



ATMOSPHERIC PRODUCTS FROM THE UPPER ATMOSPHERE RESEARCH SATELLITE (UARS)

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ABSTRACT

The Upper Atmosphere Research Satellite (UARS) was the first satellite to be launched under the Earth Observing System (EOS) science program of multi-mission observing systems of the National Aeronautics and Space Administrations (NASA). The EOS program was conceived to advance the understanding of the Earth-Atmosphere system on the global scale. The UARS was launched in September 1991 with ten instruments dedicated entirely to increase the understanding of chemistry and dynamics of the Earth's stratosphere and mesosphere. After 10 years of successful data collection (far exceeding the originally projected lifetime of 3 years), the official mission ended in September 2001. However, seven instruments aboard UARS are still operational and six regularly take measurements. It is expected that the UARS will overlap the Earth Observing System (EOS) Aura satellite (to be launched in early 2004) for several months before the end of the UARS mission. The UARS data and atmospheric chemistry and dynamics data from other satellites are archived at the NASA Goddard Earth Sciences Distributed Active Archive Center (GES DAAC) and are available free to the public and science user community. The UARS data and related documents may be accessed through the GES DAAC website (<http://daac.gsfc.nasa.gov>). This paper gives an overview of the UARS data products. Detailed information on UARS instruments, mission highlights and related publications are available from the UARS project website (<http://umpgal.gsfc.nasa.gov>). © 2003 COSPAR. Published by Elsevier Ltd. All rights reserved.

INTRODUCTION

As a major element in NASA's comprehensive Upper Atmosphere Research Program, the Upper Atmosphere Research Satellite (UARS) was launched on September 12, 1991 aboard the Space Shuttle Discovery, into a near circular orbit at an altitude of approximately 580 km with an inclination of 57°. Ten instruments (four for measuring concentrations of atmospheric trace gases, two for atmospheric dynamics variables, three for solar input irradiances, and one for energetic particle depositions) were flown aboard UARS with the goal to understand 1) the response of the upper atmospheric chemistry to natural and human perturbations, 2) the chemical processes and dynamics that control upper atmosphere structure and variability, and 3) couplings of the lower and upper atmosphere that play a major role in defining climate and climate variability.

UARS with its ten unique instruments has been providing high quality global measurements of the atmospheric parameters in the stratosphere, mesosphere, and lower thermosphere. Eleven years after launch, the UARS continues to operate and make relevant measurements. Seven of the original ten instruments aboard the UARS are still functional and six instruments regularly make measurements on a power-sharing plan. As of October 1, 2001, the UARS program started a new phase of its life called a "Traceability Mission". The schedule for UARS instrument operations has been optimized since January 2002 to be available for the validation and calibration of the future instruments aboard the new satellites.

The UARS data are unique from previous atmospheric data collected in the sense that the 10 different instruments are able to provide simultaneous measurements of the concentration of different atmospheric trace

gases (ozone, methane, water, halogens, nitrogen-containing molecules and other chemical constituents), atmospheric dynamic variables (temperature, pressure, wind fields), and measurements of the external cosmic influences acting upon the upper atmosphere (solar radiation and high energy particle depositions) on a continuing basis.

The UARS standard data products are archived at the NASA Goddard Earth Sciences Distributed Active Archive Center (GES DAAC). UARS data and other climate data sets are provided free to the public and scientists working in major climate related disciplines such as atmospheric dynamics, atmospheric chemistry, global land and ocean biosphere, and hydrological sciences. This paper provides highlights of the climate data available from the NASA GES DAAC, including data services provided by the DAAC Data Support Teams in support of the users of the data.

UARS INSTRUMENTS AND DATA PRODUCTS

Atmospheric Chemical Measurements

The UARS instruments that provide measurements of atmospheric trace gas species (including ozone, water vapor, methane, sulphur dioxide, carbon monoxide, chlorofluorocarbons, and many nitrogen & chlorine compounds) from the tropopause to the mesopause are:

- Cryogenic Limb Array Etalon Spectrometer (CLAES)
- Halogen Occultation Experiment (HALOE)
- Improved Stratospheric and Mesospheric Sounder (ISAMS)
- Microwave Limb Sounder (MLS)

ISAMS and CLAES also measured aerosols; these two instruments are no longer operating. Due to a mechanical problem ISAMS ceased working in July 1992. The cryogen in CLAES expired on schedule in April 1993. At about the same time MLS lost its 183 GHz radiometer (used for stratospheric water vapor and mesospheric ozone) but the other two radiometers (at 63 and 205 GHz) making constituent measurements were unaffected, however, presently the MLS instrument is in the standby mode for future use. At present, among the above four sensors HALOE is the only one which is making continuous measurements. HALOE uses solar occultation to measure vertical profiles of temperature, O₃, HCl, HF, NO, NO₂, CH₄, H₂O, and aerosol extinction. HALOE takes advantage of both gas filter and broadband radiometry techniques using selected portions of the spectral range from 2.45 μm to 10.04 μm

Atmospheric Dynamics Measurements

The instruments that provide atmospheric dynamic variables (stratospheric and mesospheric meridional & zonal wind fields, volume emission rate, and temperature profiles of the upper atmosphere) are:

- High Resolution Doppler Imager (HRDI)
- Wind Imaging Interferometer (WINDII)

HRDI provides coverage in the stratosphere (10-50 km) and in the mesosphere and lower thermosphere (MLT) region (50-115 km), while WINDII makes measurements in the mesosphere and thermosphere (90-300 km).

Solar Irradiance and Energy Particle Measurements

The instruments that measure solar irradiance input and particle energy flux entering the atmosphere are:

- Solar/Stellar Irradiance Comparison Experiment (SOLSTICE)
- Solar Ultraviolet Spectral Irradiance Monitor (SUSIM)
- Active Cavity Radiometer Irradiance Monitor (ACRIM II)
- Particle Environment Monitor (PEM)

SOLSTICE and SUSIM provide spectral solar UV irradiance at a spectral resolution of ~ 1 nm in spectral regions 119 to 420 nm and 115 to 410 nm, respectively. ACRIM II provides total solar irradiance. PEM provides electron, proton, and x-ray energy deposition rates, and magnetic field measurements.

Six of the original ten instruments aboard the UARS (SOLSTICE, SUSIM, PEM, HRDI, WINDII, HALOE) regularly take measurements. Detailed description of each instrument can be found in the special issue, *Journal of Geophysical Research* (98(D6), 10643-10814, 1993). The overview of the mission and the highlights are reported by Schoeberl *et al.* (1994), and Jackman and Douglass (2003). A list of many of the UARS related publications by the science team and the mission status can be found from the UARS project web site <http://umpgal.gsfc.nasa.gov>.

The UARS data sets also include two correlative products (global assimilated data fields) for verifying the geophysical parameters derived from the UARS instruments. Correlative data product from the National

Meteorological Center (NMC), now called the National Centers for Environmental Prediction (NCEP) includes temperature, winds (u and v components), moisture, and geopotential height. The correlative data product from the United Kingdom Meteorological Office (UKMO) includes temperature, meridional and zonal winds, vertical velocity (omega), and geopotential height parameters. A list of the geophysical parameters retrieved from the measurements made by the UARS instruments are given below in Tables 1-3.

Table 1. Atmospheric chemistry & dynamics measurements

PROFILES	CLAES	HALOE	ISAMS	MLS	HRDI	WINDII
O ₃	X	X	X	X		
H ₂ O	X	X	X	X		
CH ₄	X	X	X			
CH ₃ CN				X		
HNO ₃	X			X		
HF	X	X				
HCl		X				
CF ₂ Cl ₂	X					
CFCl ₃	X					
ClO				X		
ClONO ₂	X					
CO			X			
NO	X	X				
NO ₂	X	X	X			
N ₂ O	X		X			
N ₂ O ₅	X		X			
SO ₂				X		
Aerosol Extinction	X	X	X			
Geopotential Height				X		
Relative Humidity				X		
Temperature	X	X	X	X	X	X
Wind Fields					X	X
Volume Emission Rate					X	

UARS DATA PROCESSING

The UARS data were processed from instrument activations beginning in September and October 1991 through September 2001 at the UARS Central Data Handling Facility (CDHF) located at NASA Goddard Space Flight Center (GSFC). UARS science data from different instruments are archived at GES Distributed Active Archive Center (DAAC) and publicly available from the GES DAAC. These UARS data and detailed data documents may be accessed from the GES DAAC website (<http://daac.gsfc.nasa.gov>). The UARS instrument team scientists released the data to the DAAC in stages pending completion of quality assurance procedures. Any additional measured atmospheric parameters from the UARS instruments that receive endorsement from the UARS Project Scientist in the future will also be archived at the GES DAAC, as they become available from the UARS instrument teams.

Since October 2001, the UARS data have been processed at the individual instrument team locations. It should be noted that the file formats for UARS data archived in the Goddard DAAC are not the same VAX/VMS-based files obtained from the UARS CDHF. A translation tool has been used to convert from VMS keyed access with indexed organization to an IEEE sequential access with sequential organization and fixed length records.

The enhancement of data calibration and of science algorithms (for retrieving geophysical parameters from the measured and calibrated radiances and signals) is an ongoing effort. Over the years of the UARS mission many improvements have occurred and data were reprocessed producing an improved set of physical parameters and assigned a new version. These version numbers vary from sensor to sensor.

UARS DATA TYPES

The UARS data files are generated at five different processing levels:

Level 0

The basic telemetry data from the instruments after time reversal and decommutation into specific sensor files. Level 0 data have a common format.

Level 1

Calibrated measurements (e.g. counts converted to radiances) at original instrument spatial and temporal resolutions. Level 1 data have sensor specific file formats.

Level 2

Geophysical derived parameters (e.g. temperature profiles, gas concentrations, and winds) derived from the Level 1 data, at original instrument spatial ("footprint") and temporal resolutions. Level 2 data also have sensor specific file formats.

Level 3A

Geophysical parameters derived from Level 2 data, transformed into a common format and equally spaced along the measurement trajectory in:

Time

These data products are "Level 3AT" (at 65.536 second centers and about a 500 km interval along orbital track) and the associated auxiliary quality parameter files "Level 3TP". Level 3AT files are generated by the CLAES, HALOE, HRDI, ISAMS, MLS, PEM, and WINDII instruments. Level 3TP and 3AT files use the same format. However, PEM's level 3TP provide detailed energy deposition profiles of electron and proton at a higher temporal resolution, 2.048 sec for data from High Energy Particle Spectrometer (HEPS) and 65.536 sec for data from Medium Energy Particle Spectrometer (MEPS), than the corresponding electron and proton level 3AT data products, which are only produced when there are simultaneous HEPS and MEPS measurements. Altitude coverage is the same as in the 3AT files.

Latitude

These data products are "Level 3AL" (at every four degrees latitude) and associated auxiliary quality parameter files "Level 3LP". The level 3AL data values are derived from the associated level 3AT data by interpolating to the nearest 4 degree latitude (about 440 km) along the orbital track. The standard latitude values at which level 3AL records are written are from -88.0° to +88.0° latitude in 4.0 degree latitude increments along the orbital track. Level 3AL data are generated from UARS sensors CLAES, ISAMS, MLS, HRDI and WINDII.

Level 3B

UARS level 3B data are generated from the level 3AL data. The technique is based upon sequential estimation using Kalman filtering, similar to that applied to the Nimbus 7 LIMS instrument data (Haggard *et al.*, 1986). The estimator is run forward and backward in time for several days and the results combined to produce a 3B product corresponding to 1200 GMT each day. In order to minimize the impact of local time variations on the results, the 3B data are derived separately for the ascending and descending portions of the orbits. Thus for each sensor and data species there are two separate files per day (one for north-going and other for south-going satellite data, which differ by 12 hours local time at the equator) at approximately one half scale height altitude intervals.

These data are stored (in common file format) as 13 Fourier coefficients (one constant term, 6 coefficients for cosine terms, and 6 for sine terms) for each scale height altitude around the latitude circles defined by Level 3AL. In addition, another two files consisting of covariances (which provide estimates of the uncertainties inherent in the derived coefficients) are also generated separately (one for the ascending and other for the descending portions of the orbits). The following expression (Haggard *et al.*, 1986) is used to relate the level 3B Fourier coefficients a_n to the geophysical quantity x at any longitude ϕ_j :

$$x(\phi_j) = a_0 + \sum_{n=1 \text{ to } 6} \{ a_n \cos n\phi_j + a_{n+6} \sin n\phi_j \} \quad (1)$$

Table 2. Characteristics of atmospheric chemistry & dynamics products

	CLAES	HALOE	ISAMS	MLS	HRDI	WINDII
Spectral Region	3.5-12.7 μm	2.43-10.25 μm	4.6-16.6 μm	63, 183, 205 GHz	0.557-0.775 μm	0.557-0.9 μm
File Type	3AL, 3AT, 3B	Level-2 & 3AT	3AL, 3AT, 3B	3AL, 3AT, 3B	3AL & 3AT	3AL & 3AT
Data Period	Oct 91-May 93	Oct 91-Present	Sep 91-Jul 92	Sep 91-Jul 99*	Nov 91-Present	Nov 91-Present

For each UARS instrument, data is not available in all formats or file types. Level 3B data types are currently produced for the five limb viewing UARS instruments (CLAES, ISAMS, MLS, HRDI, WINDII) for which level 3AL data files exist. There is no Level 3AL or Level 3B file for the trace species profiles which are retrieved from the solar occultation measurement technique based sensor, HALOE. Level 3AL products are also not available for the instruments that measure energy input into the atmosphere (i.e., SOLSTICE, SUSIM and PEM). For SOLSTICE and SUSIM data, Level 3 definitions differ from the other sensors. The file types are Level 3AS (based on calibration coefficient extrapolated from previous degradation coefficients) and Level 3BS (based on degradation coefficients applied from pre and post degradations measurements) and contain a single array representing a daily averaged solar spectrum for each spectral interval.

Table 3. Solar irradiance & particle measuring instruments and products

	SOLSTICE	SUSIM	ACRIM II	PEM
Spectral Region	119 to 420 nm (1 nm resolution)	115 to 410 nm (1 nm resolution)	Total solar spectral region	X-rays, Medium and High energy particles
File Type	3BS	3BS	Level 2 & 3AT	3AT & 3TP
Data Period	Oct 91-Present	Oct 91-Present	Sept 91-Aug 01	Oct 91-Present
Parameters	UV irradiance	UV irradiance	Total irradiance	Electron, Proton, & X-ray energy deposition rate, and Magnetic field

SPATIAL AND VERTICAL RESOLUTION OF UARS PRODUCTS

Spatial coverage is dependent on the instrument and ranges between 80°S and 80°N. Because of the 57° orbital inclination of the spacecraft, the orbit plane precesses at the rate of 5° a day relative to the Sun, thus the limb sounders that view at 90° to the spacecraft velocity can “see” to 80° in one hemisphere and 34° in the other hemisphere providing data over all local times about every 36 days (Reber et al., 1993). In general, the UARS spacecraft is rotated in yaw by 180° on average about once every 36 days (termed a yaw cycle) in order to keep the solar panels pointing toward the sun and instruments away from the direct sun heat, thus periodically (10 times per year) alternating the hemisphere for maximum latitudinal coverage. The MLS, ISAMS, and CLAES instruments gather measurements between latitudes 80°N and 34°S in the forward (Northern Hemisphere pointing) mode, and between 80°S and 34°N in the aft (Southern Hemisphere pointing) mode. For the wind instruments, HRDI and WINDII, the nominal latitudinal coverage is between 74°N and 60°S in the forward mode and between 74S and 60N in the backward mode.

The spatial resolution of level 3AL data (latitude referenced) is 4° latitude or about 440 km along the orbital track, and 495 km for the level 3AT (time referenced) data. The vertical resolution for the level 3A data is about 2.5 km for pressure referenced data arrays, and 3 to 5 km for altitude referenced data arrays. UARS trace gas profiles for level 3 CLAES, ISAMS and MLS data are reported at a set of up to 46 standard pressure levels (in millibars) defined by the UARS science team. WINDII level 3 profiles are reported at 88 UARS standard altitude (km) grid also defined by the UARS science team. However, HRDI outputs are for both the pressure and altitude grids.

UARS DATA PRODUCT SUPPORT AVAILABLE FROM THE NASA GES DAAC

All standard UARS (Level 3 from all the sensors & Level 2 from HALOE) products, consisting of measurements of atmospheric internal structure (trace constituents, physical dynamics, radiative emission, thermal structure, density) and measurements of the external influences acting upon the upper atmosphere

(solar radiation and charged particle precipitation) and ancillary data consisting of model analyses and correlative measurements are archived at the NASA Goddard Earth Sciences (GES) DAAC.

Data Access

One of the main goals of the GES DAAC is making the data easily accessible to the wider user community. All of the data sets archived at GES DAAC are freely made available to the public and science user communities. These data sets may be accessed via several mechanisms including:

GES DAAC Search and Order

A user friendly Web-based search and order system, with full-features of spatial & temporal search <http://daac.gsfc.nasa.gov/data/>

EOS Data Gateway (EDG)

This interface provides access to satellite data that is available from all NASA data archive centers and NASA affiliated centers <http://eos.nasa.gov/imswelcome/>

Anonymous FTP Site

A majority of the UARS and other related data sets are available from the GES DAAC anonymous FTP server <ftp://daac.gsfc.nasa.gov/data/>

Read Software and Data Extraction Tools

To facilitate the use of UARS data sets, a simple read/dump programs for all of the UARS data file types (including correlative data set) are available through the Goddard DAAC. Both FORTRAN & C versions of the read programs and compiled modules for all platforms (including Windows) are available for each data type. The Goddard DAAC has also created a shell script called "read_urs" (an interface with simple read/dump programs for all of the UARS data files) to allow the users to immediately view the data they have ordered.

Other Long-term Atmospheric Chemistry, Dynamics, and Solar Irradiance Data Base at the GES DAAC

The data from the future upper atmospheric research missions, e.g., the Ozone Monitoring Instrument (OMI) the Microwave Limb Sounder (MLS) and the High Resolution Dynamics Limb Sounder (HIRDLS) aboard Aura (to be launched early 2004), as well as data from the future NPOES Preparatory Project (NPP) will also be archived at the NASA GES DAAC. The data products from several past and present atmospheric data missions, including Nimbus-4 Backscatter Ultraviolet Spectrometer, Nimbus-7 Solar Backscatter Ultraviolet Spectrometer and Limb Infrared Monitor of the Stratosphere (LIMS), a series of Total Ozone Mapping Spectrometer (TOMS) instruments, Television Infrared Observational Satellite (TIROS) Operational Vertical Sounder (TOVS) pathfinder, Data Assimilation Office (DAO), Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS), and other Aqua instruments, e.g., Atmospheric Infrared Sounder (AIRS), Advanced Microwave Sounding Unit (AMSU), and Humidity Sounder from Brazil (HSB) are also archived at the NASA GES DAAC. The continuity of the long-term solar UV measurements is maintained with the data from the Solar Radiation and Climate Experiment (SORCE) launched this year, and the continuity of the long-term atmospheric chemistry, dynamics, and solar UV measurements will be maintained with the launch of the EOS Aura spacecraft in early 2004.

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