1 Research and Development of Global Environment Measurements

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In the study of global environment measurements, two categories of research and development projects are going on: one is for satellite-borne sensor development for global scaled targets, the other is for advanced measurement technology development applied to ground-based and aircraft-borne systems. This field of research activities have been conducted so far for the expanded utilization of electromagnetic wave technologies. Recently, the activities have been focused on the global environment measurements and more effective implementation has been pursued in order to meet public interests and to exhibit visible contribution to the society. It is suggested in CRL to carry out these activities as a part of info-communications research activities and with close collaboration with science communities outside CRL. From fiscal year of 2001, CRL's organization was changed to an Independent Administrative Institution (IAI). Research management policy necessary in implementation of projects in IAI will be discussed with showing medium-term research objectives and plans in this fields. Outline of individual ongoing research projects in this field is described.

Keywords
Global environment measurements, Medium-term research objective, Medium-term research plan, Satellite-borne sensor

1 Introduction

A study of remote sensing using electromagnetic waves has been conducted at the Communications Research Laboratory (CRL) as a part of research activities aiming at the effective use of electromagnetic waves. This study deals with technologies applied to global environment measurements, an area that has recently drawn significant societal attention. In April 2001, the organization of CRL changed to Independent Administrative Institution (IAI). In order to conduct its research and development activity continuously and more extensively, CRL has been strongly encouraged to feed back its results to society, and to strengthen collaboration with outside groups and researchers.

Global environment issue is one of most significant issues we will face in the 21st century. The use of measurement technology to cope with this issue will be indispensable in understanding and monitoring the environment, and features substantially among all research activities relating to global environmental issues. It should be noted that the nature of the phenomena involved will require measurements on a global scale, and therefore satellite measurement will represent an important tool. Additionally, ground-based measurements will also be required in particular regions where certain phenomena may be clearly observed. Further, these technologies prove useful in disaster-prevention efforts. Research and development regarding the global environment issue was selected as one of the fields of priority designated by the Council for Science and Technology Policy (established in 2001), and intensified research in the field was recommended, including research on environmental monitoring and modeling.

The general flow of research activity dealing with environmental issues is to first understand the phenomena through measurement,

second to analyze the mechanisms involved and to construct a model, and third to predict future behavior using the developed models. Within this flow, CRL's major research role lies in the development of measurement technology for monitoring. The aim of this research is to realize higher accuracy than previously possible or to enable the measurement of new objects—i.e., ones that have never been measured. The development of measurement technology does not refer only to the development of sensor hardware, but also includes software technology, including the development of algorithms and data processing. CRL's responsibility in the development of measurement technology should include up to verification of the developed technologies, in order to produce scientifically products.

One of the remarkable features of this environment research is that it is being conducted under internationally coordinated frameworks and pursued under collaborative strategies. In this field of research, scientific outcomes are considered to have potential to impact world politics and economies. Ongoing research projects in this field in the CRL are performed with this responsibility, as they generate measurement data to be used in society within a framework of worldwide collaboration.

This paper describes the basic philosophy of conducting research projects in the field as a preface to this special issue and also gives an outline of ongoing research projects.

2 Objective and philosophy of global environment measurement research projects

2.1 Medium-term research objectives and research plans

IAI proceeds with its research in the way as follows: first, medium-term research objectives are provided by the Minister responsible to the IAI; second, the IAI defines medium-term research plans to implement the given objectives; and third, the IAI conducts research in accordance with these plans. The medium term is set at five years for the CRL. Year-to-year progress in research activity as well as outcomes at the end of the medium term will be subject to strict review.

The medium-term research objectives and present medium-term research plans (from fiscal year 2001 to 2005) are shown in Table 1. The medium-term research objectives that provide the guideline to our activities include revolutionary research into the development of wide-ranging, highly accurate measurement technologies, as well as the development of new ground-based measurement technologies. These given objectives fit in well with our research goals. To realize these research objectives, the medium-term research plans include two separate items: research and development of satellite-borne sensors, and research and development of ground-based remote sensors. The above research objectives and plans provide the basic guideline for research activities. A detailed methodology will be described below.

2.2 Several viewpoints on global environment measurement research

(1) Coordinated study with info-communication technology

The study of remote-sensing technologies for the global environment is considered as one of the application fields of info-communication technology, and in fact, advances in technologies essential to remote sensing have been closely linked with the development of info-communication technology. Therefore, it is advantageous to proceed with remote-sensing research and info-communication research in parallel at the same time. Conversely, because remote-sensing study comprises of practical research targeting natural phenomena, technological requirements may be defined and fed back to the development of technology in the info-communications field. The CRL can provide an ideal research environment for the simultaneous advancement of these two fields of study.

In addition, a huge volume of observation data, including images, are handled in remote-

Table 1 *Medium-term research objectives and plans (from 2001 to 2005)*

Medium-term research objectives

Research and development of technologies for electromagnetic measurements and applications: To research and develop technology to apply electromagnetic waves to the measurement of variations in the global environment and in space, application of the observed data, and establishment of the standard of space-time.

Research and development of remote-sensing technologies: To develop innovative technologies for wide-range and high-precision measurement (accuracy within approximately 10%), together with new ground-based remote-sensing technologies, in order to effectively use electromagnetic waves and light.

Medium-term research plans

Research and development of technologies for electromagnetic measurements and applications: Based on the advanced sensing technologies using radars and lidars developed to date in CRL, innovative new technology development is conducted to measure atmospheric components, clouds, precipitation, wind, land surface, and sea-surface phenomena with high precision. Research into the application of these technologies is also conducted.

(A) Comprehensive research is conducted to develop advanced satellite-borne sensors and to demonstrate their capability of measuring global environmental phenomena and contributing to the prediction of global change.

(B) Comprehensive research is conducted to develop high-precision observation technology using advanced remote sensors and to develop technologies for monitoring and predicting natural hazards.

sensing research. These data sets can be used as large volumes of content for network and database research in the field of info-communications. Research into dissemination and processing of data using these data sets provides an important opportunity for the study of high-speed networks and large-sized databases. On the remote-sensing side, on the other hand, development of prototype data-network systems is ongoing, which systems feature advanced data dissemination and processing technology drawn from recent developments in the info-communication field.

(2) Direct benefits to society and individual life

Measuring the global environment and monitoring natural disasters lead to direct benefits to society and in the lives of individuals. In efforts to contribute to these objectives, themes relating to global warming and the global water cycle issues have been selected and are being pursued in projects in the category of observation of the earth from space. Efforts in development of advanced ground-based remote-sensing technology for practical applications and in the prevention of natural disasters are also ongoing.

(3) Research with public benefits

Research in this field has potential to yield significant public benefits. However, it is not profitable in the short term, and therefore private-sector enterprises do not pursue research activities in this field. It is therefore necessary for public-sector institutions to conduct this activity with government funding. In particular, private-sector enterprises do not have a direct stake in the observation of earth from space. Only national space agencies are capable of proceeding with activity in this area. Thus, earth-observation activity features sub-

stantial weight among the various categories of space activity in the U.S. and European space agencies.

2.3 Measures to attain objectives

(1) Continual update of research subject

Research topics and objectives should be subject to continual review to pursue the forefront research, reflecting an up-to-date view of the relevant field activities throughout the world. Generally, projects relating to the observation of earth from space are large sized and costly, and require a long time to complete. Progress in these projects is often subject to the reformation of plans due to situation change within the national space agencies or other outside institutions, and also due to change in governmental budgetary conditions. It should be noted that the national space agencies in the world are working on a collaborative and competitive basis, and the interrelationships between these agencies are complicated. Determining a strategy to select the best way in management is not easy, and must be undertaken with due attention to domestic and international conditions.

(2) Project-oriented management

We intend to undertake project-oriented management that focuses on definite project goals. To this end, our policy is that the assignment of funding to projects is on a much larger scale than that of typical projects conducted in universities, and that objects of research are development of new systems, with the major emphasis on the development of hardware. The scope of research will extend to acquisition of scientific data with the developed system and to demonstration of the scientific significance of acquired data. To accomplish this goal, newly selected research themes should be of sufficient significance in terms of both science and technology, based on consultation with relevant user communities. The points of evaluation of research projects would include the feasibility as a satellite project after evaluation of its significance of new technology, its feasibility of gaining new scientific insight using the new measurement technology, or the possibility of data utilization among users. Another issue to be considered in project-oriented management is the implementation of a function to pick up unexpected outcomes and unforeseen directions of research. Another important issue centers on the identification and how to raise seeds of new research. Project-oriented management must take all of these issues into consideration.

(3) Secure research resources

Securing research resources, such as funding and personnel, is particularly important in attaining research project goals. In this research field, coordination is required between the system-development side and data users, and the CRL plays major role in system development. We plan to obtain the funding and personnel necessary to conduct research themes, by claiming research outcomes resulting from the utilization of research products to date and cases of technology transfer. Also efficient management is needed by pursuing external sources of funding with competition based research opportunities and by contracting part of CRL's projects out to researchers outside CRL.

(4) Cooperation with outside community

CRL generally is not the end user of the measurement data. Therefore, the measurement results must be useful to other institutions or researchers outside CRL who use data for scientific or practical applications. It is important to maintain close cooperation with these data users, from the system design phase through the phases of operational observation. It is also our policy that the measured data should be openly provided to the research community to promote its active utilization. We should not confine our research activity to the domestic arena but should instead promote international collaboration. We need to find research partners outside Japan for some research themes in this field, as activity relating to advanced measurement technology is relatively scarce in Japan. Further, we need to

promote international collaboration to determine the ideal observation sites for ground-based measurements throughout the world, sites that are suited to the observation of specific phenomena or to the pursuit of particular research themes.

(5) Publicizing results

It is strongly advised that we publicize our research results, particularly in visual form, and also to provide these results to the public. The impact of this publicity activity is considered to be one of the most important factors in the evaluation of research activities. Public awareness in the beginning phase or at the inception of a research project is one of the key factors in project success. Therefore, activity raising publicity—holding workshops, for example—is encouraged in this phase.

3 Research and Development Themes

Ongoing research projects consist of research and development of space-based, ground-based, and airborne measurement technologies. A schematic diagram explaining the interrelationship between research projects is shown in Fig.1. Construction of a system for data-processing, data-distribution, and networking is essential in each category of research projects. Collaboration with other institutions and researchers that use data will be actively promoted through data networking. This process enables active data use and provides for public contributions. An outline of each ongoing research project in the present medium-term is described below. Details of each project can be found in the relevant articles in this special issue.

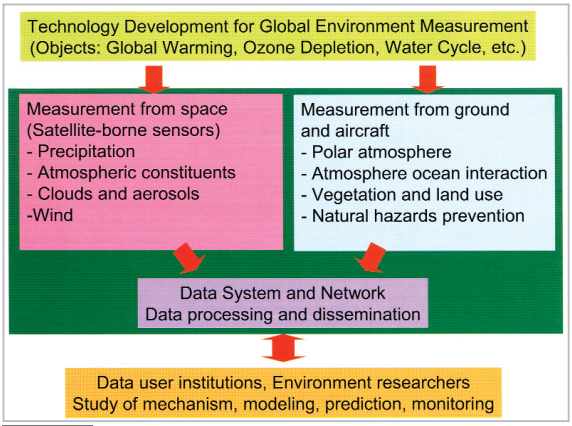


Fig.1 *Framework of the global environment measurement projects*

3.1 Research and development into space-based technologies for the measurement of global environment change

(1) Objectives and measurement targets

The purpose of the various research projects is to develop technology for highly accurate measurements that will contribute to an understanding of the phenomena of global environment change—such as global warming and ozone depletion—as well as to elucidate the mechanisms thereof. The measurement targets are the composition of the atmosphere on a global scale, water and energy circulation, cloud and radiation budget, atmospheric dynamics, vegetation distribution, and their variations. Development of space-based measurement technology is indispensable for the measurement of these phenomena on a global scale.

(2) Research contents and features

Research efforts extend from the development of new technologies for satellite-borne sensors based on newly established principles to the development of sensor algorithms to calibration and validation studies. A unique feature of satellite-borne measurement is that it measures global phenomena under nearly uniform conditions. In fact, satellite measurement provides a unique opportunity to measure many global environment phenomena. The scope of our research mainly covers the development of new technology in satellite-borne sensors, but also covers its technical demonstration in space. To attain our research objectives, the range of research encompasses the development of algorithms as well as the calibration and validation of sensors. CRL is the only institution in Japan that has the requisite experience and expertise in this field. We have a great deal of experience in the develop-

Table 2 *Satellite-borne sensors developed to measure global environment change from space*

Name of sensor	Type of sensor	Measurement objects (main objects)	Satellite program
SMILES	Superconducting submillimeter-wave limb-emission Sounder (600-GHz band)	Stratospheric ozone, trace gases (ozone depletion, global warming)	Japan Experiment Module of the International Space Station (ISS/JEM Kibo) to be launched in 2005
Precipitation radar	Microwave radar (35 GHz)	Precipitation (Water and energy cycle)	Global Precipitation Measurement (joint Japan-U.S. project) to be launched in 2008
Cloud radar	Millimeter-wave radar (94 GHz)	Clouds and weak precipitation (global warming)	EarthCARE (Japan-Europe joint project) to be launched in 2008 or 2010
Doppler lidar	Coherent Doppler lidar (wavelength:2μm)	Wind vector in troposphere; aerosols (climate changes, climate modeling)	Japan Experiment Module of the International Space Station (ISS/JEM Kibo) (expected)

ment of airborne sensors and in its operation as a preparatory stage for satellite-based measurements. In developing a future satellite-borne sensor system, it is efficient to conduct airborne experiments and to accumulate experience beforehand.

(3) Research and development themes

Ongoing projects for the research and development of satellite-borne sensors under the present medium-term research plan are summarized in Table 2.

Development of SMILES (superconducting submillimeter-wave limb-emission sounder) for experiment onboard the International Space Station

The superconducting submillimeter-wave limb-emission sounder (SMILES) is a spectroradiometer using a frequency of 640 GHz. This sensor can obtain the height profile of stratospheric trace gases with very high sensitivity using the limb-sounding method and superconducting technology. The measurement target is the distribution of stratospheric trace gases that are thought to cause ozone depletion. This highly sensitive measurement is very important because it is known that these gases are not only the cause of ozone depletion but also the source of global warming. Practical use of superconducting technology in space and the world first mechanical 4-K refrigerators for space use represent the technical breakthroughs envisioned in this project. SMILES is under development in collaboration with the National Space Development Agency (NASDA) of Japan, with the goal of its installation onboard the Japanese Experimental Module of the International Space Station (ISS/JEM Kibo) in around 2006.

Research and development of a satellite-borne 35-GHz precipitation radar

The Global Precipitation Measurement (GPM) project, which will measure rainfall distribution over the entire globe, is proceeding under Japanese and U.S. collaboration, and follows up on the Tropical Rainfall Measuring Mission (TRMM). The GPM system will consist of a primary satellite and eight constellation satellites. The primary satellite will carry a dual-frequency precipitation radar (DPR), which is expected to provide higher accuracy than the precipitation radar onboard TRMM. This project is progressing in collaboration with NASDA. The CRL is conducting research and development for a 35-GHz precipitation radar, which requires more extensive development effort in the two frequencies.

Research and development of a millimeter wave satellite-borne cloud profiling radar

A research project on the development of a satellite-borne millimeter-wave cloud profiling radar is currently underway, the objective of which is to determine three-dimensional cloud distribution on a global scale in order to evaluate the effects of clouds and aerosol on radiation budget, which represents one of largest source of uncertainty in current predictions of global warming. This research envisions the deployment of a satellite that will carry lidar and other sensors together with cloud radar, and also focuses on the study of retrieval algorithms for multi-sensor data analysis. The study of the future satellite program is conducted in collaboration with NASDA and the European Space Agency (ESA).

Research and development of a satel-

lite-borne coherent Doppler lidar for wind measurement

This involves research into the technical development of a coherent Doppler lidar system to measure the wind velocity in the atmosphere on a global scale. This system is designed to measure wind velocity with an accuracy of less than 2 m/s and also to observe aerosols and clouds. This system is tentatively designed for installation on ISS/JEM Kibo.

3.2 Research on high-precision measurement technology and its practical application

(1) Objectives and measurement targets

The objective of this category of projects is to develop remote-sensing technology from ground-based and airplane measurements that will contribute to the monitoring of variations in the atmosphere, the ocean, and on land, as well as to the monitoring of natural disasters. Through these efforts, including verification of the usefulness of the developed measurement technologies and of measurement results, significant scientific and social contributions are expected. In addition, studies on the development of data systems for control, real-time monitoring, high-speed data transmission, and dissemination of data based on the developed measurement technologies are also underway.

(2) Research contents and features

In this category of research projects, greater emphasis is placed on practical applications than in the projects described in **3.1**. Therefore we will pay greater attention to technology transfer and to patent applications from a technological point of view. From a scientific viewpoint, the dissemination of data to researchers in universities and other institutions is promoted, to pursue high-quality collaborative results through utilization of the obtained data. Regarding measurement technologies with potential applications to the observation of natural disasters, we envision a contribution to society through the provision of data to the government and news media. International collaboration is also important in this area of study, to enable field measurements at sites throughout the world best suited for observation of the phenomena involved.

(3) Research and development themes

An outline of the research themes in this category is provided. Fig.2 illustrates research flow and goals.

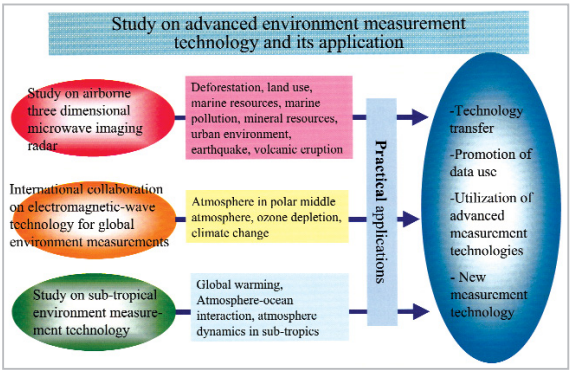


Fig.2 *Objectives and research flow in the study on advanced environment measurement technology and its application*

Development of an airborne three-dimensional microwave imaging radar

The goals are (1) to develop an airborne system of three-dimensional high-performance microwave imaging radar; (2) a study of data-processing utilizing multi-wavelength, interferometric, and polarimetric functions; and (3) development of data-application technology. Research objectives also include demonstration of usefulness in terms of monitoring and preventative measures in the event of natural hazards such as volcanic eruptions, as well as the promotion of data utilization. Experiments in this field of research and development are being conducted in collaboration with NASDA.

International cooperative research for polar atmospheric observation

The purpose of this research is to develop measurement technology using electromagnetic waves to observe the atmosphere in the polar regions. It is believed that these regions are sensitive indicators of variations in the global atmosphere. Another objective is to

prove the effectiveness of the developed measurement technology. The scientific understanding of the middle atmosphere at an altitude between 10 and 100 km gained using this measurement system will contribute to advancing understanding of the earth's atmospheric environment, including the study of relationship between the sun and the earth atmosphere.

Research and Development in measurement technology for the interaction between the atmosphere and ocean in the subtropical region

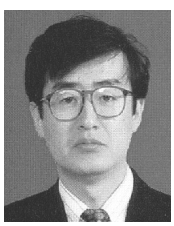
The objective is the development and demonstration of a measurement system using high-precision, high-resolution remote-sensing technology to observe the interactions between the atmosphere and the ocean in the subtropical region. Development of a data system is also an objective for purposes of data-processing and distribution. The sensors to be developed consist of a long-range oceanic radar, a wind profiler which measures atmospheric winds up to the altitude of 16 km, and a multi-parameter precipitation radar.

4 Conclusion

This paper describes the overall aspects of the projects relating to remote sensing of the global environment. Please refer to the papers describing the individual research projects for details. Four research projects are ongoing that aim at the development of satellite-borne sensors, although they are currently in different phases of research. For a relatively small institution such as the CRL, tackling numbers of such large projects is an ambitious policy. It is generally rare for large projects, such as those being involved in satellite sensor development, to proceed according to their original schedules, due to the high probability that various external factors will cause program delay. Such factors may involve a change in government policy affecting funding or an accident in a rocket or an operating satellite. Our strategy to address these issues is to first establish a basis of unique technology in terms of satellite-borne sensors, and then to try to take the opportunities to attain our final goals through international collaborations, in due course of establishing a reputation as a world-class research institution. Since CRL is virtually the only institution to work in this field in Japan, we must continue our efforts to establish original Japanese technologies.

As for the ground-based and airborne projects, the objective is to develop new sensors and to establish new remote-sensing technologies. We will attempt to observe phenomena that have not been measured (due to insufficient sensor capabilities) and thereby to point the way toward new areas of scientific exploration. Some of these efforts are now bearing fruit, as we continue to collaborate with outside researchers to maximize the results of our projects.

As an introduction to the special issue on the global environment measurement, we have presented the strategy behind our research projects and have provided a brief description of all current CRL projects. We hope that this issue is useful to researchers in the relevant fields as well as to those currently working in collaboration with us. We are also expecting that this issue may provide an opportunity for many researchers outside our field to discover a new interest in this field of study as well as in the activities of the CRL. We would like to express our gratitude to those institutions and researchers that have helped us to date and to ask for their further support and suggestions.



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Remote Sensing of Atmosphere