MICROWAVE SOUNDING INSTRUMENTS FOR FUTURE RUSSIAN METEOROLOGICAL SATELLITES

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ABSTRACT

The paper presents an overview of sounding instruments to be installed on board forthcoming "METEOR-3M" weather satellites. The key performance figures of the microwave atmospheric sounder MTVZA as well as its main missions are discussed. Finally the development of a new imaging/sounding instrument MTVZA-OK is depicted. This instrument will combine the functions of MW imager/sounder and optical imager.

1. INTRODUCTION

Russia is now developing next series polar orbiting meteorological satellites, METEOR-3M. Since there will be no great changes in future advanced IR sounder IRFS comparing with current development (Uspensky, et al, 1999), the paper is concentrated on the description of METEOR-3M Microwave Imager/Sounder MTVZA. Information will be presented on how the MTVZA measurements may be processed and analyzed for atmospheric temperature and moisture profile retrieving. The last part of paper concerns plans to develop imaging/sounding instrument MTVZA-OK. Along with combining of imaging/sounding missions this instrument will provide joint measurements in microwave and visible/infrared bands. It is planned to be installed on board forthcoming oceanographic satellite SICH-1M that is a joint undertaking between Russia and Ukraine.

2. MICROWAVE RADIOMETER MTVZA - PERFORMANCE AND MISSION OBJECTIVES

The payload composition of the first two METEOR-3M satellites should consist of the suite of sounding instruments providing remote sensing of three-dimensional fields of temperature and humidity of the atmosphere. Along with the advanced IR sounder IRFS (multi-purpose IR Fourier Transform Spectrometer) the major sensor of this suite is multichannel microwave (MW) radiometer MTVZA with a mechanical scan (providing conical scan). The primary mission of MTVZA measurements is to provide all-weather atmosphere temperature and humidity sounding capabilities to support numerical weather prediction (nwp) schemes of global and regional coverage.

2.1. MTVZA instrument design

The MW radiometer MTVZA, being designed and manufactured by the Space Observations Center, (RASA) is based on the technology of combining in space and time the multi-spectral and polarization measurements; besides it provides the simultaneous fulfillment of sounding and imaging functions. The MTVZA operating frequencies are located both in the transparent bands of 18.7, 33, 36.5, 42, 48, 91.61 GHz as well as in absorbing lines of oxygen 52-56 GHz and water vapor 22.235 and 183,31 GHz. The instrument will provide measurements of atmosphere temperature profile to approximately 15 km and water vapor profile to 6 km. The presence of some "non-standard" channels (like 42, 48 GHz) is explained by possible applications in oceanographic researches (Cherny, 1998).

The general description of MTVZA prototype instrument is given in (Uspensky at al., 1999). The notable changes in the MTVZA instrument deployed on board METEOR-3M N 1 spacecraft consist of the following:

- the channels 12-16 (see Table 6 from (Uspensky et al, 1999)) with maximum of the weighting functions at high troposphere and low stratosphere levels are eliminated; these channels will be restored for the enhanced follow-on MTVZA instruments, namely MW radiometer intended for METEOR-3M N 2 spacecraft and MTVZA-OK (see below). It means that for the 15-channel radiometer MTVZA the temperature sounding capabilities in low stratosphere will deteriorate compared with original planning.
- The continuous on-board recording of the global data set will be performed, although these data will be dumped only twice a day (not every orbit) at a dedicated ground station (in Moscow region) due to the experimental status of the first MTVZA instrument; moreover the ground segment facilities should provide processing of global data set within 3 hours of the measurements being made during last orbit.

2.2. MTVZA sounding capabilities

According to their primary rationale and mission the MTVZA measurements should contribute to the enhancement of the information support for nwp schemes. In order to assess the MTVZA sounding capabilities the information content analysis has been carried out with respect to temperature T(p) and humidity q(p) profiles retrieval. To perform the information contents analysis and to develop retrieval technique, the synthetic MTVZA measurements as well as weighting functions were calculated for mid-latitude summer atmosphere model. It follows from the comparison of our calculations with fig 1 (Goldberg, 1999) the behavior of weighting functions for MTVZA channels 7-11 and AMSU-A channels 4-8 is quite similar. The same property can be found for MTVZA channels 18-20 and AMSU-B channels 3-5. The information contents analysis that has been performed using standard approach, see e.g. (Timofeev et al, 1997), results in the following: it is possible to extract no more than 7 independent "pieces of information" with respect to desired quantities (T(p), q(p) - profiles) inherent in MTVZA measurements. Along with this the following parameters, associated to the MTVZA data informativity and accuracy of minimum variance solution of relevant inverse problem, have been calculated and analyzed (see e.g. Rodgers, 1990): contribution functions for each of MTVZA channels; relative contributions to the total retrieval error caused by instrumental noise and a priory data uncertainties; averaging kernels and their areas that characterize the relative contribution of measurements to the retrieved quantity and altitude range of the retrieval validity (vertical resolution). In particular, as a result of these studies the layer between 850 and 350 hPa is identified where the contribution to the temperature retrieval due to MTVZA measurements is more valuable than that associated to a priori data. According to the behavior of averaging kernels the vertical resolution of retrievals is not better than 250 hPa. The relative contribution to the total retrieval error from instrumental noise is rather small: the values of respective st. dev. are less than 0.5K in the layer between 1000 and 100 hPa, while the theoretical values of total error st. dev. are in the range 1.2 - 2.3K for in the layer 850-450 hPa.

Starting from these results and approach described in (Li et al, 2000) the prototype version of the temperature profile retrieval scheme has been developed and tested. It comprises of two consequent steps:
(1) linear statistical eigen vector regression (regression using principal components);
(2) iterative physical inversion algorithm based on the regularized least square estimator (RLSE) with regularization parameter defined from the discrepancy principle. The regression estimate is used as the first quess for the RLSE procedure which is initialized only providing the χ^2 (chi-square) type criterion is not satisfied. The maximum number of iterations in RLSE procedure is limited by the magnitude of 5.

The retrieval experiments with simulated MTVZA measurements (over land with known emissivities) demonstrate that the proposed inversion scheme makes it possible to estimate the T(p) profiles with accuracy of 1.5-2.5K for the layer 850-350 hPa. The minimum RMS error of 1.5K is achieved for the levels between 700 and 500 hPa. The retrieval errors increase up to 3.0K and greater for the levels below 850 hPa and above 300 hPa. It should be outlined that for the majority of cases considered (~ 70 %) the χ^2 criterion was satisfied after the performing the first step of inversion scheme. It means that the regression estimate can be treated as basic procedure for MTVZA data inversion. To conclude this subsection we outline the major steps of the Day-1 MTVZA data processing scheme (which now is under development).

1. Calibration and bias adjustment (between channel antenna temperatures and "true" brightness temperatures)
2. Test for clouds and intense precipitation occurrence
3. Determine surface conditions and surface emissivity
4. Produce initial retrievals (using statistical regression algorithm)
5. Test for χ^2 - residual
6. Iterate physical retrieval (using RLSE algorithm)
7. Test for χ^2 - residual and products quality control

It is expected that the procedures, realizing steps 1-3, should be specified using real MTVZA measurements during the commissioning phase for METEOR-3M N 1.

3. TOWARDS COMBINED OPTICAL/MICROWAVE INSTRUMENT MTVZA-OK.

Combined optical-microwave imager/sounder MTVZA-OK is planned to be one of key instrument payload of spacecraft "Sich-1M" which will be launched in 2003 on sunsynchronous orbit at an altitude of 650 km. The instrument will be used for remote sensing of ocean and land surface, as well as, for indirect measuring the global atmospheric temperature and water vapor profiles. MTVZA-OK combines both optical and microwave system deployed on a single scanning platform. Field of view (FOV) is common for optical and microwave imaging and sounding channels.

MTVZA-OK performance characteristics are presented in Table 1. Microwave frequency channel characteristics of MTVZA-OK are given in Table 2.

Optical system is a seven channel radiometer providing measurements in four solar channels (in the visible region) and in three thermal infrared channels. All channel detectors are built on linear charge-coupled device. Four solar channels are built on silicon detector, thermal channel 3.55-3.93 micrometers is built on InSb detector and thermal channels 10.4-11.5 and 11.5-12.6 micrometers are built using HgCdTe detector. Thermal channel detectors are cooled to 80 K by means of cryorefrigerator.

Standard deviation for instrumental noise signal referred to as the noise equivalent detected temperature (NEdT) is less than 0.2 K for background temperature 300K in all thermal channels. Four solar channels are characterized by signal-to-noise ratio as more than 8:1 for 0.5% albedo.

Table 1. MTVZA-OK performance characteristics.

System	Optical	Microwave
	Spectral Range (micrometers): 0.37-0.45 0.45-0.51 0.58-0.68 0.68-0.78 3.55-3.93 10.4-11.5 11.5-12.6	Frequencies (GHz): 6.9, 10.6 18.7, 23.8 31, 36.5 42, 48 52.3-57.0 89 183.31
Spatial Resolution (km)	1.1	12-260
Swath Width (km)	2000	
Data Rate (kbps)	665.4	
Conical Scanning Period (sec)	1.8	
Instability Scanning Period	10^{-4}	
Mass (kg)	100	
Power Consumed (W)	240	

Table 2. MTVZA-OK Microwave Frequency Channel Characteristics.

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Chann. No.	Center Frequency (GHz)	No. of pass bands	Band-width (MHz)	Effective FOV kmxkm	Imagery pixel kmxkm	Sensitivity K/pixel	Approximate peak sensitivity altitude (km)
1	6.9	1	350	112x260	24x24	0.3	-
2	10.6	1	100	76x177	24x24	0.5	-
3	18.7	1	200	45x104	24x24	0.4	-
4	23.8	1	400	36x86	24x24	0.3	-
5	31.5	1	1000	30x69	24x24	0.3	-
6	36.7	1	1000	26x60	24x24	0.3	-
7	42	1	1000	22x53	24x24	0.4	-
8	48	1	1000	21x47	24x24	0.4	-
9	52.28	1	400	18x43	36x36	0.4	2
10	52.85	1	400	18x43	36x36	0.4	4
11	53.33	1	400	18x43	36x36	0.4	6
12	54.40	1	400	18x43	36x36	0.4	10
13	55.45	1	400	18x43	36x36	0.4	14
14	57.290344±0.3222±0.1	4	50	18x43	48x48	0.4	20
15	57.290344±0.3222±0.05	4	20	18x43	48x48	0.7	25
16	57.290344±0.3222±0.025	4	10	18x43	48x48	0.9	29
17	57.290344±0.3222±0.01	4	5	18x43	48x48	1.3	35
18	57.290344±0.3222±0.005	4	3	18x43	48x48	1.7	42
19	89	1	4000	12x28	12x12	0.6	surface
20	183.31 ± 7.0	2	1500	7x16	24x24	0.5	1.5
21	183.31 ± 3.0	2	1000	7x16	24x24	0.6	2.9
22	183.31 ± 1.0	2	500	7x16	24x24	0.8	5.3

Channels 1-8, and 19 operate on both vertical and horizontal polarization, while other channels operate on vertical polarization only.

MTVZA-OK scanning geometry is shown in Fig. 1.The MTVZA-OK scanning platform rotates continuously about an axis parallel to the local spacecraft vertical with a period of 1.8 s during which the subsatellite point travels 12 km. The scan direction is from the right to the left when looking in the forward direction of the spacecraft, with the active scanning sector 120°, resulting in a swath width of 2000 km. The viewing angle is 55.4° and the incidence angle with respect to the Earth surface equal - 65°.

The sampling rate is 12x12 km for all microwave channels. To provide required sensitivity the size of microwave imagery pixel differs depending on channels frequency. The sampling rate is 1.1x1.1 km for all optical channels.

The microwave calibration system consists of a small mirror and a hot reference absorber, which are not rotated with scanning platform. They are positioned off axis such that they pass between the feed-horn and the parabolic reflector, occulting the feed-horn once each scan. The mirror reflects cold 2.7 K cosmic background radiation into the feed-horn, thus serving, along with the hot reference absorber. This scheme provides an overall end-to-end absolute calibration, which includes the feed-horn.

The thermal infrared calibration system consists of a mirror, reflecting cold cosmic background radiation into the objective lens, and a hot reference absorber. Calibration targets sample per scan.

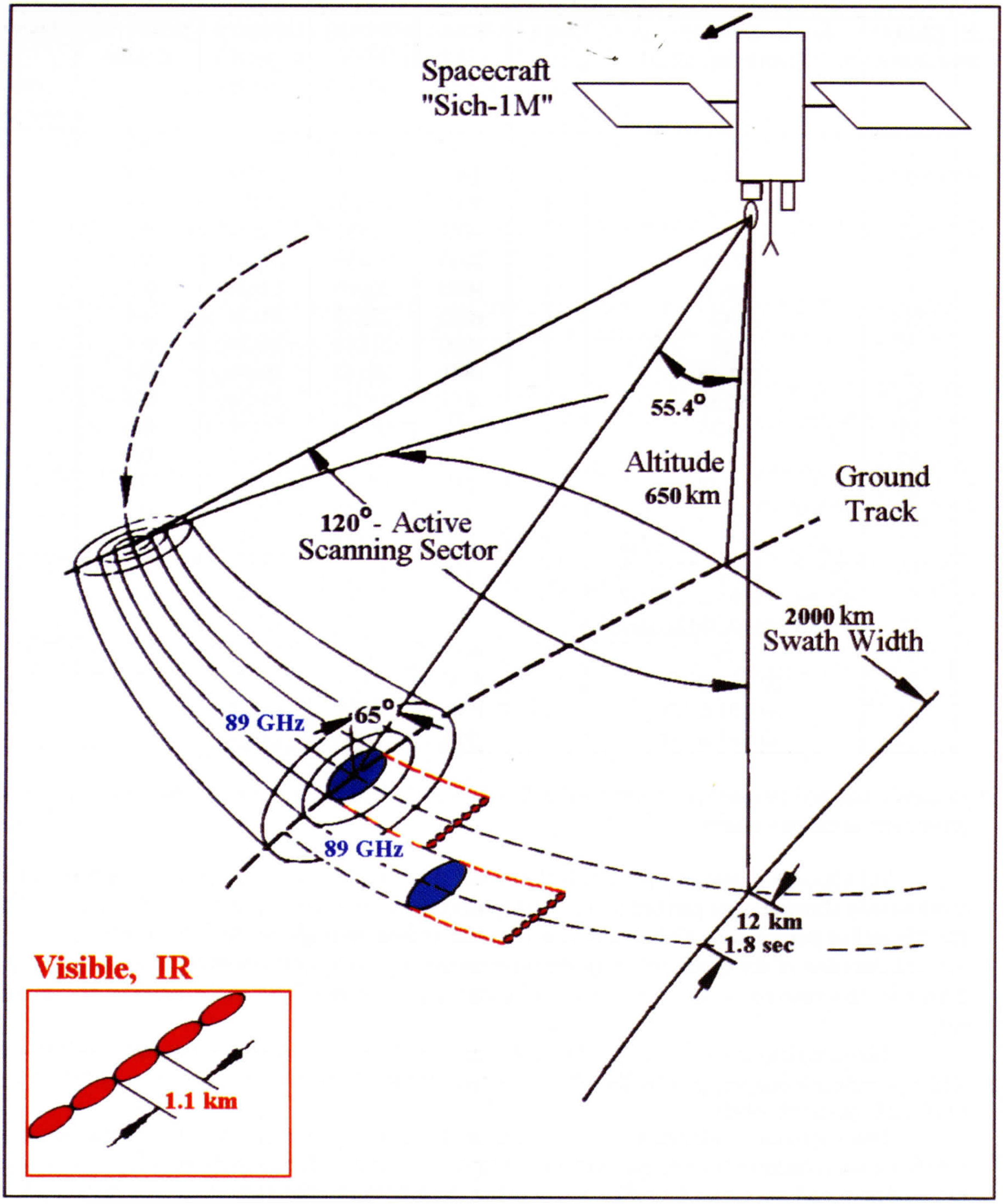

Fig. 1. MTVZA-OK scanning geometry.

It is worth to note, that the MTVZA-OK will provide some very interesting and powerful capabilities for more efficient studies of the ocean-atmosphere system. By combining optical and microwave observations in the same instrument, some beneficial advantages for determining geophysical parameters are foreseen. Both atmospheric temperature and humidity profiles, sea surface temperature and near-surface wind speed, as well as ocean color and processes within active ocean layer will be observed concurrently. It will enable to identify flows and upwelling areas as well as will lead to better understanding of ocean-atmosphere interactions. Along with this the uncertainties that often exist when multispectral and multifrequency observations are taken from different instruments at different angles and different times are removed through the MTVZA-OK capabilities. It can provide, in particular, for better detection of cloud contaminated radiances and improved accuracy of temperature and humidity retrievals.

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