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Spatial variability of precipitation regimes over Turkey

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Abstract Turkish annual precipitation regimes are analysed to provide large-scale perspective and redefine precipitation regions. Monthly total precipitation data are employed for 107 stations (1963–2002). Precipitation regime shape (seasonality) and magnitude (size) are classified using a novel multivariate methodology. Six shape and five magnitude classes are identified, which exhibit clear spatial structure. A composite (shape and magnitude) regime classification reveals dominant controls on spatial variability of precipitation. Intra-annual timing and magnitude of precipitation is highly variable due to seasonal shifts in Polar and Subtropical zones and physiographic factors. Nonetheless, the classification methodology is shown to be a powerful tool that identifies physically-interpretable precipitation regions: (1) coastal regimes for Marmara, coastal Aegean, Mediterranean and Black Sea; (2) transitional regimes in continental Aegean and Southeast Anatolia; and (3) inland regimes across central and Eastern Anatolia. This research has practical implications for understanding water resources, which are under ever growing pressure in Turkey.

Key words precipitation climatology; rainfall; regimes; regionalization; classification; Turkey

1 INTRODUCTION

Spatial variability of precipitation regimes has profound effects on water resources, aridity and desertification conditions (e.g. Frederick & Major, 1997; Kansakar *et al.*, 2004; Xoplaki *et al.*, 2004). The spatial structure of precipitation requires robust analysis to elucidate dominant patterns of variability, to regionalize areas with similar precipitation patterns, and to understand the factors and process driving emergent distributions. Therefore, the existent understanding of precipitation variability should be improved by new research and analytical method development for large countries/ regions, such as Turkey, which are characterized by climatic and physiographic complexity.

For Turkey, Türkeş (1996) explored seasonal variability in spatial patterns of mean annual rainfall totals and identified geographical factors influencing these distributions. This work divided Turkey into seven rainfall regions, based primarily on an index of seasonality (i.e. calendar season percentage of annual total rainfall). Türkeş (1998) refined the rainfall climatology of Turkey, showing: (a) the Mediterranean coast with a marked seasonal regime and peak winter rainfall; (b) the Black Sea coast with rainfall relatively uniform across the year; (c) the continental interior with spring rainfall maxima; and (d) Northeast Anatolia with peak rainfall in spring-summer. Kadioğlu *et al.* (1999) and Kadioğlu (2000) investigated precipitation patterns across Turkey using harmonic and principal component analyses, respectively. Kadioğlu *et al.* (1999) found the first and second harmonics explained >90% of the variation in precipitation and suggested maximum (minimum) precipitation occurs in December or January (August or July) across all of Turkey (cf. Türkeş, 1996, 1998). Kadioğlu (2000) used principal components (PCs) to identify spatial patterns and controls of precipitation. Retained PCs were interpreted to represent: (PC1) synoptic weather systems influencing all of Turkey; (PC2) continentality in Anatolia and the effect of mountains in eastern Turkey; and (PC3) maritime influence around the coasts. Şen & Habib (2000) developed an optimum spatial interpolation method for monthly precipitation data across Turkey, which detected two regional trends not identified previously: (1) maxima in the southwest during November to April, and (2) maxima in the north and northeast during May–October. Most recently, Ünal *et al.* (2003) applied cluster analysis to monthly average, maximum and minimum temperature and monthly total precipitation records to define homogeneous climate regions of Turkey. This research compared five clustering algorithms; each algorithm yielded seven climate zones, but with considerable differences in regional boundaries between algorithms. However, no

physical interpretation of these regions was provided by Ünal *et al.* (2003).

Hence, previous research on pan-Turkey precipitation patterns has yielded somewhat inconsistent findings, due, at least in part, to the application of a range of methods to different data sets (in terms of spatial coverage and time span). To date, analysis of spatial patterns has focused on year-to-year variation in annual totals or seasonal indices, or used monthly data to identify timing of precipitation maxima or minima. Thus, there is a need for detailed study of the intra-annual cycle (regime) of precipitation across Turkey, which investigates systematically (and jointly) spatial variation in both magnitude and timing of precipitation. Such research is necessary to provide finer-scale information of onset and cessation of wet and dry periods and a basis for more robust regionalization of spatial structure in precipitation regime, which in turn will advance understanding of the complexity in, and processes driving, the precipitation climatology of Turkey.

This paper aims to characterize the nature and dynamics of precipitation regimes across Turkey and, thus, to elucidate the key controlling factors upon spatial patterns in intra-annual precipitation behaviour. This aim is achieved through the following specific objectives: (1) to test a classification scheme that identifies the shape (timing) and magnitude (size) of annual precipitation regimes; (2) to identify precipitation regime regions across Turkey; and (3) to interpret of the emergent precipitation regime regions based on regional atmospheric circulation and the main physiographic features modifying precipitation climatology.

2 STUDY AREA

Turkey extends more than 1600 km west to east and nearly 800 km north to south with an average elevation of 1132 m (Fig. 1). Turkey is part of the greater Alp-Himalayan belt with a complex geological structure (Atalay & Mortan, 2003). Elevation increases towards the east, where the two mountain ranges (North Anatolian and Taurus) converge to form the East Anatolia Region (mean elevation >1500 m) (Atalay & Mortan, 2003).

Turkey is located mainly in the subtropical zone between the humid mid-latitude zone and dry/hot tropical zone, so experiences subtropical highs in summer and prevailing westerlies in winter (Fig. 2). A Mediterranean macroclimate of extended, warm, dry summers with occasional thunderstorms and cool, wet winters is experienced (Xoplaki, 2002; Harding, 2006). The Turkish climate is strongly influenced by the coupled pressure systems that occur over Iceland (low) and the Azores (high) (Fig. 2). To the east, the dominant pressure system is the Siberia (high) to the north and Monsoon (low) to the south (Akçar *et al.*, 2007). In winter, the prevailing air flows over Turkey are controlled by the large-scale Siberia anticyclone and polar front cyclones, and Mediterranean depressions (Tatli *et al.*, 2004). Westerly-northwesterly and easterly-northeasterly air flows are the product of polar front depressions and the Siberia anticyclone, respectively. Southwesterly and southerly air flows are the product of Mediterranean frontal depressions (Tatli *et al.*, 2004).

Turkey is affected by Polar and Tropical air masses in winter and summer, respectively. The cP (continental-Polar) is a continental, cold and dry air mass that originates from Siberia (Fig. 2), and which causes orographic rains if it becomes saturated while crossing the Black Sea (Akçar *et al.*, 2007). The mP (marine-Polar) air mass originates from the Atlantic Ocean and travels across Europe and the Balkans. It becomes unstable over Turkey and causes rainfall in coastal areas (Black Sea and Marmara) and snowfall at higher elevations and in the interior. The transport of mP air into the Mediterranean basin by the Polar jet-stream, its lifting (by changes in relief), and subsequent warming (by the Mediterranean Sea) is a major underlying mechanism of both Mediterranean cyclogenesis and the creation of the “Mediterranean air mass”. The Mediterranean trajectory of mP is more effective than the Atlantic trajectory in terms of generating rainfall (Tatli *et al.*, 2004).

3 DATA AND METHODOLOGY

3.1 Precipitation data

Monthly precipitation totals for 107 Turkish State Meteorological Service (TSMS) stations are used. Table 1 provides basic metadata for stations. These stations were selected based on record length, and for providing optimum spatial coverage across the country. Records range from 40 to 72 years; the average time span is 64 years, with the earliest record starting in 1930. A 40-year overlapping record period was identified as 1963–2002. Homogeneity of time-series was checked for all 107 stations using the Kruskal-Wallis (K-W) test. For 107 stations, statistical inhomogeneities were identified in precipitation for winter months. However, these statistically significant inhomogeneities are related to long-term variations and significant trends, not step changes in the time-series (Sariş, 2006; Türkeş *et al.*, 2008).

3.2 Regime classification methodology

Since it is important to assess the timing and size of annual precipitation regimes, a methodology is adopted that uses hierarchical, agglomerative cluster analysis to separately classify regimes according to their “shape” and “magnitude” (devised by Hannah *et al.*, 2000; adapted by Harris *et al.*, 2000; evaluated by Bower *et al.*, 2004; Kansakar *et al.*, 2004; and Hannah *et al.*, 2005).

The shape classification identifies stations with a similar form of annual regime, regardless of the absolute magnitude. In this application, the magnitude classification is based upon four indices (i.e. the mean, minimum, maximum and standard deviation of monthly values across the 40-year record) for each station, regardless of their timing. This approach has the advantage that these two important regime attributes may be interpreted separately as well as jointly by simply combining shape and magnitude classes for each station to yield a “composite” classification.

To classify precipitation regime shape independently of magnitude, the 12 long-term mean monthly observations were standardized on a station-by-station basis using z -scores (mean = 0, standard deviation = 1) prior to clustering. The four magnitude indices were derived for the long-term regime for each station; it was necessary to standardize between indices (to control for differences in their relative values) by expressing each index as z -scores across the 107 stations.

For both shape and magnitude, classification was achieved by hierarchical, agglomerative cluster analysis using Ward’s method. No single clustering algorithm is deemed universally “best”; and different algorithms identify different groupings. Ward’s method was selected because it typically outperforms other algorithms in terms of separation to give relatively dense clusters with small within-group variance (Yarnal, 1992; Griffith & Amrhein, 1997; Bower *et al.*, 2004). Ward’s method has been widely and successfully used in the climatological studies (e.g. Stone, 1989). The structure of the cluster dendrogram and breaks of slope in the agglomeration schedule (scree) plot were used to determine the appropriate number of clusters (Griffith & Amrhein, 1997). Thus, each of the 107 stations was grouped by both regime shape and magnitude, which also permitted composite shape and magnitude classification. The spatial distribution of the shape, magnitude and composite classes allowed precipitation regime regions to be identified.

4 RESULTS AND DISCUSSION

4.1 Precipitation regime shape

Six precipitation regime shape classes were identified (Fig. 3):

- Regime A. December peak with rapid onset of wet winter and gradual cessation into dry summer (33 stations).
- Regime B. December peak with extended wet winter followed by marked decline in spring to dry summer (24 stations).
- Regime C. May peak with a gradual onset (wet spring), secondary winter (December) peak and short dry summer (22 stations).
- Regime D. April–May peak with gradual onset, main rainy period in spring with marked cessation in June, and secondary winter (December) peak (12 stations).
- Regime E. May peak with rapid onset, short wet spring, relatively dry summer, secondary autumn (October) peak and dry winter (five stations).

- Regime F. October peak with rapid onset, and wet autumn-winter (11 stations).

There are considerable differences between regimes in terms of timing, number, onset and cessation of wet and dry periods (Fig. 3). Generally, the summer season (June–August) is characterized by dry spells. December is the wettest month for the two most frequent regimes (A and B = 53% of stations). Regime A is specified by a marked winter rainfall and long dry period. Similarly, Regime B has a wet winter but rainfall extends into spring. Regime C has a wet spring with a May peak and a relatively rainy winter; with a clear decline of rainfall in June. Regime D has two wet periods: April–May and December. Regime E is distinctive due to a May peak and long dry spells, especially in winter. Regime F is different from other shape classes, largely because of the rainy autumn, October peak and relatively dry spring.

The spatial distribution of precipitation regime shape classes is shown in Fig. 4. The geographical regions of Turkey (based on the major physiographic units in Fig. 1) are overlain on this map; these regions provide a convenient framework to help structure discussion of spatial precipitation patterns. Briefly, the Black Sea region is characterized by the North Anatolian Mountain range and the Mediterranean region by the Taurus Mountains. The Southeast Anatolia region represents the southeastern part of the Taurus Mountains, while the Central Anatolia and Eastern Anatolia are characterized by plateau and high plateau topography, respectively. To the west, the Marmara and Aegean regions form low-altitude plains.

The spatial distribution of regimes becomes more complex from west to east and from coast to interior regions. Table 2 and Fig. 5(a) present the frequency distribution and summary of distribution of the shape regimes by region. Marmara (86%), coastal Aegean (67%) and Mediterranean (50%) are dominated by Regime A. Regime B is found along the southeast Mediterranean coast (Amanos Mountains–Iskenderun Gulf, 44%), and interior of the Aegean (33%). The uniquely homogeneous (Regime B) region is Southeast Anatolia. Regime C dominates inland regions: Central Anatolia (47%), Eastern Anatolia (46%) and the southern interior of the Black Sea (38%). In Central Anatolia, the dominant regime is D (53%). Regime E is observed only for a few stations in the northeast part of the Eastern Anatolia region, while Regime F is confined to the coastal zone of the Black Sea (42%).

The distribution of precipitation regimes with a December peak (A and B) may be explained by winter rainfall supplied from mid-latitude (northeast Atlantic) and Mediterranean depressions which are most active during winter (Türkeş, 1998; Kostopoulou & Jones, 2007). The interior of the Aegean, southeast Mediterranean and southwest Anatolia regions (Regime B) are differentiated from coastal regions by an extended period of winter–spring precipitation. For Regime B, the rainier spring most probably reflects convective activity (Türkeş, 1998). Winter is the wettest period across Turkey, except in Eastern and Central Anatolia where spring is rainiest. May and April–May peaks (Regime C and D) are most probably caused by convective rainfall rather than frontal systems. Precipitation formation is modified by local topography in continental Anatolia (i.e. Central Anatolia, Eastern Anatolia and the southern part of the Black Sea region) (Kutiel & Türkeş 2005). The April–May rainfall peak in Central Anatolia is commonly referred to as the “Kırkikindi yağmurları” (40-afternoon rains), which indicates its convective origins. The timing of precipitation peaks for Regime C and D are similar; but there are clear differences in the length of the rainy season. Central Anatolia (D) is influenced by frontal systems during winter; whereas Eastern Anatolia and the southern Black Sea (C) experience drier winters due to small-scale high-pressure centres caused by localized thermal effects. The occurrence of Regime E (dry winter and marked May peak) in the northeast Eastern Anatolia is due to the combined effect of high topography and continentality and the Siberian High to the east, which tends to reduce winter precipitation. Indeed, the eastern part of Turkey receives much less precipitation in winter than other parts of the country (Türkeş, 1998). The occurrence of an October peak precipitation regime (Regime F) along the Black Sea coast can be explained by the frequent northeastern Atlantic originating depressions in autumn (Karaca *et al.*, 2000; Trigo *et al.* 1999). In comparison, southern regions of Turkey do not receive much autumn rain because the dominant atmospheric systems are located at northerly latitudes and the Mediterranean depression is relatively weak at this time.

In summary, intra-annual variability in the timing of precipitation (i.e. regime shape) over

Turkey is controlled mainly by the North Atlantic and Mediterranean depressions which are influential in winter. However, local factors cause modification of cyclone trajectory and, hence, the timing of precipitation (peak in spring) especially for interior and high elevation regions. The October rainfall peak for the northern Black Sea coast may be explained by prefrontal depression systems, which are only effective in northern Anatolia during the autumn.

4.2 Precipitation regime magnitude

Five regime magnitude classes can be identified that may be ordered with respect to the four precipitation magnitude indices (Table 3):

- Regime 1. Low with the lowest values for all indices (32 stations).
- Regime 2. Intermediate with the second lowest values for all indices (32 stations).
- Regime 3. Moderately-high with third highest values for all indices (35 stations).
- Regime 4. High with the second highest values for all indices (six stations).
- Regime 5. Very-high with the highest values for all indices (two stations).

Figure 6 illustrates the spatial distribution of magnitude regimes based on a simplified scheme, as shown in Fig. 5(b). The frequency distribution of regimes is summarized in Table 4. Regime 1 clearly dominates in Central Anatolia (93%), but also predominates in Eastern Anatolia (39%) and the inland parts of the Black Sea region (42%). Thrace (47%), the Aegean (60%), Southeast Anatolia (43%) and Eastern Anatolia (39%) are mainly characterized by intermediate regimes (Regime 2). Regime 3 is distributed across Anatolia (Table 4). The Anatolian part of the Marmara region (also known as South Marmara, 47%), the Black Sea coast (29%) and Mediterranean coast (50%) also have high occurrence of moderately-high regimes. Regime 4 is only detected for six stations. Southwest Turkey (17%) is represented by Regime 4. Antakya (southeast Mediterranean coast), Zonguldak and Giresun (Black Sea coast, 8%) also experience high precipitation regimes. Very-high precipitation regimes (Regime 5) are only recorded for Rize and Hopa (northeast Black Sea region, 8%).

The Central Anatolia region is characterized by the lowest magnitude regime. Dry sub-humid climatic conditions prevail here, with the Konya Plain having a semi-arid climate (Türkeş, 1999). Central Anatolia is a formation area for thermal lows and experiences continentality, thus the region has propensity for precipitation deficits (Spanos *et al.*, 2003). The transition zone between central and Eastern Anatolia are also dominated by Regime 1. The southwest part of the Black Sea region is in a rain shadow of the western Black Sea Mountains and so receives limited rainfall. The Aegean region has an intermediate regime due to a combination of maritime influence and topography. The predominantly horst and graben topography of western Turkey, which is perpendicular to the coast, does not obstruct airflow, while the Aegean Sea is the major winter–spring cyclone source areas at the sub-synoptic scale (Trigo *et al.*, 1999). Regime 2 also dominates Thrace; this area is influenced by polar front and Balkan-originated air flows (Kutieli *et al.*, 2001). Moderately-high regimes are observed for South Marmara, and coastal regions of the Aegean, Mediterranean, Southeast Anatolia and Black Sea regions (Fig. 5(b)). Relatively high precipitation for these coastal locations is the combined result of frontal and orographic rains. For example, the Taurus Mountains trim the Mediterranean coast and form a barrier to moist air. One of the most notable features of our new precipitation regionalization is the extension of moderately-high regimes toward Southeast Anatolia (previously defined as dry, semi-arid, e.g. Türkeş, 1999). Regime 3 is concentrated along the physiographic transition between the Mediterranean and Southeast Anatolia region; this zone is influenced by the Mediterranean cyclones. These weather systems are sourced from the Cyprus Low, which is an important driver of eastern Mediterranean cyclogenesis (Trigo *et al.*, 1999). The highest precipitation regimes are divided into two regimes (4 and 5) with a limited number of stations (Table 4).

In summary, precipitation regime magnitude across Turkey appears to depend on the strength of influence of mid-latitude and Mediterranean cyclones, and probably local factors. Interior regions are characterized by low (mainly convective, see Section 4.1) rainfall while coastal regions are predominantly affected by frontal and orographic precipitation. Local topography appears to be a modifier of regime magnitude: enhancing precipitation on windward slopes and reducing

precipitation penetration to cause rain shadows.

4.3 Composite (shape and magnitude) precipitation regimes

A composite precipitation classification may be achieved by combining shape and magnitude regimes, which permits standardized seasonal responses to be scaled by precipitation amount (Table 5, Fig. 7). Of the 30 possible, 16 composite regimes can be observed across 107 stations. December peak regimes (A and B) combine with intermediate and moderately-high magnitude (2 and 3). Regime 2A, 2B, 3A and 3B account for 49% of all stations. Regime A and B also combine with high magnitude, but only in three cases. April and May peak regimes (C and D) join mainly with low magnitude, and on two occasions intermediate. Overall, 1C is the most common single regime (18%). No composite regimes are found for April and May peaks with higher magnitudes (3, 4 or 5). Regime E (May peak) combines with low and intermediate magnitude in one (1E) and four (2E) instances, respectively. October peak (F) combines only with moderately-high, high and very high regimes.

The underlying spatial structure is summarized in Fig. 5(c). The coastal Aegean, Mediterranean and Marmara regions are characterized by 2A (27%, 16%, 46%), and 3A (33%, 22%, 40%), respectively. 4A was found only at one station in the Aegean and at two stations in the Mediterranean regions. The transitional areas of the Aegean and the Mediterranean are dominated by 2B (33%) and 3B (28%). Southeast Anatolia represents another transitional zone, with regimes 2B (43%) and 3B (57%). Central Anatolia is dominated by two regimes (1C = 47%; 1D = 47%). Regime 1C is specific to Eastern Anatolia (31%); this region is also characterized by 3B (23%). Regimes 3F, 4F and 5F are observed solely along the Black Sea coast, in order from west to east. There is a marked shift in regimes between the coast (3F) and the interior parts (1C) of the Black Sea region in both precipitation timing (April–October) and declining magnitude due to the rain shadow effect of the North Anatolian Mountains (sections 4.1 and 4.2).

Figure 8 simplifies the complex patterns identified above to illustrate spatially coherent regions that summarize key climate and physiographic controls on precipitation regimes across Turkey. The boundaries of regions map onto physiographic divides; they are indicative, not conclusive. According to Fig. 8, composite regimes may be classified into three groups:

- *Coastal Regimes*: Regimes 2A, 3A, 4A (clear December peak with intermediate, moderately high and high magnitudes) and 3F, 4F and 5F (marked October peak with moderately high, high and very high magnitudes). This group signifies all coastal areas of Turkey, which are under the consistent control of cyclogenesis and also affected by orographic rains.
- *Transitional Regimes*: Regimes 2B and 3B (December peak and extended rainy period to spring with intermediate and moderately high magnitude). Southeast Anatolia (which was defined as continental Mediterranean rainfall region by Türkeş (1996) and interior west Anatolia (which was defined as Mediterranean Transitional rainfall region by Türkeş, 1996) are classified as transitional regimes because they are controlled by the coupled effects of frontal and convective rainfall.
- *Inland Regimes*: Regimes 1C, 2C, 1D, 1E and 2E (May peak with low and intermediate magnitude). Continental Anatolia defines this group with a marked rainy spring period and characteristic convective rains.

In summary, the distribution of composite precipitation regimes over Turkey exhibits spatial structure with clear zoning in coastal regions and more complex patterns in transitional zones, interior and high relief regions (except Central Anatolia and Southeast Anatolia) (Fig. 8).

5 CONCLUSIONS

This paper analyses the nature and structure of precipitation regimes across Turkey and, in so doing, provides finer-scale information on intra-annual precipitation dynamics and a more robust regionalization of precipitation regimes. The study refines and extends the existing classifications of Turkish precipitation climatology. Furthermore, this research demonstrates the utility of the novel classification methodology in providing a more objective approach to categorizing two

important regime attributes: timing (shape) and magnitude. The emergent regime classes yield the most detailed and systematically joint analyses of spatial variation in magnitude and timing of precipitation across Turkey to date.

Precipitation shape regimes (seasonality) exhibit clear spatial structure from coast to interior. Marked December peak regimes (Regime A) characterize Marmara, coastal Aegean and Mediterranean regions. December peak with extended wet winter (Regime B) is dominant in the interior of Aegean and Mediterranean and Southeast Anatolia regions. The Black Sea coast experiences an October peak (Regime F) while the interior of this region is dominated by a May peak (Regime C). In Central Anatolia, the west experiences an April–May peak (Regime D) and the east is dominated by a May peak (Regime E). Eastern Anatolia show greatest complexity being characterized by Regime B in the low altitude south, Regime C in the higher altitude east and Regime E in the northeast.

In terms of magnitude, five different regimes are identified: (1) low, (2) intermediate, (3) moderately high, (4) high, and (5) very high. Low magnitude precipitation (Regime 1) occurs across Central Anatolia and the interior parts of the Black Sea and Mediterranean regions. Regime 2 typifies Thrace and Aegean regions. Regime 3 is most evident in Southeast Anatolia, South Marmara, along the Black Sea coast and in the southeast Mediterranean region. Regime 4 is observed at four stations along the south coast of the Mediterranean region and two stations on the Black Sea coast. Very high magnitude precipitation (Regime 5) is restricted to the northeast Black Sea coast.

Composite regimes scale standardized seasonal precipitation response (shape) by size (magnitude), which is necessary to yield a climatologically informative regionalization. The composite classification indicates low magnitude combined with April and May peak regimes characterize inland areas, namely Central Anatolia and Eastern Anatolia. Intermediate magnitude with December peak regimes dominate in Thrace, the interior Aegean and Southeast Anatolia. These areas may be defined as transitional zones and specify the modified Mediterranean climate regime. Moderately high to very high magnitude occur only for Marmara, Aegean and Mediterranean coasts (December peak) and Black Sea coast (October peak) regimes.

These intra-annual regime classifications indicate the key controls upon spatial patterns in Turkish precipitation to be: (1) large-scale atmospheric circulation during the winter months for coastal regions of Marmara, Black Sea, Aegean and Mediterranean regions and (2) convective rainfall for interior regions that experience a rainy spring. The physiography of Turkey has a major influence on precipitation regimes. High relief and continentality play an important role in causing rainfall deficit for interior regions; and, where mountains are located along the coast, high precipitation occurs, particularly in winter. Eastern Anatolia experiences the most intricate precipitation patterns of any region, which is linked to complex mountainous terrain. The number of gauges for the Eastern Anatolia region is not adequate to fully determine the spatial pattern in precipitation over this region. Likewise, precipitation data for the mountainous regions of the Black Sea and Mediterranean are restricted, since long-term stations are located at <700 m.

This study has refined and extended our understanding of the spatial structure in precipitation regimes over Turkey. These findings are not only of climatological interest; they have practical implications for the assessment and prediction of water resources, particularly given the growing population of Turkey. Indeed, potable water scarcity has been a significant problem for Turkey's major cities in recent years (Beler Baykal *et al.*, 2000). The regimes identified herein show clear spatiality in intra-annual timing and amount of precipitation delivery, which may potentially be used as a basis to inform sustainable water resource management. Moreover, given present concerns about future climate change/variability, it is important to extend this research on long-term average conditions to understand the year-to-year variability in precipitation and river flows to assess current and potential future water resource stress. Thus, hydroclimatological research is in progress by the authors to identify inter-annual precipitation regime variability and links to river flows across Turkey.

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Table 1 Metadata of selected precipitation stations.

Station name	Station number	Data length (years)	Latitude (°N)	Longitude (°E)	Altitude (m)	Station Name	Station number	Data length (years)	Latitude (°N)	Longitude (°E)
Adana	17351	73	37.00	35.33	27	Ipsala	17632	46	40.93	26.40
Adiyaman	17265	65	37.75	38.28	672	Iskenderun	17370	63	36.58	36.17
Ağrı	17099	65	39.72	43.05	1632	Ispir	17666	50	40.48	41.00
Akhisar	17184	66	38.92	27.85	93	Izmir	17220	65	38.43	27.17
Aksaray	17834	64	38.38	34.08	965	Kahramanmaraş	17255	49	37.60	36.93
Amasya	17085	67	40.65	35.83	412	Karaman	17932	66	37.18	33.22
Anamur	17320	59	36.08	32.83	4	Kars	17098	73	40.62	43.10
Ankara	17130	73	39.95	32.88	891	Kastamonu	17074	73	41.37	33.78
Antakya	17984	62	36.20	36.17	100	Kayseri	17196	66	38.73	35.48
Antalya	17300	73	36.88	30.70	54	Keskin	17730	46	39.68	33.62
Ardahan	17630	65	41.12	42.72	1829	Kirklareli	17052	70	41.73	27.23
Artvin	17045	57	41.18	41.82	628	Kizilcahamam	17664	46	40.47	32.65
Aydin	17234	72	37.85	27.85	56	Kilis	17978	71	36.72	37.12
Bafra	17622	50	41.57	35.92	20	Kocaeli	17066	65	40.78	29.93
Bandirma	17114	57	40.35	27.97	58	Konya	17244	73	37.73	32.48
Bayburt	17686	73	40.25	40.23	1584	Kuşadası	17232	45	37.87	27.25
Bilecik	17122	70	40.15	29.98	539	Kütahya	17725	73	39.42	29.97
Bingöl	17203	43	38.88	40.48	1177	Lüleburgaz	17600	65	41.40	27.35
Bodrum	17290	66	37.05	27.43	26	Malatya	17199	72	38.35	38.32
Burdur	17238	63	37.72	30.28	967	Malazgirt	17780	48	39.15	42.53
Ceyhan	17960	70	37.03	35.82	30	Manavgat	17954	57	36.78	31.43
Cihanbeyli	17800	51	38.65	32.93	968	Manisa	17186	73	38.62	27.43
Çanakkale	17112	66	40.15	26.42	6	Mardin	17275	64	37.30	40.73
Çankiri	17080	55	40.60	33.62	751	Mersin	17340	73	36.80	34.60
Çemişgezek	17768	64	39.07	38.92	953	Merzifon	17083	68	40.87	35.33
Çermik	17874	40	38.13	39.45	700	Muğla	17292	73	37.22	28.37
Çorlu	17054	66	41.17	27.80	83	Muş	17204	53	38.73	41.48
Çorum	17084	73	40.55	34.95	776	Niğde	17250	68	37.97	34.68
Denizli	17237	55	37.78	29.08	425	Ordu	17033	52	40.98	37.90
Dikili	17180	62	39.07	26.88	3	Pınarbaşı	17802	51	38.72	36.40
Dinar	17862	65	38.07	30.17	864	Polatli	17728	73	39.58	32.15
Divriği	17734	48	39.37	38.12	1225	Rize	17040	73	41.03	40.52
Dört Yol	17962	73	36.85	36.22	28	Salihli	17792	63	38.48	28.13
Dursunbey	17700	46	39.58	28.63	639	Samsun	17030	73	41.28	36.30
Edirne	17050	73	41.67	26.57	51	Siirt	17210	72	37.92	41.95
Edremit	17696	40	39.60	27.02	21	Silifke	17330	73	36.38	33.93
Elazığ	17201	72	38.67	39.23	990	Simav	17748	42	39.08	28.98
Ereğli	17248	52	37.50	34.05	1044	Sinop	17026	71	42.02	35.17
Erzurum	17096	73	39.92	41.27	1758	Sivas	17090	73	39.75	37.02
Fethiye	17296	64	36.62	29.12	3	Sivrihisar	17726	73	39.45	31.53
Gaziantep	17261	64	37.07	37.38	855	Şanlıurfa	17270	66	37.13	38.77
Geyve	17662	73	40.52	30.30	1000	Şebinkarahisar	17682	42	40.30	38.42
Giresun	17034	73	40.92	38.40	37	Şile	17610	63	41.18	29.37
Gökçeada	17110	65	40.20	25.90	72	Tefenni	17892	49	37.32	29.77
Gönen	17674	53	40.10	27.65	37	Tokat	17086	70	40.30	36.57
Göztepe	17062	73	40.97	29.08	33	Tosya	17650	51	41.02	34.03
Gümüşhane	17088	45	40.47	39.47	1219	Trabzon	17037	65	41.00	39.72
Hadim	17928	45	36.98	32.47	1552	Uşak	17188	73	38.68	29.40
Hakkari	17285	52	37.58	43.73	1728	Van	17172	57	38.50	43.38
Hinis	17740	65	39.37	41.70	1715	Yalova	17660	46	40.65	29.27
Hopa	17042	42	41.40	41.43	33	Yozgat	17140	49	39.82	34.80
Islahiye	17964	67	37.03	36.63	518	Zile	17681	43	40.30	35.75
Isparta	17240	72	37.77	30.55	997	Zonguldak	17022	72	41.45	31.80
Inebolu	17024	60	41.98	33.77	64					

Table 2 Precipitation regime shape class frequencies in the main geographical regions. (Percentage of regimes in each region is given in parentheses.)

Shape regime	Black Sea	Marmara	Aegean	Mediterranean	Central Anatolia	Eastern Anatolia	Southeast Anatolia
A	1 (4)	13 (86)	10 (67)	9 (50)	-	-	-
B	-	-	5 (33)	8 (44)	-	4 (31)	7 (100)
C	9 (38)	-	-	-	7 (47)	6 (46)	-
D	2 (8)	1 (7)	-	1 (6)	8 (53)	-	-
E	2 (8)	-	-	-	-	3 (23)	-
F	10 (42)	1 (7)	-	-	-	-	-

Table 3 Average values of precipitation indices for stations within the five regime magnitude classes (1: low; 2: intermediate; 3: moderately high; 4: high; 5: very high).

Precipitation Magnitude index	Regime average					Average (All stations)
	1	2	3	4	5	
Mean (mm month ⁻¹)	33.97	46.81	64.40	96.62	183.57	54.07
Max (mm month ⁻¹)	49.11	71.99	100.35	150.83	251.66	82.20
Min. (mm month ⁻¹)	0.00	0.00	0.01	0.01	0.35	0.01
Std dev. (mm month ⁻¹)	8.77	12.32	16.98	25.70	46.12	14.17
No. of stations	32	32	35	6	2	107

Table 4 Precipitation regime magnitude class frequencies in the main geographical regions. (Percentage of regimes in each region is given in parentheses.)

Magnitude Regime	Black Sea	Marmara	Aegean	Mediterranean	Central Anatolia	Eastern Anatolia	Southeast Anatolia
1	10 (42)	1 (6)	-	2 (11)	14 (93)	5 (39)	-
2	3 (13)	7 (47)	9 (60)	4 (22)	1 (7)	5 (39)	3 (43)
3	7 (29)	7 (47)	5 (33)	9 (50)	-	3 (22)	4 (57)
4	2 (8)	-	1 (7)	3 (17)	-	-	-
5	2 (8)	-	-	-	-	-	-

Table 5 Precipitation regime composite class frequencies in the main geographical regions. (Percentage of regimes in each region is given in parentheses.)

Composite Regime	Black Sea	Marmara	Aegean	Mediterranean	Central Anatolia	Eastern Anatolia	Southeast Anatolia
1B	-	-	-	1 (6)	-	-	-
1C	8 (33)	-	-	-	7 (47)	4 (31)	-
1D	1 (4)	1 (7)	-	1 (6)	7 (47)	-	-
1E	1 (4)	-	-	-	-	1 (8)	-
2A	-	7 (46)	4 (27)	3 (16)	-	-	-
2B	-	-	5 (33)	1 (5)	-	1 (8)	3 (43)
2C	1 (4)	-	-	-	-	2 (15)	-
2D	1 (4)	-	-	-	1 (6)	-	-
2E	1 (4)	-	-	-	-	2 (15)	-
3A	1 (4)	6 (40)	5 (33)	4 (22)	-	-	-
3B	-	-	-	5 (28)	-	3 (23)	4 (57)
3F	6 (25)	1 (7)	-	-	-	-	-
4A	-	-	1 (7)	2 (11)	-	-	-
4B	-	-	-	1 (6)	-	-	-
4F	2 (9)	-	-	-	-	-	-
5F	2 (9)	-	-	-	-	-	-

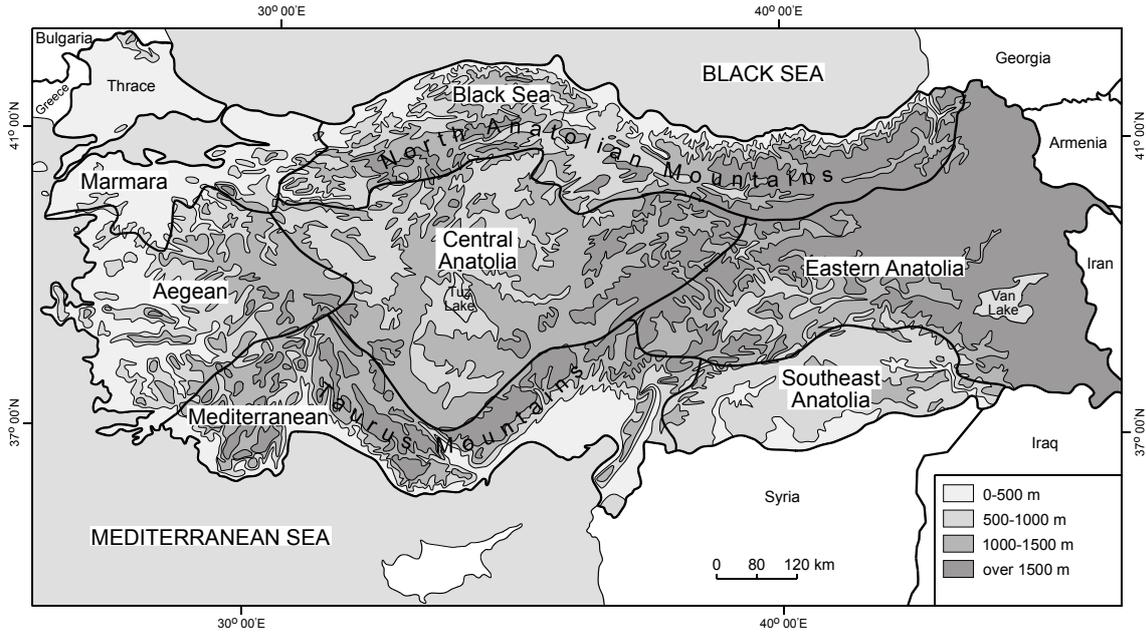


Fig. 1 Major geographic regions and elevation of Turkey.

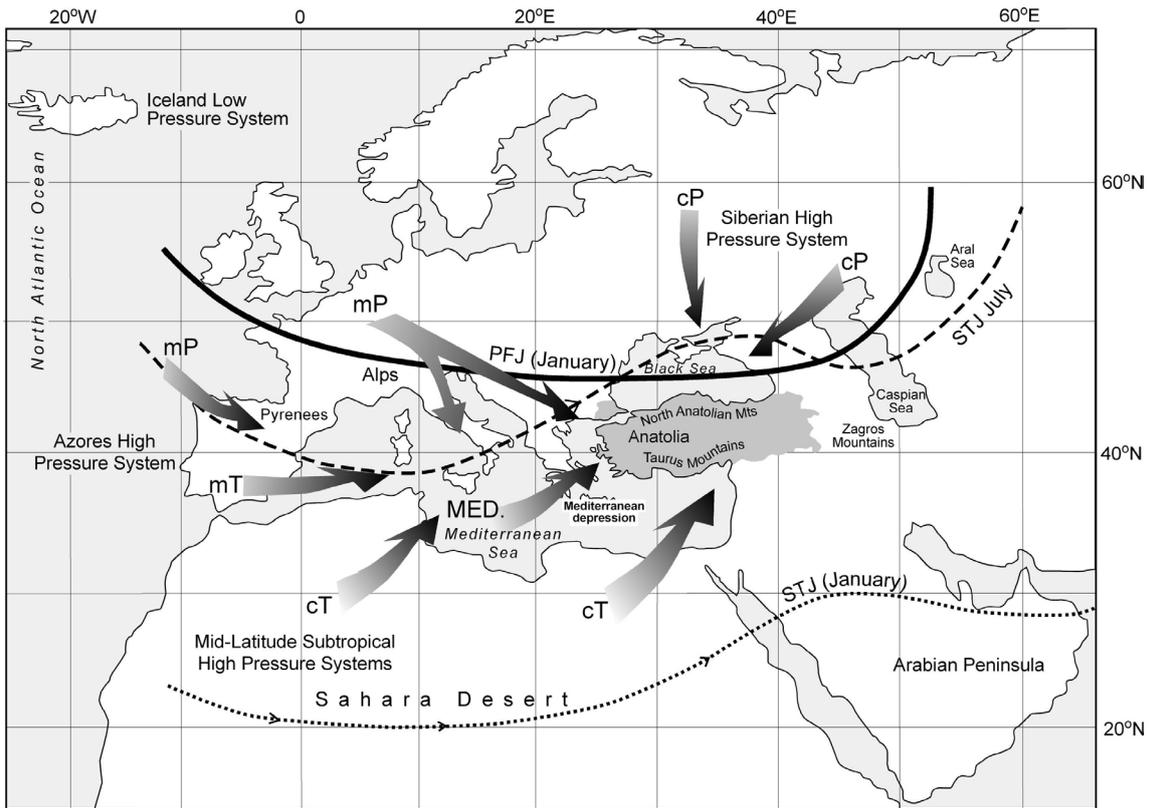


Fig. 2 Schematic diagram of air masses influencing winter and summer climate of the eastern Mediterranean region (MED: Mediterranean Air Mass; mP: Marine Polar Air Mass; cP: Continental Polar Air Mass; mT: Marine Tropical Air Mass; cT: Continental Tropical Air Mass; PFJ: Polar Front Jet; STJ: Sub-tropical Jet).

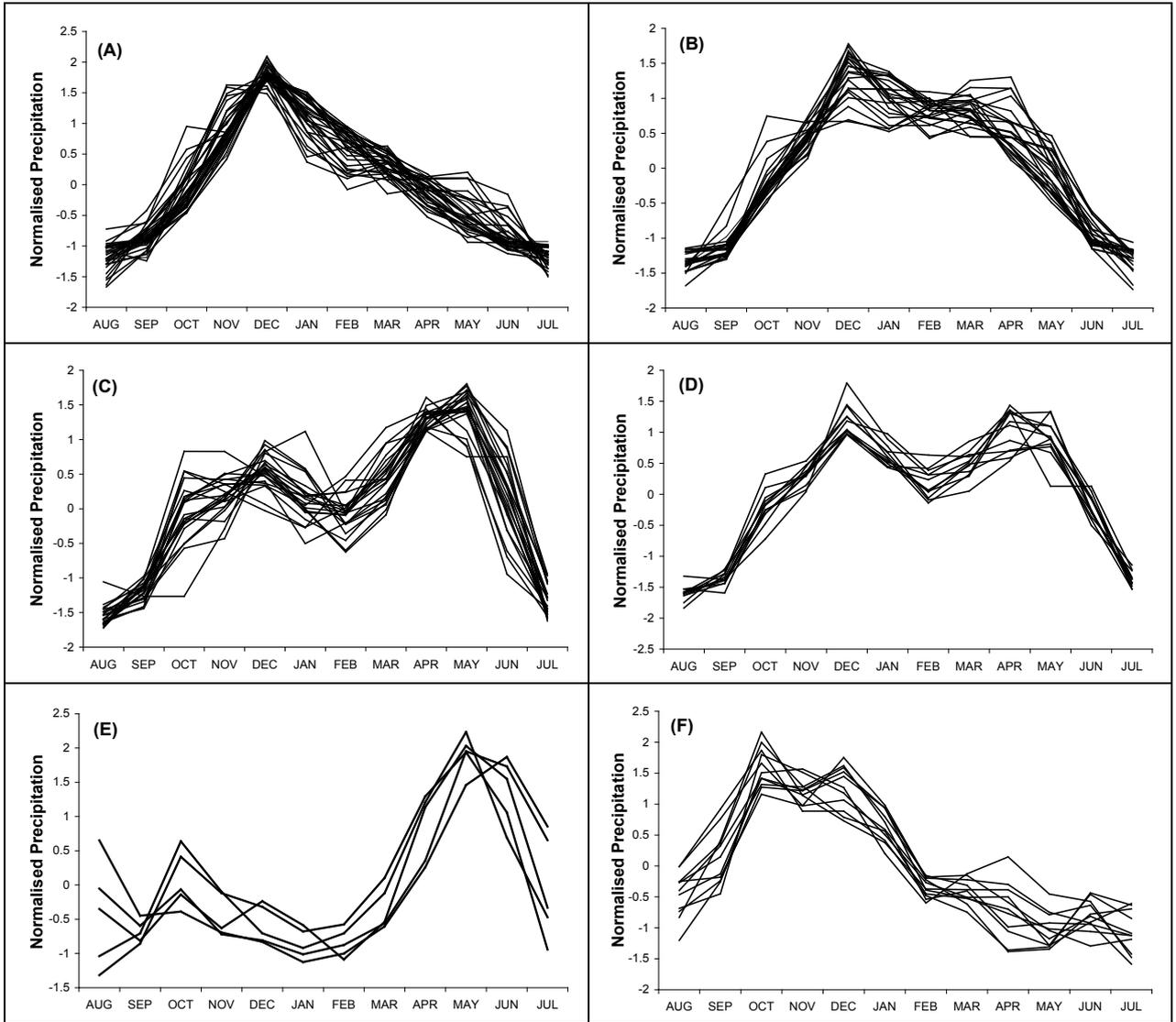


Fig. 3 Standardized (z -scores) monthly values for all stations within the precipitation regime shape regimes.

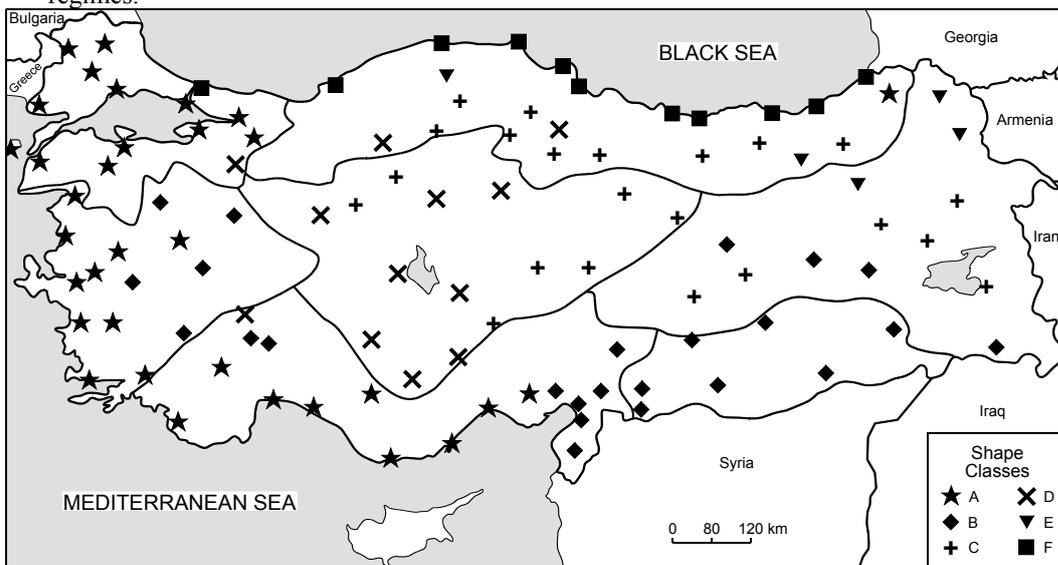


Fig. 4 Spatial distribution of precipitation regime shape across Turkey.

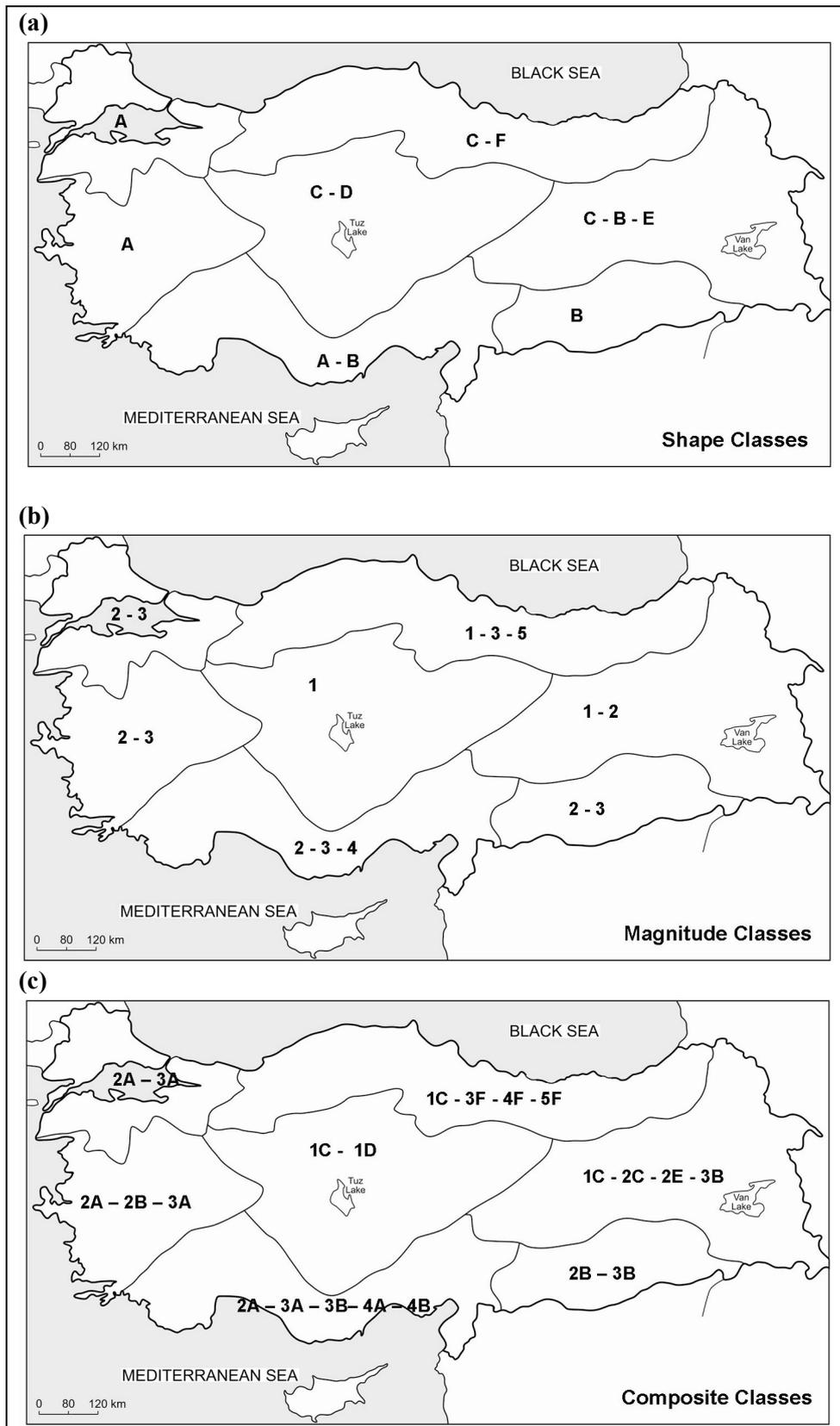


Fig. 5 Summary of spatial patterns for (a) shape, (b) magnitude, and (c) composite regimes across Turkey.

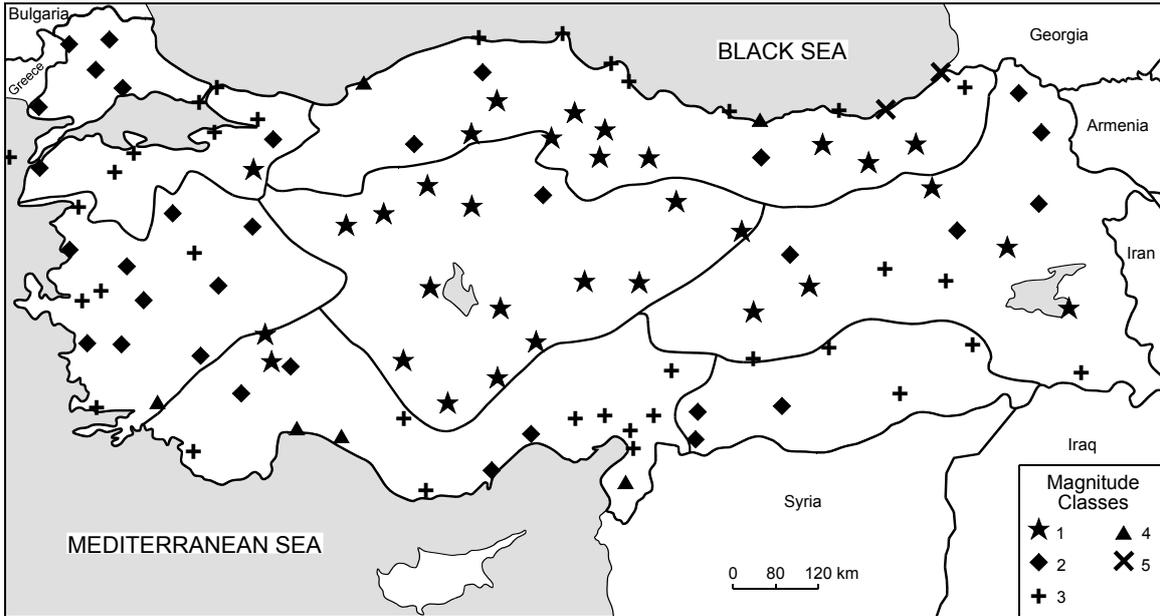


Fig. 6 Spatial distribution of precipitation magnitude regimes across Turkey.

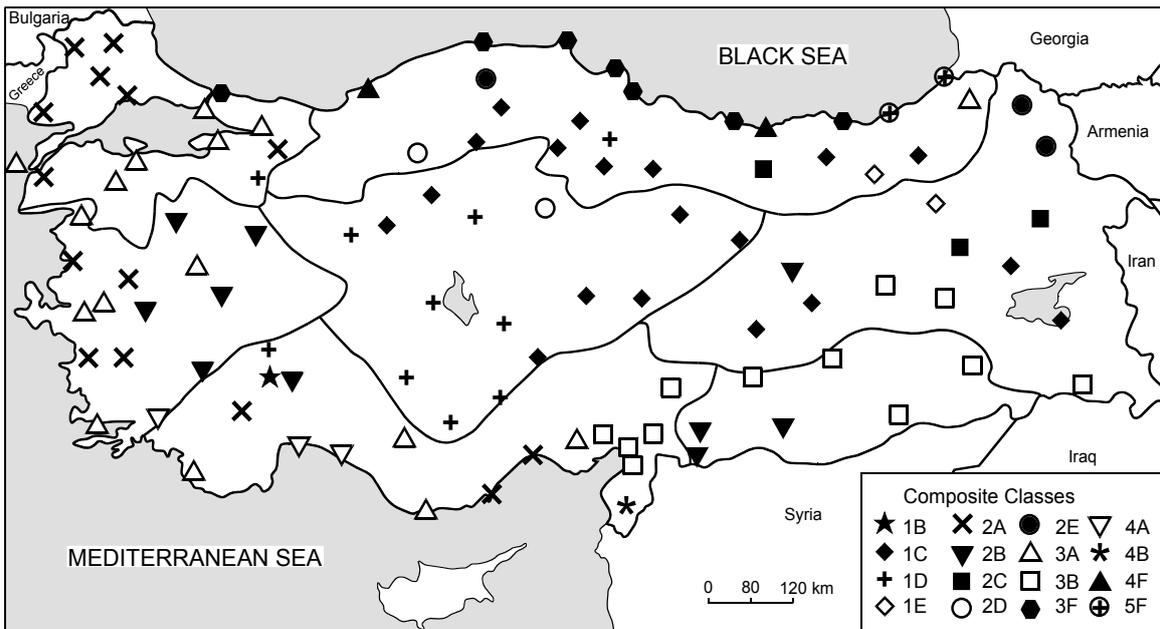


Fig. 7 Spatial distribution of composite (shape and magnitude) precipitation regimes across Turkey.

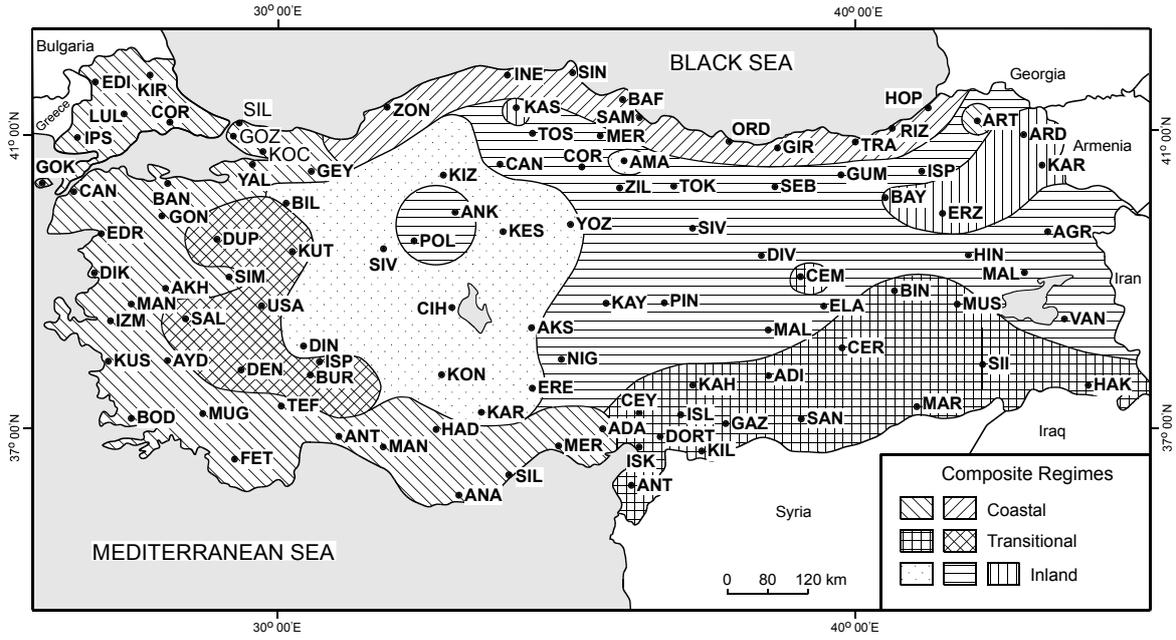


Fig. 8 Simplification of precipitation regimes of Turkey into coastal, transitional and inland regions.