ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

GÖKÇEADA MOMENTUM, HEAT AND MOISTURE FLUXES ANALYSIS

M.Sc. THESIS

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LIST OF SYMBOLS

ρ Density of air.
λ Latent heat of vaporization.
ψ_h M-O similarity function for normalized potential temperature.
ψ_Q M-O similarity function for normalized specific humidity.
ψ_m M-O similarity function for normalized velocity.
τ Momentum heat flux.
ζ Monin-Obukhov stability parameter.
θ_1 Potential temperature at z_1 .
θ_2 Potential temperature at z_2 .
θ_* Temperature scale.
λE Latent heat flux.
C_p Specific temperature at constant pressure.
C_H Transfer coefficient for heat.
C_Q Transfer coefficient for moisture.
C_M Transfer coefficient for momentum.
g Acceleration due to gravity.
H Sensible heat flux.
k Von Karman constant.
L Obukhov stability parameter.
Q_* Humidity scale.
q_1 Specific humidity at z_1 .
q_2 Specific humidity at z_2 .
RH_1 Relative humidity at z_1 .
RH_2 Relative humidity at z_2 .
T_2 Temperature at z_2 .
T_1 Temperature at z_1 .
u_* Frictional velocity.

u_2	Wind speed at z_2.
z_2	Second level measuring height ($z_2 > z_1$).
$z_\circ$	Surface roughness length.
z_1	First level measuring height.

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SUMMARY

The growing interest in the interaction between the atmosphere and the underlying surface is driven by the realization that the surface fluxes of momentum, heat, and moisture determine to an important extent the steady state of the atmosphere. The purpose of this thesis is to analysis the surface fluxes at Gökçeada.

In this study the data gared at 2 and 10 m meteorological most of Gökçeada (40° 11 N, 25° 54 E) in the center part and coastal part of island (Ugurlu) are analyzed. The wind, temperature and relative humidity measurements at Maslak (I.T.U) observation park are also taken in to account for calibration and test analysis.

The surface fluxes of momentum, sensible heat and latent heat are calculated by using the atmospheric surface layer model based on M-O similarity theory (Beliaars and Holtslag ;1990) . To define roughness height 12 sectors are consider at all three station.

Momentum fluxes observed at the Ugurlu is 1.4 times grater than central part of Gökçeada, where is considered a rural part of island. 1.2 times grater latent heat fluxes are observed at Ugurlu. The maximum upward sensible heat flux is observed in central part but the maximum downward sensible heat fluxes are observed in Ugurlu.

In this thesis, at two different places, one is urban and the other rural, the range and time variation of fluxes are studied . These result would also apply on the fields of "air-pollution modeling", "hydrology" and "wind energy". Only the limitation is data recorded in autumn, and the results encode us for further studies.

ÖZET

GÖKÇEADA'DA ISI VE MOMENTUM AKILARININ ETÜDÜ

Son yıllarda, atmosferik yüzey tabaka içindeki yüzey akılarının (momentum, türbülanslı gizli ısı ve buharlaşma gizli ısı akıları) incelenmesi konusundaki çalışmalara büyük önem verilmektedir Yüzey ısı akıları konusu yüzey tabakanın dolayısı ile de atmosferik sınır tabakanın ortalama profillerinin belirlenmesi açısından da önem taşımaktadır. Akı değerlerinin bilinmesi, kısa süreli tahmin çalışmalarında ve Atmosferik Sınır Tabaka parametrelerinin saptanmasında da gereklidir. Ayrıca, akılarla ilgili parametreler ve Atmosferik Sınır Tabakanın yüksekliği, hava kirliliği ve okyanus dalga modelleri ile ilgili çalışmalarda yüzey akılarına bağlı girdi parametreleri olarak gözönüne alınır.

Deneysel çalışmalar ve modellemelerde, yüzeydeki momentum, türbülanslı ve buharlaşma gizli akıları rutin olarak ölçülen meteorolojik parametrelerden hesaplanmaktadır, (Holtslag ve Val Ulden (1983), Van Ulden ve Holtslag (1985), Holtslag ve Debruin (1988). Bu çalışmaların amacı, Monin-Obukhov (M-O) teorisine dayalı olarak, hava kirliliği, hidroloji ve rüzgar enerjisi alanlarında atmosfer kararsızlığı sınıflamasına, bir yaklaşım getirmektir. Akılarla ilgili bu incelemeler, kısa vade hava tahmin modellerine de baz oluşturmaktadır, Holtslag ve grubu (1990).

Yüzey akıları, bitki örtüsü, toprak tipi, nemi, kar örtüsü, drenajı vb. pekçok parametreye bağlıdır. Kara yüzeyleri üzerindeki atmosferik model çalışmaları için yüzey ısı akıları Beljaars ve Holtslag (1990) tarafından hesaplanmıştır.

Burada sunulan çalışmada ortalama yer seviyesinden 2m-10m yukarıdaki yüzey tabakanın yere yakın kısmında, türbülanslı gizli ısı, buharlaşma gizli ısısı ve momentum akılarının zamansal değişimleri incelenmiştir. Çalışma üç ayrı bölgede yürütülmüştür:

i) Gökçeada DMI Istasyonu (rakımı: 71m),
ii) Gökçeada Uğurlu Istasyonu (rakım:139m),
iii) Maslak ITÜ Gözlem Parkı (rakım:139m).

Gözönüne alınan bu üç bölge deniz-kara etkileşiminin etkisinde kalmakta olup, Uğurlu Istasyonu, Maslak ve Gökçeada (DMI) Istasyonlarına nazaran mikro ölçekte daha homojen bir topoğrafyaya sahip bulunmaktadır. Bu nedenle bu iki istasyona ait analizlerin yatay ölçekte sadece 2-3km'ye kadar geçerli olduğu söylenebilir. Ancak Uğurlu istasyonunda hesaplanan değerler yaklaşık 10km'ye kadar temsili olabilmektedir.

Burada sunulan çalışmanın ilk kısmı verilerin toplanması ile ilgili olup, deneysel kısmı oluşturmaktadır. Gözlem verilerine dayalı olarak hesaplanan akı değerlerinin zaman serilerinin incelenmesi ve sonuçların karşılaştırılması ise çalışmanın teorik model kısmında ele alınmaktadır. Verilerin gözlenmesi ile ilgili alan çalışmasında öncelikle mevcut sistemler saptanmış ve gerekli diğer ölçüm sistemleri belirlenmiştir. Bu çalışmada kullanılmak üzere saptanan mevcut sistemler

i) Gökçeada (DMI) Istasyonu'nda

a) mekanik rüzgar hızı kayıt sistemi(ortalama yer seviyesinden (o.y.s) 10 m yukarıda ve saatlik ortalamalar şeklinde, rüzgar hızı (yön ve şiddet ölçümü için),
b) termograf (o.y.s'den 2 m yukarıda, saatlik sıcaklık ölçümü için),
c) higrograf (o.y.s'den 2 m yukarıda saatlik bağıl nem ölçümü için),

ii) Uğurlu Istasyonun'da

a) digital rüzgar hızı ölçüm sistemi (o.y.s'den 2 m ve 1m yukarıda),
b) digital sıcaklık ölçüm sistemi (o.y.s'den 4 m yukarıda),

iii) Maslak ITÜ Gözlem Parkında

a) anemometre (o.y.s'den 2m yukarıda, 7:00, 14:00 ve 21:00 (lokal)'de günde üz kez rüzgar hızı ölçümü için),
b) termograf (o.y.s'den 2 m yukarıda),
c) higrograf (o.y.s'den 2 m yukarıda).

Burada sunulan çalışmanın amacı doğrultusunda ek olarak bu istasyonlara monte edilen ölçüm sistemleri

a) digital sıcaklık ve nem ölçüm sistemi (o.y.s'den 2 m yukarıda 2 dakika- bir saatlik periyotlarda, sıcaklık, bağıl nem ortalama değerlerini ölçmek için ITÜ-Maslak Meteoroloji Istasyonu'na monte edilen sistem),*
b) termograf (o.y.s'den 2m yukarıda),**
b) higrograf (o.y.s'den 2m yukarıda),**

Çalışmada 28 Ekim-14 Kasım 1992 tarihleri arasında Gökçeada (DMI), Uğurlu ve Maslak istasyonları saatlik gözlem verilerine dayalı olarak ısı akısı değerleri hesaplanmıştır. Ölçüm kalibrasyon ve model test çalışmaları için ITÜ Maslak istasyonuna ait Ocak-Nisan 1993 verileri gözönüne alınmıştır. Teorik modele dayalı olarak ısı akılarının hesaplanabilmesi için digital gözlem verileri direkt olarak, mekanik olanlar ise diyagramlardan değerlendirilerek veya tablolardan alınarak bilgisayara yüklenmiştir. Bu şekilde elde edilen yüzey gözlemlerine ek olarak ilgili günlere ait Göztepe radyosonde verileri de gözönüne alınmıştır.

* ITÜ Fen Bilimleri Enstitüsü tarafından desteklenen yüksek lisans tezi projesi çerçevesinde alınmıştır.
** Gökçeada DMI Istasyonu yedek aletleri geçici süreyle Uğurlu Istasyonu'na monte edilmiştir. (Yazıcı sistemler, ITÜ Meteoroloji Mühendisliği Bölümü'nde Doç. Dr. Selahattin Incecik tarafından yapılan bir araştırma çerçevesinde yaptırılan ve bu çalışma için Gökçeada'ya nakledilen siper içine yerleştirilmiştir).

Çalışmanın teorik bölümünde saptanması gereken parametreler arasında öncelikle pürüzlülük yüksekliğinin (z_o) belirlenmesi gerekmektedir. Gökçeada (DMI) ve Uğurlu istasyonları pürüzlülük yüksekliği değerlerinin saptanması için her iki bölgenin 30 derecelik açılarla incelenen 12 sektördeki pürüzlülük parametresinin ortalama değerleri kullanılmıştır. Bu aşamada Wieringa (1981), ve Erkmen (1969)tarafından sunulan farklı yüzey karakteristikleri için sınırfandırılmış z_o değerlerinden yararlanılmıştır. z_o değerleri sırası ile Gökçeada (DMI) istasyonu için 0.52 m, Uğurlu istasyonu için 0.22 m ve Maslak (ITÜ) Maslak Istasyonu için 0.34m olarak alınmıştır.

Atmosferik yüzey tabakadaki model çalışmalarında momentum (τ), türbülanslı gizli ısı (H) ve buharlaşma gizli ısısı (λE) akıları aşağıdaki bağıntılar yardımı ile hesaplanır (Yaglom 1977),

$$\frac{\tau}{\rho u_*} = u_* \qquad (1)$$

$$-\frac{H}{\rho C_p u_*} = \theta_* \qquad (2)$$

$$-\frac{\lambda E}{\rho \lambda u_*} = Q_* \qquad (3)$$

Burada,

u_* sürtünme hızı,

θ_* sıcaklık ölçeği,

Q_* nem ölçeği,

ρ yoğunluk,

λ buharlaşma gizli ısısı,

C_p sabit basınçta özgül ısı.

u_*, θ_* ve Q_*, ısı akısı profili eşitliklerinden hesaplanabilir, Dyer (1974) ve Paulson (1970),

$$u_* = \frac{k u_2}{\ln(z_2 / z_*) - \psi_M (z_2 / L) + \psi_M (z_* / L)} \qquad (4)$$

$$\theta_* = \frac{k(\theta_2 - \theta_1)}{\ln(z_2 / z_1) - \psi_H(z_2 / L) + \psi_H(z_1 / L)} \quad (5)$$

$$Q_* = \frac{k(q_2 - q_1)}{\ln(z_2 / z_1) - \psi_Q(z_2 / L) + \psi_Q(z_1 / L)} \quad (6)$$

Burada,

z_* yüzey pürüzlülük parametresi,

u_1, u_2 iki seviyede ölçülen rüzgar şiddeti,

θ_1, θ_2 iki seviyede ölçülen potansiyel sıcaklık,

q_1, q_2 iki seviyede ölçülen nem miktarı,

k Von Karman sabiti (k= 0.4),

L Monin - Obukhov kararlılık parametresi,

ψ_h, ψ_m ve ψ_Q kararsızlık fonksiyonlarıdır. L, Monin Obukhov uzunluğu,

$$L = \frac{Tu_*^2}{kg\theta_*} \quad (7)$$

bağıntısı ile hesaplanmaktadır. Burada

g yerçekimi ivmesi,

T hava sıcaklığı.

Kararlı atmosferik tabakalaşma için L > 0, kararsız koşullarda ise L < 0, dır. Bu çalışmada saatlik ısı akısı hesaplarında M-O uzunluğunun saptanabilmesi için bir başlangıç L değeri gözönüne alınmıştır. Kararlı günler için L=36 m, kararsız tabakalaşma durumunda ise, L=-36 m başlangıç değerinden hareketle (1)-(6) eşitlikleri kullanılarak yapılan iteratif hesaplamalar sonucunda L'nin aktüel değerine yaklaşılmıştır. En çok üç adımdan sonra L değerleri arasındaki fark %5'den küçük olup, bu L değeri gözönüne alınarak ısı akıları hesaplanmıştır. Kararlılık analizinde iki seviye arasındaki (2m-10m) sıcaklık gradyanı incelenmiştir. Gökçeada (DMI) ve Maslak (ITÜ) gözlem istasyonlarındaki düşey sıcaklık pfrofilini saptayabilmek amacı ile Göztepe radyosonde istasyonu aşağı seviye gözlemleri incelenmiştir. 00:00 GMT ve 12:00 GMT sıcaklık ve nem verileri zamansal ve düşey olarak interpole edilmiş, yukarı seviyedeki (2m-10m) bu sıcaklık ve nem gradyanının Gökçeada ve Maslak istasyonlarında aynı olduğu kabul edilmiştir. Bu kabul altında, 10m yukarıdaki sıcaklık ve nem değerleri hesaplanmış ve her saat için ısı akıları belirlenmiştir.

Momentum, türbülanslı gizli ısı ve nem akılarının hesaplanabilmesi için teorik modele dayalı bir bilgisayar programı hazırlanmış, iki seviyedeki (2m-10m) rüzgar hızı, sıcaklığı ve nem değerleri bu model için girdi verileri olarak kullanılmıştır.

(4), (5) ve (6) numaralı eşitliklerdeki fonksiyonlar kararsız koşullar için aşağıdaki bağıntılara dayalı olarak hesaplanmıştır (Paulson,1970 ve Dyer, 1974)

$$\psi_M = 2\ln\left[\frac{1+x}{2}\right] + \ln\left[\frac{1+x^2}{2}\right] - 2\tan^{-1}(x) + \pi/2 \quad (8)$$

$$\psi_{H,Q} = 2\ln\left[\frac{1+x^2}{2}\right] \quad (9)$$

$$x = \left[1 - 16\frac{z}{L}\right]^{1/4} \quad (10)$$

Kararlı atmosfer koşullarında Webb (1970) tarafından önerilen,

$$\psi_M = \psi_{H,Q} = -5\frac{z}{L} \quad (11)$$

bağıntısı ile Holtslag ve De Bruin (1988) tarafından önerilen:

$$\psi_M = -a\frac{z}{L} - \left[\frac{z}{L} - \frac{c}{d}\right]\exp\left[-d\frac{z}{L}\right] - \frac{bc}{d} \qquad (12)$$

burada,

$$\psi_h = \psi_m = \psi_Q,$$

ve a=0.7, b=0.75, c=5 ve d=0.35 olarak alınmıştır.

Cabauw ve civarı için (12) numaralı bağıntıya dayalı hesaplar ve (11) numaralı bağıntıya dayalı sonuçlar arasında önemsiz bir fark olduğu belirtilmektedir, Holtslag ve De Bruin (1988). Webb (1970) tarafından önerilen (11) numaralı bağıntı yerine (12) numaralı eşitliğin kullanılması için arazinin oldukça düz ve homojen bir yapıda olması koşulu ($0 < z/L < 0.5$) koşulu aranmaktadır Hogstrom (1988).

Burada sunulan çalışmanın sonuçları aşağıda özetlenmektedir. Üçayrı gözlem yeri için z/L oranı 10^{-3} ve 10^{-4} arasında değişmekte olup, gerek (11) ve gerekse (12) numaralı eşitliklere dayalı değerler arasındaki fark değerleri momentum, türbülanslı gizli ısı ve buharlaşma gizli ısı akıları için sırası ile %0.001, %0.01 ve %0.001 mertebelerindedir.

Bu çalışmanın analiz kısmında, Gökçeada için hesaplanan akı değerleri incelenerek, kara-deniz etkileşiminin değerlendirilmesine çalışılmıştır. Gökçeada (DMI) ve Uğurlu istasyonlarında hesaplanan ısı akısı değerleri karşılaştırıldığında, buharlaşma gizli ısı akısı değerlerinin (LAMDA H) ortalama olarak Uğurlu istasyonu'nda 1.2 kez daha büyük olduğu sonucuna varılmıştır. Gökçeada (DMI) istasyonu Ada'nın şehirleşme bölgesinde, Uğurlu ise kırsal kesimde yer almaktadır. Bu nedenle şehirleşmenin olduğu bölgedeki momentum akısı değeri kırsal kesime nazaran 1.5 kez daha azdır. Gözönüne alınan bu iki inceleme bölgesinde hesaplanan türbülanslı gizli ısı akı değerleri arasında önemli fark belirlenmiştir. En yüksek pozitif (yukarıya doğru) SH değerleri DMI istasyonunda, en büyük negatif (aşağı doğru) SH değerleri ise Uğurlu istasyonunda gözlenmiştir.

Hesaplanan ortalama momentum, türbülanslı gizli ısı ve buharlaşma gizli ısı akıları Gökçeada (DMI) için sırası ile 0.27N/m2, 5.76W/m2 ve 3.8W/m2 şeklindedir. Aynı değerler Uğurlu için 0.4N/m2, 6.13W/m2 ve 4.52W/m2 olarak hesaplanmıştır.

Bu çalışmada, gözönüne alınan farklı iki bölge için (şehirsel ve kırsal) momentum, türbülanslı ve buharlaşma gizli ısı akılarının mertebe ve değişim aralığının saptanmasına, kara-deniz etkileşiminin belirlenmesine çalışılmıştır. Sadece sonbahar mevsimi için yürütülen bu çalışmanın Türkiye'nin farklı coğrafi bölgeleri için ve diğer mevsimlerdeki değişimlerin saptanmasına uygulanması bu çalışma ışığında bir sonraki araştırmanın konusunu oluşturabilecektir.

CHAPTER 1

INTRODUCTION

The surface fluxes of heat, water vapor and momentum determine to a great extent the state of the atmosphere boundary layer. As such these fluxes are the principal boundary condition for weather forecast models, air pollution dispersion models, hydrology and wind energy.

In principle the fluxes can be measured, however, usually such measurements are not available, and in a forecast model the fluxes have to be parametrize in terms of variables predicted by the model.

The atmospheric part of the interaction between the atmosphere and the surface takes place in the boundary layer with a constant flux layer near the surface (10 % of the boundary layer depth), where Monin-Obukhov theory applies. M-O similarity theory is a generally accepted framework for describing the surface layer over uniform flat and homogeneous terrain and virtually all numerical models make use of it in one or the other.

The surface fluxes are important not only because they influence the state of the atmosphere, but also because they determine the mean profiles of the surface layer and the atmosphere boundary layer, for example, Holtslag and Nieuwstadt (1986).

Experimental work and modeling efforts have attempted to parametrize the surface fluxes of momentum, heat and moisture in terms of routinely measured meteorological parameters (Holtslag and Van Ulden 1983;

Van Ulden and Holtslag 1985; Holtslag and De Bruin 1988). The purpose of these studies was to make stability classification with help of O-M theory accessible to air pollution model, hydrology and wind energy. The flux schemes are also applied in short-range weather forecast models, Holtslag et al, (1990)

In this study two different pilot area were considered, meteorology station in the center of Gökçeada (40 11N, 25 54 E) and Ugurlu in the southwest costal line as main observation points to compute the momentum, heat and moisture in two different places, one is urban and the other rural, by using model based on Monin-Obukhov similarity theory. Maslak (I.T.U) observation park is considered as a pilot area. Observations, calibration and model test are carried out at Maslak.

The basic philosophy of using this method is to provide optimal result in the same order of magnitude at the atmospheric layer, with minimum input data. A single wind speed at z_2, a surface roughness length, humidity and temperature at two heights z_1 and z_2 where ($z_2 > z_1$), to define roughness height 12 sectors are consider at two station.

The surface fluxes of momentum, sensible heat are calculated by using the atmospheric surface layer model based on M-O similarity theory (Beliaars and Holtslag; 1990). For stable atmospheric stratification two equations sets are used, Webb (1970) and De Bruin (1988). The differences flux values between these two equations under stable condition are in the range of 0.01 % and 0.001 %.

The values of fluxes in Gökçeada in order of magnitude with the result from, Aslan, Topcu, and oney (1991).

CHAPTER 2

METHODS OF DETERMINING MOMENTUM AND HEAT FLUXES

Determination of turbulent exchanges taking place between the earth and the atmosphere near their interface is of primary concern in micrometeorology. A number of methods have been devised with varying degrees of sophistication, some of which will be described hear only briefly. The emphasis here is on principles and techniques, rather than on the details of instrumentation and measurements, Arya(1988).

2.1 Surface-Drag Measurements

The only direct method of measuring shearing stress on a small sample of the surface is through the use of a carefully installed drag plate. The drag measured on sample surface area must be representative of the whole area under consideration. This presumes a reasonably uniform ground cover with small roughness elements, which remain relatively undisturbed by the installation of the drag plate. The original roughness characteristics of the surface are retained or duplicated on the top of the drag plate. The drag plate has a small annular ring around to isolate it from the surrounding area for drag force measurements using strain gauges and electromechanical transducers. The installation and successful operation of a drag plate requires considerable care, skill, and experience. For this reason, such measurements made only for certain experiments or research (e.g., the 1968 Kansas Field Program).

2.2 Energy Balance Method

There is no method exists for directly measuring the surface heat flux. A thin heat flux plate of known conductivity, with an embedded thermopile to measure temperature gradient across the plate, is often used to measure heat flux through the subsurface medium (e.g., soil, ice, and snow). But, to avoid radiative and convective effects the plate must be buried at least 10 mm below the surface. One can determine the ground heat flux H_G after applying an appropriate correction to the heat flux plate measurements. The sensible heat flux at the surface to or from air can be estimated indirectly, by using the surface energy balance or other appropriate energy budget equation and the other components of the energy balance can be estimated.

2.3 Eddy Correlation Method

The most reliable and direct measurements of turbulent exchanges of momentum and heat in the atmosphere are usually made with sophisticated fast-response turbulence instrumentation. If all fluctuation of velocity and temperature that contribute to the desired momentum and heat fluxes are faithfully sensed and recorded, one can determine their covariances simply by averaging the products of the appropriate fluctuations over any desired averaging time. The eddy correlation method of determining fluxes is simple, in practical, it requires expensive research-grad instrumentation, such as sonic, laser, or hot-wire anemometers and fine-resistance thermometers, as well as rapid data acquisition systems. The closer to the surface the turbulence measurements are made, the more severe become the instrument response problem. At heights of large than 10 m or so, light cup, vane, and propeller anemometers may also be adequate for measuring variances and fluxes. Larger averaging times may be required, however, with increasing height of measurement, because the characteristic size of large eddies usually increases with height in the PBL. The requirements of instrument leveling, orientation, calibration, and maintenance are also quit severe for accurate eddy correlation measurements.

The above-mentioned instrumental requirements have kept the eddy correlation method from being widely used, except in special research expeditions . But, continued advances in instruments and data processing might make it more practical in the near future. The method has the advantage of measuring turbulent exchanges directly, without too many restrictive assumptions about the nature of surface or of atmosphere. It is the only method available for measuring turbulent fluxes inside plant canopies, or in the wakes of hills and buildings.

2.4 Bulk Transfer Method

Indirect methods of estimating fluxes from more easily measured mean winds and temperatures in the surface layer or the whole planetary boundary layer (PBL) are based on the appropriate flux-profile relations. The simplest and the most widely used method is the bulk aerodynamic approach. This method can be used when measurements or computations (e.g., in numerical model) of mean velocity and temperature are available only at one level, in conjunction with the desired surface properties (e.g., the surface roughness and temperature).

2.5 Gradient or Aerodynamic Method

In order to use the bulk transfer method, one needs to know the surface roughness and the surface temperature. Such information is not always easy to come by. In fact, for very rough and uneven surfaces, the surface itself is not well defined and its temperature cannot be measured directly. This difficulty can be avoided by making measurements at two or more height in the surface layer. The simple gradient or aerodynamic method determining fluxes from measurements of mean difference or gradients of velocity and temperature between any two heights within the surface layer.

2.6 Profile Method

In order to minimized errors in the estimated fluxes, it is highly desirable to make measurements of mean velocity and temperature at several levels within the surface layer. A good procedure for determining fluxes from such profile measurements is to fit the appropriate flux-profile relations to the observations, using the least-square technique. In this way , the effect of random experimental errors on flux estimates can be minimized. A simple graphical procedure can also be used for the same purpose.

CHAPTER 3

FUNDAMENTAL THEORY AND METHOD

3.1 Monin-Obukhov Similarity Theory

The atmospheric surface layer under neutral conditions is characterized by a logarithmic wind profile and nearly uniform (with respect to height) profiles of momentum flux and standard deviation of turbulent velocity fluctuation. It was also mentioned that the neutral stability condition is an exception rather than the rule in the lower atmosphere. More often, the turbulent exchange of heat between the surface and the atmosphere leads to thermal stratification of the surface layer and, to some extent, of the whole PBL. It is to important to find a suitable theoretical or semiempirical framework for a quantitative description of the mean and turbulence structure of the stratified surface layer. The Monin-Obukhov similarity theory has provided the most suitable and acceptable framework for organizing and presenting the micrometeorological data, for extrapolating and predicting certain micrometeorological information where direct measurements of the same are not available.

3.1.1 The Similarity Hypothesis

The basic similarity hypothesis first proposed by Monin and Obukhov (1954) is that a horizontally homogeneous surface layer the mean flow and turbulent characteristics depend on the following variables

i. The height above the surface .
ii. The friction velocity .
iii. The surface kinematic heat flux .
iv. The buoyancy variable.

The simplifying assumptions implied in this similarity hypothesis are that the flow is horizontally homogeneous and quasistatioary, the turbulent fluxes of momentum and heat are constant (independent of height), the molecular exchange are insignificant in comparison with turbulent exchange, the rotational effects can be ignored in the surface layer, and the in influence of surface roughness, boundary layer height, and geostrophic winds is fully accounted for through U.

Independent variables in the M-O similarity hypothesis involve three fundamental dimensions (length, time, and temperature), according to Buckinghams theorem, only one independent dimensionless combination out of them can be formulate. The combination traditionally chosen in Monin-Obukhov similarity theory is the buoyancy parameter

$$\zeta = Z/L \tag{3.1}$$

where L is an important buoyancy length scale, known as the Obukhov length .

3.1.2 Empirical Forms of Similarity Function

The similarity theory based on a particular similarity hypothesis and dimensional analysis can only give functional relationships between certain dimensionless parameters. It dose not tell any thing about the forms of those function, which must be determined empirically from accurate observation during experiments, specifically designed for this purpose. Experimental verification is also required for the original similarity hypothesis, a number of experiments have been conducted at different location. The 1953 Great Plains Experiment at O'Neill, Nebraska, was one of the earliest concerted efforts in observing the PBL in which measurements were made by several different groups, using different instrumentation and techniques (Lettau and Davidson, 1957).But, as in subsequent Australian and Russian experiments in the 1960, the flux measurements suffered from severe instrument-response problems and were not very reliable. Still, these experiments could verify the general validity of M-O similarity theory and give the approximate forms of the similarity functions $\phi_m(\zeta)$, $\phi_h(\zeta)$ and $\phi_Q(\zeta)$.The experiment conducted so far, for the specific purpose of determining the M-O similarity functions, was the 1968 Kansas Field Program (Izumi, 1971).The flux-profile relation derived from Kansas Experiment are discussed in detail by Businger (1971).

3.2 Method

In atmospheric models the fluxes of momentum (τ), sensible heat (H), and latent heat (λE) are often expressed as (e.g., Louis 1979),

$$\frac{\tau}{\rho} = C_M u_2^2 \tag{3.2}$$

$$-\frac{H}{\rho C_p} = C_H u_2 (\theta_2 - \theta_1) \tag{3.3}$$

$$-\frac{\lambda E}{\rho \lambda} = C_Q u_2 (q_2 - q_1) \tag{3.4}$$

where ρ is the density of air, c_p is the specific heat at constant pressure, λ is the latent heat of vaporization. The symbols u_2 , θ_2 and q_2 are wind speed, potential temperature and specific humidity at level z_2 , θ_1 and q_1 are the corresponding values at level z_1 , and C_M , C_H , C_Q are transfer coefficients for momentum, heat and moisture.

For the surface layer C_M , C_H and C_Q can be derived from surface layer theory, which states that (e.g., Yaglom 1977),

$$\frac{\tau}{\rho u_*} = u_* \tag{3.5}$$

$$-\frac{H}{\rho C_p u_*} = \theta_* \tag{3.6}$$

$$-\frac{\lambda E}{\rho \lambda u_*} = Q_* \tag{3.7}$$

where u_* is the frictional velocity, θ_* is the temperature scale and Q_* is the humidity scale. These relations are based on Monin-Obukhov similarity theory.

A single wind speed u_2 at level z_2, a surface roughness length z_o, temperature and specific humidity at two heights z_1 , z_2 in the atmospheric surface layer are used as input data in computer program. With these data u_* , θ_* and Q_* can be calculated from the integrated flux-profile relations given by Dyer and Hicks (Dyer, 1974; Paulson, 1970), as

$$u_* = \frac{ku_2}{\ln(z_2 / z_\circ) - \psi_M(z_2 / L) + \psi_M(z_\circ / L)} \quad (3.8)$$

$$\theta_* = \frac{k(\theta_2 - \theta_1)}{\ln(z_2 / z_1) - \psi_H(z_2 / L) + \psi_H(z_1 / L)} \quad (3.9)$$

$$Q_* = \frac{k(q_2 - q_1)}{\ln(z_2 / z_1) - \psi_Q(z_2 / L) + \psi_Q(z_1 / L)} \quad (3.10)$$

where k is the von Karman constant, taken at k=0.4, and L is the Obukhov stability parameter defined by

$$L = \frac{Tu_*^2}{kg\theta_*} \quad (3.11)$$

where g is the acceleration of gravity and T air temperature, for $L < 0$ unstable condition .

The ψ_M, ψ_H and ψ_Q are dimensionless stability functions of height divided by the Obukhov length. Hogstrom (1988) concludes that the original results by Dyer, Hicks, and other (see Dyer 1974) are still a good approximation for the experimental data of the unstable surface layer. There for ψ_M, ψ_H and ψ_Q functions given by Paulson (1970) and Dyer (1974) are used in this study,

$$\psi_M = 2\ln\left[\frac{1+x}{2}\right] + \ln\left[\frac{1+x^2}{2}\right] - 2\tan^{-1}(x) + \pi/2 \quad (3.12)$$

$$\psi_{H,Q} = 2\ln\left[\frac{1+x^2}{2}\right] \tag{3.13}$$

where

$$x = \left[1 - 16\,\frac{z}{L}\right]^{1/4} \tag{3.14}$$

For stable surface layer condition

$$\psi_M = \psi_{H,Q} = -5\,\frac{z}{L} \tag{3.15}$$

As originally proposed by Webb (1970) it is fairly consistent with most data for $0 < z/L < 0.5$ (see for example, Hogstrom 1988). This limited range of validity of Eq. (3.14) confirmed by Hicks (1976), Carson and Richards (1978), and more recently by Holtslag (1984).

Hicks (1976) analyzed stable wind profiles above the flat homogeneous terrain of "Wangara" site. Holtslag (1984) used the result of Hicks in combination with an effective roughness length for the description of stable wind profiles at Cabauw. Holtslag and De Bruin (1988) find insignificant difference between ψ_M, ψ_H and ψ_Q for large magnitude of z/L . The dimensionless stability function of momentum is

$$\psi_M = -a\,\frac{z}{L} - \left[\frac{z}{L} - \frac{c}{d}\right]\exp\left[-d\,\frac{z}{L}\right] - \frac{bc}{d} \tag{3.16}$$

$$\psi_{H,Q} = \psi_M \tag{3.17}$$

where a = 0.7, b = 0.75, c = 5.0, and d = 0.35.

The differences between these two model outputs are 0.001% for momentum flux, 0.01% for sensible heat flux and 0.001% for latent heat flux.

In Eq. (3.8), the parameter z_o is known as the surface roughness lengths for momentum. This parameter is related to the geometry of the surface roughness elements and defined as the height above the zero-plane displacement height where the downward- extrapolated profile yields the surface value (zero for wind).

The surface roughness length z_o can be obtained from routine wind measurements with a method given by Wieringe (1980). This method relates z_o either to the normalized standard deviation of wind speed observed in a given period and the maximum gust recorded during the same period. If gustiness observations are not available, a crude estimate of z_o can be obtained from a visual terrain classification, (Table 3.1).

Table 3.1. Terrain classification by Wieringa (1980) in terms of aerodynamical length z_o

Class	Short terrain description	z_o(m)
1	Open sea, fetch at least 5 km	0.0002
2	Mud flats, snow, no vegetation, no obstacles	0.005
3	Open flat terrain, grass, few isolated obstacles	0.03
4	Low crops, occasional large obstacles, x/h < 20	0.10
5	High crops, scattered obstacles, 15 < x/h <20	0.25
6	Parkland, bushes, numerous obstacles, x/h = 10	0.5
7	Regular large obstacle coverage (suburb, forest)	(1.0)
8	City center with high- and low-rise building	?-?

In table 3.1 x is a typical upwind obstacle distance and h the height of the corresponding major obstacles . Class eight is theoretically intractable within the framework of boundary layer meteorology and can better be modeled in a wind tunnel. For simple modeling application it may be sufficient to use only classes 1, 3, 5, 7 and perhaps 8.

For Ugurlu z_o varies with wind direction between z_o= 0.00255 m and z_o= 0.4 m, with typical value of z_o= 0.218575 m on average, in Gökçeada between z_o= 0.2 m and z_o= 0.9 m with average value z_o= 0.517391 m and in Maslak z_o= 0.34 m.

The fluxes τ, H and λE can be obtained from the above equations starting with a prescribed values of the Obukhov stability parameter L = -36 for unstable and L = 36 for stable surface layer condition. Then u_* , θ_* and Q_* are calculated by using the equations from (3.8)-(3.17). Using Eq. (3.11), L is computed by using the estimated values of u_* , θ_* and Q_*. The new value of L is substituted in Eqs. (3.8)-(3.17) to obtain improved values for u_* , θ_* and Q_* . This cycle is repeated until successive values of L do not change more than 5 %, usually not more than three cycles are needed in order to achieve the required accuracy of 5 % for L. Then τ, H and λE are calculated with Eqs. (3.5), (3.6) and (3.7).

As input data author have used the hourly average wind speed at 10 m and the temperature at 2 m and 10 m. The temperature at z = 10 m obtained by using the 00:00 and 12:00 G.M.T upper air data of Goztepe to calculate the hourly laps rate (local time) by liner interpolation.

All the calculations needed in this work are carried out by computer program in Quick Basic version 4.5 by the author and provided in the form of appendix at the end of this thesis.

3.3 Description of datasets and instruments

In this study the data observed at 2 and 10 m in centeral part of Gökçeada (40 11 N, 25 54 E) and coastal part of island. Up to a distance of 200 m there are no obstacles or perturbations of any importance at Ugurlu. For Northeasterly winds the flow is perturbed by hills, tree rows, and village at the central part.

3.3.1 Topographic Structure

Gökçeada has different topographic structures, the highest mountain is (622 m above mean sea level). The highest of other hills change between 360 and 470 m (above m.s.l.). Fig. 3.1 show the topographic structure and position of Gökçeada.

3.3.2 Synoptic Situation

General pressure systems effect on Gökçeada are high pressure systems of Siberia and low pressure of Iceland which is originated from polar region. These two systems cause strong Northerly and Northeasterly flows in this region. The cyclones originated at the central part of Mediterranean sea cause the strong Southwesterly flows. Because of the effects of Azor Anticyclone, strong Northerly flows are observed in summer.

Gökçeada is also effected by the local fluctuations. Small low pressure systems are accompany with the different heating rates. The final result of these effects is land - sea breezes.

3.3.3 Instruments

(i) Gōkçeada meteorology station

(a) Mechanical system for hourly wind speed and direction at, 10 m.
(b) Thermograph at 2 m, for hourly temperature.
(c) Higrograph at 2 m, for hourly relative humidity.

(ii) Ugurlu station

(a) Digital wind speed system, at 2 m and 10 m.
(b) Digital temperature system, at 4 m.
(c) Thermograph at 2 m, for hourly temperature.
(d) Higrograph at 2 m, for hourly relative humidity.

(iii) Maslak observation park

(a) Anemometer at 2 m, to observe the wind speed three times (07:00, 14:00 and 21:00 local time).
(b) Thermograph at 2 m, for temperature.
(c) Higrograph at 2 m, for relative humidity.
(d) Digital temperature system.
(e) Digital relative humidity system.

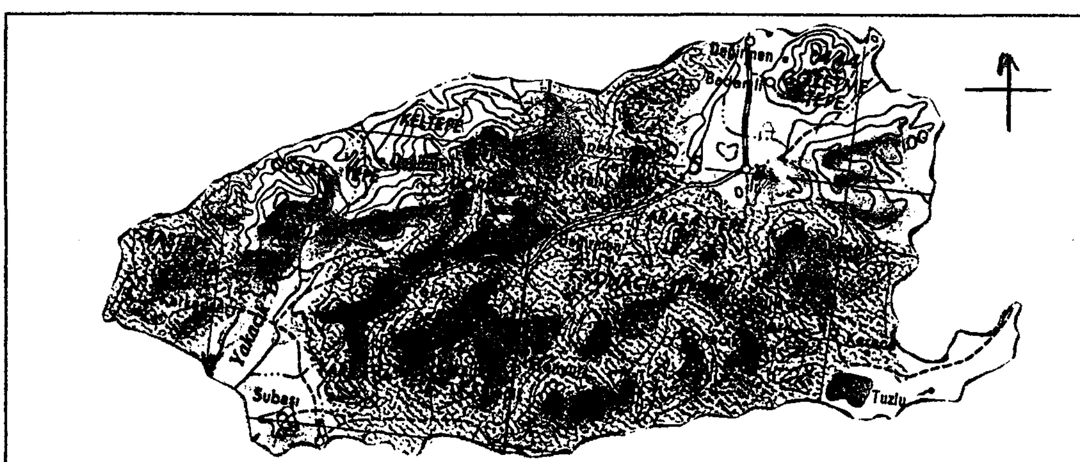

Fig.3.1 The topographic structure and position of Gōkçeada. (scale 1: 250,000)

CHAPTER 4

ANALYSIS

4.1 Test Analysis

To build up the homogeneous and comparable data Maslak (I.T.U) observation park is considered as a pilot area. Observations, calibration and model test are carried out at Maslak.

The momentum, sensible and latent heat fluxes are calculated three times per day (07:00, 14:00 and 21:00) during the same period with Gökçeada and Ugurlu, due the limitation of data. The fluxes observed as a minimum in Maslak, the average values are 0.02 (N/m_2), 0.77 (w/m_2) and 2.2 (w/m_2) respectively.

4.2 Data Analysis

4.2.1 Temperature (T)

The hourly temperature variation at two observation points, coastal line of island (Ugurlu) and central part of island (Gökçeada) , during the time period of observation, (which is start from 28 October to 14 November 1992), is shown in figure 4.1(a) and (b).

The figure shows that, the average temperatures of the two observation points are to closer to each other, with slightly change between the minimum and maximum values.

The minimum value of temperature observed in coastal line of island is 0.3° C smaller than the minimum temperature value in centeral part of island. The maximum value of temperature observed in the central part of island is 1° C grater than the maximum value in coastal line.

The large temperature variation range observed in central part and coastal line of the island.

4.2.2 Relative Humidity (RH)

Figure 4.2(a) and (b), show that the hourly relative humidity variation at two observation points, coastal line of island and central part from 28 October to 14 November 1992.

The average value of hourly relative humidity observed in central part is grater than the values of coastal line of island by 14 % .

The minimum value of relative humidity observed in central part. The maximum value is observed in coastal line of island.

The range of relative humidity variation during the observation time period is maximum in central part of island and minimum in coastal line.

4.2.3 Wind Speed (U)

The hourly wind speed variation in observation points has been shown in figure 4.3(a) and (b) during the observation period. The figure shows that, the greater average wind speed is observed in coastal line of island and the smaller one in central part of island .

The minimum value observed in central part of island is 0.1 m/s less than the minimum value measured in coastal line . The maximum value is observed in coastal line of island.

The rang of wind speed variation during the observation period is maximum in coastal line and minimum in central part of island .

4.3. Model Output Analysis

4.3.1 Friction Velocity (u_*)

The time variation of fractional velocity which is calculated by using the equation (3.8) and it is dependent of wind speed at level (z_2) and stability parameter (L), have been shown in figure 4.4(a) and (b).

As average values of fractional velocity in both coastal line and central part of island are closer to each other.

Generally, the values of maximum fractional velocity observed in coastal line is due to a maximum wind speed at that point, and the minimum values observed in central part is also due to the minimum wind speed at that point.

The fractional velocity changing during the all the period is maximum in coastal line, smaller than it in central part of island .

4.3.2 Temperature Scale (θ_*)

Figure 4.5(a) and (b) shows the time variation of temperature scale, (θ_*) which is dependent on the difference between temperature (T_1) and (T_2) at the heights (z_1) and (z_2) respectively and stability parameter (L), equation (3.9).

The minimum value of it in coastal line is slightly different with respect to central part, 0.18°K grater than the minimum value observed in central part. The maximum values at the two observation points are closer to each other.

4.3.3 Humidity Scale (Q_*)

Humidity scale depends on the deference between the two specific humidity (q_1) and (q_2) at level (z_1) and (z_2) and stability parameter (L). Figure 4.6(a) and (b) shows the time variation of humidity scale based on the equation (3.10).

According to the average values and the most of data points at the two observation points, the values are observed in both coastal line and central part of island are closer to each other.

The range of humidity scale variation in coastal line where the minimum and maximum values of humidity scale are observed is grater and less in central part of island.

4.3.4 Momentum Heat Flux ($\tau_\circ$)

From equation (3.5) it is clear that the momentum heat flux ($\tau_\circ$) depends on the square of fraction velocity (u_*^2). Figure 4.7(a) and (b) shows the time variation of momentum heat flux ($\tau_\circ$).

In general, the variation is too similar to the friction velocity variation. The maximum values are observed in coastal line and minimum values are in central part of island.

The range of variation is maximum in central part and minimum in coastal line of island.

4.3.5 Sensible Heat Flux (H)

Figure 4.8(a) and (b) shows the sensible heat flux variation which is calculated by using the equation (3.6), it depends on the both of fraction velocity (u_*) and temperature scale (θ_*) .

The positive value of sensible heat flux (H) are maximum in central part of island and minimum in coastal line of island. The variation in both cost line and center part of island is approximately the same, with different in magnitude and range of variation.

The maximum negative values of (H) are observed at the coastal line of island and the minimum negative values observed in central part .

4.3.6 Latent Heat Flux (λE)

The latent heat flux variation which is calculated by using the equation (3.7) depends on fraction velocity (u_*) and humidity scale (Q_*), shown in figure 4.9(a) and (b).

The maximum negative and positive values are observed in costal line and minimum in central part. On the other hand the latent heat flux variation is moor stable in center part with respect to costal line of island . Generally the maximum values of latent heat flux (λE) correspond to the maximum sensible heat (H) and momentum (τ_o) fluxes.

4.3.7 Obukhov Length (L)

The time variation of stability parameter (L) shows in Fig 4.10(a) and (b). In central part of island the average Obukhov length is minimum and the range of it is small with respect to the coastal line.

In general the variation in both observation points of L Values are around the critical value (0.0).

4.3.8. Daily Variation Analysis

According to the time variation of momentum flux (30 of October 1992) the range of flux values in Ugurlu are grater than Gökçeada (central part), Fig 4.11 a and b shows the time variation of momentum flux at Ugurlu and central part of Gökçeada.

By comparing daily turbulent sensible heat fluxes at two places it is concluded that the greater upward sensible heat fluxes are observed at central part and the maximum downward observed in coastal line (Ugurlu), Fig. 4.12 a and b shows the daily fluctuation of sensible heat flux.

Fig 4.13 (a) and (b) shows the grater latent heat flux gradient in morning at Ugurlu. The maximum negative and minimum values are observed in Ugurlu.

Daily variation of Monin Obukhov length are presented in Fig 4.14 (a) and (b), for Ugurlu and central part at Gökçeada . During night generally positive L values are observed, small fluctuation of L values observed between sun rise and sun set at Ugurlu

The statistics of real and model output data are provided in the form of appendix at the end of this thesis.(APPENDIX-B)

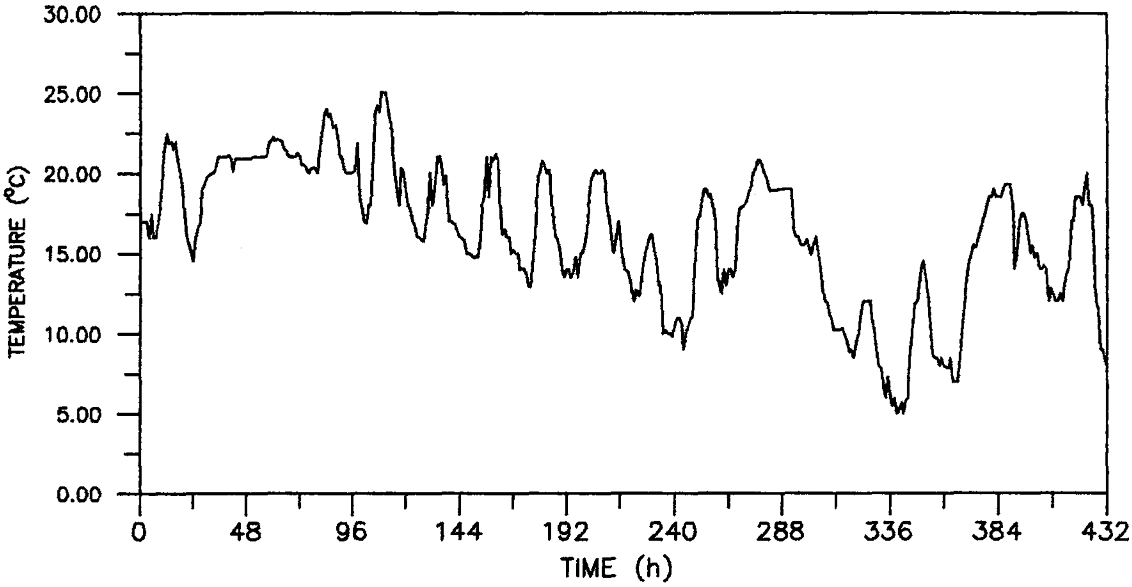

Fig. 4.1a) An observed hourly 2 meter temperature variation (T_1), at Ugurlu from 28 October 1992 to 14 November 1992.

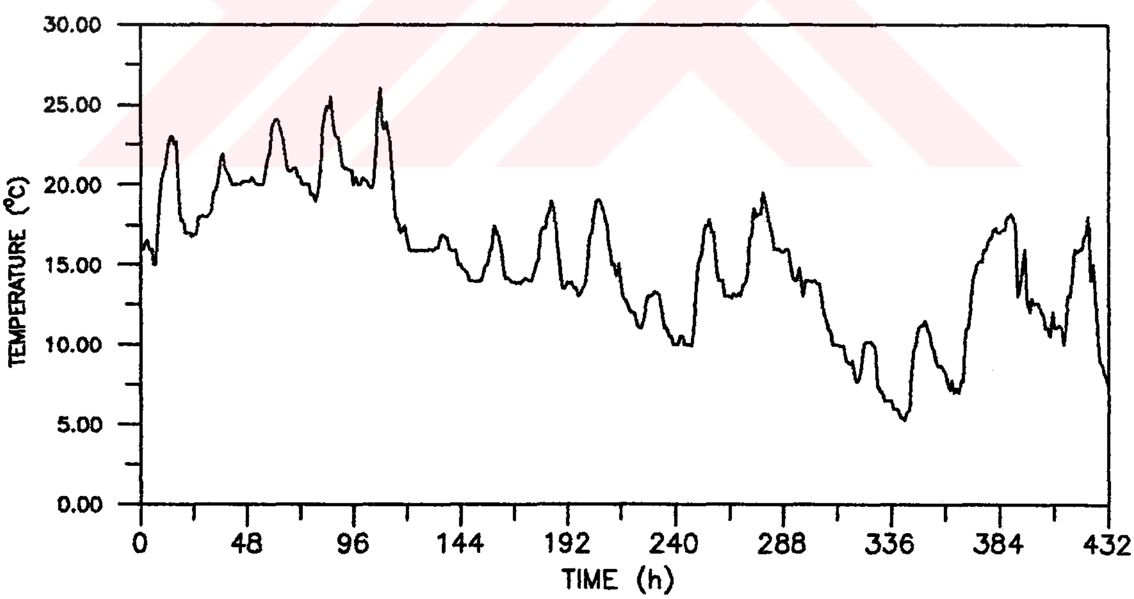

Fig. 4.1b) An observed hourly 2 meter temperature variation (T_1), at Gökçeada from 28 October 1992 to 14 November 1992.

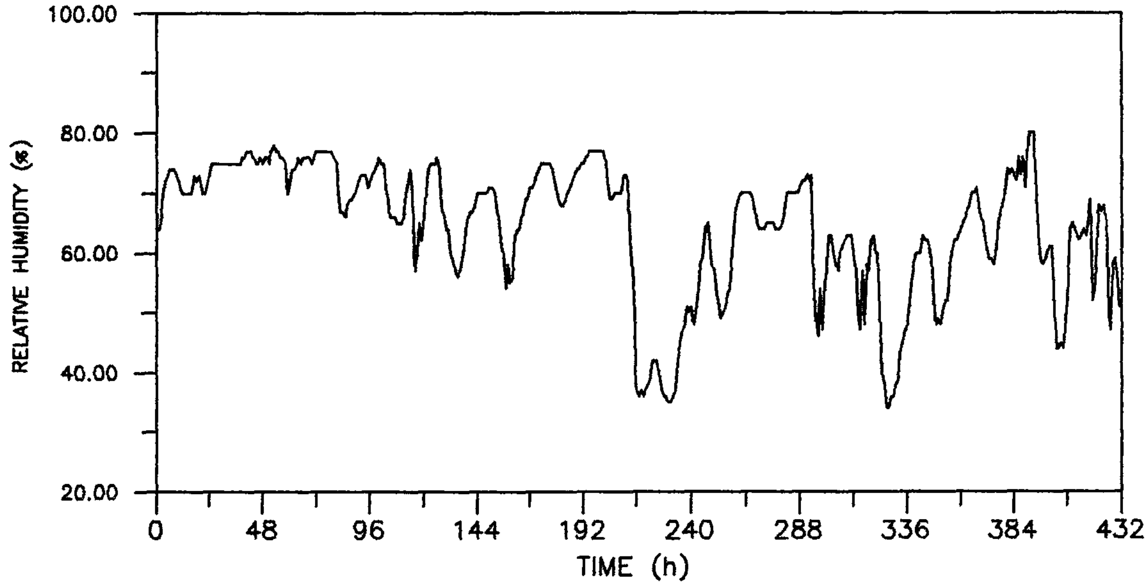

Fig. 4.2a) An observed hourly 2 meter relative humidity variation (RH_1), at Ugurlu from 28 October 1992 to 14 November 1992.

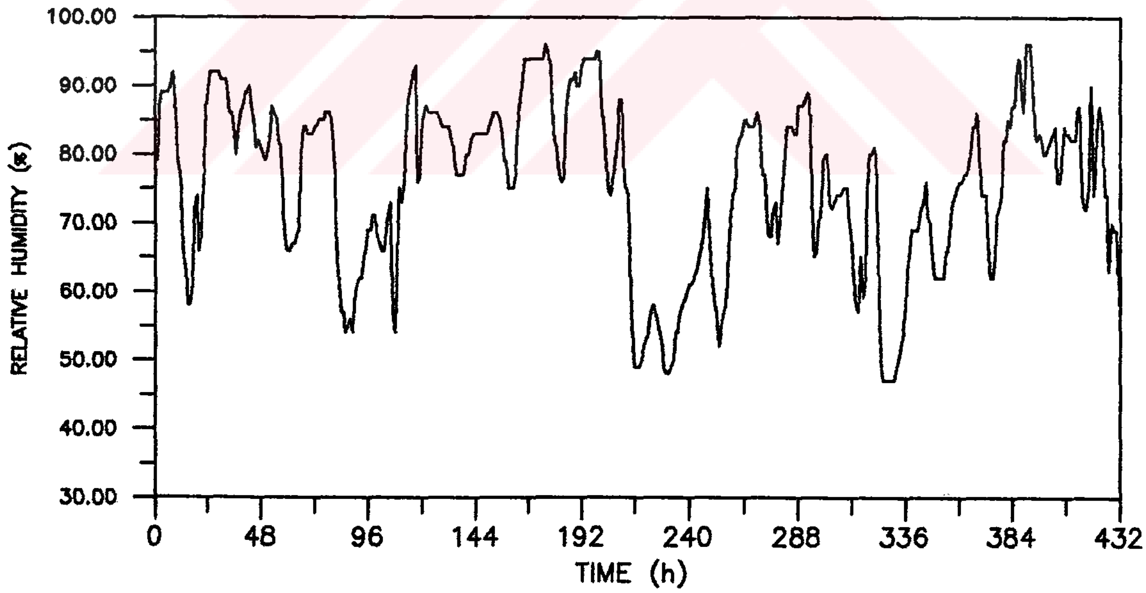

Fig. 4.2b) An observed hourly 2 meter relative humidity variation (RH_1), at Gökçeada from 28 October 1992 to 14 November 1992.

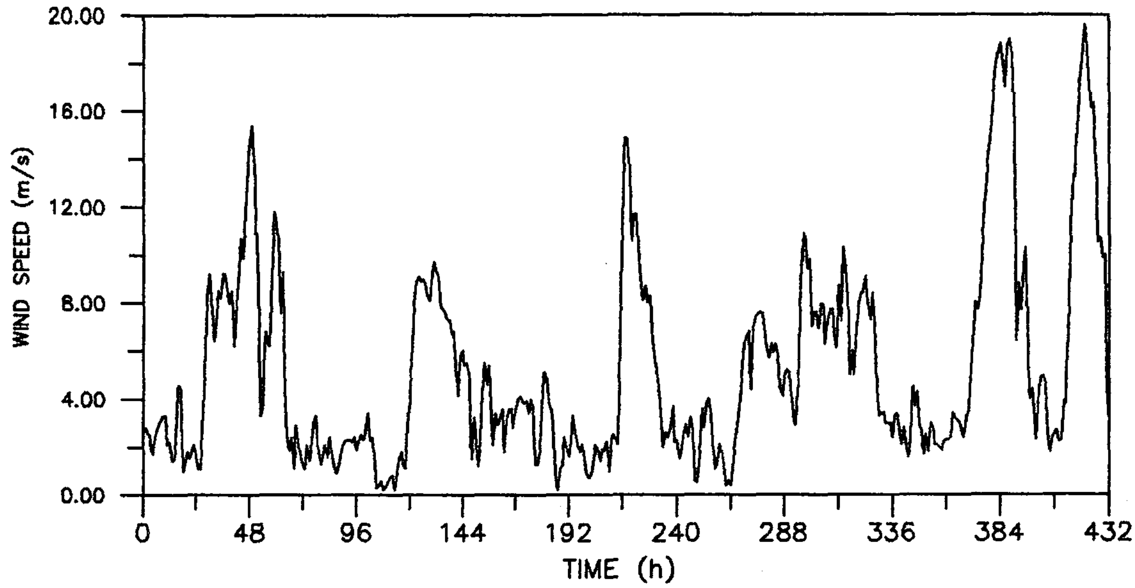

Fig. 4.3a) An observed hourly 10 meter wind speed variation (u_2), at Ugurlu from 28 October 1992 to 14 November 1992.

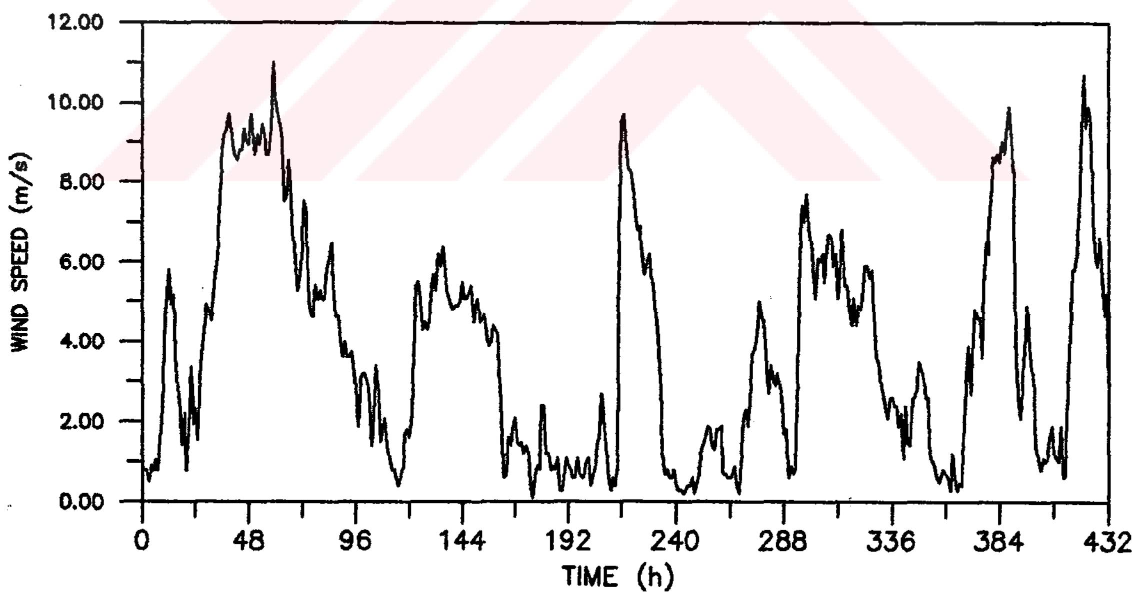

Fig. 4.3b) An observed hourly 10 meter wind speed variation (u_2), at Gökçeada from 28 October 1992 to 14 November 1992.

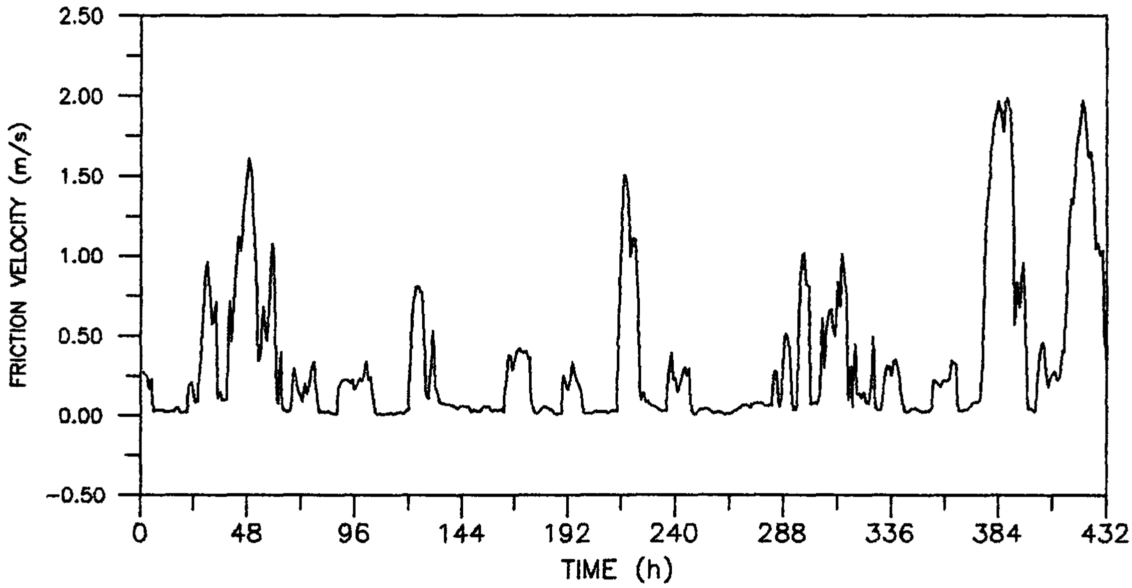

Fig. 4.4a) Calculated time variation of frictional velocity (u_*) at Ugurlu from 28 October 1992 to 14 November 1992.

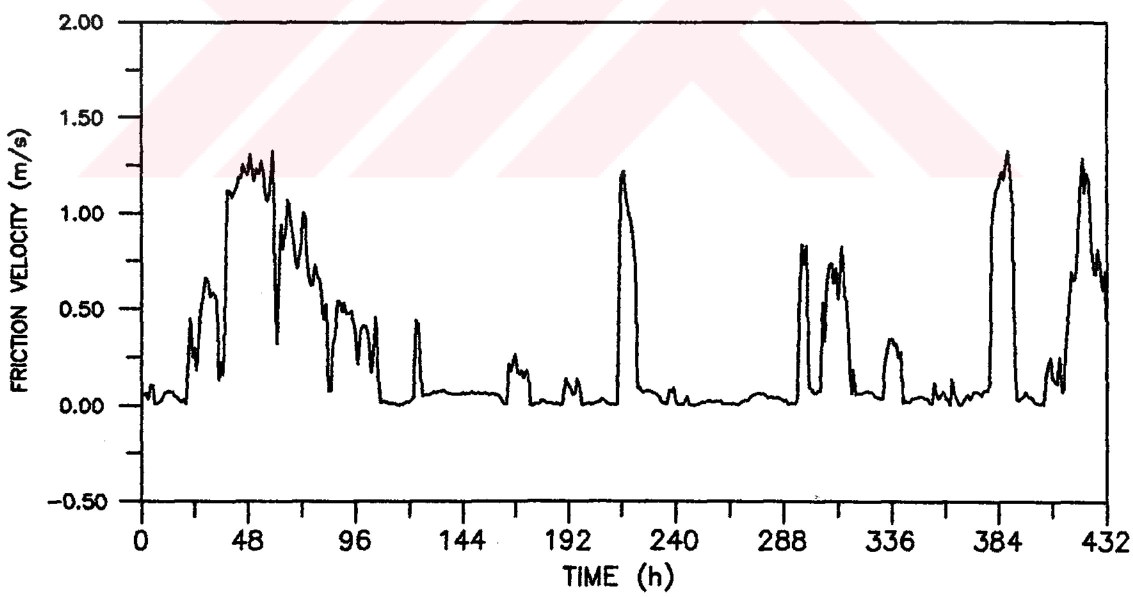

Fig. 4.4b) Calculated time variation of frictional velocity (u_*) at Gökçeada from 28 October 1992 to 14 November 1992.

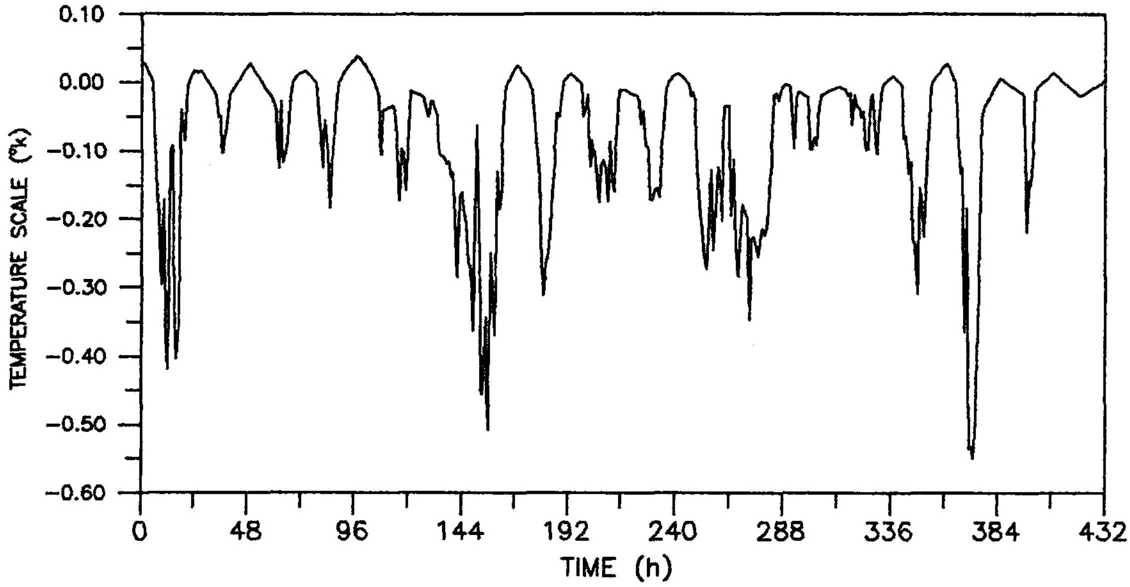

Fig. 4.5a) Calculated time variation of temperature scale (θ_*) at Ugurlu from 28 October 1992 to 14 November 1992.

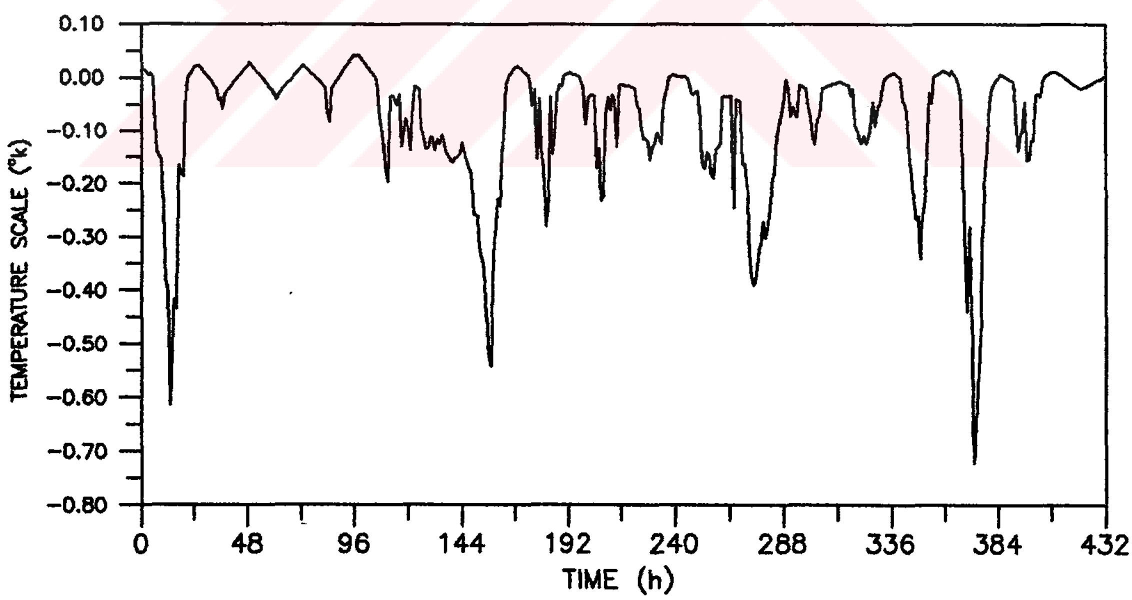

Fig. 4.5b) Calculated time variation of temperature scale (θ_*) at Gökçeada from 28 October 1992 to 14 November 1992.

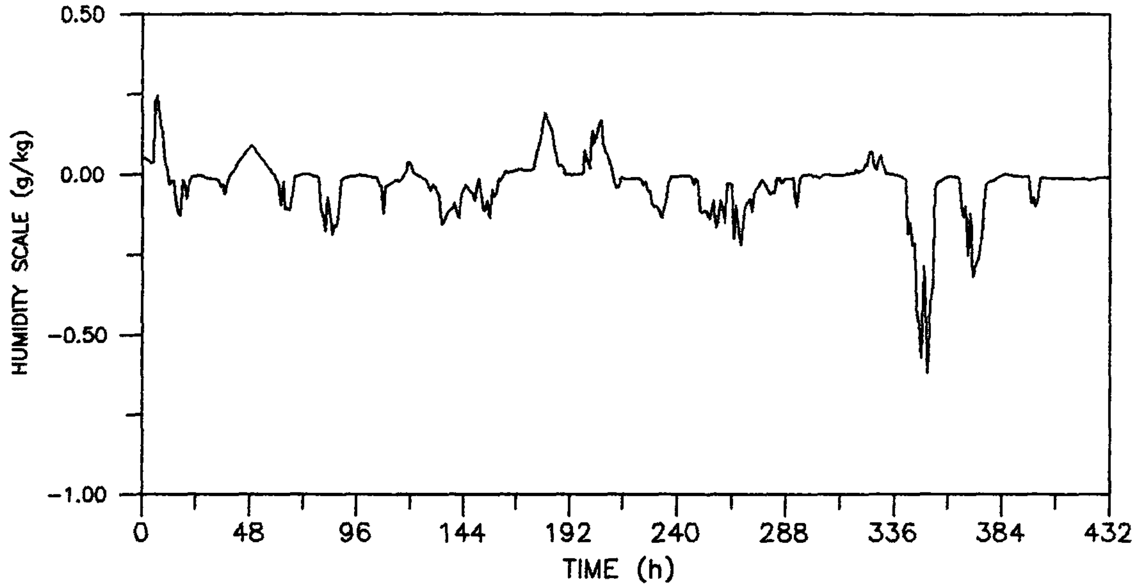

Fig. 4.6a) Calculated time variation of humidity scale (Q_*) at Ugurlu from 28 October 1992 to 14 November 1992.

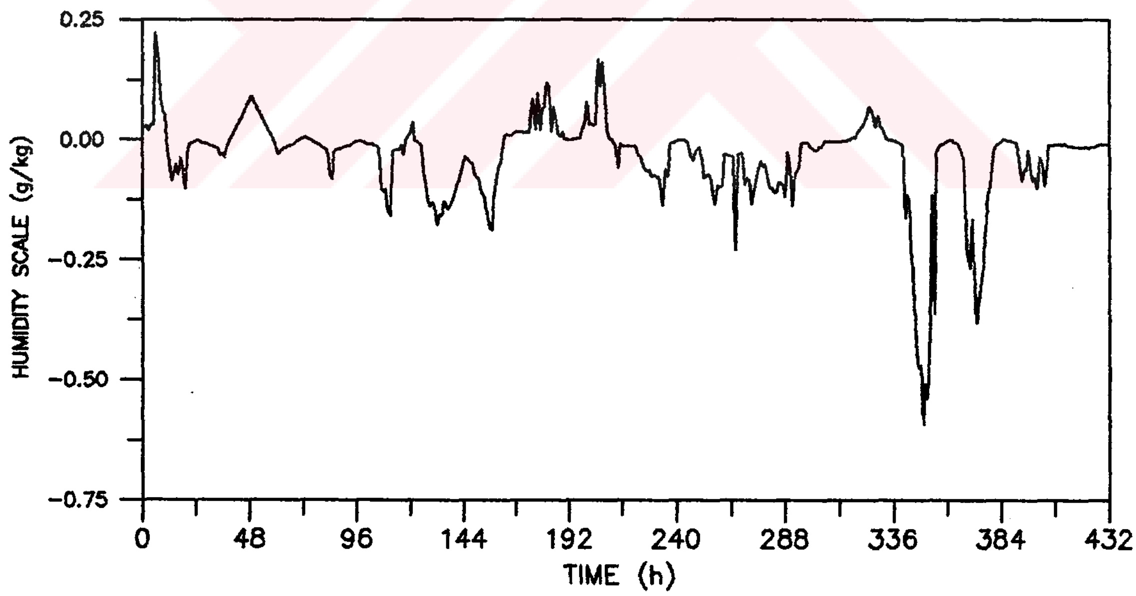

Fig. 4.6b) Calculated time variation of humidity scale (Q_*) at Gökçeada from 28 October 1992 to 14 November 1992.

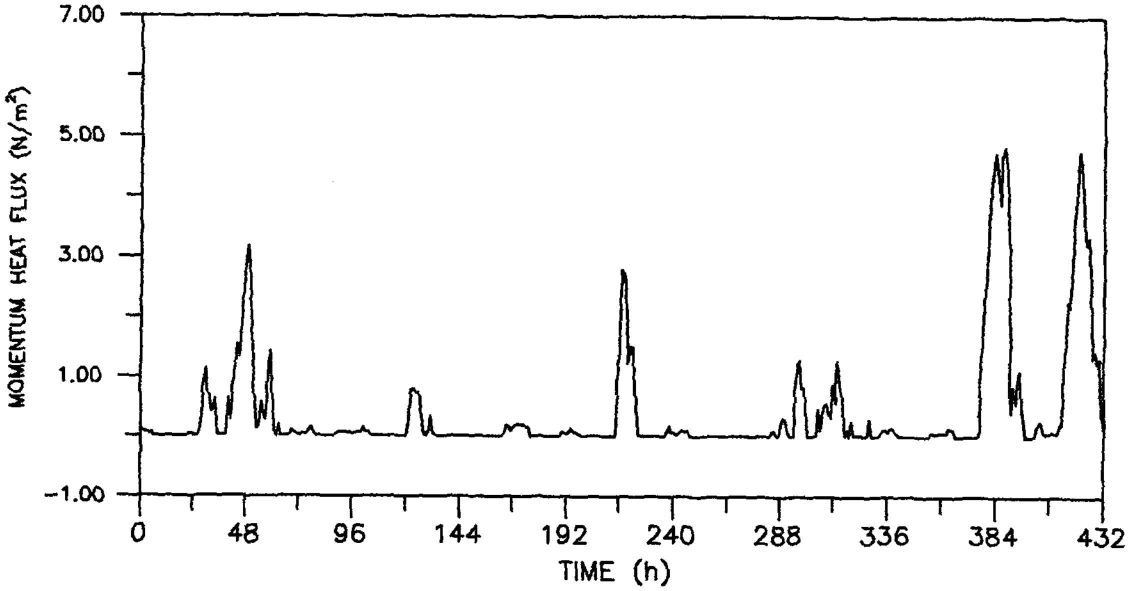

Fig. 4.7a) Calculated time variation of momentum heat flux (τ) at Ugurlu from 28 October 1992 to 14 November 1992.

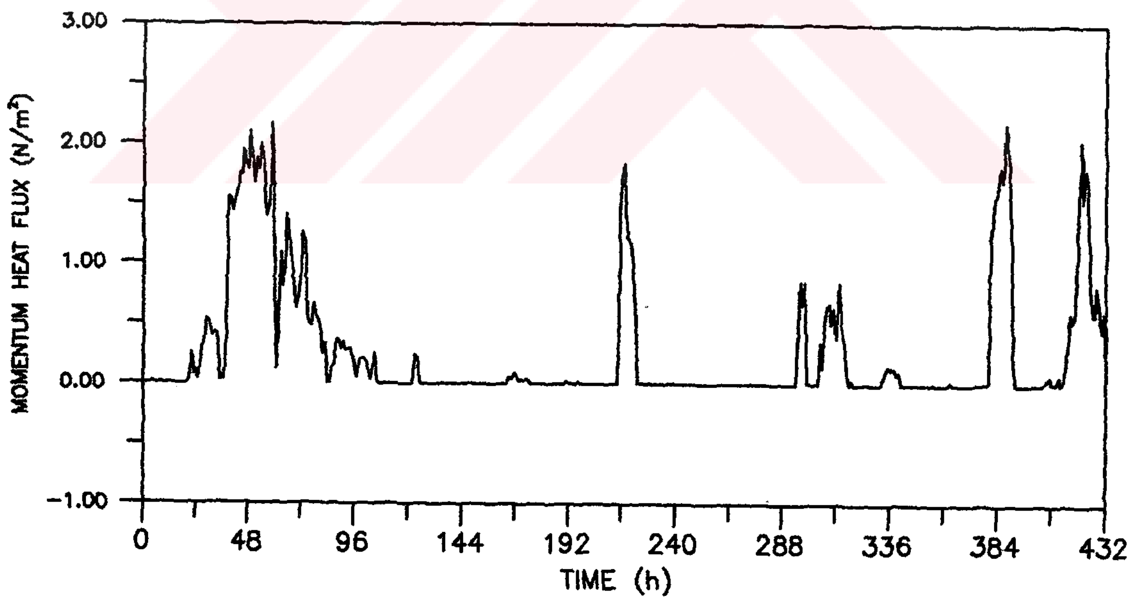

Fig. 4.7b) Calculated time variation of momentum heat flux (τ) at Gökçeada from 28 October 1992 to 14 November 1992.

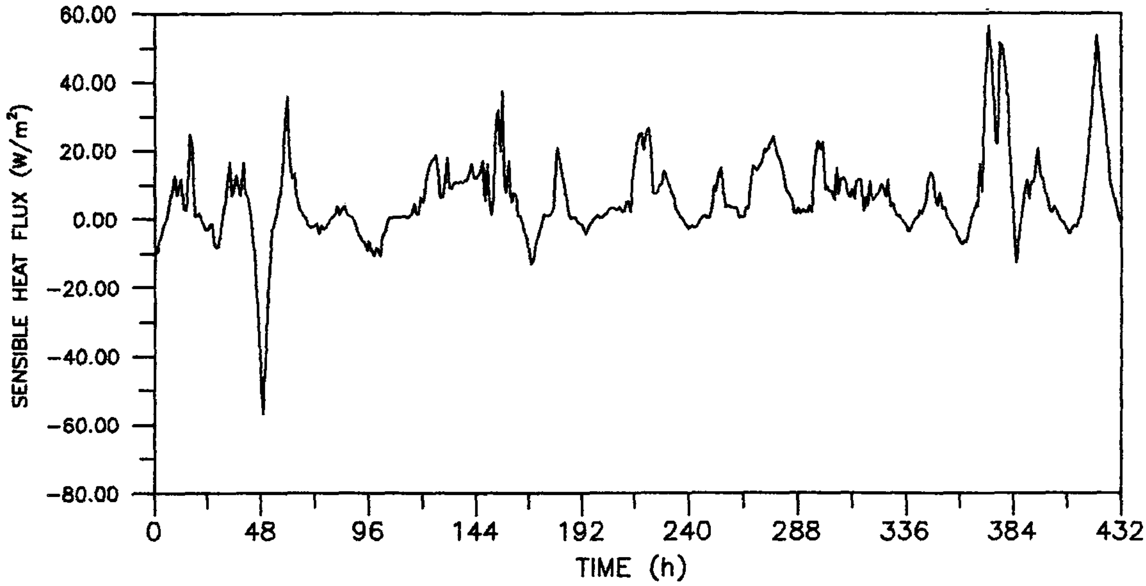

Fig. 4.8a) Calculated time variation of sensible heat flux (H) at Uğurlu from 28 October 1992 to 14 November 1992.

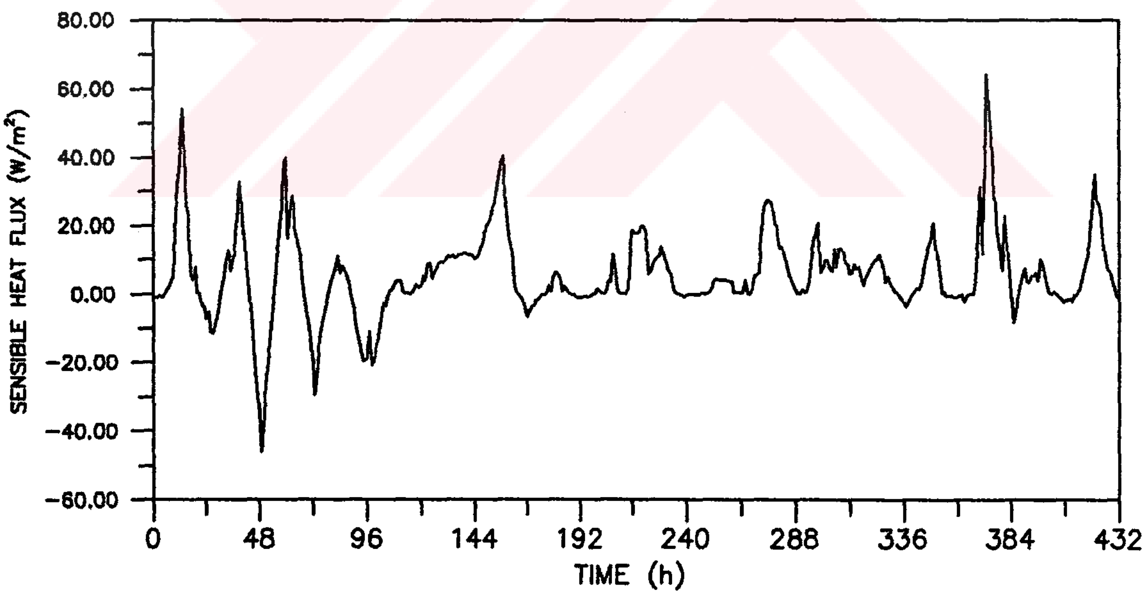

Fig. 4.8b) Calculated time variation of sensible heat flux (H) at Gökçeada from 28 October 1992 to 14 November 1992.

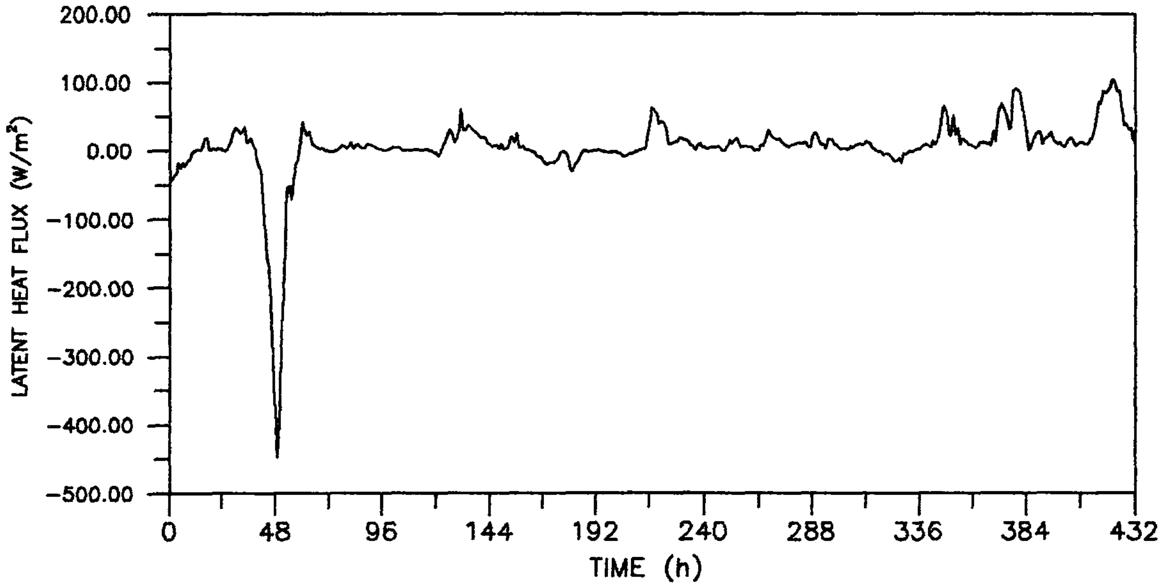

Fig. 4.9a) Calculated time variation of latent heat flux (λE) at Ugurlu from 28 October 1992 to 14 November 1992.

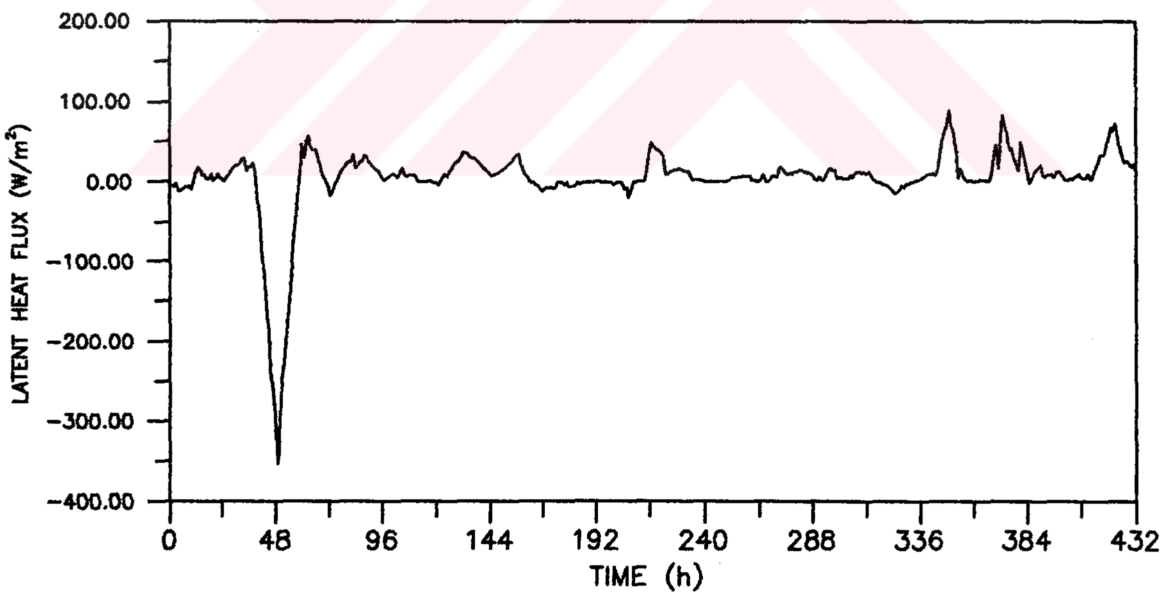

Fig. 4.9b) Calculated time variation of latent heat flux (λE) at Gökçeada from 28 October 1992 to 14 November 1992.

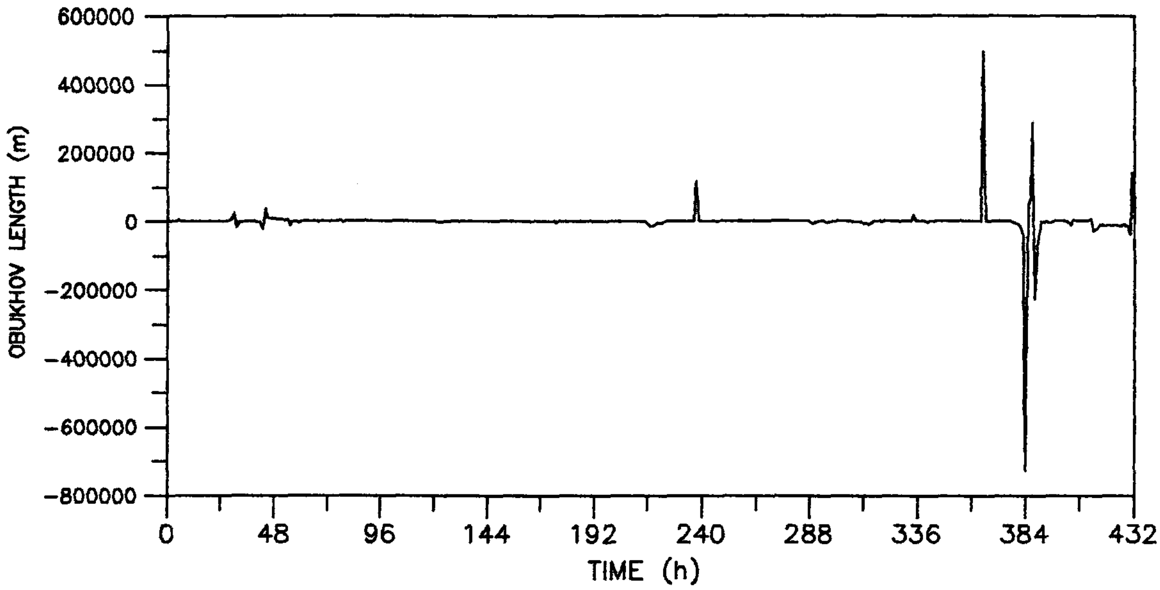

Fig. 4.10a) Calculated time variation of Obukhov length (L) at Ugurlu from 28 October 1992 to 14 November 1992.

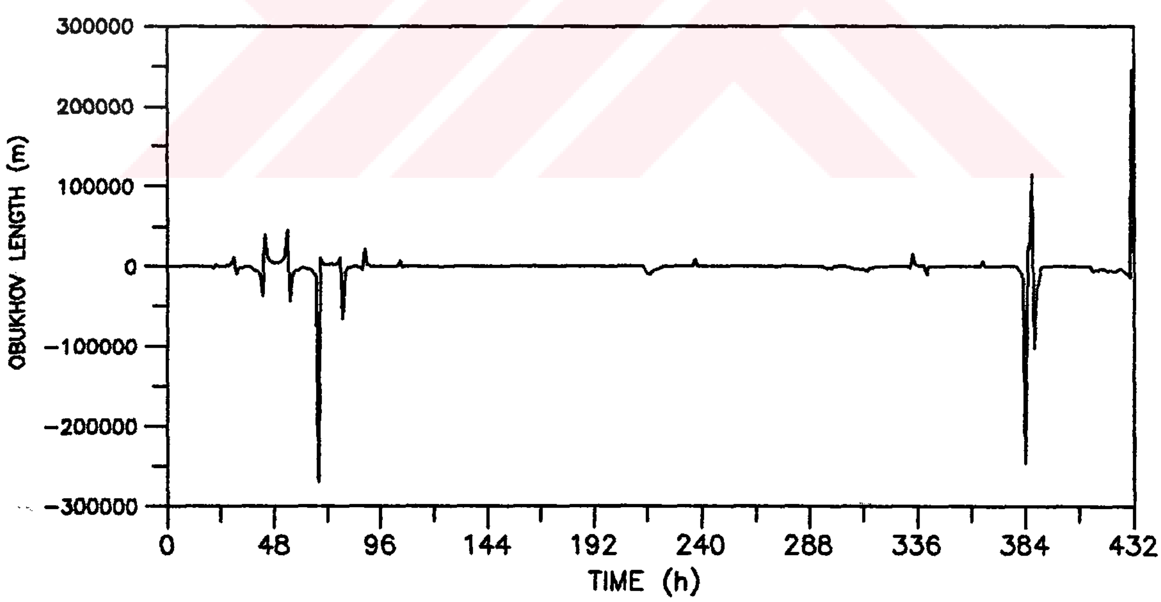

Fig. 4.10b) Calculated time variation of Obukhov length (L) at Gökçeada from 28 October 1992 to 14 November 1992.

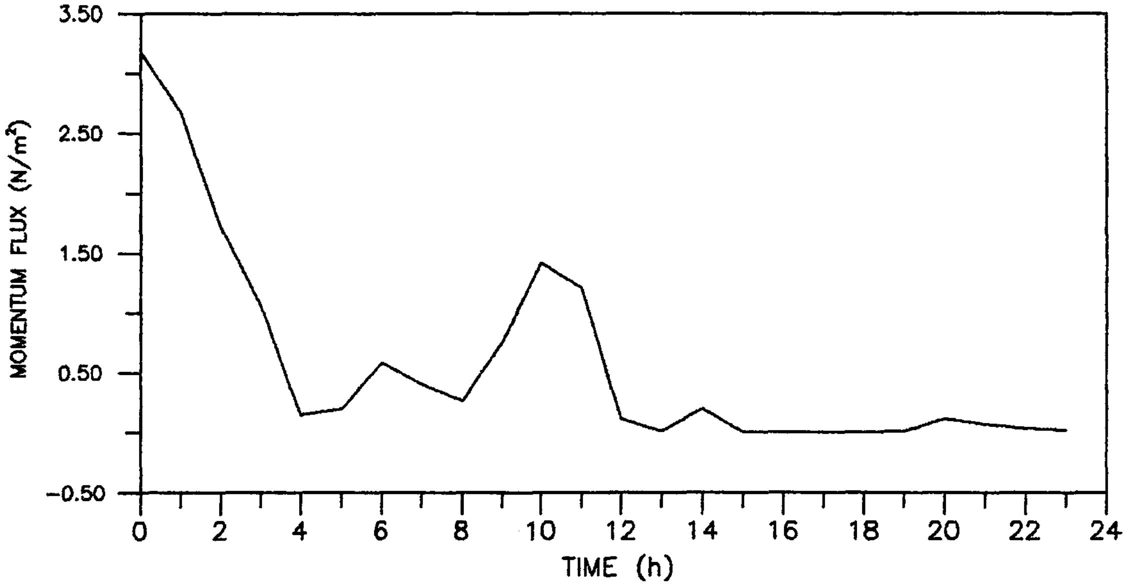

Fig. 4.11a) Calculated time variation of momentum heat flux (τ) at Ugurlu for 30 October 1992.

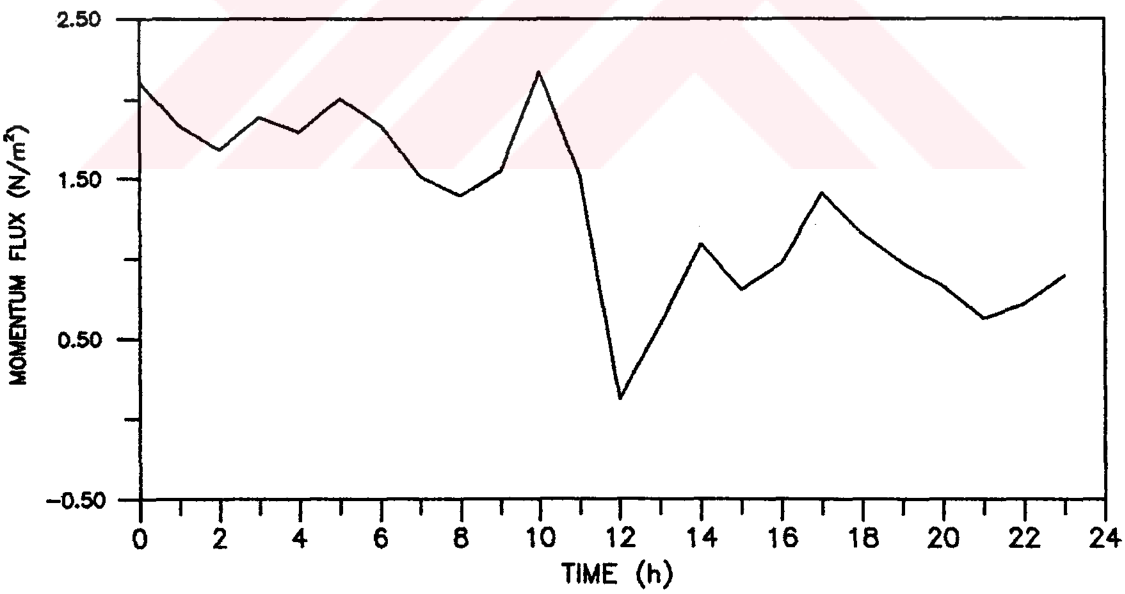

Fig. 4.11b) Calculated time variation of momentum heat flux (τ) at Gökçeada for 30 October 1992.

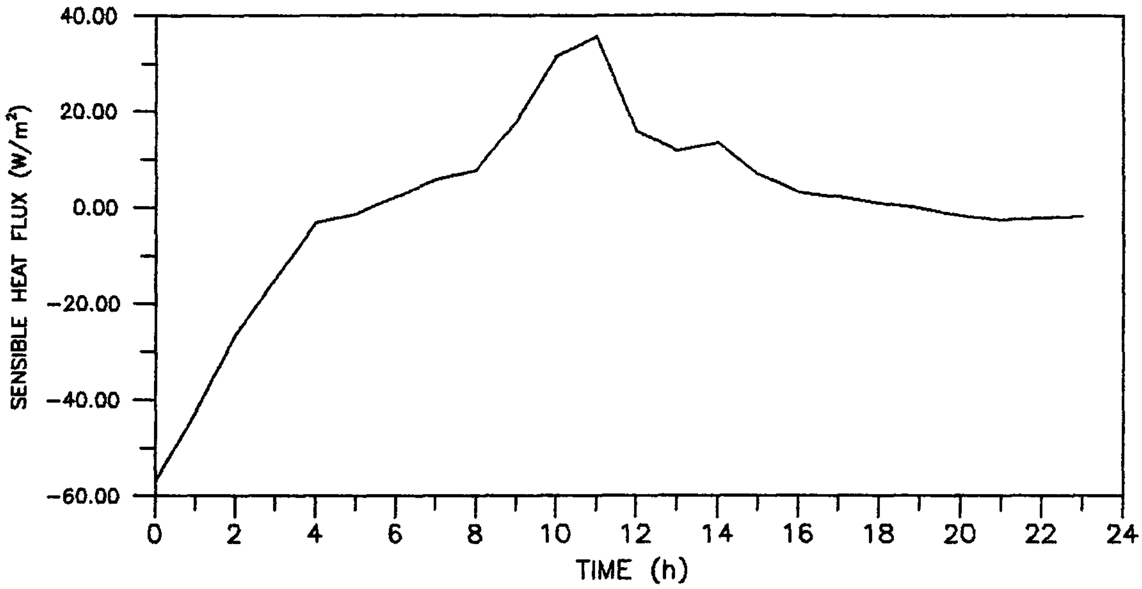

Fig. 4.12a) Calculated time variation of sensible heat flux (H) at Ugurlu for 30 October 1992.

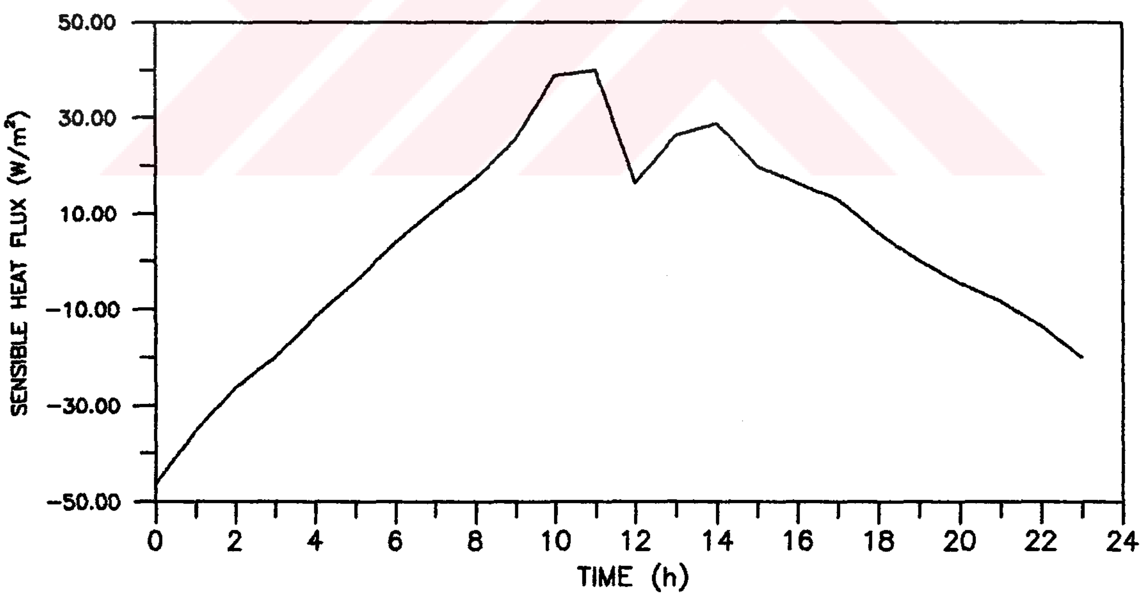

Fig. 4.12b) Calculated time variation of sensible heat flux (H) at Gökçeada for 30 October 1992.

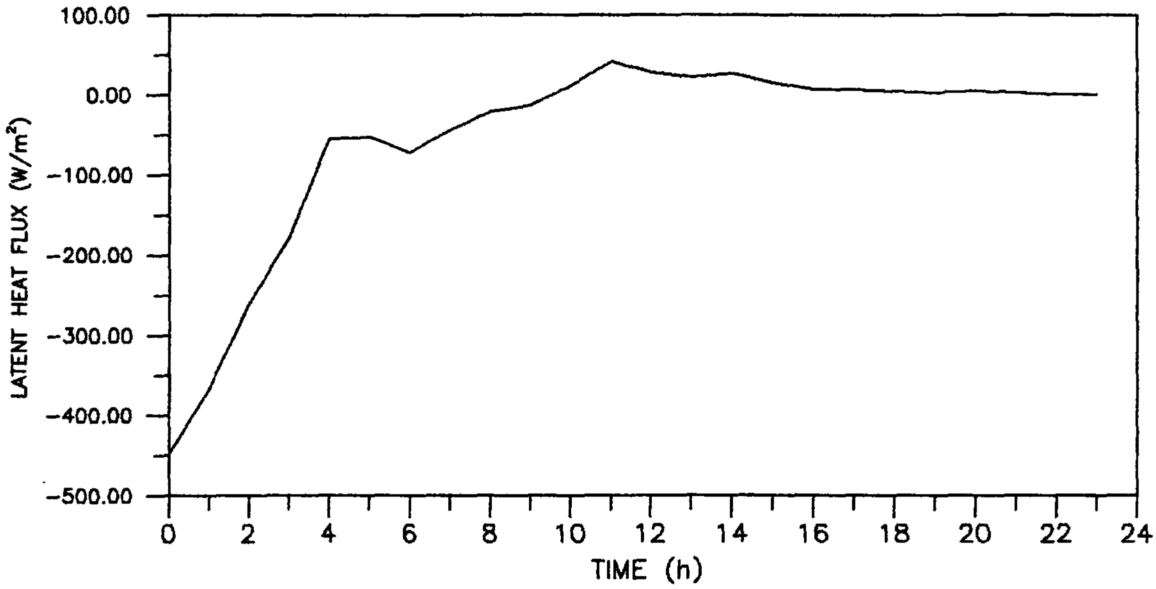

Fig. 4.13a) Calculated time variation of latent heat flux (λE) at Ugurlu for 30 October 1992.

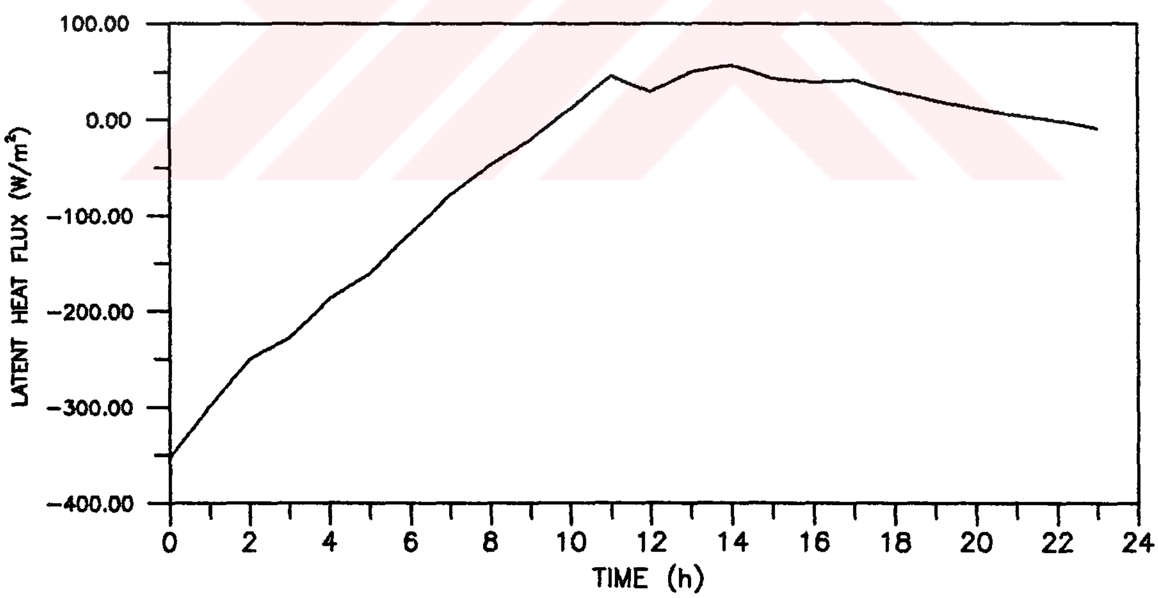

Fig. 4.13b) Calculated time variation of latent heat flux (λE) at Gökçeada for 30 October 1992.

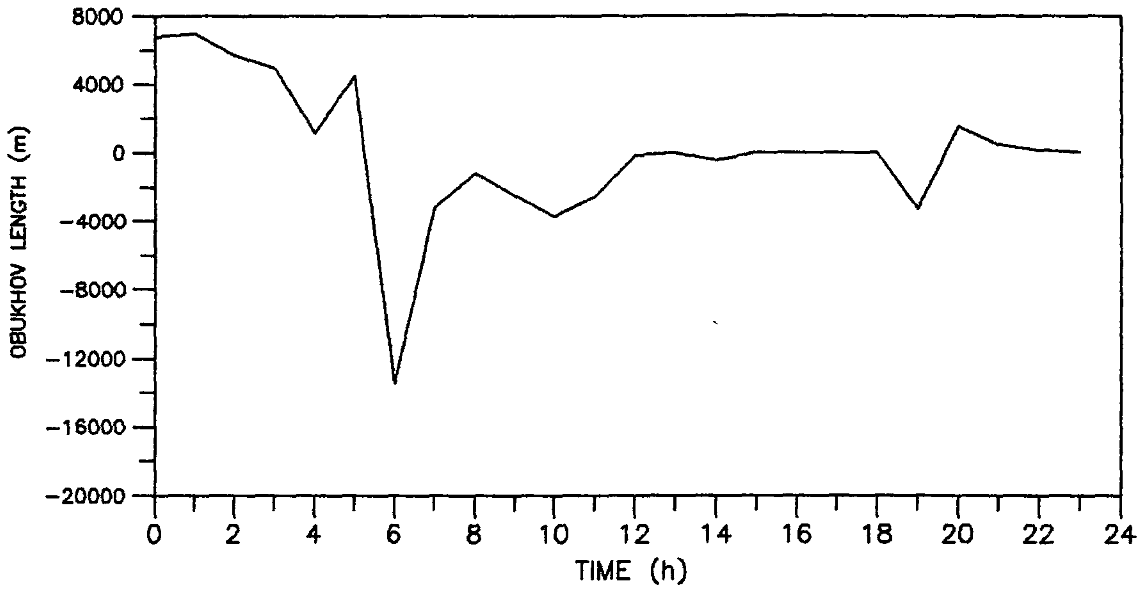

Fig. 4.14a) Calculated time variation of Obukhov length (L) at Ugurlu for 30 October 1992.

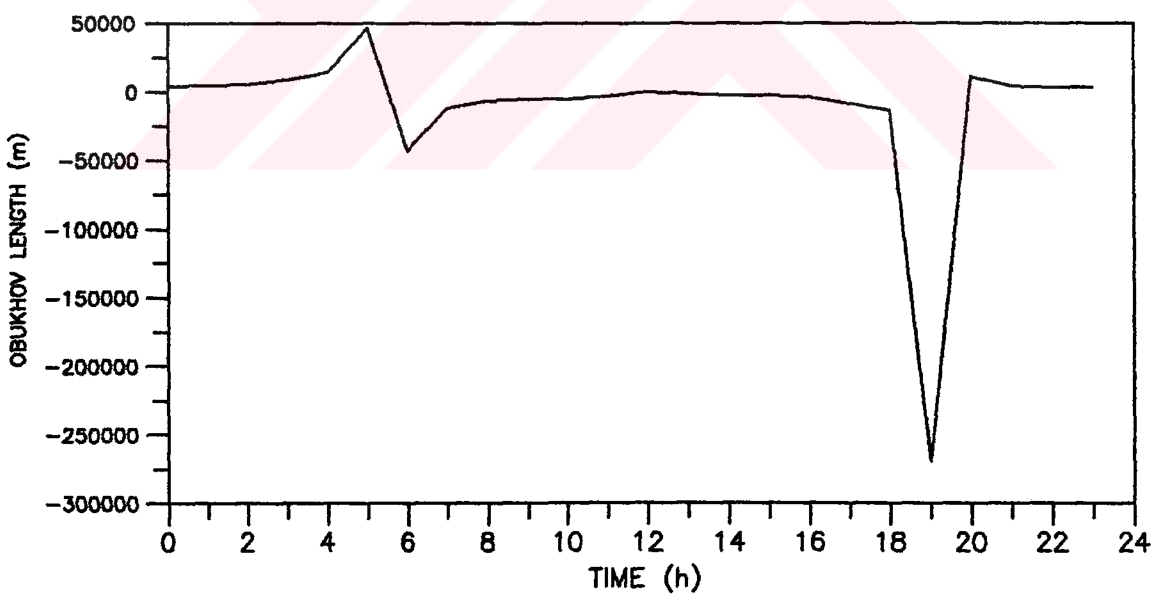

Fig. 4.14b) Calculated time variation of Obukhov length (L) at Gökçeada for 30 October 1992.

CONCLUSION

In this study the flux variations at the Gōkçeada are analyzed and sea-land interactions are observed. According to the latent heat flux (λE) at central part of island and coastal area, it is concluded that the average λE value of coastal line is 1.2 times grater than central part, the central part is also considered as an urban area, for this reason momentum flux (τ_o) variations observed at central part are 1.4 times smaller than the coastal area, which is closely related with the urbanization effects of the island. Indeed there is no important deference between sensible heat fluxes (H) of two places. The highest upward sensible heat flux is observed at central part and the highest downward is observed at Ugurlu .

The another conclusion of this thesis is related to the model results. To compute the fluxes under stable condition, two models are used, in the first one equation (3.15) is considered for all values of $z/L > 0$ and the second by using equation (3.15) for the values of z/L between 0 and 0.5 and equation (3.16) when z/L values out of that range . The differences between these two model outputs are 0.001% for momentum flux, 0.01% for sensible heat flux and 0.001% for latent heat flux.

In this thesis the range and time variation are analyzed at two different places, one is urban and the other is rural. The results would also apply on the fields of "air pollution modeling", "hydrology" and "wind energy. The fraction velocity, temperature, and humidity scales, momentum, heat and moisture flux values calculated at the atmospheric surface layer are in the same order of magnitude with the result of Businger at all (1971), Burgers and Holtslag (1990), Hacker at all (1987) and Aslan, Topcu and oney (1991).

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APPENDIX- A

COMPUTER SOFTWARE

MODEL.BAS
TO CALCULATE MOMENTUM, HEAT AND MOISTURE FLUXES

```
REM   INPUT CONSTANTS:
REM
REM    N           DATA SIZE.
REM    Z0          ROUGHNESS LENGTH (m).
REM    Z1          FIRST MEASURING HEIGHT (m).
REM    Z2          SECOND MEASURING HEIGHT (m).
REM    RO          DENSITY OF AIR (kg/m3).
REM    CP          SPECIFIC HEAT AT CONSTANT PRESSURE (J/kg C).
REM    LD          LATENT HEAT OF VAPORIZATION (J/g).
REM    G           ACCELERATION OF GRAVITY (m/s).
REM    K           VON KARMAN CONSTANT.
REM
REM   INPUT VARIABLES:
REM
REM    T1          TEMPERATURE AT HEIGHT Z1 (C).
REM    T2          TEMPERATURE AT HEIGHT Z2 (C).
REM    U2          WIND SPEED AT HEIGHT Z2 (m/s).
REM    RH1         RELATIVE HUMIDITY AT HEIGHT Z1 (%).
REM    RH2         RELATIVE HUMIDITY AT HEIGHT Z2 (%).
REM
REM   OUTPUT VARIABLES:
REM
REM   PSIH         M-O SIMILARITY FOR NORMALIZED POTENTIAL
REM                TEMPERATURE.
REM   PSIM         M-O SIMILARITY FOR NORMALIZED VELOCITY.
REM   PSIQ         M-O SIMILARITY FOR NORMALIZED SPECIFIC
REM                HUMIDITY.
REM   USR          FRICTION VELOCITY (m/s).
REM   TSR          TEMPERATURE SCALE (K).
REM   QSR          HUMIDITY SCALE (g/kg).
REM   MHF          MOMENTUM HEAT FLUX (N/m2).
REM   SHF          SENSIBLE HEAT FLUX (W/m2).
REM   LHF          LATENT HEAT FLUX (W/m2).
REM   L            OBUKHOV LENGTH (m).
REM___________________________________________________________
CLS
DIM T1(500): DIM RH1(500): DIM U2(500): DIM T2(500): DIM RH2(500)
CALL CON(NO, Z1, Z2, Z0, K, RO, CP, G, LD)
CALL RDFILE(NO, T1(), RH1(), U2(), T2(), RH2())
INPUT "WHAT DO YOU WANT TO CALL THE OUTPUT FILE ? ", OUTF$
OPEN OUTF$ FOR OUTPUT AS #2
FOR I = 1 TO NO
   T1 = T1(I) + 273
   T2 = T2(I) + 273
   U2 = U2(I)
   Q1 = SPQ(T1, RH1(I))
   Q2 = SPQ(T2, RH2(I))
   DD = (T2 - T1) + .01 * (Z2 - Z1)
     IF DD < 0 THEN
          L = -36  :'(UNSTABLE)
       ELSE
```

```
          L = 36   :'(STABLE)
     END IF
   FOR N = 1 TO 10
      USR = U2 * K / (LOG(Z2 / Z0) - PSIM(Z2 / L) + PSIM(Z0 / L))
      TSR = (T2-T1) * K / (LOG(Z2 / Z1) - PSIH(Z2 / L) + PSIH(Z1 / L))
      QSR = (Q2 - Q1) * K / (LOG(Z2 / Z1) - PSIQ(Z2 / L) + PSIQ(Z1 / L))
    NEWL = L
      L = OBUKHOV(K, G, T1, USR, TSR)
      IF ABS(L) < .5 THEN
      GOTO 20
      END IF
      IF ABS((L - NEWL) / NEWL) < .05 GOTO 20
   NEXT N
20 CALL FLUXES(RO, CP, LD, USR, TSR, QSR, MHF, SHF, LHF)
       RI = (Z2 / L)*(LOG(Z2 / Z0) - PSIH(Z2 / L)) * (LOG(Z2 / Z0) -
       PSIM(Z2/L))^-2
      PRINT #2, I, USR,TSR,QSR,MHF,SHF,LHF,L,RI
NEXT I
      CLOSE #2
REM_____________________________________________________________________
REM                    SUBROUTINE CON TO READ THE CONSTANTS
REM_____________________________________________________________________
SUB CON (NO, Z1, Z2, Z0, K, RO, CP, G, LD)
      INPUT "WHAT IS THE DATA SIZE N ? ", NO
PRINT
      INPUT "WHAT IS THE VALUE OF Z0 ?", Z0
PRINT
           Z1 = 2
           Z2 = 10
           RO = 1.23
           CP = 1005
           LD = 2450
           K = .4
           G = 9.8
END SUB
REM_____________________________________________________________________
REM      SUBROUTINE FLUXES TO CALCULATE MOMENTUM, SENSIBLE
REM                        AND LATENT HEAT FLUXES
REM_____________________________________________________________________
SUB FLUXES (RO, CP, LD, USR, TSR, QSR, MHF, SHF, LHF)
      MHF = RO * USR ^ 2
      SHF = -RO * CP * USR * TSR
      LHF = -RO * LD * USR * QSR
END SUB
REM_____________________________________________________________________
REM         OBUKHOV FUNCTION TO CALCULATE OBUKHOV LENGTH
REM_____________________________________________________________________
FUNCTION OBUKHOV (G, K, T, USR, TSR)
      OBUKHOV = (T * USR ^ 2) / (TSR * G * K)
END FUNCTION
REM_____________________________________________________________________
REM PSIH FUNCTION TO COMPUTE M-O SIMILARITY FOR NORMALIZED
REM                NORMALIZED POTENTIAL TEMPERATURE
REM_____________________________________________________________________
FUNCTION PSIH (ETA)
      IF ETA < 0 THEN           :'(UNSTABLE)
        X = (1 - 15 * ETA) ^ .25
        PSIH = 2 * LOG((1 + X ^ 2) / 2)
```

```
      ELSE                          :'(STABLE)
        IF ETA < .5 THEN            :
          PSIH = -5 * ETA
        ELSE
        END IF
       A = 0.7
        B = 0.75
       C = 5
       D = 0.35
        PSIM = -.A * ETA - (B * ETA -B*C/D) * EXP(-D * ETA) - B*C/D
      END IF
END FUNCTION
REM_____________________________________________________________________
REM          PSIM FUNCTION TO COMPUTE  M-O SIMILARITY FOR
REM                      NORMALIZED VELOCITY.
REM_____________________________________________________________________
FUNCTION PSIM (ETA)
    PI = 3.1415927#
    IF ETA < 0 THEN                 :'(UNSTABLE)
        X = (1 - 15 * ETA) ^ .25
    PSIM = LOG((1 + X ^ 2) / 2 * ((1 + X) / 2) ^ 2) - 2 * ATN(X)*(180/PI)
+ (PI / 2)
    ELSE                            :'(STABLE)
          IF ETA < .5 THEN
          PSIM = -5 * ETA
          ELSE
          END IF
         A = 0.7
          B = 0.75
         C = 5
         D = 0.35
          PSIM = -.A * ETA - (B * ETA -B*C/D) * EXP(-D * ETA) - B*C/D
    END IF
END FUNCTION
REM_____________________________________________________________________
REM         PSIQ FUNCTION TO COMPUTE   M-O SIMILARITY  FOR
REM                 NORMALIZED SPECIFIC HUMIDITY
REM_____________________________________________________________________
FUNCTION PSIQ (ETA)
      IF ETA < 0 THEN               :'(UNSTABLE)
        X = (1 - 15 * ETA) ^ .25
        PSIQ = 2 * LOG((1 + X ^ 2) / 2)
      ELSE                          :'(STABLE)
         IF ETA < .5 THEN
         PSIQ = -5 * ETA
         ELSE
         END IF
        A = 0.7
         B = 0.75
        C = 5
        D = 0.35
         PSIM = -.A * ETA - (B * ETA -B*C/D) * EXP(-D * ETA) - B*C/D
      END IF
END FUNCTION
REM_____________________________________________________________________
REM          SUBROUTINE RDFILE TO READ THE INPUT DATA FILE
REM_____________________________________________________________________
SUB RDFILE (N, T1(), RH1(), U2(), T2(), RH2())
```

```
      INPUT "WHAT IS THE NAME OF THE DATA FILE ? ", INPUTF$:
PRINT
      OPEN INPUTF$ FOR INPUT AS #1
        FOR I = 1 TO N
          IF EOF(1) THEN 10
          INPUT #1, T1(I), RH1(I), U2(I), T2(I), RH2(I)
        NEXT I
10 CLOSE
END SUB
REM_____________________________________________________________
REM                TO CALCULATE THE SPECIFIC HUMIDITY
REM_____________________________________________________________
FUNCTION SPQ (T, RH)
       A = 17.26
       B = 35.36
       P = 1020
       IF T <= 263 THEN A = 21.87
       IF T <= 263 THEN B = 7.66
       E = 6.11 * EXP(A * (T - 273.16) / (T - B))
       QS = .622 * E / (P - .378 * E)
       SPQ = QS * RH * 10
END FUNCTION
```

APPENDIX B

STATISTICAL TABLES

Table B.1 The statistic of 2 m temperature (°C), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	16.2516	15.2426
Mode	21	16
Standard deviation	4.35678	4.39127
Standard error	0.209616	0.211275
Minimum	5	5.3
Maximum	25	26
Range	20	20.7

Table B.2 The statistic of 2 m relative humidity (%), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	64.3981	75.8102
Mode	70	84
Standard deviation	10.9105	12.2982
Standard error	0.52493	0.591695
Minimum	34	47
Maximum	80	96
Range	46	49

Table B.3 The statistic of 10 m wind speed (m/s), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	5.28611	3.84123
Mode	2.2	0.6
Standard deviation	4.0026	2.77708
Standard error	0.202102	0.133612
Minimum	0.2	0.1
Maximum	19.6	11.01
Range	19.4	10.91

Table B.4 The statistic calculated fraction velocity (m/s), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	0.335573	0.284317
Mode	0.148192	0.0144082
Standard deviation	0.460897	0.377696
Standard error	0.0221749	0.0181719
Minimum	1.99363E-3	1.31531E-3
Maximum	1.98323	1.32844
Range	1.98124	1.32712

Table B.5 The statistic of calculated temperature scale (°K), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	-0.0733201	-0.0798759
Mode	-0.0356097	-0.0356097
Standard deviation	0.108155	0.120923
Standard error	5.20361E-3	5.81792E-3
Minimum	-0.549917	-0.721713
Maximum	0.0389651	0.0426688
Range	0.588882	0.764382

Table B.6 The statistic of calculated humidity scale (g/kg), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	-0.0312.61	-0.0382052
Mode	-0.0128759	-0.0132184
Standard deviation	0.0902711	0.0919624
Standard error	4.34317E-3	4.42454E-3
Minimum	-0.619137	-0.589438
Maximum	0.243916	0.212949
Range	0.863054	0.811387

Table B.7 The statistic of calculated momentum flux (N/m^2), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	0.399189	0.274487
Mode	0.027012	2.55342E-4
Standard deviation	0.958359	0.524167
Standard error	0.0446657	0.025219
Minimum	4.88871E-6	2.12796E-6
Maximum	4.83784	2.17064
Range	4.83784	2.17064

Table B.8 The statistic of calculated sensible heat flux (W/m^2), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	6.13838	5.76282
Mode	3.3646	3.75904
Standard deviation	12.2174	12.3486
Standard error	0.58781	0.594123
Minimum	-56.9466	-46.1843
Maximum	56.2421	64.213
Range	113.189	110.397

Table B.9 The statistic of calculated latent heat flux (W/m^2), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	4.52456	3.80279
Mode	6.14891	6.82045
Standard deviation	48.9985	44.8504
Standard error	2.35744	2.15787
Minimum	-448.195	-352.439
Maximum	103.919	87.9633
Range	552.114	440.402

Table B.10 The statistic of Obukhov length (m), at Ugurlu and Gökçeada from 28 October to 14 November 1992.

	Ugurlu	Gökçeada
Data size	432	432
Average	-756.837	-951.789
Mode	-.490668	-.485373
Standard deviation	47431.9	23322
Standard error	2282.07	1122.08
Minimum	-728346	-269496
Maximum	495326	245362
Range	1.22367E6	514858

Table B.11 The statistical of calculated momentum flux (N/m^2), at Ugurlu and Gökçeada for 30 October 1992.

	Ugurlu	Gökçeada
Data size	24	24
Average	0.589495	1.31103
Mode	0.113745	1.15222
Standard deviation	0.876903	0.549141
Standard error	0.178997	0.112093
Minimum	4.88564E-4	0.125071
Maximum	3.18056	2.16797
Range	3.18007	2.04289

Table B.12 The statistical of calculated sensible heat flux (W/m^2), at Ugurlu and Gökçeada for 30 October 1992.

	Ugurlu	Gökçeada
Data size	24	24
Average	0.0416278	3.06421
Mode	0.028385	0.241814
Standard deviation	20.1585	22.7524
Standard error	4.11484	4.64432
Minimum	-56.9466	-46.1843
Maximum	35.7538	39.9478
Range	92.7005	86.132

Table B.13 The statistical of calculated latent heat flux (W/m^2), at Ugurlu and Gökçeada for 30 October 1992.

	Ugurlu	Gökçeada
Data size	24	24
Average	-55.6096	-56.9509
Mode	-0.532799	-8.47352
Standard deviation	128.2	123.066
Standard error	26.1688	25.1208
Minimum	-448.195	-352.439
Maximum	42.0518	57.4094
Range	490.247	409.848

Table B.14 The statistical of calculated Obukhov length (m), at Ugurlu and Gökçeada for 30 October 1992.

	Ugurlu	Gökçeada
Data size	24	24
Average	79.2847	-11347
Mode	-1.47892	-2717.75
Standard deviation	4193.92	56948.1
Standard error	856.08	11624.5
Minimum	-12435.6	-269496
Maximum	6937.55	46661.3
Range	20373.1	316158

VITA

Abdullatif M. Latif was born in B.Gisher, Libya on December 10, 1962. completed primary and secondary education in Tripoli, Libya. In 1980 he entered Department of Meteorology, Faculty of Science, University of Al-fateh as an undergraduate student and in 1984 graduated with a degree of Bachelor of Science in Meteorology.

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