

COMPARATIVE STUDY OF SOME TERRESTRIAL ATMOSPHERE MODELS IN HYDROSTATIC BALANCE

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Abstract: The atmospheric pressure strongly influences the air pollution by triggering the convective and advective movements in which the masses of air are entrained. A high pressure favours a stable weather, the appearance of mist and thermal inversion in the cold season, or the occurrence of high temperatures in summertime. In these situations, the concentrations of pollutants increase significantly. When the atmospheric pressure is low, there are atmospheric precipitations that lead to the purification of atmosphere. According to the measured data on the vertical distribution of pressure and temperature, the hydrostatic approximation can well assess the real state of the atmosphere with quasi-static movements of the air masses. This paper presents a graphical user interface (GUI) programmed in Matlab providing support for a comparative study of the atmosphere models in hydrostatic balance. The application has equally a didactical and scientific importance.

Keywords: terrestrial atmosphere models, hydrostatic approximation, GUI application, Matlab

INTRODUCTION

The atmosphere is the gaseous shell of the Earth made up of 78.08% nitrogen, 20.94% oxygen, 0.93% argon and 0.03% carbon dioxide, the remaining few hundredths consisting of methane, ozone, water vapours, some nitrogen and sulphur compounds, as well as rare gases, i.e. hydrogen, neon, helium and krypton [1], [2]. In the study of atmosphere and the fluid mechanics, some fundamental physical variables are generally important, such as: pressure, density, temperature, speed, as well as the deterministic-statistical relationships established between them, based on the substantiating of appropriate mathematical models [3]. The atmospheric air is generally treated on a macroscopic scale in the hypothesis of continuum, and on microscopic scale as an ideal gas, according to the kinetic-molecular theory.

Under 100 km, the atmospheric composition is relatively constant (20% molecular oxygen and 80% molecular hydrogen), so that the mean molecular weight is constant. The atmosphere region is referred to as homogeneous. Over 100 km, the atmospheric components are changed and the atmosphere region is referred to as heterogeneous.

The vertical structure of the atmosphere was established in relation to the variation of the air temperature with the altitude and the chemical composition of the air, being divided into certain regions, called "layers": the troposphere, the stratosphere, the mesosphere, the thermosphere and the exosphere [1].

The hydrostatic approximation is fully justified for a resting atmosphere. The experimental data on the vertical distribution of pressure and temperature show that the hydrostatic approximation represents a very good assessment for the real state of the atmosphere [3].

The most used models of terrestrial atmosphere in hydrostatic balance, along with the Matlab GUI application

which provides support for the comparative study of the models, are presented below.

TERRESTRIAL ATMOSPHERE MODELS IN HYDROSTATIC BALANCE

The terrestrial atmosphere models in hydrostatic balance consider the atmospheric air to be an ideal gas, and are based on the hydrostatic approximation [1], [2], [3] according to which the elementary variation of pressure is expressed in the form:

$$dp = -\rho g dz \quad (1)$$

where ρ is the air density, g is the gravitational acceleration, and dz is the elementary variation of the altitude. For a greater accuracy, the geopotential gravitational acceleration was taken into consideration in the relationship (1):

$$g(z) = g_0 \cdot \frac{R_p^2}{(R_p + z)^2} \quad (2)$$

with $g_0 = 9.8 \text{ m/s}^2$, $z = \text{altitude}$ and $R_p = 6369 \text{ km}$ (radius of the Earth, considered spherical, at the sea level) – Figure 1.

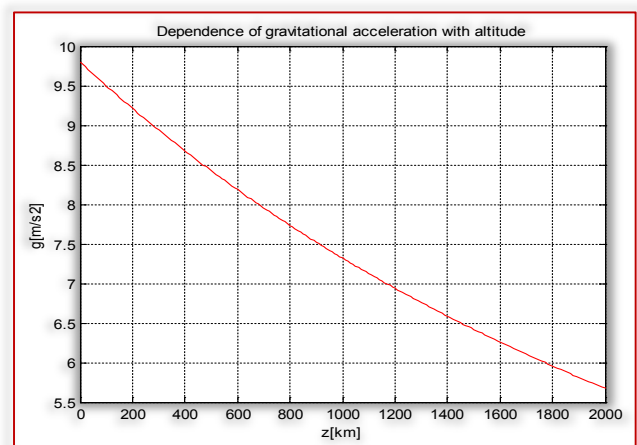


Figure 1. Dependence on altitude of the gravity acceleration

Figure 1 shows that, up to 100 km, the variation of gravitational acceleration with altitude is insignificant. The models of terrestrial atmosphere in hydrostatic balance are presented below.

a. The model of isothermal atmosphere

For the atmospheric air considered an ideal gas, the density is expressed using the thermal state equation and, after replacement in the expression of hydrostatic approximation, it results:

$$\frac{dp}{p} = -\frac{\mu_a}{RT} g dz \quad (3)$$

where μ_a is the molar mass of air, R is the universal constant of ideal gas, and T is the absolute temperature of the air.

In the case of an isothermal atmosphere model, the temperature was considered constant, independent of the altitude. By integrating the differential equation (3) under these conditions, we find the law of temperature dependence of altitude for an isothermal atmosphere:

$$p = p_0 e^{-\frac{\mu_a g}{RT} z} \quad (4)$$

where p_0 is the atmospheric pressure for $z = 0$.

As the temperature of terrestrial atmosphere varies with the height, the isothermal atmosphere model can only be used within limited height intervals.

b. The model of homogeneous atmosphere

For this model, the atmospheric density remains constant, ρ_0 . By integrating the relationship (1), we obtain a linear relationship of the atmospheric pressure with altitude:

$$p = p_0 - \rho_0 g z \quad (5)$$

i.e. the pressure decreases linearly with increasing altitude.

c. The model of polytropic atmosphere

In this model, it is considered that the temperature decreases linearly with the altitude, based on the following relationship:

$$T = T_0 - \gamma_a z \quad (6)$$

where γ_a is the vertical gradient of temperature:

$$\gamma_a = -\frac{dT}{dz} \quad (7)$$

By introducing the relationship (6) into (3) and integrating, it results:

$$p(z) = p_0 \left(\frac{T_0 - \gamma_a z}{T_0} \right)^{\frac{\mu_a g}{R \gamma_a}} \quad (8)$$

d. The international standard atmosphere model (ISA atmosphere)

The ISA atmosphere is a standardised mathematical model applied to the variation of atmospheric parameters (pressure, temperature, density, etc.) with the altitude [1]-[3].

Within the model, the ISA atmosphere is divided into layers – where the temperature varies linearly, as in the polytropic atmosphere model – table 1.

Table 1. Characteristics of atmospheric layers in the international standard atmosphere model

Layer name in ISA	Geopotential altitude at base h (in km)	Geometric altitude at base z (in km)	Temperature gradient α (in °C/km)	Temperature at the base of the layer T (in °C)	Pressure at the base of the layer p (in Pa)
Troposphere	0.0	0.0	6.5	+15.0	101325
Tropopause	11.000	11.019	0.0	-56.5	22632
Stratosphere	20.000	20.063	-1.0	-56.5	5474.9
Stratosphere	32.000	32.162	-2.8	-44.5	868.02
Stratopause	47.000	47.350	0.0	-2.5	110.91
Mesosphere	51.000	51.413	2.8	-2.5	66.939
Mesosphere	71.000	71.802	2.0	-58.5	3.9564
Mesopause	84.852	86.000	-	-86.2	0.3734

PRESENTATION OF THE COMPUTER APPLICATION ENTITLED “GRAPHICAL USER INTERFACE” (GUI), USED FOR THE STUDY OF TERRESTRIAL ATMOSPHERE MODELS IN HYDROSTATIC BALANCE

Nowadays, the increase of didactic performance is achieved by skilfully combining the traditional teaching techniques with the modern ones of multimedia type. In this regard, it is of particular importance to make and use multimedia applications for various subjects taught at courses [4] - [9].

The application for the comparative study of the terrestrial atmosphere models in hydrostatic balance is programmed in Matlab [6], [10], [11], using the GUIDE utility (Figure 2).

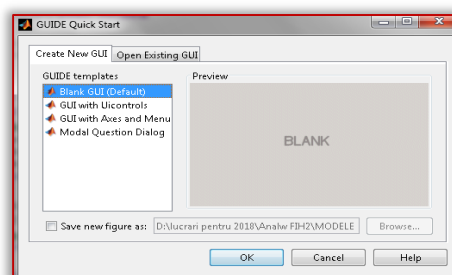


Figure 2. Running the Matlab GUIDE utility

The GUIDE utility is used to make, one by one, the application programming interfaces. For each interface, the GUIDE utility generates a graphic file “name.fig” (Figure 3) and a script with the same name “name.m” (Figure 4). The functions of the GUI elements on the interface are programmed in the Matlab script.

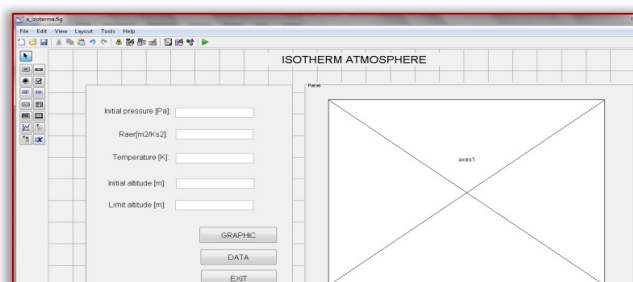


Figure 3. Graphic file of a GUI interface

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Figure 4. Matlab script afferent to a GUI interface
The file which starts the application is "start.m". For running the application, the file name is entered into the Matlab Command Window (Figure 5).

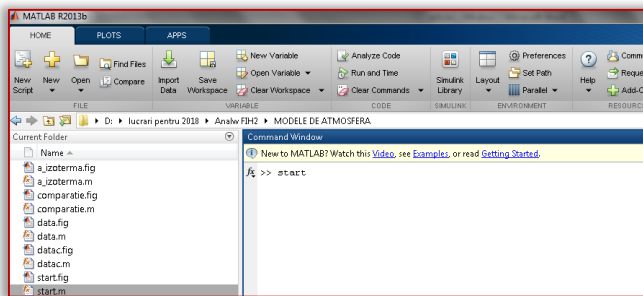


Figure 5. Running the application
From the main interface shown in Figure 6, we can reach the interfaces of the four terrestrial atmosphere models in hydrostatic balance and the interface for comparative analysis.

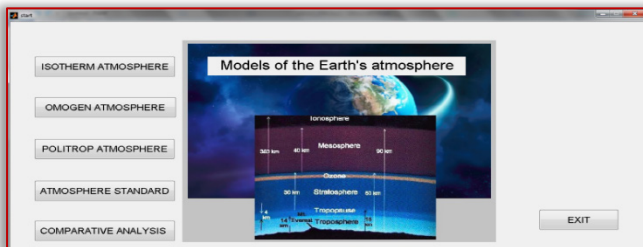


Figure 6. Main interface of the application
The interface of a model (figure 7) contains input fields for entering the calculation parameters, and two buttons. One is for the graphic representation of the atmospheric pressure versus altitude, and one for the numerical values of interest.

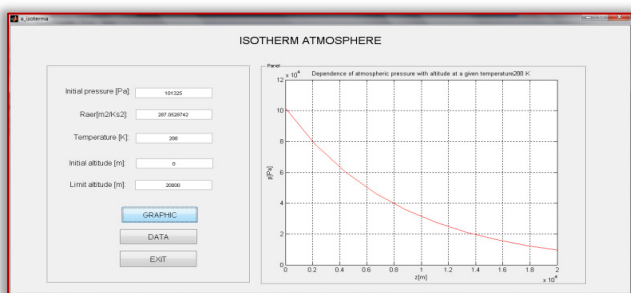


Figure 7. The interface for a terrestrial atmosphere model in hydrostatic balance

The data interface (numerical values of interest) afferent to an atmosphere model (Figure 8) presents a table with values representing the dependence of atmospheric pressure of altitude, as well as the possibility of performing a specific pressure calculation for a given altitude.

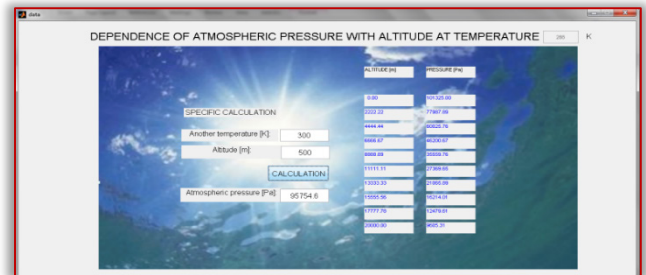


Figure 8. Data interface for a terrestrial atmosphere model in hydrostatic balance

The figures 9 and 10 show the interfaces used for the comparative analysis of the various types of terrestrial atmosphere in hydrostatic balance.

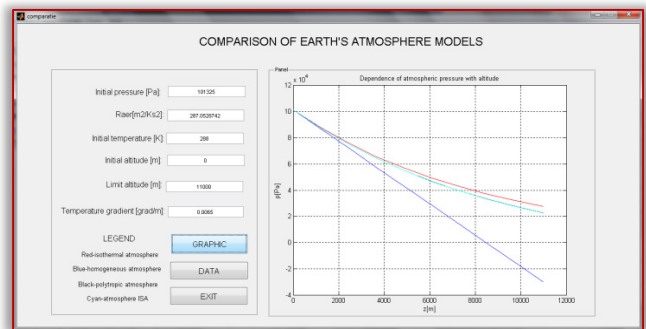


Figure 9. The interface showing the comparative study of the terrestrial atmosphere models in hydrostatic balance

Altitude [m]	$p(p_{\text{isothermal atm.}}$	$p(p_{\text{homogeneous atm.}}$	$p(p_{\text{polytrop. atm.}}$	$p(p_{\text{ISA atm.}}$
0.00	101325.00	101325.00	101325.00	101325.00
1000.00	97992.50	97992.50	97992.50	97992.50
2000.00	94742.50	94742.50	94742.50	94742.50
3000.00	91572.50	91572.50	91572.50	91572.50
4000.00	88477.50	88477.50	88477.50	88477.50
5000.00	85452.50	85452.50	85452.50	85452.50
6000.00	82492.50	82492.50	82492.50	82492.50
7000.00	79592.50	79592.50	79592.50	79592.50
8000.00	76747.50	76747.50	76747.50	76747.50
9000.00	73952.50	73952.50	73952.50	73952.50
10000.00	71202.50	71202.50	71202.50	71202.50
11000.00	68502.50	68502.50	68502.50	68502.50
12000.00	65852.50	65852.50	65852.50	65852.50
13000.00	63252.50	63252.50	63252.50	63252.50
14000.00	60702.50	60702.50	60702.50	60702.50
15000.00	58202.50	58202.50	58202.50	58202.50
16000.00	55752.50	55752.50	55752.50	55752.50
17000.00	53352.50	53352.50	53352.50	53352.50
18000.00	51002.50	51002.50	51002.50	51002.50
19000.00	48702.50	48702.50	48702.50	48702.50
20000.00	46452.50	46452.50	46452.50	46452.50
21000.00	44252.50	44252.50	44252.50	44252.50
22000.00	42102.50	42102.50	42102.50	42102.50
23000.00	40002.50	40002.50	40002.50	40002.50
24000.00	37952.50	37952.50	37952.50	37952.50
25000.00	35952.50	35952.50	35952.50	35952.50
26000.00	34002.50	34002.50	34002.50	34002.50
27000.00	32102.50	32102.50	32102.50	32102.50
28000.00	30252.50	30252.50	30252.50	30252.50
29000.00	28452.50	28452.50	28452.50	28452.50
30000.00	26702.50	26702.50	26702.50	26702.50

Figure 10. Numerical value interface for the comparative study of terrestrial atmosphere models in hydrostatic balance

CONCLUSIONS

The paper presents an application with graphical interface programmed in Matlab for comparative study of terrestrial atmosphere models in hydrostatic balance. The application enables the generation of graphs and numerical values to illustrate the dependence of the atmospheric pressure on altitude for the four models of terrestrial atmosphere in hydrostatic balance.

The Figures 9 and 10 present a comparative image of the four models for troposphere. It is found that the homogeneous atmosphere model can be used for troposphere, with indulgence at low altitudes up to 8,000 m. It is also noted that

for troposphere, the isothermal atmosphere model and the polytropic atmosphere model provide very little differing data. For troposphere, the polytropic atmosphere model coincides with the international standard atmosphere model (ISA atmosphere).

The application can be successfully used as a teaching material for the course of Atmospheric Physics and for generating values for more complex scientific analyses. The programming modality enables the application to be completed with other computational and analytical facilities useful for didactic purposes and scientific research.

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