Recent variations in the atmospheric branch of the hydrologic cycle over Turkey: Preliminary results by using ERA15 and CMAP

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1. Introduction

We used meteorological reanalysis products and precise grid precipitation data to assess seasonal and interannual variability in the large-scale hydrologic circulation over Turkey. The atmospheric water balance method is an inevitable to assess interactions between the climate changes and change of the surface parameters.

2. Data and Method

Moisture flux vectors (Q_λ, Q_ϕ) can be used to compute atmospheric moisture convergence $-\nabla_H \cdot \mathbf{Q}$. If temporal changes and horizontal transports of liquid and solid water are neglected, then $-\nabla_H \cdot \mathbf{Q} \fallingdotseq$ (Precipitation) – (Evapotranspiration). This equation is valid for spatial and temporal averages over a large area at monthly to seasonal time scales, and the equation yields estimates of evapotranspiration if regional mean precipitation data are available (e.g. Peixoto and Oort 1992).

We used the CPC Merged Analysis of Precipitation (Xie and Arkin, 1997) and ECMWF 15-year reanalysis (ERA15; Gibson et al., 1997) to assess interannual variability in the hydrologic budget over Turkey for 1979-1993, although more precise estimation is underway by using dense network of rain gauge precipitation in Turkey and ERA40 for a longer period. The vapor convergence (C) was computed as described by Yatagai (2003). We estimated the area-averaged evapotranspiration by taking difference of the precipitation (P) and (C) by monthly base. Thus we preliminarily estimated the hydrologic balance over Turkey.

3. Interannual variability of the hydrological budget

The monthly mean precipitation (P) and convergence (C) are averaged in four box domains as shown in Fig. 1: a) the entire part of Turkey [27.5E-45E; 35N-42.5N], b) the western part of Turkey [27.5E-35E; 37N-41N], c) the central part of Turkey [30E-40E; 37N-41N] and the eastern part of Turkey [35E-42.5E; 37N-41N]. The entire part of Turkey (a) and the central part of Turkey (c) correspond to the middle size region and small size region of Yatagai (2003), respectively.

Figure 2 shows the interannual variability of annual precipitation (blue), annul total moisture convergence (red) averaged in each box shown in Fig.1. Positive (negative) C indicates that precipitation (evaporation) exceeds evapotranspiration (precipitation) if temporal changes in precipitable water are negligible. The difference between P and C, or the difference between the blue and red lines, represents evapotranspiration (E) as described in section 2. This residual evapotranspiration, Ea, is also shown in Fig. 2 as a solid green line.

Annual precipitation shows decreasing trend in all box average shown in Fig. 2. For average over the relatively large domain including ocean area, namely in Fig.2a, C is almost zero from 1979 to 1988 and it shows negative value (E>P) from 1989 to 1993. During 1989 to 1993, both increasing E and decreasing P contribute to the negative C.

To interpret these signals, it is necessary to take smaller region as well as to see seasonal change. Figs.2b-d show negative convergence (E>P) is stronger in the western part than that of the central and the eastern part. Among the three, clearer decreasing trend in C is observed in the western and the central part of Turkey. Corresponding to these trends, increasing trends in E are appeared in the central and the western part.

Before looking at seasonal contribution to these diagrams, we see interannual variation of forecasted P, C and E values as well as analysis values.

Figure 3 shows preliminary estimates of interannual variability in the hydrologic budget in July over the central part of Turkey (cf. Fig.1). The graph is complicated because both forecast (dotted lines denoted by f) and analysis (solid lines denoted by a) values of precipitation (P), evapotranspiration (E), and moisture convergence (C) are shown.

The overall patterns of the time series of Pa, Ea and Ca are similar to those of annual mean values averaged in the same area (Fig.2c). Forecast precipitation, derived from the ERA15 (Pf, dotted blue line), shows good agreement with the CMAP (P) for July. These two values does not show decreasing trend.

Since July is dry season for Turkey, it is interesting that E is mostly explained by convergence because P is almost zero for summer. Arid regions in China show completely different character in the atmospheric hydrological balance (Yatagai, 2003; Yatagai et al., 2004).

The dotted green line in Fig. 3 shows ERA15 evapotranspiration (Ef) computed with a fixed land surface model in the ERA15 assimilation scheme. During the forecast, atmospheric conditions were used at each time step to compute Ef. The magnitude of Ef was almost equal to that of Ea for the first several years; however, Ef did not show a linear trend. Because it was derived from large-scale changes in the atmospheric moisture balance, Ea represents observational values that include changes in surface land/water use. In contrast, Ef includes no surface changes. The ERA15 assimilation scheme and models yielded a Pf that was very close to Pa even though the two values are independent. Even though the land surface model used to compute Ef in ERA15 does not always represent real land use (e.g., irrigation are not represented in the model), the surface parameters were constant over the 15 years. Therefore, the increase in Ea could represent increasing anthropogenic (mostly agricultural) water use that causes increasing evapotranspiration during the summer.

Similar conclusions arise from comparisons of the two types of convergence (C) in Fig. 3. The dotted red line represents Cf, which can be calculated as Pf-Ef. The solid red line, Ca, was computed from ERA15 analysis data. Cf showed no trends, whereas Ca showed a decrease in moisture convergence. Because the independent Pa did not decrease, the increase in Ea must have been caused by a decrease in Ca. Consistent data sets of both Ca and Pa are vital for assessing hydrological changes in target regions in terms of assessing both natural and anthropogenically-induced changes.

Pa and Pf, as well as Ca and Cf were both consistent over the entire Turkey for July (Fig.4). Since P is almost zero, both -C and E showed synchronized interannual variability. The box for taking entire Turkey includes not only land areas but also the adjacent oceans. Averaging this area (Fig.1), increasing trend in Ea is not large as well as that in the central part (Fig.3, Fig.4c).

A remarkable increase in Ea occurred over the western part of Turkey (Fig.4b) as well as shown in the central part, although no strong trend was evident in Ef. Similarly, Ca clearly decreased with a decadal-scale variation, while Cf showed a decadal-scale variation similar to Ca, although the trend was not very strong. On the contrary, the eastern part of Turkey (Fig.4d) no strong linear trend is appeared for 1979-1993 although Ca and Ea shows large interannual variability.

The hydrological budget in January (Fig.5) is completely different from that of July. The precipitation for all sub-domains (Fig.5a-d) show decreasing trend, and that is consistent with the result for annual precipitation (Fig.3). Similar trend is also appeared in Ca and Ea for all sub-domains.

Contributions of local evapotranspiration (Ea) and moisture convergence (Ca) to precipitation (P) differed from sub-domain to sub-domain (Fig. 5). For the entire Turkey including adjacent oceans (Fig.5a) and for the central part, (Fig.5c) Ea is almost comparable to C. Average Ea exceeds Ca in the western part, while that of Ca exceeds Ea in the eastern part.

Further analysis is currently in progress to assess the hydrologic budget for all months and over a longer period using ERA40 (Simmons, A.J. and J.K. Gibson, 2000) high-resolution analysis. A trial of making grid precipitation with dense precipitation network of Turkey and incorporating mountain effect (Xie et al., 2004) will give a better estimation of the hydrological budget, especially for the evapotranspiration over the complicated terrain.

3. Summary

Atmospheric branch of the hydrologic balance and its interannual variability is estimated using ERA15 and CMAP from 1979 to 1993 over Turkey. Discussions are concentrated with the annual mean, July mean and January mean fields.

The major results are as follows.

1) Annual precipitation decreased while annual evapotranspiration increased over most part of Turkey for 1979-1993.
2) Interannual variability in moisture divergence (negative convergence) and evapotranspiration of July showed good consistency because precipitation is very few. The July evapotranspiration increased over the central and the western part of Turkey for the period.
3) January precipitation decreased over most part of Turkey for the period. The contribution of Evapotranspiration to local precipitation is larger (smaller) in the western (eastern) part of Turkey.
4) Over the central and western part of Turkey, evapotranspiration, which was derived as a residual in the atmospheric moisture budget equation using CMAP and ERA15, showed an increasing trend. In contrast, evapotranspiration derived from the ERA15 forecast model showed no such trend. This suggests an anthropogenically-induced increase in water usage.

4. References

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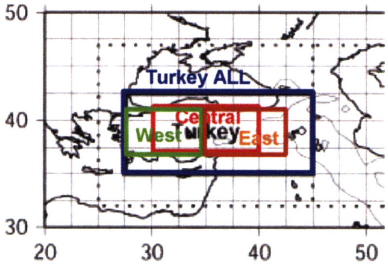

Fig. 1 Sub-domains investigated in this study. The central part of Turkey is shown in red, the western part of Turkey is shown in green, the eastern part of Turkey is shown in brown, and the box covers all part of Turkey is shown in blue.

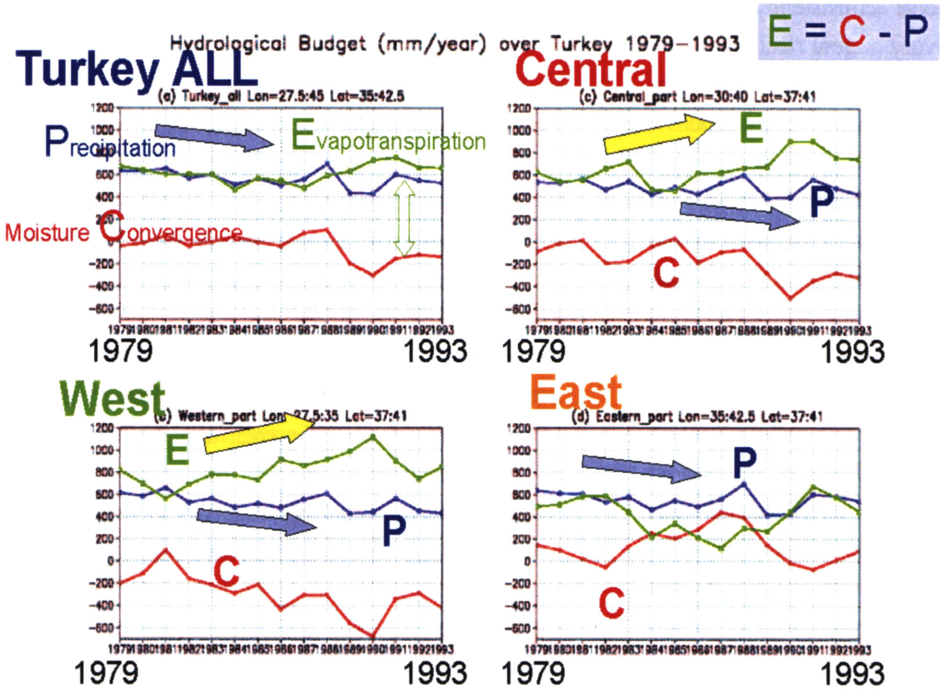

Fig 2 Variations in the hydrologic budget over (a) the entire Turkey, (b) the western part of Turkey, (c) the central part of Turkey, and (d) the eastern part of Turkey (see Fig.1, units in mm/month). Solid blue line, the CMAP precipitation (P) ; solid red line, moisture convergence (C) estimated from ERA15; solid green line, evapotranspiration estimated as residual (E) of P-C.

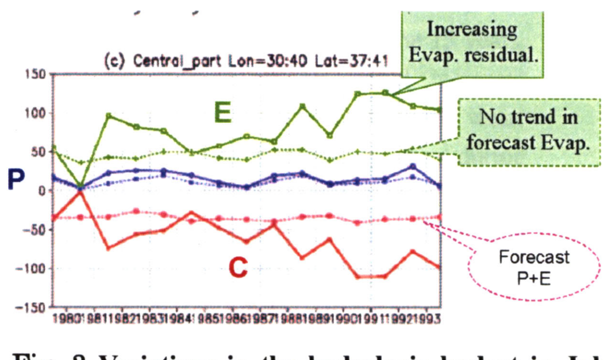

Fig. 3 Variations in the hydrologic budget in July over the central part of Turkey (units in mm/month). Dotted blue line, ERA15 forecast precipitation (Pf); solid bl ue line, CMAP precipitation (Pa); dotted green line, ERA15 forecast evapotranspiration (Ef); solid green line, evapotranspiration estimated as residual (Ea) of Pa-Ca; dotted red line, moisture convergence (Cf) estimated as Pf-Ef; solid red line, moisture convergence (Ca) estimated from ERA15.

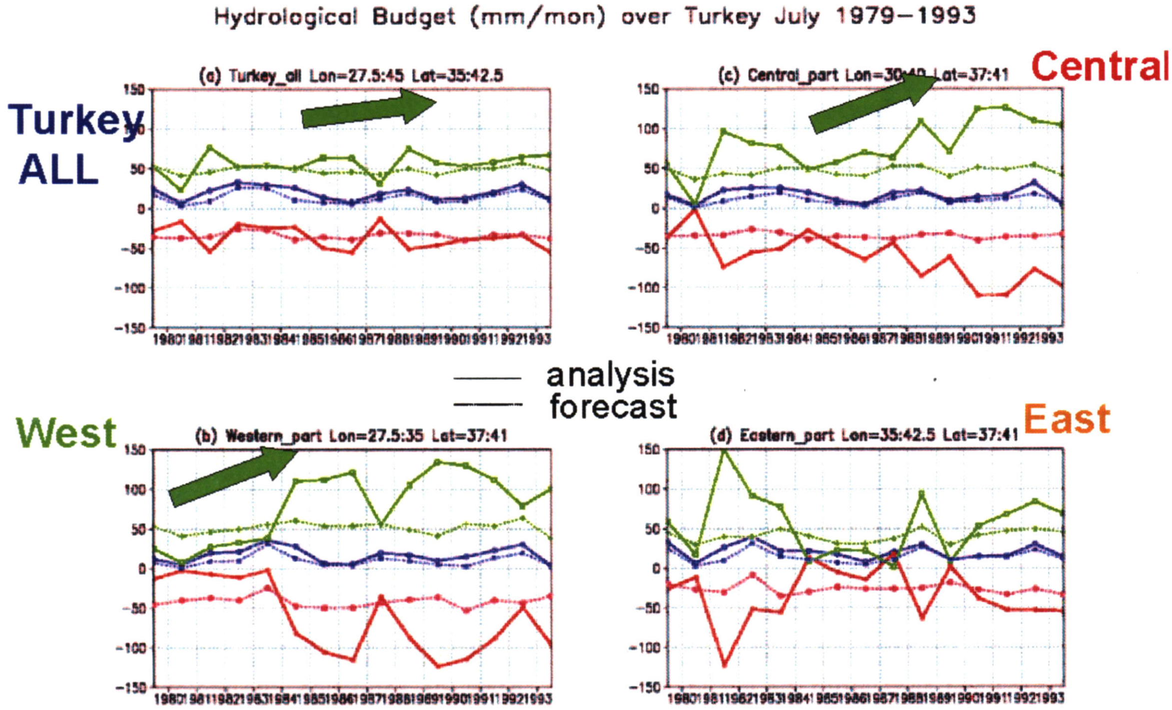

Fig 4 Variations in the hydrologic budget (mm/month) for (a) the entire Turkey, (b) the western part of Turkey, (c) the central part of Turkey, and (d) the eastern part of Turkey (see Fig.1). Details in line types/colors are the same those in Fig.3.

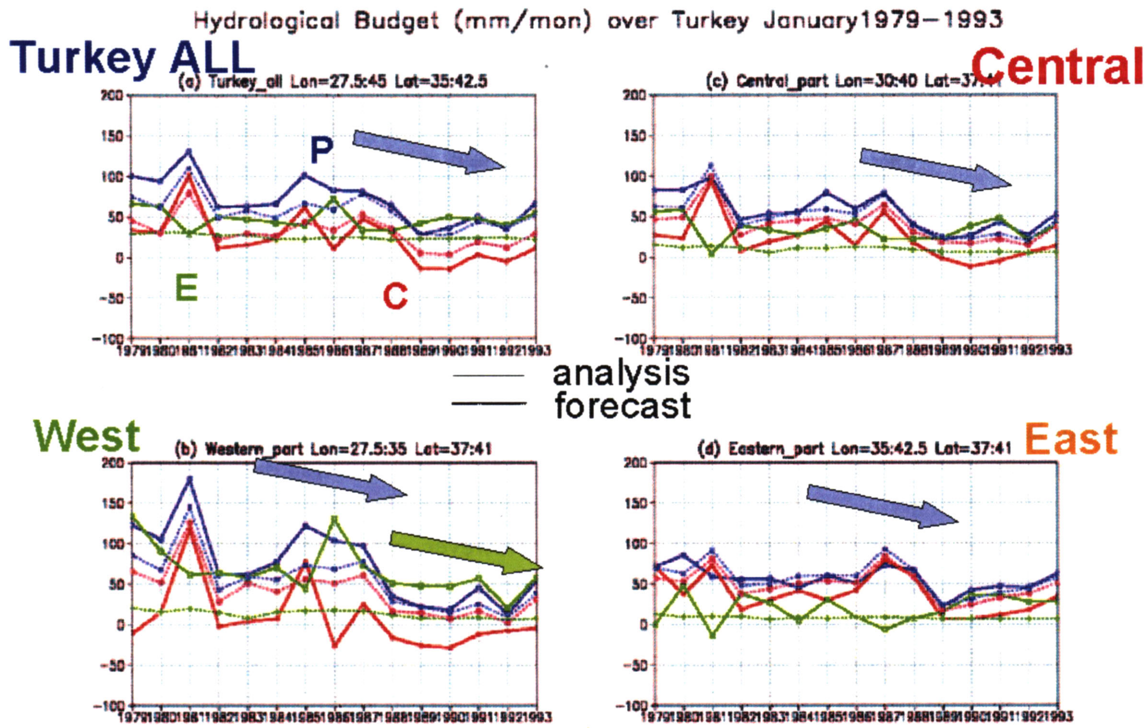

Fig 5 The same with Fig.4 but for January.