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# Commercial Potential of Remote Sensing Data from the Earth Observing System

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**National Aeronautics and Space Administration**
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## TABLE OF CONTENTS



## LIST OF TABLES



## LIST OF FIGURES

# COMMERCIAL POTENTIAL OF REMOTE SENSING DATA FROM THE EARTH OBSERVING SYSTEM (EOS) PLATFORM

by

Carolyn J. Merry and Sandra M. Tomlin

## EXECUTIVE SUMMARY

The National Aeronautics and Space Administration (NASA) recognizes that the Earth Observing System (EOS) data will have commercial potential and have worked towards a goal of ensuring full and open access to EOS data by all types of users (D. Butler 1991, pers. comm.). NASA will be developing a procedure, consistent with Public Law 98-365 and other appropriate legislation, to distribute the data on a commercial basis to non-research/non-operational users of the data (Maiden and Butler 1991). Therefore, the purpose of this project was to assess the market potential of remote sensing value-added products from the EOS platform. Sensors on the EOS platform were evaluated to determine which qualities and capabilities would be useful to the commercial user. In addition, this study was undertaken because commercial market potential of the EOS program has not been addressed in the past.

Our approach was to first investigate past and future satellite data distribution programs, such as from the Large Format Camera (LFC) and Sea Wide Field Sensor (Sea-WiFS) instruments. We developed a questionnaire to use in a telephone survey. The list of U.S. remote sensing value-added companies was compiled based on several sources. The questionnaire was designed to obtain information regarding the following:

- existing and future market for satellite data products and services
- applications for using satellite data
- problems with using satellite data
- willingness to pay for satellite data
- attitudes with respect to the commercialization of EOS data

The companies that we contacted add *value* to remotely sensed data, either by providing technical consulting services or by enhancing the original raw data. Most of the firms are service-oriented in that they provide consulting services, in addition to providing a value-added remote sensing product. The remaining companies are oriented to providing a value-added product only. Responses to our survey are summarized and presented. We also talked with the principal investigators in charge of each EOS sensor to discuss commercial opportunities of that sensor.

Based on the results of our survey and conversations with the principal investigators for the EOS sensors, a study of past commercial satellite data

ventures, and readings from the commercial remote sensing industry literature, we developed three recommendations from our study. They are:

- develop a strategic plan for commercialization of EOS data
- define a procedure for commercial users within the EOS data stream
- develop an Earth Observations Commercial Applications Program (EOCAP)-like demonstration program within NASA using EOS-simulated data

A strong commitment by NASA to support commercialization of the EOS data has to be stated. Also, timing is critical because of the impact that pending legislation (H.R. 3614) may have on the pricing policy of U.S. satellite data.

We recommend that a committee, starting with a workshop format, be established to address the subject of developing a strategic plan to commercialize the EOS data. The results from our study strongly suggests that *there is commercial potential* for data from several of the instruments, most notably the ASTER, HIRIS, SAR, and MODIS sensors. We need to objectively analyze, or perform an *autopsy,* of past commercialization efforts to recommend a commercialization structure for the upcoming EOS data. We need to determine why past commercial ventures did not work and avoid repeating their mistakes in future commercialization efforts.

We recommend three ways for the commercial user to acquire EOS data: through the Direct Broadcast and Downlink systems, through the Distributed Active Archive Centers (DAACs), or through the EOS Science Network. Operational and forecasting commercial users would require EOS data using the Direct Broadcast and Downlink systems. For these types of users, real-time data are necessary and thus they would need the most expedient method possible to receive their data. Agricultural users require processed EOS data within 48 hours for operational use of remote sensing data and thus we recommend the DAAC route for them. For strategic planning purposes, agricultural and forestry applications require a one-week delivery time and for the environmental market, a delivery period of one month is adequate. Thus, for this last group of commercial users and any other users that do not need EOS data in real-time, we recommend that they best acquire their data from the DAACs or the EOS Science Network.

We strongly feel that there will be additional applications for the EOS data by the late 1990's. The KRS Remote Sensing study for an advanced civil remote sensing system highlighted several areas for using remote sensing data. For example, global interest areas include renewable/nonrenewable resource management, ocean and coastal waterway analysis, Geographic Information Systems (GISs), geological studies, weather analysis, environment assessment, and public information. Also, there should be more applications of the Synthetic Aperture Radar (SAR) data because of the new satellites (European Remote Sensing Satellite-1 [ERS-1] launched July 1991, Japanese First Earth Resources Satellite-2

[J-ERS-1], and Radarsat) being launched in the near future (early to mid 1990s). These satellites will be providing passive microwave data to principally observe and monitor the oceans and polar ice caps. However, active radar data will also be obtained for land and water areas. These spaceborne SARs are capable of receiving data at a variety of wavelengths and with different combinations of transmitted and received polarizations, spatial resolutions and incidence angles. Thus, research in the 1990's will concentrate on understanding the SAR data for many application areas such as mapping geological features, topographic structure, land use, agriculture and forestry, in disaster prevention, and for monitoring soil moisture, coastal areas, ocean currents, bathymetric patterns, ice conditions, and wave phenomena.

## PURPOSE

Over the last decade, problems in earth science have emerged that require a multidisciplinary approach to solve. Scientific examples requiring expertise from many different disciplines include the increase in atmospheric carbon dioxide, the anticipated depletion of the ozone layer, El Nino-related modifications to weather patterns, and acid precipitation (NASA 1984). Observation capabilities are needed to address these problems, ranging from detailed in-situ and laboratory measurements to the global perspective offered by satellite remote sensing. With a clear recognition that satellite-obtained data must be used in concert with data from more conventional techniques, the National Aeronautics and Space Administration (NASA) has planned for future missions of space observations.

The U.S. Earth Observing System (EOS) data policy, as of May 1991, will make the satellite standard data products available to all researchers at the cost of reproduction within 46 to 96 hours of observation, depending on the level of processing (NASA 1991a). Also, raw data from EOS operational instruments will be made available to the National Oceanic and Atmospheric Administration (NOAA) at the point of ground reception of the data. The "EOS data and products will be available to all users; there will be no period of exclusive access" (NASA 1991a, p. 18). Procedures have not yet been developed for distributing EOS data to commercial users, but they will certainly exist before the scheduled launch of EOS-A.

NASA recognizes that EOS data will have commercial potential and has worked towards a goal of ensuring full and open access to EOS data by all types of users (D. Butler 1991, pers. comm.). NASA will be developing a procedure, consistent with Public Law 98-365 and other appropriate legislation, to distribute the data on a commercial basis to non-research/non-operational users of the data (Maiden and Butler 1991). Therefore, the purpose of this project was to assess the market potential of remote sensing value-added products from the EOS platform. Sensors on the EOS platform were evaluated to determine which qualities and capabilities would be useful to the commercial user. In addition, this study was undertaken because commercial market potential of the EOS program has not been addressed in the past.

Our approach was to first investigate past and future satellite data distribution programs, such as from the Large Format Camera (LFC) and Sea Wide Field Sensor (Sea-WiFS) instruments. We wanted to gain an insight on how these past ventures succeeded or failed. Next, we developed a questionnaire to use in a telephone survey and contacted value-added companies that market remote sensing data. The survey included questions relating to products currently on the market, future market possibilities, cost sensitivity, distribution, and potential applications of EOS data. The conversations are summarized and presented. We also talked with the principal investigators in charge of each EOS sensor to discuss commercial opportunities of that sensor. Last, we make recommendations to address the commercial opportunities of EOS data.

## THE EOS PROGRAM

EOS, the centerpiece of NASA's Mission to Planet Earth, has been designed to study the interactions of the atmosphere, land, oceans, and living organisms, using the perspective of space to observe the Earth as a global environmental system (NASA 1991a). EOS is an information system mission that includes new sensors in a low Earth orbit and a data system to serve the needs of an integrated, multidisciplinary study of the planet. EOS is to provide data for a minimum of 15 years to study global change and other related research issues through flights of polar-orbiting platforms.

The U.S. Global Change Research Program (GCRP) involves nine federal governmental units, including NASA, National Science Foundation (NSF), Department of Commerce/National Oceanic and Atmospheric Administration (NOAA), Department of the Interior (DOI), U.S. Department of Agriculture (USDA), Environmental Protection Agency (EPA), Department of Energy (DOE), Smithsonian Institution, and the Department of Defense (DoD). The goal of the GCRP program "is to gain a predictive understanding of the interactive physical, geological, chemical, biological, and social processes that regulate the total Earth system" (NASA 1991a, p. 5). "EOS is NASA's major contribution to the U.S. GCRP, serving as the cornerstone of a long-term program to document global change" (NASA 1991a, p. 5). The nature of the global change research effort requires extensive international cooperation and the GCRP is linked to the International Geosphere-Biosphere Program, the Intergovernmental Panel on Climate Change and the World Climate Research Program (NASA 1991a). Also, the EOS program involves the cooperation of the United States, the European Space Agency (ESA), and the Japanese National Space Development Agency (NASDA).

Initially, EOS-A (and EOS-B) was to consist of a large polar-orbiting platform containing 11 to 15 instruments. However, during the summer of 1991 the Engineering Review Committee and Congress recommended that NASA re-examine its program (Frieman 1991). The EOS Payload Advisory Panel, composed of EOS interdisciplinary investigators, met at a workshop 21-24 October 1991 to respond to directions from the EOS Engineering Review Committee and Congress. EOS has now been restructured "to address high-priority science and environmental policy issues in Earth system science" (Moore and others 1991, p. 505). EOS will still be collecting observations over a 15-year period, but "many important measurements are cancelled, deferred, or proposed for provision by international partners" (Moore and others 1991, p. 505). The global measurements will be obtained from international or domestic instruments that may be less capable than the EOS instruments originally proposed.

The EOS instruments recommended for flight are shown in Tables 1 and 2. The strategy used by NASA is to combine high-priority, new measurements and to continue critical data sets started by missions that preceded EOS (Moore and others 1991). A brief instrument description is included in Table 3. A technical description of these instruments is provided in Appendix A. We focused on these instruments for our study of the commercial potential of EOS data products.

To implement this suite of EOS instruments, the panel "recommends a set of similar, moderate-sized platforms, a suite of Earth Probes and additional free flyers, and an essential dependence on international instruments and platforms for which definitive commitments should be sought" (Moore and others 1991, p. 505). The instruments shown in Tables 1 and 2 focus on key scientific questions on water and energy cycles, oceans, tropospheric chemistry, land-surface hydrology/ecology, ice sheets and glaciers, stratospheric chemistry, and solid earth. Additional details on the latest recommendations for the EOS program can be found in Moore and others (1991).

The various levels of data processing for the EOS data products are shown in Table 4. For some instruments there is not a level 1B product distinct from the level 1A product, therefore, references to a level 1B product are assumed to refer to level 1A data (NASA 1991a). Level 3 products are derived geophysical parameters and include maps of ocean chlorophyll, sea surface temperature, land surface temperature, fire locations, cloud cover, vegetation index, vegetation type, biomass, atmospheric temperature and humidity profiles, net energy balance, total ozone, precipitation rate, snow cover and water content, and many others (Thompson 1990). There are also level 4 products, which are principally unique data products, that are a result of research and development by EOS participating scientists when testing new ideas and algorithms on the EOS data sets. A list of over 3,000 data products from the EOS program has been proposed (Thompson 1990). This list will be reduced to a manageable level in the order of hundreds of products by the summer of 1992 (L. Thompson 1991, pers. comm.). The level 3 and 4 products provide the types of information that commercial companies can market, since they are the result of value-added processing.

The preliminary design of the EOS Data and Information System (EOSDIS) architecture is shown in Figure 1. The EOS data will be downlinked via the Tracking and Data Relay Satellite System (TDRSS) to EOSDIS. The Direct Broadcast and Downlink systems can support transmission to ground stations for users requiring direct data reception. Presently, there are three classes of users defined by NASA: EOS team participants and scientists requiring real-time data to support experiments, international meteorological and environmental agencies requiring real-time measurements of the earth, and international partners requiring high volume data receipt from their EOS instruments. This part of EOSDIS would be an opportune place to add in a fourth class of user for direct data reception–the commercial user.

**TABLE 1 Recommended EOS instruments for the early period (1997-2001) (modified from Moore and others, 1991)**

| INSTRUMENT | COUNTRY DEVELOPING INSTRUMENT, COMMENTS |
|---|---|
| ACRIM[1] | U.S., no orbital requirement other than solar viewing |
| AIRS[1] | U.S., AIRS, AMSU-A and MHS[2] are a synergistic package that should fly on same platform |
| AMSU-A[1] | U.S. |
| ASTER[1] | Japan |
| CERES[1] | U.S., on multiple satellites in morning, afternoon, and inclined orbit |
| EOSP[1] | U.S., subject to review by EOS Atmospheres Panel |
| HiRDLS[1] | U.S./U.K. |
| LIS[1] | U.S. |
| MHS[1] | Eumetsat |
| MIMR[1] | European Space Agency |
| MISR[1] | U.S. |
| MODIS-N[2] | U.S., in both morning and afternoon orbit |
| MOPITT[2] | Canada |
| NSCAT-2[3] or STIKSCAT[1] | U.S., needed for continuity of NSCAT-1 data on ADEOS[4] which start in 1995 |
| SAGE[5] | U.S., in both sun-synchronous and inclined orbit |
| SeaWiFS | U.S., continuation of 1993 mission until launch of second MODIS-N |
| TOPEX[6]/Poseidon-2 | France/U.S., continuation of 1992 mission needed to avoid data gap |
| Assumptions: | |
| GLI[7] | on ADEOS-2 (Japan) |
| MERIS[8] | on POEM-1[9] (European Space Agency) |

[1]See instrument description in Appendix A
[2]Microwave Humidity Sounder
[3]NASA Scatterometer
[4]Advanced Earth Observing System
[5]Stratospheric Aerosol and Gas Experiment
[6]Ocean Topographic Experiment
[7]Global Imager
[8]Medium-Resolution Imaging Spectometer
[9]Polar-Orbit Earth Observation Mission

**TABLE 2 Recommended new EOS instruments for the period beyond year 2001 (after Moore and others, 1991)**

| INSTRUMENT | COUNTRY DEVELOPING INSTRUMENT, COMMENTS |
|---|---|
| ALT[1] | U.S./Europe, requirement needs to be reviewed in light of other ocean altimeters |
| GGI[2] | U.S. |
| GLRS-A[3] | U.S. |
| HIRIS[1] | U.S. |
| LAWS[4] | U.S./international, requires separate platform and adequate funding from international or domestic partner |
| MLS[5] | U.S., possible future selection |
| MODIS-T[1] | U.S., needed if GLI[6] and MERIS do not meet adequate levels of performance for measurement of ocean biota |
| SAFIRE[7] | U.S., possible future selection |
| SAR[1] | U.S./international, requires separate platform, Congressional new start and adequate funding from international or domestic partner |
| SOLSTICE[8] | U.S., no orbital requirement other than solar viewing |
| TES[9] | U.S. |

[1]See instrument description in Appendix A
[2]GPS Geoscience Instrument
[3]Geoscience Laser Ranging System
[4]Laser Atmospheric Wind Sounder
[5]Microwave Limb Sounder
[6]Global Imager
[7]Spectroscopy of the Atmosphere using Far Infrared Emission
[8]Solar Stellar Irradiance Comparison Experiment
[9]Tropospheric Emission Spectrometer

The Direct Broadcast system uses a continuous data stream rate of 15 Mbps from the following instruments: AIRS/AMSU-A/MHS, STIKSCAT, MIMR and MODIS-N. Relatively low-cost ground stations can be configured to receive, process and display the swath data from the instrument received for areas within the range of a ground antenna (NASA 1991a).

The Direct Downlink system supports an intermittent data stream rate of 115 Mbps for international partners requiring high data rate transmission. ASTER and HIRIS data will be transmitted in this mode. A large ground antenna and

**TABLE 3** **Summary of the scientific purpose for the 15 instruments proposed for the EOS platform (from NASA 1990).**

| INSTRUMENT | PURPOSE OF INSTRUMENT |
|---|---|
| ACRIM | Three total irradiance detectors to monitor the variability of total solar radiance. |
| AIRS | Atmospheric infrared sounder to measure the Earth's outgoing radiation between 3-17μm. |
| AMSU-A/-B | Microwave radiometer for measuring atmospheric temperature from the surface up to 40 km (-A) and atmospheric water vapor profile measurements (-B). |
| ASTER | Imaging radiometer to provide high spatial resolution images and with multispectral channels from visible to thermal infrared for providing baseline data sets and for studying geomorphology through stereo data acquisition. |
| CERES | Two broadband, scanning radiometers to measure the Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface. |
| EOSP | Cross-track scanning polarimeter to globally map radiance and linear polarization of reflected and scattered sunlight for 12 spectral bands from 0.41-2.2 μm. |
| EOS SAR | Three-frequency (L-, C- and X-band), multi-polarization imaging radar to monitor global deforestation, soil, snow, and canopy moisture and flood inundation, and sea ice properties. |
| HiRDLS | Infrared limb scanning radiometer to observe global distribution of temperature and concentrations of ozone, water, methane, nitrous oxide, nitric acid, dinitrogen pentoxide, nitrogen dioxide, chlorofluorocarbons, and aerosols in the upper troposphere, stratosphere, and mesosphere. |
| HIRIS | Imaging spectrometer to provide high spectral and spatial resolution images of the Earth, can sample any point on the Earth's surface a minimum of every two days. |
| LIS | Staring telescope/filter imaging system to acquire and investigate the distribution and variability of lightning over the Earth. |
| MIMR | Microwave radiometer to provide global observations on hydrologic parameters. |
| MISR | Imaging spectroradiometer to obtain continuous multi-angle imagery of the Earth through eight separate CCD-based pushbroom cameras to provide top-of-atmosphere, cloud and surface angular reflectance functions and global maps of planetary and surface albedo, and aerosol and vegetation properties. |
| MOPITT | Four-channel correlation spectrometer with cross-track scanning to measure carbon *monoxide concentrations in the troposphere.* |
| MODIS-N/T | Imaging spectrometer to measure biological and physical processes on a 1-km scale with emphasis on the study of ocean primary productivity. |
| STIKSCAT | Six stick fan-beam scatterometer to acquire all-weather measurements of surface wind speed and direction over the global oceans. |

| TABLE 4 | EOS data level definitions (modified from NASA 1991a) |
|---|---|
| **LEVEL** | **DATA DESCRIPTION** |
| 0 | Reconstructed unprocessed instrument/payload data at full resolution. |
| 1A | Reconstructed unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (i.e., platform ephemeris) computed and appended, but not applied, to the level 0 data. |
| 1B | Level 1A data that have been processed to sensor units (not all instruments will have a level 1B equivalent). |
| 2 | Derived environmental variables at the same resolution and location as the level 1 source data. |
| 3 | Variables mapped on uniform space-time grid scales, usually with some completeness and consistency. |
| 4 | Model output or results from analyses of lower level data (i.e., variables derived from multiple measurements). |

high-volume data processing using X-band facilities (similar to the Landsat and Satellite Pour l'Observation de la Terre [SPOT] ground receiving stations) are required.

Data products will be distributed through EOSDIS, as sketched in Figure 1. The System Management Center (SMC) and the EOS Operations Center (EOC) will be located at the Goddard Space Flight Center (GSFC). The Instrument Control Facilities (ICFs) will be located at GSFC and the Jet Propulsion Laboratory (JPL). The Product Generation System (PGS), the Data Archive and Distribution System (DADS) and the Information Management System (IMS) functions will be located together to form Distributed Active Archive Centers (DAACs). The DAACs are based on their scientific discipline and their prior research expertise. The proposed distribution of DAACs are shown in Table 5. These DAACs would provide another means for commercial users to obtain EOS data.

A third place for commercial users to obtain EOS data is through the EOS Science Network, shown on the left side of Figure 1. The commerical users could obtain their products through the "Other Users" part of the diagram.

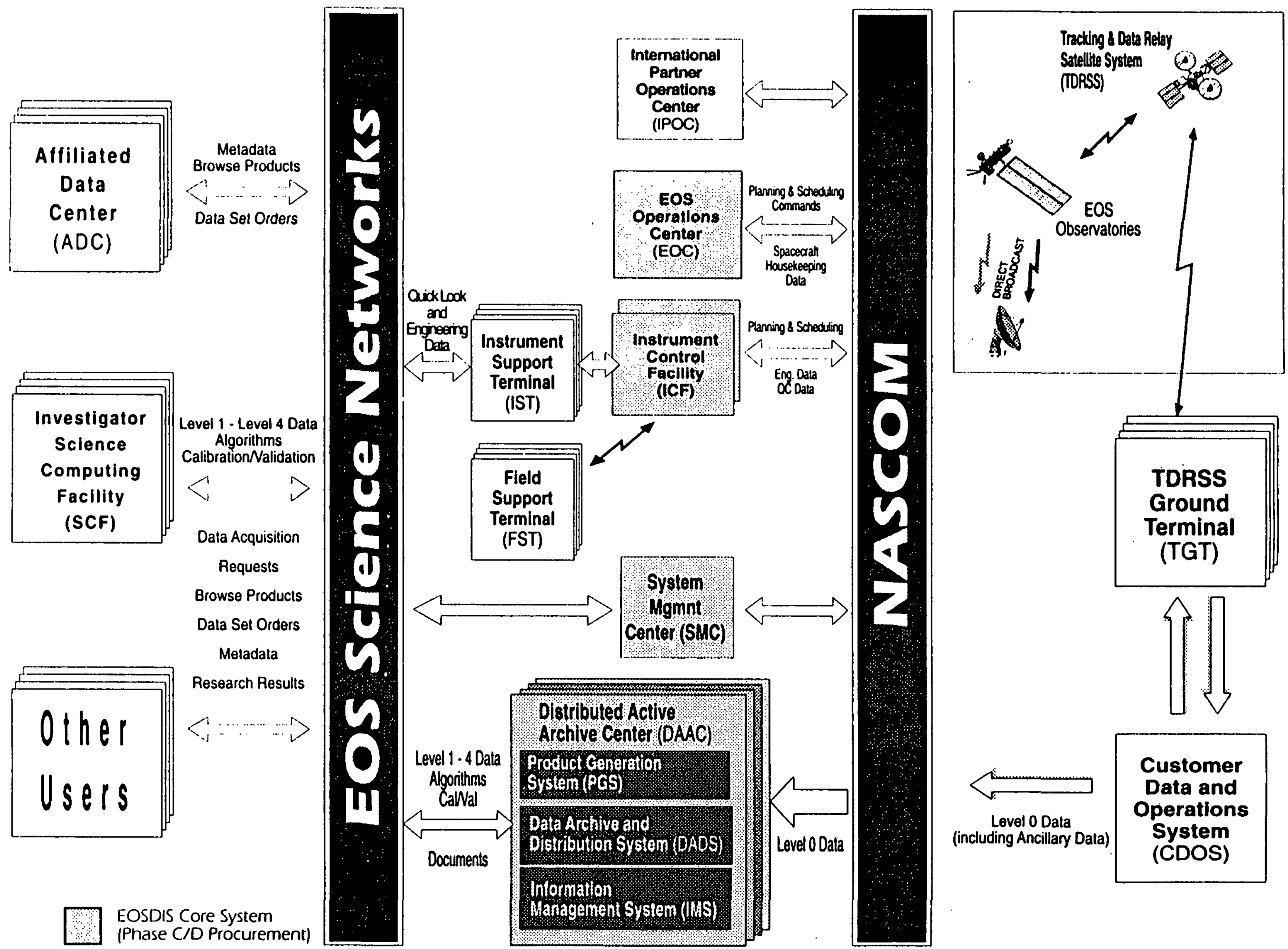


Figure 1. EOSDIS architecture (from NASA 1991a)

**TABLE 5 Proposed distribution of DAACs (modified from NASA 1991a)**

| Discipline | Location | Prior Experience |
|---|---|---|
| Upper atmosphere, atmospheric dynamics, global biosphere, geophysics | Jet Propulsion Laboratory | UARS[1], atmospheric sounding and tropospheric moisture sensing, CZCS[2], AVHRR[3] |
| Ocean circulation, air-sea interaction | Jet Propulsion Laboratory | Seasat, TOPEX, NSCAT, SSM/I[4], NODS[5] |
| Radiation budget, aerosols, tropospheric chemistry | Langley Research Center | ERBE[6], SAGE |
| Cryosphere (non-SAR) | University of Colorado | SMMR[7], SSM/I |
| Land processes imagery | EROS Data Center | Landsat, AVHRR |
| Sea ice, polar processes imagery | University of Alaska, Fairbanks | Alaska SAR facility |
| Hydrology | Marshall Space Flight Center | WetNet |

[1]Upper Atmosphere Research Satellite
[2]Coastal Zone Color Scanner
[3]Advanced Very High Resolution Radiometer
[4]Special Sensor Microwave/Images
[5]NASA Ocean Data System
[6]Earth Radiation Budget Experiment
[7]Scanning Multispectral Microwave Radiometer

Thus, we envision three ways that the commercial user would have potential access to the EOS data: the direct broadcast route, through a DAAC, or the EOS Science Network. There are no technical barriers to restrict any one of these routes for commercial access to the data.

International access to the EOS data base is also being developed. "A detailed data policy is being developed by NASA and its Earth Observations International Coordination Working Group (EO-ICWG) partners to ensure that data from the entire suite of satellites comprising the International Earth Observing System (IEOS) will be available to all users on a consistent and fair basis through any of the partner agencies. Different arrangements are foreseen depending on the type of user." (NASA 1991a, pp. 18-19)

## PAST COMMERCIALIZATION EFFORTS

Below, we have summarized the Land Remote-Sensing Commercialization Act of 1984, since it applies to U.S. data distribution policies. There have also been other efforts within NASA to commercialize satellite data. These include the Large Format Camera (LFC) and the Sea Wide Field Sensor (Sea-WiFS) programs. We investigated these two programs to evaluate past efforts for commercializing remote sensing data.

### Land Remote-Sensing Commercialization Act of 1984

The Land Remote-Sensing Commercialization Act of 1984 (Public Law 98-365) was established to commercialize the Landsat satellite system. Ownership and operation of the system was passed from the U.S. Government to a private company, Earth Observation Satellite Company (EOSAT). The Act was designed to adhere to the U.S. policy of providing non-discriminatory access to unenhanced data. The Act prohibits the private company from enhancing the data or producing a "value-added" product for sale. EOSAT only provides unenhanced or raw data from Landsat sensors to customers.

Also, this Act provides insufficient pricing flexibility to induce commerical companies to deliver remote sensing data products and services that customers want. Thus we feel that the Act is an unsuitable template to use for the EOS program.

In a related development, Rep. George Brown introduced the Land Remote Sensing Policy Act of 1991 (H.R. 3614) in October 1991. The present form of H.R. 3614 would establish an expedited procurement process to begin construction of Landsat-7, shift the Landsat program oversight from NOAA to a NASA-DoD Joint Program Office (JPO) and establish a two-tiered pricing structure favoring government agencies and non-profit entities in the United States (EOSAT 1991). The bill is expected to be marked up by the House Science, Space and Technology Committee in late February and reach the House floor in March or April, 1992.

"Representatives from the remote sensing industry urged the Committee to avoid settling up a two-tiered pricing structure that would give non-profit researchers an unfair advantage over the value-added industry. The witnesses instead suggested alternative means of making Landsat data available to environmental researchers, such as data grant programs administered by NASA." (EOSAT 1991, p. 1). If the bill passes in its present form, it would probably set precedence for developing pricing policies with the upcoming EOS data.

A study of commercial potential for a high-resolution satellite mapping system examined the issue of commercial viability. Legislation and regulatory issues were examined and interviews were conducted with administrative officials and congressional staff. For example, the House Space Science and Technology Committee "implied that changes to the Landsat Act that support commercial ventures would be entertained only if a commitment is demonstrated to carry out that venture" (KPMG Peat Marwick, 1992, p. 33). Thus, a strong commitment from NASA to support commercialization of EOS data should be in place. The "Senate staff understand nondiscriminatory issue's effect on commercial activity and seem willing to discuss options for modifying the act" (KPMG Peat Marwick, 1992, p. 34). The Department of State representatives "appear to be conditioned to avoid any tampering with the Landsat Act's nondiscriminatory principle..." but "appeared open to discussion of serious proposals" (KPMG Peat Marwick, 1992, p. 34). The Department of Commerce (Commercial Space Office) and the National Space Council were generally supportive of a commercial remote sensing satellite. From their interviews, KPMG Peat Marwick stated that "timing, however, is becoming more important because the farther down the road policy and legislation go, the more difficult it will be to effectively change them" (KPMG Peat Marwick, 1992, p. 34). Thus, we believe the commercialization issue of EOS data needs to be addressed in the very near future.

**Large Format Camera**

The LFC was developed by NASA to demonstrate the feasibility of taking high-resolution photographs from space that could be viewed in stereo (General Accounting Office 1990). The camera was designed to support 1:50,000-scale planimetric and topographic mapping with a minimum of ground control (Doyle 1985).

In 1985, NASA worked out an agreement with Martel Laboratories, Inc. to sell copies of the camera's flight imagery to U.S. private users. This was done under section 503 of the Land Remote-Sensing Commercialization Act of 1984, which "stipulates that data gathered from U.S. space programs may be sold commercially on a nondiscriminatory basis to interested commercial and private users" (General Accounting Office 1990, p. 16). Under this agreement, Martel Laboratories, Inc. paid NASA $100 for a copy of the imagery that was taken by the LFC during the October 1984 Shuttle mission and agreed to spend $35,000 to promote and market the imagery. For the next three years, Martel Laboratories, Inc. reported commercial sales losses of over $60,000 (General Accounting Office 1990). The agreement expired in November 1988.

During 1985 and 1986 NASA awarded contracts to Autometric, Inc. to explore applications and commercialization options of the LFC (General Accounting Office 1990). Their studies showed that there was a potential commercial market, but the studies did not address the cost-effectiveness of flying the LFC on shuttle missions or industry's potential to recover these costs from the sales of the LFC imagery. In 1987 NASA held discussions with private companies on commercializing the LFC, however, the companies lost interest when advised of the $20 million-per-flight cost to use the camera on the shuttle (General Accounting Office 1990). A group of companies proposed that the LFC be used on NASA's Earth Resources Research (ER-2) aircraft, but NASA has not taken any action to do so (General Accounting Office 1990).

NASA suggested that "Martel Laboratories had only made a cursory effort to market the LFC flight film" (General Accounting Office 1990, p. 16). However, section 502 of P.L. 98-365 allows all remote-sensing data gathered from U.S. space programs be made available to federally-funded researchers. Thus the LFC data were available at the EROS Data Center and researchers could get the data at a lower cost. Martel Laboratories believed that their commercial market was undermined by the LFC data being available at the EROS Data Center to researchers.

The commercialization of LFC data failed, most probably because of the distribution system. Thus, the model implied by this scenario would not be appropriate to apply to EOS commercialization.

**Sea Wide Field Sensor**

The Sea-WiFS was originally scheduled for the Landsat-6 mission. The sensor was designed to incorporate the requirements of commercial, operational and research users to provide ocean color and sea surface temperature data (EOSAT 1987). The sensor resolution is 1.13 km (the local area coverage [LAC] mode) and a second data stream is provided at a 4.5 km resolution (the global area coverage [GAC] mode) for a 2,800 km swath. The Sea-WiFS instrument contains visible and near infrared bands to use in measuring chlorophyll, pigment concentration, water optical properties, and suspended sediment. Two long wavelength infrared bands provide information on sea surface temperature to a few tenths of a degree Kelvin.

Orbital Sciences Corporation and Hughes Santa Barbara Research Center have teamed together to propose selling the Sea-WiFS data to NASA (Space Business News 1990). NASA has recently awarded the contract to them. This is an atypical situation within NASA, since they are purchasing the Sea-WiFS data from a commercial venture to provide to its research community. Normally, NASA handles the raw satellite data distribution in-house.

We will need to watch developments with the Sea-WiFS data distribution program over the next few years to determine if this is an efficient and effective way to distribute raw satellite data.

In a related project, Systems West, Inc. had proposed to work with NASA to obtain their SeaWiFS data in real-time onboard a ship to provide ocean color maps to fishing vessels. However, NASA's data transmission rate was extremely high (about 780 kilobits/sec). Systems West, Inc. design of a PC-based ground receiver on the ship could not handle the high data transmission rate.

## APPROACH TO OUR SURVEY

We conducted a survey of companies that use existing remote sensing data to determine what commercial markets and applications are presently available. These companies would presumably be familiar with the EOS program and would most likely use remote sensing data from the EOS sensors.

An initial list of U.S. remote sensing value-added companies (68) was compiled based on several sources (for example, see EOSAT 1990). Our criteria was that these companies add *value* to remotely sensed data, either by providing technical consulting services or by enhancing the original raw data. Most of these firms are service-oriented in that they provide consulting services, in addition to providing a value-added remote sensing product. The remaining companies are oriented to providing a value-added product only.

A questionnaire was designed to obtain information by telephone survey regarding the following:

- existing and future market for satellite data products and services
- applications for using satellite data
- problems with using satellite data
- willingness to pay for satellite data
- attitudes with respect to the commercialization of EOS data

The survey form used during our telephone inquiries is shown in Appendix B. We contacted all 68 companies, but tabulated results only from the companies that wanted to participate in our survey. We spoke to an individual at each company that was familiar with the firm's marketing strategy and was also knowledgeable about remote sensing. The companies were divided into two categories: those that provide a service for the remote sensing industry (33) and those companies that produce a remote sensing product (10). One of the companies provides both types of information, therefore, actual responses from 42 companies (Tables 6, 7) were incorporated into our survey results.

**TABLE 6 List of value-added companies that are service-oriented and responded to our telephone survey**

| | |
|---|---|
| Aero-Metric Engineering, Inc. | Globex, Inc. |
| Albert H. Halff Associates, Inc. | Greenhorne and O'Mara, Inc. |
| Analytical Surveys, Inc. | H. Dell Foster Associates (HDFA) |
| Applied Analysis, Inc. | Hammon, Jensen, Wallen & Associates |
| Barringer Laboratories, Inc. | Henry Truebe (consultant) |
| Battelle Memorial Institute | ITD Space Remote Sensing Center |
| Decision-Science Applications, Inc. | Intra Search, Inc. |
| Delta Data Systems, Inc. | James W. Sewall Company |
| Earth Intersections, Inc. | Landmark Applied Technologies, Inc. |
| Engineering Service Corporation | Lockheed Engineering and Sciences Company |
| Environmental Research Institute of Michigan–ERIM | Marshal Miller and Associates |
| EOSAT Company | Mississippi Institutions of Higher Learning |
| GeoBased Systems | Pacific Meridian Resources |
| Geodynamics Corporation | Rochester Institute of Technology |
| GEONEX Corporation | Satellite Exploration |
| GeoSpectra Corporation | Satellite Mapping Corporation |
| | TRIFID Corporation |

**TABLE 7 List of value-added companies that are product-oriented and responded to our telephone survey**

Apogee Services, Inc.
Cropix/Eastern Oregon Farming Co.
Earth Satellite Corporation
Kork Systems, Inc.
MARS Associates, Inc.
Remote Sensing & Image Processing Laboratory (Louisiana State University)
RPI International, Inc.
Satellite Exploration
Science and Technology Corporation
Systems West, Inc.

## SUMMARY OF THE TELEPHONE SURVEY

The results of the telephone survey are discussed in the following sections. Each question is listed, followed by a summary of the comments received from the service- and product-oriented companies. The tally of responses for each question may or may not tally to 42, depending on whether the company responded to the question.

What is your *interest in remote sensing* ?

The range of interests and services offered by the service companies was varied. The remote sensing products offered by the product-oriented firms included enhanced satellite (Landsat, SPOT) and aerial photographs (for example, geocoded images, orthophotos, and spectrally-enhanced images), mosaics, maps or data bases. Enhancements for their remote sensing images were very diversified, providing products such as geocoding, rectification of images with maps, image analysis and classification, radiometric corrections, and image integration. Integrated software and hardware systems for working with their products were also provided.

Ideally, key aspects of product packaging and pricing strategy should be considered for commercial product development of data from the EOS sensors. However, at this stage it is too premature and too early to determine what specific EOS products are forthcoming. The principal investigators responsible for an EOS instrument are developing their list of EOS data products. This process is continually being updated and changed and will not be finalized until the summer of 1992 (L. Thompson 1991, pers. comm.). Therefore, it is too soon to consider pricing policy for any EOS value-added products.

What is your *volume of business* ?

There is a large amount of revenue generated by the remote sensing products industry. Firms reported sales ranging from $200,000 to well over a million dollars (gross sales). Sales volume ranged from 12 hardware/software systemsto hundreds and thousands of maps. There was a wide range with respect to the charge for a product; a price range provided was $100 to $250,000 depending on the product provided. Most companies process the data in-house and very little work is contracted out. For the few that do contract out, contracted services include scanning, geocoding and classification.

Historical and real-time data (within 24-48 hrs) were provided to customers. Most data are provided to customers on computer compatible tape (CCT) or other media formats, such as CD-ROM, paper prints and film, and cassettes, in standard data formats (Band Sequential [BSQ], Band Interleaved by Line [BIL], Fast Format and ARC/INFO format).

Who are the *customers* ?

Most of the customer base is divided about equally between the private companies and local, state and federal government agencies. Of the 40 responses, over 52% have a customer base consisting of both private companies and government agencies. Of the remaining firms, 22% deal exclusively with private companies and 26% deal only with the government agencies.

**What are your *existing commercial markets* ?**

The leading markets for remotely sensed data included: oil, gas and mineral (22), government agencies (20), agriculture (19), forestry (16), and environmental monitoring/resource management (14). Smaller markets include the news media, fishing, planning groups, engineering, and dredging. All of the companies (31 total responses) operate nationally, while seven of these have both national and international operations. About two-thirds of the companies do business with multiple industries; the remaining third does business with a single industry. The single-industry businesses were evenly divided between working with government agencies and the oil, gas and mineral industry.

A majority of the service company respondents (26 total) indicated that they order their satellite data from the EOSAT Company (23) and SPOT Image Corporation (19); of this total, 18 companies order their data from both companies. Other suppliers of data include the Earth Resources Observation System (EROS) Data Center, the U.S. Geological Survey, Environmental Research Institute of Michigan (ERIM) and the Defense Mapping Agency (DMA) for a small number of companies.

***Problems and suggestions* for obtaining remote sensing data?**

The problems most frequently cited by companies related to the timeliness of data delivery, a requirement for better spatial resolution, the need for cloud-free scenes, an improvement of cloud cover assessment procedures, and the high cost. Other problems related to data format changes and discrepancies, lack of standardization of the product, availability of data over a particular site, restrictions on the use of satellite data, noisiness and radiometric problems with the data, unsuitable climatic conditions, and political boundary problems.

The most frequently cited suggestions for improvement were to increase the availability of data and to provide data at a better spatial resolution. Enhancing the choice of spectral bands, improving the media format, decreasing the price, and developing new sensors, such as sensors to penetrate cloud cover and ultraviolet (UV) sensors, were other suggestions.

Specific recommendations for improvement of spatial resolution included a need for 1-15 m spatial resolution and stereo coverage. One company recommended decreasing the cost so that smaller companies could purchase the data. One company was frustrated with the standard format changes.

**What has *worked well* ?**

Areas in which satellite data have worked well include land use/land cover mapping, change detection, regional coverage for general image classification, and synthetic aperture radar (SAR) data analysis. The timing and availability of satellite data compared with aerial photography has been good, particularly in providing data for the near infrared region. Custom image processing of Landsat Thematic Mapper (TM) data has worked quite well for the products industry.

**What are your new *potential* commercial markets?**

Eleven service companies indicated that they wanted to expand into markets related to the environment. Another large market for expansion included agriculture. In addition, companies wanted to move into the international arena. Other new, but smaller, areas included forestry, fishing, oil and gas, land use, hydrology, utilities, and image classification and mapping. Three companies indicated a desire to branch out in general and only three stated that they had no interest in exploring new markets.

Two product companies wanted to expand into environmental areas, such as monitoring groundwater, disposal sites, and cleanup activities, coastal zone management, conflict resolution, and regional siting. Other areas included expanding their present markets, using image analysis as a front end to a geographic information system (GIS), and developing a commercial satellite. Only one company felt that the market was saturated.

**What will be new *applications* of EOS data?**

There were several application areas identified that may be addressed in a better way by combining the EOS data with their existing data sets. These areas included temporal monitoring; environmental assessment and monitoring; resource management (forest, watershed, wildlife, wetlands); agricultural yield measurement and production forecasting; vegetative stress; species inventory; disease detection and insect control; flood and storm damage; detection of oil slicks, toxic plumes, and environmental degradation; geologic exploration; defense mapping; oceanographic mapping; land use change and land information mapping; and building national data bases.

**What are your *future plans for incorporating EOS data* ?**

Well over half of the service companies (17 of 25 responses) are planning to incorporate and handle value-added EOS data into their system. Concerns expressed for doing so related to the availability of the data, the cost of the data, the value of the data in the marketplace, timeliness for acquiring the data, and consistency of the data product format. Five companies will not incorporate the data into their system and the remaining eight companies are undecided.

To increase sales and profits, companies would propose the following additions to the EOS data set: integrated data sets (including winds, ocean color information, AVHRR, Landsat and SPOT imagery, and other spectral bands spanning the entire electromagnetic spectrum), and enhancement "hooks" for the data (to include more exotic data such as altimeter data, thermal sensor data, multispectral imagery, stereoscopic coverage, and higher spatial and spectral resolution spectrometer data).

EOS instruments specifically named by the service companies included: HIRIS (12 companies), MODIS (7 companies), and SAR (6 companies). Two EOS sensors (MISR and AMSU) were mentioned by at least one company each.

Six of the product companies were interested in incorporating EOS data into their system; two companies stated that they had no interest. Two of the companies said that they would be willing to handle value-added data from EOS. EOS instruments specifically named by the companies included: HIRIS (5 companies), MODIS (3 companies), and SAR (2 companies). Desired data sets included information on weather, agriculture and ocean currents.

The companies' future plans would depend on availability of the data, whether the data is competitively priced, and if the data are provided in a format that is easily incorporated into their system. Using EOS data will also depend on the applications required by their customers. Requirements with respect to delivery of the EOS data ranged from as soon as possible, to one to two weeks, depending on the application.

*Willingness to pay* **for the EOS data?**

A company's willingness to buy present satellite data is a function of current market prices, what can be billed to the client, and the quality and availability of the data. Most companies recommended that EOS data be priced competitively with the present Landsat and SPOT data. Some companies indicated that even the existing Landsat and SPOT prices were high, but would pay this price, if their client would pay.

Most companies have the Landsat and SPOT prices in mind. Therefore, if prices are kept in line with what EOSAT and SPOT Image Corporation charge, then the market is there for EOS data.

**Your** ***opinion on commercialization*** **of EOS data?**

It was not the intent of this study to recommend *how* NASA was to commercialize the data; our intent was to determine *what* commercial possibilities are there for EOS data. Commercial users need to be identified and defined. This is in sharp contrast to the research and operational users, which already have a clearly defined role on how they will receive the data from EOS. During the telephone survey, we did not promote the concept or hear that there should be an entity that would act as an agent of NASA to sell the EOS data. The users that we talked to only wanted a place to purchase the EOS data for use in their company.

There were a number of diverse opinions on this topic. Almost half of the service companies believe that commercializing the EOS data is a good idea. This support is linked to the general belief that competition and market-determined prices will lead to better products. The EOS products will enhance the present set of remote sensing data products, principally because of the new and improved sensors on EOS, providing better spectral resolution and more frequent coverage on a global basis, although not necessarily at a better spatial resolution. They anticipate the issues relating to data quality and availability, resolution, sensor selection, and spectral bands will be resolved in a competitive market situation.

There were nine service companies that indicated, with some reservation, that commercialization is a good idea. One concern related to the timing of commercialization. At this time, it would be too ambitious because the market needs to be developed further. Also, people need to be educated in the potential uses of data from EOS. The method of how NASA commercializes the EOS data requires further study so that the system for transferring data to a commercial user operates smoothly. Questions include: should the government be involved initially and then pass it over to a private company, or should this be purely competitive from the start, and if so, how should the companies be financed?

*Six of the service companies are opposed to commercializing data from EOS due* to marketing problems, a "public good" perception, and low profitability. Marketing problems will arise because there will be too much data and too many unresolved problems in making the data available to all users. The public good problem stems from the feeling that the EOS data are being gathered for the public's well being and, therefore, the costs of using these data should be kept low by leaving it in the public sector. The profitability of EOS data is questionable because the EOS data would have to be sold at a price lower than the competing older satellite products presently being sold in the market today (such as the AVHRR, Landsat, and SPOT data). It would be difficult to sell the volume necessary to make a profit because many potential EOS customers do not find the EOS data essential to their present-day operations.

Only one service company had no opinion on the commercialization of EOS data.

Three of the product companies thought that commercialization of EOS data was a good idea; only one company thought it was a bad idea. Two more companies thought commercialization was a good idea, but had some reservations. This was due to the fact that the anticipated higher cost of the EOS data would reduce the availability of that data to those customers with limited funds. Companies were also concerned with data accessibility, since the data volume from EOS would be so high that the data are actually not easily accessible.

## ESTIMATE OF MARKET POTENTIAL FOR REMOTE SENSING DATA

KRS Remote Sensing (1988, vol. 1, p. 10) developed projections of market growth for remote sensing data from the base year of 1988 for three scenarios described as:

- low growth (5%/year), defined as "continuation of present market (zero real growth, as a background inflation rate of 5%/year for both costs and revenues...)"
- medium growth (12%/year), defined as "stimulation of present market, but without introduction of new sensor technology"
- high growth (about 20%/year), defined as "stimulation of present market, together with the introduction of new sensor technology in the 1990s in response to market demand"

These projections were for two segments of a commercial effort: value-added information products, and a space segment (consisting of raw data sales plus ground station fees). Their market projections show that total revenue varies from $55 to $200 million for raw data sales and $100 to $375 million for value-added vendors. The value-added industry shows a higher increase in purchases. KRS attributed this increase to private industry because as "processing technologies mature, image information products will be used as major decision-making tools" (KRS Remote Sensing 1988, vol. 1, p. 11).

The KRS remote sensing study evaluated the United States policy for participation in civil remote sensing in terms of U.S. investment required and the resulting U.S. revenue/investment ratio. Ten options of satellite sensor capabilities and U.S. investment strategies were advanced and compared to determine the viability of commercializing space remote sensing. Overall, their study showed that the "ten space segment sensor/ownership options ... fail the first test of commercial viability, since revenue falls short of investment in every case" (KRS Remote Sensing 1988, vol. 1, p. 38). However, their analysis of the value-added industry can be analyzed separately in terms of projected revenues. Our principal concern is with this industry, which is considered separately from the ground segment portion in the KRS study.

The highest market weighting of remote sensing products for civil applications included the following: land use/cover (level 1/2, 3/4), soil moisture, surface minerals/soils maps, precipitation, orthomaps, and image maps. Several of the EOS sensors would provide these types of products at various spatial resolutions and include: land use/cover (MODIS, HIRIS, ASTER); soil moisture (SAR); surface minerals/soils maps (SAR, HIRIS); and precipitation (MIMR). Thus we believe that EOS data would serve to provide needed remote sensing data products as defined by the KRS Remote Sensing study.

KPMG Peat Marwick (1992) revised the KRS forecast for satellite data revenues. Their revised estimate adjusts the 1991 forecasted revenues to reflect recent estimates by SPOT Image Corporation and EOSAT. Their "revised projections suggest that annual revenues for satellite data, including ground station fees, will grow to over $368 million by the year 2000 or approximately 60% higher than was predicted by the original KRS study" (KPMG Peat Marwick 1992, p. 17). They also prepared a high case prediction in which an average annual growth rate of 25% is projected through 1995, slowing to 17% from 1995 to 2000. Revenues for satellite data (including ground stations, but excluding value-added) could reach $430 million by year 2000.

There is a high demand for spatially-referenced digital data for the minerals extraction industry and the GIS/mapping markets, which were underestimated in the original KRS study. Across all market segments, the total demand for digital imagery has been growing at more than a 25% annual rate (KPMG Peat Marwick 1992). One key factor for this increase has been the "tremendous improvement in price and performance of geographic information system hardware and software as well as the recent integration of image processing software" (KPMG Peat Marwick 1992).

Also, the revised KRS projection for the value-added revenues is slightly higher for the year 2000 at $445 million as compared to the original prediction of $379 million. KPMG Peat Marwick increased the compound annual growth rates from 19 to 21%. They also did a high case forecast in which the current 1991 market size ($324 million or four times the amount of raw data sales) was adjusted, which is the base number from which the original projections were made. Discussions with the value-added industry indicated that there is an internal expense of value-adding done by end users to transform digital imagery to a useful information form. This ratio of value-adding to raw data varies from 3:1 to as high as 15:1.

KPMG Peat Marwick indicate that the "value-added market will fall somewhere between the revised KRS estimates and the high case projection" (KPMG Peat Market 1992, p. 21). They estimate the service/value-added re-seller component of the market is 1.7 times the hardware and software side of the business. (This 1.7 multiplier is based on the Daratech 1991 study of the GIS industry, a similar related industry.) Using this multiplier times the revised KRS estimate and the high case projection of the raw data market, a possible value-added market of $560 to $731 million is predicted for the year 2000 (KPMG Peat Market 1992). This is a significant amount of value-added revenues for the remote sensing industry.

## COMMERCIAL POTENTIAL OF THE EOS INSTRUMENTS

The EOS system is a much larger system than either the LFC or the Sea-WiFS sensors for developing commercial products. There are many sensors on EOS, some of which have only research, operational or commercial potential, and some having a combination of all three potentials. Our objective was to focus on the commercial potential of value-added products from an EOS sensor, without considering how the EOS data is distributed to the commercial user, since this policy is still being discussed within NASA (Koprowski 1991). However, we have outlined general guidelines of how the data could be distributed based on our conversations with the remote sensing industry.

Our next step was to contact the principal investigators responsible for the EOS instruments to determine if any commercial opportunities had been identified during any technical discussions. Appendix A includes a technical description of the EOS instruments that will be included on EOS-A. The potential commercial opportunities for each EOS sensor are described in the following sections.

### ACRIM

The ACRIM measures total solar irradiance. During the times of subsidized solar energy, measuring solar input served as a calibration to determine the efficiency of the designed solar system. There may be some minor commercial potential for ACRIM, if a need to measure the sun's input to the atmosphere for determining climatic consequences to a specific application area, such as agriculture, is developed in the near future.

### AIRS/AMSU-A/-B

The AIRS/AMSU is designed as a commercial instrument and is being tested for delivery to NOAA for use in their weather prediction models. Therefore, commercial applications in the weather forecasting area are possible from AIRS/AMSU. Commercial weather forecasters will directly or indirectly be able to use these data for their applications, depending on how they receive the data from NOAA.

### ASTER

The ASTER instrument is an imaging radiometer that builds upon the prior predecessor instruments of the Multispectral Electronic Self-Scanning Radiometer (MESSR), OPS, Landsat and SPOT. There are three modes of spatial resolution for ASTER: three located in the visible and near infrared region between 0.5 and 0.9 μm at a 15-m resolution, six middle infrared bands between 1.6 and 2.5 μm with 30-m resolution, and five thermal bands between 8 and 12 μm at a 90-m resolution. One of the 15 m bands will allow along-track stereo viewing that can be used to general local surface digital elevation models. Products generated from this instrument will augment the present Landsat and SPOT data bases by allowing coverage of areas with improved spatial resolution (15 m) and additional thermal images at a 90-m resolution.

The ASTER sensor would have an excellent possibility for commercialization, especially in mineral and petroleum exploration, the fishing industry, and in agricultural monitoring. ASTER has about the same spectral bands as the

Landsat TM and the SPOT High Resolution Visible (HRV) sensors. Additional enhancements include digital stereo imagery and there is a better definition of temperature and emissivity for the thermal wavelength region. These qualities are particularly attractive for the geology industry. The instrument can also be used to infer oil by using five thermal bands, which measure ground heat conditions and heat flux (Koprowski and Jenks 1991). However, the instrument is not as attractive to the geology industry as the HIRIS instrument discussed in more detail later. Unique spectral signatures for mineral, rock and vegetation types are not provided with this instrument, since the spectral bands are much wider than the HIRIS channels. We anticipate that maps and image products similar to the present Landsat and SPOT product line would be possible with ASTER.

Stereo data products would be a potential commercial product, however, they would not be as detailed as the elevation data products from SPOT. The SPOT 10-m panchromatic imagery would have better spatial resolution, both in the vertical and horizontal directions. Overall, the ASTER sensor would augment the present suite of commercial data products available from Landsat and SPOT.

ASTER is being developed by the Japanese government. Draft agreements on the EOS data policy between Japan and the U.S. have been negotiated.

### CERES

The scale of observations from the CERES sensor is quite large, on the scale of the size of Chicago. This is the type of scale that researchers require for global modelling, but not for the commercial market. Therefore, there is very little commercial value for CERES data. CERES data is used in meteorological applications, such as long-term weather forecasting and in climate prediction models. A commercial company would need a large initial investment to purchase the type of computer (CRAY-type) needed to analyze the data and would also need to perform additional research to produce a reliable climate forecast model. CERES-type data is principally being used in the government, for example, the U.S. Department of Agriculture, Central Intelligence Agency (CIA) and NOAA for making two-week weather forecasts. Other government studies focus on the long-term greenhouse climate effect.

### EOSP

The EOSP sensor will provide global maps of the radiance and linear polarization of the reflected and scattered sunlight for 12 spectral bands in the visible and near infrared (NASA 1990). One possible commercial application would involve the use of polarimetry for ocean surface characteristics, such as inferring the presence of oil slicks.

Another possible commercial application would be in monitoring the background aerosol content of the atmosphere. The radiance correction factors would be a valuable service to provide to researchers using other remote sensing instruments on EOS. Atmospheric corrections will need to be performed on other EOS instrument data, such as MODIS. EOSP can provide the information needed to remove the aerosol component of the atmosphere for use in terrestrial observations.

### EOS SAR

There is a large potential commercial value for SAR data measurements. Application areas include soil and snow moisture measurements, vegetation canopy monitoring, ice type characterization, and geological mapping.

The launch of the European Remote Sensing Satellite-1 (ERS-1) satellite in July 1991 and future launches of the Japanese First Earth Resources Satellite (J-ERS-1) and Radarsat (a Canadian satellite) in the mid-1990s, will generate a market for SAR data, particularly with oil, gas and mineral exploration companies. SAR will also be important in providing information on soil moisture.

An applications demonstration program is proposed with the ERS-1 satellite (NASA 1989). These applications are in the areas of: monitoring and forecasting natural conditions or events such as snowcover and snowmelt, ice override at the coast, river-ice breakup, volcanic eruptions and catastrophic floods; using SAR in a decision-making process to manage agriculture, timber, fisheries and wildlife resources, detecting natural or man-made environmental disturbances such as hydrological balance and permafrost cover; and for operations support such as ongoing, time-sensitive work in transportation and offshore operations in ice-covered waters. These types of applications would also apply to the EOS SAR.

### HiRDLS

NOAA views the HiRDLS as an operational instrument for providing meteorological data for their use. Commercial companies benefiting from this data would include those from the airline industry. Value-added information on wind fields in the lower stratosphere could be developed for use by the airline industry.

### HIRIS

The HIRIS instrument has generated a great deal of interest within the geologic industry, principally because of the higher spatial resolution (30 m) when compared with the other EOS instruments and the detailed spectral information available with the 192 spectral bands. The unique characteristic of this instrument is its capability to obtain spectral signatures of soil, rock, mineral and vegetation types. With the 192 channels very detailed and subtle changes in the surface reflectance of materials can be detected. The instrument is still very much in the research and development stage, but its potential use by geology and oil companies is widely recognized.

There are three principal application areas that HIRIS can be used. One area is environmental surveys. Detailed monitoring of the recorded spectral signatures can be studied to determine any chemical changes to the plant and soil materials resulting in soil contamination or vegetation stress. The mineralogy of clays and iron can be studied to look for different types of rock. The instrument can be used in oil spill situations to determine the extent and thickness of the oil using band ratioing techniques. The third use of the HIRIS instrument, which was originally planned for the EOS program, is to serve as an absolute instrument calibration source for the MODIS instrument.

### LIS

There is a significant potential for commercializing the real time availability of lightning and storm activity from a LIS-type instrument. Power companies need this type of information. However, this requires that LIS be in a geostationary orbit for continuous observation. Since the EOS platform will be in a low earth orbit, there is only a short time, twice a day, that LIS data are available. Because of this, a limited potential for commercial use of this data exists for climatological applications.

### MIMR

MIMR is to be provided by the European Space Agency and a team leader has not yet been assigned (NASA 1991b). MIMR will provide global observations of a variety of parameters important to the hydrologic cycle, such as atmospheric water content, rain rate, soil moisture, ice and snow cover, and sea surface temperature. Commercial potential cannot be assessed at this time, since this instrument will be provided by the Europeans.

### MISR

There have not been any commercial applications identified for the MISR instrument at this time, since MISR is principally designed as a research instrument. The MISR instrument is designed to provide global maps of planetary and surface albedo, and aerosol and vegetation properties (NASA 1991a). There may be some commercial possibilities in the future, but not at this time.

### MOPITT

The MOPITT instrument will measure emitted and reflected radiance in the atmospheric column (NASA 1991a). These data will allow us to measure carbon monoxide and methane concentrations in the troposphere. MOPITT data products will include gridded maps of methane at a horizontal resolution of 120 km and gridded carbon monoxide soundings in three vertical layers between 0 and 15 km with 22-km horizontal resolution (NASA 1991a). At this time, there have not been any commercial applications discussed for the MOPITT data.

### MODIS-N/T

The MODIS-N/T is an optimized Ocean Color Scanner (OCS) and Sea-WiFS sensor and thus the nearshore fisheries that monitor and map ocean productivity will be a key commercial market. An important issue is the time delivery of the data, since ocean data is very volatile information and instant access is essential for this industry.

Potential markets will include the fisheries for obtaining nearshore ocean productivity maps. Again, delivery of the data to the value-added company is critical to provide a value-added product quickly to someone at sea.

### STIKSCAT

Commercial possibilities for this data have been discussed. If the data are provided in real time, within 100 minutes to 3 hours, then the data can be assimilated into operational weather forecasting systems within the government or private firms. Wind and wave forecasting systems are important for the shipping and airline industries. Timing of delivery is the key issue in commercializing the STIKSCAT data.

## RECOMMENDATIONS AND CONCLUSIONS

Based on our conversations with the remote sensing value-added companies and the principal investigators for the EOS sensors, a study of past commercial satellite data ventures, and readings from the commercial remote sensing industry literature, we developed three recommendations from our study. They include:

- develop a strategic plan for commercialization of EOS data
- define a procedure for commercial users within the EOS data stream
- develop an Earth Observations Commercial Applications Program (EOCAP)-like demonstration program within NASA using EOS-simulated data

A strong commitment by NASA to support commercialization of the EOS data has to be stated. Also, timing is critical because of the impact that pending legislation (H.R. 3614) may have on the pricing policy of U.S. satellite data.

***Recommendation 1: strategic plan for commercialization of EOS data***

We recommend that a committee, starting with a workshop format, be established to address the subject of developing a strategic plan to commercialize the EOS data. The results from our study strongly suggests that *there is commercial potential* for data from several of the instruments, most notably the ASTER, HIRIS, SAR, and MODIS sensors. We need to objectively analyze, or perform an *autopsy,* of past commercialization efforts to recommend a commercialization structure for the upcoming EOS data. For example, the particular situation that occurred between NASA and Systems West, Inc. for acquiring SeaWiFS data fell through because of the high data transmission rate. We need to determine ways to make commercial ventures work and avoid repeating their mistakes in future commercialization efforts.

The committee would include representatives from the government, the private sector (the value-added firms), and the users of remotely-sensed data. In this way an aggressive model to address the issue of commercializing the EOS data can be developed. However, we would need to ensure that both Codes C and S in NASA would endorse such an effort. The strategic plan would also need to be coordinated closely with the commercialization policies currently under development within NASA.

The following topics should be addressed by the committee in developing the plan: in what ways would the EOS data be acquired by the commercial users; if a central body is recommended for marketing and distributing the EOS data, then what is the structure of the firm(s) and are they subsidized by the government or are they to be competitive; what is an appropriate pricing policy of EOS data for commercial users; marketing strategies for the EOS data; and, should a new commercialization policy for EOS data be adopted.

The value-added companies that we talked with distinguished between "commercializing EOS data" and "getting the EOS data." There was no interest in starting a private-for-profit venture to just sell the EOS data. The companies wanted *access* to the EOS data base. Thus we do not recommend that a commercial firm act as a distributor of EOS data for the level 0, 1A and 1B data level products. For example, the EOSAT Company markets and sells Landsat data as prescribed by Public Law 98-365. This type of setup for Landsat data purchase is not the ideal vehicle for commercializing data because the vendor is prohibited from developing and marketing any value-added products. Incentives need to be provided by the government and new legislation mandated by Congress pertinent to the EOS program to allow for developing the value-added product line from EOS sensors–the level 2, 3 and 4 data level products.

*Recommendation 2: develop a procedure for commercial users within the EOS data stream*

We recommend three ways for the commercial user to acquire EOS data: through the Direct Broadcast and Downlink systems, through the DAACs, or through the EOS Science Network. For the existing commercial markets, timeliness of data delivery means different time frames.

Operational and forecasting commercial users would require EOS data using the Direct Broadcast and Downlink system. For these types of users, real-time data are necessary and thus they would need the most expedient method possible to receive their data.

Agricultural users require processed EOS data within 48 hours for operational use of remote sensing data and thus we recommend the DAAC route for them. For strategic planning purposes, agricultural and forestry applications require a one-week delivery time and for the environmental market, a delivery period of one month is adequate. Thus, for this last group of commercial users and any other users that do not need their data in real time, we recommend that they best acquire their data from the DAACs or the EOS Science Network.

Geographic information system (GIS) techniques should continue to develop and be highly sophisticated by the time that EOS data is available. The EOSDIS system will be the largest data base under the control of a GIS in the late 1990s (Maiden and Butler 1991). A large amount of present-day value-added products include the merging of spatial and other GIS-type layers with satellite data to produce a geocoded image map or other type of enhanced image. Since the EOS database will be the largest in the world, this environment would be a natural area where the commercial value-added industry will thrive. Therefore, within EOSDIS there should be a provision for commercial companies to retrieve the EOS data, along with the research and operational users of EOS data.

There is a difference between the customers of value-added data that we interviewed for this study and future customers of value-added EOS data. Today's users of Landsat and SPOT data are managing our natural resources and require higher spatial resolution data. The future users of EOS data will need information to understand global resources and do not require the high spatial resolution. The EOS data sets are typically lower in spatial resolution to address global issues. As Morain and Thome (1990) point out most "commercial users buy information, not images, and the system supplying it should be transparent to them." Thus the primary issue for the private firms is to interpret the EOS data and sell this information to the users. Spatial, spectral, temporal and radiometric resolutions are key to mapping and monitoring forestry, agricultural, and other natural resources. The EOS data will have better temporal resolutions than present-day sensors. As a result, we will be able to investigate the entire range of global processes once per week; currently, it requires more than two years to obtain global coverage.

*Recommendation 3: develop an EOCAP-like demonstration program within NASA using EOS-simulated data*

In summary, the sensors on EOS that have the strongest potential for commercial applications include the HIRIS, MODIS, SAR and ASTER. These sensors were named the most often among the value-added companies. We recommend that an EOCAP-like demonstration program be developed with NASA. If flight engineering models of the EOS instruments are developed by the research community before EOS is launched, then commercial demonstration projects can be identifed. This will best identify specific target areas for developing commercial applications with value-added remote sensing data. With this type of demonstration program, an advocate within the federal government (NASA) is there to make the EOS data available to the commercial users. Automatic incentives are there within the EOCAP program to quickly market data and services.

Private companies have the necessary infrastructure in terms of personnel and equipment to handle the EOS data. However, they would have to invest in additional data storage devices to handle the large volume of global data sets and possibly faster computer chips to process the data quickly. The payback period for this investment would be relatively short.

We strongly feel that there will be additional applications available for the EOS data by the late 1990s. The KRS Remote Sensing report highlighted several areas for using remote sensing data. For example, such global interest areas would include renewable/nonrenewable resource management, ocean and coastal waterway analysis, GIS, geological studies, weather analysis, environment assessment, and public information (KRS Remote Sensing 1988). Also, there should be more applications of the SAR data because of the new satellites (ERS-1 launched July 1991, J-ERS-1 and Radarsat) being launched in the near future (early to mid 1990s).

For the future the problem-solving approach in terms of physical and mathematical processes will work the best with EOS data. The best success will occur when an interdisciplinary team is brought together in which all processes can be studied in detail. This will help in solving global process problems from a commercial vantage point.

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# Appendices

# Appendix A

## Description of the EOS Sensors

(information adapted from NASA 1991a, 1991b).

### ACRIM

Active Cavity Radiometer Irradiance Monitor. This instrument is designed to make long-term measurements of the total solar irradiance to determine the influence of variations in solar output on climate change.

### AIRS/AMSU-A/B

Atmospheric Infrared Sounder/Advanced Microwave Sounding Units-A/B. The instrument package is designed to measure atmospheric temperature profiles with an accuracy of 1°C and will provide data on atmospheric water vapor, cloud cover, and sea- and land-surface temperatures.

The AIRS optical system is designed as a grating spectrometer, using two separate spectrometers that share a common scan mirror. The AIRS measures the Earth's radiation in 4,000 high resolution spectral channels for the wavelength regions of 3 to 8 and 8 to 17 μm. AIRS is supplemented by five channels in the visible range (0.4 to 1.1 μm). The field of view is 1.1° with a ±49° scanning capability.

The AMSU is a microwave radiometer with 20 channels divided into the AMSU-A and AMSU-B subsystems, for measuring atmospheric temperature and humidity. The AMSU-A provides atmospheric temperature measurements from the surface up to 40 km in 15 channels (23.8 GHz, 31.4 GHz, 12 channels between 50.3 to 57.3 GHz, and 89 GHz) with an instantaneous field of view (IFOV) of 3.3° and temperature resolution of 0.25-1.3°K. AMSU-B provides atmospheric water vapor profile measurements for 5 channels (89 GHz, 166 GHz, and 3 at 183 GHz). The coverage is 50° on either side of the orbital track with an IFOV of 1.1° and a temperature resolution of 1.0 to 1.2°K.

### ASTER

Advanced Spaceborne Thermal Emission and Reflection. This imaging radiometer will provide high-resolution images (15 to 90 m) from the visible to the infrared spectral regions of the land surface and clouds for climatology, hydrology, biology and geologic studies.

### CERES

Clouds and the Earth's Radiant Energy System. These broadband, scanning radiometers will provide measurements of the Earth's radiation budget through observations of short- and long-wave radiation. There are three channels in each radiometer: total radiance (0.2 to >100 μm), shortwave (0.2 to 3.5 μm) and longwave (6 to 25 μm).

**EOSP**

Earth Observing Scanner Polarimeter. This cross-track scanning polarimeter will make global observations of polarized light to help in quantifying the role of aerosols and clouds for heating and cooling the Earth, as well as to help characterize cloud properties. The instrument will map global radiance and linear polarization of reflected and scattered light for 12 spectral bands from 410 to 2,250 nm.

**EOS SAR**

EOS Synthetic Aperture Radar. This instrument will acquire multifrequency multipolarization measurements in the L band (HH, VV, HV, VH [vertical horizontal] phases) and C and X bands (HH and VV phases). The imaging radar uses electronic beam steering in the cross-track direction to acquire images at selectable incidence angles from 15 to 50°.

The instrument has a varying spatial resolution and swath width capability in three modes: 20- to 30-m resolution with a swath width of 30- to 50-km (the Local High Resolution mode), 50- to 100-m resolution with a 100- to 200-km swath (the Regional Mapping mode), and 250- to 500-m resolution with a swath width of up to 500-km (the Global Mapping mode).

EOS SAR will provide data products to monitor: soil, snow, and canopy moisture and flood inundation to determine their relationship to the global hydrologic cycle; global deforestation and forest biomass to determine their impact on the global carbon cycle; and sea ice properties to determine their impact on polar heat flux.

**HiRDLS**

High-Resolution Dynamics Limb Sounder. This instrument is an infrared radiometer used to measure levels of trace gases, such as ozone, water vapor, chlorofluorocarbons, and nitrogen compounds in the upper troposphere, stratosphere, and mesosphere. The spectral range is from 6 to 18 microns. Data is provided on a profile spacing of 4° longitude by 4° latitude for a 1-km vertical resolution.

**HIRIS**

High-Resolution Imaging Spectrometer. This spectrometer is highly programmable to make localized measurements of biological and geological processes at a 30 m resolution. There are 196 spectral bands in the range 0.4 to 2.5 μm, each band at a 10 nm spectral resolution. The purpose of this instrument is to study biological and geophysical processes, as well as interactions along borders of different ecosystems.

## LIS

Lightning Imaging Sensor. This instrument is designed to collect data on lightning distribution and variability across the Earth. This will contribute to an understanding of lightning, convective thunderstorms, and rainfall. The storm-scale spatial resolution is 10 km with a 1 ms temporal resolution. Individual storms can be monitored within the field-of-view for two minutes, long enough to estimate the lightning flashing rate.

## MIMR

Multifrequency Imaging Microwave Radiometer. MIMR is designed to obtain global observations of a variety of parameters important to the hydrologic cycle, including atmospheric water content, rain rate, soil moisture, ice and snow cover, and sea surface temperature.

## MISR

Multi-angle Imaging Spectro-Radiometer. This instrument will obtain continuous multi-angle imagery through eight separate charge coupled devices (CCD-based) pushbroom cameras, each operating at wavelengths of 440, 550, 670, and 860 nm. MISR is designed to obtain global observations of the directional characteristics of reflected light, and other information needed for studying aerosols, clouds, and the biological and geological characteristics of the land surface. Global maps of planetary and surface albedo, and aerosol and vegetation properties will be produced. Spatial resolution is 1.92 km for the global mode and 240 m for the local mode.

## MOPITT

Measurements of Pollution in the Troposphere. This instrument will obtain global measurements of carbon monoxide and methane in the troposphere. Upwelling radiance in the CO bands will be measured at 2,140 $cm^{-1}$ and 4,110 $cm^{-1}$, with profiles obtained at a resolution of 22 km horizontally, 3 km vertically with an accuracy of 10%.

## MODIS-N/T

Moderate-Resolution Imaging Spectrometer-Nadir/Tilt. This instrument is an imaging spectrometer to measure biological and physical processes to study terrestrial, oceanic and atmospheric phenomena on a scale of 1 $km^2$. One instrument is nadir-viewing (MODIS-N) and the other one has an intrack tilt capability (MODIS-T).

MODIS-N contains 36 bands for the spectral range of 0.4 to 14.54 µm. Available pixel sizes are 214 m, 428 m and 856 m. The image swath width is 2,300 km.

MODIS-T has 64 bands in the spectral range of 0.4-0.88 µm. The image swath width is 1,500 km at a pixel size of 1.1 km.

## STIKSCAT

Stick Scatterometer. This six stick fanbeam scatterometer is a microwave radar that collects all-weather measurements of surface wind speeds and directions over global oceans. Data will be acquired in two, 550-km swaths separated by a 325-km gap at nadir, resulting in daily coverage of 76% of the ice-free oceans.

# Appendix B

## Telephone Survey Questionnaires

### Appendix B1.

Telephone survey used for service-oriented value-added remote sensing companies.

SERVICES

**Current operations:**

What is your interest? What is the service that you provide?

Who are your customers? Are they private companies, universities, researchers, government labs, state and local governments?

What and where are your existing commercial markets (industries: fishing, oil and gas, dredging, forestry, agriculture, government, news media) (national or international)?

Who have you noticed to be producers of satellite derived products? Who are the customers?

What are the major problems you have had?

What has not worked for you?

How would you solve these problems?

How would you have changed your approach in providing services relative to these data?

What changes would you suggest?

What has worked well?

What has been working for you in terms of services relating to the satellite derived data (company's specialty product, e.g. climate, snow geography, land), both in the past and in the present?

**New markets:**

What potential markets would you like to get into?

**Applications:**

What are some applications you can identify for these data?

**Future Plans:**

Do you have any future plans for incorporating EOS data into your system?

Would your company handle any value-added EOS data products or services? What would your concerns be (timeliness)?

What other data would you add to this EOS data set to increase sales of value-added products or services and make a profit doing it?

**Willingness to Pay:**

How much are you willing to pay for the raw satellite data? How much are you willing to pay for the value-added products resulting from these data? How much is EOS worth to you?

**Attitude:**

What is your opinion with respect to commercializing data obtained from the EOS platform (Do you think this is too ambitious? Do you think it has been tried before and won't work? What do you think we can learn from Landsat's mistakes?)?

**Future Interest:**

Would you be interested in a list of sensors, and data sets available from these sensors once NASA has decided what to put on the EOS platform?

## Appendix B2

Telephone survey used for product-oriented value-added remote sensing companies.

### PRODUCTS

**Products:**

What satellite products do you offer?

How have these data been enhanced (geocoded, a satellite-derived data product like a land use map, orthophoto maps)?

**Distribution and Packaging:**

How much data do you distribute on an annual basis in terms of volume and dollars?

What is the time format for the data which you distribute? real time, regular processed time, historical?

How do you distribute these data (tape, diskette, CD-ROM, other media)?

Do you distribute it in any standard data format (BSQ, BIL, Fast Format)?

**Charge:**

What is the charge for it?

**Collaborators and Customers:**

Do you contract out any of your production process (packaging, distribution, film processing, any corrections to the satellite data)?

Who are your customers? Are they private companies, universities, researchers, government labs, state and local governments?

What and where are your existing commercial markets (industries: fishing, oil and gas, dredging, forestry, agriculture, government, news media) (national or international)?

**Problems:**

What has not worked for you?

How would you have changed your approach to distributing these data?

What changes would you suggest?

**What works well:**

What has been working for you in terms of distributing satellite-derived data products (company's specialty product, e.g. climate, snow geography, land), both in the past and in the present?

**New Markets:**

What potential markets would you like to get into?

What are some applications you can identify for this data?

**Future Plans:**

Do you have any future plans for incorporating EOS data into your system?

Would your company handle any value-added EOS data products?

What sensors would you anticipate using from the EOS platform?

What data sets from that sensor would you use?

What other data would you add to this EOS data set to increase sales of this product and make a profit doing it?

If you require raw data, what are your requirements with respect to the timing of delivery?

How much are you willing to pay for the raw satellite data?

What would your concerns be (timeliness)?

**Attitude:**

What is your opinion with respect to commercializing data obtained from the EOS platform (Do you think this is too ambitious? Do you think it has been tried before and won't work? What do you think we can learn from Landsat's mistakes?)?

**Future Interest:**

Would you be interested in a list of sensors, and data sets available from these sensors once NASA has decided what to put on the EOS platform?

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