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ESTIMATION OF MIXING HEIGHT USING SURFACE METEOROLOGICAL DATA IN THAILAND

Mr. Anurat Saringkarnphasit

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By	Mr. Anurat Saringkarnphasit
Field of study	Earth Sciences
Thesis Advisor	Assistant Professor Surat Bualert, Ph.D.
Thesis Co-advisor	Boossarasiri Thana, M. Sc.

Accepted by the Faculty of science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

.... Dean of Faculty of Science

(Professor Piamsak Menasveta, Ph.D.)

THESIS COMMITTEE

.... Chairman

(Assistant Professor Chakkaphan Sutthirat, Ph.D.)

.... Thesis Advisor

(Assistant Professor Surat Bualert, Ph.D.)

.... Thesis Co-advisor

(Boossarasiri Thana, M.Sc.)

.... Member

(Assistant Professor Somchai Nakapadungrat, Ph.D.)

.... Member

(Kasemsan Manomaiphiboon, Ph.D.)

อนุรัตน์ ศฤงคารภาษิต : การประมาณระดับความสูงผสม โดยใช้ข้อมูลอุตุนิยมวิทยาพื้นผิวในประเทศไทย. (ESTIMATION OF MIXING HEIGHT USING SURFACE METEOROLOGICAL DATA IN THAILAND) อ. ที่ปรึกษา: ผู้ช่วยศาสตราจารย์ ดร. สุรัตน์ บัวเลิศ, อ.ที่ปรึกษาร่วม: อาจารย์บุศราศิริ ธนะ จำนวนหน้า 157 หน้า.

ระดับความสูงผสมเป็นตัวแปรที่สำคัญของแบบจำลองการแพร่กระจายมลพิษทางอากาศ โดยทั่วไปมีวิธีการหาระดับความสูงผสมได้ 2 วิธีคือ การวิเคราะห์ข้อมูลอากาศชั้นบนที่ได้จากการตรวจวัด หรือการประมาณค่าจากข้อมูลอุตุนิยมวิทยาพื้นผิว สำหรับประเทศไทยมีการวิเคราะห์หาระดับความสูงผสมจากข้อมูลตรวจอากาศชั้นบน 5 สถานีคือ กรุงเทพมหานคร เชียงใหม่ อุบลราชธานี สงขลา และภูเก็ต ซึ่งไม่ครอบคลุมพื้นที่ทั่วประเทศ จึงมีความจำเป็นที่จะต้องประมาณค่าจากข้อมูลอุตุนิยมวิทยาพื้นผิวในพื้นที่ที่ไม่มีการตรวจวัดอากาศชั้นบน แบบจำลองที่ใช้ในการประมาณค่าระดับความสูงผสม ที่พัฒนาในประเทศเขตอบอุ่น และตัวแปรที่นำเข้าสู่แบบจำลองจะทำการตรวจวัดในเขตอบอุ่น ซึ่งมีลักษณะทางกายภาพแตกต่างจากประเทศไทยที่ตั้งอยู่ในเขตร้อนชื้น

วัตถุประสงค์ครั้งนี้ จะทำการพัฒนา และประยุกต์ตัวแปรที่ได้จากการตรวจวัดในประเทศไทย เพื่อใช้ในแบบจำลองประมาณค่าระดับความสูงผสมจากข้อมูลอุตุนิยมวิทยาพื้นผิว ข้อมูลนำเข้าแบบจำลองได้แก่ อุณหภูมิอากาศ ความชื้นสัมพันธ์ ความเร็วลม และ จำนวนเมฆที่ปกคลุมท้องฟ้า ผลลัพธ์ที่ได้จะอยู่ในรูปความสูงผสมรายชั่วโมง การทดสอบแบบจำลองการประมาณค่าความสูงผสมจากข้อมูลอุตุนิยมวิทยาพื้นผิว เปรียบเทียบกับระดับความสูงผสมที่ได้จากการตรวจอากาศชั้นบน จะทำการทดสอบโดยใช้ชุดข้อมูลของสถานีการตรวจวัดรังสีบรรยากาศเพื่อการวิจัย ที่จังหวัดสุโขทัย และชุดข้อมูลของกรมอุตุนิยมวิทยา ที่สถานีกรุงเทพฯ เชียงใหม่ อุบลราชธานี และภูเก็ต ระหว่างวันที่ 20 เมษายน – 6 มิถุนายน 2546

การทดสอบความถูกต้องของการประมาณค่าระดับความสูงผสมของสถานี สุโขทัย กรุงเทพฯ เชียงใหม่ อุบลราชธานี และ ภูเก็ต จะใช้ Factor of Two ทำการทดสอบความถูกต้อง ซึ่งได้เปอร์เซ็นความถูกต้องประมาณ 60 – 80 % สามารถสรุปได้ว่าแบบจำลอง ที่ประยุกต์ตัวแปรที่ได้จากการตรวจวัดในประเทศไทย สามารถนำไปใช้ประมาณค่าระดับความสูงผสมจากข้อมูลตรวจอากาศผิวพื้นในพื้นที่ที่ไม่มีการตรวจอากาศชั้นบนได้

ภาควิชา..............ธรณีวิทยา............ลายมือชื่อนิสิต..

สาขาวิชา...........โลกศาสตร์...........ลายมือชื่ออาจารย์ที่ปรึกษา..

ปีการศึกษา.............2549......................ลายมือชื่ออาจารย์ที่ปรึกษาร่วม......บุศราศิริ ธนะ..........................

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KEY WORD: MIXING HEIGHT / SENSIBLE HEAT FLUX / NET RADIATION / PCRAMMET MODEL

MR. ANURAT SARINGKARNPHASIT: ESTIMAION OF MIXING HEIGHT USING SURFACE METEOROLOGICAL DATA IN THAILAND. THESIS ADVISOR: ASSISTANT PROFESSOR SURAT BUALERT, Ph.D., THESIS CO-ADVISOR: BOOSSARASIRI THANA, M.Sc., 157 pp.

The height of the atmospheric boundary layer (ABL) or the mixing height (MH) is a key parameter of air pollution dispersion model. Two basic possibilities for the practical determination of the MH are its derivation from measurements of profile data, and its parameterization from routine meteorological data using simple models. In Thailand the radiosondes have been applied for MH only 5 stations (Bangkok, Chiang Mai, Ubonratchathani, Phuket and Songkhla station), so the MH is not normally available for the other stations.

The objectives of this study to develop and apply empirical parameters that measurement in Thailand to simple model, which is used to estimate MH from surface meteorological data. The model require a few routine meteorological data of air temperature, relative humidity, wind speed and total cloud cover, and its out put is in term of hourly daytime MH and nighttime MH. The most important methods of comparison between MH obtained from model and MH obtained from upper air profile measurements had been tested on data set from Observatory for Atmospheric Radiation Research at Srisamrong, Sukhothai and data collected from Thai Meteorological Department (Bangkok, Chiang Mai, Ubonratchathani, and Phuket station) during 20 April to 6 June 2003.

The results of estimation MH were tested accuracy by factor of two (FT). It found that the percentage of acceptable was about 60 – 80 %. Then, we can conclude that the simple model, which is applied the empirical parameters that measurement in Thailand can be used to estimate MH in other areas with absence of appropriate upper air sounding data.

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CHAPTER I

INTRODUCTION

1.1 Overview

One of the most important aspects of air quality monitoring involves examination of the atmospheric boundary layer (ABL) structure. The ABL is defined as the atmospheric layer that extends from the earth's surface to the geostrophic wind level, the upper limit of frictional influence from earth's surface (Huschke, 1959). Assessment of ABL provides information about lower atmospheric transport and diffusion that strongly influence the amount of pollutants present in an environment.

The height of ABL or the mixing height (MH) 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 (P. Seibert et al., 2000). It is a key parameter for air pollution models. It determines the volume available for the dispersion of pollutants and is involved in many predictive and diagnostic methods and/or models to assess pollutant concentrations, and is also an important parameter in atmospheric flow models. The MH is not measured by standard meteorological practices. However, there are two basic possibilities for the practical determinations of the MH. It can be obtained from profile measurement, either in-situ (radiosonde, tethersonde, and tower) or by remote sounding (sodar, lidar, wind profiler). The other possibility is parameterized from routine available meteorological data using simple equations or models.

1.2 Problem definition

In Thailand, There are only 5 upper air stations in the Thai Meteorological Department using radiosonde that can apply for MH (Bangkok, Chiang Mai, Ubonratchathani, Phuket, and Songkhla), and ascents one time a day at 00 UTC (or 07 SLT). That upper air data can be analyzed for the morning MH and afternoon MH. In contrast the MH data was not as much frequency as data input to the air pollution dispersion model, and not available to other stations or other areas. Thus, there was need to estimate MH from routinely meteorological data in the absence of appropriate upper air sounding data using simple equations or models.

The most current models used to study MH were developed by mid-latitude countries. Many of empirical parameters used were based on observation taken in the mid-latitude boundary layer, which is physically different from the tropical boundary layer, such as in Thailand. Then, the simple model that used to calculate MH from routine surface meteorological data in Thailand is necessary to study and to develop.

1.3 Objectives

(1) To apply some empirical parameters of turbidity coefficients (a_1, a_2), cloudiness coefficients (b_1, b_2), surface heating coefficient (c_3), and fraction of the net radiation is absorbed at the ground (c_G), which is measured at Sukhothai, Thailand., These parameters were input data to the model that used to estimate MH from surface meteorological data.

(2) To examine and compare the MH determine from model with MH derived from upper air observation data (radiosouding and wind profiler), and tested to accuracy.

(3) To address the simple model estimate MH from surface meteorological data in Thailand.

1.4 Scope of the Study

This study describes some empirical parameters, which is measured at Sukhothai , such as turbidity coefficients (a_1, a_2), cloudiness coefficients (b_1, b_2), surface heating coefficient (c_3), and fraction of the net radiation is absorbed at the ground (c_G) . These parameters will be applied to the model that used to estimate MH from surface meteorological data. Then, MH calculated from this model will be used to compare with

MH determine from profile measurement from Observatory for Atmospheric Radiation Research at Srisamrong, Sukhothai. The sections include: MH measurement by wind profiler (LAP-3000) and eight times daily MH analyzed from radiosounding by air parcel method. The modules to determine MH through parameterizations and model implemented in currently used meteorological preprocessors. The model described in this outline using semi-empirical models to estimate the surface similarity parameters of sensible heat flux (H), friction velocity (u_*), temperature scale (θ_*), and Monin-Obukhov length (L) using routinely collected meteorological variables of cloud cover, wind speed, temperature and relative humidity. These parameters were subsequently used to determine daytime and nighttime MH.

The second part of this study will display the result of testing the semi-empirical model of estimated MH on data set from Thai Meteorological Department (TMD) at Bangkok, Chiang Mai, Ubonratchathani and Phuket. Finally, we will know an impact of input data and weather condition that has been affected with the model of estimated MH and the accuracy of model that determined for MH.

1.5 Data analysis

To develop of empirical parameter using estimation sensible heat flux were carried out in rain fed paddy field in Sukhothai during 2000 - 2004, which is GAME-T and CEOP project site. At field site, microclimate measurements have been carrying out using an automatic weather station system developed by AOKI, et al. (1996).

1.5.1 Data sets for developing empirical parameters to estimated sensible heat flux

Data by GAME-T and CEOP site at Srisomrong, Sukhothai.

- 30 minutes average value of incoming solar radiation, net radiation (MF – 11 KEO), soil heat flux (P-MF-81, EKO), latent heat flux and sensible heat flux (BREBS) during 2000 – 2004.

- 30 minutes average of dry and wet-bulb temperatures, wind speed and cloud cover (SKY VIEW) during 2000 – 2004

1.5.2. Data sets for testing mixing height

- Hourly surface meteorological data measurements, such as cloud cover, wind speed, dry bulb temperature, and relative humidity at Srisomrong , Bankok, Chiang Mai, Ubonratchathani, and Phuket during 20 April to 5 June 2003.

- Continuous profile information from wind profiler (LAP-3000) during 20 April – 5 June 2003 at Srisamrong site.

- Radiosonde ascent, as frequent as possible (eight time per day during 20 to 27 April and 28 May to 5 June 2003 at Srisamrong site, and one time per day (00 UTC or 07 LST) during 20 April to 5 June 2003 at Bangkok Chiang Mai, Ubonratchathani, and Phuket station).

CHAPTER II

BACKGROUND

2.1 Atmospheric boundary layer

The atmospheric boundary layer (ABL) is in the lowest part of the troposphere where the air is influenced by the earth's surface and responded to surface forcing such as frictional drag, evapotranspiration, heat transfer, pollutant emission, and topography (Cooper and Eichinger 1994). Above the ABL, it is the free atmosphere where the effects of friction from the earth's surface are negligible and the motion of air can be treated as an ideal fluid (Glickman 2000). Within the ABL, several identifiable layers can be existed which are depended on the state of the atmosphere and local conditions. These layers are displayed in Figure 2.1 and included the surface layer, mixing layer (ML), entrainment zone, stable layer, residual layer, and capping inversion.

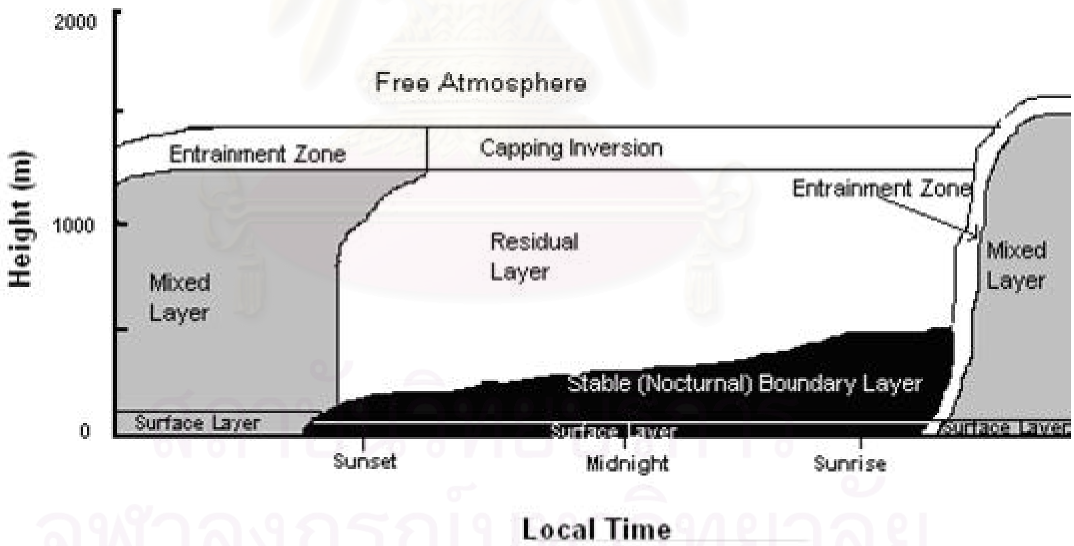


Figure 2.1: The diurnal evolution of the ABL modified from Stull, 1988.

The surface layer is the layer of the atmosphere that contacts with the earth's surface and causes the generation of mechanical turbulence by strong winds. Furthermore, wind shear is greater than the generation of buoyant turbulence associated with large thermals (Glickman 2000). The surface layer always presents, but the state of the atmosphere and time of the day determine the layer above the surface layer. During daytime convective conditions, an ML that is above the surface layer is characterized by turbulence created by forced. Moreover, free convection actively mixes such quantities as aerosols, potential temperature, and wind speed (Stull 1988). On warm sunny days, the surface forcing are dominated by the solar heating of the earth's surface and convective thermals are the main cause of development of the well-mixed PBL, which is often called the convective boundary layer (Marsik et al. 1995). At the top of the ML there exists a stable layer called the entrainment zone that is not well-mixed of which turbulence intensity decreases upwards (Seibert et al. 2000). This layer is an interface between the ML and the free atmosphere. It is often called an inversion layer because there is a temperature increased with the height. Above the entrainment zone, in the free atmosphere, the temperature is usually decreased with the height, and the atmosphere becomes less stable.

During nighttime or newly stable conditions, a residual layer occurs above the surface layer in the middle of the ABL where weak sporadic turbulence takes place. This area contains the initially uniformly-mixed potential temperature and pollutants from the ML of the previous day. With nighttime conditions of a radiatively cooled surface, the bottom of the residual layer is transformed into a stable boundary layer. The stable boundary layer forms when air is cooled by the colder surface of the earth, created a layer with stable stratification. Above the residual layer, it is a capping inversion layer, a statically stable layer that separates the residual layer and surface characteristics from the free atmosphere.

2.2 The concept of the mixing layer and definition of its height

The atmospheric boundary layer (ABL) is the layer where the earth's surface interacts with the large scale atmospheric flow. Since the substances emitted into this layer and gradually horizontally as well as vertically dispersed through the action of turbulence, and become completely mixed if sufficient time is given and sinks and sources are absent. This layer is also called the mixing layer. Since under stable conditions complete mixing is often unable to reached, the term “mixing layer” seems preferable because it emphasizes more on the process than the result. 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 include the domain influenced by nocturnal radiative exchange processes (Seibert et al. 2000).

The ABL height or mixing height (MH) is a key parameter for air pollution models. It determines the volume available for the dispersion of pollutants and is involved in many predictive and diagnostic methods and/or models to assess pollutant concentrations. It is also an important parameter in atmospheric flow mode (Seibert et al. 2000).

The MH is defined by the European Co-operation in the Field of Scientific and Technological Research (COST): 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 and become vertically dispersed by convection or mechanical turbulence within a time scale of about an hour (Seibert et al. 1998).

In order to proceed from this general definition to practical realizations, it is necessary to consider the structure of the stable boundary layer (SBL) separately and of the convective boundary layer (CBL). The development, temporal evolution, and spatial distribution of the ML height depends on many factors including variations in surface albedo, surface moisture, synoptic conditions, local circulation patterns, cloud cover, horizontal advection, land use, and the urban heat island effect (Seibert et al. 2000; Marsik et al. 1995; Dayan et al. 1988). Therefore, the ML height at a particular time and place is influenced by geographical location and environmental conditions.

For the CBL, the MH depends on the atmosphere’s ability to mix or maintain vertical motion through convectively driven turbulence by buoyancy and mechanically induced turbulence by wind shear. In an unstable atmosphere, the transition in turbulence intensity between the ML and the entrainment zone and the magnitude of the stability of the entrainment zone are important features that influence the method to determine the MH. The turbulence in the ML is usually convectively driven by such sources as heat transfer from a warm ground surface or radiative cooling from the top of clouds (Stull 1988). A well-mixed layer can develop where mixing ratios and potential temperature are nearly constant with height to the entrainment zone. The entrainment zone is marked by the entrainment of dryness, less turbulent air which allows the top of ML to be identified with a sharp moisture decrease and coincident temperature increase.

The SBL can be divided into two layers: a layer of continuous turbulence and an outer layer of sporadic or intermittent turbulence. Under the very stable conditions the layer of sporadic turbulence may extend to the ground. Since it is notoriously difficult to measure sporadic turbulence and develop to even more related scaling theory, the scaling height (*h)* used for the SBL generally is the layer of continuous turbulence. As in the convective case, however, this does not mean that turbulence is strictly confined to the region below MH (Seibert et al. 2000). .

The asymptotic case with the heat flux approaching zero from either stable or unstable stratification is often termed neutral boundary layer. It must be kept in mind, however, that even in this case stable stratification will prevail above the ABL, which limits the validity of idealized concepts based on an infinitely deep neutral boundary layer.

2.3 Methods for the determination of the mixing height

The MH is not measured by standard meteorological practices; the most common methods for determining the MH derive to the profile measurements and parameterizations using simple equation or models which require only operationally available input data from measurements.

2.3.1. Mixing height determination from profile measurements

2.3.1.1 Radiosoundings

Radiosonde systems obtain profiles of temperature, pressure, relative humidity, and wind as they ascend through the atmosphere and send these measurements to a ground receiver. MH estimates can be determined by using radiosonde data by analyzing the vertical stability of the atmosphere. For a particular time and place, these estimates depend on the atmospheric constituent and technique used for the analysis. The choice of constituent and technique has varied in the past research and is depended on the nature of the study and the local characteristics of the atmosphere.

Radiosonde temperature and wind profiles in the lower part of the atmosphere are often used for a subjective estimation of the MH. Under convective conditions, the MH is often identified with the base of an elevated inversion or stable layer, or as the height of a significant reduction in air moisture, often accompanied by wind shear (Seibert et al. 1997 – see Figure 2.2). Some authors recommend to take the inversion base altitude increased by half of the depth of inversion layer as the characteristic CBL height (Stull, 1988).

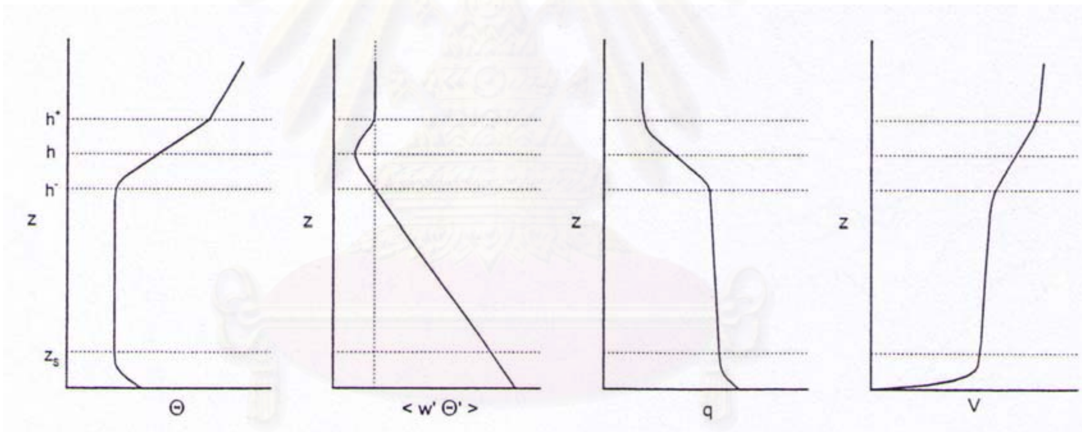


Figure 2.2: Idealized structure of the CBL and its MH (Seibert et al. 1998).

Holzworth (1964, 1967, and 1972) and others have developed objective methods to simplify and homogenize the analysis with complex stratification of the ABL and to estimate the MH under the convective conditions. The basic idea of the "Holzworth" or "parcel method" is to follow the dry adiabatic starting at the surface with the measured or expected (maximum) temperature up to its intersection with the temperature profile from the most recent radiosounding. It determines the MH as the equilibrium level of a hypothetical rising parcel of air representing a thermal. However, 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 (e.g. Miler, 1967; Garrett, 1981).

More recently, methods based on conserved variables were developed which permit analysis of air mass structures and vertical mixing (Betts and Albrecht, 1987). They involve the mixing ratio (r) (with liquid water r_T), the potential temperature θ, the virtual potential temperature (θ_v), the equivalent potential temperature (θ_e), the saturation equivalent potential temperature (θ_{es}) and the difference (p^*) between the actual pressure and the corresponding pressure of saturated air, as calculated from observations of temperature, dew point and pressure.

Figure 2.3 shows an example of a typical 12 UTC (13 LST) sounding on a clear summer day with well-developed CBL. The top of the EL (~ 3000 m asl) is marked by a minimum of p^* and maximum of θ_{es}. The base of the capping inversion (~ 2500 m asl) is characterized by a sudden decrease of p^* associated with a local minimum of θ_{es}. The inversion itself shows a relatively constant, low value of p^* which is also found often in the presence of clouds.

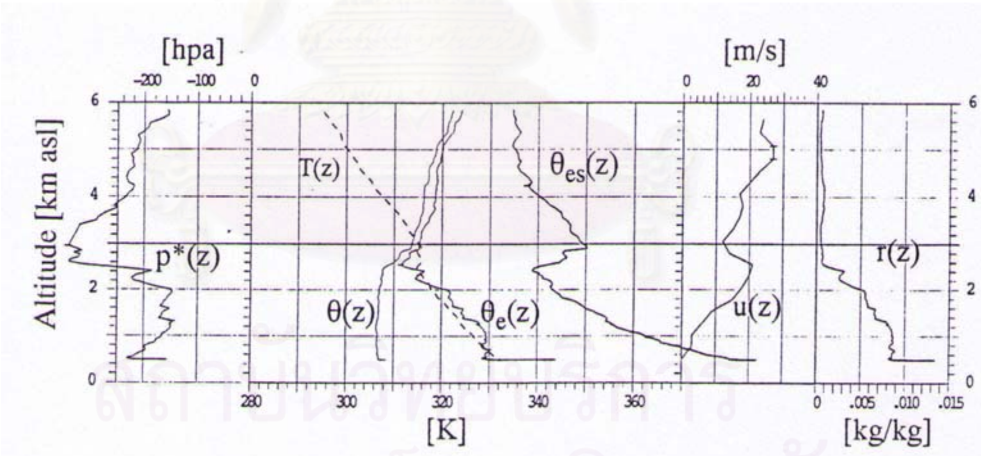


Figure 2.3: Typical summer daytime sounding (Payerne, Switzerland, 29 July 1993, 12 UTC), with profiles of the conservative variables suggested by Betts and Albrecht (1987). See text for explanations. (Seibert et al. 1998)

For 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 (e.g. Andre and Mahrt, 1982; Stull, 1983 – see Figure 2.4a). It can be described approximately by polynomial of exponential functions (Surridge and Swanepoel, 1987; Anfossi, 1989). Under such conditions it is very difficult to assess the height of the SBL.

If mechanical turbulence production is significant at least two different regions can be distinguished within the SBL, as shown by observations and numerical modeling (Garratt and Brost, 1981; Andre and Mahrt, 1982; Wetzel, 1982; Estournel and Guedaha, 1985; see Figure 2.4b). In the lower layer, the potential temperature profile is often characterized by a strong, nearly linear increase with height due to the interactive 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.

Under condition of strong winds and weak radiative cooling a layer with relatively effective mixing (though not really well-mixed) may be observed closely to the ground. It is characterized by only a slight increasing in potential temperature with height (Zeman, 1979; Roth et., 1979; see Figure 2.4c). This layer is capped by a quite shallow zone with a very sharp jump-like increasing in temperature, followed by a zone of weaker stability aloft (Seibert et al., 1998).

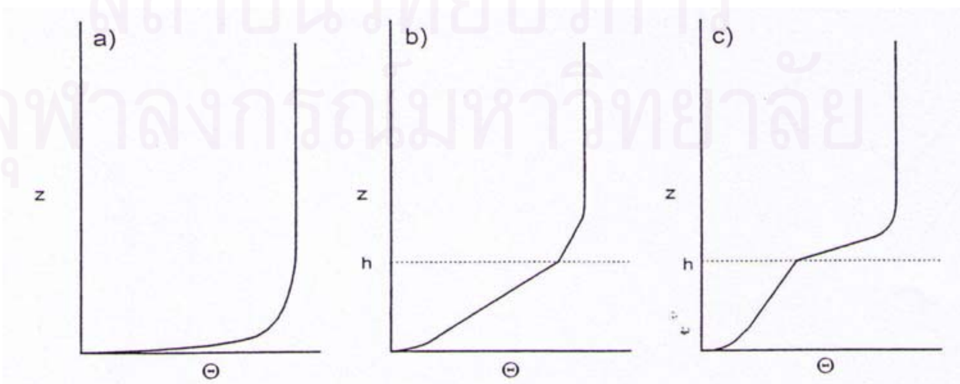


Figure 2.4: Typical vertical temperature profiles in the SBL; a) weak wind, strong stability; b) moderate wind; c) strong wind. (Seibert et al. 1998)

MH estimations based on (standard) radiosonde data may result in quite high uncertainty (e.g., Russell et al., 1974; Hanna et al., 1985; Martin et al., 1988). Specific problems occur in the stable (nocturnal) boundary layer since no universal relationship seems to exist among the profiles of temperature, humidity or wind and turbulence parameters (heat or momentum fluxes, turbulent kinetic energy) (Seibert et al. 1999). A summary of the most popular methods and algorithms derive to the MH from direct vertical sounding data is given in Table 1.

2.3.1.2 Wind profiler

Wind profiler which is an atmospheric remote sensing instrument, is observed air parcel movement by Doppler Radio Detection and Ranging or Doppler radar technique. Wind profiler utilizes the time differences between radio waves and backscattered sound to detect to the evaluated vertical temperature and wind. The return patterns from these signals can be used to interpret the atmospheric temperature and wind which in turn can be used to determine the mixing layer height (e.g., Marsik et al., 1995). During the fair conditions, the boundary layer is often more humid than the free atmosphere allowing for an interpretable boundary or interface to be present in the return signal. This signal pattern is then often used to estimate height of the mixed layer (Stull, 1988).

The MH can be determined by a wind profiler from the signal-to-noise ratio (SNR). The return signal is received primarily from the inhomogeneities of the radio refractive index (Angevine et al., 1994). These inhomogeneities depend primarily on the fluctuations of the temperature and especially the moisture fields (White et al., 1991). Since there is often a humidity gradient between mixing layer (ML) and free atmosphere, a peak can be seen in the wind profiler backscatter profile at the top of the mixing layer and SNR (Cohn and Angevine, 2000). Carl M. Berkowitz et al. (2005) approach to plot time–height cross-sections of the range-corrected SNR for a day of interest and then use digitizing software to manually select the height of maximum SNR as a function of time.

Table 2.1: MH determination from soundings or numerical model results, the type of MH as determined by each of the method is indicated by the symbols h^- , h and h^+ (Seibert et al. 1998).

Convective Boundary Layer (CBL)		
based on wind profile	based on temperature / humidity profiles	based on turbulence profiles
Height of a zone with significant wind shear in wind speed and / or wind direction	$\partial T/\partial z > 0$ (base of an elevated inversion) $\rightarrow h^-$ (e.g. Deardorff, 1974; Baxter, 1991; Betts, 1992)	$-\langle w'\Theta'\rangle$ = Max. $\rightarrow h$ (e.g. Deardorff, 1974; Weill et al., 1980)
	$\partial\Theta/\partial z > 0$ (base of an elevated stable layer) $\rightarrow h^-$ (e.g. Coulter, 1979; Hanna et al., 1985)	$\langle w'\Theta'\rangle = 0 \rightarrow h^-$ (e.g. Gamo and Yokoyama, 1979; Sorbjan et al., 1991)
	$\gamma_u < c_\gamma \gamma_{ad} \rightarrow h^-$ (Garrett, 1981, c_γ =0.8) (Sasano et al., 1982, c_γ =0.6)	Height at which ε suddenly decreases (Kukharets and Tsvang, 1979; Pekour, 1990)
	Height at which a rising parcel becomes neutrally buoyant (e.g., Holzworth, 1967; Troen and Mahrt, 1986)	Local maximum of C_T^2 (e.g., Sorbjan et al., 1991)
	Height at which moisture suddenly decreases (e.g., Melas, 1991; Lyra et al., 1992)	Significant decrease in vertical acceleration on an aircraft (Druilhet et al., 1983;, Hildebrand, 1988)
	Upper level of a layer with positive instability energy (Kuznetsova, 1989)	
	h_{Ri}: $Ri \geq Ri_C$ with Ri_C =0.25 (Vogelezang & Holtslag, 1996)	

Table 2.1 (continuation):

Stable Boundary Layer (SBL)		
based on wind profiles	based on temperature / humidity profiles	based on turbulence parameters
$\partial V/\partial z$ = Min. or $\partial\alpha/\partial z$ = Min. $\rightarrow h^+$ (Wetzel, 1982; Coulter, 1990b)	$\partial T/\partial z = 0$ (top of the surface inversion) $\rightarrow h^+$ (e.g. Coulter, 1990)	h_τ: height at which some turbulence parameter has decayed to a few % of its surface layer value, e.g.: $\tau = 0.10\ \tau_0$ (Nieuwstadt and Driedonks, 1979)
$V = V_{max}$ (height of the LLJ axis) $\rightarrow h^+$ (e.g. Clarke, 1970)	$\partial\Theta/\partial z < 3.5$ K km^{-1} (André and Mahrt, 1982) or $\partial\Theta/\partial z = 0$ (top of a stable layer) $\rightarrow h^+$	$\tau = 0.05\ \tau_0$ (Caughey et al., 1979, Brost and Wyngaard, 1978, Zeman, 1979, Melkaya, 1987)
Height of the V minimum above the LLJ axis $\rightarrow h^+$ (Businger and Arya, 1974)	$\Delta\Theta = 0.05(\Delta\Theta)_0$ (Delage, 1974) $\Delta\Theta = 0.02(\Delta\Theta)_0$ (Stull, 1983a) $T(h) = (T_{max} - T_0)/e$ (Surridge &Swanepoel, 1987)	$\tau = 0.02\ \tau_0$ (Etling and Wippermann, 1975) $\tau = 0.01\ \tau_0$ (Businger and Arya, 1974)
Upper boundary of a layer of significant wind shear (Kitaigorodskii and Joffre, 1988)	Height up to which significant cooling can be recognized from a sequence of T profiles (Melgarejo and Deardorff, 1974)	h_{TKE}: $TKE = 0.05\ (TKE)_0$ (Tjemkes and Duynkerke, 1989)
	Height of the lowest discontinuity in the T profile $\rightarrow h$ (Hanna, 1969)	h_H: $\langle w'\Theta'\rangle = 0.10\ \langle w'\Theta'\rangle_0$ (Nieuwstadt and Driedonks, 1979)
	Height at which the Θ_v profile significantly starts to deviate from a linear curve $\rightarrow h$ (Wetzel, 1982)	$\langle w'\Theta'\rangle = 0.05\ \langle w'\Theta'\rangle_0$ (Brost and Wyngaard, 1978;, Caughey, 1982, Nieuwstadt, 1984a; Mel'kaya, 1987, Estournel and Guedalia, 1990, Derbyshire, 1990)
	h_{Ri}: $Ri \geq Ri_C$ with $Ri_C = 0.25$ (Garratt, 1982a) (Vogelezang & Holtslag, 1996) $Ri_C = 0.5$ (Mahrt et al., 1982)	$\langle w'\Theta'\rangle = 0.01\ \langle w'\Theta'\rangle_0$ (Yu, 1978) $\sigma_\alpha(i) = 1.5\ [\sigma_\alpha(i+1) + \sigma_\alpha(i+2)]/2$ (Kurzeja et al., 1991)

Figure 2.5 shows the time-height evolution of the wind profiler signal to noise ratio (SNR). Superimposed in white circle is the cloud - bases detected by the ceilometers. The altitude range covered by the wind profiler with a high SNR is increase from 1000 m at 08:00 to its maximum (2,150 m) at around 11:30. The increasing in the spread of the strong wind profiler SNR which also coincide with the spread of the cloud - based is likely to be due to the development of convection in the air, which is nearly saturated. Above what appears to be the signature of the convective boundary layer, another zone of enhanced signal is highlighted in white. This line nearly coincides with a strong discontinuity in the refractive index (transition between humid layers to a dry one associated with a temperature inversion).

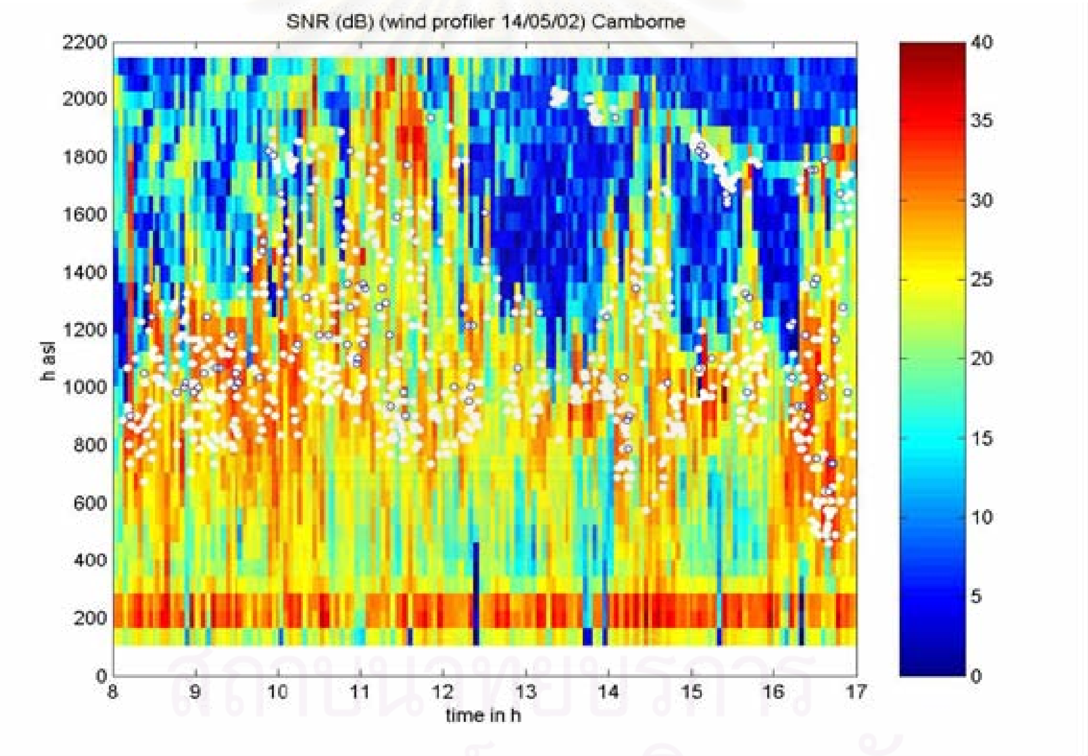


Figure 2.5: Time height series of signal to noise ratio of wind profiler (dB scale) on 14/5/02 at Camborne, showing the development of a convective boundary layer. White and blue circle show cloud base reported by ceilometers. (Catherine Gaffard et al, 2003)

Errors can result, and the ML can be difficult to determine. Also, when the peaks in the refractive index are caused by enhancements of reflectivity, which occurs in regions rather than at the top of the ML. This can be caused by such things as turbulence within or above the ABL, clouds, precipitation, insects, birds, and ground clutter (White et al. 1999). Furthermore, the lowest gate of a wind profiler system is usually not below 100m. Depending on the instrument, this can create problems when trying to resolve the SBL in detail or detecting turbulence structures in the lower ABL (Seibert et al. 2000; Marsik et al. 1995). Marsik et al. (1995) found wind profilers to have difficulty detecting turbulence structures in the lowest 400-600m of the ABL.

There has been the past research that focused on the use of wind profilers to determine the ML height, including comparisons of the ML heights estimated by wind profilers with radiosondes or other instruments. Although in most cases there was good agreement, wind profiler ML height estimates were generally higher than the ML estimates by the other instruments. The reason for higher wind profiler ML estimates was related to the nature of the study.

Angevine et al. (1994) and Grimsdell and Angevine (1998) both focused on the relationship between wind profilers and radiosondes and found a good agreement between these two instruments with a slight bias representing higher wind profiler MH. In Champaign Urbana, Illinois, Grimsdell and Angevine (1998) found this good agreement as a correlation coefficient of 0.88 for 150 estimated heights with slightly higher heights estimated from the wind profiler data. In Alabama, Angevine et al. (1994) also found the wind profiler estimates to be slightly higher than the radiosonde estimates.

Beyrich and Gorsdorf (1995) compared the ML height values determined by sodar and wind profilers in Germany during convective conditions. The agreement was quite good, with only a small bias of less than 10m. The root mean square difference of 59 samples was 38m, which was less than the wind profiler vertical resolution, and the correlation coefficient was 0.97. The largest absolute differences observed were between 80m and 100m, which occurred during the times of rapid ML growth. A slight tendency towards higher ML height values from the wind profiler existed for very shallow convective PBL; this was blamed on the uncertainties in profiler measurements due to the ground clutter.

2.3.2 Mixing height determination from parameterizations and models

As continuous profile measurements for the operational determination of the MH are not generally available, simple parameterizations based on standard surface observations and single profile data as well as numerical models are widely used in the practice of meteorological and environmental services. Simple model or parameterization equations for the MH are still very attractive for operational purposes because of their simplicity and the limited number of required input data. The model simulations or parameterizations certainly do provide numerical values of the MH with desired resolution in height and time. Modules to determine MH through parameterizations and models implemented in currently used meteorological pre-processors. There are several mixing height algorithms employed in many different pre-processors that use a variation of friction velocity (u_*),Monin-Obukhov length (L) and the Coriolis parameter (*f*) to compute mixing height. For the stable and mechanically-dominated unstable ABL, they use similarity formulae based on the wind velocity, the Monin-Obukhov length, and the Coriolis parameter while in the convective case simple slab models are integrated, based on an initial temperature profile and the surface heat flux.

Seibert et al. (2000) tested the five currently meteorological preprocessors for dispersion models. These pre-processors were OML (Olesen et al., 1987), and HPDM (Hanna and Chang, 1992), FMI (Karppinen et al., 1997, 1998), Servizi Territorio (1994), and RODOS (Mikkelsen et al., 1996; Mikkelsen and Desiato, 1993), with profile measurements (radiosonde, sodar and wind profiler) in Cabauw (Netherlands), Payerne (Swiss Midland) and SADE (Germany). All the tested parameterization schemes showed deficiencies under certain conditions. Thus requiring more flexible algorithms is able to take into account of changing and non-classical conditions. In the stable and neutral ABL, they rely on similarity formulae involving surface layer parameters and the Coriolis parameter, which is not satisfactory from a physical point of view. Richardson methods appear to be better in this respect. However, the necessary input for these methods is often not available. Using one-dimensional numerical models with higher-order turbulence closure may become a solution in the future. If surface similarity methods are used, Nieuwstadts method appears to be superior to the u_*/f approach for stable conditions.

Kim Oanh, N.T. et al. (2002), determined the mixing height in tropical meteorology condition using graphical and computational methods. Hourly surface and daily upper air observations in 2001 are used at MaeMoh site, Rayong province and at Maptaput site, Lampang province, Thailand. Simple modifications are applied for zero-order mixed layer model of Seven-Erik Gryning and Ekaterina Batbhvarova with adaptation of virtual temperature and kinematics virtual potential temperature flux to the existing set of equations. Modifications thus accounted for the effects of moisture content on air density. Consequently the mixing height increased by 3.2% at MaeMoh site and 1.5% at Maptaput site, Daily minimum and maximum mixing heights are derived from tephigram by Holzworth's graphical method for two cased with and without condensation energy consideration. In this method, affect of the condensation energy on mixing height was also taken into account. Obtained results showed a significant increasing in maximum mixing heights (23.75%). Comparisons to actual measurements obtained from remote sounding systems at both sites present good agreements with computational results for most of the days in the period of January and December 2001. there are discrepancies shown for the first and the last hour of simulations which may be related to the application conditions of the model.

Saringkarnphasit K. (2002) estimated the mixing height for 5 years surface meteorological data of Bangkok (1996-2000) in urban condition and grass roughness. The maximum average mixing height of Bangkok for urban condition is greater than monitored data. The maximum average mixing height of Bangkok for grass condition is lower than monitored data. With the determination of coefficient, the maximum estimation of urban condition is greater than grass condition. By paired t-test, the maximum mixing height for grass condition is not different from the monitored data. The standard errors of estimation (RMSE) of the maximum mixing height of both conditions are lower than 25% error. The estimation considerable fit well with the actual mixing height for both condition in Bangkok. The minimum mixing height of Bangkok was found lower than the value from rawinsonde. With the 1 year surface data (1999) in Chiang Mai, the maximum and minimum height may not be predicted by the estimation.

Jesse L. Thé et al (2001), used an estimation technique as the potentially useful areas where upper air meteorological data are not available. This section presents some comparisons between calculations of mixing heights derived from the Lakes UA Estimation Tool and mixing heights obtained by AERMET using upper air meteorological soundings. Figure 2.6 shows a comparison between the convective mixing heights obtained from the Lakes UA Estimation Tool and those obtained by AERMET from upper air soundings in Dodge City, KS. USA.

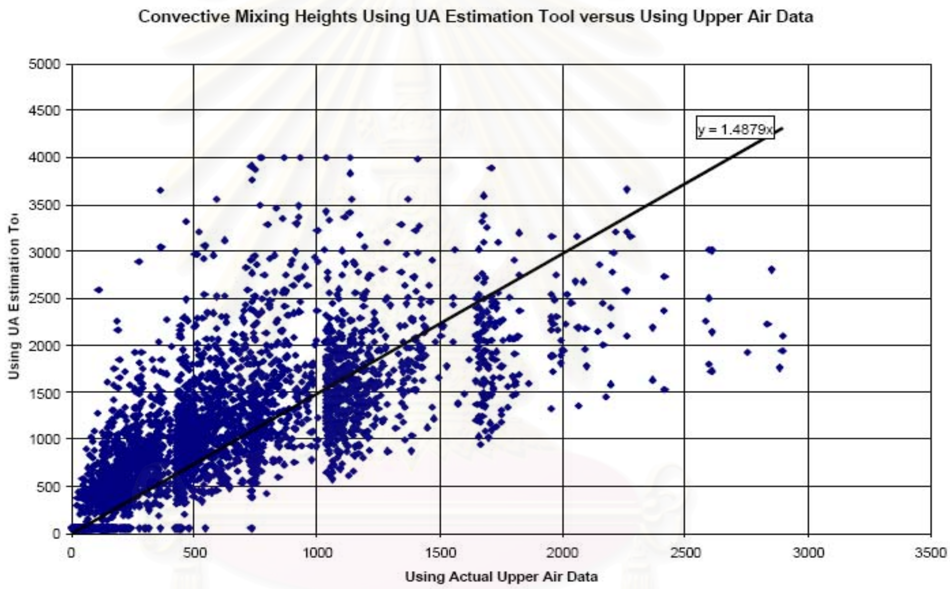


Figure 2.6: Mixing Height comparison for Dodge City, KS. (Jesse L. Thé et al, 2001)

While there is a clear correlation between the two, there is also considerable scatter. In addition, the UA Estimation Tool over predicts the mixing heights, on average, by nearly 50%. Any estimation of convective mixing heights without knowledge of the upper air temperature profile is likely to introduce errors.

J. Burzynski et al. (2004) compared the MH taken from the sodar measurement to the values calculated by CALMET (Lena and Desiato, 1999) meteorological pre-processors model in Cracow- Czyzyny (Poland) during four months period includes the following months: April, June, September and December 2001. The results of calculation are presented in the Figure 2.7 for the each of these months separately, and concluded CALMET that underestimates the mixing height in nighttime, in the daytime (unstable case) it overestimates the mixing height.

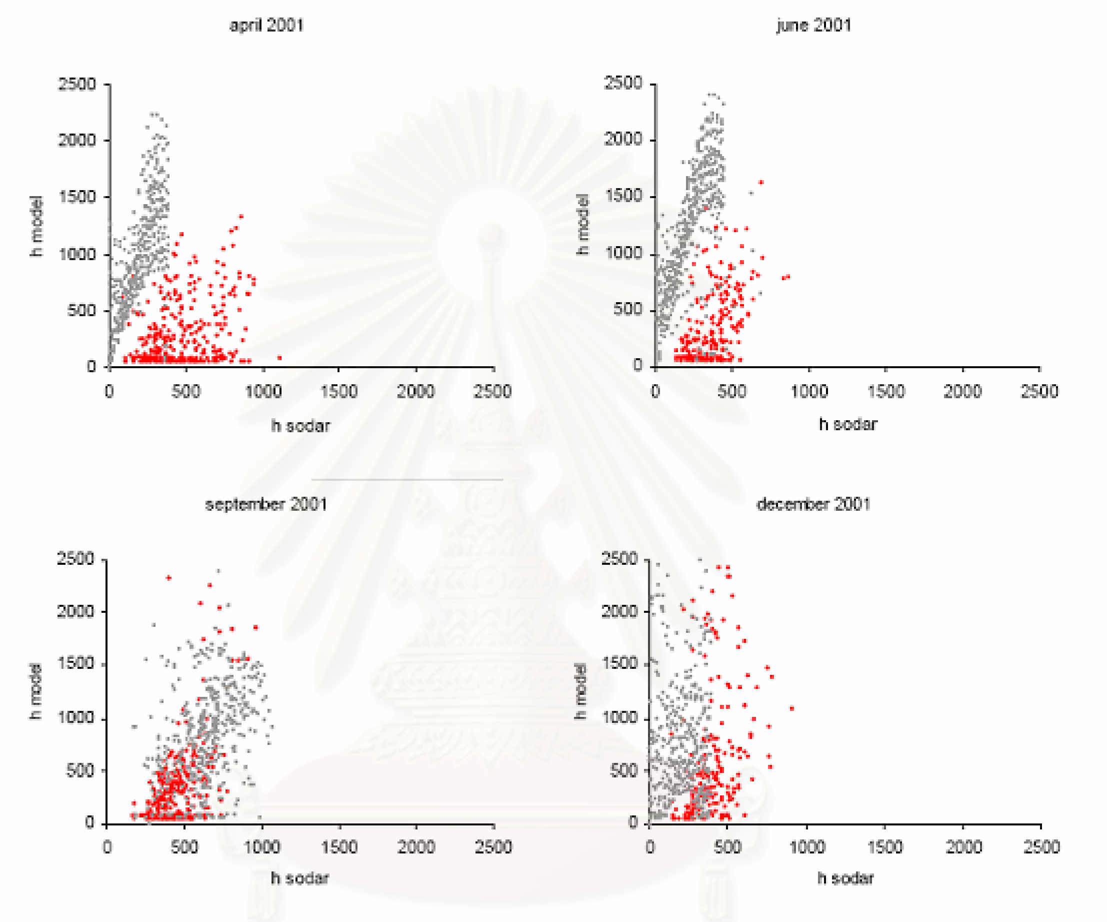


Figure 2.7: The comparison of the mixing height taken from the sodar measurement with values calculated by CALMET model, based on the ALADIN mesoscale model. April correlation coefficient r = 0.62, June r = 0.76, September r = 0.54 and December r = 0.3 (Grey dots day cases, red dots night cases) (J. Burzynski et al., 2004)

CHAPTER III

METHODOLOGY

The most important methods to determined MH have been tested on data set from Observatory for Atmospheric Radiation Research at Srisamrong, Sukhothai and data collected from Thai Meteorological Department (at Bangkok, Chiang Mai, Ubonratchathani, and Phuket station) during 20 April to 6 June 2003. MH from measurement method with wind profiler (LAP-3000) can be derived from the signal-to-noise ratio (SNR), and MH from radiosoundings data can be analyzed by air parcel method. Modules to determine MH through parameterizations from routine surface meteorological data used PCRAMMET (U.S. EPA, 1999) meteorological pre-processors modules to estimate the surface similarity parameters of sensible heat flux (H), friction velocity (u_*), temperature scale (θ_*), and Monin-Obukhov length (L) using routinely collected meteorological variables of cloud cover, wind speed, temperature and relative humidity. These parameters were subsequently used to determine daytime and nighttime MH. It is calculated using the sensible heat flux and friction velocity as proposed by Farmer (1991).

Development of empirical parameter using estimation sensible heat flux were carried out in rain fed paddy field at Srisamrong, Sukhothai during 2000 to 2004, which is GAME-T and CEOP project site. This site was selected in farmer lands. The rice seeds are sown every year by farmers after starting the rainfall period in June or July, and were harvested in November. At field site, microclimate measurements have been carrying out using an automatic weather station system developed by AOKI, et al. (1996).

3.1 Data sets for development empirical parameter and testing mixing height

3.1.1 Data set for developing empirical parameter to estimated sensible heat flux

1) 30 minutes average value of incoming solar radiation (Pyranometer), net radiation (MF – 11 KEO), soil heat flux (P-MF-81, EKO), latent heat flux and sensible heat flux (BREBS) during 2000 to 2004.

2) 30 minutes average of dry and wet-bulb temperatures, wind speed and cloud cover (Sky View) during 2000 to 2004

3.1.2 Data sets for testing mixing height

This study identify the following requirements for data sets in order to allow the testing of MH

1) Hourly surface meteorological data measurements, such as cloud cover, wind speed, dry bulb temperature, and relative humidity.
2) Radiosonde ascent, as frequent as possible (eight times per day during 20 to 27 April and 28 May to 5 June 2003 at Srisamrong site, and one time per day (00 UTC or 07 LST) during 20 April to 5 June 2003 at Bangkok, Chiang Mai, Ubonratchathani, and Phuket station).
3) Continuous profile information from wind profiler (LAP-3000) during 20 April to 5 June 2003 at Srisamrong site.

3.2 Development of empirical parameters that measurement in Thailand to estimate sensible heat flux in PCRAMMET model

The fluxes of sensible heat drive the growth and structure of the ABL. This flux affects to the principle boundary conditions for air pollution dispersion model. It is a critical parameter required to estimate the buoyant production of turbulent energy, and hence the daytime MH. However, this flux is not available in routine meteorological observation. Moreover, most current models that used to estimate sensible heat fluxes are developed by mid-latitude countries, and as such many of empirical parameters used were based on observation taken in the mid-latitude boundary layer, which is physically different from that of the tropical boundary layer. So, there is a need to develop an empirical parameter using estimation the sensible heat flux from routine meteorological data by simple equation or model in Thailand. The summary of the methods and necessary input parameter and data that used to estimate sensible heat flux are shown in Table 3.1

Table 3.1: Show a summary of the methods and necessary input parameter and data using estimated sensible heat flux.

Parameterized quantity	Method	Input parameter and data
Incoming solar radiation(Rs)	Parameterization of transmission of the atmosphere	Solar elevation (ø)
		Total cloud cover (N)
		Turbidity coefficients(a_1, a_2)
		Cloudiness coefficients(b_1, b_2)
Net radiation (Rn)	Parameterization of the terms in the surface radiation budget	Incoming solar radiation(Rs)
		Air temperature(T)
		Longwave coefficients (c_1)
		Total cloud cover (N)
		Cloudiness coefficients(c_2)
		Surface albedo(r)
		Surface heating coefficient(c_3)
Latent heat flux (λE)	Penman-Monteith equation	Net radiation (Rn)
		Relative humidity (RH)
		Air temperature(T)
Sensible heat flux (H)	Parameterization of the terms in the surface radiation budget	Net radiation (Rn)
		Latent heat flux (λE)

The estimates for the heat flux according to follow the surface energy balance expression by Oke (1978) formula which is

$$Rn = H + \lambda E + G \tag{1}$$

where Rn is the net radiation, H is the sensible heat flux, λE is the latent heat flux, and G is the soil heat flux. Each term expresses as watts per square meter (Wm^{-2}).

3.2.1 Determine turbidity coefficients (a_1, a_2) and cloudiness coefficients (b_1, b_2)

The net radiation, Rn , is estimated from total incoming solar radiation, Rs , as

$$Rn = (1 - r)Rs - In \tag{2}$$

where r is the user-specified surface albedo (dimensionless), and In is the net long-wave radiation at the earth's surface.

In the general case in which clouds are present, Rs is computed using the following formula proposed by Kasten and Czeplak (1980).

$$Rs = Rs_0 + \left(1 + b_1 N^{b_2}\right) \tag{3}$$

where N is total cloud cover, Rs_0 is the value incoming solar radiation under clear skies ,

$$Rs_0 = a_1 \sin\phi + a_2 \tag{4}$$

and a_1 and a_2 are empirical turbidity coefficients. These coefficients describe the average atmospheric attenuation of Rs_0 by water vapor and dust, which may depend on site location. The b_1 and b_2 are empirical cloudiness coefficients, which may depend on the climate of the specific site.

3.3.2 Determination surface heating coefficient (c_3)

The net long-wave radiation at the earth's surface (In) in Eq. 2 as given by Holtslag and van Ulden (1983) is parameterized as a function of temperature and cloud cover.

$$In = c_1 T^6 - \sigma T_s^4 + c_2 N \tag{5}$$

were c_1 = 5.31 x 10^{-13} $Wm^{-2}K^{-6}$ (Swinbank, 1963) and c_2 = 60 Wm^{-2} (Paltridge and Platt, 1976) is an empirical constant, σ 5.67 x 10^{-8} $Wm^{-2}K^{-4}$ is the Stefan-Boltzmann constant, T_s is the surface radiation temperature. Since the surface radiation temperature is not normally available Holtslag and van Ulden (1983) approximate $L^- = -\sigma T_s^4$ by

$$L^- = \sigma T^4 + 4\sigma T^3 (T_s - T) \tag{6}$$

and

$$4\sigma T^3 (T_s - T) = c_3 Rn \tag{7}$$

where c3 is surface heating coefficient that derived from net radiation and surface radiation temperature, then Eq. 5 is become

$$In = c_1 T^6 + c_2 N - \sigma T^4 - c_3 Rn \quad (8)$$

Substituting Eq. 3, Eq. 4 and Eq. 8 into Eq. 2, Holtslag and van Ulden (1983) estimate the net radiation as

$$Rn = \frac{(1-r)Rs + c_1 T^6 - \sigma T^4 + c_2 N}{1 + c_3} \quad (9)$$

3.2.3 Determination the fraction of net radiation is absorbed at the ground (c_G)

For a land surface, soil heat flux is mostly less if compared to net radiation during daytime. A good estimate for soil heat flux (De Bruin and Holtslag, 1982) is

$$G = c_G Rn \quad (10)$$

where c_G the fraction of the net radiation is absorbed at the ground, and specified by the user.

3.2.4 Estimation latent heat flux (λE) and sensible heat flux (H)

The latent heat flux (λE) is described by the Penman-Monteith equation (Monteith, 1981), which is

$$\lambda E = \frac{\Delta(Rn - G) + \rho_a c_p (e_s - e_a)/r_a}{\Delta + \gamma(1 + r_s / r_a)} \quad (11)$$

where Δ is the slope of the saturation vapor pressure-temperature curve, ρ_a is air density, c_p is the specific heat of air, e_a is vapor pressure of the air at reference measurement height z, and e_s is the saturated vapor pressure at a dew point temperature equal to the air temperature at z, $(e_s - e_a)$ is the vapor pressure deficit, r_a is the aerodynamic resistance, r_s is the surface (canopy) resistance, and γ is the psychometric constant.

After, estimation of net radiation from Eq. 5, soil heat flux from Eq. 6 and latent heat flux from Eq. 7, the sensible heat flux is obtained from Eq. 4 as

$$H = (1 - c_G) Rn - \lambda E \quad (12)$$

3.3 Determination of mixing height

There are two possibilities for practical determination of the MH. One can be obtained from profile measurements. The other possibility is to use parameterizations or simple models with only a few measured parameters for input. Details of the method determined MH is as followed

.

3.3.1. Mixing height based on radiosoundings

The profiles of potential temperature (θ) analyzed from radiosondes were used to determine the mixing height. Potential temperature is defined as the temperature a parcel of dry air would have if brought dry adiabatically to 1000 mb. Dry adiabatically refers to parcel movement along a line of constant θ. At this point, it may be helpful to state that θ is mathematically defined by

$$\theta = T(1000/P)^k$$

(13)

where *P* is the pressure in mb, *T* is temperature in K at the initial state referenced from the (arbitrarily selected) standard pressure level of 1000 mb, and the exponent K is a constant equal to 0.286 (Huschke, 1959).

In daytime or convective situations, the MH was estimated from radiosounding potential temperature profiles using the parcel method (Holzworth, 1964, 1967, and 1972). Its principle is to follow the dry adiabate (constant θ) starting at the surface up to its intersection with the actual potential temperature profile (Fig.3.1). For one time per day radiosonde ascent, Holzworth method (Holzworth, 1964, 1967) provides twice-per-day (morning and afternoon) mixing heights. 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 intersects the vertical temperature profile observed at 07 LST (Figure 3.1). The plus 5 °C factor was determined arbitrarily by Holzworth (1967) from analyzing urban and rural temperature differences and was applied to account for heating that occurred shortly after sunrise. The afternoon mixing height is defined as the height above the ground in which the dry adiabatic extension of the afternoon maximum temperature intercepts the vertical temperature profile observed at 07 LST (Figure 3.2).

In nighttime or stable situations, the reference MH was determined in three different ways using the sole temperature profile shown in Figure 3.3.

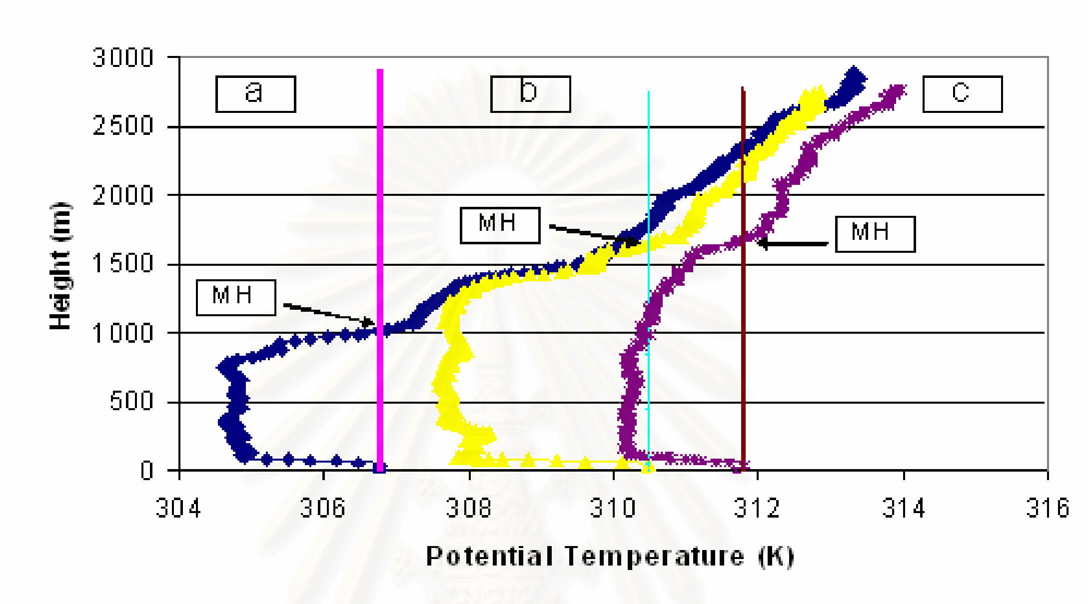


Figure 3.1: Illustration of the parcel method. Potential temperature profile at Srisamrong, Sukhothai, on 20 April. 2003: (a) 03 UTC, (b) 06 UTC, (c) 09 UTC

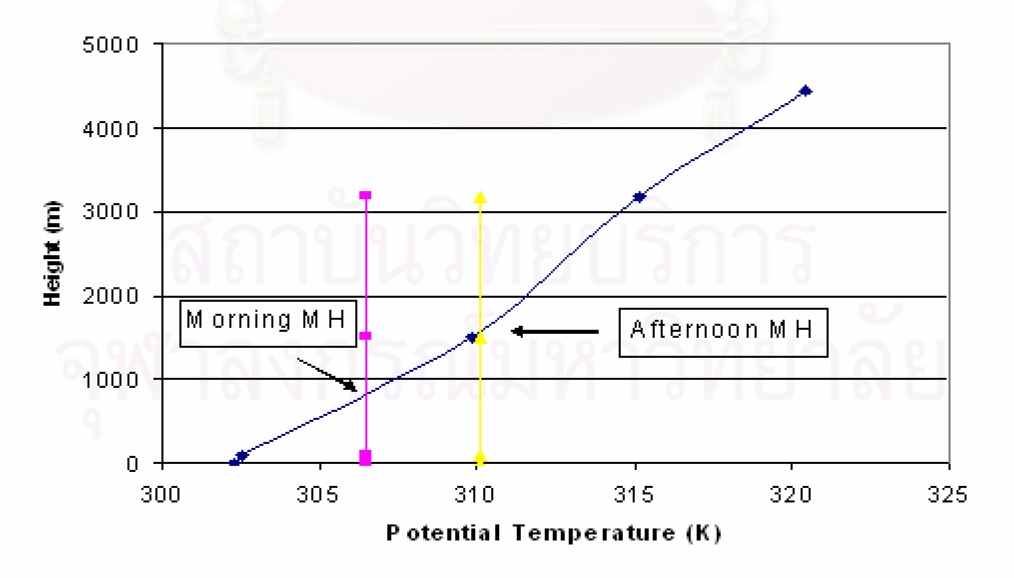


Figure 3.2: Illustration of the Holzworth method provides morning MH and afternoon MH. Potential temperature profile at Bangkok, 23 April. 2003, 00 UTC (07 LST)

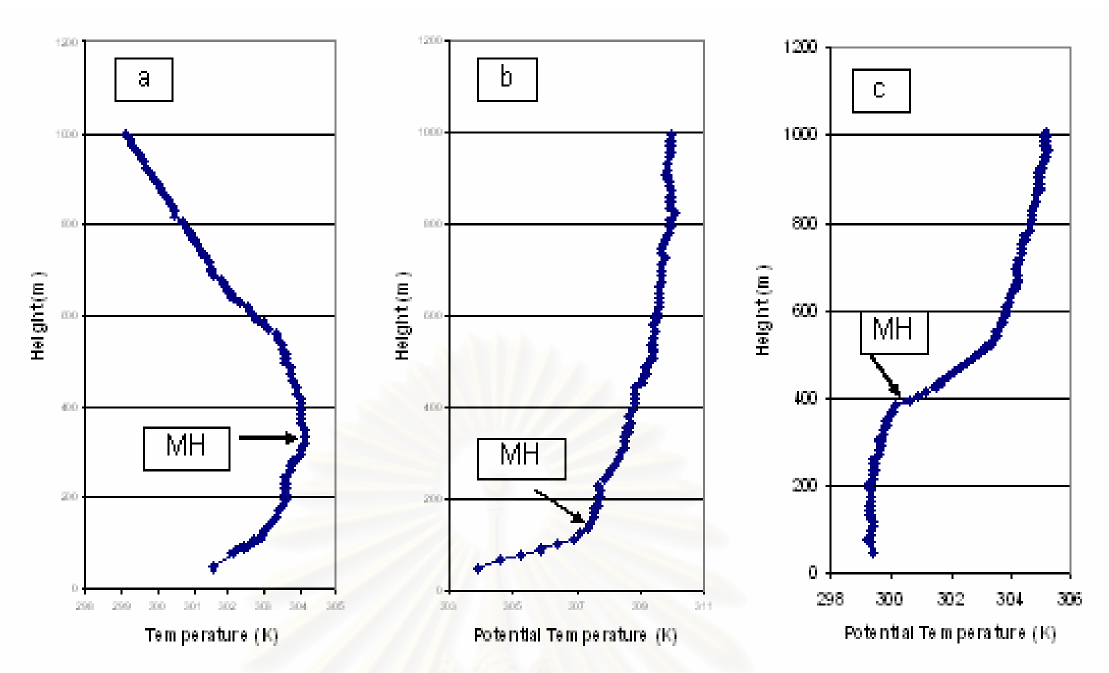


Fig. 3.3: Three ways for determining the reference mixing height from temperature profiles at Srisamrong, Sukhothai: (a) weak wind and strong stability, the height of the surface inversion (23 April. 2003, 15 UTC), (b) moderate wind, potential temperature nearly linear increase with height at lower level and weaker temperature gradient at upper level (21 April 2003, 15 UTC) and (c) strong winds, sharp potential temperature increase above MH (23 April 2003, 18 UTC).

3.3.2. Method for derived the mixing height from wind profiler measurements

The MH can be determined by a wind profiler from the signal-to-noise ratio (SNR). The return signal is received primarily from the inhomogeneities of the radio refractive index (Angevine et al., 1994). These inhomogeneities depend primarily on the fluctuations of the temperature and especially the moisture fields (White et al., 1991). Since there is often a humidity gradient between mixing layer (ML) and free atmosphere, a peak can be seen in wind profiler backscatter profile at the top of the mixing layer and SNR (Cohn and Angevine, 2000).

This study, the MH derived from SNR profile, it is to plot height cross-sections of the range corrected SNR and select the height of maximum SNR (Figure 3.4).This is the practical approach used by Berkowitz et al. (2005).

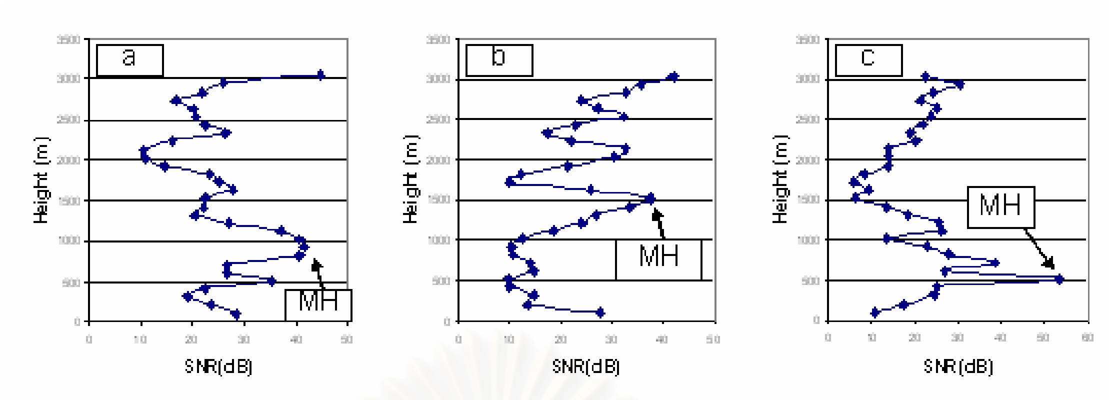


Figure 3.4: An example of the signal-to-noise ratio (SNR) profile on 24 April 2003 at Srisamrong, Sukhothai: (a) 00 UTC, (b) 09 UTC and (c) 21 UTC.

3.3.3 Mixing height estimated by empirical modules

PCRAMMET is a PC version of the original RAMMET (U.S. EPA 1998b) program. It can be employed to estimate surface parameters using to calculate a MH in the absence of appropriate upper air sounding data. This technique described in this outline uses PCRAMMET models to estimate the surface similarity parameters of friction velocity (u_*), sensible heat flux (H), temperature scale (θ_*), and Monin-Obukhov length (L) using routinely collected meteorological variables of cloud cover, wind speed, temperature and relative humidity. These parameters are subsequently used to determine daytime MH (convective boundary layer) and nighttime MH (stable boundary layer).

3.3.3.1 Daytime mixing height estimates.

Daytime refers to period from one hour after sunrise to one hour before sunset. The daytime MH or CBL mixing height is estimated using sensible heat flux, friction velocity, and Monin-Obukhov length. The Monin-Obukhov length is used to determine whether daytime MH estimates will be calculated using a neutral or an unstable MH equation. If the absolute value of the Monin-Obukhov length is greater than 100 meters, the neutral MH equation is used; otherwise, the unstable MH equation is employed.

1) Estimation of sensible heat flux in CBL.

During daytime convective conditions (L < 0), the surface of the earth is heated, resulting in an upward transfer of heat. Hourly estimates of this heat flux are required to estimate u_* and L. The sensible heat flux is estimated from cloud cover, air temperature, wind speed and relative humidity as described in section 3.2.

2) Estimation of friction velocity during neutral condition.

Under neutral condition, the value of friction velocity is based on the classical logarithmic wind profile:

$$u_{*_n} = \frac{kU}{\ln(z/z_0)} \tag{14}$$

where u_{*_n} is neutral friction velocity (m/s)

k is the von Karman constant = 0.4

U is wind speed (m/s)

z is wind measurement height (m)

z_0 is surface roughness length (m)

3) Estimation of friction velocity during unstable condition.

The analytical formula proposed by Wang and Chen (1980) is used to determine friction velocity during unstable conditions:

$$u_* = \frac{kU}{\ln(z/z_0)}\left[1 + d_1 \ln(1 + d_2 d_3)\right] \tag{15}$$

where u_* is friction velocity (m/s)

$d_1 = 0.128 + 0.005\ln(z/z_0)$ if $(z/z_0) \leq 0.01$

= 0.107 if $(z/z_0) \succ 0.01$

$d_2 = 1.95 + 32.6(z/z_0)^{0.45}$

$$d_3 = \left[\frac{H}{\rho C_p}\right]\left[\frac{kgz}{Tu_{*_n}^3}\right]$$

where H is sensible heat flux (Wm^{-2})

ρ is atmospheric density (kg/m^3)

C_p is specific heat constant pressure (J/Kkg)

g is acceleration due to gravity (9.8 m/s^2)

T is ambient air temperature (K)

The first term of the equation is based upon the classical logarithmic wind profile. The term in Brackets represents the correction for instability.

4) Estimation of Monin-Obukhov length.

The Monin-Obukhov length is related to the height below which mechanically generated turbulence dominates the buoyant production of turbulence. The mechanical production of turbulence energy results from the shearing action that occurs when the mean wind flow contact the ground. In contrast, the buoyant production of turbulence energy is the results from heating of the atmosphere adjacent to the ground. The mechanical and buoyant productions of turbulence energy are directly related to the friction velocity and sensible heat flux. The Monin-Obukhov length is defined as;

$$L = \frac{-u_*^3 T \rho C_p}{kgH} \qquad (16)$$

During unstable conditions L is negative, with condition becoming more unstable as L approaches zero. The Monin-Obukhov length becomes positive at night, as buoyant forces become negative and act to dampen mechanical turbulence.

5) Estimation of daytime mixing height.

For unstable conditions, the daytime mixing height (Z_i) is calculated using the sensible heat flux and friction velocity as proposed by Farmer (1991). The integrated sensible heat flux is calculated by summing the values for each hour after sun rise.

$$Z_i = \sqrt{Z_n^2 + 1400\sum_0^n H} \qquad (17)$$

$$Z_n = \frac{u_*}{4f}$$

Where f is Coriolis parameter

If the absolute value of the calculated Monin-Obukhov length is greater than 100 meter, the following expression is used to determine the neutral mixing height:

$$Z_n = \frac{u_{*_n}}{4f} \tag{18}$$

3.3.3.2 Nighttime mixing height estimates.

Nighttime refers to the period from one hour before sunset to one hour after sunrise. During stable conditions, the temperature scale is used to calculate the stable friction velocity, sensible heat flux, and Monin-Obukhov length are based on an approach outlined by Venkatram (1980), which are subsequently used to determine nighttime mixing height. If the absolute value of the Monin-Obukhov length is greater than 100 meter, the neutral mixing height equation is used.

1) Estimation of temperature scale.

The estimate temperature scale is based upon the method proposed by Holtslag and van Ulden (1985):

$$\theta_* = 0.09\left[1 - 0.5\left(\frac{TO}{10}\right)^2\right] \tag{19}$$

where TO is total opaque or total sky cover in tenths

2) Estimation of friction velocity.

The friction velocity is determined from formula that used in HPDM (Hanna and Chang, 1993) and CTDMPLUS (Perry, 1992):

$$u_* = \frac{C_D U}{2}\left[1 + \sqrt{1 - \left(\frac{2U_0}{\sqrt{C_D}U}\right)^2}\right] \quad \text{for } U \geq U_{cr} \tag{20}$$

where $C_D = \dfrac{k}{\ln(z/z_0)}$, $U_0 = \sqrt{\dfrac{\beta_m z g \theta_*}{T}}$ and β_m = 4.7is a dimensionless constant.

To obtain real-valued solutions for u_*, the following formula must to hold.

$$\frac{4U_0^2}{C_D U^2} \le 1 \tag{21}$$

If this condition holds, u_* is computed from Eq. 14. If this condition does not hold (under very stable conditions), the solution to the quadratic equation is imaginary, and a slightly different approach is taken.

Equality in the above condition corresponds to a minimum wind speed, U_{cr}, at which (and above) a real-valued solution to Eq. 14 is

$$U_{cr} = \sqrt{\frac{4\beta_m z g \theta_*}{T C_D}} \tag{22}$$

For this value, there is a corresponding friction velocity, U_{*cr}, such that

$$U_{*cr} = \frac{C_D U_{cr}}{2} \tag{23}$$

For wind speeds less than this critical value, Eq. 14 no longer yields a real-valued solution, and it is desirable to have $u_* \to 0$ as $U \to 0$. Therefore, for $U \prec U_{cr}$, u_{*cr} is scaled by the ratio U / U_{cr}, and u_* is calculated as

$$u_* = u_{*cr} \frac{U}{U_{cr}} \tag{24}$$

For U < U_{*cr}, van Ulden and Holtslag (1985) showed that there is a nearly linear variation of θ_* with u_*. Therefore, θ_* is similarly scaled as

$$\theta_* = \theta_{*cr} \frac{u_*}{u_{*cr}} \tag{25}$$

3) Estimation of sensible heat flux.

The sensible heat flux is estimated using the friction velocity and the temperature scale for the turbulent heat transfer using the following formula:

$$H = -\rho C_p u_* \vartheta_* \tag{26}$$

4) Estimation of Monin-Obukhov length.

The Monin-Obukhov length is determined from:

$$L = \frac{Tu_*^2}{kg\theta_*} \tag{27}$$

As noted above, the Monin-Obukhov length becomes positive at night, as buoyant force become negative and act to dampen maghanical turbulence.

5) Determination of nighttime mixing height.

The nighttime mixing height is estimated using the sensible heat flux and friction velocity during stable condition as proposed by Farmer (1991).

$$Z_{ST} = \frac{Z_n Z_0}{\sqrt[3]{Z_n^3 + Z_0^3}} \tag{28}$$

where $Z_0 = \dfrac{21500u_*^2}{\sqrt{|H|}}$, and $Z_n = \dfrac{u_*}{4f}$

If the absolute value of the calculated Monin-Obukhov length is greater than 100 meters, the following expression defines the neutral mixing height.

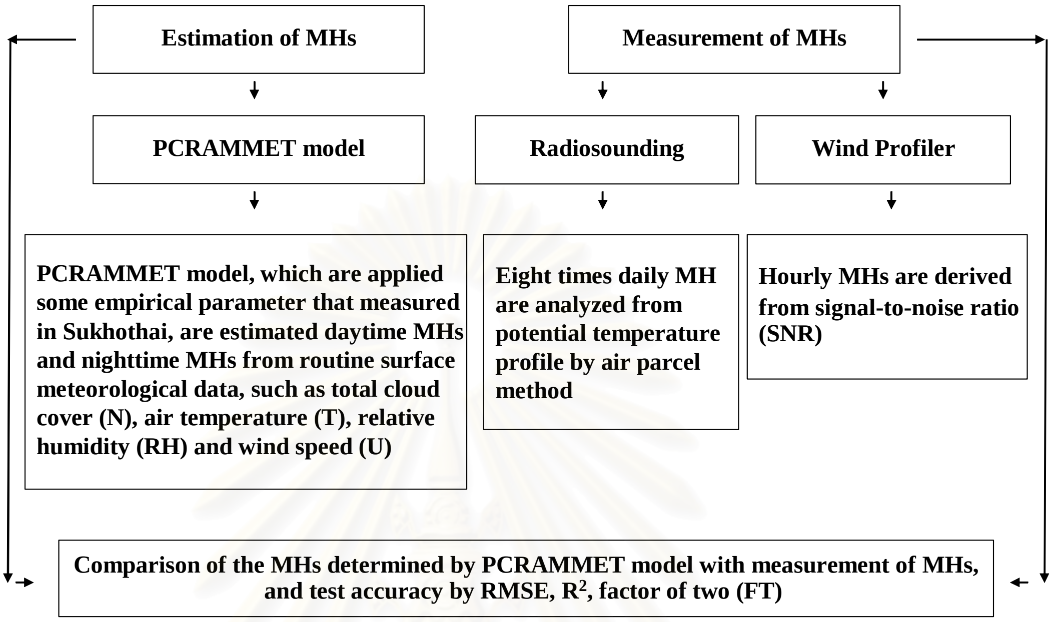
$$Z_n = \frac{u_*}{4f} \tag{29}$$

3.4 Study procedures

The procedures for this study (Figure 3.5), the MH values generated by model are compared to a MH from profile measurements (radiosounding and wind profiler). It can be described in terms of three primary objectives:

Procedures of study

Step 1- Study to determination MH in Sukhothai



Step 2 - Testing PCRAMMET model to determine MH in Bangkok, Chiang Mai, Ubonrachathani and Phuket

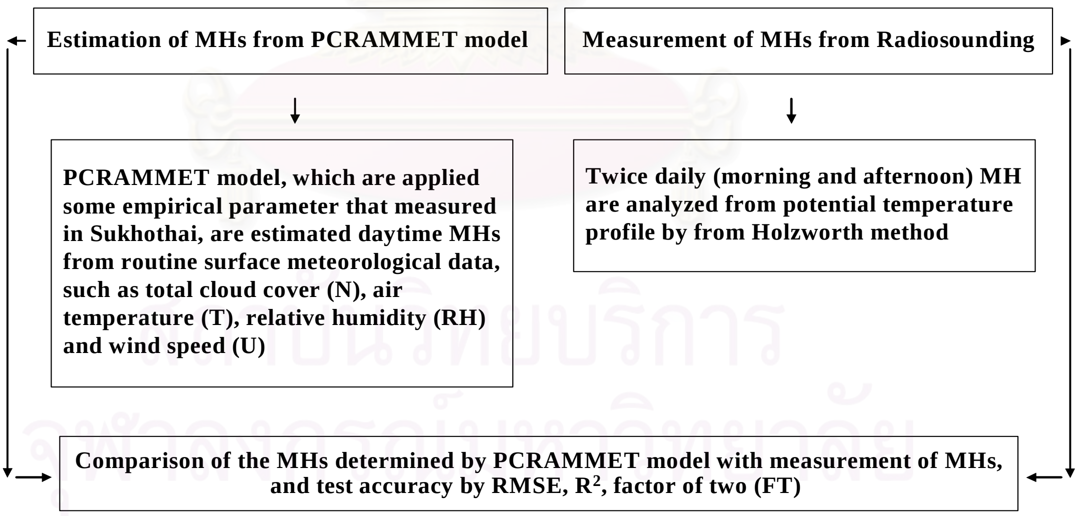


Figure 3.5: The study of procedures to estimate of MH using surface Meteorological data in Thailand

3.4.1 Estimated MH from model, which is applied empirical parameter that measurement in Thailand.

The empirical parameters of turbidity coefficients (a_1, a_2), cloudiness coefficients (b_1, b_2), surface heating coefficient (c_3), and fraction of the net radiation is absorbed at the ground (c_G), which is measured in Sukhothai, Thailand, are applied to estimated daytime sensible heat flux in PCRAMMET model. This model is used to estimate the surface similarity parameters of sensible heat flux (H), friction velocity (u_*), temperature scale (θ_*), and Monin-Obukhov length (L) using routinely collected meteorological variables of cloud cover (N), wind speed (U), temperature (T) and relative humidity (RH). These parameters are subsequently used to determine daytime and nighttime MH. Details of calculates MH is given in section 3.2 and 3.3.3

3.4.2 Comparison of the MH determined by model with measurement of radiosounding and wind profiler in Sukhothai, Thailand.

The MH calculated by empirical model in section 3.5.1 are compared to MH from measurement method with continuous profile information from wind profiler (LAP-3000) during 20 April to 6 June 2003, and eight times daily MH that analyze from radiosounding by air parcel method during 20 to 27 April and 28 May to 5 June 2003. The results of calculation are tested accuracy by root-mean-square errors (RMSE), correlation coefficient (R^2) and factor of two (FT) (Chang, J.C. and Hanna S.R., 2004). It was included in the BOOT Statistical Model Evaluation Software Package, Version 2.0 (Chang, J.C. and Hanna S.R., 2005)

$$RMSE = (\overline{(x-y)^2})^{0.5} \qquad (30)$$

where x is measurement value, y is calculate value.

$$FT = \frac{0.5x \prec n \prec 2x}{N} \times 100\% \qquad (31)$$

where x is measurements value, n is number of calculate value, N total number of measurements.

3.4.3 Using model to determine MH in other area of Thailand.

PCRAMMET meteorological pre-processor is used to determine MH in other area of Thailand, it is tested on data set of Thai Meteorological Department in Bangkok, Chiang Mai, Ubonratchathani and Phuket. The calculated values of MH are compared twice daily (morning and afternoon) mixing heights that analyze from radiosounding by Holzworth method during 20 April to 5 June 2003. The results of calculation are tested accuracy by root-mean-square errors (RMSE), correlation coefficient (R^2) and factor of two (FT).

CHAPTER IV

RESULTS AND DISCUSSION

The empirical parameters that used to estimation sensible heat flux had been developed on five years data set (2000 to 2004) of GAME-T and CEOP project site that measurement in rain fed paddy field at Srisamrong, Sukhothai. And, the most important methods of comparison between MH obtained from model and MH obtained from upper air profile measurement had been tested on data set from the Observatory for Atmospheric Radiation Research at Srisamrong, Sukhothai and data collected from Thai Meteorological Department (Bangkok, Chiang Mai, Ubonratchathani, and Phuket station) during 20 April to 6 June 2003. The results and discussion of this study are as followed:

4.1 Empirical parameters for Thailand

Five years data set (2000 to 2004) of GAME-T and CEOP project site measurement in rain fed paddy field at Sukhothai were applied to determine the empirical parameters of turbidity coefficients (a_1, a_2), cloudiness coefficients (b_1, b_2), surface heating coefficient (c_3). Furthermore, fraction of the net radiation is absorbed at the ground (c_G). These parameters were used to estimate daytime sensible heat flux in PCRAMMET model. The results of development of these empirical parameters are as followed:

4.1.1 Turbidity coefficients (a_1, a_2) and cloudiness coefficients (b_1, b_2)

The turbidity coefficients (a_1, a_2) and cloudiness coefficients (b_1, b_2) were used to parameterize the incoming solar radiation (Rs) by transmission of the atmosphere method that described in section 3.2.1. For four years (2000 to 2003) of observations of Rs for solar elevation $\phi \geq 10^{\circ}$ and total cloud cover in Sukhothai, Thailand were used to compute the coefficients a_1, a_2, b_1 and b_2 by means of a least square regression technique. These obtained a_1 = 1355 Wm^{-2}, a_2 = -167 Wm^{-2}, b_1 = -0.66 and b_2 = 2.9 (Figure 4.1), these value and cloud cover were used to estimate Rs in whole year 2004. The comparison of estimation Rs with whole year in 2004 of pyranometer measurements of Rs in Sukhothai were found good agreement (Figure 4.2), it appeared that an estimation error was 106 Wm^{-2} and R^2 was 0.87.

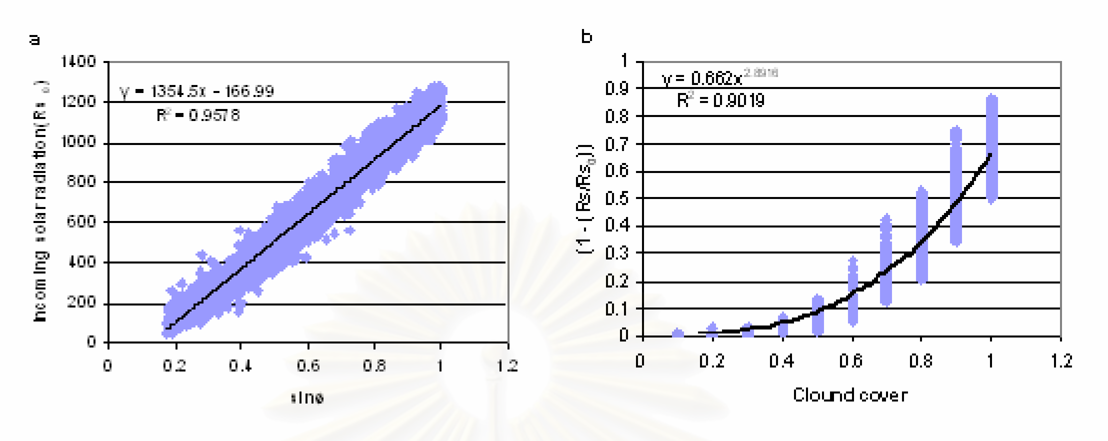


Figure.4.1: The value of (a) turbidity coefficients (a_1, a_2) and (b) cloudiness coefficients (b_1, b_2) was computed by means of a least square regression technique.

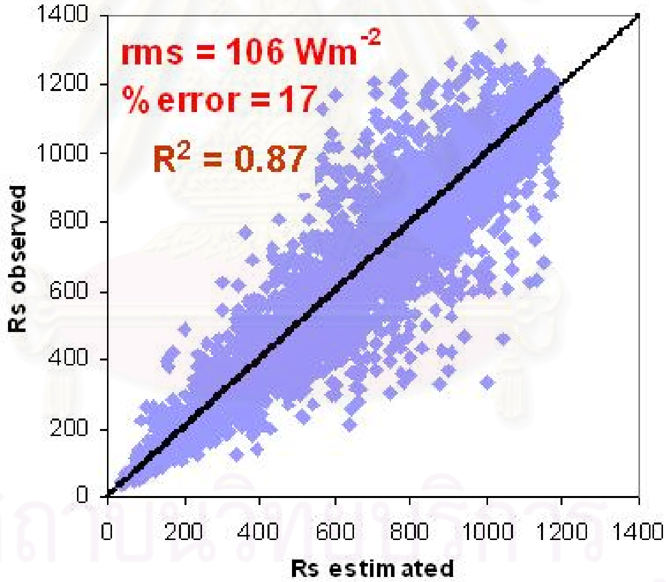


Figure 4.2: The comparison of 30 minutes average of measurement incoming solar radiation with estimated values at Sukhothai was given whole year 2004.

4.1.2 Surface heating coefficient (c_3)

The surface heating coefficient was used to parameterize the net radiation (Rn) in terms of surface radiation budget that described in section 3.2.2. For observation of the net radiation and the surface radiation temperature at Sukhothai during January to

April 2003 were used to computation c_3 by means of a least square regression technique. It obtained c_3 = 0.1 (Figure 4.3). This value, cloud cover, air temperature and solar radiation from section 4.1.1 were used to estimate Rn by Eq.9 in section 3.3.2. The comparisons of estimation Rn with whole year in 2004 of measurements of Rn in Sukhothai were found good agreement (Figure 4.4). It appeared that an estimation error was 68 Wm^{-2} and R^2 was 0.87.

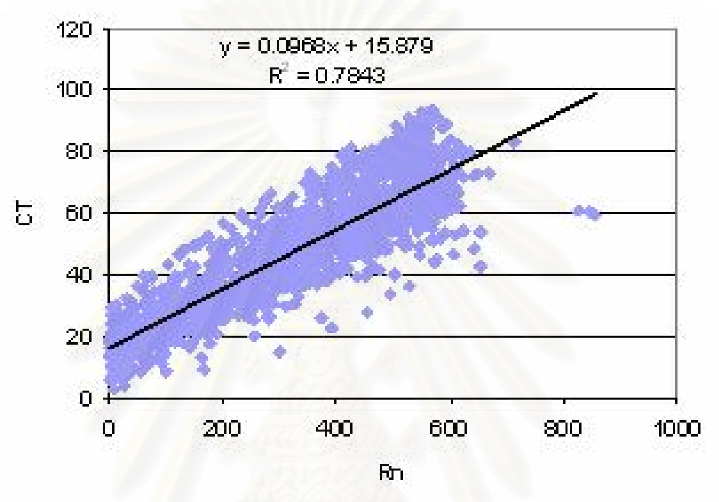


Figure 4.3: The correction term between CT ($4\sigma T^3(T_s - T)$) with half-hourly observation of the net radiation Rn and surface temperature (T_s) at paddy field at Sukhothai for some day on January to April 2003 without wind speed and cloud cover effect.

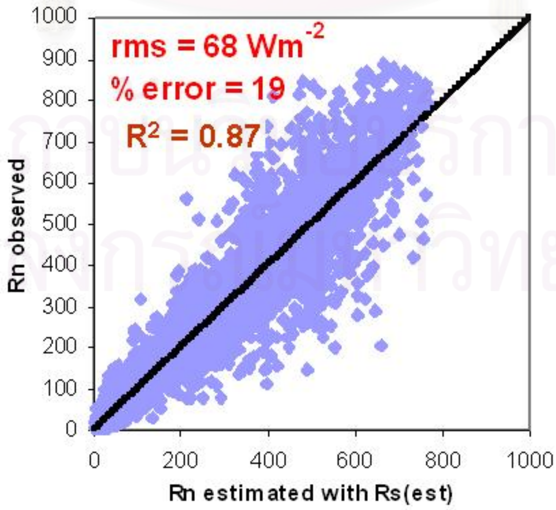


Figure 4.4: The comparison of measured half-hourly averages of the net radiation Rn with estimated values at Sukhothai was given whole year 2004.

4.1.3. Fraction of net radiation is absorbed at the ground (c_G)

The fraction of net radiation is absorbed at the ground (c_G) was used to parameterize the soil heat flux (G) that described in section 3.2.3. For four years observations of net radiation and soil heat flux at Sukhothai during 2000 to 2003 were used to computation c_G using means of a least square regression technique. These obtained c_G = 0.12 for dry season and c_G = 0.05 for wet season (Figure 4.5), and used these value and Rn in section 4.1.2 to estimate G in whole year 2004. The comparison of estimation G with whole year in 2004 of measurements of G at Sukhothai was found fine agreement (Figure 4.6). It appeared that an estimation error was 15 Wm^{-2} and R^2 was 0.64.

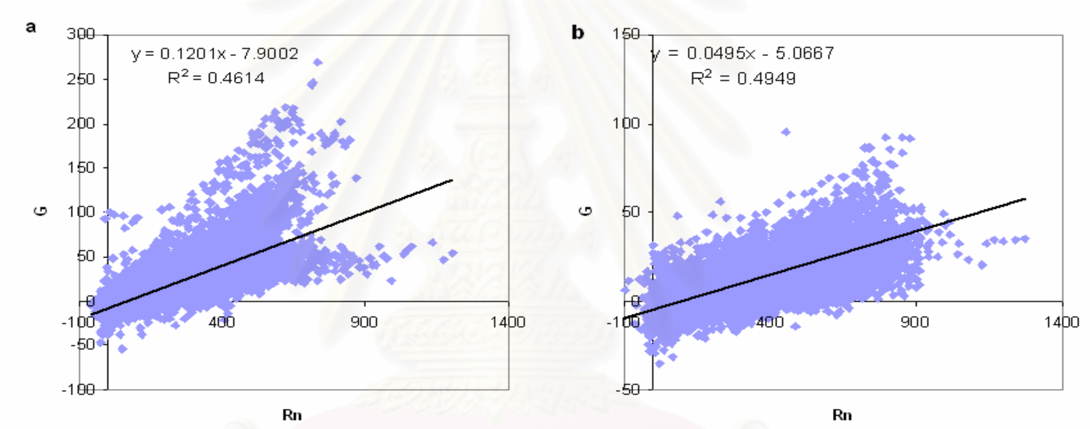


Figure 4.5: The value of fraction of the net radiation is absorbed at the ground (c_G) computed by means of a least square regression technique, (a) dry season, (b) wet season.

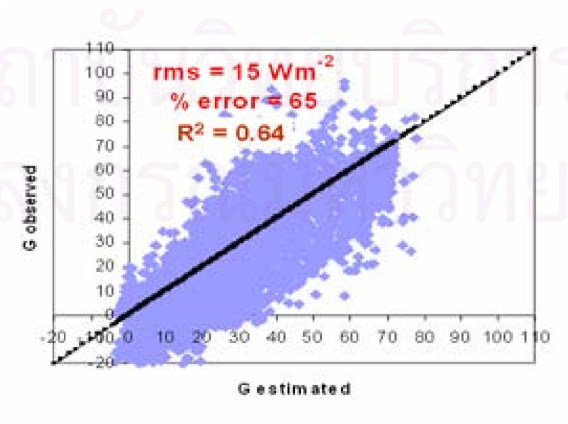


Figure 4.6: The comparison of 30 minutes average of measurement soil heat flux with estimated values at Sukhothai was given whole year 2004.

4.1.4 Estimation latent heat flux (λE) and sensible heat flux (H)

This section there will be compared the latent heat flux and sensible heat flux, which were calculated by method that described in Section 3.2.3 with the whole year 2004 of 30 minutes measurement of latent heat flux and sensible heat flux obtained from Bowen ratio energy balance technique (BREB) at Sukhothai. The comparison had been performed good agreement for latent heat flux (Figure 4.7) and fair agreement for sensible heat flux (Figure 4.8). It appeared that the estimation error was 83 Wm^{-2} and R^2 was 0.83 for latent heat flux, and the estimation error was 36 Wm^{-2} and R^2 was 0.45 for sensible heat flux.

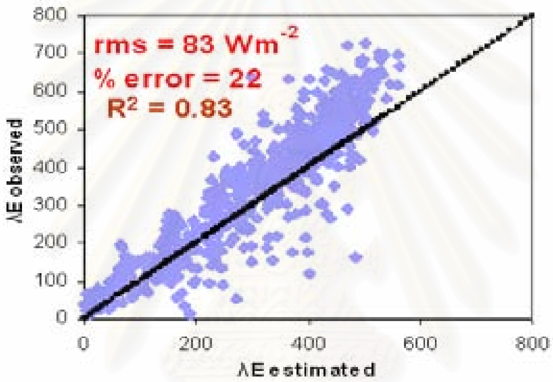


Figure 4.7: The comparison of the latent heat flux measured from Bowen ratio energy balance technique (BREB) with estimated value at Sukhothai was given whole year 2004.

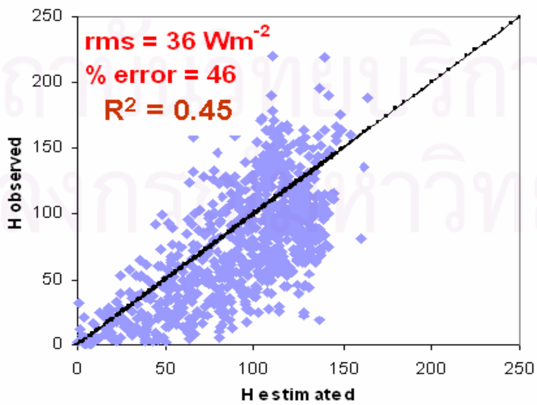


Figure 4.8: The comparison of the sensible heat flux measured from Bowen ratio energy balance technique (BREB) with estimated value at Sukhothai was given whole year 2004.

Because, the estimation of daytime sensible heat flux from parameters that development for Thailand was simplicity, the result of estimation was fair agreement with observations. Then, this method was useful for many applications in boundary layer meteorology and used to calculate daytime MH.

4.2 Estimated MH from model, which is applied empirical parameter that measurement in Thailand.

The PCRAMMET meteorological pre-processor model is applied to some empirical parameters for measurement in Sukhothai, Thailand, such as turbidity coefficients (a_1, a_2), cloudiness coefficients (b_1, b_2), surface heating coefficient (c_3), and fraction of the net radiation which is absorbed at the ground (c_G), are calculated the surface similarity parameters of friction velocity (u_*), sensible heat flux (H), temperature scale (θ_*), and Monin-Obukhov length (L) using routinely collected meteorological variables of cloud cover, wind speed, temperature and relative humidity. These parameters are subsequently used to determine daytime MH (convective boundary layer) and nighttime MH (stable boundary layer), which is calculated by using the sensible heat flux and friction velocity as proposed by Farmer (1991). The results are presented in an Appendix A.

4.3 Comparison between the MH derived from wind profiler and MH obtained from upper air sounding.

The comparison of two measurement MH methods using daytime data indicates a very good agreement between the results of MH obtained from radiosounding by parcel method with wind profiler derived MHs (Figure 4.9a), and quietly fair agreement in nighttime MH (Figure 4.9b). Because the MH from wind profiler, it was derived in step levels, which are about 100 metes with different rang. Meanwhile, the MH from radiosounding is continuation profile. It will be over analysis in wind profiler. However, there are good agreement between the results of MH obtained from radiosounding and MH obtained from wind profiler, when there were analyzed together between daytime and nighttime data (Figure 4.9c).

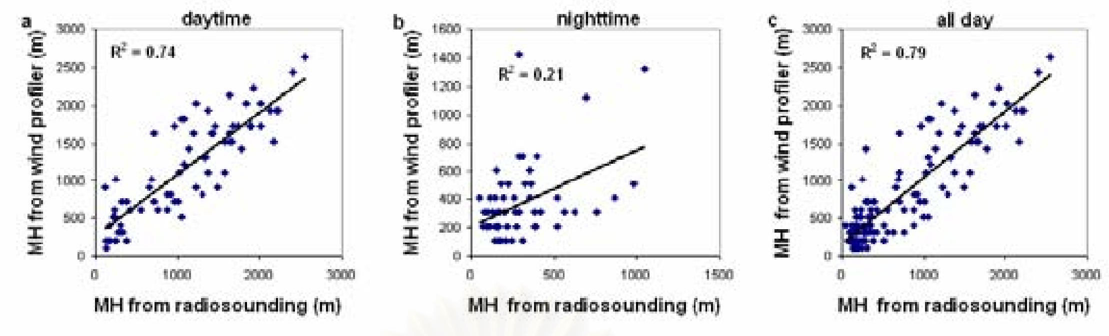


Figure 4.9: The comparison between the MH derived from wind profiler and MH obtained from upper air sounding, (a) daytime MH with R^2 = 0.74, (b) nighttime MH with R^2 = 0.21, and (c) all daytime MH and nighttime MH with R^2 = 0.79.

4.4 Comparison of the MH determined by model with profile measurement in Sukhothai.

The MH that was calculated by model was compared with MH for the measurement method with continuous profile information from wind profiler (LAP-3000). It was derived from signal-to-noise ratio (SNR), during 20 April to 6 June 2003 and eight times daily MH that analyze from radiosounding by air parcel method during 20 to 27 April and 28 May to 5 June 2003.

4.4.1 Daytime mixing height

The comparison of daytime MHs determined by model with profile measurement indicates a fine agreement between the results of the MHs calculated by model with MHs analyze from radiosounding by parcel method, as well as with MHs evaluated continuous profile information from wind profiler, which derived from SNR (Figure 4.10, and 4.11). The model appears estimated error that root mean square error (RMSE) is 699 meters for radiosounding and 720 meters for wind profiler. While there is a clear correlation between the two comparisons, there is also considerable scatter with correlation coefficient R^2 = 0.38 for radiosounding and R^2 = 0.26 for wind profiler. When there is considers an accuracy of model from factor of two (FT), there are found 75% accepted for radiosounding and 80% for wind profiler.

In addition, the MHs from model over predicts, on average from acceptable values by nearly 27% for radiosounding and 19% for wind profiler. The over estimation is usually appeared in morning until noon of the day, which has fog, mist or haze occurred, moreover it is appeared in the day has raining occurred (Figure 4.12).

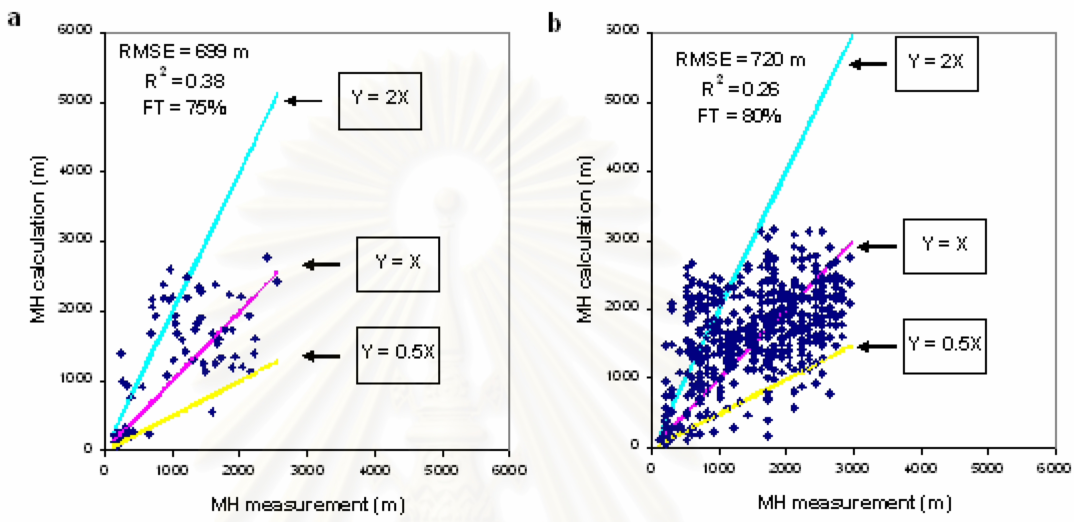


Figure 4.10: The comparison of the daytime MHs taken from the profile measurement with values was calculated by model in Sukhothai, (a) radiosounding during 20 to 27 April and 28 May to 5 June 2003, (b) wind profiler (LAP-3000) during 20 April to 6 June 2003.

Where, there is phenomenon of mist and/or haze occurred in morning until noon during 20 to 23 and 25 April (report from Sukhothai Weather Observation). The atmosphere was in low temperature, high moisture and table condition of atmospheric stability, the MH will be lower than the normal case, and the MH from model will be over estimate MHs (Figure 4.12). For the raining phenomena on 2 to 3 June (report from Sukhothai Weather Observation), the atmosphere was in low temperature, high moisture and stable condition of atmospheric stability, while the wind speed is strong during rain fall, it will be make over estimation of MH (Figure 4.12).

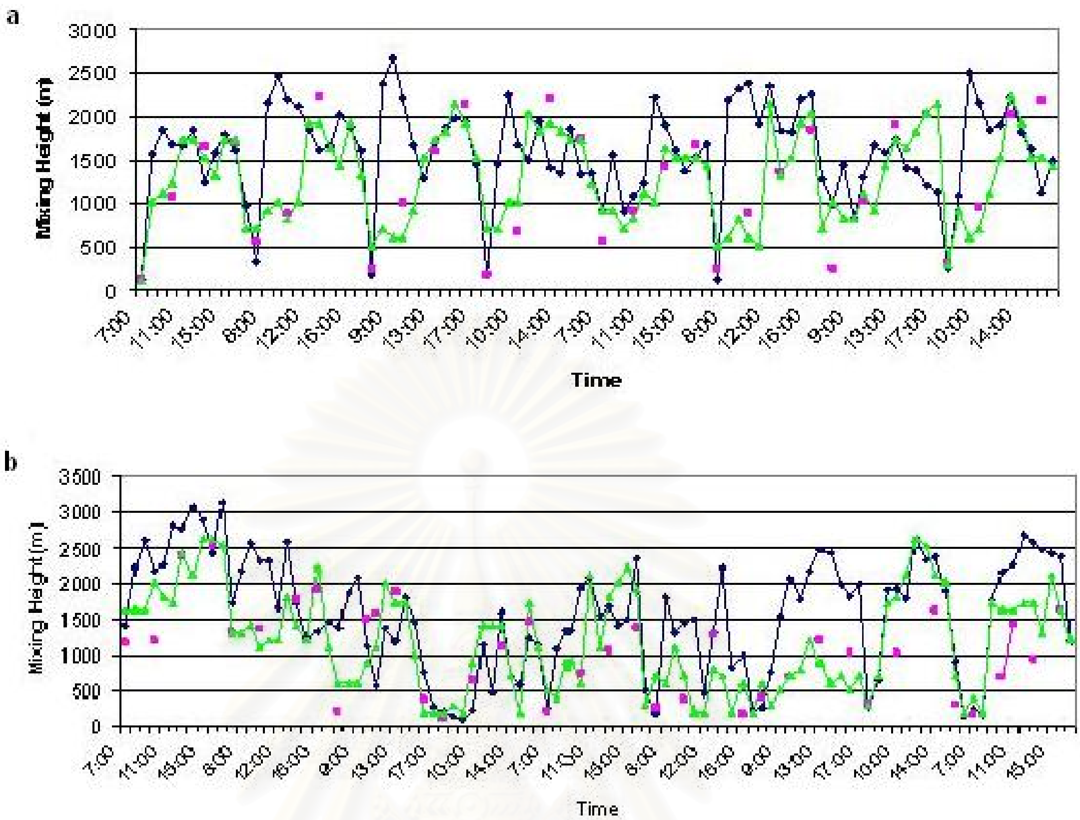


Figure 4.11: The comparison between the MHs calculated by model (blue line), and obtained from profile measurement with wind profiler (green line), and upper air soundings (pink dot), (a) during 20 to 27 April 2003, (b) 28 May to 5 June 2003.

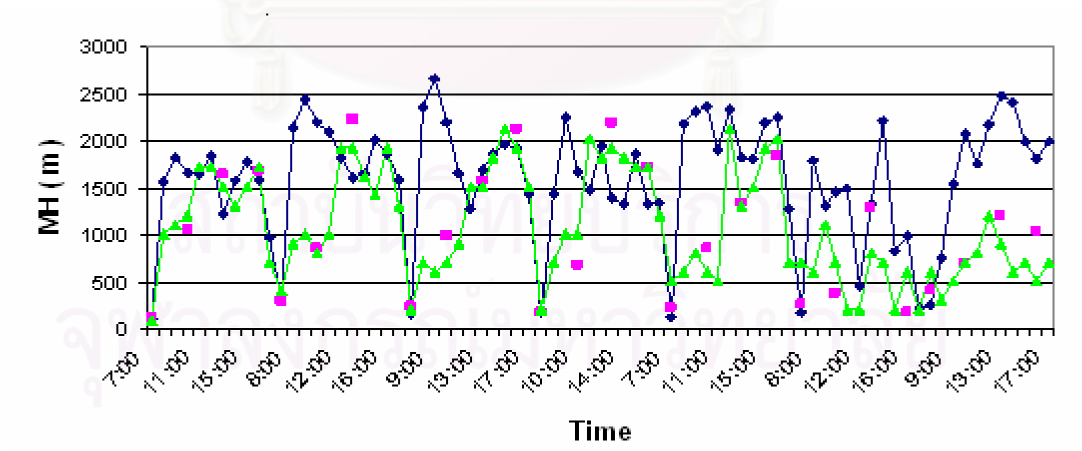


Figure 4.12: The over estimation MH, is affected from mist and/or haze during 20 to 23, 25 April 2003 and 2 to 3 June 2003. Note: MHs from calculation (blue line), MHs from measurement (green line, pink dot)

For this case, we found that it came from the affect of wind speed is a key parameter of the model using determined MH. It shows a fine correlation coefficient (R^2 = 0.54) between calculated MH and wind speed (Figure 4.13a), and quietly fair correlation coefficient (R^2 = 0.28) between calculated MH and temperature (Figure 4.13b). While, the temperature is control the value of measured MH, it shows a fine correlation coefficient (R^2 = 0.56) between the measured MH and the temperature (Figure 4.13d). It also shows the quietly fair correlation coefficient (R^2 = 0.16) between the measured MH and the wind speed (Figure 4.13c). It represented that the model uncertainly predicted MH, when consideration only wind speed parameter, which is the main parameter to control the estimation MH model. It is a good correlation with MH calculation, but quietly fair correlation with MH measurement.

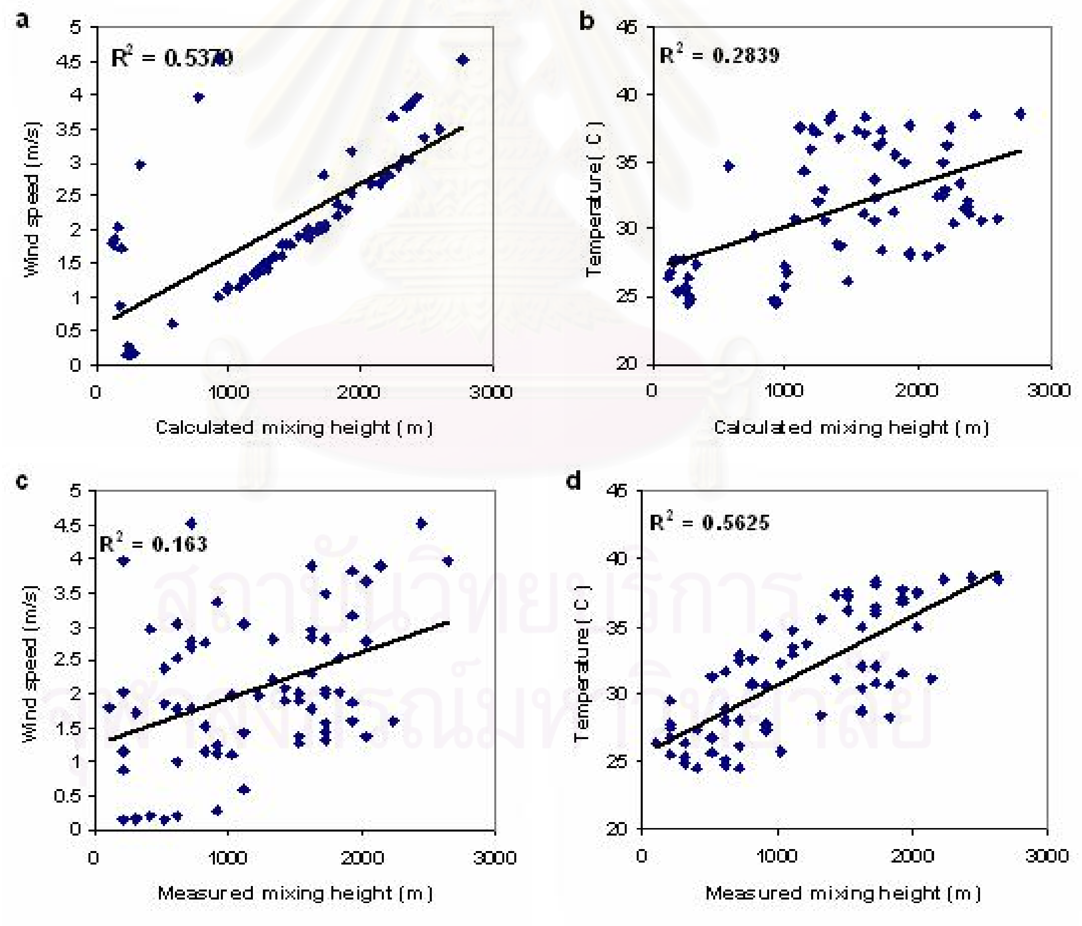


Figure 4.13: The correlation between input parameters and MH, (a) calculation of MH and wind speed, (b) calculation of MH and temperature, (c) measurement of MH and wind speed, (d) measurement of MH and temperature.

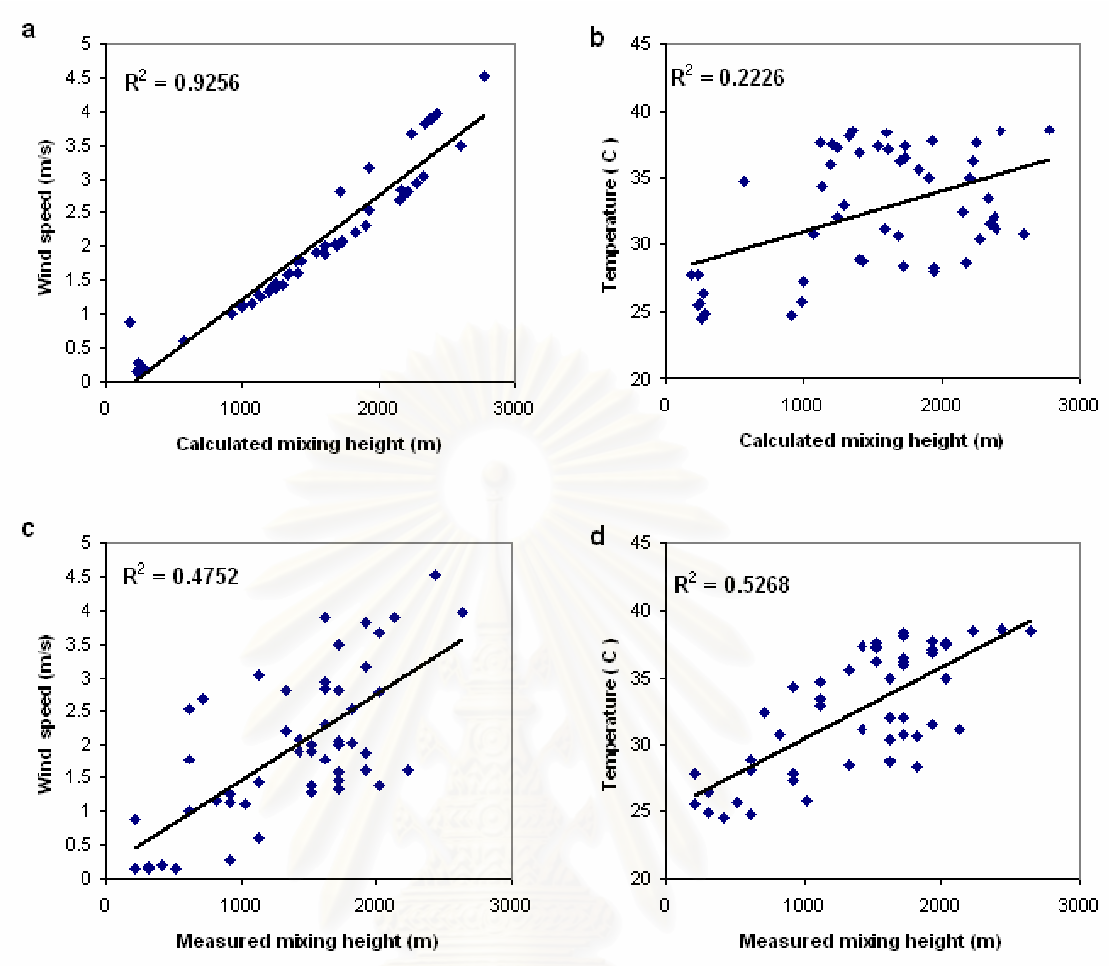


Figure 4.14: The correlation between input parameters and MH after the deleted data of the day has mist, haze and raining phenomena, (a) calculation of MH and wind speed, (b) calculation of MH and temperature, (c) measurement of MH and wind speed, (d) measurement of MH and temperature.

When the deleted data of the day has mist, haze and raining phenomena, the very good correlation coefficient (R^2 = 0.92) between the calculated MH and the wind speed (Figure 4.14a), quietly fair correlation coefficient (R^2 = 0.22) between calculated MH and temperature (Figure 4.14b), fine correlation coefficient (R^2 = 0.47) between measured MH and wind speed (Figure 4.14c), and fine correlation (R^2 = 0.53) between measured MH and temperature (Figure 4.14d) were founded. For quietly fair correlation coefficient between calculated MH and temperature was come from an error of estimated sensible heat flux that one of two key parameters are using to calculate MH.

For the fact of nature phenomena, MH is not controlled only by wind speed parameter, but also it will be controlled by temperature, humidity and sensible heat flux Then, there will be the test multi-regression between MH and wind speed, and temperature by SPSS software (detail of output give in Appendix C). There are found that fine relationship between MH and parameter of wind speed and temperature. It appears that the R^2 is 0.64 for MH calculation and R^2 is 0.59 for MH measurement. After delete data of the day has mist, haze and raining phenomena. The good relationship between MH and parameter of wind speed and temperature was found. It appears that the R^2 is 0.93 for MH calculation and R^2 is 0.70 for MH measurement.

4.4.2 Nighttime mixing height

The comparison of nighttime MHs is indicated with fair agreement between the results of the MHs calculated by the model and MHs analyzed from radiosounding by parcel method, and with MHs evaluated continuous profile information from wind profiler by deriving from SNR (Figure 4.15 and 4.16). The model appears estimated error that root mean square error (RMSE) is 407 meters for radiosounding and 315 meters for wind profiler. While there is a clear correlation between the two comparisons, there is also considerable scatter with correlation coefficient R^2 = 0.37 for radiosounding and R^2 = 0.19 for wind profiler. When there is considers an accuracy of model from factor of two (FT), there are found 57% accepted for radiosounding and 62% for wind profiler.

In addition, the calculation MH has under estimate, on average from acceptable value, by nearly 40% for radiosounding and 55% for wind profiler. The under estimation is usually appeared in midnight until morning of the day. In this time, the wind speed usually is calm and low value. It will be make a calculation of MHs is vary low, when compared with measurement MHs (Figure 4.16b).

Moreover, the estimation of temperature scale (θ_*), which is a key parameter of nighttime MH model, is not applied parameter that measurement in Thailand. Then, the results of calculated nighttime MH may be not being accurate when comparing to the results of estimated daytime MH.

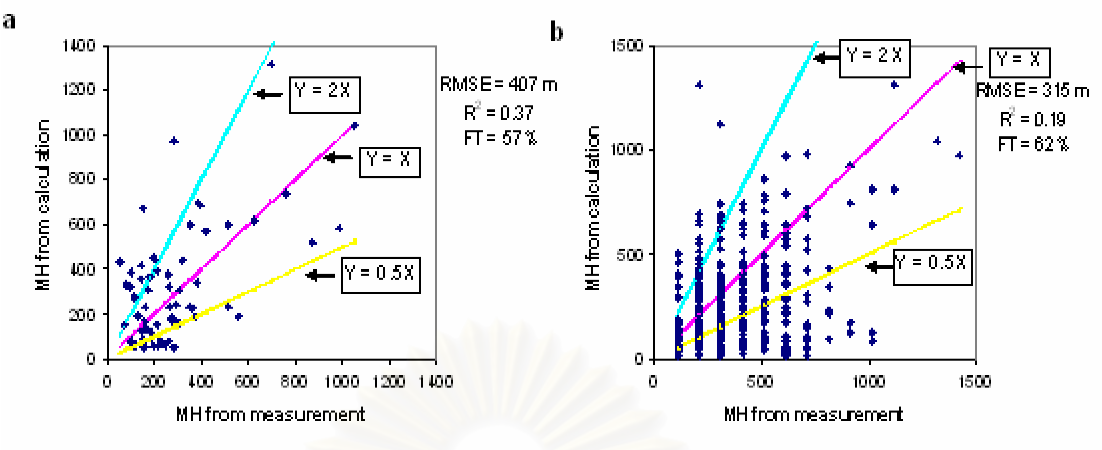


Figure 4.15: The comparison between the nighttime MHs taken from the profile measurement with values was calculated by model in Sukhothai, (a) radiosounding during 20 to 27 April and 28 May to 5 June 2003, (b) wind profiler (LAP-3000) during 20 April to 6 June 2003.

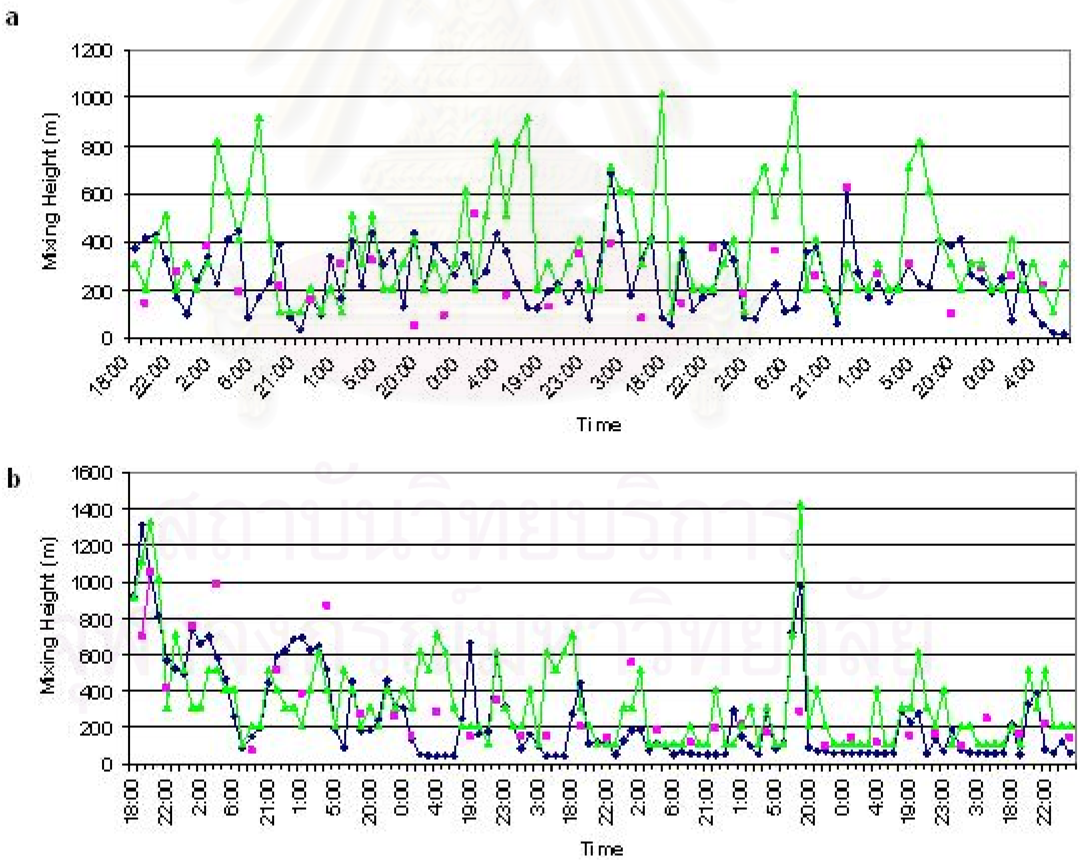


Figure 4.16: The comparison between the nighttime MHs calculated by model (blue line), and obtained from profile measurement with wind profiler (green line) and upper air soundings (pink dot), (a) during 20 to 27 April 2003, (b) 28 May to 5 June 2003.

4.5 Using model to determine MH in other area of Thailand.

The model, which is used to apply to some empirical parameters tot measured at Sukhothai, is used to determine MH in other areas of Thailand. The data set of Thai Meteorological Department at Bangkok, Chiang Mai, Ubonratchathani and Phuket is used to testing. There are testing on difference terrain, urban area for Bangkok, valley area for Chiang Mai, high land paddy field for Ubonratchathani, and coaster area for Phuket. The details of condition that was used for calculation was given in Appendix D. The calculated values of MH are compared with twice a day (morning and afternoon) MHs, that analyze from radiosounding by Holzworth method during 20 April to 5 June 2003. The results of calculation are presented in Appendix B, the comparison as follow.

4.5.1 Comparison of MHs in Bangkok

The comparison of morning MHs and afternoon MHs obtained from upper air soundings by Holzworth method with values calculated by model, is indicated fair agreement (Figure 4.17 and 4.18). The root mean square error (RMSE) of estimation is 1011 meters. While there is a clear correlation between the two comparisons, there is also considerable scatter with correlation coefficient R^2 = 0.25. When there is considers an accuracy of model from factor of two (FT), there are found 71% accepted. In addition, the calculation model over predicts the MHs, on the average from the acceptable values, by nearly 40%.

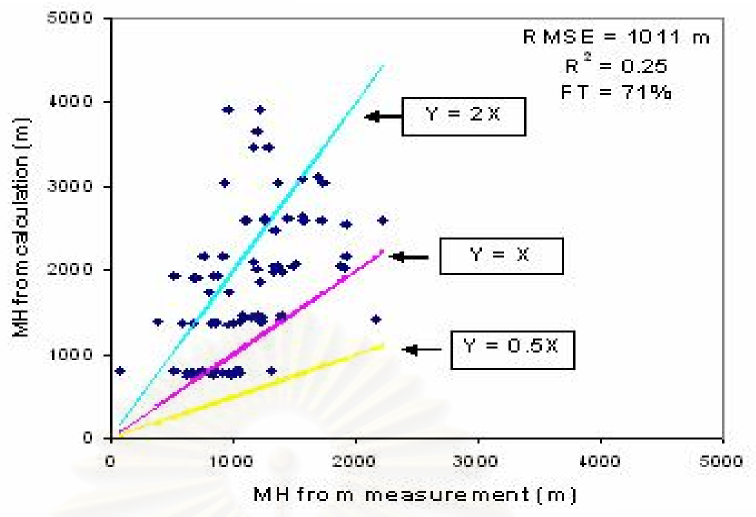


Figure 4.17: The comparison of the morning MHs and afternoon MHs obtained from upper air soundings by Holzworth method with values was calculated by PCRAMMET model in Bangkok during 23 April to 6 June 2003.

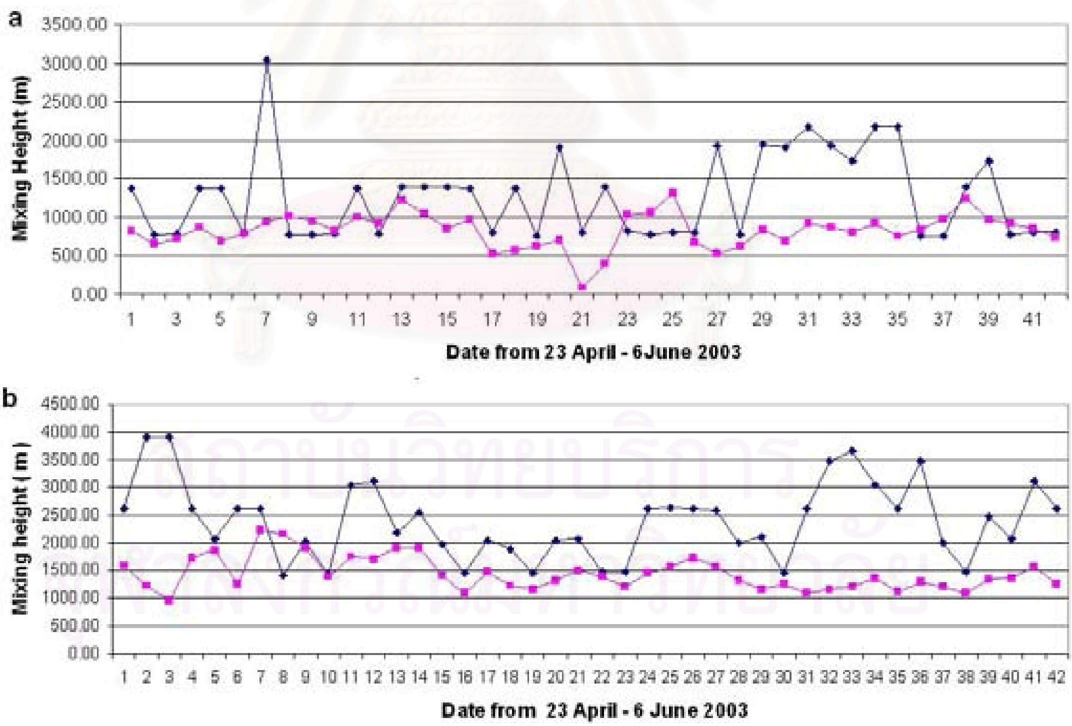


Figure 4.18: The comparison of the MHs obtained from upper air soundings by Holzworth method (pink line) with values was calculated by model (blue line) in Bangkok during 23 April to 6 June 2003, (a) morning MHs, (b) afternoon MHs

4.5.2 Comparison of MHs in Chiang Mai.

The comparison of morning MHs and afternoon MHs obtained from upper air soundings by Holzworth method with values was calculated by model, is indicated fair agreement (Figure 4.19 and 4.20). The root mean square error (RMSE) of estimation is 792 meters. While there is a clear correlation between the two comparisons, there is also considerable scatter, correlation coefficient R^2 = 0.22. When there is considers an accuracy of model from factor of two (FT), there are found 80% accepted. In addition, the calculation model over predicts the MHs, on the average from the acceptable values, by nearly 22%.

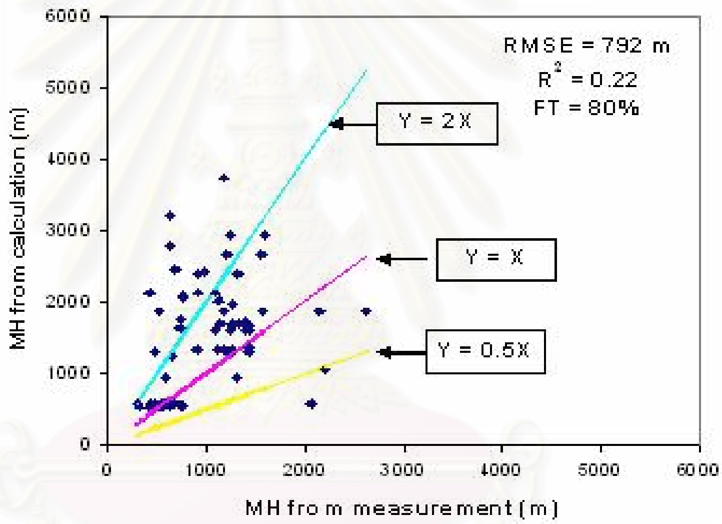


Figure 4.19: The comparison between the morning MHs and afternoon MHs obtained from upper air soundings by Holzworth method with values was calculated by the model in Chiang Mai during 20 April to 6 June 2003.

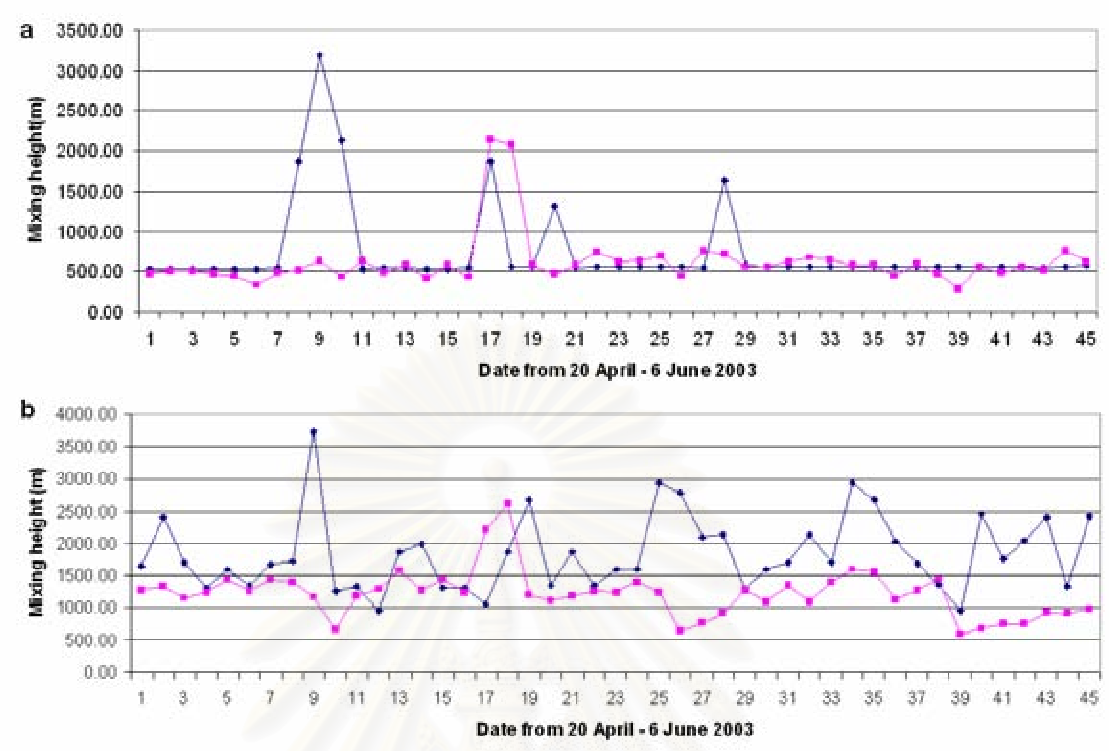


Figure 4.20: The comparison of the MHs obtained from upper air soundings by Holzworth method (pink line) with values was calculated by model (blue line) in Chiang Mai during 20 April to 6 June 2003, (a) morning MHs, (b) afternoon MHs

4.5.3 Comparison of MHs in Ubonratchathani

The comparison of morning MHs and afternoon MHs obtained from upper air soundings by Holzworth method with values was calculated by model, is indicated fine agreement (Figure 4.21 and 4.22). The root mean square error (RMSE) of estimation is 647 meters. While there is a clear correlation between the two comparisons, there is also considerable scatter with correlation coefficient R^2 = 0.37. When there is considers an accuracy of model from factor of two (FT), there are found 73% accepted. In addition, the calculation model over predicts the MHs, on the average from the acceptable values, by nearly 36%.

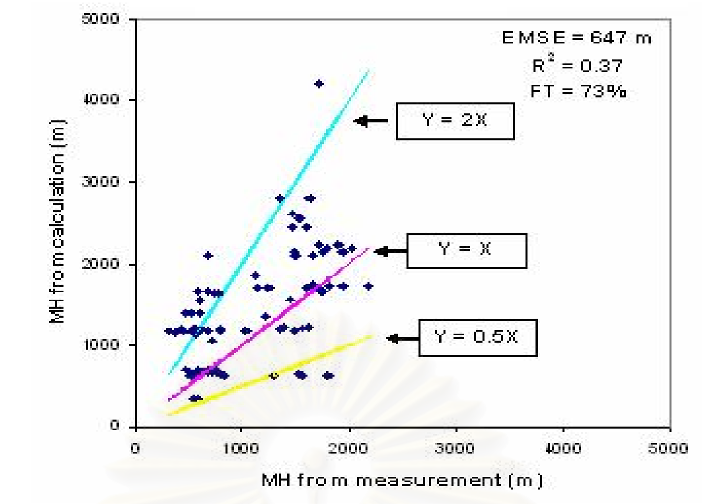


Figure 4.21: The comparison of the morning MHs and afternoon MHs obtained from upper air soundings by Holzworth method with values was calculated by model in Ubonratchathani during 20 April to 6 June 2003.

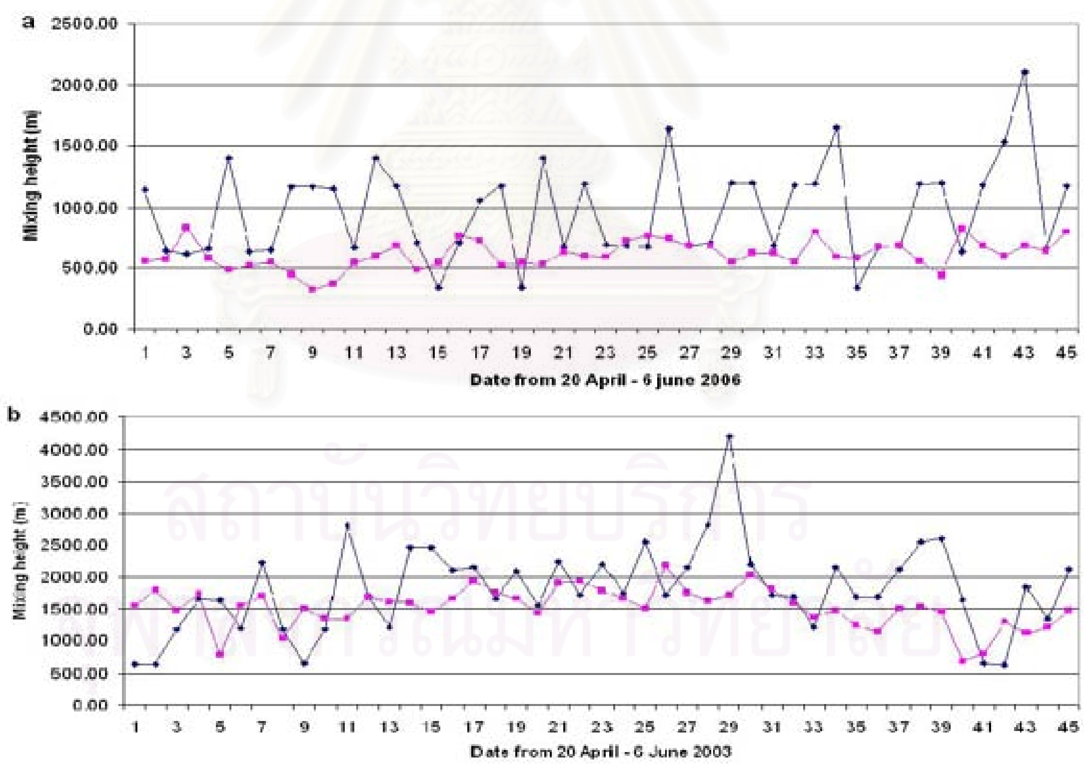


Figure 4.22: The comparison of the MHs obtained from upper air soundings by Holzworth method (pink line) with values was calculated by model (blue line) in Ubonratchathani during 20 April to 6 June 2003, (a) morning MHs, (b) afternoon MHs

4.5.4 Comparison of MHs in Phuket

The comparison of morning MHs and afternoon MHs obtained from upper air soundings by Holzworth method with values calculated by model, is indicated fair agreement (Figure 4.23 and 4.24). The root mean square error (RMSE) of estimation is 1945 meters. While there is a clear correlation between the two comparisons, there is also considerable scatter with correlation coefficient R^2 = 0.29. When there is considers an accuracy of model from factor of two (FT), there are found 65% accepted. In addition, the calculation model over predicts the MHs, on the average from the acceptable values, by nearly 50%.

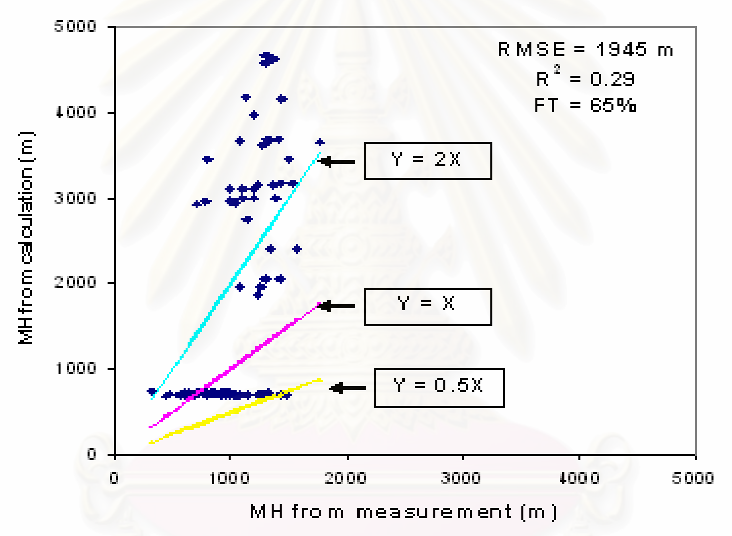


Figure 4.23: The comparison between the morning MHs and afternoon MHs obtained from upper air soundings by Holzworth method with values was calculated by model in Phuket during 20 April to 6 June 2003.

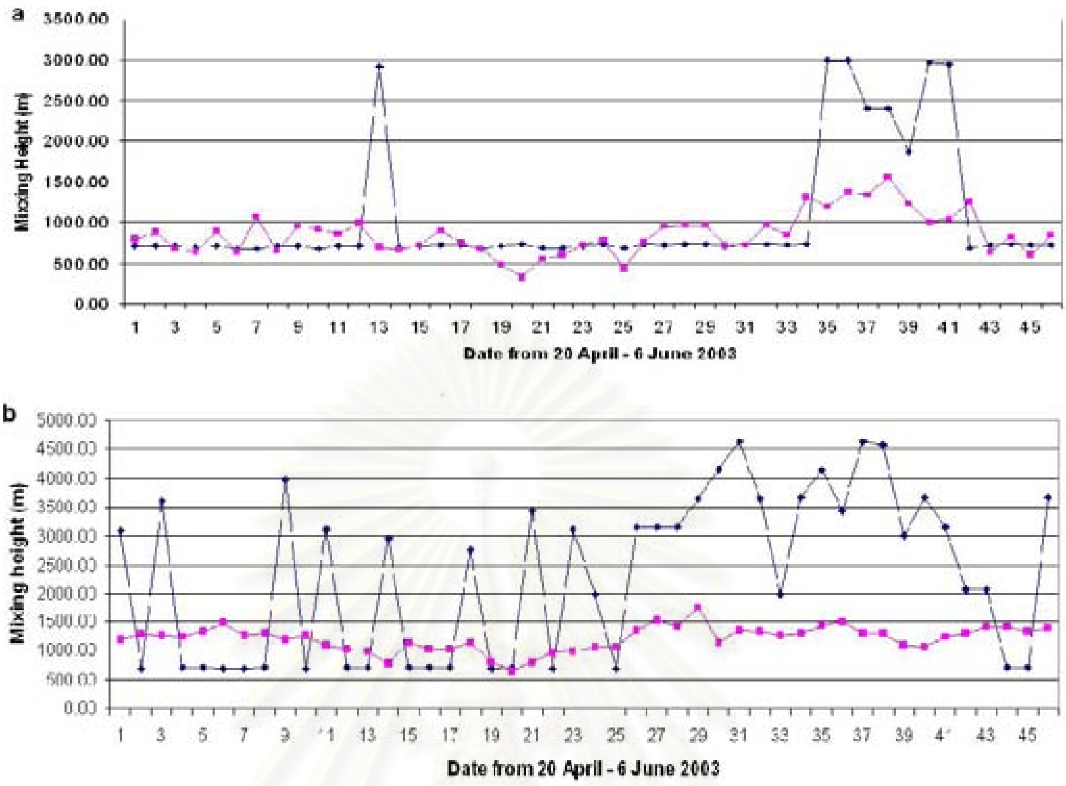


Figure 4.24: The comparison of the MHs obtained from upper air soundings by Holzworth method (pink line) with values is calculated by model (blue line) in Phuket during 20 April to 6 June 2003, (a) morning MHs, (b) afternoon MHs

The over estimation of comparison between MHs obtained from model and MHs obtained by Holzworth method from upper air soundings in Bangkok, Chiang Mai, Ubonratchathani and Phuket. These are mainly appeared in afternoon MHs. Especially occurred on raining day that has strong wind and low temperature. Because the wind speed is a key parameter to control MHs by calculated from the model (Figure 4.25a), while MHs from radiosounding is controlled by temperature (Figure 4.25b). Moreover the over estimation at Bangkok may be occurred from the local condition of the input data. The model data were generated by the meteorological pre-processor PCRAMMET for the location of the urban meteorological station, Bangkok Metropolises. While the measurement data are coming from the measurements conducted at the Bang Na agrometrological station, which is rural location. Then the result of calculation with urban condition is found greater than the measurement values. For the Phuket station, it found that the over estimation is found greater than other stations; it comes from Coriolis parameter (*f*). The Coriolis force at Phuket is less than other stations. When using the formulae $Z_n = u_* / f$ to calculate MHs, it gave the result more than other sites. Moreover, Phuket is a coaster terrain, which has cold marine air flows inland due to the sea breeze. The higher density cold air flows underneath the warmer inland air, forming the inversion configuration (warm air over cold air) and has low mixing height.

For the morning MHs, it is a good estimation, when the wind speed is calm (wind speed not more than 1 Knot or 0.5 m/s), show in figure 4.26.

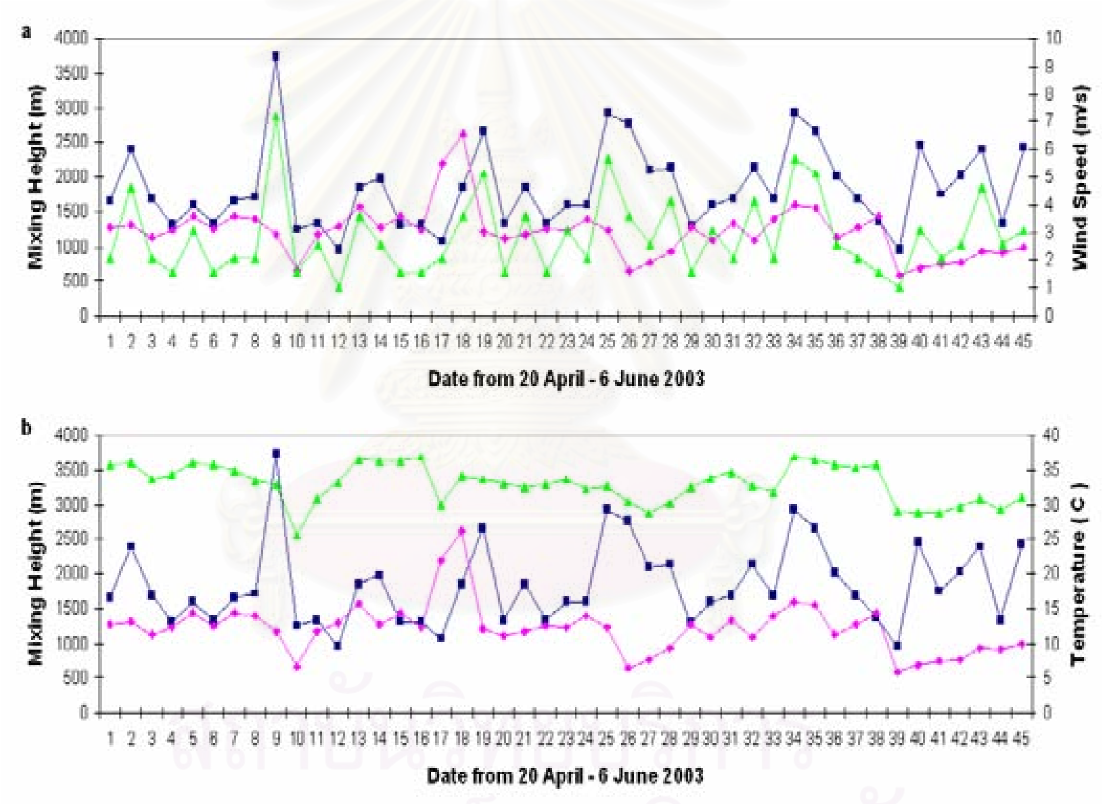


Figure 4.25: The comparison between input parameter, which has effected to afternoon MHs are obtained from the model (blue line) and MHs obtained by Holzworth method from upper air soundings (pink line) at Chiang Mai, (a) Temperature (green line), (b) wind speed (green line)

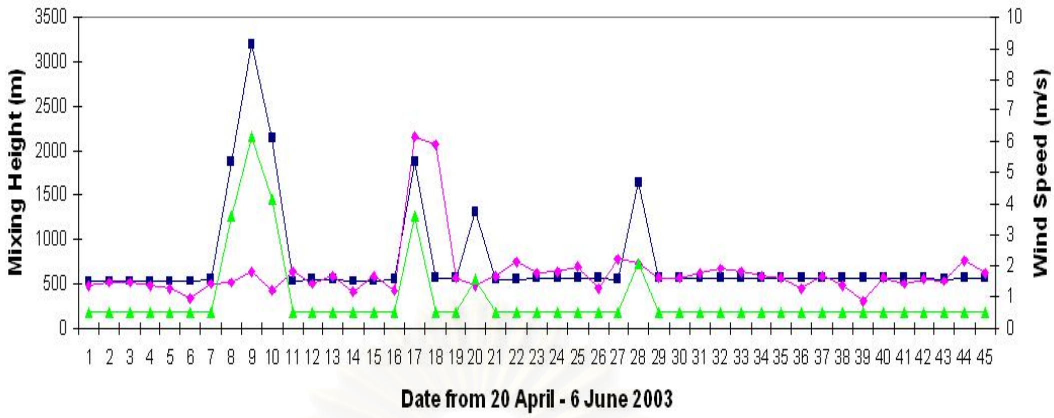


Figure 4.26: The comparison between wind speed (green line), afternoon MHs that obtained from model (blue line) and by Holzworth method from upper air soundings (pink line) at Chiang Mai.

CHAPTER V

SUMMARY AND CONCLUSIONS

This paper indicates the development empirical parameters of turbidity coefficients (a_1, a_2), cloudiness coefficients (b_1, b_2), surface heating coefficient (c_3), and fraction of the net radiation is absorbed at the ground (c_G), that measurement in rain fed paddy field at Srisamrong, Sukhothai. These parameters are used to estimate the daytime sensible heat flux in PCRAMMET model. This model was used to determine the surface similarity parameters of sensible heat flux (H), friction velocity (u_*), temperature scale (θ_*), and Monin-Obukhov length (L) from the surface meteorological data. These parameters were subsequently used to calculation daytime and nighttime MH.

5.1 Development empirical parameters for Thailand

Five years data set (2000 to 2004) of GAME-T and CEOP project site that measurement in rain fed paddy field at Sukhothai were applied to determine the empirical parameters for Thailand. It found that the empirical parameters of turbidity coefficients (a_1, a_2) = 1355 Wm^{-2} for a1 and = -167 Wm^{-2} for a_2, cloudiness coefficients (b_1, b_2) = - 0.66 for b_1 and = 2.9 for b_2, surface heating coefficient (c_3) = 0.1, and fraction of the net radiation is absorbed at the ground (c_G) = 0.12 for dry season and c_G = 0.05 for wet season. These parameters were tested by estimation of the daytime sensible heat flux on full year 2004 in the rain fed paddy field at Srisamrong, Sukhothai. Because of the estimation of daytime sensible heat flux from parameters that development for Thailand was simplicity, and the result of estimation was fair agreement with observations. Then, we can conclude that these parameters are useful for many applications in boundary layer meteorology, and can be applied to the model that used to calculates the daytime MH.

5.2 Determination mixing height in Thailand

The results of estimation MH are compared to MH from measurement method in the continuous profile information from wind profiler (LAP-3000), which derived from signal-to-noise ratio (SNR), during 20 April to 6 June 2003 and eight times daily MH was analyzed from radiosounding by air parcel method between measurement on 20 to 27 April and 28 May to 5 June 2003 at Sukhothai Thailand. After that, the PCRAMMET model will be apply these empirical parameters, were tested to calculate MH in other areas of Thailand. There were tests on difference terrain, urban area for Bangkok, valley area for Chiang Mai, high land paddy field for Ubonratchathani, coaster area for Phuket during 20 April to 6 June 2003.

. Because MH is a key parameter for air pollution models, it determines the volume available for the dispersion of pollutants. Moreover, the comparison of the calculated MHs with measured MHs at Sukhothai is indicated fine agreement for daytime MH and fair agreement for nighttime MH. After test the model, which applied these empirical parameters to estimate daytime MH in other areas with different terrain such as urban area for Bangkok, valley area for Chiang Mai, high land paddy field for Ubonratchathani , coaster area for Phuket. These are indicated with the fine agreement for Ubonratchathani, and fair agreement for Bangkok, Chiang Mai and Phuket. The results of estimation MH were tested accuracy by factor of two (FT), it found that the percentage of acceptable was about 60 – 80 %. Then we can conclude that:

(1) The PCRAMMET model, which was applied the empirical parameters of turbidity coefficients (a_1, a_2), cloudiness coefficients (b_1, b_2), surface heating coefficient (c_3), and fraction of the net radiation is absorbed at the ground (c_G), can be used to parameterize the surface similarity parameters of sensible heat flux (H), friction velocity (u_*), temperature scale (θ_*), and Monin-Obukhov length (L) from the surface meteorological data. These parameters can be used to calculate the daytime MH in other areas of Thailand with the absence of appropriate upper air sounding data.

(2) The results of model have been over estimated for the daytime MH and under estimated for the nighttime MH. The over estimation is usually occurred during the day with fog, mist, haze and rain phenomena; it is a limit of the model.

(3) The nighttime MH, there would be study about estimation of temperature scale (θ_*) because temperature scale is a key parameter of the nighttime MH model. It would be develop the empirical parameter for measurement in Thailand to estimate of temperature scale.

(4) The results of calculation MH at Bangkok and Phuket have more estimation error, and then they would be more study about the terrain condition that input to the model.

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APPENDIX A

Table shows Estimated MH from PCRAMMET meteorological pre-processor model at Sukhothai

Table A-1: Daytime MH at Srisamrong Sukhothai during 20 April to 6 June 2003

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
20-04-03	7:00	120.38	137.00	108.00
20-04-03	8:00	1559.83		1019.00
20-04-03	9:00	1840.06		1120.00
20-04-03	10:00	1670.02	1074.00	1221.00
20-04-03	11:00	1653.98		1727.00
20-04-03	12:00	1842.09		1727.00
20-04-03	13:00	1240.93	1644.00	1525.00
20-04-03	14:00	1575.64		1323.00
20-04-03	15:00	1788.84		1727.00
20-04-03	16:00	1603.03	1688.00	1727.00
20-04-03	17:00	976.63		715.00
21-04-03	7:00	328.93	560.00	715.00
21-04-03	8:00	2144.01		918.00
21-04-03	9:00	2448.99		1019.00
21-04-03	10:00	2191.88	875.00	817.00
21-04-03	11:00	2102.79		1019.00
21-04-03	12:00	1838.84		1930.00
21-04-03	13:00	1609.95	2229.00	1930.00
21-04-03	14:00	1665.35		1626.00
21-04-03	15:00	2010.70		1434.00
21-04-03	16:00	1864.82		1930.00
21-04-03	17:00	1607.81		1323.00
22-04-03	7:00	161.30	246.00	513.00
22-04-03	8:00	2373.95		715.00
22-04-03	9:00	2666.67		614.00
22-04-03	10:00	2201.13	1005.00	614.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
22-04-03	11:00	1666.25		918.00
22-04-03	12:00	1283.79		1525.00
22-04-03	13:00	1694.99	1586.00	1727.00
22-04-03	14:00	1869.93		1828.00
22-04-03	15:00	1965.66		2132.00
22-04-03	16:00	1932.90	2128.00	1930.00
22-04-03	17:00	1451.11		1525.00
23-04-03	7:00	177.44	179.00	715.00
23-04-03	8:00	1454.39		715.00
23-04-03	9:00	2249.98		1019.00
23-04-03	10:00	1678.51	683.00	1019.00
23-04-03	11:00	1489.32		2031.00
23-04-03	12:00	1942.61		1828.00
23-04-03	13:00	1403.79	2201.00	1930.00
23-04-03	14:00	1338.88		1828.00
23-04-03	15:00	1861.46		1727.00
23-04-03	16:00	1333.86	1734.00	1727.00
23-04-03	17:00	1348.23		1221.00
24-04-03	7:00	920.03	554.00	918.00
24-04-03	8:00	1546.69		918.00
24-04-03	9:00	909.05		715.00
24-04-03	10:00	1074.63	919.00	817.00
24-04-03	11:00	1223.71		1120.00
24-04-03	12:00	2220.70		1019.00
24-04-03	13:00	1898.92	1427.00	1626.00
24-04-03	14:00	1605.65		1525.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
24-04-03	15:00	1374.15		1525.00
24-04-03	16:00	1539.99	1672.00	1525.00
24-04-03	17:00	1678.52		1424.00
25-04-03	7:00	128.41	239.00	513.00
25-04-03	8:00	2184.26		614.00
25-04-03	9:00	2316.90		817.00
25-04-03	10:00	2371.29	873.00	614.00
25-04-03	11:00	1911.76		513.00
25-04-03	12:00	2338.97		2132.00
25-04-03	13:00	1831.41	1347.00	1323.00
25-04-03	14:00	1811.04		1525.00
25-04-03	15:00	2196.03		1930.00
25-04-03	16:00	2242.79	1846.00	2031.00
25-04-03	17:00	1290.45		715.00
26-04-03	7:00	989.75	245.00	1019.00
26-04-03	8:00	1440.63		817.00
26-04-03	9:00	819.53		817.00
26-04-03	10:00	1291.75	1018.00	1120.00
26-04-03	11:00	1654.86		918.00
26-04-03	12:00	1570.23		1424.00
26-04-03	13:00	1730.30	1891.00	1727.00
26-04-03	14:00	1394.08		1626.00
26-04-03	15:00	1387.73		1828.00
26-04-03	16:00	1203.86	2021.00	2031.00
26-04-03	17:00	1124.02		2132.00
27-04-03	7:00	269.39	306.00	311.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
27-04-03	8:00	1093.06		918.00
27-04-03	9:00	2502.50		614.00
27-04-03	10:00	2148.38	951.00	715.00
27-04-03	11:00	1842.78		1120.00
27-04-03	12:00	1895.22		1525.00
27-04-03	13:00	2214.78	2012.00	2233.00
27-04-03	14:00	1816.03		1930.00
27-04-03	15:00	1622.71		1525.00
27-04-03	16:00	1121.32	2175.00	1525.00
27-04-03	17:00	1485.41		1424.00
28-04-03	7:00	997.66	112.00	918.00
28-04-03	8:00	430.81		817.00
28-04-03	9:00	1396.00		412.00
28-04-03	10:00	2072.45		912.00
28-04-03	11:00	809.92		1019.00
28-04-03	12:00	1554.38		513.00
28-04-03	13:00	1993.46		1930.00
28-04-03	14:00	1803.82		1727.00
28-04-03	15:00	1226.76		1727.00
28-04-03	16:00	705.64		1727.00
28-04-03	17:00	1130.93		1828.00
29-04-03	7:00	195.75		311.00
29-04-03	8:00	755.31		513.00
29-04-03	9:00	1018.01		614.00
29-04-03	10:00	1248.89		1120.00
29-04-03	11:00	1745.61		817.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
29-04-03	12:00	1465.97		1828.00
29-04-03	13:00	1827.56		2031.00
29-04-03	14:00	1667.37		2132.00
29-04-03	15:00	2911.25		2132.00
29-04-03	16:00	2598.21		2233.00
29-04-03	17:00	1520.83		2436.00
30-04-03	7:00	197.22		614.00
30-04-03	8:00	779.20		614.00
30-04-03	9:00	1429.45		715.00
30-04-03	10:00	1584.26		1221.00
30-04-03	11:00	1783.49		2739.00
30-04-03	12:00	2226.33		2739.00
30-04-03	13:00	1621.38		2537.00
30-04-03	14:00	1773.72		2537.00
30-04-03	15:00	1277.92		1727.00
30-04-03	16:00	1413.70		1828.00
30-04-03	17:00	1609.35		1930.00
01-05-03	7:00	185.66		311.00
01-05-03	8:00	1423.03		817.00
01-05-03	9:00	1848.88		918.00
01-05-03	10:00	2173.52		513.00
01-05-03	11:00	1993.17		311.00
01-05-03	12:00	2087.18		311.00
01-05-03	13:00	2314.18		513.00
01-05-03	14:00	2199.43		513.00
01-05-03	15:00	1833.36		1019.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
01-05-03	16:00	2072.58		1626.00
01-05-03	17:00	2105.93		311.00
02-05-03	7:00	1007.84		614.00
02-05-03	8:00	1613.57		1626.00
02-05-03	9:00	1453.66		1221.00
02-05-03	10:00	1392.00		1323.00
02-05-03	11:00	1750.33		2233.00
02-05-03	12:00	2217.80		2233.00
02-05-03	13:00	1909.18		2638.00
02-05-03	14:00	1630.57		2334.00
02-05-03	15:00	1755.76		2233.00
02-05-03	16:00	1671.76		2537.00
02-05-03	17:00	726.88		1019.00
03-05-03	7:00	1485.39		1424.00
03-05-03	8:00	1787.57		2334.00
03-05-03	9:00	2114.83		2031.00
03-05-03	10:00	2399.02		2436.00
03-05-03	11:00	2113.99		1727.00
03-05-03	12:00	1838.80		2232.00
03-05-03	13:00	2131.60		2840.00
03-05-03	14:00	1750.98		2233.00
03-05-03	15:00	2354.62		2537.00
03-05-03	16:00	2441.82		1828.00
03-05-03	17:00	2530.34		1828.00
04-05-03	7:00	1489.52		1221.00
04-05-03	8:00	1941.91		1221.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
04-05-03	9:00	1427.53		817.00
04-05-03	10:00	2168.41		2436.00
04-05-03	11:00	2259.94		2436.00
04-05-03	12:00	2272.55		2436.00
04-05-03	13:00	1991.86		1930.00
04-05-03	14:00	2126.42		2233.00
04-05-03	15:00	1771.13		2537.00
04-05-03	16:00	2190.98		2638.00
04-05-03	17:00	2497.13		2739.00
05-05-03	7:00	752.20		715.00
05-05-03	8:00	824.85		614.00
05-05-03	9:00	1813.23		1019.00
05-05-03	10:00	2442.52		2840.00
05-05-03	11:00	2477.65		2537.00
05-05-03	12:00	2251.57		2537.00
05-05-03	13:00	2428.00		2840.00
05-05-03	14:00	1900.18		2334.00
05-05-03	15:00	1869.31		2031.00
05-05-03	16:00	1659.48		2031.00
05-05-03	17:00	1495.60		1930.00
06-05-03	7:00	1209.54		715.00
06-05-03	8:00	1761.46		918.00
06-05-03	9:00	2088.14		1019.00
06-05-03	10:00	2273.09		918.00
06-05-03	11:00	2253.14		1019.00
06-05-03	12:00	2113.18		1828.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
06-05-03	13:00	1955.02		1828.00
06-05-03	14:00	2554.21		2436.00
06-05-03	15:00	1901.35		2334.00
06-05-03	16:00	2084.25		2941.00
06-05-03	17:00	1231.29		2233.00
07-05-03	7:00	1422.50		614.00
07-05-03	8:00	2259.51		513.00
07-05-03	9:00	2323.25		1221.00
07-05-03	10:00	1907.72		2739.00
07-05-03	11:00	1592.70		2638.00
07-05-03	12:00	1894.64		2537.00
07-05-03	13:00	1274.77		2334.00
07-05-03	14:00	1346.34		2233.00
07-05-03	15:00	2270.65		2840.00
07-05-03	16:00	1522.43		2537.00
07-05-03	17:00	816.03		2132.00
08-05-03	7:00	845.01		311.00
08-05-03	8:00	920.85		817.00
08-05-03	9:00	2162.62		614.00
08-05-03	10:00	2299.58		513.00
08-05-03	11:00	2025.04		513.00
08-05-03	12:00	1476.15		2537.00
08-05-03	13:00	1789.23		2840.00
08-05-03	14:00	1607.84		2840.00
08-05-03	15:00	1438.51		1120.00
08-05-03	16:00	1789.15		2638.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
08-05-03	17:00	1151.22		1626.00
09-05-03	7:00	515.33		513.00
09-05-03	8:00	1583.30		513.00
09-05-03	9:00	1861.75		513.00
09-05-03	10:00	2190.47		918.00
09-05-03	11:00	2080.84		210.00
09-05-03	12:00	1466.90		614.00
09-05-03	13:00	1939.53		210.00
09-05-03	14:00	2036.10		311.00
09-05-03	15:00	2169.72		1120.00
09-05-03	16:00	1496.13		1525.00
09-05-03	17:00	1425.53		2233.00
10-05-03	7:00	1381.30		1120.00
10-05-03	8:00	1522.21		1120.00
10-05-03	9:00	1457.80		1019.00
10-05-03	10:00	1241.42		715.00
10-05-03	11:00	1345.74		614.00
10-05-03	12:00	1377.72		1019.00
10-05-03	13:00	803.59		2638.00
10-05-03	14:00	928.09		2436.00
10-05-03	15:00	1738.20		2132.00
10-05-03	16:00	1716.72		2334.00
10-05-03	17:00	2349.81		1930.00
12-05-03	7:00	860.77		715.00
12-05-03	8:00	1118.69		918.00
12-05-03	9:00	999.08		715.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
12-05-03	10:00	1892.25		2739.00
12-05-03	11:00	1977.80		2638.00
12-05-03	12:00	1762.47		2739.00
12-05-03	13:00	1937.92		2840.00
12-05-03	14:00	2877.67		2233.00
12-05-03	15:00	3148.98		1828.00
12-05-03	16:00	3050.62		1727.00
12-05-03	17:00	2253.92		1930.00
13-05-03	7:00	1009.33		1019.00
13-05-03	8:00	1364.04		614.00
13-05-03	9:00	1331.62		715.00
13-05-03	10:00	1625.34		2031.00
13-05-03	11:00	1308.96		614.00
13-05-03	12:00	1676.15		918.00
13-05-03	13:00	1009.00		1727.00
13-05-03	14:00	1392.63		1727.00
13-05-03	15:00	1633.05		2436.00
13-05-03	16:00	1610.55		1626.00
13-05-03	17:00	2015.07		2537.00
14-05-03	7:00	836.96		715.00
14-05-03	8:00	408.69		210.00
14-05-03	9:00	1484.12		210.00
14-05-03	10:00	1829.46		817.00
14-05-03	11:00	991.01		1828.00
14-05-03	12:00	1811.92		1828.00
14-05-03	13:00	1313.02		2031.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
14-05-03	14:00	1311.26		1930.00
14-05-03	15:00	1975.50		2638.00
14-05-03	16:00	2153.14		2537.00
14-05-03	17:00	1940.08		1828.00
15-05-03	7:00	310.51		210.00
15-05-03	8:00	376.74		210.00
15-05-03	9:00	507.94		513.00
15-05-03	10:00	860.61		1019.00
15-05-03	11:00	744.75		1727.00
15-05-03	12:00	596.73		2132.00
15-05-03	13:00	1548.87		2334.00
15-05-03	14:00	2245.95		2537.00
15-05-03	15:00	1600.67		2436.00
15-05-03	16:00	2153.30		2334.00
15-05-03	17:00	2639.23		2436.00
16-05-03	7:00	291.13		412.00
16-05-03	8:00	1901.66		2233.00
16-05-03	9:00	2315.61		2233.00
16-05-03	10:00	2400.58		1323.00
16-05-03	11:00	2731.47		1828.00
16-05-03	12:00	2208.84		2739.00
16-05-03	13:00	2688.33		2739.00
16-05-03	14:00	1770.74		2334.00
16-05-03	15:00	2378.77		2941.00
16-05-03	16:00	2173.37		2840.00
16-05-03	17:00	1922.33		2436.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
17-05-03	7:00	1482.64		210.00
17-05-03	8:00	2110.87		1019.00
17-05-03	9:00	2409.63		2132.00
17-05-03	10:00	2164.60		2132.00
17-05-03	11:00	2268.35		2537.00
17-05-03	12:00	2412.08		2537.00
17-05-03	13:00	1075.13		2537.00
17-05-03	14:00	1762.63		2334.00
17-05-03	15:00	2758.92		2334.00
17-05-03	16:00	2639.27		2638.00
17-05-03	17:00	2762.34		2941.00
18-05-03	7:00	309.53		614.00
18-05-03	8:00	1646.80		918.00
18-05-03	9:00	2145.57		1930.00
18-05-03	10:00	2036.76		2638.00
18-05-03	11:00	1981.44		2638.00
18-05-03	12:00	2049.14		2436.00
18-05-03	13:00	2406.06		1727.00
18-05-03	14:00	1526.40		1525.00
18-05-03	15:00	1758.54		1424.00
18-05-03	16:00	1567.74		1424.00
18-05-03	17:00	885.67		2233.00
19-05-03	7:00	522.27		817.00
19-05-03	8:00	752.72		715.00
19-05-03	9:00	2416.53		1828.00
19-05-03	10:00	2421.68		1727.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
19-05-03	11:00	2325.56		918.00
19-05-03	12:00	2141.34		1019.00
19-05-03	13:00	2463.13		2638.00
19-05-03	14:00	2719.96		1828.00
19-05-03	15:00	3127.20		2334.00
19-05-03	16:00	3113.98		1626.00
19-05-03	17:00	2727.57		1727.00
20-05-03	7:00	475.77		715.00
20-05-03	8:00	1099.59		1930.00
20-05-03	9:00	1723.78		2233.00
20-05-03	10:00	2242.53		1930.00
20-05-03	11:00	2022.22		2132.00
20-05-03	12:00	2191.04		1930.00
20-05-03	13:00	1843.44		1828.00
20-05-03	14:00	1346.63		918.00
20-05-03	15:00	670.02		1323.00
20-05-03	16:00	807.65		1727.00
20-05-03	17:00	401.35		1727.00
21-05-03	7:00	945.22		210.00
21-05-03	8:00	287.10		1221.00
21-05-03	9:00	1720.29		2132.00
21-05-03	10:00	1127.25		2233.00
21-05-03	11:00	1758.86		1727.00
21-05-03	12:00	175.87		1727.00
21-05-03	13:00	1852.52		2436.00
21-05-03	14:00	1469.60		2739.00

Table A-1 (continuation)

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
21-05-03	15:00	1779.33		2537.00
21-05-03	16:00	630.26		1626.00
21-05-03	17:00	1396.95		1727.00
22-05-03	7:00	1697.67		715.00
22-05-03	8:00	1747.91		918.00
22-05-03	9:00	2050.06		715.00
22-05-03	10:00	1488.89		311.00
22-05-03	11:00	934.01		1221.00
22-05-03	12:00	1910.16		1626.00
22-05-03	13:00	1887.96		1930.00
22-05-03	14:00	1931.57		2739.00
22-05-03	15:00	1590.02		2638.00
22-05-03	16:00	1581.45		2233.00
22-05-03	17:00	1808.72		2436.00
23-05-03	7:00	468.11		918.00
23-05-03	8:00	1079.86		715.00
23-05-03	9:00	1501.84		614.00
23-05-03	10:00	1408.80		513.00
23-05-03	11:00	1303.81		1120.00
23-05-03	12:00	1549.53		1221.00
23-05-03	13:00	1308.02		2537.00
23-05-03	14:00	1337.84		2334.00
23-05-03	15:00	1152.23		2334.00
23-05-03	16:00	1697.85		2233.00
23-05-03	17:00	1596.98		1930.00
24-05-03	7:00	261.90		412.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
24-05-03	8:00	1409.44		817.00
24-05-03	9:00	1985.19		817.00
24-05-03	10:00	2601.93		513.00
24-05-03	11:00	1660.66		715.00
24-05-03	12:00	1658.80		1120.00
24-05-03	13:00	1444.80		1019.00
24-05-03	14:00	1980.94		1626.00
24-05-03	15:00	2221.54		2132.00
24-05-03	16:00	1906.88		1828.00
24-05-03	17:00	2163.57		2334.00
25-05-03	7:00	1016.25		614.00
25-05-03	8:00	1155.84		817.00
25-05-03	9:00	1588.71		817.00
25-05-03	10:00	1081.82		513.00
25-05-03	11:00	1868.54		1626.00
25-05-03	12:00	1690.95		1930.00
25-05-03	13:00	2110.03		2537.00
25-05-03	14:00	1236.86		2436.00
25-05-03	15:00	2031.35		2638.00
25-05-03	16:00	2100.55		2132.00
25-05-03	17:00	1554.16		2537.00
26-05-03	7:00	286.36		311.00
26-05-03	8:00	2070.18		817.00
26-05-03	9:00	2350.34		817.00
26-05-03	10:00	2198.72		2537.00
26-05-03	11:00	1936.63		2031.00

Table A-1 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
26-05-03	12:00	2270.03		1424.00
26-05-03	13:00	2729.98		2132.00
26-05-03	14:00	2147.93		2132.00
26-05-03	15:00	2136.33		2132.00
26-05-03	16:00	2128.49		2739.00
26-05-03	17:00	1818.92		2537.00
27-05-03	7:00	1596.93		1221.00
27-05-03	8:00	2034.61		2031.00
27-05-03	9:00	2661.46		1424.00
27-05-03	10:00	2164.14		1626.00
27-05-03	11:00	2410.51		2436.00
27-05-03	12:00	2723.63		2233.00
27-05-03	13:00	2408.20		2739.00
27-05-03	14:00	2314.68		2739.00
27-05-03	15:00	2193.61		2537.00
27-05-03	16:00	2389.52		2941.00
27-05-03	17:00	2219.74		1626.00
28-05-03	7:00	1426.19	1185.00	1626.00
28-05-03	8:00	2225.91		1626.00
28-05-03	9:00	2624.46		1626.00
28-05-03	10:00	2195.87	1212.00	2031.00
28-05-03	11:00	2274.03		1828.00
28-05-03	12:00	2811.41		1727.00
28-05-03	13:00	2774.67	2403.00	2436.00
28-05-03	14:00	3087.87		2132.00
28/5/2003	15:00	2897.52		2638.00

Table A-1 (continuation)

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
28-05-03	16:00	2429.47	2545.00	2639.00
28-05-03	17:00	3132.21		2537.00
29-05-03	7:00	1720.11	1330.00	1323.00
29-05-03	8:00	2188.09		1323.00
29-05-03	9:00	2572.12		1424.00
29-05-03	10:00	2323.52	1381.00	1120.00
29-05-03	11:00	2320.48		1221.00
29-05-03	12:00	1661.25		1221.00
29-05-03	13:00	2587.15		1828.00
29-05-03	14:00	1726.36	1776.00	1424.00
29-05-03	15:00	1242.36		1221.00
29-05-03	16:00	1348.87	1924.00	2233.00
29-05-03	17:00	1464.53		1120.00
30-05-03	7:00	1397.43	229.00	614.00
30-05-03	8:00	1877.80		614.00
30-05-03	9:00	2087.61		614.00
30-05-03	10:00	1137.29	1499.00	918.00
30-05-03	11:00	568.47	1576.00	1120.00
30-05-03	12:00	1394.57		2013.00
30-05-03	13:00	1196.14	1893.00	1727.00
30-05-03	14:00	1811.26		1727.00
30-05-03	15:00	1468.61		1019.00
30-05-03	16:00	771.50	384.00	210.00
30-05-03	17:00	291.56		210.00
31-05-03	7:00	228.09	132.00	210.00
31-05-03	8:00	143.45		311.00

Table A-1 (continuation)

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
31-05-03	9:00	90.02		210.00
31-05-03	10:00	236.07	654.00	918.00
31-05-03	11:00	1148.97		1424.00
31-05-03	12:00	485.87		1424.00
31-05-03	13:00	1590.32	1133.00	1424.00
31-05-03	14:00	707.65		715.00
31-05-03	15:00	586.62		210.00
31-05-03	16:00	1248.41	1466.00	1727.00
31-05-03	17:00	1151.89		1120.00
01-06-03	9:00	1355.74		919.00
01-06-03	10:00	1935.24	752.00	614.00
01-06-03	11:00	2100.06		2132.00
01-06-03	12:00	1566.35		1120.00
01-06-03	13:00	1678.71	1076.00	1828.00
01-06-03	14:00	1429.65		2031.00
01-06-03	15:00	1508.37		2233.00
01-06-03	16:00	2343.56	1383.00	1930.00
01-06-03	17:00	2087.55		311.00
02-06-03	7:00	191.21	271.00	311.00
02-06-03	8:00	1801.61		513.00
02-06-03	9:00	1321.93		210.00
02-06-03	10:00	1469.17	382.00	715.00
02-06-03	11:00	1505.72		210.00
02-06-03	12:00	471.01		210.00
02-06-03	13:00	1327.28	1302.00	817.00
02-06-03	14:00	2224.37		715.00

Table A-1 (continuation)

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
02-06-03	15:00	837.81		210.00
02-06-03	16:00	1002.44	176.00	210.00
02-06-03	17:00	233.69		210.00
03-06-03	7:00	270.55	420.00	614.00
03-06-03	8:00	761.93		311.00
03-06-03	9:00	1544.53		513.00
03-06-03	10:00	2076.85	703.00	715.00
03-06-03	11:00	1771.05		817.00
03-06-03	12:00	2187.37		1221.00
03-06-03	13:00	2483.55	1219.00	918.00
03-06-03	14:00	2421.39		614.00
03-06-03	15:00	1994.37		715.00
03-06-03	16:00	1824.56	1042.00	513.00
03-06-03	17:00	1998.86		715.00
04-06-03	7:00	285.62	328.00	311.00
04-06-03	8:00	660.22		715.00
04-06-03	9:00	1913.92		1727.00
04-06-03	10:00	1934.08	1046.00	1828.00
04-06-03	11:00	1791.85		2132.00
04-06-03	12:00	2631.55		2638.00
04-06-03	13:00	2328.35		2537.00
04-06-03	14:00	2386.13	1637.00	2132.00
04-06-03	15:00	1902.34		2031.00
04-06-03	16:00	928.79	315.00	715.00
04-06-03	17:00	149.36		210.00
05-06-03	7:00	259.88	170.00	412.00

Table A-1 (continuation)

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
05-06-03	8:00	182.93		210.00
05-06-03	9:00	1772.44		1727.00
05-06-03	10:00	2169.02	703.00	1626.00
05-06-03	11:00	2273.60	1433.00	1626.00
05-06-03	12:00	2685.61		1727.00
05-06-03	13:00	2596.30	960.00	1727.00
05-06-03	14:00	2481.96		1323.00
05-06-03	15:00	2421.24		2132.00
05-06-03	16:00	2380.81	1635.00	1626.00
05-06-03	17:00	1199.25		1221.00
06-06-03	7:00	306.87		412.00
06-06-03	8:00	1976.34		1828.00
06-06-03	9:00	1794.97		1828.00
06-06-03	10:00	1947.40		2233.00
06-06-03	11:00	1300.76		1930.00
06-06-03	12:00	2217.35		1525.00
06-06-03	13:00	2036.62		1930.00
06-06-03	14:00	1937.92		2233.00
06-06-03	15:00	1577.68		1930.00
06-06-03	16:00	1683.59		2233.00
06-06-03	17:00	734.22		1727.00

Table A-2: Nighttime MH at Srisamrong Sukhothai during 20 April to 6 June 2003

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
20-04-03	18:00	370.83		311.00
20-04-03	19:00	416.48	143.00	210.00
20-04-03	20:00	432.83		412.00
20-04-03	21:00	327.43		513.00
20-04-03	22:00	168.80	275.00	210.00
20-04-03	23:00	98.49		311.00
20-04-03	24:00	236.41		210.00
21-04-03	1:00	335.14	380.00	311.00
21-04-03	2:00	226.98		817.00
21-04-03	3:00	410.15		614.00
21-04-03	4:00	448.69	191.00	412.00
21-04-03	5:00	81.96		614.00
21-04-03	6:00	169.46		918.00
21-04-03	18:00	232.73		412.00
21-04-03	19:00	388.18	211.00	108.00
21-04-03	20:00	85.55		108.00
21-04-03	21:00	34.60		108.00
21-04-03	22:00	164.34	157.00	210.00
21-04-03	23:00	98.27		108.00
21-04-03	24:00	337.42		210.00
22-04-03	1:00	161.77	307.00	108.00
22-04-03	2:00	406.33		513.00
22-04-03	3:00	219.99		311.00
22-04-03	4:00	438.29	322.00	513.00
22-04-03	5:00	306.66		210.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
22-04-03	6:00	358.03		210.00
22-04-03	18:00	128.43		311.00
22-04-03	19:00	435.19	50.00	412.00
22-04-03	20:00	206.84		210.00
22-04-03	21:00	388.57		311.00
22-04-03	22:00	320.97	94.00	210.00
22-04-03	23:00	262.92		311.00
22-04-03	24:00	349.08		614.00
23-04-03	1:00	228.50	514.00	210.00
23-04-03	2:00	277.77		513.00
23-04-03	3:00	429.63		817.00
23-04-03	4:00	361.51	178.00	513.00
23-04-03	5:00	226.72		817.00
23-04-03	6:00	125.85		918.00
23-04-03	18:00	123.29		210.00
23-04-03	19:00	195.03	129.00	311.00
23-04-03	20:00	220.97		210.00
23-04-03	21:00	150.82		311.00
23-04-03	22:00	229.32	350.00	412.00
23-04-03	23:00	77.57		210.00
23-04-03	24:00	318.57		210.00
24-04-03	1:00	682.97	394.00	715.00
24-04-03	2:00	443.11		614.00
24-04-03	3:00	177.29		614.00
24-04-03	4:00	328.91	81.00	311.00
24-04-03	5:00	414.36		412.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
24-04-03	6:00	82.65		1019.00
24-04-03	18:00	53.69		108.00
24-04-03	19:00	354.94	142.00	412.00
24-04-03	20:00	114.98		210.00
24-04-03	21:00	169.82		210.00
24-04-03	22:00	188.15	379.00	210.00
24-04-03	23:00	393.46		311.00
24-04-03	24:00	321.22		412.00
25-04-30	1:00	85.55	183.00	108.00
25-04-30	2:00	77.68		614.00
25-04-30	3:00	165.05		715.00
25-04-30	4:00	223.08	361.00	513.00
25-04-30	5:00	108.30		715.00
25-04-30	6:00	126.42		1019.00
25-04-30	18:00	355.29		210.00
25-04-30	19:00	376.09	257.00	412.00
25-04-30	20:00	205.87		210.00
25-04-30	21:00	61.46		108.00
25-04-30	22:00	618.58	625.00	311.00
25-04-30	23:00	271.78		210.00
25-04-30	24:00	166.19		210.00
26-04-30	1:00	230.03	263.00	311.00
26-04-30	2:00	150.74		210.00
26-04-30	3:00	209.37		210.00
26-04-30	4:00	302.08	308.00	715.00
26-04-30	5:00	226.04		817.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
26-04-30	6:00	215.52		614.00
26-04-03	18:00	407.71		412.00
26-04-03	19:00	383.88	97.00	311.00
26-04-03	20:00	411.69		210.00
26-04-03	21:00	264.27		311.00
26-04-03	22:00	237.91	290.00	311.00
26-04-03	23:00	188.48		210.00
26-04-03	24:00	246.98		210.00
27-04-03	1:00	75.37	260.00	412.00
27-04-03	2:00	306.05		210.00
27-04-03	3:00	103.86		311.00
27-04-03	4:00	54.53	216.00	210.00
27-04-03	5:00	17.42		108.00
27-04-03	6:00	17.22		311.00
27-04-03	18:00	55.18		210.00
27-04-03	19:00	274.19	112.00	210.00
27-04-03	20:00	396.98		311.00
27-04-03	21:00	426.75		513.00
27-04-03	22:00	64.36		210.00
27-04-03	23:00	156.30		210.00
27-04-03	24:00	361.44		210.00
28-04-03	1:00	143.86		210.00
28-04-03	2:00	115.88		311.00
28-04-03	3:00	168.28		108.00
28-04-03	4:00	116.70		412.00
28-04-03	5:00	235.67		412.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
28-04-03	6:00	141.27		715.00
28-04-03	18:00	180.07		311.00
28-04-03	19:00	180.36		412.00
28-04-03	20:00	217.45		210.00
28-04-03	21:00	384.02		210.00
28-04-03	22:00	129.69		311.00
28-04-03	23:00	183.17		210.00
28-04-03	24:00	22.10		311.00
29-04-03	1:00	29.61		210.00
29-04-03	2:00	17.33		210.00
29-04-03	3:00	21.57		614.00
29-04-03	4:00	16.49		715.00
29-04-03	5:00	108.68		614.00
29-04-03	6:00	16.21		614.00
29-04-03	18:00	110.11		210.00
29-04-03	19:00	70.52		311.00
29-04-03	20:00	279.57		210.00
29-04-03	21:00	362.29		210.00
29-04-03	22:00	83.92		614.00
29-04-03	23:00	80.84		210.00
29-04-03	24:00	58.57		108.00
30-04-03	1:00	113.54		311.00
30-04-03	2:00	68.28		311.00
30-04-03	3:00	25.33		412.00
30-04-03	4:00	31.53		311.00
30-04-03	5:00	79.57		715.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
30-04-03	6:00	46.72		311.00
30-04-03	18:00	77.45		311.00
30-04-03	19:00	74.81		210.00
30-04-03	20:00	106.17		108.00
30-04-03	21:00	52.35		210.00
30-04-03	22:00	79.44		108.00
30-04-03	23:00	56.70		108.00
30-04-03	24:00	304.29		210.00
01-05-03	1:00	276.47		210.00
01-05-03	2:00	425.02		715.00
01-05-03	3:00	439.48		513.00
01-05-03	4:00	400.93		614.00
01-05-03	5:00	307.96		311.00
01-05-03	6:00	221.13		817.00
01-05-03	18:00	288.95		210.00
01-05-03	19:00	285.31		210.00
01-05-03	20:00	271.16		311.00
01-05-03	21:00	81.70		108.00
01-05-03	22:00	375.64		412.00
01-05-03	23:00	296.96		412.00
01-05-03	24:00	258.39		210.00
02-05-03	1:00	70.24		210.00
02-05-03	2:00	316.75		210.00
02-05-03	3:00	107.66		513.00
02-05-03	4:00	170.99		311.00
02-05-03	5:00	211.96		817.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
02-05-03	6:00	214.99		412.00
02-05-03	18:00	312.21		311.00
02-05-03	19:00	317.32		210.00
02-05-03	20:00	270.42		412.00
02-05-03	21:00	249.32		412.00
02-05-03	22:00	74.26		210.00
02-05-03	23:00	70.82		108.00
02-05-03	24:00	331.32		412.00
03-05-03	1:00	289.57		311.00
03-05-03	2:00	136.73		311.00
03-05-03	3:00	344.95		817.00
03-05-03	4:00	390.57		513.00
03-05-03	5:00	115.77		210.00
03-05-03	6:00	202.12		210.00
03-05-03	18:00	572.09		715.00
03-05-03	19:00	429.69		412.00
03-05-03	20:00	342.42		513.00
03-05-03	21:00	224.88		513.00
03-05-03	22:00	350.70		412.00
03-05-03	23:00	186.24		412.00
03-05-03	24:00	92.94		817.00
04-05-03	1:00	144.21		108.00
04-05-03	2:00	345.97		210.00
04-05-03	3:00	163.08		412.00
04-05-03	4:00	242.50		311.00
04-05-03	5:00	61.30		210.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
04-05-03	6:00	443.44		513.00
04-05-03	18:00	858.41		513.00
04-05-03	19:00	568.26		614.00
04-05-03	20:00	535.52		614.00
04-05-03	21:00	493.85		513.00
04-05-03	22:00	450.31		311.00
04-05-03	23:00	216.61		513.00
04-05-03	24:00	245.63		412.00
05-05-03	1:00	179.27		210.00
05-05-03	2:00	88.79		412.00
05-05-03	3:00	374.13		311.00
05-05-03	4:00	39.26		210.00
05-05-03	5:00	36.90		311.00
05-05-03	6:00	225.75		614.00
05-05-03	18:00	271.10		311.00
05-05-03	19:00	416.29		210.00
05-05-03	20:00	277.94		412.00
05-05-03	21:00	197.01		311.00
05-05-03	22:00	355.24		412.00
05-05-03	23:00	322.00		412.00
05-05-03	24:00	437.92		210.00
06-05-03	1:00	273.00		311.00
06-05-03	2:00	346.85		614.00
06-05-03	3:00	399.07		311.00
06-05-03	4:00	152.06		311.00
06-05-03	5:00	402.37		311.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
06-05-03	6:00	254.69		311.00
06-05-03	18:00	241.30		210.00
06-05-03	19:00	34.56		311.00
06-05-03	20:00	109.45		210.00
06-05-03	21:00	143.06		412.00
06-05-03	22:00	348.33		311.00
06-05-03	23:00	225.86		210.00
06-05-03	24:00	100.33		210.00
07-05-03	1:00	148.08		210.00
07-05-03	2:00	146.24		210.00
07-05-03	3:00	39.24		108.00
07-05-03	4:00	39.62		412.00
07-05-03	5:00	43.62		108.00
07-05-03	6:00	40.22		412.00
07-05-03	18:00	214.61		210.00
07-05-03	19:00	34.57		614.00
07-05-03	20:00	40.36		210.00
07-05-03	21:00	39.32		210.00
07-05-03	22:00	38.75		210.00
07-05-03	23:00	38.21		210.00
07-05-03	24:00	213.31		210.00
08-05-03	1:00	37.63		210.00
08-05-03	2:00	40.39		108.00
08-05-03	3:00	183.44		513.00
08-05-03	4:00	155.86		412.00
08-05-03	5:00	220.60		210.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
08-05-03	6:00	352.15		513.00
08-05-03	18:00	718.44		715.00
08-05-03	19:00	407.50		311.00
08-05-03	20:00	367.05		210.00
08-05-03	21:00	224.28		210.00
08-05-03	22:00	291.75		210.00
08-05-03	23:00	306.24		311.00
08-05-03	24:00	831.58		715.00
09-05-03	1:00	1004.93		1221.00
09-05-03	2:00	790.76		614.00
09-05-03	3:00	643.74		1019.00
09-05-03	4:00	188.53		311.00
09-05-03	5:00	107.61		513.00
09-05-03	6:00	195.64		311.00
09-05-03	18:00	51.96		210.00
09-05-03	19:00	83.29		210.00
09-05-03	20:00	45.48		210.00
09-05-03	21:00	45.43		412.00
09-05-03	22:00	45.68		311.00
09-05-03	23:00	45.74		210.00
09-05-03	24:00	92.36		210.00
10-05-03	1:00	182.08		311.00
10-05-03	2:00	333.72		412.00
10-05-03	3:00	85.18		210.00
10-05-03	4:00	50.72		108.00
10-05-03	5:00	238.04		412.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
10-05-03	6:00	259.23		311.00
10-05-03	18:00	243.56		614.00
10-05-03	19:00	182.16		210.00
10-05-03	20:00	645.26		210.00
10-05-03	21:00	313.90		311.00
10-05-03	22:00	435.65		210.00
10-05-03	23:00	219.85		210.00
10-05-03	24:00	198.04		311.00
12-05-03	1:00	74.87		210.00
12-05-03	2:00	154.51		715.00
12-05-03	3:00	104.62		210.00
12-05-03	4:00	47.92		210.00
12-05-03	5:00	85.94		210.00
12-05-03	6:00	157.17		412.00
12-05-03	18:00	222.08		210.00
12-05-03	19:00	219.46		210.00
12-05-03	20:00	57.92		210.00
12-05-03	21:00	117.53		210.00
12-05-03	22:00	58.62		210.00
12-05-03	23:00	59.39		210.00
12-05-03	24:00	60.14		210.00
13-05-03	1:00	52.36		311.00
13-05-03	2:00	79.69		412.00
13-05-03	3:00	341.93		311.00
13-05-03	4:00	236.84		412.00
13-05-03	5:00	120.93		210.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
13-05-03	6:00	369.44		412.00
13-05-03	18:00	169.80		513.00
13-05-03	19:00	166.38		210.00
13-05-03	20:00	76.84		210.00
13-05-03	21:00	324.41		210.00
13-05-03	22:00	108.91		108.00
13-05-03	23:00	315.39		412.00
13-05-03	24:00	326.86		513.00
14-05-03	1:00	302.91		210.00
14-05-03	2:00	230.80		412.00
14-05-03	3:00	204.24		311.00
14-05-03	4:00	94.75		311.00
14-05-03	5:00	210.58		210.00
14-05-03	6:00	94.38		108.00
14-05-03	18:00	305.41		311.00
14-05-03	19:00	121.18		210.00
14-05-03	20:00	213.36		210.00
14-05-03	21:00	360.16		311.00
14-05-03	22:00	162.52		311.00
14-05-03	23:00	149.87		210.00
14-05-03	24:00	186.45		210.00
15-05-03	1:00	65.29		311.00
15-05-03	2:00	63.66		210.00
15-05-03	3:00	71.49		108.00
15-05-03	4:00	60.24		311.00
15-05-03	5:00	62.63		210.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
15-05-03	6:00	59.87		210.00
15-05-03	18:00	506.93		412.00
15-05-03	19:00	113.04		412.00
15-05-03	20:00	407.80		210.00
15-05-03	21:00	483.69		210.00
15-05-03	22:00	324.51		210.00
15-05-03	23:00	238.75		311.00
15-05-03	24:00	491.78		513.00
16-05-03	1:00	308.84		311.00
16-05-03	2:00	71.38		108.00
16-05-03	3:00	200.66		210.00
16-05-03	4:00	56.70		412.00
16-05-03	5:00	55.35		210.00
16-05-03	6:00	57.99		210.00
16-05-03	18:00	128.73		108.00
16-05-03	19:00	328.08		210.00
16-05-03	20:00	187.11		311.00
16-05-03	21:00	328.27		412.00
16-05-03	22:00	646.58		412.00
16-05-03	23:00	270.61		412.00
16-05-03	24:00	312.05		412.00
17-05-03	1:00	358.93		614.00
17-05-03	2:00	333.34		513.00
17-05-03	3:00	226.59		311.00
17-05-03	4:00	188.19		210.00
17-05-03	5:00	148.79		210.00

Table A-2 (continuation)

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
17-05-03	6:00	75.32		210.00
17-05-03	18:00	976.16		715.00
17-05-03	19:00	639.95		513.00
17-05-03	20:00	212.56		513.00
17-05-03	21:00	407.02		513.00
17-05-03	22:00	362.03		210.00
17-05-03	23:00	343.31		311.00
17-05-03	24:00	403.31		311.00
18-05-03	1:00	340.95		210.00
18-05-03	2:00	55.03		210.00
18-05-03	3:00	54.37		210.00
18-05-03	4:00	60.17		108.00
18-05-03	5:00	53.53		108.00
18-05-03	6:00	53.47		108.00
18-05-03	18:00	710.80		412.00
18-05-03	19:00	291.98		210.00
18-05-03	20:00	349.20		311.00
18-05-03	21:00	133.53		210.00
18-05-03	22:00	138.53		210.00
18-05-03	23:00	226.43		210.00
18-05-03	24:00	93.78		210.00
19-05-03	1:00	132.41		108.00
19-05-03	2:00	92.34		210.00
19-05-03	3:00	104.31		210.00
19-05-03	4:00	84.60		108.00
19-05-03	5:00	58.41		108.00

Table A-2 (continuation)

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
19-05-03	6:00	58.84		108.00
19-05-03	18:00	1313.81		210.00
19-05-03	19:00	454.92		210.00
19-05-03	20:00	323.81		311.00
19-05-03	21:00	361.41		210.00
19-05-03	22:00	274.30		210.00
19-05-03	23:00	379.89		311.00
19-05-03	24:00	61.60		311.00
20-05-03	1:00	76.27		210.00
20-05-03	2:00	358.80		311.00
20-05-03	3:00	92.58		108.00
20-05-03	4:00	61.08		108.00
20-05-03	5:00	54.80		210.00
20-05-03	6:00	87.55		210.00
20-05-03	18:00	165.12		108.00
20-05-03	19:00	216.63		210.00
20-05-03	20:00	196.11		311.00
20-05-03	21:00	151.67		210.00
20-05-03	22:00	139.30		210.00
20-05-03	23:00	145.09		210.00
20-05-03	24:00	159.44		210.00
21-05-03	1:00	129.10		412.00
21-05-03	2:00	394.46		210.00
21-05-03	3:00	164.52		210.00
21-05-03	4:00	87.50		513.00
21-05-03	5:00	53.20		108.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
21-05-03	6:00	50.28		311.00
21-05-03	18:00	120.23		210.00
21-05-03	19:00	51.00		311.00
21-05-03	20:00	345.63		108.00
21-05-03	21:00	1121.92		311.00
21-05-03	22:00	758.08		513.00
21-05-03	23:00	316.89		412.00
21-05-03	24:00	490.16		513.00
22-05-03	1:00	257.32		311.00
22-05-03	2:00	365.75		412.00
22-05-03	3:00	249.97		513.00
22-05-03	4:00	211.07		614.00
22-05-03	5:00	191.61		513.00
22-05-03	6:00	212.64		817.00
22-05-03	18:00	269.59		210.00
22-05-03	19:00	237.47		210.00
22-05-03	20:00	58.11		210.00
22-05-03	21:00	230.34		210.00
22-05-03	22:00	60.70		210.00
22-05-03	23:00	59.43		210.00
22-05-03	24:00	203.95		210.00
23-05-03	1:00	138.16		210.00
23-05-03	2:00	155.29		210.00
23-05-03	3:00	103.65		108.00
23-05-03	4:00	67.72		311.00
23-05-03	5:00	54.85		311.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
23-05-03	6:00	54.53		108.00
23-05-03	18:00	210.32		210.00
23-05-03	19:00	80.85		210.00
23-05-03	20:00	604.90		513.00
23-05-03	21:00	298.70		614.00
23-05-03	22:00	45.66		210.00
23-05-03	23:00	238.49		311.00
23-05-03	24:00	47.21		108.00
24-05-03	1:00	154.13		311.00
24-05-03	2:00	44.56		108.00
24-05-03	3:00	137.27		210.00
24-05-03	4:00	274.84		311.00
24-05-03	5:00	74.06		513.00
24-05-03	6:00	44.28		715.00
24-05-03	18:00	1534.78		1323.00
24-05-03	19:00	86.57		311.00
24-05-03	20:00	171.86		210.00
24-05-03	21:00	99.24		311.00
24-05-03	22:00	162.26		210.00
24-05-03	23:00	87.36		210.00
24-05-03	24:00	296.43		311.00
25-05-03	1:00	218.04		412.00
25-05-03	2:00	103.31		108.00
25-05-03	3:00	56.03		108.00
25-05-03	4:00	185.15		412.00
25-05-03	5:00	127.10		513.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
25-05-03	6:00	96.85		715.00
25-05-03	18:00	414.66		513.00
25-05-03	19:00	82.22		210.00
25-05-03	20:00	401.61		210.00
25-05-03	21:00	650.88		412.00
25-05-03	22:00	312.91		311.00
25-05-03	23:00	214.32		210.00
25-05-03	24:00	238.10		311.00
26-05-03	1:00	124.54		210.00
26-05-03	2:00	383.19		311.00
26-05-03	3:00	189.92		311.00
26-05-03	4:00	188.72		311.00
26-05-03	5:00	188.24		108.00
26-05-03	6:00	143.51		311.00
26-05-03	18:00	744.36		918.00
26-05-03	19:00	815.78		1120.00
26-05-03	20:00	969.28		615.00
26-05-03	21:00	782.16		513.00
26-05-03	22:00	571.53		210.00
26-05-03	23:00	469.91		210.00
26-05-03	24:00	404.83		108.00
27-05-03	1:00	528.48		311.00
27-05-03	2:00	454.53		311.00
27-05-03	3:00	236.72		311.00
27-05-03	4:00	230.97		210.00
27-05-03	5:00	145.64		210.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
27-05-03	6:00	234.86		210.00
27-05-03	18:00	684.11		311.00
27-05-03	19:00	736.60		412.00
27-05-03	20:00	514.75		210.00
27-05-03	21:00	617.26		311.00
27-05-03	22:00	588.84		412.00
27-05-03	23:00	550.26		210.00
27-05-03	24:00	467.49		210.00
28-05-03	1:00	684.26		311.00
28-05-03	2:00	503.39		1120.00
28-05-03	3:00	460.80		1221.00
28-05-03	4:00	403.11		918.00
28-05-03	5:00	186.25		210.00
28-05-03	6:00	151.87		210.00
28-05-03	18:00	920.09		912.00
28-05-03	19:00	1313.33	698.00	1120.00
28-05-03	20:00	1041.82	1049.00	1323.00
28-05-03	21:00	812.45		1019.00
28-05-03	22:00	565.49	418.00	311.00
28-05-03	23:00	522.22		715.00
28-05-03	24:00	491.19		513.00
29-05-03	1:00	736.57	758.00	311.00
29-05-03	2:00	661.64		311.00
29-05-03	3:00	701.41		513.00
29-05-03	4:00	582.06	985.00	513.00
29-05-03	5:00	466.52		412.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
29-05-03	6:00	258.22		412.00
29-05-03	18:00	84.22		109.00
29-05-03	19:00	150.33	73.00	210.00
29-05-03	20:00	205.60		210.00
29-05-03	21:00	442.23		513.00
29-05-03	22:00	596.94	515.00	412.00
29-05-03	23:00	622.77		311.00
29-05-03	24:00	688.01		311.00
30-05-03	1:00	692.97	385.00	210.00
30-05-03	2:00	625.47		412.00
30-05-03	3:00	643.47		614.00
30-05-03	4:00	517.94	870.00	412.00
30-05-03	5:00	197.90		210.00
30-05-03	6:00	90.68		513.00
30-05-03	18:00	452.75		412.00
30-05-03	19:00	180.07	275.00	210.00
30-05-03	20:00	180.35		311.00
30-05-03	21:00	244.41		210.00
30-05-03	22:00	460.35		412.00
30-05-03	23:00	323.25	264.00	311.00
30-05-03	24:00	308.14		412.00
31-05-03	1:00	134.36	160.00	311.00
31-05-03	2:00	51.14		614.00
31-05-03	3:00	47.02		513.00
31-05-03	4:00	48.98	285.00	715.00
31-05-03	5:00	47.25		614.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
31-05-03	6:00	47.76		311.00
31-05-03	18:00	249.50		210.00
31-05-03	19:00	666.73	153.00	210.00
31-05-03	20:00	165.76		210.00
31-05-03	21:00	174.08		108.00
31-05-03	22:00	598.52	352.00	614.00
31-05-03	23:00	311.57		311.00
31-05-03	24:00	207.96		210.00
01-06-03	1:00	85.18	151.00	210.00
01-06-03	2:00	162.22		412.00
01-06-03	3:00	100.60		108.00
01-06-03	4:00	47.61	153.00	614.00
01-06-03	5:00	48.63		513.00
01-06-03	6:00	48.83		614.00
01-06-03	18:00	273.30		715.00
01-06-03	19:00	442.74	201.00	311.00
01-06-03	20:00	110.28		210.00
01-06-03	21:00	118.39		108.00
01-06-03	22:00	120.46	146.00	108.00
01-06-03	23:00	51.32		108.00
01-06-03	24:00	127.64		311.00
02-06-03	1:00	186.06	557.00	311.00
02-06-03	2:00	188.35		513.00
02-06-03	3:00	70.10		108.00
02-06-03	4:00	119.03	182.00	108.00
02-06-03	5:00	99.40		108.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
02-06-03	6:00	51.21		108.00
02-06-03	18:00	62.16		108.00
02-06-03	19:00	61.35	115.00	210.00
02-06-03	20:00	54.57		108.00
02-06-03	21:00	54.39		108.00
02-06-03	22:00	52.65	193.00	412.00
02-06-03	23:00	52.82		108.00
02-06-03	24:00	292.10		108.00
03-06-03	1:00	149.52	214.00	210.00
03-06-03	2:00	95.72		311.00
03-06-03	3:00	48.99		108.00
03-06-03	4:00	303.61	173.00	311.00
03-06-03	5:00	88.04		108.00
03-06-03	6:00	126.46		108.00
03-06-03	18:00	716.54		715.00
03-06-03	19:00	974.98	285.00	1424.00
03-06-03	20:00	91.21		210.00
03-06-03	21:00	73.10		412.00
03-06-03	22:00	70.40	99.00	210.00
03-06-03	23:00	61.82		108.00
03-06-03	24:00	60.28		108.00
04-06-03	1:00	57.60	141.00	108.00
04-06-03	2:00	57.07		108.00
04-06-03	3:00	56.69		108.00
04-06-03	4:00	57.12	116.00	412.00
04-06-03	5:00	56.95		108.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
04-06-03	6:00	56.85		108.00
04-06-03	18:00	293.09		311.00
04-06-03	19:00	231.74	159.00	311.00
04-06-03	20:00	278.54		614.00
04-06-03	21:00	59.64		311.00
04-06-03	22:00	133.98	164.00	210.00
04-06-03	23:00	68.77		412.00
04-06-03	24:00	189.75		108.00
05-06-03	1:00	78.65	100.00	210.00
05-06-03	2:00	67.89		210.00
05-06-03	3:00	61.89		108.00
05-06-03	4:00	60.26	245.00	108.00
05-06-03	5:00	59.26		108.00
05-06-03	6:00	59.68		108.00
05-06-03	18:00	215.85		210.00
05-06-03	19:00	54.13	162.00	108.00
05-06-03	20:00	323.55		513.00
05-06-03	21:00	393.24		311.00
05-06-03	22:00	79.86	224.00	513.00
05-06-03	23:00	60.46		210.00
05-06-03	24:00	123.76		210.00
06-06-03	1:00	61.30	145.00	210.00
06-06-03	2:00	51.37		210.00
06-06-03	3:00	206.08		210.00
06-06-03	4:00	51.41		614.00
06-06-03	5:00	51.44		311.00

Table A-2 (continuation):

dd-mm-yy	Time	MH-estimation (m)	MH-radiosounding (m)	MH-wind profiler (m)
06-06-03	6:00	51.59		108.00
06-06-03	18:00	110.15		513.00
06-06-03	19:00	108.56		210.00
06-06-03	20:00	272.20		210.00
06-06-03	21:00	173.20		614.00
06-06-03	22:00	121.24		210.00
06-06-03	23:00	302.58		210.00
06-06-03	24:00	170.05		412.00

APPENDIX B

Table shows Using PCRAMMET meteorological pre-processor to determine MH in other area of Thailand.

Table B-1: Morning and afternoon MH at Bangkok during 23 April to 6 June 2003

dd-mm-yy	Est-Mo-MH (m)	Mea-Mo-MH (m)	Est-Af-MH (m)	Mea-Af-MH (m)
23-04-03	1371.61	820.00	2607.78	1580.00
24-04-03	770.89	660.00	3911.67	1220.00
26-04-03	778.26	720.00	3911.67	960.00
27-04-03	1373.86	860.00	2607.78	1720.00
28-04-03	1380.08	680.00	2062.38	1870.00
29-04-03	782.63	790.00	2615.32	1260.00
30-04-03	3042.41	930.00	2607.01	2220.00
01-05-03	769.03	1020.00	1417.33	2160.00
02-05-03	769.14	950.00	2029.24	1910.00
03-05-03	786.15	810.00	1427.74	1380.00
04-05-03	1381.07	990.00	3042.41	1740.00
05-05-03	780.19	920.00	3112.66	1700.00
06-05-03	1383.02	1220.00	2173.15	1920.00
07-05-03	1384.09	1050.00	2554.48	1920.00
08-05-03	1383.85	850.00	1982.71	1400.00
10-05-03	1366.78	960.00	1445.75	1090.00
11-05-03	798.54	520.00	2044.62	1480.00
12-05-03	1369.92	580.00	1877.64	1220.00
13-05-03	750.88	620.00	1448.48	1150.00
14-05-03	1912.35	700.00	2047.75	1320.00
15-05-03	806.22	80.00	2071.41	1510.00

Note: Est-Mo-MH is estimation of morning MH

Mea-Mo-MH is measurement of morning MH

Est-Af-MH is estimation of afternoon MH

Mea-Af-MH is measurement of afternoon MH

Table B-1(continuation):

dd-mm-yy	Est-Mo-MH (m)	Mea-Mo-MH (m)	Est-Af-MH (m)	Mea-Af-MH (m)
16-05-03	1392.55	390.00	1483.51	1390.00
17-05-03	816.25	1035.00	1467.27	1200.00
18-05-03	775.20	1060.00	2617.59	1450.00
19-05-03	797.00	1310.00	2638.95	1570.00
20-05-03	794.05	670.00	2607.78	1720.00
21-05-03	1932.46	520.00	2598.10	1570.00
22-05-03	776.11	620.00	1993.67	1320.00
24-05-03	1950.60	840.00	2106.95	1170.00
25-05-03	1912.72	680.00	1444.24	1240.00
26-05-03	2173.15	920.00	2607.78	1100.00
27-05-03	1933.21	870.00	3477.04	1170.00
28-05-03	1738.52	800.00	3662.95	1200.00
29-05-03	2173.15	920.00	3042.41	1360.00
30-05-03	2173.15	760.00	2607.78	1120.00
31-05-03	752.03	830.00	3477.04	1290.00
01-06-03	751.96	980.00	2010.97	1200.00
02-06-03	1392.19	1240.00	1475.48	1080.00
03-06-03	1738.52	970.00	2481.56	1340.00
04-06-03	775.04	910.00	2067.51	1370.00
05-06-03	804.82	850.00	3104.61	1560.00
06-06-03	799.69	740.00	2607.78	1260.00

Note: Est-Mo-MH is estimation of morning MH

Mea-Mo-MH is measurement of morning MH

Est-Af-MH is estimation of afternoon MH

Mea-Af-MH is measurement of afternoon MH

Table B-2: Morning and afternoon MH at Chiang Mai during 20 April to 6 June 2003

dd-mm-yy	Est-Mo-MH (m)	Mea-Mo-MH (m)	Est-Af-MH (m)	Mea-Af-MH (m)
20-04-03	528.48	480.00	1657.38	1280.00
21-04-03	528.16	510.00	2400.96	1320.00
22-04-03	528.90	510.00	1701.57	1140.00
23-04-03	537.53	470.00	1317.26	1240.00
24-04-03	538.67	440.00	1600.64	1440.00
25-04-03	533.43	335.00	1339.05	1260.00
28-04-03	540.78	490.00	1663.66	1440.00
29-04-03	1867.42	520.00	1725.57	1400.00
30-04-03	3201.29	640.00	3734.83	1170.00
01-05-03	2134.19	430.00	1247.86	660.00
02-05-03	538.46	640.00	1333.87	1180.00
03-05-03	545.52	490.00	941.83	1300.00
04-05-03	546.21	580.00	1867.42	1580.00
05-05-03	538.70	415.00	1985.80	1280.00
06-05-03	537.75	580.00	1314.37	1440.00
07-05-03	541.40	430.00	1313.63	1230.00
09-05-03	1867.42	2150.00	1067.10	2210.00
10-05-03	563.53	2070.00	1867.42	2620.00
11-05-03	564.75	570.00	2667.74	1210.00
12-05-03	1312.37	480.00	1341.93	1110.00
13-05-03	546.87	580.00	1867.42	1180.00
14-05-03	555.09	750.00	1342.95	1250.00
15-05-03	563.02	620.00	1600.64	1240.00
16-05-03	566.66	630.00	1600.00	1400.00
17-05-03	567.04	685.00	2934.51	1240.00

Table B-2(continuation):

dd-mm-yy	Est-Mo-MH (m)	Mea-Mo-MH (m)	Est-Af-MH (m)	Mea-Af-MH (m)
18-05-03	563.63	440.00	2777.27	640.00
19-05-03	548.19	770.00	2101.80	770.00
20-05-03	1645.44	725.00	2134.19	920.00
21-05-03	571.67	560.00	1286.70	1265.00
22-05-03	566.27	560.00	1600.64	1100.00
23-05-03	567.24	615.00	1704.16	1340.00
24-05-03	562.86	670.00	2134.19	1100.00
25-05-03	568.72	645.00	1706.58	1395.00
26-05-03	566.78	580.00	2934.51	1590.00
27-05-03	566.93	570.00	2667.74	1560.00
28-05-03	565.92	450.00	2025.91	1130.00
29-05-03	566.78	590.00	1692.24	1280.00
30-05-03	564.34	470.00	1369.51	1440.00
31-05-03	564.69	295.00	941.76	585.00
01-06-03	558.25	565.00	2455.66	680.00
02-06-03	558.19	490.00	1757.22	750.00
03-06-03	557.85	555.00	2050.48	760.00
04-06-03	548.65	525.00	2400.96	930.00
05-06-03	558.21	760.00	1333.87	910.00
06-06-03	569.62	620.00	2428.07	985.00

Table B-3: Morning and afternoon MH at Ubonratchathani during 20 April to 6 June 2003

dd-mm-yy	Est-Mo-MH (m)	Mea-Mo-MH (m)	Est-Af-MH (m)	Mea-Af-MH (m)
20-04-03	1134.96	560.00	633.06	1560.00
21-04-03	642.85	570.00	633.00	1800.00
22-04-03	611.84	830.00	1185.56	1490.00
23-04-03	656.33	580.00	1659.35	1740.00
24-04-03	1406.47	480.00	1644.23	780.00
25-04-03	635.25	520.00	1206.23	1560.00
26-04-03	647.32	550.00	2226.90	1710.00
27-04-03	1163.40	450.00	1180.08	1040.00
28-04-03	1163.44	320.00	639.08	1520.00
29-04-03	1145.57	370.00	1188.98	1350.00
30-04-03	663.89	540.00	2812.93	1350.00
01-05-03	1406.47	600.00	1710.92	1700.00
02-05-03	1169.16	680.00	1218.19	1620.00
03-05-03	703.23	480.00	2461.32	1600.00
04-05-03	341.38	540.00	2461.32	1460.00
05-05-03	703.23	760.00	2099.46	1660.00
06-05-03	1054.85	720.00	2140.72	1940.00
07-05-03	1169.94	520.00	1658.88	1760.00
08-05-03	341.38	540.00	2090.94	1660.00
09-05-03	1406.47	530.00	1554.11	1440.00
10-05-03	675.58	630.00	2228.76	1900.00

Note: Est-Mo-MH is estimation of morning MH

Mea-Mo-MH is measurement of morning MH

Est-Af-MH is estimation of afternoon MH

Mea-Af-MH is measurement of afternoon MH

Table B-3 (continuation):

dd-mm-yy	Est-Mo-MH (m)	Mea-Mo-MH (m)	Est-Af-MH (m)	Mea-Af-MH (m)
11-05-03	1186.18	600.00	1727.70	1940.00
12-05-03	686.12	590.00	2194.86	1790.00
13-05-03	678.56	720.00	1736.27	1660.00
14-05-03	669.86	760.00	2556.28	1520.00
15-05-03	1646.65	740.00	1729.97	2180.00
16-05-03	683.37	680.00	2138.58	1760.00
17-05-03	703.23	680.00	2812.93	1630.00
18-05-03	1199.66	550.00	4219.40	1720.00
19-05-03	1200.02	620.00	2189.70	2030.00
20-05-03	679.17	620.00	1722.60	1820.00
21-05-03	1180.13	550.00	1692.73	1600.00
22-05-03	1189.71	800.00	1222.34	1380.00
23-05-03	1652.08	590.00	2144.75	1490.00
24-05-03	341.38	580.00	1699.52	1250.00
25-05-03	671.76	670.00	1699.52	1140.00
26-05-03	679.34	680.00	2109.70	1510.00
27-05-03	1188.56	560.00	2555.36	1550.00
28-05-03	1192.95	440.00	2615.89	1460.00
01-06-03	633.98	820.00	1656.91	680.00
02-06-03	1177.98	680.00	643.61	800.00
03-06-03	1538.43	600.00	620.88	1300.00
04-06-03	2109.70	680.00	1847.30	1120.00
05-06-03	656.54	640.00	1344.09	1220.00
06-06-03	1175.04	800.00	2109.70	1480.00

Table B- 4: Morning and afternoon MH at Phuket during 20 April to 6 June 2003

dd-mm-yy	Est-Mo-MH (m)	Mea-Mo-MH (m)	Est-Af-MH (m)	Mea-Af-MH (m)
20-04-03	711.26	800.00	3100.27	1200.00
21-04-03	710.68	880.00	697.24	1280.00
23-04-03	714.58	680.00	3600.50	1270.00
24-04-03	703.55	640.00	698.00	1240.00
25-04-03	712.85	890.00	700.55	1320.00
26-04-03	675.87	640.00	691.21	1470.00
27-04-03	676.90	1060.00	693.38	1260.00
28-04-03	715.66	650.00	701.88	1310.00
29-04-03	714.86	950.00	3973.89	1200.00
30-04-03	677.69	920.00	689.48	1270.00
01-05-03	717.36	860.00	3105.89	1100.00
02-05-03	717.54	990.00	700.54	1030.00
03-05-03	2925.51	700.00	702.37	990.00
04-05-03	696.56	660.00	2957.03	780.00
05-05-03	717.92	720.00	702.62	1140.00
06-05-03	719.09	910.00	704.00	1040.00
07-05-03	719.32	750.00	703.23	1020.00
09-05-03	679.32	670.00	2749.84	1140.00
10-05-03	708.34	480.00	697.09	800.00
11-05-03	731.43	320.00	709.13	640.00
12-05-03	689.66	560.00	3437.30	800.00

Note: Est-Mo-MH is estimation of morning MH

Mea-Mo-MH is measurement of morning MH

Est-Af-MH is estimation of afternoon MH

Mea-Af-MH is measurement of afternoon MH

Table B- 4 (continuation):

dd-mm-yy	Est-Mo-MH (m)	Mea-Mo-MH (m)	Est-Af-MH (m)	Mea-Af-MH (m)
13-05-03	689.25	600.00	695.66	960.00
14-05-03	708.42	720.00	3110.56	980.00
15-05-03	731.12	790.00	1967.91	1080.00
16-05-03	689.37	440.00	694.73	1080.00
17-05-03	733.82	760.00	3153.64	1360.00
18-05-03	719.35	950.00	3158.81	1530.00
19-05-03	730.76	960.00	3160.12	1420.00
20-05-03	731.53	960.00	3655.99	1760.00
21-05-03	708.16	710.00	4163.19	1130.00
22-05-03	732.64	720.00	4626.38	1360.00
23-05-03	730.58	960.00	3658.30	1330.00
24-05-03	729.77	840.00	1968.28	1260.00
25-05-03	730.92	1310.00	3675.95	1310.00
26-05-03	2989.67	1200.00	4152.13	1430.00
27-05-03	2989.93	1380.00	3437.30	1500.00
28-05-03	2406.11	1340.00	4644.94	1300.00
29-05-03	2406.11	1560.00	4563.13	1300.00
30-05-03	1869.21	1230.00	2999.11	1100.00
31-05-03	2973.03	1000.00	3666.11	1080.00
01-06-03	2943.43	1040.00	3147.79	1240.00
02-06-03	688.73	1250.00	2054.14	1300.00
03-06-03	729.55	640.00	2057.58	1420.00
04-06-03	730.49	820.00	701.63	1420.00
05-06-03	729.70	600.00	700.00	1340.00
06-06-03	722.86	840.00	3677.78	1400.00

APPENDIX C

Multi-regression between mixing height and wind speed, temperature

Table C-1:Multi-regression between calculated mixing height and wind speed, temperature

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	U10	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	TL	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Zi-est

Note: Zi-est is calculated mixing height

U10 is wind speed, TL is temperature

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.733[a]	.538	.531	**********
2	.807[b]	.651	.641	**********

a. Predictors: (Constant), U10

b. Predictors: (Constant), U10, TL

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.1E+07	1	20714506.6	79.144	.000[a]
	Residual	1.8E+07	68	261730.367		
	Total	3.9E+07	69			
2	Regression	2.5E+07	2	12540249.9	62.553	.000[b]
	Residual	1.3E+07	67	200472.714		
	Total	3.9E+07	69			

a. Predictors: (Constant), U10

b. Predictors: (Constant), U10, TL

c. Dependent Variable: Zi-est

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	383.764	131.953		2.908	.005
	U10	500.955	56.310	.733	8.896	.000
2	(Constant)	-1343.726	387.766		-3.465	.001
	U10	432.147	51.440	.633	8.401	.000
	TL	59.305	12.708	.351	4.667	.000

a. Dependent Variable: Zi-est

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	TL	.351[a]	4.667	.000	.495	.918

a. Predictors in the Model: (Constant), U10

b. Dependent Variable: Zi-est

Table C-2: Multi-regression between measured mixing height and wind speed, temperature

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	TL	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	U10	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Z-obs

Note: Z-obs is measured mixing height

U10 is wind speed, TL is temperature

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.750[a]	.562	.556	430.163
2	.775[b]	.601	.589	413.678

a. Predictors: (Constant), TL

b. Predictors: (Constant), TL, U10

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.6E+07	1	16176668.9	87.422	.000[a]
	Residual	1.3E+07	68	185040.566		
	Total	2.9E+07	69			
2	Regression	1.7E+07	2	8646885.533	50.528	.000[b]
	Residual	1.1E+07	67	171129.200		
	Total	2.9E+07	69			

a. Predictors: (Constant), TL

b. Predictors: (Constant), TL, U10

c. Dependent Variable: Z-obs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2269.704	372.462		-6.094	.000
	TL	109.365	11.697	.750	9.350	.000
2	(Constant)	-2250.681	358.265		-6.282	.000
	TL	100.766	11.741	.691	8.582	.000
	U10	121.429	47.527	.206	2.555	.013

a. Dependent Variable: Z-obs

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	U10	.206[a]	2.555	.013	.298	.918

a. Predictors in the Model: (Constant), TL

b. Dependent Variable: Z-obs

Correlations

Correlations

		Zi-est	Z-obs	U10	TL	RHL	H-Rs-est
Zi-est	Pearson Correlation	1	.636*	.733*	.533*	-.444*	.610*
	Sig. (2-tailed)	.	.000	.000	.000	.000	.000
	N	70	70	70	70	70	70
Z-obs	Pearson Correlation	.636*	1	.404*	.750*	-.690*	.411*
	Sig. (2-tailed)	.000	.	.001	.000	.000	.000
	N	70	70	70	70	70	70
U10	Pearson Correlation	.733*	.404*	1	.287*	-.242*	.280*
	Sig. (2-tailed)	.000	.001	.	.016	.044	.019
	N	70	70	70	70	70	70
TL	Pearson Correlation	.533*	.750*	.287*	1	-.966*	.585*
	Sig. (2-tailed)	.000	.000	.016	.	.000	.000
	N	70	70	70	70	70	70
RHL	Pearson Correlation	-.444*	-.690*	-.242*	-.966*	1	-.543*
	Sig. (2-tailed)	.000	.000	.044	.000	.	.000
	N	70	70	70	70	70	70
H-Rs-est	Pearson Correlation	.610*	.411*	.280*	.585*	-.543*	1
	Sig. (2-tailed)	.000	.000	.019	.000	.000	.
	N	70	70	70	70	70	70

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table C-3: Multi – regression between calculated mixing height and wind speed, temperature after delete data of the day has mist, haze and raining phenomena

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	U10	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	TL	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Zi-est

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.962[a]	.926	.924	**********
2	.966[b]	.932	.930	**********

a. Predictors: (Constant), U10

b. Predictors: (Constant), U10, TL

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.3E+07	1	22586546.6	609.566	.000[a]
	Residual	1815620	49	37053.463		
	Total	2.4E+07	50			
2	Regression	2.3E+07	2	11375807.9	330.822	.000[b]
	Residual	1650550	48	34386.468		
	Total	2.4E+07	50			

a. Predictors: (Constant), U10

b. Predictors: (Constant), U10, TL

c. Dependent Variable: Zi-est

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	313.085	55.123		5.680	.000
	U10	600.749	24.332	.962	24.689	.000
2	(Constant)	-95.721	193.995		-.493	.624
	U10	577.490	25.732	.925	22.442	.000
	TL	13.988	6.384	.090	2.191	.033

a. Dependent Variable: Zi-est

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	TL	.090[a]	2.191	.033	.302	.830

a. Predictors in the Model: (Constant), U10

b. Dependent Variable: Zi-est

Table C-4: Multi – regression between measured mixing height and wind speed, temperature after delete data of the day has mist, haze and raining phenomena

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	TL	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	U10	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Z-obs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.726[a]	.527	.517	420.476
2	.843[b]	.710	.698	332.580

a. Predictors: (Constant), TL

b. Predictors: (Constant), TL, U10

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9644765	1	9644764.621	54.552	.000[a]
	Residual	8663183	49	176799.661		
	Total	1.8E+07	50			
2	Regression	1.3E+07	2	6499348.311	58.759	.000[b]
	Residual	5309251	48	110609.404		
	Total	1.8E+07	50			

a. Predictors: (Constant), TL

b. Predictors: (Constant), TL, U10

c. Dependent Variable: Z-obs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1770.574	432.755		-4.091	.000
	TL	97.396	13.187	.726	7.386	.000
2	(Constant)	-1427.069	347.930		-4.102	.000
	TL	71.384	11.450	.532	6.234	.000
	U10	254.132	46.151	.470	5.507	.000

a. Dependent Variable: Z-obs

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	U10	.470[a]	5.507	.000	.622	.830

a. Predictors in the Model: (Constant), TL

b. Dependent Variable: Z-obs

Correlations

Correlations

		Zi-est	Z-obs	U10	TL	RHL	H-Rs-est
Zi-est	Pearson Correlation	1	.711*	.962*	.472*	-.403*	.482*
	Sig. (2-tailed)	.	.000	.000	.000	.003	.000
	N	51	51	51	51	51	51
Z-obs	Pearson Correlation	.711*	1	.689*	.726*	-.654*	.374*
	Sig. (2-tailed)	.000	.	.000	.000	.000	.007
	N	51	51	51	51	51	51
U10	Pearson Correlation	.962*	.689*	1	.413*	-.341*	.350*
	Sig. (2-tailed)	.000	.000	.	.003	.014	.012
	N	51	51	51	51	51	51
TL	Pearson Correlation	.472*	.726*	.413*	1	-.968*	.530*
	Sig. (2-tailed)	.000	.000	.003	.	.000	.000
	N	51	51	51	51	51	51
RHL	Pearson Correlation	-.403*	-.654*	-.341*	-.968*	1	-.489*
	Sig. (2-tailed)	.003	.000	.014	.000	.	.000
	N	51	51	51	51	51	51
H-Rs-est	Pearson Correlation	.482*	.374*	.350*	.530*	-.489*	1
	Sig. (2-tailed)	.000	.007	.012	.000	.000	.
	N	51	51	51	51	51	51

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX D

Terrain condition used to calculation MH

Terrain condition used for calculation MH

For calculation daytime MH, there are some parameters that are specified by the user. They depend on the coverage of terrain condition. The parameters depend on difference terrain as follow.

1. Low land paddy at Sukhothai.

   Surface albedo (r) = 0.4 for bare soil

   = 0.25 for agriculture crops

   Surface roughness (Z_0) = 0.01 for bare soil

   = 0.2 for agriculture crops

2. Urban area at Bangkok

   Surface albedo (r) = 0.25

   Surface roughness (Z_0) = 0.4

3. Valley area at Chiang Mai

   Surface albedo (r) = 0.25

   Surface roughness (Z_0) = 0.2

   Note: For Chiang Mai, we use rural area. Source (Oke, 1987)

4. High land paddy field at Ubonratchathani

   Surface albedo (r) = 0.4 for bare soil

   = 0.25 for agriculture crops

   Surface roughness (Z_0) = 0.01 for bare soil

   = 0.2 for agriculture crops

5. Coaster area at Phuket

   Surface albedo (r) = 0.25

   Surface roughness (Z_0) = 0.2

   Note: For Phuket, we use rural area.

   Note: Source of all condition (Oke, 1987)

Table D-1 : Radiative properties of natural materials (Oke, 1987)

Surface	Remarks	Albedo α	Emissivity ε
Soils	Dark, wet Light, dry	0·05– 0·40	0·90– 0·98
Desert		0·20–0·45	0·84–0·91
Grass	Long (1·0 m) Short (0·02 m)	0·16– 0·26	0·90– 0·95
Agricultural crops, tundra		0·18–0·25	0·90–0·99
Orchards		0·15–0·20	
Forests			
Deciduous	Bare Leaved	0·15– 0·20	0·97– 0·98
Coniferous		0·05–0·15	0·97–0·99
Water	Small zenith angle Large zenith angle	0·03–0·10 0·10–1·00	0·92–0·97 0·92–0·97
Snow	Old Fresh	0·40– 0·95	0·82– 0·99
Ice	Sea Glacier	0·30–0·45 0·20–0·40	0·92–0·97

Table D-2 : Aerodynamic properties of natural surfaces (Oke, 1987)

Surface	Remarks	z_0 Roughness length (m)	d Zero plane displacement* (m)
Water†	Still – open sea	$0{\cdot}1-10{\cdot}0 \times 10^{-5}$	–
Ice	Smooth	$0{\cdot}1 \times 10^{-4}$	–
Snow		$0{\cdot}5-10{\cdot}0 \times 10^{-4}$	–
Sand, desert		0·0003	–
Soils		0·001–0·01	–
Grass†	0·02–0·1 m	0·003–0·01	$\leq$ 0·07
	0·25–1·0 m	0·04–0·10	$\leq$ 0·66
Agricultural crops†		0·04–0·20	$\leq$ 3·0
Orchards†		0·5–1·0	$\leq$ 4·0
Forests†	Deciduous	1·0–6·0	$\leq$ 20·0
	Coniferous	1·0–6·0	$\leq$ 30·0

Table D-3 : Radiative properties of typical urban materials and areas (Oke, 1987)

Surface	α Albedo	ε Emissivity	Surface	α Albedo	ε Emissivity
1. *Roads*			4. *Windows*		
Asphalt	0·05–0·20	0·95	Clear glass		
2. *Walls*			zenith angle less than 40°	0·08	0·87–0·94
Concrete	0·10–0·35	0·71–0·90	zenith angle 40 to 80°	0·09–0·52	0·87–0·92
Brick	0·20–0·40	0·90–0·92			
Stone	0·20–0·35	0·85–0·95			
Wood		0·90	5. *Paints*		
3. *Roofs*			White, whitewash	0·50–0·90	0·85–0·95
Tar and gravel	0·08–0·18	0·92	Red, brown, green	0·20–0·35	0·85–0·95
Tile	0·10–0·35	0·90	Black	0·02–0·15	0·90–0·98
Slate	0·10	0·90	6. *Urban areas*†		
Thatch	0·15–0·20		Range	0·10–0·27	0·85–0·96
Corrugated iron	0·10–0·16	0·13–0·28	Average	0·15	~0·95

Table D-4 : Typical roughness length of urbanized terrain (Oke, 1987)

Terrain	z_0 (m)
Scattered settlement (farms, villages, trees, hedges)	0·2–0·6
Suburban	
– (low density residences and gardens)	0·4–1·2
– (high density)	0·8–1·8
Urban	
– (high density, <5 storey row and block buildings)	1·5–2·5
– (urban high density plus multi-storey blocks)	2·5–10

VITAE

Mr. Anurat Saringkarnphasit was born on 28 November 1970, at Bangkok. In 1985, he graduated with a B.Sc. degree in Physics, Faculty of Science, Chiang Mai University. At present, he is study the Master program on Earth Science, Department of Geology, Faculty of Science, Chulalongkorn University. During his studied the M.Sc. program, he has researched concerning the “Daytime Estimation of the Heat Budget from Routine Meteorological Data at Non- Irrigated Paddy Field in Sukhothai, Thailand” at Atmospheric Environment Laboratory, Tokyo University of Agriculture and Technology, Japan, during October 2004 to September 2005. It is a Short-Term Exchange Program in Science and Engineering (STEP), with JASSO scholarship supported. During his study in Japan he was attend and present the research to the “Joint Meeting on Environmental Engineering in Agriculture 2005” on September 12 – 15, 2005, at Kanazawa University, Kanazawa, Japan.

He was serves as Meteorologist at Thai Meteorological Department from 1985 to present. During his work at Meteorological Department, he has attended training and seminar inside and outside Thailand concerning to Meteorology, Numerical Weather Prediction, Agriculture Weather Forecasting and Software Development for Meteorology.