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Construction of an Integrated Earth Observation System Driven by Utilization Needs
— Promotion of GEOSS, which was Introduced at the Evian G8 Summit and Endorsed at the Gleneagles Summit —

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1 Introduction

The recent Delphi analysis[1] of important science and technology themes for Japan demonstrated that researcher interest in "Earth observation" is extremely high. Out of the 858 themes listed, 14 of the top 20 themes considered most important involved areas where Earth observation can make useful contributions including global warming, climate change, and disaster management. Despite this, the promotion of Earth observation in Japan has not necessarily been driven by utilization needs. In addition, remote sensing from space and *in situ* observations has not usually been well coordinated. These tendencies are also common in the USA and Europe, which lead the world in Earth observation.

In Japan, however, in December 2004, the Council for Science and Technology Policy (CSTP) called for "construction of an integrated Earth observation system driven by utilization needs" in its "Promotion Strategy for Earth Observation"[2]. In addition, the February 2005 Third Earth Observation Summit approved a 10-year Implementation Plan for the Global Earth Observation System of Systems (GEOSS), beginning a new initiative in international Earth observation. In other words, the strategy is now shifting away from the development of individual systems driven by technological seeds towards the construction of an integrated Earth observation system driven by utilization needs. Furthermore, in an action plan[3] agreed upon at the July 2005 Gleneagles (UK) summit of developed nations, the G8 countries agreed to promote the GEOSS 10-year Implementation Plan.

In GEOSS, the "Earth observation systems" is an integrated concept of *in situ* observation and satellite observation. The elements comprising these multiple "systems" include systems for *in situ* observation of climate, the atmosphere, oceans, disasters, ecosystems, coasts, and so on, as well as satellite observation systems carried out by Earth observation satellites equipped with various instruments. Satellite observation enables the continuous acquisition of a broad range of data, but correction of that data through comparison with *in situ* observation further increases their accuracy. Integration of data from *in situ* observation and satellite observation of a single phenomenon is the technical issue.

With the exception of weather observation, there have been no organizations that operate integrated satellite and *in situ* observation on an ongoing basis in Japan. This has been a weak point in the promotion of international Earth observation initiatives for Japan. As a result of international cooperation, the Integrated Global Observing Strategy Partnership (IGOS-P) was therefore established in 1998 as an experiment in integrated Earth observation. In IGOS-P, Japan works jointly with the USA, Europe, and others, taking the lead in such areas as climate change and the water cycle. The results of IGOS-P will serve as input for the GEOSS 10-year Implementation Plan. As data collection should continue into the future, new observation technology should be incorporated and an Earth observation system, driven by utilization needs, should be constructed. This report provides an overview of *in situ* and satellite observation and, based on the integration of these techniques now occurring in the USA and Europe and recent trends in the development of new observation technology, offers proposals on 1) the establishment of an institution to carry out ongoing satellite observation, 2) expansion of *in situ* observation through the increased utilization of ODA, and 3) the development of new satellite observation technology, driven by utilization needs.

2 Global Earth Observation System of Systems (GEOSS)

2-1 Circumstances from warnings of an Earth in crisis to GEOSS

In 1972, the Club of Rome published a research report entitled *The Limits to Growth*, predicting and warning the world of the dangers of resource depletion, food shortages, and so on that would accompany with rapid population growth on a global scale. Subsequently, with the steadily growing economy constrained by factors such as energy-conservation technology developed in response to oil crises and by the collapse of the bubble economy, the sense of crisis regarding global limits receded somewhat. The economic growth of China and India, however, has brought actualized problems such as resource use and air pollution, while the impact of greenhouse gas emissions on global warming has also become clearer. This has once again shone a spotlight on the global scale of these social problems. Table 1 depicts the course of international progress related to Earth observation since the beginning of the 21st century.

During this period, the Integrated Global Observing Strategy Partnership (IGOS-P) was implemented, beginning in 1998. By means of international cooperation, various types of existing data on eight global themes such as marine, atmospheric chemistry, the carbon cycle, and the water cycle are being integrated into an experimental database while the equipment necessary for constant observation is prepared.

2-2 GEOSS 10-year Implementation Plan

The GEOSS 10-year Implementation Plan approved at the Third Earth Observation Summit was advanced by the “ad hoc intergovernmental Group on Earth Observations” (ad hoc GEO). At the Third Earth Observation Summit in 2005, the ad hoc GEO was succeeded by the “intergovernmental Group on Earth Observations” (GEO) in order to carry out the 10-year Implementation Plan. This plan includes nine goals and objectives for an Earth observation

Table 1 : International progress related to Earth observation in the 21st century

Month & year held	Meeting name	Location held	Major purposes, documents, etc.
October 2002	World Summit on Sustainable Development	Johannesburg (Republic of South Africa)	Take international action on bridging the gaps between developed and developing countries, threats to the global environment, etc.
June 2003	Summit of developed nations	Evian (France)	Agreement on “Science and Technology for Sustainable Development: G8 Action Plan” [4]
July 2003	First Earth Observation Summit	Washington, DC (USA)	Aimed to construct a framework for international cooperation on Earth observation initiatives
April 2004	Second Earth Observation Summit	Tokyo (Japan)	Adopted framework documents for the GEOSS 10-year Implementation Plan
February 2005	Third Earth Observation Summit	Brussels (Belgium)	Approved the GEOSS 10-year Implementation Plan
July 2005	Summit of developed nations	Gleneagles (UK)	Major themes were climate change and African issues. GEOSS promotion was stipulated in the action plan.

system and five common methods by which to achieve them.

(1) The nine goals and objectives of the Earth observation system

The nine goals and objectives of GEOSS are grouped into "societal benefit areas". The observation technology developed and the data accumulated to date will probably be utilized in multiple areas. The nine areas are 1) "Disasters": reducing loss of life and property from natural and human-induced disasters, 2) "Health": understanding environmental factors affecting human health and well-being, 3) "Energy": Improving management of energy resources, 4) "Climate": Understanding, assessing, predicting, mitigating, and adapting to climate variability and change, 5) "Water": improving water-resource management through better understanding of the water cycle, 6) "Weather": improving weather information, forecasting, and warning, 7) "Ecosystems": improving the management and protection of terrestrial, coastal, and marine ecosystems, 8) "Agriculture": supporting sustainable agriculture and combating desertification, 9) "Biodiversity": understanding, monitoring, and conserving biodiversity (abbreviated titles are in quotation marks).

The USA has analyzed the importance of past observation data to each societal benefit area[5]. Table 2 shows some excerpts from this analysis. Because the observation data are roughly

Table 2 : Relationship between observation data and GEOSS's societal benefit areas

Observation data \ GEOSS's societal benefit areas	Disasters	Health	Energy	Climate	Water	Weather	Eco-systems	Agri-culture	Oceans*
Land use	Moderate	High	Moderate	Moderate	Moderate	Moderate	High	High	Low
Ecosystem parameters	Low	Moderate	Low	High	Moderate	Low	High	High	High
Fires	High	High	Low	Low	Low	Low	High	High	Low
Snow and ice	Moderate	Moderate	Moderate	High	High	Moderate	Moderate	Moderate	Moderate
Temperature / ocean surface temperature	High	High	High	High	Moderate	High	High	High	High
Water quality	High	High	Low	Low	Moderate	Low	High	High	High
Ocean circulation	Low	Low	Low	High	Low	Moderate	High	Low	High
Ocean color (chlorophyll)	Low	High	Low	Low	Low	Low	High	Low	High
Atmospheric components	High	High	High	High	High	Low	Low	Low	Moderate
Wind speed and direction	High	High	Low	High	Low	High	Moderate	Moderate	High
Cloud volume	Moderate	Low	Low	High	Low	High	Low	Moderate	Moderate
Space atmosphere	High	Moderate	High	Low	Low	Low	Low	Low	Low
Earthquakes and volcanoes	High	Low	Low	Moderate	Low	Low	Low	Low	Low

High: High importance　Moderate: Moderate importance　Low: Low importance

* GEOSS includes the area of "Biodiversity" rather than "Oceans".

Source: USA materials[5]

equivalent to the eight IGOS-P themes of oceans, atmospheric chemistry, terrestrial, terrestrial disasters, and snow/ice etc., Table 2 also shows the degree of connection between IGOS-P and GEOSS.

(2) Common methods

In order to realize goals in the above societal benefit areas, GEOSS includes the following five common methods: 1) adoption of new means of observation and the improvement and linkage of existing observation systems, 2) appropriate data sharing, 3) ensuring interoperability, 4) facilitation of research and development, and 5) capacity-building in developing countries.

3 Trends in *in situ* observation systems

In situ observation systems are systems that measure terrestrial weather, ocean temperature and pressure, and so on, and integrate global data. This section provides an overview of weather, ocean, and terrestrial observation systems implemented mainly by the United Nations.

3-1 Weather observation systems

In 1992, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established the Global Climate Observing System (GCOS)[6] in order to strengthen various forms of terrestrial, ocean, and space monitoring and scientific observation. Signatory countries to the framework agreement on climate change have a duty not only to strictly abide by the Kyoto Protocol, but also to scientifically evaluate the results and to work to further advance climate change prediction. In order to distinguish changes related to global warming from changes in the natural environment such as solar activity, volcanic eruptions, and El Niño, long-term and highly accurate observation is necessary. In addition, in order to carry out research that compares various types of data, measurements collected from each country during each observation period must be standardized and checked. This sort of long-term, "systematic climate change observation" on a global scale is vital for research on global environmental change.

In Japan, the Japan Meteorological Agency (JMA), which uses the observations of weather satellites and oceanographic observation vessels to forecast the weather, cooperates with GCOS.

3-2 Ocean observation systems

Along with the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), institutions such as the World Meteorological Organization and the United Nations Environment Program promote and sponsor the Global Ocean Observing System (GOOS)[7] in order to gather scientific data through the use and improvement of existing ocean observation systems and to disseminate them widely throughout society in order to contribute to sustainable development. Japanese activities carried out in conjunction with GOOS include the establishment of a subcommittee on GOOS by the Science Council of Japan's Liaison Committee on Marine Science. Several oceanographic research institutions, such as the University of Tokyo's Ocean Research Institute and Hokkaido University's Division of Earth and Planetary Sciences, participate in research on individual themes within GOOS.

Since 1983, the Hydrographic and Oceanographic Department of the Japan Coast Guard has been accumulating observation data for research on the western Pacific. The Coast Guard's Japan Oceanographic Data Center (JODC) makes this data widely available.

Oceangoing robots called Argo floats, which form a floating observation network around the world, are an example of new *in situ* observation equipment for oceans. Argo floats usually drift at a depth of 1,000 m, but about every 10 days they descend to 2,000 m and then rise to the surface, measuring pressure, temperature, and salinity along the way. After reaching the surface, they transmit their observation data to satellites. To date, over 3,000 Argo floats have been released by various ships. Of these, communications from about 1,000 have failed, so plans call for more to be added until the goal of 3,000 operating units is reached. The oceanographic data obtained by each country's floats are transmitted to the Argo

Information Center in France. In Japan, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) releases Argo floats and collects and analyzes the data.

One of GOOS's pilot projects is the Global Ocean Data Assimilation Experiment, which can predict the occurrence of the El Niño effect by measuring both surface and underwater temperatures[8]. Ships traveling the world's oceans have, for many years, measured the underwater temperatures of the seas they traverse. Oceanographers have analyzed those records and collated the past 150 years of ocean temperature data (Data assimilation). With the addition of satellite observation of surface temperature and precipitation to existing *in situ* observations of underwater temperature and salinity, it is hoped that it will be easier to predict the occurrence of the El Niño effect in the future.

3-3 Terrestrial observation systems

The United Nations Food and Agriculture Organization (FAO), the International Council of Scientific Unions (ICSU), the United Nations Educational, Scientific and Cultural Organization, the United Nations Environment Program, and the World Meteorological Organization sponsor the Global Terrestrial Observing System (GTOS)[9]. GTOS is a system for gathering data related to terrestrial ecosystems, including food, water, living things, and so on, and transmitting them to users. GTOS is concerned with 1) the possibility of producing sufficient food for an expanding population, 2) supply and demand relationships regarding water resources, 3) threats to human beings and ecosystems from hazardous waste, 4) biodiversity, and 5) the impact of climate change on terrestrial ecosystems. GTOS is aiming for expanded observation of these areas, sustained data collection, and the successful implementation of systems for analysis and forecasting. Observations currently carried out by GTOS include the monitoring of terrestrial ecosystems, primary productivity, terrestrial carbon, forests, land cover, and land-based and freshwater ecosystems along coastlines.

4 Trends in satellite observation systems

4-1 Trends in U.S. Earth observation satellite technology

(1) The history of NASA's development and operation of Earth observation satellites

The National Aeronautics and Space Administration (NASA) has carried out the development of satellite Earth observation technology since the earliest days of space development. It launched its first weather satellite, TIROS, in 1960 and the terrestrial observation satellite LANDSAT 1 in 1972. In 1983, jurisdiction over LANDSAT shifted to the National Oceanic and Atmospheric Administration (NOAA) and NOAA transferred the operation and ongoing development of LANDSAT to the EOSAT company. This means that monitoring was then carried out by the private sector. EOSAT, however, was unable to successfully compete with French commercial Earth observation satellite "Satellite Probatoire d'Observation de la Terre (SPOT)" and did not achieve the expected sales of satellite images. In 1992, therefore, NASA and the Department of Defense (DoD) took over management of LANDSAT operations. However, NASA's budget for Earth observation was cut sharply, so the observation system was reconfigured using mid-sized satellites such as Terra and Aqua[10]. In addition, NASA has launched further satellites for the observation of oceans, the ozone layer, and so on.

Following recent policy shifts, NASA is now giving priority to manned Moon exploration and Mars exploration, so funds for Earth observation and other fields are decreasing, but NASA is still developing new Earth observation satellites. The Earth observation satellite on which NASA is currently concentrating its efforts is the Orbiting Carbon Observatory (OCO)[11], which will be used for research on the carbon cycle.

(2) NOAA's weather satellites

The National Oceanic and Atmospheric Administration (NOAA) operates the Geostationary Operation Environment Satellites

Table 3 : Earth observation satellite instruments under development in Japan

Satellite name	Instrument name		Developing organization	Observation band
ALOS	Phased array type L-band synthetic aperture radar	PALSAR	JAROS / JAXA	Microwaves
	Panchromatic remote-sensing instrument for stereo mapping	PRISM	JAXA	Visible and near infrared light
	Advanced visible and near infrared radiometer-2	AVNIR-2		Visible and near infrared light
GOSAT	Greenhouse gas observation sensor		Ministry of the Environment / NIES / JAXA	Near infrared to far infrared
	Cloud/aerosol observation sensor			Visible to short wavelength infrared light
GPM	Dual precipitation radar	DPR	NiCT/JAXA	Microwaves

(GOES) and Polar Orbiting Weather Satellites (NOAA satellites). The NOAA-18 satellite, launched by NASA on May 20, 2005, was transferred to NOAA once it reached regular operational status. This satellite carries six kinds of observation sensors, including an advanced very high-resolution radiometer (AVHRR). The United States Air Force (USAF) also operates Defense Meteorological Satellites (DMSP) which carry various Special Sensor Microwave (SSM) equipments and are in continuous use. The final satellite in the DMSP program, DMSP-F20, is due to be launched in 2011. The program will then be integrated with NOAA's polar orbiting satellites.

(3) Private-sector commercial Earth observation satellites

U.S. commercial Earth observation satellites include OrbView, QuickBird, and IKONOS. Space Imaging, Inc., a subsidiary of Lockheed Martin Corp., uses its compact IKONOS satellite to acquire images with a resolution of 1 m from an altitude of 700 km, and sells them. This satellite can also take images of designated locations according to the requirements of customers and has a much higher resolution than that of France's SPOT, which had previously been considered "high-resolution".

4-2 Trends in European Earth observation satellite technology

In 1995, the European Space Agency (ESA) launched the second European Remote Sensing Satellite (ERS-2), the successor to 1991's ERS-1, and in 2002 it launched the environmental monitoring satellite Envisat with improved observation instruments. Because observation data were acquired continuously throughout this time, Europe's satellite observation program can be considered mature.

For weather observation, the European Meteorological Satellite Organization (EUMETSAT) launched seven Meteosat geostationary environmental satellites over a period of 20 years, and then began operating the next-generation Geostationary Operation Environment Satellite (Meteosat Second Generation: MSG) in 2002. It is currently developing the polar orbiting weather satellite (MetOp) for launch in 2006.

As noted above, France's commercial Earth observation satellite SPOT has lost its superiority due to its low image resolution compared to IKONOS, but it remains competitive internationally because of its applications in agriculture for observing vegetation distribution, and its use in compiling topographical maps.

4-3 Trends in Japanese Earth observation satellite technology

In the field of Japanese satellite observation, led by the Japan Aerospace Exploration Agency (JAXA), the Japan Resources Observation System Organization (JAROS), a foundation formed under the jurisdiction of the Ministry of the Economy, Trade and Industry (METI), the Ministry of the Environment (MOE) and the National Institute for Environmental Studies (NIES); the National Institute of Information and Communication Technology (NiCT) under the Ministry of Internal Affairs and Communications (MIAC); and so on, developed observation sensors in accordance with utilization needs, enabling Japan to accumulate technology that now leads the world in satellite observation.

JAXA has continued development of Earth observation satellites and analysis programs and the work of promoting data usage formerly carried out by the National Space Development Agency of Japan (NASDA). An Advanced Land Observing Satellite (ALOS) is scheduled for launch via H-II A launch vehicle during fiscal 2005. In addition, JAXA is developing the Greenhouse Gases Observing Satellite (GOSAT)[12] in conjunction with the Ministry of the Environment and the National Institute for Environmental Studies as a GEOSS-centered initiative on global warming. The Japan Resources Observation System Organization has completed development of the Phased Array type L-band Synthetic Aperture Radar (PALSAR) that will be carried by ALOS, and it is now ready for launch. Following the successful development of Precipitation Radar (PR) for the Tropical Rainfall Measuring Mission (TRMM), the National Institute of Information and Communication Technology is now carrying out research and development into leading-edge information and communications technology such as Dual Precipitation Radar (DPR) for the main Global Precipitation Measurement (GPM)[13] satellite and disaster monitoring through the use of aircraft radar. Table 3 shows the observation instruments being developed by these institutions.

4-4 Progress in satellite observation by countries in Asia and Africa

In Asia, China, India, and South Korea give priority to the development and operation of Earth observation satellites as tools for their own economic development and as contributions to neighboring countries. China operates weather satellites (in both geostationary and polar orbits), resource exploration satellites, marine observation satellites, space environment observation satellites, and so on, carrying out its Dragon Program with the assistance of European Envisat satellites[14]. India also develops and operates geostationary environmental satellites, terrestrial observation satellites, marine observation satellites, cartographical satellites[15], and so on, and has reached the level of selling images commercially. South Korea already operates the camera-equipped Arirang 1 satellite (KOMPSAT-1), and will launch Arirang 2 (KOMPSAT-2) during 2005. It aims to achieve a resolution of 1 m or less. South Korea's activities are attracting attention because they are an attempt to use satellites to carry out joint government-private commercial activities. The South Korean government will launch Arirang 2, but the South Korean venture company Satrec Initiative[16] will sell receiving stations to users in Korea and abroad. In addition, Israel and Taiwan have multiple Earth observation satellites.

As for Earth observation satellites in Africa, the Republic of South Africa launched a Sunsat satellite in 1999, and Morocco launched the MAROC-TUBSAT satellite, with help from the Technical University of Berlin, in 2001. In addition, Algeria launched the Alsat-1 satellite in 2002, and Nigeria launched the Nigeriasat-1 satellite in 2003, and they are now both in operation. However, these countries are not yet very advanced in the technical development of Earth observation satellites and, right from the beginning, their policies have been driven by such needs as disaster monitoring. They therefore participate in international cooperative groups that simultaneously operate multiple Earth observation satellites in order to realize societal benefits for their own countries.

4-5 Committee on Earth Observation Satellites (CEOS)

A major partner in IGOS-P is the Committee on Earth Observation Satellites (CEOS)[17], which consists mainly of the various space agencies that develop and operate Earth observation satellites. CEOS was established in 1984 in response to a recommendation from the 1982 Economic Summit of Industrialized Nations' Panel of Experts on Satellite Remote Sensing, which held in Paris. To date, it has cooperated on areas of fundamental research related to the acquisition, processing, and utilization of Earth observation data, such as data format standards and catalog interoperability. As shown in Table 4, CEOS members (including associates) include space agencies, meteorological agencies, remote sensing agencies, support institutions, and related programs. Major participants include 21 institutions from 17 individual countries, including 3 from Europe. Associate members comprise 21 institutions, mainly government support institutions that propose policies on Earth observation, UN agencies, and related programs. Relevant institutions can participate in the observation program regardless of their CEOS membership status.

In Japan's case, the Japan Meteorological Agency, the Remote Sensing Technology Center of Japan (RESTEC), and so on are not yet CEOS members. In the future, however, it is hoped that institutions that are driven by utilization needs (a position different from that of Ministry of Education, Culture, Sports, Science and Technology (MEXT)/JAXA, which develops technological seeds) will participate in CEOS.

5 Trends in the construction of integrated earth observation systems in the USA and Europe

5-1 The USA's Integrated Earth Observing System (IEOS)

In April 2004, NASA, NOAA, DoD, the Department of Energy (DOE) and other agencies published the "Strategic Plan for the U.S. Integrated Earth Observation System" compiled by the Interagency Working Group on Earth Observations, a part of the National Science and Technology Council's Committee on Environment and Natural Resources. The USA's GEOSS 10-year Implementation Plan will proceed in accordance with this document. It sets out a policy of putting effort into warning of natural disasters as a short-term goal for IEOS for the fiscal 2007 budget[18].

The USA utilizes the shared societal benefit areas in international action on GEOSS, but in domestic plans it replaces "biodiversity" with "oceans" (See Table 2). Conservation of biodiversity can be seen as a facet of ocean resource issues but, from the perspective of biodiversity, ocean biodiversity is only one component. In light of the importance of terrestrial biodiversity, this strained definition of a societal benefit area by the USA may have a negative impact on international cooperation.

NASA's Goddard Space Flight Center (GSFC) researches the most advanced systems related to Earth observation and collects much of the world's Earth observation data in its GCMD server[19]. By use of this resource, one can determine where different types of observation data are located. The server acts as the U.S. contact point for the Committee on Earth Observation Satellites' International Direct Network (CEOS/IDN).

Table 4 : CEOS member institutions (including associates)

Space agencies	16, including NASA and MEXT/JAXA
Weather agencies	3, NOAA (USA), Russia, Europe
Remote sensing agencies	3, Canada, China, Thailand
Government support institutions	8, including the EC
UN support agencies	8, including UNESCO
Programs	7, including GCOS

The U.S. Environmental Protection Agency (EPA) provides 45 types of real-time observation data, 37 databases, 50 kinds of models, 34 decision-making tools, and 33 programs encompassing observation targets such as air, water, land, and ecosystems, all laid out in a graphical interface[20]. General users can access real-time data from observations of air, soil, and so on made by organizations under its umbrella. For example, if one wants information on ultraviolet rays, one need only enter a zip (postal) code or city name to see a display of the current UV index and any warnings about exposure.

Despite such efforts to disseminate user-oriented Earth observation systems in the USA, they still do not reach the level of the "integrated observation system" envisioned for GEOSS.

5-2 Europe's Global Monitoring for Environment and Security (GMES)

In February 2004, the European Commission (EC) adopted an action plan on GMES. The purpose of this plan is to utilize satellite and *in situ* observation data to support decision-making on the environment and security and to provide user-oriented services. For example, GMES is intended to be useful in the management of disasters such as forest fires and floods and in addressing various environmental issues. The action plan for GMES even includes aspects such as supervising institutions and procuring funds, and it specifies the functions to be established by 2008. Target dates differ by category but functions include 1) an organizational framework for GMES, 2) a framework for dialog with users, 3) implementation of high-priority services, 4) strategies for data and information, 5) development of capacity and interfaces to improve data and information access, traffic, and sharing, 6) elemental development of space capability, 7) supplemental utilization of existing in situ observation, evaluation of its capabilities, and implementation plans for new developments, 8) surveys and practical actions (including provision of adequate funding) to support service quality and progress, 9) the GMES international partnership policy, and 10) ensuring the sustainability of GMES services through the adoption of financing mechanisms. Even in Europe, however, data obtained from many different information sources are still not fully integrated.

6 New research examples and ideas on earth observation methods which Japan should note

6-1 Broad observation of the water cycle by satellites equipped with laser interferometers

Japan has led the world in research on the water cycle. Research in this field, on the "establishment of water cycle informatics", has been underway since fiscal 2003, facilitated by the Special Coordination Funds for Promoting Science and Technology. As part of this program, the assimilation of terrestrial observation data and construction of a database integrating them with satellite observation is now underway. Based on such successes, Japan views the water cycle as a high-priority area. However, terrestrial observation and conventional satellite observation may explain only part of the behavior of the water cycle. One possible method of effecting a deeper understanding the water cycle is to utilize laser interferometers to measure gravitational anomalies between pairs of satellites. The USA and Germany launched the gravitational observation satellite GRACE for just such a purpose and are now analyzing its data, demonstrating the effectiveness of this method for water cycle research[21]. In Japan as well, in November 2004, the Earthquake Research Institute of the University of Tokyo, the Kyoto University Faculty of Science, and the National Institute of Information and Communications Technology led a research conference to consider a satellite gravity mission to view the Earth's "flow". Researchers who participated in the conference recommended the development of laser interferometers with even higher resolution than GRACE. Unfortunately, however, this new research trend is not yet included in the GEOSS 10-year Implementation Plan. Utilization of satellite gravity missions to advance research on the water cycle should be considered.

6-2 Earthquake detection by observation of electromagnetic waves

Among those societal benefit areas mentioned above, earthquake countermeasures are considered the policy area most important for Japan's national safety and security. Numerous seismometers have been placed in underground and on the bottom of sea, establishing a system for the early detection of earthquakes. In the field of earthquake detection, while ***in situ*** observation with seismometers and so on has comprised the mainstream approach, but another research has also begun on radically different methods of observation technology.

For example, the French electromagnetic wave observation satellite DEMETER was launched in June 2004 and is collecting research data on the relationship between electromagnetic wave anomalies and the occurrence of earthquakes[22]. In the USA, the Quakesat satellite, launched by a private-sector company, detected electromagnetic waves believed to have been generated by an earthquake.

In Japan, since 2003, the Japan Aerospace Exploration Agency has analyzed the correlation between earthquake occurrence and the plasma parameter data obtained by the solar observation satellite Hinotori (orbit inclination 30°, altitude 600 km) launched by the Institute of Space and

Astronautical Science (ISAS) in 1981. Research in this area should be encouraged in order to carry out more of this type of analysis.

6-3 Weather observation from quasi-zenith orbits

Improving the accuracy of weather forecasts is another goal of GEOSS. In Japan, the Ministry of Land, Infrastructure and Transport (MLIT) operates the Multi-functional Transport Satellite Himawari 6 (MTSAT-1R), which includes weather observation functions. It carries out observations every 30 minutes across a broad swath of the Pacific Rim from its position above the equator at 140° east longitude, enhancing the accuracy of weather forecasts.

If at least three satellites with weather observation sensors equivalent to those aboard the Himawari 6 were to be placed in orbits of Quasi-Zenith Satellite System (QZSS)[23], they could carry out continuous observation of the Arctic and Antarctic, which cannot be covered by a geostationary satellite. Japan currently has no polar orbiting weather satellites and is dependent on observation data from the USA's NOAA satellites. Because quasi-zenith weather satellites have a lower resolution than NOAA satellites, they could not immediately replace them but, by constantly observing the Arctic region, which has a strong influence on weather in the northern hemisphere, they could play an important role in supplementing NOAA satellites and geostationary meteorological satellites.

6-4 Research on relationships between solar activity and Earth systems

We know that the Sun's activity directly affects the Earth's biosphere. For example, in an international workshop on space weather held in Tokyo in April 2005, new research was announced showing that when "flux ropes", generated as helical extensions of the Sun's magnetic field by solar flares, penetrate the Earth's magnetosphere they create magnetic storms. Of further note was the report that when the interplanetary space magnetic fields of these helixes are oriented towards the Earth's South Pole, they have a stronger influence on Earth's radioactive and electromagnetic plasma environments than when they are oriented towards the North Pole. When carrying out Earth observation, observing changes in the space environment such as solar activity and changes in the magnetic fields of solar winds and understanding their long-term relationships with the Earth's weather have now become important[24]. In the Council for Science and Technology Policy's "Promotion Strategy for Earth Observation", "Earth science" is also among the 15 promotion strategies listed. Through observations not only of solar activity, but also of geospace, the upper atmosphere, ocean and lake sediments, and ultradeep drilling, we can gain a more complete understanding of the relationships between Earth systems and the expanding humanosphere.

7 Improving data processing environments

Because Earth observation systems add to their vast amounts of accumulated data, day by day, proper data processing is a serious issue. A number of methods have been developed in order to process the huge amounts of Earth observation data collected and to extract meaningful information from them. Advanced supercomputer systems play a large role in this data processing. Japan's representative supercomputer system is the Earth Simulator at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). According to the Linpack benchmark, some US supercomputers have already exceeded its performance, but it remains among the world leaders in actual speed of large-scale numerical simulation.

The technologies cultivated through the development and operation of the Earth Simulator should be applied to the processing and analysis of satellite data, and a data processing environment should be developed that meets diverse needs. In particular, maximizing the use of networks would greatly increase convenience. In 2005, remote use of the Earth Simulator, which had previously only been available within its own building, became possible through Super SINET.

From the point of view of the data processing environment, development and use of a supercomputer system that can outperform the

Earth Simulator should contribute to expanded science and technology successes for Japan. The Earth Simulator works around the clock, but it still cannot meet the widespread demand for its calculations, so only users in selected fields can utilize it. In order to create a data processing environment that would give its many users easy access, for example, the Remote Sensing Technology Center of Japan (which has ability to analyze various Earth observation data) could be further developed to implement the operation of a multi-supercomputer system that provides easy access for a broad range of researchers.

8 Conclusion — Proposals for an optimal Japanese integrated earth observation system —

"U.S.-Japan Space Policy: A Framework for 21st Century Cooperation"[25], published by the USA's Center for Strategic and International Studies (CSIS) in 2003, offers three scenarios for future Japan-U.S. relations regarding Earth observation:

A: "U.S.-dominant". At this point, the USA has little use for Japanese capabilities, but Japan is still reliant on the USA, and this inequality continues.

B: "Autonomy". Japan develops fully autonomous capabilities, its reliance on the USA declines, and there is little real value created by any cooperation.

C: "Partnership". Japan develops a strong capability of its own while also increasing its collaboration with the USA. The two countries allocate resources and costs and create joint frameworks to share imagery on a real-time basis.

The Center for Strategic and International Studies argues that there is sufficient value in cooperation between Japan and the U.S. on space issues to overcome the disincentives but, in order to obtain these benefits, frameworks must first be established to allocate appropriate areas of responsibility and provide incentives to the institutions involved.

It is my opinion that given this U.S. view, Japan is likely to proceed with a Japan-U.S. partnership by promoting GEOSS, as described above. At the same time, Japan must also turn its attention to seeking partnerships not only with the USA, but also with Europe and Asia, especially China.

Outlined below are some proposals for points that Japan should bear in mind as it moves forward with GEOSS.

(1) Proposal 1: Establishment of an institution to carry out constant satellite observation

The biggest problem when attempting to integrate *in situ* and satellite observation is the question of whether a workable system for constant satellite observation can be established. At present, this is considered a structural issue within the Japanese system. JAXA is a research and development institution, so it is limited to the development of new types of satellites and cannot provide satellites with constant performance for continuous use. If satellite specifications are broadened and opened up for international tender, inexpensive foreign-made Earth observation satellites might be purchased. Compared with commercial communications satellites, where there was an obvious capability gap with the USA and Europe, Earth observation satellites, with their more complex specifications requiring advanced robotic technologies, might well become a Japanese specialty. In order to accomplish this, however, an institution is needed that can procure and operate Earth observation satellites on a continuous basis. One possibility is to establish a Japan Remote Sensing Center as an affiliate of the Remote Sensing Technology Center of Japan under the jurisdiction of the government, and for it to become a member of CEOS along with JAXA. In order to promote integrated Earth observation in Japan, the Subdivision on R&D Planning and Evaluation of the Council for Science and Technology established a subcommittee on the promotion of Earth observation. Without an organization to lead the implementation of integrated observation, however, no matter how often the importance of integration is touted, there is a danger that 10 years will pass without any real progress being made in implementing the plan. The reason that the situation has stagnated in this way is because of the inflexibility of Japan's budget system, which makes it difficult, from a funding perspective, to induce policies in fields where change is swift. An institution must be established with the ability to lead the construction of an Earth observation system that transcends agency boundaries and meets user needs. Currently, there are large organizations such as JAXA and the Japan Meteorological Agency that have advanced technical capabilities, but neither is in a position to take a broad view of GEOSS as a whole.

(2) Proposal 2: Measures to expand *in situ* observation by using ODA

Already, the invitation of representatives from developing countries such as the Republic of South Africa to attend the summits of industrialized nations is paving the way for international cooperation on Earth observation and measures against global warming. Japan could quantitatively express its international contribution to Earth observation by dedicating a set percentage of ODA, say 10%, for GEOSS use. When given a choice between aid for economic development and aid for the protection of the global environment, ODA recipients will tend to prefer the economic development option but Japan should devise means to distribute GEOSS ODA to developing countries that want to share the benefits of IGOS-P and have the ability to do so. This kind of financial assistance, clearly defining the role of contributions made to GEOSS through ODA, could be expected to help create a commitment to balancing economic growth with the protection of the environment in developing countries. If this kind of measure can fill in some gaps in current observation, it would also bring about the global benefit of improving the accuracy of Earth observation systems.

(3) Proposal 3: Development of new satellite observation technology driven by utilization needs

Japan is already working on the development of the Greenhouse Gases Observing Satellite (GOSAT), which will contribute at the forefront of international research by observing the distribution of greenhouse gases and their sources. Japan's efforts on IGOS-P in societal benefit areas such as disaster mitigation, weather, and the water cycle while moving towards GEOSS have been well received. In the future, an integrated observation system should be further developed to incorporate important observed phenomena for which data is currently lacking, and to make better use of existing data where important relationships have yet to be recognized. New observation methods that should be developed are likely to center on satellite observation, and the question of how to raise the necessary funding for obtaining data for use in societal benefit areas must be addressed. I believe that only when Japan has unique technologies, Japan can build equal partnerships not only with the USA, but with Europe and Asia as well. However, institutions developing new observation technology should not give priority only to seeds-oriented technologies, but instead should always emphasize on utilization needs-oriented technology.

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