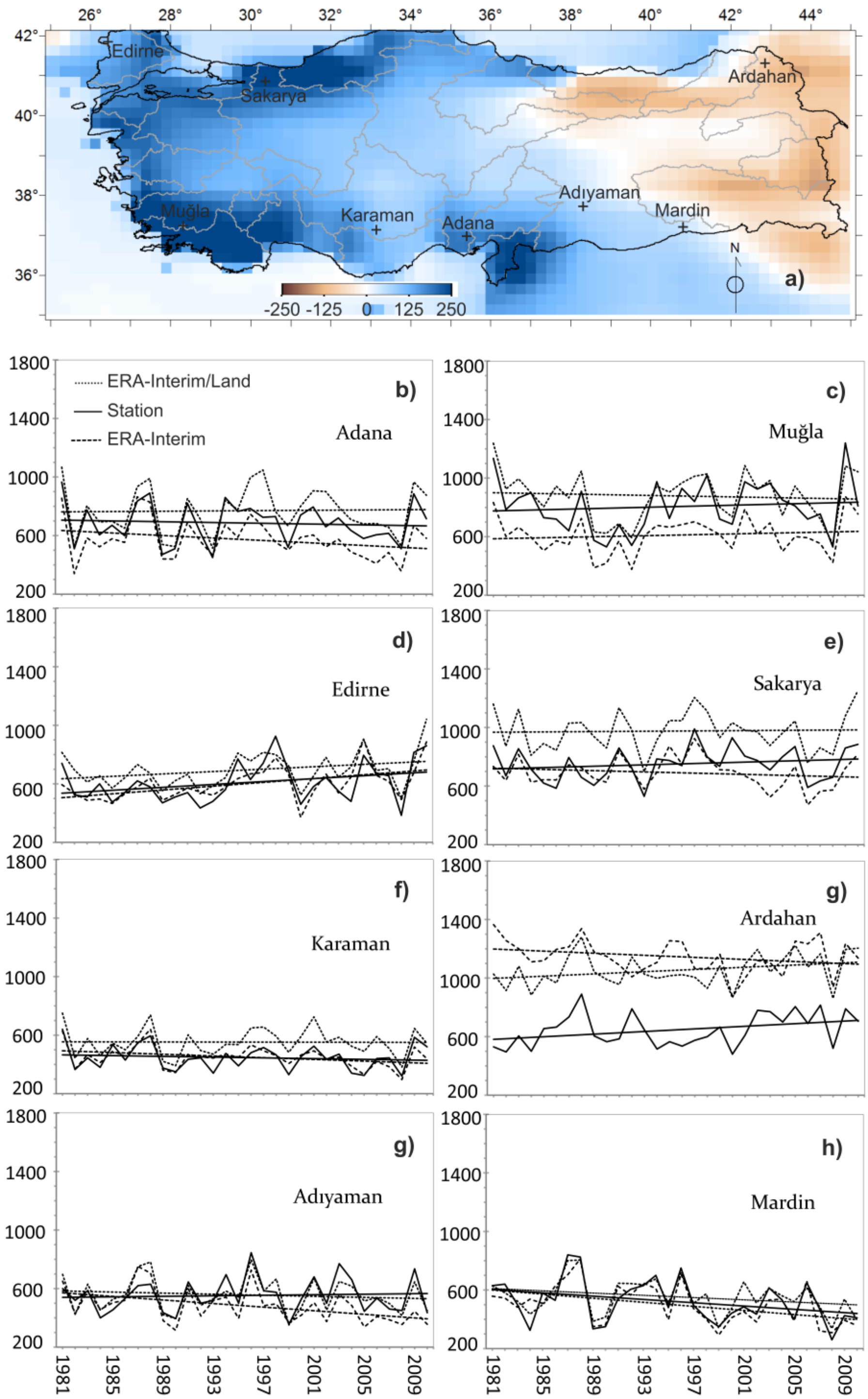

Figure 5a. The difference of the average yearly total precipitation estimations between ERA-Interim/Land and ERA-Interim for the study period, **b-h)** the comparison of the yearly total precipitations by ERA-Interim/Land and ERA-Interim products with meteorological observations.

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3.3 Snow water equivalent

Runoff from snowmelt-dominated basins in the mountainous and semi-arid regions of eastern Turkey accounts for 60-70% of the total annual runoff for the region (DSI, 2009). Therefore, inter-annual changes of snowfall quantities are especially important for the mountainous regions in Eastern Anatolia. According to the ERA-Interim dataset (Figures 6a and 6c), there has been highly significant decreasing trends ($p<0.01$) of snow water equivalent (SWE) in the upstream parts of Euphrates, Kizilirmak and Seyhan basins up to 250 mm decrease totally for the32-years study period. Apart from the decreasing trends, ERA-Interim dataset revealed significant increasing trends of SWE in the South-western Turkey, and in various regions along the Black Sea coast. However, according to the ERA-Interim/Land dataset (Figures 6b and 6d), which is said to be a model improvement integrating a new snow scheme by Dutra et al. (2010), there have been no considerable trends with respect to SWE throughout the country.

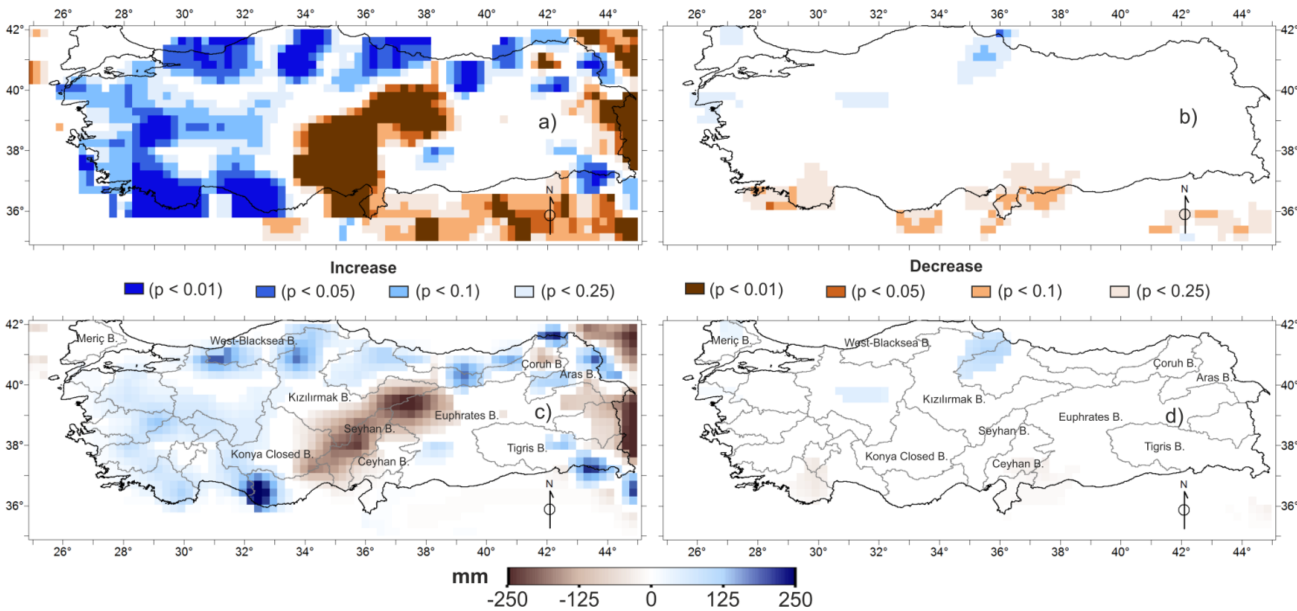

Figure 6. The distribution of **a)** the presence and the direction of Snow Water Equivalent (SWE) trends by ERA-Interim, **b)** the magnitudes of the SWE trends by ERA-Interim, **c)** the presence and the direction of SWE trends by ERA-Interim/Land and **d)** the magnitudes of the SWE trends by ERA-Interim/Land over the 32-years study period (1979-2010).

3.4 Evapotranspiration

With respect to evapotranspiration (ET) trends, while both ERA-Interim and ERA-Interim/Land show similar trends over Mediterranean, Aegean and Black Sea and some areas in the South-east, the two datasets indicate rather contradicting trends over the land along Anatolian peninsula (Figures 7a and 7b). Such a general pattern of consistent ET trends over sea and non-consistent over the land between ERA-Interim and ERA-Interim/Land can possibly be attributed to the different controlling mechanisms of ET (Seneviratne et al., 2010): over sea, ET is generally energy-limited (i.e. temperature and

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incoming radiation), while over land, ET is mainly water-limited (i.e. precipitation and soil moisture) especially for semi-arid regions. Therefore, clearly increasing trend of air temperature over the entire study area (Fig. 2) mainly explains the increasing trend of ET over sea as detected by both datasets. On the other hand, as precipitation becomes more controlling than air temperature over semi-arid lands, the contradicting trends of precipitation shown in Figure 4 is reflected similarly for the ET trends detected by ERA-Interim and ERA-Interim/Land along the Anatolian peninsula from West to East. In terms of magnitude of ET trends (Figures 7c and 7d), both datasets indicate the highest increasing ET trends (up to 250 mm totally) occurred over the Mediterranean coast in the South-west, where the highest rates of temperature increase were experienced too as shown in Figure 2b.

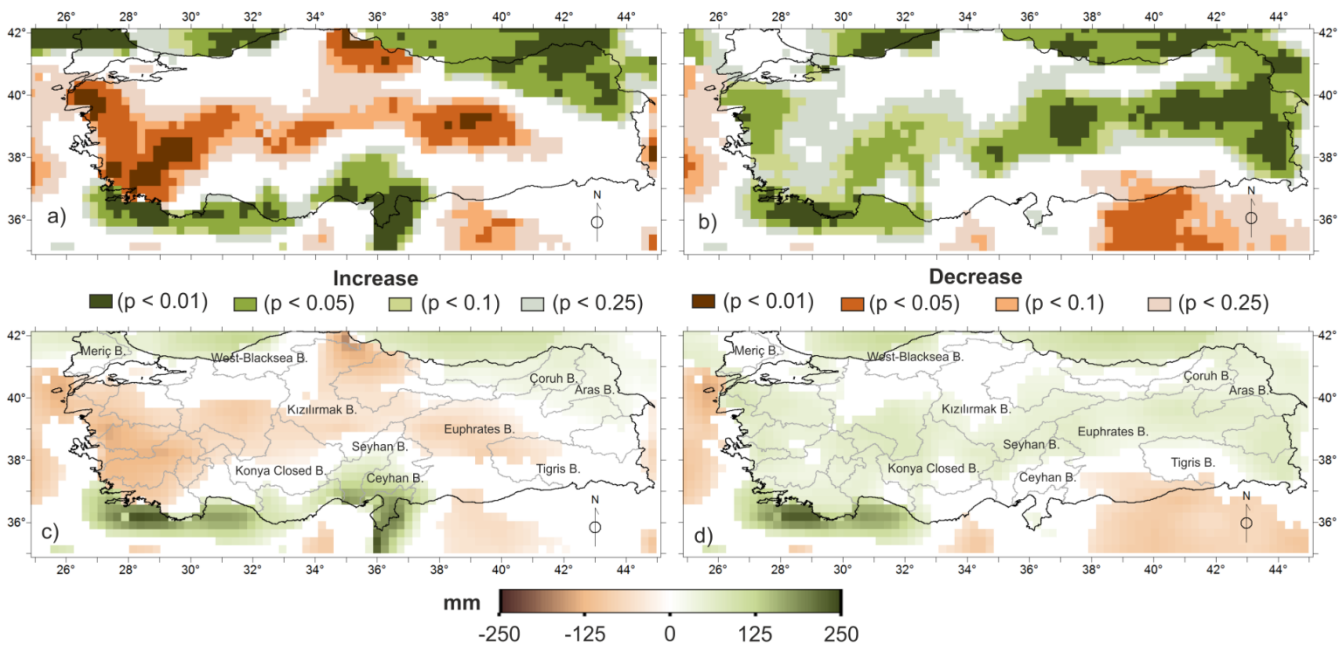

Figure 7. The distribution of **a)** the presence and the direction of Evapotranspiration (ET) trends by ERA-Interim, **b)** the magnitudes of the ET trends by ERA-Interim, **c)** the presence and the direction of ET trends by ERA-Interim/Land and **d)** the magnitudes of the ET trends by ERA-Interim/Land over the 32-years study period (1979-2010).

3.5 Runoff

As the remainder of the water balance equation, runoff can be considered an integration of other hydrological variables and especially important to represent the changes in the surface water resources. Similar to precipitation and SWE trends, ERA-Interim revealed significantly decreasing trends of runoff at various basins with varying degree (the highest decrease occurring in the upstream of Euphrates, Kizilirmak and Seyhan). In contrast, ERA-Interim/Land indicated only minor increasing trends of runoff in some areas in central Anatolia, together with some limited decreasing trends of runoff in the

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South-east regions. Indeed, analyzing the streamflow trends in Eastern Anatolia, Yucel et al. (2014) found that only two of the streamflow stations out of fifteen showed evidence for the significant change (both decreasing trends) in the total annual river discharges between 1970 and 2010. Their study also indicated that, despite little change in the total annual discharges, the timing of spring streamflow has significantly shifted earlier in the year during the study period.

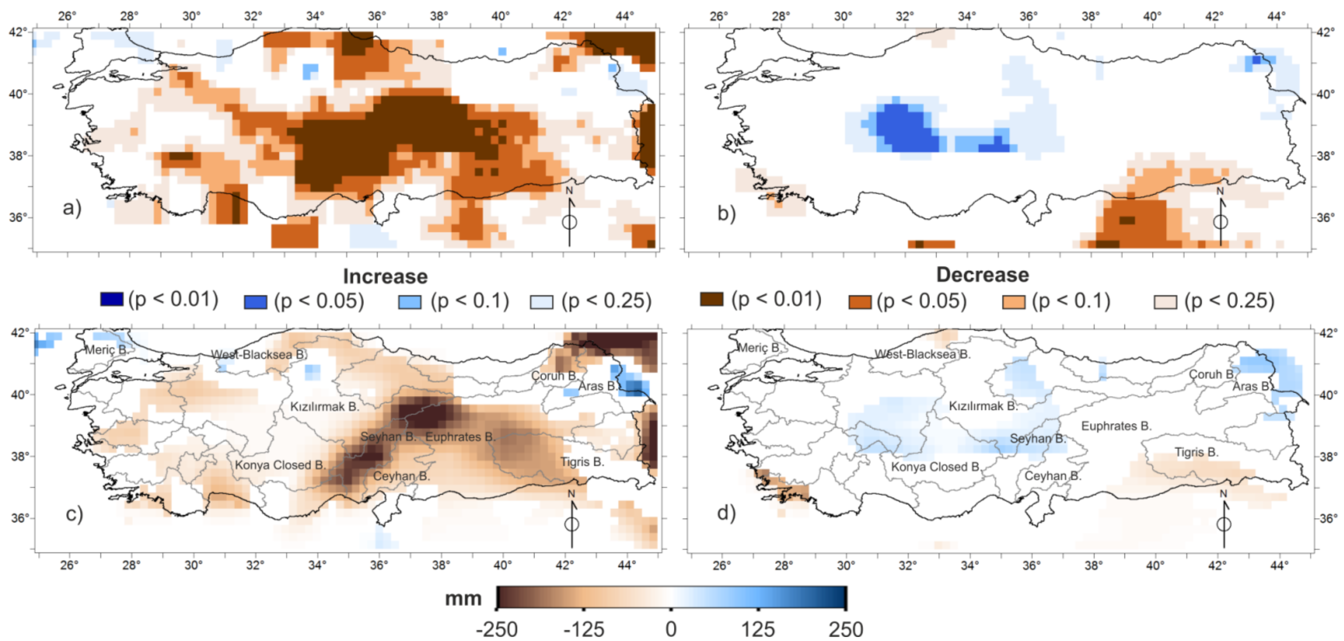

Figure 8. The distribution of **a)** the presence and the direction of Runoff trends by ERA-Interim, **b)** the magnitudes of the Runoff trends by ERA-Interim, **c)** the presence and the direction of Runoff trends by ERA-Interim/Land and **d)** the magnitudes of the Runoff trends by ERA-Interim/Land over the 32-years study period (1979-2010).

4 Discussion and Conclusions

In this study, we assessed the spatiotemporal trends in several hydro-climate variables from 1979 to 2010 in Turkey, one of the vulnerable countries of the Eastern Mediterranean to climate change, using the two reanalysis products of ECMWF: ERA-Interim and ERA-Interim/Land, namely.

With respect to air temperature, ERA-Interim reanalysis dataset revealed a warming of averagely 1.26 °C [0.8 to 1.8] in Turkey from 1979 to 2010, with high confidence intervals (95 to 99%) mostly. Such an increasing trend of air temperature was confirmed by the comparisons with the measurements from several meteorological stations and also other trend analyses studies in Turkey, such as Yucel et al. (2014) who detected an increasing trend of 1.3 °C between 1970 and 2010 in the Eastern Anatolia. According to the 5th Assessment Report (IPCC, 2014), the globally averaged combined land and ocean surface temperature increased about 0.72°C [0.49°C to 0.89°C] over the period 1951–2012. The 5th Assessment Report states

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that the estimated globally averaged air temperature trends are unlikely to be affected from any uncorrected urban heat-island effects and land use change effects by more than 10%.

Our study also revealed that the warming was about 0.3 °C higher in the lowlands (< 1,000 m.a.s.l.) than the high landscapes (> 2,000 m.a.s.l.). Geographically, the largest warming (up to 1.8 °C) occurred in the Western coastal areas next to Aegean Sea and in the South-East regions (and in other Middle East countries including Iraq and Syria), which is also expressed by Sen et al. (2011) who explain such a pattern is due to the propagation of warmer air from over the Balkans and Aegean Sea toward eastern Anatolia after about 25 February based on the assessment of 850 hPa temperature differences between 1990-2006 and 1972-1988 periods.

With respect to the regional trends in hydrological variables, ERA-Interim and ERA-Interim/Land revealed quite different pictures: the ERA-Interim dataset indicated that there have been significant decreasing trends of precipitation, snow water equivalent and runoff in some parts of inner/South-eastern Anatolia (up to 250 mm decrease totally in the upstream of Euphrates, Kizilirmak and Seyhan basins), while ERA-Interim/Land showed none or minor trends in the same areas. Comparison of the precipitation trends by the two datasets with some rain gauge data distributed over Turkey revealed that none of the products is consistently closer to the observations. Analyzing the meteorological and streamflow point data distributed over Eastern Anatolia, Yucel et al. (2014) indicated that there are generally no statistically meaningful trends in annual total precipitation and the river discharges (only two of the fifteen stations showed evidence for decreasing trend) over the study period (1970-2010), while the timing of spring streamflow has significantly shifted earlier in the year. Although Sönmez et al. (2013) indicated dominantly negative trends for the snow cover over Turkey, the study period was relatively short (2004-2012) for a reliable trend analysis. Among the hydrological variables, the only consistent hydrological trend detected by both datasets was the increase of evapotranspiration over Mediterranean and Black Sea, whose magnitude was especially considerable (up to 250 mm totally) over the Mediterranean coast in the South-west Turkey. The highest degree of warming in the same region possibly explains such a high increase of evapotranspiration, because evapotranspiration is generally energy-controlled (i.e. temperature and incoming radiation) over the sea.

Based on the trend assessment of the hydrological trends by the two datasets and the comparisons with the observation data and other trend studies in the study area we can conclude that, except for some evapotranspiration trends over Mediterranean and Black Sea, there have not been clear and considerable trends of precipitation, snow water equivalent and runoff quantities over Turkey from 1979 to 2010, despite the considerable warming for the same period throughout the country. In this respect, we can suggest that, the impacts of global warming on the water cycle are rather unpredictable especially at regional scale. Indeed, 5th Assessment Report also declares low confidence for detecting long-term positive or negative trends in hydrological cycle over different latitudinal zones due to data quality, data completeness or disagreement amongst available estimates.

Finally, with respect to possible sources of error in the analysis, we should note that verification of the grid-based reanalysis data with the point-based station data prone to certain errors as stations may not be representative of a large area especially

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in mountainous complex terrains. Indeed, we observed large differences when the precipitation estimates by the reanalysis data compared with the stations in mountainous regions.

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