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GLOBAL OZONE DATA FROM THE METEOR-3/TOMS ULTRAVIOLET SPECTROMETER

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ABSTRACT

A new TOMS instrument (Total Ozone Mapping Spectrometer) was launched from the Plesetsk Cosomodrome, Russia on August 15, 1991. The purpose of the joint project between the U.S. and Russia was to continue the long-term record of ozone measurements from Nimbus-7/TOMS (launched in October 1978). Ozone data from the two satellites compare very closely. When the orbital positions were nearly the same, the comparison over the entire globe showed an offset of 2% with a standard deviation of 5%. Comparisons were made with several ground based M124 and Dobson stations showing good agreement in absolute value and with the day-to-day variations seen by the ground stations.

INTRODUCTION

The United States and the former Soviet Union agreed to a cooperative project that would put a US instrument (TOMS) for measuring ozone into space onboard a Soviet rocket (Cyclone) and spacecraft (Meteor-3). Meteor-3/TOMS (Total Ozone Mapping Spectrometer) was launched from the Plesetsk Cosmodrome, USSR at 12:15 Moscow Standard Time (MST) on August 15, 1991. The spacecraft was launched into a 1200 km high orbit with an inclination angle of 82.5 degrees precessing at a rate of 1.3° per day toward the sunrise terminator. Ozone data have been returned daily from the spacecraft since August 23, 1991 with an error rate smaller than 1 in 10^6.

The TOMS instrument on board the Meteor spacecraft is nearly identical to the Nimbus-7/TOMS launched in October, 1978 (Heath et al., 1975). The most significant modification is the use of a different diffuser plate assembly, as the first optical element of the spectrometer, to improve the instrument's in-flight self-calibration capability. The wavelength channels, cross-track scan rates, the Ebert-Fastie spectrometer design, electronics, and angular field of view are approximately the same as Nimbus-7/TOMS. When the equator crossing time is near that of Nimbus-7/TOMS, complete global ozone coverage of the sunlit atmosphere is obtained on a daily basis. However, when the spacecraft orbit processes near the day-night terminator, only partial geographic coverage of the atmosphere is obtained by the spectrometer.

In this paper we present the global ozone variation from Meteor-3/TOMS (M3TOMS) for selected days since August 23, 1991 with comparisons to the results from Nimbus-7/TOMS (N7TOMS). The ozone data are also compared with Russian ground station data (M124 instruments) at Molodezhnaya and Syoma. Global ozone maps and ozone maps of the South Polar ozone hole from M3TOMS are shown and compared with those from N7TOMS. In addition to the ozone data, we discuss the calibration and expected accuracy of M3TOMS, and show some of the effects on the ozone data arising from high solar zenith angles and the presence of stratospheric aerosols. The characteristics of the new 3-plate diffuser assembly are discussed and compared with N7TOMS. A summary of the instrument characteristics and orbital parameters are given in Table 1.

METEOR-3/TOMS OPERATING PLAN

Under the agreement between NASA and CAO, TOMS data are recorded in 24 hour blocks in the spacecraft, transmitted to ground stations in both Russia (Obninsk) and the U.S. (Wallops Island, Virginia) each day, then relayed to data processing centers at Goddard Space Flight Center and CAO at Dolgoprudny.

TABLE 1

Meteor-3/TOMS Characteristics

Altitude	1202 km
Inclination	82.5°
Orbital Period	109 min
Orbital Eccentricity	$< 2 \times 10^{-3}$
Orbital Precession Period	212 days
Launch Time	Aug 15, 1991 at 12:15 pm Moscow Standard Time
First Ozone Data	August 22, 1991
Number of Orbits/Day	13.210
Field of View	3° x 3° ±0.1°
Wavelength Calibration	Mercury Line at 296.7 nm
Wavelength Channels	312.35, 317.4, 331.13, 339.73, 359.0, 380.16 nm
Spectrometer Bandwidth	1.1 nm
Cross-Track Scan Angle	±51°
Number of Scenes/Scan	35
Ground Size-Nadir View	64 x 64 km
3-Plate Diffuser Exposure	Daily, 1-Week, 15-Weeks
Expected Spacecraft Lifetime	3 years

Commands for control of TOMS are prepared at GSFC and sent be E-mail to CAO where they are delivered to the Moscow Flight Control Center (FCC) for transmission to the spacecraft. Orbital elements are determined in Russia and relayed to GSFC for use in instrument operations and in data processing. Instrument health is monitored at GSFC while the spacecraft is controlled and monitored by the Moscow FCC.

The data are processed in parallel at GSFC and CAO using algorithms which have been shown to yield nearly identical ozone values, but were developed independently under the agreement. Both algorithms use albedo tables and instrument calibrations produced at GSFC.

METEOR-3 ORBIT

The polar orbit of Meteor is inclined at 82.5 degrees, and processes in local time by 24 hours in 212 days (see Table 1). Global coverage varies with the equator crossing time, ranging from complete coverage with noon equator crossings to partial coverage when the orbit lies near the sunrise or sunset terminator. The amount of twilight coverage depends on the angle between the satellite orbit plane and the terminator plane. The angle varies as the earth's declination changes seasonally between ±23°. On September 28, 1991 the planes were nearly parallel, and nearly complete global coverage was obtained at twilight at all latitudes. In January, the equator crossing was again near the terminator, but with an angle relative to the terminator line. The result was that much of the northern hemisphere data was lost as the satellite moved into the night. Extension of the 13-year N7TOMS ozone trends can be determined, even with intermittent full-global coverage, if the lifetime of the Meteor-3 satellite is at least 2 years.

BRIEF DESCRIPTION OF METEOR-3/TOMS

The M3TOMS instrument is a space-qualified refurbished engineering model of the N7TOMS flight instrument. Except for the new diffuser plate assembly, the two instruments are nearly identical. The TOMS instrument is a single Fastie-Ebert spectrometer measuring six discrete wavelength channels. The wavelength selection is accomplished by using an array of exit slits on a rotating chopper wheel. The pre-flight calibrated wavelength channels are 312.353±0.051, 317.4±0.04, 331.13±0.04, 339.73±0.05, 359.0±0.04, and 380.16±0.12 nm with a bandwidth of 1.1±0.01 nm. For brevity, these channels are referred to by their first three digits (312, 317, 331, 340, 360, and 380 nm).

The TOMS instrument has a 3 x 3° nadir field of view of the Earth's surface, and uses a cross-track scanner (35 scenes, ±51° from the nadir position) to produce continuous scene coverage between adjacent orbits. The scanner stops at each of the 35 scenes while the rotating chopper wheel sequentially selects the six wavelength channels. For the 1202 km high orbit, the nadir position scene size on the Earth's surface is approximately 64 x 64 km.

The f/5 TOMS monochrometer consists of a 250 mm focal length mirror that collimates incoming light onto the 52 x 52 mm grating (2400 groves/mm with a dispersion of 1.3nm/mm) and focuses light from the grating onto the exit slit. The exit lens forms an image of the slit on a common particle-shielded photomultiplier tube (PMT) for each wavelength. An onboard mercury calibration lamp is used daily to check for in-flight wavelength drift.

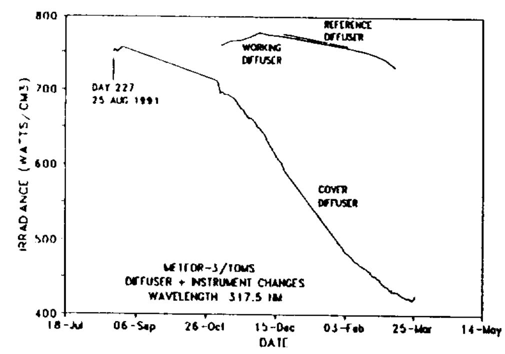


Figure 1. The change in reflectivity of the 3-plate diffuser system used for M3TOMS. Time periods when the orbit has precessed outside of the range of view angles for calibrated measurement of the solar irradiance are connected by straight lines. The figure shows the rapid decrease in the cover diffuser reflectivity with continuous exposure to space, and almost no change in the protected working and reference diffuser plate reflectivities.

DIFFUSER PLATE ASSEMBLY

A diffuser plate becomes the first optical element whenever the TOMS instrument is commanded to directly view the sun to measure solar irradiance. A ratio of the solar irradiance at each wavelength to the measured Earth-atmosphere radiance is used to determine the amount of atmospheric ozone. This ratio, the directional albedo, cancels the gain of the spectrometer, but not the reflectivity of the diffuser plate (Herman et al., 1991). For this reason the diffuser plate reflectivity and goniometry must be accurately known.

Based on experience with N7TOMS since November 1978, it is known that the diffuser plate gradually loses reflectivity as it is exposed the space environment. This rate is not known in advance. For the purpose of determining ozone trends, the Pair Justification Method (PJM) was developed to obtain in-flight calibration of the single N7TOMS diffuser plate reflectivity (Herman et al., 1991). M3TOMS uses a 3-plate diffuser carousel, where plate 1 (the cover) is exposed constantly, plate 2 (working plate) is exposed once per week when the orbit is within ±3 hours of noon, and plate 3 (reference plate) is exposed about once every 15 weeks, or 2 times per 212 days.

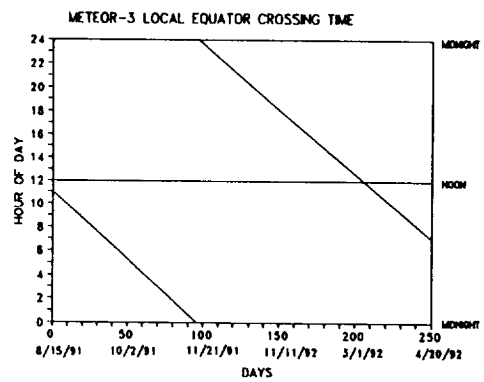


Figure 2. Meteor-3 local equator crossing time vs days since launch (8/15/91)

Figure 1 shows the relative solar signals during the first 200 days after launch obtained from the three plates at the 380 nm wavelength used for surface reflectivity data. The Cover signal has decreased by nearly 40% while the Working and Reference signals have remained nearly constant and in close agreement as expected based on the exposure-related degradation model. The small variations of the Working diffuser signal are due to changes in the radiometric response of the instrument. Unlike N7TOMS, comparisons between the three diffuser plates permit reflectivity changes of the continuously exposed cover plate to be separated from spectrometer gain changes. The combination of the 3-plate system with the PJM is expected to provide accurate diffuser plate reflectivities as a function of time over the life of the M3TOMS instrument. With a single diffuser plate on N7TOMS, an ozone trend accuracy of ±1.4% over 11 years was achieved using the PJM method, and an absolute ozone accuracy of ±4% was obtained from a

combination of the preflight calibration and in-flight calibration. Most of this error resulted from differences in the preflight calibration relative to in-flight diffuser reflectivities at the beginning of the mission.
During the time when the orbital plane is away from the terminator, there is nearly complete coverage of the globe every day (about 13.2 orbits per day). The complete coverage is provided by the cross orbital-track scanning of 105° for 35 scenes (200 ms per scene plus 1 second retrace) every 8 seconds. The data from adjacent orbits are combined to provide the continuous coverage of the sunlit globe. Because of the inclination of the orbit (82.5°) and the orbital drift, there are periodic gaps in the global ozone coverage (see Figure 2).

Additional uncertainties in the ozone data from M3TOMS occur as its orbit drifts with respect to the sun vector, causing changes in both the zenith and azimuth angles. This contrasts with N7TOMS, whose orbit was nearly sun-synchronous (equator crossing time near noon) since Nov. 1978. The orbital drift problem affects both the ozone trend determination and the day-to-day earth images of ozone. Figure 3 shows an example of partial global ozone coverage during May 1992 when the orbit crosses the terminator from day into night in the southern hemisphere. Complete global coverage returned during June, 1992.

The situation is further complicated by the 212 day orbital-drift period not being synchronized with the 365 day seasonal period. This means that some terminator crossings have the satellite's orbit parallel to the terminator, and some are at an angle determined by the orbital inclination angle (82.5°) and the range of seasonal solar declination angles (±23°). The black region of the ozone map represents the absence of sunlight in the viewing region. As the satellite crosses the terminator, part of the scans are into the dark region and part into the sunlit region. When this occurs, the individual scan lines from scans 29 to 35 are clearly visible because of the lack of overlap at high scan angles.

CALIBRATION

The data processing currently uses a preliminary prelaunch calibration while pre- and post-launch calibrations are under evaluation. The current processing assumes stable instrument characteristics in orbit, which is borne out by the comparison with Nimbus TOMS and by the preliminary evaluation of changes in the radiometric calibration. New calibration constants have been derived from in-flight solar calibration data and a review of the prelaunch laboratory calibration constants.

The comparison with N7TOMS ozone data show closer agreement using the new calibration constants. The comparison is performed when the orbits of M3TOMS and N7TOMS have nearly the same equator crossing time and viewing angles. Comparisons can be made for both the ozone amount and the ground reflectivity. Of particular interest is the ground reflectivity of the Antarctic and Greenland ice cover, and the sea surface minimum reflectivity. Using the new constants, the data will be reprocessed during the summer of 1992 for archival and release in late September 1992.

COMPARISON OF M3TOMS AND N7TOMS OZONE DATA

When the equator crossing times are between 9 am and 3 pm the quality of the data and degree of global coverage are comparable to N7TOMS (Krueger, 1989, and Krueger et al., 1992). Figure 4 shows a comparison of M3TOMS ozone data with N7TOMS data from March 18, 1992.

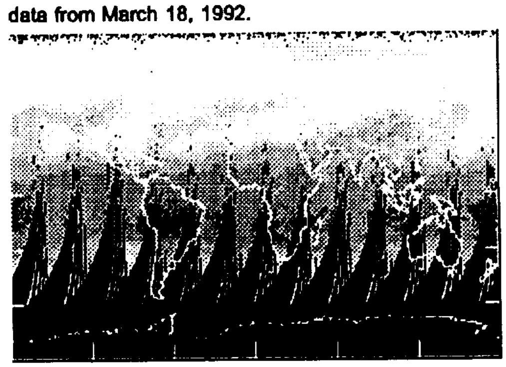


Figure 3. An example of a global ozone map obtained when the Meteor-3 spacecraft orbit is crossing the terminator into southern hemisphere night at a small angle near the equator on May 8, 1992. The black region is when TOMS is in the dark. Complete global coverage returned in the last week of May.

On this day the observing geometry is nearly the same. Both satellites had equator crossing times near 11 am, local time. Two global ozone maps are shown at the top, and a histogram of B-pair ozone differences is shown at the bottom. The histogram shows the differences on a pixel-by-pixel basis summed over the entire globe. The differences are in a near normal distribution with a 2% bias (distance of the distribution center from 0) and a 5% standard deviation. Part of the differences are related to the ground based calibration constants currently under review. In addition to differences caused by using the initial calibration constants, the presence of substantial amounts of atmospheric aerosols viewed at different scattering angles introduces differences between M3TOMS and N7TOMS.

COMPARISON WITH GROUND BASED MEASUREMENTS

Comparisons with ground based data are obtained by using a specially prepared overpass data set from the high resolution (64 x 64 km individual scans) Meteor-3/TOMS ozone data, or from global ozone maps. The ozone maps are formed by combining the measurements from each of the scan elements into a latitude-longitude grid measuring about 1° x 1.5°.

Figures 5 and 6 show typical examples of ground based comparisons with M124 instruments based at Molodezhnaya and Syowa from August to the end of November 1991. The lower and upper portions of Figures 4 and 5 show that the time variation of ozone over the stations agree very closely with the M3TOMS ozone amounts. The absolute agreement in these cases is within 5 to 6%, with a very high degree of correlation.

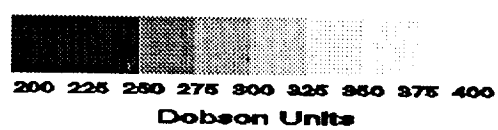
Where there is overlapping data for a given grid cell, the data from the more accurate scan positions nearer to nadir-view are used. The number of overlapping scan elements increases towards the polar regions.

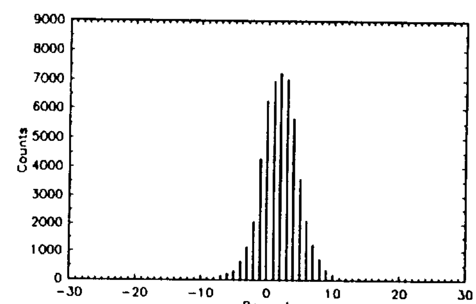
CONCLUSION

The launch of the U.S. TOMS instrument on board a Russian Meteor-3 spacecraft has proved to be highly successful. The first nine months of operation show that the Meteor-3/TOMS instrument is performing as

Nimbus-7/TOMS 3/18/92

Meteor-3/TOMS 3/18/92





(M3TOMS - N7TOMS)/N7TOMS

Figure 4. A global comparison of the ozone data from Nimbus-7/TOMS and Meteor-3/TOMS on March 18, 1992 when the orbits were almost at the same equator crossing time (10:45 am). The histogram is a pixel by pixel comparison showing the frequency of occurrences of differences between the 2 data sets. In this case, the ozone maps are almost the same with a 1% average offset and a 3% standard deviation.

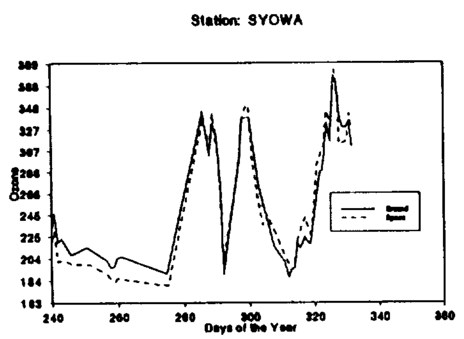


Figure 5. A comparison between the ozone amount obtained from the ground station at Syowa with M3TOMS.

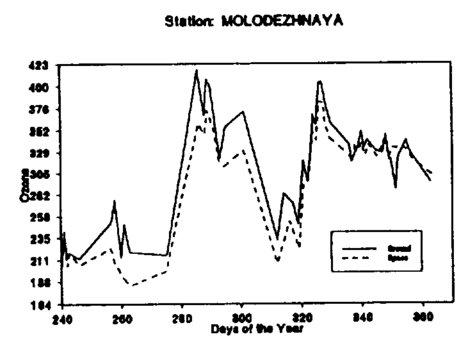


Figure 6. A comparison between the ozone amount obtained from the ground station at Molodezhnaya with M3TOMS.

well as the original Nimbus-7/TOMS. Based on the good agreement between the two satellite instruments and ground based measurements, it is expected that the data can be used to extend the long-term trend measurements. In addition to long-term monitoring the global ozone amounts, the M3TOMS provides daily coverage of most of the globe, coverage of the evolution of the Antarctic ozone hole, and monitoring of ozone decreases in the northern hemisphere during the winter and spring months (see Herman et al., 1992).

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