Appendix D: Non-U.S. Earth Observation Satellite Programs

Many countries routinely use satellite remote sensing for land planning, weather forecasting, environmental monitoring, and other purposes. Most of these countries share data with the United States, neighboring countries, and international organizations. This appendix summarizes the remote sensing systems of other countries and organizations.

EUROPE

Development of remote sensing spacecraft in Europe is under the management of the European Space Agency (ESA), a consortium of 13 member states-Austria, Belgium, Denmark, Germany, France, Ireland, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom. Finland has ESA Associate Member status, and there is an agreement for close cooperation with Canada. Since ESA'S inception in May 1975, it has pursued an Earth observation program.

Meteosat/MOP

ESA'S Earth observation program was based initially on a series of pre-operational meteorological satellites, called Meteosat. [1] The first—Meteosat l—was launched in November 1977 and placed in a geostationary orbit, but suffered an onboard imaging failure after two years of service. A second pre-operational Meteosat was launched in June 1981. Yet another of the series, a Meteosat P2 (a refurbished engineering model for the pre-operational series), was deployed in June 1988.

The first spacecraft of the Meteosat Operational Programme (MOP-1) was launched in March 1989 and carried four independent imaging

[1] *What's the Forecast? The European Space Meteorology Operational Programme*, European Space Agency, ESA F-01, 2nd Edition, ESTEC, Noordwijk, The Netherlands, January 1989.

channels. MOP-2 was orbited in March 1991,[2] and MOP-3, the sixth spacecraft of the Meteosat series, will be ready for launch in late 1993. It will have an expected seven-year life.

The MOP satellites are developed and operated by ESA on behalf of the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat).[3] Formed in January 1987, Eumetsat is composed of 16 member states: Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, and the United Kingdom. Eumetsat manages the operational Meteosat program, while ESA procures, launches and operates the spacecraft on a reimbursable basis for Eumetsat. In general, the Meteosat/MOP spacecraft design, instrumentation, and operation are similar to the U.S. NOAA SMS/GOES spacecraft. The spin-stabilized spacecraft carry:

- a visible-infrared radiometer to provide high-quality day/night cloud cover data and to take radiance temperatures of the Earth's atmosphere, and
- a meteorological data collection system to disseminate image data to user stations, to collect data from various Earth-based platforms, and to relay data from polar-orbiting satellites.

The satellite's principal payload is a high-resolution radiometer. This instrument allows imaging of the Earth in three spectral bands: visible light; thermal infrared; and infrared "water vapor" (see table D-l).

Meteosat spacecraft are positioned to survey the whole of Europe, as well as most parts of Africa, the Middle East and the Atlantic Ocean. The satellites relay images and data to the Meteosat Operations Control Centre within ESA'S Space Operations Control Centre in Darmstadt, Germany. The Meteorological Information Extraction Centre, located within the Meteosat control center, distributes the satellite data to various users.

Meteosat is part of a program involving four geostationary satellites (nominally, two American, one European and one Japanese) that constitutes the basis of the World Weather Watch of the Global Atmosphere Research Program. Data from the Meteosat series is received in Europe directly from the satellites and relayed to the United States.[4] Meteosat data are used in various international research projects. Recently, as the result of an agreement between Eumetsat and NOAA, ESA moved Meteosat to a position of 75°W longitude in order to provide better coverage of the United States (see ch. 3).[5]

Eumetsat

Eumetsat manages the Meteosat series of geostationary satellites and is NOAA's partner in the follow-on NOAA-K, L, and M satellites. Eumetsat is headquartered in Darmstadt, Germany, and is establishing a remote sensing ground infrastructure, including data processing and archives. Eumetsat is developing user access policies for full and open access to data in the meteorological tradition, but is also providing incentive for European countries to become members and share the financial burden of maintaining and improving operational meteorological services. Non-member countries are likely to pay for data through royalties or license fees. Encryption of satellite data would allow enforcement of any Eumetsat pricing policies.[6]

The Meteorological Information Extraction Centre in Darmstadt develops products in support of the International Satellite Cloud Climatology Project, with selected products supplied to the Global Telecommunications System of the World Meteorological Organization (WMO) as part of the World Weather Watch. These data are archived at ESA'S Operations Control Centre, which also controls and operates the Meteosat satellites for Eumetsat.

European Remote Sensing Satellite (ERS)

The ERS-1 satellite was launched into polar orbit by an Ariane booster in July 1991 and was declared

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2 *MOP-2: Meteosat Operational Programme*, ESA/EUMETSAT, European Space Agency, ESA C-6, January 1991.

3 "ESA Hands over Meteosat-5 to EUMETSAT," *ESA News Release*, No. 2, European Space Agency, Paris, France, Jan. 14, 1992.

4 NOAA archives Meteosat data for use in the U.S.

5 "Meteosat-3 t. the Rescue . . . of NOAA," in *ESA Newsletter, No. 9*, European Space Agency, Paris, France, November 1991.

6 Lisa R. Shaffer, "The Data Management Challenge," presented at Annual Meeting of the American Association for the Advancement of Science, Washington, DC, February 1991.

Table D-l—Spectral Coverage of Selected Remote Sensing Satellites

Satellite	Landsat 5	Landsat 6	NOAA-11	NOAA-12	GOES	TOPEX/Poseidon
Owner	U.S.	U.S.	U.S.	U.S.	U.S.	U.S.
Launch Date	1985	1993*	9-88	5-91	5-87	12-92
Average Resolution	30 m	30 m/15 m	1 km/4 km	1 km/4 km	4 km	2-10 cm
Swath Width	185 km	185 km			3000 km	N/A
Spectral Coverage:						
Ultraviolet	N/A	N/A	N/A	N/A	N/A	N/A
Blue	.45-.52	.45-.52	N/A	N/A	.55-.75	N/A
Green	.52-.60	.52-.60	.58-.68	.58-.68	.55-.75	N/A
Red	.63-.89	.63-.89	N/A	N/A	.55-.75	N/A
Near Infrared	.76-.90	.76-.90	.72-1.10/ 3.55-3.93	.72-1.10/ 3.55-3.93	N/A	N/A
Mid Infrared	1.55-1.75/ 2.08-2.35	1.55-1.75/ 2.08-2.35	N/A	10.5-11.5 11.5-12.5	N/A	N/A
Thermal IR	10.4-12.5 (120 km res)	10.4-12.5 (120 km res)	N/A	N/A	9.7-12.8/12.3-13.0	N/A
Microwave	N/A	N/A	N/A	N/A	N/A	13.6;5.3;18.0;21.0;37.0;13.65 GHz
Panchromatic	N/A	15 m	N/A	N/A	N/A	N/A

* Antlclpatcd launch

Table D-l-Spectral Coverage of Selected Remote Sensing Satellites-Continued

[7] “ERS-1 Now Declared Operational,” *ESA News Release*, European Space Agency, Paris, France, Jan. 27, 1992.

Satellite	Meteor 2	Meteor-3	Okeon-0	Resurs-0	Resurs-F	FY-1B	IRS 1-B
Owner	CIS	CIS	CIS	CIS	ClS	China	India
Launch Date	Numerous	8-91	2.90	4-88	5-91, 6 launched in 1990-91	9-90	3-88/8-9 1
Average Resolution	2 km/1km	.5 km	200 m-600 m	10-30 m	10-30 m	*1.1 km*	72 **m**
Swath Width	2100/2600 km	2600 km	variable	180 km	180 km		148 km
Speectral Coverage							
Ultraviolet	NIA	.25-,38 (3-5 km rcs)	N/A	N/A	NIA	NIA	N/A
Blue	NIA	N/A	NIA	NIA	NIA	.48-53	45-.52
Green	.50-,70	.50-,80	50-.60	.50-60	NIA	.53-.58	52-59
Red	NIA	NIA	60-70 (2 **channels)**	60-70	.63-70 (6 channels,	.58-68	62-68
Near Infrared	NIA	NIA	70-80 .80-1 10	NIA	NIA	.725 -1.10	.77-86
Mid Infrared	8-12 (8 km rcs.)	10-12.50 11.5012.50	1050-1150 1150-1250	.70-80 80-1.10	N/A	10.5 -12.5	NIA
Thermal IR	141-18,7 (30 km rcs)	9.65-187 (42 km rcs)	NIA	104-126	N/A	NIA	N/A
Microwave	NIA	NIA	.8 **cm band/6-15** km rcs, 3.15 cm band/l -2 km rcs	.8-4.5 cm band 17-90 km rcs 9,2 cm SAR 200 m rcs	NIA	N/A	NIA
Panchrornatic	*N/JA*	N/A	NIA	N/A	N/A	N/A	365 m 7425 km

operational six months later.[7] Operating from a sun-synchronous, near-polar orbit, ERS-1 is the largest and most complex of ESA'S Earth observation satellites.[8] The ERS-1 platform is based on a design developed for the French SPOT program.

From a 98.5-degree orbit at 785-km altitude, ERS-1 makes use of a synthetic aperture radar (SAR) to study the relationships between the oceans, ice, land, and the atmosphere. The SAR'S all-weather, day-and-night sensing capability is critical for polar areas that are frequently obscured by clouds, fog, or long periods of darkness.

The primary mission objectives of ERS-1 include:[9]

- improving understanding of oceans/atmosphere interactions in climatic models;
- advancing the knowledge of ocean circulation and transfer of energy;
- providing more reliable estimates of the mass of the Arctic and Antarctic ice sheets;
- enhancing the monitoring of pollution and dynamic coastal processes;
- improving the detection and management of land use change.

Data from ERS-1 allows researchers to:

- study ocean circulation and global wind/wave relationships;
- monitor ice and iceberg distribution;
- more accurately determine the ocean geode;
- assist in short and medium-term weather forecasting, including the determination of wind speed;
- locate pelagic fish through monitoring of ocean temperature fronts.

The spacecraft's synthetic aperture radar provides all-weather, high-resolution (30 meters) imagery in 100-km-wide swaths over oceans, polar regions, and land. A core suite of onboard microwave sensors is supported by additional instruments (see table D-l).

ESA has developed a ground system for ERS-1, including centers for receiving, processing, validating, disseminating and archiving data:

- *the Mission Management and Control Centre (MMCC) in* Darmstadt, Germany, which carries out all satellite operations control and management, including instrument operational scheduling;
- *ESA ground stations* at Kiruna (Sweden), Fucino (Italy), Gatineau and Prince Albert (Canada), and Maspalomas (Canary Islands, Spain) which provide the main network for data acquisition and the processing/dissemination of fast-delivery products;
- *national ground stations* around the world receive ERS-1 high-rate data by arrangement with ESA, extending the coverage potential of the high-resolution SAR imaging mission. One such ground station, funded by NASA, is the Alaska SAR facility at the University of Alaska Fairbanks. This facility, combined with two SAR stations in Canada and one in Sweden, provide nearly complete satellite coverage of Alaska and the Arctic for the first time;[10]
- the *Earthnet ERS-1 Central Facility (EECF) in* Italy, which carries out all user interface functions, including cataloging, handling of user requests, payload operation planning, scheduling of data processing and dissemination, quality control of data products and sensor performance monitoring;
- *Processing and Archiving Facilities (PAFs) located* in the United Kingdom, Germany, France, and Italy which are the main centers for the generation of off-line precision products and the archiving of ERS-1 data and products;
- *user centers and individuals,* such as national and international meteorological services, oceanographic institutes, and various research centers.

[7] "ERS-1 *Now* Declared operational, " *ESA News Release,* European Space Agency, Paris, France, Jan. 27, 1992.

[8] *The Data Book of ERS-1: The European Renwte Sensing Satellite,* ESA BR-75, European Space Agency Publications Division, ES'I'EC, Noordwijk, The Netherlands, 1991. Pam Vass, and Malcolm Handoll. *UK ERS-1 Reference Manual,* DC-MA-EOS-ED-0001, Issue No. 1.0, Royal Aerospace Establishment, Farnborough, UK, January 1991.

[9] R. Holdaway, "UK Instruments for Mission to Planet Earth, " presented at 42nd Congress of the International Astronautical Federation (IAF), (IAF-91-139), Montreal, Canada, Oct. 5-11, 1991; Ian pinker, "Satellite Sees All," *Space,* vol. 7, No. 6, November/December 1991, pp. 8-12.

[10] "Satellite Facility Ready as ERS-1 Launched," *Geophysical Institute Quarter/y,* vol. 9, Nos. 3 & 4, Fairbanks, Alaska, summer 1991.

An ERS-2 spacecraft, a follow-on mission to ERS-1, is an approved ESA project for launch in 1994, thereby offering uninterrupted data collection from 1991 until the initiation of ESA'S Polar Orbit Earth Observation Missions (POEM) program scheduled to begin orbital operations in 1998. ESA will first launch Envisat, an experimental ecological monitoring satellite. Later, around 2000, ESA will launch the Metop satellite, designed to provide operational meteorological data. Eumetsat will provide data from the Metop system in cooperation with NOAA (see ch. 3 and ch. 8), ERS-2, along with ERS-1 instrumentation, will carry the Global Ozone Monitoring Experiment package to analyze atmospheric chemistry, using medium-resolution spectrometry in the ultraviolet and visible regions of the spectrum to examine ozone and other chemical substances in the troposphere and stratosphere.

The ERSC Consortium (Eurimage, Radarsat International, and SPOT Image Consortium) is responsible for worldwide commercial distribution of ERS-1 data and products to users. Eurimage is owned by four companies: Telespazio (Italy), Dornier (Germany), Satimage (Sweden), and British Aerospace (United Kingdom), with each as a 25 percent shareholder. Eurimage is responsible for the distribution of all ESA products within Europe and the Middle East, Radarsat distributes products in North America. SPOT is responsible for distribution to remaining world markets.[11]

The European Space Agency's remote sensing data management program is called Earthnet.[12] This group is headquartered in Frascati, Italy, at the European Scientific Research Institution (ESRIN).[13] ESA primarily serves European users, but data from Earthnet are available to any user for a price, either directly or through Eurimage. Earthnet provides basic remote sensing data in digital and photographic format, while higher level products are turned over to value-added firms for production and distribution. Users from countries who contributed to the cost of the program are given preferential prices.

FRANCE

Systeme Probatoire d'Observation de la Terre (SPOT)

The SPOT-1 spacecraft was launched in February 1986 by Centre National D'Etudes Spatiales (CNES), the French space agency, as an operational, commercial satellite. The SPOT program represents a $1.7 billion investment through the end of the decade.[14] CNES acts as overall program leader and manager with full responsibility for satellite launches and orbital control and related funding. Government/industry organizations participating in the SPOT program are led by CNES, the Swedish Space Corporation in Sweden, and the Societe Nationale d'Investissement of Belgium.

SPOT-1 was placed in a sun-synchronous, near-polar orbit of 824 X 829 km altitude, with a design lifetime of two years. Every 369 revolutions around the Earth (every 26 days), SPOT-1 arrives at the same place over the globe. SPOT-1 carries twin pushbroom CCD High Resolution Visible (HRV) Imaging Instruments. The HRV can point up to 27 degrees off the satellite track, allowing the satellite to reimage places on the surface within 2 or 3 days. Also onboard are two magnetic tape data recorders and a telemetry transmitter. Until December 1990, the HRV observed in three spectral bands in multispectral mode with a swath width (nadir viewing) of 60 km; and in panchromatic mode with a swath width of 60 km (see table D-l). SPOT-1 attained a ground resolution of 20 meters in multispectral mode, and 10 meters in panchromatic mode. SPOT-1 off-nadir viewing yielded stereoscopic pairs of images of a given area during successive satellite passes. A standard SPOT-1 scene covers an area 60 X 60 km.

SPOT-1 lifetime of two years stretched until its first retirement in 1990, after suffering from a failing

[11] Peter de Selding, "ESA Signs Long-awaited Imagery Sales Deal," *Space News*, vol. 3, No. 5, Feb. 10-16, 1992, pp. 4; "ESA Initiates Commercial Distribution of ERS-1 Data," *ESA News Release*, No. 8, European Space Agency, Paris, France, Feb. 7, 1992.

[12] Shaffer, op. cit., footnote 6.

[13] Earthnet was originally established t. receive and make available Earth observation data from non-ESA satellites, such as Landsat and MOS, Tires-N, Seasat, HCMM, Nimbus-7, and SPOT, but is now the focal point for ESA remote sensing data management, with substantial ERS-1 responsibilities.

[14] *Launching SPOT 2-Information File*, Centre National d'Etudes Spatiales, Toulouse France, 1989; "France: Remote Sensing Program," in *Science and Technology Perspectives*, Foreign Broadcast Information Service, vol. 5, No. 4, Apr. 30, 1990, pp. 11-12.

onboard tape recording system. The satellite was reactivated in March 1992,[15] with ground operators making use of SPOT-1 imaging instruments and real-time acquisition mode. By providing operational service, SPOT-1 is being used to meet a data demand during the northern hemisphere growing season, and to reduce the workload on SPOT-2 over high-demand areas.

SPOT-2 was launched in January 1990 as a replica of SPOT-1. Only minor modifications were used in the building of SPOT-2: use of improved charge coupled devices (CCD); improved calibration housing; and the addition of a high-precision orbit determination system.

A SPOT-3 has been built and is ready for launch when needed, to assure continuity of SPOT services until the year 2000. SPOT-3 will exhibit the same capability as the first two SPOT spacecraft, but will also carry a Polar Ozone and Aerosol Measurement instrument for the USAF Space Test Program.

SPOT-4 has been approved for development, and should be ready in 1994 in the event of a SPOT-3 failure. SPOT-4 is considered the first of the second-generation Earth observation platform series. SPOT 4 will be built around an improved platform that will have an expected operational life of five years.[16] SPOT-4 will have increased on-board instrumentation capacity and performance, including more than double the electric, computing, and recording capacity. The High Resolution Visible Imaging Sensors carried onboard SPOTS 1-3 are to be upgraded to High Resolution Visible Infra-Red by the addition of a mid-infrared band (1.58-1 .75 microns) .17

Beyond SPOT-4, discussions are underway concerning synthetic aperture radar and optical instruments, such as a new stereo, high-resolution imager.[18] CNES is studying the potential for developing a microwave subfamily within the SPOT family of remote sensing satellites using the SPOT-4 spacecraft bus. Using a synthetic aperture radar, such a spacecraft could be introduced in parallel with the optical SPOT family after 2000.[19] The radar-carrying satellite would be operated on a commercial basis and would maximize use of the SPOT receiving station network, as well as commercial and product delivery facilities.

SPOT satellites transmit data to an expanding network of receiving stations. Major space imagery receiving stations are located at Toulouse, France, and in Kiruna, Sweden. Other receiving stations capable of receiving SPOT data are located in Canada, India, Brazil, Thailand, Japan, Pakistan, South Africa, and Saudi Arabia, as well as the European Space Agency's station in the Canary Islands, Spain. Actual operation of the satellite is carried out by CNES at SPOT mission control in Toulouse.

Formed in 1978 and located in Reston, Virginia, SPOT Image, Inc. provides U.S. businesses, universities, and government agencies a range of products and services based on SPOT data.[20] The worldwide commercial headquarters, SPOT Image, S. A., is anchored in France, with SPOT Imaging Services in Australia and SPOT Asia located in Singapore. SPOT distributors are present in over 50 countries around the world.

Helios

Common with the development of a SPOT-4 is the Helios reconnaissance satellite being built for the French Ministry of Defense.[21] This satellite received approval in 1988. Italy and Spain are partners in this project, contributing 14 percent and 7 percent of the funding, respectively. Helios will have a reported resolution of about 1 m. Helios-1 should be ready for launch in 1994, possibly followed 2 years later by Helios-2.

15 ''SPOT-1 Resumes Operational Service, " *SPOT Image Corporation Press Release,* Reston, VA, Mar. 27, 1992.

16 J.M. Au&~, C. Billard, and P. Ranzoli. ' 'The SPOT MKII Bus, A Key to Earth Observation in the '90s, ' presented at the 42nd Congress of the International Aeronautical Federation (IAF-91-013), Montreal, Canada, Oct. 5-11, 1991.

17 C. Fratter, Alain Baudoin et al., ''A Stereo, High Resolution Concept for the Future of the SPOT Program, ' presented at the 42nd Congress of the International Astronautical Federation (IAF-91-128), Montreal, Canada, Oct. 5-11, 1991.

18 D. Seguela, J.P. Durpaire et al., "GLOBSAT: A French Proposal for Earth Environment Monitoring from Polar Orbit,'' @F-91-120), Montreal Canada, Oct. 5-11, 1991.

19 J.P. Aguttes, D. Massonnet, and O. Grosjean. "A New Radar System for the French Program in the '00s," presented at 40th Congress of the International Astronautical Federation (IAF-89-124), Malaga, Spain, Oct. 7-13, 1989.

20 Stephane Chenard, "SPOT's Subsidized Success Story, " in *Space Markets,* February 1990, pp. 102-103.

21 *Annual Report* 1$290, Centre National D'Etudes Spatiales (CNES), Paris, France, pp. 65-68.

The Ministry of Defense has appointed CNES to act as overall system architect for Helios and has given it procurement responsibility for the Helios segment. The Western European Union (WEU) has established a facility in Torrejon, Spain, to analyze images from SPOT and Landsat. It will also receive some imagery from Helios.[22]

TOPEX/Poseidon

Launched in July 1992 aboard an Ariane booster, TOPEX/Poseidon is studying the topography of the ocean's surface and ocean currents worldwide. The project is a joint undertaking, initiated in September 1983 between France and the United States. The spacecraft is the result of the merger of two similar programs: NASA's Ocean Topography Experiment (TOPEX) and France's CNES Poseidon experiment.

The launch marked the first time a NASA spacecraft was launched by an Ariane booster.[23] The satellite should operate for at least three years and is comprised of two French and five U.S. instruments: a NASA radar altimeter; a NASA laser retroreflector assembly; a NASA frequency reference unit; a NASA TOPEX microwave radiometer; a Jet Propulsion Laboratory global positioning system demonstration receiver; a CNES solid state altimeter; and the CNES Determination d'Orbite et Radiopositionement Integre par Satellite (DORIS) receiver.

From its 1,334-km altitude, the TOPEX has a fixed ground track that repeats every 127 circuits of Earth (9.9 days). Using NASA tracking and data relay satellites, as well as laser tracking from the ground, the satellite's orbit around the Earth can be pinpointed within an accuracy of 13 centimeters. A comparison of the distance between satellite and sea surface with the distance between the satellite and the Earth's center allows for accurate topographic mapping of the ocean,

The U.S. radar altimeter operates with a prime channel of 13.6 GHz in the Ku-band and a secondary channel at 5.3 GHz in the C-band. The microwave radiometer is a four-channel, three-frequency sensor that operates at 18, 21, and 31 GHz to measure the correction for the tropospheric water vapor content of the altimeter nadir column to an accuracy of 1.2 cm. The French radar altimeter is a single-frequency (13.65 GHz) experimental sensor, with an accuracy of about 2 cm. The CNES DORIS dual-frequency (401 and 2036 Mhz) dopplerreceiver achieves an accuracy of 10 cm.

Data received from the TOPEX/Poseidon will assist in the World Ocean Circulation Experiment (WOCE), and the Tropical Ocean Global Atmosphere (TOGA) program.

JAPAN

The Japanese are engaged in an active remote sensing satellite program and are expected to expand their work in this arena, both in ground and space segments.[24] Movements into the commercial sales of remote sensing data seem likely, as Japan moves into a continuity of data flow from their own Earth Resources Satellite (JERS-1) and the Advanced Earth Observing Satellite (ADEOS).

The Geostationary Meteorological Satellite (GMS)

GMS "Himawari" series satellites have contributed to the improvement of Japan's meteorological services and development of weather satellite technology .25 Data gathered by the GMS satellites are shared with the World Weather Watch, Operational weather data, including monitoring of cloud cover, temperature profiles, real-time storm monitoring, and severe storm warning, are key missions objectives of the GMS series. The cloud distribution pictures are used in countries of Southeast Asia and the Western Pacific.

The first satellite in the GMS series was launched by a U.S. Delta rocket in July 1977, with later GMS satellites boosted by Japan's own N-II and H-1 rockets. GMS-2 and the GMS-3 were launched in August 1981 and August 1984, respectively, with the H-1 launching the GMS-4 in September 1989. Now under development for a projected 1994 launch is the GMS-5, which is expected to conclude the series.

Japan's space agency, NASDA, developed the first two GMS satellites and the Japan Meteorological

22 peter B. deSelding, "Potential Partners Give Helios Follow-On Cool Response,' ***Space News,*** June 28, p. 5.

23 R, Hall, ''TOPEX/Poseidon Satellite: Enabling a Joint U, S. French Mission for Global Ocean Study,' presented at 41st congress Of the International Astronautical Federation, (IAF-9O-1O1), Dresden, Germany, Oct. 6-12, 1990.

24 *NASDA-National Space Development Agency of Japan, Tokyo,* Japan, 1991.

25 *Geostationary Meteorological Satellite-5*, National Space Development Agency of Japan, 3/10T, Tokyo, Japan, 1991.

Agency was in charge of the installation of ground facilities needed for their operations. Since GMS-3, the two agencies share the development costs of the satellite. NASDA is responsible for development efforts, while the Japan Meteorological Agency manages the operation of the satellites and the distribution of data.

Design of the GMS, which is manufactured by Hughes Communications and Space Group and Japan's NEC, draws heavily from the Hughes-built U.S. GOES meteorological satellite. The GMS satellites are spin-stabilized, and carry radiometers, the space environment monitor, along with a data collection system, which gathers environmental data from ground-based instruments. The GMS-3 was replaced by the GMS-4 as the primary GMS satellite, but is still capable of transmitting cloud photos over the earth 28 times per day. GMS-4 provides 1.25-km resolution in the visible channel, and 5-km resolution in the infrared charnel. Sensors onboard the GMS-4 include a single imaging Visible and Infrared Spin Scan Radiometer (VISSR) operating in 0.5 to 0.75 microns visible band and 10.5 to 12.5 microns in the infrared band. This instrument provides a full-disc Earth image in less than a half hour, simultaneously in both visible and infrared bands. The visible channel consists of four detectors (with four backup detectors) that scan simultaneously, covering a 1.1-km area. The GMS-4 also carries a space environment monitor to survey radiation levels at geostationary altitude and to monitor solar protons, electrons, and alpha particles.

GMS-5 will be launched in late 1994, and will be similar to the GMS-4 design. It will carry a Search and Rescue experiment on behalf of the Ministry of Transport of Japan.

Marine Observation Satellite (MOS-1, MOS-1b)

The MOS-1 is Japan's first domestically developed Earth observation satellite.[26] MOS-1 was launched in February 1987 from Tanegashima Space Center by an N-II rocket. Its successor, MOS-lb, was launched by a H-I rocket in February 1990. These spacecraft were sent into a sun-synchronous orbit of approximately 909 km and have a 17-day recurrent period, circling the Earth 14 times a day. The two spacecraft can be operated in a simultaneous and/or independent mode.

MOS-1 and MOS-lb (also called MOMO-1 and MOMO-lb) are dedicated to the following mission objectives:

- Establishment of fundamental technology for Earth observation satellites;
- Experimental observation of the Earth, in particular the oceans, such as water turbidity of coastal areas, red tide, ice distribution; development of observation sensors; verification of their functions and performance;
- Basic experiments using the MOS data collection system.

Each of the spacecraft carries three sensors: a Multispectrum Electronic Self-Scanning Radiometer; a Visible and Thermal Infrared Radiometer and a Microwave Scanning Radiometer (table D-l). Both satellites are designed for a two-year lifetime.

Facilities to receive data directly from the MOS series are located at Japan's Earth Observation Center in Hatoyama-cho, Hiki-gun, Saitama prefecture. Data processing facilities have also been set up by NASDA at the Remote Sensing Center of the National Research Council of Thailand, located in a suburb of Bangkok. This Thailand station can receive MOS data over Thailand, Bangladesh, Bhutan, Cambodia, Malaysia, Vietnam; and part of China, India, Indonesia, Nepal and Philippines. The Thailand collection center transports monthly data to Japan's Earth Observation Center and NASDA for processing and generation of products.

MOS products are available for a fee from the Remote Sensing Technology Center of Japan (RESTEC). RESTEC was established under the guidance of the Science and Technology Agency and NASDA in 1975 as a foundation, with the assistance of Mitsui & Co., Ltd. and the Mitsubishi Corporation.

Earth Resources Satellite-1 (JERS-1)

JERS-1 is a joint project of the Science and Technology Agency, NASDA, and the Ministry of International Trade and Industry (MITI). JERS-1 was

[26] *Marine Observation Satellite-i,* National Space Development Agency of Japan, 8/5T, Tokyo, Japan, 1990. Keiji Maruo, "Remote Sensing Activities in Japan, ' in *Space Commercialization: Satellite Technology,* edited by F. Shahrokhi, N. Jasentuliyana, and N. Tarabzouni, vol. 128 of *Progess in Astronautics and Aeronautics*, American Institute of Aeronautics and Astronautics, Washington, DC, 1990.

[27] *Earth Resources Satellite-1*, National Space Development Agency of Japan, 3/10T, Tokyo, Japan, 1991.

launched by an H-I rocket in February 1992,[27] Problems with a balky radar antenna were overcome in the early months of the mission.

The JERS-1 is Japan's third domestic remote sensing satellite (following the MOS-1 and MOS-lb) and will observe Earth using optical sensors and an L-band SAR for two years. JERS-1 will enable the overlaying of optical multispectral data with all-weather radar imagery. JERS-1 was placed in a sun-synchronous orbit of approximately 570 km. Its recurrent period over the same location is 44 days.

The primary purpose of JERS-1 is to verify functions and performance of optical sensors and a synthetic aperture radar, and to establish an integrated system for observing the Earths resources. Earth observations are to focus on land use, agriculture, forestry, fishery, environmental preservation, disaster prevention, and coastal zone monitoring.

The JERS-1 radar system has day/night and all-weather observation capabilities. Resolution of the radar is 18 meters with a swath width of 75 km. The SAR is capable of an off-nadir angle of 35 degrees (table D-l), An onboard recorder records SAR and OPS data when no data receiving station is available, allowing JERS-1 to attain global coverage.

In Japan, JERS-1 data are received at NASDA'S Earth Observation Center, Saitama. In addition, .JERS -1 data are received at the Tokai University in Kumamoto Prefecture, the Showa Base in the Antarctic, and the Thailand MOS-1 station. Under a NASDA-NASA Memorandum of Understanding, the NASA-funded SAR station in Fairbanks, Alaska, also receives JERS-1 data. These data overlap the SAR data from the already-orbiting European ERS-1 mission and the Canadian Radarsat mission, planned for launch in 1994.

Advanced Earth Observation Satellite (ADEOS)

The main objective of ADEOS, the next generation of Japanese Earth observation satellites, is to continue and further advance Earth observation technology spurred by the MOS-1 and JERS-1 programs. The spacecraft is to have a 3-year lifetime.[28] ADEOS will have a sun-synchronous, 98.6 degree inclination orbit with a crossing time of 10:30 am, and a repeat cycle of 41 days.

ADEOS will verify functions and performance of two NASDA sensors, the Ocean Color and Temperature Scanner (OCTS) and the Advanced Visible and Near Infrared Radiometer (AVNIR). The OCTS will be used for marine observation with high precision, and the AVNIR for land and coastal observation with high resolution.[29]

NASA plans to fly the Total Ozone Mapping Spectrometer (TOMS) aboard ADEOS, as well as a NASA Scatterometer (NSCAT), which will provide accurate measurements of ocean surface winds. Such a device was demonstrated during the U.S. Seasat program in 1978.

Along with the U, S.-provided sensors, the Interferometric Monitor for Greenhouse Gases (IMG) will be provided by the Ministry of International Trade and Industry of Japan, the Improved Limb Atmospheric Spectrometer and the Retroreflector in Space will be provided by the Environment Agency of Japan. Lastly, the Polarization and Directionality of the Earth's Reflectance (POLDER) instrument is to be provided by the French space agency, CNES,

The ADEOS program will also conduct experiments on Earth observation data relay using the Engineering Test Satellite-VI and the Experimental Data Relay and Tracking Satellite to enhance global observation capabilities. Lastly, Japanese officials expect to demonstrate the ADEOS modular design they believe necessary to build future Japanese polar-orbiting platforms.

ADEOS was initially to be launched by the H-II rocket in early 1995, but delays in the H-II program and problems integrating non-Japanese instruments have caused a slip in schedule. Japan now plans a February 1996 launch.

The OCTS instrument planned for ADEOS is to be a multispectral radiometer designed to measure global ocean color and sea surface temperature simultaneously during the day. It is based on the VTIR instrument flown on the MOS-1 series. OCTS spatial resolution will be approximately 700 meters, with a 1,400-krn swath width. The OCTS will be pointable on

28 *(ADEOS) Advanced* Earth *Observing* Satellite, National Space Development Agency of Japan, 3/10T, Tokyo, Japan, 1991.

29 N. Iwasaki, Makoto Kajii et al., ' 'Status of ADEOS Mission Sensors, ' presented at 42d Congress of the International Astronautical Federation (IAF-91-144), Montreal, Canada, Oct. 5-11, 1991.

command and capable of tilting along track to either side of nadir.

The AVNIR is a high spatial resolution multispectral radiometer for Earth observing during the day in visible and near-infrared regions. AVNIR is a third-generation sensor using CCD technology, preceded by MESSER of the MOS-1 and OPS of the JERS-1. The sensor swath width is approximately 80 km. AVNIR is equipped with a pointing mechanism that selects the observing path arbitrarily in the cross track direction of ADEOS flight.

Major specifications of the sensors aboard ADEOS are as follows:

- The NASA *Scatterometer (NSCAT)* can measure surface wind speed and direction over the global oceans. Swath width: 1,200 km; frequency: 13.995 GHz; wind speed measurement accuracy: 2 m/s.; direction accuracy of 20 degrees (at spatial resolution of 50 km). This sensor will observe globally, day and night;
- The NASA *Total Ozone Mapping Spectrometer* (TOMS) will observe ozone changes, evaluate changes in ultraviolet radiation and sense sulfur dioxide in the atmosphere. Swath width: 2,795 km; wavelengths: 304.0, 312.5, 325.0, 317.5, 332.6 and 360 microns. This sensor will operate in the day on a global basis;
- The CNES *Polarization and Directionality of the Earth's Reflectance (POLDER)* sensor will observe solar radiation reflected by the Earth's atmosphere. Swath width: 1,440 X 1,920 km; wavelengths: 0.443, 0.490, 0.520, 0.565, 0.670, 0.765, 0.880, 0.950 microns. This device will operate in the day on a global basis;
- MITT's *Interferometric Monitor for Greenhouse Gases (IMG)* will observe carbon dioxide and other greenhouse gases. Swath width: 20 km; wavelengths: 3.3-14 microns. This sensor will observe globally, day and night;
- Environment Agency of Japan's *Improved Limb Atmospheric Spectrometer (ILAS)* will observe the micro-ingredients in the atmosphere over high-latitude areas on the Earth's limb. Wavelengths: 0.75-0.78 and 6.2-11.8 microns. This sensor will operate on a regional basis;
- Environment Agency of Japan's *Retroreflector in Space (RIS)* that measures ozone, fluorocarbons, carbon dioxide, etc., by laser beam absorption. Laser beam is transmitted from ground station and reflected on ADEOS. Wavelengths: 0.3-14 microns. This experiment will be done on a regional basis.

Mission operation of ADEOS will be controlled from the NASDA Earth Observation Center (EOC). However, the limited visibility of ADEOS by the EOC will require use of foreign, near-polar ground stations as well, Data rate for direct transmission from ADEOS is a maximum of 100 megabits per second (Mbps).

Future Planning

Future plans by Japan in Earth observation satellites center on a number of post-ADEOS sensors and satellites, as well as enhancement of the remote sensing ground segment, data networks, remote sensing training activities, and marketing.[30]

Tropical Rainfall Measurement Mission (TRMM)-TRMM is detailed in appendix A.

Japanese Polar Orbiting Platform (JPOP)--Japanese officials expect this platform to succeed ADEOS in the late 1990s and to constitute a Japanese contribution to the international Earth observation system. The JPOP is expected to be launched by H-II rocket into Sun-synchronous orbit after 1998.

Ground Facilities—Use of NASDA'S Earth Observation Center (EOC) will increase given its role in the data reception and processing of Landsat, SPOT, MOS-1, MOS-lb, JERS-1 and ADEOS data.

Data Distribution

The role of the Remote Sensing Technology Center of Japan (RESTEC) will likely grow in future years.[31] RESTEC handles data distribution for Landsat, MOS, and SPOT to general users in Japan and foreign customers. NASDA data policy for MOS-1 is to charge for the cost of reproduction and handling. NASDA is responsible for processing JERS-1 data, but RESTEC

30 *Monitoring the Earth Environment from Space: A Scenario of Earth Observation for the Next Decade,* National Space Development Agency of Japan (NASDA), Tokyo, Japan.

31 *RESTEC, Remote Sensing Technology Center of Japan, To&o,* Japan, 1991.

will distribute the NASDA-processed JERS-1 data to Japanese and foreign users.

Japanese geography and politics permit only one satellite tracking and receiving facility, which does not view Earth-orbiting spacecraft often enough to permit global data acquisition and relay to Earth of tape recorded data. Until Japan establishes a data relay satellite capability, it must rely on international cooperation to obtain data from its satellites.[32]

COMMONWEALTH OF INDEPENDENT STATES (CIS)

The former Soviet Union's space activities show a great and expanding interest in Earth observation, not only for military purposes, but for assessing resources on a regional and global scale.[33]

Beyond military spaceborne reconnaissance assets, the Soviet meteorological and remote sensing programs have been forged into an integrated network, comprising various spacecraft. Today the CIS operates eight different types of space platforms-both piloted and automated spacecraft-that provide global environmental data, and it is proposing even more systems for the future.[34] This network is comprised of Meteor 2 and Meteor 3-series satellites; the Okean-O spacecraft; the Resurs-0, Resurs-Fl and Resurs-F2 satellites; and the piloted Mir space station complex.

Soviet authorities have claimed that their nation's meteorological and remote sensing satellites provide an economic savings of some one billion rubles each year. Indeed, Earth observation data are widely used in the former Soviet Union for land and forestry management, mapping soil erosion threats, studying ice situations in polar areas, and monitoring earthquake and avalanche hazards.[35]

Meteor

Meteor was the first civil applications satellite deployed by the former USSR. It is comparable, in many ways, to the U.S. NOAA series. Following a long stretch of testing under the Cosmos satellite label, the first Meteor was identified as such in 1969. Numbers of Meteor l-class spacecraft were launched and then replaced (after 1975) by the current Meteor 2-class spacecraft and (after 1985), by the Meteor 3 satellite. Meteor 2 and Meteor 3 satellites are routinely launched, typically twice a year.

Meteor 2 satellites are placed in 950-km polar orbits, with two or three of this class of spacecraft in operation at all times. Grouped in a constellation, individual Meteor 2 satellites gather data from one-fifth of the globe during a single circuit of Earth, relaying data on clouds, ice cover, and atmospheric radiation levels. Two of these satellites provide 80 percent coverage of the Earth's surface in six hours.

Onboard a Meteor 2 satellite are scanning radiometers for direct imaging and global coverage; a scanning infrared radiometer for global coverage; and a scanning infrared spectrometer, covering eight channels (table D-l). Automatic Picture Transmission (APT) is carried out from a Meteor 2-class satellite at frequencies between 137 and 138 Mhz, therefore compatible with international APT formats. Some 15,000 APT terminals exist across the CIS territories.

The newer Meteor 3-class satellites are being placed into higher orbits, 1,200 km, in order to prevent coverage gaps in the equatorial regions. Payload of Meteor 3 spacecraft are similar to Meteor 2 satellites (table D-l). Also onboard Meteor 3-class spacecraft is a radiation measurement device to record electron and proton charges in the space environment.

The Meteor 3 satellites are designed to accommodate additional payload packages. For example, the August 1991 Meteor 3 launch carried NASA's Total Ozone Mapping Spectrometer (TOMS).[36] Russia plans to fly Earth radiation budget instruments provided by CNES aboard a future Meteor 3.

Russian authorities have discussed developing a Geostationary Operational Meteorological Satellite

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32 See Shaffer, op. cit. footnote 6.

33 Nicholas L. Johnson, *The Soviet Year in Space 1990*, Teledyne Brown Engineering, Colorado Springs, CO, 1991.

34 Neville Kidger, "The Soviet Unmanned Space Fleet,'' *Spaceflight*, vol. **32**, July 1990, pp. 236-239.

35 Marcia Smith, *Soviet Space Commercialization Activities*, CRS Report for Congress, Congressional Research Service, 88-473 SPR, Washington DC, July 6, 1988. Kazakov, Roudolf V. *Applications of Soviet Remote Sensing Data for Studies of Natural Resources and Mapping Purposes*. Sojuzkarta Company, Moscow, 1991.

36 Brian Dunbar and Dolores Beasley, *NASA* News, "Soviets to Launch NASA Instrument to Study Ozone Levels,' Release 91-127, NASA Headquarters, Washington, DC, Aug. 12, 1991; *NASA Meteor-3/TOMS Press Kit,* NASA Headquarters, Washington, DC, Aug. 12, 1991.

(GOMS) that would carry a sensor suite similar to the NOAA GOES-Next satellite series. Economic turmoil in Russia has delayed GOMS deployment. GOMS would acquire, in real time, television images of the Earth's surface and cloud cover in the visible (0.4-0.7 microns) and infrared (10.5 -12.5 microns) regions of the spectrum, providing resolutions of 1-2 km and 5-8 km, respectively, with a total field of view of 13,500 km **X** 13,500 km.

Okean-O

Toward the end of the 1980s, the former Soviet Union developed the Resurs system of remote sensing satellites, of which Okean-O is a part. Okean-O is a series of all-weather oceanographic satellites with real aperture side-looking radars. These satellites are built to provide all-weather monitoring of ice conditions; wind-induced seaway, storms and cyclones; flood regions; and ocean surface phenomena.

A standard Okean-O is placed in a 630- to 660-krn orbit. The spacecraft carries a side-looking radar, a microwave scanning radiometer, a medium-resolution multispectral (4-channel) scanner and a high-resolution multispectral (2-channel) scanner.

Okean satellites make use of the APT frequency of 137.4 Mhz. A data collection and distribution system called Condor allows data to be culled by Okean spacecraft from ground-based instruments, then relayed to ground stations. These data can then be relayed directly to ships at sea via communications satellites.

A follow-on to Okean-O has been discussed for launch in 1993. Significant changes include addition of a second side-looking radar. The modified Okean would then provide coverage on both sides of the satellite's flight path, sweeping out a wider swath, but retaining the same resolution. In addition, a more advanced multispectral scanner will make use of three visible bands with a resolution of 200 meters and three infrared bands yielding a 600-meter resolution.

Resurs-O

The Resurs-O spacecraft are roughly comparable to the U.S. Landsat system. These digital Earth resources satellites, derived from the Meteor series, circle Earth at altitudes of 600 km to 650 km in sun-synchronous orbit. They carry a multiple multispectral instrument package, operating in the visible to thermal infrared, and have been touted for their ability to detect industrial pollution.[37] Remote sensing hardware aboard Resurs-O comprise two high-resolution, multiband (3-channel)CCD scanners, a medium-resolution multiband (5-channel) conical seamer, a multiband (4-channel) microwave radiometer, and a side-looking synthetic aperture radar. The Resurs-O spacecraft can process some data in orbit and relay realtime data at 7.68 mbps.

Russians officials plan a follow-on to this series carrying high-resolution optical sensors capable of 15- to 20-meter resolution. Discussions have also been held about establishing commercial Resurs-O receiving stations in Sweden, as well as the United Kingdom.

Resurs-F

This class satellite mimics CIS military reconnaissance spacecraft by using a capsule containing exposed film that is ejected by the spacecraft and returned to Earth under parachute.[38] Resurs-F1 and Resurs-F2 spacecraft use the Vostok reentry sphere, used previously to launch the frost cosmonauts into orbit.

The Resurs-Fl typically flies at 250 km to 400 km altitude for a two-week period and carries a three-channel multispectral system which includes three KATE-200 cameras and two KFA-1OOO cameras. The KATE-200 camera provides three spectral bands for Earth observing (table D-1) at a swath width of 180 km. Stereoscopic imagery can be accomplished with an overlap of 20, 60, or 80 percent. Resolution varies, according to spectral band and survey altitude, from 10 to 30 meters. The KFA-1OOO cameras provide 300 *x* 300 mm frame window size with images capable of being taken in stereo, with an overlap of 60 percent.

The Resurs-F2 spacecraft normally cover Earth in 3- to 4-week periods (sometimes as long as 45 days) in a variable orbit of 259 km to 277 km. Onboard is the MK-4 camera system which can survey the Earth using a set of four cameras, Six spectral channels from 0.635 to 0.700 are available. Imagery provided by Resurs-Fl

[37] *Resours-O-Space System for Ecological Monitoring, The* Soviet Association for the Earth Remote Sensing, MOSCOW, December 1990.

[38] "USSR: Orbital Materials Processing" also details Earth resources photographic return capsules. *Science and Technology Perspectives*, Foreign Broadcast Information Service, vol. 5, No. 6, June 29, 1990, pp. 5-7.

and F2 spacecraft are being offered commercially through the Soyuzkarta company .39

Almaz

Recently, the CIS collected a wealth of data from its A1maz satellite. Almaz-1 was a large spacecraft equipped with synthetic aperture radar (SAR) for day/night operations. Launched in March 1991 and operated until October 1992, the Almaz followed a 300-krn-high orbit, and provided coverage of an appointed region at intervals of one to three days. Its orbital position was corrected every 18-31 days, and accounted for considerable fuel use. The orbit was also changed frequently to comply with customers' requests. A similar bus-sized, radar-equipped prototype spacecraft-Cosmos-l 870-was launched in 1987, and was based upon that of the piloted Salyut and Mir space stations.[40] Cosmos- 1870 operated for two years, producing radar imagery of 25 to 30 meters resolution.

An Almaz Corporation was formed to stimulate commercial use of the satellite data. G1avkosmos, the civil space arm in Russia, NPO Machinostroyenia, and the U.S.-based Space Commerce Corporation of Houston, Texas, established a joint Data Processing and Customer Support Center in Moscow to assist customers in using Almaz data. The French company, SPOT Image, also markets Almaz data in the United States and Canada. In 1992, Hughes STX Corp. of Lanham, Maryland, signed an agreement with Almaz Corp. of Houston to be exclusive worldwide commercial marketer, distributor, processor and licenser of data from the Almaz-l spacecraft.[41] According to some reports, Almaz data sales have been slow; a sales target of $2 million for 1992 may have been unrealistic.[42]

The Russians would like to launch and operate an Almaz-2. However, lack of capital and a weak market for Almaz data have prevented such arrangements.

Mir

Since the first crew occupied the Mir space station in 1986, cosmonauts onboard the orbiting complex have completed numerous experiments dedicated to Earth remote sensing. Various Earth imaging systems have been flown to the Mir, such as the Kate-200, KFA-1OOO, and the MK4 camera hardware also used on board the Resurs-1 and Resurs-2 satellites.

The Kavant-2 module, attached to the central core of the Mir in December 1989, carried the MKF-6M camera, capable of imaging Earth at a resolution of 22.5 m.

Of significance is the potential for further expansion of the Mir complex to include a Priroda remote-sensing module, which has been under development for several years. Russia plans to attach the Priroda module to Mir in late 1994. Use of instruments carried inside the module would be geared to monitoring ocean surface temperatures, ice cover, wind speed at the ocean surface, and surveying concentrations of aerosols and gases in the atmosphere.

INDIA

India has invested heavily in space-based remote sensing. The Indian Space Research Organization (ISRO) is the primary government space agency for the country, organized under the government's Department of Space. The ISRO Satellite Centre is the primary laboratory for design, building, and testing of Indian satellites.

A National Remote Sensing Agency was established in 1975 and is charged with shaping an operational remote sensing system for India. Since 1979, India's central Earth station in Shadnagar has received U.S. NOAA spacecraft data, as well as information transmitted by Landsat, SPOT, and the country's own Indian Remote Sensing (IRS) spacecraft. IRS is the data mainstay for India, accounting for over 72 percent of the data requests by users, followed by Landsat at 18 percent and SPOT around 6 percent .43

India's remote sensing program centers on use of the Indian Satellite (INSAT) series, two Bhaskara spacecraft, the Rohini satellites, and the Indian Remote

39 *Soyuzkarta*. **Foreign Trade** Assoiation, Kartex, Moscow. Sovero No. 28 1/88.

40 *Buyer's* Guide *Almaz* Radar Remote *Sensing Satellite*. Space Commerce Corporation, Houston. Texas; William B. Wirin, ''New Vision from Space: ALMAZ," *Aerospace & Defense Science,* October/November 1990, pp. 19-22, William B. Wirin, *Almaz: Looking Through Clouds,* presented at 1 1th Symposium EARSel, Graz, Austria, July 3-5, 1991.

41 "Hughes STX Signs Agreement on Data from Russian Satellite, " *The Washington Post,* Mar. 2, 1992, p. 7.

42 Daniel J. Marcus, ''Ahnaz Team Fears Shutdown Without More Foreign Sales,' *Space News,* vol. *3,* No. *3,* Jan. 27-Feb. 2, 1992, p. 23.

43 *Inventory of Remote Sensing Facilities and Activities in the ESCAP Region*, United *Nations* Inventory Report: India, December 1990.

Sensing satellite series: IRS-1A and IRS-lB, Along with the development of these spacecraft, India has pursued an independent launch capability, although U. S., Soviet, and European boosters have also been utilized to launch Indian satellites.

Bhaskara

The Bhaskara series served as experimental spacecraft, launched by Soviet boosters in 1979 and 1981. The Bhaskara spacecraft were each placed in a roughly 400-mile-high Earth orbit. Both satellites carried slow scan vidicon equipment and passive microwave radiometers. The satellite's vidicon equipment operated in 0.54-0.66 micron and 0.75-0.85 micron spectral channels, and produced images for land use, snow cover, coastal processes, and for forestry purposes. The radiometers operated in the 19, 22, and 31 GHz range and collected data on sea surface phenomena, water vapor and liquid water content.

Rohini

The Rohini series began with Rohini-1 launched into Earth orbit in July 1980, using India's national booster, the SLV-3, While the initial Rohini was apparently used to measure rocket performance, Rohini-2, orbited in May 1981, carried remote sensing equipment but operated for only 9 days. Rohini-3 was orbited in April 1983 and also carried equipment for "remote sensing' purposes. Material provided by ISRO for this assessment contains no mention of the Rohini series. Western officials have claimed these satellites are designed to assist in the creation of an Indian military reconnaissance capability.

INSAT

The Indian National Satellite system combines both Earth observation and domestic communications functions. The INSAT spacecraft built to date have been of American design, purchased by India from Ford Aerospace. The INSAT-lA was launched in April 1982 by a U.S. Delta rocket, but suffered problems during deployment of spacecraft hardware. An INSAT 1B was subsequently launched using a U.S. Space Shuttle in August 1983. INSAT 1C was launched by an Ariane booster in July 1988, and an INSAT ID was rocketed into orbit by a commercial U.S. Delta in June 1990.

INSAT remote sensing activities center on using a two-channel Very High Resolution Radiometer (VHRR) that yields 0.55-0.75 micron visible and 10.5-12.5 micron infrared images of the Earth. From their geostationary altitude, INSAT spacecraft produce imagery every 30 minutes. INSAT-series spacecraft have a design life of some ten years. In addition to imagery, the INSAT satellites relay data collected from some 100 hydrological, oceanographic, and meteorological ground stations.

INSAT-2 is under development, and will be constructed by ISRO and Indian companies and launched by an Ariane booster. Similar in capabilities to previous INSATS, the INSAT-2 is expected to yield higher VHRR resolution in the 2 km visible and 8 krn infrared. A series of two INSAT-2 test spacecraft and three additional operational satellites is now being planned.

Indian Remote Sensing Satellite (IRS)

As India's first domestic dedicated Earth resources satellite program, the IRS series provides continuous coverage of the country, with an indigenous ground system network handling data reception, data processing and data dissemination. India's National Natural Resources Management System uses IRS data for many projects.

To date, two IRS satellites have been launched: IRS-1A in March 1988 by a Russian launcher; and IRS-l B in August 1991, also launched by a Russian booster, Both IRS spacecraft carry identical onboard hardware.

IRS-1A and IRS-lB are the backbone of India's Natural Resources Management System; both are in 904-km polar sun-synchronous orbit. Each carries two payloads employing Linear Imaging Self-scanning Sensors (LISS), which operate in a pushbroom scanning mode using CCD linear arrays. The IRS satellites have a 22-day repeat cycle. The LISS-I imaging sensor system constitutes a camera operating in four spectral bands compatible with the output from Landsat-series Thematic Mapper and SPOT HRV instruments (table D-l), Geometric resolution of the LISS-I is 72 meters at a swath of 148 km. The LISS-IIA and B are comprised of two cameras operating in 0.45 to 0.86 microns with a ground resolution of 36.5 meters, each with a swath of 74 km. The two units are located on either side of the LISS-I and view either side of the ground track with a 3-km lateral overlap.

Data products from the IRS can be transmitted in real time, or by way of tape recorder. As part of the National Remote Sensing Agency's international services, IRS data are available to all countries which are within the coverage zone of the Indian ground station located at Hyderabad: Afghanistan, Bahrain, Bangladesh, Bhutan, Burma, Cambodia, China, Indonesia, Iran, Laos, Malaysia, Maldives, Mali, Nepal, Oman, Pakistan, Qatar, Saudi Arabia, Singapore, Socotra, Somalia, Sri Lanka, Thailand, United Arab Emirates, the CIS (former USSR), Vietnam, and Yemen. These countries can receive the raw/processed data directly from the NRSA Data Center.

IRS Follow-on Series

Second-generation IRS-l C and 1D satellites are being designed to incorporate sensors with resolutions of about 20 meters in multispectral bands and better than 10 meters in the panchromatic band apart from stereo viewing, revisit and onboard data recording capabilities. ISRO is planning to add a band in Short Wave IR (SWIR) at a spatial resolution of 70 meters. In addition, a Wide Field Sensor (WiFS) with 180 meters spatial resolution and a larger swath of about 770 km is planned for monitoring vegetation.

India expects to launch IRS-l C sometime in 1994, while IRS-l D will be launched in 1995 or 1996. An IRS-series spacecraft capable of microwave remote sensing—similar to Europe's ERS-1—is also under consideration for launching in the late '90s.

Ground Facilities

IRS data are regularly acquired at the National Remote Sensing Agency (NRSA) Earth station at Shadnagar, Hyderabad. Five regional remote sensing service centers have been established to provide users digital analysis and interpretation of IRS data and other remotely sensed satellite information. The centers are located at Bangalore, Dehra Dun, Jodhpur, Nagpur and Kharagpur. Also, state remote sensing centers in all 21 states have been established to carry out projects of direct relevance to the states and/or participate in national programs.

The use of low-cost PC-based digital image processing systems have permitted widespread applications of remote sensing data throughout India. IRS data have been used to monitor drought, map saline/alkaline soils, estimate large area crop production, and inventory urban sprawl of all cities with populations greater than one million.

CHINA

China's remote sensing activities have been tied to satellite communications and geographic information systems designed to alert the government of environmental situations, such as impending flood conditions and to estimate disaster damage.[44] Capable of launching its own satellites with its Long March boosters, China's remote sensing work centers around the Feng Yun (FY) satellite series to gather meteorological data,[45] while China's FSW (see below) recoverable satellites have returned film of remotely sensed scenes to Earth-useful for commercial and military purposes.[46] In December 1986, the Chinese inaugurated operational use of a Landsat receiving station, purchased from the United States. China pays a $600,000 annual access fee to EOSAT to use the Landsat ground terminal.[47] China can market the data without restriction. The station is positioned at Miyun, northeast of Beijing, with processing facilities situated northwest of Beijing. Lastly, China and Brazil are cooperating on the Earth Resources Satellite system comprised of two spacecraft and several Earth stations.

Feng Yun (FY)

The Feng Yun (FY) "Wind and Cloud" satellites are built for meteorological purposes, to monitor conditions of China's vast territory and coastline, Two of the FY series have been launched since September 1988.

While China can obtain realtime cloud NOAA/TIROS-N data, this information is not in the three-dimensional

44 C. Fang-yun, Tong Kai, and Yang Jia-chi, "The Proposal About Constructing the National Disaster Monitoring, Forecast and Control System," presented at 42d Congress of the International Astronautical Federation, (IAF-91-113), Montreal, Canada, Oct. 5-11, 1991.

45 M. Zhizhong, and Xu Fuxiang, "Chinese Meteorological Satellites and Technical Experiment of the Satellites," presented at 42d Congress of the International Astronautical Federation (IAF-91-017), Montreal, Canada, Oct. 5-11, 1991.

46 Recoverable *Satellite—FSW—Micorgravity Test Platform*, Chinese Academy of Space Technology, Beijing, China.

47 Marcia Smith, *Space Commercialization in China and Japan*, CRS Report for Congress, (88-519 SPR), Congressional Research Service, Washington, DC, July 28, 1988, pp. 8-9.

format needed for medium and long-range weather forecasting, numerical forecasting, and climate research. Similarly, China has access to data from the Japanese geostationary meteorological satellite but this satellite is positioned to the east of China, seriously distorting cloud imagery of the vast western part of China. Therefore, beginning in the 1970s, China started its own polar-orbiting meteorological satellite program, followed in the mid-1980s with plans to develop a geostationary meteorological satellite.

The FY-1 had a one-year design lifetime, but failed after 39 days. During its life, China's first experimental weather satellite relayed high-quality imagery to Earth. While four visible channels from the satellite broadcast successfully, signals from the infrared charnel were poor, apparently as a result of contamination of the infrared sensing hardware at the launch site. An attitude control failure shortened the mission of the satellite.

The FY-1 made 14 cycles per day (seven passes per day over Chinese territory) in a near polar sun-synchronous orbit with an altitude of 900 km. Part of its instrument package contained two scanning five-channel Advanced Very High Resolution Radiometers (AVHRRS), four in the visible spectrum and one in infrared (table D-1). Day and night cloud images were acquired, permitting measurements of sea surface state and silt and chlorophyll concentrations in brine.

Use of C band frequency permitted the FY-1 to incorporate a High Resolution Picture Transmission system in a data format the same as that of the NOAA/TIROS-N and with a ground resolution of 1.1 km. Also, an APT transmitter sent realtime cloud images with a resolution of 4 km.

Hardware changes were made in the design of FY-l B, orbited in September 1990. Further refinement of the FY-1 class satellite, according to some sources, suggest China may launch an FY-l C and FY-lD satellite, then embody that technical expertise into a fully modified FY-1 satellite.

At present, the development of FY-2A is underway, with a launch set for the mid-1990s. This satellite will be placed in geostationary orbit over China and is to provide almost instantaneous weather/climate data collection over every region of China and Asia, as well as most parts of Oceania.

Fanhui Shi Weixing (FSW) Recoverable Satellite

The Chinese FSW commercial platform series is capable of carrying various kinds of equipment into orbit, including remote sensing hardware. Presently, an FSW-I and larger FSW-II platform are being made available by the Chinese Academy of Space Technology. These are geared primarily for microgravity research purposes. The FSW-I recoverable satellite can remain in orbit for 5 to 8 days and is replete with telemetry for realtime data transmission, or tape recorders for data storage. Recoverable payloads of 20 kg are possible. For the FSW-II, recoverable payload weight of 150 kg is possible, with the satellite able to remain in orbit for 10 to 15 days. The price for use of an FSW recoverable satellite has been reported to be $30,000 to $50,000 per kilogram.

The FSW is similar to the satellite recovery concept used in the U.S. Air Force Discovery program of the late 1950s and early 1960s. Previous FSW returnable capsules have reportedly been used for capturing high-quality imagery for military reconnaissance purposes.

China-Brazil Earth Resources Satellite (CBERS)

Initiated by an agreement signed July 6, 1988, China and Brazil have jointly pursued a cooperative project to build two remote sensing satellites, each capable of SPOT-like performance using linear CCDs.[48] The CBERS-1 and CBERS-2 would be designed by the Xian Research Institute of Radio Technology, which would also supply the imaging system. Brazil's Institute of Space Research (INPE), near Sao Paulo, would be responsible for satellite structure, power supply, data collection system and other items.

China would take on the larger financial stake for the CBERS satellites-70 percent to Brazil's 30 percent. In U.S. dollars this percentage split represents an investment of $105 million, with Brazil spending $45 million.

Prior to the first CBERS launching, Satellite de Coleta de Dados 1 (SCD-1) was orbited in 1992. This first Brazilian-made satellite is an environmental data collection satellite to be followed by an SCD-2 launch

48 *China-Brazil Earth Resources Satellite-CBERS*, Institute de Pesquisas Espaciais, Sao Jose dos Campos, Brazil. [no date]

in 1993. Each will be placed in 750-km orbits. Two Sensoriarnento Remoto (SSR) satellites are also to be launched, in 1995 and in 1996, respectively. Carrying CCD cameras capable of 200-meter resolution, the SSR-1 and SSR-2 are to be placed in 642-km, sun-synchronous orbits.

The CBERS project completed its phase B work in 1989, when the preliminary design of the satellite was completed. The project is currently in the development and engineering phase with some contracts with Brazilian industries established. Because of budget difficulties, work on the project has been slowed.

Launch of the CBERS-1 appears now to be planned for 1995, with the satellite placed in a 778-km sun-synchronous orbit. CBERS-2 launch is targeted for 1996. The CBERS five-channel linear CCD would provide visible and panchromatic coverage. Spectral bands would range from 0.51 microns to 0,89 microns. Ground resolution of the CCD camera is 20 meters. A CBERS infrared multispectral scanner would include four channels between 0.5 and 12.5 microns. The infrared multispectral scanner would yield an 80-meter ground resolution, CBERS imagery is designed to rival SPOT and Landsat data. China's Great Wall Industry Corp. and Brazil's Avibras Aeroespacial in *1989* signed a joint venture agreement to establish INSCOM, a company that would specialize in establishing a ground data handling network. Like China, Brazil has a Landsat ground station, operating a facility since 1973, A data processing center was established there the following year.

INTERNATIONAL COOPERATION IN REMOTE SENSING

Global climate change knows no national borders. Satellite observations of the Earth, therefore, must in time become a truly international activity. A myriad of organizations now play key roles in the attempt to coordinate the scientific study of Earth's biosphere, These include groups from the national and international scientific community; government agencies; and intergovernmental science bodies.[49]

Key Organizations

The International Council of Scientific Unions (ICSU)--created in 1931 as an autonomous federation consisting of 20 disciplinary scientific unions and 70 national member organizations---has endorsed and runs the International Geosphere-Biosphere Program (IGBP) to help determine the interactive physical, chemical and biological processes that regulate the total Earth system, including the influences of human actions on those processes.

The IGBP, in turn, involves the United Nations (UN) World Meteorological Organization (WMO), the United Nations Educational, Scientific, and cultural Organization (UNESCO), and the United Nations Environment Program (UNEP), which, in turn, is coordinating the World Climate Research Program **(WCRP).**

In 1988, the UN established the Intergovernmental Panel on Climate Change (IPCC), sponsored jointly by the WMO and the UNEP. The IPCC serves as a primary international forum for addressing climate change, with three working groups that: assess scientific evidence on climate change; assess likely impacts resulting from such change; and consider possible response strategies for limiting or adapting to climate change.

As a member of ICSU, the National Academy of Sciences' National Research Council (NRC) participates in the IGBP through its Committee on Global Change (CGC), which is reviewing the U.S. Global Change Research Program (USGCRP). Another NRC entity, the Committee on Earth Studies (CES), is providing the federal government with advice on the study of the Earth from space.

Remote sensing for environmental monitoring cuts across territory, airspace and economic zones of the Earth's nation states, where the systematic exchange of data or joint access will necessitate international

49 Marcia S. Smith, and John R. Justus, Mission to *PlanetEarth and the U.S. Global Change Research Program,* CRS *Report* for Congress, Congressional Research Service, 90-300 SPR, June 19, 1990; James D. Baker, "Observing Global Change from Space: Science & Technology, ' presented at Annual Meeting of the American Association for the Advancement of Science, Washington, DC, February 1991; *Climate Change: The IPCC Scientific Assessment,* J.T. Houghton, G.J. Jenkins and J.J. Ephraums, eds., Cambridge University Press, Cambridge, MA, 1990, pp. 315-328; *Assessment of Satellite Earth Observation Programs-1991*, Committee on Earth Studies, Space Studies Board, Commission on Physical Sciences, Mathematics, and Applications, Nationat Research Council, Washington, DC, 1991; and Congress of the United States, Office of Technology Assessment, *Changing By Degrees: Steps to Reduce Greenhouse Gases* (OTA-OE-O-482, Washington DC: U.S. Government Printing Office, February 1991), pp. 282-283.

agreement. Compatibility among observation systems, data exchanges, and the setting of data product standards is key to establishing a meaningful and unified global research program of Earth observation.

A recent example of this is exploratory discussions between the European Space Agency (ESA) and the Japanese Minister for Science and Technology, who also chairs Japan's Space Activities Commission.[50] Both parties agreed to study the prospects for wider cooperation between ESA and Japan on observations of the Earth and its environment, using next-generation meteorological satellites. In addition, ESA and Japan will study the relay of data by European and Japanese data relay satellites.

The following paragraphs summarize the work of three organizations that are attempting to coordinate data gathered globally, or are wrestling with the policy issues attendant to the acquisition and interpretation of remote sensing information.

Consortium for International Earth Science Information Network (CIESIN)

The U.S. Congress, on Oct. 18, 1989, mandated through Public Law No. 101-144 an effort to "integrate and facilitate the use of information from government-wide Earth monitoring systems" for understanding global change. The law stipulated that NASA should take the lead in broadening the work now planned for the Earth Observing System ''to create a network and the required associated facilities to integrate and facilitate the use of information from government-wide Earth monitoring systems. CIESIN was chartered in October 1989 as a nonprofit corporation in the State of Michigan to accomplish this. The founding members are the Environmental Research Institute of Michigan (ERIM), Michigan State University, Saginaw Valley State University, and the University of Michigan.[51] CIESIN membership has been expanded to include New York Polytechnic Institute, and the University of California.

According to CIESIN, the organizational mix brings expertise in the fields of the natural Earth sciences, remote sensing and its international applications, public policy, the social sciences, electronic networking, media, and education. The group has been established to enable scientists and policymakers to model, predict, and understand global change on an international scale. CIESIN has embarked on networking global change resources as an early priority.

Committee on Earth Observation Satellites

The Committee on Earth Observation Satellites (CEOS) was created in 1984 as a result of recommendations from the Economic Summit of Industrialized Nations. Members of CEOS are government agencies with funding and program responsibilities for satellite observations and data management. The United Kingdom served as CEOS secretariat in 1992. Japan will host the CEOS plenary in 1993, followed by Germany in 1994.

At the CEOS plenary level, agencies are represented by the head of the agency or Earth observation division: NOAA and NASA for the U. S., ASI (Wily), BNSC (UK), CNES (France), CSA (Canada), CSIRO (Australia), DARA (Germany), ESA (Europe), Eumetsat (Europe), INPE (Brazil), ISRO (India), STA (Japan), and the Swedish National Space Board.

Governmental bodies with a space-based Earth observation program in the early stages of development or with significant ground segment activities that support CEOS member agency programs may qualify for observer status. Current observers are agencies from Canada, New Zealand, and Norway.

CEOS members intend for the organization to serve as *the* focal point for international coordination of space-related Earth observation activities, including those related to global change. Policy and technical issues of common interest related to the whole spectrum of Earth observations satellite missions and data received from such are to be addressed by CEOS.

CEOS has been successful in interacting with both international scientific programs—ICSU/IGBP, WCRP—as well as intergovernmental user organizations-IPCC, WMO, the Intergovernmental Oceanographic Commission (IOC), the United Nations Environmental Program (UNEP)-in order to enhance and further focus space agency Earth observation mission planning on global change requirements.

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[50] ''ESA and Japan Meet on Space Cooperation" *ESA News Release, No. 12,* European Space Agency, Paris, France, March 11, 1992.

[51] ''Information for a Changing World-Strategies for Integration and Use of Global Change Information,'' Executive Summary of a Report to Congress, Consortium for International Earth Science Information Network (CIESIN), May 15, 1991.

Space Agency Forum on ISY (SAFISY)

The International Space Year (ISY) of 1992 promulgated the establishment in 1988 of SAFISY, a coordination group of the world space agencies.[52] SAFISY provided a mechanism, through periodic meetings, for the agencies to share ideas and pool resources in connection with the International Space Year.

Panels of experts were established by SAFISY, two of which are scientific in nature, The Panel of Experts on Earth Science and Technology monitored projects that are designed to provide worldwide assessment of threats to the environment through satellite observations and the development of predictive models. The Panel of Experts on Space Science monitored projects under the theme ‘‘Perspectives from Space, ’ emphasizing that unlimited perspectives are gained through all aspects of space science study and through venturing out into space.

A third SAFISY panel, Panel of Experts on Education and Applications, was geared to promote ISY educational activities internationally, many of which deal with satellite remote sensing.

52 Space Agency Forum on the International Space Year-Third Meeting (SAFISY-3), NASDA CM-147, Kyoto, Japan, May 17-18, l~o.