Using Signals of Television Broadcasting for Investigation of Dynamic Processes In Mesopause-Lower Thermosphere

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Abstract: ***The aim of this work is a theoretical study of the possibility of using terrestrial television broadcasting signals as sounding signals for mesosphere-lower thermosphere (MLT) wind measurements by the radio meteor method.***

Keywords: Mesosphere-lower thermosphere (MLT), radio meteor method, meteor trail, television broadcasting signals.

1. Introduction

The radio meteor method is the main one for obtaining regular information on dynamic processes in the mesopause-lower thermosphere (MLT), height range from 75 to 110 km [1, 2]. Information on dynamic processes is in demand during creation of global atmospheric air circulation models, monitoring global climate changes, predicting the propagation conditions of HF radio waves or the magnitude of ionospheric delays in the signals of Global Navigation Satellite Systems like GPS, GLONASS and for calculating the trajectories of space vehicles returning to the Earth.

In order to increase the volume of experimental data on dynamic processes in MLT, a series of coordinated radio-meteor measurements are regularly conducted within the framework of international research projects funded by NASA (National Aeronautics and Space Administration of the United States of America), DLR (German Center for Aviation and Cosmonautics), CEDAR (International Community for the Study of Energy and Dynamic Interactions in the Earth's Atmosphere). For these measurements different ground-based remote sensing methods of the atmosphere are involved. The principle of wind speed measurement by the radio meteor method is based on recording the Doppler frequency shift of sounding signals reflected from meteor trails. Meteor radars emit such signals with a power of few kilowatts or more and allow determining coordinates of the reflecting regions of meteor trails and their drift velocity along the direction of sounding [3, 4].

The high cost of operation of modern meteor radars complicates creation of network of such radars and limits the time of continuous radio meteor measurements.

One of the solutions that reduces cost of such measurements is the use of television or radio broadcasting transmitters as sources of a sounding signal. In [5-7] it is shown that television broadcasting signals (TBS) can be used for observations of meteor trails. The prospect of using TBS for monitoring of meteor trails is due to the fact that for this purpose it is not required to radiate a specialized sounding signal. Within the framework of the international project "Global Meteor Scatter Network" a network of receivers for estimation of meteor activity using signals from television and radio broadcasting stations was created.

The purpose of this work is study of the feasibility of using TBS for wind speed measurements in MLT region by the radio meteor method.

2. Theoretical Aspects of Wind Speed Measurements by the Radio Meteor Method Using Television Broadcasting Signals

The system that realizes measurements of the wind speed in the MLT by the radio meteor method using TBS as sounding signals can be classified as bistatic radar. This is due to the fact that the distance between the receiver position and the source of sounding signals (TV transmitter) is comparable or exceeds the distance to the target (meteor trail).

Under this section, it is assumed that the coordinates of a TV transmitter are known a priori. In fact, this condition is not always fulfilled because of the large number of radio transmitters of a single radio channel whose signals can be received by reflection from meteor trails. In the next section (section 2), a technique for identifying the transmitter of received TV signal will be proposed.

The Doppler frequency shift (DFS, Fd) for bistatic radars can be calculated as [8, 9]:

$$F_d = \frac{1}{\lambda}\cdot\vec{V}\cdot(\vec{r_1}+\vec{r_2}) = \frac{1}{\lambda}\cdot\left(\vec{V}\cdot\vec{r_1}+\vec{V}\cdot\vec{r_2}\right), \quad (1)$$

where

F_d − Doppler shift of the carrier frequency of the sounding signal;

$\vec{V}$ – the velocity vector of the target (the drift of reflecting region of the meteor trail);

$\vec{r}_1$, $\vec{r}_2$ – unit vectors in the directions from the meteor trail to receiver and transmitter positions;

$\lambda = c/f_0$ – wavelength of a sounding signal;

f_0 – carrier frequency;

c – speed of light.

According to formula (1) and figure 1, the DFS of the sounding signal emitted at point B and received at point C is determined by the sum of scalar products $\vec{V}\cdot\vec{r}_1$ and $\vec{V}\cdot\vec{r}_2$, or, in other words by two projections of the meteor trail drift vector onto the propagation path of the sounding signal (segments AB and AC, Figure 1).

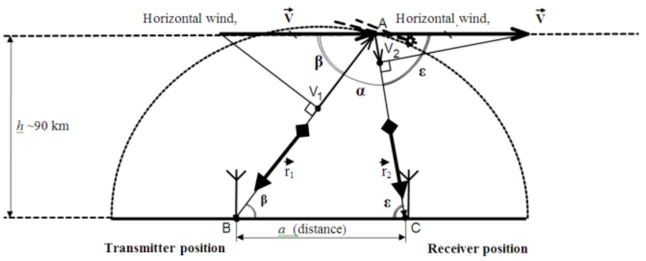


Figure 1

For constant direction and magnitude of the vector $\vec{V}$ the DFS of the reflected signal will be different; it depends on heights (h), azimuths (φ) and elevation angles (ε) of meteor trails relative to the receiver or transmitter position.

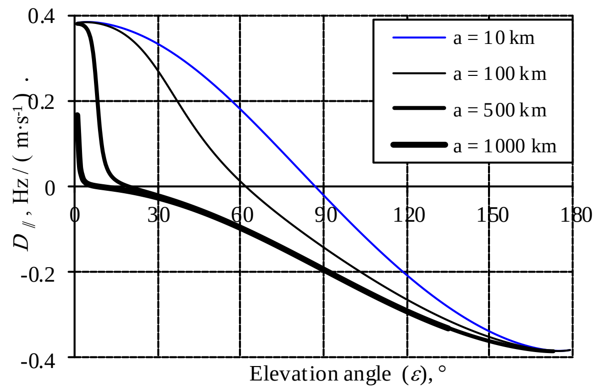
Figure 2 shows the dependency of $D = \frac{F_d}{|\vec{V}|}$ from the ε of a meteor trail relative to the receiver position. The value of D characterizes the DFS of the signal reflected from the meteor trail relative to the modulus of its drift velocity vector. The dependencies in Figure 2 are calculated by formula (1) for the following special cases:

1) "Longitudinal" drift of the meteor trail in the longitudinal plane (D||, figure 2(a)). The longitudinal plane is a plane that contains the receiver and transmitter positions and which is orthogonal to the earth surface. If the transmitter position is located in the East or the West relative to the receiver position, then the "longitudinal" component corresponds to the zonal component of the drift velocity of a meteor trail. The direction of the drift is assumed to be from the transmitter towards the receiver position;
2) "Transversal" drift of the meteor trail in the transversal plane containing the receiver position. (D⊥, figure 2(b)). The transversal plane is a plane that is orthogonal to the "longitudinal" one and to the earth surface. When the transmitter position is located in the East or in the West relative to the receiver position, the "transversal" component corresponds to the meridional component of the drift velocity of a meteor trail.

It should be noted that D|| and D⊥ characterize the drift of a meteor trail relative to the receiver and transmitter positions, these values are independent from orientation of the trail in space.

The calculation for the cases № 1 and 2 were performed under the assumption that the wind motions in the MLT are horizontal [3, 4], taking into account the curvature of the earth surface, for a constant magnitude of the drift velocity of a meteor trail, $|\vec{V}|$ = 1 m/s at 90 km height, for different distances between receiver and transmitter positions (see a on figure 1). The carrier frequency of the sounding signal corresponds to the nominal value of the image signal carrier frequency of the second television radio channel, [10], f_0 = 59,25 MHz.

a)



b)

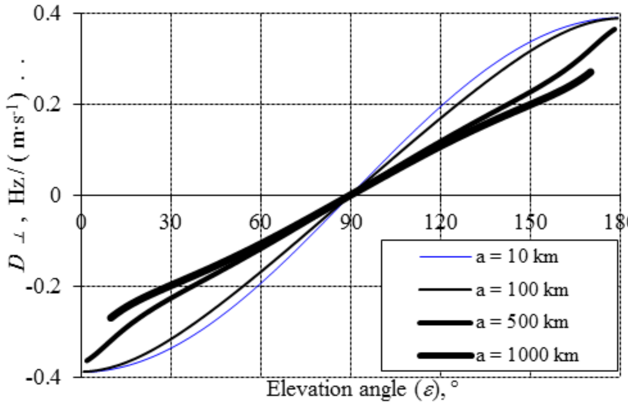


Figure 2

From Figure 2 it can be seen that same order of the DFS can be caused either by the longitudinal or transversal drift of the meteor trail. Moreover, depending on the value of ε, the same drift component of the meteor trail can cause either positive or negative DFS of the reflected signals. For certain ε the DFS is independent from the longitudinal or transversal component of the drift velocity (values of ε when $D_{||}(\varepsilon) = 0$ or $D_{\perp}(\varepsilon) = 0$, see figure 2). Consequently, there is an ambiguity of estimation of any component of the drift velocity of a meteor trail using values of DFS of the reflected signal.

For estimation of the ambiguity and possibility of extraction of a certain component of the meteor trail drift velocity, it is proposed to use the selection coefficient of the longitudinal drift component:

$$S_{||} = \frac{|D_{||}|}{|D_{||}| + |D_{\perp}|}$$

The selection coefficient $S_{||}$ quantifies the contribution of the longitudinal component of the meteor trail drift to the overall value of DFS of the reflected signal. The values of $S_{||}$ close to unity show that for the corresponding φ and ε of the meteor trail the DFS of the reflected signal is determined only by its longitudinal drift and vice versa.

Figure 3 presents the contour plot of values $S_{||}$ for different φ, ε of a meteor trail for the case when the transmitter position lies westward related to the receiver position. The distance between the positions is a = 500 km (the values of φ, ε, a are given relative to the receiver position).

Figure 3 shows that the region of maximum values of $S_{||}$ corresponds to meteor trails with elevation angles ε close to 90° or located in a direction away from the transmitter position.

For the selection of the DFS caused by the longitudinal drift of a meteor trail and for estimation of the corresponding MLT wind speed component, only those signals should be used which are reflected either from meteor trails above the receiver position or in a direction away from the transmitter position (see figure 3, the area of maximum $S_{||}$ values) [11]. For a = 100...700 km maximum $S_{||}$ values correspond to range of elevation angles ε = 90°+/-30° for the condition when $S_{||}$ is not less than 0.7 of its maxima or to the range of elevation angles ε = 90°+/-45° for the condition when $S_{||}$ is not less than 0.5. Such spatial selection of meteor trails above the receiver position can be realized by a vertically pointing antenna. Beamwidth of the antenna should not exceed 60...90°, which is relatively easy to realizable for this frequency range.

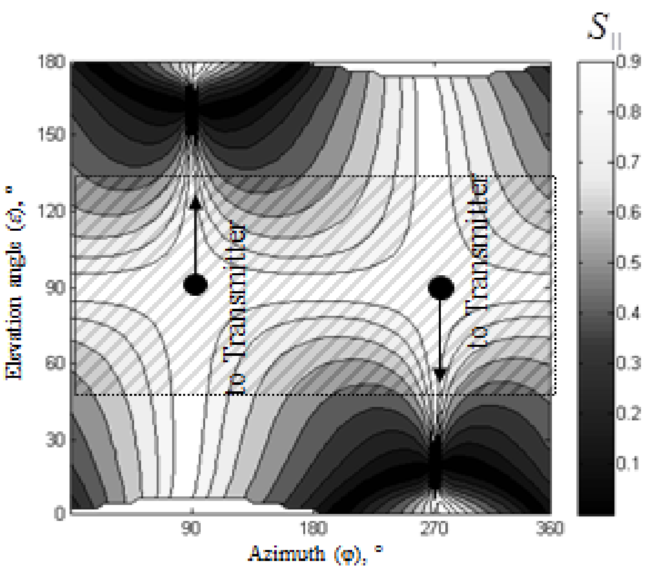


Figure 3

As the distance between the receiver and transmitter positions increases, the size of region with the maximum $S_{||}$ value expands too. However, with the increase of a, the probability of shielding of the propagation path of the sounding signal by the spherical earth surface increases too. This fact limits the range of possible values of φ and ε of meteor trails, from which a reflected signal can be received.

Such influence of the earth surface can also be observed for a = 500...700 km in the absence of atmospheric refraction for meteor trails with ε > 170° (ε < 10° in the opposite to receiver direction), see figure 3.

It should also be noted that in the area above the receiver position within ε = 90° ± 45° $D_{||}$ component has a constant sign, and $D_{\perp}$ component has the opposite sign for ε > 90° and ε < 90° (see Figure 2). Consequently, in the assumption of the symmetric distribution of ε of meteor trails above the receiver position within the specified region, the average value of $D_{\perp}$ component calculated by some set of reflected signals will tend to 0, in contrast to the average value $D_{||}$. Furthermore, the coefficient $S_{||}$ calculated from mean $D_{||}$ and $D_{\perp}$ values will exceed the same one calculated by single values. It follows from the above that analysis of the average values of the DFS of signals reflected from the meteor trails above the receiver position allows to estimate the magnitude of the longitudinal component of the wind speed with better accuracy than the estimates based on single DFS values. Level of such improvement of accuracy is determined by the real distribution of ε of meteor trails above the receiver position.

From a practical point of view, the receiving of signals reflected from meteor trails above the receiver position has the following advantage: vertical orientation of the antenna pattern maximum in the receiver position suppresses signals propagated by ground-wave. It can be signals either from the transmitter position or from nearby transmitters on adjacent frequencies. Due high power such signals can cause intermodulation interference and mask the signals reflected from the meteor trails.

Moreover, the vertical orientation of the receiving antenna creates equal conditions for the receiving of signals reflected from meteor trails, which are transmitted by different transmitters at different azimuths relative to the receiver position. Each transmitter can be paired with the corresponding longitudinal component of meteor trail drift velocity. Orientation of component is determined by the azimuth of a transmitter at the receiver position. Consequently, it is possible to measure different components of the wind speed for the same volume above the receiver position by receiving TV the signals from different transmitters. It allows determining the vector of wind speed in MLT using results of such measurements.

3. Television Broadcasting Signals of the Second Radio Channel for MLT Wind Speed Measurements Over Kharkiv, Ukraine

There are no TV transmitters of the second radio channel in Kharkiv and nearby suburbs. It creates the beneficial conditions for receiving signals from remote TV transmitters of the second radio channel (see Table 1) by reflection from meteor trails [12, 13]. However, it should be noted that the reception of television signals reflected from meteor trails is not always possible in the conditions of real interference environment (due to presence of signals from high-power transmitters at adjacent frequencies (within an octave) and the possibility of long-range tropospheric propagation of signals from remote TV transmitters [12]).

Table 1: Location and operating frequencies of TV transmitters of second radio channel whose signals can be received by reflection from the meteor trails in Kharkiv, Ukraine

Location of transmitter	*φ*, *a* (relative to	Operating frequency, MHz	Power , kW
Kiev	279°; 414 km	59.25; (0 kHz)	340
Stary Oskol	38°; 173 km	59.239583; (–10.4 kHz)	20
Dubky	14°; 865 km	59.239583; (–10.4 kHz)	113
Borysoglebsk	40°; 436 km	59.260417; (+10.4 kHz)	40
Bălţi	251°; 656 km	59.239583; (–10.4 kHz)	109
Briansk	36°; 380 km	59.260417; (+10.4 kHz)	36
Vilnus	309°; 907 km	59.253906; (+ 3.9 kHz)	177
Krasnodar	159°; 593 km	59.244792; (– 5.2 kHz)	27

For measurement of the meteor trail drift velocity using reflected television signals, it is necessary to identify the source of the received signal (a TV transmitter) and determine its azimuth relative to the receiver position.

The identification of the source of the received signal can be performed by the value of its carrier frequency. The value of the carrier frequency of the television signals (f_0) emitted by a specific TV transmitter is the sum of the nominal carrier frequency (constant for all radio stations within a single radio channel) and carrier frequency offset (CFO). The CFO values are set individually for each TV transmitter during planning of a broadcast television network. The possible values of CFO are defined in the national standards [10] and have order of magnitude of tens of kHz.

Therefore, an estimation of the carrier frequency of a TV signal reflected from a meteor trail allows obtaining the following information [11]:

1. A coarse estimation of the frequency (to the order of magnitude of kHz) allows identifying the source of the signal. Unambiguous identification is not always possible, because some TV transmitters have the same operating frequencies (the same CFO), see Table 1. However, this estimation provides a significant reduction of the list of possible sources of the received TV signals.
2. An accurate estimation of the frequency (to the order of magnitude of Hz) and its shift from the operating frequency of the TV transmitter allows estimating DFS caused by the drift of a meteor trail along the direction from the receiver position towards the identified TV transmitter.

The average duration of a radio-signal reflected from a meteor trail is about 0.1 s (up to 2 s) [1−4]. The stability of the carrier frequency of a television signal during such short time intervals is not regulated in the appropriate standards [10, 14]. However, this parameter is critical for the measurement of the meteor trail drift velocity by the technique described above.

In [15] there are presented the results of the experimental estimation of the standard deviation of the TV vision signal carrier frequencies (δ_{meas}). Such stability measurements were carried out using ground-wave signals of TV transmitters at Stary Oskol (second TV channel) and Kharkiv (third TV channel). The measurement time interval (τ_{meas}) was chosen equal to the average time of existence of meteor trail (0.1 s) and more. It was found that δ_{meas} equals to 2 Hz (for τ_{meas} = 0.1 s); 0.3 Hz (for τ_{meas} = 10 s); 1 Hz (for τ_{meas} = 24 h). The obtained values of δ_{meas} do not exceed the typical values of the Doppler shift caused by the drift of a meteor trail. Hence the vision carrier frequency of TV signal is sufficiently stable for estimation of the reflected signal DFS.

4. Structure of Device for MLT Wind Measurement by the Radio Meteor Method Using Television Broadcasting Signals

For MLT wind measurements based on the above described technique, it is proposed to use a device with structure that consists of a receiving antenna, a specialized radio receiver, analog-to-digital converter (ADC), a reference frequency source and a computer for digital signal processing [16]. The receiving antenna is three-element Yagi type. The maximum of the antenna pattern points vertically, its beamwidth should not exceed 90° in 1 MHz bandwidth relative to nominal frequency of the second TV channel. The antenna with such characteristics is used for spatial selection of signals reflected from meteor trails in the area above the receiver position. It corresponds to the above mentioned requirements for selection of DFS, which is caused by the "longitudinal" component of meteor trail drift velocity or wind speed in MLT.

The receiver is of superheterodyne type with single frequency conversion [16]. It has two outputs: the first one, the output of amplitude limiter, is intended to estimation of carrier frequency of the received signal. The second one, the output of amplitude detector, is intended to recognition of reflected signal and for estimation of its power. The receiver has fixed set of operating frequencies that correspond to the nominal values of TV signal carrier frequencies of first to third channels (49.75 MHz; 59.25 MHz; 77.25 MHz), [10]. Intermediate frequency (IF) of the receiver is 6.5 MHz, IF channel bandwidth is 160 kHz, selectivity is 40 dB. Adjacent and image channel selectivity of the receiver radio frequency channel is at least 60 dB. High adjacent and image channel selectivity allows to receive signals reflected from meteor trails in urban conditions with noisy environment. It is achieved by using a helical resonator filter as a preselector of the receiver [17].

The reference frequency source is used as a local oscillator of the receiver and for clocking of ADC. The relative instability of used reference frequency source («Frequency synthesizer» type Ч6-31) is $5\cdot10^{-10}$ for 10 s time interval; $5\cdot10^{-8}$ for 24 h time interval; $5\cdot10^{-7}$ for 6 month time interval. The on/off frequency error is $5\cdot10^{-8}$.

A series of test measurements showed that the device allows estimating the frequency of a radio signal of few microvolts amplitude over a measurement time interval of 0.1 s with a standard deviation error in the order of magnitude of few Hz. The expected DFS of the TV signals reflected from meteor trails significantly exceeds this error (for meteor trails with drift speeds up to 150 m/s [1, 2] the DFS is 20...40 Hz, it corresponds to the range of elevation angles of a meteor trail at a receiver position $\varepsilon = 90°\pm45°$). Consequently, the specifications of such device are sufficient for estimation of DFS of TV signals after reflection from a meteor trail and for further MLT wind measurement..

5. Conclusions

The possibility of using television broadcasting signals as sounding signals for measurement of wind speed in the mesopause-lower thermosphere by the radio-meteor method was investigated. Such use of television broadcast signals allows excluding the transmitter device from the measuring system and, therefore, reducing the cost of the measurements. The described equipment can be taken as the basis for creating spatially-distributed observation points for monitoring of wind motions vector in the mesopause-lower thermosphere on the basis of existing television broadcasting network.

References

[1] McKinley D., "Meteor Science and Engineering", 1961.
[2] Kashcheyev, B.L., Lebedinets, V.N. and Lagutin, M.F., "Meteoric Phenomena in the Earth's atmosphere" (in russ.), Moscow: Science, 1967.
[3] Oleynikov A.N., Kashcheyev B.L., "Investigation of atmospheric dynamic processes in the mesopause - lower thermosphere by the radio meteor method" (in russ.), Remote methods and means for studying processes in the Earth's atmosphere, Kharkiv: KNURE, pp. 133-172, 2002.
[4] Hocking, W.K., Fuller, B. and Vandepeer, B., "Real-time determination of meteor-related parameters utilizing modern digital technology", J. Atmos. Solar-Terr. Phys. Vol. 63, pp. 155-169, 2001.
[5] Oleynikov A.N., Sosnovchik D.M. and Shkarlet A.I., "The use of television broadcasting signals for investigation of variations of the meteor channel coverage factor" (in russ.), Bulletin of the State University of Information and Communication Technologies, V.4, №3. pp. 143-149, 2006.
[6] Lykov Y.V. and Oleynikov A.N., "Investigation of the characteristics of meteor radio channel using external sources of radio emission" (in russ.), Bulletin DUIKT, V6. №4, pp.296-303, 2008.
[7] Oleynikov A.N., Sosnovchik D.M., Lykov Y.V., Kukush V.D. and Makovetsky S.A., "Use of television broadcasting signals for study of processes in the meteor zone of the Earth's atmosphere" (in russ.), All-Ukr. Interd. Scientific-technical. Radio engineering, No. 160, pp. 47–55, 2010.
[8] Skolnik M. "Radar handbook",V.4, 1978.
[9] Chernyak V.S. "Multi-position radiolocation" (in russ.), 1993..
[10] GOST 7845-92. "Broadcasting system. Main settings. Measurement methods" (in russ.), 01.01.1993.
[11] Kukush V.D., Oleynikov A.M. and Makovetskyi S.O., "Process of wind measurement by the meteor radiolocation method with use of television broadcast signals" (in ukr.), patent of Ukraine on the useful model No u2010 08168, Ukraine, IPC code (2006.01) G01S 13/58, date of submission 30.06.2010, issuing date 10.03.2011.
[12] Oleynikov A.N., Lykov Y.V. and Kukush V.D., "Increase the efficiency of the space-diversity meteor radar system" (in russ.), All-Ukrainian bulletin "Radiotechnika", Vol. 157, pp. 5–12, 2009.
[13] Radio-Frequenzen und Senderkarten weltweit. URL: http://www.fmscan.de.
[14] GOST 20532-83. "Radio television transmitters of I-V bands. Basic parameters, technical requirements and measurement methods" (in russ.), 01.07.1984.
[15] Kukush V.D. and Oleynikov A.N., "Estimation of possibility of meteor trail drift velocity measurements using television broadcast signals" (in russ.), Proc. 11-th International Conference "Modern Information & Electronic Technologies", Odessa, p. 218, 2010.
[16] Kukush V.D., Oleynikov A.M and Makovetskyi S.O., "Device for wind measurement by the meteor radiolocation method with use of television broadcast signals" (in ukr.), patent of Ukraine on the useful model, No 2010 13684, Ukraine, IPC code (2009) G01S 13/58, date of submission 18.11.2010, issuing date 09.02.2011.
[17] Hansell, G.E., "Filter design and evaluation", 1974.