

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

**IMPACT OF BOUNDARY LAYER METEOROLOGY
ON AIR QUALITY IN URBAN AREAS**

Ph.D. THESIS

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Department of Meteorological Engineering

Atmospheric Sciences Programme

APRIL 2024

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

**KENTSEL ALANLARDA SINIR TABAKA METEOROLOJİSİNİN
HAVA KALİTESİ ÜZERİNE ETKİSİ**

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FOREWORD

The intersection of boundary layer meteorology and urban air quality represents one of the most critical frontiers in environmental science today. It is here, within the complex dynamics of the urban atmosphere, that I have chosen to make my mark with my PhD thesis titled "Impact of Boundary Layer Meteorology on Air Quality in Urban Areas". This work not only signifies a formidable academic endeavor but also highlights a profound commitment to unraveling the mechanisms through which atmospheric conditions affect urban life.

In this thesis, I leverage my extensive background in physics, alongside my proficiency in C, C++, Python, and R programming languages, to dissect the intricate relationship between meteorological phenomena in the boundary layer and their consequences on air pollution levels in urban environments. Through meticulous research and innovative analytical techniques, my findings offer groundbreaking insights into how urban planning and environmental policies can be informed and improved to safeguard public health and the urban ecosystem.

I would like to express my deepest gratitude to my esteemed advisors, Prof. Dr. Ali DENİZ and Prof. Dr. Alper ÜNAL. Their extensive knowledge and experience, guiding suggestions, and unwavering support have been invaluable in the completion of this thesis. Throughout my research, their inspiration, contributions to my academic development, and patience in the face of challenges have been profoundly impactful. I am immensely grateful to Prof. Dr. Ali DENİZ and Prof. Dr. Alper ÜNAL not only for being exceptional mentors but also for serving as significant guides in my academic journey.

Last, but certainly not least, I would like to thank my parents, Hasan and Fatma SEZEN, for their sincere love, enormous support and enthusiasm throughout my academic and professional life, and to my wife Ayşe SEZEN, who shared with me the pains and the happiness during the last three years. Without her endless love and support, this could not have been possible.

April 2024

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ABBREVIATIONS

BL	: Boundary layer
FA	: Free atmosphere
KZ	: Kolmogorov-Zurbenko
LLJ	: Low-level jet
ML	: Mixing layer
NBL	: Nocturnal boundary layer
NRL	: Neutral boundary layer
PM	: Particulate matter
SBL	: Stable boundary layer
TKE	: Turbulent kinetic energy
UBL	: Unstable boundary layer
WT	: Wavelet transform



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IMPACT OF BOUNDARY LAYER METEOROLOGY ON AIR QUALITY IN URBAN AREAS

SUMMARY

This thesis investigates the impact of boundary layer meteorology on urban air quality, focusing specifically on Turkey's diverse climatic and topographical landscape. The study leverages extensive data from air quality monitoring stations across Turkey, spanning from 2010 to 2021, to analyze hourly PM_{10} concentration levels. Advanced analytical techniques, including the Kolmogorov-Zurbenko filter, anomaly technique, and wavelet transform method, are employed to decompose the PM_{10} time series into short-term, seasonal, and long-term components. This approach aims to isolate the effects of meteorological conditions and emissions on air quality, providing a detailed understanding of the interplay between these factors.

The thesis begins by delineating the structure and dynamics of the atmospheric boundary layer (BL), emphasizing its critical role in the vertical and horizontal transport of pollutants, heat, moisture, and momentum. The BL's variability, influenced by daily solar heating and surface characteristics, facilitates distinct meteorological phenomena, including the formation of the Mixed Layer (ML), Residual Layer (RL), and Stable Boundary Layer (SBL). Each of these layers impacts pollutant dispersion differently, and their dynamics are explored in detail.

The study area encompasses Turkey, a country with varied elevations and climates, contributing to its complex air quality dynamics. Particularly, the urban centers, where approximately half of the population resides, are focal points for the study due to their significant contributions to the nation's GDP and their distinct air quality challenges. The analysis focuses on the correlations between PM_{10} concentrations and potential temperature differences across various atmospheric levels, examining how these relationships vary by city, season, and time of day.

Key findings highlight the significant influence of boundary layer dynamics on PM_{10} concentration variability. Seasonal and topographical factors play a critical role in shaping air pollution patterns, with distinct variations observed across different urban centers. The regression analyses reveal a complex interplay between PM_{10} levels and meteorological variables such as temperature, pressure, and wind speed. For instance, wind speed generally correlates with decreased PM_{10} levels due to enhanced dispersion, though exceptions exist due to specific local topographical and meteorological conditions.

The thesis underscores the importance of vertical atmospheric analysis in understanding air pollution dynamics. The study's detailed examination of potential temperature profiles and their relationship with PM_{10} concentrations provides deeper insights into the factors influencing urban air quality. It reveals distinct seasonal patterns and

stability regimes, allowing for a nuanced understanding of how atmospheric conditions affect pollution levels.

In conclusion, this thesis offers actionable insights for urban planning and environmental policy aimed at improving urban air quality. It emphasizes the need for comprehensive air quality management strategies that integrate both anthropogenic emissions and natural meteorological conditions. Recommendations include enhanced emissions control measures and the consideration of meteorological factors in urban planning and policy-making. Future research should focus on extending the time series data and employing advanced statistical techniques to further validate and expand upon these findings, thereby contributing to more effective air quality management and pollution mitigation strategies.



KENTSEL ALANLARDA SINIR TABAKA METEOROLOJİSİNİN HAVA KALİTESİ ÜZERİNE ETKİSİ

ÖZET

Bu tez, sınır tabakası meteorolojisinin kentsel hava kalitesi üzerindeki etkilerini, özellikle Türkiye'nin çeşitli iklimsel ve topografik yapısı üzerine odaklanarak incelemektedir. Çalışma, 2010-2021 yılları arasında Türkiye genelindeki hava kalitesi izleme istasyonlarından alınan verileri kullanarak saatlik PM_{10} konsantrasyon seviyelerini analiz etmektedir. PM_{10} zaman serilerini kısa vadeli, mevsimsel ve uzun vadeli bileşenlere ayırmak için Kolmogorov-Zurbenko filtresi, anomali tekniği ve Wavelet dönüşümü yöntemi gibi ileri düzey analitik teknikler kullanılmaktadır. Bu yaklaşım, meteorolojik koşullar ve emisyonların hava kalitesi üzerindeki etkilerini izole etmeyi ve bu faktörler arasındaki etkileşimi detaylı bir şekilde anlamayı amaçlamaktadır.

Tez, atmosferik sınır tabakasının yapısını ve dinamiklerini ayrıntılı bir şekilde ele alarak başlamakta, bu tabakanın kirleticilerin, ısıнын, nemin ve momentumun dikey ve yatay taşınımındaki kritik rolünü vurgulamaktadır. Güneşin günlük ısıtması ve yüzey özelliklerinden etkilenen sınır tabakası, karışma katmanı (ML), kalıntı katmanı (RL) ve kararlı sınır tabakası (SBL) gibi farklı meteorolojik fenomenlerin oluşmasına neden olur. Her bir tabaka, kirleticilerin yayılmasını farklı şekillerde etkiler ve bu dinamikler detaylı olarak incelenir.

Çalışma alanı olarak Türkiye, farklı yükseklikler ve iklimler içeren karmaşık bir hava kalitesi dinamiklerine sahip bir ülke olarak seçilmiştir. Özellikle nüfusun yaklaşık yarısının yaşadığı kentsel merkezler, ülkenin GSYİH'sine önemli katkılarından ve belirgin hava kalitesi sorunlarından dolayı çalışmanın odak noktası olmuştur. Analiz, farklı şehirlerde, mevsimlerde ve günün saatlerinde PM_{10} konsantrasyonları ile çeşitli atmosferik seviyelerdeki potansiyel sıcaklık farkları arasındaki korelasyonlara odaklanmaktadır.

Ana bulgular, sınır tabakası dinamiklerinin PM_{10} konsantrasyon değişkenliği üzerinde önemli bir etkisi olduğunu göstermektedir. Mevsimsel ve topografik faktörler, kentsel hava kirliliği modellerini şekillendirmede kritik rol oynar ve farklı kentsel merkezlerde belirgin varyasyonlar gözlemlenmiştir. Regresyon analizleri, PM_{10} seviyeleri ile sıcaklık, basınç ve rüzgar hızı gibi meteorolojik değişkenler arasında karmaşık bir etkileşim olduğunu ortaya koymaktadır. Örneğin, rüzgar hızı genellikle PM_{10} seviyelerinin azalmasıyla ilişkilendirilmiş ve bu da daha fazla yayılma ve karışmaya yol açmıştır. Ancak, belirli yerel koşullar nedeniyle bu genel eğilimin dışında kalan istisnalar da bulunmaktadır.

Tez, dikey atmosferik analizin hava kirliliği dinamiklerini anlamada önemini vurgulamaktadır. Potansiyel sıcaklık profillerinin ve bu profillerin PM_{10} konsantrasyonları ile

ilişkilerinin detaylı bir şekilde incelenmesi, kentsel hava kalitesini etkileyen faktörler hakkında daha derin bir anlayış sağlamaktadır. Mevsimsel kalıplar ve stabilite rejimleri arasındaki belirgin farklar, atmosferik koşulların kirlilik seviyelerini nasıl etkilediğini anlamamıza yardımcı olmaktadır.

Sonuç olarak, bu tez, kentsel planlama ve çevre politikası için uygulanabilir bilgiler sunmaktadır. Emisyon kontrol önlemlerinin güçlendirilmesi ve meteorolojik faktörlerin kentsel planlama ve politika yapımında dikkate alınması gerekliliğini vurgulamaktadır. Gelecekteki araştırmalar, bu bulguları doğrulamak ve genişletmek için daha uzun zaman serisi verileri ve gelişmiş istatistiksel teknikler kullanmaya odaklanmalıdır. Bu şekilde, daha etkili hava kalitesi yönetimi ve kirlilik azaltma stratejilerine katkıda bulunulabilecektir.

Bu çalışmada kullanılan veriler, Türkiye genelinde çeşitli şehirlerdeki hava kalitesi izleme istasyonlarından elde edilmiştir. İstanbul, Ankara, İzmir, Bursa gibi büyük şehirler ile farklı iklimsel ve topografik özelliklere sahip şehirler seçilmiştir. Veriler, PM₁₀ konsantrasyonlarının saatlik ölçümlerini içermekte ve bu ölçümler, sınır tabakası meteorolojisinin kentsel hava kalitesi üzerindeki etkilerini değerlendirmek için kullanılmıştır.

Çalışmanın metodolojisi, KZ filtresi ve Wavelet dönüşümü yöntemi gibi zaman serisi analiz tekniklerini kapsamaktadır. Bu yöntemler, PM₁₀ zaman serilerini kısa vadeli, mevsimsel ve uzun vadeli bileşenlere ayırarak, her bir bileşenin hava kalitesi üzerindeki etkilerini izole etmeyi ve analiz etmeyi mümkün kılmaktadır. Ayrıca, farklı meteorolojik değişkenler ile PM₁₀ konsantrasyonları arasındaki ilişkileri belirlemek için regresyon analizleri kullanılmıştır.

Bulgular, Türkiye genelinde hava kalitesinin iyileştiğini göstermektedir, ancak belirli şehirlerde ve dönemlerde istisnalar gözlemlenmiştir. Örneğin, Adana ve Kayseri gibi şehirlerde PM₁₀ seviyelerinde hafif artışlar gözlemlenmiştir. Bu durum, bu şehirlerdeki yerel emisyon kaynaklarının ve meteorolojik koşulların hava kalitesini nasıl etkilediğini göstermektedir.

Regresyon analizleri, PM₁₀ konsantrasyonları ile meteorolojik değişkenler arasında anlamlı ilişkiler olduğunu ortaya koymaktadır. Örneğin, rüzgar hızı genellikle PM₁₀ seviyelerinin azalmasıyla ilişkilendirilmiştir, bu da daha fazla hava karışımı ve kirleticilerin yayılması ile açıklanabilir. Ancak, bu ilişki her zaman geçerli olmamakta ve belirli yerel koşullar bu genel eğilimden sapmalara neden olabilmektedir.

Çalışmanın sonuçları, kentsel hava kalitesinin iyileştirilmesi için emisyon kontrol stratejilerinin önemini vurgulamaktadır. Ayrıca, meteorolojik koşulların kentsel planlama ve çevre politikalarında dikkate alınması gerekliliğini ortaya koymaktadır. Gelecekteki çalışmalar, daha uzun zaman serisi verileri ve gelişmiş istatistiksel teknikler kullanarak bu bulguların doğruluğunu artırabilir ve daha etkili hava kalitesi yönetimi stratejileri geliştirilmesine katkıda bulunabilir.

Bu tez çalışması, sınır tabakası meteorolojisinin kentsel hava kalitesi üzerindeki etkilerini detaylı bir şekilde inceleyerek, bu alanda önemli bir bilgi kaynağı oluşturmaktadır. Çalışmanın bulguları, kentsel planlama ve çevre politikaları için değerli bilgiler sunmakta ve hava kalitesinin iyileştirilmesi için stratejik önerilerde bulunmaktadır.

Bu çalışmada, Türkiye'nin çeşitli şehirlerinde bulunan hava kalitesi izleme istasyonlarından elde edilen veriler analiz edilmiştir. Bu şehirler arasında İstanbul, Ankara, İzmir, Bursa, Adana, Antalya, Gaziantep, Konya, Kayseri, Mersin, Eskişehir ve Trabzon bulunmaktadır. Bu şehirler, farklı iklimsel ve topografik özelliklere sahip olmaları nedeniyle seçilmiştir. Veriler, PM₁₀ konsantrasyonlarının saatlik ölçümlerini içermektedir ve bu ölçümler, sınır tabakası meteorolojisinin kentsel hava kalitesi üzerindeki etkilerini değerlendirmek için kullanılmıştır.

Çalışmanın metodolojisi, PM₁₀ zaman serilerini kısa vadeli, mevsimsel ve uzun vadeli bileşenlere ayırmak için kullanılan KZ filtresi ve Wavelet dönüşümü yöntemi gibi zaman serisi analiz tekniklerini içermektedir. Bu yöntemler, her bir bileşenin hava kalitesi üzerindeki etkilerini izole etmeyi ve analiz etmeyi mümkün kılmaktadır. Ayrıca, farklı meteorolojik değişkenler ile PM₁₀ konsantrasyonları arasındaki ilişkileri belirlemek için regresyon analizleri kullanılmıştır.

Çalışmada kullanılan KZ filtresi, zaman serisi analizlerinde özellikle uzun vadeli trendleri ve kısa vadeli dalgalanmaları ayırtmada etkili bir yöntem olarak öne çıkmaktadır. Bu yöntem, PM₁₀ konsantrasyonlarındaki değişimlerin kısa vadeli, mevsimsel ve uzun vadeli bileşenlerini belirleyerek, her bir bileşenin hava kalitesi üzerindeki etkilerini daha net bir şekilde ortaya koymaktadır. Ayrıca, Wavelet dönüşümü yöntemi, zaman serisi verilerini farklı frekans bileşenlerine ayırarak, veri setinin çok boyutlu analizini sağlamaktadır. Çalışmada elde edilen bulgular, Türkiye genelinde hava kalitesinin iyileştiğini göstermektedir. Ancak, belirli şehirlerde ve dönemlerde istisnalar gözlemlenmiştir. Örneğin, Adana ve Kayseri gibi şehirlerde PM₁₀ seviyelerinde hafif artışlar gözlemlenmiştir. Bu durum, bu şehirlerdeki yerel emisyon kaynaklarının ve meteorolojik koşulların hava kalitesini nasıl etkilediğini göstermektedir.

Regresyon analizleri, PM₁₀ konsantrasyonları ile meteorolojik değişkenler arasında anlamlı ilişkiler olduğunu ortaya koymaktadır. Örneğin, rüzgar hızı genellikle PM₁₀ seviyelerinin azalmasıyla ilişkilendirilmiştir, bu da daha fazla hava karışımı ve kirleticilerin yayılması ile açıklanabilir. Ancak, bu ilişki her zaman geçerli olmamakta ve belirli yerel koşullar bu genel eğilimden sapmalara neden olabilmektedir.

Çalışmanın sonuçları, kentsel hava kalitesinin iyileştirilmesi için emisyon kontrol stratejilerinin önemini vurgulamaktadır. Ayrıca, meteorolojik koşulların kentsel planlama ve çevre politikalarında dikkate alınması gerekliliğini ortaya koymaktadır. Gelecekteki çalışmalar, daha uzun zaman serisi verileri ve gelişmiş istatistiksel teknikler kullanarak bu bulguların doğruluğunu artırabilir ve daha etkili hava kalitesi yönetimi stratejileri geliştirilmesine katkıda bulunabilir.

Tez, sınır tabakası meteorolojisinin kentsel hava kalitesi üzerindeki etkilerini detaylı bir şekilde inceleyerek, bu alanda önemli bir bilgi kaynağı oluşturmaktadır. Çalışmanın bulguları, kentsel planlama ve çevre politikaları için değerli bilgiler sunmakta ve hava kalitesinin iyileştirilmesi için stratejik önerilerde bulunmaktadır. Emisyonların kontrol altına alınması ve azaltılması stratejileri, kirlilik azaltma ve halk sağlığını koruma amacıyla belirlenen hedeflere ulaşmada kilit rol oynamaktadır. Ayrıca, hava kalitesinin iyileştirilmesi için meteorolojik koşulların ve hava akımlarının dikkate alınması gerektiği vurgulanmaktadır.

Bu çalışma, Türkiye’deki hava kalitesini etkileyen faktörler hakkında kapsamlı bir anlayış sunmaktadır. Özellikle kentsel alanlarda sınır tabakası dinamiklerinin hava kalitesi üzerindeki etkileri, hem teorik hem de pratik açıdan detaylı bir şekilde analiz edilmiştir. Çalışmanın sonuçları, emisyon kontrol stratejileri ve çevre politikaları geliştirme sürecinde önemli bir rehberlik sağlamaktadır.

Gelecekteki çalışmalar, bu bulguların doğruluğunu artırmak ve genişletmek için daha uzun zaman serisi verileri ve gelişmiş istatistiksel teknikler kullanmayı hedeflemelidir. Bu şekilde, daha etkili hava kalitesi yönetimi ve kirlilik azaltma stratejileri geliştirilebilir. Ayrıca, yerel ve bölgesel düzeyde hava kalitesini iyileştirmeye yönelik politika ve uygulamaların geliştirilmesinde önemli katkılar sağlanabilir.

Sonuç olarak, bu tez, sınır tabakası meteorolojisinin kentsel hava kalitesi üzerindeki etkilerini kapsamlı bir şekilde ele alarak, bu alanda önemli bir bilgi kaynağı oluşturmuştur. Çalışmanın bulguları, kentsel planlama ve çevre politikaları için değerli bilgiler sunmakta ve hava kalitesinin iyileştirilmesi için stratejik önerilerde bulunmaktadır. Bu tez çalışması, Türkiye genelinde hava kalitesinin iyileştirilmesi ve halk sağlığının korunması amacıyla emisyon kontrol stratejilerinin önemini vurgulayan önemli bir araştırmadır.

1. INTRODUCTION

1.1 Purpose of Thesis

We live on the Earth's surface and are affected by the atmospheric conditions near the surface. The depth of this layer typically reaches up to 3000 *m* above the surface and is referred to as the boundary layer (BL). The region above this is known as the free atmosphere (FA). The BL is significantly influenced by surface characteristics such as heat flux, moisture, wind speed, etc.

Stull [1] defined the BL as “that part of the troposphere that is directly influenced by the presence of the Earth's surface and responds to surface forcings within a timescale of about an hour or less.” The depth of this layer can vary both temporally and spatially, ranging from hundreds of meters to a few kilometers.

The purpose of the thesis is to explore how the atmospheric boundary layer affects urban air quality, focusing on Turkey's unique climatic and topographical context. It details the boundary layer's dynamics, including its structure and how it influences pollutant dispersion through vertical and horizontal transport mechanisms. The study uses data from air quality monitoring stations across Turkey, analyzing PM₁₀ (PM that is 10 micrometers or less in diameter) concentration levels from 2010 to 2021. By employing advanced analytical techniques like the Kolmogorov-Zurbenko (KZ) filter, the thesis isolates the effects of meteorological conditions and emissions on air quality. Findings highlight the complex relationship between the boundary layer's behavior, air pollution levels, and weather conditions, emphasizing the impact of seasonal and topographical factors on urban air quality. The thesis concludes with recommendations for emissions control and comprehensive air quality management strategies, acknowledging the need for an integrated approach that considers both anthropogenic emissions and natural meteorological conditions to improve urban air quality.

1.2 Literature Review

One of the key characteristics of the BL, especially over land, is the diurnal variation of temperature near the surface, primarily caused by the surface absorbing a significant amount of solar energy. This energy warms the air above the surface and is propagated into the BL through transport processes such as turbulence, which is also used to determine the depth of the BL.

Turbulence is primarily responsible for the vertical transportation of quantities such as moisture, heat, momentum, and pollutants, while the mean wind controls the horizontal advection. The horizontal mean wind typically ranges from 2 to 10 m/s , and the vertical mean wind ranges from millimeters to centimeters per second. The high frequency of turbulence occurrence near the ground distinguishes the BL from the rest of the atmosphere.

To study turbulence or waves, variables are first split into a mean part and a perturbation part. The mean part represents, for example, the effect of the mean temperature or wind, while the perturbation part represents the effect of waves or turbulence.

Buoyancy is a force that generates turbulence in the BL. Warm air rises because it is lighter than the surrounding air, making it positively buoyant. The virtual temperature is the temperature that dry air must have to equal the density of moist air at the same pressure. Therefore, variations in virtual temperature can be used instead of variations in density. The virtual potential temperature is similar to potential temperature but excludes temperature variations caused by changes in the pressure altitude of an air parcel.

Water can absorb large amounts of heat from the sun with little change in temperature. Consequently, the slow variation of sea surface temperature leads to a slowly varying BL depth over oceans compared to land. The BL depth over oceans is mostly influenced by synoptic and mesoscale processes. Moreover, the BL tends to be thinner in high-pressure regions than in low-pressure regions due to subsidence and low-level horizontal divergence. The diurnal cycle more clearly affects the BL structure over

land surfaces and in high-pressure regions, as illustrated in Figure 1.1. It can be divided into three major components:

1. Mixed Layer (ML),
2. Residual Layer (RL),
3. Stable Boundary Layer (SBL) or Nocturnal Boundary Layer (NBL).

If clouds are present in the ML, it is further subdivided into a cloud layer and a sub-cloud layer. The surface layer is the region at the bottom of the BL where turbulent fluxes and stress vary by less than 10% of their magnitude. In the lowest few centimeters of air, molecular transport dominates over turbulent transport. This layer is referred to as the microlayer or interfacial layer.

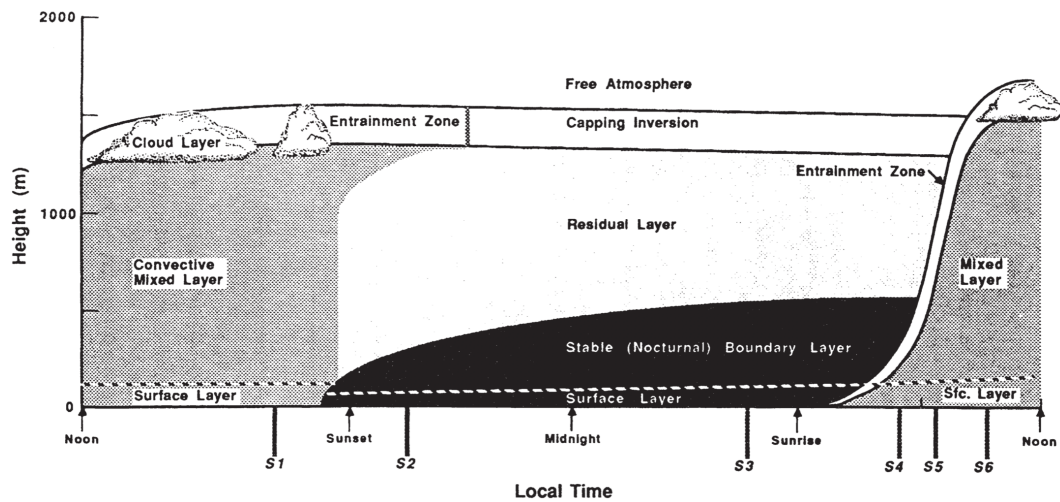


Figure 1.1 : Boundary Layer (The famous drawing is taken from [1]).

1.2.1 Mixed layer

The ML is named for the uniformity of variables like potential temperature and humidity throughout its height, achieved through intense vertical mixing, as shown in Figure 1.2. This mixing can originate from mechanical shears or be driven by buoyancy from convection. Convectively driven MLs typically exhibit a more homogeneous mix compared to mechanically driven ones, due to convection's preference for vertical movements over the horizontal ones favored by shear anisotropy. Near-ground shears are often more crucial for inducing mixing within the ML than shears at its top in

atmospheric conditions. Nevertheless, shears at the top of the ML can lead to the formation of a distinct layer. A ML where buoyant turbulence is the primary mixing mechanism is termed a convective boundary layer (CBL) or convective ML.

Turbulence within the ML is predominantly generated by buoyancy. However, a nearly well-mixed layer can also develop in areas experiencing strong winds. Convective motions primarily arise from heat transfer from the warm ground surface and radiative cooling at the cloud layer's top. Warm air creates rising thermals in the former case, while the latter results in sinking thermals from cloud tops downwards. The ML is marked by vigorous mixing in a statistically unstable environment, characterized by rising thermals. It attains its greatest depth in the late afternoon, expanding by drawing in or mixing down less turbulent air from above. This turbulence evenly distributes heat, moisture, and momentum vertically. Pollutants released from smokestacks exhibit a distinctive looping pattern and become confined within the ML.

The profiles of virtual temperature, mixing ratio, pollutant concentration, and wind speed typically observed are illustrated in Figure 1.2. Within the ML, the virtual potential temperature profile is nearly adiabatic throughout its middle portion but becomes super-adiabatic within the surface layer. This minimum near the ML's center is due to heating from the ground and the entrainment of warmer air from above, which slightly increases potential temperatures in these areas. A capping stable layer at the ML's apex impedes the ascent of thermals, termed the entrainment zone, where mixing into the ML takes place. This capping stable layer is often referred to as the inversion layer, regardless of the stability's magnitude.

The apex of the ML, denoted as z_i , is commonly identified by the level exhibiting the most negative heat flux. This level typically aligns with the midpoint of the entrainment zone, often corresponding to the altitude where the capping inversion is most pronounced, as depicted in Figure 1.2. The capping inversion functions as a boundary between the ML and the FA. An alternative method to determine the average depth of the ML is by identifying the altitude at which an air parcel, ascending undiluted from the surface, achieves neutral buoyancy.

Wind speeds within the ML are sub-geostrophic and exhibit nearly constant values across the middle portion of the ML. The profile of wind speed approaches a logarithmic pattern within the surface layer, diminishing to nearly zero as the ground is neared. Throughout the ML, wind directions veer slightly towards areas of low pressure across the isobars and maintain consistent orientation with height in its middle section. Closer to the ground, within the surface layer, wind directions shift to form increasingly larger angles with the isobars, sometimes reaching up to 45 degrees, indicating a significant deviation as the surface is approached.

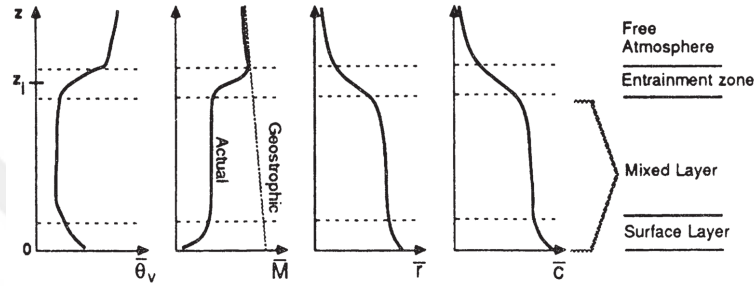


Figure 1.2 : Standard daytime profiles for mean virtual temperature $\bar{\theta}_v$, wind velocity $\bar{M}$ (where $\bar{M}^2 = \bar{u}^2 + \bar{v}^2$), water vapor mixing ratio $\bar{r}$, and pollutant concentration $\bar{c}$ (taken from [1]).

Mixing ratios typically decrease with altitude, a trend that mirrors the evaporation from below and the entrainment of drier air from above. This moisture reduction is particularly noticeable across the top of the ML and is often used in conjunction with potential temperature profiles to determine the ML's upper boundary from rawinsonde soundings.

Pollutant sources are predominantly located near the surface, leading to potential increases in concentration within the ML, while concentrations in the FA remain comparatively low. Thermals can distribute pollutants throughout the ML, but the stable layer above acts as a barrier, effectively “trapping” pollutants beneath. This phenomenon, especially prevalent in high-pressure areas, results in pollutants being confined below an “inversion layer”, (especially in high-pressure regions) thereby contributing to pollution alerts in major urban centers.

1.2.2 Residual layer

Approximately half an hour before sunset, thermals subside, and turbulence diminishes within the previously well-mixed layer, leading to the formation of what is termed the residual layer. This designation is because the initial mean state and concentration variables within the RL mirror those of the now-dissipated ML. For example, passive tracers that were introduced into the daytime ML will stay suspended in the RL throughout the night if there's no advection. The RL is characterized by neutral stratification, and turbulence within this layer exhibits nearly equal intensity across all directions. As a result, smoke plumes released into the RL tend to disperse uniformly in all directions, a phenomenon known as coning. The cooling rate across the RL is almost uniform, maintaining the RL's virtual potential temperature profile close to adiabatic.

Indeed, the RL does not strictly fit within the BL definition, primarily because it lacks direct contact with the ground. During the night, the depth of the SBL gradually expands, altering the lower portion of the RL. Consequently, the remaining part of the RL is unaffected by the turbulent transport of surface-related properties.

1.2.3 Stable boundary layer

At night, the lower segment of the RL transitions into the SBL. The air within the SBL is statistically stable, characterized by weaker and sporadic turbulence. Surface winds often become lighter or even calm during the nighttime, while the winds aloft can become supergeostrophic. This condition leads to the formation of a phenomenon known as the low-level jet or nocturnal jet.

In the statistically stable conditions of the night, turbulence is generally suppressed, yet the nocturnal jet can enhance wind shears that, in turn, generate turbulence. Consequently, mixing within the SBL can occur intermittently, depending on the presence of this turbulence. The character of the SBL is defined by the balance between the mechanical generation of turbulence and its suppression by atmospheric stability. Therefore, the SBL can exhibit a range of conditions, from being well-mixed to entirely

non-turbulent. At times, turbulence within the SBL is sporadic and patchy, leading to a decoupling of the upper portions of the boundary layer from surface influences. This complexity presents significant challenges in accurately describing and modeling the structure of the SBL.

The boundary between the SBL and the RL above is not distinctly defined; instead, it transitions smoothly into the RL, contrasting with the more clearly defined top of the daytime ML. Therefore, the top of the SBL is identified either as the upper limit of the stable layer or the height at which the intensity of turbulence decreases to a small fraction of its value at the surface.

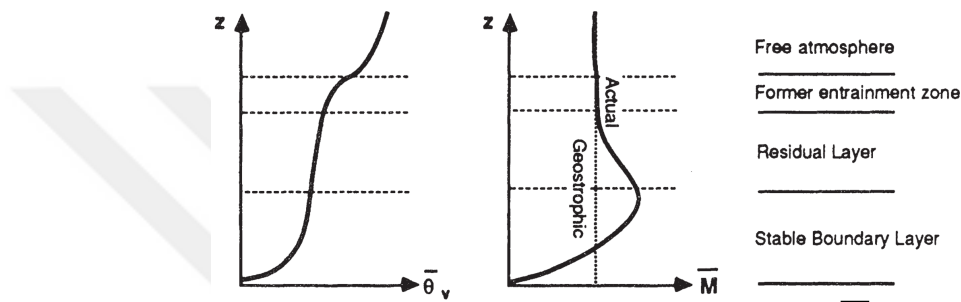


Figure 1.3 : Average profiles of virtual potential temperature, $\bar{\theta}_v$, and wind speed, $\bar{M}$, for theoretical SBL under high-pressure conditions (taken from [1]).

Within the confines of the stable layer, the dispersion of pollutants is markedly restricted in the vertical direction while exhibiting rapid expansion in the horizontal plane, a phenomenon colloquially referred to as fanning. This pattern persists even in the absence of nocturnal emissions from a singular source, courtesy of the pronounced wind shears and the variability in wind directions at night, which facilitate the transportation of air masses with distinct tracer concentrations across varying altitudes, culminating in the formation of a stratified, “layer-cake” appearance of tracer concentration. This stratification is not limited to aerosols alone but extends to other atmospheric constituents such as temperature, humidity, and turbulence levels. Concurrently, the nocturnal environment provides a unique setting for the chemical interactions of photosensitive compounds already ensconced within these layered air masses, enabling them to undergo chemical reactions in the absence of solar radiation, thereby altering the chemical composition and potentially the physical properties of these layers.

The nocturnal wind behavior exhibits considerable complexity, characterized by a marked dichotomy in wind speed profiles with respect to altitude. Close to the ground, wind speeds are often minimal, presenting as light breezes or entirely calm conditions. However, at altitudes in the vicinity of 200 m, a dramatic escalation is observed as wind speeds ascend to the range of 10 – 30 m/s, indicative of the nocturnal jet phenomenon. Progressing a few hundred meters above the domain of this low-level jet, a notable deceleration in wind speed is observed, with values gravitating towards those closer to the geostrophic wind speed, which serves as a theoretical approximation of wind behavior in the absence of frictional forces. This vertical stratification in wind speed is further complicated by the presence of pronounced shears and a rapid directional shift in the wind below the jet, coupled with the tendency of lower-level winds to orient towards areas of low pressure, thereby crossing isobars at acute angles, a behavior that underscores the multifaceted nature of nocturnal wind dynamics.

Wave motions are a common occurrence within the SBL, facilitating the propagation of gravity waves and often confining many of the higher-frequency waves close to the ground level. An interesting aspect of the SBL's dynamics is its ability to form during daylight hours, particularly when the surface is cooler than the overlying air. This phenomenon is frequently observed during scenarios of warm-air advection over a colder surface, exemplified by conditions following the passage of a warm front or in coastal areas adjacent to colder bodies of water. Such circumstances underscore the dynamic interplay between surface temperature differentials and atmospheric motion, contributing to the complexity and variability of BL processes.

The typical profiles of mean variables within the SBL, particularly under conditions of weak turbulent mixing, are depicted in Figure 1.4. In these scenarios, stability exhibits a gradient from stronger near the surface to neutral at higher altitudes within the layer. When the stability near the surface is sufficiently pronounced to induce a temperature gradient that increases with height, this lower segment of the SBL is denoted as a temperature inversion. In certain instances, especially during nighttime conditions when atmospheric cooling of the ground leads to a pronounced stability increase with height, the entire SBL may colloquially be referred to as a nocturnal inversion. This terminology highlights the characteristic temperature profile of the SBL during periods

of minimal solar heating, where the inversion serves as a stabilizing mechanism that suppresses vertical air movement and, consequently, mixing within the layer.

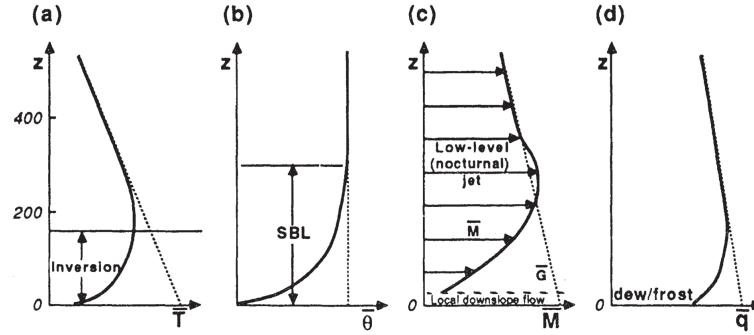


Figure 1.4 : Common SBL profiles include: (a) mean absolute temperature, (b) mean potential temperature, (c) mean wind speed, and (d) mean specific humidity (taken from [1]).

In urban environments, the ML can persist throughout the night, a phenomenon attributable to the substantial heat capacity of buildings and streets, coupled with the thermal output from transportation and space heating. This urban heat island effect prevents the formation of the shallow SBLs that are typically observed in the early evening within the neighboring rural countryside. As the night progresses and the rural SBL deepens beyond the height of urban structures, a distinct layer of air within the city may remain well mixed. This urban ML is, however, bounded above by a stable layer, creating a unique atmospheric structure where the lower urban atmosphere maintains a degree of turbulence and mixing not found in surrounding rural areas. This situation underscores the significant impact of urbanization on local microclimates, particularly in terms of thermal dynamics and atmospheric mixing processes.

Wind characteristics within the SBL exhibit a high degree of complexity, particularly influenced by the nocturnal cooling of air and the subsequent density-driven motions. In the lowest 2 to 10m, cold air can engage in downslope movement, a process often referred to as cold air drainage, where the wind direction is predominantly dictated by the local topography. Factors such as buoyancy, friction, and entrainment play crucial roles in determining wind speed within this layer, leading to a scenario where the wind might either be calm, especially in flat terrains or at the bottom of valleys, or exhibit variable speeds and directions in areas with more pronounced topographical features. This interplay of atmospheric and physical geographical factors contributes

to the intricate behavior of winds in the SBL, reflecting the significant influence of surface-induced effects on near-ground wind patterns.

In the upper reaches of the SBL, synoptic and mesoscale forcings emerge as pivotal influences, markedly impacting the wind profile. Within this domain, wind speed may incrementally increase with altitude, culminating in a maximum velocity proximate to the SBL's zenith. This peak wind speed, occasionally surpassing the geostrophic wind speed, represents an equilibrium state reflecting a balance between pressure gradient forces and the Coriolis effect, referred to as the nocturnal jet. Characteristically, wind directions within this layer often undergo veering, or a clockwise rotation with height, aligning more closely with the geostrophic wind direction above the jet's maximum velocity point. The transition to geostrophic conditions above the nocturnal jet is typically smooth, encompassing both wind speed and direction. Notably, the wind profile within the SBL is dynamic, subject to temporal evolution throughout the course of the night, reflecting the complex interplay of atmospheric forces at play within this nocturnally stable environment.

Classifying humidity within the SBL presents challenges, as the nocturnal behavior of moisture is influenced by various competing processes. On one hand, surface evaporation can persist into the night, driven by residual heat or specific environmental conditions. On the other, cooler temperatures may lead to dew or frost formation in different locations or under alternate circumstances. The presence of strong moisture gradients near the surface is a common occurrence, especially in scenarios characterized by weak turbulence, where the limited mixing fails to homogenize humidity levels throughout the layer.

The delicate equilibrium between turbulence and atmospheric stability plays a pivotal role in determining the moisture dynamics of the lower atmosphere. This balance is particularly evident in the formation and behavior of fog versus dew. Fog formation, its subsequent dissipation, thickening, or vertical lifting, exemplifies the intricate interplay between surface cooling, moisture availability, and the turbulent mixing of air. These processes collectively dictate the moisture distribution and visibility

conditions at ground level, highlighting the complexity of atmospheric moisture dynamics during stable nocturnal conditions.

1.2.3.1 Bulk measures of SBL depth and strength

The strength of the SBL is quantitatively determined by the potential temperature difference between the air in the RL, denoted as $\overline{\theta}_0$ and the air near the surface, represented by $\overline{\theta}_s$. This differential serves as an indicator of the cooling extent experienced since the onset of the SBL, essentially marking the transition from daytime mixing to nocturnal stability, because the potential temperature of the RL closely mirrors the initial near-surface air temperature at the time of this transition, as illustrated in Figure 1.5. The magnitude of SBL strength is variable, commencing from zero at the transition point and potentially escalating to values approximately on the order of 15°C by the onset of morning. This variability in strength is largely influenced by the degree of turbulence present, with stronger turbulence typically associated with lesser cooling and a weaker SBL, and vice versa.

$$\Delta\overline{\theta}_s = \overline{\theta}_0 - \overline{\theta}_s \quad (1.1)$$

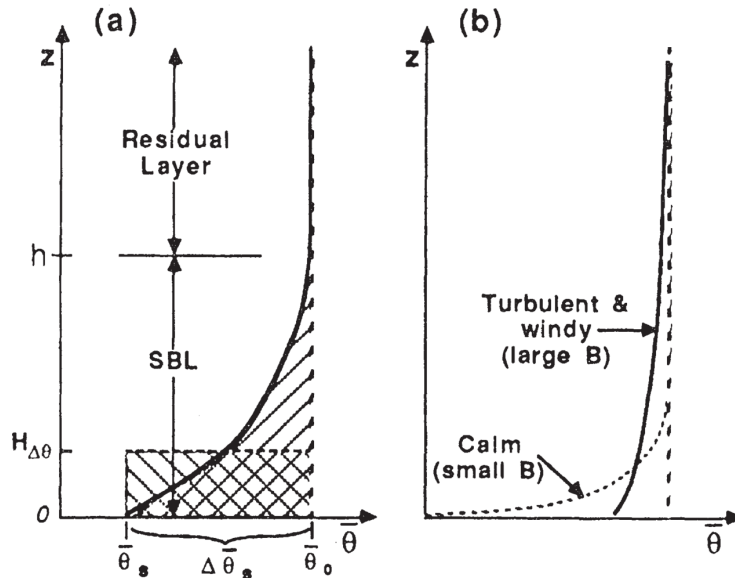


Figure 1.5 : (a) Descriptions of SBL intensity, represented by $\Delta\overline{\theta}_s$, and its thickness, denoted as h . The cumulative depth measure, $H_{\Delta\theta}$, is determined in a way that the rectangular area defined by $H_{\Delta\theta} \times \Delta\overline{\theta}_s$ matches the area beneath the potential temperature profile. (b) Changes in the comprehensive turbulence metric, B , and the configuration of the profile in relation to the level of turbulence (taken from [1]).

Quantifying the height, h , of the SBL's top presents challenges, primarily due to the often gradual transition from the SBL to the RL aloft, without a distinct demarcation. Consequently, numerous definitions of SBL depth found in the literature rely on comparative analyses between the state of the SBL at higher altitudes and the conditions near the surface. For instance, h might be determined by identifying the lowest altitude at which specific criteria are met, reflecting a change in the atmospheric properties that signify the transition from the SBL to the overlying RL. These criteria can include shifts in temperature gradient, turbulence intensity, humidity levels, or other atmospheric variables that illustrate the vertical extent of the SBL's influence. Given the variability of these conditions, the precise determination of h requires careful consideration of local atmospheric dynamics and the specific characteristics of the SBL under observation. The height h can thus be characterized using several different atmospheric conditions, including:

- The point at which the vertical gradient of mean potential temperature, $\partial\bar{T}/\partial z$, becomes zero, marking the stable layer's top where the lapse rate transitions to adiabatic.
- The height at which the vertical gradient of mean temperature, $\partial\bar{T}/\partial z$, equals zero, identifying the inversion top with an isothermal lapse rate.
- The altitude where turbulent kinetic energy (TKE) falls to zero, indicating the top of the turbulent or mixed layer, if one is present.
- The height where TKE reduces to 5% of its value at the surface, a measure indicating significantly diminished turbulence.
- The level at which the mean wind speed, $\bar{M}$, reaches its maximum, often corresponding to the nocturnal jet level.
- The point where mean wind speed, $\bar{M}$, equals the geostrophic wind speed, $\bar{G}$, signaling the transition to the bottom of the FA where winds adhere to geostrophic balance.
- The disappearance of sodar returns, which indicates the cessation of temperature fluctuations and marks the upper limit of the layer experiencing such fluctuations.

These criteria offer a spectrum of methods to quantify the SBL's vertical extent, each reflecting different dynamic and thermodynamic properties of the atmosphere. The selection of a particular definition often depends on the specific research focus or operational requirement, as well as the availability of data to support the analysis.

The height of the SBL top exhibits significant variability, ranging from virtually non-existent at the moment of transition to exceeding $1000m$ under certain conditions. Typically, however, the depth of the SBL develops to approximately 100 to $500m$. Utilizing definitions that necessitate a gradient or flux to equal zero for identifying SBL depth presents substantial challenges, as these metrics often asymptotically approach zero without precisely reaching it. This subtlety can lead to discrepancies among researchers using identical criteria on the same dataset, as variations in experimental data can influence the selection of different SBL depths.

The challenge of comparing SBL models and standardizing data across different studies is compounded by the variety of depth definitions employed by different investigators. Mahrt and Heald [2] have documented instances where these divergent definitions correlate poorly with one another, even when analyzing the same SBL. This inconsistency underscores the complexity of accurately characterizing the SBL and highlights the necessity for a nuanced understanding and interpretation of atmospheric data, as well as the potential for enhanced collaboration and standardization within the field to improve comparative analyses and model validation efforts.

The integral depth scale, H_ξ , offers an alternative approach for quantifying the depth of the SBL that accommodates the often gradual transition between the SBL and the RL without requiring a sharp demarcation. This measure is defined mathematically as:

$$H_\xi = \frac{\int_z \xi dz}{\xi_s} \quad (1.2)$$

where ξ represents a chosen variable relevant to the SBL's characteristics, such as TKE, the shear stress $\overline{u'w'}$, or the potential temperature difference $\Delta\bar{\theta}$. The integral in the numerator calculates the cumulative value of ξ from a reference height z upwards, and this total is then normalized by the surface value of ξ , denoted as ξ_s , to determine the depth scale.

This methodology enables the depth of the SBL to be estimated even in the absence of a clearly defined top, facilitating analysis in situations where traditional metrics may not apply. When ξ is chosen as the potential temperature difference, the resulting depth scale, $H_{\Delta\theta}$, typically varies from 0 to about 150m, providing a quantitative measure of the SBL's vertical extent that is especially useful for studies lacking precise separation between the SBL and overlying atmospheric layers. This integral depth scale, as outlined, allows for a more nuanced understanding of the SBL depth, accommodating the complex, variable nature of atmospheric layering observed in empirical data.

After modifying the equation that determines the depth of the SBL by replacing $\Delta\theta$ with ξ , we derive a formula that calculates the accumulated cooling inside the SBL, detailed as follows:

$$\int_0^h \Delta\theta dz = \Delta\theta_s \cdot H_{\Delta\theta} \quad (1.3)$$

This equation highlights the integral of the potential temperature difference ($\Delta\theta$) over the height of the SBL, from the surface (0) to its top (h), equating it to the product of the surface potential temperature difference ($\Delta\theta_s$) and the integral depth scale ($H_{\Delta\theta}$). The representation encapsulates the total cooling effect captured within the vertical extent of the SBL, effectively summarizing the thermal variation induced since its formation.

Additionally, a bulk turbulence scale, B , is introduced, derived from the bulk depth scale related to temperature, which is mathematically defined as:

$$B = \frac{H_{\Delta\theta}}{\Delta\theta_s} \quad (1.4)$$

This scale, B , inversely relates the depth scale of the potential temperature difference to the surface potential temperature difference, providing a dimension that captures the extent of turbulence within the SBL. High values of B indicate deeper SBLs characterized by minor surface temperature variations, suggesting a more pronounced influence of external forcings (e.g., wind or topographical effects) that foster turbulence and mixing. Conversely, low values of B are indicative of shallower SBLs with significant surface cooling, reflecting conditions of limited external forcing.

and subdued turbulence. The typical range for B spans from 3 m/K , denoting light turbulence, to 15 m/K , signifying strong turbulence, thereby serving as a measure of the turbulence's impact on the SBL's thermal structure. This concept offers valuable insights into the dynamics of the SBL, facilitating the assessment of its response to various atmospheric conditions.

1.2.3.2 Simplified representations of potential temperature profiles

The diversity of flow states observed within the SBL has necessitated the development of multiple idealized models to capture the long-time averaged characteristics of these layers. Given the vast array of atmospheric conditions, terrain types, and external forcings that can influence the SBL, no single model is universally applicable across all scenarios. Instead, the selection of the most appropriate model requires a case-by-case evaluation, taking into account the specific features and dynamics of the atmosphere in question. This approach ensures that the chosen model best represents the observed phenomena, allowing for more accurate predictions and analyses of the SBL's behavior under various conditions. Consequently, researchers and practitioners must carefully consider the unique aspects of each situation to identify the model that most effectively captures the complexity and nuances of the SBL in question.

Stable mixed layer

Within the spectrum of SBL models, the Stable Mixed Layer represents one extreme characterized by strong winds, robust turbulence, and minimal surface cooling. This scenario fosters conditions conducive to the formation of well-mixed layers, as discussed by Zeman in 1979. In such layers, the dynamics are akin to those described in the ML section, where the distribution of potential temperature difference, $\Delta\bar{\theta}(z)$, is governed by:

$$\Delta\bar{\theta}(z) = \begin{cases} 0 & \text{for } z > h \\ \text{constant} & \text{for } z \leq h \end{cases} \quad (1.5)$$

This equation delineates the vertical profile of the potential temperature difference within the SBL, indicating that above the height h , the difference $\Delta\bar{\theta}(z)$ is zero,

signifying no variation in potential temperature with height beyond this boundary. Conversely, for heights z less than or equal to h , $\Delta\bar{\theta}(z)$ remains constant, illustrating the well-mixed nature of this layer where the potential temperature is uniform across its depth. This idealized representation captures the essence of a stable mixed layer under conditions of strong dynamical mixing, serving as a foundational concept in understanding the behavior of the SBL under specific atmospheric conditions.

In the context of a well-mixed SBL, buoyancy predominantly acts as a sink rather than a source of turbulence. Nevertheless, sufficient mechanical mixing, induced by wind shears, compensates for this, facilitating the creation of a ML as depicted in Figure 1.6a. This layer has the capacity to increase in depth through the process of entrainment, despite the fact that entrainment rates typically diminish over the course of the night as the stability within the entrainment zone intensifies. It is straightforward to demonstrate that, for a well-mixed layer, the integral depth scale, $H_{\Delta\theta}$, precisely equates to the actual depth of the SBL, denoted as h , thereby affirming the direct correspondence between the conceptual model and the observable characteristics of the SBL.

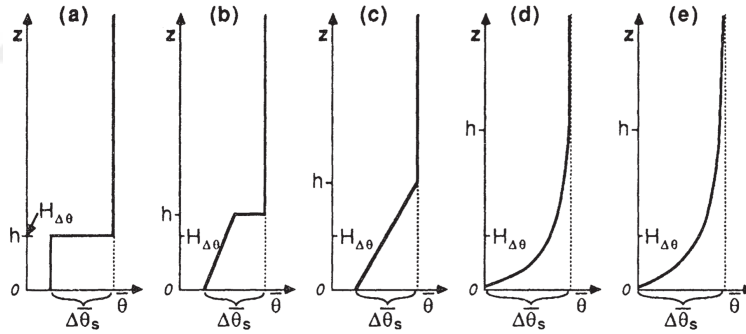


Figure 1.6 : Simplified representations of the SBL potential temperature profile include: (a) well-mixed; (b) linearly-mixed; (c) linear; (d) polynomial; (e) exponential (taken from [1]).

Moreover, the well-mixed SBL is not exclusively limited to conditions devoid of atmospheric phenomena such as fog or stratocumulus clouds. On the contrary, in scenarios where strong radiative cooling at the cloud top is present, convective mixing is initiated, which, in turn, serves as a source of turbulence. Under these circumstances, buoyancy contributes to the generation of turbulence, highlighting the dynamic interplay between radiative processes and mechanical forces in shaping the structure and behavior of the SBL. This nuanced understanding of the well-mixed

SBL, including its formation mechanisms and evolution over time, underscores the complexity of atmospheric boundary layers and their sensitivity to a broad spectrum of environmental factors.

Mixed-linear

Another idealized model for the SBL incorporates a potential temperature increase, often modeled linearly, with height while featuring a pronounced temperature step, $\Delta\bar{\theta}_h$, at the SBL's top, as depicted in Figure 1.6b. This scenario typically arises under conditions of moderately strong winds and turbulence:

$$\Delta\bar{\theta}(z) = \begin{cases} 0 & \text{for } z > h \\ (1 - \frac{z}{h}) \Delta\bar{\theta}_s + (\frac{z}{h}) \Delta\bar{\theta}_h & \text{for } z \leq h \end{cases} \quad (1.6)$$

This configuration, which reflects a layer that is not entirely well mixed, occurs under slightly weaker mechanical forcings compared to the fully ML scenario. The equation accounts for a linear gradation of potential temperature within the SBL, transitioning smoothly from the surface value, $\Delta\bar{\theta}_s$, to the step change at the top, $\Delta\bar{\theta}_h$. The relationship between the top of the SBL and the integral depth scale is given by $h = 2[\Delta\bar{\theta}_s/(\Delta\bar{\theta}_s + \Delta\bar{\theta}_h)]H_{\Delta\theta}$, illustrating how the depth of the SBL is influenced by the distribution of temperature within the layer.

Linear

A third idealization, proposed by Estournel et al. [3], introduces a linear increase in potential temperature from a finite value near the surface, $\Delta\bar{\theta}_s$, to zero at the top of the SBL, depicted in Figure 1.6c. This model simplifies the temperature gradient within the SBL to a straight-line increase, aligning with the concept that the potential temperature difference decreases linearly with height until it reaches zero at the boundary's top. For this scenario, the relationship between the SBL depth and the integral depth scale is straightforward, with $h = 2H_{\Delta\theta}$, indicating that the actual depth of the SBL is twice the value of the integral depth scale based on the potential temperature difference from the surface.

$$\Delta\bar{\theta}(z) = \begin{cases} 0 & \text{for } z > h \\ (1 - \frac{z}{h}) \Delta\bar{\theta}_s & \text{for } z \leq h \end{cases} \quad (1.7)$$

This equation models the potential temperature profile within the SBL, highlighting a linear progression of temperature increase from the surface up to the layer's upper limit. This idealization reflects a more straightforward atmospheric condition, where the potential temperature increment is directly proportional to the height within the layer, simplifying the analysis of the SBL's thermal structure.

Polynomial

The SBL can also be characterized using a polynomial approach, as described by Yamada [4]. This model employs a polynomial function to represent the variation of potential temperature from the surface upwards, ensuring that the function passes through the surface value of potential temperature and exhibits a zero gradient at the SBL's top, as illustrated in Figure 1.6d.

$$\Delta\bar{\theta}(z) = \begin{cases} 0 & \text{for } z > h \\ (1 - \frac{z}{h})^\alpha \Delta\bar{\theta}_s & \text{for } z \leq h \end{cases} \quad (1.8)$$

In this equation, the parameter α , which typically takes values of 2 or 3, modulates the curvature of the potential temperature profile within the SBL, thereby allowing for a more nuanced representation of temperature variation with height. The relationship between the integral depth scale and the top of the SBL is given by $h = (1 + \alpha)H_{\Delta\theta}$, indicating that the actual depth of the SBL can be derived from the integral depth scale, multiplied by a factor dependent on the chosen value of α .

This polynomial model provides a flexible framework for describing the thermal structure of the SBL, accommodating a range of atmospheric conditions by adjusting the value of α . The requirement to specify h remains consistent across all four parameterizations discussed, underscoring the necessity of defining the SBL's depth for accurate modeling.

Exponential

The final approach to modeling the SBL employs an exponential potential temperature profile, as proposed in various studies ([5]–[8]). This model utilizes the integral depth scale, $H_{\Delta\theta}$, to define the e-folding depth of the potential temperature decrease, depicted in Figure 1.6e.

$$\Delta\bar{\theta}(z) = \Delta\bar{\theta}_s e^{-z/H_{\Delta\theta}} \quad (1.9)$$

Given the absence of a clearly defined top of the SBL in this scheme, an arbitrary criterion is adopted to determine the layer's depth, h . For instance, if h is designated as the height at which $\Delta\bar{\theta}$ decreases to 5% of its surface value, then $h = 3H_{\Delta\theta}$. Alternatively, if h is defined by the point where $\Delta\bar{\theta}$ reaches 2% of its surface value, then $h = 4H_{\Delta\theta}$. These stipulations illustrate the challenges and potential errors in estimating the depth of the SBL for a profile lacking a distinct upper boundary, thereby highlighting the adaptability of the exponential model to various atmospheric conditions without a precise demarcation of the layer's extent.

1.2.3.3 Turbulence

Turbulence within the SBL manifests in various forms, as identified by Mahrt and Gamage [9]. In certain cases, the SBL experiences continuous and robust turbulence throughout its entire depth. Conversely, there are instances where turbulence is sporadic, weak, and intermittent; however, when averaged over a few hours, the turbulence flux may seem to be uniformly affecting the entire depth of the SBL. Additionally, observations have sometimes revealed turbulence aloft that appears relatively independent of surface processes.

In conditions devoid of fog or stratocumulus, turbulence within the SBL is primarily mechanically generated, typically by wind shears. Near the ground, wind shear arises from the frictional interaction with the ambient flow. Aloft, variations in geostrophic wind speed with height can also induce shear. The formation of a low-level jet intensifies shears both below and above the jet's peak. On sloping terrain, shears may

develop atop the drainage flow layer, as discussed by Mahrt [10]. Furthermore, the interaction with buoyancy waves can either augment or diminish shears in different areas. Additionally, obstacles such as trees and buildings can create wake turbulence, contributing to the complexity of turbulence patterns within the SBL.

The Richardson number serves as a crucial metric for pinpointing turbulence locations within the SBL. Andre and Mahrt [11] present, in Figure 1.7, the potential temperature and wind profiles from a case study, alongside the corresponding vertical Richardson number profile. Regions where the Richardson number falls below 0.5 are highlighted, denoting areas where turbulence is anticipated, thereby offering insights into the dynamic and multifaceted nature of turbulence within the SBL.

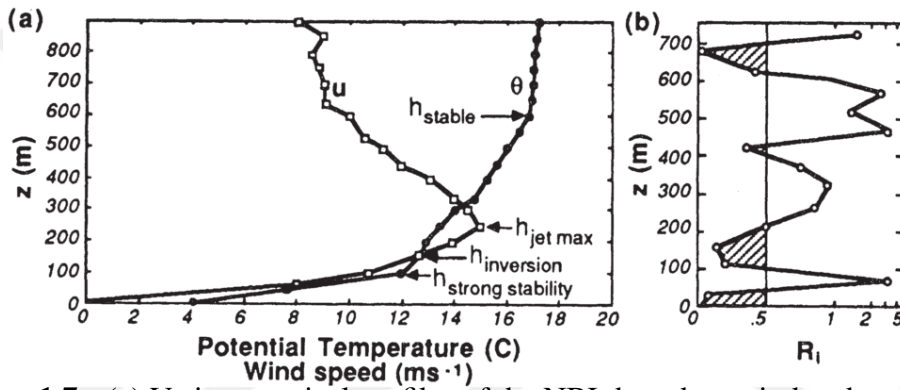


Figure 1.7 : (a) Various vertical profiles of the NBL based on wind and potential temperature for Wangara Day 14 at 0300 LST. (b) Corresponding Richardson number profile (taken from [1]).

During nocturnal periods, the turbulent layers within the SBL can exhibit dynamic behavior, characterized by formation, dissipation, and reformation at different altitudes. Research by Mahrt et al. [2] has shown that at altitudes corresponding to the maximum of the low-level jet (LLJ), the Richardson number tends to be large, indicating less turbulence. However, just above the jet, where wind shears are more pronounced and static stability is reduced, smaller Richardson numbers and increased turbulence intensity have been observed, highlighting the complex interplay between wind shear, static stability, and turbulence within the SBL.

The task of forecasting the Richardson number within the SBL is fraught with uncertainty due to its high sensitivity to relatively minor variations in the gradients of potential temperature and wind profile. Additionally, the use of coarse measurements

to calculate the bulk Richardson number over a broad layer might suggest a nonturbulent state (indicated by a large Richardson number), whereas more detailed, higher-resolution measurements across the same layer could reveal the presence of thin, turbulent layers characterized by low Richardson numbers. This discrepancy underscores the challenges in accurately characterizing and predicting turbulence within the SBL, necessitating a nuanced approach to the analysis of atmospheric stability and turbulence based on the spatial and temporal resolution of observational data.

1.2.3.4 Low-level (nocturnal) jet

The LLJ is characterized as a thin, fast-moving airstream, with maximum wind speeds typically ranging from 10 to 20 m/s , and is usually found at altitudes between 100 and 300 m above the ground. Instances have been reported where peak speeds reached up to 30 m/s , with the altitude of the peak sometimes extending as high as 900 m above ground level. The spatial extent of the LLJ can span hundreds of kilometers in width and a thousand kilometers in length, resembling more of a broad sheet than a narrow ribbon in certain scenarios. Commonly, LLJs form during nighttime and achieve peak velocity in the hours before dawn, hence the term nocturnal jets.

Criteria for identifying LLJs have varied among researchers. Some have specified minimum wind speeds (e.g., 12, 16, or 20 m/s) at altitudes below certain thresholds (e.g., 1000, 1500, or 2500 m), while others have looked for speeds that exceed geostrophic winds ([12,13]). A pragmatic approach defines the LLJ as the presence of a relative maximum in wind speed that exceeds speeds above it by more than 2 m/s within the lowest 1500 m of the atmosphere.

Various causes for the LLJ have been proposed [14], including:

- Synoptic-scale baroclinicity linked to atmospheric patterns
- Terrain-induced baroclinicity
- Dynamics of frontal zones
- Acceleration by advection

- Flow modifications like splitting, ducting, and confluence due to orographic features
- Diurnal land-sea air circulation patterns
- Circulatory systems in mountainous and valley regions
- Oscillatory motions due to the Earth's rotation

This range of factors underscores the complexity and diversity of mechanisms contributing to the formation and evolution of LLJs, highlighting their significance in atmospheric dynamics and weather forecasting.

1.2.4 Virtual potential temperature evolution

The evolution of the virtual potential temperature profile, as captured through radiosonde measurements at times denoted by flags S1 through S6 in Figure 1.1, is illustrated in Figure 1.8.

The profile of virtual potential temperature typically suffices for distinguishing different segments of the BL. Nonetheless, an exception exists where the lapse rate within the middle sections of the RL and the ML is adiabatic. While the mid-portion of the ML is statistically unstable, the corresponding section of the RL is considered statistically neutral.

To resolve this, examination of the air beneath the adiabatic layer is necessary. If this lower air is superadiabatic, then the layers above are deemed statistically unstable. Conversely, if not, the adiabatic layer is classified as statistically neutral.

Smoke released into the top of the NBL or the RL seldom disperses down to the ground during nighttime due to limited turbulence. Instead, these smoke plumes can be carried hundreds of kilometers away from their origin. Smoke within the RL may spread until the lower edge of the plume encounters the upper limit of the NBL. The pronounced static stability and a general decrease in turbulence limit the downward mixing into the NBL. Occasionally, the upper portion of a smoke plume may continue to ascend into neutral air, a process known as lofting.

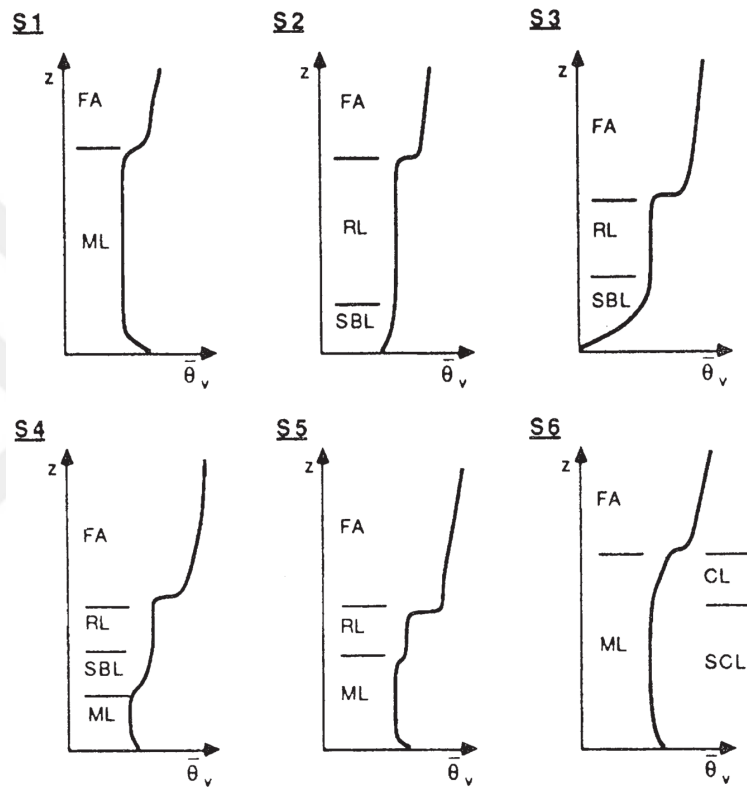


Figure 1.8 : Profiles of average virtual potential temperature, $\bar{\theta}_v$, illustrating the boundary layer's progression throughout a daily cycle beginning around 1600 local time. Soundings S1-S6 are each marked with a launch time shown in Figure 1.1 (taken from [1]).

1.2.5 Stability concepts

The transition between turbulent and laminar flows is governed by the stability of the flow. Unstable flows tend to become or remain turbulent, whereas stable flows tend to become or remain laminar. The onset of turbulence or maintenance of laminar flow can be influenced by numerous factors, with certain conditions acting to destabilize the flow and others serving to stabilize it. When the cumulative impact of destabilizing factors outweighs that of the stabilizing factors, turbulence is likely to ensue.

To facilitate analysis, these influencing factors are often quantified as dimensionless ratios, thereby simplifying the complexity of fluid dynamics into more manageable terms. Key dimensionless parameters include the Reynolds number, Richardson number, Rossby number, Froude number, and Rayleigh number. Each of these numbers encapsulates specific aspects of the flow's characteristics or the forces acting upon it, aiding in the assessment of flow stability. However, it's noteworthy that not all stability parameters are expressed in dimensionless form; for example, static stability is typically described in terms of its direct physical attributes rather than as a dimensionless ratio.

This framework of stability concepts provides a structured approach to understanding the dynamic behavior of flows, distinguishing between conditions conducive to turbulence and those favoring laminar flow. By evaluating the relative influences of various dimensional and dimensionless parameters, one can deduce the prevailing state of stability within a given fluid system.

Static stability quantifies the potential for buoyant convection within a fluid medium, with “static” implying a state devoid of motion, thereby indicating that this form of stability is unaffected by wind dynamics. A statically unstable condition arises when less dense air (either warmer and/or moister) is situated beneath more dense air, creating a predisposition for upward convection.

Local Definitions: Within basic meteorology education, static stability is often introduced through a local perspective, predicated on the immediate lapse rate. However, this local definition encounters limitations within convective mixed layers (MLs), where the movement of thermals either ascending from near the surface

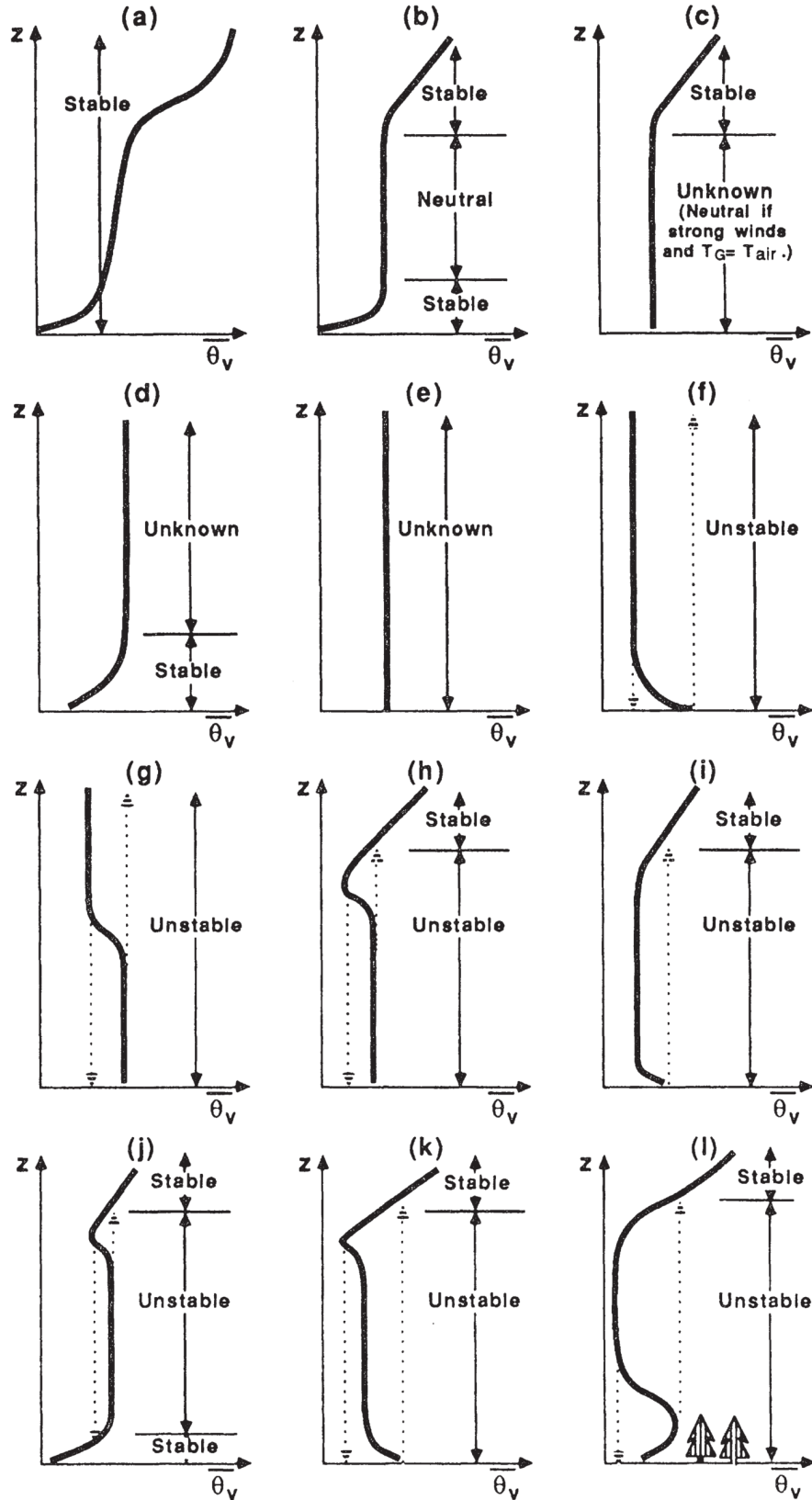


Figure 1.9 : Static stability characterized by the variation in the profile of mean virtual potential temperature, $\bar{\theta}_v$. Dotted lines represent the trajectory of air parcels (taken from [1]).

or descending from cloud tops is driven by their relative buoyancy rather than the surrounding lapse rate.

For instance, within the central portion of a convective ML, where the lapse rate aligns closely with the adiabatic, the application of a traditional local definition might mistakenly suggest neutral stability. It's crucial to distinguish between “adiabatic lapse rate” and “neutral stability”. An adiabatic lapse rate, in terms of virtual potential temperature, may signify conditions of stability, neutrality, or instability, contingent upon the presence of convection and the buoyancy flux. Neutral stability, on the other hand, describes a specific scenario characterized by an adiabatic lapse rate devoid of convection. Consequently, these terms should not be used interchangeably, and the use of “neutral lapse rate” is discouraged. It follows that relying solely on local lapse rate measurements proves inadequate for ascertaining static stability. A comprehensive understanding necessitates either a full profile of the mean virtual potential temperature, $\overline{\theta_v}$, or measurements of turbulent buoyancy flux.

In scenarios lacking direct insights into convection dynamics or buoyancy flux data, static stability can still be deduced from the complete $\overline{\theta_v}$ profile across the BL, as illustrated in Figure 1.9. This figure underscores that partial profile knowledge may yield ambiguous stability assessments and highlights numerous instances where traditional local definitions fall short.

1.2.6 The Richardson number

1.2.6.1 Flux Richardson number

Within a statically stable environment, the dynamics of turbulent vertical motions contend with the restoring force exerted by gravity. Consequently, buoyancy acts as a suppressive force against turbulence, whereas wind shears contribute to the mechanical generation of turbulence. This dynamic interplay is quantified by the flux Richardson number, R_f , expressed as:

$$R_f = \frac{\left(\frac{g}{\theta_v}\right) \left(\overline{w'\theta_v'}\right)}{\left(\overline{u'w'}\right) \frac{\partial \overline{U}}{\partial z} + \left(\overline{v'w'}\right) \frac{\partial \overline{V}}{\partial z}} \quad (1.10)$$

In contexts where the flow is statically unstable, the R_f typically assumes negative values, given that the denominator is usually negative. Conversely, R_f equals zero in the case of neutral flows and is positive for statically stable flows. Richardson suggested that a flux Richardson number of $R_f = +1$ represents a critical threshold; values of R_f less than +1 indicate that static stability does not sufficiently counteract the mechanical generation of turbulence. Negative R_f values further amplify turbulence generation. Thus, he concluded that:

- Flow IS turbulent (dynamically unstable) when $R_f < +1$
- Flow BECOMES laminar (dynamically stable) when $R_f > +1$

By definition, statically unstable flow is inherently dynamically unstable, underscoring the pivotal role of the Richardson number in diagnosing the stability and turbulence characteristics of atmospheric flows.

1.2.6.2 Gradient Richardson number

The gradient Richardson number, R_i , is defined by the equation:

$$R_i = \frac{\left(\frac{g}{\theta_v}\right) \frac{\partial \overline{\theta_v}}{\partial z}}{\left(\frac{\partial \overline{U}}{\partial z}\right)^2 + \left(\frac{\partial \overline{V}}{\partial z}\right)^2} \quad (1.11)$$

When the term “Richardson number” is used without qualification, it typically refers to the gradient Richardson number. The criteria for dynamic stability can be summarized as:

- Laminar flow transitions to turbulent when $R_i < R_c$
- Turbulent flow reverts to laminar when $R_i > R_T$

While the exact values of R_c (critical Richardson number for the onset of turbulence) and R_T (Richardson number threshold for the cessation of turbulence) are subject to debate, values of $R_c = 0.21$ to 0.25 and $R_T = 1.0$ are generally accepted as effective. This discrepancy indicates a hysteresis effect, where R_T exceeds R_c .

Negative Richardson numbers signify flow that is both statically and dynamically unstable, invariably leading to turbulence. Conversely, positive Richardson numbers denote static stability, yet within the range of $0 < R_i < 1$, positive Richardson numbers can indicate dynamic instability, with the potential for turbulence dependent on the flow's historical context. Specifically, non-turbulent flow becomes turbulent around $R_i = 0.25$, while presently turbulent flow remains so provided $R_i < 1$.

1.2.6.3 Bulk Richardson number

The derivation of a critical Richardson number, $R_c \cong 0.25$, is grounded in local assessments of wind shear and temperature gradient. However, meteorologists often lack precise local gradient data, instead relying on measurements at discrete vertical intervals. By substituting the local gradients, $\partial \bar{\theta}_v / \partial z$, with finite differences, $\Delta \bar{\theta}_v / \Delta z$, and similarly approximating $\partial \bar{U} / \partial z$ and $\partial \bar{V} / \partial z$ with $\Delta \bar{U} / \Delta z$ and $\Delta \bar{V} / \Delta z$ respectively, we can introduce the concept of the bulk Richardson number, R_B :

$$R_B = \frac{g \Delta \bar{\theta}_v \Delta z}{\bar{\theta}_v \left[(\Delta \bar{U})^2 + (\Delta \bar{V})^2 \right]} \quad (1.12)$$

This iteration of the Richardson number is prevalently utilized in meteorological analyses due to the nature of rawinsonde data and numerical weather forecasts, which provide wind and temperature measurements at distinct spatial points. The finite differences are defined in a manner such as $\Delta \bar{U} = \bar{U}(z_{top}) - \bar{U}(z_{bottom})$.

It is important to note, however, that the critical value of 0.25 is only directly applicable to local gradients and not to finite differences across broader layers. The broader the layer considered, the greater the potential to average out significant gradients present within smaller subsections of the layer, leading to:

1. Increased uncertainty in predicting turbulence occurrence,
2. The necessity to adopt a theoretically unjustifiable, but pragmatically reasonable, larger critical Richardson number to accommodate the smoothed gradients.

Thus, the critical Richardson number tends to approach 0.25 more closely as the thickness of the analyzed layer decreases.

1.2.7 Urban heat island

Urban areas significantly contribute to anthropogenic heat and pollution. Characterized by vast expanses of impermeable surfaces such as asphalt and concrete, particularly in downtown areas, cities exhibit higher temperatures compared to their surrounding rural environments. These surfaces possess high heat capacities and low albedos, which enable them to absorb and retain incoming solar radiation as sensible heat.

The most notable temperature disparities between urban and rural locales typically occur during nighttime. Even in the presence of a well-established SBL over the surrounding countryside, urban areas often maintain a shallow convective ML at night, largely due to the heat emitted by the city. Studies have indicated that cities with populations of approximately 1000 inhabitants may experience temperature excesses of 2 to 3° C compared to rural surroundings, while larger cities with populations exceeding a million can exhibit excesses of 8 to 12° C [15,16].

1.2.8 Impact of emissions in boundary layer

Air pollution manifests as a grave environmental and public health concern when atmospheric concentrations of deleterious chemicals escalate to levels that are detrimental to ecological and human health. Amongst these pollutants, particulate matter (PM), sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen oxides (NO_X) are the most prevalent, with PM, categorized according to its aerodynamic diameter into PM_1 , $PM_{2.5}$, and PM_{10} , recognized for its profound impact on human health as evidenced in studies by [17,18]. The World Health Organization, in 2016, attributed approximately 4.2 million premature mortalities globally to outdoor air pollution. Elevated concentrations of PM not only pose a risk to human health but also inflict damage upon ecosystems and impair visibility, which underscores the importance of meticulous monitoring and analysis of PM levels, thereby equipping policymakers with crucial data to enact effective control measures.

Meteorological conditions exert a profound influence on the variations of air quality, which can obscure the effects of temporal changes in emission levels [19,20]. Differentiating the impacts of policy changes or meteorological factors from those of weather and seasonality is often subtle and challenging when analyzing time series data. It is essential to apply a method capable of accurately decomposing the short-term component from the baseline trend in the data. This is critical for a proper analysis and precise interpretation of time series of PM and meteorological variables. Among the most widely employed methods are the anomaly technique, the wavelet transform (WT), and the KZ filter. The anomaly method involves calculating yearly and monthly averages for each interval in the data set, to extract the long-term and seasonal components of the time series. The deviation of the monthly averages from the original time series defines the short-term component [21]. The WT, introduced to climate time series analysis by [22], is a generalization of the Fourier transform, using localized base functions that can adapt in scale, offering flexibility in resolution across frequency and time domains. This allows for a minimal number of base functions to match the majority of high and low-frequency signals effectively.

Rao et al. [23] introduced the KZ-filter as a means to discern the contributions of physical processes and emissions sources to concentrations of air pollutants. The KZ-filter, fundamentally a low-pass filter, is predicated on the moving average concept applied to time series data. Eskridge et al. [24] posit that while the Wavelet Transform (WT) and KZ-filter exhibit comparable efficacy in partitioning components of air quality data, the anomaly method is notably less effective. The inherent characteristics of meteorological and air quality datasets facilitate the distinction between short-term and long-term variations [23,25]. Moreover, the KZ-filter is recognized for its superior confidence in long-term trend analysis compared to other methods [24]. It is advantageous in its direct applicability to datasets with missing observations, unlike the WT and anomaly techniques which necessitate gap-filling strategies. Furthermore, the simplicity of the KZ-filter's usage is highlighted. This study opts for the KZ-filter to decompose the time series into its respective components, given its enhanced accuracy and straightforward implementation.

Previous studies such as those by [26]–[29] have employed the KZ-filter time series method to analyze long-term trends of O_3 and to adjust for meteorological parameters. The method's efficacy was tested by Wise and Comrie [20] in the Southwestern United States specifically for PM_{10} and O_3 . Moreover, Sá et al. [30] investigated the impact of meteorological factors on O_3 , NO_2 , and PM_{10} in Portugal over a decade. Seo et al. [31] utilized the KZ-filter to examine the influence of meteorological variables and emissions on concentrations of O_3 , NO_2 , SO_2 , CO , and PM_{10} in Seoul, South Korea.

Chen et al. [32] applied the KZ-filter in conjunction with WRF-CMAQ modeling to evaluate the impact of meteorological conditions and emission control efforts on $PM_{2.5}$ reduction in Beijing. They quantified that emission reductions contributed to 80.6% and 78.6% of the $PM_{2.5}$ concentration decrease as per the KZ-filter and WRF-CMAQ, respectively. In another study, Mousavinezhad et al. [33] utilized data from an extensive network of ground stations, along with meteorological reanalysis datasets, to assess trends in surface O_3 , NO_2 , and $PM_{2.5}$ across China's heavily polluted megacities from 2015 to 2019, also examining the meteorological and emission precursors' contributions to O_3 variability via the KZ-filter. Han et al. [34] focused on evaluating regional PM concentrations based on the vertical distribution within the boundary layer. Gao et al. [35] and Chaurasia and Mohan [36] introduced an innovative statistical method integrating meteorological filtering, spectral analysis, and the KZ-filter for estimating background ambient pollutant levels.

PM has emerged as a significant environmental issue in Turkey, attributed to its rapid economic growth over recent decades and its geographical proximity to dust source areas [37]. Research on PM_{10} concentrations has been conducted at both regional and national levels in Turkey [38,39]. An assessment of Turkey's air quality, focusing on 16 metropolitan cities and examining pollutants such as PM_{10} , SO_2 , NO_2 , and O_3 was conducted by Toros et al. [40], which revealed that daily average PM values exceeded $50 \mu g/m^3$ in 75% of these cities between 2010 and 2012. However, there remains a research gap in quantifying emissions and meteorological contributions to the spatio-temporal variations of PM_{10} in the region.

This thesis aims to address this gap by i) analyzing the spatio-temporal variation of PM_{10} measurements, ii) exploring the influence of meteorological conditions and long-term emission changes on air quality, and iii) developing a methodology to quantify the respective contributions of meteorology and emissions to air pollution fluctuations. The results will enhance the understanding of the causative factors affecting PM_{10} concentration variability and improve the comprehension of the processes underlying these measurements in the selected cities.



2. MATERIAL and METHODS

2.1 Study Area and Data

Turkey straddles the juncture of two continents, Europe and Asia, located within the latitudinal bounds of $35^{\circ}N$ to $42^{\circ}N$ and longitudinal range from $26^{\circ}E$ to $44^{\circ}E$ as depicted in Figure 2.1. The country spans an area of $783,562\text{ km}^2$, characterized by a diverse topography that includes expansive plains, elevated plateaus with an average altitude of $1132m$, and an escalation in elevation towards the eastern parts of Anatolia. This varied terrain, alongside the mountain ranges running parallel to the Mediterranean and Black Seas, contributes to the heterogeneity of climatic conditions across the Anatolian peninsula. The prevailing Mediterranean climate engenders four distinct seasons, influenced markedly by the seasonal interplay between frontal depressions accompanied by polar air masses and the high-pressure systems associated with maritime tropical and continental tropical air masses in subsidence. The climate, during the summer months, is predominantly shaped by tropical airstreams emanating from the northern African and Arabian deserts, which usher in a prolonged period of warm (to hot) and arid conditions [40,41]. Conversely, the winter season is under the sway of the polar front, with frigid air masses originating from the Balkan Peninsula, and the core of low pressure situated over the Mediterranean that guides frontal systems eastward. Additionally, the presence of high-pressure systems, notably the Azores during summer and the Siberian during winter, play a pivotal role in the seasonal climatic dynamics [42].

The population distribution in Turkey exhibits a significant concentration within its twelve metropolitan cities, with İstanbul, Ankara, and İzmir representing 18.5%, 6.8%, and 5.3% of the national population, respectively [43]. Collectively, these twelve cities harbor around 40 million residents, accounting for approximately 50% of Turkey's total populace. Notably, about 33% of Turkey's inhabitants reside across six coastal cities, contributing to 47.2% of the nation's Gross Domestic Product (GDP) [44]. The

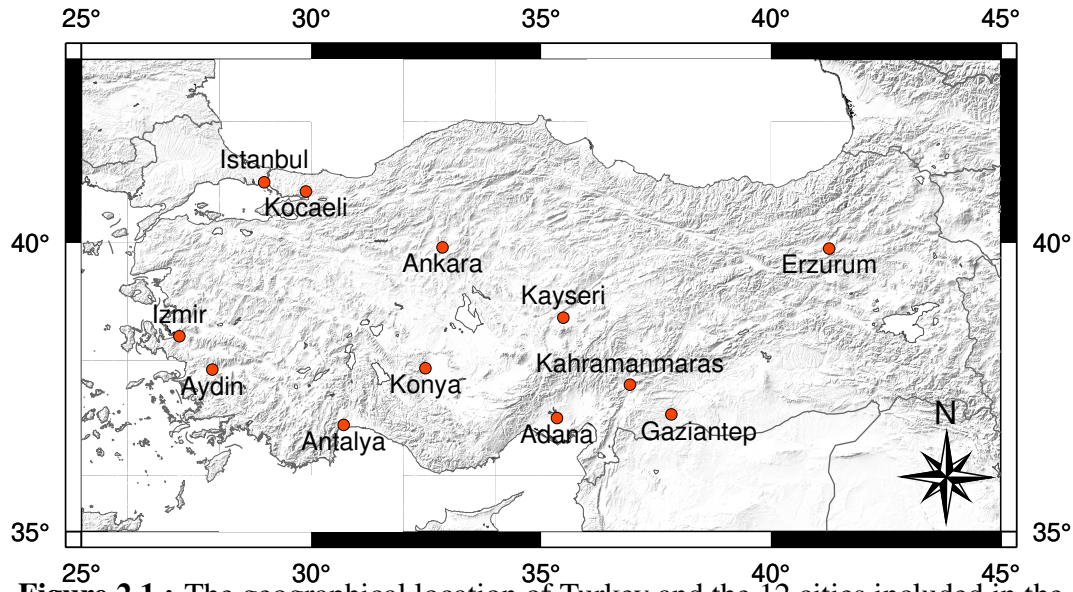


Figure 2.1 : The geographical location of Turkey and the 12 cities included in the research.

coastal cities, on average, are situated at an elevation of about 42m, whereas cities like Erzurum, Kayseri, and Konya are elevated beyond 1000m. Detailed demographics and geographical data for these selected cities are cataloged in Table 2.1, with their specific locations depicted in Figure 2.1. It is evident from this illustration that half of these cities, namely Aydin, Antalya, Adana, İstanbul, Kocaeli and İzmir are coastal, while the remainder, including Konya, Ankara, Kayseri, G. Antep, K. Maras and Erzurum are inland.

Hourly PM₁₀ concentration data spanning the years 2010 to 2021 were sourced from 36 air quality monitoring stations overseen by the Turkish Ministry of Environment, Urbanization, and Climate Change (TMEUCC) across the selected cities. Selection criteria for the stations included a requirement that the total percentage of missing data be under 30%, with daily averages computed when the daily missing data did not exceed 30%. Among these 36 stations, the minimum, average, and maximum percentages of missing data were found to be 3.3%, 10.9%, and 28.6%, respectively. Daily average PM₁₀ concentrations were derived from the hourly data using a 15% trimmed mean method, a robust estimator for normally distributed data that remains unaffected by minor proportions of outliers [45,46]. For cities hosting multiple monitoring stations, daily averages were aggregated across all stations, revealing a satisfactory spatial homogeneity (with coefficients of variation for PM₁₀

Table 2.1 : Population, GDP and Altitude of the cities.

City	Population	Percent of Total Population (%)	GDP (%)	Elevation (m)
İstanbul	15 462 452	18.5	31.2	120
Ankara	5 663 322	6.8	9.0	850
İzmir	4 394 694	5.3	6.2	2
Antalya	2 548 308	3.1	2.9	39
Adana	2 258 718	2.7	2.0	23
Konya	2 250 020	2.7	2.1	1016
G. Antep	2 101 157	2.5	1.8	843
Kocaeli	1 997 258	2.4	3.9	3
Kayseri	1 421 455	1.7	1.5	1071
K. Maras	1 168 163	1.4	0.8	568
Aydin	1 119 084	1.3	1.0	64
Erzurum	758 279	0.9	0.6	1890
Total	41 142 190	49.2	62.9	-

at approximately 0.16 across stations). Additionally, hourly measurements of wind speed, temperature, and pressure for the same period were obtained from the Turkish State Meteorological Services(TSMS), with daily averages calculated employing the identical methodology utilized for PM₁₀.

Figure 2.2 presents a summary of the statistical analysis conducted on PM₁₀ concentrations and various meteorological variables within the study, with the data organized in ascending order based on mean PM₁₀ concentrations. It was observed that average PM₁₀ levels in Adana, Erzurum, İzmir, and Antalya remain below the threshold of 50 $\mu\text{g}/\text{m}^3$, whereas the remaining eight cities exhibit higher concentrations, with some reaching up to 70 $\mu\text{g}/\text{m}^3$. Temperature trends indicate a higher warmth at lower elevations, with over half of the temperature data fluctuating within a mean interval of $\pm 10^\circ \text{C}$. Notably, the temperature disparity between summer and winter seasons is more pronounced in inland cities, with exploratory analyses highlighting increased temperature variability during winter, particularly in Erzurum. Wind speed averages remain below 2m/s with the exception of Erzurum, İzmir, Antalya, Konya, and Ankara, among which Erzurum and Konya display the greatest variability in wind speed. Additionally, there exists an inverse relationship between average atmospheric pressure and elevation, with coastal cities such as Adana,

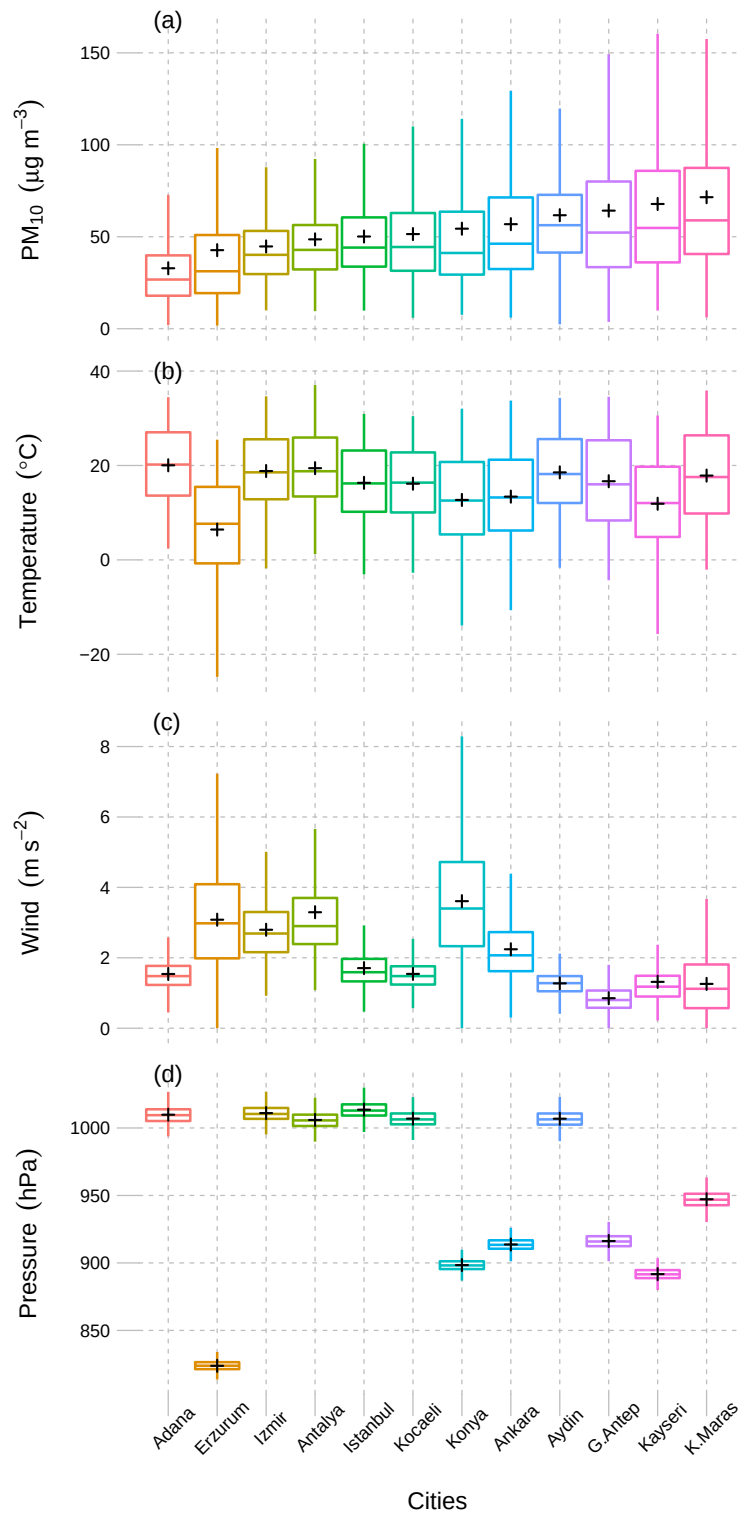


Figure 2.2 : Summary statistics for PM₁₀ concentrations and meteorological variables.

İzmir, Antalya, İstanbul, Kocaeli, and Aydın registering higher actual pressures and a relatively greater variance in pressure compared to their inland counterparts.

Coastal cities benefit from sea-land interactions and the lack of surrounding high elevations, which facilitates the dispersion of PM_{10} particles even under conditions of low wind, generally resulting in cleaner air when compared to inland cities. An exception to this pattern is observed in Erzurum, situated at an elevation of approximately 1900m. Erzurum's geographic setting on a vast plateau encircled by mountains, coupled with its frequent snow coverage and potential for extremely low temperatures reaching down to $-25^{\circ}C$, fosters conditions for relatively warm and ascending air currents that aid in elevating pollution away from ground level. Furthermore, daily average wind speeds in Erzurum, as well as in Antalya and Konya, have been recorded to reach up to 6m/s, underscoring the significant role of wind in pollutant dispersion within these regions.

2.2 Methodology

The daily PM_{10} concentration time series is analytically decomposed into short-term, seasonal, and long-term components [47]. The short-term component is primarily influenced by day-to-day variations in weather conditions and transient fluctuations in emission levels. Seasonal fluctuations, on the other hand, stem from the cyclical nature of meteorological conditions [48] and patterns in energy consumption [49]. The long-term trend can be attributed to overarching changes in emission rates, the dynamics of pollutant transport, shifts in socioeconomic factors, and the implementation of various environmental policies.

The elucidation of meteorological processes and emission source impacts on air pollutant concentration variability is markedly enhanced by segregating seasonality and long-term trends from short-term variations. To accomplish this temporal decomposition, techniques such as the KZ-filter method, the anomaly technique, and the wavelet transform method are prevalently employed. Notably, the KZ-filter method distinguishes itself by accommodating time series with missing data without introducing biases, as it assigns equal weight to all data points. This feature eliminates the need for the special handling of gaps that is necessary with the anomaly and wavelet

transform methods, thereby simplifying the analysis process. Furthermore, Eskridge et al. [24] advocate for the KZ-filter method, attributing to it a confidence level approximately tenfold superior to that of other methods for the analysis of long-term trends.

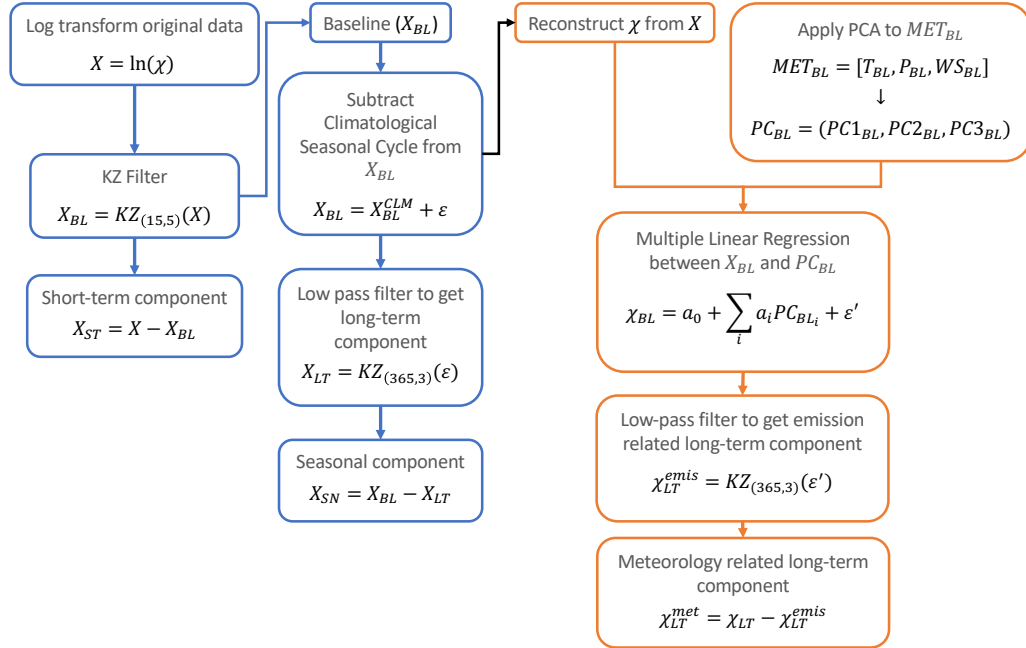


Figure 2.3 : A diagram illustrating the process of breaking down the PM₁₀ time series into its temporal components and employing multiple linear regression to isolate the long-term elements.

The KZ-filter, a powerful low-pass filter, is constructed through multiple iterations of a straightforward moving average process. The operational mechanism of the filter for a given iteration $KZ_{(m,p)}$ is mathematically articulated in Equation 2.1:

$$Y_i = \frac{1}{m} \sum_{l=-k}^k A_{l+k} \quad (2.1)$$

where k delineates the count of observations included on either side of the target value, thereby defining $m = 2k + 1$ as the extent of the moving window. The parameter p signifies the iteration count, and A represents the input time series data. The filter's capacity to eliminate high-frequency fluctuations for periods shorter than the effective filter width is modulated by adjusting m (the window length) and p (the iteration count), with the effective filter width determined as $N \geq m \times p^{1/2}$.

In the thesis, the application of the KZ-filter method, specifically $KZ_{(15,5)}$ and $KZ_{(365,3)}$ filters, was instrumental in refining the dataset by eliminating variabilities associated with periods shorter than their respective cut-off periods of 33 days and 1.7 years. This methodology effectively removed the short-term fluctuations, thereby enabling a focused analysis on the long-term component of the data. Such an approach aligns with the precedents set in previous studies utilizing the KZ-filter, which have similarly employed filters with equivalent effective widths and cut-off periods to discern long-term trends and patterns within their respective datasets [19,20,30,31].

Daily average concentrations for PM_{10} data were computed from the hourly records employing a 15% trimmed mean method. To facilitate the analysis, the raw daily PM_{10} data (χ) underwent a transformation into natural logarithm values, denoted as $X = \ln(\chi)$, prior to the analytical processes. This transformation aims to stabilize the variance across each component of the data. The adoption of the natural logarithm not only ensures variance stabilization but also renders the short-term component stationary, significantly reducing its dependence on seasonal variations, thereby enhancing the robustness of the analysis [47].

The time series of log-transformed PM_{10} concentration (X) can be decomposed into three distinct components as indicated in Equation Equation 2.2:

$$X = X_{ST} + X_{SN} + X_{LT} \quad (2.2)$$

where X_{ST} , X_{SN} , and X_{LT} represent the short-term, seasonal, and long-term components of the log-transformed PM_{10} concentration (X), respectively. The baseline air quality (X_{BL}), equivalent to $KZ_{(15,5)}(X)$, is defined as the aggregate of the seasonal and long-term components as shown in Equation 2.3:

$$X_{BL} = KZ_{(15,5)}(X) = X_{SN} + X_{LT} \quad (2.3)$$

Subsequently, the short-term component is derived by subtracting (2.3) from (2.1), as detailed in Equation 2.4:

$$X_{ST} = X - KZ_{(15,5)}(X) \quad (2.4)$$

The baseline is further decomposed into its repeated seasonal cycle (X_{BL}^{CLM}) and residuals (ϵ), as per [31], and represented in Equation 2.5:

$$X_{BL} = X_{BL}^{CLM} + \epsilon \quad (2.5)$$

Applying the $KZ_{(365,3)}$ filter to ϵ isolates the long-term component (X_{LT}) from minor seasonal variabilities, as shown in Equation 2.6:

$$X_{LT} = KZ_{(365,3)}(\epsilon) \quad (2.6)$$

The seasonal component X_{SN} , constituting the pure seasonal climatology X_{BL}^{CLM} and the minor seasonality ($\epsilon - KZ_{(365,3)}(\epsilon)$), is then defined by rearranging (2.3) in Equation 2.7:

$$X_{SN} = X_{BL} - X_{LT} \quad (2.7)$$

Upon successfully decomposing the log-transformed PM_{10} concentration time series (X) into its short-term (X_{ST}), long-term (X_{LT}), and seasonal (X_{SN}) components using the KZ-filter method, the subsequent analytical phase involves further partitioning the long-term component X_{LT} into two distinct segments. These segments are presumed to correlate with emissions (X_{LT}^{emis}) and meteorological influences (X_{LT}^{met}), reflecting the study's focus on evaluating the long-term impacts attributed to changes in meteorology and emissions. Thus, the baseline air quality can be redefined in accordance with Equation 2.3 as follows:

$$X_{BL} = X_{SN} + X_{LT}^{emis} + X_{LT}^{met} \quad (2.8)$$

This redefinition enables a comprehensive examination of the baseline air quality, facilitating a deeper understanding of the individual contributions from emission and meteorological factors to the long-term trends observed in PM_{10} concentration data.

It is crucial to note that the transformation from log-transformed PM_{10} concentration data back to their original scale involves the exponential function, denoted as $\chi_{BL} = \exp(X_{BL})$, $\chi_{ST} = \exp(X_{ST})$, and $\chi = \exp(X)$. Here, χ_{BL} signifies the baseline concentration, and the relation $X_{ST} = \chi/\chi_{BL}$ is established. Similarly, $\chi_{SN} = \exp(X_{SN})$ and $\chi_{LT} = \exp(X_{LT})$ represent the exponential transformations for the seasonal and long-term components, respectively. The term χ_{SN} denotes the seasonal variation in concentration devoid of any trend, while χ_{LT} can be construed as the ratio χ_{BL}/χ_{SN} , absent of the mean concentration level. To facilitate comparative analysis in terms of means, the mean of χ_{BL} can be incorporated into χ_{LT} . Consequently, the thesis presents $\chi_{LT} + \overline{\chi_{BL}}$ in Figure 3.1. Subsequently, χ_{BL} serves as a foundational element in establishing a direct linear correlation between PM_{10} concentrations and meteorological variables.

In this thesis, centered meteorological variables, including wind speed (W), temperature (T), and pressure (P), were meticulously analyzed. The methodological steps outlined in Equations 2.2 and 2.3 were applied to each of these variables to calculate their respective meteorological baselines (MET_{BL}) utilizing the $KZ_{(15,5)}$ filter. Notably, a significant correlation (> 0.7) between temperature (T) and pressure (P) was observed across almost all cities, indicating a potential collinearity issue. To address this, Principal Component Analysis (PCA) was employed on MET_{BL} , resulting in the derivation of principal components $PC_{BL} = (PC1_{BL}, PC2_{BL}, PC3_{BL})$. Subsequently, a stepwise Multiple Linear Regression (MLR) was conducted to model the relationship between the baseline concentration χ_{BL} and the principal components PC_{BL} , as expressed in Equation 2.9:

$$\chi_{BL} = a_0 + \sum_i a_i PC_{BL_i} + \epsilon' \quad (2.9)$$

Here, ϵ' encapsulates the non-meteorological long-term variability, primarily emissions-related (χ_{LT}^{emis}), alongside the minor seasonal fluctuations unaccounted for by the MLR. The emissions-related long-term component of χ_{LT} is isolated by applying the $KZ_{(365,3)}$ filter to ϵ' , as detailed in Equation 2.10, and the

meteorology-related long-term component (χ_{LT}^{met}) is then discerned by subtracting χ_{LT}^{emis} from the total χ_{LT} , as shown in Equation 2.11:

$$\chi_{LT}^{emis} = KZ_{(365,3)}(\epsilon') \quad (2.10)$$

$$\chi_{LT}^{met} = \chi_{LT} - \chi_{LT}^{emis} \quad (2.11)$$

The comprehensive steps to break down the PM_{10} time series are briefly summarized in Figure 2.3.

In the second phase of the research, PM_{10} concentrations and the vertical potential temperature profile of eight cities (İstanbul, İzmir, Isparta, Ankara, Erzurum, Samsun, Adana and Diyarbakır) are analyzed using the Equation 2.12. These cities were chosen because balloon observations are conducted there and $\delta\theta$ was calculated between 20 hPa and 5 hPa levels of the atmosphere. In the thesis, δ_s is chosen as $0.6^\circ C$ which is average of $1.0^\circ C$ and $0.2^\circ C$ for land and ocean, respectively; which is detailed in Liu and Liang [50].

$$\Delta\theta = \theta_5 - \theta_2 \begin{cases} < -\delta_s & \text{for UBL} \rightarrow \text{An unstable regime} \\ > +\delta_s & \text{for SBL} \rightarrow \text{A stable regime} \\ \text{else} & \text{for NRL} \rightarrow \text{A neutral regime} \end{cases} \quad (2.12)$$

Firstly, $\Delta\theta = \theta_5 - \theta_2$ is calculated and stability regimes are classified according to the rule at Equation 2.12. Then, an extensive analysis of theta differences and constructed stability regimes.

After that, $\Delta\theta$ is calculated for each pressure level of the atmosphere and paired with corresponding PM_{10} concentration and Pearson correlation coefficient between $\Delta\theta$ for each level and paired PM_{10} concentration is calculated. These correlations are mapped in the figures and compared to each other in terms of seasonal, monthly and hourly categories.

3. RESULTS

3.1 The Long-term Meteorological and Emission Impacts on Air Quality

The temporal decomposition of PM_{10} concentration (χ) across the selected cities was meticulously conducted, with the outcomes illustrated in Figure 3.1, showcasing both the baseline (χ_{BL}) and the long-term (χ_{LT}) components of the data. The range of PM_{10} concentrations spanned from $20 \mu g/m^3$ to $200 \mu g/m^3$ across all cities, with the baseline component effectively capturing the intrinsic seasonality and long-term variations inherent within the dataset. Noteworthy observations include significant anomalies in cities like Adana, where PM_{10} concentrations were observed to exceed typical values by more than threefold on specific dates, such as on 31 October 2013 and 08 September 2015. In contrast, cities like Kayseri and K. Maras exhibited pronounced seasonal fluctuations, whereas İstanbul and İzmir demonstrated relatively subdued seasonality. Overall, a general trend of reduction in PM_{10} levels was identified across the dataset; however, exceptions were noted in Adana and Kayseri, which displayed marginal increases.

The decomposition of the long-term component of the data (χ_{LT}) into its meteorological and emission-driven aspects was conducted as delineated in the methodology section. The resulting linear regression coefficients, which quantify the relationship between PM_{10} concentrations and scaled meteorological variables, are presented in Table 3.1. Examination of this table reveals that the regression coefficient for temperature is consistently negative across all surveyed cities, with values ranging from -14.7 in Kayseri to -2.0 in İstanbul, indicating a general decrease in PM_{10} levels with rising temperatures. An exception to this pattern is observed in Adana, where a positive temperature coefficient of 4.3 contrasts with a negative pressure coefficient of -4.2 . Additionally, the correlation coefficient between temperature (T) and pressure (P) in Adana is -0.9 , suggesting a tendency for higher PM_{10} concentrations during the summer months.

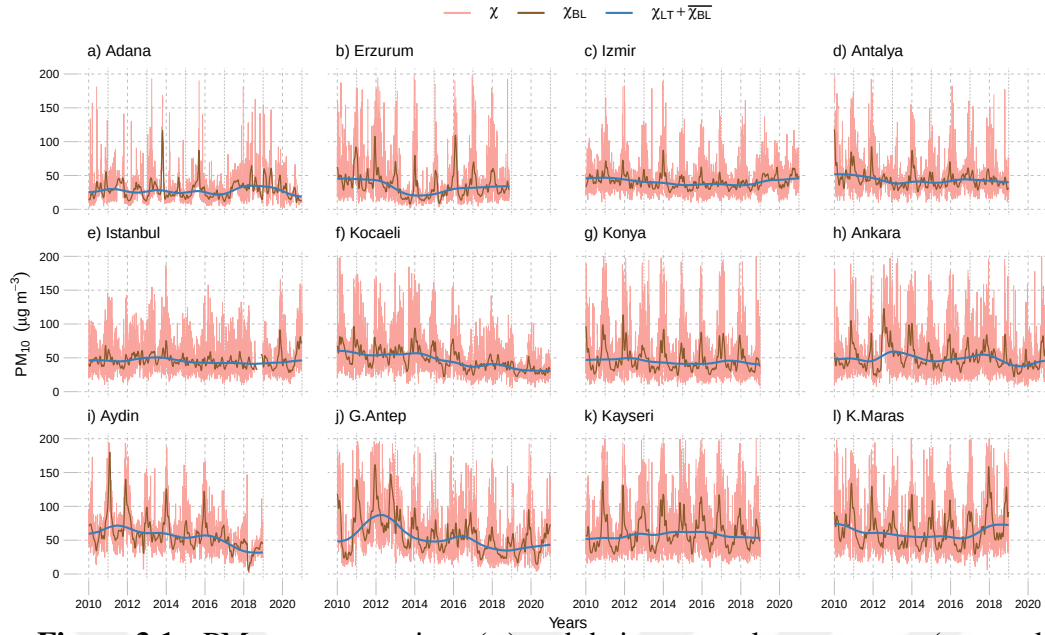


Figure 3.1 : PM_{10} concentrations (χ) and their temporal components (χ_{BL} and $\chi_{LT} + \chi_{BL}$ representing the baseline and sum of long-term components plus average of χ_{BL} , respectively).

Saharan dust episodes have a widespread impact across Turkey, affecting regions from the west and south to the east and north [51]. Conversely, dust intrusions from the Arabian Peninsula predominantly influence the southeastern areas of Turkey. This differential impact is attributed to the high elevation and complex terrain characterizing eastern Anatolia, which act as barriers to dust transportation [52,53]. Notably, among the cities studied, Adana and G. Antep experience more significant effects from dust intrusion originating from the Arabian Peninsula. Adana's geographical positioning near the Mediterranean Sea places it directly in the path of dust transport from the north of the Arabian Peninsula. Additionally, the significance of Adana as a major hub for agricultural production within Turkey is emphasized, further underscoring the potential implications of dust episodes on local environmental and economic conditions.

The regression analysis revealed that wind speed (WS) generally correlates negatively with PM_{10} concentrations across the cities studied, with coefficients ranging from -32.3 for Kayseri to -1.1 for Adana. This suggests a decrease in PM_{10} concentrations as wind speed increases, indicative of enhanced dispersion of particulate matter under stronger wind conditions. An exception is observed in Aydin, where a slight increase in PM_{10} concentration is noted with increasing wind speed, attributed to a positive

Table 3.1 : Linear Model Coefficients for baseline PM₁₀ (χ_{BL}) vs. scaled meteorological parameters (I , T_{BL} , WS_{BL} and P_{BL} are intercept, temperature, wind speed and pressure, respectively).

Station	Model Variable Coefficients				Adjusted- R^2
	I	T_{BL}	WS_{BL}	P_{BL}	
Adana	29.1	4.3	-1.1	-4.2	0.11
Erzurum	35.8	-11.0	-20.9	6.6	0.42
İzmir	41.2	-2.9	-8.8	5.2	0.18
Antalya	44.4	-3.7	-8.8	5.3	0.27
İstanbul	46.0	-2.0	-5.3	3.6	0.12
Kocaeli	47.3	-6.2	-5.4	5.2	0.20
Konya	46.7	-11.3	-23.5	16.0	0.54
Ankara	50.7	-3.1	-6.7	16.4	0.28
Aydin	58.3	-12.1	2.2	15.0	0.29
G. Antep	57.6	-12.7	-23.1	16.6	0.31
Kayseri	60.4	-14.7	-32.3	27.3	0.62
K. Maras	64.3	-13.0	-16.4	18.5	0.38

regression coefficient of $2.2 \mu\text{g}/\text{m}^3$ per unit increase in WS . However, the Pearson correlation coefficient of 0.04 for Aydin indicates a negligible direct relationship between PM₁₀ and wind speed. The observed positive coefficient in Aydin is likely due to the concurrent long-term decrease in both PM₁₀ and wind speed, rendering the actual impact of WS on PM₁₀ minimal in comparison to other variables such as temperature (T) and pressure (P). For instance, temperature variations in Aydin, approximately 20°C , correlate with a $-31 \mu\text{g}/\text{m}^3$ change in PM₁₀, whereas wind speed variations around $1\text{m}/\text{s}$ correspond to a change of approximately $6 \mu\text{g}/\text{m}^3$. Regarding pressure, the regression coefficients are predominantly positive, ranging from 3.6 for İstanbul to 27.3 for Kayseri, with Adana being an exception at -4.2 . The adjusted- R^2 values from the regression equations, indicating the proportion of variability in PM₁₀ concentrations explained by the model, vary significantly across cities, from 0.11 in Adana to 0.62 in Kayseri.

A comprehensive linear trend analysis was conducted on the long-term components of PM₁₀ concentration (χ_{LT}), including its emission-related (χ_{LT}^{emis}) and meteorology-related (χ_{LT}^{met}) segments, to elucidate the long-term changes within the dataset. The analysis, predicated on a significance level of $p - \text{value} < 0.05$, is

depicted in Figure 3.2. The derived coefficients, representing changes per decade, are showcased within these figures for each component. Remarkably, the majority of cases exhibited a declining trend in χ_{LT} , with slope values spanning from $-39.61 \mu g/m^3$ in Aydin to $-1.21 \mu g/m^3$ in K. Maras per 10 years, indicating a general reduction in long-term PM₁₀ levels. Conversely, Adana and Kayseri demonstrated a marginal upward trend in χ_{LT} , with slopes calculated at $1.01 \mu g/m^3$ and $3.10 \mu g/m^3$ per 10 years, respectively.

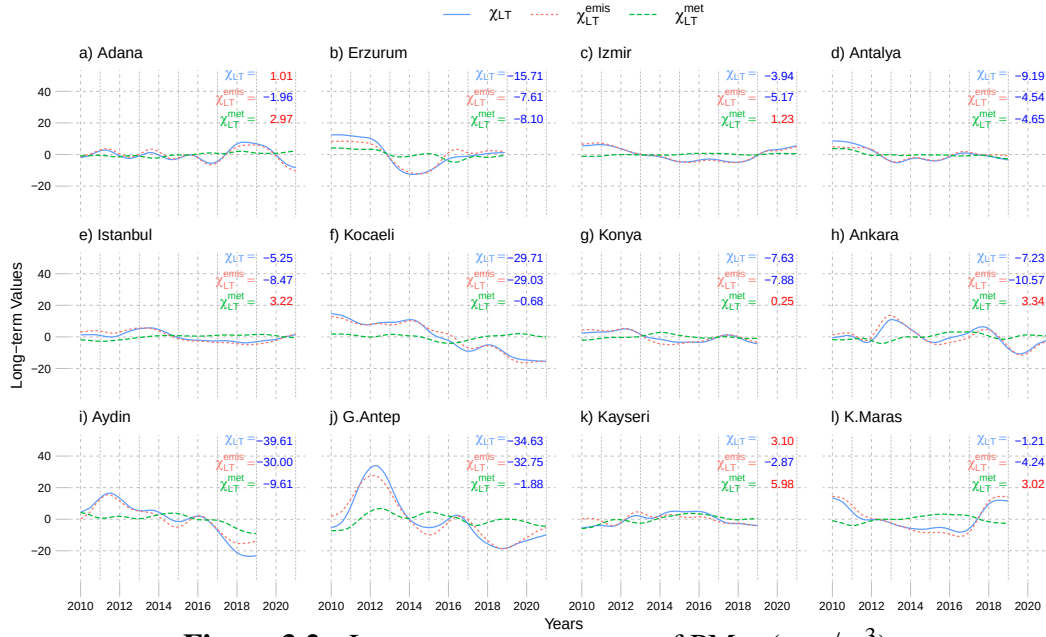


Figure 3.2 : Long-term components of PM₁₀ ($\mu g/m^3$).

The trend analysis for the emission-related component of long-term PM₁₀ concentration (χ_{LT}^{emis}) illustrates a uniform decreasing trend across all cities, with reductions varying from $-32.75 \mu g/m^3$ in G. Antep to $-0.96 \mu g/m^3$ in Adana per decade. This signifies a general improvement in air quality attributable to reduced emissions over the period of study. Conversely, the meteorology-related component (χ_{LT}^{met}) displays a mixed trend. Specifically, seven out of the twelve cities analyzed exhibit an increasing trend in χ_{LT}^{met} , with increments ranging from $0.25 \mu g/m^3$ in Konya to $5.98 \mu g/m^3$ in Kayseri per decade. This indicates a potential exacerbation of PM₁₀ levels due to meteorological conditions in these areas. On the other hand, cities experiencing a decrease in χ_{LT}^{met} , including Aydin and G. Antep, show trends varying between $-9.61 \mu g/m^3$ and $-1.88 \mu g/m^3$ per decade, respectively, suggesting that

Table 3.2 : Total variances of daily PM₁₀ (χ) time series and relative contributions (%) of variances and covariances of decomposed components.

Station	Variance						Covariance			
	X	Relative contributions (%) ^{1,2}					X_{ST}, X_{SN}	X_{SN}, X_{LT}	X_{ST}, X_{LT}	$X_{LT}^{emis}, X_{LT}^{met}$
		X_{ST}	X_{SN}	X_{LT}	X_{LT}^{emis}	X_{LT}^{met}				
Adana	1019	68.9	13.4	1.5	1.5	0.1	7.0	0.8	0.3	-0.1
Erzurum	1621	64.0	15.7	4.2	2.8	0.4	7.1	0.1	0.8	0.5
İzmir	574	75.0	11.6	2.6	3.0	0.1	5.2	0.3	-0.1	-0.2
Antalya	697	65.2	16.2	2.4	1.3	0.3	6.8	0.7	0.5	0.4
İstanbul	588	75.8	12.7	1.3	2.2	0.3	4.8	0.3	0.0	-0.6
Kocaeli	824	59.9	13.2	11.9	11.5	0.4	4.9	1.2	1.4	0.0
Konya	1761	68.3	13.7	0.5	0.7	0.1	8.3	0.2	0.2	-0.1
Ankara	1236	63.4	18.8	2.3	2.9	0.3	6.4	1.1	0.3	-0.4
Aydin	1008	35.9	35.9	13.1	7.9	1.2	6.1	1.5	0.5	2.0
G. Antep	2219	54.6	20.0	10.3	8.2	0.6	5.0	1.6	0.6	0.7
Kayseri	1923	59.3	23.4	0.7	0.3	0.3	8.0	0.2	0.1	0.0
K. Maras	2225	60.5	21.5	2.1	3.4	0.2	7.0	0.4	0.4	-0.8
Mean	1308	62.6	18.0	4.4	3.8	0.4	6.4	0.7	0.4	0.1

¹ $var(X) = var(X_{ST}) + var(X_{SN}) + var(X_{LT}) + 2[cov(X_{ST}, X_{SN}) + cov(X_{SN}, X_{LT}) + cov(X_{ST}, X_{LT})]$

² $var(X_{LT}) = var(X_{LT}^{emis}) + var(X_{LT}^{met}) + 2[cov(X_{LT}^{emis}, X_{LT}^{met})]$

meteorological changes in these locales may have contributed to an improvement in air quality.

Table 3.2 elucidates the complexity of PM₁₀ concentration variability, showcasing the diverse roles of short-term (χ_{ST}), seasonal (χ_{SN}), long-term (χ_{LT}), emission-related (χ_{LT}^{emis}), and meteorology-related (χ_{LT}^{met}) components in influencing overall variance and their inter-component covariances. The equation for total variance estimation, detailed in the table's footnote, underscores the multifaceted nature of the dataset's variability, which spans from 574 in İzmir to 2225 for K. Maras. Predominantly, short-term fluctuations significantly impact variability, with contributions ranging from 35.9% in Aydın to 75.8% in İstanbul, averaging at 62.6% across the cities. This underscores the influence of daily environmental and anthropogenic factors on air quality. Seasonal variations also play a critical role, contributing between 11.6% and 35.9% for İzmir and Aydın respectively, with an average of 18.0%, highlighting the cyclical impact of climate on particulate matter concentrations.

The analysis further reveals that long-term changes contribute the least to the overall variance, with a notable exception in Aydın, where it reaches up to 13.1%, suggesting

significant air quality evolution over time possibly due to sustained environmental shifts or policy implementations. Among the components, the emission-related variance (χ_{LT}^{emis}) showcases a range between 0.7% and 11.5% for Konya and Kocaeli, respectively, indicating the role of industrial and vehicular emissions in shaping long-term PM₁₀ concentration trends. In contrast, the meteorological component's contribution remains minimal, especially highlighted in cities like Aydin, emphasizing the subtle influence of climatic changes over the years.

This detailed variance and covariance analysis not only highlights the intricate dynamics governing air quality fluctuations but also stresses the necessity for comprehensive air quality management strategies that address both human-induced emissions and natural meteorological conditions. Such insights facilitate the formulation of city-specific interventions, aiming to mitigate the detrimental effects of particulate matter pollution on public health and the environment.

3.2 The Effect of Vertical Atmospheric Profile on PM₁₀

This section details and discusses the effect of vertical atmospheric profiles on PM₁₀ concentrations, emphasizing the role of the boundary layer. Liu-Liang's stability regimes were estimated by calculating potential temperature differences between the 20 hPa and 5 hPa levels of the atmosphere, and comparing these differences against the threshold $\delta_s = 0.6$.

3.2.1 Potential temperature differences between the 20 hPa and 5 hPa levels

Table 3.3, Table 3.4 and Table 3.5 present detailed summaries of potential temperature differences for eight cities in Turkey. They include various columns such as the city name, the hour (00Z and 12Z) and the season of observation (Fall, Winter, Spring, Summer). The tables also detail the count and percentage of instances with negative and positive temperature differences. Additionally, they provides descriptive statistics for these differences, including the minimum value, the first quartile (value below which 25% of observations fall), the median (middle value of observations), the mean (average temperature difference), the third quartile (value below which 75% of observations fall), and the maximum recorded temperature difference. This detailed

Table 3.3 : A summary of potential temperature difference between 20 and 5hPa above surface.

City	Negatives	%	Positives	%	Min.	1 st Qu.	Median	Mean	3 rd Qu.	Max.
İstanbul	2705	31	5984	69	-18.8	-0.1	0.3	0.9	0.5	14.1
İzmir	2757	31	6227	69	-12.6	-0.1	0.2	0.8	0.4	7.1
Isparta	2649	31	6039	70	-12.4	-0.1	0.4	1.3	0.8	11.0
Ankara	2700	36	4730	64	-8.7	-0.2	0.2	1.1	0.6	12.6
Erzurum	2375	28	6202	72	-18.2	-0.1	0.5	1.4	0.8	14.3
Samsun	1648	19	6875	81	-10.7	0.1	0.5	1.7	0.9	12.5
Adana	2893	34	5656	66	-11.6	-0.1	0.2	1.5	0.9	17.6
Diyarbakır	2335	32	5061	68	-22.4	-0.1	0.4	2.0	1.0	14.5

breakdown helps in understanding the seasonal variations and trends in potential temperature differences for each city.

Table 3.3 presents a summary of potential temperature differences between 20 hPa and 5 hPa above the surface for eight cities in Turkey. For all cities, the percentage of positive temperature differences is higher than the percentage of negative differences, indicating that positive temperature differences are more common.

The minimum values indicate the lowest recorded potential temperature difference, with Diyarbakır having the lowest minimum value of -22.4 and Ankara having the highest minimum value of -8.7 . The first quartile values show that most of the cities have slightly negative to almost zero values in this quartile. The median values are close to zero for all cities, indicating that half of the observations are slightly negative or slightly positive.

The mean potential temperature difference is positive for all cities, suggesting an overall tendency toward positive temperature differences. The third quartile values are consistently higher than the median, reinforcing the tendency toward positive differences. The maximum recorded potential temperature difference is highest in Adana (17.6) and lowest in İzmir (7.1).

City-wise, İstanbul has a high number of positive instances (69%) and a mean difference of 0.9. İzmir is similar to İstanbul with a high number of positive instances (69%) and a mean of 0.8. Isparta has a higher percentage of positive differences (70%) and a mean of 1.3. Ankara shows a lower percentage of positive differences (64%) and a mean of 1.1. Erzurum has the highest percentage of positive differences (72%) and a

Table 3.4 : An hourly summary of potential temperature difference between 20 and 5hPa above surface.

City	Hour	Negatives	%	Positives	%	Min.	1 st Qu.	Median	Mean	3 rd Qu.	Max.
İstanbul	00Z	283	7	4060	93	-7.0	0.3	0.7	1.3	1.0	14.0
	12Z	2422	56	1924	44	-18.8	-0.4	-0.1	0.2	-0.1	8.4
İzmir	00Z	254	6	4227	94	-8.5	0.3	0.7	1.3	0.9	5.4
	12Z	2503	56	2000	44	-12.6	-0.3	-0.1	0.2	-0.1	7.1
Isparta	00Z	50	1	4304	99	-10.8	0.6	1.3	2.3	1.7	11.0
	12Z	2599	60	1735	40	-12.4	-0.4	-0.1	0.1	-0.1	8.2
Ankara	00Z	224	6	3435	94	-7.3	0.4	1.1	2.2	1.4	12.6
	12Z	2476	66	1295	34	-8.7	-0.4	-0.1	0.1	-0.3	5.5
Erzurum	00Z	137	3	4134	97	-18.2	0.6	1.2	2.0	1.5	14.3
	12Z	2238	52	2068	48	-14.7	-0.4	-0.0	0.3	0.0	9.0
Samsun	00Z	132	3	4173	97	-2.6	0.5	1.3	2.3	1.5	12.5
	12Z	1516	36	2702	64	-10.7	-0.1	0.1	0.5	0.4	11.4
Adana	00Z	248	6	4035	94	-11.6	0.5	1.4	3.0	2.0	17.6
	12Z	2645	62	1621	38	-10.6	-0.4	-0.1	0.1	-0.1	10.4
Diyarbakır	00Z	66	2	3640	98	-12.7	1.0	1.9	3.1	2.2	14.5
	12Z	2269	61	1421	39	-22.4	-0.4	-0.1	0.1	-0.2	12.3

mean of 1.4. Samsun has the highest percentage of positive differences (81%) and the highest mean of 1.7. Adana has a moderate percentage of positive differences (66%) but the highest maximum value (17.6) and a high mean (1.5). Diyarbakır, with the lowest minimum value (−22.4), has a high percentage of positive differences (68%) and the highest mean (2.0).

The analysis reveals that positive potential temperature differences between 20 hPa and 5 hPa above the surface are more common than negative differences across all examined cities. The mean differences are positive for all cities, with Samsun and Diyarbakır having the highest means. Diyarbakır also records the lowest minimum value, while Adana has the highest maximum value. This indicates a general tendency toward positive temperature differences, with regional variations in the magnitude and frequency of these differences.

Table 3.4 provides an hourly summary of potential temperature differences between 20 hPa and 5 hPa above the surface for eight cities in Turkey. Each column in the table represents specific metrics for these differences, including the number and percentage of negative and positive instances, as well as descriptive statistics such as the minimum, first quartile, median, mean, third quartile, and maximum values.

The hourly data reveals that at 00Z, all cities show a significantly higher percentage of positive temperature differences, with values ranging from 93% to 99%. This is consistent with the overall trend observed in the Table 3.3, indicating that positive temperature differences are more frequent. In contrast, at 12Z, the percentage of positive differences drops notably, reflecting more variability in temperature differences during this time. For example, İstanbul shows 56% positive differences at 12Z compared to 93% at 00Z.

The number of negative instances is consistently higher at 12Z across all cities, with percentages ranging from 34% to 66%. This contrasts sharply with the 00Z observations, where the percentages of negative differences are very low (1% to 7%). This indicates that daytime observations tend to have more variability, including a higher frequency of negative temperature differences.

In terms of descriptive statistics, the minimum values at 12Z are generally lower than those at 00Z, suggesting a greater range of negative temperature differences during the daytime observations. For instance, Diyarbakır records a minimum of -22.4 at 12Z compared to -12.7 at 00Z. The mean values at 00Z are consistently higher than those at 12Z, reflecting the dominance of positive differences during nighttime observations. The median values at 00Z are all positive, whereas at 12Z, the median values are closer to zero or slightly negative for most cities.

City-wise observations show significant variations between the two observation times. İstanbul has a mean of 1.3 at 00Z and only 0.2 at 12Z, indicating a substantial drop in positive differences during the day. İzmir exhibits a similar pattern, with means of 1.3 at 00Z and 0.2 at 12Z. Isparta has a very high percentage of positive instances at 00Z (99%) and a mean of 2.3, but at 12Z, the mean drops to 0.1. Ankara follows this trend with a mean of 2.2 at 00Z and 0.1 at 12Z.

Erzurum shows a significant decrease in the percentage of positive differences from 97% at 00Z to 48% at 12Z, with corresponding means of 2.0 and 0.3. Samsun consistently has high positive percentages at both times, but the mean drops from 2.3 at 00Z to 0.5 at 12Z. Adana records the highest maximum value at 00Z (17.6) and a notable mean of 3.0, but at 12Z, the mean is only 0.1. Diyarbakır, with the highest

mean value at 00Z (3.1), shows a significant drop to 0.1 at 12Z, indicating the greatest range in temperature differences.

These detailed hourly observations reinforce the overall findings that positive temperature differences are more frequent and higher in magnitude, particularly during nighttime observations (00Z). The data also highlights the variability in temperature differences during daytime (12Z), with a higher occurrence of negative values and lower mean differences. Based on the hourly potential temperature differences between 20 hPa and 5 hPa above the surface, the cities can be grouped by their similarities and differences.

- İstanbul and İzmir: Both cities show similar patterns in terms of the percentage of positive differences at 00Z (93% and 94% respectively) and a notable drop at 12Z (44% and 44%). Their mean values at 00Z are both 1.3, while at 12Z they both have a mean of 0.2, indicating a consistent pattern in temperature differences between the two times.
- Isparta and Ankara: These cities exhibit very high percentages of positive differences at 00Z (99% and 94%) and substantial drops at 12Z (40% and 34%). Their mean values at 00Z are 2.3 and 2.2, respectively, and at 12Z, both have a mean of 0.1. This shows similar variability and magnitudes in their temperature differences.
- Erzurum and Samsun: Both cities have high percentages of positive differences at 00Z (97%) and notable drops at 12Z (48% and 64%). Their mean values at 00Z are 2.0 and 2.3, respectively, and at 12Z, they have means of 0.3 and 0.5, indicating similar trends in their temperature differences.
- Adana and Diyarbakır: These cities differ significantly from the others. Adana shows a high mean value at 00Z (3.0) and a substantial drop at 12Z (0.1), with the highest maximum value recorded (17.6). Diyarbakır also shows a high mean at 00Z (3.1) but a significant drop at 12Z (0.1), with the lowest minimum value recorded at 12Z (-22.4). Despite their internal similarity, their extreme values and patterns distinguish them from other cities.

Table 3.5 : A seasonal summary of potential temperature difference between 20 and 5hPa above surface.

City	Season	Negatives	%	Positives	%	Min.	1 st Qu.	Median	Mean	3 rd Qu.	Max.
İstanbul	Fall	798	37	1349	63	-3.0	-0.3	0.3	0.8	0.3	5.7
	Winter	629	31	1428	69	-7.0	-0.1	0.3	0.9	0.4	6.6
	Spring	613	28	1550	72	-17.4	-0.0	0.2	0.8	0.5	14.0
	Summer	665	29	1657	71	-18.8	-0.1	0.3	1.1	0.6	8.4
İzmir	Fall	788	34	1523	66	-4.1	-0.2	0.2	0.6	0.3	4.7
	Winter	641	29	1558	71	-8.5	-0.1	0.3	0.8	0.4	7.1
	Spring	609	28	1581	72	-12.6	-0.0	0.2	0.8	0.5	5.4
	Summer	719	31	1565	69	-5.6	-0.1	0.2	0.8	0.4	5.2
Isparta	Fall	795	35	1508	65	-3.3	-0.2	0.3	1.4	0.7	11.0
	Winter	636	32	1365	68	-2.7	-0.1	0.4	1.7	1.0	8.8
	Spring	495	23	1694	77	-12.4	0.0	0.4	1.0	0.7	8.3
	Summer	723	33	1472	67	-10.8	-0.1	0.3	1.2	0.7	8.2
Ankara	Fall	770	40	1168	60	-5.9	-0.3	0.2	0.8	0.3	9.1
	Winter	650	38	1072	62	-8.0	-0.2	0.2	1.6	0.8	11.6
	Spring	522	29	1274	71	-7.3	-0.0	0.2	0.9	0.6	12.5
	Summer	758	38	1216	62	-8.7	-0.2	0.1	1.1	0.6	6.6
Erzurum	Fall	721	35	1363	65	-5.9	-0.2	0.4	1.2	0.5	11.7
	Winter	668	32	1442	68	-12.5	-0.1	0.4	1.4	0.7	11.1
	Spring	303	14	1870	86	-18.2	0.2	0.9	2.3	1.4	12.7
	Summer	683	31	1527	69	-6.6	-0.1	0.3	1.0	0.5	14.3
Samsun	Fall	565	26	1635	74	-2.8	-0.0	0.5	1.8	0.8	6.6
	Winter	410	20	1646	80	-4.7	0.0	0.5	1.7	0.9	7.9
	Spring	381	18	1746	82	-10.7	0.1	0.4	1.2	0.8	8.9
	Summer	292	14	1848	86	-2.4	0.1	0.7	2.0	1.3	12.5
Adana	Fall	997	45	1197	55	-3.2	-0.3	0.0	0.3	0.1	17.6
	Winter	641	31	1441	69	-10.6	-0.1	0.4	2.3	1.3	8.9
	Spring	480	23	1633	77	-10.5	0.0	0.5	2.4	1.4	10.4
	Summer	775	36	1385	64	-11.6	-0.1	0.3	1.7	1.0	9.3
Diyarbakır	Fall	647	36	1147	64	-11.5	-0.3	0.4	2.0	0.9	7.4
	Winter	611	32	1302	68	-22.4	-0.1	0.4	2.6	1.3	8.7
	Spring	471	26	1364	74	-3.6	-0.0	0.4	1.5	0.9	14.5
	Summer	606	33	1248	67	-4.9	-0.1	0.3	1.8	0.9	12.0

- Ankara and Isparta compared to İstanbul and İzmir: While Ankara and Isparta have a significant drop in positive differences at 12Z (34% and 40%), İstanbul and İzmir show a higher percentage of positive differences at 12Z (44%), indicating a more stable pattern in temperature differences during the day for the latter two cities.

Overall, İstanbul and İzmir exhibit similar trends, as do Isparta and Ankara, and Erzurum and Samsun. In contrast, Adana and Diyarbakır stand out with their extreme values and greater variability in temperature differences.

The Table 3.5 provides a seasonal summary of potential temperature differences between 20hPa and 5hPa above the surface for eight cities in Turkey.

- İstanbul: The seasonal data for İstanbul shows a consistent pattern of positive temperature differences being more frequent than negative ones across all seasons. The percentage of positive differences ranges from 63% in Fall to 72% in Spring. The mean values are higher in Summer(1.1) compared to other seasons, indicating greater temperature differences during this period.
- İzmir: Similar to İstanbul, İzmir exhibits a higher percentage of positive differences in all seasons, with the highest in Spring (72%) and Winter (71%). The mean values are relatively consistent across seasons, with a slight increase in Summer (0.8), showing a stable pattern in temperature differences throughout the year.
- Isparta: Isparta shows the highest percentage of positive differences in Spring (77%) and the lowest in Fall (65%). The mean values are highest in Winter (1.7) and lowest in Fall (1.4), indicating greater temperature differences during the colder months.
- Ankara: The seasonal data for Ankara indicates a lower percentage of positive differences in Fall (60%) compared to other seasons. The highest mean value is observed in Winter (1.6), suggesting significant temperature differences during this season. The variability in the percentage of positives and mean values highlights differences in temperature dynamics across seasons.
- Erzurum: Erzurum has the highest percentage of positive differences in Spring (86%) and the lowest in Winter (68%). The mean values are highest in Spring (2.3) and lowest in Summer (1.0), indicating more substantial temperature differences during Spring.
- Samsun: Samsun consistently shows a high percentage of positive differences, especially in Summer (86%) and Spring (82%). The mean values are highest in Fall (1.8) and Winter (1.7), reflecting stable temperature differences across seasons with notable peaks in these periods.
- Adana: The data for Adana reveals the highest percentage of positive differences in Winter (69%) and Spring (77%). The mean values are highest in Winter (2.3) and Spring (2.4), indicating substantial temperature differences during these seasons.

The highest maximum value is recorded in Fall (17.6), showing extreme variations during this period.

- **Diyarbakır:** Diyarbakır shows the highest percentage of positive differences in Winter (68%) and Spring (74%). The mean values are highest in Winter (2.6) and Fall (2.0), suggesting significant temperature differences during these seasons. The lowest minimum value is recorded in Winter (-22.4), indicating extreme negative differences during this period.

The seasonal data reinforces the overall trends observed in the hourly and overall summaries. Positive temperature differences are more frequent and higher in magnitude across all seasons, particularly during Winter and Spring. The variability in the percentage of positives and mean values across seasons highlights the dynamic nature of temperature differences in these cities. Cities like Erzurum and Samsun show consistently high positive differences, while Adana and Diyarbakır exhibit greater variability with extreme values in certain seasons.

3.2.2 Stability regimes

Potential temperature differences between 20hPa and 5hPa levels are classified as unstable, neutral, or stable based on the criteria that $\theta_{20} - \theta_5$ is lower than $-\delta_s$, between $-\delta_s$ and δ_s or greater than δ_s , respectively. δ_s was chosen as $0.6^\circ C$ here.

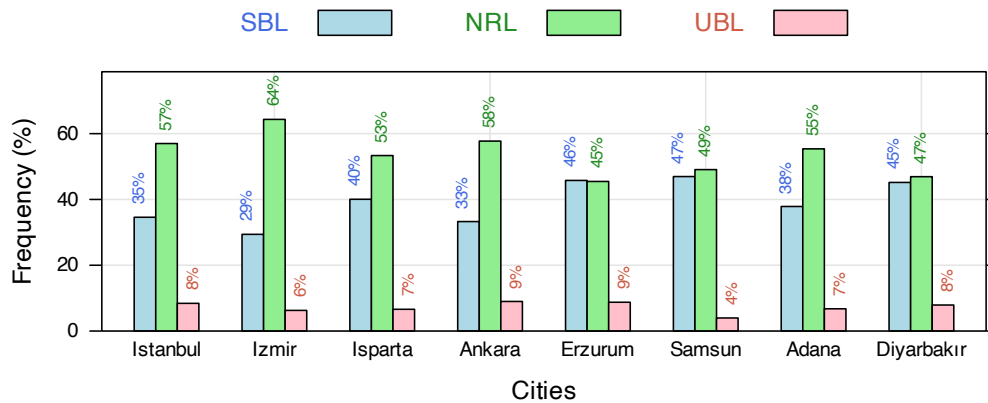


Figure 3.3 : Stability regimes across eight cities in Turkey (data given in Table 3.6).

The Figure 3.3 provides a summary of Liu-liang stability regimes, categorizing the stability into three types: Stable Boundary Layer (SBL), Neutral Regime Layer (NRL),

Table 3.6 : Liu-liang stability regimes for eight cities in Turkey.

City	Percent (%)			Count			Total
	SBL	NRL	UBL	SBL	NRL	UBL	
İstanbul	34.6	57.0	8.4	3019	4975	735	8729
İzmir	29.4	64.3	6.3	2337	5115	499	7951
Isparta	40.0	53.3	6.6	3101	4130	512	7743
Ankara	33.3	57.7	9.0	2739	4752	740	8231
Erzurum	45.8	45.5	8.8	3829	3803	732	8364
Samsun	47.0	49.1	4.0	4067	4250	344	8661
Adana	37.9	55.4	6.8	3336	4879	596	8811
Diyarbakır	45.2	46.9	7.9	3769	3915	660	8344
Min.	29.4	45.5	4.0	2337.0	3803.0	344.0	7743.0
1 st Qu.	34.3	48.5	6.5	2949.0	4076.2	508.8	8161.0
Median	39.0	54.4	7.3	3218.5	4501.0	628.0	8354.0
Mean	39.1	53.7	7.2	3274.6	4477.4	602.2	8354.2
3 rd Qu.	45.3	57.2	8.5	3784.0	4903.0	732.8	8678.0
Max.	47.0	64.3	9.0	4067.0	5115.0	740.0	8811.0
Std. Dev.	6.5	6.3	1.7	591.0	511.9	142.6	377.0

and Unstable Boundary Layer (UBL). The vertical bars shows the frequency (%) of Liu-liang stability regimes for each city. The data is presented in the Table 3.6 with both percentage and count for each city, along with summary statistics such as minimum, first quartile, median, mean, third quartile, maximum, and standard deviation.

The majority of the observations across all cities fall under the NRL category, with percentages ranging from 45.5% in Erzurum to 64.3% in İzmir. The percentage of SBL ranges from 29.4% in İzmir to 47% in Samsun. The percentage of UBL is the lowest, ranging from 4% in Samsun to 9% in Ankara. The standard deviation values indicate the variability in the distribution of stability regimes among the cities. The percentages for SBL and NRL have higher standard deviations (6.5 and 6.3 respectively), while UBL has a lower standard deviation (1.7), indicating more consistency in the occurrence of UBL across cities. The counts also show variability, with NRL counts having a standard deviation of 511.9, and SBL and UBL having 591 and 142.6 respectively.

İstanbul shows a balanced distribution with 34.6% SBL, 57.0% NRL, and 8.4% UBL. The total count of observations is 8729, which is close to the median total count of

8354. İzmir has the lowest percentage of SBL (29.4%) and the highest percentage of NRL (64.3%). The total count of observations is 7951, the lowest among all cities. Isparta exhibits a high percentage of SBL (40.0%) and a moderate percentage of NRL (53.3%). The total count of observations is 7743, the lowest among the cities. Ankara shows a higher percentage of UBL (9.0%), the highest among all cities. The total count of observations is 8231. Erzurum has a balanced distribution with 45.8% SBL and 45.5% NRL, the lowest percentage of NRL among all cities. The total count of observations is 8364. Samsun exhibits the highest percentage of SBL (47.0%) and the lowest percentage of UBL (4.0%). The total count of observations is 8661, close to the upper quartile. Adana shows a moderate distribution with 37.9% SBL, 55.4% NRL, and 6.8% UBL. The total count of observations is 8811, the highest among all cities. Diyarbakır has a high percentage of SBL (45.2%) and a balanced percentage of NRL (46.9%). The total count of observations is 8344.

The previous findings indicated a general trend of positive temperature differences being more frequent and higher in magnitude. The current table's data on stability regimes complements these findings by providing insight into the atmospheric stability conditions. Cities like Samsun and Erzurum, which had high positive temperature differences, show high percentages of SBL and balanced distributions in NRL, indicating stable atmospheric conditions. Adana and Diyarbakır, which exhibited greater variability and extreme temperature differences, show higher percentages of SBL and balanced distributions in NRL, suggesting varying stability conditions.

3.2.2.1 Hourly analysis of stability regimes

The Table 3.7 presents an hourly summary of Liu-liang stability regimes, categorizing stability into three types: SBL, NRL, and UBL. The data is presented for each city at two different times (00Z and 12Z) in terms of both percentage and count. Additionally, the data includes a summary statistics such as minimum, first quartile, median, mean, third quartile, maximum, and standard deviation. Also, the percentages that is presented in the Table 3.7 is depicted in Figure 3.4.

The percentage of SBL is significantly higher at 00Z compared to 12Z for all cities. This indicates more stable atmospheric conditions during nighttime. Conversely, NRL

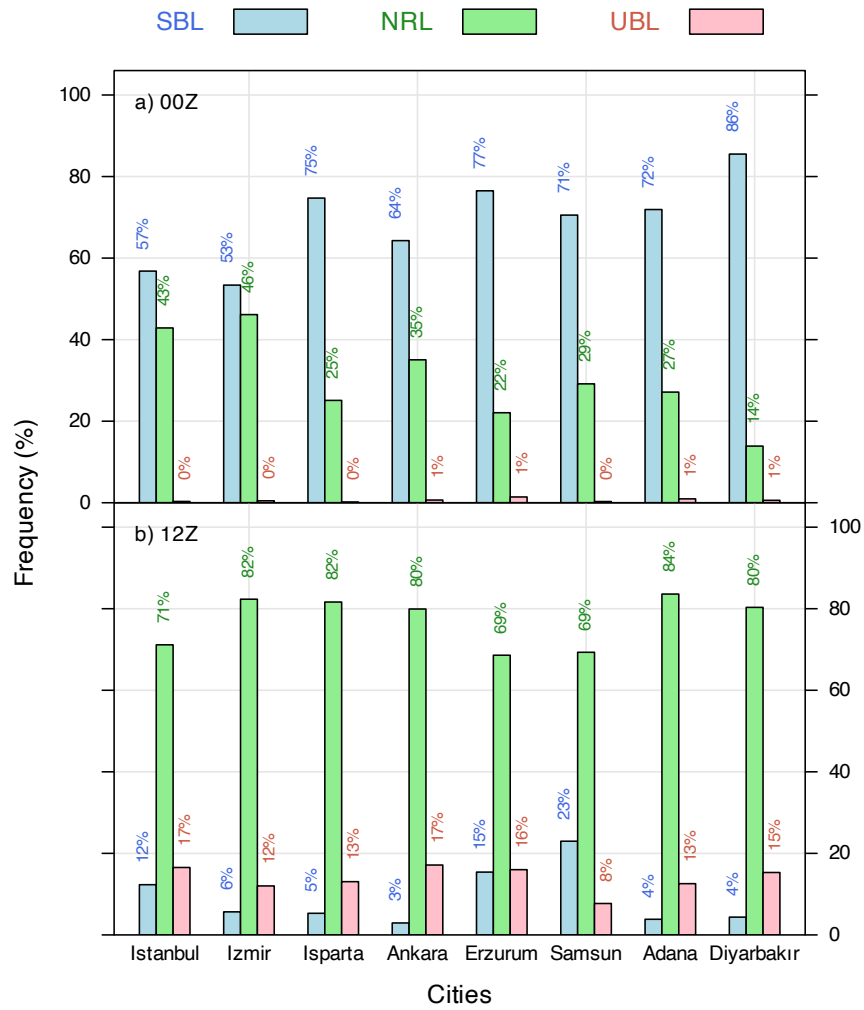


Figure 3.4 : Hourly Liu-liang stability regimes across eight cities in Turkey (data given in Table 3.7).

Table 3.7 : Hourly Liu-liang stability regimes for eight cities in Turkey.

City	(UTC) Hour	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
İstanbul	00Z	56.8	42.9	0.3	2482	1873	14	4369
	12Z	12.3	71.1	16.5	537	3102	721	4360
İzmir	00Z	53.4	46.1	0.5	2111	1825	19	3955
	12Z	5.7	82.3	12.0	226	3290	480	3996
Isparta	00Z	74.7	25.1	0.2	2896	973	7	3876
	12Z	5.3	81.6	13.1	205	3157	505	3867
Ankara	00Z	64.3	35.1	0.7	2617	1427	27	4071
	12Z	2.9	79.9	17.1	122	3325	713	4160
Erzurum	00Z	76.5	22.1	1.4	3181	918	59	4158
	12Z	15.4	68.6	16.0	648	2885	673	4206
Samsun	00Z	70.5	29.2	0.3	3080	1273	13	4366
	12Z	23.0	69.3	7.7	987	2977	331	4295
Adana	00Z	71.9	27.1	1.0	3167	1195	42	4404
	12Z	3.8	83.6	12.6	169	3684	554	4407
Diyarbakır	00Z	85.5	13.9	0.6	3588	583	25	4196
	12Z	4.4	80.3	15.3	181	3332	635	4148
Min.		2.9	13.9	0.2	122.0	583.0	7.0	3867.0
1 st Qu.		5.6	28.7	0.6	220.8	1253.5	23.5	4052.2
Median		38.2	57.4	4.6	1549.0	2379.0	195.0	4178.0
Mean		39.2	53.6	7.2	1637.3	2238.7	301.1	4177.1
3 rd Qu.		70.9	80.0	13.6	2942.0	3190.2	574.2	4361.5
Max.		85.5	83.6	17.1	3588.0	3684.0	721.0	4407.0
Std. Dev.		32.2	25.7	7.1	1349.6	1070.6	299.2	183.9

percentages are higher at 12Z for all cities, suggesting neutral conditions are more prevalent during daytime. UBL percentages, representing unstable conditions, are generally higher at 12Z, indicating that unstable atmospheric conditions are more frequent during the daytime. The standard deviation values indicate the variability in the distribution of stability regimes among the cities. SBL has the highest standard deviation (32.2), followed by NRL (25.7) and UBL (7.1). City-specific Observations: İstanbul at 00Z shows a high percentage of SBL (56.8%) and a very low percentage of UBL (0.3%). At 12Z, the percentage of NRL increases significantly to 71.1%, and UBL rises to 16.5%, indicating more neutral and unstable conditions during the daytime. İzmir At 00Z, İzmir has a high percentage of SBL (53.4%) and a low percentage of UBL (0.5%). At 12Z, the percentage of NRL is the highest among all cities (82.3%), with UBL at 12.0%, indicating predominantly neutral conditions during the day. Isparta exhibits the highest percentage of SBL at 00Z (74.7%) and the lowest UBL percentage (0.2%). At 12Z, the percentage of NRL rises to 81.6%, and UBL to 13.1%, showing a significant shift to neutral and unstable conditions during the daytime. Ankara shows a high percentage of SBL at 00Z (64.3%) and a low percentage of UBL (0.7%). At 12Z, NRL dominates at 79.9%, and UBL is the highest among all cities (17.1%), indicating a considerable increase in unstable conditions during the day. Erzurum at 00Z has a high percentage of SBL (76.5%) and the highest UBL percentage at this time (1.4%). At 12Z, the percentage of NRL increases to 68.6%, and UBL rises to 16.0%, reflecting a shift towards neutral and unstable conditions during the day. Samsun exhibits a high percentage of SBL at 00Z (70.5%) and a very low percentage of UBL (0.3%). At 12Z, NRL increases to 69.3%, with UBL at 7.7%, indicating more neutral conditions during the daytime. Adana shows a high percentage of SBL at 00Z (71.9%) and a low percentage of UBL (1.0%). At 12Z, NRL is the highest among all cities (83.6%), with UBL at 12.6%, indicating predominantly neutral conditions during the day. Diyarbakır exhibits the highest percentage of SBL at 00Z (85.5%) and a very low percentage of UBL (0.6%). At 12Z, the percentage of NRL is high (80.3%), with UBL at 15.3%, indicating a significant shift towards neutral and unstable conditions during the day.

The previous findings showed that positive temperature differences were more frequent and higher in magnitude. The current table's data on stability regimes complements these findings by providing insight into the hourly atmospheric stability conditions. Cities like İstanbul and İzmir, which had significant positive temperature differences, show high percentages of NRL and UBL during the daytime, indicating that these conditions contribute to the observed temperature differences. Isparta and Ankara exhibit significant shifts from stable conditions at 00Z to neutral and unstable conditions at 12Z, reflecting the dynamic nature of their temperature differences. Erzurum and Samsun, which had high positive temperature differences, show consistent patterns of stability and neutral conditions across the day. Adana and Diyarbakır, with greater variability and extreme temperature differences, display substantial shifts from stable to neutral and unstable conditions between 00Z and 12Z, highlighting the influence of stability regimes on their temperature dynamics.

3.2.2.2 Seasonal analysis of stability regimes

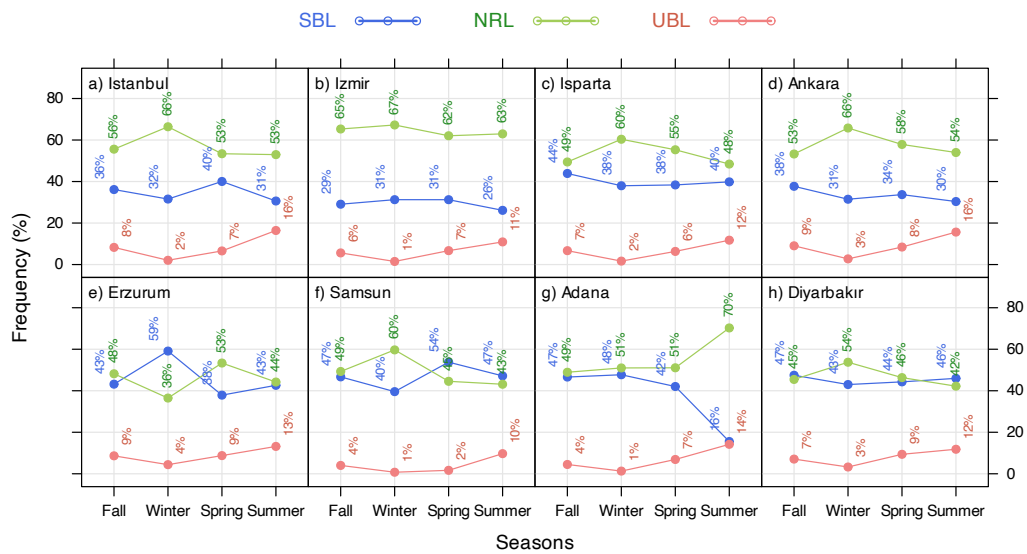


Figure 3.5 : Seasonal Liu-liang stability regimes across eight cities in Turkey (data given in Table 3.8).

The Table 3.8 and Figure 3.5 provides a seasonal summary of Liu-liang stability regimes for eight cities in Turkey. It categorizes the stability into three types: SBL, NRL, and UBL. The data is presented in both percentage and count for each city across different seasons (Fall, Winter, Spring, Summer).

The overall distribution of stability regimes shows a dominance of NRL, with percentages ranging from 36.5% in Erzurum during Winter to 70.3% in Adana during Summer. SBL percentages vary significantly, with the highest being 59.1% in Erzurum during Winter. UBL percentages are generally lower, with the highest being 16.4% in İstanbul during Summer.

- İstanbul: The percentage of NRL is highest during Winter (66.4%) and lowest during Summer (53.0%). The percentage of UBL is highest during Summer (16.4%), indicating more unstable conditions in this season.
- İzmir: NRL is consistently high across all seasons, peaking during Winter (67.2%). The percentage of UBL is lowest during Winter (1.5%) and highest during Summer (10.9%).
- Isparta: SBL is highest during Fall (43.9%) and Winter (38.0%), while NRL dominates during Winter (60.4%). The percentage of UBL is highest during Summer (11.7%).
- Ankara: NRL is highest during Winter (65.8%) and lowest during Fall (53.3%). The percentage of UBL is highest during Summer (15.6%), indicating more unstable conditions in this season.
- Erzurum: SBL is highest during Winter (59.1%), with the lowest percentage of NRL (36.5%). The percentage of UBL is highest during Summer (13.2%). Erzurum stands out with the highest percentage of SBL during Winter (59.1%), indicating extremely stable conditions in this season. Additionally, it has the lowest percentage of NRL during Winter (36.5%), contrasting with its higher NRL percentages in other seasons. The percentage of UBL in Erzurum is relatively consistent but peaks during Summer (13.2%).
- Samsun: Samsun exhibits distinct seasonality with the highest percentage of SBL during Spring (53.8%) and Fall (46.7%). This is contrasted by a relatively low percentage of NRL during Spring (44.6%), which is significantly lower than its Winter NRL percentage (59.7%). The percentage of UBL in Samsun is consistently low across all seasons, with a slight peak during Summer (9.7%).

Table 3.8 : Seasonal Liu-liang stability regimes for eight cities in Turkey.

City	Season	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
İstanbul	Fall	36.1	55.6	8.3	756	1163	173	2092
	Winter	31.6	66.4	2.1	675	1420	44	2139
	Spring	40.0	53.4	6.6	896	1195	147	2238
	Summer	30.6	53.0	16.4	692	1197	371	2260
İzmir	Fall	29.1	65.3	5.6	544	1222	105	1871
	Winter	31.3	67.2	1.5	608	1308	29	1945
	Spring	31.2	62.1	6.7	639	1269	137	2045
	Summer	26.1	63.0	10.9	546	1316	228	2090
Isparta	Fall	43.9	49.4	6.7	872	982	133	1987
	Winter	38.0	60.4	1.7	732	1164	32	1928
	Spring	38.4	55.3	6.3	727	1048	120	1895
	Summer	39.8	48.4	11.7	770	936	227	1933
Ankara	Fall	37.7	53.3	9.0	739	1044	177	1960
	Winter	31.5	65.8	2.7	632	1321	55	2008
	Spring	33.7	57.9	8.4	743	1276	186	2205
	Summer	30.4	54.0	15.6	625	1111	322	2058
Erzurum	Fall	43.2	48.2	8.6	854	953	171	1978
	Winter	59.1	36.5	4.4	1264	780	94	2138
	Spring	37.9	53.4	8.8	796	1121	184	2101
	Summer	42.6	44.2	13.2	915	949	283	2147
Samsun	Fall	46.7	49.3	4.0	951	1004	82	2037
	Winter	39.6	59.7	0.7	850	1282	16	2148
	Spring	53.8	44.6	1.7	1259	1043	39	2341
	Summer	47.2	43.1	9.7	1007	921	207	2135
Adana	Fall	46.6	48.9	4.5	1029	1080	99	2208
	Winter	47.7	51.0	1.3	1033	1104	28	2165
	Spring	42.0	51.1	6.9	927	1126	152	2205
	Summer	15.5	70.3	14.2	347	1569	317	2233
Diyarbakır	Fall	47.5	45.5	7.1	966	925	144	2035
	Winter	43.0	53.7	3.3	896	1120	68	2084
	Spring	44.3	46.3	9.4	930	973	197	2100
	Summer	46.0	42.2	11.8	977	897	251	2125
Min.		15.5	36.5	0.7	347.0	780.0	16.0	1871.0
1 st Qu.		31.5	48.4	3.8	687.8	979.8	78.5	2002.8
Median		39.7	53.3	6.8	823.0	1115.5	145.5	2096.0
Mean		39.1	53.7	7.2	818.7	1119.3	150.6	2088.6
3 rd Qu.		44.7	59.9	9.5	935.2	1233.8	199.5	2152.2
Max.		59.1	70.3	16.4	1264.0	1569.0	371.0	2341.0
Std. Dev.		8.7	8.3	4.3	198.8	171.4	93.4	114.8

- Adana: NRL is highest during Summer (70.3%) and lowest during Fall (48.9%). The percentage of UBL is highest during Summer (14.2%). Adana displays significant seasonal variation, especially in Summer, where it has the highest percentage of NRL (70.3%) among all cities and seasons. Conversely, its SBL percentage drops drastically to 15.5% during Summer, the lowest among all observations. This indicates a shift towards more neutral conditions during the hotter months. The percentage of UBL is also relatively high during Summer (14.2%).
- Diyarbakır: SBL is highest during Fall (47.5%) and lowest during Winter (43.0%). The percentage of UBL is highest during Summer (11.8%).

Cities like İstanbul and İzmir, which had significant positive temperature differences, show higher percentages of NRL and UBL during Summer, indicating these conditions contribute to the observed temperature differences. Isparta and Ankara exhibit significant shifts from stable conditions during Fall and Winter to more neutral and unstable conditions during Spring and Summer, reflecting the dynamic nature of their temperature differences. Erzurum and Samsun, with high positive temperature differences, show consistent patterns of stability and neutral conditions across the seasons. Adana and Diyarbakır display substantial shifts from stable to neutral and unstable conditions between Fall and Summer, highlighting the influence of stability regimes on their temperature dynamics. Erzurum, Samsun and Adana differ from the others due to their pronounced seasonal shifts in stability regimes, highlighting their unique atmospheric dynamics. Erzurum and Samsun tend to have more stable conditions during specific seasons, while Adana shows a substantial shift towards neutral conditions in Summer.

In terms of seasonal stability regimes, İstanbul, İzmir, Isparta and Ankara have clearly higher NRL frequency than SBL frequency in all seasons comparing to other cities. However, Interestingly, SBL frequency exceeds the NRL frequency In Erzurum in winter. Also, Erzurum has highest UBL frequency (4%) in winter comparing to other cities. This can be attributed long term snow cover in winter in Erzurum. While NRL and SBL frequencies are around 50% in Adana in Fall, Winter and Spring, They drift

away from each other in Summer. This can be attributed to decrease of nighttime SBL frequencies in Summer (See Figure 3.6-a7). This is distinctive feature of Adana city. Diyarbakır has almost equal (around 50%) NRL and SBL frequencies in all seasons comparing to other cities.

3.2.2.3 Seasonal and hourly analysis of stability regimes

The Figure 3.6 provides a comprehensive summary of Liu-liang stability regimes across eight cities in Turkey, categorized by season and hour (00Z and 12Z). Each stability regime is represented as a percentage and count. Maximum and minimum values in each column are highlighted in red and blue, respectively.

- İstanbul: At 00Z, SBL percentages are high across all seasons, peaking in Spring (63.4%) and Fall (62.4%). SBL and NRL frequencies are very close to each other in Winter (48.5% & 51.4%) and Summer (52.8% & 46.6%). Percentages of UBL are very close to 0%.

At 12Z, NRL dominates, especially in Winter (81.2%) and Fall (74.4%). Highest SBL percentages are in Winter and Spring (14.8% & 16.8%). The percentage of UBL is highest during Summer (32.4%) and Fall (16.8%).

- İzmir: At 00Z, SBL percentages are relatively high across all seasons, with Spring having the highest (58.4%). The SBL and NRL frequencies are close in Fall and Winter (54.3% & 45.0%, 54.3% & 45.4%). The percentage of UBL is consistently low, near 0%.

At 12Z, NRL is significantly high, especially in Winter (89.0%) and Fall (85.4%). The SBL percentages are lowest in Summer (5.6%) and Spring (4.5%). The percentage of UBL is highest in Summer (21.0%) and Spring (13.2%); lowest in Winter (2.7%).

- Isparta: At 00Z, SBL is significantly high across all seasons, peaking in Fall (83.5%) and Summer (76.8%). The NRL percentages are lowest in Summer (23.1%) and Fall (16.3%). The percentage of UBL is near 0% in all seasons.

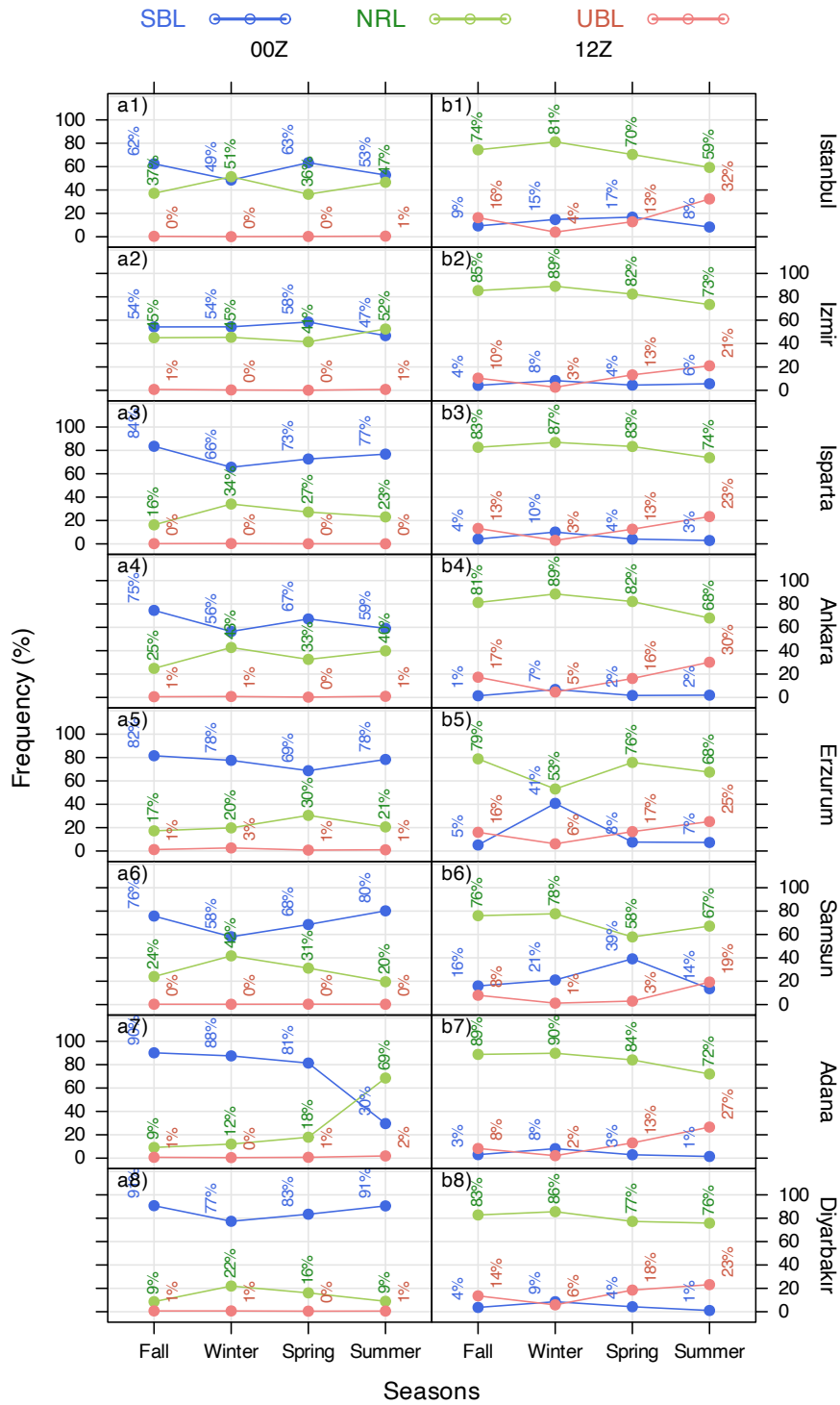


Figure 3.6 : Seasonal and hourly Liu-liang stability regimes across eight cities in Turkey (data given in Appendix Table A.1).

At 12Z, NRL is dominant, particularly in Winter (86.9%) and Fall (82.7%). The highest SBL percentages are in Winter (10.1%) and Spring (4.1%). The percentage of UBL is highest in Summer (23.4%) and Fall (13.2%).

- Ankara: At 00Z, SBL is consistently high, with Fall showing the highest percentage (74.5%) and Spring (67.2%). The NRL percentages are relatively close in Winter (42.7%) and Summer (39.9%). The percentage of UBL is very low, near 0%.

At 12Z, NRL is very high, especially in Winter (88.5%) and Fall (81.3%). The highest SBL percentages are in Winter (6.8%) and Spring (1.7%). The percentage of UBL is highest in Summer (30.1%) and Fall (17.3%); lowest in Winter (4.6%).

- Erzurum: At 00Z, SBL is very high, especially in Fall (81.5%) and Summer (78.4%). The NRL percentages are lowest in Fall (17.3%) and Summer (20.6%). The percentage of UBL is low, with Winter having the highest (2.6%).

At 12Z, NRL dominates, particularly in Fall (78.9%) and Spring (75.8%). The highest SBL percentages are in Winter (40.8%) and Summer (7.3%) while the lowest NRL percentage is in Winter (53.1%). The percentage of UBL is highest in Summer (25.2%) and Spring (16.6%).

- Samsun: At 00Z, SBL is consistently high across all seasons, peaking in Summer (80.2%) and Fall (75.7%). The NRL percentage is highest in Winter (41.7%) while the SBL percentage is the lowest (58%). The percentage of UBL is very low, near 0%.

At 12Z, NRL is high, particularly in Winter (77.7%) and Fall (76.1%). The highest SBL percentages are in Spring (39.1%) and Winter (21.1%). The percentage of UBL is highest in Summer (19.3%) and Fall (8.0%).

- Adana: At 00Z, SBL is extremely high in Fall (90.1%), Winter (87.5%) and Spring (81.4%); but lowest (29.6%) and lower than NRL (68.5%) percent in Summer. The NRL percentages are very low in Fall (9.1%), Winter (12.0%) and Spring (17.9%). The percentage of UBL is very low, near 0%.

At 12Z, NRL is dominant, especially in Winter (89.8%) and Fall (88.8%). The highest SBL percentages are in Winter (8.1%) and Spring (2.9%). The percentage of UBL is highest in Summer (26.6%) and Spring (13.0%).

- Diyarbakır: At 00Z, SBL is very high across all seasons, particularly in Fall (90.7%) and Summer (90.5%). The NRL percentages are lowest in Fall (8.6%) and Summer (8.9%). The percentage of UBL is very low, near 0%.

At 12Z, NRL is high, especially in Winter (85.6%) and Fall (82.8%). The highest SBL percentages are in Winter (8.5%) and Spring (4.2%). The percentage of UBL is highest in Summer (23.2%) and Spring (18.5%).

The highest percentage of SBL is observed in Diyarbakır at 00Z during Fall (90.7%), while the lowest is in Diyarbakır at 12Z during Summer (1.0%). This indicates that stable conditions are more prevalent during nighttime, especially in Fall. The highest percentage of NRL is observed in Adana at 12Z during Winter (89.8%), and the lowest is in Diyarbakır at 00Z during Fall (8.6%). Neutral conditions dominate during the daytime, particularly in Winter. The highest percentage of UBL is found in İstanbul at 12Z during Summer (32.4%), whereas the lowest is in Isparta at 00Z during Spring and Summer (0.1%). Unstable conditions are more frequent during the daytime, especially in Summer.

These findings highlight the significant influence of season and time of day on the stability regimes in these cities. Stable conditions are more common during nighttime and in Fall, while neutral and unstable conditions are more common during the daytime and in Summer. However, at 00Z, Adana shows a significant difference in Summer with lowest SBL percentage (29.6%) against highest NRL percentage (68.5%). The gap between SBL and NRL are relatively high in Diyarbakır, Samsun, Erzurum and Isparta comparing to other cities. This gap is smaller in İstanbul, İzmir and Ankara. At 12Z, the NRL percentages are significantly high in all seasons. SBL percentages are relatively higher than UBL percentages in Winter. However, In Winter, SBL percentage (40.8%) for Erzurum is significantly higher than UBL (6.2%); In Spring, SBL percentage (39.1%) for Samsun is significantly higher than UBL (2.9%) comparing to other cities.

Based on the analysis, the cities that stand out with distinct stability regime patterns are Adana, Diyarbakır, and Erzurum.

Adana: Adana exhibits a significant difference in Summer at 00Z, with the lowest SBL percentage (29.6%) and the highest NRL percentage (68.5%). This deviation is unique among the cities, as stable conditions are generally dominant at 00Z across other cities. Additionally, at 12Z, Adana has one of the highest NRL percentages during Winter (89.8%) and Fall (88.8%), indicating a strong prevalence of neutral conditions during the daytime in these seasons.

Diyarbakır: Diyarbakır shows exceptionally high SBL percentages at 00Z across all seasons, particularly in Fall (90.7%) and Summer (90.5%). This consistency in stable conditions during nighttime is more pronounced than in other cities. Furthermore, at 12Z, Diyarbakır has the lowest SBL percentage in Summer (1.0%), which contrasts sharply with its high nighttime SBL values.

Erzurum: Erzurum stands out with its high SBL percentages at 00Z, especially in Fall (81.5%) and Summer (78.4%). At 12Z, it has a notably higher SBL percentage during Winter (40.8%) compared to other cities, indicating a tendency towards stable conditions even during the daytime in Winter. Additionally, the UBL percentages in Erzurum are significantly higher in Summer (25.2%) and Spring (16.6%) at 12Z, showing a higher frequency of unstable conditions during these seasons.

These cities exhibit stability regime patterns that are distinct from the others, highlighting unique atmospheric dynamics that influence their stability regimes differently based on season and time of day.

3.2.2.4 Monthly analysis of stability regimes

The Figure 3.7 provides a comprehensive summary of Liu-liang stability regimes across eight cities in Turkey, categorized by months. Each stability regime is represented as a percentage and count. SBL, NRL and UBL frequencies are shown in blue, green and red colors, respectively.

- **İstanbul:** In İstanbul, NRL percentages are generally higher than SBL across most months. The highest NRL percentage occurs in December (68.8%) and the lowest

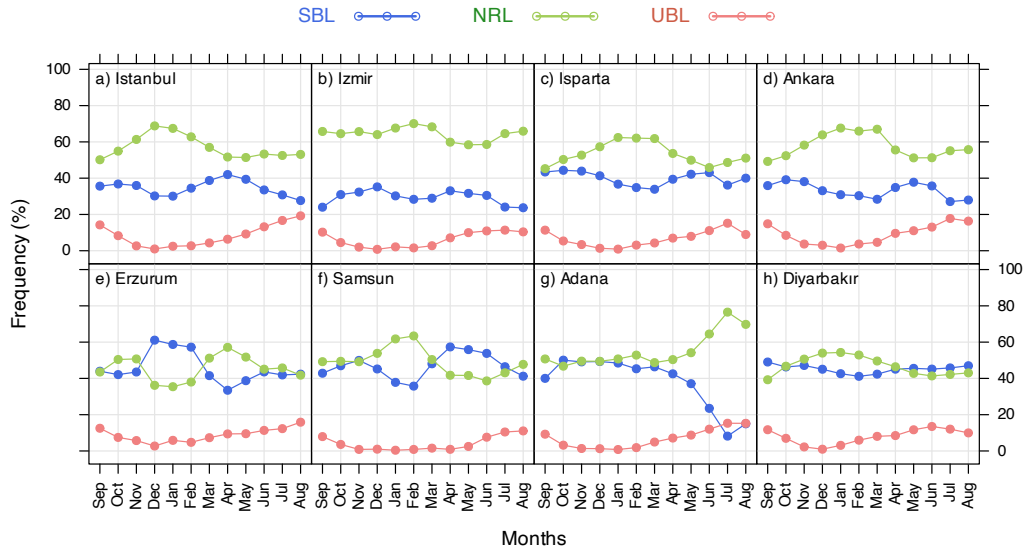


Figure 3.7 : Monthly Liu-liang stability regimes across eight cities in Turkey (data given in Appendix Table A.2).

in September (50.2%). SBL percentages are highest in April (42.0%) and lowest in August (27.7%). UBL percentages are relatively low, peaking in August (19.2%) and at their minimum in December (1.0%).

- **İzmir:** In İzmir, NRL is consistently higher than SBL throughout the year. The highest NRL percentage is observed in February (70.1%), while the lowest is in April (59.9%). SBL peaks in December (35.2%) and is at its lowest in August (23.7%). UBL remains low, with the highest percentage in July (11.4%) and the lowest in December (0.8%).
- **Isparta:** Isparta shows a higher SBL percentage in most months compared to NRL, except for the winter months. The highest SBL percentage is in October (44.3%) and the lowest in February (33.9%). NRL peaks in January (62.4%) and is at its minimum in September (45.2%). UBL is consistently low, peaking in July (15.2%) and at its minimum in January (0.9%).
- **Ankara:** In Ankara, NRL generally exceeds SBL percentages. The highest NRL percentage occurs in January (67.6%) and the lowest in September (49.2%). SBL peaks in October (39.1%) and is lowest in July (27.1%). UBL percentages are highest in July (17.8%) and lowest in January (1.5%).

- Erzurum: Erzurum exhibits higher SBL percentages, especially in winter months. The highest SBL percentage is in December (61.1%) and the lowest in April (33.5%). NRL is highest in April (57.1%) and lowest in January (35.4%). UBL percentages are highest in August (15.9%) and at their minimum in December (2.7%).
- Samsun: In Samsun, SBL percentages are generally high, particularly in spring and summer. The highest SBL percentage is in April (57.3%) and the lowest in February (35.7%). NRL peaks in February (63.4%) and is at its minimum in June (38.6%). UBL percentages are low, with the highest in July (11.0%) and the lowest in January (0.4%).
- Adana: Adana shows a significant seasonal variation, with NRL percentages generally higher in summer months. The highest NRL percentage is in July (76.5%) and the lowest in October (46.7%). SBL peaks in October (50.1%) and is at its minimum in July (8.2%). UBL percentages are highest in July (15.3%) and lowest in January (0.8%).
- Diyarbakır: In Diyarbakır, SBL percentages are generally high, particularly in fall and winter months. The highest SBL percentage is in September (49.0%) and the lowest in February (41.2%). NRL is highest in January (54.3%) and lowest in September (39.3%). UBL percentages are low, with the highest in June (13.5%) and the lowest in December (1.0%).

Cities can be grouped based on the dominance of SBL, NRL, and UBL percentages across months. İstanbul, İzmir, Isparta, and Ankara usually have higher NRL percentages. In contrast, Erzurum, Samsun, Adana, and Diyarbakır often show SBL exceeding NRL in several months. Unstable conditions are generally low across all cities, with occasional peaks in summer months.

Overall, İstanbul and İzmir exhibit a more stable pattern with consistently higher NRL percentages, whereas Erzurum and Diyarbakır show higher SBL percentages, indicating more stable conditions in these cities. Adana shows significant differences in summer with high NRL and low SBL percentages, making it unique among the

analyzed cities. This detailed comparison highlights the seasonal and diurnal variations in stability regimes, reflecting the diverse atmospheric dynamics influencing each city's stability conditions.

3.2.2.5 Monthly and hourly analysis of stability regimes

The Figure 3.8 provides a comprehensive summary of Liu-liang stability regimes across eight cities in Turkey, categorized by month and hour (00Z and 12Z). Each stability regime is represented as a percentage and count. Maximum and minimum values in each column are highlighted in red and blue, respectively. The data to plot the figure given in Appendix Table A.3.

- **İstanbul:**

00Z: SBL percentages are high across all months, peaking in April (65.8%) and September (63.0%). NRL is highest in August (52.2%) and lowest in April (34.0%). UBL percentages are close to zero in most months.

12Z: NRL dominates, especially in December (85.8%) and November (82.8%). Highest SBL percentages are in February (19.7%) and March (17.5%). UBL is highest in August (38.1%) and July (33.5%).

- **İzmir:**

00Z: SBL percentages are relatively high across all months, with April having the highest (61.4%) and August the lowest (40.6%). NRL percentages are consistently high, especially in July (56.2%) and August (58.8%). UBL remains near zero in most months.

12Z: NRL is significantly high, especially in February (92.0%) and November (91.4%). SBL percentages are lowest in July (5.4%) and August (7.0%). UBL is highest in July (21.7%) and June (21.0%).

- **Isparta:**

00Z: SBL is significantly high across all months, peaking in September (84.0%) and June (80.6%). NRL is lowest in September (15.6%) and highest in December (29.4%). UBL percentages are very close to zero.

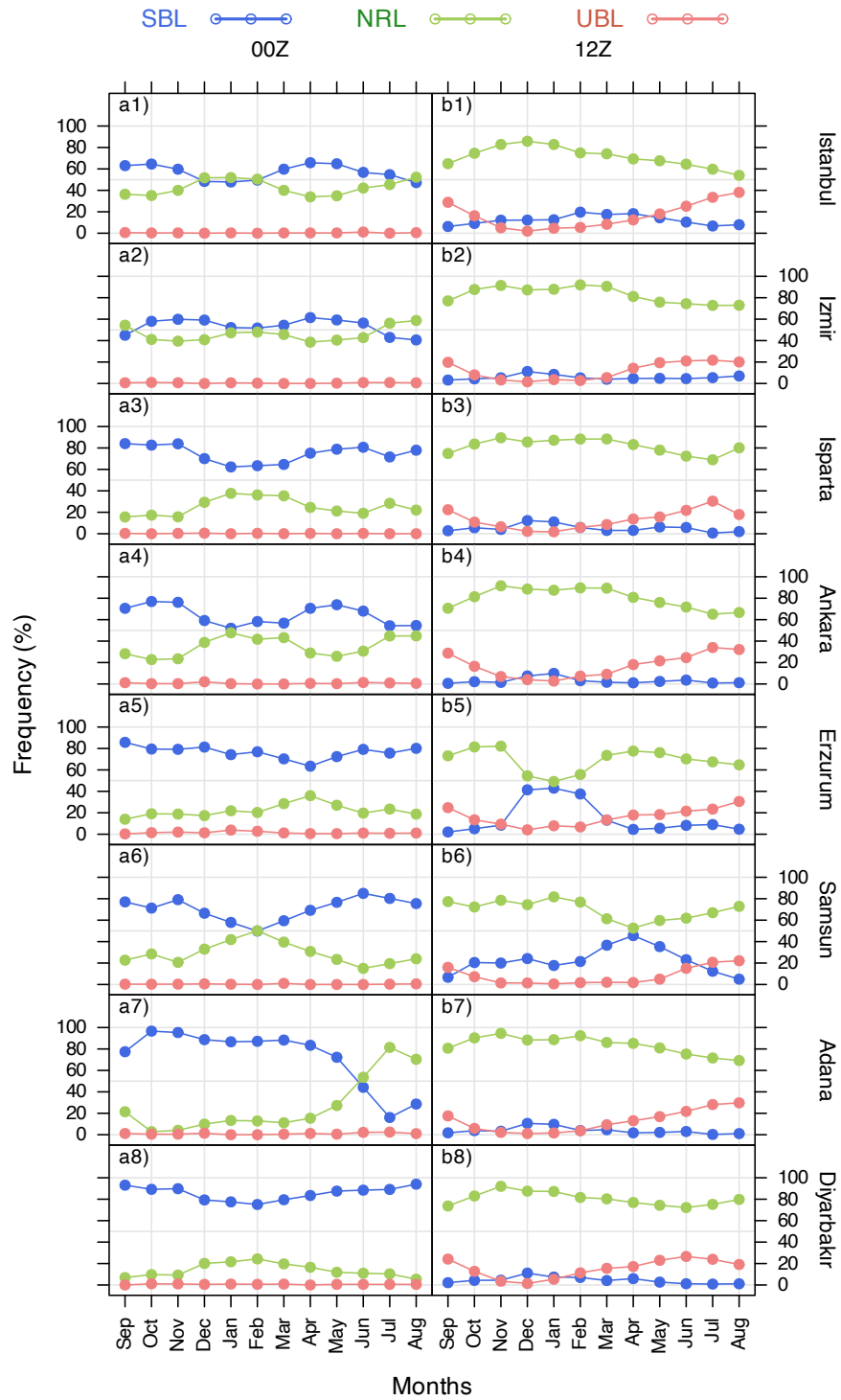


Figure 3.8 : Monthly and hourly Liu-liang stability regimes across eight cities in Turkey (data given in Appendix Table A.3).

12Z: NRL dominates, particularly in February (88.3%) and March (88.4%). Highest SBL percentages are in January (11.0%) and December (12.3%). UBL is highest in July (30.4%) and June (21.8%).

- Ankara:

00Z: SBL is consistently high, with October (76.9%) and November (76.2%) showing the highest percentages. NRL is highest in January (47.7%) and lowest in October (22.7%). UBL percentages are very low.

12Z: NRL is very high, especially in November (91.6%) and February (89.6%). SBL percentages are lowest in September (0.6%) and February (3.0%). UBL is highest in July (34.0%) and June (24.6%).

- Erzurum:

00Z: SBL is very high, especially in September (85.7%) and December (81.3%). NRL percentages are lowest in September (14.0%) and highest in March (28.5%). UBL is close to zero in most months.

12Z: NRL dominates, particularly in October (81.4%) and April (77.6%). SBL percentages are highest in December (41.4%) and January (43.0%). UBL is highest in August (30.6%) and July (23.4%).

- Samsun:

00Z: SBL is consistently high, with June (85.0%) and July (80.3%) showing the highest percentages. NRL is highest in February (50.1%) and lowest in June (15.0%). UBL is very low in most months.

12Z: NRL is high, particularly in January (81.7%) and February (76.9%). SBL percentages are highest in April (45.6%) and March (36.6%). UBL is highest in August (22.2%) and July (20.7%).

- Adana:

00Z: SBL is extremely high in October (96.7%) and November (95.3%). NRL is very low in October (2.8%) and November (4.1%). UBL percentages are very low across all months.

12Z: NRL is dominant, especially in November (94.6%) and February (92.4%). SBL percentages are highest in June (10.6%) and January (9.7%). UBL is highest in August (29.7%) and July (28.1%).

- Diyarbakır:

00Z: SBL is very high across all months, particularly in September (93.1%) and August (94.0%). NRL percentages are lowest in September (6.9%) and highest in January (21.6%). UBL is very low.

12Z: NRL is high, especially in November (92.0%) and April (76.9%). SBL percentages are highest in January (7.4%) and February (7.0%). UBL is highest in June (26.6%) and August (19.1%).

Cities with consistently high SBL percentages: Isparta, Erzurum, and Diyarbakır show high SBL across all months, indicating more stable nighttime conditions. Cities with higher NRL percentages at night: İstanbul, İzmir, Ankara, and Samsun have notable NRL percentages, especially in winter months.

Cities dominated by NRL during the day: İstanbul, İzmir, Ankara, and Adana exhibit high NRL percentages, particularly in winter months. Cities with higher SBL percentages during the day: Isparta and Erzurum show relatively higher SBL percentages during the daytime, especially in winter months. Cities with significant UBL percentages: İstanbul and Adana show high UBL percentages, particularly in summer months, indicating more unstable conditions during the day.

In overall, cities with dominant NRL percentages both at night and during the day: İstanbul, İzmir, and Ankara consistently show higher NRL percentages, indicating more neutral conditions. Cities with high SBL percentages at night and varying regimes during the day: Isparta, Erzurum, and Diyarbakır exhibit high SBL percentages at night but show significant changes during the day. Cities with significant seasonal variations: Adana and Samsun display noticeable seasonal differences, with Adana having extreme NRL percentages in summer and winter and Samsun showing high SBL in summer and high NRL in winter.

3.2.3 Correlations between PM₁₀ values and potential temperature differences across vertical atmospheric levels

The analysis of correlations between PM₁₀ concentrations and potential temperature differences across vertical atmospheric levels provides crucial insights into the atmospheric dynamics of eight cities in Turkey: İstanbul, İzmir, Isparta, Ankara, Erzurum, Samsun, Adana, and Diyarbakır. By examining the correlations at various temporal scales—seasonal, monthly, and hourly—the study captures the intricate patterns of how PM₁₀ interacts with temperature stratification in the atmosphere. Seasonal correlations highlight how different times of the year affect the relationship between air quality and potential temperature differences across vertical atmospheric levels. Monthly correlations provide a more granular view, revealing the variations and trends within each season. Hourly correlations offer an even finer resolution, uncovering diurnal patterns and the influence of daily activities on PM₁₀ levels and temperature differences. The figures' color-coded correlations, with red indicating positive correlations and blue indicating negative correlations and white or light shades showing near-zero or no correlation, allow for a clear visual interpretation of these complex interactions. The Y-axis represents the upper pressure levels (hPa), while the X-axis represents the lower pressure levels (hPa).

3.2.3.1 Overall correlations for cities

Figure 3.9 presents the overall correlations between PM₁₀ values and potential temperature differences across vertical atmospheric levels for eight cities in Turkey: İstanbul, İzmir, Isparta, Ankara, Erzurum, Samsun, Adana, and Diyarbakır. The Y-axis represents the upper pressure levels (hPa), while the X-axis represents the lower pressure levels (hPa). The color bar on the right indicates the correlation values, with red shades representing positive correlations, blue shades indicating negative correlations, and white or light shades showing near-zero or no correlation.

Each panel corresponds to a different city, with the titles of the panels displaying the city names. Contour lines within each panel represent levels of constant correlation. The maximum (Mx) and minimum (Mn) correlation values are annotated in red and

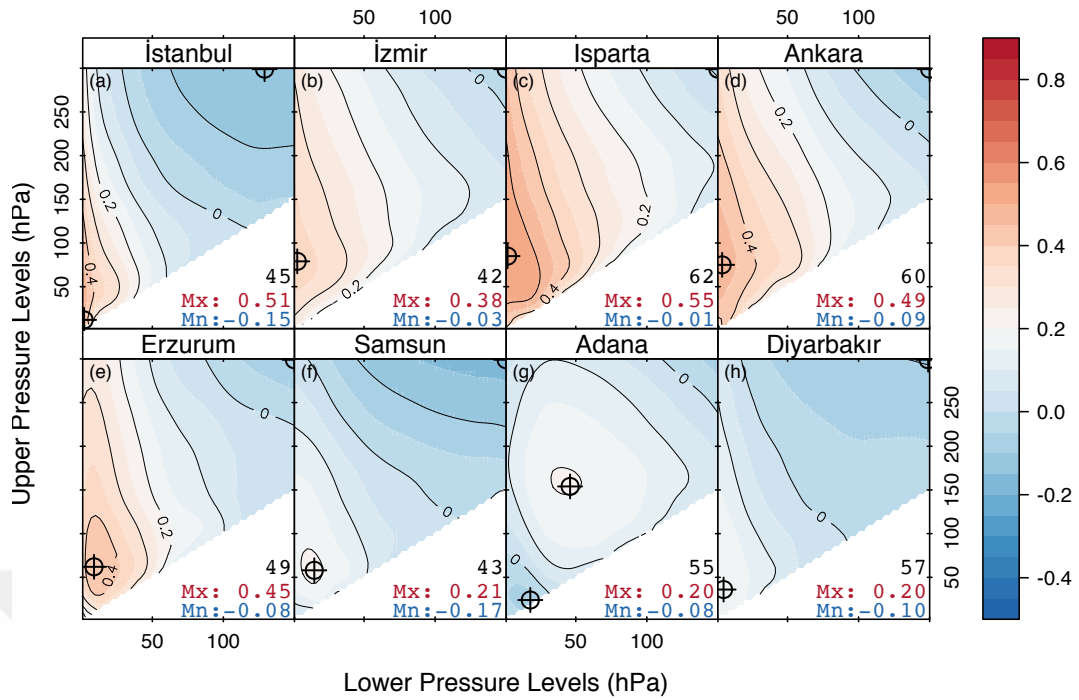


Figure 3.9 : Correlation between PM_{10} concentrations and potential temperature differences across vertical atmospheric levels for eight cities in Turkey (Extremes are given in Table 3.9).

blue, respectively, providing a quick reference for the range of correlations observed in each city.

For İstanbul, the maximum correlation (Mx) is 0.51, and the minimum correlation (Mn) is -0.15 . The panel for İstanbul shows areas with positive correlations in the higher pressure levels and negative correlations in the lower pressure levels. İzmir has a maximum correlation of 0.38 and a minimum of -0.03 , with positive correlations being less pronounced and a mix of slight positive and negative correlations observed.

In Isparta, the maximum correlation is 0.55, and the minimum is -0.01 . This city shows strong positive correlations in the mid-pressure levels, with near-zero negative correlations. Ankara exhibits a maximum correlation of 0.49 and a minimum of -0.09 , with positive correlations dominating, particularly in mid-to-high pressure levels.

Erzurum shows a similar pattern to Ankara, with a maximum correlation of 0.45 and a minimum of -0.08 . Positive correlations are mainly observed in the mid-to-high pressure levels. Samsun, with a maximum correlation of 0.21 and a minimum of

Table 3.9 : Maximum and minimum correlations between PM₁₀ concentrations and potential temperature differences for eight cities.

City	Maximum	Minimum
İstanbul	0.51	-0.15
İzmir	0.38	-0.03
Isparta	0.55	-0.01
Ankara	0.49	-0.09
Erzurum	0.45	-0.08
Samsun	0.21	-0.17
Adana	0.20	-0.08
Diyarbakır	0.20	-0.10

−0.17, generally shows weaker correlations, with some negative values appearing more prominently.

Adana exhibits mostly weak positive correlations, with isolated negative spots, with a maximum correlation of 0.20 and a minimum of −0.08. Diyarbakır also shows weak correlations overall, with both positive and negative areas, having a maximum correlation of 0.20 and a minimum of −0.10.

Overall, most cities show a mix of positive and negative correlations, with positive correlations typically being stronger. Higher pressure levels (closer to the surface) generally exhibit more pronounced correlations compared to lower pressure levels (higher in the atmosphere). Positive correlations suggest that as PM₁₀ increases, the potential temperature differences also increase, indicating a possible relationship between pollution levels and temperature stratification. Conversely, negative correlations suggest an inverse relationship, where increases in PM₁₀ might correspond to decreases in potential temperature differences. Isparta, Ankara and İstanbul shows strong positive correlations, indicating a significant relationship. Erzurum and İzmir has moderate positive correlations, indicating a noticeable but less strong relationship. Samsun, Adana and Diyarbakır shows weak correlations, indicating a minimal relationship between PM₁₀ concentrations and potential temperature differences. Figure 3.9 provides a detailed view of how air pollution (PM₁₀) is associated with temperature profiles in different cities, potentially offering insights into local atmospheric dynamics and pollution effects.

3.2.3.2 Correlations by hours

Figure 3.10 illustrates the correlations between PM_{10} concentrations and potential temperature differences across vertical atmospheric levels for eight cities in Turkey—Istanbul, İzmir, Isparta, Ankara, Erzurum, Samsun, Adana, and Diyarbakır—both during the night and day. The Y-axis represents the upper pressure levels (hPa), while the X-axis represents the lower pressure levels (hPa). The color bar on the right indicates the correlation values, where red shades signify positive correlations, blue shades denote negative correlations, and white or light shades represent near-zero or no correlation.

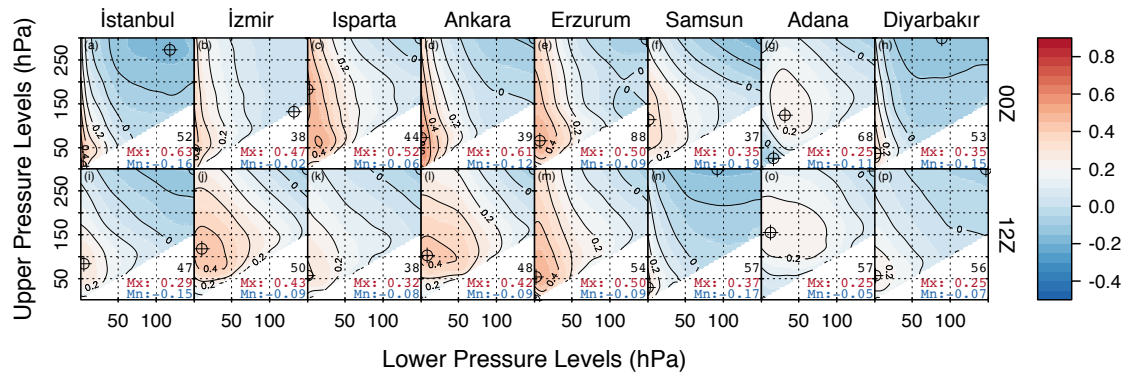


Figure 3.10 : Correlation between PM_{10} concentrations and potential temperature differences across vertical atmospheric levels for eight cities in Turkey at night and day (Extremes are given in Table 3.10).

Each city is represented in two panels: the top row (panels a-h) corresponds to nighttime data, while the bottom row (panels i-p) represents daytime data. The city names are displayed above the respective panels. Contour lines within each panel indicate levels of constant correlation. The maximum and minimum correlation values are annotated in red and blue, respectively, within each panel, providing a clear range of correlations observed for each city.

For İstanbul, the maximum correlation during the night (panel a) is 0.63, and the minimum correlation is -0.16 . During the day (panel i), the maximum correlation is 0.29, and the minimum is -0.15 . This city exhibits stronger positive correlations at night compared to the day, with both periods showing areas of negative correlations.

Table 3.10 : Maximum and minimum correlations between PM₁₀ concentrations and potential temperature differences for various cities during night and day.

City	Maximum		Minimum	
	Night	Day	Night	Day
İstanbul	0.63	0.29	-0.16	-0.15
İzmir	0.47	0.43	-0.02	-0.09
Isparta	0.52	0.32	-0.06	-0.08
Ankara	0.61	0.42	-0.12	-0.09
Erzurum	0.50	0.50	-0.09	-0.09
Samsun	0.35	0.37	-0.19	-0.17
Adana	0.25	0.25	-0.11	-0.05
Diyarbakır	0.35	0.25	-0.15	-0.07

In İzmir, the maximum nighttime correlation (panel b) is 0.47, and the minimum is -0.02 . During the day (panel j), the maximum is 0.43, and the minimum is 0.09. İzmir displays moderate positive correlations during both night and day, with slightly stronger positive correlations at night.

Isparta shows a maximum nighttime correlation (panel c) of 0.52 and a minimum of -0.06 . During the day (panel k), the maximum correlation is 0.32, and the minimum is -0.09 . Positive correlations are more pronounced at night, while daytime correlations are weaker but still positive.

Ankara exhibits a maximum nighttime correlation (panel d) of 0.61 and a minimum of -0.12 . During the day (panel l), the maximum is 0.42, and the minimum is 0.09. This city shows strong positive correlations at night, with positive correlations persisting during the day but at a lower intensity.

Erzurum has a maximum nighttime correlation (panel e) of 0.50 and a minimum of -0.19 . During the day (panel m), the maximum correlation is 0.50, and the minimum is -0.09 . Both periods display similar positive correlations, with slightly more pronounced negative correlations at night.

In Samsun, the maximum nighttime correlation (panel f) is 0.35, and the minimum is -0.15 . During the day (panel n), the maximum correlation is 0.37, and the minimum is -0.17 . Samsun shows comparable levels of correlation during both periods, with slightly stronger positive correlations during the day.

Adana shows a maximum nighttime correlation (panel g) of 0.25 and a minimum of -0.11 . During the day (panel o), the maximum correlation is 0.25, and the minimum is -0.05 . Correlations are weak but positive during both periods, with daytime correlations being slightly stronger.

Diyarbakır exhibits a maximum nighttime correlation (panel h) of 0.35 and a minimum of -0.15 . During the day (panel p), the maximum correlation is 0.25, and the minimum is -0.07 . Positive correlations are stronger at night, with weaker but still positive correlations during the day.

Overall, Figure 3.10 shows that most cities have stronger positive correlations at night compared to the day, with higher pressure levels (closer to the surface) generally exhibiting more pronounced correlations. Positive correlations suggest that as PM_{10} increases, potential temperature differences also increase, indicating a potential relationship between pollution levels and temperature stratification. Negative correlations suggest an inverse relationship, where increases in PM_{10} might correspond to decreases in potential temperature differences. This figure offers insights into how air pollution interacts with temperature profiles in different urban areas during both night and day, reflecting local atmospheric dynamics.

3.2.3.3 Correlations by seasons

Figure 3.11 illustrates the seasonal correlations between PM_{10} concentrations and potential temperature differences across vertical atmospheric levels for eight cities in Turkey—Istanbul, İzmir, Isparta, Ankara, Erzurum, Samsun, Adana, and Diyarbakır. The Y-axis represents the upper pressure levels (hPa), while the X-axis represents the lower pressure levels (hPa). The color bar on the right indicates the correlation values, where red shades signify positive correlations, blue shades denote negative correlations, and white or light shades represent near-zero or no correlation.

Each city is represented across four panels corresponding to the four seasons: fall (a1-a8), winter (b1-b8), spring (c1-c8), and summer (d1-d8). The city names are displayed above the respective columns of panels. Contour lines within each panel indicate levels of constant correlation. The maximum (Mx) and minimum (Mn)

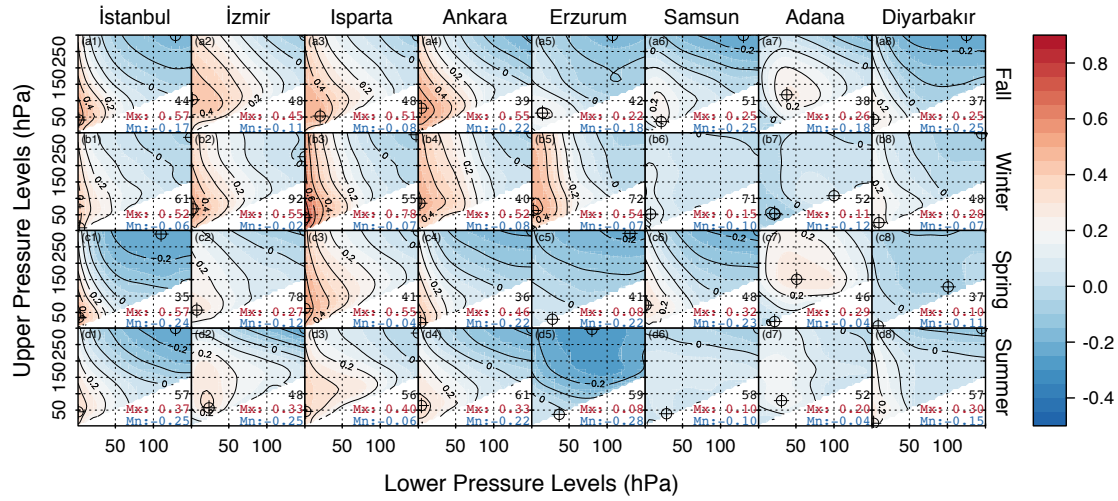


Figure 3.11 : Seasonal correlations between PM_{10} concentrations and potential temperature differences across vertical atmospheric levels for eight cities in Turkey (Extremes are given in Table 3.11).

Table 3.11 : Maximum and minimum correlations between PM_{10} concentrations and potential temperature differences for various cities during seasons.

City	Maximum				Minimum			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
İstanbul	0.57	0.52	0.57	0.37	-0.17	-0.06	-0.24	-0.25
İzmir	0.45	0.55	0.27	0.33	-0.11	-0.02	-0.12	-0.25
Isparta	0.51	0.78	0.55	0.40	-0.08	-0.07	-0.04	-0.06
Ankara	0.55	0.52	0.46	0.33	-0.22	-0.08	-0.22	-0.22
Erzurum	0.22	0.54	0.08	0.08	-0.18	-0.07	-0.22	-0.28
Samsun	0.25	0.15	0.32	0.10	-0.25	-0.10	-0.23	-0.10
Adana	0.26	0.11	0.29	0.20	-0.18	-0.12	-0.04	-0.04
Diyarbakır	0.25	0.28	0.10	0.30	-0.25	-0.07	-0.11	-0.15

correlation values are annotated in red and blue, respectively, within each panel, providing a clear range of correlations observed for each city during each season.

İstanbul shows strong positive correlations in Fall (0.57) and Spring (0.57), with Winter (0.52) also indicating significant positive correlation, while Summer shows the lowest maximum correlation (0.37). İzmir exhibits the highest correlation in Winter (0.55), with moderate correlations in Fall (0.45) and Spring (0.27), and the lowest in Summer (0.33). Isparta has the highest maximum correlation in Winter (0.78), followed by Fall (0.51) and Spring (0.55), with Summer showing a moderate correlation (0.40). Ankara shows strong correlations in Fall (0.55) and Winter (0.52), with lower but still

positive correlations in Spring (0.46) and Summer (0.33). Erzurum exhibits the highest correlation in Winter (0.54), with Fall showing a moderate correlation (0.22), and very low correlations in Spring and Summer (both 0.08). Samsun has moderate correlations in Spring (0.32) and Fall (0.25), with lower correlations in Winter (0.15) and Summer (0.10). Adana shows moderate correlations in Spring (0.29) and Fall (0.26), with lower correlations in Summer (0.20) and Winter (0.11). Diyarbakır exhibits moderate correlations in Summer (0.30) and Winter (0.28), with lower correlations in Fall (0.25) and Spring (0.10).

In summary, the Table 3.11 reveals that the relationship between PM_{10} concentrations and potential temperature differences varies significantly across seasons and cities. Winter generally shows higher positive correlations, particularly for cities like Isparta and İzmir. Fall also demonstrates strong positive correlations, especially in cities like İstanbul and Ankara. Spring shows moderate correlations, with some cities like İstanbul and Isparta still maintaining relatively high values. Summer generally exhibits the lowest maximum correlations, indicating a weaker relationship during this season. Negative correlations are present in all cities across all seasons, indicating periods where higher PM_{10} concentrations are associated with lower potential temperature differences. The extent of these negative correlations varies, with Summer and Spring often showing more negative values compared to Fall and Winter.

Overall, Figure 3.11 shows that most cities exhibit stronger positive correlations in winter and fall, with higher pressure levels (closer to the surface) generally exhibiting more pronounced correlations. Positive correlations suggest that as PM_{10} increases, potential temperature differences also increase, indicating a potential relationship between pollution levels and temperature stratification. Negative correlations suggest an inverse relationship, where increases in PM_{10} might correspond to decreases in potential temperature differences. This figure offers insights into how air pollution (PM_{10}) interacts with temperature profiles in different urban areas during different seasons, reflecting local atmospheric dynamics.

3.2.3.4 Correlations by months

Figure 3.12 illustrates the correlations between PM_{10} concentrations and potential temperature differences across vertical atmospheric levels for eight cities in Turkey—Istanbul, İzmir, Isparta, Ankara, Erzurum, Samsun, Adana, and Diyarbakır—on a monthly basis. The Y-axis represents the upper pressure levels (hPa), while the X-axis represents the lower pressure levels (hPa). The color bar on the right indicates the correlation values, where red shades signify positive correlations, blue shades denote negative correlations, and white or light shades represent near-zero or no correlation.

Each city is represented across twelve panels corresponding to the twelve months from September to August. The city names are displayed above the respective columns of panels, while the months are labeled on the right side of the figure. Contour lines within each panel indicate levels of constant correlation. The maximum and minimum correlation values are annotated in red and blue, respectively, within each panel, providing a clear range of correlations observed for each city during each month. The provided table and plot show the monthly maximum and minimum correlations between PM_{10} concentrations and potential temperature differences for eight cities in Turkey. The analysis focuses on comparing the cities in terms of their monthly correlation maximums and patterns in the plot panels.

- **Istanbul:** Exhibits relatively high maximum correlations throughout the year, peaking in March (0.64) and November (0.61). The plot shows consistent positive correlations, particularly in the colder months.
- **İzmir:** Shows high maximum correlations in December (0.58) and February (0.57). The plot indicates that correlations are stronger in the winter months and decrease during summer.
- **Isparta:** Demonstrates the highest maximum correlations among all cities, particularly in December (0.81), January (0.78), and February (0.78). The plot consistently shows strong positive correlations across most months.

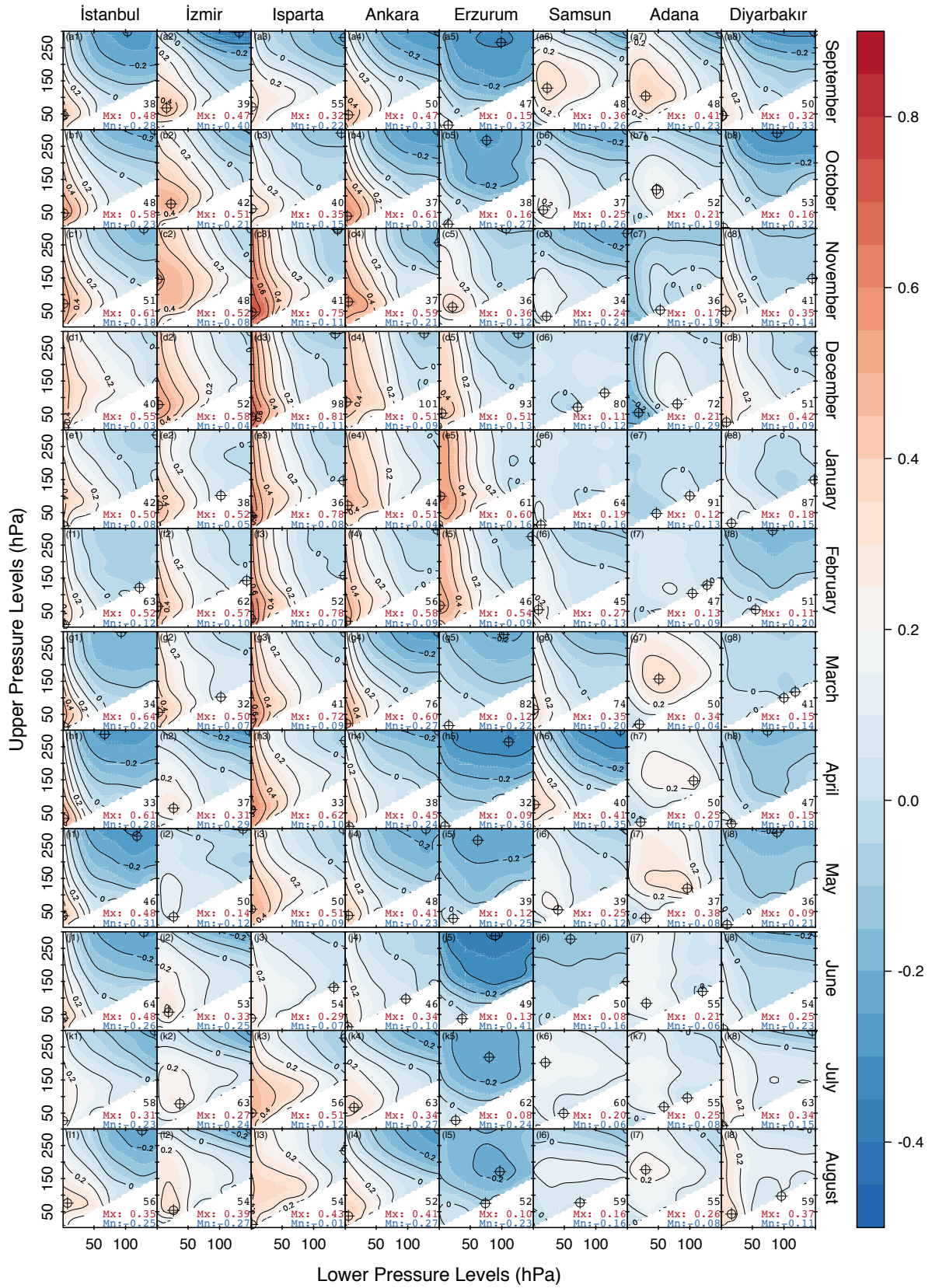


Figure 3.12 : The correlations between PM_{10} and potential temperature differences between vertical levels of the atmosphere (Extremes are given in Table 3.12).

Table 3.12 : Monthly maximum correlations between PM₁₀ concentrations and potential temperature differences for eight cities.

	İstanbul	İzmir	Isparta	Ankara	Erzurum	Samsun	Adana	Diyarbakır
Months	Maximum							
Sep	0.48	0.47	0.32	0.47	0.15	0.36	0.41	0.32
Oct	0.58	0.51	0.35	0.61	0.16	0.25	0.21	0.16
Nov	0.61	0.52	0.75	0.59	0.36	0.24	0.17	0.35
Dec	0.55	0.58	0.81	0.51	0.51	0.11	0.21	0.42
Jan	0.50	0.52	0.78	0.51	0.60	0.19	0.12	0.18
Feb	0.52	0.57	0.78	0.58	0.54	0.27	0.13	0.11
Mar	0.64	0.50	0.72	0.60	0.12	0.35	0.34	0.15
Apr	0.61	0.31	0.62	0.45	0.09	0.41	0.25	0.15
May	0.48	0.14	0.51	0.41	0.12	0.25	0.38	0.09
Jun	0.48	0.33	0.29	0.34	0.13	0.08	0.21	0.25
Jul	0.31	0.27	0.51	0.34	0.08	0.20	0.25	0.34
Aug	0.35	0.39	0.43	0.41	0.10	0.16	0.26	0.37
	Minimum							
Sep	-0.28	-0.40	-0.22	-0.31	-0.32	-0.26	-0.23	-0.33
Oct	-0.23	-0.21	-0.15	-0.30	-0.27	-0.26	-0.19	-0.32
Nov	-0.18	-0.08	-0.11	-0.21	-0.12	-0.24	-0.19	-0.14
Dec	-0.03	-0.04	-0.11	-0.09	-0.13	-0.12	-0.29	-0.09
Jan	-0.08	-0.05	-0.08	-0.04	-0.16	-0.16	-0.13	-0.15
Feb	-0.12	-0.10	-0.07	-0.09	-0.09	-0.13	-0.09	-0.20
Mar	-0.20	-0.07	-0.09	-0.27	-0.22	-0.20	-0.04	-0.14
Apr	-0.28	-0.29	-0.10	-0.24	-0.36	-0.35	-0.07	-0.18
May	-0.31	-0.12	-0.09	-0.23	-0.25	-0.12	-0.08	-0.21
Jun	-0.26	-0.25	-0.07	-0.10	-0.41	-0.16	-0.06	-0.23
Jul	-0.23	-0.24	-0.12	-0.27	-0.24	-0.06	-0.08	-0.15
Aug	-0.25	-0.27	-0.01	-0.27	-0.23	-0.16	-0.08	-0.11

- Ankara: Also exhibits high maximum correlations, especially in October (0.61) and March (0.60). The plot shows that Ankara has strong positive correlations in both winter and spring.
- Erzurum: Shows significant maximum correlations in the winter months, particularly January (0.60) and December (0.51). The plot highlights weaker correlations in the warmer months.
- Samsun: Exhibits moderate maximum correlations with peaks in February (0.27) and September (0.36). The plot shows less variation compared to other cities, with generally lower correlations.
- Adana: Shows moderate maximum correlations, particularly in September (0.41) and August (0.37). The plot indicates that Adana has weaker correlations overall.
- Diyarbakır: Demonstrates varied correlations with peaks in December (0.42) and August (0.37). The plot shows lower correlations overall, similar to Adana.
- Similarities:
 - İstanbul and İzmir: Both cities show high correlations in the winter months and lower in the summer.
 - Isparta and Ankara: These cities exhibit strong positive correlations throughout the year, particularly in the colder months.
- Distinct Characteristics:
 - Erzurum: Unique for its strong correlations only in the winter months, with significantly lower values during the rest of the year.
 - Samsun and Adana: Both cities show generally lower correlations, with less seasonal variation compared to others.
 - Diyarbakır: Exhibits more variability in correlations, with peaks in both summer and winter.

In summary, the analysis of monthly correlations between PM₁₀ concentrations and potential temperature differences across eight cities in Turkey reveals significant

seasonal and regional variations. Cities like İstanbul and İzmir show higher correlations during the winter months, indicating a stronger relationship between PM₁₀ levels and temperature stratification in colder periods. Isparta and Ankara exhibit consistently strong correlations throughout the year, particularly during winter, suggesting a robust interaction between air quality and atmospheric conditions. In contrast, Erzurum's correlations are predominantly high in the winter months, with minimal correlation during the summer, highlighting the impact of severe winter conditions. Samsun and Adana display moderate to low correlations with less seasonal variation, indicating a more stable but weaker relationship. Diyarbakır, on the other hand, shows varied correlations with notable peaks in both summer and winter, reflecting a more complex interaction pattern. These findings highlight the importance of considering both temporal and regional factors when assessing air quality and its atmospheric interactions.

4. DISCUSSION and CONCLUSION

Particulate matter constitutes a significant air quality concern in Turkey, as evidenced by levels persistently exceeding permissible limits. This study's analytical endeavors have discerned that, among twelve scrutinized major cities in Turkey, merely Adana, Erzurum, and İzmir PM₁₀ concentrations at or below the 45 $\mu\text{g}/\text{m}^3$ threshold. This threshold aligns with the 24-hour Air Quality Guideline (AQG) delineated by [54]. Notably, with the exception of Erzurum, these cities are situated along the coast, potentially benefiting from maritime influences conducive to pollutant dispersion. Conversely, Erzurum's unique geographic and climatic conditions, characterized by its inland location on an expansive plateau encircled by mountains and an elevation nearing 2000 meters, coupled with prevalent snow coverage, contribute to atmospheric dispersion dynamics that favor reduced PM₁₀ levels.

Conversely, the remaining inland cities, with Aydin characterized as a semi-inland city due to its unique geographical positioning, exhibit PM₁₀ concentrations surpassing the 45 $\mu\text{g}/\text{m}^3$ threshold, delineated within a range of 55 $\mu\text{g}/\text{m}^3$ to 71.5 $\mu\text{g}/\text{m}^3$. This disparity accentuates a notable variance in PM₁₀ levels, with inland cities demonstrating heightened variability (spanning between 1236 and 2225, averaging at 1830) in comparison to their coastal counterparts (where variability ranges from 574 to 1019, with a mean of 785). Such distinctions underscore the influence of geographic and topographic factors on air pollutant dispersion, highlighting the challenges faced by inland cities in mitigating PM₁₀ levels due to their inherent environmental and climatic conditions.

Moreover, substantial discrepancies in PM₁₀ concentrations are observed even among coastal cities, attributed to distinct geographical and meteorological conditions. Aydin, nestled in a valley with mountains aligned in an east-west direction, presents a unique case. Its eastern boundary opens towards the Aegean Sea, while the western frontier extends into the inland territories of Turkey. This geographical setup predominantly

favors westerly winds, yet the local topography induces atmospheric inversions under non-westerly wind conditions, contributing to Aydin's classification as a semi-inland city. In contrast, Adana, located at the southern edge of Turkey, benefits from its proximity to the Mediterranean Sea, which facilitates windy conditions conducive to the dispersion of air pollutants. The divergent PM₁₀ levels between Adana and Aydin can thus be ascribed to the interplay of their respective wind patterns, topographical features, and, potentially, variations in emission sources, albeit these differences in emissions remain to be quantified precisely.

The methodology adopted in this thesis facilitated the decomposition of PM₁₀ data into its long-term, seasonal, and short-term components, revealing distinct variability patterns across the surveyed cities. Predominantly, short-term variability accounts for a substantial portion of total variability, exceeding fifty percent in almost all cities, except for Aydin, where it constitutes less than forty percent. On average, coastal cities exhibit a higher propensity for short-term variability, explaining roughly 70 percent of the total variance (spanning between 60 and 76 percent), in contrast to 61 percent observed in inland cities (ranging between 54 and 68 percent).

Seasonal variability emerges as a significant factor, particularly in inland cities such as Aydin, Kayseri, K. Maras, and G. Antep, where it explains over twenty percent of the variability. With an average of 18.9 percent, inland cities exhibit a higher degree of seasonal variability compared to coastal cities, which average at 13.4 percent. This distinction is largely attributed to the topographical features and proximity to the sea, with inland cities' mountainous surroundings enhancing inversion effects that inhibit pollutant dispersion, thereby heightening seasonality compared to the more dispersion-favorable coastal cities.

Furthermore, long-term variability is notably pronounced in Aydin, Kocaeli, and G. Antep, contributing to over ten percent of total variability. These findings indicate that the employed methodology was particularly adept at elucidating seasonal and long-term variations in inland cities. Conversely, for coastal cities, while the overall variability was less pronounced, the methodology predominantly captured short-term

variability, somewhat overlooking the contributions from seasonal and long-term changes.

Overall, the analysis indicates a negative trend in long-term PM_{10} concentration changes for ten out of the twelve cities studied, with reductions ranging from $-39.6 \mu g/m^3$ to $-1.2 \mu g/m^3$. Only Adana and Kayseri exhibited positive long-term changes, with increments between $1.0 \mu g/m^3$ and $3.1 \mu g/m^3$. These observations suggest that, throughout the selected timeframe, PM_{10} levels in the majority of the selected cities have either declined or remained relatively stable.

The KZ-filter method has been recognized as a potent tool for the decomposition of air pollution time series, facilitating insightful assessments of pollutant trends, including PM_{10} , across different geographies such as the United States [19], Portugal [30], and South Korea [31]. These studies collectively highlight that the variability in long-term data for pollutants like O_3 and NO_2 is more aptly elucidated by meteorological variables compared to PM_{10} data. Particularly, the research by Seo et al. [31] in Seoul, South Korea, which incorporates emission inventory considerations alongside multiple pollutants, mirrors the analytical depth of our study, albeit with a focus on the distinctive meteorological and emission effects on PM_{10} within the diverse topographical landscape of Turkey.

Seo et al.'s findings indicate a notable decreasing long-term trend in pollutant levels, potentially linked to a sub-regional increase in wind speed. This observation is paralleled by a concurrent decline in both emission-related (χ_{LT}^{emis}) and meteorology-related (χ_{LT}^{met}) components of PM_{10} , underscoring the intertwined impact of emission control measures and meteorological factors on pollutant trends in Seoul. Such comparative insights not only validate the utility of the KZ-filter method in isolating the intricate dynamics influencing air quality but also emphasize the broader implications of regional atmospheric conditions and emission mitigation strategies on the long-term evolution of particulate matter concentrations.

In this thesis, the direct influence of wind on PM_{10} concentration is identified as negligible. However, it is imperative to underscore that a comprehensive investigation into the stability levels of the boundary layer, particularly up to 500m above ground,

is essential for a deeper understanding of the observed phenomena. The complexity of ground-based PM_{10} levels transcends the explanatory power of surface wind speed and atmospheric boundary layer height when considered in isolation. This is due to intricate atmospheric dynamics such as fanning, lofting, fumigation, and the occurrence of nocturnal jets within a SBL, which significantly influence pollutant dispersion patterns [1]. The high elevation and complex terrain characteristic of Turkish cities further accentuate the impact of these conditions, necessitating a nuanced analysis that incorporates the multifaceted interactions between atmospheric conditions and particulate matter concentrations.

The examination of long-term changes in the meteorology-related component of PM_{10} concentrations (χ_{LT}^{met}) reveals a relatively constant trend, underscoring that variations in long-term PM_{10} levels (χ_{LT}) are predominantly dictated by the emission-related component (χ_{LT}^{emis}). This observation suggests that as the impact of emissions diminishes over time, a corresponding reduction in PM_{10} levels is observed across most cities. The implication here is clear: emission control and reduction strategies play a crucial role in mitigating particulate matter pollution, highlighting the effectiveness of environmental policies and technological advancements in improving air quality. The relatively stable influence of meteorological factors on long-term trends further emphasizes the pivotal role of anthropogenic emissions in shaping the trajectory of PM_{10} concentrations.

Figure 4.1 displays the trajectory of national emission totals for the decade spanning 2010 to 2019, as sourced from the Republic of Turkey Ministry of Environment and Urbanization and Climate Change (TMEUCC) [55]. A notable decline in PM_{10} emissions is observed, decreasing from 350kt in 2010 to 250kt in 2019, equivalent to an annual reduction of approximately 11kt. While SO_2 emissions exhibit a marginal downtrend, punctuated by a nadir between 2013 and 2015, NO_X emissions present a significant yearly increase of 9.8kt, stabilizing somewhat prior to 2016. These trends in the national emission inventory echo the analytical outcomes delineated in this thesis, confirming a concurrent decrease in both direct PM_{10} and SO_2 emissions alongside PM_{10} concentrations within the studied cities. Particularly noteworthy is the augmented contribution of electric generation to NO_X emissions

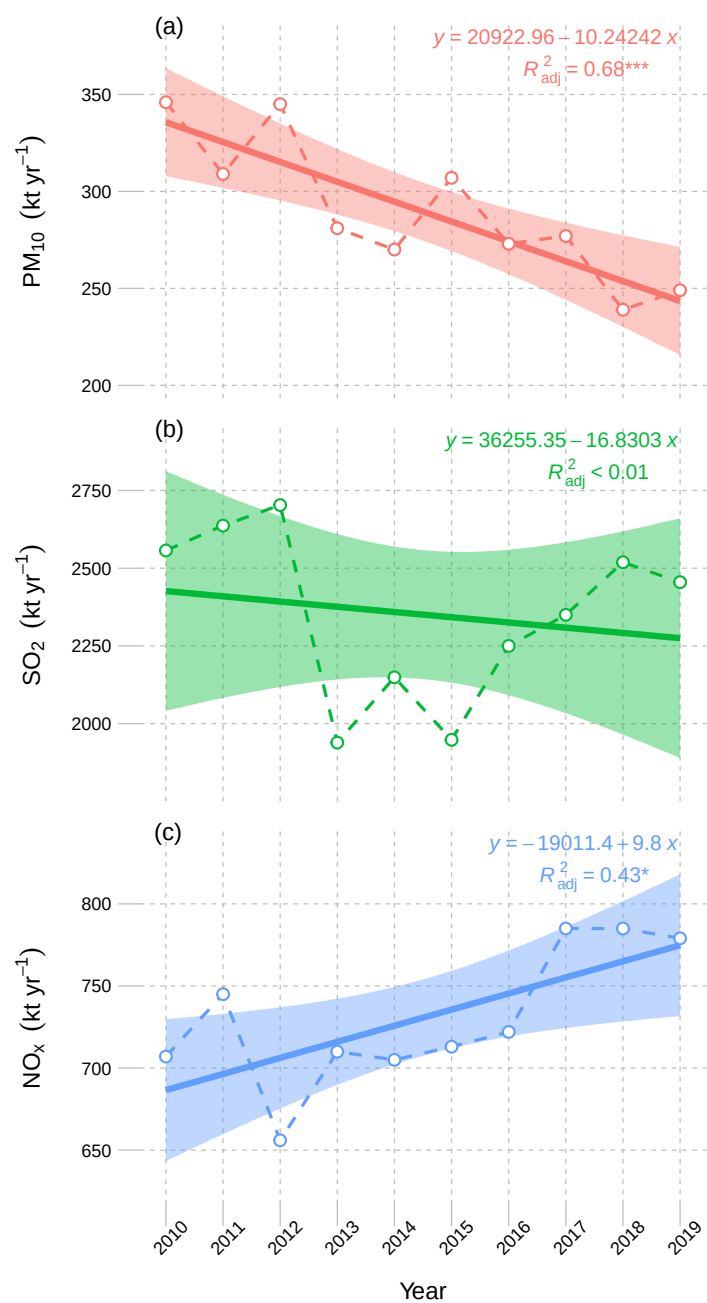


Figure 4.1 : National total emissions for PM₁₀, SO₂ and NO_x, from 2010-2019, with the shaded area indicating the confidence interval).

throughout the 2010-2019 period. In the context of K. Maras, which experienced a PM_{10} concentration surge post-2017, the presence of four major coal-fired power plants—boasting a collective installed capacity of $2795MW$ and an annual output of $6.8GWh$ (representing about 7% of Turkey’s coal thermal plant production) [56]—suggests a plausible link between the city’s rising PM_{10} levels and its electric generation activities, as mirrored by the uptick in NO_x emissions.

The findings articulated in this thesis underscore the KZ-filter methodology’s adeptness at disentangling short-term, seasonal, and long-term variations within air quality datasets, whilst elucidating the nuanced influences of meteorological conditions and emissions on these dynamics. The determination of background concentrations emerges as a pivotal aspect for enhancing our comprehension of local meteorological impacts and emission source contributions to air quality. Echoing the perspectives of Han et al. [34] and Gao et al. [35], it is posited that a deeper exploration into the atmospheric boundary layer’s vertical characteristics, the chemical makeup of aerosols, and the deployment of numerical models like CMAQ would significantly refine our understanding of background concentrations. Pursuant to these insights, such comprehensive analyses are earmarked for future investigative endeavors, aiming to bolster the precision and scope of air quality assessment methodologies.

Vertical atmospheric analysis is a crucial aspect of meteorological studies, providing insights into the structure and dynamics of the atmosphere. One key parameter in this analysis is the potential temperature (θ), which is used to assess the thermal stability of the atmosphere. The difference in potential temperature ($\Delta\theta$) between different atmospheric layers serves as an indicator of atmospheric stability regimes. Stability regimes, classified into stable, neutral, and unstable categories, have significant implications for the dispersion and concentration of pollutants such as particulate matter (PM_{10}). In this study, we investigate the correlation between vertical profiles of $\Delta\theta$ and PM_{10} concentrations across various cities in Turkey. By analyzing long-term data, we aim to understand how different stability regimes influence the distribution and levels of PM_{10} , thereby providing valuable insights for air quality management and policy formulation.

The analysis of potential temperature differences between 20 hPa and 5 hPa levels across eight cities in Turkey reveals significant findings about the atmospheric stability and its relationship with PM₁₀ concentrations. Overall, positive potential temperature differences are more common across all cities, indicating a tendency towards stable atmospheric conditions. Cities like Samsun and Diyarbakır exhibit the highest mean potential temperature differences, suggesting more frequent stable conditions, particularly during the night.

Hourly Analysis shows that positive temperature differences are significantly more frequent at 00Z compared to 12Z across all cities. This suggests that stable atmospheric conditions are more prevalent during the night, while the day shows more variability, including higher instances of negative differences. Seasonal Analysis shows that positive temperature differences are more frequent in winter and fall, with summer showing the lowest frequency of positive differences. This seasonal variation indicates that stable atmospheric conditions are more common during the colder months.

The Liu-liang stability regimes indicate that most cities experience a higher frequency of NRL conditions, with SBL conditions also being significant. UBL conditions are less frequent but are more common during the day and in summer.

Overall maximum and minimum correlations are shown on the Figure 4.2. Cities like Isparta, Ankara, and İstanbul show strong positive correlations between PM₁₀ concentrations and potential temperature differences, indicating a significant relationship between air pollution and temperature stratification. Erzurum and İzmir have moderate positive correlations, while Samsun, Adana, and Diyarbakır show weaker correlations. Hourly and Seasonal Correlations: Positive correlations are generally stronger at night and during winter, indicating that stable atmospheric conditions at these times contribute to higher PM₁₀ concentrations. Negative correlations, although less common, suggest that in some cases, higher PM₁₀ concentrations correspond to lower potential temperature differences, possibly due to turbulent mixing during the day or in summer.

The analysis highlights the significant impact of atmospheric stability on PM₁₀ concentrations. The frequent occurrence of positive temperature differences and stable

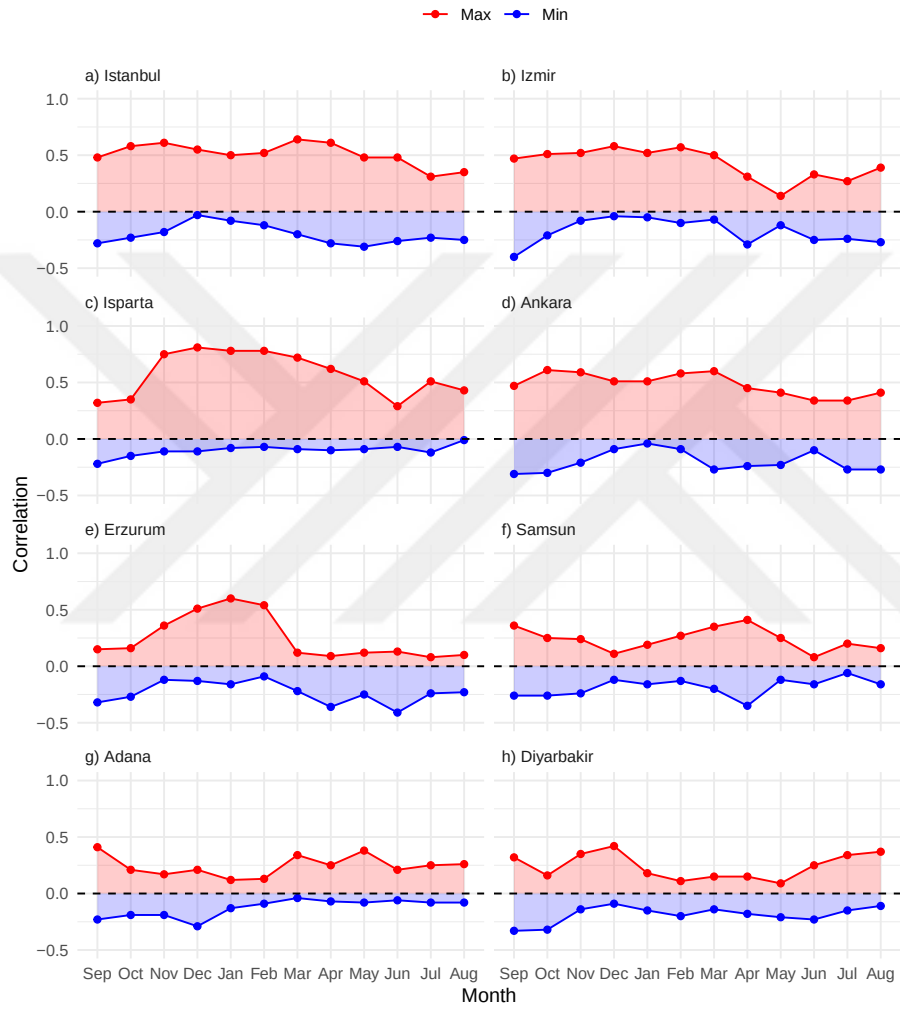


Figure 4.2 : Monthly maximum and minimum correlations between PM₁₀ concentrations and potential temperature differences in eight cities.

conditions during the night and winter months suggests that these periods are critical for higher air pollution levels. Understanding these patterns can help in developing targeted air quality management strategies, particularly focusing on nighttime and winter conditions to mitigate high PM₁₀ concentrations in urban areas. Future studies could further investigate the underlying mechanisms driving these correlations and explore mitigation measures tailored to the specific atmospheric conditions of each city.

This study has laid the groundwork for understanding the effect of vertical atmospheric profiles on PM₁₀ concentrations across various cities in Turkey. However, there are several areas where future research could expand and deepen our understanding:

- **Long-term Trend Analysis:** Extending the analysis to include more recent data and projecting future trends could provide insights into how PM₁₀ concentrations and potential temperature differences evolve over time under changing climatic conditions.
- **Impact of Meteorological Factors:** Investigating the influence of other meteorological factors such as wind speed, humidity, and precipitation on PM₁₀ concentrations could offer a more comprehensive understanding of air quality dynamics.
- **Regional Comparisons:** Expanding the study to include additional regions, both within Turkey and internationally, could help identify broader patterns and regional differences in the relationship between vertical atmospheric profiles and PM₁₀ concentrations.
- **Machine Learning Approaches:** Employing advanced machine learning techniques to model and predict PM₁₀ concentrations based on potential temperature differences and other meteorological variables could enhance the accuracy and reliability of air quality forecasts.
- **Health Impact Studies:** Linking the observed PM₁₀ concentrations and stability regimes with health data could provide valuable insights into the public health implications of air pollution under different atmospheric conditions.

- **High-Resolution Modeling:** Utilizing high-resolution atmospheric models to simulate the detailed interactions between PM_{10} and atmospheric stability could improve our understanding of local air quality phenomena and help design more effective mitigation strategies.
- **Policy Implications:** Investigating the effectiveness of current air quality management policies and proposing new strategies based on the findings of this study could support policymakers in making informed decisions to improve air quality and public health.

By addressing these areas, future research can build upon the findings of this study to provide a more detailed and actionable understanding of the factors influencing PM_{10} concentrations and their broader implications.

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APPENDICES

APPENDIX A : Tables





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Table A.1 : Seasonal and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Season	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
İstanbul	00Z	Fall	62.4	37.2	0.4	660	393	4	1057
		Winter	48.5	51.4	0.1	516	546	1	1063
		Spring	63.4	36.3	0.3	708	406	3	1117
		Summer	52.8	46.6	0.5	598	528	6	1132
	12Z	Fall	9.3	74.4	16.3	96	770	169	1035
		Winter	14.8	81.2	4.0	159	874	43	1076
		Spring	16.8	70.4	12.8	188	789	144	1121
		Summer	8.3	59.3	32.4	94	669	365	1128
İstanbul	All	Min.	8.3	36.3	0.1	94.0	393.0	1.0	1035.0
		1 st Qu.	13.4	44.3	0.4	143.2	497.5	3.8	1061.5
		Median	32.7	55.3	2.3	352.0	607.5	24.5	1096.5
		Mean	34.5	57.1	8.3	377.4	621.9	91.9	1091.1
		3 rd Qu.	55.2	71.4	13.7	613.5	774.8	150.2	1122.8
		Max.	63.4	81.2	32.4	708.0	874.0	365.0	1132.0
		Std. Dev.	24.4	17.0	11.6	267.3	181.0	129.2	37.7
İzmir	00Z	Fall	54.3	45.0	0.8	504	418	7	929
		Winter	54.3	45.4	0.3	527	440	3	970
		Spring	58.4	41.5	0.1	593	421	1	1015
		Summer	46.8	52.4	0.8	487	546	8	1041
	12Z	Fall	4.2	85.4	10.4	40	804	98	942
		Winter	8.3	89.0	2.7	81	868	26	975
		Spring	4.5	82.3	13.2	46	848	136	1030
		Summer	5.6	73.4	21.0	59	770	220	1049
İzmir	All	Min.	4.2	41.5	0.1	40.0	418.0	1.0	929.0
		1 st Qu.	5.3	45.3	0.6	55.8	435.2	6.0	963.0
		Median	27.5	62.9	1.7	284.0	658.0	17.0	995.0
		Mean	29.6	64.3	6.1	292.1	639.4	62.4	993.9
		3 rd Qu.	54.3	83.1	11.1	509.8	815.0	107.5	1032.8
		Max.	58.4	89.0	21.0	593.0	868.0	220.0	1049.0
		Std. Dev.	25.8	20.2	7.8	254.0	201.8	81.2	46.0

Table A.1 (Continued) : Seasonal and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Season	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
Isparta	00Z	Fall	83.5	16.3	0.2	831	162	2	995
		Winter	65.6	34.1	0.3	635	330	3	968
		Spring	72.7	27.2	0.1	688	258	1	947
		Summer	76.8	23.1	0.1	742	223	1	966
	12Z	Fall	4.1	82.7	13.2	41	820	131	992
		Winter	10.1	86.9	3.0	97	834	29	960
		Spring	4.1	83.3	12.6	39	790	119	948
		Summer	2.9	73.7	23.4	28	713	226	967
Isparta	All	Min.	2.9	16.3	0.1	28.0	162.0	1.0	947.0
		1 st Qu.	4.1	26.2	0.2	40.5	249.2	1.8	957.0
		Median	37.9	53.9	1.7	366.0	521.5	16.0	966.5
		Mean	40.0	53.4	6.6	387.6	516.2	64.0	967.9
		3 rd Qu.	73.7	82.8	12.7	701.5	797.5	122.0	974.0
		Max.	83.5	86.9	23.4	831.0	834.0	226.0	995.0
		Std. Dev.	37.4	30.8	8.8	364.3	297.5	84.9	17.8
Ankara	00Z	Fall	74.5	24.9	0.6	725	242	6	973
		Winter	56.5	42.7	0.8	563	426	8	997
		Spring	67.2	32.6	0.3	724	351	3	1078
		Summer	59.1	39.9	1.0	605	408	10	1023
	12Z	Fall	1.4	81.3	17.3	14	802	171	987
		Winter	6.8	88.5	4.6	69	895	47	1011
		Spring	1.7	82.1	16.2	19	925	183	1127
		Summer	1.9	67.9	30.1	20	703	312	1035
Ankara	All	Min.	1.4	24.9	0.3	14.0	242.0	3.0	973.0
		1 st Qu.	1.9	38.1	0.8	19.8	393.8	7.5	994.5
		Median	31.6	55.3	2.8	316.0	564.5	28.5	1017.0
		Mean	33.6	57.5	8.9	342.4	594.0	92.5	1028.9
		3 rd Qu.	61.1	81.5	16.5	634.8	825.2	174.0	1045.8
		Max.	74.5	88.5	30.1	725.0	925.0	312.0	1127.0
		Std. Dev.	33.3	25.2	11.1	338.2	267.5	115.9	51.2

Table A.1 (Continued) : Seasonal and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Season	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
Erzurum	00Z	Fall	81.5	17.3	1.2	803	170	12	985
		Winter	77.6	19.8	2.6	827	211	28	1066
		Spring	68.8	30.5	0.8	715	317	8	1040
		Summer	78.4	20.6	1.0	836	220	11	1067
	12Z	Fall	5.1	78.9	16.0	51	783	159	993
		Winter	40.8	53.1	6.2	437	569	66	1072
		Spring	7.6	75.8	16.6	81	804	176	1061
		Summer	7.3	67.5	25.2	79	729	272	1080
Erzurum	All	Min.	5.1	17.3	0.8	51.0	170.0	8.0	985.0
		1 st Qu.	7.6	20.4	1.2	80.5	217.8	11.8	1028.2
		Median	54.8	41.8	4.4	576.0	443.0	47.0	1063.5
		Mean	45.9	45.4	8.7	478.6	475.4	91.5	1045.5
		3 rd Qu.	77.8	69.6	16.2	809.0	742.5	163.2	1068.2
		Max.	81.5	78.9	25.2	836.0	804.0	272.0	1080.0
		Std. Dev.	34.8	26.4	9.3	361.1	274.9	99.1	36.8
Samsun	00Z	Fall	75.7	24.0	0.3	793	251	3	1047
		Winter	58.0	41.7	0.3	624	448	3	1075
		Spring	68.5	31.2	0.3	800	364	4	1168
		Summer	80.2	19.5	0.3	863	210	3	1076
	12Z	Fall	16.0	76.1	8.0	158	753	79	990
		Winter	21.1	77.7	1.2	226	834	13	1073
		Spring	39.1	57.9	3.0	459	679	35	1173
		Summer	13.6	67.1	19.3	144	711	204	1059
Samsun	All	Min.	13.6	19.5	0.3	144.0	210.0	3.0	990.0
		1 st Qu.	19.8	29.4	0.3	209.0	335.8	3.0	1056.0
		Median	48.6	49.8	0.8	541.5	563.5	8.5	1074.0
		Mean	46.5	49.4	4.1	508.4	531.2	43.0	1082.6
		3 rd Qu.	70.3	69.4	4.2	794.8	721.5	46.0	1099.0
		Max.	80.2	77.7	19.3	863.0	834.0	204.0	1173.0
		Std. Dev.	27.6	23.4	6.7	303.1	242.5	70.2	61.0

Table A.1 (Continued) : Seasonal and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Season	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
Adana	00Z	Fall	90.1	9.1	0.7	996	101	8	1105
		Winter	87.5	12.0	0.5	945	130	5	1080
		Spring	81.4	17.9	0.7	895	197	8	1100
		Summer	29.6	68.5	1.9	331	767	21	1119
	12Z	Fall	3.0	88.8	8.3	33	979	91	1103
		Winter	8.1	89.8	2.1	88	974	23	1085
		Spring	2.9	84.1	13.0	32	929	144	1105
		Summer	1.4	72.0	26.6	16	802	296	1114
Adana	All	Min.	1.4	9.1	0.5	16.0	101.0	5.0	1080.0
		1 st Qu.	3.0	16.4	0.7	32.8	180.2	8.0	1096.2
		Median	18.8	70.3	2.0	209.5	784.5	22.0	1104.0
		Mean	38.0	55.3	6.7	417.0	609.9	74.5	1101.4
		3 rd Qu.	82.9	85.2	9.4	907.5	940.2	104.2	1107.2
		Max.	90.1	89.8	26.6	996.0	979.0	296.0	1119.0
		Std. Dev.	41.1	35.8	9.2	449.5	395.0	102.4	13.2
Diyarbakır	00Z	Fall	90.7	8.6	0.7	929	88	7	1024
		Winter	77.4	22.0	0.7	807	229	7	1043
		Spring	83.4	16.1	0.5	886	171	5	1062
		Summer	90.5	8.9	0.6	966	95	6	1067
	12Z	Fall	3.7	82.8	13.6	37	837	137	1011
		Winter	8.5	85.6	5.9	89	891	61	1041
		Spring	4.2	77.3	18.5	44	802	192	1038
		Summer	1.0	75.8	23.2	11	802	245	1058
Diyarbakır	All	Min.	1.0	8.6	0.5	11.0	88.0	5.0	1011.0
		1 st Qu.	4.1	14.3	0.6	42.2	152.0	6.8	1034.5
		Median	43.0	48.9	3.3	448.0	515.5	34.0	1042.0
		Mean	44.9	47.1	7.9	471.1	489.4	82.5	1043.0
		3 rd Qu.	85.2	78.6	14.8	896.8	810.8	150.8	1059.0
		Max.	90.7	85.6	23.2	966.0	891.0	245.0	1067.0
		Std. Dev.	43.6	35.9	9.2	458.0	371.0	96.4	19.2

Table A.1 (Continued) : Seasonal and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Season	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
All	All	Min.	1.0	8.6	0.1	11.0	88.0	1.0	929.0
		1 st Qu.	6.5	29.7	0.5	66.5	302.2	5.8	994.5
		Median	39.9	55.5	2.0	448.0	619.0	22.0	1048.0
		Mean	39.1	53.7	7.2	409.3	559.7	75.3	1044.3
		3 rd Qu.	69.7	78.0	13.2	724.2	802.0	138.8	1078.5
		Max.	90.7	89.8	32.4	996.0	979.0	365.0	1173.0
		Std. Dev.	32.7	26.7	8.9	343.3	277.8	94.9	57.6

Table A.2 : Monthly percentages and counts of Liu-liang stability regimes for eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Month	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
İstanbul	Sep	35.6	50.2	14.2	235	331	94	660
	Oct	36.8	54.9	8.3	266	397	60	723
	Nov	36.0	61.4	2.7	255	435	19	709
	Dec	30.2	68.8	1.0	216	492	7	715
	Jan	30.1	67.4	2.5	219	491	18	728
	Feb	34.5	62.8	2.7	240	437	19	696
	Mar	38.7	57.0	4.3	297	437	33	767
	Apr	42.0	51.7	6.4	317	390	48	755
	May	39.4	51.4	9.2	282	368	66	716
	Jun	33.5	53.3	13.2	244	388	96	728
	Jul	30.8	52.5	16.7	238	406	129	773
	Aug	27.7	53.1	19.2	210	403	146	759
İstanbul	Min.	27.7	50.2	1.0	210.0	331.0	7.0	660.0
	1 st Qu.	30.6	52.3	2.7	231.0	389.5	19.0	713.5
	Median	35.0	54.1	7.3	242.0	404.5	54.0	725.5
	Mean	34.6	57.0	8.4	251.6	414.6	61.2	727.4
	3 rd Qu.	37.3	61.7	13.5	270.0	437.0	94.5	756.0
	Max.	42.0	68.8	19.2	317.0	492.0	146.0	773.0
	Std. Dev.	4.3	6.5	6.2	33.3	46.9	46.2	32.4

Table A.2 (Continued) : Monthly percentages and counts of Liu-liang stability regimes for eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Month	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
İzmir	Sep	24.0	65.8	10.2	150	411	64	625
	Oct	30.9	64.5	4.5	199	415	29	643
	Nov	32.3	65.7	2.0	195	396	12	603
	Dec	35.2	64.0	0.8	227	413	5	645
	Jan	30.2	67.6	2.1	199	445	14	658
	Feb	28.3	70.1	1.6	182	450	10	642
	Mar	28.9	68.3	2.8	189	446	18	653
	Apr	33.0	59.9	7.1	228	413	49	690
	May	31.6	58.4	10.0	222	410	70	702
	Jun	30.5	58.6	10.9	215	413	77	705
	Jul	24.1	64.6	11.4	176	472	83	731
	Aug	23.7	65.9	10.4	155	431	68	654
İzmir	Min.	23.7	58.4	0.8	150.0	396.0	5.0	603.0
	1 st Qu.	27.3	63.0	2.1	180.5	412.5	13.5	642.8
	Median	30.4	65.1	5.8	197.0	414.0	39.0	653.5
	Mean	29.4	64.4	6.1	194.8	426.2	41.6	662.6
	3 rd Qu.	31.8	66.3	10.3	216.8	445.2	68.5	693.0
	Max.	35.2	70.1	11.4	228.0	472.0	83.0	731.0
	Std. Dev.	3.8	3.7	4.2	26.0	22.3	29.7	37.0

Table A.2 (Continued) : Monthly percentages and counts of Liu-liang stability regimes for eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Month	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
Isparta	Sep	43.4	45.2	11.3	283	295	74	652
	Oct	44.3	50.3	5.4	305	346	37	688
	Nov	43.9	52.7	3.4	284	341	22	647
	Dec	41.3	57.3	1.4	305	423	10	738
	Jan	36.7	62.4	0.9	247	420	6	673
	Feb	34.8	62.1	3.1	180	321	16	517
	Mar	33.9	61.8	4.3	222	405	28	655
	Apr	39.4	53.6	7.0	255	347	45	647
	May	42.2	49.9	7.9	250	296	47	593
	Jun	43.1	45.8	11.1	295	314	76	685
	Jul	36.2	48.7	15.2	229	308	96	633
	Aug	40.0	51.1	8.9	246	314	55	615
Isparta	Min.	33.9	45.2	0.9	180.0	295.0	6.0	517.0
	1 st Qu.	36.6	49.6	3.3	241.8	312.5	20.5	628.5
	Median	40.7	51.9	6.2	252.5	331.0	41.0	649.5
	Mean	39.9	53.4	6.7	258.4	344.2	42.7	645.2
	3 rd Qu.	43.2	58.4	9.5	286.8	361.5	59.8	676.0
	Max.	44.3	62.4	15.2	305.0	423.0	96.0	738.0
	Std. Dev.	3.7	6.2	4.4	37.7	46.8	28.5	54.9

Table A.2 (Continued) : Monthly percentages and counts of Liu-liang stability regimes for eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Month	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
Ankara	Sep	35.9	49.2	14.8	237	325	98	660
	Oct	39.1	52.4	8.5	254	340	55	649
	Nov	38.1	58.2	3.7	248	379	24	651
	Dec	33.1	63.9	3.0	229	442	21	692
	Jan	30.9	67.6	1.5	206	451	10	667
	Feb	30.4	65.9	3.7	197	428	24	649
	Mar	28.4	67.0	4.6	208	491	34	733
	Apr	34.9	55.6	9.6	251	400	69	720
	May	37.8	51.2	11.0	284	385	83	752
	Jun	35.7	51.3	13.0	255	366	93	714
	Jul	27.1	55.1	17.8	180	366	118	664
	Aug	27.9	55.7	16.3	190	379	111	680
Ankara	Min.	27.1	49.2	1.5	180.0	325.0	10.0	649.0
	1 st Qu.	29.9	52.1	3.7	203.8	366.0	24.0	657.8
	Median	34.0	55.6	9.0	233.0	382.0	62.0	673.5
	Mean	33.3	57.8	9.0	228.2	396.0	61.7	685.9
	3 rd Qu.	36.4	64.4	13.5	251.8	431.5	94.2	715.5
	Max.	39.1	67.6	17.8	284.0	491.0	118.0	752.0
	Std. Dev.	4.2	6.7	5.7	31.8	48.5	38.6	35.8

Table A.2 (Continued) : Monthly percentages and counts of Liu-liang stability regimes for eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Month	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
Erzurum	Sep	44.0	43.5	12.5	295	292	84	671
	Oct	42.1	50.4	7.5	293	351	52	696
	Nov	43.5	50.7	5.7	266	310	35	611
	Dec	61.1	36.2	2.7	471	279	21	771
	Jan	58.7	35.4	5.9	421	254	42	717
	Feb	57.2	38.0	4.8	372	247	31	650
	Mar	41.5	51.2	7.3	284	350	50	684
	Apr	33.5	57.1	9.4	235	401	66	702
	May	38.7	51.7	9.5	277	370	68	715
	Jun	43.6	45.1	11.3	315	326	82	723
	Jul	41.9	45.8	12.3	293	320	86	699
	Aug	42.3	41.8	15.9	307	303	115	725
Erzurum	Min.	33.5	35.4	2.7	235.0	247.0	21.0	611.0
	1 st Qu.	41.8	40.8	5.8	282.2	288.8	40.2	680.8
	Median	42.9	45.4	8.4	294.0	315.0	59.0	700.5
	Mean	45.7	45.6	8.7	319.1	316.9	61.0	697.0
	3 rd Qu.	47.3	50.8	11.6	329.2	350.2	82.5	718.5
	Max.	61.1	57.1	15.9	471.0	401.0	115.0	771.0
	Std. Dev.	8.6	6.9	3.8	68.3	46.1	27.5	40.6

Table A.2 (Continued) : Monthly percentages and counts of Liu-liang stability regimes for eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Month	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
Samsun	Sep	42.9	49.2	7.9	276	317	51	644
	Oct	47.0	49.4	3.6	326	343	25	694
	Nov	49.9	49.2	0.9	349	344	6	699
	Dec	45.2	53.8	1.0	320	381	7	708
	Jan	37.8	61.8	0.4	278	454	3	735
	Feb	35.7	63.4	0.9	252	447	6	705
	Mar	48.1	50.4	1.6	371	389	12	772
	Apr	57.3	41.7	0.9	441	321	7	769
	May	55.9	41.6	2.5	447	333	20	800
	Jun	53.8	38.6	7.6	383	275	54	712
	Jul	46.4	43.1	10.5	333	309	75	717
	Aug	41.2	47.7	11.0	291	337	78	706
Samsun	Min.	35.7	38.6	0.4	252.0	275.0	3.0	644.0
	1 st Qu.	42.4	42.8	0.9	287.8	320.0	6.8	703.5
	Median	46.7	49.2	2.0	329.5	340.0	16.0	710.0
	Mean	46.8	49.2	4.1	338.9	354.2	28.7	721.8
	3 rd Qu.	50.9	51.2	7.7	374.0	383.0	51.8	743.5
	Max.	57.3	63.4	11.0	447.0	454.0	78.0	800.0
	Std. Dev.	6.8	7.7	4.0	62.7	54.2	28.1	41.8

Table A.2 (Continued) : Monthly percentages and counts of Liu-liang stability regimes for eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Month	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
Adana	Sep	40.0	50.7	9.2	277	351	64	692
	Oct	50.1	46.7	3.2	392	366	25	783
	Nov	49.1	49.5	1.4	360	363	10	733
	Dec	49.3	49.4	1.3	352	353	9	714
	Jan	48.5	50.7	0.8	362	379	6	747
	Feb	45.3	52.8	1.8	319	372	13	704
	Mar	46.4	48.7	4.9	358	376	38	772
	Apr	42.5	50.4	7.1	293	347	49	689
	May	37.1	54.2	8.7	276	403	65	744
	Jun	23.5	64.5	12.0	172	472	88	732
	Jul	8.2	76.5	15.3	60	561	112	733
	Aug	15.0	69.8	15.2	115	536	117	768
Adana	Min.	8.2	46.7	0.8	60.0	347.0	6.0	689.0
	1 st Qu.	33.7	49.5	1.7	250.0	360.5	12.2	711.5
	Median	43.9	50.7	6.0	306.0	374.0	43.5	733.0
	Mean	37.9	55.3	6.8	278.0	406.6	49.7	734.2
	3 rd Qu.	48.6	56.7	9.9	358.5	420.2	70.8	752.2
	Max.	50.1	76.5	15.3	392.0	561.0	117.0	783.0
	Std. Dev.	14.4	9.5	5.4	107.0	74.4	39.9	30.7

Table A.2 (Continued) : Monthly percentages and counts of Liu-liang stability regimes for eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Month	Percent (%)			Count			Total
		SBL	NRL	UBL	SBL	NRL	UBL	
Diyarbakır	Sep	49.0	39.3	11.7	331	265	79	675
	Oct	46.3	46.7	7.0	339	342	51	732
	Nov	47.1	50.6	2.2	296	318	14	628
	Dec	45.1	54.0	1.0	324	388	7	719
	Jan	42.6	54.3	3.1	302	385	22	709
	Feb	41.2	52.9	5.9	270	347	39	656
	Mar	42.3	49.6	8.1	310	363	59	732
	Apr	45.1	46.4	8.5	308	317	58	683
	May	45.5	42.8	11.7	312	293	80	685
	Jun	45.1	41.4	13.5	311	285	93	689
	Jul	45.8	42.2	12.0	331	305	87	723
	Aug	47.0	43.1	10.0	335	307	71	713
Diyarbakır	Min.	41.2	39.3	1.0	270.0	265.0	7.0	628.0
	1 st Qu.	44.4	42.6	5.2	306.5	302.0	34.8	681.0
	Median	45.3	46.6	8.3	311.5	317.5	58.5	699.0
	Mean	45.2	46.9	7.9	314.1	326.2	55.0	695.3
	3 rd Qu.	46.5	51.2	11.7	331.0	351.0	79.2	720.0
	Max.	49.0	54.3	13.5	339.0	388.0	93.0	732.0
	Std. Dev.	2.2	5.3	4.2	19.6	39.1	29.1	32.1
All	Min.	8.2	35.4	0.4	60.0	247.0	3.0	517.0
	1st Qu.	33.4	49.1	2.7	227.8	324.0	19.0	659.5
	Median	39.7	52.1	7.1	276.5	369.0	49.0	702.0
	Mean	39.1	53.7	7.2	272.9	373.1	50.2	696.2
	3rd Qu.	45.1	61.5	11.0	312.8	413.0	76.2	728.0
	Max.	61.1	76.5	19.2	471.0	561.0	146.0	800.0
	Std. Dev.	9.1	8.8	4.9	70.7	62.1	34.7	47.7

Table A.3 : Monthly and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Month	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
İstanbul	00Z	Sep	63.0	36.4	0.6	215	124	2	341
		Oct	64.5	35.2	0.3	233	127	1	361
		Nov	59.7	40.0	0.3	212	142	1	355
		Dec	48.3	51.7	0.0	172	184	0	356
		Jan	47.8	51.9	0.3	173	188	1	362
		Feb	49.6	50.4	0.0	171	174	0	345
		Mar	59.7	40.0	0.3	230	154	1	385
		Apr	65.8	34.0	0.3	248	128	1	377
		May	64.8	34.9	0.3	230	124	1	355
		Jun	56.7	42.1	1.1	206	153	4	363
		Jul	54.6	45.4	0.0	212	176	0	388
		Aug	47.2	52.2	0.5	180	199	2	381
	12Z	Sep	6.3	64.9	28.8	20	207	92	319
		Oct	9.1	74.6	16.3	33	270	59	362
		Nov	12.1	82.8	5.1	43	293	18	354
		Dec	12.3	85.8	1.9	44	308	7	359
		Jan	12.6	82.8	4.6	46	303	17	366
		Feb	19.7	74.9	5.4	69	263	19	351
		Mar	17.5	74.1	8.4	67	283	32	382
		Apr	18.3	69.3	12.4	69	262	47	378
		May	14.4	67.6	18.0	52	244	65	361
		Jun	10.4	64.4	25.2	38	235	92	365
		Jul	6.8	59.7	33.5	26	230	129	385
		Aug	7.9	54.0	38.1	30	204	144	378
İstanbul	All	Min.	6.3	34.0	0.0	20.0	124.0	0.0	319.0
		1 st Qu.	12.2	41.6	0.3	43.8	153.8	1.0	355.0
		Median	33.5	53.1	1.5	120.0	201.5	5.5	362.0
		Mean	34.6	57.0	8.4	125.8	207.3	30.6	363.7
		3 rd Qu.	57.5	70.5	13.4	212.0	262.2	50.0	378.0
		Max.	65.8	85.8	38.1	248.0	308.0	144.0	388.0
		Std. Dev.	23.5	16.7	11.9	85.6	60.7	43.6	16.3

Table A.3 (Continued) : Monthly and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Month	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
İzmir	00Z	Sep	45.0	54.3	0.6	140	169	2	311
		Oct	58.0	41.1	0.9	185	131	3	319
		Nov	59.9	39.5	0.7	179	118	2	299
		Dec	59.1	40.9	0.0	191	132	0	323
		Jan	52.1	47.3	0.6	171	155	2	328
		Feb	51.7	48.0	0.3	165	153	1	319
		Mar	54.3	45.7	0.0	176	148	0	324
		Apr	61.4	38.6	0.0	212	133	0	345
		May	59.2	40.5	0.3	205	140	1	346
		Jun	56.4	42.8	0.8	199	151	3	353
		Jul	43.0	56.2	0.8	156	204	3	363
		Aug	40.6	58.8	0.6	132	191	2	325
	12Z	Sep	3.2	77.1	19.7	10	242	62	314
		Oct	4.3	87.7	8.0	14	284	26	324
		Nov	5.3	91.4	3.3	16	278	10	304
		Dec	11.2	87.3	1.6	36	281	5	322
		Jan	8.5	87.9	3.6	28	290	12	330
		Feb	5.3	92.0	2.8	17	297	9	323
		Mar	4.0	90.6	5.5	13	298	18	329
		Apr	4.6	81.2	14.2	16	280	49	345
		May	4.8	75.8	19.4	17	270	69	356
		Jun	4.5	74.4	21.0	16	262	74	352
		Jul	5.4	72.8	21.7	20	268	80	368
		Aug	7.0	72.9	20.1	23	240	66	329
İzmir	All	Min.	3.2	38.6	0.0	10.0	118.0	0.0	299.0
		1 st Qu.	5.1	45.0	0.6	16.8	150.2	2.0	321.2
		Median	25.9	65.8	1.2	84.0	222.0	4.0	326.5
		Mean	29.5	64.4	6.1	97.4	213.1	20.8	331.3
		3 rd Qu.	54.8	82.7	9.6	176.8	278.5	31.8	345.2
		Max.	61.4	92.0	21.7	212.0	298.0	80.0	368.0
		Std. Dev.	24.9	19.9	8.1	82.2	66.1	28.2	18.2

Table A.3 (Continued) : Monthly and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Month	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
Isparta	00Z	Sep	84.0	15.6	0.3	274	51	1	326
		Oct	82.7	17.3	0.0	286	60	0	346
		Nov	83.9	15.8	0.3	271	51	1	323
		Dec	70.1	29.4	0.5	260	109	2	371
		Jan	62.3	37.7	0.0	210	127	0	337
		Feb	63.5	36.2	0.4	165	94	1	260
		Mar	64.6	35.4	0.0	212	116	0	328
		Apr	75.2	24.5	0.3	245	80	1	326
		May	78.8	21.2	0.0	231	62	0	293
		Jun	80.6	19.1	0.3	275	65	1	341
		Jul	71.6	28.4	0.0	227	90	0	317
		Aug	77.9	22.1	0.0	240	68	0	308
	12Z	Sep	2.8	74.8	22.4	9	244	73	326
		Oct	5.6	83.6	10.8	19	286	37	342
		Nov	4.0	89.5	6.5	13	290	21	324
		Dec	12.3	85.6	2.2	45	314	8	367
		Jan	11.0	87.2	1.8	37	293	6	336
		Feb	5.8	88.3	5.8	15	227	15	257
		Mar	3.1	88.4	8.6	10	289	28	327
		Apr	3.1	83.2	13.7	10	267	44	321
		May	6.3	78.0	15.7	19	234	47	300
		Jun	5.8	72.4	21.8	20	249	75	344
		Jul	0.6	69.0	30.4	2	218	96	316
		Aug	2.0	80.1	17.9	6	246	55	307
Isparta	All	Min.	0.6	15.6	0.0	2.0	51.0	0.0	257.0
		1 st Qu.	5.2	23.9	0.2	14.5	77.0	0.8	314.0
		Median	37.3	53.3	1.2	105.0	172.5	4.0	326.0
		Mean	39.9	53.4	6.7	129.2	172.1	21.3	322.6
		3 rd Qu.	75.8	83.3	11.5	241.2	253.5	38.8	338.0
		Max.	84.0	89.5	30.4	286.0	314.0	96.0	371.0
		Std. Dev.	36.0	29.7	9.0	117.4	97.0	29.0	26.9

Table A.3 (Continued) : Monthly and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Month	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
Ankara	00Z	Sep	70.6	28.2	1.2	235	94	4	333
		Oct	76.9	22.7	0.3	247	73	1	321
		Nov	76.2	23.5	0.3	243	75	1	319
		Dec	59.2	38.8	2.0	203	133	7	343
		Jan	52.0	47.7	0.3	173	159	1	333
		Feb	58.3	41.7	0.0	187	134	0	321
		Mar	56.7	43.3	0.0	202	154	0	356
		Apr	70.6	28.9	0.6	247	101	2	350
		May	73.9	25.8	0.3	275	96	1	372
		Jun	68.0	30.6	1.4	242	109	5	356
		Jul	54.3	44.8	0.9	177	146	3	326
		Aug	54.5	44.9	0.6	186	153	2	341
	12Z	Sep	0.6	70.6	28.7	2	231	94	327
		Oct	2.1	81.4	16.5	7	267	54	328
		Nov	1.5	91.6	6.9	5	304	23	332
		Dec	7.4	88.5	4.0	26	309	14	349
		Jan	9.9	87.4	2.7	33	292	9	334
		Feb	3.0	89.6	7.3	10	294	24	328
		Mar	1.6	89.4	9.0	6	337	34	377
		Apr	1.1	80.8	18.1	4	299	67	370
		May	2.4	76.1	21.6	9	289	82	380
		Jun	3.6	71.8	24.6	13	257	88	358
		Jul	0.9	65.1	34.0	3	220	115	338
		Aug	1.2	66.7	32.2	4	226	109	339
Ankara	All	Min.	0.6	22.7	0.0	2.0	73.0	0.0	319.0
		1 st Qu.	2.0	36.7	0.5	6.8	127.0	1.8	328.0
		Median	30.9	56.4	2.4	103.0	189.5	8.0	338.5
		Mean	33.6	57.5	8.9	114.1	198.0	30.8	343.0
		3 rd Qu.	61.4	81.0	16.9	211.0	289.8	57.2	356.0
		Max.	76.9	91.6	34.0	275.0	337.0	115.0	380.0
		Std. Dev.	32.0	24.7	11.4	108.9	87.4	39.4	18.3

Table A.3 (Continued) : Monthly and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Month	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
Erzurum	00Z	Sep	85.7	14.0	0.3	288	47	1	336
		Oct	79.5	19.1	1.4	275	66	5	346
		Nov	79.2	18.8	2.0	240	57	6	303
		Dec	81.3	17.4	1.3	309	66	5	380
		Jan	74.2	21.9	3.9	268	79	14	361
		Feb	76.9	20.3	2.8	250	66	9	325
		Mar	70.3	28.5	1.2	239	97	4	340
		Apr	63.5	35.9	0.6	219	124	2	345
		May	72.4	27.0	0.6	257	96	2	355
		Jun	79.2	19.7	1.1	285	71	4	360
		Jul	75.7	23.5	0.9	261	81	3	345
		Aug	80.1	18.8	1.1	290	68	4	362
	12Z	Sep	2.1	73.1	24.8	7	245	83	335
		Oct	5.1	81.4	13.4	18	285	47	350
		Nov	8.4	82.1	9.4	26	253	29	308
		Dec	41.4	54.5	4.1	162	213	16	391
		Jan	43.0	49.2	7.9	153	175	28	356
		Feb	37.5	55.7	6.8	122	181	22	325
		Mar	13.1	73.5	13.4	45	253	46	344
		Apr	4.5	77.6	17.9	16	277	64	357
		May	5.6	76.1	18.3	20	274	66	360
		Jun	8.3	70.2	21.5	30	255	78	363
		Jul	9.0	67.5	23.4	32	239	83	354
		Aug	4.7	64.7	30.6	17	235	111	363
Erzurum	All	Min.	2.1	14.0	0.3	7.0	47.0	1.0	303.0
		1 st Qu.	8.4	20.2	1.2	29.0	70.2	4.0	339.0
		Median	53.2	42.5	4.0	190.5	149.5	15.0	352.0
		Mean	45.9	45.4	8.7	159.5	158.5	30.5	348.5
		3 rd Qu.	77.5	71.0	14.6	262.8	247.0	51.2	360.2
		Max.	85.7	82.1	30.6	309.0	285.0	111.0	391.0
		Std. Dev.	33.4	25.4	9.4	116.1	88.4	33.3	20.1

Table A.3 (Continued) : Monthly and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Month	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
Samsun	00Z	Sep	77.0	22.7	0.3	255	75	1	331
		Oct	71.3	28.5	0.3	258	103	1	362
		Nov	79.1	20.6	0.3	280	73	1	354
		Dec	66.5	33.0	0.6	234	116	2	352
		Jan	57.9	41.8	0.3	213	154	1	368
		Feb	49.9	50.1	0.0	177	178	0	355
		Mar	59.4	39.5	1.0	230	153	4	387
		Apr	69.2	30.8	0.0	265	118	0	383
		May	76.6	23.4	0.0	305	93	0	398
		Jun	85.0	15.0	0.0	300	53	0	353
		Jul	80.3	19.4	0.3	289	70	1	360
		Aug	75.5	24.0	0.6	274	87	2	363
	12Z	Sep	6.7	77.3	16.0	21	242	50	313
		Oct	20.5	72.3	7.2	68	240	24	332
		Nov	20.0	78.6	1.4	69	271	5	345
		Dec	24.2	74.4	1.4	86	265	5	356
		Jan	17.7	81.7	0.5	65	300	2	367
		Feb	21.4	76.9	1.7	75	269	6	350
		Mar	36.6	61.3	2.1	141	236	8	385
		Apr	45.6	52.6	1.8	176	203	7	386
		May	35.3	59.7	5.0	142	240	20	402
		Jun	23.1	61.8	15.0	83	222	54	359
		Jul	12.3	66.9	20.7	44	239	74	357
		Aug	5.0	72.9	22.2	17	250	76	343
Samsun	All	Min.	5.0	15.0	0.0	17.0	53.0	0.0	313.0
		1 st Qu.	21.2	27.3	0.3	73.5	100.5	1.0	351.5
		Median	47.7	51.4	0.8	176.5	190.5	3.0	358.0
		Mean	46.5	49.4	4.1	169.5	177.1	14.3	360.9
		3 rd Qu.	72.3	72.4	2.8	259.8	240.5	11.0	371.8
		Max.	85.0	81.7	22.2	305.0	300.0	76.0	402.0
		Std. Dev.	27.0	22.9	6.9	98.7	79.3	23.7	21.4

Table A.3 (Continued) : Monthly and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Month	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
Adana	00Z	Sep	77.4	21.4	1.1	271	75	4	350
		Oct	96.7	2.8	0.5	377	11	2	390
		Nov	95.3	4.1	0.5	348	15	2	365
		Dec	88.7	9.9	1.4	314	35	5	354
		Jan	86.7	13.3	0.0	326	50	0	376
		Feb	87.1	12.9	0.0	305	45	0	350
		Mar	88.3	11.2	0.5	340	43	2	385
		Apr	83.4	15.4	1.2	287	53	4	344
		May	72.2	27.2	0.5	268	101	2	371
		Jun	44.2	53.6	2.2	161	195	8	364
		Jul	16.1	81.5	2.5	59	299	9	367
		Aug	28.6	70.4	1.0	111	273	4	388
	12Z	Sep	1.8	80.7	17.5	6	276	60	342
		Oct	3.8	90.3	5.9	15	355	23	393
		Nov	3.3	94.6	2.2	12	348	8	368
		Dec	10.6	88.3	1.1	38	318	4	360
		Jan	9.7	88.7	1.6	36	329	6	371
		Feb	4.0	92.4	3.7	14	327	13	354
		Mar	4.7	86.0	9.3	18	333	36	387
		Apr	1.7	85.2	13.0	6	294	45	345
		May	2.1	81.0	16.9	8	302	63	373
		Jun	3.0	75.3	21.7	11	277	80	368
		Jul	0.3	71.6	28.1	1	262	103	366
		Aug	1.1	69.2	29.7	4	263	113	380
Adana	All	Min.	0.3	2.8	0.0	1.0	11.0	0.0	342.0
		1 st Qu.	3.2	14.9	0.9	11.8	52.2	3.5	354.0
		Median	13.3	71.0	1.9	48.5	268.0	7.0	367.5
		Mean	37.9	55.3	6.8	139.0	203.3	24.8	367.1
		3 rd Qu.	84.2	85.4	10.2	291.5	306.0	38.2	377.0
		Max.	96.7	94.6	29.7	377.0	355.0	113.0	393.0
		Std. Dev.	39.6	34.7	9.3	145.4	128.4	34.2	15.2

Table A.3 (Continued) : Monthly and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Month	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
Diyarbakır	00Z	Sep	93.1	6.9	0.0	324	24	0	348
		Oct	89.2	9.7	1.1	323	35	4	362
		Nov	89.8	9.2	1.0	282	29	3	314
		Dec	79.3	20.1	0.6	284	72	2	358
		Jan	77.5	21.6	0.8	276	77	3	356
		Feb	75.1	24.3	0.6	247	80	2	329
		Mar	79.5	19.7	0.8	295	73	3	371
		Apr	83.5	16.5	0.0	288	57	0	345
		May	87.6	11.8	0.6	303	41	2	346
		Jun	88.5	11.0	0.6	307	38	2	347
		Jul	89.1	10.3	0.5	328	38	2	368
		Aug	94.0	5.4	0.6	331	19	2	352
	12Z	Sep	2.1	73.7	24.2	7	241	79	327
		Oct	4.3	83.0	12.7	16	307	47	370
		Nov	4.5	92.0	3.5	14	289	11	314
		Dec	11.1	87.5	1.4	40	316	5	361
		Jan	7.4	87.3	5.4	26	308	19	353
		Feb	7.0	81.7	11.3	23	267	37	327
		Mar	4.2	80.3	15.5	15	290	56	361
		Apr	5.9	76.9	17.2	20	260	58	338
		May	2.7	74.3	23.0	9	252	78	339
		Jun	1.2	72.2	26.6	4	247	91	342
		Jul	0.8	75.2	23.9	3	267	85	355
		Aug	1.1	79.8	19.1	4	288	69	361
Diyarbakır	All	Min.	0.8	5.4	0.0	3.0	19.0	0.0	314.0
		1 st Qu.	4.3	11.6	0.6	14.8	40.2	2.0	338.8
		Median	43.1	48.3	1.2	143.5	160.5	4.5	350.0
		Mean	44.9	47.1	8.0	157.0	163.1	27.5	347.7
		3 rd Qu.	87.8	79.9	15.9	297.0	272.2	56.5	361.0
		Max.	94.0	92.0	26.6	331.0	316.0	91.0	371.0
		Std. Dev.	41.7	34.5	9.6	146.3	119.3	33.0	16.4

Table A.3 (Continued) : Monthly and hourly percentages and counts of Liu-liang stability regimes across eight cities. Maximum and minimum values in each column are highlighted in red and blue, respectively.

City	Hour	Month	Percent (%)			Count			Total
			SBL	NRL	UBL	SBL	NRL	UBL	
All	All	Min.	0.3	2.8	0.0	1.0	11.0	0.0	257.0
		1 st Qu.	5.5	28.4	0.5	18.8	96.0	2.0	329.0
		Median	41.0	55.1	1.6	141.5	203.5	5.5	350.5
		Mean	39.1	53.7	7.2	136.4	186.6	25.1	348.1
		3 rd Qu.	71.4	77.4	13.4	243.5	269.2	47.0	363.0
		Max.	96.7	94.6	38.1	377.0	355.0	144.0	402.0
		Std. Dev.	32.8	26.9	9.5	115.1	93.9	33.4	24.1

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- **Sezen I.**, Ercelik E., Ghale Y. A. G., Deniz, A., Unal A. (2023). Application of Kolmogorov-Zurbenko filter to quantify the long-term meteorological and emission impacts on air quality *Atmospheric Research*, 288 (2023),106714.

OTHER PUBLICATIONS, PRESENTATIONS AND PATENTS: