METEOR-3M/SAGE III: Algorithm, Results & Validation.

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Abstract – The algorithm to produce the slant path transmission profiles of the atmosphere from the METEOR-3M/SAGE III observations and the algorithm for the ozone, nitrogen dioxide and aerosol extinction profiles determination are presented. A change in the optical properties of the atmosphere inside the 0.5 km layer is described by the polynomial of the second power. The concept of matrix of effective lengths of the ways of solar ray in the layers is introduced.

The results of routine data processing is compared with the SAGE III, HALOE, POAM III profiles produced by NASA LaRC and with the balloon ozone sounding at the Salekhard and Yakutsk stations.

Keywords: METEOR-3M/SAGE III Mission, Inversion Algorithm, Ozone, Nitrogen dioxide, Aerosol Extinction

1. INTRODUCTION

10 December 2001 is realized the starting of Russian meteorological s/c, on board which is established the spectrophotometer of NASA USA, intended for monitoring of the aerosol and gaseous species of the Earth's atmosphere. Meteor-3M/SAGE III accomplishes everyday observations from March 2002 on the present time. The results of observations are transferred to the ground receiving stations of the USA and Russia, where independent data processing is conducted. The routine processing of the SAGE III raw data are conducted in Russia at the Central Aerological Observatory. The goal of the article is to outline the main structure of in-line processing algorithms that were developed to produce the vertical profiles of ozone and nitrogen dioxide concentrations and aerosol extinction, and demonstrate some results and their validation.

The SAGE III instrument measures the intensity of the direct or reflected from the Moon solar radiation, which passed through the Earth's atmosphere into the zone of tangent heights from the surface of the Earth or upper boundary of cloudiness up to 300 km. Only the observations by the Sun are discussed here. The raw data are simultaneously measured intensities of radiation in 87 spectral channels and time of conducting measurement according to the time scale of instrument. At the tangent heights from 300 km to 100 km the spectral calibration of all SAGE III channels is conducted and is measured the value of signal in the channels as the function of the position of the instrument field of view (IFOV) on the solar disk. The SAGE III IFOV provide with vertical resolution of approximately 0.5 km at the tangent point /LaRC 475-00-109 ATBD/. Near the Earth surface these value increases as a result of refraction.

The overall algorithm may be separated into two parts. The first is the transmission algorithm that produces the slant path transmission profiles for all spectral channels, usually in the region of tangent heights from 8 to 100 km. The second is the inversion algorithm that separates a contribution of all optically active atmospheric components and produce the vertical profiles of the concentration of ozone, dioxide of nitrogen and aerosol extinction.

The results of routine METEOR-3M/SAGE III data processing based on the algorithms were compared with SAGE III vertical profiles of ozone, nitrogen dioxide and aerosol extinction calculated by NASA Langley Research Center and with the results of HALOE and SAGE II data. The results of the SAGE III ozone profiles validation according to the balloon ozone sounding at the Salekhard and Yakutsk stations are also presented.

2. TRANSMISSION ALGORITHM

The task of algorithm is to determine the transmission of the atmosphere along the ray of sounding on the regular grid of tangent heights from 0 to 100 km with a step of 0.5 km. To do this the following technology is used:

1. Partition of information flow into the separate scans and bringing of SAGE III time scale to ground-based standard time. Determination for each moment of the observations: s/c position and velocity vector; the plane of scanning; local radius of curvature the trace of the Earth surface with the plane of scanning; calculation of the refraction using temperature and pressure profiles; real and apparent positions of upper and lower boundaries of the Sun in the plane of scanning.

2. For a scan, separately for up and down scans: theoretical calculation of a scan time taking into account the refraction effect, determination the Sun's edges time positions and the experimental scan time and estimation the s/c rotation around its center of mass. Determination IFOV position on the solar disk, Fig. 1, calculation of the light angle on the scanning mirror and normalize its reflection coefficient for the spectral channel. The Suns edges are determined as a points of intersection of the polynomial that circumscribe the Solar intensity contour, with the time scale.

3. Determination of the mean exoatmospheric Sun radiant fluxes and their dispersion in the spectral channels as the function of the instrument IFOV position on the solar disk, Fig. 2 and Fig. 3, and flagged the sunspot edges. They are determined by the analysis of the first derivative values of the signal as a function of the IFOV position on the Sun and the data inside these edges are not used for further processing of the event. For the transmission profiles calculation the central part of the Sun from 7 to 26 angular minutes is used there the relative dispersion don' exceeds $5 \cdot 10^{-4}$, Fig. 3.
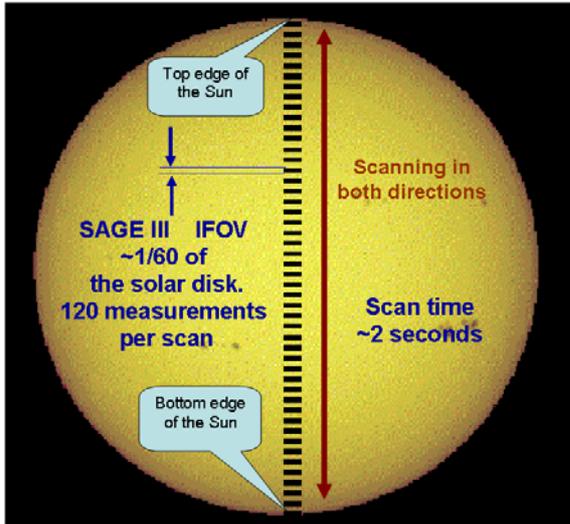
Figure 1. SAGE III IFOV positions on the Sun.
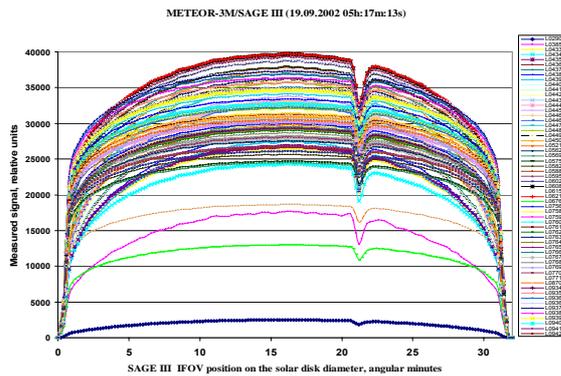
Figure 2. Radiant flux in the spectral channels as the function of the IFOV position on the solar disk.
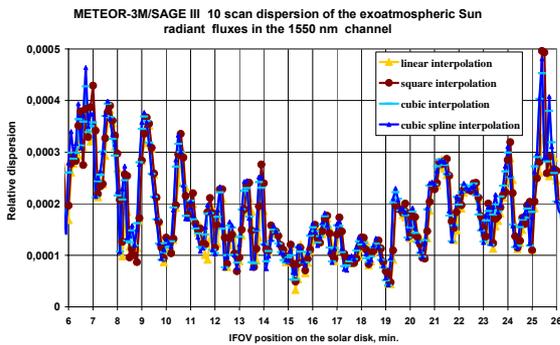
Figure 3. Relative dispersion of the radiant flux in the 1550 nm spectral channels as the functions of the IFOV position on the solar disk.

4. For each spectral channel: calculation of the transmission and its dispersion at the tangent height mesh points in the range form 0.5 to 100 km height with step 0.5 km. The second power polynomial is utilized to smooth the profile: least-squares method determines the polynomial in the neighborhood +\- 0.5 km of the mesh point. The value of the polynomial at this mesh point is the averaged transmission. This method smoothes the function and does not cause strong degradation of the vertical resolution. Fig. 4 presents the optical depth profile, which is the minus logarithm of the transmission function, produced from the SAGE III measurements.
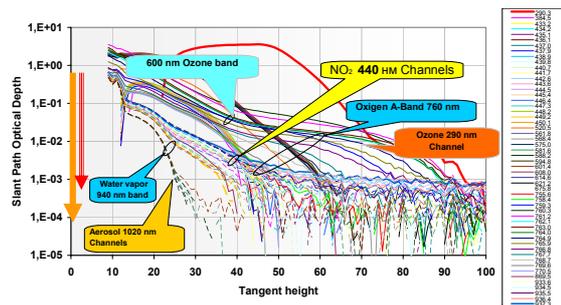
Figure 4. Measured atmosphere slant path optical depth as a function of the tangent height for SAGE III spectral channels.

Fig. 4 provides some estimation of the SAGE III information possibilities.

3. INVERSION ALGORITHM

The goal of the algorithm is to determine the vertical profiles of ozone and nitrogen dioxide concentrations and aerosol extinction. The following technology is used:

1. At the first step the Rayleigh scattering is removed. The forward calculation method is used for this procedure.

2 A change in the optical properties of the atmosphere inside the layer in 0.5 km is described by the polynomial of the second power. For determining the values of gases concentration and aerosol extinction in the mesh points of heights is introduced the concept of matrix of effective lengths of the ways of solar ray in the layers. These path lengths also take into account the effect of refraction and differ from the lengths of the solar ray trajectory in the layers. The product (multiplication) of the effective path length in the layer on the local extinction of the atmosphere at the node point is equal to the integration of the optical depth inside the layer. This matrix permits to use simple Gauss method to calculate the vertical profiles of the total extinction of ozone, NO_2 and aerosol.

3. On this step the vertical profile of total extinction is separated on the ozone, NO_2 and aerosol extinctions. Up to 29 spectral channels are simultaneously utilized. The procedure uses least-squares method for the 29 linear equations with 5 unknowns – ozone and nitrogen dioxide concentrations and 3 unknowns coefficient for the spectral dependence of aerosol extinction. The effective ozone and nitrogen dioxide cross

sections are calculated for the SAGE III spectral channels considering the heterogeneity of the solar spectrum, temperature dependence of cross sections, instrument band pass function.

4. VALIDATION

The results of routine data processing were compared with the same results of the NASA Langley Research Center routine processing of the METEOR-3M/SAGE III data and with the profiles retrieved from HALOE and SAGE II data. There was also comparison of the SAGE III ozone profiles with the simultaneous balloon ozone sounding at the Salekhard station during SOLVE II. Fig. 5 presents the ozone balloon profile smoothed to 0.5 km vertical resolution, and SAGE III profiles produced by LaRC and CAO routine processing. The CAO's algorithm methodically overestimates ozone concentration under 15 km. As seen on Fig.6 the difference exceeds 30% at the 10 km altitude. Fig.6 demonstrate the mean-square deviations between CAO and LaRC ozone profiles for the 26 profiles that were used during SOLVE II mission. The difference between individual CAO and LaRC ozone profiles may run up to 40% at the height of 10 km.
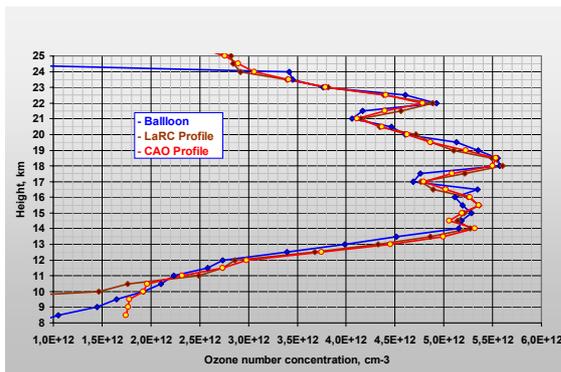
Figure 5. Ozone profiles from balloon sounding at the Salekhard station (67°N, 67E°) and SAGE III sounding (66°N, 65E°) December 13, 2002.
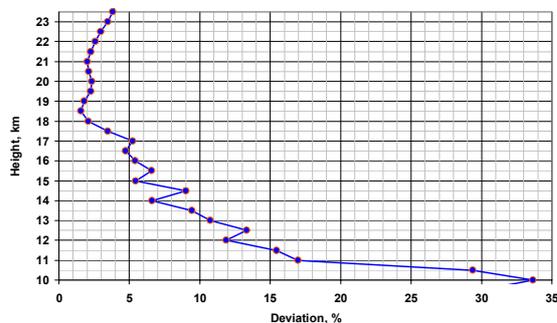
Figure 6. The mean-square deviations of the SAGE III ozone profiles from simultaneous balloon sounding at the Salekhard station (16 profiles).
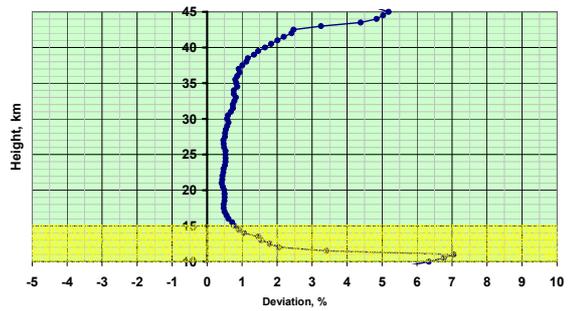
Figure 7. The mean-square deviations between CAO and Langley Research Center SAGE III ozone profiles

The comparison of the SAGE III and HALOE ozone profile for the September 11, 2002 is presented on the Fig.8. The measurements by both instruments were carried out at the same location but with a time shift approximately 10 hours.
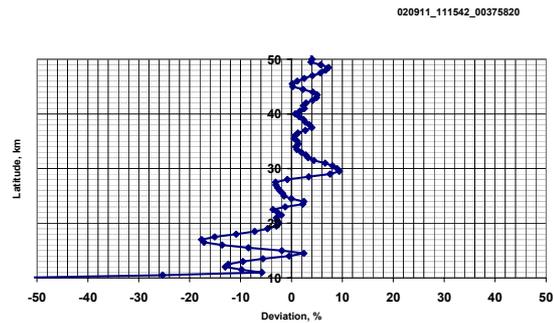
Figure 8. The comparison of the SAGE III (CAO) and HALOE (LaRC) ozone profiles.

Fig. 9 demonstrates that SAGE III has more wide range of altitude for nitrogen dioxide measurements then POAM -3 instrument /Home Page for the POAM II & III Missions/.
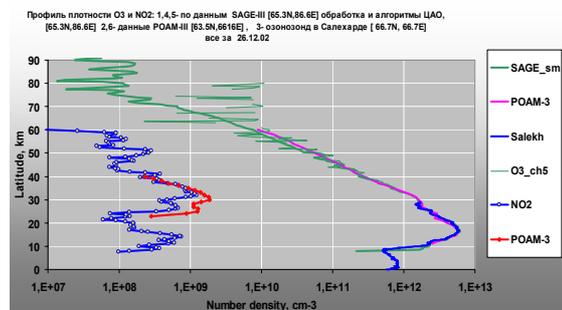
Figure 9. The SAGE III (CAO - NO2) and POAM-3 (red line) nitrogen dioside profiles.

5.   CONCLUTIONS.

METEOR-3M/SAGE III is the reliable source of operational experimental information about the global distribution of the profiles of ozone, nitrogen dioxide and aerosol extinction since March 2002. Authors developed robust algorithm for routine METEOR-3M/SAGE III data processing. The results of comparisons and validation show a need to improve the algorithm for the latitudes under 15 km.

5. ACKNOWLEDGEMENTS

6. References from Websites

http://haloedata.larc.nasa.gov/home/
http://wvms.nrl.navy.mil/POAM/poam.html