SUDDEN STRATOSPHERIC WARMING IN 2015-2016: STUDY WITH SATELLITE PASSIVE MICROWAVE DATA AND ERA5 REANALYSIS

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ABSTRACT

A sudden stratospheric warming (SSW) is a large-scale meteorological disturbance that usually takes place in the arctic region. In the present research, the formation, characteristics, intensity and duration of SSW events over the North polar area in 2015-2016 winter months are studied by using the satellite passive microwave, reanalysis (ERA-Interim) and radiosonde time series. The MTVZA-GY microwave radiometer data onboard Meteor-M N 2 were collected before, during and after the SSW events. The measurements obtained by 10 microwave channels in the range between 52.8 and 57.6 GHz characterize the air temperature variations in the troposphere and stratosphere up to about 42-45 km. The detailed study was carried out over several circular areas in the vicinity of radiosonde stations located mainly in and around Greenland. Comparison of MTVZA-GY, ERA5 and radiosonde time series allowed to monitor the evolution of the SSWs, estimate their temporal characteristics, horizontal and vertical gradients of air temperature.

Index Terms— *S*udden stratospheric warming, Meteor-M N 2 MTVZA-GY, ERA5, Greenland, radiosonde data, air temperature, brightness temperatures, modeling

1. INTRODUCTION

*S*udden stratospheric warmings were discovered more than 60 years ago [2]. These events have a profound impact on winter surface climate, including increased frequency of cold air outbreaks over Eurasia and North America and anomalous warming over Greenland and eastern Canada [3]. Four types of the SSW have been have classified. These include major midwinter warming in January–February, minor warming, Canadian warming, and final warming. Recently published a SSW compendium based on the data from six different reanalyses covers almost 60-years periods (1958-2014) and allow users to investigate the importance of SSW events in many processes in the Earth atmosphere [2]. Various satellite sensors are used to improve understanding of these large scale phenomena and find indicators (precursors) of their appearance [1, 6]. In our study, the SSWs in 2015-2016 will be considered. The main data sets include the Meteor-M N 2 MTVZA-GY microwave radiometer data [5, 10], ERA5 reanalysis [4] and radiosonde data from several stations in the Northern Atlantic Ocean and in Greenland. The combination of these data allows to trace the warming processes both in the stratosphere and troposphere at the various spatiotemporal scales.

The detailed analysis of the SSW event in January 2015 is given in [8]. The event was determined as minor sudden stratospheric warming, which, however, had strong impact on lower stratospheric polar processing. The SSW in February - March 2016 was classified as a final warming [9]. The sharp increase of stratosphere temperature was observed on 5-7 March 2016. This bright signature covered the large area as follows from the analysis of MTVZA-GY data at several frequencies, ERA5 reanalysis dataset and was confirmed by radiosonde profiles at altitudes below 35 km obtained at several polar stations. The unusually high values of stratosphere temperature were also measured by ALOMAR RMR lidar (69 N, 16 E) on 6 March [11].

The main purpose of our research is to retrieve the evolution of the SSW events in 2015 and 2016 with high temporal resolution by the joint analysis of the various remote sensing, model and in situ data on the stratosphere and troposphere temperature variations.

2. DATA SETS

Two SSW events were identifiable during the 2014-2015 and 2015-2016 Arctic winters [7, 8]. Two time intervals were selected for detailed study of the origin and development of SSW: 20 December 2014 – 20 January 2015 and 1 February 15 March 2016. The main sources of information on the SSWs were passive microwave measurements from the Russian meteorological satellite "Meteor-M" No. 2, ERA5 reanalysis data and atmospheric sounding data obtained by 11 polar radiosonde stations in Greenland and in the surrounding polar areas.

The spacecraft "Meteor-M" N 2 has been launched on 8 July 2014 into a sun synchronous orbit at an altitude of about 830 km with an inclination of 98.7º, orbit period of 101.4 min, and a local time ascending node of 21:13. A microwave radiometer MTVZA-GY is used as the meteorological imaging/sounding system for remote sensing of the ocean and land surface, as well as, for measuring the global total atmospheric water vapor content, total cloud liquid water content, atmospheric temperature and water vapor profiles [5, 10]. MTVZA-GY operating frequencies are located both in the transparent windows of atmosphere 10.6, 18.7, 23.8, 31.5, 36.5, 42.0, 48.0, and 91.65 GHz, at low-frequency slope of strong oxygen absorption band 52-57 GHz and around water vapor absorption line 183.31 GHz. A swath width is equal to 1500 km and the incidence angle with respect to the Earth surface is 65°. MTVZA-GY oxygen channel frequencies are given in Table 1 [5, 11].

Table 1 MTVZA-GY oxygen channel frequencies

Channel symbols	Center Frequency (GHz), $\nu_0 = 57.290344$ GHz
O1	52.80
O2	53.30
O3	53.80
O4	54.64
O5	55.63
O6	$\nu_0 \pm 0.3222 \pm 0.1$
O7	$\nu_0 \pm 0.3222 \pm 0.05$
O8	$\nu_0 \pm 0.3222 \pm 0.025$
O9	$\nu_0 \pm 0.3222 \pm 0.01$
O10	$\nu_0 \pm 0.3222 \pm 0.005$

Effective field of view (FOV) of MTVZA-GY channels was equal 21 × 48 km and imagery pixel size was 48 × 48 km. Channel sensitivity was 0.4 K/pixel for O1-O6 channels, 0.7 for O7, 0.9 for O8, 1.3 for O9 and 1.7 K/pixel for O10.

Calibration of MTVZA-GY channels was performed using the hot reference absorber with temperature about 250 K and the cold cosmic background radiation reflected by small mirror [5, 11].

The ERA5 is the fifth generation of the ECMWF atmospheric reanalyses of the global climate, which provides hourly estimates of a large number of environmental variables including atmospheric temperature and humidity. The data cover the Earth on a 30 km grid and resolve the atmosphere using 137 levels from the surface up to a height h = 80 km [4]. We used ERA5 data to submit the atmosphere temperature maps at 7 levels and compare them with the brightness temperature fields derived by MTVZA-GY at O4-O10 oxygen channels. The ECMWF reanalysis data were taken from www.ecmwf.int/en/forecasts/datasets

Radiosonde data were downloaded from http://weather.uwyo.edu/upperair/sounding.html for the time intervals 20 December 2014 – 20 January 2015 and 1 February - 15 March 2016 for the following stations: 71082 04320 (Danmarkshavn, 76.76 N, 18.66 W), 01028 (Bjornoya, 74.51 N, 9.01 E), 04417 (Summit, 72.57 N, 38.45 W, height 3255 m), 04339 (Ittoqqortoormiit, 70.48 N, 21.95W, (Alert, 82.50 N, 62.35 W), 71917 (Eureka, 79.98 N, 85.93 W), 21.95 W), 01001 (Jan Mayen, 70.93 N, 8.66 W), 04220 (Aasiaat, 68.70 N, 52.85 W), 04360 (Tasiilaq, 65.60 N, 37.63 W), 01010 (Andoya, 69.30 N, 16.13 E), 04018 (Keflavikurflugvollur, 63.96 N, 22.60 W), 04270 (Narsarsuaq, 61.15 N, 45.43 W), 06011 (Torshavn, 62.01 N, 6.76 W), and 03005 (Lerwick, 60.13 N, 1.18W). Their location is shown in Figure 1.

Radiosondes were issued at 00 and 12 Z. Maximum altitudes of radiosonde measurements $H_{\max}$ changed from station to station. To illustrate, $H_{\max}$ ≈20-22 km for 04417 station and ≈25-30 km for 04339 and 01028 stations.

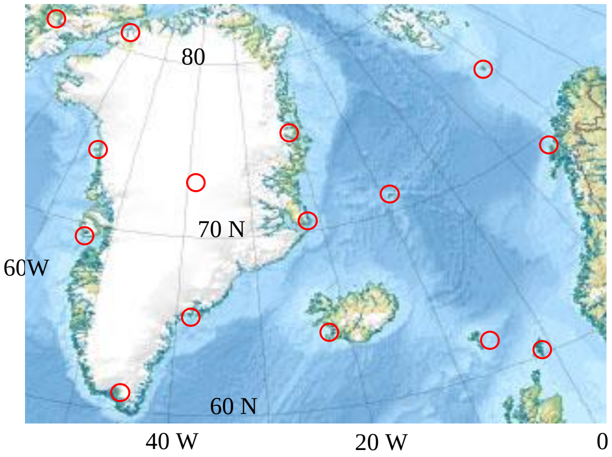

Figure 1. Red circles mark the location of r/s stations.

3. METHODS

Different MTVZA-GY channels were used to monitor air temperature $T(h)$ in the various layers of the atmosphere in accordance with the shape (width) and maximum location of the weighting functions. The temperature of low stratosphere and upper troposphere was expressed at O7-O4 channels. The variations of the low and middle stratosphere temperature manifested themselves at O7-O10 channels. The brightness temperatures (T_Bs) of oxygen channels were found using the onboard calibration. The T_Bs over the circular reference areas with diameter of 200 km served to study the spatiotemporal changes of air temperature. The T_Bs were found for all orbits which crossed the reference areas during the periods under study. T_Bs represented the averaged value of all pixels within a given area.

The T_Bs values at MTVZA-GY frequencies were also computed using the radiosonde (r/s) profiles of atmospheric pressure, temperature and humidity as the input data [5]. The spatial variations of air temperature during the SSW evolution were considered with T_B maps which were drawn for particular orbits. The gradients of air temperature were estimated by the analysis of T_B maps and ERA-5-derived atmosphere temperatures at various levels. The displacement of the warmings caused by the atmospheric circulation was estimated by comparing of the T_B time series derived for the reference areas.

4. RESULTS

During the sudden stratospheric warming events the stratosphere temperature and thus the brightness temperatures increase sharply. Time series of T_Bs at O4-O10 channels were acquired for the all reference areas from 1 December 2014 to 30 November 2016. The subseries for the period 1 November - 30 April, 2015 and 2016 were taken for comparison of the MTVZA-GY, radiosonde and reanalysis data. The T_B variations at the O8 channel over the Summit reference area are shown in Figure 2 for two five-month periods. The maximum of the weighting function at the frequency bands of the O8 channel is at altitudes of about 27-31 km (at a level of 10 hPa).

For several days in late December - early January 2015, the brightness temperature on channel 8 increased from 185 to 250 K, and then dropped to 200 K by the end of January (Figure 2a). The similar sharp T_B increase was observed between 5 and 10 March 2016 (Figure 2b).

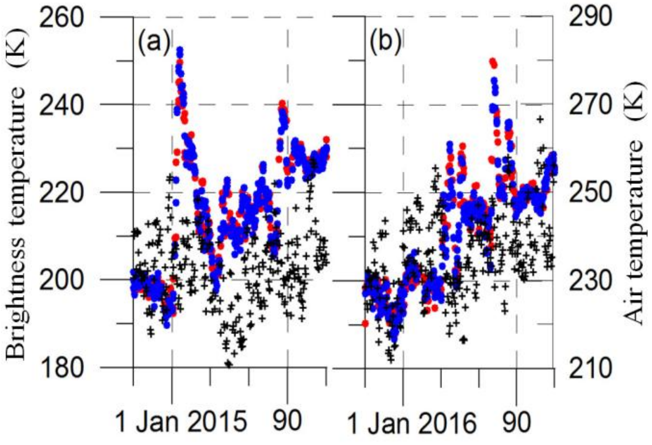

Figure 2. The T_B time series over the Summit station area for O8 channel during the miner SSW in January 2015 (a) and the final SSW in February - March 2016 (b). The red and blue dots are the T_B values in Kelvin for the ascending and descending orbits, correspondingly (left scale); the crests are the air surface temperature in Kelvin (right scale).

Most of Summit station radiosondes reached only 20-22 km. To simulate the brightness temperatures, radiosondes with a maximum altitude H_{max} = 30-32 km and more were chosen from stations Danmarkshavn (04339) and Narsarsuaq (04270) as shown in Figure 3. The simulation was performed using the average temperature profile of the stratosphere at heights $h > H_{max}$, taking into account the geographic location of station and season. This explains the difference between the simulated T_Bs and T_Bs measured by MTVZA-GY at O6-O10 channels, variations of which are determined by the variations of the air temperature in the stratosphere.

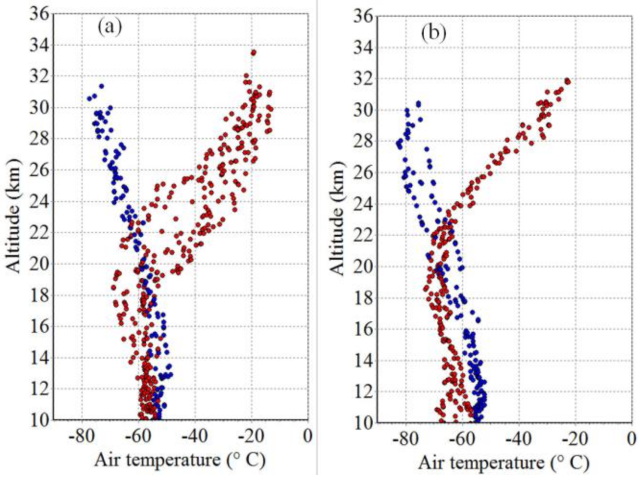

Figure 3. Radiosonde vertical profiles of air temperature before (1-3 January) and during (6-9 January 2015) sudden stratospheric warming at Narsarsuaq (04270) (a) and at Danmarkshavn (4339) (b) stations

Measurements at the O9 and O10 channels are used to sense the stratosphere temperature at the higher altitudes. To illustrate, the time series of the T_Bs at O8-O10 channels measured over the r/s stations 04220 (Aasiaat, the western Greenland) and 01001 (Jan Mayen) are shown in Figure 4.

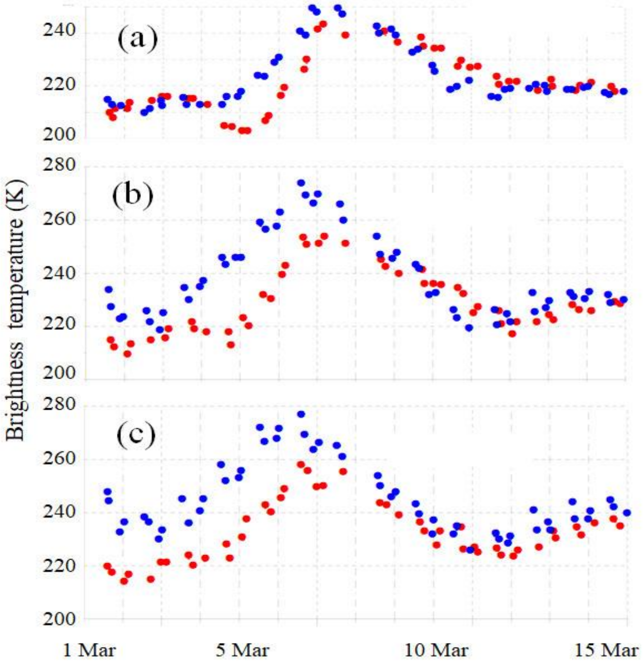

Figure 4. Time series of the brightness temperatures for the period 1-15 March 2016 obtained by the MTVZA-GY channels O8 (a), O9 (b) and O10 (c) over the radiosonde

stations 04220 Aasiaat (68.70 N, 52.85 W, red dots) and 01001 Jan Mayen (70.93 N, 8, 66 W, blue dots).

The latitudinal and longitude changes in the temperature of different layers of the atmosphere were well pronounced in the fields of T_Bs daily recorded on O4-O10 channels at the ascending and descending orbits.

The time series of the MTVZA-GY brightness temperatures show an agreement with the ERA5 reanalysis data. The ERA5 data over the Summit station acquired from 25 December 2014 to 13 January 2015 show a sudden warming of air temperature on 2 January at altitude of approximately 45-50 km (Figure 5). In successive days the warming became higher and propagated to the lower altitudes [8].

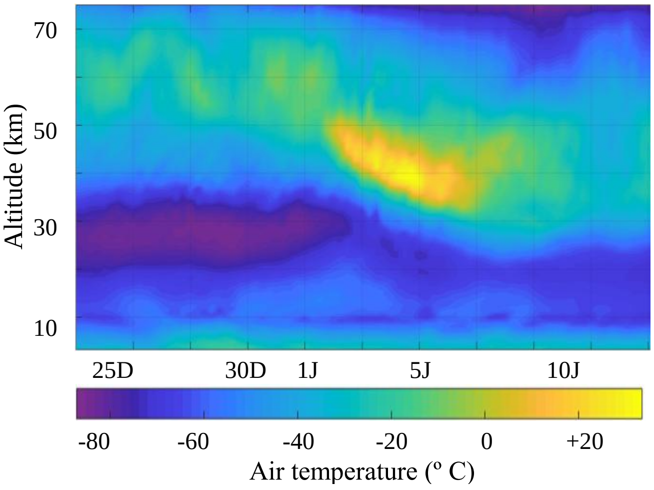

Figure 5. Time series of ERA5 air temperature from surface to 75 km over the Summit station (04417, 72.57 N, 38.45 W) from 24 December 2014 to 13 January 2015.

5. CONCLUSIONS

Sudden stratospheric warmings lead to extreme variability in Northern Hemisphere polar temperatures. This variability manifests itself in the changes of the brightness temperatures of the different layers of the troposphere, low and middle stratosphere measured by multichannel microwave radiometer MTVZA-GY onboard Meteor-M No. 2 meteorological satellite [10]. The T_B time series were constructed for circular areas the centers of which coincided with the centers of radiosonde stations located in Greenland and in the surrounding polar regions. Satellite measurements were compared with the $T(h)$ fields retrieved from the ERA5 reanalysis data and with the radiosonde vertical profiles of air temperature. The fast abrupt changes of $T(h)$ were measured by the all used techniques. Combination of satellite passive microwave, reanalysis and radiosonde data allows to monitor the SSW development and evolution.

6. REFERENCES

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