İSTANBUL TECHNICAL UNIVERSITY ★ EURASIA INSTITUTE OF EARTH SCIENCES

DETERMINATION OF LAST GLACIAL EQUILIBRIUM LINE ALTITUDES OF TURKEY BY GLACIAL MASS BALANCE MODEL

M.Sc. THESIS

Savaş GÜNDÜZ

Department of Solid Earth Sciences

Geodynamics Programme

JUNE 2018

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Thesis Advisor: Assoc. Prof. Dr. Mehmet Akif SARIKAYA

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ AVRASYA YER BİLİMLERİ ENSTİTÜSÜ

TÜRKİYE'DE SON BUZUL DÖNEMİ DENGE ÇİZGİSİ YÜKSEKLİĞİNİN KÜTLE DENGESİ MODELİ İLE BELİRLENMESİ

YÜKSEK LİSANS TEZİ

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‘‘…to my mother’’

FOREWORD

I would like to thank my supervisor, Mehmet Akif Sarıkaya who encouraged me to study glacier and glacier geomorphology. He always showed unconditional help and patience to us. This work would not be completed without his helps. He inspires us with his works and we will always admire his works. I also would like to thank Attila Çiner for his advises and guiding comments.

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June 2018 Savaş Gündüz

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ABBREVIATIONS

DEM	:	Digital Elevation Model
ELA	:	Equilibrium Line Altitude
GIS	:	Geographic Information System
LG	:	Late Glacial
LGM	:	Last Glacial Maximum
AAR	:	The accumulation area ratio
MELM	:	The Maximum elevation of lateral moraines
Prec	:	Precipitation
Temp	:	Temperature
lat, lon	:	Latitude and Longitude
PISM	:	Parallel Ice Sheet Modelling
ka	:	killo annum, (thousands of years)
acc	:	Accumulation
abl	:	Ablation

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DETERMINATION OF LAST GLACIAL EQUILIBRIUM LINE ALTITUDES OF TURKEY BY GLACIAL MASS BALANCE MODEL

SUMMARY

Turkey is located in the Eastern part of Mediterranean region between 36°N and 42°N latitude and 26°E and 45°E longitude. Turkey's climatic and topographic features have strong contrasts which indicate a characteristic feature for Turkey. As a general view, Turkey has a varied topography for its all geographical regions. Turkey is a mid-latitude country located with a relatively high topography. In the current climate of Turkey, glaciers do not occupy large areas but it is known that paleo-glaciers covered larger areas during the Last Glacial stage based on earlier studies. There is a close relationship between climate and equilibrium line altitude (ELA) of a glacier. Glaciers are the most commonly used indicators for climate change.

The purpose of this study is to calculate Turkey's ELA by glacial mass balance model during the Last Glacial Maximum (LGM) and compare with previous studies. For this purpose, monthly present day temperature and precipitation were used to make paleo-climatic estimations. The Last Glacial stage ELA were determined by a glacier mass balance model and compared with previous studies. In total, 25 glacial areas have been studied. Using the monthly temperature and precipitation data obtained from WorldClim, annual ablation was calculated by positive degree day model and annual accumulation were calculated assuming that precipitation falls as snow at 0°C. Calculations made by an in-house Matlab program. Annual mass balances were found with the difference between the accumulation and ablation values. The simulations for the last glacial period were firstly done with the precipitation was kept the same as the present conditions, and the temperature depressions was changed between -8°C and -12°C. In the second case, the temperature was kept constant (-10°C lower than today), the precipitation was changed from drier (%25 drier) to humid (%25 wetter) conditions than today. Accordingly, the last glacial paleo-equilibrium line altitudes in Turkey were calculated and spatially compared with earlier studies.

When temperature is 10°C cooler than today and precipitation is in the present day condition (Precipitation=1), ELA decreasing from south of Turkey to the north. It is almost between 2400-2500 m a.s.l. in the Southeast Taurus. In Akdağ and Beydağ, ELA is more than 2200 m a.s.l in Sandıras, Davraz, Dedegöl, Geyikdağ, Aladağlar and Bolkar, ELA is about 2200 m. It has a decreasing pattern toward to north. Erciyes and Soğanlı Mountains have ELA 2000-2200 m. In Uludağ which is situated in the north part of the Turkey it is in between 1600-1800 m.

In the eastern part of Turkey, ELA is higher when it compared with western Turkey. In Buzul and İkiyaka Mountains, ELA is in between 2600-2700 m. Southeast part of Turkey has the highest ELA value. For –10°C temperature decrease and same as today's precipitation values (from south to north) there is a decreasing pattern. It shows that there is clear latitude effect in Turkey's ELA.

From west to east ELA is increasing as elevation ‘increasing from west to east. It also shows that elevation affects the ELA in Turkey because elevation is increasing from west to east. The places where elevation is high have higher ELA compared to other places in the Turkey.

According to the study of Messerli (1967), ELA is 2300 m in the Black Sea region. When the temperature -8 °C below today and present day precipitation condition, ELA estimates of 2000-2100 m in the Black Sea close the Messerli’s estimates. In the Mediterranean ELA is around 2500 m. For Mediterranean, all results that I have are higher than 2000 m. This can indicate ELA is almost same values in the Mediterranean in LGM.

In the south east region that have most of the glaciers, ELA is between 2700-2800 m in the study of Messerli (1967). It is more than 2400-2500 m in southeast region for all the cases applied. That also shows that there is a match between these values. In the west part of Turkey, ELA is around 2300 m in Messerli (1967) study but in this part, I got lower ELA values when it compares to Messerli (1967)’s study.

TÜRKİYE'DE SON BUZUL DÖNEMİ DENGE ÇİZGİSİ YÜKSEKLİĞİNİN KÜTLE DENGESİ MODELİ İLE BELİRLENMESİ

ÖZET

Türkiye, Akdeniz bölgesinin doğu kesiminde 36 ° ve 42 ° Enlem, 26 ° ve 45 ° Doğu boylamları arasında yer almaktadır. İklimi ve topografyası ile Türkiye, farklı özelliklere sahip bir ülkedir. Türkiye, nispeten yüksek bir topoğrafyaya sahip bir orta enlem ülkesidir. Bu özellik sayesinde, diğer bölgeler kadar olmasa da, modern ve geçmiş dönem buzullarına ev sahipliği yapması için iyi bir potansiyele sahiptir. Türkiye'nin mevcut ikliminde, buzullar büyük alanlar işgal etmemekle birlikte, daha önceki çalışmalara göre geçmiş dönem buzullarının son buzul evresinde daha geniş alanları kapladığı anlaşılmaktadır. Bir bölgedeki yıllık ortalama kar yağışı olan bir buzulun iklim ve kalıcı kar sınırı (ELA) arasında yakın bir ilişki vardır. Buzullar, iklim değişikliği için en çok kullanılan göstergelerdir.

Bu çalışmanın amacı, Türkiye'nin Son Buzul Maksimum (LGM) 'deki Kalıcı Kar Sınırı'nı tanımlamak ve önceki çalışmalarla karşılaştırmaktır. Bu amaçla, bazı iklim tahminleri yapmak için yıllık mevcut sıcaklık ve yağış değerleri kullanılmıştır. Türkiye'nin son buzul dönemi kalıcı kar sınırı, bir kütle dengesi modeli ile belirlenmiş ve önceki çalışmalarla karşılaştırılmıştır. Toplamda 25 buzul alanı çalışılmıştır. WorldClim'den elde edilen aylık sıcaklık ve yağış verilerini kullanarak, yıllık erime (ablasyon) pozitif dereceli günler modeli ile hesaplanmış ve yağışların sıfırın altındaki sıcaklıklarda kar olarak düştüğü varsayılarak yıllık birikim (accumulation) hesaplanmıştır. Bilgisayar tabanlı Matlab programı tarafından yapılan hesaplamalar ile bu iki değer arasındaki fark ile yıllık kütle dengeleri bulunmuştur. Son buzul dönemine ait simülasyonlar ilk olarak yağış değerleri kullanılarak yapılmıştır, yağışlar mevcut koşullarla sabit tutulmuş ve sıcaklık -8 ° C ile -12 ° C arasında değiştirilmiştir. İkinci durumda, sıcaklık sabit tutulmuştur (günümüze göre -10°C daha düşük), yağış değerleri ise daha kurak (% 25 daha kuru) ve daha yağışlı (% 25) olarak değiştirilmiştir. Buna göre, Türkiye'deki son buzul dönemi kalıcı kar sınırı (ELA) hesaplanmış ve daha önceki çalışmalarla karşılaştırılmıştır.

Sıcaklık eksi on (-10°C) derece daha düşük ve yağış günümüz şartlarında olduğunda, Türkiye'nin güney kısmından kuzey kısmına doğru alçalan ELA değerleri görülür. Güney Toros dağlarında neredeyse 2400-2500 arasındadır. Akdağ ve Beydağ'da ELA 2200 metreden yüksektir. Sandıras, Davraz, Dedegöl, Geyikdağ, Aladağlar ve Bolkar'da ELA yaklaşık 2200 metredir. Kuzeye doğru azalan bir yönelime sahiptir. Erciyes ve Soğanlı Dağları'nda ise ELA 2000-2200 m arasındadır. Türkiye'nin kuzey kesiminde yer alan Uludağ da ise 1600-1800 m arasındadır.

Türkiye'nin doğu kesiminde ELA, Batı kısmı ile kıyaslandığında daha yüksek bir seviyeye ulaşmıştır. Buzul ve İkiyaka Dağlarında ELA 2600-2700 m arasındadır. Türkiye'nin güneydoğu kısmı en yüksek ELA değerine sahiptir. - 10°C ve 1 mm yağış değerleri için (güneyden kuzeye) azalan bir yönelim vardır.

Bu da Türkiye'nin kalıcı kar sınırında açık bir enlem etkisi olduğunu göstermektedir. ELA, batıdan doğuya doğru, yükseltiye parelel olarak artmaktadır. Ayrıca yükseltinin batıdan doğuya doğru artması, yükseltinin ELA ile paralellik gösterdiği görülür.

Messerli'nin (1967) yılı çalışmasına göre, ELA Karadeniz bölgesinde 2300 m civarındadır. Bu çalışmada ise sıcaklığın -8°C daha düşük ve bugünkü yağış koşullarında, ELA, Karadeniz Bölgesi'nde 2000-2100 metredir. Akdeniz'de ELA 2500 m civarındadır. Akdeniz için sonuçların çoğu 2000 m'den daha yüksekte yer almaktadır. Bu değerler Messerli (1967)'nin ELA değerlerine yakındır.

Buzulların büyük kısmının yer aldığı Güneydoğu Toroslarda, ELA, Messerli'nin (1967) çalışmasında 2700-2800 m arasındadır. Bu çalışmada ise tüm değerlerde ELA 2400-2500 m'den fazladır. Bu sonuç değerler arasında bir benzerlik olduğunu gösterir. Türkiye'nin batısında, ELA, Messerli'nin (1967) çalışmasında 2300 m civarındadır ancak bu çalışmada, Messerli (1967) çalışmasına göre daha düşük ELA değerleri elde edilmiştir.

1.INTRODUCTION

1.1 Study Area

Turkey is located in the Eastern part of Mediterranean region between 36°N and 42°N latitude and 26°E and 45°E longitude. Turkey's climatic and topographic features have strong contrasts which indicate a characteristic feature for Turkey. As a general view, Turkey has a very varied topography for its all different regions. Turkey has a very varied and high topography especially in the East. Turkey's elevation varies from region to region but in the west part of Turkey it is less than 500 m a.s.l in the western lowlands. In the central Anatolian Plateau, it is 1100 m a.s.l and it is very high in the south, north and east plateau that is much over 3000 m a.s.l. Elevation is increasing from west to east part of Turkey in general view. Some of the mountains tops lie above the modern snowline (Kurter and Sungur, 1980; Kurter, 1991) and have climatic conditions suitable for glaciers and ice caps (Çiner, 2004; Sarıkaya, 2009, 2010a, b)
Mountains in the Turkey has distributed in a non-regular pattern. There are mainly two mountain ranges which are South Anatolian Mountain Ranges and North Anatolian Mountain Ranges. These two main ranges occupied most of the Turkey's glaciated mountains. They are also a part of And-Himalayan Mountain Range. There are also some volcanic mountains that are not active in modern time. They do not show a regular distribution in Turkey. Figure 1 indicates the glaciated mountains and their locations in Turkey. It also contains the vicinity (shown in square) that studied around the mountains.

Turkey's position as a Mediterranean and mid-latitude country, it has strong climatic and topographic differences. There are many glaciated mountains that spread over particularly East Black Sea and East Anatolia High Lands (Kurter and Sungur, 1980; Kurter, 1991).

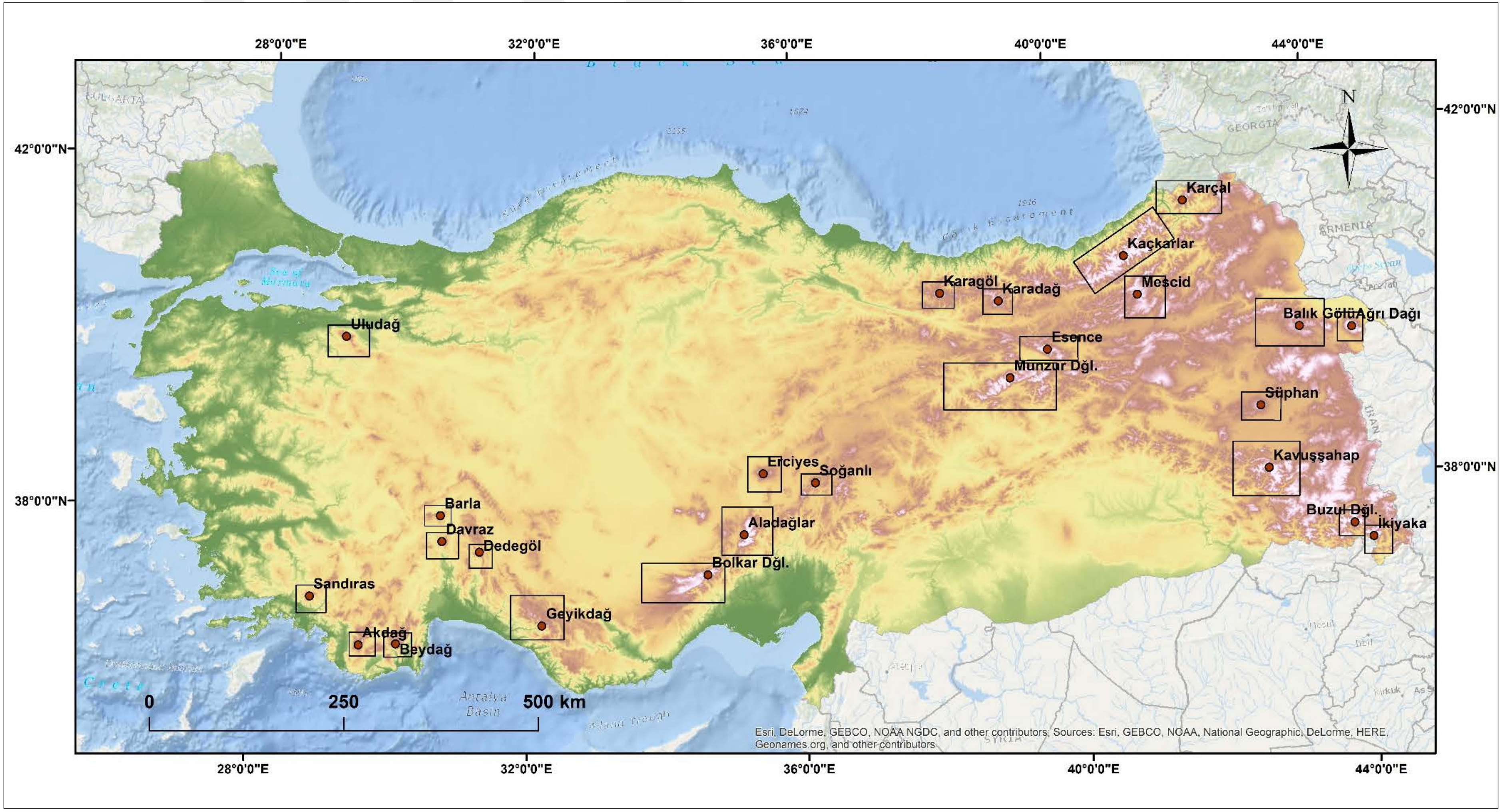

Figure 1.1: Glaciated Mountains in Turkey according to Sarıkaya and Çiner (2015)

In today’s climatic conditions, there are many countries that have abundant glaciers but Turkey is not the one of the first country that comes to minds when the topic is glacier and glacier deposits. However, it has a potential glacial background when recent researches indicate important information about glaciers developed during the Quaternary (Zreda et al., 2006; 2011; Akçar et al., 2007, 2008; Sarıkaya et al., 2008, 2009; Zahno et al., 2009, 2010; Dede et al., 2017)

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Turkey’s present glacial mountains and Late Quaternary glacial mountains deposits and landforms are generally situated in the three regions: (1) the Taurus Mountains, along the Mediterranean coast and south-eastern Turkey; (2) the mountain ranges in the Eastern Black Sea Region and (3) the volcanoes and independent mountain chains scattered in the Anatolian Plateau (Kurter and Sungur, 1980, Çiner, 2004).

The Taurus Mountain Range (Mediterranean coast and Southeast Turkey) is the first part and two thirds of the present day glaciers concentrated in the south-east part of Taurus Mountain. In that area, Mount Cilo (4168) is hosting more than ten glaciers compare to others. Present snowline (ELA) is between 3000 m a.s.l. For the Last Glacial snowline is estimated around 2800 m. In the central Taurus, Aladağlar (3756 m) and Bolkardağ (3524 m) are the two most important mountains where give a chance to have glaciers even it is a small amount at present. But there is no any other present glaciers in the west Taurus, even it has some signs of past glacial activity in the area (Last Glacial snowline is estimated to be around 2200 m) (Çiner, 2003).

The second part is East Black Sea coast also known as Pontic Mountain Range in some studies. The highest peak of the Eastern Mountain range is Mount Kaçkar (3932 m) that is the east edge of the North Anatolian Mountain Range. Five glaciers are developed in this area. There are also several other mountains such as Verçenik (3710 m), Altıparmak (3353 m), Karagöl (3107 m) and Karadağ (3331 m) that support various glaciers. The present ELA is much lower on the north facing slopes (3100-3200 m) compared to that of south face which has (3550 m) ELA. The reason behind this is effect of more humid air masses. The Last Glacial Snowline elevation was 2600 m on average (Çiner, 2003).

The last part of glacial mountain in Turkey is volcanoes and independent mountains scattered in the Anatolian plateau. In the interior part of the country, volcanoes such as Mount Ağrı also known as Ararat (5137 m), with an ice cap of around 10 km; Mount Süphan (4058 m) and Mount Erciyes (3917 m) indicate signs of glacial activity and there are some signs active glaciers. There are also Mount Uludağ (2543 m), Mount Mercan also known as Munzur (3368 m) and Mount Mescid (3239 m) in the central Anatolia have traces of past glacial activity (Çiner, 2003).

Turkey's high topography especially in the eastern parts enable to have glaciers mostly when it compares to the other regions. In figure 1, Turkey's glaciated mountain are shown in digital elevation model map. It clearly shows that high topography support glacier abundance in those regions have high topography. In a broad perspective, limited data are available on Turkish glaciers. But recent observations show that the glacier recession at least the beginning of the 20th century.

Glaciers are so sensitive proxy for climatic fluctuations, for that fact the extension of a glaciers or retreating of a glacier is directly related to the climate and climatic changes (Sarıkaya et al., 2008). For that reason, glaciers can be used as an indicator for climatic changes and paleo glaciers can estimate by using climatic variations over the time. Present temperature and precipitations can be used in order to observe last glaciers changes. Variation records can be used to estimate paleo climate conditions by different temperature and precipitation values. By doing this, temperature and precipitations changes can be estimated from past to present. Moreover, these data can be considered as input to a model of the paleo glaciers.

Most of the glaciated mountains in Turkey were studied by Turkish and foreigner researchers. Table 1 indicates the all twenty-five mountains that we studied on them with the information of latitude, longitude, elevation and earlier researchers. There is also LGM and present snowline information. Turkey has two main mountain range which are North Anatolian and South Anatolian (Taurus) Mountains. There are also some Volcanic mountains in Turkey. Some of these mountains have glaciers on them. Defining and studying glacier mountains were done first by foreigner researchers.

Table 1.1: List of Glaciated Mountains in Turkey

	Location of the Peak					
Name of the Mountain	Lat (°N)	Lon (°E)	Elev.(m)	LGM (m)	Present Snowline (m)	Source
Ağrı	39,7018	44,2983	5137	3000	4300	Sarıkaya (2012)
Akdağ	36,5439	29,5674	3016	2518	3500	Sarıkaya et al. (2014)
Aladağlar	37,8366	35,1453	3756	2700	3450	Zreda et al. (2011)
Balık Gölü	39,7766	43,5274	2804	?	4300	Birman (1968)
Barla	38,0531	30,722	2800	2450	3750	Louis (1944); Ardos (1977)
Beydağ	36,5684	30,1017	3086	2575	3600	Louis (1944); Messerli (1967)
Bolkar	37,3862	34,6087	3524	2650	3675	Çiner and Sarıkaya (2015)
Buzul (Cilo)	37,4877	44,0012	4135	2450	3600	Erinç (1952); Yavaşlı et al. (2015)
Davraz	37,7571	30,7317	2637	2450	3750	Louis (1944); Messerli (1967)
Dedegöl	37,6437	31,2835	2992	2375	3400	Zahno et al. (2009)
Erciyes	38,5318	35,4469	3917	2700	3550	Sarıkaya et al. (2009)
Esence (Keşiş)	39,7836	39,7548	3477	2750	3650	Akkan and Tuncel (1993)
Geyikdağ	36,8075	32,2021	2850	2500	3400	Çiner et al. (2015)
İkiyaka (Sat)	37,3105	44,2502	3794	2600	3600	Bobek (1940)
Kaçkarlar	40,8354	41,1614	3932	2700	3150	Akçar et al. (2007; 2008); Reber et al. (2014); Doğu et al. (1993)
Karadağ	40,3793	39,071	3331	2725	3500	Gürgen (2001)
Karagöl	40,5101	38,1928	3107	2650	3500	Planhol and Bilgin (1961)
Karçal	41,3472	41,983	3431	2600	3400	Gürgen and Yeşilyurt (2012); Dede (2016)
Kavuşşahap	38,2146	42,8563	3503	3000	3400	Doğu (2009); Yeşilyurt et al. (2018); Schweizer (1975)
Mescid	40,3273	41,1673	3239	2750	3650	Yalçınlar (1951); Atalay (1984); Kahraman (2016)
Munzur	39,4934	39,1669	3368	2750	3650	Bilgin (1972)
Sandıras	37,0814	28,838	2295	2000	3250	Sarıkaya at al. (2008)
Soğanlı	38,4084	36,2119	3075	2610	3550	Ege and Tonbul (2005)
Süphan	38,9309	42,8326	4058	3200	3850	Kesici (2005); Schweizer (1975)
Uludağ	40,0706	29,2215	2543	2400	3500	Zahno et al. (2010); Akçar et al (2014)

Turkey has two main mountain range which are North Anatolian and South Anatolian (Taurus) Mountains. There are also some Volcanic mountains in Turkey. Some of these mountains have glaciers on them. Defining and studying glacier mountains were done first by foreigner researchers. Most of the glaciated mountains in Turkey were studied by Turkish and foreigner researchers. Table 1 indicates the all twenty-five mountains that we studied on them with the information of latitude, longitude, elevation and earlier researchers. There is also LGM and present snowline information.

1.2 Purpose of Study

The purpose of this study is to define Turkey's Equilibrium Line Altitude in Last Glacial Maximum (LGM) and compare with previous studies. For this purpose, annual present day temperature and precipitation were used to make these estimations. To carry out this, temperature and precipitation values were changed to different values to have a prediction and estimation about ELA in the LGM in Turkey. As glaciers respond the climatic changes very fast, it is a very good way to estimate climatic changes and their rate. It is also going to show how climate has changed and how it was and how it is now. To carry out this purpose surface mass balance was used to define former Equilibrium Line Altitude (ELA). ArcGIS and Matlab programs also were used to define Equilibrium Line Altitudes (ELA). By defining them we can compare past and present Equilibrium Line Altitude changes and can see how it changed during the years. By doing this, climate change can be guessed. The climate anomaly can be defined how it changed, does it have an increasing or decreasing phenome during the years.

1.3 Climate

1.3.1 Paleoclimate conditions

Today, glaciers are not occupied a large area in Turkey but glaciers were in the most extensive condition in Turkey during the LGM which is about last 22 ka (ka: thousands years), and they were correlated with the global LGM chron (between 19 and 23 ka) due to ^{36}Cl cosmogenic exposure ages of moraines show (Sarıkaya et al., 2009). According to these cosmogenic dating result, LGM glaciers started retreating 21.3±0.9 ka ago on Erciyes Mountain, located in central Turkey, and 20.4±1.3 ka ago on Sandıras Mountain, located in southeastern Turkey. It was also stated that glaciers showed changes by 14.6±1.2 ka ago (Late Glacial) on Erciyes Mountain (Sarıkaya et al., 2009).

There are two main indicaters for climate which are temperature and precipitation. Both temperature and precipitation were different from today's values. For temperature, there is a general view that temperature was colder than today's temperature. According to climatic data that collected from East Mediterraenen Basin, Climate was colder in the LGM (Robinson et al., 2006). The isotop study in Soreq

Cave in İsrail indicated that LGM was the coldest peiod in the last 25 ka years (Bar-Matthews et al., 1997). By using cave deposits, the temperature in LGM was identifed between -8°C and -12°C (Mcgarry et al., 2004). There are also some computer based model that show climate was between -8°C and -12°C (Robinson et al., 2006). For precipitation there are two different ideas. First one is climate was rainier than today's and the second one climate was drier than today's climate. For precipitation there is no a coomon idea like temperature values.

To make assumption about former climate and glaciers, today's climatic condition was used. Present temperature and precipitation belong to glaciated mountain vicinity (shown in figure 1) were used in order to reconstruct paleo climatic conditions in those areas.

1.3.2 Present climate conditions

Today's climate data were used to reconstruct the paleoclimatic conditions. These required present temperature and precipitation data were obtained from WorldClim (http://www.worldclim.org). These data indicate the monthly average temperature and precipitation values for study areas. For each distinctive mountain, annual precipitation and temperature values were obtained and used to make any estimation about their former conditions. As a general perspective, Turkey is located in the mid-latitude and has Mediterranean climate and dry climate due to reason of high elevation values.

Geographic location and having different types of landforms lead to have different characteristics of climate in Turkey. Temperate climate is dominant in coastal Turkey which are Black Sea and Mediterranean Region mostly. Unlike coastal regions, inner regions have continental climate. Main reason may be the North Anatolian and South Anatolian Mountain Ranges prevent the temperate weather to reach inner parts of Turkey and cause rain shadow effect on region.

Turkey's climate varies from region to region. Mainly it has three basic climate types that they are Continental in the central, east and south Anatolia; Mediterranean climate in the south Anatolia and Black sea climate in the north Anatolia.

The recent climate in the southeastern Turkey is defined as dry/hot in summer seasons and wet/temperate in winter seasons (Kendrew,1961). Winter seasons are moderately wet.

The summer seasons are hot and the average summer temperature for June, July and August (JJA) on the southeastern part of Turkey is about 26°C and for winter temperature which is for December, January and February (DJF) is about 10°C.

Turkey has a dry and hot climate for summer time. South part of Turkey is warmer than other regions. Figure 1.2 shows the annual summer temperature for June, July and August months. As in the Figure 1.2, Southeast and south parts are the warmer places during the summer in Turkey. Due to latitude affect it is a normal anomaly but with an extra reason which is continentally in southeast is extremely hot compared with other places. But in the high topographic places especially in the eastern Black sea and in east Anatolia, the temperature for summer is lower. There are also some mountains in the south Anatolia that have glaciated mountains even it is the one of the hottest places in summer season. In central is moderately hot. Glaciers are remaining during the all year. This is one the characteristic of the glaciers.

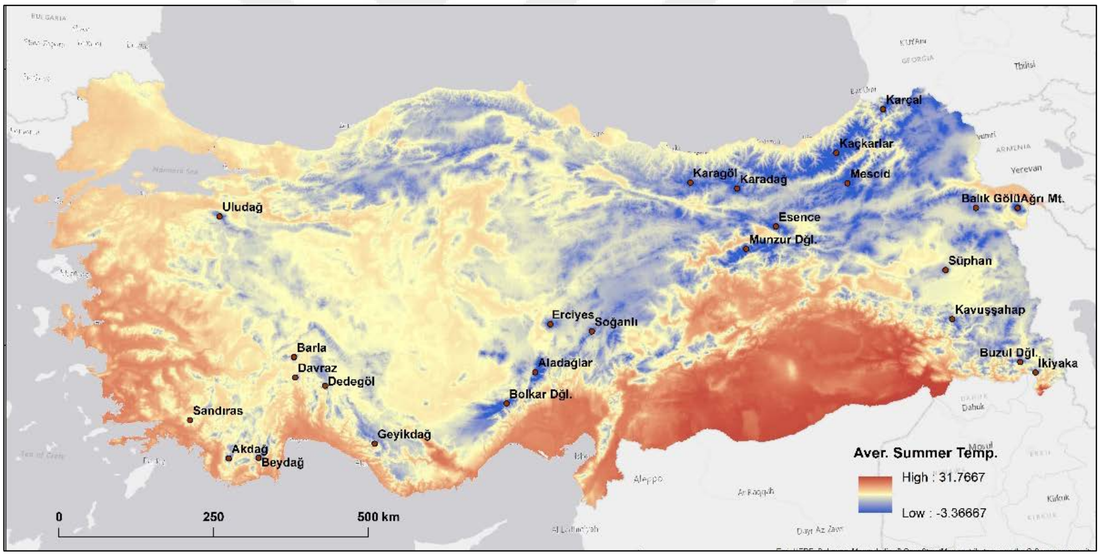

Figure 1.2: Average Summer Temperature for three months (JJA) in Turkey

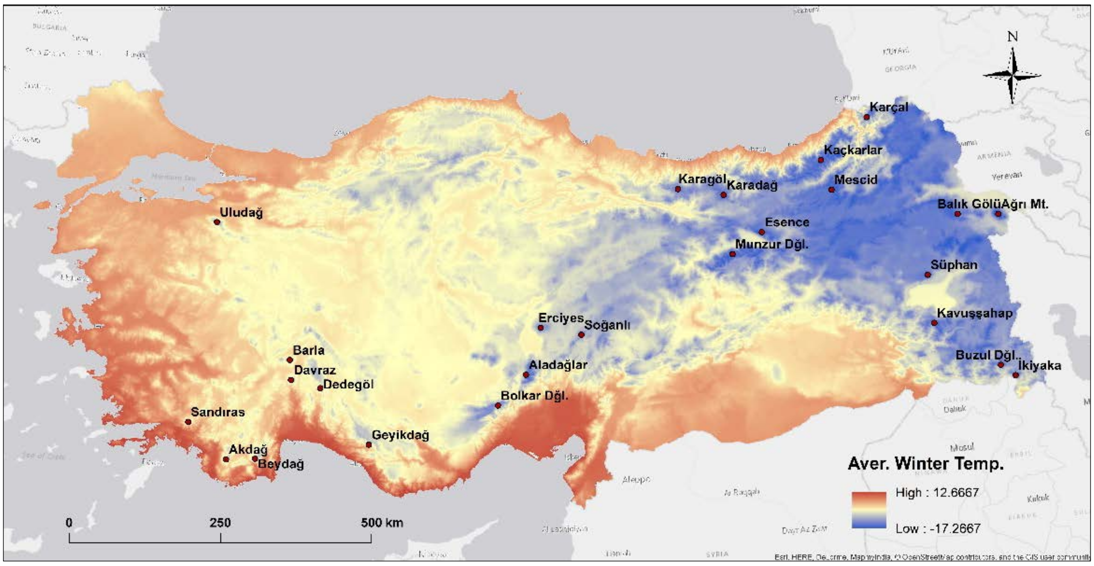

Figure 1.3: Average Winter Temperature for three months (DJF) in Turkey

The southern and western coastal areas have a Mediterranean climate in general, but in eastern and northern Turkey has a more complex climate based on a number of factors. Main factor is extremely varied and high topography in Turkey. There is very high topography in east but a moderate topography in western parts and coastal parts. Elevation is increasing from west to east. Another factor for north, there is an inland sea (the Black Sea) to the north that makes this area more humid and warm climate. However, in southeast part of Turkey that joins Syria and Middle East is very hot in summer and southern coastline around the Mediterranean is only about 500 km across the hot continent Africa that makes this part very hot in summer. Most of the Turkey is high plateau and the topography become more mountainous toward the east part of Turkey. Even in the lower-lying west the terrain is mostly hilly (https://www.metoffice.gov.uk/).

In general, Turkey is hot or warm in summer seasons, and cold or very cold in winter seasons. However, coasts are much milder in winter than inlands. In the east, winter precipitation on inlands and mountains is often snow which lasts for about 3-4 months. Annual mean temperature is high in coasts. Typical summer daily maxima range from about 26-28°C along the Black Sea coastline to 34°C towards the east of the Mediterranean coastline. Typical winter daytime maxima range dramatically from 15°C at Adana for example to inlands in the east only -4°C in Erzurum for example (https://www.metoffice.gov.uk/).

In summer, southern coastal areas are mostly dry and sunny; precipitation amounts to around 650 mm/year at Adana, most of it in the winter season half of the year. In inner parts, a double precipitation cycle merges, peaking in both autumn and spring. Despite higher altitude, inland areas have lower annual totals than on the coast. (https://www.metoffice.gov.uk/).

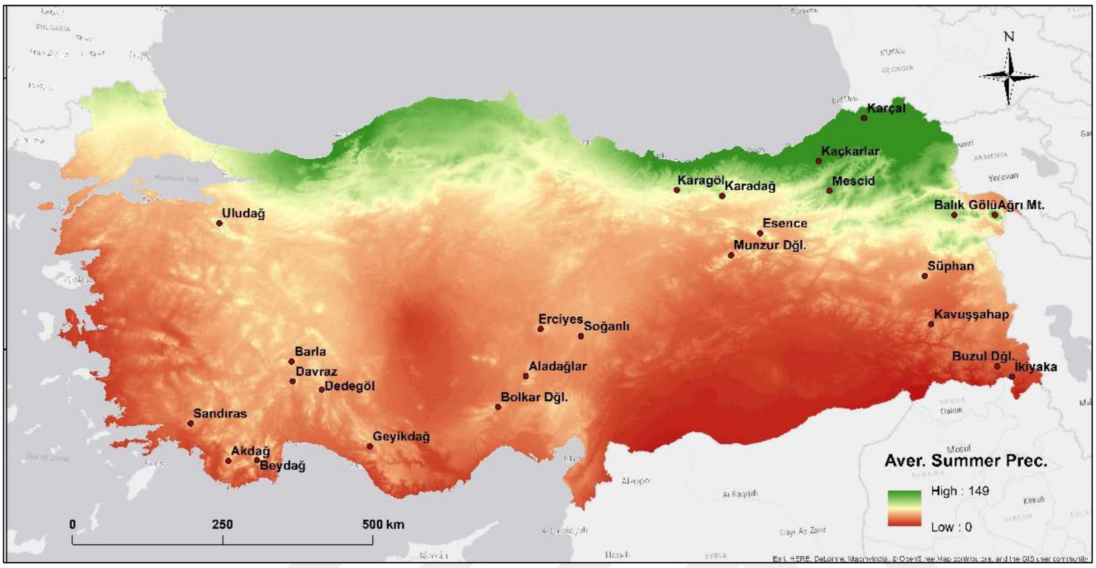

Figure 1.4: Average Summer Precipitation for three months (JJA) in Turkey

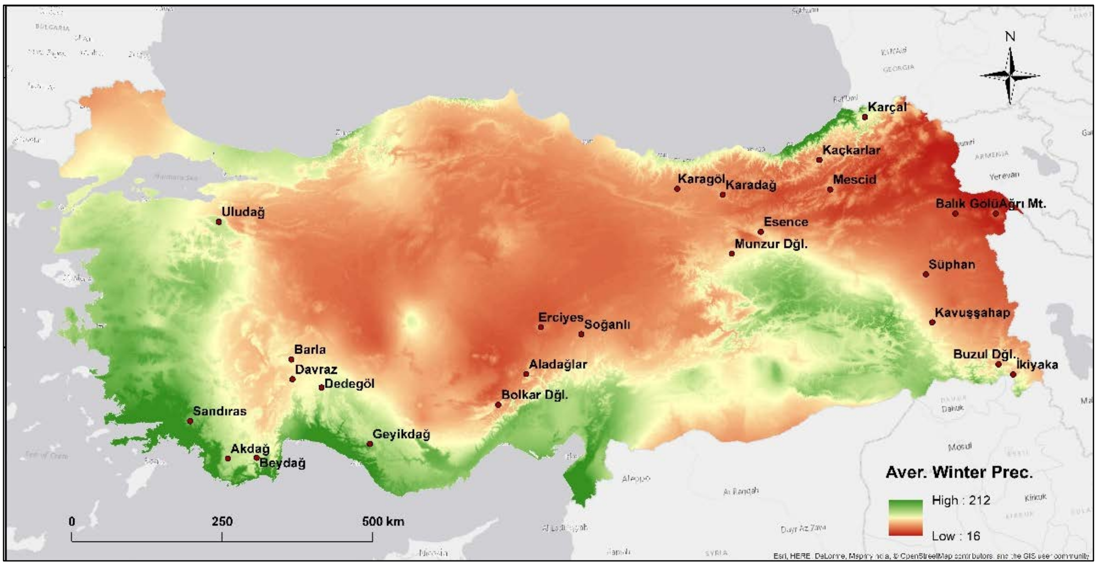

Figure 1.5: Average Winter Precipitation for three months (DJF) in Turkey

1.4 Previous Studies

The Earth has experienced both the glacial and interglacial periods through the Quaternary period. And some parts of the earth's surface has been covered by ice sheets and glaciers during the glacier periods. Thus the Pleistocene is considered to be synonymous with the 'Ice Age' (Turoğlu, 2011).

Turkey's glacier studies are concentrated especially in the last fifty years of last century. Most of studies are done in the last years. The existence of the glaciers of Turkey was recognized first by foreign researchers. Ainsworth (1842) and Palgrave (1872) were the first researchers that reported the existence of glaciers of Taurus Mountains and the Eastern Black Sea Mountain also known as Pontic Range. But there is no a systematic investigation until the beginning of the twentieth century.

Maunsell (1901), Bobek (1940), Louis (1944), İzbırak (1951), Erinç (1953), Blumenthal (1952, 1958) and Wright (1962) studied glaciers and collected glacio-geological data and they studied especially on the south-eastern Taurus Mountain Range which is the highest and most mountainous part of the country where quarter of the recent studies are concentrated (Sarıkaya, 2010a).

Sırrı Erinc, the pioneer of the glacial geology in Turkey, published detailed papers on glaciers and variations in equilibrium line altitude (Erinc, 1944, 1951, 1952, 1953, 1978). After that, Messerli (1964 1967), then Birman (1968) and Atalay (1987) studied and presented summary papers on recent Turkish glaciers. In the last quarter of the 20th century, Landsat (Kurter and Sungur, 1980; Kurter, 1991) and ASTER (Advanced Space born Thermal Emission and Reflection Radiometer; Sarıkaya, 2010a) were some satellite that used to report extension of modern Turkish glaciers such as Mount Ağrı (Ararat). More recently, cosmogenic dating of moraine boulders are used by researchers to quantify and timing Quaternary glaciations. Figure 1.6 is a study done by Messerli in 1967. The study shows the ELA in LGM in Turkey. In 2011, this study modified by Sarıkaya et al., 2011 by comparing modern ELA and LGM ELA.

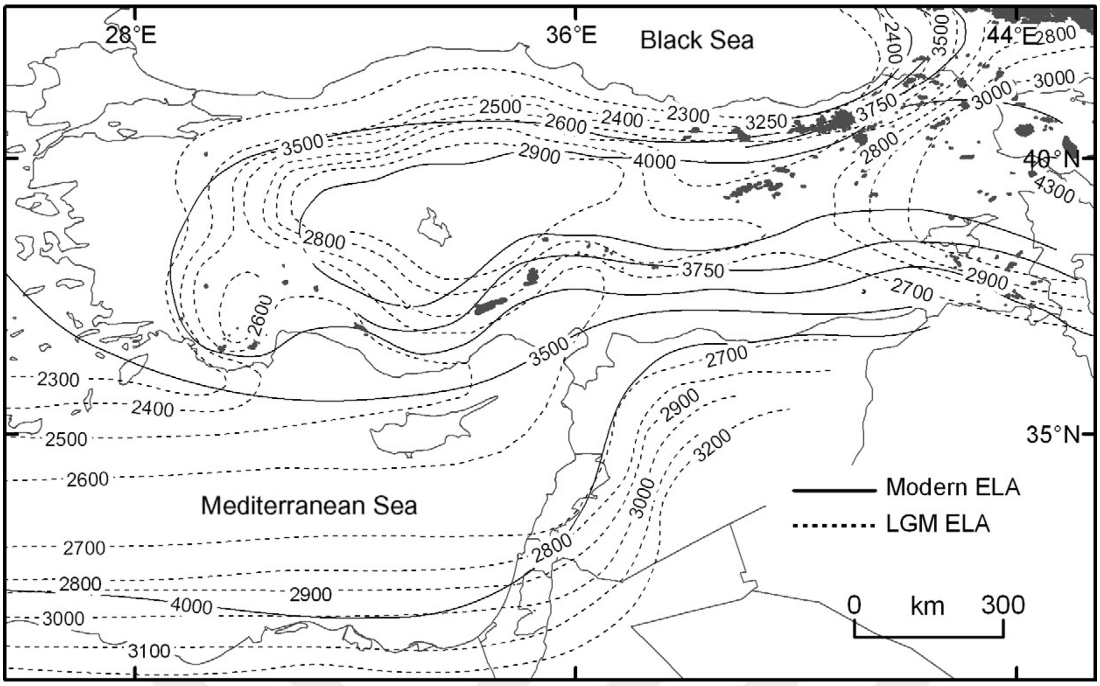

Figure 1.6: ELAs of modern (solid lines) and LGM (dotted lines) glaciers, adapted from Messerli (1967). The grey areas show the maximum extent of Late Quaternary glacial deposits) (Sarıkaya et al., 2011)

2.METHODOLOGY

To carry out this study, several process has been done to calculate the Equilibrium Line Altitude (ELA) of Turkey. For this, some computer based program were used such as ArcGIS, Matlab. To make simulations, today's climatic values (temperature and precipitations) were used. Precipitation and temperature data were extracted from Worldclim. For each month, precipitation and temperature values were downloaded in 30 sec. Turkey was clipped from the world map and for each month annual precipitation and annual temperature maps are made by using PISM. Mean precipitation and mean temperature maps also were made by using these data.

2.1 Surface Mass Balance

The difference between the accumulation and ablation of ice of a certain location and time is called as surface mass balance (also called the glacial yearly budget). It is an accounting of the input/output relationship of snow, firn and ice over a certain time interval. The equation for mass balance is;

$$M = \sum acc - \sum abl: \qquad (2.1)$$

In the formula, *M* is mass balance and *acc* shows accumulation and *abl* shows ablation in a definite year. The accumulation term is used to define adding the water equivalent of ice and snow to a glacier. The primary sources for accumulation are snowfall, rain, water that freezes on the surface, avalanches from the valley walls, and the freeze of meltwater at the base of the glacier. The ablation is the other term that removes snow and ice. And it includes melting, evaporation, wind erosion and sublimation. There is also a kind of ablation that is called as calving which means that huge masses break from the ice in an ocean or marine areas. In figure 2.1, 2.2 and 2.3 three mass balance situations are showed. Advancing, retarating and balance situations are representing the movement of a glacier in a definite place.

The time interval for the mass balance calculations is defined as the budget year. Temperature and precipitation are main factors on accumulation and ablation on a certain area. There are three conditions between accumulation and ablation. They are glacial advance, equilibrium state and glacial retreating. If the accumulation is greater than then ablation process, toe or terminus of the glacier advances to unglaciated areas. This process is called as *glacial advance*. During the advances, terminus moves downslope in mountain glaciers.

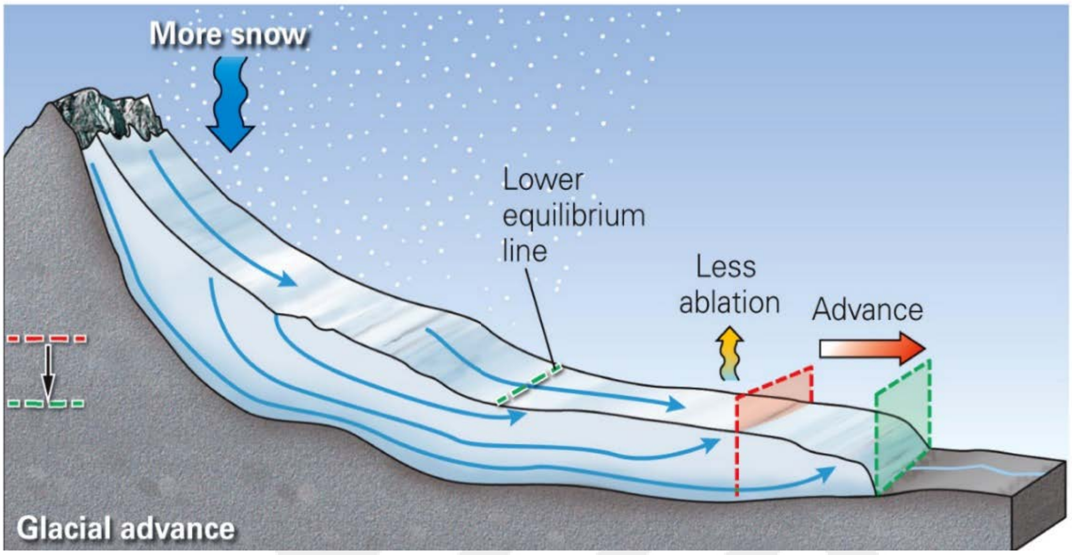

Figure 2.1: The glacier advances if accumulation exceeds ablation. The terminus moves farther from the origin and the ice is thickening (Strandberg et al., 2011)

The second condition is *equilibrium state* that occurs when the rate of ablation and accumulation are equal over the entire glacier. Inputs and output budget are equal during the glaciation. The position of the terminal is not changed seen as in figure 2.2. The glacier mass balance is in equilibrium. Although the glaciers continuous to flow, the terminus position is not changed because of the ablation.

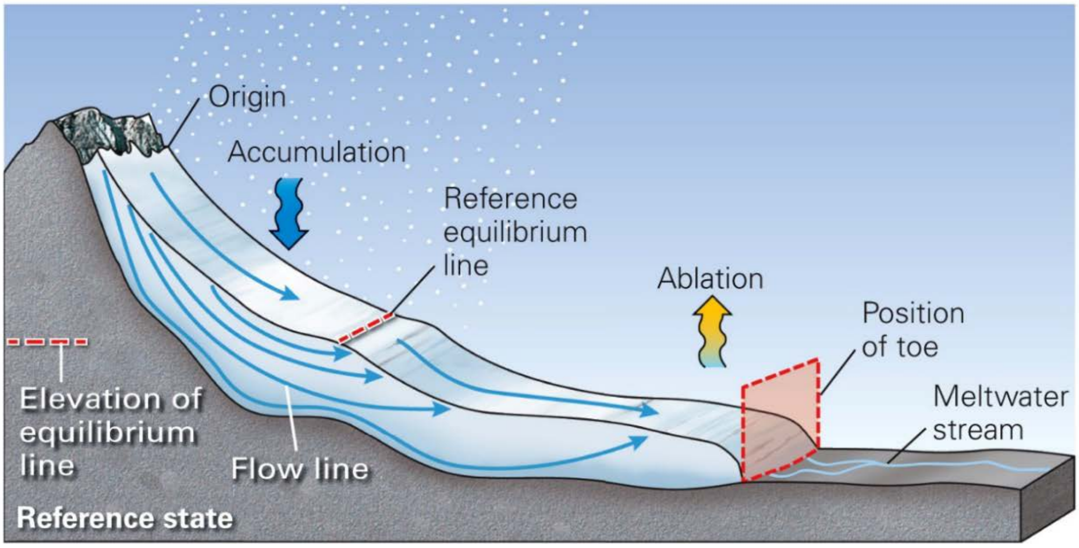

Figure 2.2: The position of the terminus represents a balance between addition by accumulation and loss by ablation(Strandberg et al., 2011)

The third and last case is the rate of accumulation is less than ablation rate. In this case, the position of terminus moves back toward the origin of the glaciers. Glacial retreat is the term used for this case also can be seen in the figure 2.3.

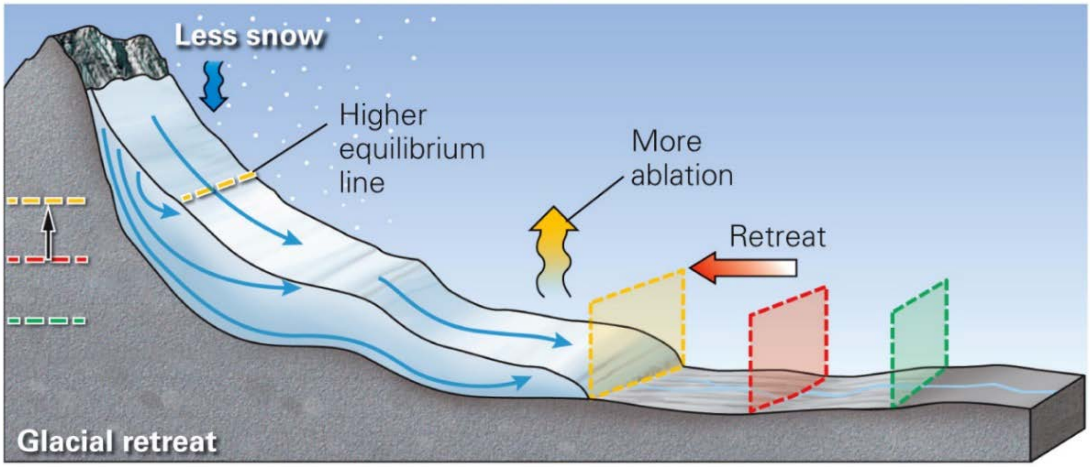

Figure 2.3: The glacier retreats and thins if ablation exceeds accumulation. The toe moves back, even though ice continues to flow toward the terminus (Strandberg et al., 2011)

As a result, in the case of glacier has positive mass balance, more accumulation is occurred than ablation during a budget year. In negative mass balance, there is more ablation than accumulation means that excess of ablation. Mass balance zero means equality between ablation and accumulation. To have glaciers in an area, glacial advance should be dominant in that area.

2.2 Equilibrium Line Altitude (ELA)

Equilibrium line Altitude (ELA) is the division point between accumulation and ablation zones on a glacier. The glacier gathers snow or ice as mass above then ELA and ablation processes are dominant rather than accumulation processes below the ELA. (Figure 2.4) At that altitude, accumulation of snow and ablation is balanced in an exact point. This term is very important for some calculations as it would be in mass balance calculations. If the ELA rises, mass balance of a glacier also rises. The falling in the level of ELA leads to mass balance decreasing. This relationship is very important for mass balance calculations. ELA is also very important indicator for climate and it can change with time. This changing in ELA and its changing speed is an important indicator for climatic studies. It was about 2300-3000 m in Anatolian mountains during the Last Glacial Maximum (LGM, 21,000 calendar years ago).

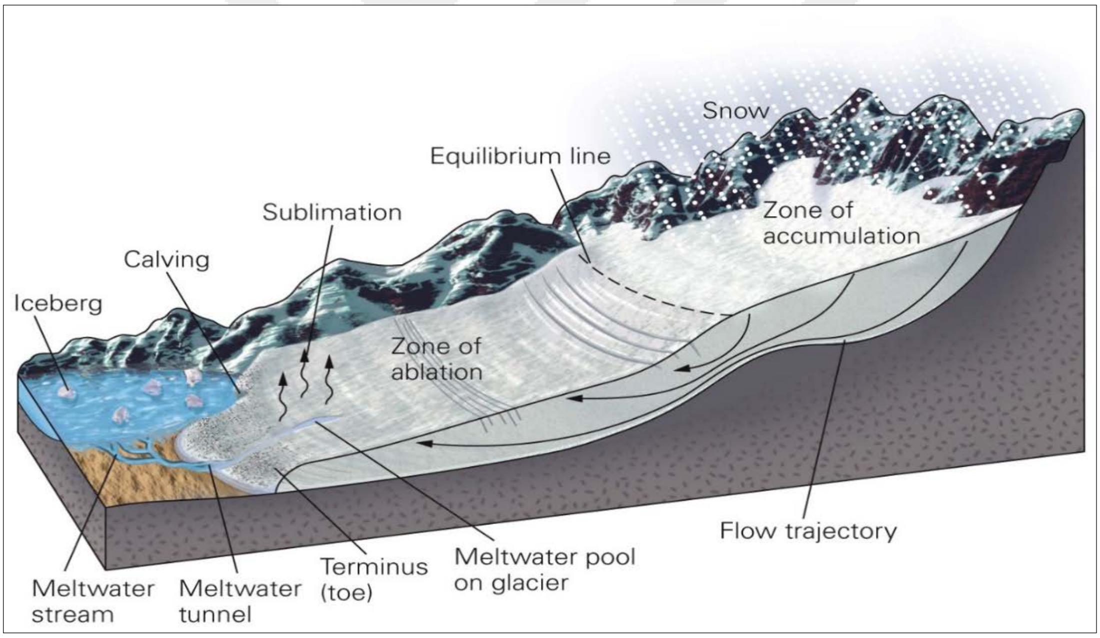

Figure 2.4: The equilibrium line separates the zone of accumulation from the zone of ablation. As indicated by arrows, ice flows down in the zone of accumulation and up in the zone of ablation(Strandberg et al., 2011)

2.3 Climate Data Input (Worldclim)

Climate data for PISM consist of two main parameters which are (1) average monthly mean temperature [°C] and (2) average monthly precipitation [mm]. WorldClim Global Data website is used to get these data (*http://www.worldclim.org*). For twenty-five glaciated mountains, twelve months temperature and precipitation values were downloaded.

WorldClim is a set of global climate layers (gridded climate data) with a spatial resolution of about 1 km² (Hijmans et al., 2005). Minimum, mean and maximum temperature and precipitation values are available in website. Temperature and precipitation values are available for 1960-1990. The data layers were generated through interpolation of average climate data from weather stations on a 30 arc-second resolution grid (about 1 km² resolution) (Hijmans et al., 2005).

For this study, average monthly mean temperature [°C] and average monthly precipitation [mm] values are obtained from WorldClim. Each study area has 12 temperaure, 12 precipitation and one topography values. These data were used as input in Matlab Program. For temperature [°C] three basic conditions were used. They were between (-8°C) and (-12°C). For precipitation input, dry and rainier conditions were used as input data. Howeve elevation was used as an input. In order to run program, text files are needed for a defined place for temperature, precipitation and DEM values. They are Digital Elevation Model (DEM), temperature and precipitation values. PISM uses Network Common Data Form (NetCDF) as input file type. This a machine-independent data format that supports the creation, access and sharing of array-oriented scientific data (Boulder, 2017).

2.4 Preparing Data for PISM Matlab Code

PISM uses Network Common Data Form (NetCDF) as input file type. This a machine-independent data format that supports the creation, access and sharing of array-oriented scientific data (Boulder, 2017). In a *.nc file, different variables can be defined, for example, temperature, precipitation, ice thickness etc. A code was written in MATLAB to create and modify to NetCDF files (Candaş,2017). There are three main functions. The *smb_cal.m* function uses the temperature and precipitation data as input and calculates surface mass balance over a year. The first section of code calculates the Positive Degree Days and accumulation as stated in Section 2.

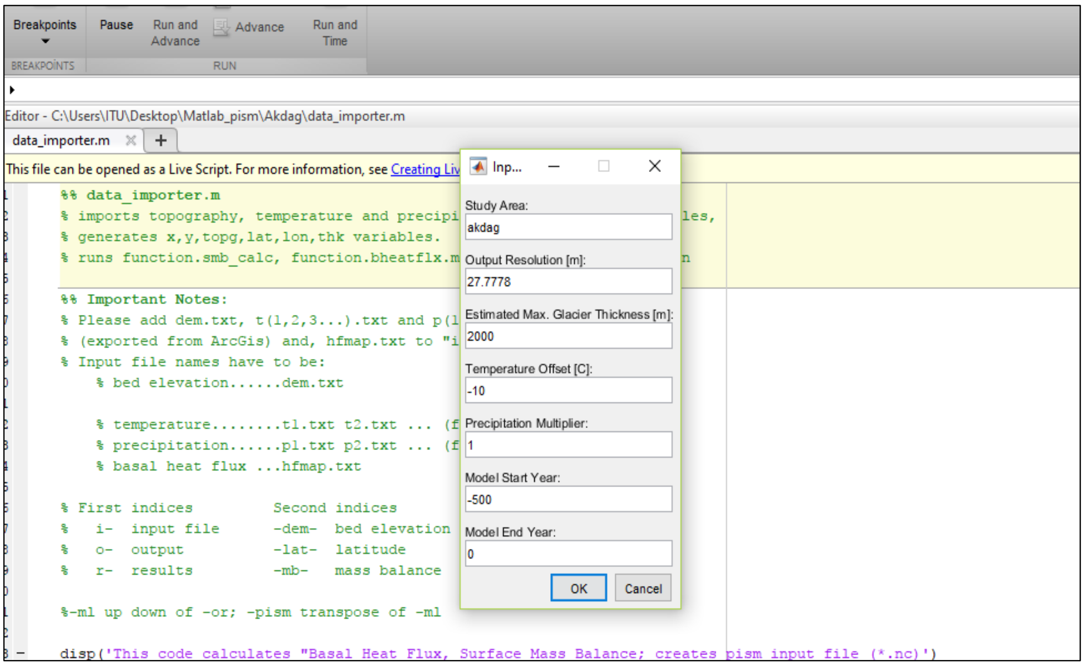

Figure 2.5: The input screen to create NetCDF file. The study area, x and y axis resolution, climatic forcings (Temperature offset and precipitation multiplier), and model time can be defined (Candaş,2017)

In this study, paleo climatic conditions have been created by changing present climatic temperature and precipitation values the study areas and spatial resolutions were defined on the input screen. In order to run program, text files are needed for a defined place for temperature, precipitation and DEM values. They are Digital Elevation Model (DEM), temperature and precipitation values. After entering mountain name and its values whatever we need like dem, temperature and precipitation, the model run and produced these values. For all glaciated mountain areas, one Dem, 12 precipitation and 12 temperature values were produced in text format which is should be in that format to be run in MATLAB program. Figure 2.5 indicates the input screen of Matlab program which is temperature and precipitation values can be changed and applied. Main parameters are temperature and precipitation values. For temperature and precipitation, different values were applied to see ELA variations in different regions.

2.5 Matlab Calculation for Mass Balance and ELA

In order to calculate former Equilibrium Line Altitude (ELA); Dem, temperature and precipitation values were obtained from model builder in ArcGIS. To make calculation, values should be in text format. In figure 2.6 temperature values are ready to use them in MATLAB program. For each area there are three different values which are Digital elevation model, twelve temperature values for each month and twelve precipitation values for each month. These three values are needed to calculate the Equilibrium Line Altitude. For each months, these texts were processed in MATLAB. Except for dem, temperature and precipitation values have been changed to get different assumption for ELA. In figure 2.7, the txt. format for data is showed. For each climatic data which are temperature and precipitation, this format is used in order to use them in Matlab program.

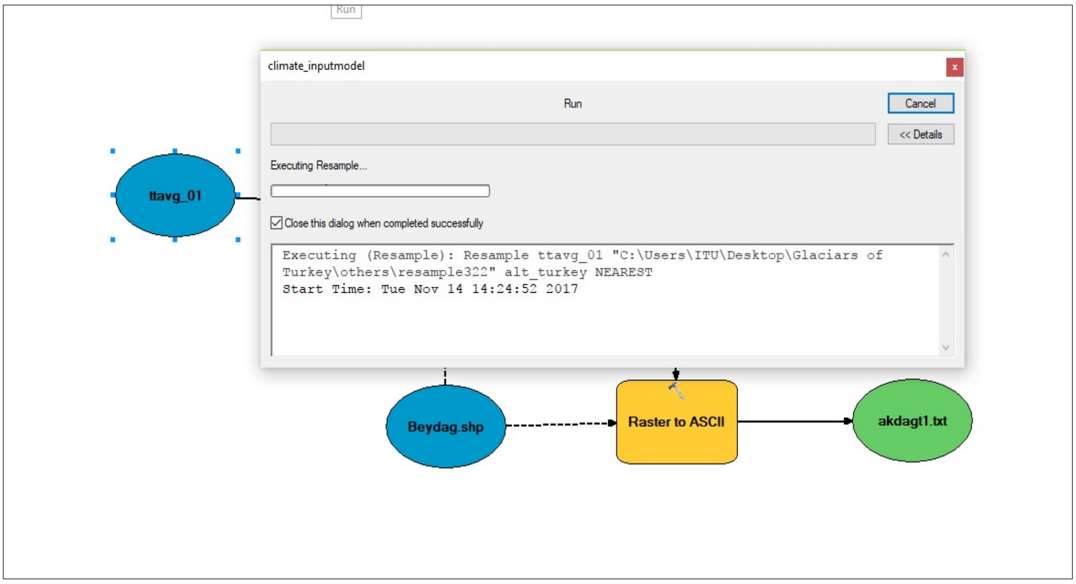

Figure 2.6: Preparing Dem, temperature and precipitation txt. file format for Matlab program

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yllcorner      36.514360707103
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Figure 2.7: An example txt. format of temperature value

At the end of process, we obtained an ELA for each mountains. For the temperature, -8, -9 -10, -11, -12 were used to define an ELA. As the temperature decrease, Ela border decreasing that means in cold condition ELA is in the low altitude. So in the cold climatic condition, glaciation formation is good enough to develop a glacier on the top of the mountains. On the other hands, in humid or warm climatic conditions, ELA border raised and even in some temperature it exceeded mountain top height. That means accumulation is less than ablation. In that case, the formation of a glacier is not possible in the area. For glacier formation, there is need for both cold weather conditions and snowier conditions.

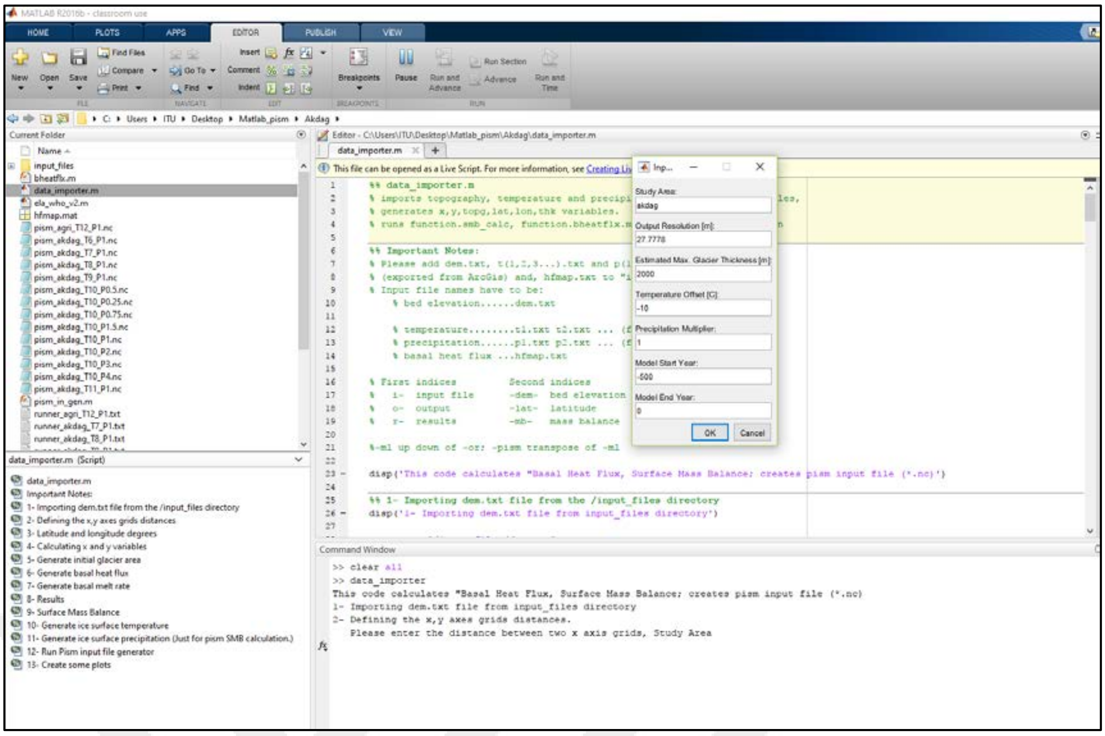

Figure 2.8: The input screen to create NetCDF file . The study area, x and y axis resolution, climatic forcings (Temperature offset and precipitation multiplier), and model time can be defined.

For precipitation also values have been changed and different values were used. For dry to wet conditions, different precipitation values were used. These precipitation values were 0.25, 0.50, 0.75, 1, 1.25, 1.5, 1.75, 2. As the precipitation increased ELA again decreased to lower height which is good for glaciation in the area. Figures 2.8, 2.9 and 2.10 indicate the process of ELA generation in Matlab program. In the last step, ELA of target place is obtained and which topography is over the ELA and which Places are under ELA is clearly defined in the figure 2.10. Blue colour in the figure indicates the places that defined as glacier. Black line shows the ELA. Red, yellow and colours indicate the places that glacier formations are not suitable. These areas are not suitable because of adequate temperature and precipitation values.

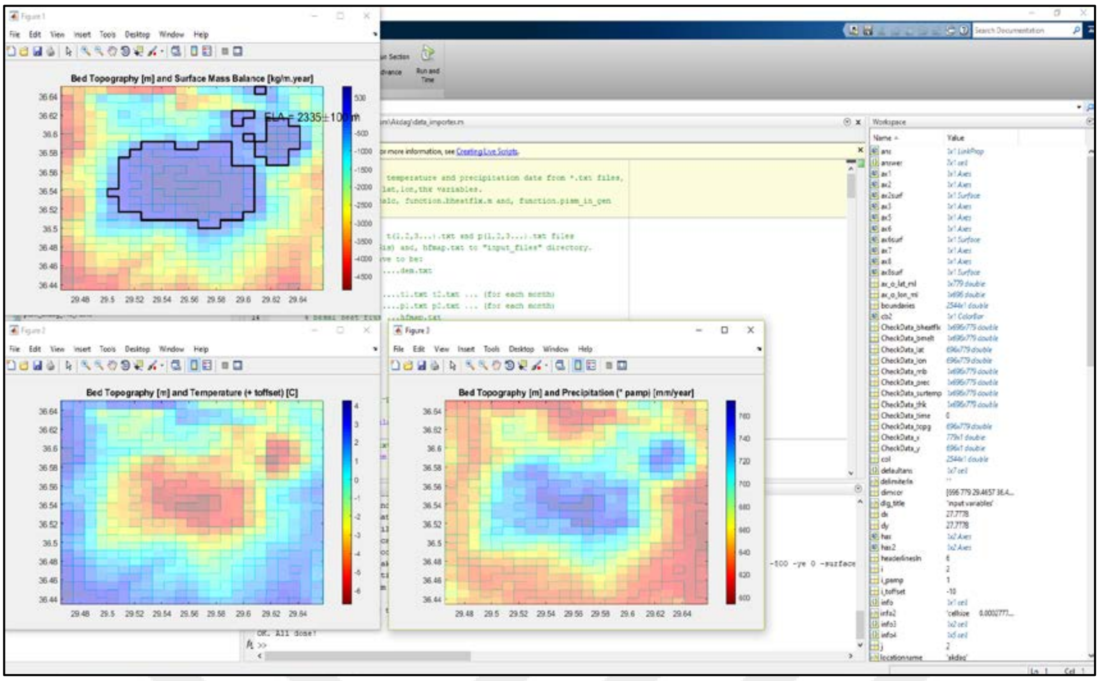

Figure 2.9: The output screen of modelling for ELA

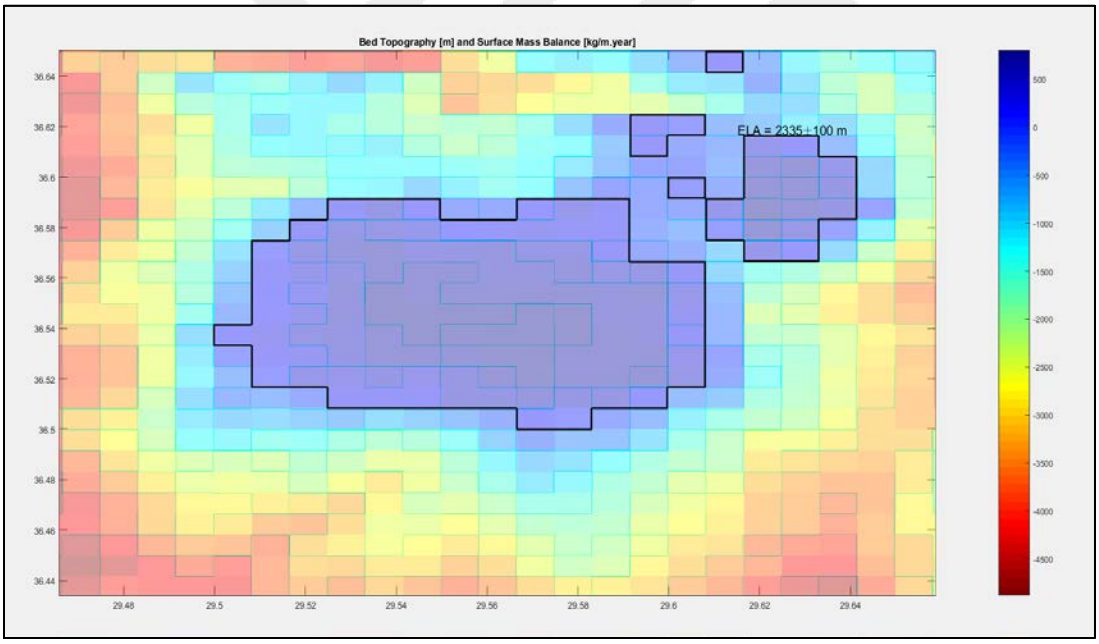

Figure 2.10: The output screen of ELA Calculation

3.RESULTS

Several conditions for temperature and precipitation were applied to make simulations. Three different temperature (-8, -10, -12) were selected and used and three different precipitation values were used in simulations. Three different temperature have used to show temperature were colder than today's temperature and show the different between present conditions, cold and the hot temperature. For precipitation, three different value also were used. (%25 drier), (present day conditions) and (%25 rainier) were used as precipitation values. They show a range from dry to wet conditions.

The simulations for the last glacial period were firstly done with the precipitation was kept the same as the present conditions, and the temperature was changed between -8ºC and -12ºC. In the second case, the temperature was kept constant (-10ºC lower than today), the precipitation was changed from drier (%25 drier) to rainier (%25 wetter) conditions. Accordingly, the last glacial paleo-equilibrium line altitudes in Turkey were calculated and compared with earlier studies.

Table 3.1 and 3.2 show ELA results for each mountains for defined temperature and precipitation. For diffreent results, different colours were used. Each colours show different elevation values which aims to make it more understandable and meaningful. Grey colours show ELA below 1500 m. Light green show ELA between 1500 and 2000 m. Orange colour show ELA between 2000-2500 m. yellow colour show ELA between 2500-3000 meter. Blue shows ELA higher than 3000 meter. When the temperature and precipitations values are not enough to generate glacier, ELA is over the glacier mountains. ELA is not generated and white colours are representing thses areas. Sandıras mountains do not have ELA when the temperature increase to minus -9°C, -8°C and -7°C temperature.

Table 3.1 : Equilibrium Line Altitude (ELA) in different temperature values with fixed precipitation values

				T: -12, P:1			*T: -11, P:1*			*T: -10, P:1*			*T: -9, P:1*			*T: -8, P:1*			*T: -7, P:1*			*T: -6, P: 1*		
Name of the Mountain	**Lat (°N)**	**Lon (°E)**	**Elev.(m)**	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error
Ağrı	39.7018	44.2983	5137	1932	±	577	1943	±	588	1995	±	593	1979	±	602	2015	±	620	2047	±	640	2076	±	651
Akdağ	36.5439	29.5674	3016	2034	±	122	2207	±	116	2335	±	100	2520	±	90	2636	±	52	2794	±	65		±	
Aladağlar	37.8366	35.1453	3756	1875	±	133	2041	±	151	2236	±	156	2429	±	186	2627	±	194	2809	±	169	2953	±	152
Balık Gölü	39.7766	43.5274	2804	2093	±	353	2110	±	358	2126	±	362	2141	±	371	2145	±	377	2147	±	382	2148	±	382
Barla	38.0531	30.722	2800	1837	±	122	2007	±	117	2129	±	122	2137	±	112	2423	±	111	2553	±	64	2611	±	28
Beydağ	36.5684	30.1017	3086	2065	±	127	2214	±	112	2340	±	115	2473	±	124	2595	±	115	2634	±	184	2827	±	28
Bolkar	37.3862	34.6087	3524	1943	±	127	2103	±	145	2281	±	141	2445	±	115	2600	±	122	2755	±	113	2895	±	95
Buzul (Cilo)	37.4877	44.0012	4135	2564	±	146	2800	±	160	2969	±	169	3113	±	196	3214	±	221	3302	±	251	3421	±	291
Davraz	37.7571	30.7317	2637	1861	±	181	2022	±	165	2196	±	145	2328	±	142	2518	±	23	2525	±	0		±	
Dedegöl	37.6437	31.2835	2992	1926	±	158	2075	±	167	2256	±	137	2391	±	115	2607	±	107	2716	±	65	2834	±	35
Erciyes	38.5318	35.4469	3917	1848	±	90	1989	±	87	2146	±	90	2304	±	91	2446	±	97	2642	±	110	2839	±	89
Esence (Keşiş)	39.7836	39.7548	3477	1994	±	122	1854	±	126	2113	±	119	2265	±	130	2399	±	125	2534	±	119	2673	±	121
Geyikdağ	36.8075	32.2021	2850	2017	±	106	1847	±	99	2184	±	93	2346	±	92	2493	±	118	2646	±	87		±	
İkiyaka (Sat)	37.3105	44.2502	3794	2356	±	394	2384	±	434	2380	±	454	2362	±	459	2357	±	459	2327	±	436	2331	±	431
Kaçkarlar	40.8354	41.1614	3932	1880	±	711	1889	±	698	1914	±	688	1946	±	689	1980	±	703	2012	±	725	2043	±	746
Karadağ	40.3793	39.071	3331	1698	±	92	1816	±	112	1906	±	99	2057	±	105	2222	±	109	2379	±	105	2537	±	100
Karagöl	40.5101	38.1928	3107		±		1526	±	127	1755	±	92	1941	±	84	2116	±	93	2289	±	71	2450	±	84
Karçal	41.3472	41.983	3431	1389	±	375	1579	±	280	1787	±	218	1972	±	192	2138	±	143	2282	±	121	2413	±	98
Kavuşşahap	38.2146	42.8563	3503	2339	±	196	2508	±	189	2672	±	185	2812	±	169	2930	±	178	3047	±	160	3119	±	131
Mescid	40.3273	41.1673	3239	1914	±	108	2039	±	106	2168	±	113	2285	±	105	2419	±	97	2562	±	95	2715	±	89
Munzur	39.4934	39.1669	3368		±		1971	±	147	2142	±	152	2314	±	162	2468	±	155	2608	±	144	2747	±	116
Sandıras	37.0814	28.838	2295	1892	±	53	2073	±	62	2219	±	0		±			±			±			±	
Soğanlı	38.4084	36.2119	3075	1839	±	150	1924	±	101	2107	±	83	2331	±	118	2476	±	145	2630	±	148	2806	±	26
Süphan	38.9309	42.8326	4058	2198	±	102	2416	±	124	2597	±	127	2819	±	139	3020	±	123	3182	±	155	3363	±	115
Uludağ	40.0706	29.2215	2543	1280	±	84	1494	±	134	1699	±	109	1877	±	97	2058	±	111	2257	±	98	2349	±	63

Table 3.2: Equilibrium Line Altitude (ELA) for diffrent precipitation values with fixed temperature values

				T: -10, P: 0.25			T: -10, P:0.50			T: -10, P:0.75			T: -10, P:1			T:-10, P:1.25			T: -10, P:1.5			T: -10, P:2			T: -10, P:3			T: -10, P:4		
Name of the Mountai	Lat (°N)	Lon (°E)	Elev.(m)	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error	ELA	±	Error
Ağrı	39.7018	44.2983	5137	2017	±	631	1982	±	604	1968	±	601	1995	±	593	1947	±	593	1942	±	590	1941	±	584	1928	±	575	1906	±	568
Akdağ	36.5439	29.5674	3016	2698	±	57	2573	±	72	2441	±	95	2335	±	100	2272	±	94	2207	±	116	2064	±	177	1858	±	113	1610	±	89
Aladağlar	37.8366	35.1453	3756	2654	±	188	2464	±	189	2348	±	188	2236	±	156	2153	±	160	2078	±	150	1959	±	127	1801	±	139	1651	±	139
Balık Gölü	39.7766	43.5274	2804	2145	±	379	2142	±	373	2135	±	368	2126	±	362	2118	±	360	2113	±	360	2104	±	357	2082	±	351	2052	±	356
Barla	38.0531	30.722	2800	2506	±	745	2345	±	82	2190	±	132	2129	±	122	2101	±	103	2017	±	107	1879	±	129	1720	±	146	1494	±	146
Beydağ	36.5684	30.1017	3086	2602	±	131	2496	±	142	2409	±	129	2340	±	15	2269	±	119	2208	±	117	2107	±	131	1903	±	124	1734	±	112
Bolkar	37.3862	34.6087	3524	2629	±	123	2470	±	115	2371	±	129	2281	±	141	2201	±	132	2130	±	141	2021	±	134	1864	±	126	1729	±	132
Buzul (Cilo)	37.4877	44.0012	4135	3280	±	255	3180	±	211	3075	±	172	2969	±	169	2874	±	151	2778	±	161	2497	±	157	2125	±	143	1881	±	179
Davraz	37.7571	30.7317	2637	2525	±	0	2402	±	106	2286	±	146	2196	±	145	2117	±	123	2046	±	149	1934	±	165	1682	±	169	1462	±	122
Dedegöl	37.6437	31.2835	2992	2625	±	111	2423	±	124	2339	±	110	2256	±	137	2162	±	160	2089	±	159	1965	±	152	1725	±	149	1474	±	70
Erciyes	38.5318	35.4469	3917	2457	±	103	2323	±	88	2201	±	87	2146	±	90	2063	±	80	2029	±	79	1934	±	78	1796	±	94	1664	±	95
Esence (Keşiş)	39.7836	39.7548	3477	2459	±	130	2330	±	137	2197	±	132	2113	±	119	2049	±	112	1995	±	115	1909	±	118	1820	±	112	1701	±	108
Geyikdağ	36.8075	32.2021	2850	2552	±	111	2390	±	105	2286	±	91	2184	±	93	2100	±	98	2017	±	104	1884	±	104	1661	±	115	1299	±	147
İkiyaka (Sat)	37.3105	44.2502	3794	2330	±	440	2366	±	464	2369	±	465	2380	±	454	2385	±	439	2389	±	423	2344	±	385	2231	±	361	2130	±	390
Kaçkarlar	40.8354	41.1614	3932	1988	±	709	1952	±	689	1929	±	686	1914	±	688	1904	±	689	1893	±	695	1866	±	704	1877	±	714	1873	±	724
Karadağ	40.3793	39.071	3331	2258	±	117	2089	±	105	1979	±	104	1906	±	99	1873	±	99	1832	±	107	1774	±	100	1656	±	73	1591	±	58
Karagöl	40.5101	38.1928	3107	2140	±	95	1971	±	83	1875	±	88	1755	±	92	1700	±	112	1595	±	88	1366	±	110		±			±	
Karçal	41.3472	41.983	3431	2187	±	128	2033	±	170	1878	±	201	1787	±	218	1690	±	256	1595	±	282	1461	±	355	1355	±	441	1185	±	568
Kavuşşahap	38.2146	42.8563	3503	3026	±	166	2884	±	178	2776	±	174	2672	±	185	2568	±	191	2460	±	191	2300	±	200	2081	±	200	1892	±	221
Mescid	40.3273	41.1673	3239	2444	±	98	2313	±	111	2231	±	108	2168	±	113	2107	±	103	2062	±	109	1991	±	106	1867	±	113	1782	±	134
Munzur	39.4934	39.1669	3368	2549	±	148		±		2252	±	159	2142	±	152	2045	±	149		±		1823	±	144	1681	±	165	1558	±	169
Sandıras	37.0814	28.838	2295		±			±			±		2219	±	0	2156	±	35	2073	±	62	1898	±	47	1594	±	68	1285	±	84
Soğanlı	38.4084	36.2119	3075	2507	±	132	2343	±	118	2213	±	131	2107	±	83	2020	±	91	1963	±	89	1862	±	117	1717	±	129		±	
Süphan	38.9309	42.8326	4058	3118	±	160	2939	±	99	2769	±	125	2597	±	127	2514	±	107	2411	±	119	2222	±	90	2006	±	70	1909	±	62
Uludağ	40.0706	29.2215	2543	2095	±	117	1930	±	89	1804	±	92	1699	±	109	1620	±	110	1508	±	131	1341	±	103	1066	±	106	875	±	88

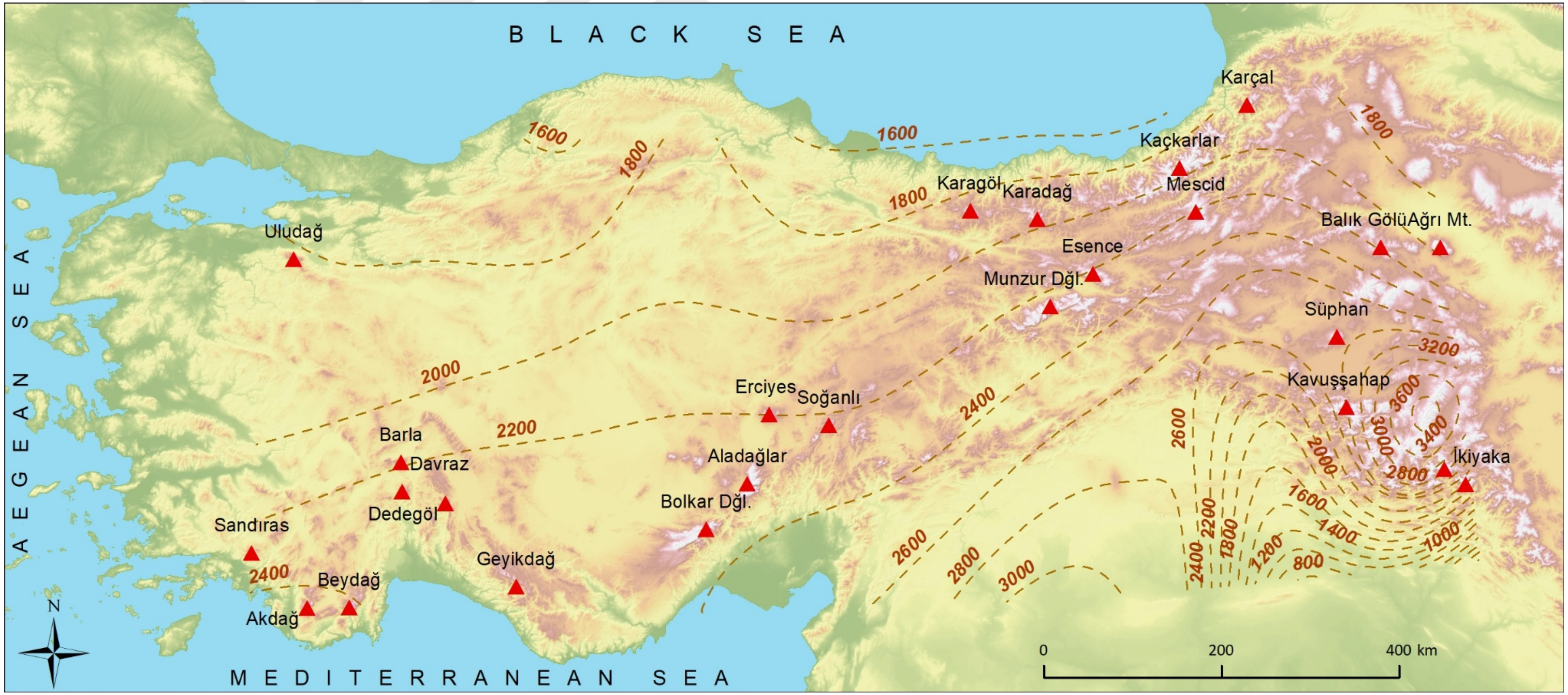

Figure 3.1: Equilibrium Line Altitude (ELA) for (-10°) Temperature and 25% decreased Precipitation (T=-10, P=0.75)

In the first case, temperature was kept constant as (-10°C) and precipitation were changed from dry conditions to wetter conditions. In figure 3.1 dry condition was applied. Precipitation is selected as (25% drier) and temperature was -10°C. When the precipitation values are drier than today's precipitation values, ELA starts higher than 2000 m in the west of the Turkey. In Sandıras mountain which is located almost in the most west part, ELA is between 2200-2400 m. In Uludağ mountains, ELA is between 1800-2000 m. It has an increasing pattern by its ELA border from west to east part of Turkey. In Akdağ Mountain which is located east, ELA is about 2400 m. In Barla, Davraz, Dedegöl, Erciyes, Soğanlı Munzur, Esence Kaçkarlar and in Mescid Mountains, ELA is between 2200-2400 m. In the east part of Turkey, ELA is reaching higher elevation due to high topography and elevation. In Kavuşşahap, Buzul and İkiyaka mountains, ELA is more than 2500 m. In these climatic values which are more drier and colder than today's climatic condition, ELA is decreasing especially in the middle part of Turkey due to then Latitude affect. In this case, ELA is higher in the Southeastern Anatolian Mountains. And it is lower in the west Anatolian. In north Anatolia, ELA is between 1600-1800 m. In the north part, it reaches the lowest ELA value due to latitude effect.

In the figure 3.1 , latitude effect can be seen in from Mediterranean region to Blacksea including Middle Anatolia. In Mediterranean, ELA is starts from 2400 m. In Erciyes it is about 2200 m. ELA is decreasing 2000 near the Blacksea. In Blacksea it is 1800 m even reaches 1600 in some places. So for this values latitute effect can be seen in Turkey . ELA is reaching lowest level in Blacksea due to high precipitation valuee and low temperature values. In Southeast Taurus, ELA is not indicating lowest level. In those high topographic areas, ELA is low because of low precipitation values even it has hing topographic values and low temperatures.

Most of the glacier mountains are located in the Blacksea, Mediterranean and East Anatolia. So, ELA results are representing more reguler results in those areas. But in west Anatolia this situation is opposite.

This case is indicating lowest precipitation values. To have glacier in a definite place Precitation is one of the leading factor. More precipitation and cold weather conditions are the most convenient conditions to have glaciers in a place.

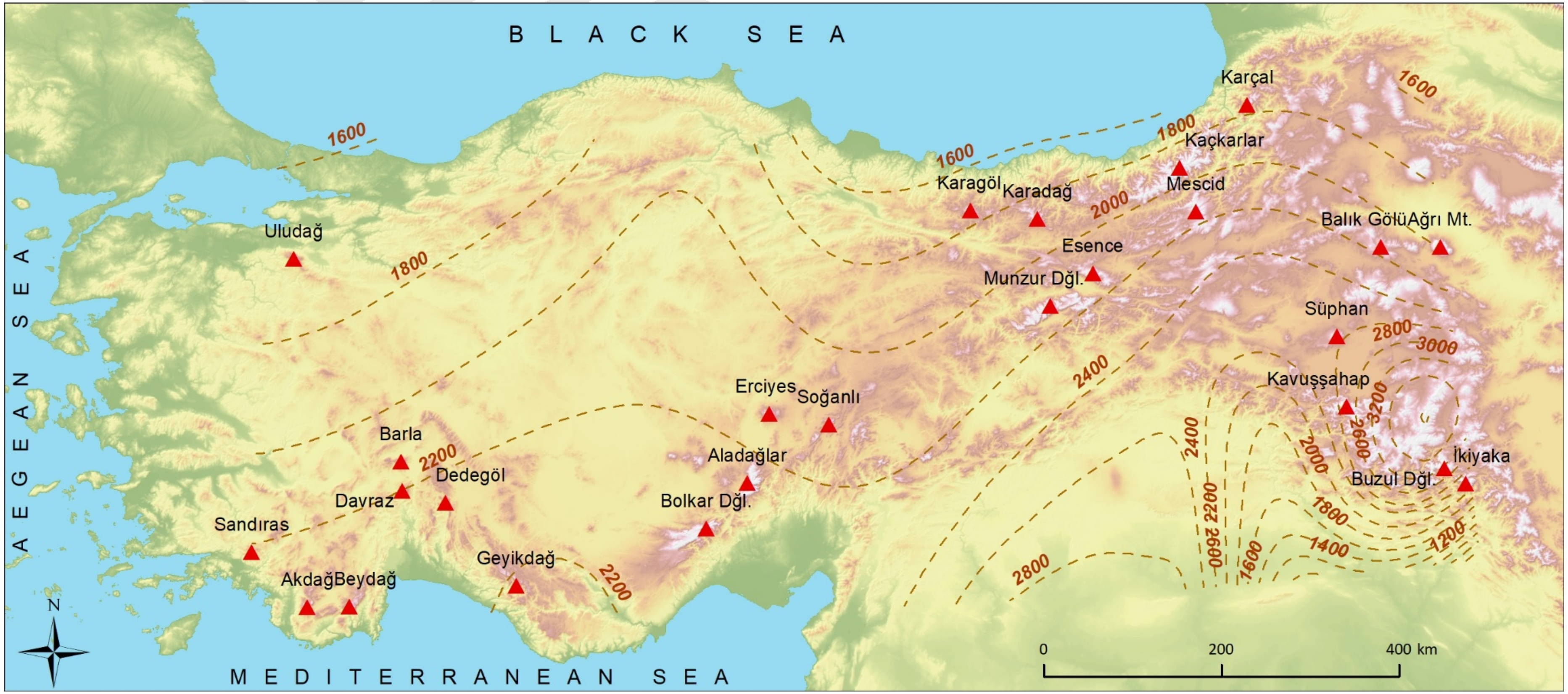

Figure 3.2: Equilibrium Line Altitude (ELA) for (-10) Temperature and Present day Precipitation conditions (T=-10, P=1)

In the second case, temperature is minus ten (-10) and precipitation is in the present day condition, ELA decreasing from south part of Turkey to the north side. It is almost between 2200-2300 in South Anatolian Mountains. In Akdağ and Beydağ, ELA is close the 2300 m. In Sandıras, Davraz, Dedegöl, Geyikdağ, Aladağlar and Bolkar, ELA is about 2200 m. It has a decreasing pattern toward to north. Erciyes and Soğanlı Mountains are between 2000-2200 m. In Uludağ which is situated in the north part of the Turkey it is between 1800-1700 m.

In the east part of Turkey, ELA is higher when it compared with western Turkey. In Buzul and İkiyaka Mountains, ELA is between 2600-2700 m. Southeast part of Turkey has the highest ELA value.

For – 10 and present day precipitation value (from south to north) there is a decreasing pattern. It shows that there is clear latitude effect in Turkey's ELA. And from west to east ELA is increasing as elevation 'increasing from West to east. It also shows that elevation affects the ELA in Turkey because elevation is increasing from west to east.

In this case, Temperature is minus ten (-10) and precipitation is in the present day condition. ELA values have reached lower levels when the precipitation values increased. Figure 3.2 ELA values are lower than ELA values in figure 3.1. main reason is precipitation is good enough to generate more glaciers in those values in Turkey.

In these values, latitude effect can be seen obviously all across Turkey except Southeast part. Having lack of enough precipitation and high topography, put this region as an exception.

Blacksea region especialy east Blacksea shows the lowest ELA values which means has more precipitation and low temperature values in addition to its location, the latitude effect.

Most of the Mediterranean Region has ELA more than 2200 m. In southeast Turkey, ELA reaches 2600-2700 m due to high topography and low precipitation. That causes that glaciers can not occupy this areas even it has a good potential with aspect to topography.

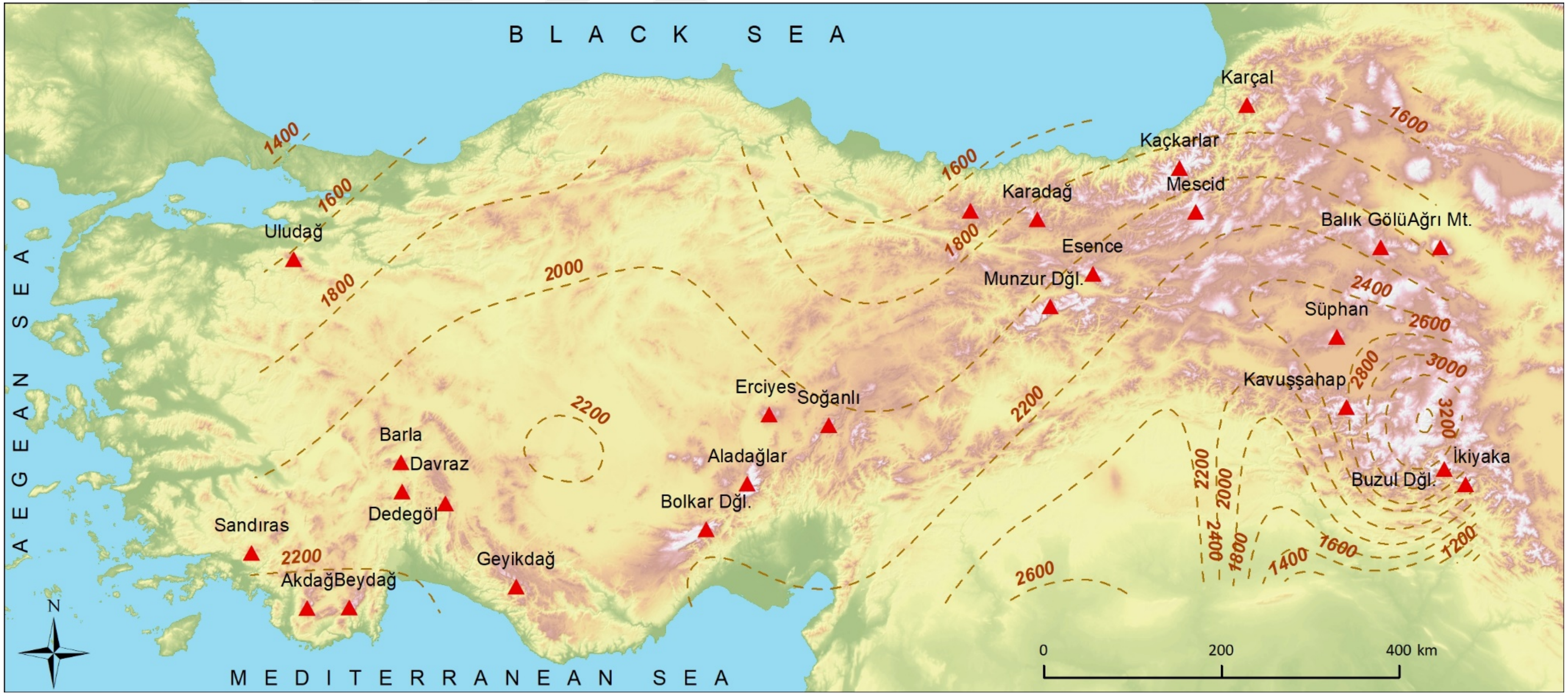

Figure 3.3: Equilibrium Line Altitude (ELA) for (-10) Temperature and 25% increased Precipitation (T=-10, P=1.25)

In the third condition that the weather is rainier and temperature is minus ten (-10), in the West Anatolia, ELA has a clear decreasing from South to North. In this areas there is latitude affect as it can be seen in the map. In Uludağ, ELA is between 1600-1800 m. In Sandıras, Davraz, Dedegöl, Geyikdağ, Bolkar and Aladağlar it is between 2000-2200 m. All these mountains are located in the same mountain range which is Taurus Mountains. In the middle part of Turkey, it is about 2000 m. In Erciyes and Soğanlı Mountain, it is between 2000 and 2200 m. But in southeast and northeast of Turkey ELA is higher than other regions. It is about 2800 m in Buzul and İkiyaka mountains. Kavuşşahap is between 2700-2800 m. In the Ağrı and Balıklake it is between 2000-2200 m. In Munzur, Mescid and Esence it is between 2000-2200 m. ın Kackarlar, ELA is 1800-2000 m. In Karçal it is between1600-1800 m. In these conditions Uludağ has the lowest ELA value when compared with other mountains.

When the temperature is minus ten (-10) and precipitation is increased about 25% more than present day precipitation, ELA is indicating lower values compares to the figure 3.1 and 3.2 ELA values. In low temperature and enough precipitation, ELA is reaching lower topography in Turkey. In this condition also, there is a latitude effect in Turkey. ELA is starting 2200 m in Mediterranean and goes 2000, 1900, 1700, 1600 and 1400 in Blacksea region. This is easly indicating latitude effect in most Turkey. Southeast Turkey is showing an exception to this latitude effect situation accoding to hing topography and low precipitation values compred to the other regions.

Uludağ is representing a indicater for Marmara region. ELA is between 1600-1800 m in this areas. So it can be said that ELA ia about 1600-1700 in this areas. But in Boshporus, ELA is about 1400 m.

In this situation, precipitation is higher and temperature is minus ten (-10°C). To have glacier in a definite place, it is the most convenient situation by having more precipitation and colder weather conditions.

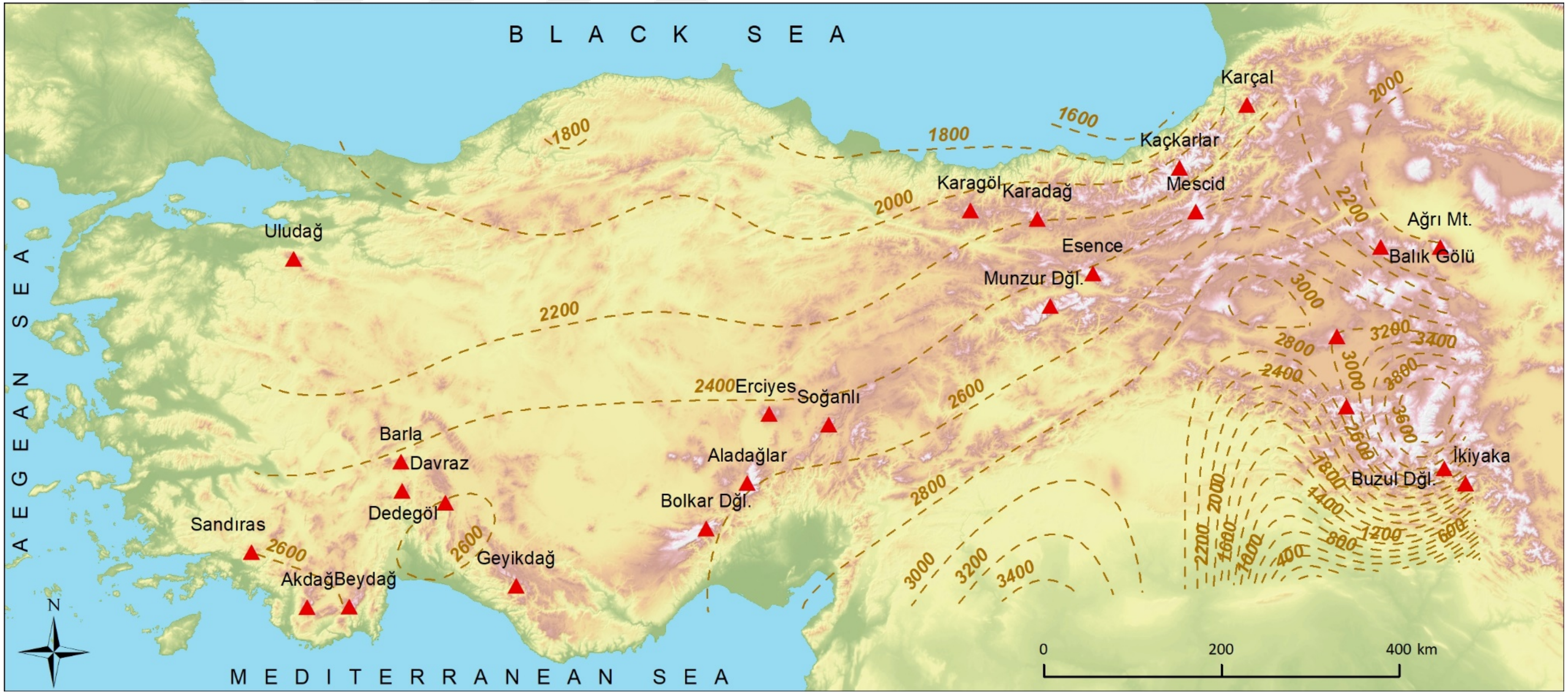

Figure 3.4: Equilibrium Line Altitude (ELA) for (-8) Temperature and present day precipitation condition (T=-8, P=1)

In the case of precipitation is constant and temperature is changing, three different temperatures were used to show different temperature conditions. When the climatic condition is warmer, (-8) temperature and precipitation condition is present day condition, ELA is indicating a more regular pattern increasing toward the east Anatolia. This shows that elevation and ELA is representing a simultaneously increasing from west to east.In Sandıras Mountain, ELA is about 2600 m. There is an obvious increasing from west to east as elevation increase from west to east. In Uludağ, it is between 1800-2000 m but closer 1800 m. In Akdağ, it is nearly 2600 m. In Beydağ it is about 2600 m. In Davraz and Barla, it is 2400 m. In Dedegöl, ELA is between 2500-2600 m. In Geyikdağ, ELA is between 2600-2800 m. In the central Taurus Mountains, ELA is between 2400-2600 (Bolkar, Aladağlar, Erciyes and Soğanlı). In the northern Blacksea, in Karagöl, Karçal, Kaçkarlar and Karadağ ELA is between 2000-2200 m. In lower latitude, in Munzur, Esence and Mescid, ELA is 2300-2400 m. In Ağrı and Balıklake it is between 2000-2200 m. In Süphan Mountain it is between 2900-3000 m. highest ELA in this climatic conditions are in the southeast Taurus. In Kavuşşahap, Buzul and İkiyaka mountains ELA is more than 2200 m. As a general view for this condition, ELA is increasing from west to east and from northern Black Sea to Southeastern Taurus.

In the figure 3.4 , latitude effect can be seen in from Mediterranean region to Blacksea including Middle Anatolia. In Mediterranean, ELA is starts from 2600 m. In Erciyes it is about 2400 m. ELA is decreasing 2000 near the Blacksea. In Blacksea it is 1800 m even reaches 1600 in some places. So for this values latitute effect can be seen in Turkey . ELA is reaching lowest level in Blacksea due to high precipitation valuee and low temperature values. In Southeast Taurus, ELA is not indicating lowest level. In those high topographic areas, ELA is low because of low precipitation values even it has hing topographic values and low temperatures.

Most of the glacier mountains are located in the Blacksea, Mediterranean and East Anatolia. So, ELA results are representing more reguler results in those areas. But in west Anatolia this situation is opposite.

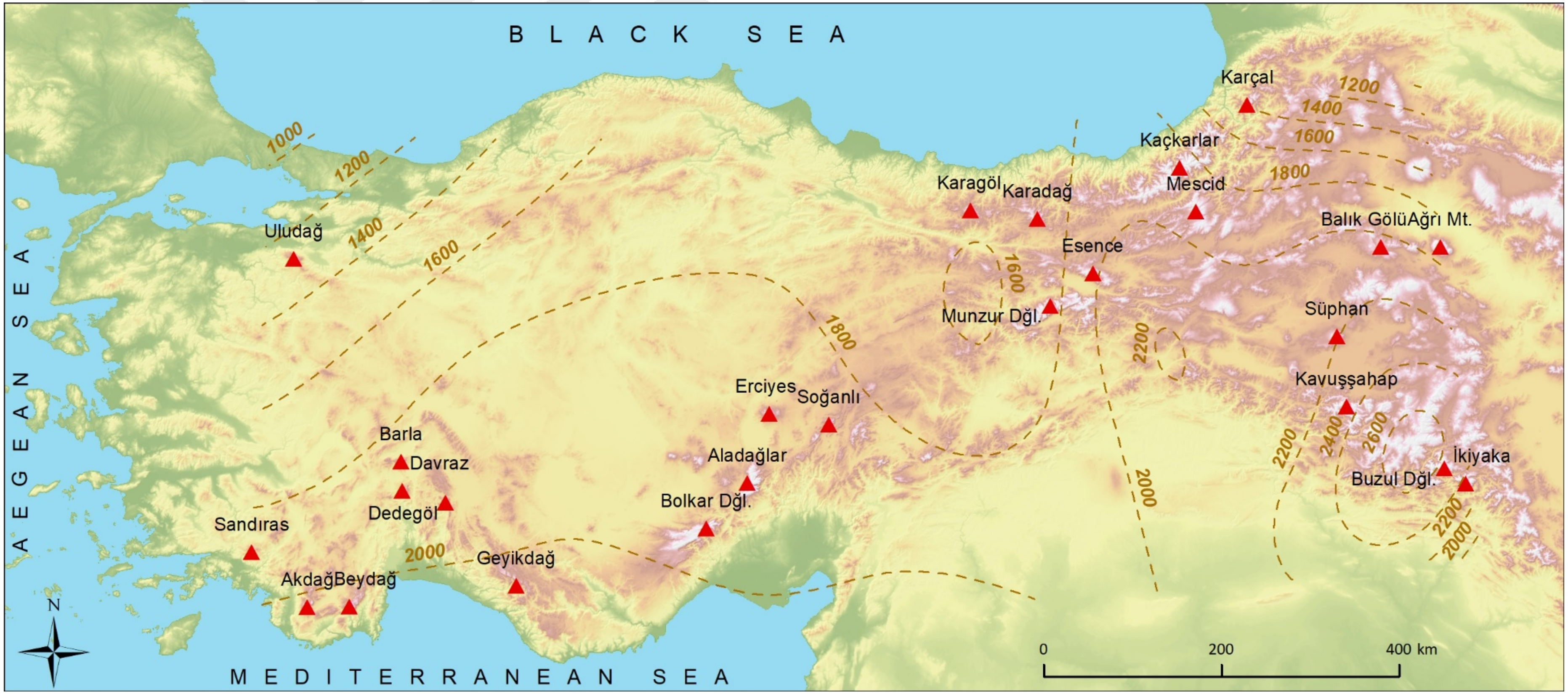

Figure 3.5: Equilibrium Line Altitude (ELA) for (-12) Temperature and present precipitation condition (T=-12, P=1)

In the coldest temperature that is minus twelve (-12) and present day precipitation, ELA is reaching its lower level. That means in the lower temperature conditions, glaciers are more constant and are more abundant. In this condition, when the temperature is lower, Glaciers reach the low level and stay more constant. But in this temperature value, ELA results are as regular as in the minus ten (-10). Due to continentally, inner part's ELA values are reaching the lowest level when it is compared with other climatic conditions.

In the North part it is between 1200- 1400 m. In Uludağ, it is less than 1400 m. In South Anatolian Mountains, In Akdağ, Beydağ, Geyikdağ it is almost 2000 m. In Sandıras, Barla, Davraz and Dedegöl Mountains it is between 1800-2000 m. In Erciyes Mountain, it is between 1800-2000 m. In Sandıras Mountain, it is about 1800 m. Akdağ and Beydağ is more than 2000 m. Geyikdağ is between 2000-2100 m. Bolkar and Aladağlar is almost 1900 m.

In Karagöl Mountain ELA is about 1500 m which is the lowest ELA for it in northeast Blacksea region. In Karadağ Mountain it is nearly 1700 m. In Esence Mountain, ELA is about 2000 m in this temperature value. Right behind the Esence, in Munzur Mountain ELA is about 1850 m. In Karçal Mountain, it is between the 1400-1500 m. In Kaçkarlar ELA is about 1800 m. In Mescid Mountain, it more than 1800 m. In Ağrı and Balık Lake, there is no a big difference between other temperature values. In Ağrı Mountain, ELA is around 2000 m and in Balık Lake it is also nearly 2000 m. In Süphan and Kavuşşahap it is 2200 m. In the southeast part, in Buzul and İkiyaka it is more than 2200 m.

This case is representing coldest temperature and present day precipitation climatic values. It leads some ELA fluctutaions in Turkey due to its various topography and climatic variations. This prevents a clear latitude effect in Turkey. ELA is indicating non-regular lines.

4.DISCUSSION

ELA calculations were done for twenty-five glaciated mountains in Turkey. Three temperature and three precipitations situations were applied to Turkey’s twenty-five glaciated mountains in Matlab program. For each cases different results were obtained. When the temperature is (-10) and the precipitation is (25% drier), Mountains in the Black Sea has about 1600-1800 m ELA. In Mediterranean it is between 2400-2600 m. In the south east side, it is more than 2500 m. In the west side it is between 2000-2400 m with a decreasing pattern from south to north.

In the case the temperature is (-10) and the precipitation is (present day and 25% increased), ELA is about 1600-1800 in Black Sea, 2200-2300 in Mediterranean, 2800 m in Southeast and about 2200 in the west side of Turkey. But when the precipitation is constant (present day x1mm) and precipitation is (-8), ELA is 1800-1900 m in Black Sea, 2400-2600 in Mediterranean, 2600 m in South East and 2200-2400 m in the West Anatolia.

When the temperature is (-12) and precipitation is constant, present day condition, ELA is between 1300-1500 in Black Sea, is about 2000 m in Mediterranean, between 2300-2400 m in Souteast Anatolia and 1700-1800 m in West Anatolia.

According to the study of Messerli (1967), ELA is 2300 m in the Black Sea region. In the temperature (-8) and present day precipitation condition, ELA is 1800-2000 m in the Black Sea that are different from each other. In the Mediterranean ELA is around 2500 m. For Mediterranean, all results that we have are higher than 2000 m. This can indicate ELA is almost same values in the Mediterranean in LGM.

In the south east region that have most of the glaciers, ELA is between 2700-2800 m in the study of Messerli (1967). It is more than 2400-2500 m in southeast region for all the cases applied. That also shows that there is a match between these values. In the west part of Turkey, ELA is around 2300 m in Messerli (1967) study but in this part, ELA values were same (2300-2400 m) when it compares to Messerli (1967) study.

ELA is around 2200 m in the Black Sea in the study of Erinç (1978). When the temperature is (-8) there is a close result for ELA in these region. But in the Mediterranean and South east region there is a similar ELA result. In the South Anatolian region, ELA is between 2500-2600 m. In this part there is a close relationship with our results. For the six different cases, ELA is around 2300-2400 m that have a close result.

In the south east part, ELA is around 2800 m. In this study, for each case, we have got around 2500-2600 m ELA in this region.

In present day precipitation conditions and (-8℃) temperature, Kavuşşahap mountain (3634 m) which is located in the south of Lake Van, has about 2600-2700 m ELA. According to Yeşilyurt et al., (2018) in Kavuşşahap mountain which is a part of Southeast Taurus Mountains, ELA was 900-1250 m lower and the climate was at least 8-11℃ colder than today. In this study, ELA is between 2600-2700 m in Kavuşşahap Mountain. According to Yeşilyurt et al., (2018) ELA is 2987 m due to AAR 0.65 and 2670 m due MELM methods. In the second method, there is a suitable result with this study but in the first method, there is a diffrence between them.

In Kaçkar mountain, ELA is about 2300 m according to present day precipitation and (-8℃) temperature values, but according to Doğu et al., (1993) Kaçkarlar has 2700 m ELA and glacial traces reach to 2000 m in the north, reach 2200 m in the south part.

According to Louis (1994), ELA is 2400-2500 m in the Mediterranean Region. In this study, for present day precipitation and (-8℃) temperature values, ELA is about 2500 m in Mediterranean Region which means there is a suitable result for this region.

In the Eastern Blacksea Region, ELA is between 220-2400 According to Louis (1994), ELA in this region is between 2300-2500 m which is a similar results. For southeast Taurus, ELA is 2600-2700 m. But according to Louis (1994), ELA is higher in this region. It is between 2800-3200 m. In some parts, it reaches to 3300-3400 m in southeast Taurus.

It is clear that present day precipitation values and -8°C temperature showed the most similar results with other studies. Especially in the regions that most glaciated mountains located, Blacksea Region, Mediterranean and Southeast Taurus Mountains, there are reasonable results for ELA's in LGM.

5.CONCLUSION

Today's annual temperature and precipitation data were obtained from Worldclim and used to make assumptions about past climate conditions and glaciers. After having numeric values for each mountain, these values were used to obtain ELA. In total, 25 glacial areas have been studied. Using the monthly temperature and precipitation data obtained from WorldClim, annual ablation was calculated by positive grade day model and annual accumulation were calculated assuming that precipitation falls as snow at temperatures below zero. Calculations made by an in-house Matlab program(Candaş, 2017). Annual mass balances were found with the difference between these two values. The simulations for the last glacial period were firstly done with the precipitation was kept the same as the present conditions, and the temperature was changed between -8ºC and -12ºC. In the second case, the temperature was kept constant (-10ºC lower than today), the precipitation was changed from drier (%25 drier) to rainier (%25 wetter) conditions. After applying these parameters, we got some ELA results for each mountains to make a map of ELA for all Turkey glaciated mountains.

In the first condition that temperature is (-10) and precipitation is (25% drier than today), ELA starts higher than 2000 m in the west of the Turkey. In Sandıras mountain which is located almost in the most west part, ELA is between 2200-2400 m. In Uludağ mountains, ELA is between 1800-2000 m. It has an increasing pattern by its ELA border from west to east part of Turkey. In Akdağ Mountain which is located east, ELA is about 2400 m. In Barla, Davraz, Dedegöl, Erciyes, Soğanlı Munzur, Esence Kaçkarlar and in Mescid Mountains, ELA is between 2200-2400 m. In the east part of Turkey, ELA is reaching higher elevation due to high topography and elevation. In Kavuşşahap, Buzul and İkiyaka mountains, ELA is more than 2500 m. In these climatic values which are more drier and colder than today's climatic condition, ELA is decreasing especially in the middle part of Turkey due to then Latitude affect. In this case, ELA is higher in the Southeastern Anatolian Mountains.

When the temperature is (-10) and precipitation is (present day condition), ELA decreasing from south part of Turkey to the north side. It is almost between 2200-2300 in South Anatolian Mountains. In Akdağ and Beydağ, ELA is close the 2300 m. In Sandıras, Davraz, Dedegöl, Geyikdağ, Aladağlar and Bolkar, ELA is about 2200 m. It has a decreasing pattern toward to north. Erciyes and Soğanlı Mountains are between 2000-2200 m. In Uludağ which is situated in the north part of the Turkey it is between 1800-1700 m. In the east part of Turkey, ELA is higher when it compared with western Turkey. In Buzul and İkiyaka Mountains, ELA is between 2600-2700 m. Southeast part of Turkey has the highest ELA value. For – 10 and present day precipitation value (from south to north) there is a decreasing pattern. It shows that there is clear latitude effect in Turkey's ELA.

When the temperature is (-10) and the weather is rainier (25% wetter), in the West Anatolia, ELA has a clear decreasing from South to North. In this areas there is latitude affect as it can be seen in the map. In Uludağ, ELA is between 1600-1800 m. In Sandıras, Davraz, Dedegöl, Geyikdağ, Bolkar and Aladağlar it is between 2000-2200 m. All these mountains are located in the same mountain range which is Taurus Mountains. In the middle part of Turkey, it is about 2000 m. In Erciyes and Soğanlı Mountain, it is between 2000 and 2200 m. But in southeast and northeast of Turkey ELA is higher than other regions. It is about 2800 m in Buzul and İkiyaka mountains. Kavuşşahap is between 2700-2800 m. In the Ağrı and Balıklake it is between 2000-2200 m. In Munzur, Mescid and Esence it is between 2000-2200 m. ın Kackarlar, ELA is 1800-2000 m. In Karçal it is between1600-1800 m. In these conditions Uludağ has the lowest ELA value when compared with other mountains.

For temperature, three different cases were applied from -8 to -12 and precipitation was constant as (present day condition). In the first case when the precipitation was present day condition and temperature is (-8), ELA is indicating a more regular pattern increasing toward the east Anatolia. This shows that elevation and ELA is representing a simultaneously increasing from west to east.In Sandıras Mountain, ELA is about 2600 m. There is an obvious increasing from west to east as elevation increase from west to east. In Uludağ, it is between 1800-2000 m but closer 1800 m. In Akdağ, it is nearly 2600 m. In Beydağ it is about 2600 m. In Davraz and Barla, it is 2400 m. In Dedegöl, ELA is between 2500-2600 m. In Geyikdağ, ELA is between 2600-2800 m. In the central Taurus Mountains, ELA is between 2400-2600 (Bolkar, Aladağlar, Erciyes and Soğanlı). In the northern Blacksea, in Karagöl, Karçal, Kaçkarlar and Karadağ ELA is between 2000-2200 m. In lower latitude, in Munzur, Esence and Mescid, ELA is 2300-2400 m. In Ağrı and Balıklake it is between 2000-2200 m. In

Süphan Mountain it is between 2900-3000 m. highest ELA in this climatic conditions are in the southeast Taurus. In Kavuşşahap, Buzul and İkiyaka mountains ELA is more than 2200 m. As a general view for this condition, ELA is increasing from west to east and from northern Black Sea to Southeastern Taurus.

In the coldest temperature that is minus twelve (-12) and present day precipitation, In the coldest temperature that is minus twelve (-12) and present day precipitation, ELA is reaching its lower level. That means in the lower temperature conditions, glaciers are more constant and are more abundant. In this condition, when the temperature is lower, Glaciers reach the low level and stay more constant. But in this temperature value, ELA results are as regular as in the minus ten (-10). Due to continentally, inner part's ELA values are reaching the lowest level when it is compared with other climatic conditions.

As a general view, Turkey's topography and geographical features are dominant on ELA borders. In all conditions, ELA is increasing from west to east parts and reaches its top in the southeast Taurus and low level in the west Anatolian.

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