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Earth Remote Sensing at the Jet Propulsion Laboratory

Diane L. Evans
Deputy Manager
Earth and Space Science Program
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Introduction

Remote Sensing activities at the Jet Propulsion Laboratory (JPL) are extremely diverse. They range from studies of the interstellar medium and cosmic background radiation to ground-based and satellite observations of comets, asteroids, planetary surfaces, planetary atmospheres, and geopotential fields. Earth Remote Sensing at JPL emphasizes quantitative interpretation of biological, chemical, and physical remote sensing signatures of the Earth's atmosphere, oceans, land surface and crust, and of the interfaces between them. Researchers use data acquired from aircraft, balloon and satellite platforms in conjunction with laboratory experimentation, field work, and theoretical modelling to address such key global problems as ozone depletion, climate change, volcanism, and tectonism.

While research is becoming largely interdisciplinary in nature, JPL scientists are building on strengths in traditional areas of expertise, such as Atmospheric Chemistry and Processes, Oceanography, Geology, and Geodynamics. This paper provides brief examples of research being done in these areas, in which remote sensing is used as a tool; and a description of the associated instrument and mission activities. It also describes opportunities for future interdisciplinary research including interactions between the atmosphere, the land surface, and the land biosphere; and studies of the upper troposphere-lower stratosphere using data from aircraft, balloon and spaceborne sensors.

Atmospheric Chemistry and Processes.

The NASA Upper Atmosphere Research Program was Congressionally mandated in 1975 to include research, technology and monitoring to understand the composition and structure of the upper atmosphere and its susceptibility to human and natural perturbations. Specific objectives of the research at JPL are to understand anomalies such as the Antarctic ozone hole, conduct ground-based, balloon and aircraft experiments to monitor atmospheric chemistry, provide ground truth for the Upper Atmosphere Research Satellite (UARS), develop retrieval techniques for atmospheric parameters, and develop ncw sensors for measurements of atmospheric trace species, temperature, and dynamics. These field activities are closely tied to JPL's strong laboratory research programs in kinetics, photochemistry and spectroscopy.

During October 1991- March 1992, several JPL instruments were flown as part of the Arctic stratosphere campaign aboard the NASA ER-2 and DC-8 aircraft. Instruments included the Airborne Laser Infrared Absorption Spectrometer, the Mark IV Fourier Transform Infrared Solar Spectrometer, and the Microwave Temperature Profiler. Measurements included ozone abundance relative to tracers to identify loss of ozone; temperature profiles around flight altitudes; and column abundances of tracers, reservoirs, and source gases to monitor changes across the vortex boundary.

The Mark IV instrument is also used for observations from high altitude research balloons, as are the Far Infrared Limb Observing Spectrometer (FILOS), which measures OH; the Balloon Microwave Limb Sounder (BMLS), which measures ClO and 03; and the Submillimeter Limb Sounder (SLS), which measures C1O, 03, H20, and HC1. Also, as part of this program, a ground-based ozone lidar at JPL's Table Mountain Facility provides routine, long term measurements of stratospheric ozone as part of NASA's Network for the Detection of Stratospheric Change.

In addition to aircraft, balloon and field instruments, several spaceborne instruments provide data for upper atmosphere research, including the Microwave Limb sounder (MLS), which is currently flying on UARS and will be upgraded for the Earth Observing System Chemistry Mission (EOS-CHEM); the Active Cavity Radiometer Irradiance Monitor (ACRIM) instrument which flew on the Solar Maximum Mission, is currently flying on UARS, and will fly on EOS-CHEM; and the Atmospheric Trace Molecule Spectroscopy (ATMOS) experiment, which flew on the Space Shuttle as part of Spacelab 3 in April 1985, on the Atmospheric Laboratory for Applications and science (ATLAS-1) in March 1992, and will fly on ATLAS-2 scheduled for March 1993.

Microwave Limb Sounder. After a decade of balloon and aircraft experiments, UARS MLS has become the first spaceborne instrument to measure ClO on a global scale (Figure 1; Froidevaux et al., 1992; Waters, 1992; Waters et al., 1992). These data are essential since the abundance of ClO is a measure of the rate at which chlorine destroys 03. Simultaneous UARS MLS measurements of O_3 and H20 are providing additional information on stratospheric ozone chemistry. UARS MLS measurements of S02 and 02 have also been made in the plume of Mount Pinatubo Volcano (Read et al., 1992). The UARS MLS was turned on only a few days after launch, and a ground truth/validation was carried out a week later using JPL's balloon-based instruments.

The UARS MLS uses heterodyne radiometers operating at 205, 183 and 63 GHz. The 183-GHz radiometer was contributed as part of a collaborative effort with groups in the United Kingdom. The antenna's 1.6-m vertical dimension gives a 205-GHz field of view which is vertically scanned to measure profiles. Six spectral bands from the radiometers are input to six filter banks, each of which separates the signal into 15 spectral channels, measures the power in each channel and digitizes the result for telemetry. The instrument integration time is approximately 2 seconds, and a vertical scan is performed every minute.

Active Cavity Radiometer Irradiance Monitor. ACRIM represents the latest in pyrheliometric technology focussed on monitoring and verification of solar irradiance variability begun by ACRIM I on the Solar Maximum Mission (e.g. WillSon et al., 1988) and ACRIM II on the Upper Atmosphere Research Satellite (e.g. EOS Reference Handbook, 1991). Earth's climate is determined by how much of the Sun's radiant energy falls on our planet's surface, oceans and atmosphere. Although the total solar irradiance (TSI) has long been called the "solar constant," it is now known to vary. Changes in TSI of as little as 0.5% per century can cause fundamental changes in climate and may result in extremes of weather ranging from the global ice ages to tropical conditions that have occurred more than once in Earth's history. The EOS ACRIM will measure solar irradiance with a precision of 10 ppm. When combined with data from ACRIM I and 11, EOS ACRIM will provide data on solar variations that require relatively long time scales of observation.

Atmospheric Trace Molecule Spectroscopy. ATMOS uses a Fourier Transform Spectrometer and infrared solar absorption spectroscopy for detailed evaluations of stratospheric chemical composition. The instrument has a spectral response from 4,800 to 600 cm–l at a resolution of 0.01 cm-l. From the altitudes typically achieved by the Space Shuttle, the orbital periods during which the Sun is eclipsed by Earth's atmosphere are normally about 2.5 to 3 minutes in duration. During such periods, ATMOS obtains a single measurement (or spectrum) every 2.2 seconds. This allows the instrument to obtain a set of spectra during each sunrise or sunset corresponding to height intervals in the atmosphere of approximately 4 km. These sets of spectra provide the basis for retrieving the concentration versus height profiles of a variety of atmospheric constituents.

Vertical concentration profiles were obtained during the first ATMOS flight aboard the Space Shuttle Challenger during the Spacelab 3 mission in April-May 1985. Data returned by ATMOS included the first measurements of several previously undetected atmospheric species, a complete inventory of all nitrogen oxide species and the simultaneous measurement of the halogenated source gases — the CFCS — and halogen sink gases — HC1 and HF — involved in the ozone depletion problem.

Oceanography

The overall objectives of the JPL Oceanography activities are to understand ocean circulation, productivity, air-sea interactions, and the role of polar ice in the hydrological cycle and global climate. JPL scientists are active in several ongoing international programs including the World Ocean Circulation Experiment (WOCE), the Tropical Ocean and Global Atmosphere (TOGA) experiment, and the Joint Global Ocean Flux Study (JGOFS). These programs are being carried out under the sponsorship of the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Program (IGBP) to better describe and understand global ocean circulation and its relationship to climate change, to study the year-to-year variability of the tropical oceans and their coupling to the global atmosphere, and to better understand the ocean's role in the global carbon cycle. In addition, a state-of-the-art airborne rain radar and infrared radiometer from JPL are being deployed in a TOGA field experiment.

Key to JPL Oceanography research activities are the use of altimeter observations to determine global ocean circulation, scatterometer observations to determine wind stress and the forcing of ocean circulation, infrared and microwave observations to determine heat content and the transport of heat and momentum bet ween the atmosphere and ocean, and ocean color measurements for estimating plant biomass and productivity. JPL is responsible for spaceborne missions and instruments to acquire some of these critical data sets, and operates the Physical Oceanography Distributed Active Archive Center for the EOS Data and Information System which houses the complete set of satellite ocean data.

TOPEX/POSEIDON. TOPEX/POSEIDON, which was developed jointly by NASA and The Centre National d'Etudes Spatiales (CNES) was successfully launched on August 10, 1992. TOPEX/I'OSEIDON will usc radar altimetry to measure sea-surface height over 90 percent of the world's ice-free oceans during its three to five year lifetime. In combination with a precise determination of the spacecraft orbit, the altimetry data will yield global maps of ocean topography (Figure 2; Fu and Patzert, 1992, Christensen et al., 1992).

The TOPEX/POSEIDON spacecraft carries a suite of six instruments, provided by the United States and France (e.g. TOPEX/POSEIDON Science Working Team, 1991). The primary instrument is the NASA dual-frequency TOPEX altimeter, operating at 5.3 and 13.6 GHz, which draws upon a long heritage of single-frequency instruments extending back to Seasat (e.g. Hayne et al., 1992). The mission also carries an advanced, experimental solid-state POSEIDON altimeter, which uses the same antenna as the NASA altimeter but operates at a single frequency of 13.6 GHz. The companion TOPEX microwave radiometer operates at frequencies of 18, 21, and 37 GHz to" provide estimates of total atmospheric water-vapor content (e.g. Keihm et al., 1992). The 21-GHz channel is the primary measurement channel; the 18-GHz and 37-GHz channels are used to remove the effects of wind speed and cloud cover, respectively. These data allow reduction of the water-vapor delay error to 1 cm, permitting an overall altimetric precision of 3 cm.

The NASA tracking system operates by laser ranging to reflectors arrayed around the altimeter antenna, which permit the satellite to be intermittently tracked by a worldwide, ground-based network of 12 laser stations. These data will be used with computer models of the Earth's global gravity field for precision orbit determination and calibration of the altimeters. The CNES Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) tracking system determines the satellite's velocity by measuring the Doppler shifts of two microwave frequencies (2,036 MHz and 401 MHz) transmitted by a global network of some 50 ground-based beacons whose positions arc known within a few centimeters(e.g. Dorrer et al., 1992). The mission also carries an experimental Global Positioning System (GPS) receiver which provides continuous spacecraft tracking with a potential accuracy of 10 cm or better (Melbourne et al., 1992). Based on the success of TOPEX/POSEIDON, discussions are underway between NASA and CNES for a follow-on ocean altimeter mission to provide critical measurements of ocean circulation between TOPEX/POSEIDON and the EOS Altimetry (EOS-ALT) mission which is planned for early in the next decade.

NSCAT. Scatterometer observations to determine wind stress and the forcing of ocean circulation will be the focus of the NASA Scatterometer (NSCAT) which is scheduled to fly as part of Japan's Advanced Earth Observing Satellite (ADEOS) in early 1996 (e.g. Naderi et al., 1991; Liu, 1993). Although a single-swath scatterometer operating at C-band is presently flying on the European Space Agency's Remote Sensing Satellite-1 (ERS-1) mission, NSCAT will be the first spaceborne dual-swath, Ku-band scatterometer to fly since SeaSat. Discussions are ongoing to ensure continuity of similar scatterometer measurements with a flight of NSCAT-2 on ADEOS-II early in the next decade.

NSCAT will measure wind speeds and directions over at least 90% of the icc-free global oceans every 2 days. An array of six, 3-m-long antennas will scan two 600-km bands of ocean — onc band on each side of the instrument's orbital path, separated by a gap of approximately 330 km. Ground computers will produce wind measurements within 2 weeks of receiving raw NSCAT data from the ADEOS spacecraft, with no backlog, throughout the 3-year mission. In preparation for NSCAT, an aircraft instrument, NUSCAT has been developed, and is beginning operations on the NASA C-130 aircraft.

Alaska SAR Facility. Polar oceanography at JPL has emphasized the usc of microwave observations to determine heat content and the transport of heat and momentum between the atmosphere and ocean (e.g. Alaska SAR Facility Prelaunch Science Working Team, 1989). In August, 1991 the Alaska Synthetic Aperture Radar Facility (ASF) in Fairbanks, which was designed and built by JPL for NASA, began gathering and processing radar data from ERS-1. Automated geocoding, classification and change detection algorithms have also been implemented in the ASF Geophysical Processor System (GPS) (e.g. Kwok et al., 1990, Kwok et al., 1992), and ice motion is routinely mapped. Approximately 10 minutes of SAR data pcr day can be processed through ASF, covering almost half a million square km of the Earth's surface. Plans are to upgrade this facility to allow acquisition and processing of SAR data from the Japanese Earth Resources Satellite (JERS-1) and the Canadian Radarsat *in* addition to ERS-1 (e.g. Thomas, 1991).

Geology and Geodynamics

Solid Earth science research at JPL includes volcanic process studies, tectonic and stratigraphic analyses, studies of the Earth's interior structure and dynamical processes, and interactions between the solid Earth and the oceans and atmosphere. JPL has long been NASA's lead center in Geology, and the lead center in the development and deployment of GPS-based geodesy. The Program includes process modeling; development of field, aircraft, and satellite remote sensing instrumentation; creation of innovative data analysis techniques; and development and deployment of geodetic systems.

Airborne facility instruments which have been developed and built to support scientific research within the NASA Geology program include the Airborne Visible/infrared Imaging Spectrometer (AVIRIS) which flies on the NASA ER-2 aircraft, the Airborne Synthetic Aperture Radar (AIRSAR) which flies on the NASA DC-8 aircraft, and the Thermal Infrared Multispectral Scanner (TIMS) which flies on the NASA C-130 aircraft (Figure 3). These instruments are currently supporting a wide range of Earth Science investigations including Ecosystems (e.g. Way et al., 1990; Durden et al., 1991; Elvidge et al., 1991; Beaudoin et al., 1992; MacDonald et al., 1992), Hydrology (e.g. Schmugge et al., 1990; Shi and Dozier, 1992; Shi et al., 1992; Nolin and Dozier, 1991), and Oceanography (e.g. Pilorz and Davis, 1990; Drinkwater et al., 1991), in addition to Geology (e.g. Abrams et al., 1990; Lang et al., 1990; van Zyl et al., *1991;* Farr, 1992; Ray et al., 1992; Weitz and Farr, 1992).

AVIRIS. The Airborne Visible/Infrared Imaging Spectrometer is the first imaging spectrometer to cover the entire solar reflected portion of the spectrum (e.g. Green, 1991). AVIRIS provides calibrated data in 224 narrow, contiguous spectral bands covering 0.4 to 2.45 μm for studies in the earth sciences across a wide range of disciplines. In addition, the instrument serves as a testbed for calibration algorithm development and is being used to calibrate and validate the performance of other optical sensors.

AVIRIS became operational in 1989. The AVIRIS project consists of the flight hardware, a dedicated calibration laboratory, a dedicated data facility and an operations team with expertise in experiment design, system maintenance and operations and data calibration and distribution. During a typical year, AVIRIS is available for data acquisition flights for 6 months and undergoes routine preventive maintenance and calibration for 6 months. During the operations period, 30 to 40 launches for up to 50 science investigators are conducted, in addition to several launches for system checkout and calibration. On a typical launch, Up to 50 scenes of data arc acquired and processed. Each scene is about 11 km square with a nominal resolution of 20 m.

AIRSAR. The Airborne Synthetic Aperture Radar (AIRSAR) is a three-frequency fully polarimetric SAR (van Zyl et al., 1992). AIRSAR data provide prototype data for the Shuttle Imaging Radar-C (SIR-C) and the EOS SAR and is currently being used to develop and test geophysical algorithms in a wide range of Earth 'Science disciplines. AIRSAR data are acquired at P-band (wavelength=68 cm), L-band (wavelength=24 cm), and C-band (wavelength=5.6 cm) with a nominal spatial resolution of 10 m.

Engineering evaluation flights were conducted in 1988 and the system became fully operational in 1989. During a typical year, AIRSAR is available for data acquisition for a period of 6 months and undergoes preventive maintenance for another 6 months. During a typical flight season, two to three flights are conducted weekly. On a typical flight day, up to 4 hours of data are acquired. An AIRSAR-processed scene covers about 12 km square and is made up of images in Stokes matrix format at all three frequencies. During a typical flight season, data are acquired for 50 to 70 investigators.

TIMS. The TIMS instrument is a six-channel spectrometer with a spectral range between 8 and 12 μm (e.g. Kahle, 1987). The instrument provides measurements of spectral radiance which is separated into estimates of spectral emissivity and surface kinetic temperature. Temperature measurements are used in studies of the surface radiation balance, evaporation and evapotranspiration, volcanic processes, and thermal inertia and compositional maps. The spectral emittance data can be used to distinguish between silicate and non-silicate materials, and map carbonates and hydrothermally altered rocks. The nominal swath width is 5 km and nominal resolution is 8 m. TIMS is frequently flown on the NASA C-1 30, with data distribution through the EROS Data Center. Data from this instrument are currently being used in support of algorithm development for the EOS Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), which is scheduled to fly on the EOS-AM platform.

A Look to the Future

Examples of interdisciplinary research which will be the focus of research activities at JPL over the next decade include studies of, 1) interactions between the atmosphere, the land surface, and the land biosphere, particularly as addressed by international programs such as a Boreal Ecosystem-Atmosphere Study (BOREAS) and the Global Energy and Water Cycle Experiment (GEWEX), and 2) the upper troposphere-lower stratosphere using data from aircraft, balloon and spaceborne sensors. These areas of research will build on previous experience and the body of existing remote sensing data, as well as exploit upcoming mission opportunities such as SIR-C/X-SAR, the Global Topographic Mapping Mission (TOPSAT), and EOS. They will also, no doubt, impel development of new measurement concepts, such as cloud height and soil salinity.

SIR-C/X-SAR. The Shuttle Imaging Radar–C (SIR–C)/X–Band Synthetic Aperture Radar (X–SAR), a joint project of NASA, the German Space Agency and the Italian Space Agency is the next evolutionary step in NASA's Spaceborne Imaging Radar (SIR) program that began with the Seasat SAR in 1978, and continued with SIR-A in 1981 and SIR-B in 1984.

SIR–C/X–SAR will be the first spaceborne radar system to simultaneously acquire images at multiple wavelengths and polarizations. SIR-C, built by JPL for NASA, is a two-frequency radar operating at L-band (23-cm wavelength) and C-band (6-cm wavelength). SIR–C will have the capability to transmit and receive horizontally and vertically polarized waves at both frequencies. Images will be acquired from 15- to 55° angles of incidence with HH, HV, VH and VV polarizations. X–SAR, which is provided by Germany and Italy, is a single-polarization radar operating at X-band (3-cm wavelength), The X–SAR antenna, mounted on a bridge structure that is tilted mechanically to align the X-band beam with the L- and C-band beams, will provide VV polarization images.

SIR–C/X–SAR will fly aboard the Space Shuttle as part of the Space Radar Laboratory (SRL). SRL–1 will fly in early 1994, with the remaining two launches scheduled for 1995 and 1996. The three flights will be scheduled so that data can be acquired in different seasons for studies of vegetation, snow and soil moisture.

TOPSAT. TOPSAT is a proposed Earth Probe Mission for the 1997-1998 timeframe which would obtain a complete, high resolution, contiguous digital map of the elevation of 90% of the Earth's land mass using radar interferometry. TOPSAT horizontal resolution will be 30 m, and vertical accuracy will be 2-5 m, depending on the surface slope. There is also a proposal to obtain high resolution (300 m) and very high vertical accuracy maps (10 cm) of the polar ice sheets and other low relief areas up to 850 latitude using laser altimetry.

Topographic information is required for many Earth Science investigations. Examples of studies where TOPSAT data will be used include those involving estimates of solar radiation and snow-melt, models of evapotranspiration and mass and energy exchange with the atmosphere, geological structures, tectonic deformation, soil and drainage network development, estimates of soil carbon storage, and corrections for distortions in remote sensing data. As a proof of concept for such a SAR interferometry mission, a prototype instrument called TOPSAR has been developed on the NASA DC-8 aircraft as part of the AIRSAR system described above. Data have been acquired over several sites in the U.S. and Europe, and digital elevation models(DEMs) have been produced (e.g. Evans et al., 1992).

EOS. JPL scientists are involved in many aspects of EOS; as Interdisciplinary Scientists, Instrument PIs, and Facility Instrument Team Members and Team Leaders. In addition to the activities mentioned in the previous sections, JPL will be responsible for the Multi-angle Imaging SpectroRadiometer (MISR) which is scheduled to fly on the EOS AM Platform; the Atmospheric Infrared Sounder (AIRS), which will fly on the EOS I'M platform, and the Tropospheric Emission Spectrometer (TES) which will fly on the second EOS AM Platform. The ASTER Science Project at JPL is jointly responsible with the Japanese for algorithm development and validation, requirements definition, mission operations, and in-flight calibration. Finally, modified versions of the High-Resolution Imaging Spectrometer (HIRIS) and the EOS Synthetic Aperture Radar, both JPL Facility Instruments, are also planned to fly as part of the EOS program.

MISR. The Multi-angle Imaging SpectroRadiometer, will be used study the effects of geophysical processes and human activities on Earth's ecology and climate (e.g. Diner et al., 1991). MISR will focus on Earth's 10 wer atmosphere and surface, providing mul tispectral images at different viewing geometries with continuous, global data collection over the sunlit Earth at all viewing angles. MISR uscs nine separate charged coupled device (CCD)-based pushbroom cameras, onc at nadir, plus eight other symmetric fore-aft views up to +/- 70.5° along-track. Images are recorded in four spectral bands centered at 443,555,670, and 865 nm, in selectable resolutions ranging from 275 m to 2.2 km.

MISR will measure the abundance and properties of tropospheric aerosols, including those arising from industrial and volcanic emissions, natural biogenic sources, slash-and-burn agriculture, and desertification. This will provide crucial information for assessing the global impact of aerosols on the Earth's shortwave radiation budget. Multi-angle reflectance measurements of different cloud types, classifiable by their spatial characteristics as seen in the high-resolution MISR images and by cloud height distribution retrieved using stereo techniques, will improve our understanding of the effects of clouds on the Earth's climate. Surface bidirectional reflectance obtained from MISR will provide estimates of albedo, leading to more accurate methods of representing surface-atmosphere interactions in climate models, particularly over vegetated terrain. Multi-angle observations also are sensitive to the geometric characteristics of the surface, enabling new approaches to surface cover classification.

AIRS. The Atmospheric Infrared Sounder (AIRS), a high spectral resolution sounder, has been selected on the EOS PM platform (EOS Reference Handbook, 1991). The same platform will also carry two operational microwave sounders — the National Oceanographic and Atmospheric Administration (NOAA) Advanced Microwave Sounding Unit-A (AMSU–A) and the European Meteorological Satellite's Microwave Humidity Sounder (MHS). AIRS is designed to meet NOAA's requirements for a high-resolution infrared sounder to fly on future operational weather satellites. Measurements from AIRS, AMSU–A and MHS will be analyzed jointly to filter out cloud effects from the infrared data in order to derive clear-column temperature profiles and surface temperatures with high vertical resolution and accuracy.

AIRS, AMSU–A and MHS will provide a wide range of data products. For the atmosphere, these instruments will supply temperature profile, humidity profile, total precipitable water, fractional cloud cover, cloud-top height and cloud-top temperature data. For the land, they will provide skin surface temperature, plus day and night land surface temperature difference. For the ocean, they will provide skin surface temperature. Global measurements of outgoing day/night long-wave surface flux will also be obtained. AIRS is designed to cover the spectral range between 0.4 and 15.4 μm and measure simultaneously in over 3,600 spectral channels, with a spectral resolution of 1,200 ($\lambda/\Delta\lambda$). This high resolution enables separation of unwanted spectral emissions and provides spectrally clean windows, which are ideal for surface observations. All channels will be downlinked routinely.

TES. The Tropospheric Emission Spectrometer is an imaging Fourier transform spectrometer operating over the wavelength range of 2.3 to 17pm (e.g. Beer. and Glavich, 1989). TES is designed to measure the distributions of most minor gases in the troposphere. This is done by imaging downward to provide geographically located spectra, and by imaging the limb to provide simultaneous spectra in 2,3-km vertical slices of the limb from the ground to about 32 km. The two TES down-looking modes, at the option of investigators, either provide local data or support a large-scale mapping of gas distributions.

A general objective of TES is to generate a database of the three-dimensional distribution of gases important to tropospheric chemistry, troposphere-biosphere interactions and troposphere–stratosphere exchange — on global, regional and local scales. A second general objective is to employ the databases as input to models of the present and future states of Earth's lower atmosphere. TES will also study volcanic emissions for mitigation of hazards, indication of the chemical state of the magma, prediction of eruptions and quantification of the role of volcanoes as sources of atmospheric aerosols.

ASTER. The Advanced Spaceborne Thermal Emission Reflectance Radiometer will provide surface temperature and emissivity estimates, surface reflected radiances, and digital elevation maps for studies of surface heat fluxes; geology, soils and volcanoes; cloud characteristics; ecosystems and hydrology; and glacial and sca ice processes (e.g. Kahle et al., 1991). The ASTER instrument is being built by the Japanese Government based on science requirements of the ASTER Science Team. ASTER spectral coverage includes three bands covering 0.52-0.82 μm at 15 m spatial resolution; six bands covering 1.60-2.43 μm at 30 m resolution; and five spectral bands covering 8.125-11.65 μm at 90 m resolution. There is also a single band covering 0.76-0.86 μm which can be used to acquire stereo images.

ASTER has the goal of a cloud-free map of the entire Earth's surface in five years. Special data products will include surface classification maps, geologic maps, soil/mineral/vegetation indices, evapotranspiration, thermal inertia, volcanic age maps, slope and lineament maps, glacier extent, and sea ice distribution. The stereo capability will also permit generation of DEMs over selected areas.

HIRIS. The High-Resolution Imaging Spectrometer will provide the Earth science community with the high-resolution spatial and spectral remote sensing data needed to address a broad range of questions in the following disciplines: oceanography and limnology; geology and soils science; terrestrial ecology, including studies of vegetation, snow and ice; and atmospheric studies. The higher resolution capabilities provided by HIRIS, both spatially and spectrally, will be used to identify and understand the processes recognizable in the lower resolution EOS data sets (e.g. Goetz, 1992).

The original concept for HIRIS is a pointable pushbroom imaging spectrometer, in which a line of 800 ground pixels (each 30 m square) are imaged through a spectrometer slit onto an area array detector. Onc axis of each detector corresponds to the crosstrack spatial information while the other axis is the dispersed spectra for that pixel. Along-track images are built Up as the slit is carried forward by the platform's orbital motion. The resulting data can bc envisioned as an image cube with spatial axes (along track and crosstrack) and an orthogonal spectral axis. Slicing the data cube horizontally produces any onc of 192 different wavelength spatial images, while a vertical slice produces a spectrum of any of the ground pixels. A modification to the original concept that is being studied is to lower the spatial resolution of HIRIS to 60 m, and to incorporate a panchromatic sharpening band.

EOS SAR. The EOS SAR mission which is currently under study will provide for the first time a long-duration radar observing system with multifrequency and multipolarization capabilities (e.g. Way and Smith, 1992). These capabilities arc needed to generate geophysical data products as part of the EOS study of global change. EOS SAR will fill an important gap by monitoring the following processes: (1) forest biomass, global deforestation and their impact on increasing carbon dioxide levels; (2) soil, snow and canopy moisture and flood inundation, as well as their relationship to the global hydrologic cycle; (3) polar ice properties and their impact on the polar heat flux, and (4) volcanic, erosional and mountain-building processes.

EOS SAR will consist of three synthetic aperture radar systems: an L-band radar with quadruple polarizations, a C-band radar with dual polarizations and an X-band radar with dual polarizations. The X-band system may bc supplied by the German Space Agency. Each of the radar systems will bc of the phased-array type, will bc capable of steering the beam electronically in elevation to acquire a variety of targets and will have variable resolutions and swath widths. In the high-resolution mode, EOS SAR is designed to provide 30-m resolution over a swath of up to 50 km; the regional mapping mode will provide 100-m resolution over a swath of up to 200 km, and the global mapping mode will utilize SCANSAR imaging to offer 250-m resolution over a 400-km swath.

Conclusions

In this brief overview of remote sensing activities at JPL, I have tried to convey the breadth, high quality, and significance of the work being accomplished. Because of space limitations, I haven't covered all areas of remote sensing, nor given ample credit to the individuals responsible for the activities I have described. I can only hope that after this introduction, readers will feel motivated to learn mom about the exciting research being done at JPL, and either contact me directly or consult some of the references below.

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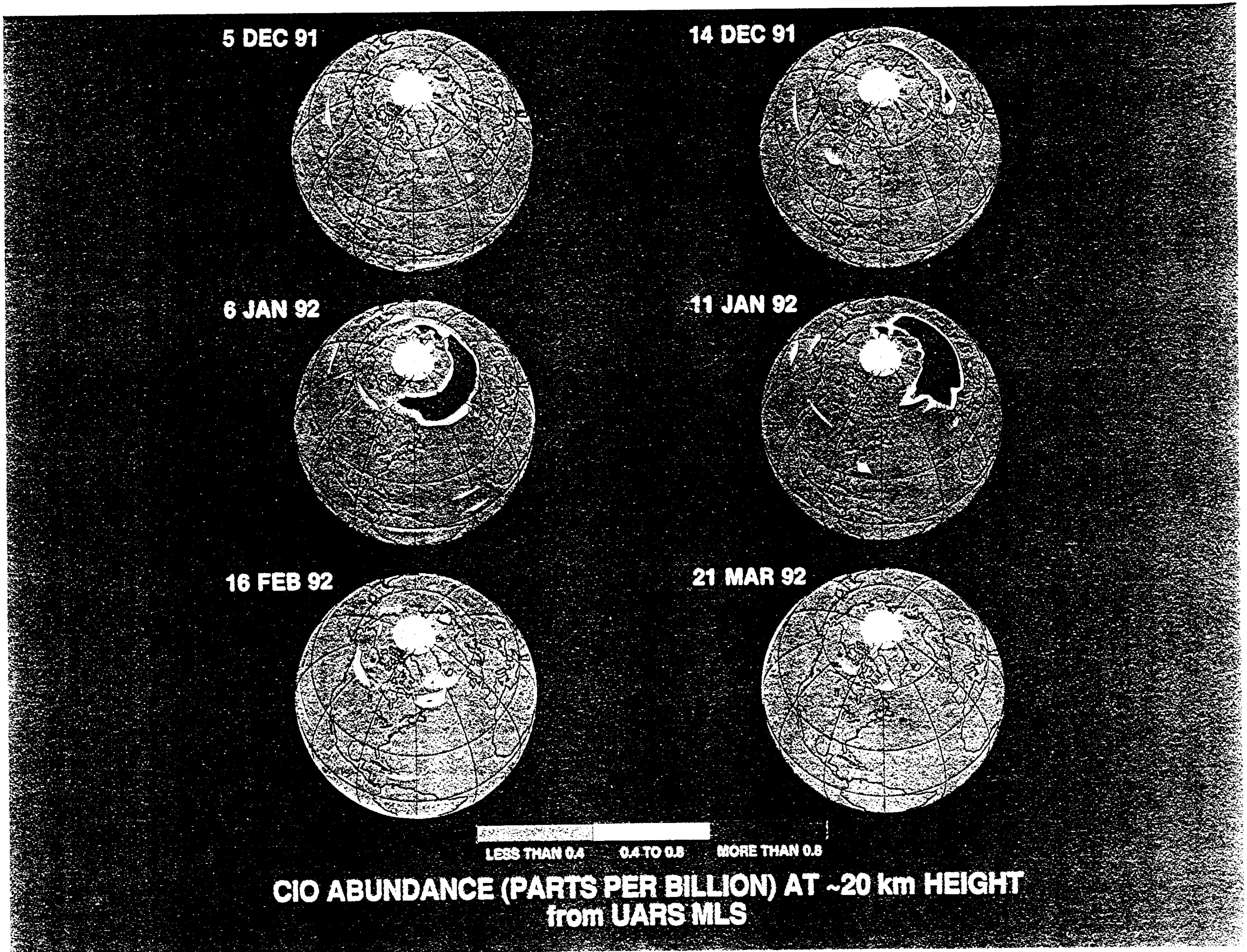
Figure Captions

Figure 1. C1O abundance at 20 km height from UARS MLS. These data are essential since the abundance of C1O is a measure of the rate at which chlorine destroys 03.

Figure 2. Map of ocean topography produced from the TOPEX/POSEIDON altimeter. The total relief of ocean topogrphy shown in this image is about 2 m. The maximum sea level is located in the western pacific Ocean (shown in white) and the minimum is shown around Antarctica (shown in blue and purple).

Figure 3. AVIRIS, TIMS and AIRSAR images covering the alluvial fans on the west side of Death Valley, CA. Because desert varnish and desert pavements on the fan surfaces are sensitive to local climatic conditions, their distributions can be used to constrain models of past climate change (e.g. Arvidson ct al., 1993).


5 DEC 91
14 DEC 91
6 JAN 92
11 JAN 92
16 FEB 92
21 MAR 92
LESS THAN 0.4
0.4 TO 0.8
MORE THAN 0.8
ClO ABUNDANCE (PARTS PER BILLION) AT ~20 km HEIGHT
from UARS MLS

MULTISENSOR IMAGE ANALYSIS

DEATH VALLEY, CA

AVIRIS

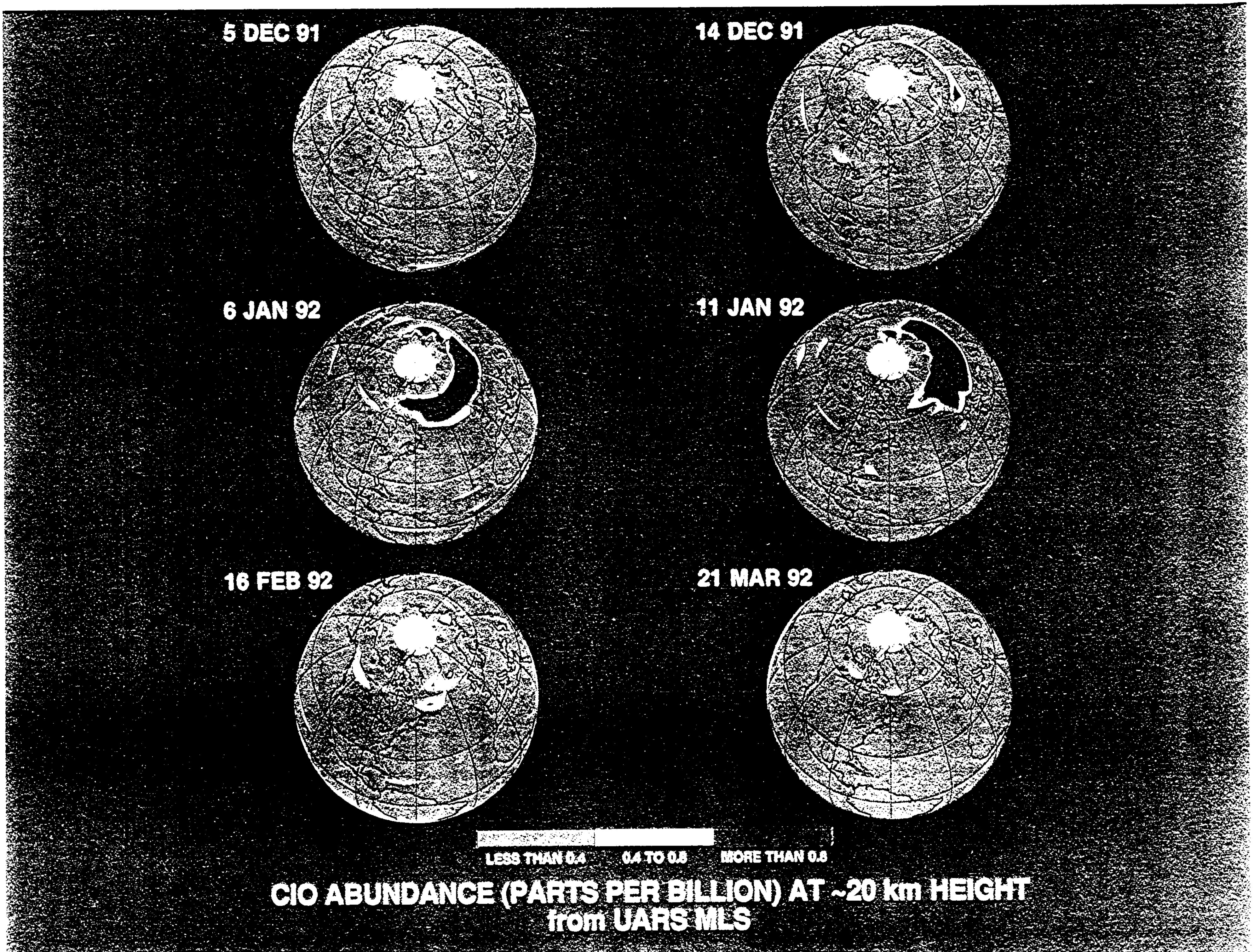
RED = 0.51 μm
GREEN = 1.67 μm
BLUE = 2.2 μm

TIMS

RED = 10.2-10.9 μm
GREEN = 8.9-9.3 μm
BLUE = 8.1-8.5 μm

AIRSAR

RED = 67 cm (PHH)
GREEN = 24 cm (LHH)
BLUE = 5.6 cm (CHH)



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