Results of tropospheric thermodynamics monitoring by the multichannel ground-based microwave system "Microradcom"

E.N.Kadygrov, Yu.V.Agapov, E.V.Ganshin, A.G.Gorelik, A.K.Kniazev, E.A.Miller,
V.V.Nekrasov,A.N.Shaposhnikov, T.A. Tochilkina, A.V.Troitsky

Central Aerological Observatory, Roshydromet
141700, Moscow region, Dolgoprudny, Pervomayskaya 3, Russia
tel. +7 (495) 579-94-55, tel/fax +7 (495) 408-77-58, e-mail: rpo.attex@gmail.com

Introduction

In 2012-2013 Central Aerological Observatory (CAO) was designed and commissioned a new ground-based complex which was named "Microradkom".Operation of the system is based on the features of the radiowave propagation of 20 - 60 GHz range. It provides nearly continuous measurements of temperature profiles of the troposphere (with detailing on a separate channel of the atmospheric boundary layer temperature profiles), total water vapor content (moisture content of the atmosphere), the total content of the liquid-water in the atmosphere (water content of clouds), the measurement of surface meteorological parameters, as well as video of clouds in zenith direction.Continuous measurements using complex "Microradkom" are observed in CAO in close proximity to the aerological station "Dolgoprudny" since 1 March 2012. Surface temperatures, humidity, pressure and wind are simultaneously recording.The complex has no analogues in Russia, its technical characteristics are as good as foreign analogues (USA, Germany), and performance (reliability and ease of use in a very wide range of ambient temperatures) currently has no equal in the world.

The measurement technique and the basic characteristics of the "Microradkom"

Operating principle of "Microradkom" complex is based on reception of self atmospheric thermal radiation in the range of millimeter radiowaves (frequencies from 20 GHz to 60 GHz, or wavelengths from 15 to 5 mm respectively).Ability to determine the meteorological parameters of the atmosphere with use of radiometric method is based on spectral features of the received radiation and on mutual coupling of the characteristics of this radiation (brightness temperature and absorption coefficient) with investigated meteorological parameters [1-4].Since these features are associated with the absorption of radiowaves by molecules of water vapor (22.235 GHz spectral line) and molecular oxygen (spectral lines near 60 GHz), then received self radioradiation of the atmosphere will substantially depend on the concentration of these gases and their height distribution, as well as the temperature stratification of the atmosphere (Fig. 1) [2,4,5].With the availability of hydro-formations in the atmosphere (clouds, rain), radioemission of the atmosphere strongly depends on the phase composition, the amount of liquid water and the temperature of these formations [2,3].This is especially important in so-called "window of transparence" (8 mm wavelength or frequency of 87.5 GHz), where the contribution of the gas components of water vapor and molecular oxygen is minimal (see Fig. 1) [2-5].The above mentioned circumstances determined the operating frequencies of the complex "Microradkom" and the composition of its technical devices [5,6].The most complex device is a six-channels microwave radiometer with frequency channels in the range of 53-57 GHz, the sensitivity of each channel is not worse than 0.1 K at integration time of 1 s. This radiometer able to measure the temperature profiles of the atmosphere up to 10 km (under cloudless conditions) and 3 - 5 km in the presence of cloud cover (depending on the water content of clouds) [6]. The reinstatement of the temperature profiles occurs by solving the inverse problem of the equation for the measured brightness temperature [1-2, 4]:

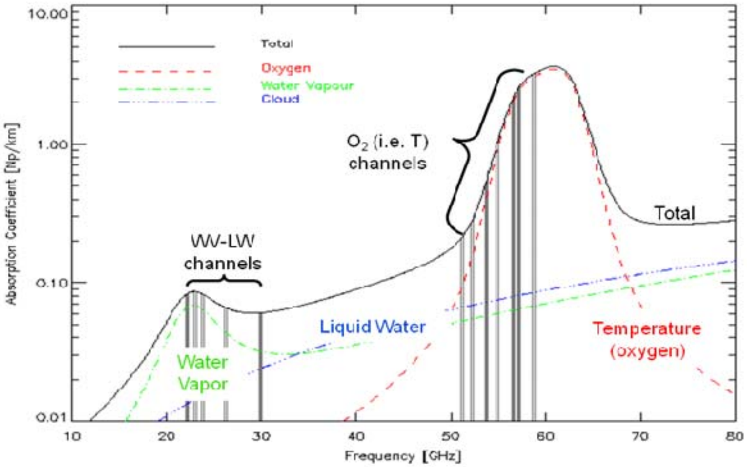

Fig.1. Absorption of radio waves in water vapor, molecular oxygen and hydro-formations [DomeNicoCimini 2010]

$$T_Я(\theta) = \frac{1}{\cos\theta}\int_0^H T(h)\gamma(h,T)\exp\left(-\frac{1}{\cos\theta}\int_0^h \gamma(h',T)dh'\right)dh = \int_0^H T(h)K(h,\theta)dh\,, \tag{1}$$

where H ≈ 20 km - the upper limit above which the contribution of radio emission in the atmosphere can be neglected, K - kernel, linearized by substituting the extrapolated values of the temperature $T^э$ (h) to the kernel K (ν, θ, h, T). Absorption coefficient consists of three parts, and depends on the temperature, water vapor content and water content of the clouds [1-5]:

$$\gamma_\nu(h) = \gamma_{O_2}(h) + \gamma_{H_2O}(h) + \gamma_W(h) \tag{2}$$

Restoring temperature profiles of the troposphere used brightness temperature values obtained at each of the six measuring frequency channels, as well as the measured values of total water vapor content and information about the water content of clouds and intensity of rain precipitation [4,5].Frequency of data issue of tropospheric temperature profile is not more than 600 sec, vertical spacing is 1 km and recovery error of temperature profiles is 0.5 ° C - 2.0 ° C [6].Temperature profile's recovery is performed by using statistical regularization by applying matrix of aerological data [2,5].

Microwave radiometer with the frequency of 56.6 GHz and sensivity 0.05 K (hight range 0 - 1.6 km with temporal output data frequency is not more than 600 c with vertical resolution step is 100 m, atmospheric temperature profiles reconstruction error is not more than 0.5 °C) is used optionaly to measure temperature profiles of atmospheric boundary layer [6,7].Data from this channel are also used when reconstructing the troposphere temperature profiles, which improves the accuracy of the solution of the inverse problem [5].

Measurement of the total water vapor content in the atmospheric column (integrated water content) with error not exceeding 0.2 g/cm2 produced by usual microwave radiometer with frequency 22.225 GHz (wavelength 13.5 mm) [1-3,5,9-15].It uses microwave switching radiometer with a straight receiver and three-cascade microwave amplifier at the input. It provides sensitivity of 0.04 K with an observation's time constant of 1 sec [5].

Fourth microwave radiometer of the complex with a frequency of 37.5 GHz (wavelength 8 mm) provides total liquid water content's measuring in the atmospheric column (integrated liquid-water content or atmosphere's liquid water) with an error not more than 0.05 kg/m2 (in the interval of 0 - 2 kg/m2) [1-3.5, 9-15].Information about synchronously measured by space and time data of moisture content and water content of the atmosphere is used to restore a troposphere temperature profiles. The complex also includes an automatic meteorological station, cloud observation system and GPS / GLONASS navigator.General view is presented in Fig. 2.Inside a tonar (trailer-van) there is a climate control system which provides the temperature of 20+/-2 C (three of four microwave radiometers are inside). Range of external temperatures is from -50 to 50 C.

Fig.2. Measuring complex "Microradkom" based on tonar.

Results of measurements

"Microdadkom" complex's measurements are made almost continuously from March 2012 to January 2014 in Central Aerological Observatory (Dolgoprudny, Moscow region). Aerological station "Dolgoprudny" where meteorological radiosondes are launched twice a day, which allows periodic comparison of data and remote sensing, is located in the immediate vicinity (100 m). Examples of the temperature profiles comparison's results obtained using "Microradkom" and radiosonde are presented in Fig. 3.

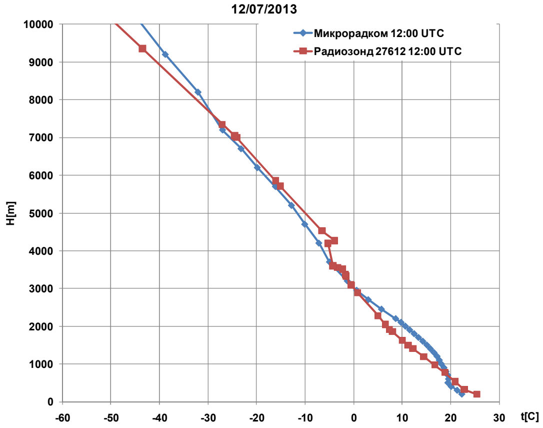

Fig. 3. Example of data comparison (12.07.2013)

Comparisons with more than 100 launches of radiosonde were made. Standard deviations in temperature profile's data are not more than 0.5 C for the atmospheric boundary layer and 1.8 C for the higher layers of the troposphere.

Comparison atmospheric moisture content data, computed on continuous data from "Microradkom" and discrete data and radiosondes are also made regularly. Example of such comparisons is shown in Fig. 4.

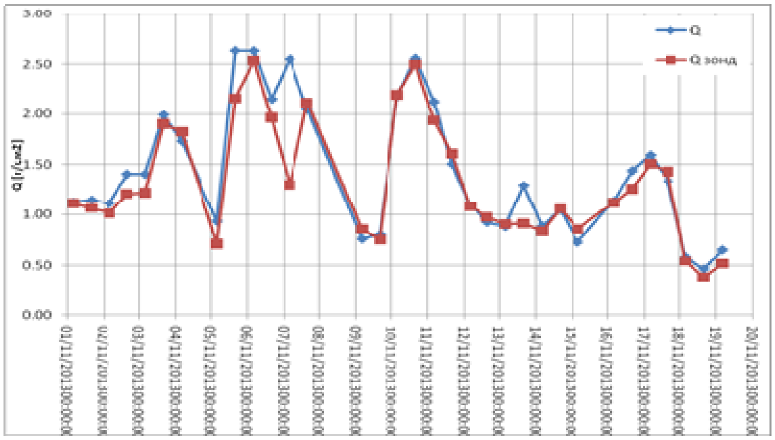

Fig. 4. Results comparisons of total water vapor content in the atmospheric column (Q), measured by the radiosonde (aerological station "Dolgoprudny") and "Microradkom" (data obtained from 01 to 20 November 2013)

Unfortunately, atmospheric liquid water content data cannot be compared so simply, because radiosondes do not make such measurements, and meteorological radars have too big error for such measurements. Usually liquid water content of clouds is measured using special sensors on the meteolaboratory aircrafts. In 2013 laboratory aircraft "Roshydromet" based on Yak-42D was designed. So in future it will possible to make such comparison, but not earlier than 2015. At current time it remains to give credibility in high stability and sensitivity of "Microradkom" and to make water content analysis of clouds, including semitransparent, using data from 13.5 and 8 mm channels. Fig. 5 shows brightness temperature record example of these channels if there is a cirrus clouds above the point of observation. This data allows us to observe phase transitions of the moisture in the clouds. Information about the variations of warm clouds and vapor liquid can be seen in radiation level on the channel 1.35 cm-radiation level on the channel of 0.8 cm diagram or similar dependencies of brightness temperature. Fig. 6 shows the crossplot of change of brightness temperature during the day. Angular variation $T_{я}1= f (T_{я}2)$ characterizes the change of processes occurring in the atmosphere and its microstructure. These factors may belong to following features: water vapor increase in cloud (the curve is steeper), the formation of large crystals, the appearance of a multilayer clouds where each layer can have its own composition and structure and appearance of ice crystals in this cloud.Supposing that there is some standard curve that describes behavior of brightness temperature's interdependence changes at a certain value of the integral water content.For cloudless atmosphere, water content value can be taken as zero. If the dependence $T_{я}1,35 = f (T_{я}0,8)$ is steeper than the standard, then the water vapor contained in the cloud gives much greater contribution, or it can mean the appearance of ice crystals in this cloud. The effect can also be caused by the emergence of large droplets, which can decrease the level of radiation at a wavelength of 0.8 cm (thin clouds and brume).In case when the tilt angle of dependence Tя1,35 = f (Tя0,8) is lower (closer to the horizontal axis), it indicates a relative reduction of the vapor role and a rise of liquid moisture's influence, while size of the cloud's drops is increasing.It is possible in a relatively thin cloud with very high water content.

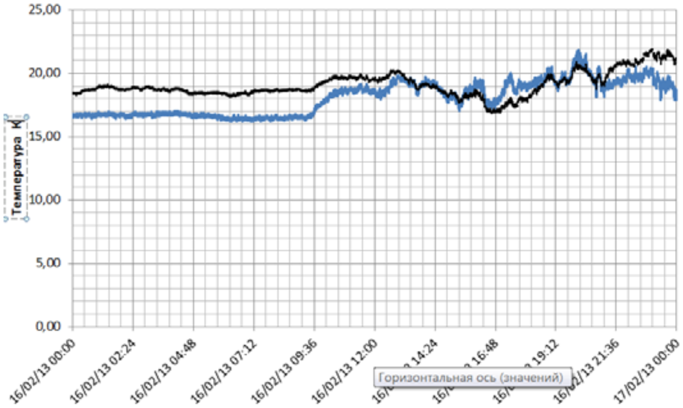

Fig. 5. Brightness temperature's changing in going from a clear sky to cirrus clouds. The upper curve is radiation channel 1.35 cm, bottom is on channel 0.8 cm (measured 16 February 2013)

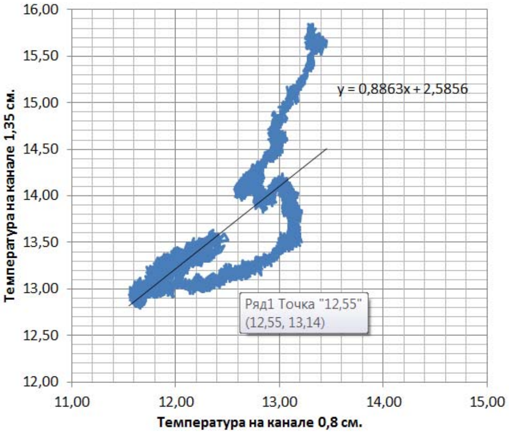

Fig. 6. Brightness temperature on the channel 1.35 cm - brightness temperature on channel 0.8 cm dependence. Plot for the values of 24.12.2012

Conclusion

Designed in CAO newest radiometric complex "Microradkom" with high sensitivity and stability offers a unique opportunity to monitor the thermodynamic state of the troposphere, as well as to explore the cloud at different stages of its development. Channels of 5 mm range allow to measure temperature profiles of the troposphere up to an altitude of 10 km, 13.5 and 8 mm channels allow to make an estimate of phase transitions inside the cloud (liquid and vapor moisture). It is important information for the estimation of the thermodynamic state of the troposphere and its dynamics. Following features allow us to obtain measurement results simultaneously in time and space: high sensitivity, direction diagrams combined in space, continuity and simultaneity by time for multiwavelength measurements. It also allows us to study the characteristics of the cloud, including the thin clouds and even brume.

References

1. *Ulaby F.T., R.K. Moore, and A.K. Fung*. Microwave Remote Sensing, Active and Passive. V. 1. Microwave Remote Sensing. Fundamentals and Radiometry.// Reading, M.A.: Addison – Wesley, 1981, 456 P.
2. *Kadygrov E.N., Pick D.R.* The potential for temperature retrieval from an angular- scanning single-channel microwave radiometer and some comparisons with in situ observations.// Meteorological Applications, 1998, V.5, Issue 4, P. 393-404.
3. *Westwater E.R., Han Y., Irisov V.G., Levskiy V., Kadygrov E.N., Viazankin A.S.* Remote sensing of boundary layer temperature profiles by a scanning 5-mm microwave radiometer and RASS: Comparison Experiments.// Journal of Atmosp., and Ocean. Techn., 1999,V. 16, July , P. 805-818.
4. *Westwater E.R.* The accuracy of water vapor and cloud liquid determination by dual frequency ground-based radiometry//Radio Science, 1978, № 4, P. 667-685.
5. *Solhein F., Godwin J., Westmaster E., Han Y., Keihm S., Marsh K., Ware R.* 1998 Radiometric profiling of temperature, water vapor and cloud liquid water using various inversion methods. Radio Sci, 33, pp. 393-404.
6. *Czerala H., Crewell S., Simmer C., Thiele A.* Integration of polarization features in ground-based microwave observations as caused by horizontally aligned oblate raindrops // J. of Appl. Meteorology, 2001, vol. 40, pp 1918-1932.