EO-1 Technology Validation Extended Mission
Background Information and Tasking Questionnaire

Overview

The Earth Observing-1 (EO-1) is a New Millennium Mission Program. The focus of this mission is the demonstration of advanced technologies for use on next generation earth remote sensing systems. This mission will have achieved many of its objectives by November 2001. The satellite, which had a planned life of 12 to 18 months, has continued to operate well and anticipated life could be two years or more. Based on the success of the first year validation and demonstration of interest, NASA has approved extending the mission beyond one year and to open the opportunity for participation by the broader data user community and with the emerging commercial sector. This will contribute to the EO-1 validation program by getting a broader range of user inputs for sensor technology performance assessments. The additional acquisitions available during the extended mission provide remote sensing data users an opportunity to evaluate first hand the benefits of the Advanced Land Imager (ALI) and Hyperion technologies and data on their own sites.

A summary of the instruments and the operations conditions is given below to help the reader understand the benefits and limitations of the EO-1 system and its instruments. In developing an access plan for users of EO-1 data, a number of underlying assumptions were identified. In addition, a data policy and reimbursable agreement are being established. These are also described below. All of these are not yet in a final state and potential user comments are being solicited.

It is NASA's intent, in facilitating the extended mission, to maintain the technology validation nature of EO-1. Thus, data users are expected to provide feedback to NASA on the benefits and limitations in using the EO-1 data. This should be documented in a report or other written format. This information will be part of the EO-1 technology validation public record with the exception that proprietary data that is clearly identified will be protected.

Since EO-1 is a technology demonstrator and not an operational system, emphasis has been placed on creating a baseline offering to you that is simple and provides good value. For example, the archive will be automated to the maximum extent possible to encourage minimum cost and rapid turnaround. Thus, only radiometrically corrected data (Level 1) will be available from the archive. Other processing may be available from other sources. NASA will provide sample data sets for analysis. These data sets will facilitate your evaluation of present EO-1 capabilities and data.

EO-1 Instruments

The EO-1 mission includes three instruments: Advanced Land Imager (ALI), Hyperion and LEISA Atmospheric Corrector (LAC). ALI is an advanced multispectral instrument and Hyperion and LAC are hyperspectral instruments. A summary of the characteristics is given in the table below.

Parameters	EO-1		
	ALI	HYPERION	AC
Spectral Range	0.4 - 2.4 µm	0.4 - 2.5 µm	0.9 - 1.6 µm
Spatial Resolution	30 m	30 m	250 m
Swath Width	37 km	7.6 km	185 km
Spectral Resolution	Variable	10 nm	6 nm
Spectral Coverage	Discrete	Continuous	Continuous
Pan Band Resolution	10 m	N/A	N/A
Total Number of Bands	10	220	256

The instruments are mounted on the nadir deck and are boresighted with ALI and Hyperion on the eastern segment of the LAC swath. Background data on each of the instruments are provided in the balance of this section. More detailed information is available on the EO-1 website: http://eo1.gsfc.nasa.gov.

Advanced Land Imager (ALI) System Description

ALI is designed to produce images directly comparable to those of the Enhanced Thematic Mapper Plus (ETM+) of Landsat 7. Ultimately, it is anticipated that ALI support can establish data continuity with previous Landsats and demonstrate advanced capability and innovative approaches to future land imaging.

The ALI telescope is a reflective triplet design with a 12.5 cm unobscured aperture diameter and a field of view (FOV) of 15° by 1.256°. It employs reflecting optics throughout, to cover the fullest possible spectral range. The design uses four mirrors: the primary is an off-axis asphere, the secondary is an ellipsoid, and the tertiary is a concave sphere; the fourth mirror is a flat folding mirror (see below). This technology will enable the use of large detector arrays in the focal plane to cover the entire 185 km swath equivalent to Landsat in a "push broom" mode. The optical design features a flat focal plane and telecentric performance, which greatly simplifies the placement of the filter and detector array assemblies.

The design features silicon carbide mirrors and an Invar structure with appropriate mounting and attachment fittings. Silicon carbide has many favorable properties for space optical systems. It possesses high stiffness, high thermal conductivity, and low thermal expansion. Although it has been used for space optical elements previously, it has not been used for such large mirrors of this design.

For the EO-1 technology demonstration, a 3-degree FOV segment within the focal plane is populated with detectors. This gives a crosstrack coverage of 37 km. The intent is to provide adequate flight validation of the imaging technologies within the EO-1 program cost and schedule constraints. The multispectral/panchromatic (MS/Pan) array has 10 spectral bands in the visible/near infrared (VNIR) and short wave infrared (SWIR). The pan covers the visible portion of the VNIR spectrum and has a 10 m spatial resolution. The MS detectors have a 30 m ground resolution. Four sensor chip assembles (SCAs) make up the focal plane. For every MS band each SCA contains 320 detectors in the cross-track direction, while the pan band contains 960 detectors. The pan enhances spatial resolution and the multispectral enhances both the number of channels and signal to noise with respect to Landsat ETM.

The MS/Pan arrays use VNIR detectors integrated with the Readout Integrated Circuit (ROIC). The SWIR detectors made of mercury-cadmium-telluride (HgCdTe) promise high performance over the 900 to 2500 nm spectral region at temperatures that can be reached by passive or thermoelectric cooling. The nominal focal plane temperature is 220 K and is maintained by the use of a radiator. The spectral coverage is summarized below.

Band	**Wavelength (nm)**	MS-4	775-805
Pan	480-690	MS-4’	845-890
MS-1’	433-453	MS-5’	1200-1300
MS-1	450-515	MS-5	1550-1750
MS-2	525-605	MS-7	2080-2350
MS-3	630-690		

Summary of the ALI spectral coverage.

The Advanced Land Imager is demonstrating an innovative approach toward accurate radiometric calibration on orbit, using precisely controlled amounts of the incident solar irradiance. The solar calibration is performed using a controlled variable aperture and a Spectralon diffuser deployed in front of the secondary mirror. In addition, the in-flight calibration includes a three level internal source, lunar calibration and vicarious ground calibration.

Hyperion System Description

The Hyperion instrument provides high quality calibrated data that supports evaluation of hyperspectral technology for Earth observing missions. The Hyperion is a push broom instrument. Each “image” taken in this push broom configuration captures the spectrum of a line 30m long by 7.6 km wide (perpendicular to the satellite motion). Hyperion has a single telescope and two spectrometers, one visible/near infrared (VNIR) spectrometer and one short-wave infrared (SWIR) spectrometer. The Hyperion instrument consists of three physical units (a) the Hyperion Sensor Assembly (HSA); (b) the Hyperion Electronics Assembly (HEA); and (c) Cryocooler Electronics Assembly (CEA). The HSA includes the optical systems, cryocooler, in-flight calibration system and the high-speed focal plane electronics. The HEA contains the interface and control electronics for the instrument and the CEA controls cryocooler operation. These units are placed on the deck of the spacecraft with the viewing direction along the major axes of the spacecraft.

The Hyperion Sensor Assembly (HSA) includes the telescope, the two grating spectrometers and the supporting focal plane electronics and cooling system. The Hyperion telescope (foreoptics) is a three-mirror astigmat design. All of the mirrors in the system along with the structure holding the optical elements are constructed of aluminum so that the mirrors and housing all expand and contract at the same rates. This results in an athermal design over a limited temperature range. In operation, the housing will be maintained at $20^0 \pm 2^0$C for precision imaging and alignment.

The Hyperion telescope images the Earth onto a slit that defines the instantaneous field-of-view which is 0.624^0 wide (i.e., 7.6 km swath width from a 705 km altitude) by 42.55 μ radians (30 meters) in the satellite velocity direction. This slit image of the Earth is relayed at a magnification of 1.38:1 to two focal planes in the two grating imaging spectrometers. A dichroic filter in the system reflects the band from 400 to 1,000 nm to one-spectrometer and transmits the band from 900 to 2,500 nm to the other spectrometer. The SWIR overlap with the VNIR from 900 to 1000 nm allows cross calibration between the two spectrometers. Both spectrometers use a 3-reflector Offner optical configuration with a JPL convex grating.

The visible/near-infrared (VNIR) spectrometer has an array of 60 μm pixels created by aggregating 3x3 sub-arrays of a 20 μm CCD detector array. The VNIR spectrometer uses a 60 (spectral) by 256 (spatial) pixel array, which provides a 10nm spectral bandwidth over a range of 400-1000 nm. The short wave infrared (SWIR) spectrometer has 60 μm, HgCdTe detectors in an array of 160 (spectral) x 256 (spatial) channels. Similar to the VNIR, the SWIR spectral bandwidth is 10 nm. Thus, the spectral range of the instrument extends from approximately 400 to 2,500 nm with a spectral resolution of 10nm. The HgCdTe detectors in the SWIR spectrometer are cooled by an advanced TRW cryocooler and are maintained at 120 K during data collections.

A common calibration system is provided for both the VNIR and SWIR spectrometers. The solar calibration utilizes a diffuse reflector on the backside of the optical cover to provide uniform illumination across the focal plane arrays. The cover is set at a 37-degree angle and the spacecraft is oriented such that the sun enters the solar baffle normal to the earth viewing direction. Solar calibration data is used as the primary source for monitoring radiometric stability, with ground site (vicarious) and lunar imaging treated as secondary calibration data.

LEISA Atmospheric Corrector

The third EO-1 instrument is the LEISA Atmospheric Corrector (LAC). This is a compact instrument that measures the spectral region that is sensitive to atmospheric variations.

The LAC uses three 256 x 256 pixel InGaAs IR detector focal plane assemblies in a single module. Each array covers a five degree FOV to obtain a swath width of 185 km (15 degrees). A state-of-the-art wedged dielectric film etalon filter (linear variable etalon) is placed in very close proximity to a two-dimensional IR detector array. This produces a 2-D spatial image that varies in wavelength along one dimension. The filter is 1.024 cm x 1.024 cm and covers the 890 to 1600 nm spectral region at a resolution of 30 – 40 cm^{-1}, with a linear dependence of wave number on position. Reflective ¼-wave stacked layers placed on both sides of one, or more, ½-wave etalon cavity(s) provide the spectral resolution. Order sorting of the etalon is accomplished with lower resolution filter layers. In operation, the two-dimensional spatial image is formed by a small, wide field of view lens. Unlike the grating spectrometer that captures the spectra at a point "instantaneously", the spectrum for the LAC is obtained as the orbital motion of the spacecraft scans the image across the focal plane in wavelength, thereby creating a three-dimensional spectral map. The spatial resolution is determined by the spatial resolution of the imaging optic, the image scan speed, and the readout rate of the array. For the EO-1 application, the single pixel spatial resolution is 360 x 360 $\mu radian^2$ corresponding to a single pixel field of view of 250 m x 250 m (at nadir) from a 700 km orbit and a readout rate of approximately 30 Hz. Because the spatial resolution is relatively coarse (250 meters) and the wedge uses light efficiently, the optical system is compact. Counterbalancing this simplicity of design is the need to build up the spectral image over a series of frames. This puts increased requirements on the satellite attitude and control system. For LAC, this is not severe handicap due to large pixel size.

The LAC is intended to correct for water vapor variations using the information in the 890 to 1600 nm region and to detect cirrus clouds (through the 1380 nm channel). In addition to atmospheric monitoring, LAC will also image the Earth and provide an opportunity to test the wedge imaging spectrometer concept. The imaging data will be cross-referenced to the Hyperion data where the footprints overlap.

EO-1 Operations

EO-1 is in an orbit that provides for "formation flight" with Landsat 7, Terra and the Argentine SAC-C. This is a 705 km circular, sun-synchronous (polar) orbit at a 98.2 degree inclination. This orbit provides access to the entire surface of the earth. It also allows EO-1 to match the Landsat-7 ground track within one minute, and collect nearly identical images for later comparison on the ground.

EO-1 data collections are taken on approximately eight orbits per day. A data collection event (DCE) includes external image data and the internal calibrations needed to support them. The external image may be for application assessment or calibration.

Standard image sizes have been developed to facilitate data processing. For ALI, it is 37 km wide and 85 km long (in track). For Hyperion, an image is 7.5 km wide by 85 km long. For the Atmospheric Corrector, it is 180 km wide by 85 km long. The spacecraft is capable of a

22-degree roll angle (or more) and that permits viewing a Landsat swath adjacent to the ground track swath. With this side-look capability, a given target on the Earth's surface can be imaged up to 3 times during the 16-day orbital ground track repeat. In this case, the angles of observation would be different because of the spacecraft roll required.

Data from the instruments is stored on-board the spacecraft in a "WARP" solid-state recorder. The data is downlinked and transmitted to GSFC for Level 0 processing which includes removal of transmission artifacts and reordering of the data formats. These image data along with the flight data (housekeeping data) and ancillary data form a complete Level 0 data set. ALI data is radiometrically corrected and a Level 1 data set is created by GSFC. The Hyperion data is transmitted to TRW for assessment and Level 1 processing. Radiometric calibration formats the image and applies a radiometric calibration based on coefficients derived from both laboratory and on-orbit calibration data. The ancillary data is converted into engineering units to facilitate their later use. The different data types (image, metadata and ancillary data) are then combined into a standard data set and subject to a quality assessment. These Level 1 data are the products available to the user during the extended mission.

Draft Assumptions:

It is NASA's intent in facilitating the extended mission to maintain the technology validation nature of EO-1. Thus, collaborators are expected to provide feedback to NASA on the benefits and limitations in using EO-1 data. Access to EO-1 for the broader user community will be on the basis of a Space Act Agreement with NASA.

Use the following assumptions to guide your response to the tasking questionnaire. These assumptions may be changed as NASA develops the final EO-1 operational, data, and pricing policies. The final policies will be made available (along with the sample data sets) before you will be asked to place any firm orders. If you would like to recommend changes in the assumptions below, please do so, along with the rationale for your recommendation, in the comments section of the questionnaire itself.

Draft Operational Assumptions:

1. Opportunities for tasking are open to all parties. The Extended Mission will end about September 30, 2002 or until NASA terminates EO-1 operations, whichever occurs first.

2. The EO-1 orbit is currently one minute behind Landsat 7 and covers the same path/row system and 16-day cycle. Users may therefore refer to the Landsat 7 scheduling to make a date selection for EO-1 images. Landsat 7 scheduling is available at http://landsat7.usgs.gov.

   EDC will post new schedules and conditions on the Landsat 7 web site in the event of Landsat 7 orbit changes or other factors that may impact the user.

3. General EO-1 information can be obtained from the EO-1 website at http://eo1.gsfc.nasa.gov. New information is added periodically.

Draft Data Policies:

There are generally two broad types of data products: (1) EO-1-generated image products and (2) reports on the findings of NASA's and the collaborator's investigation.

1. A technical panel will coordinate and establish tasking priorities. More concrete data policies and priorities will be available prior to negotiating a final tasking agreement.

2. Image products: In general, it is contemplated that all images taken under collaboration will become public when delivered by NASA to the archive. Delivery to the archive will occur immediately upon image creation unless the collaborator and NASA agreed to a period of exclusive use. The collaborator may request a period of exclusive use of the image data for up to 6 months. NASA must agree to this period of exclusive use in advance. During the time period of exclusive use both NASA and the collaborator may only use the imaging data for research and/or analysis purposes as part of each party's own internal scientific investigation. At the end of the period of exclusive use, NASA will release the imaging data to the archive at which time it will become available to the public.

3. Reports: Collaborators will be expected to provide feedback to NASA on the benefits and limitations in using the EO-1 image products exchanged under the collaboration. Therefore, it is contemplated that the collaborator will furnish NASA with a report by its principal investigator describing the results of its internal investigation by 120 days after receipt of EO-1 data. These reports will form part of the results of the EO-1 mission and will become public. Also, NASA agrees to honor any requests to withhold attribution for any images or reports generated under this agreement upon request. Unless otherwise agreed, NASA intends to publicly report its own findings at any time during the collaboration.

4. Data products will be Level 1 products covering a standard ground surface area as indicated in paragraph 5 below. Data product latency from time of collection will be 5-15 days. The latency is dependent on the downlink site selected by the mission operations team.

5. Any scene area may be ordered by providing the central location. The size of an ALI image is approximately 37 km wide x 85 km long (3145 sq km). The size of a Hyperion image is approximately 7.5 km wide x 85 km long (638 sq km). For the Atmospheric Corrector, it is 180 km wide by 85 km long.

6. EO-1's mission is to flight validate new technologies. The instruments are technology demonstration items. While early EO-1 data has met all expectations, users should not expect these instruments to produce images over large surface areas with the same consistency as an operational system (e.g. Landsat-7). Users can evaluate EO-1 data products by viewing analysis results on the EO-1 website

    - http://eo1.gsfc.nasa.gov

   or by viewing data samples that will be provided.

Draft Reimbursable Agreement:

1. Applicants should assume reimbursable levels similar to those stated in this section. NASA is preparing final reimbursement levels at this time and will discuss these with applicants individually at the time of formal agreements preparation.

2. There will be separate reimbursements for systems tasking and data processing.

3. For the tasking, reimbursement is on a per instrument basis. A tasking request may be for Hyperion, ALI, AC or any combination thereof. Although the reimbursements have not been fixed yet, for the purposes of this research questionnaire, assume that the reimbursement for a one instrument tasking request is $1500. The reimbursements for simultaneous instrument participation in a collect during a single DCE are (a) $1800 for two instruments and (b) $2000 for three instruments.

4. For data processing, the reimbursement to process collected data to Level 1 is estimated $500 per instrument per tasking request and will be in addition to the tasking request reimbursement in paragraph 3 above. For data already in the archive, reimbursement is estimated at $500 per instrument for each image ordered.

5. For high priority tasking on short notice, a supplemental reimbursement of $1000 would be added to the total reimbursement.

6. If a requestor asks that NASA delay data insertion into the archive for a period of 6 months, a supplement amount of $500 will be added to the requestor's total reimbursement.

7. Block orders will be given a 5% discount to the total order expense for an order of 10 scenes or more, a 10% discount to the total order expense for an order of 30 scenes or more, and 20% for 100 scenes or more.

8. Each tasking reimbursement, including block orders, must be submitted to NASA once NASA has scheduled the site for imaging. Once a task has been scheduled users accept all weather/cloud obscuration risks. Selected weather risk information is available for user assessment from EDC as part of the Landsat 7 LTAP. This LTAP is not part of the EO-1 operations program, but NASA will try to avoid cloud areas if possible during task planning and acquisition.

9. If satellite operations eliminate the possibility of fulfilling the orders over the duration of the extended mission, no reimbursement of tasking expenses will be required.