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Aplicability of average values of meterological elements

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In practice it is important to know the statistical characteristics of meteorological elements, their nature being that of random variables characterized by average values and dispersion. Results of investigation of meteorological elements′ nature are given and optimum measuring time for calculating average values is determined.

Key words: **meteorological measuring, meteorological elements, average value, statistical characteristics, projectile flight, artillery fire.**

Introduction

WEATHER (in synoptic sense) is characterised by physical atmosphere processes that are mutually dependent for a certain time interval in some domain of space. Atmosphere characteristics can be measured and are called meteorological elements. In these measurings air temperature, pressure, moisture, wind speed and direction, cloudiness, etc: can be determined taken into account. All meteorological elements can't be taken into account in the study of projectile dynamics and only the nature of temperature, air pressure, wind magnitude and its direction will be considered. Of all the calculated meteorological elements, air temperature is the most important, for its pressure depends on height variation, i.e. the generated wind magnitude and its direction. From the moment when meteorological elements are determined by measuring, until the time of processing and forming meteorological message, time pass, and making the measuring out-of-date. Space and time variation of meteorological elements can be observed through meteorological message accuracy: accuracy decreases with time increasing from the moment of forming the meteorological message (long-lasting meteorological message) and with increasing the distance from firing position. In this article the nature of average values of meteorological elements and time of validity will be demonstrated. In practical applications, some relations concerning the nature of meteorological elements must be observed in order to avoid making huge errors.

Atmosphere and its properties

On its way from the gun to the target a projectile passes through the atmosphere enveloping the Earth. Air is a mixture of various gases and water vapour. Composition of gases in the air varies little with altitude. However mass variation and density are considerable $[5-8]$. On the altitude of 5.5km, total air mass is 50%, at 11 km 7.5%, and at 22km only 0.96%. Relative air density γ distribution dependence on altitude in percents is given in Table 1.

Table 1. Relative air density distribution on altitudes

Altitude (km)	γ(%)	Altitude (km)	γ(%)
0	100	33	1
6	50	48	0,1
18	10	93	0,0001

Physical atmosphere processes are mutually dependent and for a certain time interval in the predefined place or area are characterized as weather (in synoptic sense). Atmosphere characteristics can be measured and are called meteorological elements. The most significant element is temperature, for its variations dependence on the pressure. It is followed by wind magnitude and direction. Air temperature is the degree of its warming for which heat (energy) is used. Sun is a heat source which warm the surface from which the Sun beams are reflected and transfering heat to the air. Heat transfer to the air is done by radiation, conductivity and convection. Heat balance Earth – Sun in percents is given on Fig.1, where:

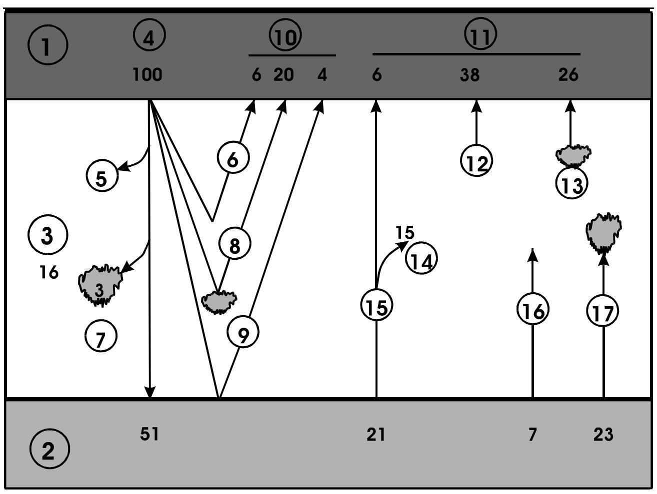

Figure 1. Earth – Sun heat balance

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1 -universe, 2 –earth, sea, 3 -atmosphere, 4 –input sun radiation, 5 - H_2O absorbed by the surface, O_3, 6 –rejected by air, 7 –absorbed in clouds, 8 –rejected from clouds, 9 –rejected from ground, 10 –rejected sun radiation, 11 – output infrared radiation, 12 -radiation H_2O, CO_2, 13 – radiation of clouds, 14 –absorbed from H_2O, CO_2, 15 –pure infrared radiation from ground, 16 –variable heat flux, 17 - latent heat flux.

It can be seen from Fig.1 that out of 100% sun energy, 19% is absorbed on its way through the atmosphere, i.e.: 16% air admixture and 3% in the clouds, and the rest of 30% is reflected back: 20% from the clouds, 6% from the air admixture and 4% from the surface. Remaining 51% is absorbed by the surface and it is used for air heating: 21% for radiation, 7% for conductivity and 23% for convection. Not only temperature, but also pressure and wind depend on the surface heat balance. Meteorological elements magnitudes vary in horizontal and vertical direction. In vertical direction there is a pattern in the variation of meteorological elements, but in the horizontal direction there is no evidence of the surface influence. For the sake facilitating the study of meteorological elements variation, atmosphere is devided into leyers. Partitions and names of the layers are given in Fig.2. First partition is troposphere, closest to the surface and in middle geographic latitudes varying 10-12 km in depth, but can reach 17-18 km above the equator. Inside the troposphere, three under layers can be noticed. Within the first one 1-2 km deep mostly mechanical and earth ground heat influence the meteorological elements. In the second, ranging from the upper limit of the first leyer and spreading 6-7 km the influence the surface is smaller, but in the third, that influence is almost absent.

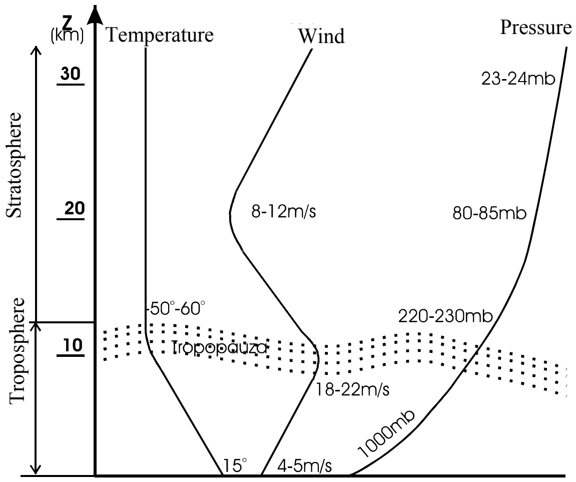

Figure 2. Atmosphere layers and meteorogical elements variations

Second layer is named stratosphere. Between troposphere and stratosphere an underlayer, 100m to 2km deep, called tropopause is situated. Troposphere's characteristic is that in it the temperature variation with height is nearly constant, but the gradient is negative. In tropopause, the gradient is not constant, and in stratosphere isothermia exists.

Meteorogical elements variations

If the measured values of the meteorological elemenats are known, their application is greatly facilitaded. However, due to the turbulent nature of the atmospheric proceses, they can be considered average values of their variations in a certain time interval. For the estimation of the values, the data given in Table 2 can be usefull.

Table 2. Order of meteorological elements and its derivatives

	V_s	V_v	p	l/p	T
1	10^{0}-10^{1}	10^{-2}-10^{-1}	10^{5}	10°	10^{2}
∂/∂_s	10^{-5}-10^{-4}	10^{-7}-10^{-6}	10^{-4}-10^{-2}	10^{-8}-10^{-7}	10^{-5}-10^{-4}
∂/∂_z	10^{-3}-10^{-2}	10^{-5}-10^{-4}	10^{1}	10^{-4}	10^{-3}-10^{-2}
∂/∂_t	10^{-4}-10^{-3}	10^{-6}-10^{-5}	10^{-2}-10^{-1}	10^{-7}-10^{-6}	10^{-4}-10^{-3}
$\partial^2/\partial s$	10^{-10}-10^{-9}	10^{-9}-10^{-9}	10^{-9}-10^{-8}	10^{-13}-10^{-12}	10^{-10}-10^{-9}

The values given in Table 2 are most common in practice for horizontal V_s and vertical V_v wind velocity, pressure p, specific volume l/ρ and temperature T(°K) and their derivatives related to horizontal distance ∂/∂_s, vertical height ∂/∂_z and time ∂/∂_t. All values reffer to lower troposphere leyers. Meteorological elements depend on the atmosphere heat balance. If stationary state in which heat is transfered by radiation is considered, i.e. rays of the determined wave lenght are the only energy sources. Then theoretically, temperature profile from which can be viewed the domain of temperature influence, can be seen as well as the domain of other heat transfer influences can be determined. A possible temperature profile is given by the following equation [5]

$$T(z) = \left[\frac{1-A}{2\sigma} S_0 \cos\nu \left(1 + 1.66 a_0 \ \rho \ H \ e^{-\frac{z}{H}}\right)\right]^{\frac{1}{4}} \quad (1)$$

and for $a_0 \rho H = 1$ and $(1-A) S_0 \cos\nu = 0.3$ cal/(cm^2.min) is given on Fig.3.

In eq.1 σ is Stefan-Bolcman constant, (l-A) $S\cos\upsilon$ is related to parameters of short-wave radiation Earth-atmosphere. Model characteristic, given by curve 1, that it is fast temperature variation near the surface, for $z = 0$, $dT/dz = -19.5\,(^{\circ}\mathrm{K})$/km, for z=3.2 km, $dT/dz = -6.5(^{\circ}\mathrm{K})$/km, at $z > 10$km, $dT/dz = 0$. Curve 2, 3, i 4 are references given by other authors. For curve 2 conditions are the same as for curve 1. Curve 3 is obtained at termical equalibrium and convection is taken into account in the atmosphere without clouds, and for curve 4 convection with clouds is taken into account. It is obvious that convection mostly changes the temperature profile in the troposphere, and a just little in the stratosphere. Models of temperature profile are smooth lines which is not the case in nature. Temperature measurements give only discreet points that can be connected by straight lines - [6].

Horizontal air dynamics parallel to the surface are called wind. Wind is defined by two quantities: magnitude and direction. From the point of view of macro-dynamics, wind stems from the pressure difference between two dinstict points on the surface, which is in direct correlation with the atmospheric heat balance above the north and south hemispheres. Micro-dynamics depend on the surface shape and are characteristical for first underleyer of the tropopause. All dynamics of the air mass are of turbulent nature, regardles of the leyer altitude.

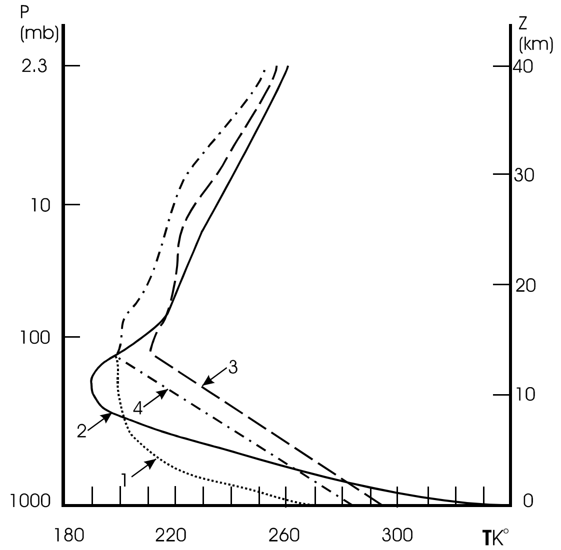

Figure 3. Temperature profile at radiation equilibrium and at termical equilibrium with convection

Average values of meteorological elements

Turbulent nature of meteorological elements variations, in particular temperature and wind as values most interesting in practice, particular mathematical methods are required for studying and recording them in the form suitable for application. When turbulent processes are in question, small perturbance of initial state can not be taken into account for forecast. For it, meteorological elements have random variable attributes with a certain law of distribution, mean value - average and dispersion σ. Some turbulent processes, with value a can be represented in form

$$a = \overline{a} + a' \tag{2}$$

where a, $\overline{a}$, a' are related to current, average and pulsation value variable in question, and then $V_{i,i=1,2,3}$, p, ρ T. Meteorological elements $V_{i,i=1,2,3}$, p, ρ, T are variables that vary daily and randomly. The average values can be calculated for infinite time interval and large number of measured data. Intervals of interes are finite, and number of seqences is one. Ergodic hypothesis enable the substitution of average values obtained from large number of measured data with average values obtained in finite time interval T. For stationary process the following expression for $\overline{a}$

$$\overline{a}(t) = \lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} a(t+\tau)d\tau = const \tag{3}$$

In case of finite time interval T, non-infinite average values depend on size T. In Fig.4 possible situations are illustrated.

Curve in Fig.4: a) illustrates small variation of average values in T; b) interval T_3 or T_4 is chosen so that it is not a part of average, but for T_1 and T_2 it is. In the close energy spectre, most energy consumation is in lower atmosphere layers for creating fast variation - pulsation of meteorological elements. In Fig.5 results of amplitude E_ω distribution of wind pulsation near surface in frequent domain $\omega = 0.0007 - 900\ (Hz * 3600)$ are given.

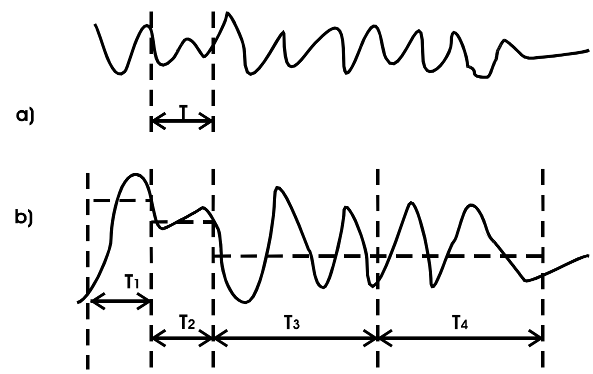

Figure 4. Typical variation of meteorological elements in time at various intervals

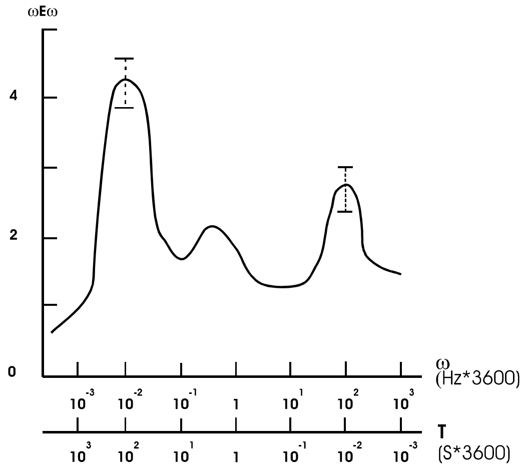

Figure 5. Wind speed spectre near the surface

On apcise in Fig.5 $\ln\omega$, on ordinate is ωE_ω is given. It can be seen from the figure that pulsation energy is concentrated in two domains: in pulsation domain of large scale (sinoptic domain) with centre near $\omega_1 = 0.01(Hz * 3600)$ and in pulsation domain of small scale with centre near $\omega_2 = 80(Hz * 3600)$. An aproximate expression for wind speed as function of two members can be obtained.

$$v(t) = A_1 \sin\omega_1 t + A_2 \sin\omega_2 t \tag{4}$$

and average value

$$\overline{v}(t) = A_1 \frac{2\sin\omega_1 t \sin\omega_1 \frac{T}{2}}{\omega_1 T} + A_2 \frac{2\sin\omega_2 t \sin\omega_2 \frac{T}{2}}{\omega_2 T} \tag{5}$$

Choosing interval T as

$$\omega_1 T = \frac{1}{\omega_2 T} >> \quad 1 \tag{6}$$

The following is obtained:

$$\overline{v}(t) = A_1 \sin\omega_1 t \tag{7}$$

It is obvious from (7) that v does not depend on T in domain of small scale spectre. Therefore, an interval T can be chosen such, that $v(t) = \overline{v}(t)$ can be taken with sufficient eccuracy. Conclusion in the case of wind is valid for other meteorological elements. Under such circumstances, for finite interval T, expression for average values of meteorological elements will be

$$\overline{a}(x_i,t)=\frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} a(x_i,t+\tau)d\tau \qquad (8)$$

Curves of average values variations for meteorological elements can be seen in Fig.2.

Statistical relations among average values of meteorological elements

Space and time variation of meteorological elements can be determined if more meteorological stations that do atmosphere sondage simultaneously exist. If there is only one sondage, which is most often the case, variation of meteorological elements can be considered through meteorological message accuracy: accuracy is diminishing with time increasing from moment of forming meteorological message (meteorological message long-lasting) and with increasing the distance from firing position. This accuraccy formulation is logical, but it is not mathematical, for it does not define criteria for validation characteristic values of random variables. Factors that participate in total error of the measured meteorological elements from the moment when they are determined by measuring to time of processing and forming meteorological message are - [1, 3]: - errors due to measuring meteorological elements by atmosphere sondage; - errors due to time variations of meteorological elements by atmosphere sondage; - errors due to space-distance variations from meteorological station to firing position. Study of atmosphere leyer characteristics gives certain useful relations - [4]. Therefore, it is concluded that speed variation of average wind and average temperature variation for 1 hour correspond to distance variation of 25 km. Pressure variation at surface for 1 hour correspond to distance variation of 50 km. Given relations enable drawing up tables of average values $(\overline{m})$ and dispersion (σ) that indicate size of meteorological elements accuracy at the moment of application. Table entries are in function of time duration of sondage results Δt_y :

- for wind components W_x, W_z and air temperature variation $\Delta\tau$, Table 3 and 4 with respect to altitude Y_i(km), where Δt_y is calculated as:

$$\Delta t_y = \Delta t + \frac{\Delta d}{25} \qquad (9)$$

and where Δt is real elapsed time from moment of meteorogical message construction to moment of its application, Δd (in km) is the distance from meteorogical station to firing position.

Table 4. Dispersion $\sigma|\delta\Delta\tau|$ (^oC)

Δt_y	Y_i(km)										
	0.2	0.4	0.8	1.2	1.6	2	4	8	12	18	25-30
0	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.4
1	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.7	0.6	0.5
2	1.5	1.4	1.3	1.2	1.2	1.2	1.1	1.0	0.9	0.7	0.6
4	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.2	0.9	0.8
8	2.6	2.4	2.3	2.1	2.1	2.0	1.8	1.7	1.5	1.2	1.0
12	3.1	2.8	2.7	2.6	2.5	2.4	2.2	2.1	1.8	1.4	1.2

For variation of pressure at surface Δh_0, Table 5, Δt_y is

Table 5. Dispersion $\sigma|\Delta h_0|$ (mmHg)

Δt_y	0	1	2	4	8	12
$\sigma(\Delta h_0)$	1.3	1.4	1.6	1.8	2.2	2.6

Calculated errors are in relation to mean values, average $\overline{m}$. They depend on the Earth area, given in tables in relation to midle Europe. In Table 6 $\overline{m}$ for temperature variation $\Delta\tau$, $\overline{m}|\Delta\tau|$ (^oC) and its dispersions $\sigma|\Delta\tau|$ $(^\circ C)$ are given.

Table 6. Average $\overline{m}|\Delta\tau|$ and Dispersion $\sigma|\Delta\tau|$ $(^\circ C)$

Y_i(m)	$\overline{m}\|\Delta\tau\|$	$\sigma\|\Delta\tau\|$	Y_i(m)	$\overline{m}\|\Delta\tau\|$	$\sigma\|\Delta\tau\|$
0	-12.6	9.8	2600	-9.9	7.6
200	-12.3	9.6	3000	-9.6	7.4
400	-12.1	9.4	3400	-9.3	7.2
600	-11.9	9.2	3800	-9.0	7.0
800	-11.7	9.0	4200	-8.7	6.8
1000	-11.5	8.8	4600	-8.4	6.6
1400	-11.1	8.4	5000	-8.1	6.5
1800	-10.7	8.1	6000	-7.5	6.4
2200	-10.3	7.9	7500	-6.9	6.3

Table 7. Dispersion $\sigma|W_X| = \sigma|W_Z|$ (m/s)

Y_i (m)	$\sigma\|W_x,W_z\|$	Y_i (m)	$\sigma\|W_x,W_z\|$	Y_i (m)	$\sigma\|W_x,W_z\|$
0	2.7	1400	4.9	3800	5.5
200	3.2	1800	5.1	4200	5.5
400	3.7	2200	5.2	4600	5.5
600	4.1	2600	5.3	5000	5.6
800	4.4	3000	5.3	6000	6.1
1000	4.6	3400	5.4	7500	6.6

Wind average values are equal 0, and wind dispersion components W_x and W_z are given in Table 7. Correlation coefficients $r\left|\Delta\tau^{Y_i},\Delta\tau^{Y_j}\right|$ that give the degree of relation dependence among random variables that express temperature variance for different altitudes, are given in Table 8.

Table 8. Correlation coefficients $r\left|\Delta\tau^{Y_i},\Delta\tau^{Y_j}\right|$

Yj (m)	Y_i (m)							
	200	600	1000	1400	1800	2200	2600	3000
200	1	0.96	0.92	0.89	0.86	0.84	0.82	0.81
600		1	0.93	0.95	0.91	0.88	0.85	0.83
1000			1	0.95	0.93	0.91	0.88	0.85
1400				1	0.98	0.94	0.90	0.88
1800					1	0.98	0.94	0.91
2200						1	0.98	0.94
2600							1	0.98
3000								1

Table 9. Correlation coefficients $r\left|W_{x,z}{}^{Y_i}, W_{x,z}{}^{Y_j}\right|$

Y_j(m)	Y_i(m)							
	200	600	1000	1400	1800	2200	2600	3000
200	1	0.93	0.91	0.89	0.89	0.88	0.88	0.88
600		1	0.97	0.95	0.93	0.91	0.91	0.90
1000			1	0.98	0.96	0.94	0.93	0.92
1400				1	0.98	0.96	0.95	0.94
1800					1	0.98	0.96	0.95
2200						1	0.98	0.97
2600							1	0.98
3000								1

Correlation coefficients $r\left|W_{x,z}{}^{Y_i}, W_{x,z}{}^{Y_j}\right|$ that give degree of relations dependence among random variables that express wind components for different altitudes are given in Table 9.

Discusion

Eq. (6) can be used for obtaining estimation of optimal period T for which average values - [9] ought to be calculated.

$$T = \frac{1}{\sqrt{\omega_1 \omega_2}} = \frac{1}{\sqrt{0.1 \cdot 80}} = 67 \text{ (mi nuts)} \qquad (11)$$

Experimental determining of vertical air dynamics and turbolence can be carried out by considering the increasing in vertical air flow between isobar surfaces on levels $\Delta\pi_k$ - [10]. If radio-sonde measurements are done every 30s, average values for 5 minute comprise 11 measurings, for which time leyer depth grows to 1500m, which is approximately equal to isobar leyer. Depth of leyer k, H_k, can be determined from streight line equation

$$H_k = H_{k-1} + \tau W_k \qquad (12)$$

where τ -time (in minutes), W_k - vertical radio-sonde speed, constant for given leyer. Height dispersion H_k, D_H, is calculated as

$$D_H = \frac{1}{\text{n-1}} \sum_{i=1}^{\text{n}} H_{kj} - \tau_j W_k \qquad (13)$$

Values of standard deviation $\sigma_H = \sqrt{D_H}$ will represent integral turbulent intensity in some frequent range ω. If air masses oscilate with ω, for 5min and wind speed $W_k = 5$m/s, under radar beam inclination approximately equal 30°, horizontal distance will be L_1=3000m and speed V=10m/s. If ω is given as

$$\omega = 2\pi \frac{V}{L} \qquad (14)$$

for given condition ω_1=0.0209rad/s.

For sample frequences 30s, Nikvist frequence is equal

$$\omega_N = \frac{\pi}{\Delta t} \qquad (15)$$

meaning ω_N =0.105rad/s.

It can be seen that frequencies are in the range of 0.0209rad/s< ω <0.105rad/s. Frequencies greather than Nikvists will produce considerable numerical errors. Time range diminishing in averaging is possible in high frequence domain, which is important during the study of near surface phenomena. However time range of averaging increasing in low frequencies domain is possible for account of increasing time range, which is in accordance with (11).

Conclusion

Projectile moving from the gun to the target passes throught atmosphere which envelopes the Earth. Physical atmosphere processes are mutualy dependent and for a certain time interval in predefined surface are characterized as weather (in sinoptic sense). Atmosphere characteristics can be measured and they are called meteorological elements. The most important one is temperature, due to its variations depending on pressure, and is followed by wind magnitude and direction. Not only temperature, but pressure and wind magnitude and its direction as well, depend on the Earth heat balance. Meteorogical elements vary in altitude and horizontal. In vertical direction there is a patern in variation of meteorological elements, but in the horizontal direction there is no evidence of the surface influence due to the surrounding nature. For the sake of facilitating the study of meteorological elements variation, atmosphere is devided into layers. The first one - troposphere is closest to the surface and in middle geographic latitudes varying 10-12 km in depth, but reaching up to 17-18 km above the equator. Inside the troposphere, three underlayers can be noticed. In the first underlayer 1-2 km deep mostly mechanical and surface heat influence the meteorological elements. In the second underlayer, from the upper limit of the first layer 6-7 km the influenceof the surface is smaller, but in the third that influence is almost absent. The second layer is called stratosphere. Between troposphere and stratosphere an underlayer called tropopause is situated, 100m to 2km deep. A characteristicof the troposphere is that the temperature gradient in it is negative and nearly constant. In the tropopause, the gradient is not constant, and in the stratosphere isothermia exists. In the troposphere the wind direction and magnitude are not predictable near the surface; the magnitude becomes constant with the positive gradient and unpredictable direction. In the stratosphere the wind magnitude and direction are also unpredictable, the direction is changed in relation to the previous layer as a rule, but the wind magnitude and direction are constant for a longer time period during the day.

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Upotrebljivost srednjih vrednosti meteoroloških elemenata

Poznavanjem prirode i statističkih karakteristika merenih meteoroloških elemenata (vetar, pritisak, temperatura) koji imaju atribute slučajne veličine (karakterišu ih srednja vrednost i rasturanje), u praksi se mogu korisno upotrebiti prilikom obrade rezultata visinskog merenja. Najvažniji podatak koji se mora unapred znati je vreme važenja merenih meteoroloških podataka. Istražena je priroda meteoroloških elemenata i nadjen optimalan interval merenja pogodan za osrednjavanje.

Ključne reči: **meteorološko merenje, meteorološki podaci, srednja vrednost, statističke karakteristike, let projektila, artiljerijsko gađanje.**

Les possibilités d'emploi des valeurs moyennes des éléments météorologiques

Quand on connait les caractéristiques statistiques des éléments météorologiques mesurés (vent, pression, température) qui ont des attributs des valeurs occasionnelles (valeur moy-enne et dispersion), on peut les utiliser en pratique lors du traitement de leur mesurement d'altitude. La donnée la plus importante qu'il faut connaitre à l'avance est le temps de validité des données météorologiques mesurées. On a examiné leur nature et on a trouvé l'intervalle de mesurage.

Mots clés: **mesurage météorologique, données météorologiques, valeur moyenne, caractéristiques statistiques, vol de projectile, tir d'artillerie.**

Употребительность среднего значения метеорологических элементов

Познанием статистических характеристик измереных метеорологических элементов (ветер, давление, температура), которые считаются случайными величинами (среднее значение и рассредоточение), их в практике возможно употребить при обработке их высотных измерений. Важнейшее данное, которое нужно знать вперед, это срок важности измереных метеорологических данных. Исследована их сущность и найден интервал измерения.

Ключевые слова: метеорологическое измерение, метеорологические данные, среднее значение, статистические характеристики, полет снаряда, артиллерийское ведение огня.