

T.C.
MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN
PURE AND APPLIED SCIENCES

DETERMINATION OF ATMOSPHERIC MIXING
HEIGHTS USING GÖZTEPE RADIOSONDE
MEASUREMENTS

Soner ATALAY

THESIS
FOR THE DEGREE OF MASTER OF SCIENCE
IN
ENVIRONMENTAL ENGINEERING

SUPERVISOR
Prof. Dr. Gürcan R. ORALTAY

İSTANBUL 2008

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ACKNOWLEDGEMENTS

Firstly, I want to thank my adviser, Prof.Dr. R. Gürcan ORALTAY. This thesis would not have been possible without your support. Thank you for your patience and allowing me to use your data.

Finally, I would like to thank The Hollywood Film Industry time flows like a river with their movies.

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ABSTRACT

DETERMINATION OF ATMOSPHERIC MIXING HEIGHTS USING GÖZTEPE RADIOSONDE MEASUREMENTS

In environmental meteorology, mixing height is an important parameter because it defines the height to which pollutants, released at the ground, are vertically dispersed by convection or mechanical turbulence within a certain time scale of about an hour or less. Reliable values of mixing height are needed, e.g., for environmental monitoring as well as the prediction of pollutant concentrations. Therefore, greater efforts are being made to improve the estimation of mixing heights. Radiosonde ascents provide the most common database for mixing-height estimation. Mixing heights obtained from these ascents are also used in meteorological pre-processors. Mixing height data are among the most required information in the air pollution modeling studies. These data are available in most of the developed countries' data banks. Since no data bank were available for Turkey, available radiosonde measurements were analyzed. At the end of the study, valuable information on the vertical structure of the atmosphere was gathered.

Variation of mixing height was determined by analyzing the twice daily Göztepe radiosonde measurements of 1995-96 obtained from the State Meteorological Office. Holzworth, Coulter, Goldman, Heffter and Stull methods used for the determination of morning and afternoon mixing heights. Stull method was accepted as the most effective method for determination of the mixing height in the morning and afternoon cases.

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ÖZET

GÖZTEPE RADIO-SONDE RASATLARI KULLANILARAK ATMOSFERİK KARIŞIM YÜKSEKLİĞİNİN TANIMLANMASI

Karışım yüksekliği saatlik veya saatten daha kısa zaman içerisinde konveksiyon veya mekanik türbülansla dikey yönde yayılımı tanımlamasından dolayı Çevre Meteorolojisinde önemli bir parametredir. Kirletici konsantrasyonlarının tahmininde de güvenilebilir karışım yüksekliği değerlerine gereksinim duyulmaktadır. Karışım yüksekliği ölçümünü geliştirmek için birçok çaba sarf edilmiştir. Radio-Sonde gönderimleri karışım yüksekliği tahmini için en çok kullanılan metoddur. Bu gönderimlerden elde edilen karışım yükseklikleri meteorolojik ön işlemcilerde de kullanılmaktadır. Karışım yükseklikleri hava kirliliği modelleme çalışmalarında en çok ihtiyaç duyulan bilgiler arasındadır. Bu bilgiler çoğu gelişmiş ülke bilgi bankalarında bulunmaktadır. Böyle veri bankalarının ülkemizde bulunmaması nedeniyle, yapılan bu çalışma sonucunda atmosfer düşey yapısı ile ilgili değerli bilgi birikimi sağlanmıştır.

Karışım yüksekliği değişimi 1995-1996 yıllarında Devlet Meteoroloji Ofisinin sağladığı günde iki defa yapılan Göztepe Radio-Sonde rasatlarının analizi ile belirlenmiştir. Holzworth, Coulter, Goldman, Heffter ve Stull metotları sabah ve öğleden sonra karışım yüksekliği hesabında kullanılmıştır. Stull metodunun sabahları ve akşamları karışım yükseliği tanımlanmasında en etkili yöntem olduğu sonucuna varılmıştır.

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DETERMINATION OF ATMOSPHERIC MIXING HEIGHTS USING GÖZTEPE RADIOSONDE MEASUREMENTS

In environmental meteorology, the mixing height is an important parameter because it defines the height to which pollutants, released at the ground, are vertically dispersed by convection or mechanical turbulence within a certain time scale of about an hour or less. Reliable values of the mixing height are needed, e.g., for environmental monitoring as well as the prediction of pollutant concentrations. Therefore, greater efforts are being made to improve the estimation of mixing heights.

Although the mixing height data are among the most required information in the air pollution modeling studies, there is limited information about the vertical structure of the atmosphere in Turkey. This study will provide important information of the vertical structure of the atmosphere and fill the gap in this area in Istanbul..

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SYMBOLS

C_n^2	: Refraction structure parameter	$m^{-2/3}$
C_p	: Specific heat at constant pressure	$J\ kg^{-1}\ K^{-1}$
C_T^2	: Temperature structure parameter	$K\ m^{-2/3}$
e	: Water pressure	mbar
ε	: Constant equal to 0.622	-
f	: Coriolis parameter	s^{-1}
g	: Acceleration due to gravity	$m\ s^{-2}$
H	: Surface buoyancy flux	$W\ m^{-2}$
L	: Monin Obukhov length	m
p	: Air pressure	mbar
Ri	: Gradient Richardson number	-
T	: Air Temperature	K
T_v	: Virtual temperature	K
Θ	: Potential Temperature	K
Θ_v	: Virtual Potential Temperature	K
u	: Horizontal component of wind speed	$m\ s^{-1}$
u^*	: Friction velocity	$m\ s^{-1}$
z	: Height	m
z_i	: Convective boundary layer depth	m

ABBREVIATIONS

ABL	: Atmospheric boundary layer
CBL	: Convective boundary layer
CL	: Cloud layer
FA	: Free atmosphere
Lidar	: Light detecting and ranging
LLJ	: Low-level jet
MH	: Mixing Height
ML	: Well Mixed layer
NWP	: Numerical weather prediction
PBL	: Planetary boundary layer
Radar	: Radio detecting and ranging
RL	: Residual layer
SBL	: Stable boundary layer
SCL	: Subcloud layer
Sodar	: Sound detecting and ranging
TKE	: Turbulence kinetic energy

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CHAPTER I

INTRODUCTION and AIM

Introduction

Seibert et al. stated in 1997 that “The atmospheric boundary layer (ABL) is the layer where interactions take place between the earth's surface (which captures most of the incoming solar energy and redistributes it in different forms) and the large scale atmospheric flow (which is driven by this energy)”. This transfer of energy is partly accomplished by turbulent eddies. The ABL transfers latent heat, momentum and atmospheric constituents between the surface and higher atmospheric levels.

According to Seibert et al., “The great importance of the exchange of many trace constituents (e.g., SO₂, NO_x, O₃, CO₂, CH₄ and non-methane volatile organic compounds - NMVOCs) which are often emitted into or deposited from the atmosphere to terrestrial and aquatic ecosystems via the ABL has been recognized as one of the main links in global biogeochemical cycles. It is thus of primary importance to be able to understand, measure, parameterize, simulate and predict the structure and behaviour of the ABL”, (1997).

There are two different mechanisms which are called wind shear and buoyancy produces atmospheric turbulence. In the ABL, the main source of wind shear is surface friction, but there may be also wind shear due to baroclinity or certain mesoscale phenomena such as lowlevel jets, flow channelling or at the interface of different flow layers. Positive buoyancy is mainly produced by heating from the ground, sometimes also by radiative cooling of elevated layers or by overturning of gravity waves. Negative buoyancy - as experienced by eddies under statically stable stratification - is an important sink for turbulent kinetic energy (TKE) in the atmosphere. The actual level of turbulence in the atmosphere is thus mainly the result of shear and / or buoyancy production, advection, buoyant destruction, and molecular dissipation.

In his project, “Mixing Height Determination for Dispersion Modelling”, Seibert et

al., indicates that the height h of the ABL is one of the fundamental parameters to characterize its structure. Measurements, parameterizations and predictions of the height of the ABL have many theoretical and practical applications such as the prediction of pollutant concentrations or of surface temperature, the scaling of turbulence measurements or the treatment of the ABL in numerical weather prediction and climate models. (1997)

Based on the project of Seibert et al., “Two basic ABL-regimes can be distinguished according to the dominant production mechanism of the turbulence, namely the convective and the stable boundary layer”.

Thermal heating induced by strong insolation causes positive buoyancy at the earth's surface and is the main source of turbulence in the convective boundary layer (CBL). In the CBL, organized convective structures (so-called thermal plumes) can be observed. They generate an intensive vertical exchange of energy and matter, and consequently all properties are rather well-mixed over most of the CBL. This mixing is often limited in its vertical extension by a stable layer (often an inversion) aloft, the height of which varies depending on the site and on the season. Typical values of this level over Europe range between a few hundred meters and 2-3 km above ground. (1997)

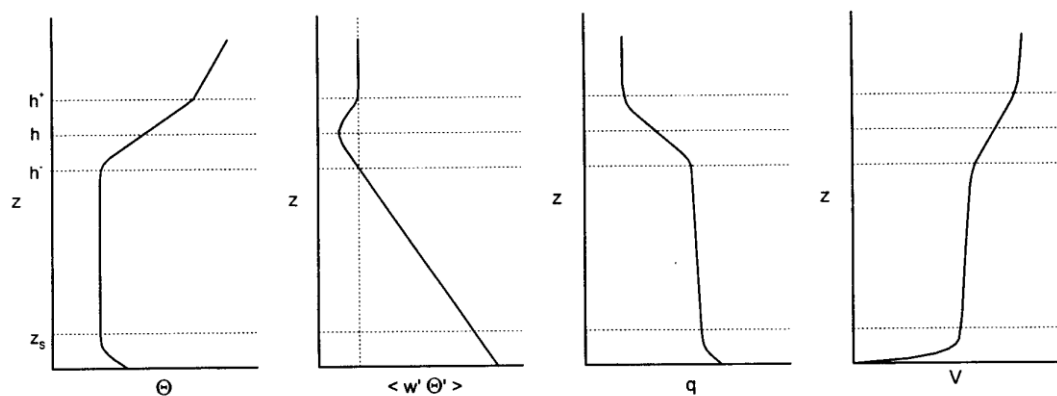


Figure I-1. Idealized structure of the CBL, (Seibert et al., 1997).

The typical structure of the CBL is sketched in Figure I-1. Three different sublayers can be distinguished:

- i) The surface layer (SL) which covers about 5-10 % of the whole CBL. The SL is characterized by a super-adiabatic lapse rate, a decrease of specific humidity with

height and a significant vertical wind shear. These features of the profiles of mean meteorological variables can be, in most cases, well described by the Monin-Obukhov similarity theory (MOST). The turbulent fluxes of heat, moisture and momentum are assumed to be roughly constant with height in the SL.

ii) The *well-mixed layer* (ML) embeds the major part of the CBL (50-80%). Within the ML, the vertical profiles of most mean meteorological variables are roughly constant with height due to the intensive vertical mixing. This especially holds for potential temperature but with minor restrictions also for specific humidity, concentrations of trace gases and aerosols, and for wind speed and wind direction.

iii) The *entrainment layer* (EL), forms a transition zone between the ML and the stably stratified, quasi-nonturbulent free atmosphere above. it is characterized by two counteracting processes: the penetration of the most energetic thermals into the stable layer aloft, and the entrainment of warm and (in the absence of clouds) dry air from above into the ML. The EL is mostly defined in a horizontally or temporally averaged sense since the instantaneous transition zone between the ML and the free atmosphere can be quite thin. The EL comprises typically 10-30% of the total depth of the CBL, but can be even deeper than the ML, especially in the morning. Typical features of the EL are a strongly positive temperature lapse rate, a sharp decrease of specific humidity and sometimes significant vertical wind shear. Sharp gradients of aerosol and trace gas concentrations are also often observed across the EL. In so-called zero-order jump models, which are often used in practice, the depth of the EL is neglected (see Fig. I-2).

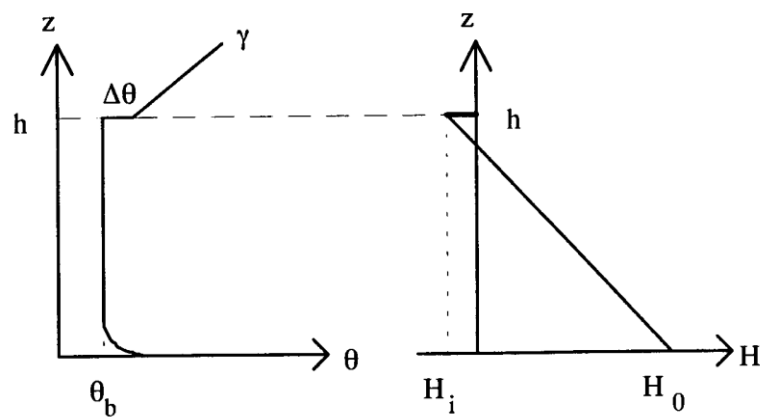


Figure I-2. Idealized Profiles of the potential temperature and the turbulent heat flux in a zero-order jump model of the CBL, (Seibert et al., 1997).

Seibert et al., stated that “The evolution of the CBL on clear, sunny days can be characterized by four basic stages:

- i) Formation of a shallow CBL near the ground, starting with the morning insolation and growing gradually until the nocturnal surface inversion has been completely destroyed. The typical growth rate of the CBL-depth is 10 ... 100 m/h.
- ii) Rapid CBL-growth across the near-neutral residual layer of the previous day, up to the level of the capping inversion with a rate of 100 ... 1000 m/h.
- iii) Consolidation of the well-mixed CBL whereby its depth grows - if at all - only slowly, due to penetration of thermals into the stably stratified free atmosphere and influenced by large-scale vertical motions at the CBL-top.
- iv) Decay of the thermally driven turbulence and vertical mixing followed by the formation of a shallow stable layer close to the ground which converts the CBL into an elevated residual layer for the following day (see phase II)” (1997).

Under stable conditions, in the absence of buoyant turbulence production, wind shear is the only mechanism creating turbulence, and stable background stratification associated with negative buoyancy will act as a sink for TKE. Therefore, in the stable boundary layer (SBL), a sensitive equilibrium exists between production and destruction of turbulence. Consequently, turbulence does not necessarily occur continuously but may have an intermittent or patchy character. Since the general level of turbulence is weak, other effects such as radiative cooling, gravity waves, advection or subsidence may also influence the structure of the SBL. Thus a great variety of SBL structure types can be observed.

Seibert et al. asserts, “The temperature profile in the SBL is strongly governed by longwave radiative cooling beginning at the surface and progressing upwards. Usually, this process results in the formation of a near-surface temperature inversion. Under conditions of weak pressure gradients, weak surface winds and hence weak mechanical turbulence production, the strongest temperature gradients occur near the surface, and the vertical profile of (potential) temperature shows a curvature continuously decreasing with height. It can be described approximately by polynomial or exponential functions. Under such conditions it is very difficult to assess the height of the SBL” (1997).

According to Seibert et al, “If mechanical turbulence production is significant, at least two different regions can be distinguished within the SBL, as shown by

observations and numerical modelling. In the lower layer, the potential temperature profile is often characterized by a strong, nearly linear increase with height due to the interaction of radiative cooling of the earth surface and turbulent exchange. In the upper layer, radiative cooling of the atmosphere itself is the dominant mechanism resulting in a much weaker temperature gradient” (1997).

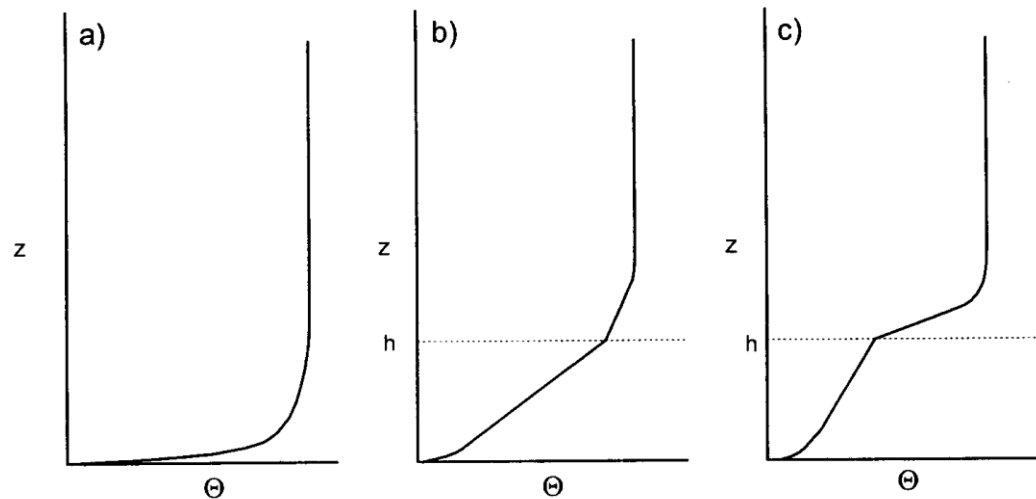


Figure I-3. Typical vertical temperature profiles in the SBL; a) weak wind, strong stability; b) moderate wind; c) strong wind, (Seibert et al., 1997).

Substances emitted into the ABL are gradually dispersed horizontally and vertically through the action of turbulence, and finally become completely mixed over this layer if sufficient time is given and if there are no significant sinks. Therefore, it has become customary in air pollution meteorology to use the term "mixed layer" or "mixing layer". On the other hand, since under stable conditions complete mixing is often not reached, e.g. for a plume from an elevated stack within the range covered by many dispersion models, the term "mixing layer" seems preferable, because it emphasizes more the process than the result. The term "mixed layer" shall be reserved for the well-mixed boundary layer typically encountered under sufficiently convective conditions. Obviously, the mixing layer coincides with the ABL if the latter is defined as the turbulent domain of the atmosphere adjacent to the ground.

However, other definitions of the ABL have also been used which may, e.g., include the domain influenced by nocturnal radiative exchange processes. The height (or depth - depending on whether you look at it from below or from above) of the mixing layer is an important parameter in dispersion modelling and its

determination. It will be denoted by the short term *mixing height (MH)* and the letter *h*. Seibert et al., stated in 1997 that the practical determination of the MH, and sometimes even its definition, is not trivial, and there are many associated practical and theoretical problems. This is reflected in the following selection of definitions which have been given in the literature.

- The MH is defined as the height above the surface through which *relatively vigorous vertical mixing* occurs. (Holzworth, 1972)
- The MH refers to the *height above ground of the layer of the atmosphere adjacent to the surface* where vigorous mixing occurs as a *result of thermal and mechanical turbulence*. (Norton and Hoidale, 1976)
- In general *h* may be defined as the height up to which *significant turbulent transfer of heat, mass and momentum* between the local earth surface and the atmosphere occur when averaged over a *period of the order of one hour* In air pollution meteorology, *h* is commonly known as the mixing depth. (Arya, 1981)
- The term MH is used ... to denote the level of a potential barrier to the dispersion of pollutants at the *interface between stable and less stable air* (Maughan et al., 1982).
- The mixing height, based on the temperature structure, can therefore be defined as the height at which a ground-based unstable to neutral vertical temperature profile becomes stable (Baxter, 1991).
- The MH (is) defined to describe the height to which the pollutants would mix over a *relatively short period of time, 1-2 hours* (Baxter, 1991).
- The MH defines the vertical extent of vigorous thermal turbulence *during daytime* heating and thus sets a limit to *upward mixing* of pollutants (Myrick et al., 1994).

It can be seen that these definitions represent quite different ideas on how to define the mixing height. It seems also that the MH definitions of different authors have to be seen in the context of the data available to them.

The definition I have adopted as a general guideline for this project is:

The mixing height is the height of the layer adjacent to the ground over which pollutants or any constituents emitted within this layer or entrained into it become vertically dispersed by convection or mechanical turbulence within a time scale of about an hour.

According to Seibert et al., in order to proceed from this general definition to practical realizations, it is necessary to consider the structure of the stable and of the convective ABL, (1997).

Figure I-1 depicted the structure of the CBL; the important feature with respect to the MH definition is the entrainment layer, a zone which is not well-mixed and where turbulence intensity declines from its bottom to its top. (Seibert et al., 1997)

I.1. DETERMINATION OF THE MIXING HEIGHT FROM MEASUREMENTS

I.1.1. Mixing Height Estimations From Radiosoundings

Radiosoundings are the most common source of data which can be used to determine the mixing height for operational purposes. Rawinsonde measurements extend well beyond the height of the whole ABL, they are widely distributed throughout Europe, and the data are continuously quality-controlled. On the other hand, it is a shortcoming of the sounding programme that, as a rule, at most of the stations, measurements are only taken twice daily at specified synoptic times. Consequently the soundings can only be used in order to have a reference level at launching time (00 UTC, 12 UTC) to be compared with model evaluations of the MH. Advanced meteorological pre-processors utilize information from both ground meteorological measurements and sounding profiles in order to better characterize the boundary layer structure and evaluate the MH, especially for convective conditions (e.g., Olesen et al, 1987, 1992). Other fundamental limitations of radiosoundings are the poor vertical resolution of data with respect to boundary layer studies and the loss of accuracy due to the sensor lag constant bounded with the ascent rate of the sonde. Due to the relatively high ascent rate, the radiosonde gives only a "snapshot" like information on the ABL structure which might be of limited representativity. For research purposes, the use of special boundary layer sondes with shorter time constant of the meteorological sensors and a smaller balloon (i.e. a slower ascent rate) may partially compensate the shortcomings of sensor response.

Routine rawinsonde measurements can be analyzed to determine temperature inversion and temperature lapse conditions in the lower part of the atmosphere. Under convective conditions, the mixing height is often identified with the base of

an elevated inversion or stable layer, or the height of a significant reduction in air moisture. Some authors recommend to take the inversion base altitude increased by half of the depth of the inversion layer as the characteristic CBL height (Stull, 1988). Holzworth (1964, 1967, 1972) and others have developed objective methods (categories and summation techniques) to simplify and homogenize the analysis of the often complex stratification of the ABL and to estimate the mixing height (under convective conditions). The method based on Holzworth is to follow the dry adiabat starting at the surface with the measured or expected maximum temperature up to its intersection with the temperature profile from the most recent radiosounding. Different refinements to this simple scheme have been suggested to account for temperature advection, subsidence and other effects. It should be remarked, however, that this method strongly depends on the surface temperature, and a high uncertainty in the estimated MH value may result in situations without a pronounced inversion at the CBL top. Different authors pointed out that the MH determined by the "Holzworth method" is not strongly correlated with observed trace gas concentrations.

More recently, methods based on conserved variables were developed which permit analysis of air mass structures and vertical mixing (Betts and Albrecht, 1987).

Seibert et al., stated in 1997 that an example of a typical 12 UTC (13 LST) sounding on a clear summer day with well-developed CBL in figure I-4. The top of the EL is about 3000 m above sea level. The base of the capping inversion is about 2500 m above sea level.

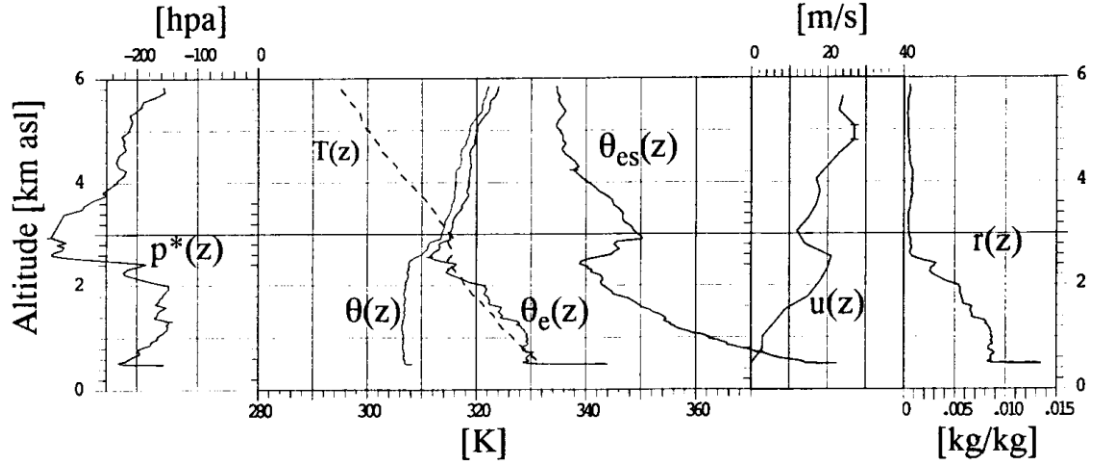


Figure I-4. Typical summer day sounding Payeme, Switzerland, 29 July 1993. 15 UTC with profiles of the conservative variables suggested by Betts and Albrecht (1987).

Betts and Albrecht (1987) have developed these criteria on the basis of averaged and smoothed profiles. They estimated that averaging the basic data at each 10 hPa pressure level best preserved the vertical thermodynamic profiles of the individual soundings. For the study of an individual profile, a refinement of the criteria is necessary to differentiate the main features from secondary stratification. Such a refinement has been performed by Tercier et al. (1995) to determine the mixing height from radiosoundings in the POLLUMET field campaign.

Seibert et al. asserts, “Another popular approach is the use of bulk Richardson number methods” (e.g., Troen and Mahrt, 1986; Holtslag and van Ulden, 1996). They differ mainly in the choice of the level for the near-surface temperature and wind, parameterization of shear production of turbulence in the surface layer, and the consideration of an excess temperature under convective conditions.

Parcel methods can be understood as a simplification of the Ri number methods where the shear contribution is neglected. Thus they are only suited for unstable conditions. Wotawa et al. (1996) is cited by Seibert et al., applied a parcel model using vertical profiles of temperature and specific humidity and taking the MH as the height where the dry static energy of a lifted parcel equals the one at the starting (surface) level plus an eddy excess energy. This eddy excess energy is calculated from the surface fluxes of buoyancy and momentum using a mixed-layer scaling approach of Troen and Mahrt (1986), suggested also by Beljaars and Betts (1992).

Table I-1. Critical assessment of different methods to determine the MH. ✓ fulfilled; (✓) Partly fulfilled; — Not fulfilled

	Continuous data output	Lowest level close to the ground, high resolution < 200 .. 500 m	Range of 2-3 km covered	Determination of turbulence parameters or trace gas conc.
<i>In-situ measurements:</i>				
Radiosonde	—	(✓)	✓	—
Tethered balloon	—	✓	—	(✓)
Mast	✓	(✓)	—	✓
Aircraft	—	—	✓	✓
<i>Remote sounding:</i>				
Lidar	(✓)	(✓)	✓	✓
Sodar	✓	✓	—	✓
Radar	✓	—	✓	✓
RASS	(✓)	(✓)	—	(✓)
<i>Numer. models</i>	(✓)	(✓)	✓	✓

I.1.2. Mixing Height Estimation From Remote Sensing Systems

According to Seibert et al., "In many countries remote sensing systems (lidars, sodars, wind profiling radars) are more introduced into operational application. They provide an interesting alternative for MH estimation. The basic advantages of remote sensing systems are the possibility of continuous operation and the fact that the systems do not cause any distortion or modification of the investigated flow" (1997). According to Seibert et al., "Among the different remote sensing systems, the sodar is one of the simpler and less expensive systems, making it well suited for routine operation". The physical principle underlying the operation of sodars is the scattering of sound at small-scale inhomogeneities in the vertical profile of the acoustic refractive index. These are basically due to temperature inhomogeneities and can be the result of either turbulent fluctuations or of the local gradient of the mean temperature. The intensity of these inhomogeneities can be quantitatively characterized by the structure parameters of the refractive index C_n^2 and of

temperature C_T^2 , respectively, which hence determine the backscatter sound intensity measured with the acoustic sounder. Experimental studies as well as results of numerical models have shown certain typical features of the vertical profiles of C_T^2 under stable and convective conditions, which can be used to derive the MH from profiles of the backscatter intensity. In addition, sodar systems with Doppler capability allow determination of the mean wind and vertical velocity variance profiles which may also be employed for MH determination using idealized model assumptions. On the other hand, it must be remarked that the vertical range of most sodars is limited to a maximum of about 1 km; often it is much less. Nevertheless, MH estimates have been one of the "classical" applications of acoustic sounders for about 20 years. Lidars allow the measurement of aerosol or trace gas concentration profiles and may therefore be considered to provide direct measurements of the MH. Since the top of a convectively mixed layer is often associated with strong gradients of the aerosol content, a simple aerosol backscatter lidar seems especially suited to determine the convective MH. The data analysis of differential absorption lidars, used to measure the concentration profiles of trace gases, requires an aerosol correction. This may result in quite high uncertainties of the derived gas concentrations in regions with strong changes of aerosol content and composition, i.e., just at the top of the ML. However, even the interpretation of data from aerosol lidars is not often straightforward, since it does not allow to decide whether the detected aerosol layers are really the result of ongoing vertical mixing or whether they originate from advective transport or past accumulation. Under stable conditions, problems in mixing height estimation from lidar data come from the fact that the vertical gradients in the aerosol content are much smaller than those at the top of the convective ML. Moreover, in the evening, it usually takes some time until a sufficiently clear discontinuity in the backscatter intensity profile develops at the top of the SBL, within the previously well-mixed layer. (1997)

I.1.3. Other Empirical Methods

Guedalia et al, 1980 and Nicolas et al, 1985, 1988 are cited by Seibert et al., "Another indirect estimation of the MH described in the literature is based on measurements of concentration changes of the non-reactive noble gas radon, which is basically emitted from natural sources by exhalation from the soil". However, as

pointed out in Guedalia et al. (1980), such measurements do not allow a direct estimate of the MH but rather provide a value which might be called an "equivalent mixing height" characterizing the overall dispersion conditions, (1997).

Seibert et al., asserts “Similarly, attempts have been reported to estimate the MH from simultaneous measurements of SO₂ ground concentration and the total column depth (e.g., Cappellani and Bielli, 1995). This method assumes the SO₂ mixing ratio to be either constant with height or to follow a specific profile inside the ML and the complete absence of SO₂ above the ML. It is obvious that such a method will be applicable only for certain regions and very specific atmospheric conditions and even then large uncertainties have to be expected”, (1997).

Problem Definition and Research Objective:

In environmental meteorology, the mixing height is an important parameter because it defines the height to which pollutants, released at the ground, are vertically dispersed by convection or mechanical turbulence within a certain time scale of about an hour or less. Reliable values of the mixing height are needed, e.g., for environmental monitoring as well as the prediction of pollutant concentrations. Therefore, greater efforts are being made to improve the estimation of mixing heights. Radiosonde ascents still provide the most common database for mixing-height estimation which is also used in meteorological pre-processors.

Variation of mixing height will be determined by analyzing the twice daily Göztepe radiosonde measurements of 1995 and 1996 which were obtained from the State Meteorological Office. The main objective of this study is to address the methodology concerns of the Holzworth technique. Moreover alternative methods for computing mixing height Stull, (1988; 1991), Coulter (1979), Goldman(1980) and Heffter(1980) is introduced. In order to evaluate and compare the methods with the Holzworth technique, data bank were determined twice daily (00 and 12 GMT) for the period of 1995 and 1996.

Mixing height data are among the most required information in the air pollution modeling studies. These data are available in most of the developed countries' data banks. Lack of information on our site causes uncertainties in air pollution studies in Turkey. At the end of the study, valuable information on the vertical structure of the atmosphere will be gathered.

Phases of the Study:

- Re-formatting of data for State Meteorology Office
- Development of programs to calculate mixing heights. Fortran, visual basic and excell programing will be performed for this purpose.
- The data will be analyzed by using the programs developed. With the help of the vertical profiles of mentioned parameters. Stability classes and mixing heights will be calculated.
- A data bank will be developed to be used for further modeling studies.

Table I-2. Measuring platforms and methods for MH determination. (Seibert et al., 1997).

Method	Advantages	Shortcomings	Examples
Direct Measuring Techniques / Sensor Platforms			
Radiosonde	- routine ascents for many years all over the world, therefore especially suited for climatological studies - measured data transmitted via international communication networks with very short time delay, therefore well suited for operational use - compatibility with measurements in the free atmosphere	- crossing the ABL along a slanted path within a few minutes, provides a "snapshot" like profile - limited height resolution of routine ascents - operationally only 2-4 soundings per day at fixed times, even during field experiments higher sequence than 1,5-3 hours not possible - tracking problems at low levels (site-dependent)	Holzworth, 1964, 1967 Norton and Hoidale, 1976 Gutsche and Lefebvre, 1981 Bernhardt et al., 1982
Tethered balloon	- ascent velocity can be chosen according to the desired vertical resolution - turbulence and trace gas concentration measurements possible	- limited to field campaigns, no unmanned operation - synchronous profile measurement difficult - limited measurement range, casually below 500 m - not possible in cases of high wind speed or strong Convection	Van Gogh and Zib, 1978 Hayashi, 1980 Bachvarova and Gryning, 1994 Derbyshire, 1995
Mast	- installation of a large number of different sensor types possible including detailed turbulence measurements - continuous operation	- very high installation / operation costs - Limited range: 200-300 m - high vertical resolution requires a high number of sensors (increasing costs)	Kottmeier, 1982 Kurzeja et al., 1991 Cabauw Tower (NL) Boulder Atmospherie Obs. (USA)

Table I-2. Continue.

Aircraft and Remote Sensing Techniques			
Aircraft	- possibility to operate many different sensors, including mean meteorology, chemistry, and turbulence sensors, as well as remote sensing systems - provides spatial information, admirably suited for mesoscale studies	- high costs, only for special field studies - operation mostly limited to daylight hours - lowest flight level subject to restrictions (security)	Druilhet et al., 1983 Hildebrand, 1988 Jachum et al., 1991
Radar / Windprofiler	- ground based and aircraft based operation possible (for radar only) - alternating RHI/PPI-Scan for 3D-studies (for radar only) - high sampling rate and continuous operation	- lowest range normally not below 200 m - limited vertical resolution (50-250 m) - expensive - frequency allocation problems within Europe - interpretation not always straightforward	Noonkester, 1976 Kaimal et al., 1982 Connolly and Dagle, 1991 Angevine et al., 1994
Lidar	- ground-based and aircraft-based operation possible - alternating RHI/PPI-Scan for 3D-studies - high sampling rate - return signals originate directly from aerosols ("pollution")	- expensive - unattended operation of ten not possible for safety reasons - limited range resolution and lowest range gate - tracer necessary (gas, aerosol) - interpretation sometimes ambiguous	Sasano et al., 1982 Boers et al., 1984 Hashmonay et al., 1991 Dupont, 1991 McElroy and Smith, 1991 van Pul et al., 1994
Sodar	- relatively simple, not very expensive: suited for unmanned long-term operation - high temporal and vertical resolution	- limited sounding range (500-1000 m) - sensitivity to environmental noise - noise contamination to the environment - interpretation requires experience, sometimes Ambiguous	Russell and Uthe, 1978a,b Nieuwstadt, 1984b, Jones, 1985 Singal, 1988 Beyrich, 1993, 1994b, 1995

I.2. METEOROLOGICAL PRE-PROCESSORS

According to Seibert et al., major researchers develop and use a pre-existing meteorological pre-processor to determine the boundary layer variables used in dispersion models (1997). Based on Lena's and Desiato's article (1999), these models provide three-dimensional mass-adjusted wind fields and scaling parameters (like friction velocity u^* , Monin Obukhov length L , Coriolis Force f , and mixing height h). The major pre-processors are OML, HPDM and RODOS.

I.2.1. The OML Meteorological Pre-processor

The meteorological pre-processor of the Danish dispersion model OML contains a module for the mixing height calculation. It is described in detail in Olesen et al. (1987, 1992) and also Martin Piringer (1998). Each hour, the module computes a mechanical and, during daytime, a convective mixing height and selects the larger one as the actual value. A minimum value of 150 m is applied, however.

Based on the project of Seibert et al. "The mechanical mixing height is calculated as $h = 0.25 u^*/f$. The convective mixing height is obtained from the integration of the prognostic equations. The initial values of the mixing height and the temperature jump through the entrainment layer are determined from the heat flux during the hour in which the heat flux first becomes positive and from the temperature gradient near the ground, respectively".

I.2.2. The HPDM Meteorological Pre-processor

The role of the meteorological pre-processor of the Hybrid Plume Dispersion Model (HPDM) is to produce time series of hourly values of the surface heat and momentum fluxes and of the mixing depth, using observations of wind speed, cloudiness, surface roughness length, surface moisture availability and albedo. This pre-processor accepts a wide variety of possible input data. It uses boundary layer theory to solve the surface energy balance, determines the mixing depth using upper air data, and derives vertical profiles of wind, temperature and turbulence. If observations of these derived variables, including the mixing depth are available, they can be used directly in the model. However, the pre-processor in its standard form does not accept observed fluxes. The source code had thus to be modified in

the present study in order to use measured fluxes, (Seibert et al., 1997).

Seibert et al. is cited by Hanna and Chang (1991) as stating that HPDM uses the following ways to estimate the mixing height:

Night-time: The interpolation formula of Nieuwstadt (1981), based on U^* , L^* and f is used.

Daytime: During daytime, two separate mixing heights are calculated. One is obtained with Carson's (1973) prognostic Formula which parameterizes the entrainment heat flux, A second MH is calculated, according to a suggestion of Weil and Brower (1983), considering solely the growth rate of the CBL due to mechanical turbulence. Finally, the larger value is taken as the convective mixing height.

Neutral conditions (irrespective of the time of the day): The u^*/f formula is used with the constant $c = 0.3$; neutral conditions are defined as Pasquill-Gifford stability category D. The stability category is computed from L^* and z_0 using Golder's (1972) relations.

I.2.3. The Rodos Pre-processor

Seibert et al. is quoted by Mikkelsen et al. (1996) stated in 1997 that “MET-RODOS is a comprehensive atmospheric transport and diffusion module, designed for operational use within the real-time, on-line emergency management system RODOS”. It contains a sub-system for the computation of local-scale wind fields and micro-meteorological scaling parameters (Deme et al., 1996; Mikkelsen and Desiata, 1993). The mixing height can be calculated from NWP model output utilizing the bulk Richardson number method. The determination of the MH from measurements, which was tested here, is based on the following routines:

During daytime, the mixed-layer growth model proposed by Batchvarora and Gryning is used. The integration starts with an initial value of h equal to 50 m; the lapse rate is taken from the previous midnight sounding. The MH during night is calculated with Nieuwstadt's (1981) Formula.

CHAPTER II

BACKGROUND

Determination of Stability

The three stability classifications correspond to: superadiabatic $dT/dZ < \Gamma_d$; adiabatic $dT/dZ = -\Gamma_d$; and subadiabatic $dT/dZ > \Gamma_d$; where T is temperature and Γ_d ($9.8^\circ\text{C km}^{-1}$) is the dry adiabatic lapse rate. A temperature inversion, where $dT/dZ > 0$, is also subadiabatic.

Table II-1. Traditional determination of static stability for unsaturated air, from Stull (1991)

Local Lapse Rate		Local Static Stability	
Name	$d\Theta/dz$	dT/dz	
Superadiabatic	Negative	$< -\Gamma_d$	Unstable
Adiabatic	Zero	$= -\Gamma_d$	Neutral
Subadiabatic	Positive	$> -\Gamma_d$	Stable

Most explanations of static stability start by displacing an air parcel an infinitesimal distance from an arbitrary starting height within the ambient environment. This is a logical approach that closely follows the generic definition of stability. However, in unstable conditions the parcel can continue to rise or sink across large distances, forced by the buoyancy of the parcel with respect to the environment. This parcel can buoyantly move through neighboring regions having locally adiabatic or subadiabatic lapse rates, that would have traditionally been classified as neutral or stable. Given the observation of vigorous convective turbulence within these regions, we must conclude that the local lapse rate gives us incomplete information about the response of the flow. (Stull, 1991)

There appears to be a paradox between the commonly used local definitions of static stability and the practical techniques to determine the turbulent state of the air. Some meteorologists already utilize nonlocal approaches whenever they estimate the buoyancy of an air parcel by comparing its temperature with that of the surrounding environment. For example, in thunderstorm situations an air parcel might rise from the surface to the midtroposphere, where its continued instability is measured by the parcel-environment temperature difference, not by the local lapse rate of the environment. The midtroposphere region might be highly turbulent at mesoscales due to the thunderstorm convection, even though the local environmental lapse rate is subadiabatic. Such parcel versus environment measures of static stability are also appropriate and, indeed, necessary for unsaturated situations, (Stull,1991).

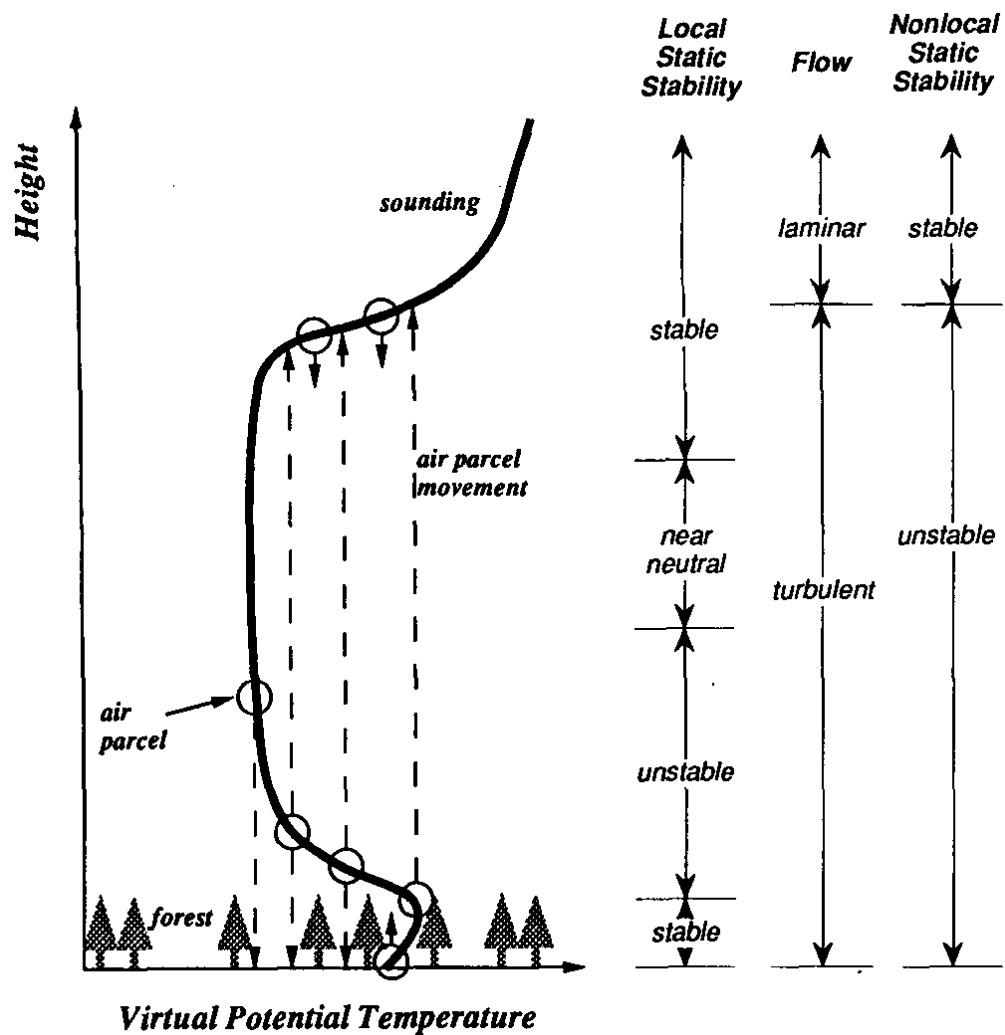


Figure II-1. Local and nonlocal interpretation of stability and flow, (Stull, 1991).

Stability Determination from a Sounding

Typical observed virtual potential temperature sounding (heavy solid line) showing a convective mixed layer over a forest canopy. Air parcels are represented by small circles and parcel movements are tracked with dashed lines. Local lapse rate determines the local static stability; parcel buoyancy and movement determines the nonlocal stability; and nonlocal stability determines the flow state.

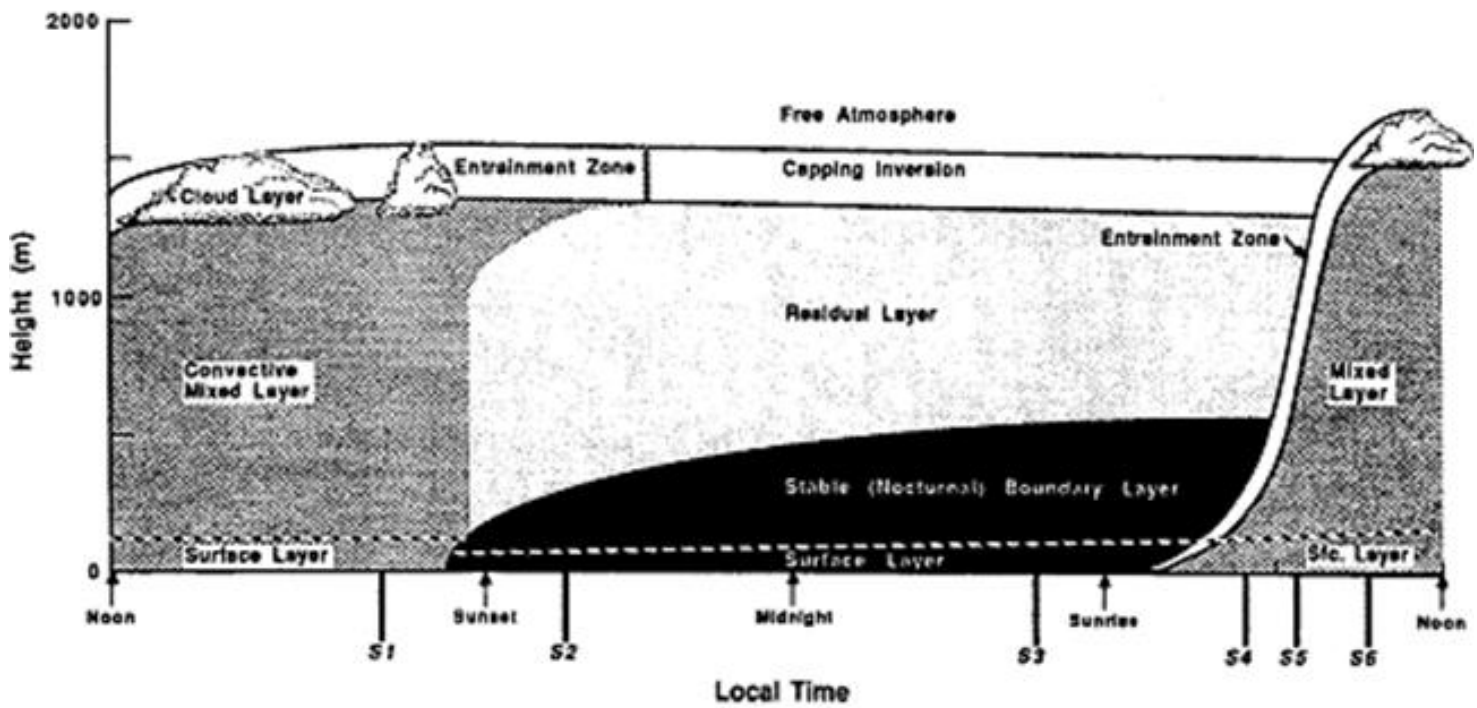


Figure II -2. The diurnal evolution of the PBL. Time markers indicated by S1-S6 will be used in Figure II-3, (Stull, 1988).

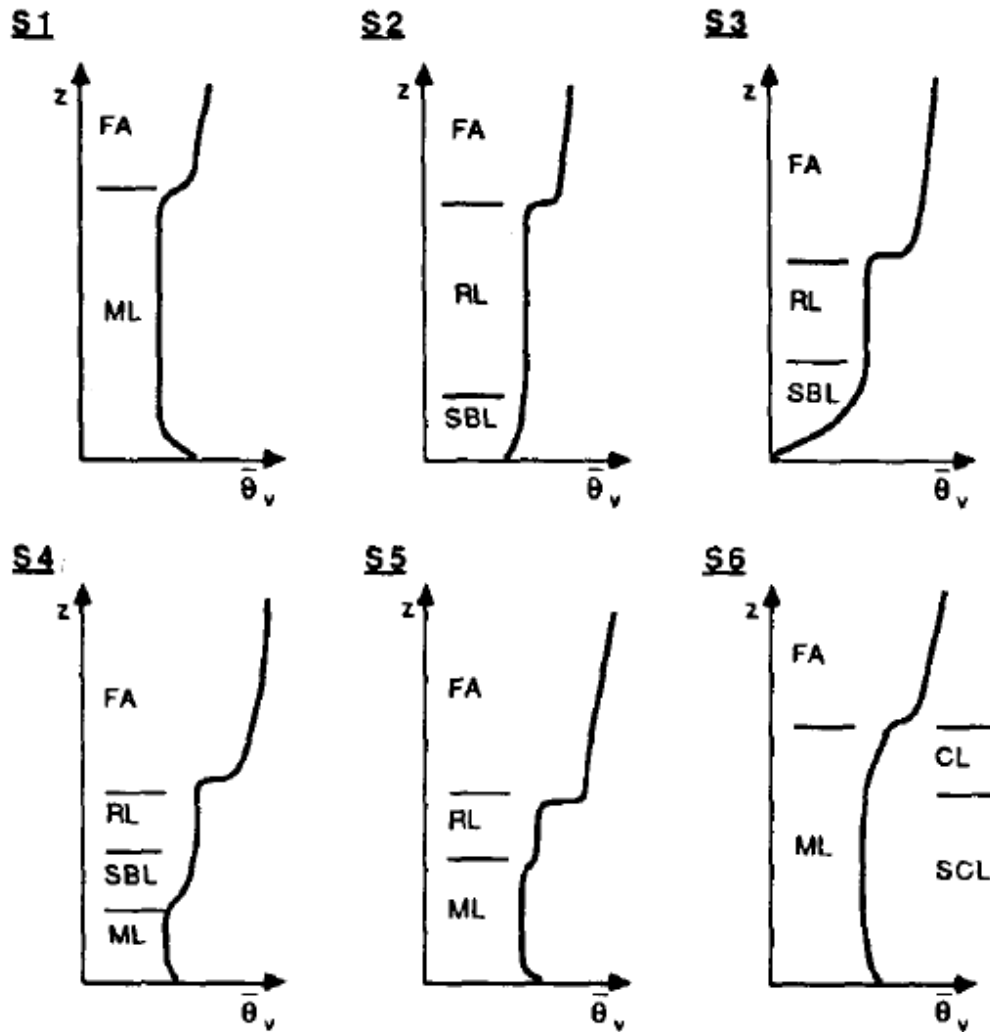


Figure II-3. Profiles of mean virtual potential temperature, illustrating the boundary layer evolution during a diurnal cycle starting in the late afternoon. S1-S6 identify each sounding with an associated launch time indicated in Figure II-3. (FA = free atmosphere, ML = mixed layer, RL = residual layer, SBL = stable boundary layer, CL = cloud layer, SCL = subcloud layer) (Stull, 1988).

The profile of the mean virtual potential temperature in a well developed convective boundary layer in the afternoon (profile S1) is shown in Figure II-3. Throughout the mixed layer, the virtual potential temperature is nearly constant. The daily cycle of a CBL can be divided into four phases (Stull, 1988; Seibert et al., 1997). The first stage is the formation of a shallow mixed layer (ML). This process is comparably slow with growth rates in the order of 10 to 100 m h⁻¹ as the strong nocturnal surface inversion caps the growing ML until this inversion is completely destroyed (see profile S4) (Seibert et al., 1997). By the time the

increasing ML has reached the base of the residual layer (RL), the second phase of rapid ML growth starts (see profile S5). Until the ML has reached the capping inversion, growth rates of 100 to 1000 m h⁻¹ can be observed as there is virtually no stable layer that covers the ML. The following phase is characterised by a relatively constant ML depth that only experiences slow changes caused by entrainment and subsidence and lasts most of the afternoon until shortly before sunset. The final depth varies largely amongst different regions of the world but is typically in the order of 1 to 2 km over land in mid-latitudes (Stull, 1988). The depth of the convective mixed layer z_i marks the depth with the most negative heat flux and the strongest capping inversion, which is near the middle of the entrainment zone (Stull, 1988).

Stability Classes

According to Mohan Manju and Siddiqui, atmospheric stability is commonly evoked in many dispersion studies as the single parameter used to define the turbulent state of the atmosphere or to describe the dispersion capabilities of the atmosphere. For many applications the details of the turbulent boundary layer are not known and recourse is made to simple categorizations of atmospheric conditions in terms of different stabilities to broadly classify the boundary layer's dispersive properties. In the popular Gaussian models, an index of atmospheric stability usually determines the functional form of the various algorithm which in turn calculates the concentration of pollutants. The other important parameter which has significant role to play in atmospheric dispersion is boundary layer depth. This is regarded as a lid where no transport of pollutants occurs across the lid, and unimpeded mixing takes place underneath. A modification in many of the recent models is that initial penetration of the lid from below is allowed. In several models, this is also involved in the parameterisation of the dispersion coefficients. However, the focus of attention in the present study is the various schemes for atmospheric stability classification which define the turbulent state of the atmosphere and also reflect upon the dispersion capabilities of the atmosphere. There are mainly six atmospheric stabilities designated as A (highly unstable or convective), B (moderately unstable), C (slightly unstable), D (neutral), E (moderately stable), and F (extremely stable). Later, stability G is also included to

represent low wind nighttime stable conditions (Table II-2), (1998).

Table II-2. Pasquill stability classification from Mohan Manju and Siddiqui T. A. 1998.

^a (Ref. Davies and Singh, 1985; Journal of Hazardous Materials 11, 1985). Excluding 1 h after sunrise and 1 h before sunset.

^b Night was originally defined to include periods of 1 h before sunset and after sunrise. These 2 h are always categorised here as D.

^c Pasquill said that in light winds on clear nights the vertical spread may be less than for category F but excluded such cases because the surface plume is unlikely to have any definable travel. However, they are important from the point of view of the build up of pollution and category G (nighttime, 0 or 1 okta of cloud, wind speed 0 or 0.5 ms⁻¹) has been added.

Wind speed (m s ⁻¹)	Daytime ^a incoming solar radiation (W m ⁻²)				Within 1 h before sunset or after sunrise ^b	Nighttime cloud amount (oktas)		
	(m s ⁻¹) strong (>600)	Moderate (300–600)	Slight (<300)	Overcast		0–3	4–7	8
≤ 2.0	A	A–B	B	C	D	F or G ^c	F	D
2.0–3.0	A–B	B	C	C	D	F	E	D
3.0–5.0	B	B–C	C	C	D	E	D	D
5.0–6.0	C	C–D	D	D	D	D	D	D
> 6.0	C	D	D	D	D	D	D	D

CHAPTER III

THE STUDY

Twice daily radiosonde measurements of 1995 and 1996 which were obtained from State Meteorological Office Göztepe Station were used to determine mixing heights. Holzworth (1967), Coulter (1979), Goldman (1980), Heffter (1980) and Stull, (1988; 1991) methods used in the study.

III.1. DATA

Data contain January, February, March, April, May, June, July, August, September, October, November, December for 1995 mornings and 1995 afternoons; February, March, April, May, June, October, November, December for 1996 mornings and afternoons and also July, August and September for 1996 mornings. There is an example of a sounding profile used in this study in Appendix A. The vertical resolution for the radiosonde data were approximately 10m below 1500meters and 50 meters above 1500 meters. In order to evaluate and compare the methods with the Holzworth technique, mixing heights were determined by analyzing twice daily radiosondings (00:00 and 12:00 GMT) for the period of 1995 and 1996.

III.2. MIXING HEIGHT COMPUTATIONS

III.2.1 Calculations of Relevant Atmospheric Parameters

In order to determine the mixing height, profiles of temperatures (T), potential temperature (Θ) and virtual potential temperature (Θ_v) were calculated. Potential Temperature is defined as the temperature that dry air would have brought to 1000 mb by adiabatic expansion or compression. The formula to calculate the potential temperature at this study is:

$$\Theta = (T \times (1000/P)^{0.286}) \text{ where,}$$

Θ : Potential Temperature (Kelvin)

T: Temperature (Kelvin)

P: Pressure at the specific altitude (mbar)

The formula to calculate the virtual potential temperature is:

$\Theta_v = (T_v \times (1000/P)^{0.286})$ where,

Θ_v : Virtual Potential Temperature (Kelvin)

T: Virtual Temperature (Kelvin)

P: Pressure at the specific altitude (mbar)

T_v : Virtual Temperature (Kelvin)

Virtual temperature contains moisture parameter, and can differ from the potential temperature with a value of 0 to 4 degrees and calculated by;

$T_v = T / ((1 - (e/p) \times (1 - \epsilon)))$ where,

T_v : Virtual Temperature as Kelvin

T: Temperature (Kelvin)

e: Water pressure (mbar)

ϵ : Constant equal to 0.622

P: Pressure at the specific altitude (mbar)

III.2.2. Methods Used In Computation of Mixing Height

Methods used in the study are explained below; Holzworth (1967), Coulter (1979), Goldman(1980), Heffter(1980) and Stull (1988; 1991), respectively.

III.2.2.1. Holzworth Method

Commonly mixing heights undergo through a large diurnal variation. Although not measured directly, they can be calculated approximately from routine meteorological measurements. This method investigate two times of the day, morning and the afternoon. The morning mixing height is calculated as the height above ground at which the dry adiabatic extension of the morning minimum surface temperature plus 5°C intersected the vertical temperature profile observed at 00:00 Greenwich Median Time (GMT). The afternoon mixing height is less complicated than the morning, but was calculated in the same way, except that instead of the minimum temperature plus 5°C. The afternoon mixing height is based on the level above ground at which the adiabatic ascent of the sounding surface temperature intersects the temperature profile. Refinements to the Holzworth method depend on the location and nature of the study.

III.2.2.2. Coulter Method

Coulter (1979) described a method of estimating the daytime mixing height using the local static stability procedure. He defined it as the altitude, once above the surface layer, at which the potential temperature first became greater than adiabatic.

III.2.2.3. Goldman Method

Goldman (1980) established a similar method that defined the mixed layer height as the lowest level at which the vertical temperature gradient a stable lapse rate through a significant atmospheric layer. The identified stable layer had to occur above a surface-based, well-mixed layer that contained an unstable or neutral lapse rate. Further, the lapse rate present within the selected stable layer had to be greater than (more positive than) or equal to $0,5^{\circ}\text{C}/100\text{meters}$ and occur through a depth of 100 meters.

III.2.2.4. Heffter Method

Heffter(1980) described another method for National Oceanic and Atmospheric Administration/Air Resources Laboratory (NOAA/ARL). In this method potential temperature profiles are computed for each sounding. The profiles are analyzed for the existence of the ‘Critical Inversion’ which is assumed to mark the top of the mixed layer. In this scheme, a critical inversion is defined as the lowest inversion that meets the following two criteria:

i) $\Delta\Theta/\Delta Z \geq 0,005 \text{ K m}^{-1}$

ii) $\Theta_{\text{top}} - \Theta_{\text{base}} \geq 2\text{K}$

where $\Delta\Theta/\Delta Z$ is the potential temperature lapse rate in the inversion layer and Θ_{top} and Θ_{base} refer to the potential temperatures at the top and the bottom of the critical inversion layer. The height of the mixing layer is that point in the inversion layer at which the inversion layer at which the temperature is 2K above at the inversion base.

III.2.2.5. Stull Method

Four preliminary steps are necessary prior to determining static stability:

i) The whole environmental sounding should be known. The vertical bounds of this domain should be at solid surfaces, or at heights where nonlocal parcel vertical

motions are known not to be significant. For example, the bounds can be the ground and the stratosphere. For a simplified presentation in a textbook, the bounds could be two hypothetical solid surfaces. Soundings that do not end at such bounds lead to uncertainty in the stability determination, as described later.

ii) Conceptually, air parcels should be displaced a small distance initially up and down from all possible starting points within the sounding domain. Practically, we need only test (displace) parcels up from the relative maxima and down from the relative minima of virtual potential temperature in the sounding.

iii) Air parcel movement after the initial displacement should be based on parcel buoyancy. This buoyancy is measured by comparing virtual temperatures of the parcel and the environment at the same height. In dry environments, or environments of nearly constant mixing ratio with height, the temperature can be used instead of virtual temperature for simplicity. Buoyant motion is associated with cold parcels that sink and warm parcels that rise.

iV) Displaced air parcels that would continue to move buoyantly from their origin should be tracked all the way to their ending point of neutral buoyancy (neglecting overshoot), which is the height where the parcel virtual temperature equals the environmental virtual temperature. By neglecting overshoot, we ignore the possibility that parcel kinetic energy could allow nonbuoyant penetration through thin stable layers toward regions where the parcel is again buoyant. This happens in nature to some extent, and could be utilized in a more sophisticated nonlocal definition of stability (not pursued here). (Stull, 1991)

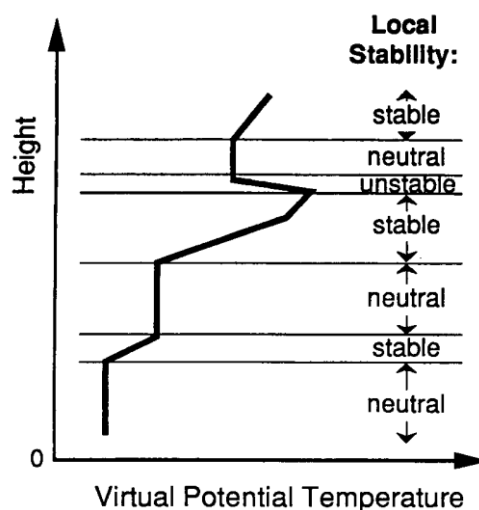


Figure III-1. An example of local static stability

Figure III-1 shows an example of local static stability. Once parcel movements have been tracked, the stability of portions of the sounding domain must be determined in the following order:

i) Unstable: those regions within which parcels can enter and transit under their own buoyancy; that is, regions where they move in the same direction as their buoyant force vector. This works even if the parcel originated a finite distance away from its destination. Note that individual parcels need not traverse the whole unstable region. For example, if a subregion is buoyantly traversed by one air parcel, and a partially overlapping subregion is traversed by a different buoyant air parcel, then the whole region formed as the union of those two subregions is identified as "unstable." The special case of contiguous but nonoverlapping unstable subregions can occur in nature and laboratory tanks (e.g., two turbulent mixed layers separated by a strong temperature or density step), and should be classified as adjacent but independent unstable layers.

ii) Stable: those regions of subadiabatic lapse rate that are not unstable.

iii) Neutral: those regions of adiabatic lapse rate that are not unstable.

iV) Unknown: those top or bottom portions of the sounding that are apparently stable or neutral but do not end at a material surface such as the ground. The reason is that above or below the known sounding region might be a region of cold or warm temperature, respectively, that could provide a source for buoyant parcels.

An efficient two-step method for determining the stability of a sounding is to use the classical local lapse-rate definitions to make a first guess for all layers. If any layers are unstable according to the classical definition, then a parcel from the bottom of the unstable layer should be lifted until it becomes neutrally buoyant. Similarly, a parcel from the top of the first-guess unstable layer should be lowered to its equilibrium level. The domain of such buoyant parcel movement takes precedent over any first-guess stable or neutral layers, and defines the nonlocally unstable regions. (Stull, 1991) Computation of mixing height is not straight forward. Computed results in Stull method have to be checked by an expert because of the complex structure of the method (As shown in figure III-2).

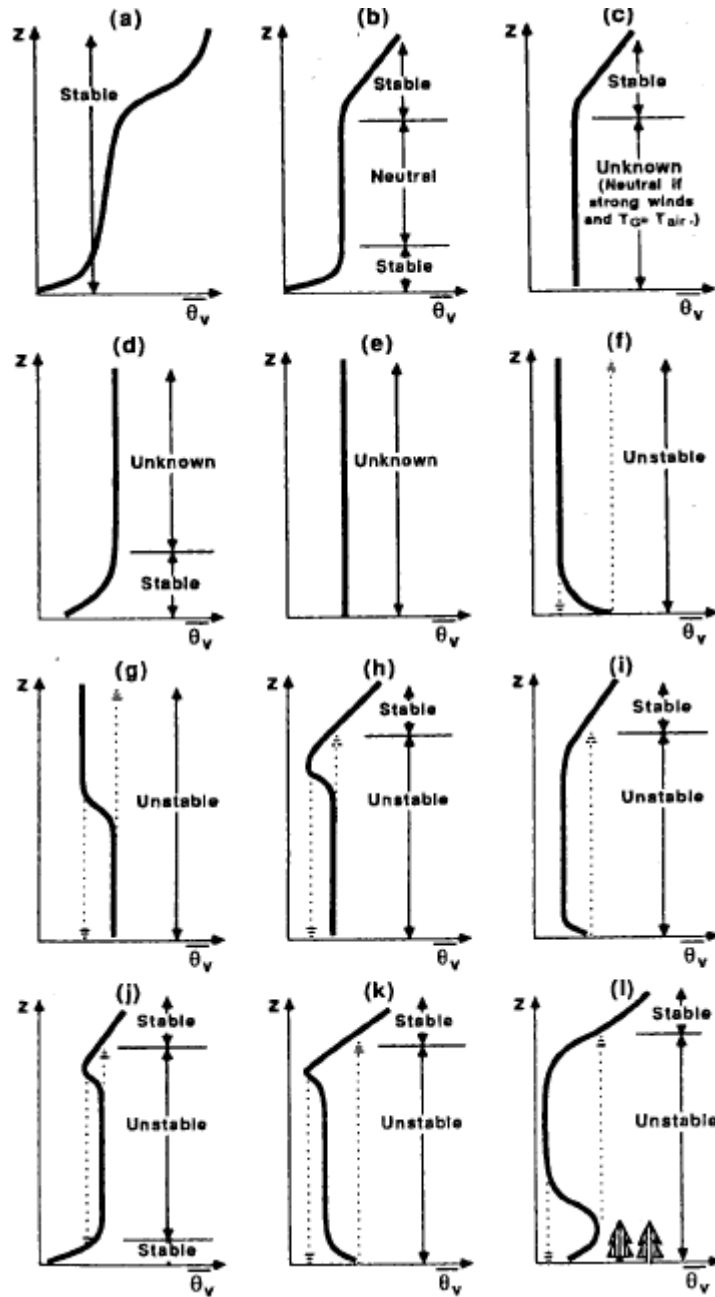


Figure III-2. Determining of nonlocal static stability using the methodology discussed by Stull (1988, 1991).

CHAPTER IV

RESULTS AND DISCUSSION

Holzworth (1967), Coulter (1979), Goldman (1980), Heffter (1980) and Stull (1988; 1991) methods used in the study. Vertical profiles of temperatures of twice daily radiosonde measurements are depicted in Appendix B-1 and B-2.

In order to compute Holzworth, Coulter, Goldman, Heffter and Stull methods a computer program was developed. In the program, mixing heights were calculated using the principles explained in Chapter III-2.2. Working process schedule is explained in the following examples.

Calculation of the Morning Mixing Height

Figure IV-1 shows the computing result for morning mixing height by the Holzworth method. Temperature distribution is replaced with potential temperature distribution. The morning mixing height is computed as the height above ground at which the dry adiabatic extension of the morning minimum surface temperature plus 5°C (as seen in vertical line) intersected the vertical temperature profile observed at 00:00 GMT. The result is 1318 meters as shown in the figure IV-1.

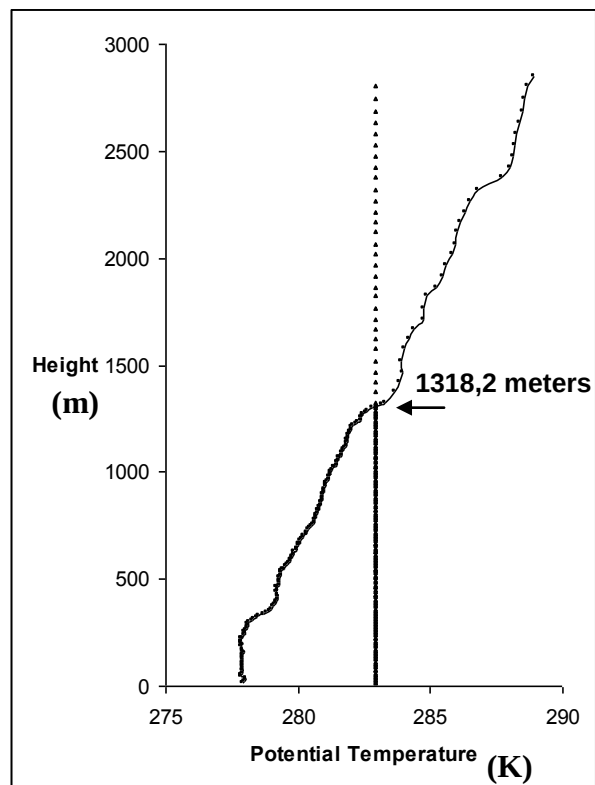


Figure IV-1. Holzworth Method used in mixing height computing in the morning on 11.1.1995.

Figure IV-2 shows the computing result for morning mixing height by the Coulter method. Computer program defines it as the altitude, once above the surface layer, at which the change of potential temperature with height ($d\Theta/dz$) first became greater than adiabatic with the help of the potential temperature distribution with height. As we see on the figure mixing height is 30 meters where $d\Theta/dz$ first becomes greater than 0.

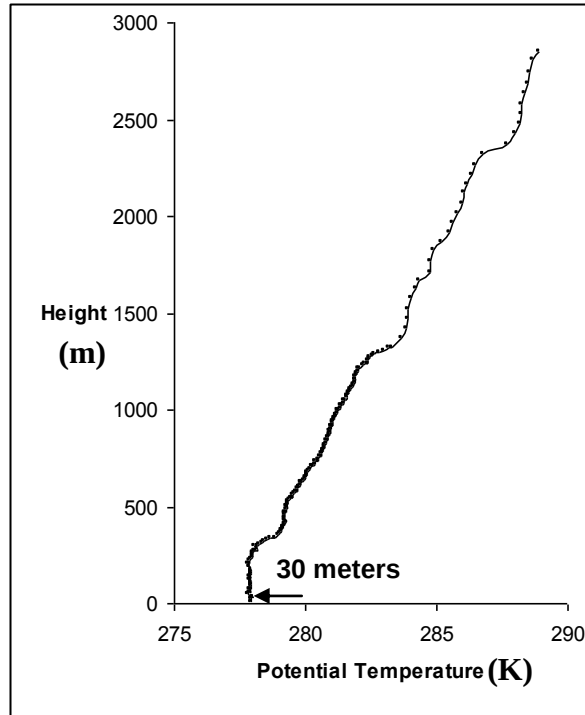


Figure IV-2. Coulter Method used in mixing height computing in the morning on 11.1.1995.

After the checking of computed result, the mixing height as Coulter method has to change 258 meters.

Goldman method based on the lapse rate present within the selected stable layer had to be greater than or equal to $0,005^{\circ}\text{C}/\text{m}$ and occur through a depth of 100 meters. Although, there are lapse rates greater than $0,005^{\circ}\text{C}/\text{m}$ as seen in the figure IV-3, there can not be seen a depth of 100 meters. In conclusion, there is not mixing height as predicted by Goldman method for this day in the morning.

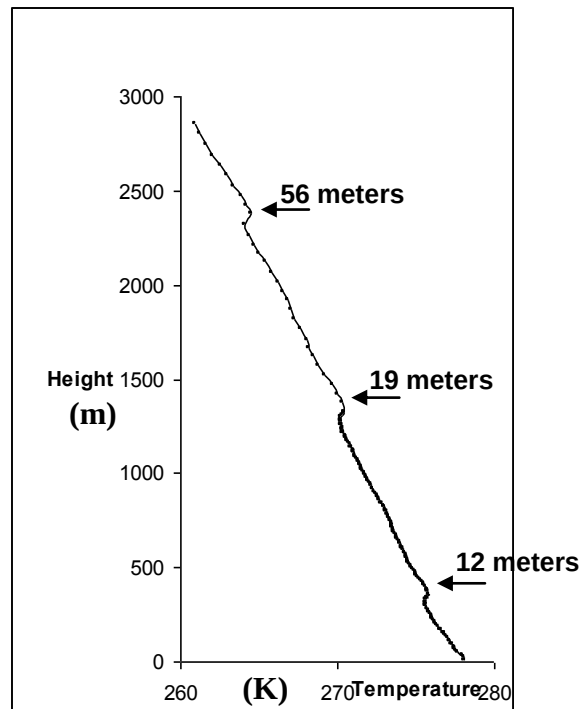


Figure IV-3. Goldman method used in mixing height computing in the morning on 11.1.1995.

Heffter method is a critical inversion is defined as the lowest inversion that meets the following two criteria:

i) $\Delta\Theta/\Delta Z \geq 0,005 \text{ K m}^{-1}$

ii) $\Theta_{\text{top}} - \Theta_{\text{base}} \geq 2\text{K}$

where $\Delta\Theta/\Delta Z$ is the potential temperature lapse rate in the inversion layer. In spite of the altitudes where $\Delta\Theta/\Delta Z \geq 0,005 \text{ K m}^{-1}$, there could not be seen any $\Theta_{\text{top}} - \Theta_{\text{base}} \geq 2\text{K}$ on 11.01.1995 in the morning, so there is not any mixing height as predicted by the Heffter method. For the day, $\Theta_{\text{top}} - \Theta_{\text{base}}$ is depicted in the figure IV-4.

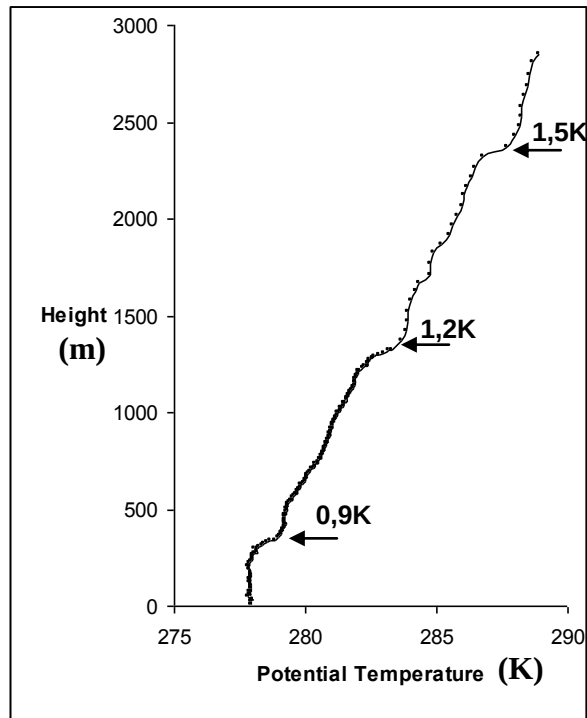


Figure IV-4. Heffter method used in mixing height computing in the morning on 11.1.1995.

For the Stull method, determining the stability of a sounding is to use the classical local lapse-rate definitions to make a first guess for all layers. If any layers are unstable according to the classical definition, then a parcel from the bottom of the unstable layer should be lifted until it becomes neutrally buoyant. Similarly, a parcel from the top of the first-guess unstable layer should be lowered to its equilibrium level. The domain of such buoyant parcel movement takes precedent over any first-guess stable or neutral layers, and defines the nonlocally unstable regions. Stull method uses virtual potential temperature and Figure IV-5 shows the computed result for morning mixing height. Computation of mixing height is not straightforward, and the result (1305,6meters) did not depict the actual result for the 11.01.1995 in the morning. With the expert check the result differs to 342,2 meters as shown in the figure IV-5.

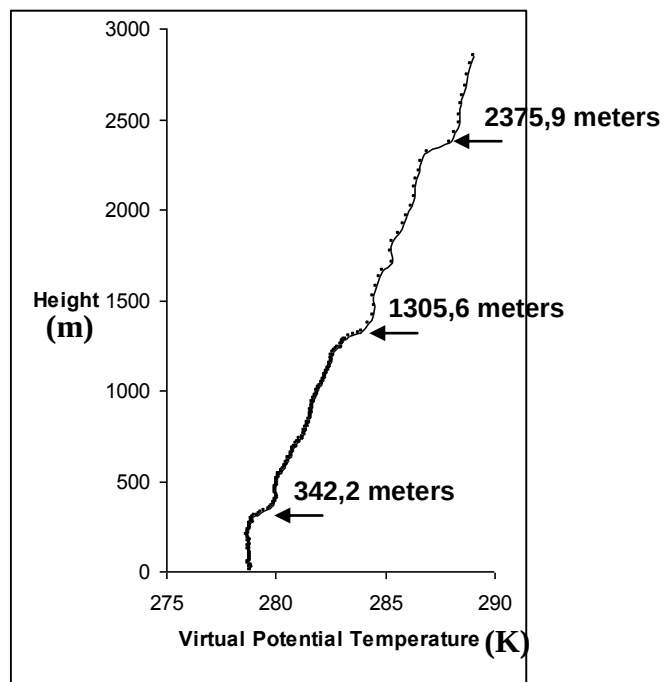


Figure IV-5. Stull method used in mixing height computing in the morning on 11.1.1995.

Morning mixing heights obtained from Holzworth, Coulter, Goldman, Heffter and Stull methods are shown in the following table IV-1.

Table IV-1. Mixing Heights obtained from the computing program for the 11.1.1995 in the morning using Holzworth, Coulter, Goldman, Heffter and Stull methods.

	Holzworth	Coulter	Goldman	Heffter	Stull
00:00GMT	1318,2m	258,1m	-	-	342,2m

Mixing height results in the table IV-1 in the morning on 11.1.1995 are depicted in the figure IV-6.

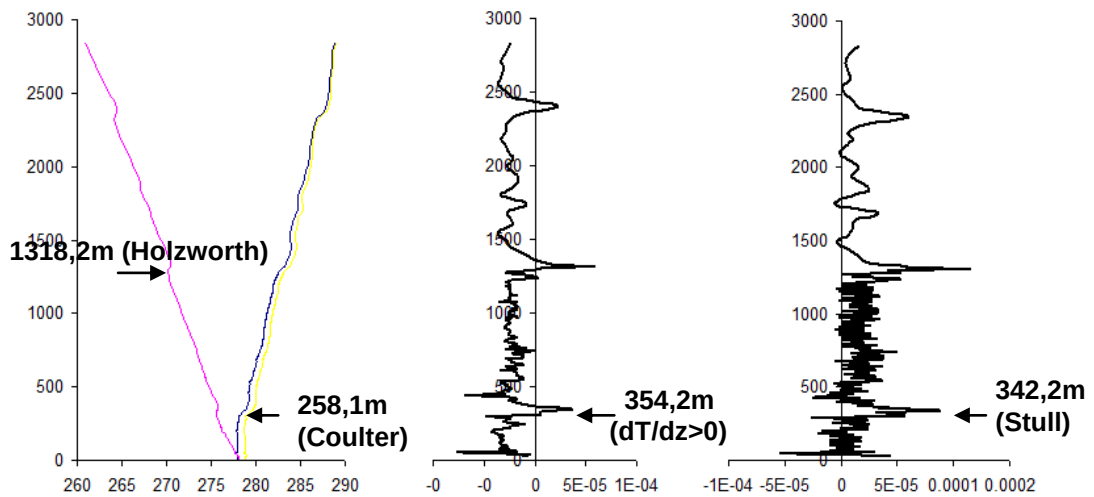


Figure IV-6. Temperature profiles as Kelvin and their derivatives (Pink curve is the temperature profile, blue curve is potential temperature profile, yellow curve is virtual potential profile and the black curves are dT/dz profile and $d\theta_v/dz$, respectively.) in the morning on 11.1.1995 and the mixing heights.

Calculation of the Afternoon Mixing Height

The afternoon mixing height is based on Holzworth method is the level above at which the adiabatic ascent of the sounding intersects the temperature profile. Figure IV-7 shows the Holzworth method used in mixing height computing in the afternoon on 29.1.1995. The results is 55,2 meters which is very low for the afternoon mixing height.

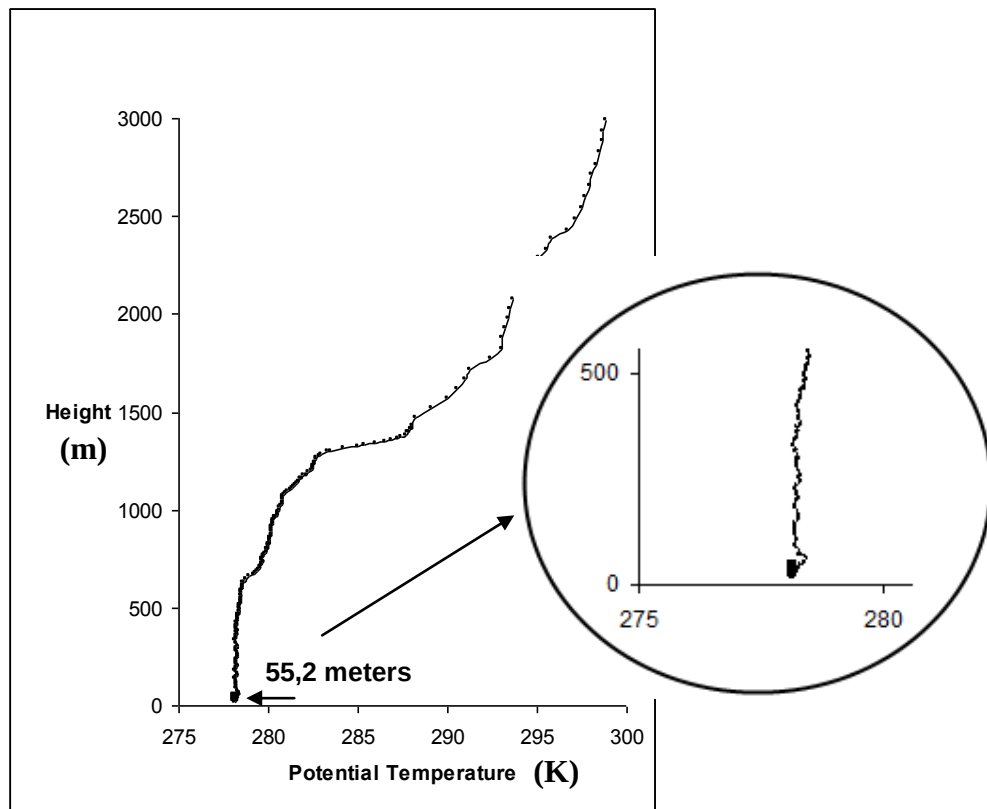


Figure IV-7. Holzworth method used in mixing height computing in the afternoon on 29.1.1995.

Figure IV-8 shows the computing result for the Coulter method for afternoon mixing heights. Computer program defined it as the altitude, once above the surface layer, at which the potential temperature first became greater than adiabatic with the help of the $d\Theta/dz$ distribution with height as in the morning. As we see on the figure mixing height is 33,1 meters where $d\Theta/dz$ first became greater than 0.

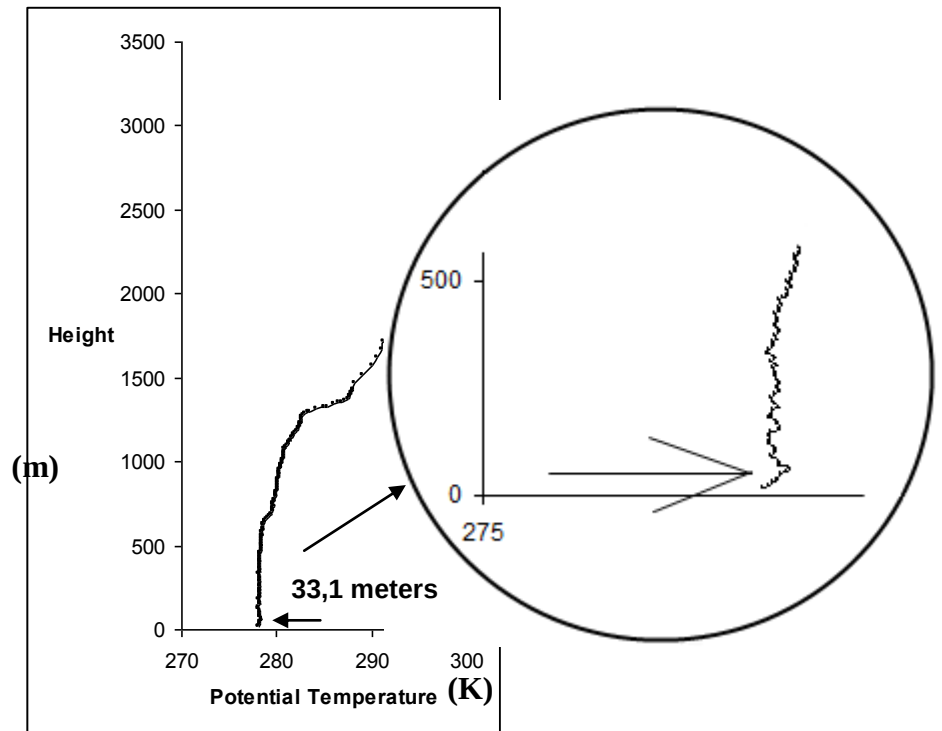


Figure IV-8. Coulter method used in mixing height computing in the afternoon on 29.1.1995.

After the checking of computed result, the mixing height as Coulter method has to change 523 meters.

Mixing height obtained by the Goldman method is the starting height of a stable layer with a lapse rate greater than or equal to $0,005^{\circ}\text{C}/\text{m}$ for 100m thickness. Figure IV-9 shows the computing result for the Goldman method for afternoon mixing heights. This condition is satisfied starting at 1268 meters for a depth of 105 meters. (Figure IV.9)

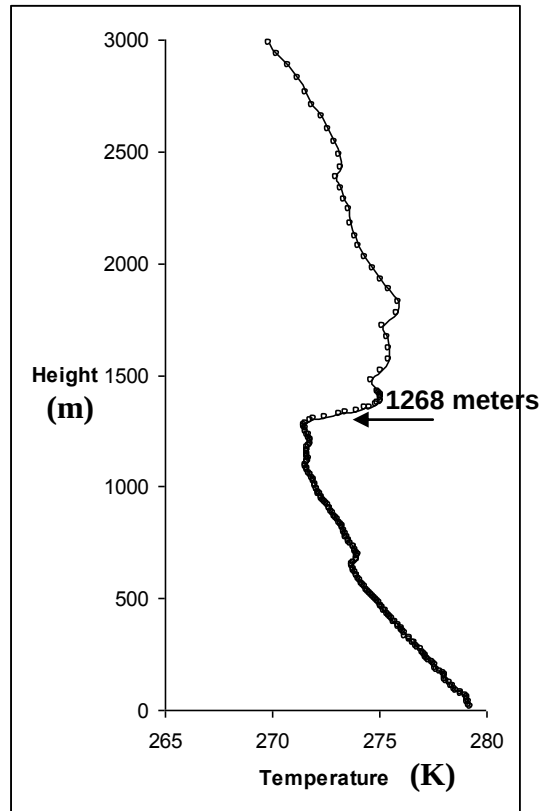


Figure IV-9. Goldman method used in mixing height computing in the afternoon on 29.1.1995. Horizontal axis depicts the temperature as Kelvin and vertical axis depicts the height as meters.

Afternoon mixing height for Heffter method is defined as the lowest inversion that meets the following two criteria same as in the morning case:

i) $\Delta\Theta/\Delta Z \geq 0,005 \text{ K m}^{-1}$

ii) $\Theta_{\text{top}} - \Theta_{\text{base}} \geq 2\text{K}$

where $\Delta\Theta/\Delta Z$ is the potential temperature lapse rate in the inversion layer. The computed Heffter mixing height is meeting above criteria for the day 29.1.1995 as 1323,6 meters is depicted in the figure IV-10.

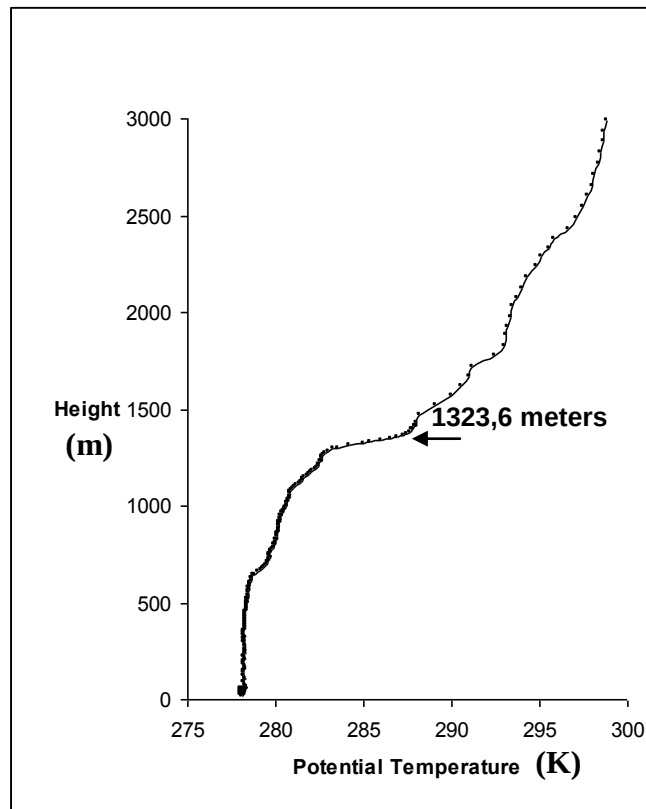


Figure IV-10. Heffter method used in mixing height computing in the afternoon on 29.1.1995.

In Stull method, determining the stability of a sounding is to use the classical local lapse-rate definitions to make a first guess for all layers. If any layers are unstable according to the classical definition, then a parcel from the bottom of the unstable layer should be lifted until it becomes neutrally buoyant. Similarly, a parcel from the top of the first-guess unstable layer should be lowered to its equilibrium level. The domain of such buoyant parcel movement takes precedent over any first-guess stable or neutral layers, and defines the nonlocally unstable regions. The result is depicted on the figure IV-11 (1329meters) for the day.

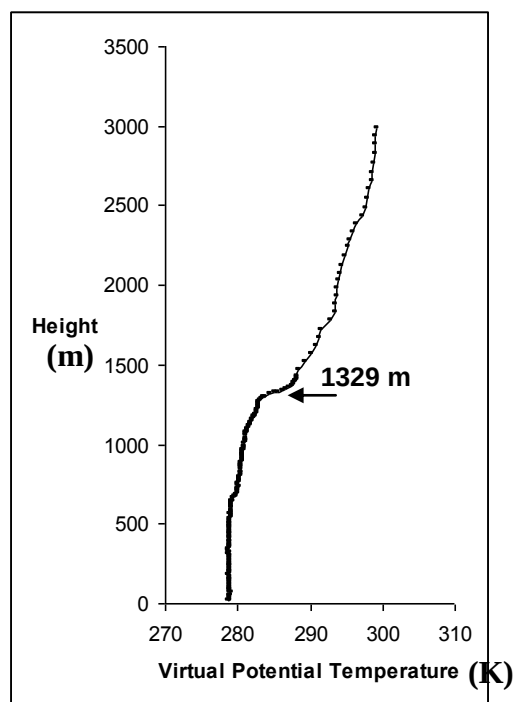


Figure IV-11. Stull method used in mixing height computing in the afternoon on 29.1.1995.

Afternoon mixing heights obtained from Holzworth, Coulter, Goldman, Heffter and Stull methods for 29.1.1995 are summarized in the table IV-2 for comparison.

Table IV-2. Mixing Heights obtained from the computing program for the 29.1.1995 in the afternoon using Holzworth, Coulter, Goldman, Heffter and Stull methods.

	Holzworth	Coulter	Goldman	Heffter	Stull
12:00GMT	55.2m	522,5m	1268m	1323,6m	1329.1m

Mixing height results in the table IV-2 in the afternoon on 29.1.1995 are also depicted in the figure IV-12.

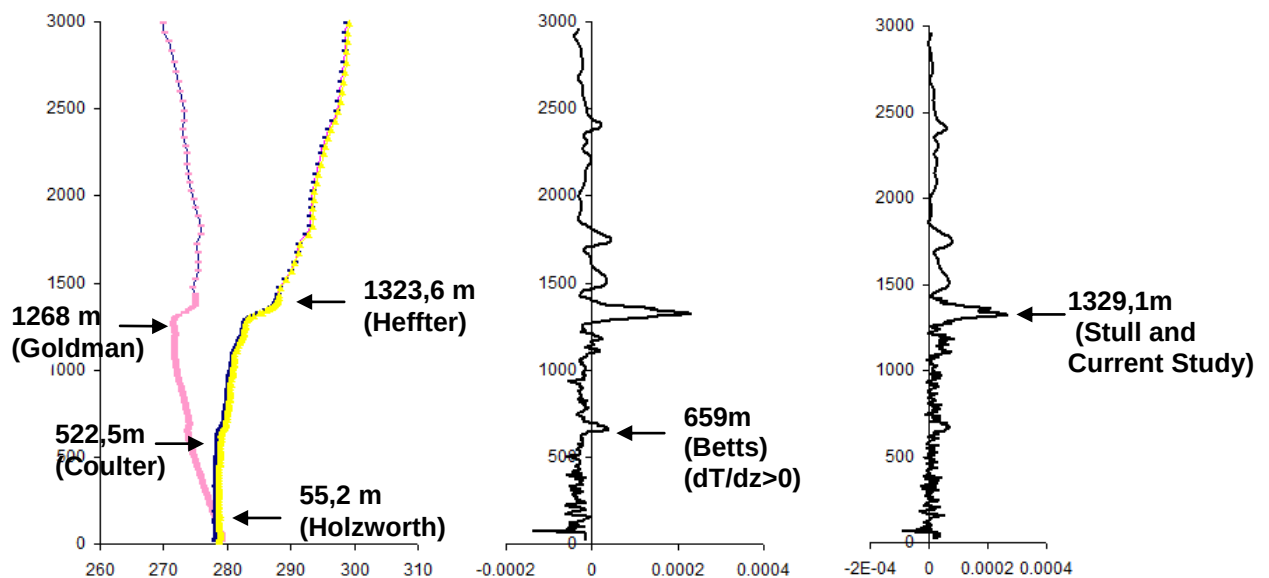


Figure IV-12. Methods used in mixing height computing in the afternoon on 29.1.1995. Temperature profiles as Kelvin and their derivatives (Pink curve is the temperature profile, blue curve is potential temperature profile, yellow curve is virtual potential profile and the black curves are dT/dz profile and $d\Theta_v/dz$, respectively.)

I approve that the mixing height computing from radiosonde measurements for 12:00 GMT (in the afternoon) will be better if the $\max(d\Theta_v/dZ) = 1329,1$ meters will be selected. The method is depicted in the figure IV-12.

Methods described above were applied at radiosonde measurements of 1995 and 1996 and twice daily mixing heights were obtained. Following figures show the results for morning and afternoon mixing heights graphically (Figures IV-13 to IV-55) on daily basis for each month.

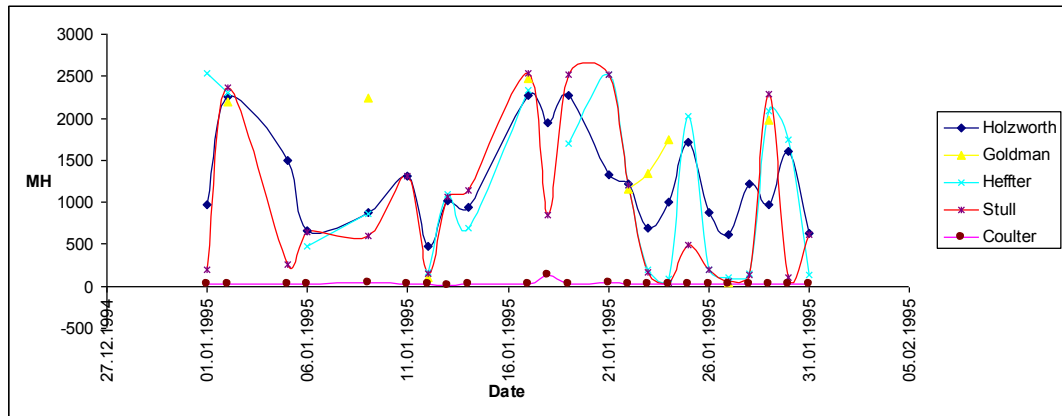


Figure IV-13. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in January, 1995 in the morning.

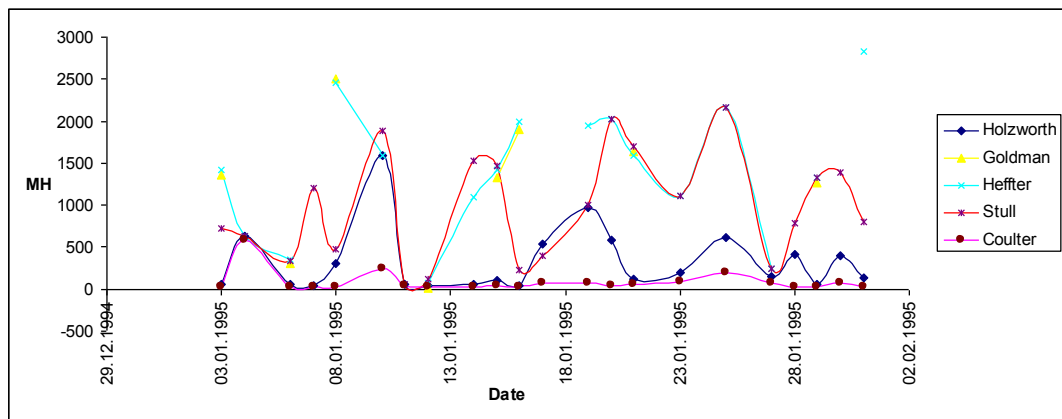


Figure IV-14. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in January, 1995 in the afternoon.

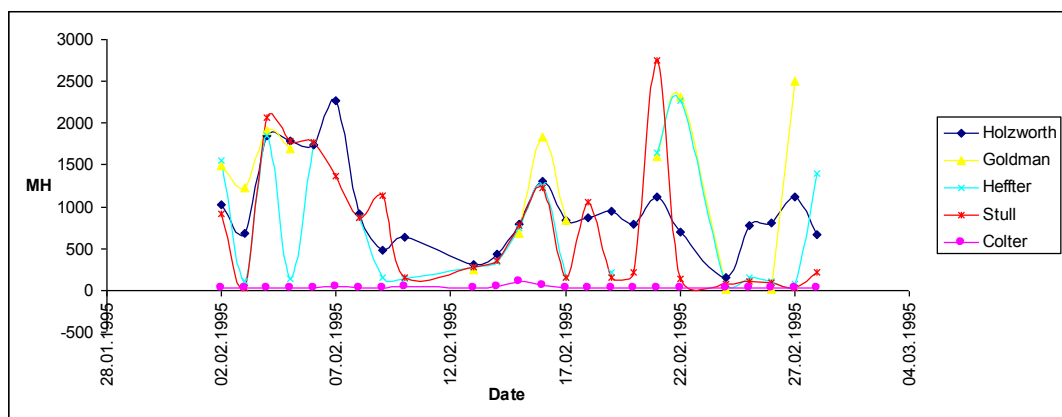


Figure IV-15. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in February, 1995 in the morning.

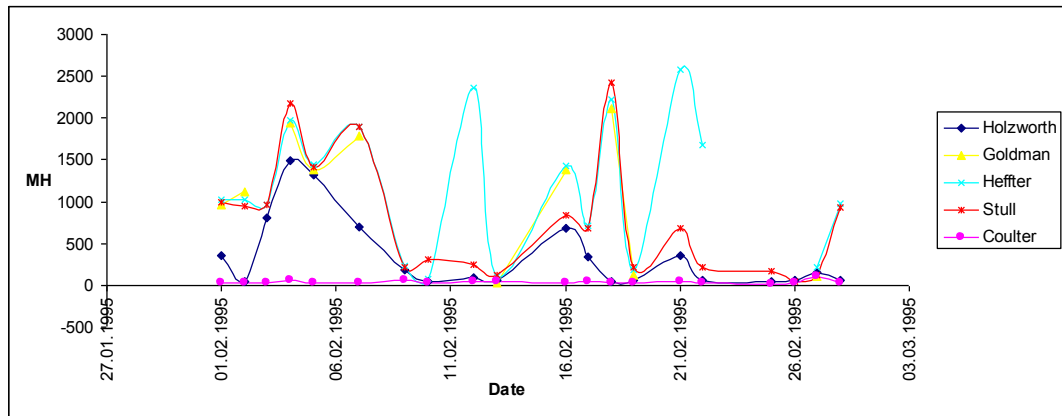


Figure IV-16. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in February, 1995 in the afternoon.

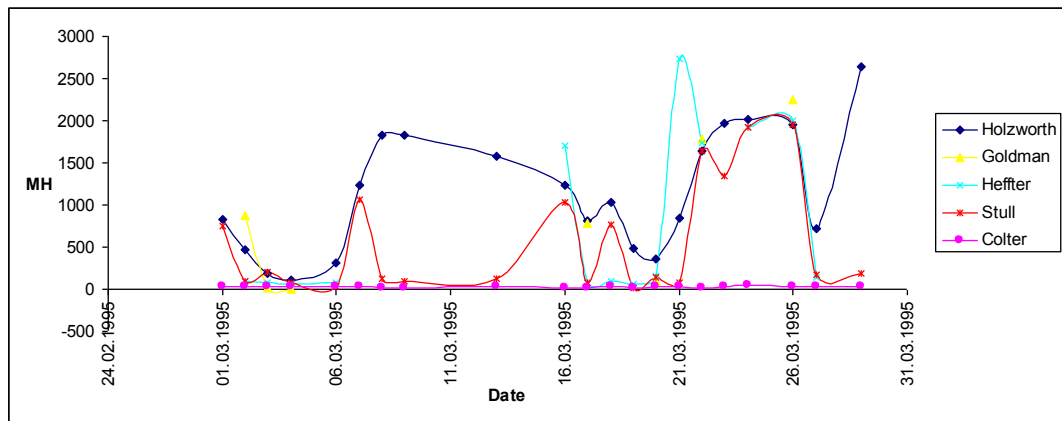


Figure IV-17. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in March, 1995 in the morning.

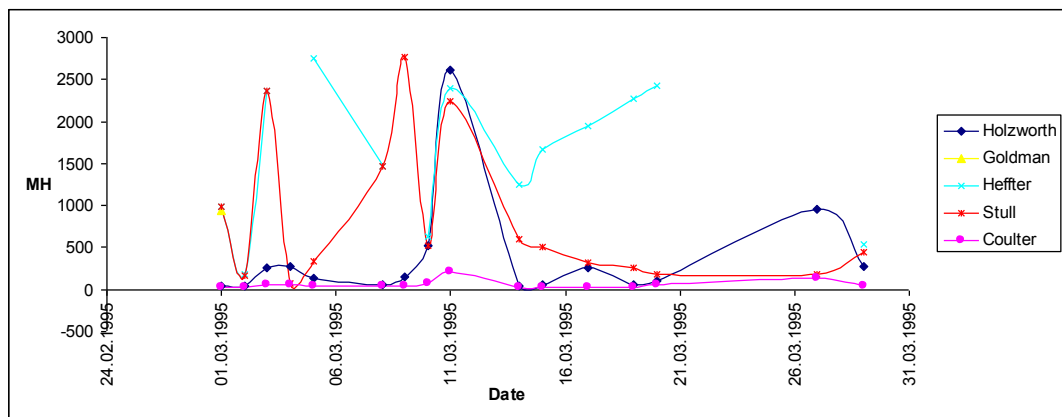


Figure IV-18. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in March, 1995 in the afternoon.

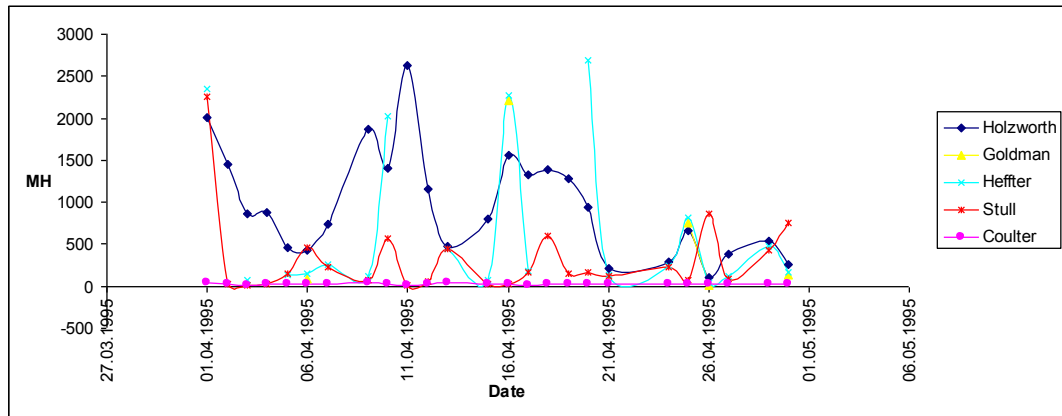


Figure IV-19. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in April, 1995 in the morning.

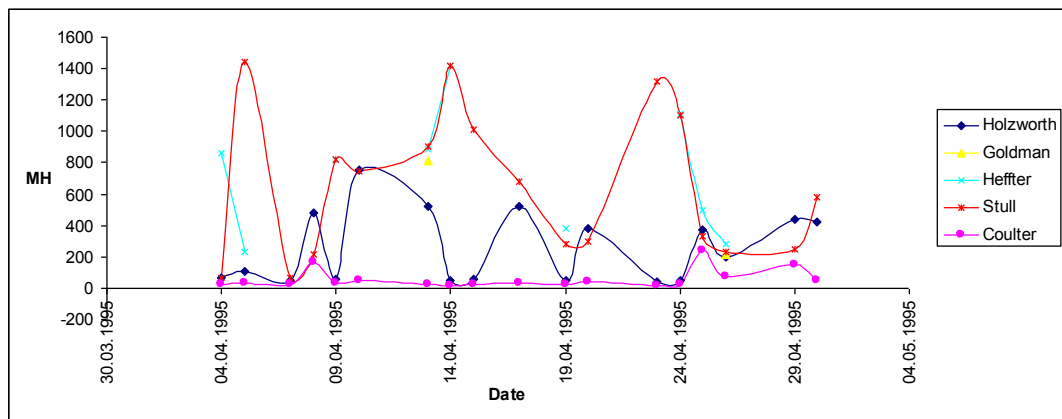


Figure IV-20. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in April, 1995 in the afternoon.

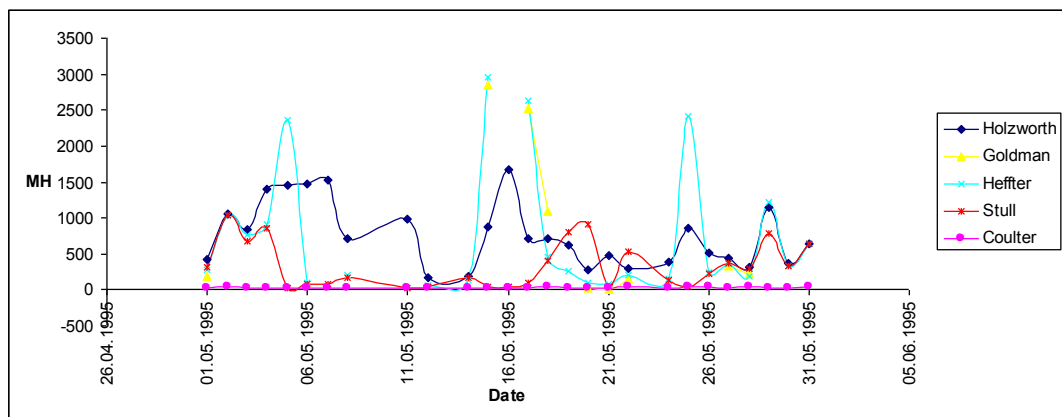


Figure IV-21. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in May, 1995 in the morning.

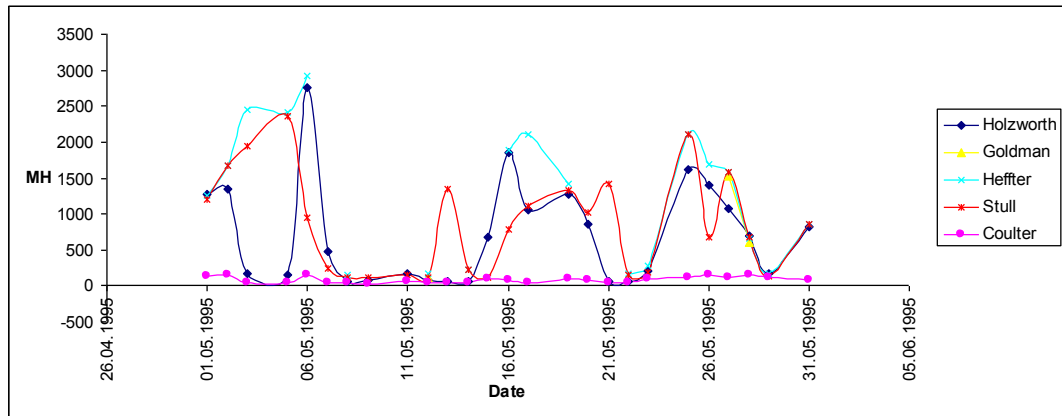


Figure IV-22. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in May, 1995 in the afternoon.

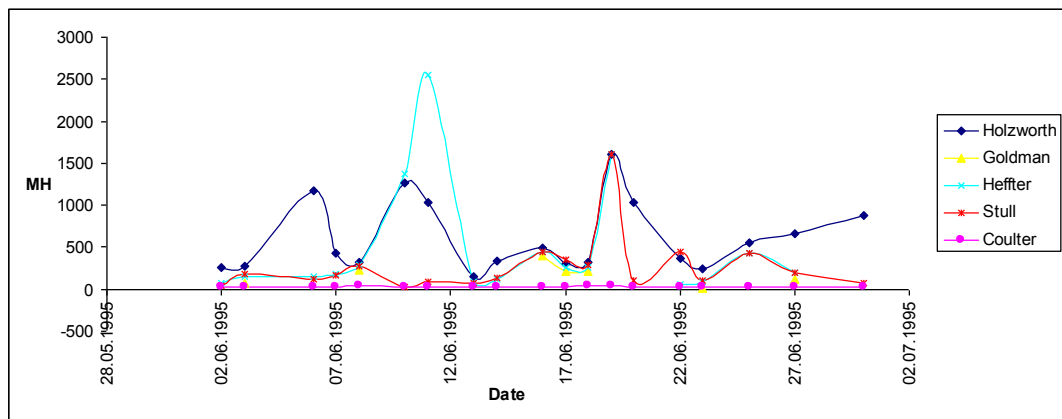


Figure IV-23. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in June, 1995 in the morning.

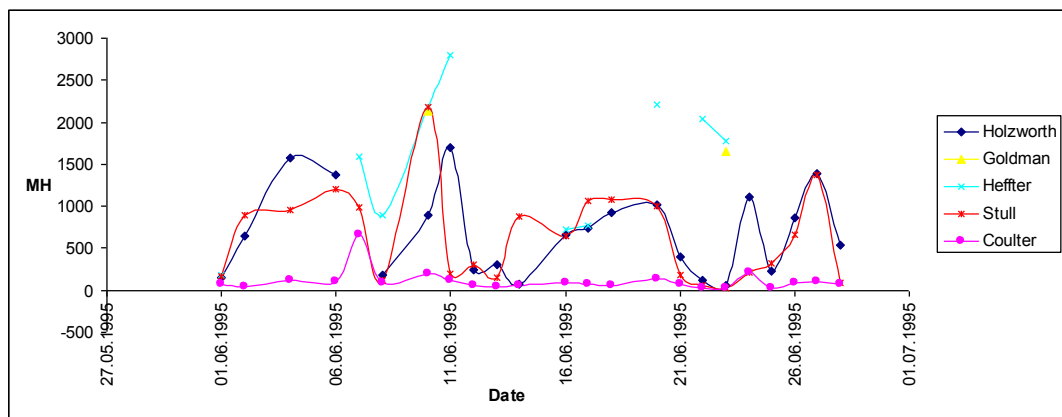


Figure IV-24. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in June, 1995 in the afternoon.

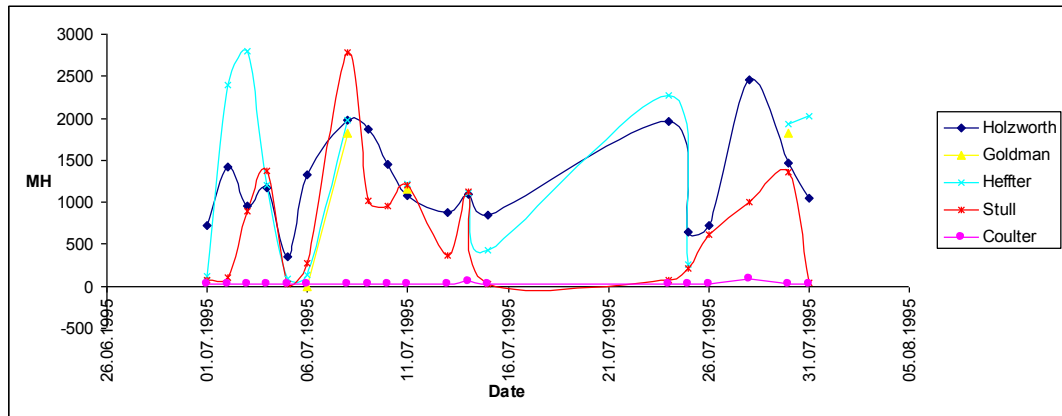


Figure IV-25. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in July, 1995 in the morning.

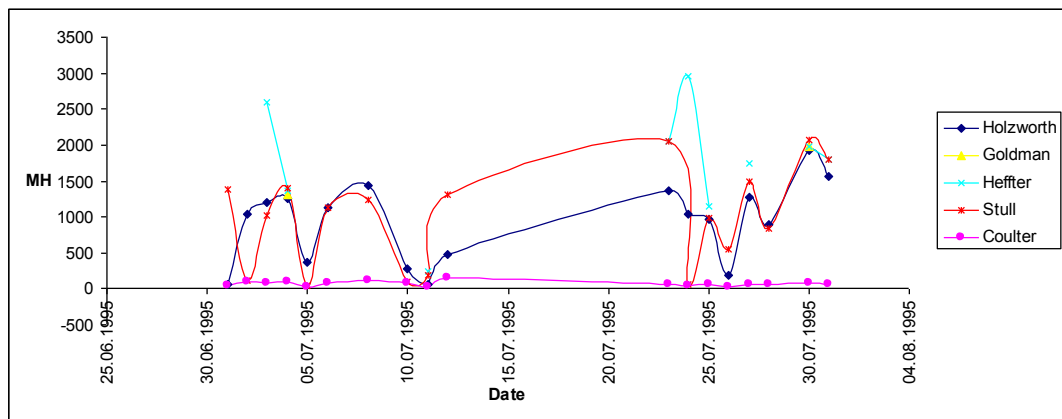


Figure IV-26. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in July, 1995 in the afternoon.

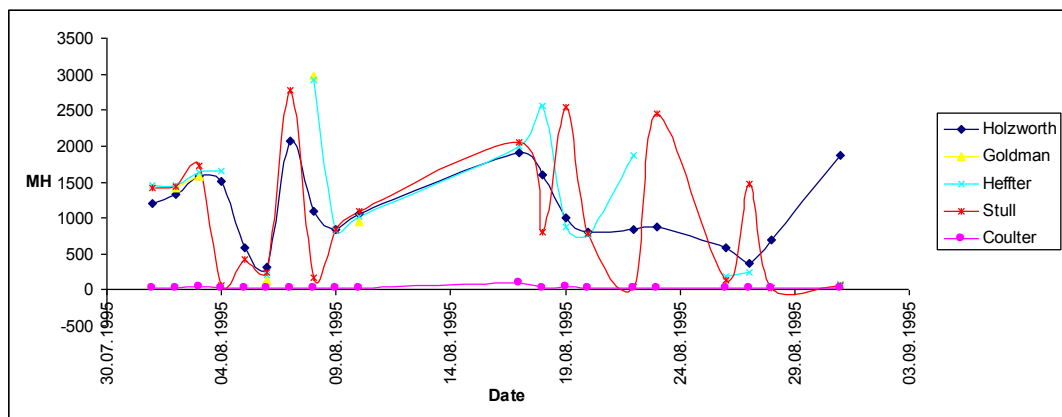


Figure IV-27. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in August, 1995 in the morning.

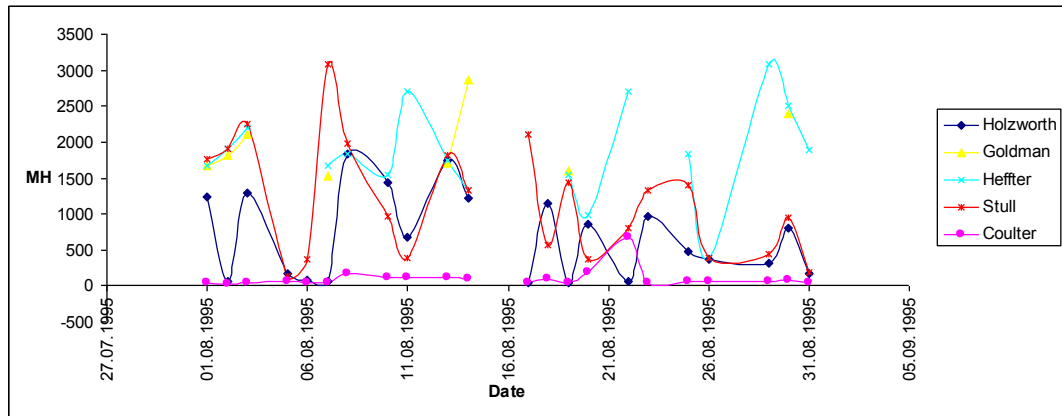


Figure IV-28. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in August, 1995 in the afternoon.

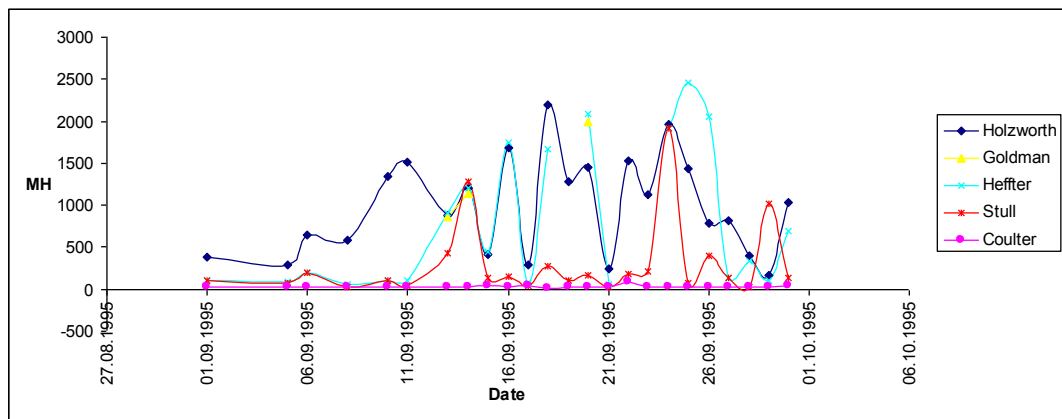


Figure IV-29. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in September, 1995 in the morning.

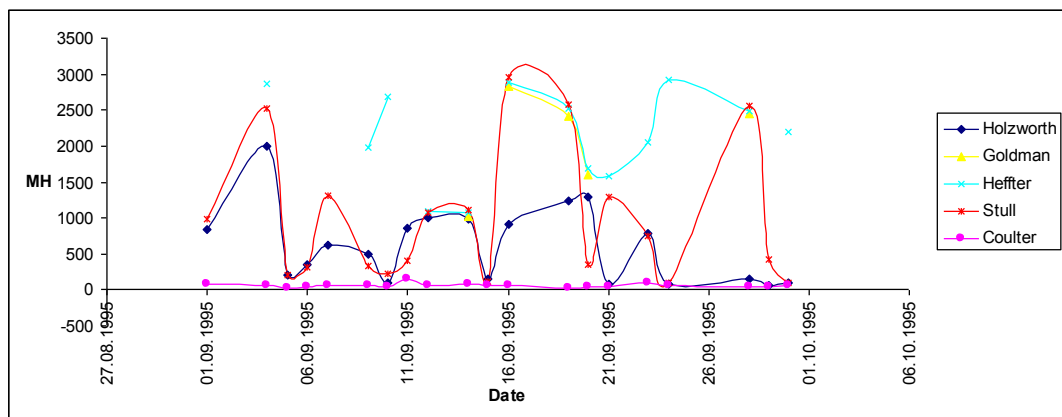


Figure IV-30. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in September, 1995 in the afternoon.

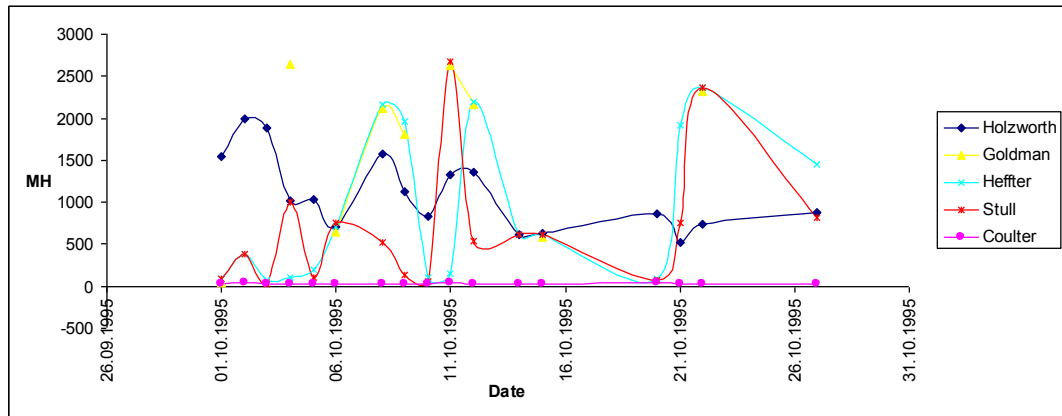


Figure IV-31. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in October, 1995 in the morning.

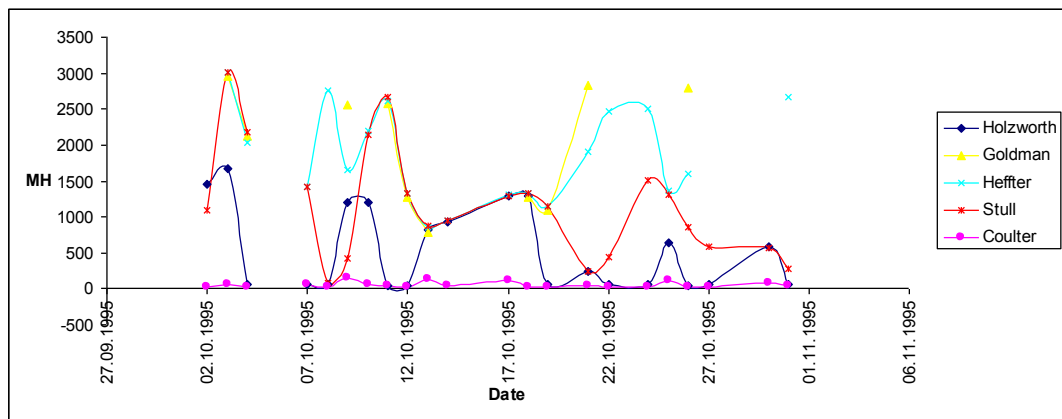


Figure IV-32. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in October, 1995 in the afternoon.

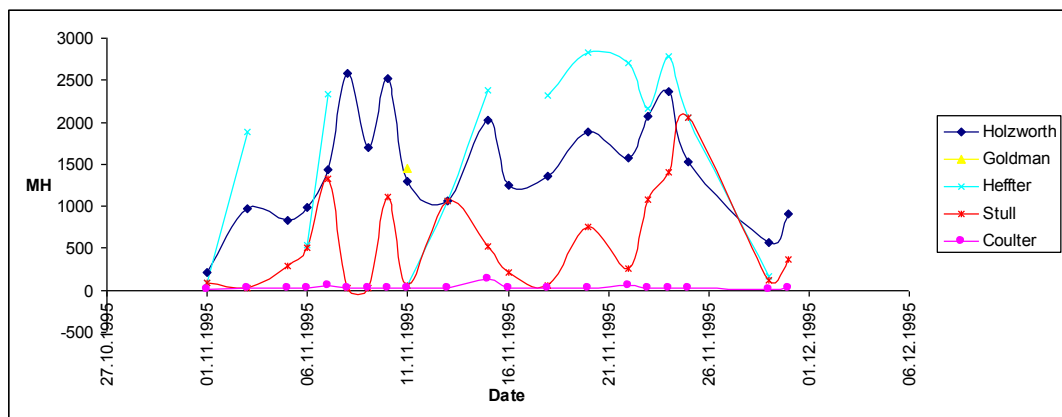


Figure IV-33. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in November, 1995 in the morning.

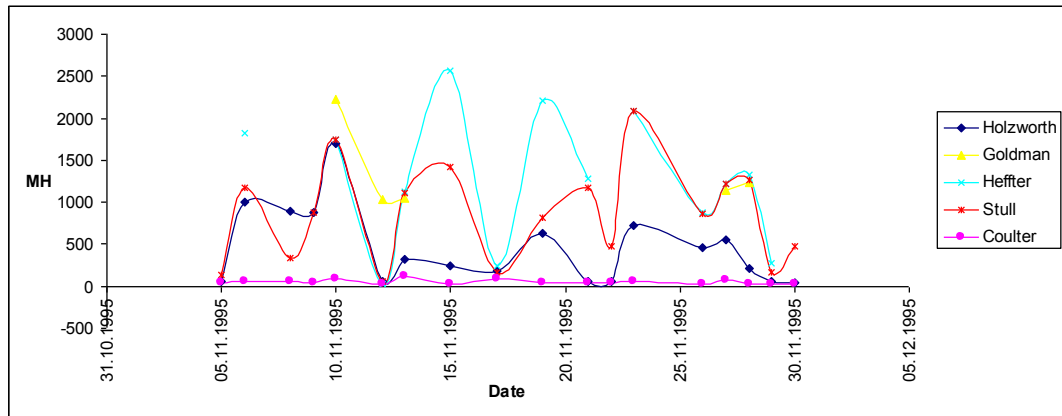


Figure IV-34. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in November, 1995 in the afternoon.

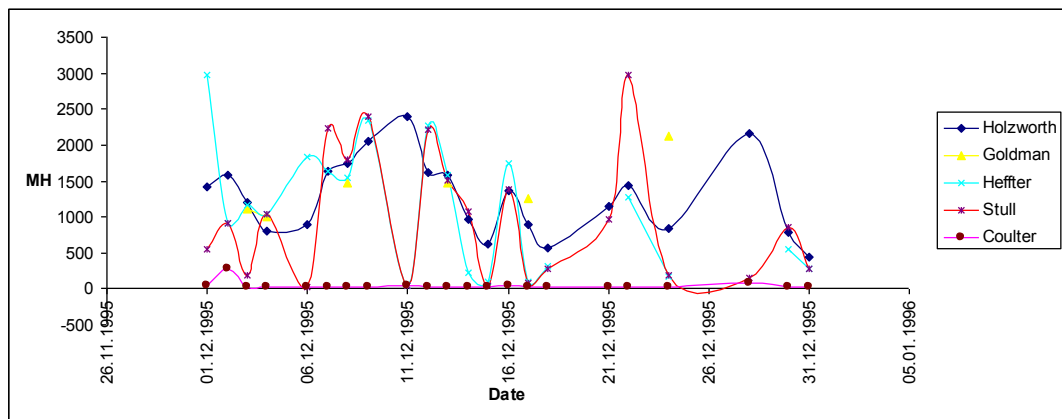


Figure IV-35. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in December, 1995 in the morning.

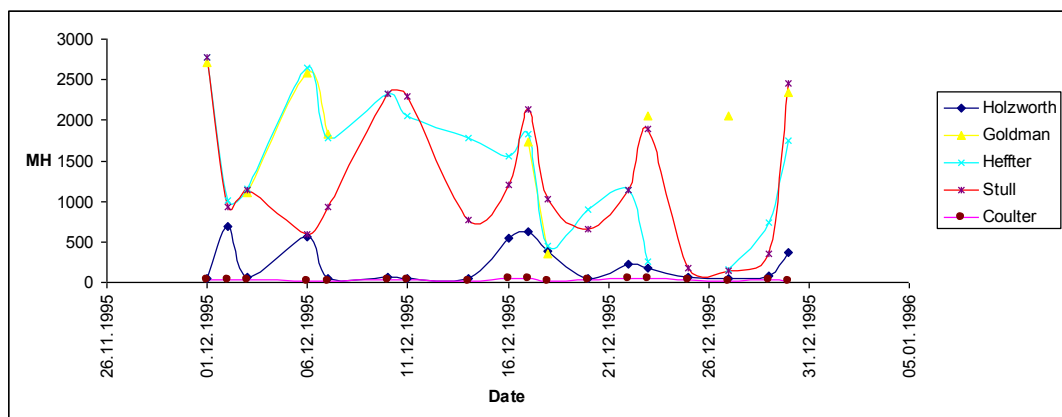


Figure IV-36. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in December, 1995 in the afternoon.

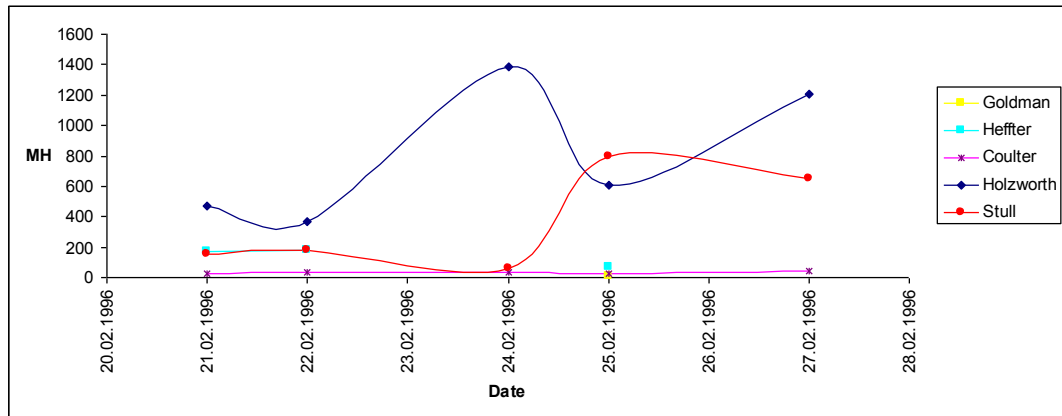


Figure IV-37. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in February, 1996 in the morning.

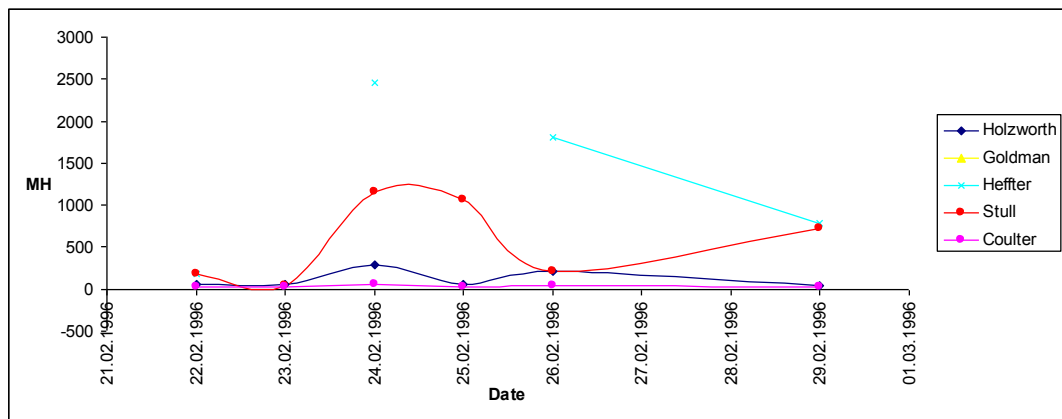


Figure IV-38. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in February, 1996 in the afternoon.

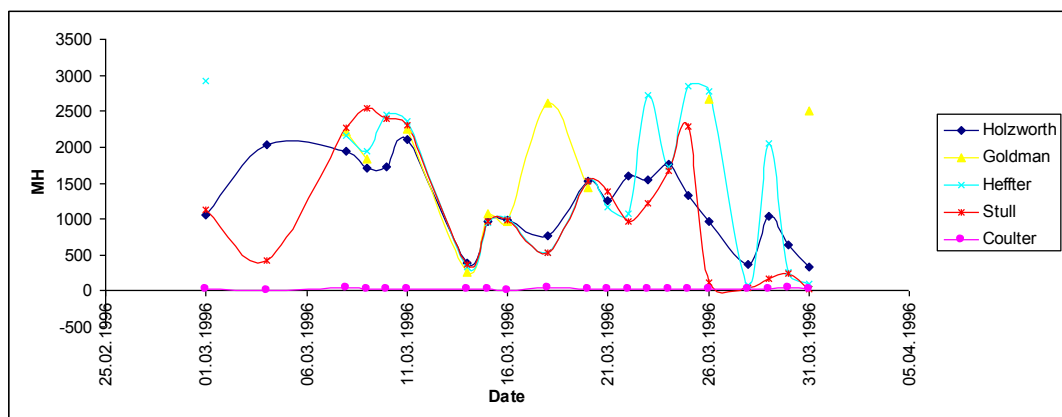


Figure IV-39. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in March, 1996 in the morning.

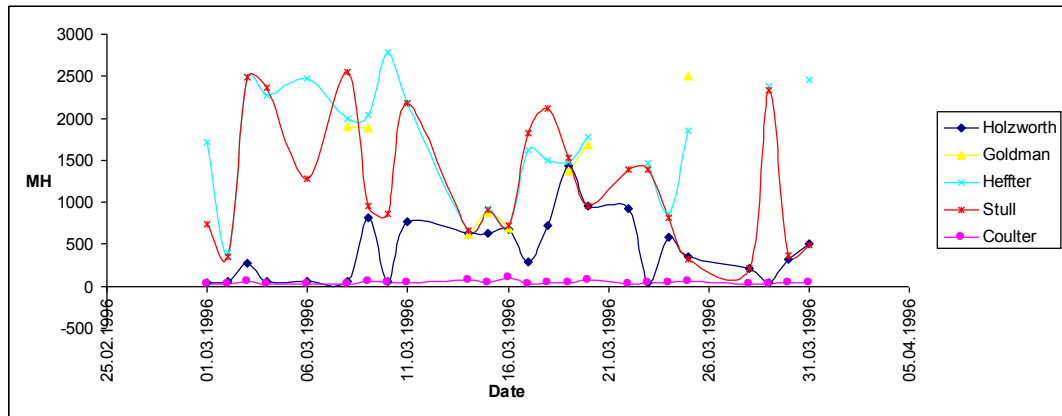


Figure IV-40. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in March, 1996 in the afternoon.

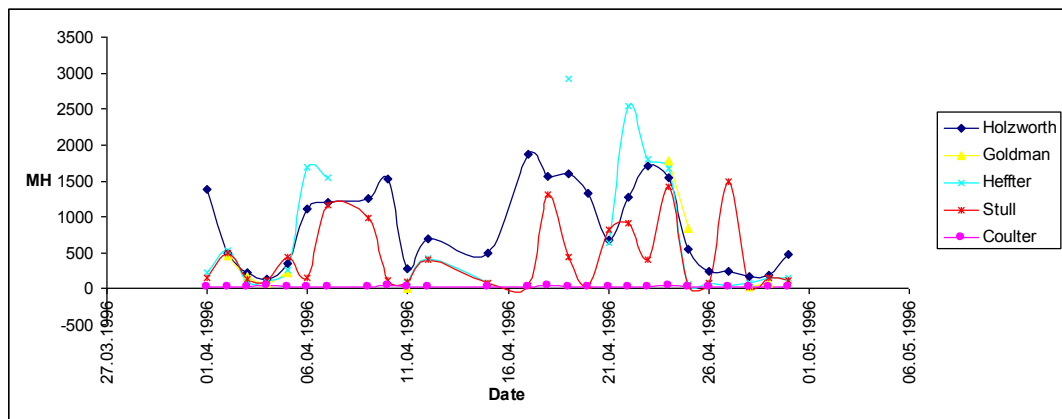


Figure IV-41. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in April, 1996 in the morning.

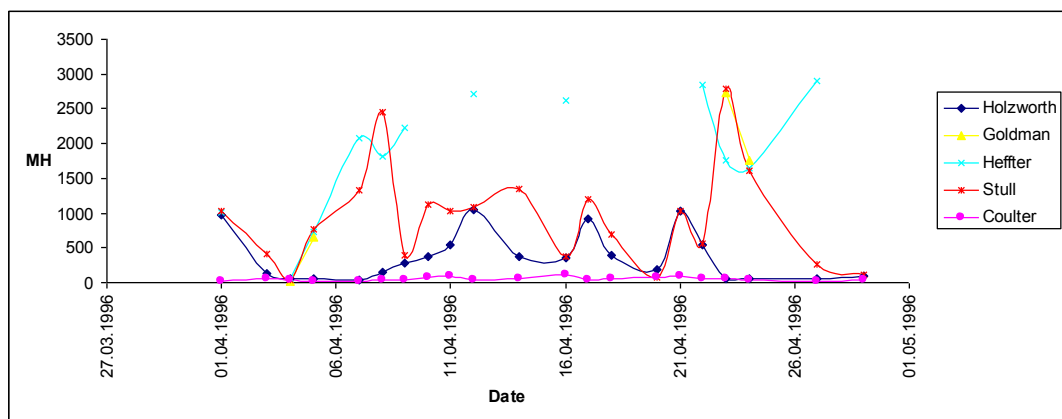


Figure IV-42. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in April, 1996 in the afternoon.

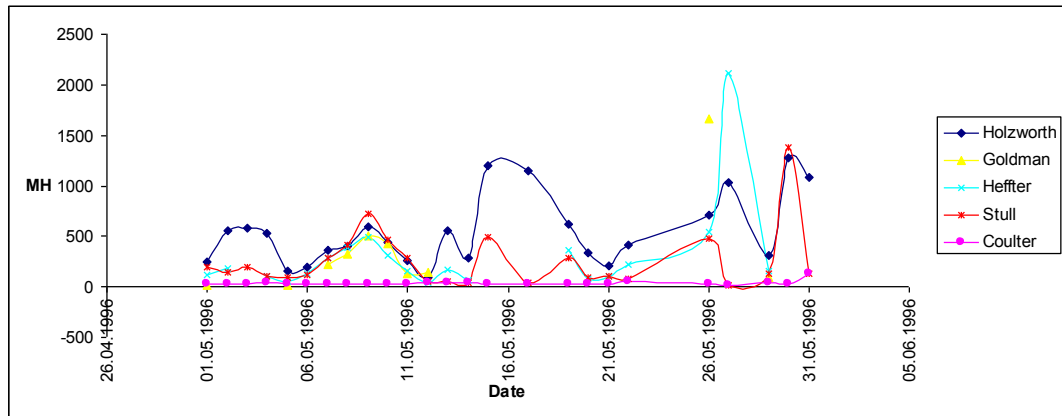


Figure IV-43. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in May, 1996 in the morning.

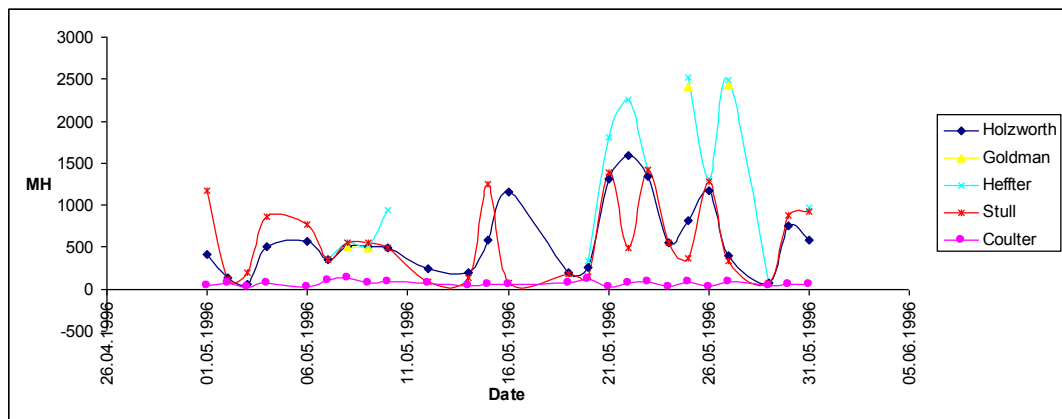


Figure IV-44. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in May, 1996 in the afternoon.

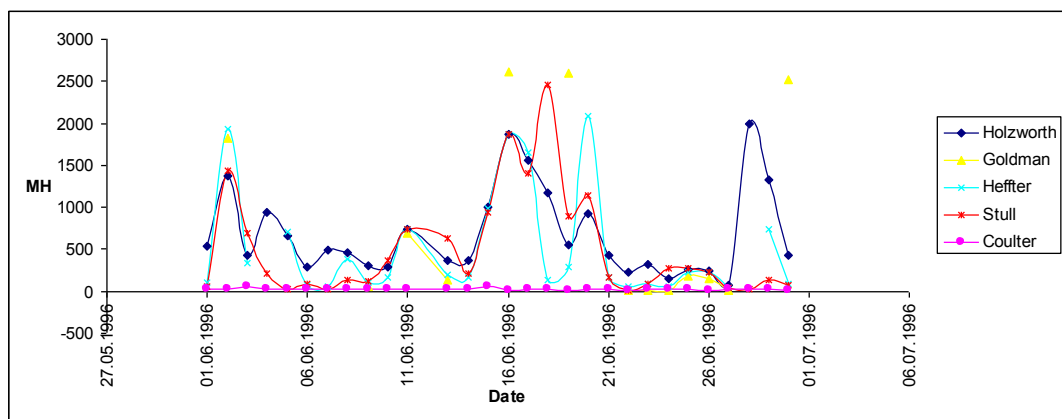


Figure IV-45. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in June, 1996 in the morning.

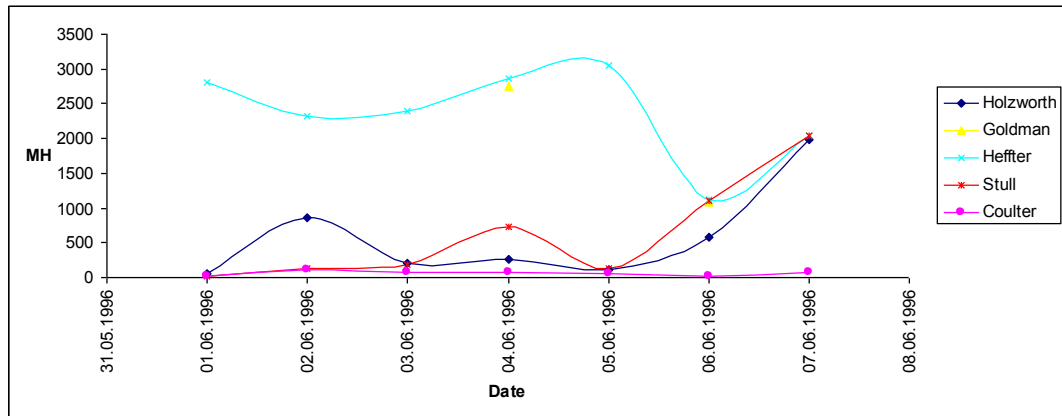


Figure IV-46. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in June, 1996 in the afternoon.

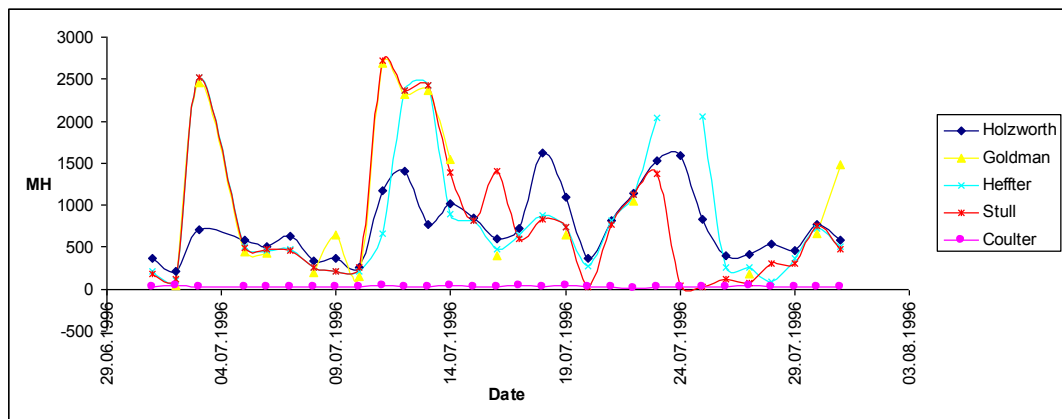


Figure IV-47. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in July, 1996 in the morning.

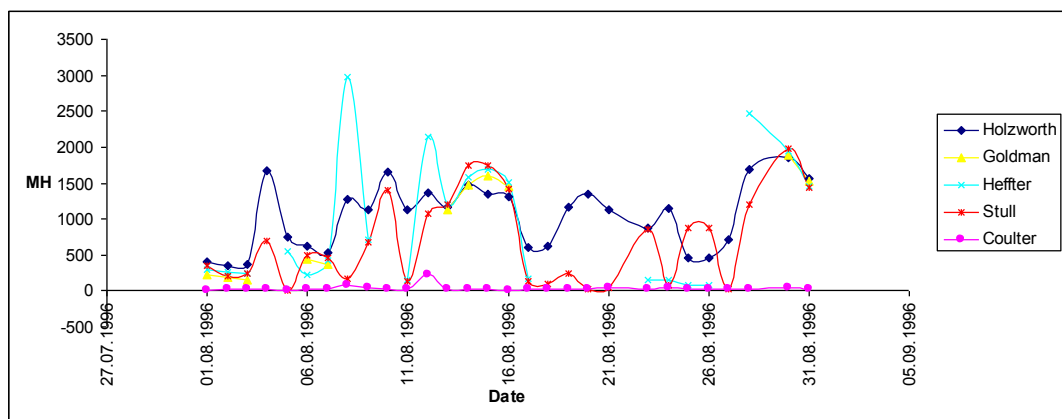


Figure IV-48. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in August, 1996 in the morning.

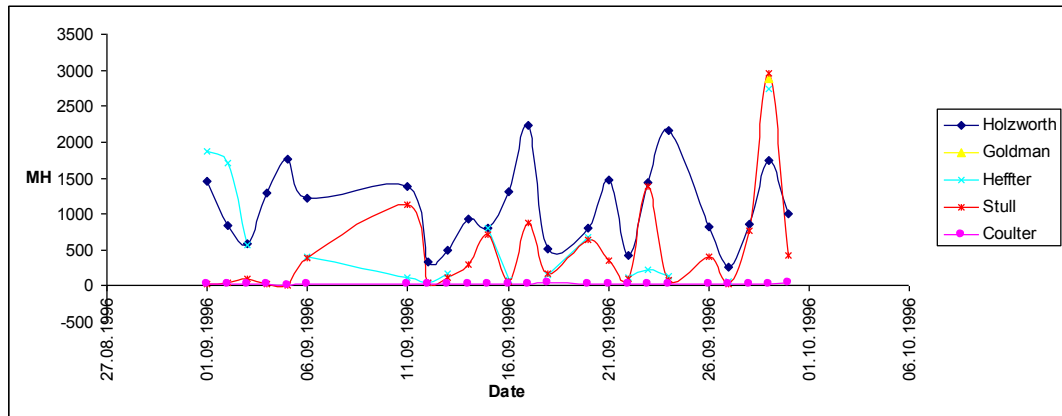


Figure IV-49. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in September, 1996 in the morning.

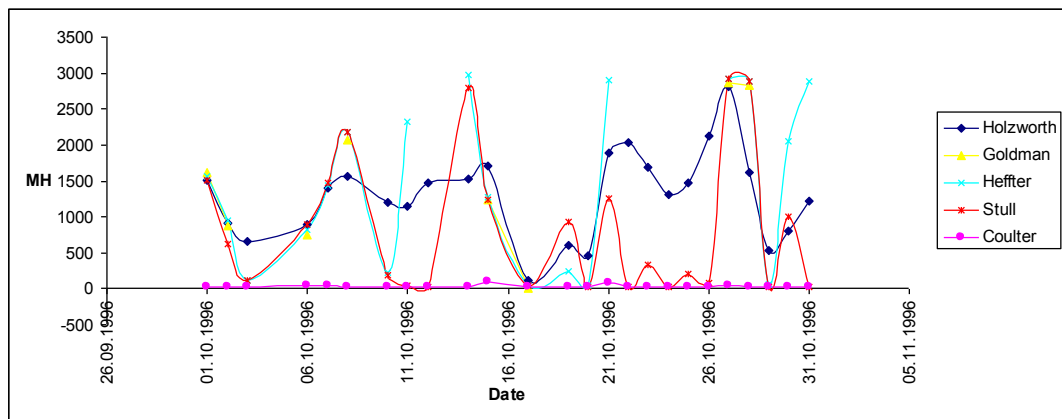


Figure IV-50. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in October, 1996 in the morning.

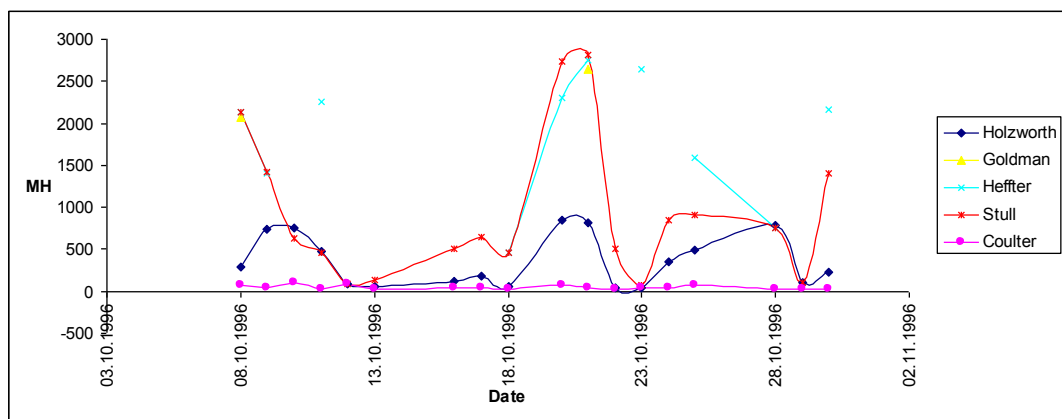


Figure IV-51. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in October, 1996 in the afternoon.

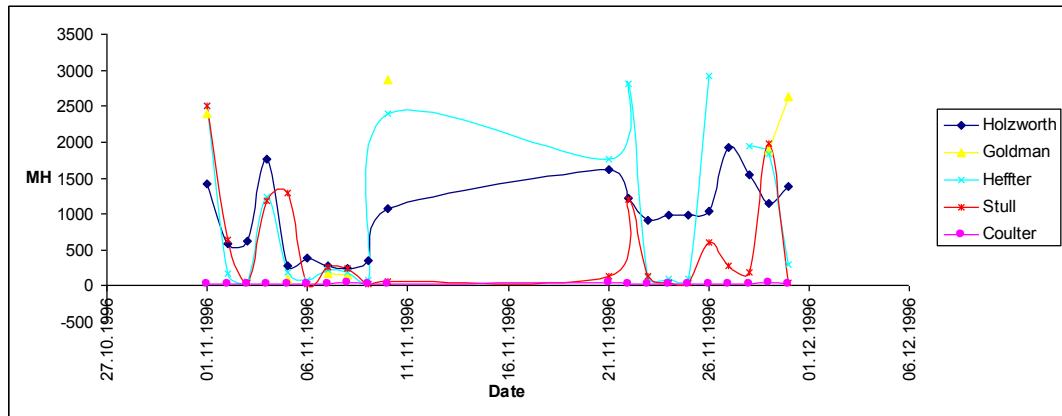


Figure IV-52. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in November, 1996 in the morning.

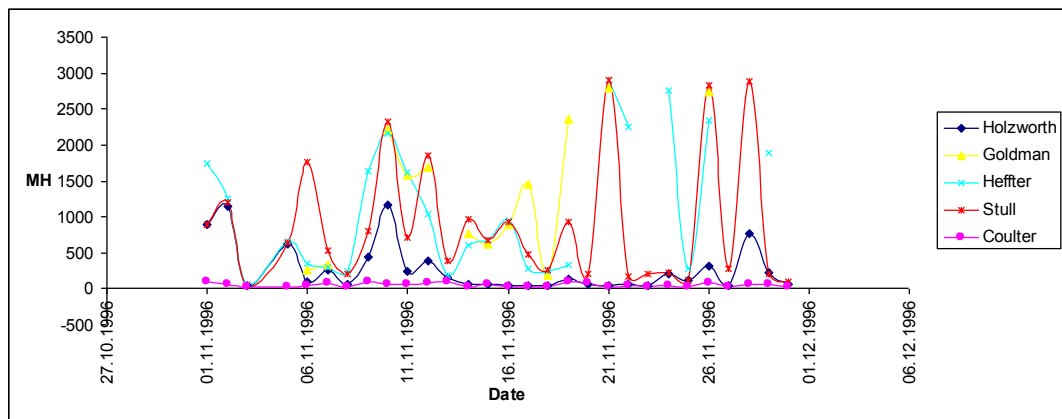


Figure IV-53. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in November, 1996 in the afternoon.

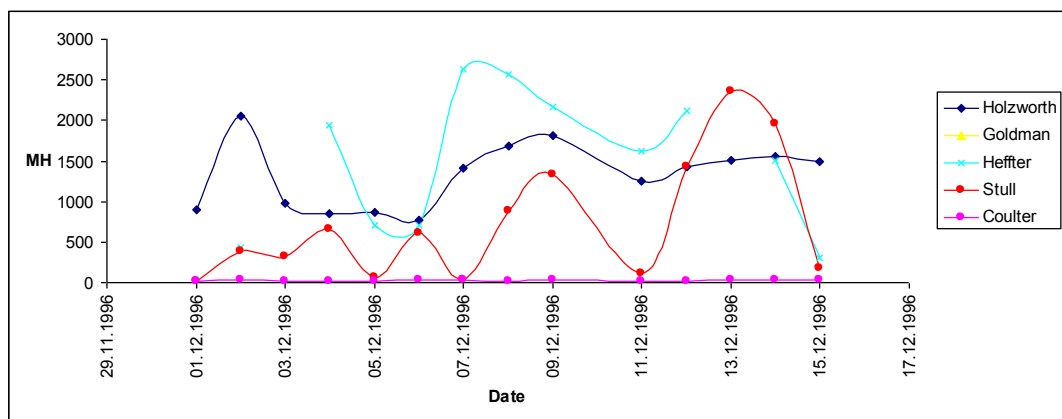


Figure IV-54. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in December, 1996 in the morning.

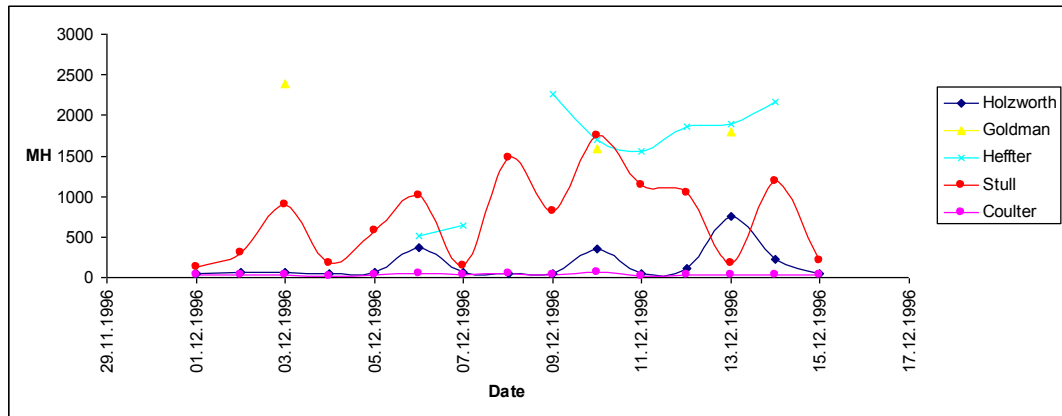


Figure IV-55. Holzworth, Coulter, Goldman, Heffter and Stull methods used in mixing height computing in December, 1996 in the afternoon.

Monthly and Seasonal Averages of Mixing Heights

Monthly averaged mixing heights for 1995 and 1996 are given in the following figures. Figure IV-56 and figure IV-57 show morning and afternoon mixing heights for 1995 respectively. Morning and afternoon mixing heights for 1996 are shown in figure IV-58 and figure IV-59 respectively. Results are also shown in the table IV-3 and IV-4:

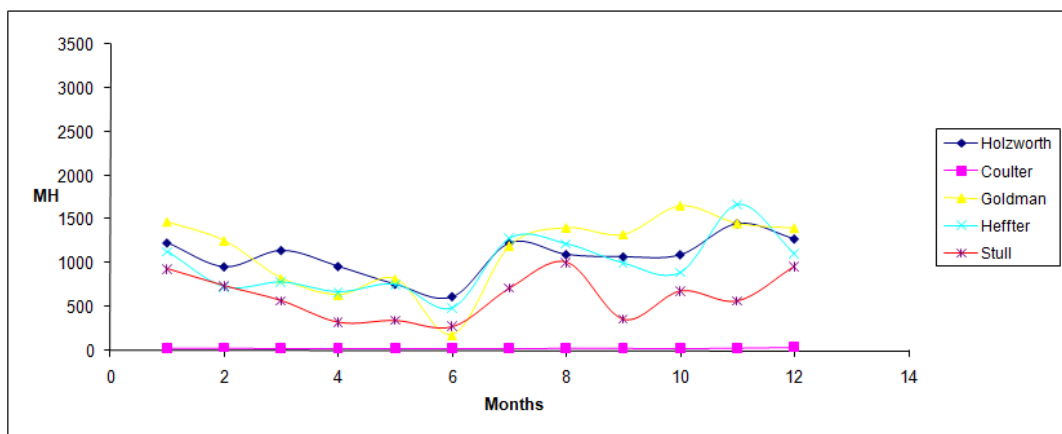


Figure IV-56. Average monthly mixing height values are computed from Holzworth, Coulter, Goldman, Heffter and Stull methods for 1995 in the morning.

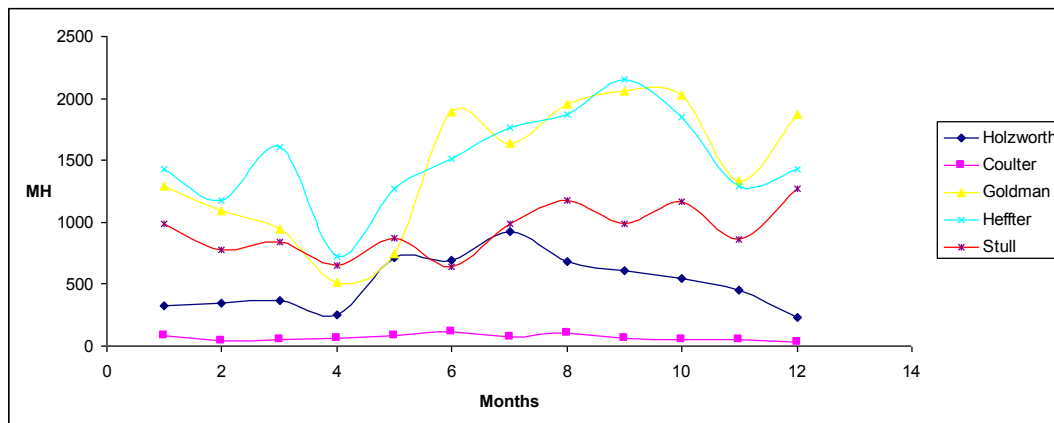


Figure IV-57. Average monthly mixing height values are computed from Holzworth, Coulter, Goldman, Heffter and Stull methods for 1995 in the afternoon.

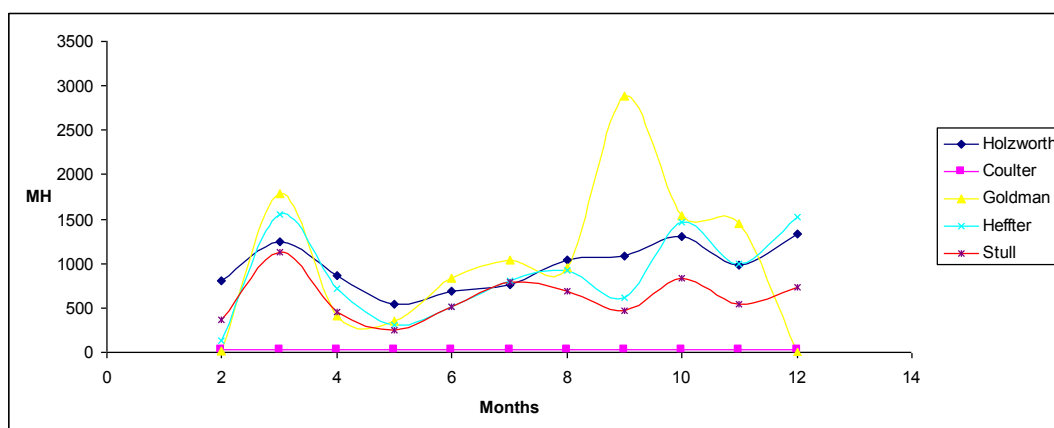


Figure IV-58. Average monthly mixing height values are computed from Holzworth, Coulter, Goldman, Heffter and Stull methods for 1996 in the morning.

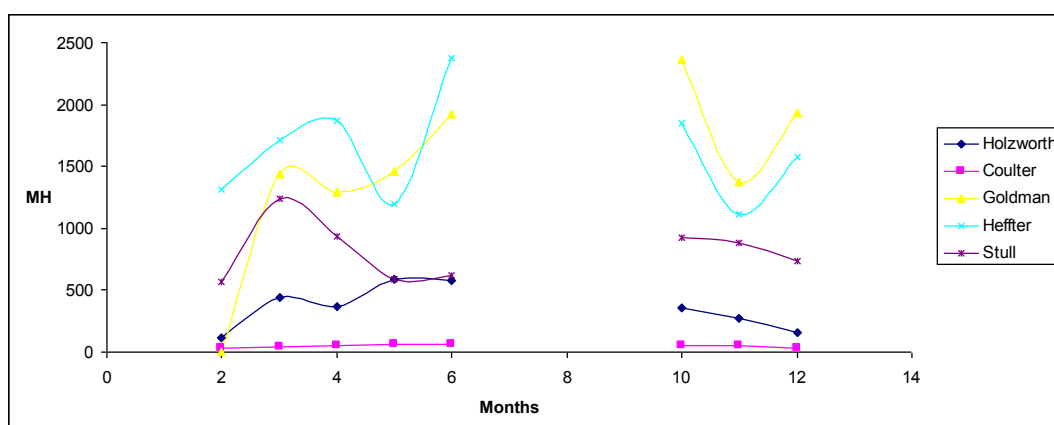


Figure IV-59. Average monthly mixing height values are computed from Holzworth, Coulter, Goldman, Heffter and Stull methods for 1996 in the afternoon.

If we approve the Heffter method for the computed results; The highest average monthly values for mornings in 1995 occur in November; July; August and January. However, the highest average monthly values in 1996 occur in March; December; October and November.

The highest average monthly values for afternoons in 1995 occur in September; August; October and July. The highest average monthly values for afternoons in 1996 occur in June, April, October and March. Finally, for the maximum average monthly afternoon mixing heights occur in Summer months. For detailed monthly and seasonal average values 1995 through 1996 see table IV-3 and IV-4 and appendix C-1 and C-2.

Table IV-3. Average monthly and seasonal mixing heights obtained from the computing program from 1995 through 1996 in the morning using Holzworth, Coulter, Goldman, Heffter and Stull methods are depicted. For expanded appearance see Appendix C-1.

Average Mixing Heights (in The Morning)													
Seasons		Winter		Spring			Summer			Autumn			
Months		January	February	March	April	May	June	July	August	September	October	November	December
1995 (Monthly)	Holzworth	1233.4	959.7	1147.7	963.2	759.4	616.2	1234.0	1100.7	1074.7	1098.7	1456.1	1279.3
	Coulter	32.6	34.2	28.6	26.7	28.7	31.4	29.3	31.6	31.7	27.8	33.7	41.9
	Goldman	1475.6	1258.3	828.4	639.4	821.8	181.6	1202.0	1408.2	1331.7	1660.7	1457.0	1404.5
	Heffter	1131.4	728.7	782.5	671.4	756.9	490.2	1283.2	1219.1	999.0	895.1	1669.1	1105.8
	Stull	933.1	738.0	567.4	320.6	340.5	271.0	711.3	1007.5	354.3	678.9	565.6	963.0
1996 (Monthly)	Holzworth		806.1	1238.6	867.6	544.4	682.3	755.6	1039.1	1088.5	1307.2	987.0	1326.0
	Coulter		31.4	26.0	28.9	34.4	26.3	28.4	34.6	26.7	33.2	27.4	27.0
	Goldman		12.0	1782.0	407.3	352.9	829.8	1042.8	950.4	2891.0	1530.5	1455.3	-
	Heffter		138.6	1548.2	723.2	303.3	508.2	806.5	929.3	615.3	1467.8	1001.3	1517.4
	Stull		367.6	1122.3	446.9	255.2	509.0	789.0	686.7	463.4	835.0	545.4	737.8
1995 (Seasonal)	Holzworth	1096.6		956.8			983.6			1209.8			
	Coulter	33.4		28.0			30.8			31.1			
	Goldman	1366.9		763.2			930.6			1483.1			
	Heffter	930.1		736.9			997.5			1187.8			
	Stull	835.6		409.5			663.3			532.9			
1996 (Seasonal)	Holzworth	1042.7		883.5			825.7			1127.6			1326.0
	Coulter	36.6		29.8			29.8			29.1			27.0
	Goldman	708.3		847.4			941.0			1958.9			-
	Heffter	622.2		858.3			748.0			1028.1			1517.4
	Stull	665.3		608.1			661.5			614.6			737.8

Table IV-4. Average monthly and seasonal mixing heights obtained from the computing program from 1995 through 1996 in the afternoon using Holzworth, Coulter, Goldman, Heffter and Stull methods are depicted. For expanded appearance see Appendix C-2.

Average Mixing Heights (In The Afternoon)													
Seasons		Winter		Spring			Summer			Autumn			
Months		January	February	March	April	May	June	July	August	September	October	November	December
1995 (Monthly)	Holzworth	325.7	345.9	365.1	256.6	711.5	689.7	919.5	685.6	614.3	543.6	450.2	228.5
	Coulter	85.9	36.8	54.8	57.8	80.5	111.8	72.3	101.2	60.7	54.2	48.1	32.4
	Goldman	1288.8	1096.7	941.0	510.5	749.3	1891.5	1639.0	1958.6	2059.0	2026.1	1336.0	1865.8
	Heffter	1426.9	1171.9	1606.5	719.6	1273.1	1514.4	1763.6	1870.0	2158.4	1848.9	1293.0	1430.3
	Stull	982.3	782.1	838.0	652.4	868.5	641.2	988.4	1179.5	982.9	1170.2	863.6	1275.4
1996 (Monthly)	Holzworth		120.1	438.2	367.0	589.4	580.8				358.9	270.2	157.9
	Coulter		35.0	43.4	50.3	64.6	63.7				47.6	49.9	34.8
	Goldman		-	1439.8	1290.5	1459.0	1920.0				2359.5	1377.0	1930.0
	Heffter		1308.0	1715.8	1868.3	1195.3	2370.7				1846.5	1115.4	1572.3
	Stull		564.2	1240.5	936.5	586.8	618.0				923.9	886.6	734.0
1995 (Seasonal)	Holzworth	335.8		444.4			764.9				536.1		
	Coulter	61.3		64.4			95.1				54.3		
	Goldman	1192.7		733.6			1829.7				1807.0		
	Heffter	1299.4		1199.7			1716.0				1766.7		
	Stull	882.2		786.3			936.3				1005.6		
1996 (Seasonal)	Holzworth	174.3		464.9			580.8			314.5		157.9	
	Coulter	33.7		52.8			63.7			48.7		34.8	
	Goldman	1865.8		1396.4			1920.0			1868.3		1930.0	
	Heffter	1369.1		1593.1			2370.7			1481.0		1572.3	
	Stull	919.8		921.3			618.0			905.3		734.0	

Seasonal averages for mornings in 1995 and 1996 are given in the figures IV-60 and IV-61 respectively.

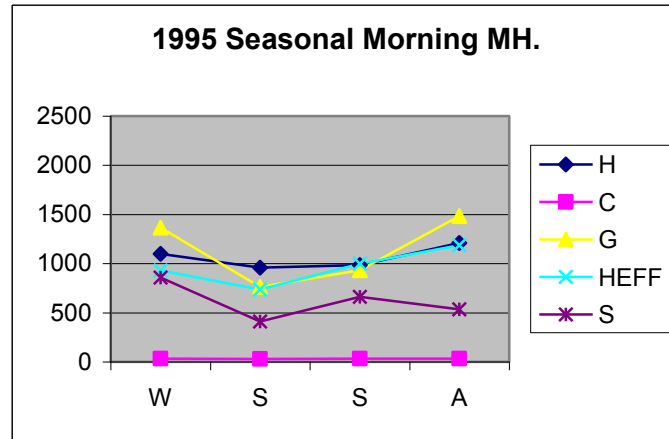


Figure IV-60. Average seasonal mixing height values are computed from Holzworth, Coulter, Goldman, Heffter and Stull methods for 1995 in morning cases.

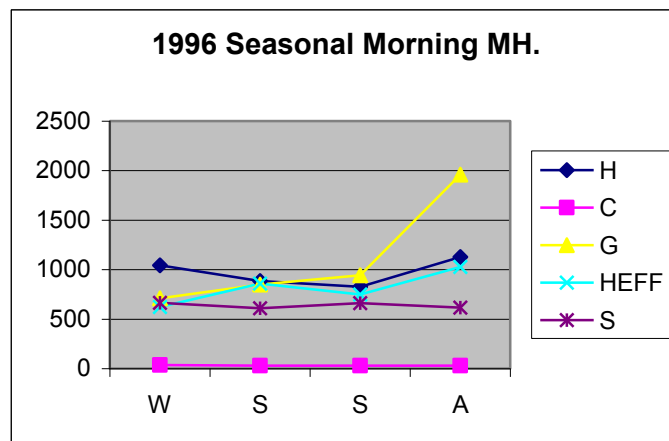


Figure IV-61. Average seasonal mixing height values are computed from Holzworth, Coulter, Goldman, Heffter and Stull methods for 1996 in morning cases.

If we approve the Heffter method for the computed results; the highest average seasonal values for mornings in 1995 occur in Autumn; Summer; Winter and Spring respectively. In 1996 the average morning mixing height values differs to autumn; spring; winter and summer, respectively.

Investigation of figures reveal that Coulter method gives too small values. Figure IV-62 and figure IV-63 show average values of mixing heights obtained by four methods except Coulter method for 1995 and 1996 morning, respectively. Average mixing heights are in good agreement with Heffter and Holzworth mixing heights.

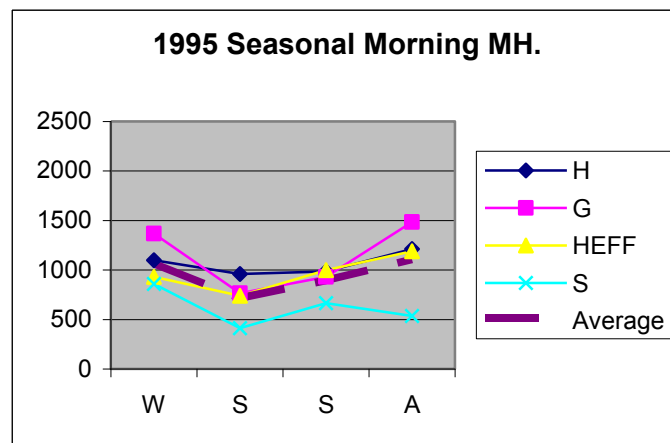


Figure IV-62. Average seasonal mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods and average of the four methods for 1995 in morning case.

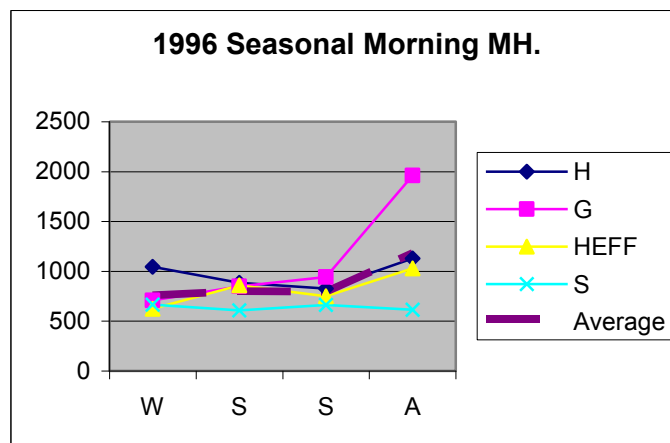


Figure IV-63. Average seasonal mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods and average of the four methods for 1996 in morning case.

Seasonal averages for afternoons in 1995 and 1996 are given in figure IV-64 and figure IV-65 for 1995 afternoon and 1996 afternoon, respectively.

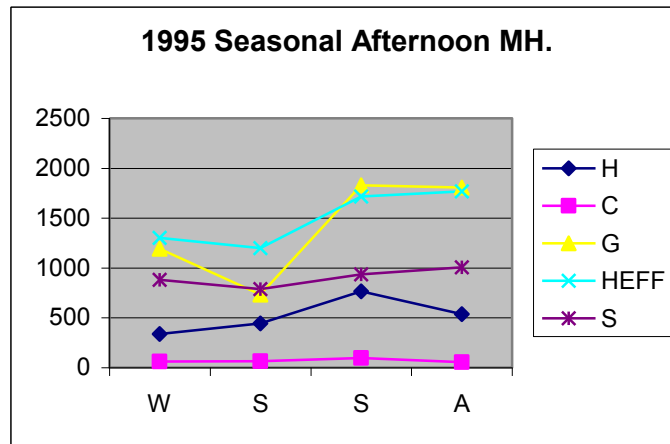


Figure IV-64. Average seasonal mixing height values are computed from Holzworth, Coulter, Goldman, Heffter and Stull methods for 1995 in afternoon case.

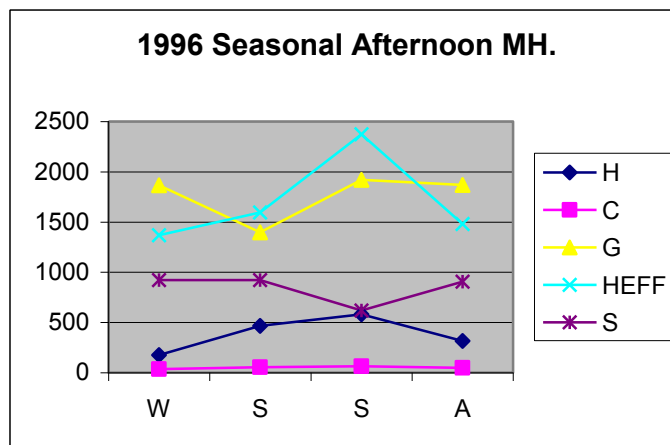


Figure IV-65. Average seasonal mixing height values are computed from Holzworth, Coulter, Goldman, Heffter and Stull methods for 1996 in afternoon case.

In these figures, it can be seen that Coulter method again gives the lowest results.

Average of the four methods, except Coulter, are shown in figures IV-66 and IV-67, respectively.

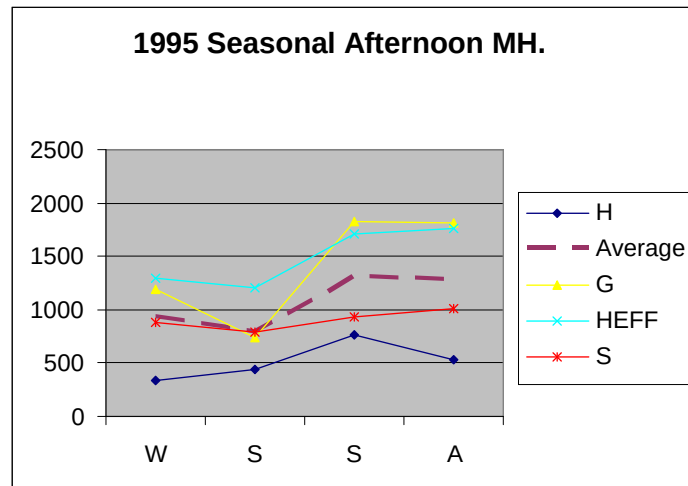


Figure IV-66. Average seasonal mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods and average of the four methods for 1995 in afternoon case.

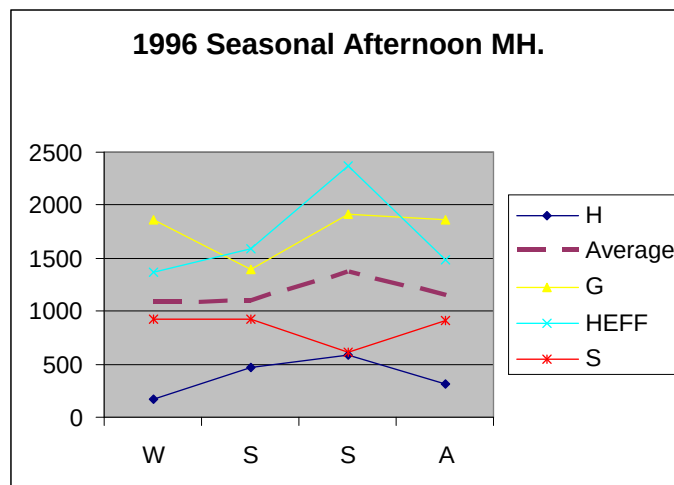


Figure IV-67. Average seasonal mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods and average of the four methods described for 1996 in afternoon case.

If we approve the Heffter method for the computed results for the period 1995 through 1996: The highest afternoon mixing height values for seasonal average occur in summer in 1996, followed by the Autumn 1995, Summer 1995, Spring 1996, Winter 1997 (Data contains 1996 December), Autumn 1996, Winter 1996, Winter 1995 and Spring 1995. The results are: 2371, 1767, 1716, 1593, 1572.3,

1481, 1369, 1299, 1200 meters, respectively. In general, summer mixing heights are greater than winter mixing heights.

Comparison of the methods:

Morning (02:00 LST) Mixing Heights

In order to compare the mixing heights obtained by different methods, differences were calculated as the Stull method has taken as the base (Table IV-5).

Table IV-5. Monthly averaged mixing heights obtained from the computing program for 1995 and 1996 in the morning using Holzworth, Coulter, Goldman, Heffter and Stull methods.

Month,1995	Stull	Coulter-Stull	Holzworth-Stull	Goldman-Stull	Heffter-Stull
January	933.1	-900.6	300.3	542.4	198.3
February	738.0	-703.9	221.6	520.3	-9.4
March	567.4	-538.8	580.3	261.1	215.1
April	320.6	-293.9	642.6	318.8	350.8
May	340.5	-311.8	418.9	481.3	416.5
June	271.0	-239.6	345.2	-89.4	219.2
July	711.3	-682.1	522.6	490.7	571.9
August	1007.5	-975.9	93.1	400.7	211.6
September	354.3	-322.6	720.4	977.4	644.7
October	678.9	-651.1	419.8	981.8	216.2
November	565.6	-531.9	890.5	891.4	1103.5
December	963.0	-921.1	316.3	441.5	142.8
Month, 1996	Stull	Coulter-Stull	Holzworth-Stull	Goldman-Stull	Heffter-Stull
January	-	-	-	-	-
February	367.6	-336.3	438.4	-355.6	-229.0
March	1122.3	-1096.3	116.3	659.7	425.9
April	446.9	-417.9	420.7	-39.5	276.4
May	255.2	-220.8	289.2	97.7	48.1
June	509.0	-482.7	173.3	320.9	-0.7
July	789.0	-760.6	-33.4	253.8	17.5
August	686.7	-652.1	352.4	263.7	242.6
September	463.4	-436.8	625.0	2427.6	151.9
October	835.0	-801.9	472.1	695.5	632.7
November	545.4	-517.9	441.7	909.9	455.9
December	737.8	-710.7	588.3	-	779.6

As seen in the figures Coulter method gives lowest results both in 1995 and 1996. Holzworth method gives higher results because of the additional 5 degrees. Goldman and Heffter methods computed higher results as compared to Stull method in 1995 and Goldman method resulted in surplus (because of the requirement of 100 meters between inversion top and base can seen in September, 1996) compared to Stull Method in 1996.

The most striking point in the computing results for an average of year in Holzworth method is the consequences of additional 5 degrees. It affects the results with a possitive surplus in the mornings. However, there is 6/23 consistent results in the January, 1995; and 5/19 consistent results in the July, 1995 with the Stull method in the morning. Graphical display of Stull minus Holzworth mixing height results can be seen in figures IV-68 and IV-69.

The other important result for mornings is that the Coulter method gives lower heights than the Holzworth method. Graphical display can be seen in figures IV-68 and IV-69 as Stull minus Coulter mixing height results.

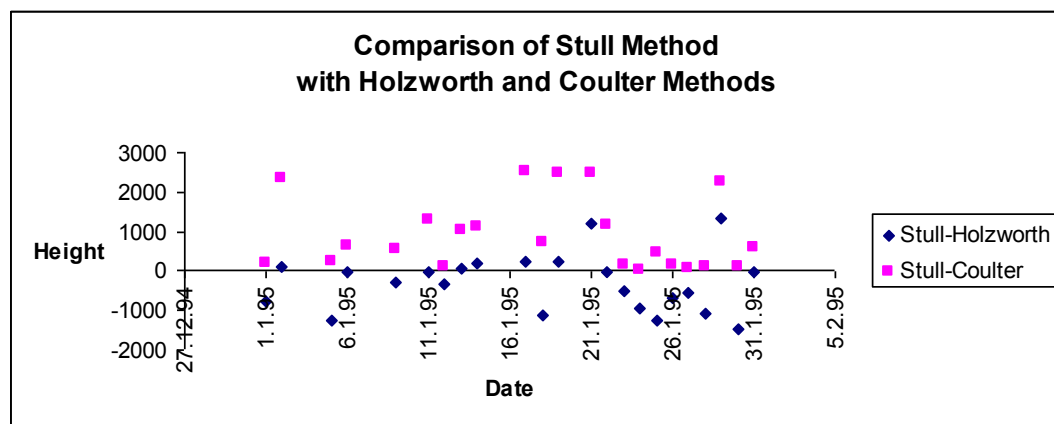


Figure IV-68. Stull minus Holzworth and Stull minus Coulter mixing height results for the January, 1995 in the morning.

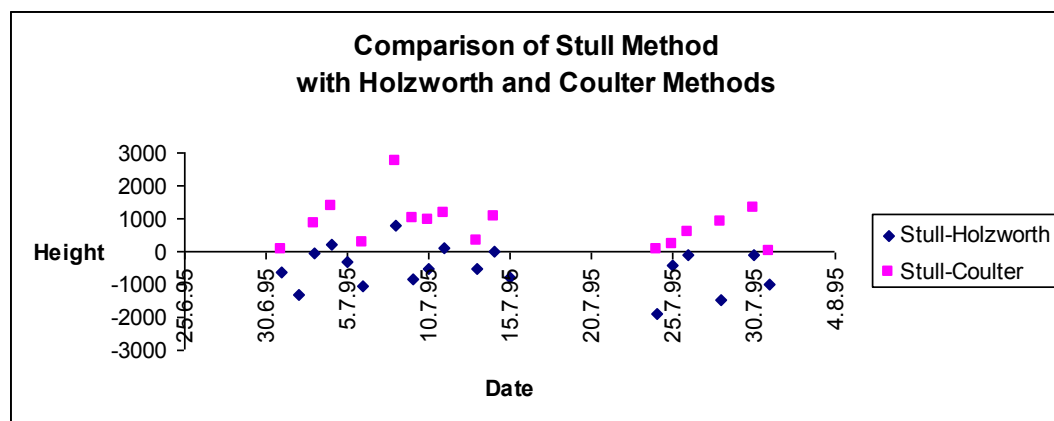


Figure IV-69. Stull minus Holzworth and Stull minus Coulter mixing height results for the July, 1995 in the morning.

Stull method for mornings show lower results as compared to Holzworth, Goldman and Heffter metods.

Afternoon (14:00 LST) Mixing Heights

In order to compare the mixing heights obtained by different methods, differences were calculated as the Stull method again has taken as the base (Table IV-6).

Table IV-6. Mixing Heights obtained from the computing program for 1995 and 1996 in the afternoon using Holzworth, Coulter, Goldman, Heffter and Stull methods.

Month, 1995	Stull	Coulter-Stull	Holzworth-Stull	Goldman-Stull	Heffter-Stull
January	982.3	-896.5	-656.6	306.4	444.6
February	782.1	-745.3	-436.2	314.6	389.8
March	838.0	-783.3	-472.9	103.0	768.4
April	652.4	-594.6	-395.9	-141.9	67.1
May	868.5	-788.0	-157.0	-119.2	404.6
June	641.2	-529.4	48.5	1250.3	873.2
July	988.4	-916.0	-68.8	650.7	775.3
August	1179.5	-1078.3	-493.9	779.1	690.5
September	982.9	-922.2	-368.6	1076.1	1175.5
October	1170.2	-1116.0	-626.6	855.9	678.7
November	863.6	-815.5	-413.4	472.4	429.4
December	1275.4	-1243.0	-1046.9	590.4	154.9
Month, 1996	Stull	Coulter-Stull	Holzworth-Stull	Goldman-Stull	Heffter-Stull
January	-	-	-	-	-
February	564.2	-529.2	-444.1	-	743.7
March	1240.5	-1197.1	-802.3	199.3	475.3
April	936.5	-886.2	-569.5	354.0	931.7
May	586.8	-522.2	2.6	872.2	608.5
June	618.0	-554.3	-37.2	1302.0	1752.7
July	-	-	-	-	-
August	-	-	-	-	-
September	-	-	-	-	-
October	923.9	-876.4	-565.0	1435.6	922.6
November	886.6	-836.7	-616.4	490.4	228.8
December	734.0	-699.2	-576.1	1196.0	838.3

As seen in the figures Coulter method gives lowest results both in 1995 and 1996. Holzworth method gives lower results compared to Stull Method. Goldman and Heffter methods mostly compute higher results as compared to Stull method both in 1995 and 1996.

The most striking point for afternoon is the parcel method that is carried out by Stull. It is more successful as compared to Holzworth. Holzworth technique checks the parcel movements on the surface but the Stull method based on the parcel movements so it gives the higher heights. Moreover, Coulter method gives lower results because of the temperature fluctuation on surface layer on the

afternoons. For the detailed depiction of results for the Stull method with Holzworth and Coulter methods there are figures IV-70 and IV-71 below.

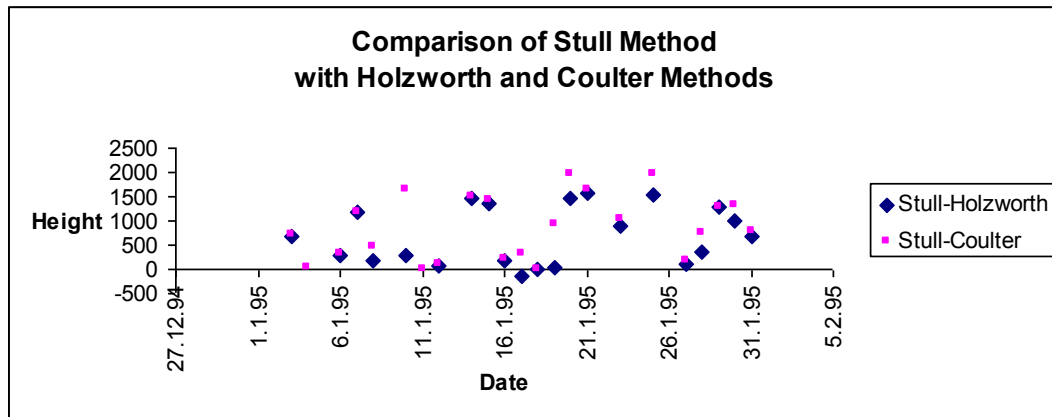


Figure IV-70. Stull minus Holzworth and Stull minus Coulter mixing height results for the January, 1995 in the afternoon.

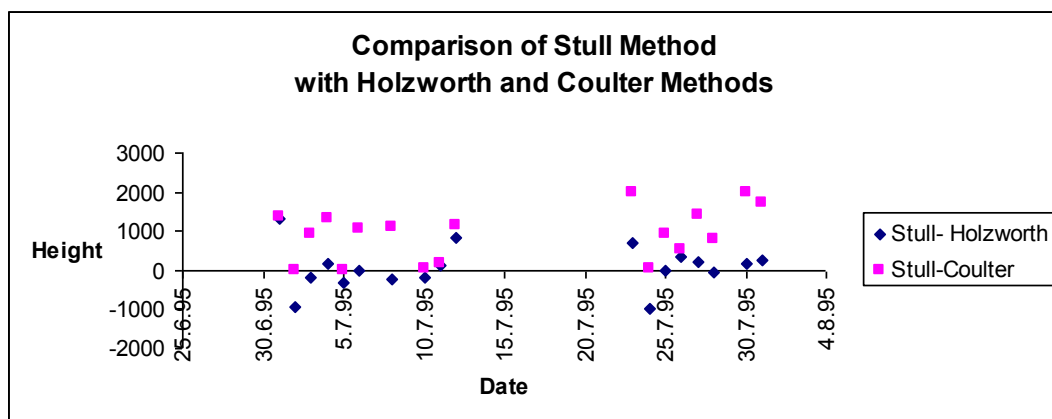


Figure IV-71. Stull minus Holzworth and Stull minus Coulter mixing height results for the July, 1995 in the afternoon.

The Goldman Method gives the highest mixing heights for afternoons.

Heffter method and Stull method give the nearest results to each other as compared to the other methods. Furthermore, Heffter method can not compute the mixing heights for 5/22 days in January, 1995; and 9/18 days in July, 1995 because of the 2K requirement between the inversion top and the inversion base.

Cases for the distribution of Mixing Height

There have been determined 3 cases for the determination of mixing height.

- i) Stable Case
- ii) Stable – Case 3 (s3)
- iii) Unstable Case as figured below.

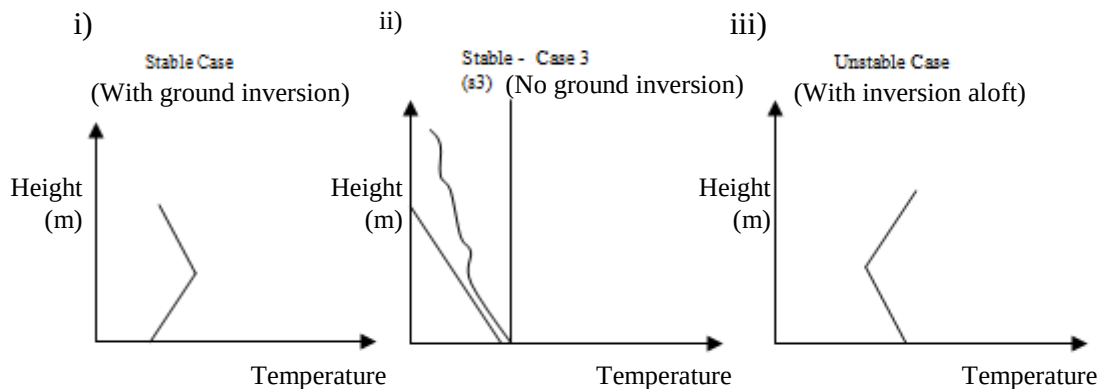


Figure IV-72. Determination of mixing heights as three cases: i) Stable ii) Stable – Case 3 and iii) Unstable Case.

- i) Stable Case: Temperature increase can be seen and there is a ground based inversion.
- ii) Stable Case 3: There is not a ground based inversion and temperature fluctuation can be seen.
- iii) Unstable Case: Temperature decreases to the inversion aloft.

Percentages of each case in 1995 are given in table IV-7. Investigation of the table reveals that stable case is dominant in mornings and unstable case is dominant in afternoons.

1995

Percentages of each case in 1996 are given in table IV-7. As shown in the table stable case is dominant in mornings and unstable case is dominant in afternoons.

Table IV-7. Number of each cases gathered from the computation of mixing height in 1995.

Distribution of Daily Mixing Heights in 1995						
	Morning	Morning (Percentage)	Afternoon	Afternoon (Percentage)	Total	Total (Percentage)
Stable	170	65.1	22	9.2	192.0	38.3
Stable - Case3	1	0.4	0	0.0	1.0	0.2
Unstable	90	34.5	218	90.8	308.0	61.5
Total	261	100.0	240	100.0	501.0	100.0

The following figures show the detailed distribution of monthly averaged morning mixing heights for 1995 cases. (Stable and unstable cases)

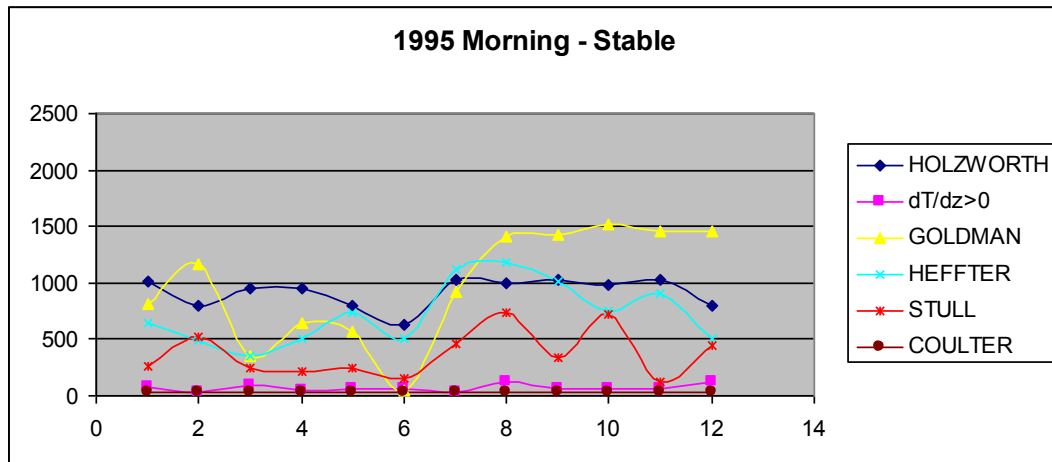


Figure IV-73. Average monthly mixing height values are computed from Holzworth, Coulter, Goldman, Heffter, Stull methods and the method based on $dT/dz > 0$ are described for 1995 in morning case under stable conditions.

As shown in the figure IV-73, Holzworth, Goldman, Heffter and Stull methods give comparable mixing heights, while the Stull method computes the lowest of these.

Investigation of figure IV-74 reveals that the conditions for Heffter, Goldman and Holzworth satisfied, most of the time all methods give the closest agreement.

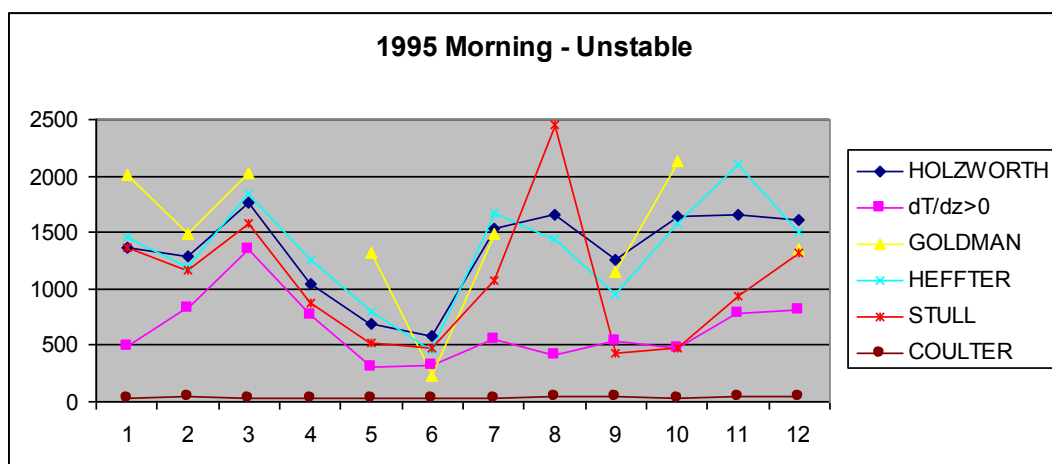


Figure IV-74. Average monthly mixing height values are computed from Holzworth, Coulter, Goldman, Heffter, Stull methods and the method based on $dT/dz > 0$ are described for 1995 in morning case under unstable conditions.

Calculated 1995 afternoon mixing heights are shown in figures IV-75 and IV-76 for stable and unstable cases, respectively. As shown in the figure IV-75, Goldman, Heffter and Stull methods give comparable mixing heights, while the Stull method computes the lowest of these.

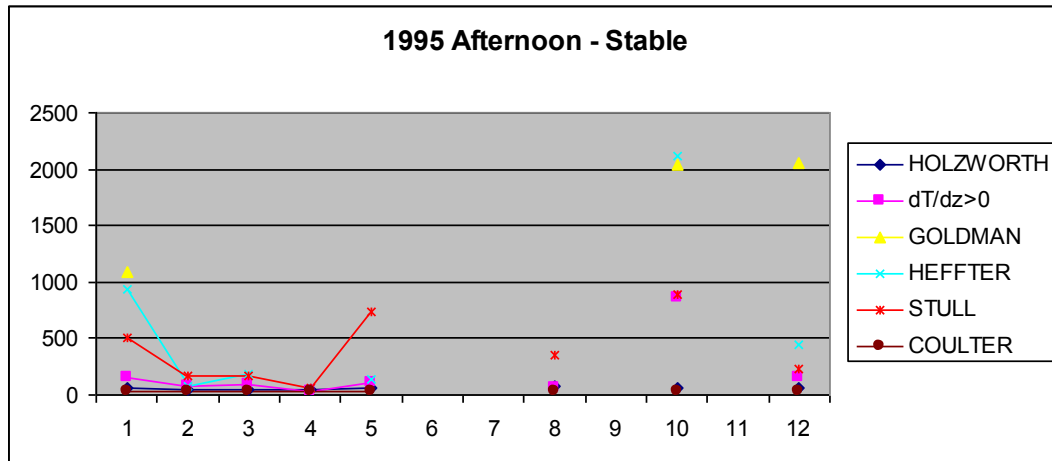


Figure IV-75. Average monthly mixing height values are computed from Holzworth, Coulter, Goldman, Heffter, Stull methods and the method based on $dT/dz > 0$ are described for 1995 in afternoon case under stable conditions.

As shown in the figure IV-76 the computation of afternoon mixing height by Stull, Heffter and Goldman methods gives comparable results for the unstable case.

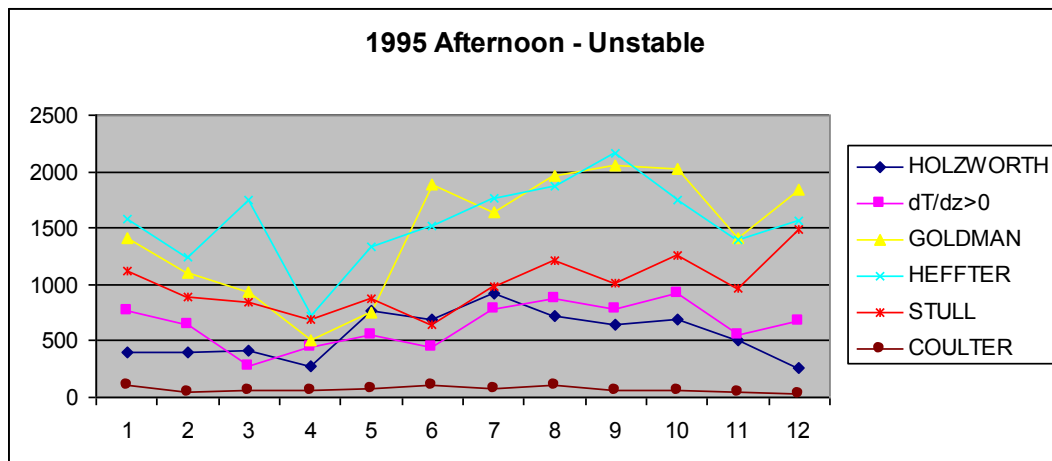


Figure IV-76. Average monthly mixing height values are computed from Holzworth, Coulter, Goldman, Heffter, Stull methods and the method based on $dT/dz > 0$ are described for 1995 in afternoon case under unstable conditions.

Figure IV-77 shows the comparison of the average mixing height obtained by Holzworth, Goldman, Heffter and Stull methods for the stable case to the average of four methods for all cases. Similarly, comparison of the average mixing height obtained by four methods for unstable case to all cases is shown in figure IV-78.. As seen in the figures, average mixing heights for stable cases are smaller than the all case averages, while unstable mixing heights are higher than the all cases average mixing heights.

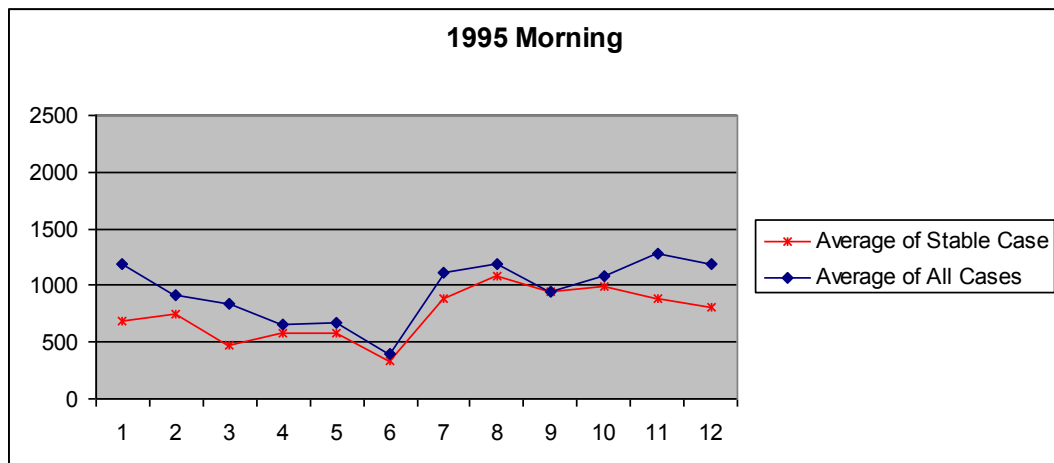


Figure IV-77. Average of monthly mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods with stable case and without cases for 1995 in the morning.

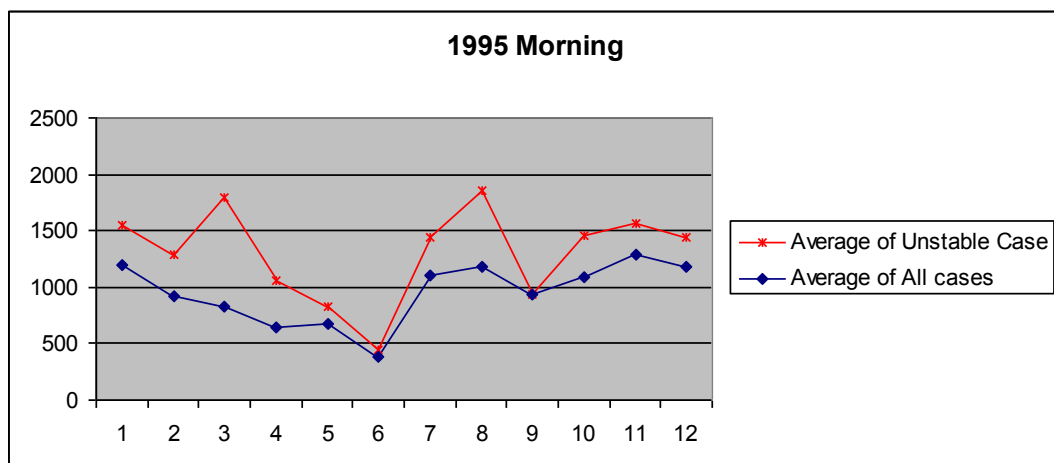


Figure IV-78. Average of monthly mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods with unstable case and without cases for 1995 in the morning.

The following tables show the detailed distribution of average morning mixing heights in 1995 with stable and unstable cases and all cases. As shown in the tables IV-8 and IV-9, average morning mixing heights without cases are about 200 meters higher than stable case average morning mixing heights for 1995 and can change month to month. As shown in the table IV-9 unstable case average morning mixing heights are about 550 meters higher than stable case average morning mixing heights in 1995 and can change month to month.

Table IV-8. Monthly averages of mixing heights from the computation of mixing height for 1995 morning without cases.

Months, 1995	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	Average of H,G,HEFF and S
January	1233.4	334.3	1475.6	1131.4	933.1	32.6	1193.4
February	959.7	302.9	1258.3	728.7	738.0	34.2	921.2
March	1147.7	395.9	828.4	782.5	567.4	28.6	831.5
April	963.2	162.8	639.4	671.4	320.6	26.7	648.7
May	759.4	143.4	821.8	756.9	340.5	28.7	669.7
June	616.2	160.9	181.6	490.2	271.0	31.4	389.7
July	1234.0	253.3	1202.0	1283.2	711.3	29.3	1107.6
August	1100.7	172.6	1408.2	1219.1	1007.5	31.6	1183.9
September	1074.7	165.1	1331.7	999.0	354.3	31.7	939.9
October	1098.7	133.0	1660.7	895.1	678.9	27.8	1083.3
November	1456.1	439.9	1457.0	1669.1	565.6	33.7	1287.0
December	1279.3	533.9	1404.5	1105.8	963.0	41.9	1188.2

Table IV-9. Monthly averages of mixing heights from the computation of mixing height for 1995 morning stable and unstable cases.

	Stable							Unstable						
Months, 1995	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	AVERAGE Of H,G, HEFF and S	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	AVERAGE Of H,G, HEFF and S
January	1017.8	79.5	810.0	641.1	261.3	37.6	682.5	1372.1	498.1	2008.0	1458.3	1365.1	29.4	1550.9
February	793.3	38.2	1159.4	492.9	523.2	28.2	742.2	1292.5	832.4	1480.8	1200.2	1167.7	46.1	1285.3
March	954.6	96.9	351.8	358.0	251.3	27.2	478.9	1765.6	1352.6	2020.0	1843.6	1578.9	32.9	1802.0
April	947.4	47.1	639.4	513.5	215.6	25.6	579.0	1046.4	770.5		1263.5	871.9	32.5	1060.6
May	793.7	64.5	574.0	729.7	248.3	28.2	586.4	690.7	301.1	1317.3	802.3	524.8	29.8	833.8
June	632.1	63.5	41.5	509.2	153.2	27.8	334.0	589.0	327.8	237.6	463.0	473.0	37.4	440.6
July	1020.6	35.1	914.5	1126.1	453.0	24.7	878.5	1527.4	553.3	1489.5	1676.0	1066.6	35.5	1439.9
August	996.0	128.0	1408.2	1185.9	736.0	28.2	1081.5	1659.1	410.2		1434.9	2455.4	50.2	1849.8
September	1025.5	66.1	1425.5	1006.9	335.5	27.6	948.3	1259.3	536.4	1144.0	944.3	424.8	47.5	943.1
October	981.3	60.2	1524.1	747.4	721.7	27.8	993.6	1646.2	473.2	2138.5	1584.3	479.2	28.0	1462.1
November	1032.1	55.7	1457.0	902.4	119.3	23.6	877.7	1662.1	788.4		2095.1	938.9	41.5	1565.4
December	798.0	123.4	1460.7	508.5	440.3	27.5	801.8	1612.6	818.1	1348.3	1504.0	1324.9	52.0	1447.5

As shown in the figure IV-79 and IV-80, the average of Holzworth, Goldman, Heffter and Stull methods for stable and unstable cases and all cases are depicted for detailed review of 1995 afternoons. As seen in the figures below, average of all cases have 650 meters higher values than average of stable cases.

Investigation of figure IV-80 shows that average mixing heights for unstable cases are in close agreement with all case averages for 1995 afternoon soundings.

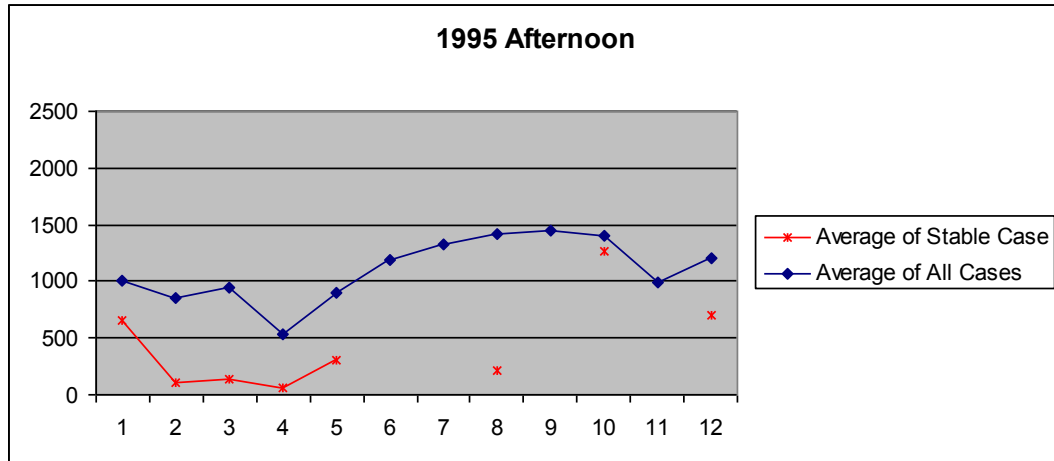


Figure IV-79. Average of monthly mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods with stable case and without cases for 1995 in the afternoon.

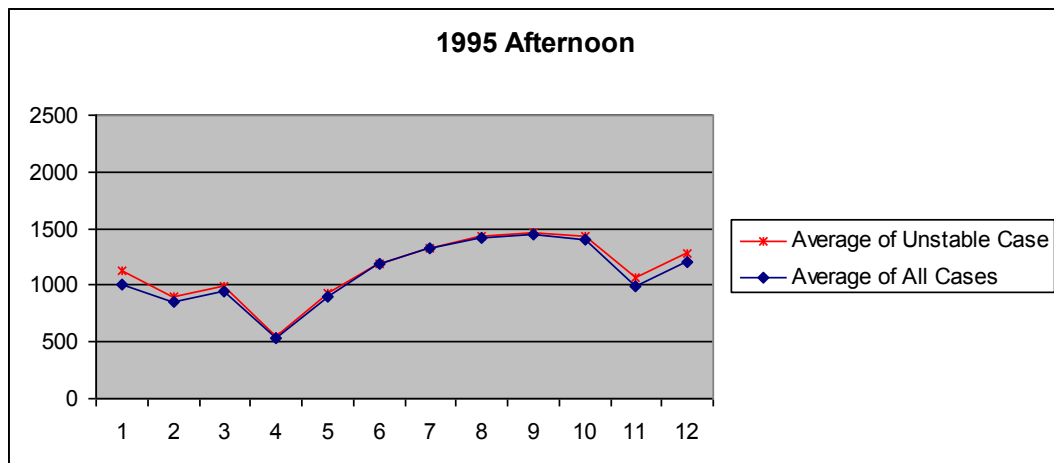


Figure IV-80. Average of monthly mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods with unstable case and without cases for 1995 in the afternoon.

For the stable case 3 determination of mixing height can be wrong because of the uncertainties in atmospheric profile. Moreover, as Holzworth method as seen in the figure IV-72 part –ii, the dry adiabatic extension of the surface temperature profile doesn't intersect the temperature profile.

For 1995 morning unstable case Holzworth method gives the nearest results to the average of Goldman, Holzworth, Heffter and Stull methods. After the Holzworth method Heffter, Stull and Goldman method give nearest results, respectively.

For 1995 afternoon unstable case Stull method gives the nearest results to the average of Goldman, Holzworth, Heffter and Stull methods.

The following tables show the detailed distribution of average afternoon mixing heights in 1995 with stable and unstable cases and all cases. As shown in the tables IV-10 and IV-11 average afternoon mixing heights without cases are about 650 meters higher than stable case average afternoon mixing heights for 1995 and can change month to month. As shown in the table IV-11 unstable case average afternoon mixing heights are about 700 meters higher than stable case average morning mixing heights in 1995 and can change month to month.

Table IV-10. 1995 average monthly afternoon mixing heights without cases.

Months, 1995	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	Average of H,G,HEFF and S
January	325.7	629.4	1288.8	1426.9	982.3	85.9	1005.9
February	345.9	556.6	1096.7	1171.9	782.1	36.8	849.1
March	365.1	265.2	941.0	1606.5	838.0	54.8	937.7
April	256.6	426.6	510.5	719.6	652.4	57.8	534.8
May	711.5	520.8	749.3	1273.1	868.5	80.5	900.6
June	689.7	442.9	1891.5	1514.4	641.2	111.8	1184.2
July	919.5	780.6	1639.0	1763.6	988.4	72.3	1327.6
August	685.6	841.1	1958.6	1870.0	1179.5	101.2	1423.4
September	614.3	748.2	2059.0	2158.4	982.9	60.7	1453.7
October	543.6	906.6	2026.1	1848.9	1170.2	54.2	1397.2
November	450.2	487.5	1336.0	1293.0	863.6	48.1	985.7
December	228.5	585.7	1865.8	1430.3	1275.4	32.4	1200.0

Table IV-11. Monthly averages of mixing heights from the computation of mixing height for 1995 afternoon stable and unstable cases.

	Stable							Unstable						
Months, 1995	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	AVERAGE Of H,G, HEFF and S	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	AVERAGE Of H,G, HEFF and S
January	66.9	158.0	1088.0	929.0	509.0	35.5	648.2	401.9	768.0	1409.2	1580.1	1121.6	100.7	1128.2
February	48.9	78.6	-	81.1	173.9	25.3	101.3	398.3	640.9	1096.7	1236.0	889.4	38.8	905.1
March	48.7	91.3	-	182.6	164.3	24.3	131.9	409.3	274.0	941.0	1749.1	841.6	58.3	985.3
April	51.1	25.6	-	-	66.5	25.6	58.8	268.6	450.2	510.5	719.6	686.9	59.7	546.4
May	58.9	103.4	-	145.2	732.5	38.2	312.2	765.9	555.6	749.3	1335.8	879.8	84.0	932.7
June	-	-	-	-	-	-	-	689.7	442.9	1891.5	1514.4	641.2	111.8	1184.2
July	-	-	-	-	-	-	-	919.5	780.6	1639.0	1763.6	988.4	72.3	1327.6
August	76.0	64.3	-	-	359.8	35.1	217.9	714.6	878.1	1958.6	1870.0	1218.5	104.3	1440.4
September	-	-	-	-	-	-	-	643.9	780.6	2059.0	2158.4	1012.8	61.7	1468.5
October	55.5	864.8	2033.5	2115.3	884.6	27.9	1272.2	687.2	916.4	2024.3	1753.7	1254.2	62.0	1429.9
November	-	-	-	-	-	-	-	499.2	551.1	1411.0	1397.9	959.2	49.8	1066.8
December	62.6	158.1	2057.0	451.2	227.7	27.4	699.6	261.6	671.3	1841.9	1560.8	1484.9	33.4	1287.3

1996

Percentages of each case in 1996 are given in table IV-12. As shown in the table stable case is dominant in mornings and unstable case is dominant in afternoons as in 1995.

Table IV-12. Number of each cases gathered from the computation of mixing height in 1996.

Distribution of Daily Mixing Heights in 1996						
	Morning	Morning (Percentage)	Afternoon	Afternoon (Percentage)	Total	Total (Percentage)
Stable	141	56.9	27	18.6	168	42.7
Stable - Case3	2	0.8	2	1.4	4	1.0
Unstable	105	42.3	116	80.0	221	56.2
Total	248	100.0	145	100.0	393	100.0

The following figures (Figure IV-81, figure IV-82, figure IV-83, figure IV-84, figure IV-85 and figure IV-86) show the detailed distribution of average morning mixing heights for 1996 cases. (Stable, Stable case 3 and unstable cases)

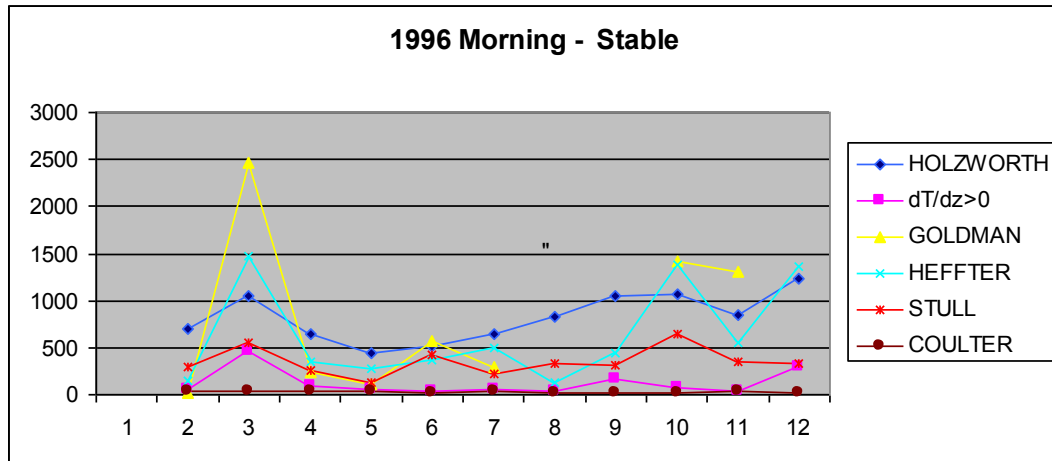


Figure IV-81. Average monthly mixing height values are computed from Holzworth, dT/dz>0, Goldman, Heffter, Stull and Coulter method are depicted for 1996 in morning case under stable conditions.

As shown in the figure IV-81, Holzworth, Goldman, Heffter and Stull methods give comparable mixing heights, while the Stull method computes the lowest of these. (Same situation as 1995 morning stable case which was shown in figure IV-73)

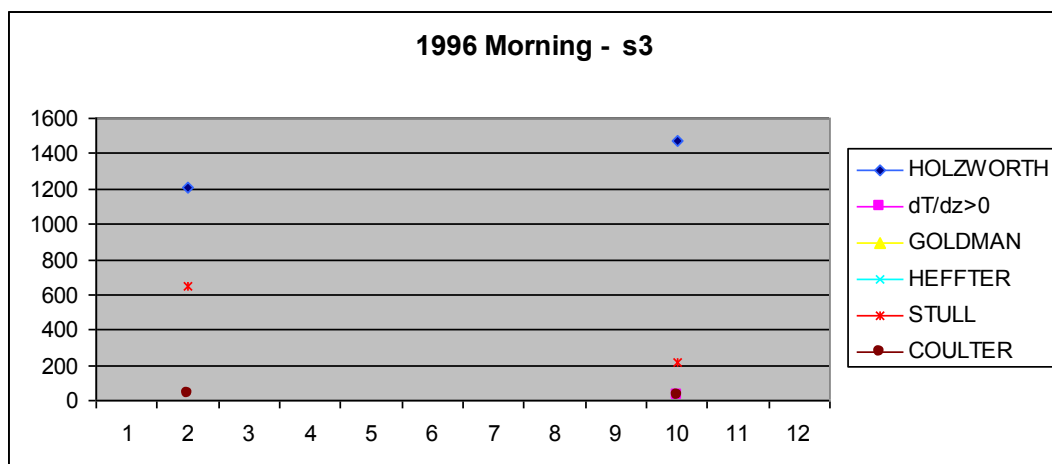


Figure IV-82. Average monthly mixing height values are computed from Holzworth, dT/dz>0, Goldman, Heffter, Stull and Coulter method are depicted for 1996 in morning case under stable case 3 conditions.

S3 case give too different mixing heights.(Figure IV-82)

Investigation of figure IV-83 reveals that the conditions for Heffter, Goldman and Holzworth satisfied, most of the time all methods give the closest agreement. (Same as figure IV-74.)

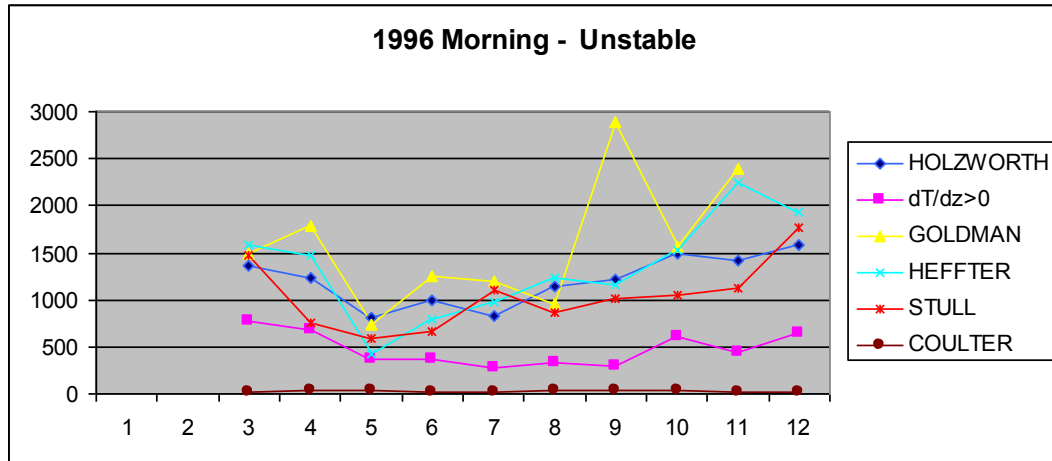


Figure IV-83. Average monthly mixing height values are computed from Holzworth, $dT/dz > 0$, Goldman, Heffter, Stull and Coulter method are depicted for 1996 in morning case under unstable conditions.

As shown in the figure IV-84 the computation of afternoon mixing height gives too low results for the stable case.

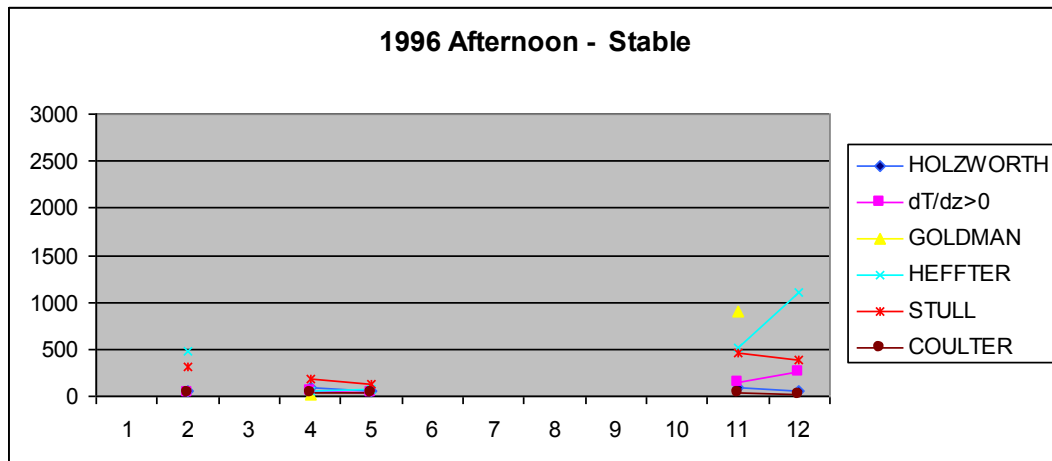


Figure IV-84. Average monthly mixing height values are computed from Holzworth, $dT/dz > 0$, Goldman, Heffter, Stull and Coulter method are depicted for 1996 in afternoon case under stable conditions.

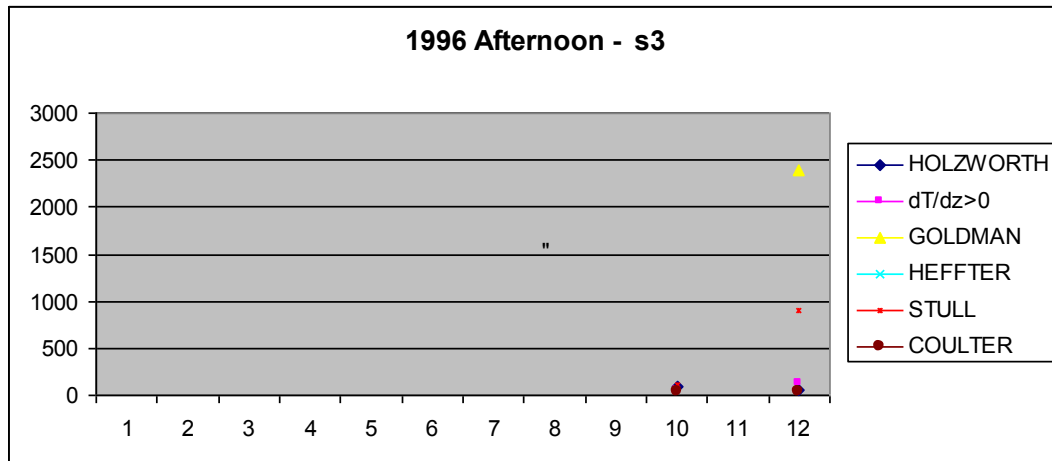


Figure IV-85. Average monthly mixing height values are computed from Holzworth, $dT/dz>0$, Goldman, Heffter, Stull and Coulter method are depicted for 1996 in afternoon under stable case 3 conditions.

S3 case give too different mixing heights (Fig IV-85). As shown in the figure IV-86 the computation of afternoon mixing height gives comparable results by Stull, Heffter and Goldman methods with the unstable case. (Same situation as in figure IV-76.) It is worth to mention that Heffter method calculates the highest mixing heights.

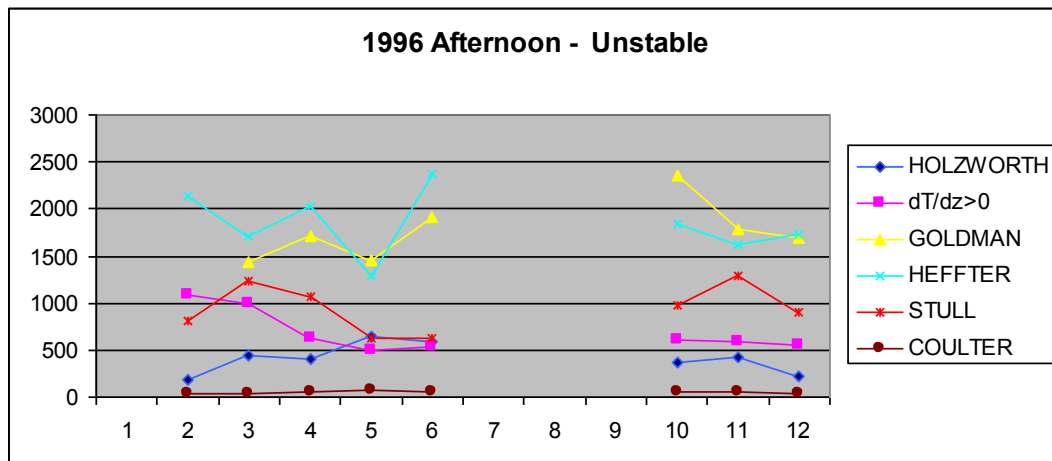


Figure IV-86. Average monthly mixing height values are computed from Holzworth, $dT/dz>0$, Goldman, Heffter, Stull and Coulter method are depicted for 1996 in afternoon under unstable case conditions.

As shown in the figure IV-87 and IV-88, the average of Holzworth, Goldman, Heffter and Stull methods for stable and unstable cases and without cases are depicted for detailed review of 1996 mornings. As seen in the figures below, average of all cases are higher values than average of stable cases and average of all cases are smaller values than average of unstable cases in 1995 mornings.

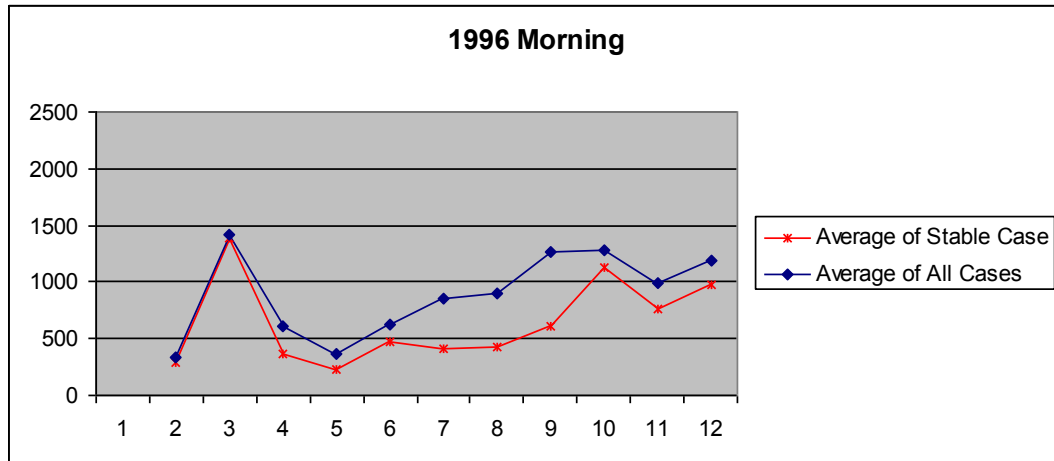


Figure IV-87. Average of monthly mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods with stable case and without cases for 1996 in the morning.

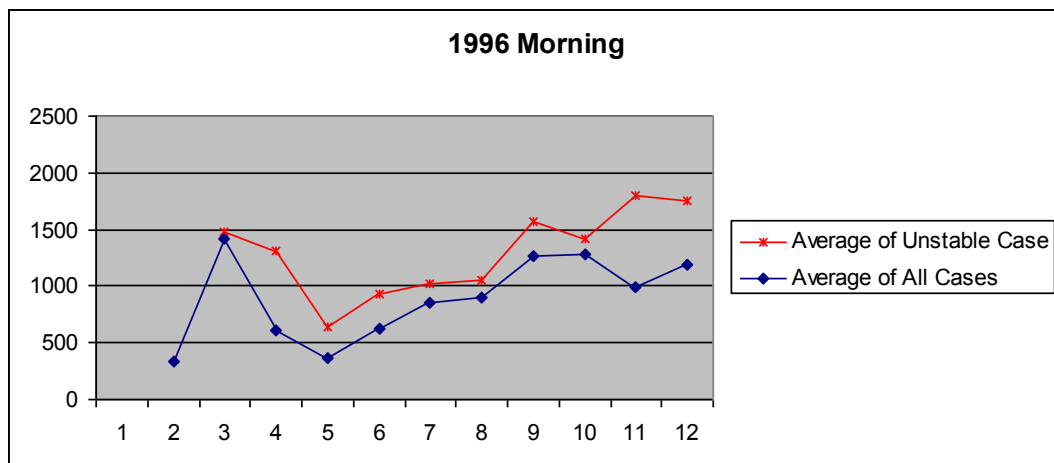


Figure IV-88. Average of monthly mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods with unstable case and without cases for 1996 in the morning.

The following tables show the detailed distribution of average morning mixing heights in 1996 with stable and unstable cases and without cases. As shown in the tables IV-13 and IV-14, average morning mixing heights without cases are about 250 meters higher than stable case average morning mixing heights for 1996 and can change month to month. As shown in the table IV-14 unstable case average morning mixing heights are about 650 meters higher than stable case average morning mixing heights in 1996 and can change month to month.

Table IV-13. 1996 average monthly morning mixing heights without cases.

Months, 1996	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	Average of H,G,HEFF and S
January	-	-	-	-	-	-	-
February	806.1	53.6	12.0	138.6	367.6	31.4	331.1
March	1238.6	652.9	1782.0	1548.2	1122.3	26.0	1422.8
April	867.6	315.7	407.3	723.2	446.9	28.9	611.2
May	544.4	137.9	352.9	303.3	255.2	34.4	364.0
June	682.3	155.2	829.8	508.2	509.0	26.3	632.3
July	755.6	195.2	1042.8	806.5	789.0	28.4	848.4
August	1039.1	232.4	950.4	929.3	686.7	34.6	901.4
September	1088.5	192.5	2891.0	615.3	463.4	26.7	1264.5
October	1307.2	343.9	1530.5	1467.8	835.0	33.2	1285.1
November	987.0	138.4	1455.3	1001.3	545.4	27.4	997.2
December	1326.0	388.8	-	1517.4	737.8	27.0	1193.7

Table IV-14. Monthly averages of mixing heights from the computation of mixing height for 1996 morning stable and unstable cases.

	Stable							Unstable						
Months, 1995	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	AVERAGE Of H,G, HEFF and S	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	AVERAGE Of H,G, HEFF and S
January	-	-	-	-	-	-	-	-	-	-	-	-	-	-
February	706.6	53.6	12.0	138.6	296.7	29.5	288.5	-	-	-	-	-	-	-
March	1045.7	452.3	2459.7	1478.8	554.2	28.2	1384.6	1357.4	776.4	1491.6	1585.6	1471.9	24.6	1476.6
April	638.2	89.4	235.9	347.4	250.8	28.3	368.1	1234.6	677.9	1779.0	1474.8	760.6	29.9	1312.2
May	438.8	49.0	101.7	271.8	128.3	31.5	235.1	815.9	366.6	729.8	429.4	581.8	42.0	639.2
June	515.2	44.2	569.8	366.4	428.3	26.9	469.9	999.9	366.2	1246.0	792.0	662.3	25.2	925.0
July	637.9	63.7	288.7	501.6	228.9	30.8	414.3	823.7	271.4	1204.4	966.9	1113.2	27.0	1027.1
August	829.9	35.8		130.4	337.2	27.1	432.5	1149.3	335.9	950.4	1229.0	870.7	38.5	1049.8
September	1056.5	167.1		435.8	321.1	26.3	604.5	1210.0	289.2	2891.0	1153.8	1004.3	28.1	1564.8
October	1068.3	65.3	1416.5	1380.3	635.7	25.2	1125.2	1496.6	603.7	1568.5	1531.4	1051.5	40.1	1412.0
November	846.4	36.0	1299.3	557.9	352.1	28.1	763.9	1408.9	445.6	2391.0	2242.7	1125.1	25.4	1791.9
December	1225.4	288.8		1363.1	326.1	27.2	971.5	1577.5	638.6		1928.8	1766.9	26.7	1757.7

As shown in the figure IV-89 and IV-90, the average of Holzworth, Goldman, Heffter and Stull methods for stable and unstable cases and all cases are depicted for detailed review of 1996 afternoons. As seen in the figures below, average of all cases have higher values than average of stable cases.

Investigation of figure IV-90 shows that average mixing heights for unstable cases are in close agreement with all case averages for 1996 afternoon soundings.

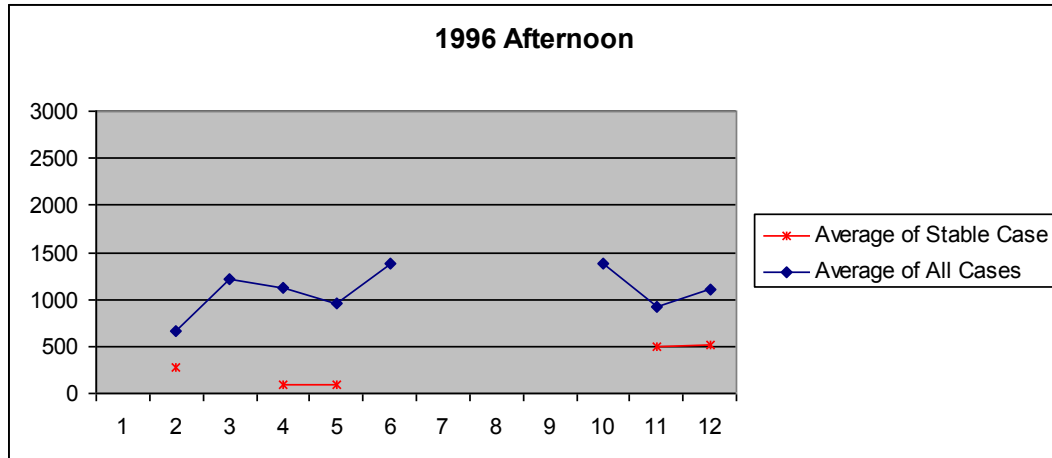


Figure IV-89. Average of monthly mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods with stable case and without cases for 1996 in the afternoon.

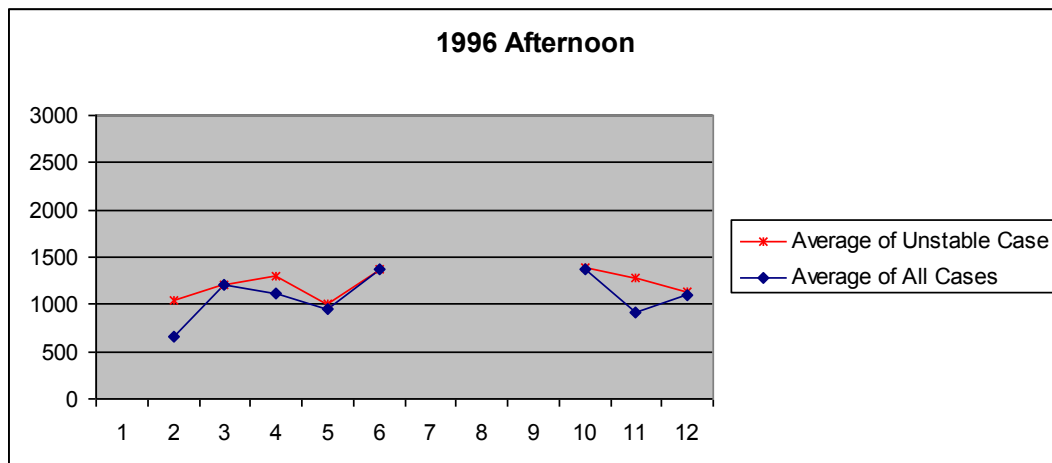


Figure IV-90. Average of monthly mixing height values are computed from Holzworth, Goldman, Heffter and Stull methods with unstable case and without cases for 1996 in the afternoon.

The following tables show the detailed distribution of average afternoon mixing heights in 1996 with stable and unstable cases and without cases. As shown in the tables IV-15 and IV-16, average afternoon mixing heights without cases are about 800 meters higher than stable case average afternoon mixing heights for 1996 and can change month to month. As shown in the table IV-14 unstable case average afternoon mixing heights are about 900 meters higher than stable case average afternoon mixing heights in 1996 and can change month to month.

Table IV-15. 1996 average monthly afternoon mixing heights without cases.

Months, 1996	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	Average of H,G,HEFF and S
January	-	-	-	-	-	-	-
February	120.1	448.3	-	1308.0	564.2	35.0	664.1
March	438.2	985.9	1439.8	1715.8	1240.5	43.4	1208.6
April	367.0	529.3	1290.5	1868.3	936.5	50.3	1115.6
May	589.4	455.2	1459.0	1195.3	586.8	64.6	957.6
June	580.8	538.3	1920.0	2370.7	618.0	63.7	1372.4
July	-	-	-	-	-	-	-
August	-	-	-	-	-	-	-
September	-	-	-	-	-	-	-
October	358.9	576.1	2359.5	1846.5	923.9	47.6	1372.2
November	270.2	377.7	1377.0	1115.4	886.6	49.9	912.3
December	157.9	429.3	1930.0	1572.3	734.0	34.8	1098.5

Table IV-16. Monthly averages of mixing heights from the computation of mixing height for 1996 afternoon stable and unstable cases.

	Stable							Unstable						
Months, 1996	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	AVERAGE Of H,G, HEFF and S	HOLZWORTH	dT/dz>0	GOLDMAN	HEFFTER	STULL	COULTER	AVERAGE Of H,G, HEFF and S
January	-	-	-	-	-	-	-	-	-	-	-	-	-	-
February	52.2	28.1		481.4	314.1	28.1	282.6	188.1	1078.6		2134.5	814.3	41.9	1045.6
March	-	-	-	-	-	-	-	438.2	985.9	1439.8	1715.8	1240.5	43.4	1208.6
April	91.3	51.2	17.0	51.4	184.8	40.4	86.1	413.0	619.0	1715.0	2033.4	1061.8	51.9	1305.8
May	62.0	37.1		67.3	134.1	37.1	87.8	635.3	493.2	1459.0	1289.3	626.2	67.0	1002.5
June	-	-	-	-	-	-	-	580.8	538.3	1920.0	2370.7	618.0	63.7	1372.4
July	-	-	-	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	-	-	-	-	-	-	-	-	-	-	-
September	-	-	-	-	-	-	-	-	-	-	-	-	-	-
October	-	-	-	-	-	-	-	374.4	606.9	2359.5	1846.5	972.3	48.5	1388.2
November	99.9	150.3	894.8	514.4	461.7	39.4	492.7	429.1	590.0	1790.3	1623.8	1283.2	59.7	1281.6
December	53.4	259.9		1096.2	391.7	25.3	513.8	226.7	556.5	1697.0	1731.0	906.3	40.3	1140.2

CHAPTER V

CONCLUDING REMARKS AND RECOMMENDATIONS

The results of this study are based on the mixing height methodology comparison of Holzworth, Coulter, Goldman, Heffter and Stull. From the comparison of the methodologies, significant differences were found in computed mixing height values for both 00:00 and 12:00 GMT cases.

Firstly, the main difference for 00:00 GMT is the $T+5^{\circ}\text{C}$ concept which causes inconsistent results by the methodology of Holzworth. The methodology for the 00:00 GMT used in Holzworth method consists of an arbitrary chosen additional 5°C that resulted in values of mixing heights are excessively high (i.e., Figure IV-11 and IV-12). This situation is also seen in both Goldman and Heffter methods (detailed results for Goldman and Heffter methods can seen in Appendix C-1 and C-2).

Second concern in methodology is the static stability. It consists of both the 00:00 GMT and the 12:00 GMT. To determine the static stability, the Stull method tracks all possible parcel movements (negatively and positively buoyant), whereas the Holzworth technique only examines the ascent of the surface parcel. This can generate misleading mixing height values if only the surface parcel is used for estimation because significant instability can be elevated (i.e., Figure IV-6 and IV-10).

A third issue is based on the temperature profile that is important in the decision mechanism. The Stull method incorporates moisture gradient by using virtual potential temperature, whereas the Holzworth technique just uses potential temperature. In many instances, the use of potential temperature is probably sufficient, however moisture gradient can affect the temperature distribution in small intervals in lower troposphere. (the existence of sharp moisture gradients at the surface).

During instances of strong vertical motions or horizontal advection, the atmospheric structure is constantly changing, and height values computed from the Stull method can be inaccurate. Misrepresentation of mixing height occurs because profiles used are only snapshots in time, and levels to which parcels are tracked may be unrealistic, especially when height estimation is performed using spatially and temporally coarse radiosonde data (i.e., Appendix B-1 4.1.1995.GMT12 and 18.1.1995.GMT12). Therefore, it is suggested that the Stull method be used over the Holzworth technique for air quality dispersion modeling. The Stull technique is clearly more comprehensive in its overall assessment of instability. It always accounts for moisture and does not require the use of arbitrary concepts (e.g., $T+5^{\circ}\text{C}$).

In morning cases ground based inversion most effectively computed by Stull method and in afternoon cases computation of capping inversion gave similar results by Goldman, Heffter and Stull methods.

In afternoon cases the Holzworth method mostly underestimates the mixing heights because of the temperature fluctuation and local static stability. The differences between the local static stability and the nonlocal static stability that used in Stull defined obviously in chapter II and III. Under convective conditions there seems large mixing height fluctuations in the afternoons.

If we approve the Heffter method for the computed results; The highest average monthly values for mornings in 1995 occur in November; July; August and January, respectively. However, the highest average monthly values in 1996 occur in March; December; October and November, respectively.

If we approve the Heffter method for the computed results; the highest average monthly values for afternoons in 1995 occur in September; August; October and July, respectively. The highest average monthly values for afternoons in 1996 occur in June; April; October and March, respectively. Finally, for the maximum average monthly afternoon mixing heights occur in summer months. For detailed monthly and seasonal average values 1995 through 1996 see table IV-5 and IV-6 and appendix C-1 and C-2.

Computation of mixing height in the mornings change between all cases and stable case both in 1995 and 1996. Results for all cases are approximately 250 meters greater than stable case in 1995 and 200 meters greater in 1996.

Computation of mixing height in the afternoons does not change for all cases and unstable cases in 1995. Results for all cases are approximately 50 meters smaller than unstable case in 1995 and 100 meters smaller in 1996.

The computation of morning mixing height most effectively computed by Stull method with the stable case.

The computation of afternoon mixing height effectively computed by Stull, Heffter and Goldman methods with the unstable case, respectively.

In conclusion, Stull method provides better mixing height values both in 00:00 GMT and 12:00 GMT. However, computation of Heffter and Goldman methods results' both in monthly and seasonally are consistent in afternoon cases.

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APPENDIX A

DATE(GMT) TIME(GMT) ASCENT NO. SYS T. NAME STATION SONDE
 94.12.31 23:56 0101A IST 17062 0N007

TIME second	PRESSURE hpa	HEIGHT m-as	TEMP °C	HUMIDITY percent	DIRECTION degrees	SPEED knots
1	999.89	1000	5.3	12.2	94.38	200
2	999.29	999	10.7	12.17	94.34	201
4	998.07	998	21.3	12.12	94.26	201
5	997.46	997	26.7	12.09	94.22	201
7	996.25	996	37.4	12.09	94.09	202
9	995.04	995	48	12.09	93.97	202
10	994.43	994	53.4	12.09	93.9	203
12	993.22	993	64	12.09	93.78	203
14	992.01	992	74.7	12.09	93.65	204
15	991.41	991	80.1	12.09	93.59	204
17	990.16	990	90.7	12.15	93.46	205
19	988.87	989	101.4	12.26	93.34	205
20	988.22	988	106.7	12.31	93.27	205
21	987.44	987	112.1	12.31	93.21	206
23	985.9	986	122.7	12.32	93.08	206
24	985.12	985	128.1	12.32	93.02	206
25	984.35	984	133.4	12.32	92.96	207
27	982.8	983	144.1	12.32	92.83	207
28	982.03	982	149.4	12.3	92.77	207
29	981.26	981	154.8	12.28	92.71	208
30	980.49	980	160.1	12.26	92.64	208
32	978.95	979	170.8	12.26	92.52	209
33	978.18	978	176.1	12.27	92.45	209
35	977.08	977	186.8	12.14	92.27	209
37	975.97	976	197.5	12.09	92.1	210
38	975.42	975	202.8	12.16	92.04	210
40	974.31	974	213.5	12.14	91.89	211

42	973.21	973	224.1	12.08	91.87	211	12.3
44	972.1	972	234.8	12.07	91.91	212	12.4
46	971	971	245.5	12.05	91.66	212	12.5
47	970.45	970	250.8	12.05	91.59	213	12.6
49	969.35	969	261.5	12.04	91.46	213	12.7
51	968.25	968	272.2	12.03	91.4	214	12.8
53	967.11	967	282.8	12.01	91.32	214	12.9
55	965.91	966	293.5	11.99	91.41	215	13
56	965.32	965	298.9	11.96	91.37	215	13.1
58	964.13	964	309.5	11.92	91.16	215	13.2
60	962.94	963	320.2	11.89	91.02	216	13.3
61	962.34	962	325.1	11.86	91.05	216	13.4
63	961.16	961	335	11.82	91.08	216	13.5
65	959.97	960	344.9	11.77	91.17	217	13.7
66	959.38	959	349.8	11.75	91.25	217	13.7
68	958.2	958	359.7	11.72	91.57	217	13.9
70	957.05	957	369.5	11.68	91.79	217	14
71	956.49	956	374.5	11.66	91.88	218	14.1
73	955.43	955	384.3	11.61	92.3	218	14.3
75	954.38	954	394.2	11.54	92.74	218	14.4
77	953.33	953	404.1	11.46	92.82	219	14.5
79	952.28	952	413.9	11.38	92.9	219	14.7
81	951.22	951	423.8	11.32	93.07	219	14.8
83	950.18	950	433.7	11.24	93.24	219	15
85	949.13	949	443.5	11.15	93.47	220	15.1
87	948.08	948	453.4	11.07	93.74	220	15.3
89	947.04	947	463.3	10.94	94.36	220	15.4
91	945.96	946	473.1	10.89	94.51	221	15.6
92	945.41	945	478.1	10.84	94.49	221	15.6
94	944.29	944	487.9	10.76	94.51	221	15.8
96	943.18	943	497.8	10.7	94.68	221	15.9
98	942.08	942	507.7	10.64	94.93	222	16.1
100	940.97	941	517.5	10.52	95.2	222	16.2
101	940.42	940	522.5	10.48	95.34	222	16.3
103	939.32	939	532.3	10.42	95.42	222	16.5
105	938.22	938	542.2	10.38	95.31	223	16.6
107	937.12	937	552.1	10.32	95.44	223	16.7
109	936	936	561.9	10.22	95.62	223	16.9
110	935.43	935	566.9	10.15	95.61	223	17

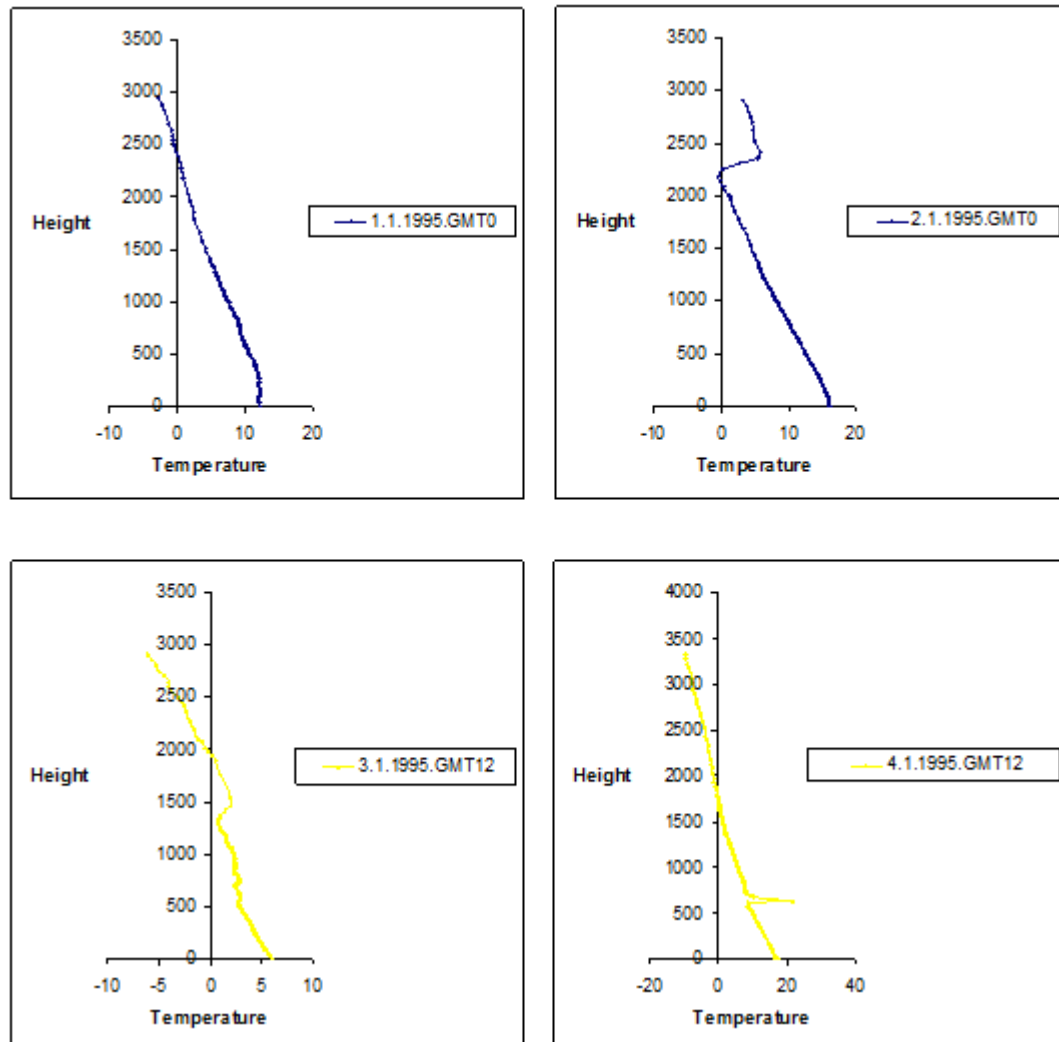
112	934.27	934	576.7	10.03	95.51	224	17.1
114	933.1	933	586.6	9.97	95.5	224	17.3
116	931.93	932	596.5	9.91	95.49	224	17.4
117	931.35	931	601.4	9.88	95.52	225	17.5
119	930.19	930	611.3	9.82	95.62	225	17.6
121	929.03	929	621.1	9.73	95.9	225	17.8
122	928.45	928	626.1	9.69	95.88	225	17.9
124	927.29	927	635.9	9.66	95.89	225	18.1
126	926.13	926	645.8	9.64	95.94	226	18.3
128	924.97	925	655.7	9.61	95.86	226	18.4
129	924.39	924	660.6	9.57	95.85	226	18.5
131	923.23	923	670.5	9.53	95.79	226	18.7
133	922.08	922	680.3	9.46	95.6	226	18.9
135	920.92	921	690.2	9.41	95.27	227	19.1
136	920.34	920	695.1	9.41	95.21	227	19.2
138	919.2	919	705	9.4	95.09	227	19.4
140	918.04	918	714.9	9.39	95.1	227	19.5
141	917.47	917	719.8	9.38	95.17	227	19.6
143	916.32	916	729.7	9.36	95.1	227	19.8
145	915.2	915	739.5	9.3	95.02	228	20
147	914.15	914	749.4	9.26	95.14	228	20.2
149	913.13	913	759.3	9.23	95.18	228	20.4
151	912.11	912	769.1	9.18	95.13	228	20.5
153	911.09	911	779	9.12	95.13	228	20.7
155	910.08	910	788.9	9.08	95.08	229	20.9
157	909.07	909	798.7	9.05	95.08	229	21.1
159	908.06	908	808.6	9.01	95.2	229	21.3
161	907.04	907	818.5	8.96	95.44	229	21.5
163	906.03	906	828.3	8.87	95.59	229	21.6
165	905.02	905	838.2	8.78	95.89	230	21.8
167	904.04	904	848.1	8.68	96.13	230	22
169	903.06	903	857.9	8.63	96.29	230	22.2
171	902.08	902	867.8	8.58	96.49	230	22.4
173	901.1	901	877.7	8.51	96.65	230	22.6
175	900.13	900	887.5	8.42	96.85	231	22.7
177	899.15	899	897.4	8.31	97.15	231	22.9
179	898.17	898	907.3	8.26	97.35	231	23.1
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183	896.22	896	927	8.12	97.79	231	23.6

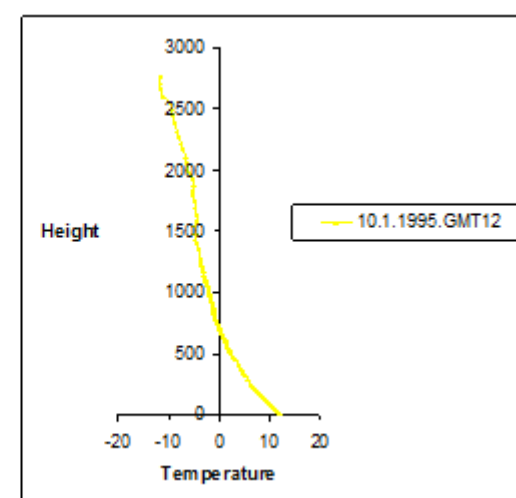
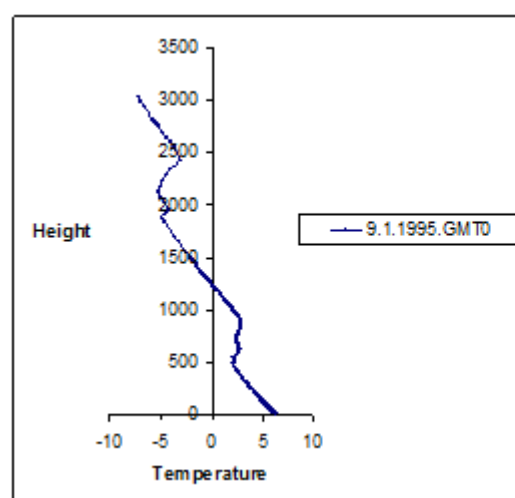
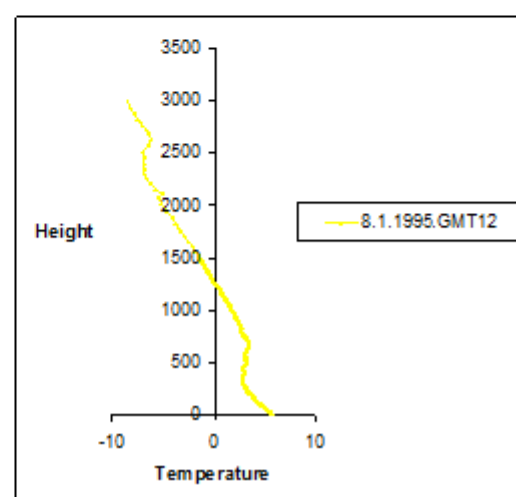
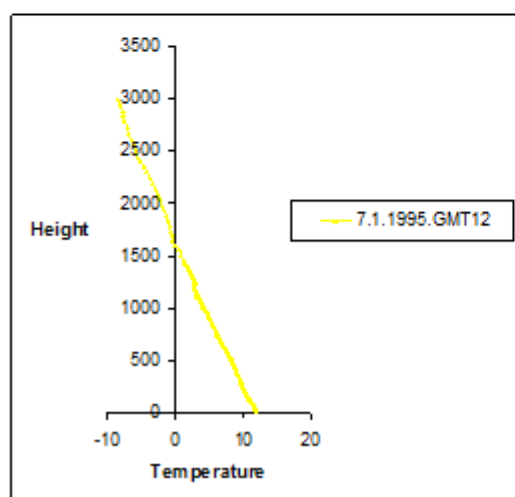
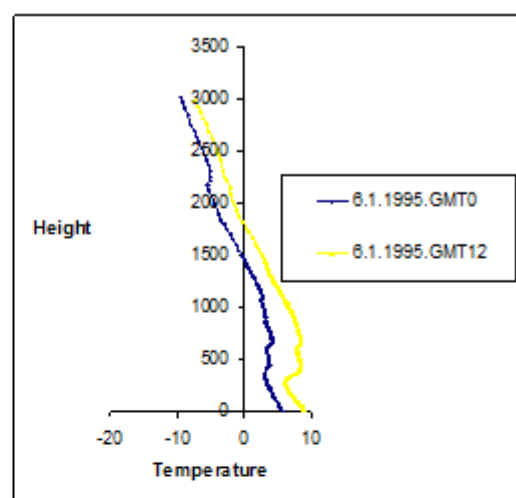
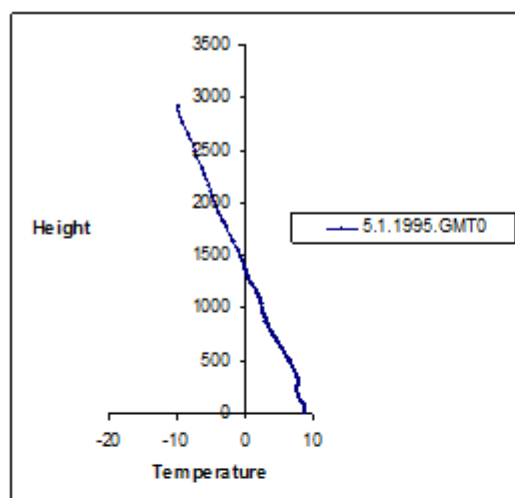
185	895.25	895	936.9	8.04	97.89	231	23.8
187	894.19	894	946.7	7.97	98.13	231	24
189	893.06	893	956.6	7.88	98.43	231	24.3
190	892.49	892	961.5	7.85	98.54	232	24.4
192	891.35	891	971.4	7.78	98.76	232	24.6
194	890.22	890	981.3	7.71	98.9	232	24.8
196	889.09	889	991.2	7.62	99.13	232	25.1
198	887.96	888	1001	7.53	99.29	232	25.3
199	887.39	887	1006	7.47	99.46	232	25.4
201	886.27	886	1015.8	7.38	99.57	232	25.7
203	885.14	885	1025.7	7.29	99.7	232	25.9
205	884.07	884	1035.6	7.22	99.83	232	26.1
207	883.08	883	1045.4	7.15	99.93	232	26.4
209	882.08	882	1055.3	7.08	100	232	26.6
211	881.08	881	1065.2	7	100	233	26.8
213	880.09	880	1075.1	6.93	100	233	27.1
215	879.09	879	1084.9	6.88	100	233	27.3
217	878.1	878	1094.8	6.83	100	233	27.5
219	877.1	877	1104.7	6.78	100	233	27.8
221	876.11	876	1114.5	6.73	100	233	28
223	875.12	875	1124.4	6.67	100	233	28.2
225	874.14	874	1134.3	6.6	100	233	28.5
227	873.17	873	1144.1	6.54	100	233	28.7
229	872.2	872	1154	6.47	100	233	28.9
231	871.24	871	1163.9	6.43	100	234	29.2
233	870.27	870	1173.8	6.34	100	234	29.4
235	869.3	869	1183.6	6.28	100	234	29.6
237	868.34	868	1193.5	6.24	100	234	29.9
239	867.38	867	1203.4	6.18	100	234	30.1
241	866.42	866	1213.2	6.14	100	234	30.4
243	865.46	865	1223.1	6.04	100	234	30.7
245	864.48	864	1233	5.99	100	234	31
247	863.48	863	1242.8	5.92	100	234	31.4
249	862.49	862	1252.7	5.87	100	234	31.7
251	861.49	861	1262.6	5.81	100	234	32
254	860.01	860	1277.4	5.69	100	234	32.5
256	859.01	859	1287.2	5.64	100	235	32.8
258	858.03	858	1297.1	5.59	100	235	33.2
260	857.04	857	1307	5.53	100	235	33.5

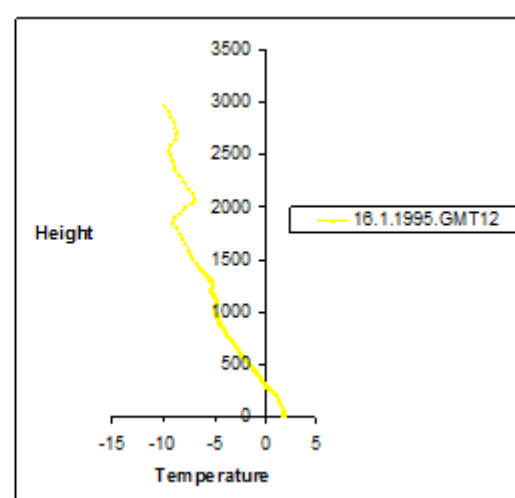
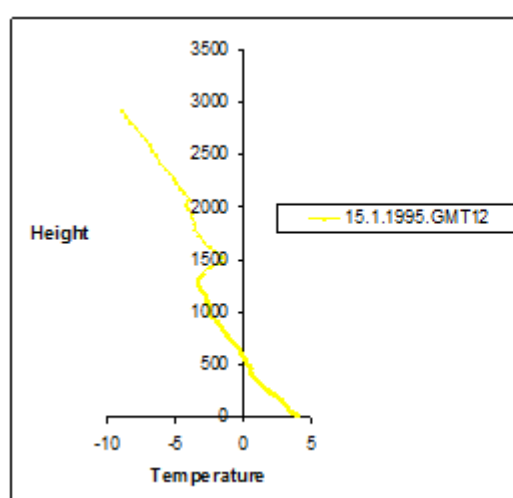
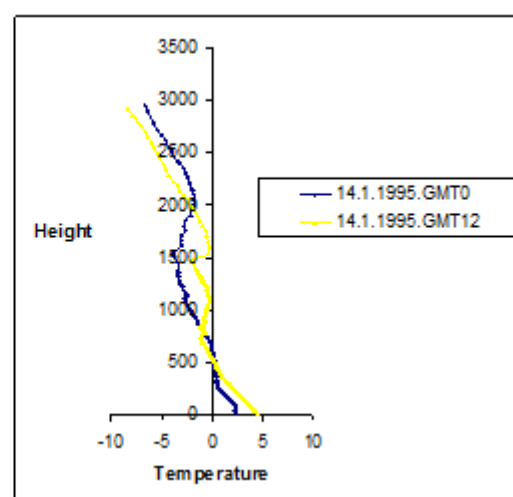
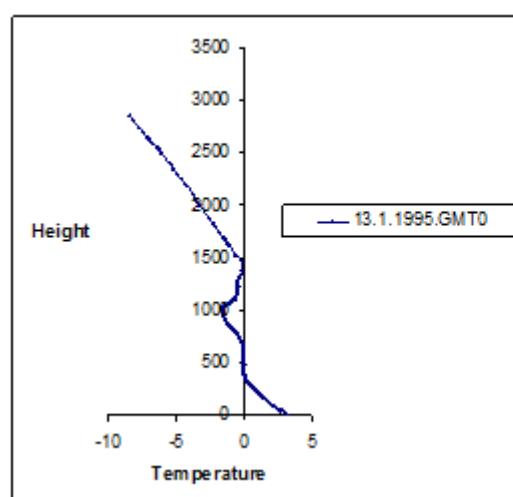
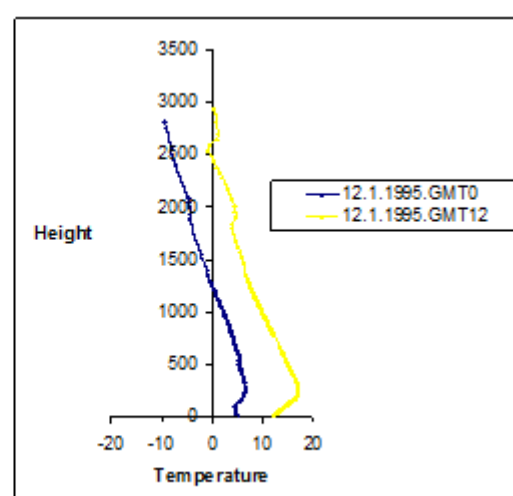
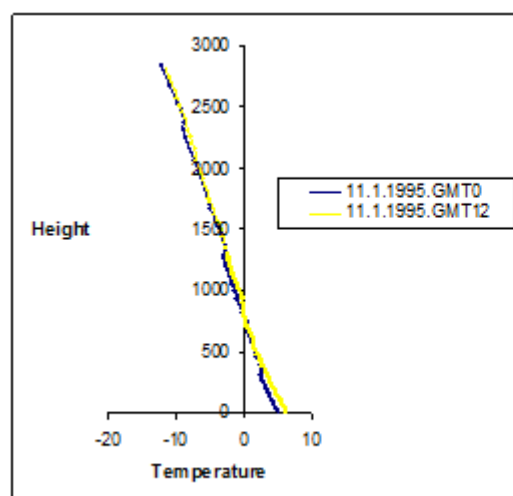
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264	855.06	855	1326.7	5.41	100	235	34.2
266	853.99	854	1336.6	5.31	100	235	34.5
267	853.45	853	1341.5	5.27	100	235	34.7
269	852.38	852	1351.4	5.22	100	235	35
271	851.31	851	1361.2	5.15	100	235	35.3
273	850.24	850	1371.1	5.06	100	235	35.6
282	845.44	845	1415.5	4.74	100	235	37.1
292	840.37	840	1464.8	4.45	99.99	236	38.8
302	835.37	835	1514.2	4.13	99.96	236	40.4
313	830.05	830	1568.4	3.82	99.9	236	42.2
323	825.23	825	1617.8	3.53	99.85	236	43.9
332	820.47	820	1662.2	3.28	99.79	237	45.3
342	815.14	815	1711.5	2.98	99.74	237	47
351	809.94	810	1755.9	2.71	99.72	237	48.4
359	805.39	805	1795.4	2.45	99.69	237	49.7
369	800.03	800	1854.2	2.43	99.69	237	51.5
378	795.16	795	1908.1	2.22	99.74	237	53.1
387	790.1	790	1961.9	1.95	99.79	237	54.7
396	784.98	785	2015.8	1.66	99.79	238	56.3
404	780.3	780	2063.7	1.45	99.77	238	57.7
413	775.38	775	2117.6	1.19	99.74	238	59.3
423	770.34	770	2177.5	0.88	99.78	238	61
432	765.34	765	2231.5	0.74	99.88	238	62.6
440	760.37	760	2279.6	0.61	99.92	238	64
449	755.07	755	2333.6	0.44	99.92	238	65.6
458	750.01	750	2387.6	0.17	99.91	238	67.2
466	745.38	745	2435.7	-0.13	99.92	238	68.6
475	740.08	740	2489.7	-0.39	99.9	238	70.2
483	735.21	735	2537.7	-0.54	99.88	238	71.6
491	730.3	730	2585.9	-0.67	99.87	238	73
500	725.11	725	2640	-0.73	99.86	238	74.6
509	720.06	720	2694.2	-1.18	99.63	238	76.2
519	715.31	715	2754.3	-1.56	98.45	238	78
530	710.08	710	2820.5	-1.97	97.15	238	79.9
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551	700.1	700	2946.4	-2.76	94.67	238	83.6

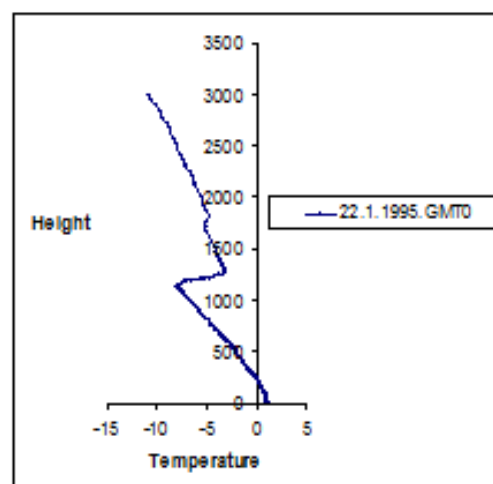
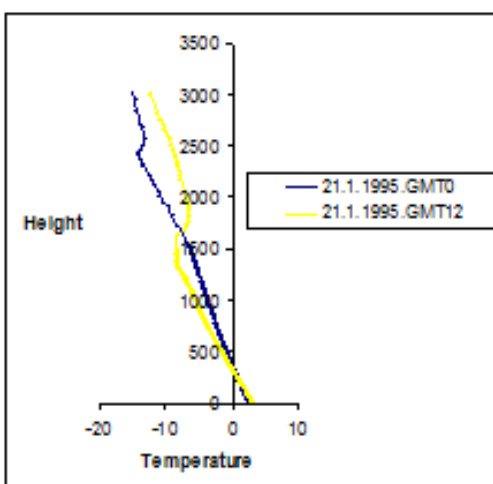
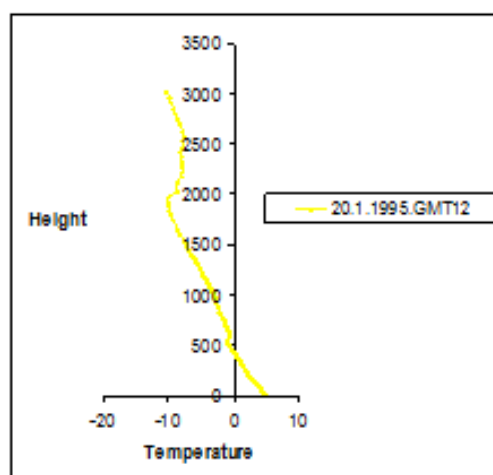
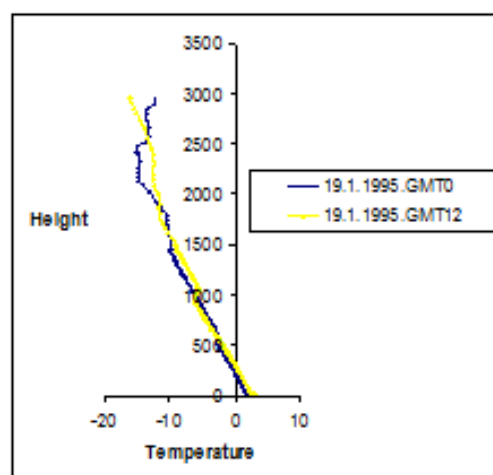
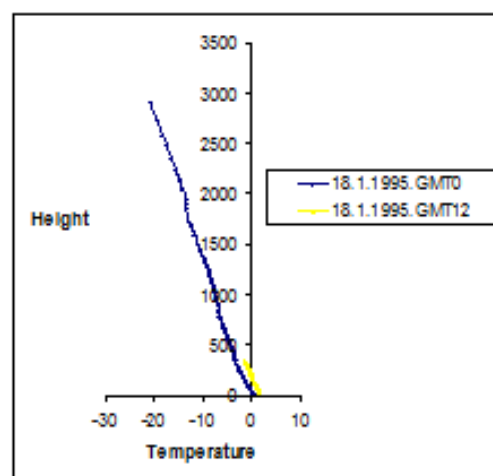
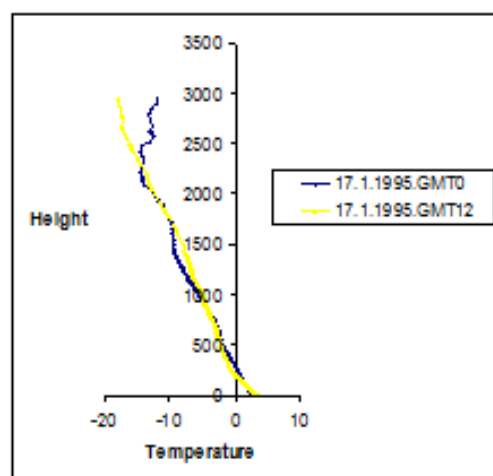
APPENDIX B - 1

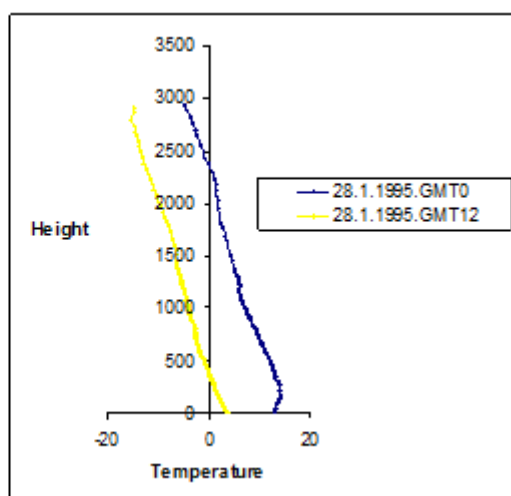
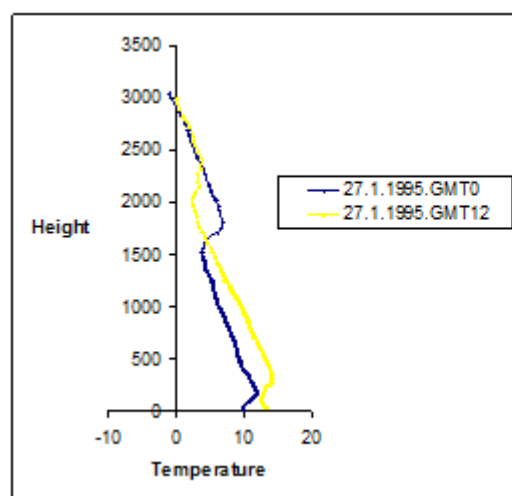
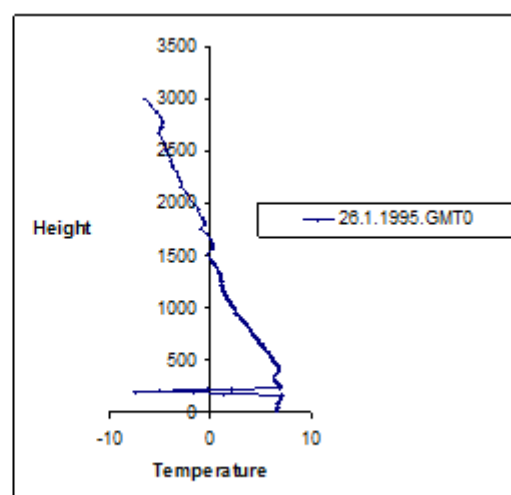
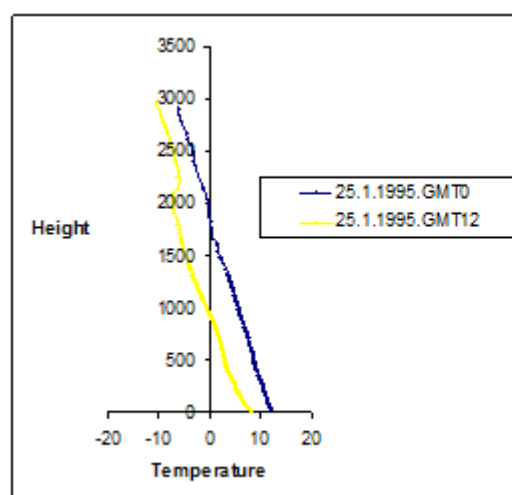
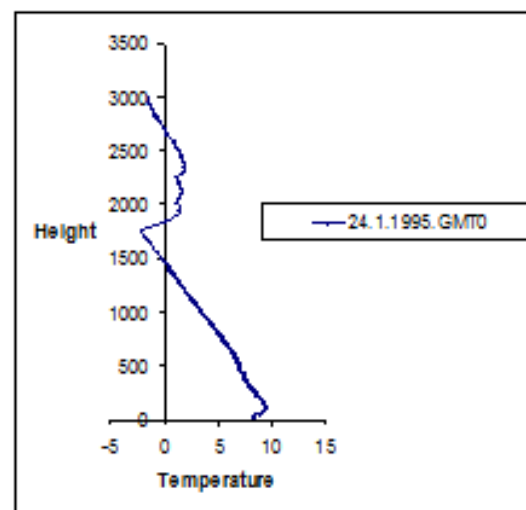
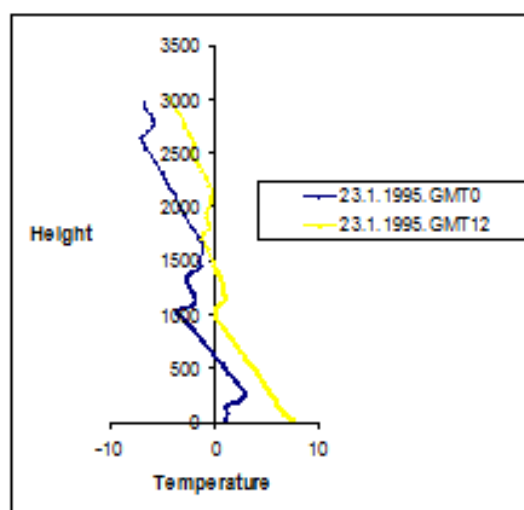
Temperature Distribution Graphs of January, 1995. Vertical profiles of temperatures of twice daily radiosonde measurements are depicted. Days and times are given in the legend entries. The vertical axis depicts height as meters and the horizontal axis depicts the temperature as degrees celcius.

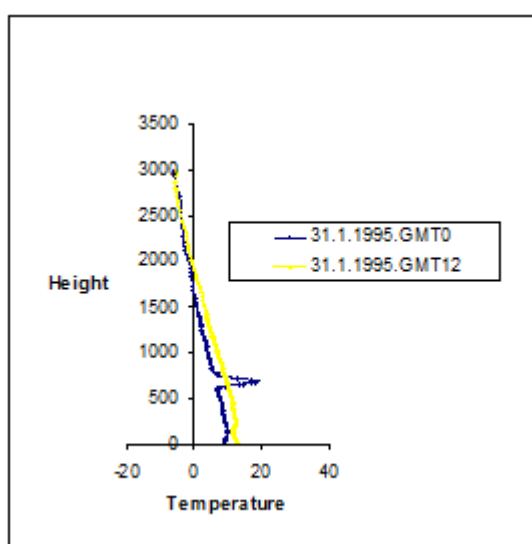
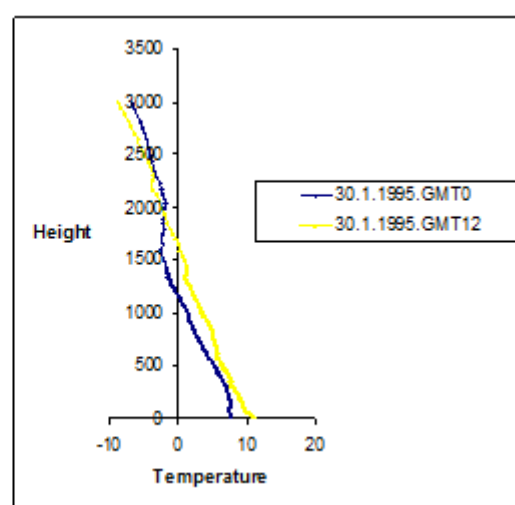
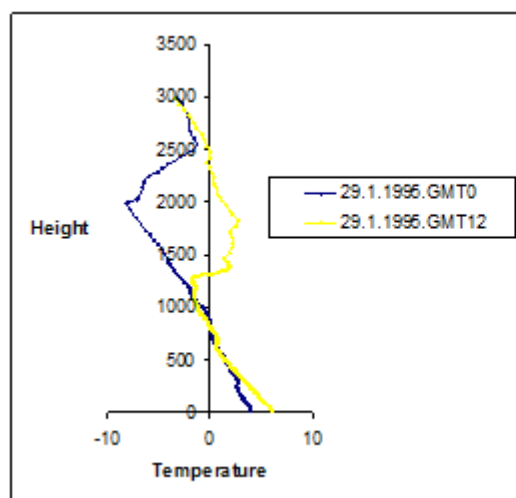






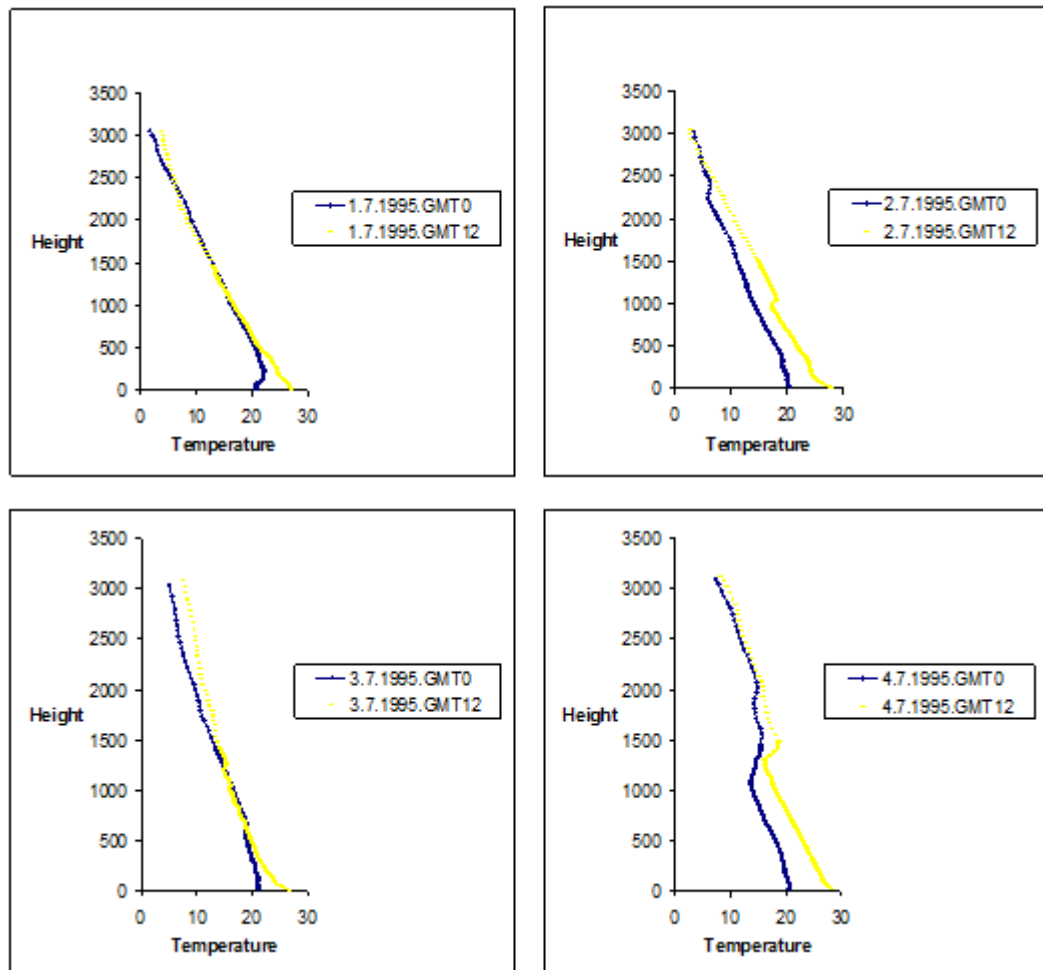


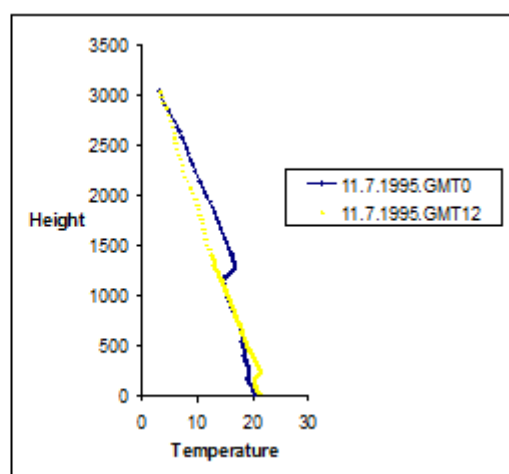
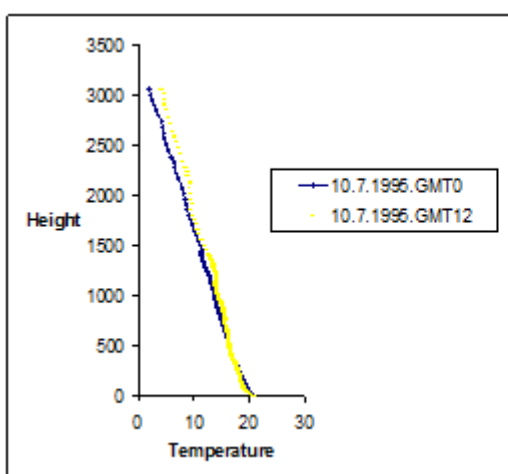
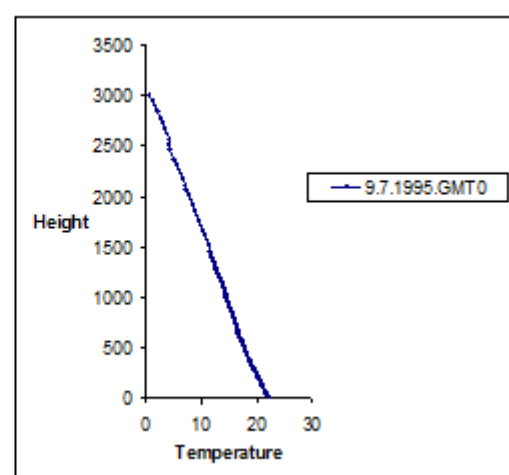
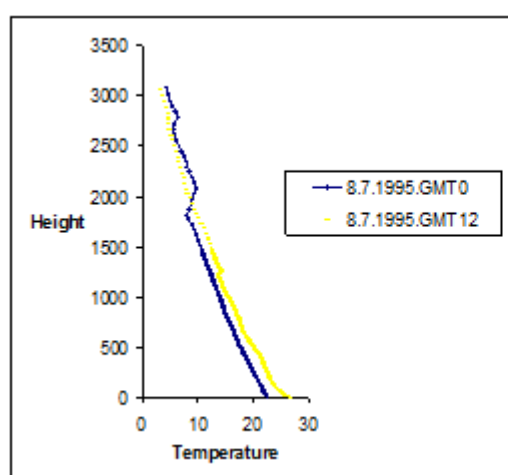
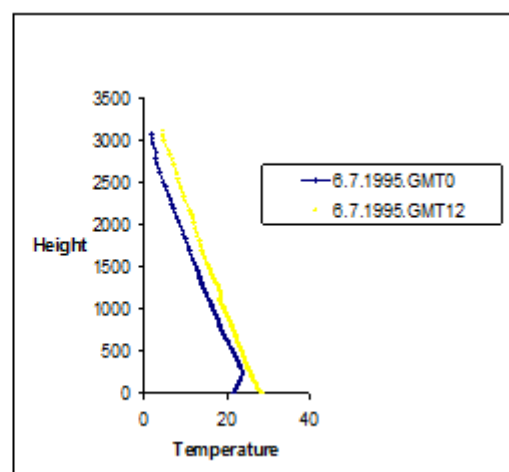
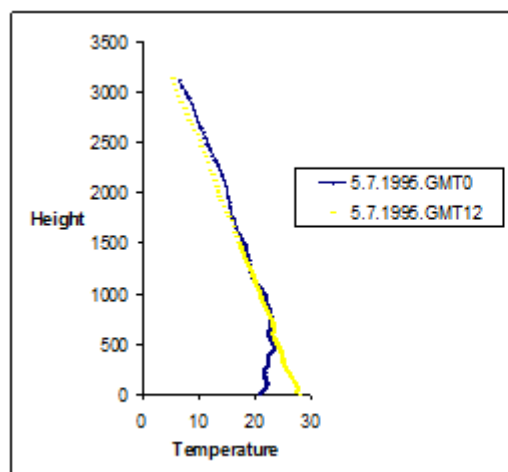


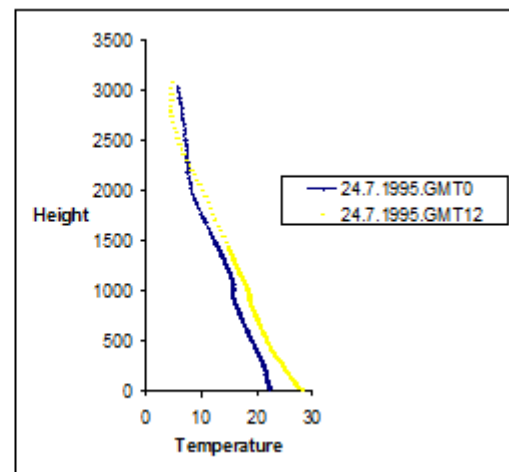
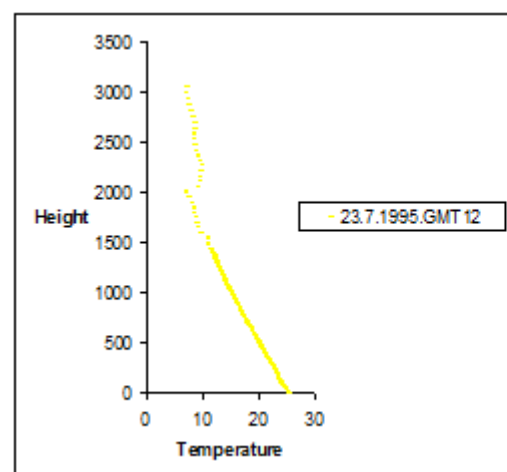
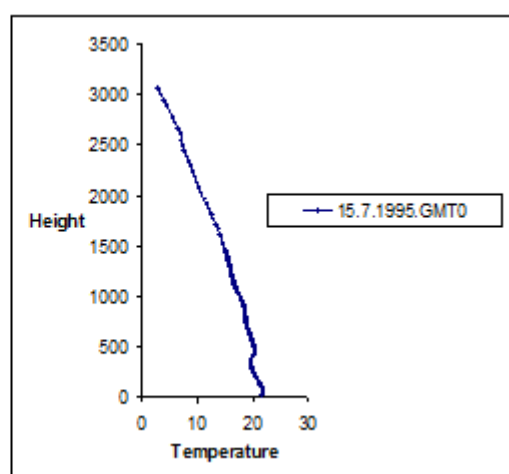
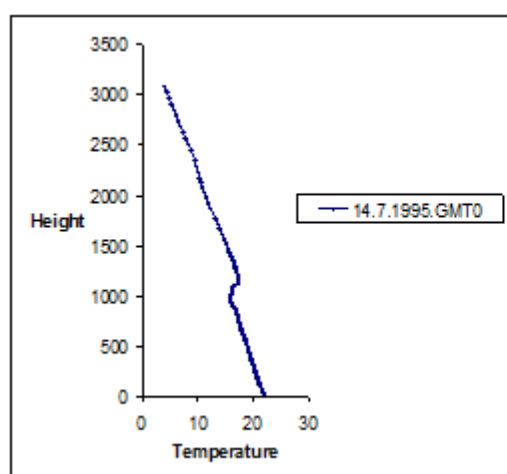
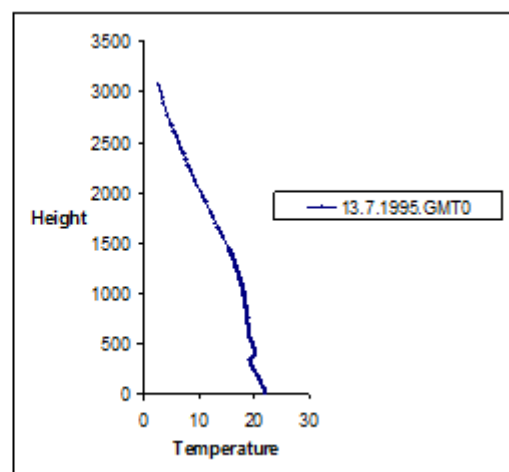
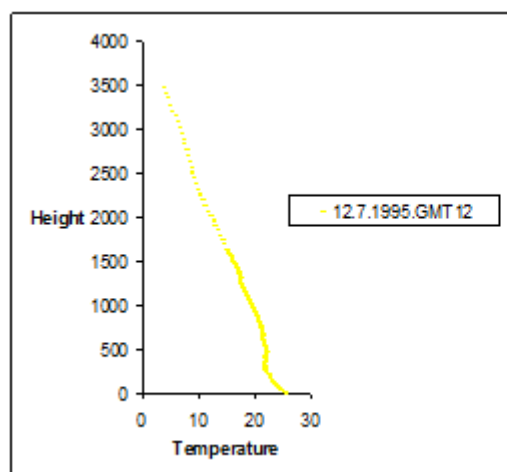


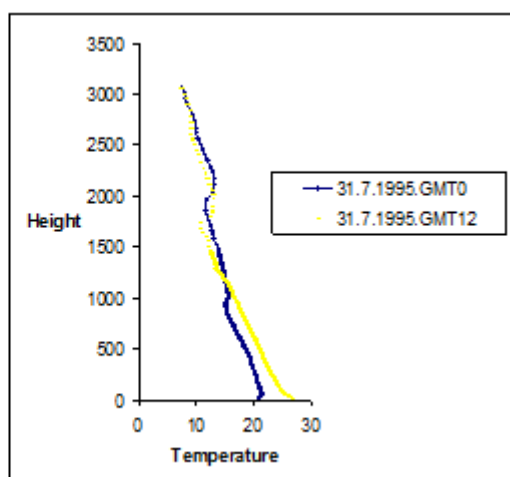
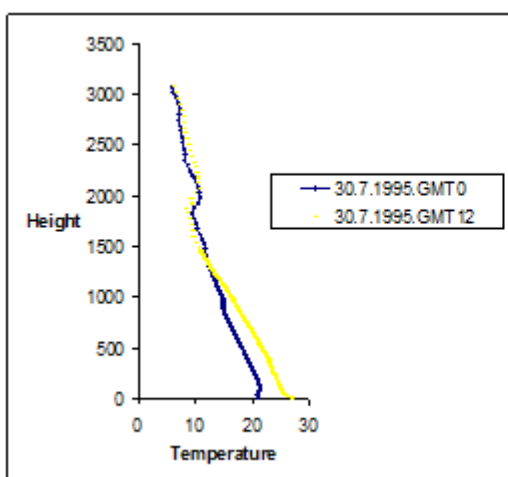
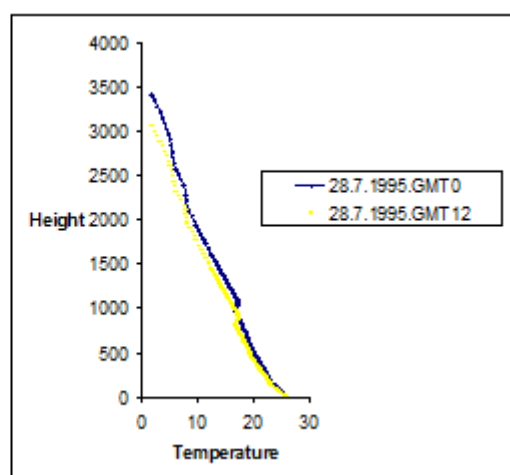
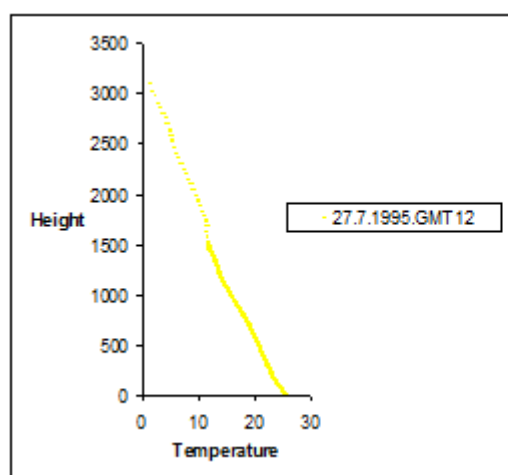
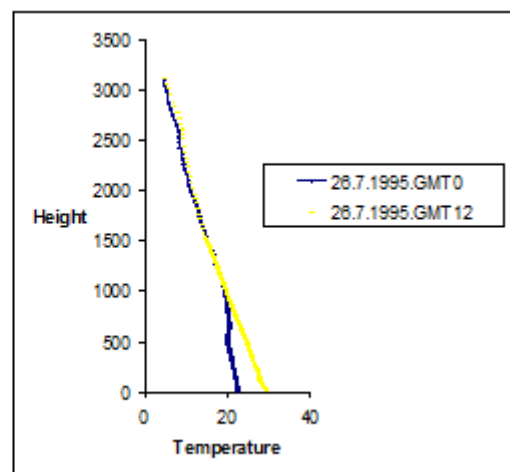
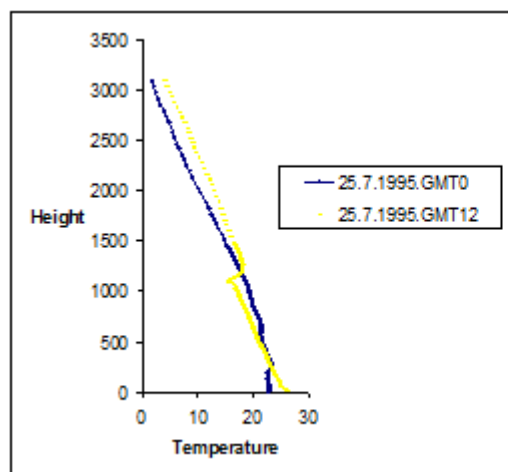
APPENDIX B - 2

Temperature Distribution Graphs of July, 1995. Vertical profiles of temperatures of twice daily radiosonde measurements are depicted. Days and times are given in the legend entries. The vertical axis depicts height as meters and the horizontal axis depicts the temperature as degrees celcius.









APPENDIX C – 1

Average monthly and seasonal mixing heights obtained from the computing program from 1995 through 1996 in the morning is depicted in the table.

Average Mixing Heights (In The Morning)						
Seasons		Winter		Spring		
Months		January	February	March	April	May
1995 (Monthly)	Holzworth	1233.4	959.7	1147.7	963.2	759.4
	Coulter	32.6	34.2	28.6	26.7	28.7
	Goldman	1475.6	1258.3	828.4	639.4	821.8
	Heffter	1131.4	728.7	782.5	671.4	756.9
	Stull	933.1	738.0	567.4	320.6	340.5
1996 (Monthly)	Holzworth		806.1	1238.6	867.6	544.4
	Coulter		31.4	26.0	28.9	34.4
	Goldman		12.0	1782.0	407.3	352.9
	Heffter		138.6	1548.2	723.2	303.3
	Stull		367.6	1122.3	446.9	255.2
1995 (Seasonal)	Holzworth	1096.6	956.8			
	Coulter	33.4	28.0			
	Goldman	1366.9	763.2			
	Heffter	930.1	736.9			
	Stull	835.6	409.5			
1996 (Seasonal)	Holzworth	1042.7	883.5			
	Coulter	36.6	29.8			
	Goldman	708.3	847.4			
	Heffter	622.2	858.3			
	Stull	665.3	608.1			

Average Mixing Heights (In The Morning)						
Summer			Autumn			
June	July	August	September	October	November	December
616.2	1234.0	1100.7	1074.7	1098.7	1456.1	1279.3
31.4	29.3	31.6	31.7	27.8	33.7	41.9
181.6	1202.0	1408.2	1331.7	1660.7	1457.0	1404.5
490.2	1283.2	1219.1	999.0	895.1	1669.1	1105.8
271.0	711.3	1007.5	354.3	678.9	565.6	963.0
682.3	755.6	1039.1	1088.5	1307.2	987.0	1326.0
26.3	28.4	34.6	26.7	33.2	27.4	27.0
829.8	1042.8	950.4	2891.0	1530.5	1455.3	-
508.2	806.5	929.3	615.3	1467.8	1001.3	1517.4
509.0	789.0	686.7	463.4	835.0	545.4	737.8
983.6			1209.8			
30.8			31.1			
930.6			1483.1			
997.5			1187.8			
663.3			532.9			
825.7			1127.6			1326.0
29.8			29.1			27.0
941.0			1958.9			-
748.0			1028.1			1517.4
661.5			614.6			737.8

APPENDIX C – 2

Average monthly and seasonal mixing heights obtained from the computing program from 1995 through 1996 in the afternoon is depicted in the table.

Average Mixing Heights (In The Afternoon)						
Seasons		Winter		Spring		
Months		January	February	March	April	May
1995 (Monthly)	Holzworth	325.7	345.9	365.1	256.6	711.5
	Coulter	85.9	36.8	54.8	57.8	80.5
	Goldman	1288.8	1096.7	941.0	510.5	749.3
	Heffter	1426.9	1171.9	1606.5	719.6	1273.1
	Stull	982.3	782.1	838.0	652.4	868.5
1996 (Monthly)	Holzworth		120.1	438.2	367.0	589.4
	Coulter		35.0	43.4	50.3	64.6
	Goldman		-	1439.8	1290.5	1459.0
	Heffter		1308.0	1715.8	1868.3	1195.3
	Stull		564.2	1240.5	936.5	586.8
1995 (Seasonal)	Holzworth	335.8	444.4			
	Coulter	61.3	64.4			
	Goldman	1192.7	733.6			
	Heffter	1299.4	1199.7			
	Stull	882.2	786.3			
1996 (Seasonal)	Holzworth	174.3	464.9			
	Coulter	33.7	52.8			
	Goldman	1865.8	1396.4			
	Heffter	1369.1	1593.1			
	Stull	919.8	921.3			

Average Mixing Heights (In The Afternoon)						
Summer			Autumn			
June	July	August	September	October	November	December
689.7	919.5	685.6	614.3	543.6	450.2	228.5
111.8	72.3	101.2	60.7	54.2	48.1	32.4
1891.5	1639.0	1958.6	2059.0	2026.1	1336.0	1865.8
1514.4	1763.6	1870.0	2158.4	1848.9	1293.0	1430.3
641.2	988.4	1179.5	982.9	1170.2	863.6	1275.4
580.8				358.9	270.2	157.9
63.7				47.6	49.9	34.8
1920.0				2359.5	1377.0	1930.0
2370.7				1846.5	1115.4	1572.3
618.0				923.9	886.6	734.0
764.9			536.1			
95.1			54.3			
1829.7			1807.0			
1716.0			1766.7			
936.3			1005.6			
580.8			314.5			157.9
63.7			48.7			34.8
1920.0			1868.3			1930.0
2370.7			1481.0			1572.3
618.0			905.3			734.0

CURRICULUM VITAE

Soner ATALAY was born in Istanbul. In June 2006, he graduated from ITU with a B.S. degree in Environmental Engineering . Upon graduation from University of Marmara with Masters degree in 2008, he plans on continuing his education with a Doctorate degree in Environmental Engineering in USA.