Raytheon
Raytheon STX Corporation

Nimbus/TOMS Science Data Operations Support

FINAL REPORT

NASA Contract No. NAS5-31755
May 11, 1998

Ms. Veronica Stubbs  
NASA GSFC  
Contract Specialist, Code 219  
Building 16, Room 224  
Greenbelt, MD 20771-0001

Subject: Final Contract Report/ Contract NAS5-31755 (Raytheon STX No. 3036)  
POP: July 1992 – May 1998 (Base and Extension)

Dear Ms. Stubbs:

In accordance with Revision No. 48 of Contract NAS5-31755, enclosed please find the Final Contract Report.

If you have any questions or comments regarding this deliverable, please contact me at 301-441-4021.

Sincerely,

Jeff Childs  
Program Manager

Enclosures

cc: COTR, Code 916  
Publications & Graphics, Code 253.1
FINAL REPORT - UV Remote Sensing Project
Contract No. NAS5-31755

NASA GSFC COTR: Dr. J. Herman
Raytheon STX Program Manager: Dr. J. Childs
Raytheon STX Task Leaders: Mr. W. Byerly, Dr. R. Cebula, Mr. C. Wellemeyer

CONTRACT MISSION STATEMENT:

The contractor shall: (1) participate in and provide analysis of laboratory and in-flight calibration of UV sensors used for space observations of backscattered UV radiation; (2) provide support to the TOMS Science Operations Center, including generating instrument command lists and analysis of TOMS health and safety data; (3) develop and maintain software and algorithms designed to capture and process raw spacecraft and instrument data, convert the instrument output into measured radiance and irradiances, and produce scientifically valid products; (4) process the TOMS data into Level 1, Level 2, and Level 3 data products; and (5) provide analysis of the science data products in support of NASA GFSC Code 916’s research.

WORK PERFORMED:

Missions Supported

Raytheon STX Corporation (RSTX) supported the following missions, covering the data periods listed in parenthesis, during the period July 1992 through May 1998:

- Nimbus-7 SBUV, TOMS, ERB, and SAM II (October 1978 - May 1993)
- ADEOS TOMS (August 1996 - June 1997)
- Earth Probe (EP) TOMS (July 1996 - present)
- NOAA-9 SBUV/2 (December 1984 - February 1998)
- NOAA-11 SBUV/2 (September 1988 - April 1995)
- NOAA-13 SBUV/2 (August 1993)
- NOAA-14 SBUV/2 (December 1994 - present)
- SSBUV (Eight missions, October 1989 - January 1996, including four flights during the current period of performance)

Instrument Calibration and Characterization

RSTX analysts supported the prelaunch calibrations of the Meteor-3, ADEOS and EP TOMS, and the NOAA-14 SBUV/2 instruments. Support was also provided for the prelaunch calibrations of SBUV/2 Flight Model units numbers 3, 6, and 7 (these sensors are scheduled to fly on future NOAA operational spacecraft from approximately 1999 through the first decade of the next century). RSTX personnel participated in the acquisition of calibration data at the instrument vendors’ sites and provided detailed analysis of all spectroradiometric calibration data. Prelaunch and postlaunch calibration analysis was also provided for each SSBUV mission. Key accomplishments and findings included:
- Determined errors in the vendor-supplied Meteor-3, ADEOS and EP wavelength calibrations.
- Developed a new technique to improve the accuracy of fitting procedures used with NIST-supplied lamp calibrations.
- Developed a method to evaluate the long-term stability of D2 lamps via comparisons with other, more stable sources in conjunction with sensor data.
- Supported research and development of new laboratory radiance targets - specifically, the use of integrating sphere targets.

RSTX provided analysis of calibration and characterization data from each of missions previously listed. This included analyzing initial checkout (Activation and Evaluation Phase) data, monitoring instrument health and safety, and characterizing long-term sensor degradation on-orbit. Where sensor performance problems were identified, RSTX personnel worked with Government and other contractor personnel to create "work-arounds" in order to maximize sensor lifetime and minimize impact to the science data products. Key accomplishments and findings included:

- Evaluated the impact of attitude errors on the TOMS spacecraft.
- Developed techniques to use solar data as a wavelength calibration source for the TOMS, SBUV/2, and SSBUV instruments.
- Analyzed A & E phase data from the ADEOS and EP TOMS and the NOAA-14 SBUV/2 instruments.
- Monitored housekeeping data from all SBUV and TOMS instruments.
- Determined long-term calibrations for the Nimbus-7, Meteor-3, ADEOS, and EP TOMS instruments.
- Created and enhanced methodology to derive each instrument's goniometric characterization using inflight data.
- Provided the Version 6.1 calibrations for the NOAA-9 and NOAA-11 sensors.
- Used SSBUV underflights of the NOAA-9 and NOAA-11 SBUV/2 instruments to determine their absolute calibrations and validate their long-term characterizations.
- Developed a technique to use the sun as a vicarious calibration source in order to evaluate short-term sensor changes.
- Developed use of ice radiances for long-term sensor changes.
- Evaluated the NOAA-14 SBUV/2 CCR failure.
- Monitored, evaluated, and created work-arounds for NOAA-14 SBUV/2 grating drive errors.
- Supported EP TOMS "stare mode" operations.

Results of RSTX's calibration work are documented in the following Contractor Reports, NASA Reference Publications, and journal papers:


Software Development and Maintenance

Throughout the contract period RSTX developed software systems and performed adaptive, corrective and enhancement maintenance on the TOMS, SBUV/2, and SSBUV data systems.

Major RSTX software development and maintenance activities included:

- Converted TOMS and SBUV/2 data systems from IBM MVT to IBM MVS; then from IBM MVS to VAX VMS; then from VAX VMS to SGI UNIX
- Automated TOMS data communications, science processing, and data distribution
- Developed near real-time processing systems for Meteor-3, EP, and ADEOS TOMS
- Developed L0-L3 science data processing systems for EP/TOMS and ADEOS/TOMS
- Developed ADEOS/TOMS mission operations software
- Defined and tested ADEOS TOMS science operations interfaces
- Developed TOMS Standard Products in Hierarchical Data Format (HDF)
- Implemented Version 6 SBUV/2, and Versions 6.5 and 7 TOMS, retrieval algorithms
- Colocated increased resolution terrain heights, improved cloud climatology, and new surface category codes to each TOMS field of view (all missions)
- Developed IDL image generation and product validation tools
- Developed the TOMS Web Site
- Added new products (erythemal UV, aerosol, overpass, zonal means) to the TOMS processing systems

Adaptations to accommodate changes in EP/TOMS operations (i.e. "stare mode") and orbit geometry (500 km to 740 km) were also developed and installed into the processing system.

Documentation produced by RSTX during software development and maintenance include:


Byerly, W., ADEOS/TOMS Science Data Product Specification, January 1996


Data Processing

RSTX provided data processing services for GSFC Code 916 including data ingest, QC monitoring, problem resolution, science product generation, and product verification.

Key data processing activities included:

- Level 0/1 processing of Nimbus-7 VIP telemetry
- Level 2-3 processing of Nimbus-7 SBUV, TOMS, ERB, and SAM-II
- NOAA-11 SBUV/2 Level 2 processing
- Version 6.5 reprocessing of Nimbus-7 and Meteor-3 TOMS
- Version 7 reprocessing of Nimbus-7, Meteor-3, and ADEOS TOMS
- Near real-time processing of Meteor-3, ADEOS, and EP TOMS
- Near real-time data distribution to NASA EOC (ADEOS), NOAA NESDIS (EP), and the Internet (all)
- GSFC DAAC archival of Version 7 Nimbus, Meteor, and ADEOS TOMS products
- Transfer and conversion of TOMS and SBUV/2 data from IBM mainframe to UniTree and from Unitree to Code 916 mass storage
- Processed and provided the final reprocessing of ozone, solar, and special observation data from all eight SSBUV flights, archived these data at the GSFC DAAC;
- Processed sweep mode solar spectral irradiance and discrete mode Mg II solar data from all operational SBUV/2 instruments;

Weekly processing reports were delivered to GSFC Code 916.

Algorithm Development

The RSTX algorithm development effort can be divided into SBUV and TOMS ozone algorithm development and the development of algorithms for the derivation of other atmospheric parameters. The main components of the SBUV algorithm development effort consist of:
• Enhancements to correct for SBUV/2 grating drive positioning errors.
• Enhancements to compensate for non-functional CCR on N14 SBUV/2.
• Initial development of V7 SBUV profiling algorithm.

The major component of the TOMS algorithm development was the enhancement to Version 7. The principal elements of this enhancement included:

• Use of an improved cloud height climatology and partial cloud model.
• Accounting for the effect of variations in profile shape at high solar zenith angles.
• Discarding the use of effective absorption coefficients.
• Accounting for the effects of Rotational Raman Scattering
• And additional improvements to the radiative model.

The improvements in the Version 7 algorithm provided a new level of detailed information in the algorithmic residuals. The analysis of this information lead to the improvement or development of algorithms for the retrieval of other atmospheric parameters. These include:

• Sulfur dioxide
• Cloud height
• Stratospheric volcanic aerosol
• UV radiation at the Earth surface
• Tropospheric aerosol
• Volcanic ash

RSTX analysts also supported the retrieval of Nitrous Oxide from radiances measured by SSBUV. Validation efforts based on comparison with independent measurements has also lead to involvement with algorithms for hand held radiometers and upper level climatology for in situ balloonsonde measurements.

An important aspect of documenting algorithm performance is the sensitivity study. Sensitivity in a derived parameter to effects not taken into account by the retrieval algorithm is a necessary factor in evaluating the error budget and considering enhancements to the algorithms. Over the course of the contract, a number of sensitivity studies have been performed.

Results of RSTX's algorithm development and data processing efforts are documented in the following Contractor Reports, NASA Reference Publications, and journal papers:


**Data Validation and Analysis of Science Products**

Data validation is closely linked to algorithm development. All of the algorithm development work sited above has been supported by RSTX through both external and internal validation. Data from the various BUV instruments including:

- BUV (N4 BUV, N7 SBUV, N9 SBUV2, N11 SBUV2, N14 SBUV2 and SSBUV)
- TOMS (N7, M3, ADEOS, and EP)
Have been validated based on comparisons with measurements and radiances simulated based on measurements from independent instruments including:

- Ground based (Dobson, Umkehr, Brewer, Microtops, and sun photometer)
- In situ (Balloonsonde and aircraft missions)
- Satellites (SAGE, SME, MLS, HALOE, GOME, CLAES, TOVS, AVHRR, GOES)

RSTX personnel have also worked to support ground measurements made by SBUV2 pre-flight. Also we have begun an internal ground measurement program based on commercial spectrometers and photometers for use in validating the new surface ultraviolet product.

Some of the more valuable forms of validation have been derived from internal analysis of BUV and TOMS measurements. Many of these techniques have been used by RSTX to calibrate BUV instruments when traditional in-flight calibration systems have been unavailable or have failed. These internal methods include:

- Pair justification
- Scene stabilization
- Langley analysis
- Spectral discrimination
- Background SOI
- Radiance and irradiance based comparisons with other BUV measurement systems.

The solar measurements are primarily made by the BUV instruments to provide I/F for the derivation of ozone, but they are a valuable measurement in and of themselves. A significant effort has gone into the analysis and validation of the solar flux measurements. Key accomplishments and findings included:

- Created and maintained the SBUV/2-SSBUV solar irradiance web page (http://ssbuv.nasa.gsfc.gov/solar.html);
- Analyzed solar irradiance data from all eight SSBUV missions, compared these data to other Space Shuttle and satellite-borne solar instruments, and used these data to provide a correction for long-term drift in the NOAA-11 SBUV/2 solar data.
- Analyzed special observation data from the SSBUV-4 through SSBUV-8 missions, including NO, SO2, lunar albedo, and modified ozone retrieval data sets.
- Used SSBUV data to validate GOME ozone and solar data.
- ETC

As a part of the validation process, a certain amount of analysis has been carried out by RSTX personnel in support of the contract. These studies of derived parameters include analysis of global distribution, long-term trends, and local episodic events.

Results of RSTX's data validation and analysis of science products are documented in the following Contractor Reports, NASA Reference Publications, and journal papers:


