DETERMINATION OF ATMOSPHERIC BOUNDARY LAYER HEIGHTS BY RADIOSONDE DATA

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Abstract

The heights of atmospheric boundary layer (ABL) are considered one of the most important parameters for meeting regulatory requirements and assessing the site for construction of nuclear power plants. Therefore, collecting upper layers of meteorological data are necessarily required from the Integrated Global Radiosonde Archive (IGRA) version 2, for the City of Mersa Matruh, a coastal City located about 240 km west of Alexandria. Based on parcel method, the height of mixing layer (HML), which is the height of lower bound of ABL is computed by a dedicated computer program developed in FORTRAN 90.The parcel method depends on the calculation of virtual potential temperature (VPT) as well as other relevant moisture variables. The upper layer meteorological data for 2019 were collected and manipulated; the methodologies are present with analyzing the results. Monthly mixing height data were recommended from Regulatory Guide 4.2-R3, for the purpose of preparation the environmental reports for site permission of Nuclear Power Plants.

Keywords: *Atmospheric boundary layer, Integrated Global Radiosonde Archive (IGRA) version 2, parcel method, height of mixing layer (HML), virtual potential temperature*

1. Introduction

The atmospheric boundary layer (ABL) or the planetary boundary layer (PBL) is the layer in which the earth's surface interacts with the large-scale atmospheric flow. The effluent substances emitted into this layer disperse horizontally and vertically due to turbulence, completely mixed for sufficient time, and well sinks and sources are absent, this layer known as the height of mixing layer (HML) [1]. The HML is a basic parameter in atmospheric air pollution models that determines the available volume for dispersion of pollutants [2] and the formation of turbulence in the PBL [3].

The PBL is the lower part of the atmosphere, which is of primary importance to weather, climate, and air quality. The processes within it control the exchange momentum, moisture, and the trace elements between the Earth's surfaces and the free troposphere. The PBL structure can be variable and complex [4]; [5]; [6]; [7]), and its height (or depth) is mainly used to characterize the vertical extent of mixing through the PBL and the level where exchanges with the free troposphere may occur [8]; [9]. There is no direct measurement of HML yet. It can be inferred from surface based remote sensing data [10]) or computed from radiosonde observations [11].

2. Radiosonde Observations and Derived Data

The IGRA data set is a collection of global radiosonde observations from nearly 2800 stations around the globe. The data set includes the following variables: atmospheric pressure, geopotential height, air temperature, dew point temperature, relative humidity, wind speed and direction. The data also provides a derived data set with computed atmospheric stability parameters, and calculated geopotential height, relative humidity, potential temperature, virtual potential temperature etc., as well as the gradients of several variables.

3. Determination of Planetary Boundary Layer Heights

There are four commonly used methods for estimating HML from radiosonde profiles [12], but "parcel method" [13] is used in this context; and a hypothetical air parcel is assumed [2]. In the parcel method, a mixing layer may exist if the air parcel ascends under the atmospheric condition, then its height, at which the air parcel is in equilibrium with the environment, can be determined by comparing the value of virtual potential temperature (VPT) at the surface to the values aloft. With a radiosonde profile, VPT is computed based on measured temperature and humidity, and then the mixing height can be found from the VPT profile. Because it is simple and intuitive, this method often is used including the IGRA derived products.

Although HML can be visually determined from radiosonde profile, an automated process was developed using FORTRAN 90 computer program based on the methodology described by [14] with a modification in which the VPT is used instead of potential temperature to account for moist air.

The algorithm starts with checking if a VPT decrease aloft from surface; if it is true then following the parcel path along the VPT profile to search for the height at which VPT is equal to the surface VPT. To reduce the uncertainty caused by radiosonde data error the search of HML is capping by 5 km above station surface. Limited by the vertical resolution of measurements, an exact point at which VPT is equal to the surface VPT may not be found in the data. So the search of HML by the program is designed to find the first level at which the VPT starts to be equal to or greater than the surface VPT. In the latter case, the pressure at HML is linearly interpolated from the VPT values at mixing layer and the sounding levels blow and above, and then the HML is computed through the hydrostatic equation from pressure.

3. Results and Discussions

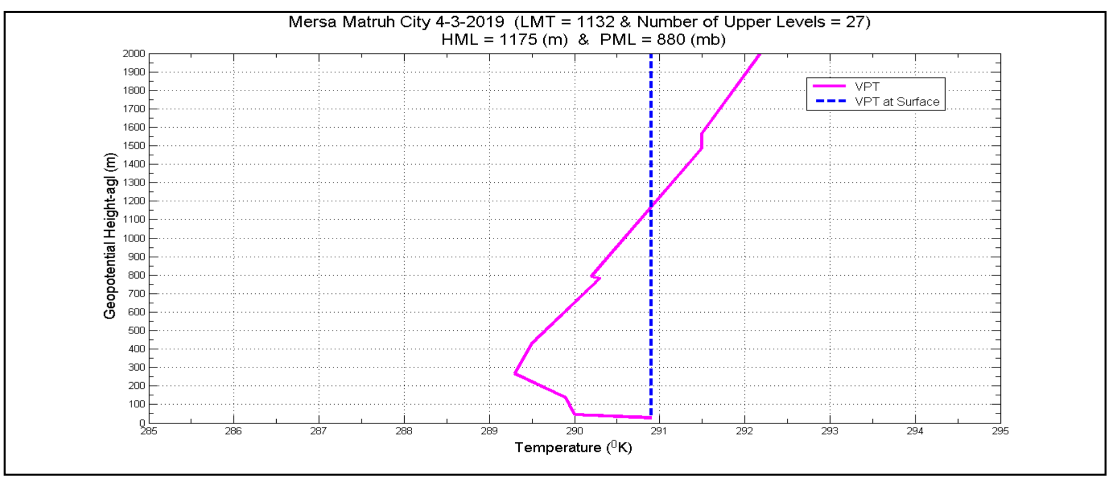

Figure 1. The existence location top of HML

The radiosonde data collected for 2019 and determination of HML are analyzing by parcel method, the data are representing numerically and graphically. The HML and the pressure are shown in Figure 1. In the graph, the top of MLH are print, according to the methodology [14].

For comparison purposes, Figure 2 represents nonexistence location of required height, because at the beginning VPT increases with height in contrary with the methodology given. Figure 3 represent the HML for months of every mid season.

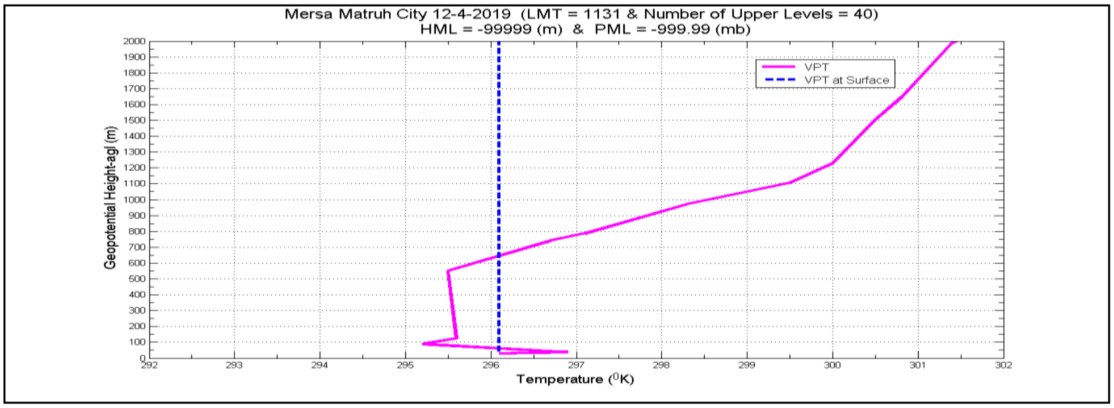

Figure 2. Non-existance location top of MLH

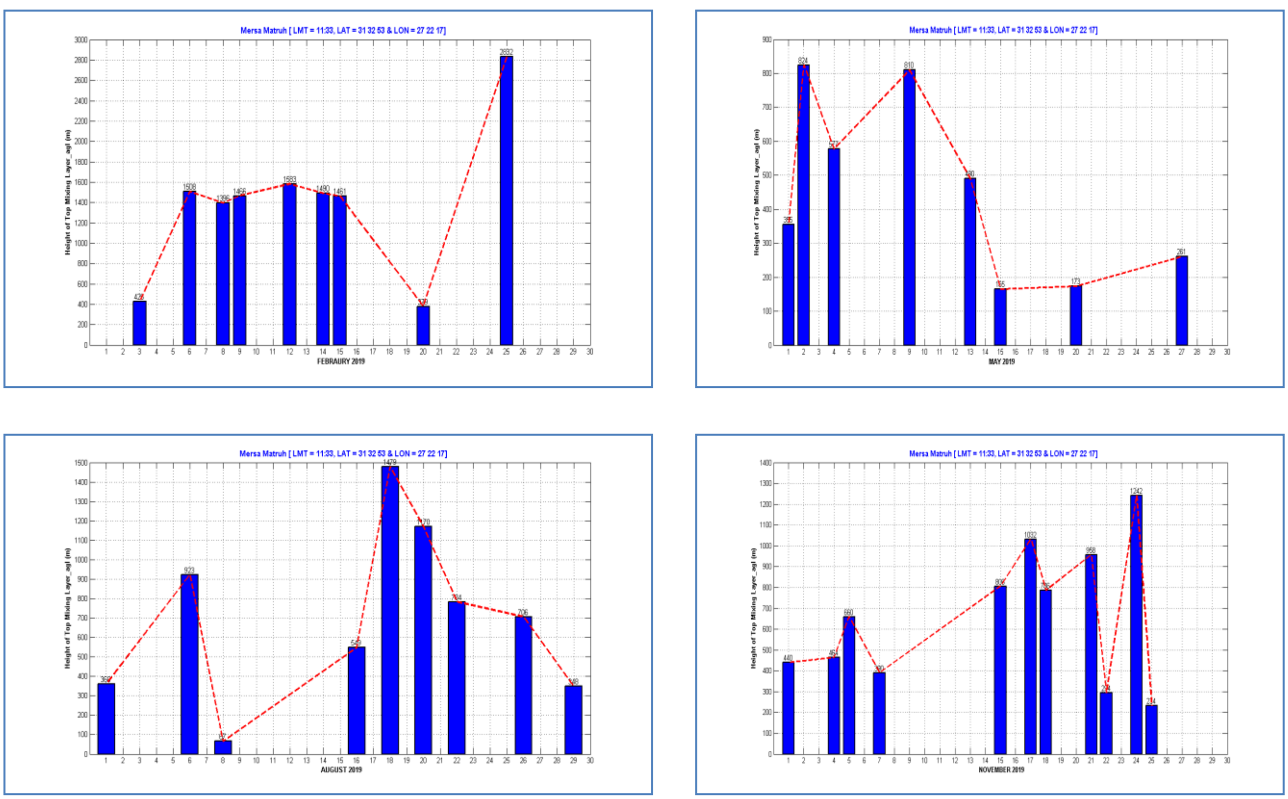

Figure 3. The top of mixing layer height for each of mid seasonaly month of the year of 2019.

The developed FORTRAN 90 computer program could analyze any period and/or any of locations of global stations. Unfortunately, the IGRA data are given once in a day almost at 12:00 AM, and some time rarely at 00:00, but for regulatory purposes the hourly HML are necessarily required, these could be achievements by launching Radiosonde twice a day, which requires extra equipment and complication procedures location.

Thereafter by the aid of the meteorological preprocessor program, RAMMET [15], used by the Industrial Source Complex (ISC) dispersion model [16] uses an interpolation scheme to assign hourly rural and urban HML mainly on the early morning and afternoon where HML calculation is done using Holzworth procedures [17]. Hourly HML, for use in regulatory dispersion modeling, are interpolated from these twice per day estimates.

Recently, by using surface meteorological data and data collected from launched Radiosonde equipment have been used for the evaluation of maximum and minimum HML from South Valley University in Egypt [18].

4.1 The Geopotential Height

The geopotential height (GPH) has been estimated by applying the hydrostatic balance to the atmospheric layer. From hydrostatic equation, the GPH is defined as [19]:

$$Z = \left(\frac{R\,\bar{T}}{g_0}\right)\ ln\left(\frac{P_0}{P}\right), \quad (1)$$

where g_0; is the globally averaged acceleration due to gravity at the Earth's surface. Equation (1) is one form of hypsometric equation. The quantity (Z) called the "thickness" of the layer between pressure levels P_0 and P and usually represented by Z_T.

The hypsometric equation tells us that the thickness of a layer between two pressure levels is proportional to the mean temperature of that layer. For colder (warmer) layers, the pressure decreases more (less) rapidly with height. The quantity $\left(\frac{R\bar{T}}{g_0}\right)$ is defined as the scale height H. In addition, the thickness is represented as Z_T.

From equation (1), it is seen that the pressure decreases exponentially with geopotential height in an isothermal atmosphere by a factor of 1/e per scale height. Geopotential height is used as the vertical coordinate in most atmospheric applications in which energy plays an important role.

Another form of hypsometric formula may be derived from the altitude at the present location from the atmospheric pressure, temperature, and sea-level pressure, which can be defined [20] as:

$$h□ = \frac{\left(\left(\frac{P_0}{P}\right)^{\frac{1}{5.257}} - 1\right) \times (T + 273.15)}{0.0065} \quad (2)$$

The atmospheric pressure observed is adjusted to the equivalent sea level pressure in order to construct the isobaric weather map. If the altitude is more than 11km high above sea level, the hypsometric formula (2) cannot apply because the temperature lapse rate varies considerably with altitude.

The drawing graph for the two equations is shown in Figure 4. Noting that the two curves are nearly identical up to 3 km, therefore, the two equations could be applied up to this limit.

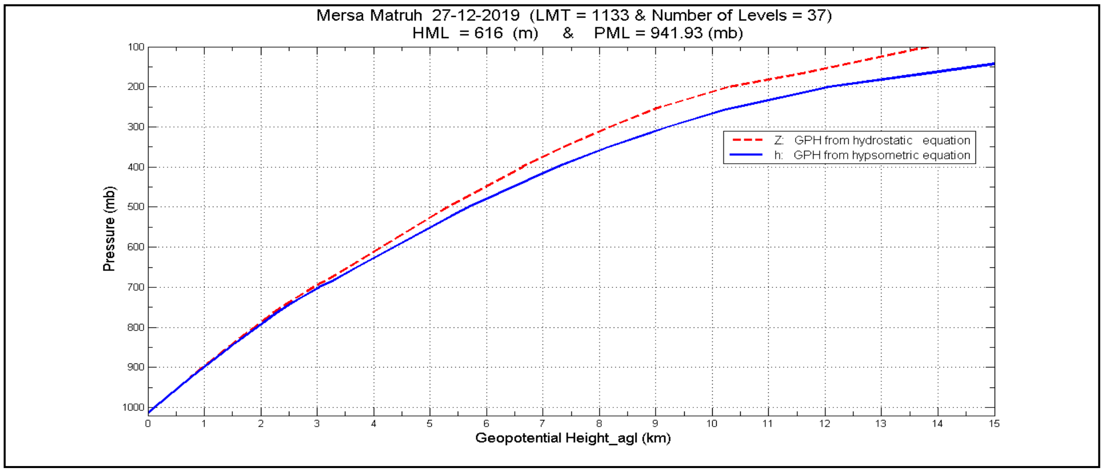

Figure 4. Calculated geopotential height from different forms

It is recommended determining monthly mixing layer height as given from Regulatory Guide 4.2, revision3, for the preparation of environmental reports for site permission of Nuclear Power Plants [21].

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تحديد أرتفاعات طبقة الحد الجوي ببيانات المسبار الراديوي

مدحت محمد عبد العال

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الملخص

تعتبر ارتفاعات طبقة الحدية الجوية (ABL) من أهم المعايير لتلبية المتطلبات التنظيمية وكذلك لتقييم موقع إنشاء محطات الطاقة النووية. تم الحصول علي البيانات المناخية الازمة لطبقات الجو العليا من خلال (IGRA-2) الأرشيف العالمي للمسبار الراديوي (Radiosonde) المتكامل الإصدارالثاني وذلك لمدينة مرسى مطروح، وهي مدينة ساحلية تقع على بعد حوالي ٢٤٠ كم غرب مدينة الإسكندرية. استنادًا إلى طريقة parcel (method)، وتعتمد هذة الطريقة على حساب درجة الحرارة المحتملة الأفتراضية (VPT) بالإضافة إلى متغيرات الرطوبة الأخرى ذات الصلة. تم حساب طبقة ارتفاع الخلط، الجوي وتعتبر الحد الأدنى لإرتفاع (ABL)، بواسطة برنامج حاسب ألي مخصص بأستخدام فورتران-٩٠. تم استخدام البيانات المناخية لطبقة الجو العليا لعام ٢٠١٩. المنهجيات المستخدمة مع تحليل النتائج موصي بها من الدليل التنظيمي (Regulatory Guide 4.2/Rev.3) **ومن ضمنها** وجوب الحصول علي بيانات أرتفاع طبقة الخلط الشهرية للموقع، وذلك لإعداد التقارير البيئية الازمة للحصول على إذن قبول موقع محطة طاقة نووية.